
HPX Documentation

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The STE || AR Group

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USER DOCUMENTATION

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Welcome to the *HPX* documentation!

If you're new to *HPX* you can get started with the *Quick start* guide. Don't forget to read the *Terminology* section to learn about the most important concepts in *HPX*. The *Examples* give you a feel for how it is to write real *HPX* applications and the *Manual* contains detailed information about everything from building *HPX* to debugging it. There are links to blog posts and videos about *HPX* in *Additional material*.

You can find a comprehensive list of contact options on [Support for deploying and using HPX¹](#). Do not hesitate to contact us if you can't find what you are looking for in the documentation!

See *Citing HPX* for details on how to cite *HPX* in publications. See *HPX users* for a list of institutions and projects using *HPX*.

There are also available a [PDF](#) version of this documentation as well as a [Single HTML Page](#).

¹ <https://github.com/STELLAR-GROUP/hpx/blob/master/.github/SUPPORT.md>

WHAT IS *HPX*?

HPX is a C++ Standard Library for Concurrency and Parallelism. It implements all of the corresponding facilities as defined by the C++ Standard. Additionally, in *HPX* we implement functionalities proposed as part of the ongoing C++ standardization process. We also extend the C++ Standard APIs to the distributed case. *HPX* is developed by the STE||AR group (see *People*).

The goal of *HPX* is to create a high quality, freely available, open source implementation of a new programming model for conventional systems, such as classic Linux based Beowulf clusters or multi-socket highly parallel SMP nodes. At the same time, we want to have a very modular and well designed runtime system architecture which would allow us to port our implementation onto new computer system architectures. We want to use real-world applications to drive the development of the runtime system, coining out required functionalities and converging onto a stable API which will provide a smooth migration path for developers.

The API exposed by *HPX* is not only modeled after the interfaces defined by the C++11/14/17/20 ISO standard. It also adheres to the programming guidelines used by the Boost collection of C++ libraries. We aim to improve the scalability of today's applications and to expose new levels of parallelism which are necessary to take advantage of the exascale systems of the future.

WHAT'S SO SPECIAL ABOUT *HPX*?

- *HPX* exposes a uniform, standards-oriented API for ease of programming parallel and distributed applications.
- It enables programmers to write fully asynchronous code using hundreds of millions of threads.
- *HPX* provides unified syntax and semantics for local and remote operations.
- *HPX* makes concurrency manageable with dataflow and future based synchronization.
- It implements a rich set of runtime services supporting a broad range of use cases.
- *HPX* exposes a uniform, flexible, and extendable performance counter framework which can enable runtime adaptivity
- It is designed to solve problems conventionally considered to be scaling-impaired.
- *HPX* has been designed and developed for systems of any scale, from hand-held devices to very large scale systems.
- It is the first fully functional implementation of the ParalleX execution model.
- *HPX* is published under a liberal open-source license and has an open, active, and thriving developer community.

2.1 Quick start

The following steps will help you get started with *HPX*. Before getting started, make sure you have all the necessary prerequisites, which are listed in `_prerequisites`. After *Installing HPX*, you can check how to run a simple example *Hello, World!*. *Writing task-based applications* explains how you can get started with *HPX*. You can refer to our *Migration guide* if you use other APIs for parallelism (like OpenMP, MPI or Intel Threading Building Blocks (TBB)) and you would like to convert your code to *HPX* code.

2.1.1 Installing *HPX*

The easiest way to install *HPX* on your system is by choosing one of the steps below:

1. **vcpkg**

You can download and install *HPX* using the `vcpkg`² dependency manager:

```
$ vcpkg install hpx
```

2. **Spack**

Another way to install *HPX* is using `Spack`³:

² <https://github.com/Microsoft/vcpkg>

³ <https://spack.readthedocs.io/en/latest/>

```
$ spack install hpx
```

3. Fedora

Installation can be done with Fedora⁴ as well:

```
$ dnf install hpx*
```

4. Arch Linux

HPX is available in the Arch User Repository (AUR)⁵ as `hpx` too.

More information or alternatives regarding the installation can be found in the *Building HPX*, a detailed guide with thorough explanation of ways to build and use HPX.

2.1.2 Hello, World!

To get started with this minimal example you need to create a new project directory and a file `CMakeLists.txt` with the contents below in order to build an executable using CMake⁶ and HPX:

```
cmake_minimum_required(VERSION 3.19)
project(my_hpx_project CXX)
find_package(HPX REQUIRED)
add_executable(my_hpx_program main.cpp)
target_link_libraries(my_hpx_program HPX::hpx HPX::wrap_main HPX::iostreams_component)
```

The next step is to create a `main.cpp` with the contents below:

```
// Including 'hpx/hpx_main.hpp' instead of the usual 'hpx/hpx_init.hpp' enables
// to use the plain C-main below as the direct main HPX entry point.
#include <hpx/hpx_main.hpp>
#include <hpx/iostream.hpp>

int main()
{
    // Say hello to the world!
    hpx::cout << "Hello World!\n" << std::flush;
    return 0;
}
```

Then, in your project directory run the following:

```
$ mkdir build && cd build
$ cmake -DHPX_DIR=</path/to/hpx/installation> ..
$ make all
$ ./my_hpx_program
```

```
$ ./my_hpx_program
Hello World!
```

The program looks almost like a regular C++ hello world with the exception of the two includes and `hpx::cout`.

⁴ <https://fedoraproject.org/wiki/DNF>

⁵ https://wiki.archlinux.org/title/Arch_User_Repository

⁶ <https://www.cmake.org>

- When you include `hpx_main.hpp` *HPX* makes sure that `main` actually gets launched on the *HPX* runtime. So while it looks almost the same you can now use futures, `async`, parallel algorithms and more which make use of the *HPX* runtime with lightweight threads.
- `hpx::cout` is a replacement for `std::cout` to make sure printing never blocks a lightweight thread. You can read more about `hpx::cout` in *The HPX I/O-streams component*.

Note:

- You will most likely have more than one `main.cpp` file in your project. See the section on *Using HPX with CMake-based projects* for more details on how to use `add_hpx_executable`.
- `HPX::wrap_main` is required if you are implicitly using `main()` as the runtime entry point. See *Re-use the main() function as the main HPX entry point* for more information.
- `HPX::iostreams_component` is optional for a minimal project but lets us use the *HPX* equivalent of `std::cout`, i.e., the *HPX The HPX I/O-streams component* functionality in our application.
- You do not have to let *HPX* take over your `main` function like in the example. See *Starting the HPX runtime* for more details on how to initialize and run the *HPX* runtime.

Caution: Ensure that *HPX* is installed with `HPX_WITH_DISTRIBUTED_RUNTIME=ON` to prevent encountering an error indicating that the `HPX::iostreams_component` target is not found.

When including `hpx_main.hpp` the user-defined `main` gets renamed and the real `main` function is defined by *HPX*. This means that the user-defined `main` must include a return statement, unlike the real `main`. If you do not include the return statement, you may end up with confusing compile time errors mentioning `user_main` or even runtime errors.

2.1.3 Writing task-based applications

So far we haven't done anything that can't be done using the C++ standard library. In this section we will give a short overview of what you can do with *HPX* on a single node. The essence is to avoid global synchronization and break up your application into small, composable tasks whose dependencies control the flow of your application. Remember, however, that *HPX* allows you to write distributed applications similarly to how you would write applications for a single node (see *Why HPX?* and *Writing distributed applications*).

If you are already familiar with `async` and `future` from the C++ standard library, the same functionality is available in *HPX*.

The following terminology is essential when talking about task-based C++ programs:

- **lightweight thread:** Essential for good performance with task-based programs. Lightweight refers to smaller stacks and faster context switching compared to OS threads. Smaller overheads allow the program to be broken up into smaller tasks, which in turns helps the runtime fully utilize all processing units.
- **async:** The most basic way of launching tasks asynchronously. Returns a `future<T>`.
- **future<T>:** Represents a value of type `T` that will be ready in the future. The value can be retrieved with `get` (blocking) and one can check if the value is ready with `is_ready` (non-blocking).
- **shared_future<T>:** Same as `future<T>` but can be copied (similar to `std::unique_ptr` vs `std::shared_ptr`).
- **continuation:** A function that is to be run after a previous task has run (represented by a future). `then` is a method of `future<T>` that takes a function to run next. Used to build up dataflow DAGs (directed acyclic

graphs). `shared_futures` help you split up nodes in the DAG and functions like `when_all` help you join nodes in the DAG.

The following example is a collection of the most commonly used functionality in *HPX*:

```
#include <hpx/algorithm.hpp>
#include <hpx/future.hpp>
#include <hpx/init.hpp>

#include <iostream>
#include <random>
#include <vector>

void final_task(hpx::future<hpx::tuple<hpx::future<double>, hpx::future<void>>>)
{
    std::cout << "in final_task" << std::endl;
}

int hpx_main()
{
    // A function can be launched asynchronously. The program will not block
    // here until the result is available.
    hpx::future<int> f = hpx::async([]() { return 42; });
    std::cout << "Just launched a task!" << std::endl;

    // Use get to retrieve the value from the future. This will block this task
    // until the future is ready, but the HPX runtime will schedule other tasks
    // if there are tasks available.
    std::cout << "f contains " << f.get() << std::endl;

    // Let's launch another task.
    hpx::future<double> g = hpx::async([]() { return 3.14; });

    // Tasks can be chained using the then method. The continuation takes the
    // future as an argument.
    hpx::future<double> result = g.then([](hpx::future<double>&& gg) {
        // This function will be called once g is ready. gg is g moved
        // into the continuation.
        return gg.get() * 42.0 * 42.0;
    });

    // You can check if a future is ready with the is_ready method.
    std::cout << "Result is ready? " << result.is_ready() << std::endl;

    // You can launch other work in the meantime. Let's sort a vector.
    std::vector<int> v(1000000);

    // We fill the vector synchronously and sequentially.
    hpx::generate(hpx::execution::seq, std::begin(v), std::end(v), &std::rand);

    // We can launch the sort in parallel and asynchronously.
    hpx::future<void> done_sorting =
        hpx::sort(hpx::execution::par(           // In parallel.
                 hpx::execution::task),       // Asynchronously.
```

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```
        std::begin(v), std::end(v));

    // We launch the final task when the vector has been sorted and result is
    // ready using when_all.
    auto all = hpx::when_all(result, done_sorting).then(&final_task);

    // We can wait for all to be ready.
    all.wait();

    // all must be ready at this point because we waited for it to be ready.
    std::cout << (all.is_ready() ? "all is ready!" : "all is not ready...")
               << std::endl;

    return hpx::local::finalize();
}

int main(int argc, char* argv[])
{
    return hpx::local::init(hpx_main, argc, argv);
}
```

Try copying the contents to your `main.cpp` file and look at the output. It can be a good idea to go through the program step by step with a debugger. You can also try changing the types or adding new arguments to functions to make sure you can get the types to match. The type of the `then` method can be especially tricky to get right (the continuation needs to take the future as an argument).

Note: *HPX* programs accept command line arguments. The most important one is `--hpx:threads=N` to set the number of OS threads used by *HPX*. *HPX* uses one thread per core by default. Play around with the example above and see what difference the number of threads makes on the `sort` function. See [Launching and configuring HPX applications](#) for more details on how and what options you can pass to *HPX*.

Tip: The example above used the construction `hpx::when_all(...).then(...)`. For convenience and performance it is a good idea to replace uses of `hpx::when_all(...).then(...)` with `dataflow`. See [Dataflow](#) for more details on `dataflow`.

Tip: If possible, try to use the provided parallel algorithms instead of writing your own implementation. This can save you time and the resulting program is often faster.

2.1.4 Next steps

If you haven't done so already, reading the *Terminology* section will help you get familiar with the terms used in *HPX*. The *Examples* section contains small, self-contained walkthroughs of example *HPX* programs. The *Local to remote* example is a thorough, realistic example starting from a single node implementation and going stepwise to a distributed implementation.

The *Manual* contains detailed information on writing, building and running *HPX* applications.

2.2 Examples

The following sections analyze some examples to help you get familiar with the *HPX* style of programming. We start off with simple examples that utilize basic *HPX* elements and then begin to expose the reader to the more complex and powerful *HPX* concepts. Section *Building tests and examples* shows how you can build the examples.

2.2.1 Asynchronous execution

The Fibonacci sequence is a sequence of numbers starting with 0 and 1 where every subsequent number is the sum of the previous two numbers. In this example, we will use *HPX* to calculate the value of the *n*-th element of the Fibonacci sequence. In order to compute this problem in parallel, we will use a facility known as a future.

As shown in the Fig. 2.1 below, a future encapsulates a delayed computation. It acts as a proxy for a result initially not known, most of the time because the computation of the result has not completed yet. The future synchronizes the access of this value by optionally suspending any *HPX*-threads requesting the result until the value is available. When a future is created, it spawns a new *HPX*-thread (either remotely with a *parcel* or locally by placing it into the thread queue) which, when run, will execute the function associated with the future. The arguments of the function are bound when the future is created.

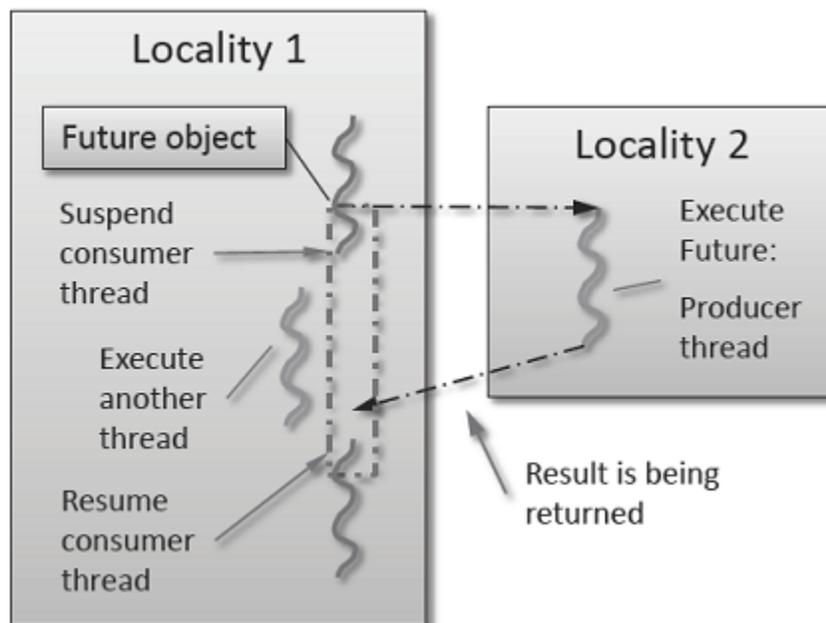


Fig. 2.1: Schematic of a future execution.

Once the function has finished executing, a write operation is performed on the future. The write operation marks the future as completed, and optionally stores data returned by the function. When the result of the delayed computation is needed, a read operation is performed on the future. If the future's function hasn't completed when a read operation is performed on it, the reader *HPX*-thread is suspended until the future is ready. The future facility allows *HPX* to schedule work early in a program so that when the function value is needed it will already be calculated and available. We use this property in our Fibonacci example below to enable its parallel execution.

Setup

The source code for this example can be found here: `fibonacci_local.cpp`.

To compile this program, go to your *HPX* build directory (see *Building HPX* for information on configuring and building *HPX*) and enter:

```
$ make examples.quickstart.fibonacci_local
```

To run the program type:

```
$ ./bin/fibonacci_local
```

This should print (time should be approximate):

```
fibonacci(10) == 55
elapsed time: 0.002430 [s]
```

This run used the default settings, which calculate the tenth element of the Fibonacci sequence. To declare which Fibonacci value you want to calculate, use the `--n-value` option. Additionally you can use the `--hpx:threads` option to declare how many OS-threads you wish to use when running the program. For instance, running:

```
$ ./bin/fibonacci --n-value 20 --hpx:threads 4
```

Will yield:

```
fibonacci(20) == 6765
elapsed time: 0.062854 [s]
```

Walkthrough

Now that you have compiled and run the code, let's look at how the code works. Since this code is written in C++, we will begin with the `main()` function. Here you can see that in *HPX*, `main()` is only used to initialize the runtime system. It is important to note that application-specific command line options are defined here. *HPX* uses `Boost.Program_options`⁷ for command line processing. You can see that our programs `--n-value` option is set by calling the `add_options()` method on an instance of `hpx::program_options::options_description`. The default value of the variable is set to 10. This is why when we ran the program for the first time without using the `--n-value` option the program returned the 10th value of the Fibonacci sequence. The constructor argument of the description is the text that appears when a user uses the `--hpx:help` option to see what command line options are available. `HPX_APPLICATION_STRING` is a macro that expands to a string constant containing the name of the *HPX* application currently being compiled.

In *HPX* `main()` is used to initialize the runtime system and pass the command line arguments to the program. If you wish to add command line options to your program you would add them here using the instance of the Boost class `options_description`, and invoking the public member function `.add_options()` (see *Boost Documentation*⁸ for more details). `hpx::init` calls `hpx_main()` after setting up *HPX*, which is where the logic of our program is encoded.

⁷ https://www.boost.org/doc/html/program_options.html

⁸ <https://www.boost.org/doc/>

```

int main(int argc, char* argv[])
{
    // Configure application-specific options
    hpx::program_options::options_description desc_commandline(
        "Usage: " HPX_APPLICATION_STRING " [options]");

    // clang-format off
    desc_commandline.add_options()
        ("n-value",
         hpx::program_options::value<std::uint64_t>()->default_value(10),
         "n value for the Fibonacci function")
        ;
    // clang-format on

    // Initialize and run HPX
    hpx::local::init_params init_args;
    init_args.desc_cmdline = desc_commandline;

    return hpx::local::init(hpx_main, argc, argv, init_args);
}

```

The `hpx::init` function in `main()` starts the runtime system, and invokes `hpx_main()` as the first *HPX*-thread. Below we can see that the basic program is simple. The command line option `--n-value` is read in, a timer (`hpx::chrono::high_resolution_timer`) is set up to record the time it takes to do the computation, the fibonacci function is invoked synchronously, and the answer is printed out.

```

int hpx_main(hpx::program_options::variables_map& vm)
{
    hpx::threads::add_scheduler_mode(
        hpx::threads::policies::scheduler_mode::fast_idle_mode);

    // extract command line argument, i.e. fib(N)
    std::uint64_t n = vm["n-value"].as<std::uint64_t>();

    {
        // Keep track of the time required to execute.
        hpx::chrono::high_resolution_timer t;

        std::uint64_t r = fibonacci(n);

        char const* fmt = "fibonacci({1}) == {2}\\nelapsed time: {3} [s]\\n";
        hpx::util::format_to(std::cout, fmt, n, r, t.elapsed());
    }

    return hpx::local::finalize();    // Handles HPX shutdown
}

```

The fibonacci function itself is synchronous as the work done inside is asynchronous. To understand what is happening we have to look inside the fibonacci function:

```

std::uint64_t fibonacci(std::uint64_t n)
{
    if (n < 2)

```

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```
    return n;

    hpx::future<std::uint64_t> n1 = hpx::async(fibonacci, n - 1);
    std::uint64_t n2 = fibonacci(n - 2);

    return n1.get() + n2;    // wait for the Future to return their values
}
```

This block of code looks similar to regular C++ code. First, if $(n < 2)$, meaning n is 0 or 1, then we return 0 or 1 (recall the first element of the Fibonacci sequence is 0 and the second is 1). If n is larger than 1 we spawn two new tasks whose results are contained in $n1$ and $n2$. This is done using `hpx::async` which takes as arguments a function (function pointer, object or lambda) and the arguments to the function. Instead of returning a `std::uint64_t` like `fibonacci` does, `hpx::async` returns a future of a `std::uint64_t`, i.e. `hpx::future<std::uint64_t>`. Each of these futures represents an asynchronous, recursive call to `fibonacci`. After we've created the futures, we wait for both of them to finish computing, we add them together, and return that value as our result. We get the values from the futures using the `get` method. The recursive call tree will continue until n is equal to 0 or 1, at which point the value can be returned because it is implicitly known. When this termination condition is reached, the futures can then be added up, producing the n -th value of the Fibonacci sequence.

Note that calling `get` potentially blocks the calling *HPX*-thread, and lets other *HPX*-threads run in the meantime. There are, however, more efficient ways of doing this. `examples/quickstart/fibonacci_futures.cpp` contains many more variations of locally computing the Fibonacci numbers, where each method makes different tradeoffs in where asynchrony and parallelism is applied. To get started, however, the method above is sufficient and optimizations can be applied once you are more familiar with *HPX*. The example *Dataflow* presents dataflow, which is a way to more efficiently chain together multiple tasks.

2.2.2 Parallel algorithms

This program will perform a matrix multiplication in parallel. The output will look something like this:

```
Matrix A is :
4 9 6
1 9 8

Matrix B is :
4 9
6 1
9 8

Resultant Matrix is :
124 93
130 82
```

Setup

The source code for this example can be found here: `matrix_multiplication.cpp`.

To compile this program, go to your *HPX* build directory (see *Building HPX* for information on configuring and building *HPX*) and enter:

```
$ make examples.quickstart.matrix_multiplication
```

To run the program type:

```
$ ./bin/matrix_multiplication
```

or:

```
$ ./bin/matrix_multiplication --n 2 --m 3 --k 2 --s 100 --l 0 --u 10
```

where the first matrix is $n \times m$ and the second $m \times k$, s is the seed for creating the random values of the matrices and the range of these values is $[l,u]$

This should print:

```
Matrix A is :
4 9 6
1 9 8

Matrix B is :
4 9
6 1
9 8

Resultant Matrix is :
124 93
130 82
```

Notice that the numbers may be different because of the random initialization of the matrices.

Walkthrough

Now that you have compiled and run the code, let's look at how the code works.

First, `main()` is used to initialize the runtime system and pass the command line arguments to the program. `hpx::init` calls `hpx_main()` after setting up HPX, which is where our program is implemented.

```
int main(int argc, char* argv[])
{
    using namespace hpx::program_options;
    options_description cmdline("usage: " HPX_APPLICATION_STRING " [options]");
    // clang-format off
    cmdline.add_options()
        ("n",
         hpx::program_options::value<std::size_t>()->default_value(2),
         "Number of rows of first matrix")
        ("m",
         hpx::program_options::value<std::size_t>()->default_value(3),
```

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```

    "Number of columns of first matrix (equal to the number of rows of "
    "second matrix)")
    ("k",
    hpx::program_options::value<std::size_t>()->default_value(2),
    "Number of columns of second matrix")
    ("seed,s",
    hpx::program_options::value<unsigned int>(),
    "The random number generator seed to use for this run")
    ("l",
    hpx::program_options::value<int>()->default_value(0),
    "Lower limit of range of values")
    ("u",
    hpx::program_options::value<int>()->default_value(10),
    "Upper limit of range of values");
    // clang-format on
    hpx::local::init_params init_args;
    init_args.desc_cmdline = cmdline;

    return hpx::local::init(hpx_main, argc, argv, init_args);
}

```

Proceeding to the `hpx_main()` function, we can see that matrix multiplication can be done very easily.

```

int hpx_main(hpx::program_options::variables_map& vm)
{
    using element_type = int;

    // Define matrix sizes
    std::size_t const rowsA = vm["n"].as<std::size_t>();
    std::size_t const colsA = vm["m"].as<std::size_t>();
    std::size_t const rowsB = colsA;
    std::size_t const colsB = vm["k"].as<std::size_t>();
    std::size_t const rowsR = rowsA;
    std::size_t const colsR = colsB;

    // Initialize matrices A and B
    std::vector<int> A(rowsA * colsA);
    std::vector<int> B(rowsB * colsB);
    std::vector<int> R(rowsR * colsR);

    // Define seed
    unsigned int seed = std::random_device{}();
    if (vm.count("seed"))
        seed = vm["seed"].as<unsigned int>();

    gen.seed(seed);
    std::cout << "using seed: " << seed << std::endl;

    // Define range of values
    int const lower = vm["l"].as<int>();
    int const upper = vm["u"].as<int>();
}

```

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```

// Matrices have random values in the range [lower, upper]
std::uniform_int_distribution<element_type> dis(lower, upper);
auto generator = std::bind(dis, gen);
hpx::ranges::generate(A, generator);
hpx::ranges::generate(B, generator);

// Perform matrix multiplication
hpx::experimental::for_loop(hpx::execution::par, 0, rowsA, [&](auto i) {
    hpx::experimental::for_loop(0, colsB, [&](auto j) {
        R[i * colsR + j] = 0;
        hpx::experimental::for_loop(0, rowsB, [&](auto k) {
            R[i * colsR + j] += A[i * colsA + k] * B[k * colsB + j];
        });
    });
});

// Print all 3 matrices
print_matrix(A, rowsA, colsA, "A");
print_matrix(B, rowsB, colsB, "B");
print_matrix(R, rowsR, colsR, "R");

return hpx::local::finalize();
}

```

First, the dimensions of the matrices are defined. If they were not given as command-line arguments, their default values are 2 x 3 for the first matrix and 3 x 2 for the second. We use standard vectors to define the matrices to be multiplied as well as the resultant matrix.

To give some random initial values to our matrices, we use `std::uniform_int_distribution`⁹. Then, `std::bind()` is used along with `hpx::ranges::generate()` to yield two matrices A and B, which contain values in the range of [0, 10] or in the range defined by the user at the command-line arguments. The seed to generate the values can also be defined by the user.

The next step is to perform the matrix multiplication in parallel. This can be done by just using an `hpx::experimental::for_loop` combined with a parallel execution policy `hpx::execution::par` as the outer loop of the multiplication. Note that the execution of `hpx::experimental::for_loop` without specifying an execution policy is equivalent to specifying `hpx::execution::seq` as the execution policy.

Finally, the matrices A, B that are multiplied as well as the resultant matrix R are printed using the following function.

```

void print_matrix(std::vector<int> const& M, std::size_t rows, std::size_t cols,
    char const* message)
{
    std::cout << "\nMatrix " << message << " is:" << std::endl;
    for (std::size_t i = 0; i < rows; i++)
    {
        for (std::size_t j = 0; j < cols; j++)
            std::cout << M[i * cols + j] << " ";
        std::cout << "\n";
    }
}

```

⁹ https://en.cppreference.com/w/cpp/numeric/random/uniform_int_distribution

2.2.3 Asynchronous execution with actions

This example extends the *previous example* by introducing *actions*: functions that can be run remotely. In this example, however, we will still only run the action locally. The mechanism to execute *actions* stays the same: `hpx::async`. Later examples will demonstrate running actions on remote *localities* (e.g. *Remote execution with actions*).

Setup

The source code for this example can be found here: `fibonacci.cpp`.

To compile this program, go to your *HPX* build directory (see *Building HPX* for information on configuring and building *HPX*) and enter:

```
$ make examples.quickstart.fibonacci
```

To run the program type:

```
$ ./bin/fibonacci
```

This should print (time should be approximate):

```
fibonacci(10) == 55
elapsed time: 0.00186288 [s]
```

This run used the default settings, which calculate the tenth element of the Fibonacci sequence. To declare which Fibonacci value you want to calculate, use the `--n-value` option. Additionally you can use the `--hpx:threads` option to declare how many OS-threads you wish to use when running the program. For instance, running:

```
$ ./bin/fibonacci --n-value 20 --hpx:threads 4
```

Will yield:

```
fibonacci(20) == 6765
elapsed time: 0.233827 [s]
```

Walkthrough

The code needed to initialize the *HPX* runtime is the same as in the *previous example*:

```
int main(int argc, char* argv[])
{
    // Configure application-specific options
    hpx::program_options::options_description desc_commandline(
        "Usage: " HPX_APPLICATION_STRING " [options]");

    desc_commandline.add_options("n-value",
        hpx::program_options::value<std::uint64_t>()->default_value(10),
        "n value for the Fibonacci function");

    // Initialize and run HPX
    hpx::init_params init_args;
    init_args.desc_cmdline = desc_commandline;
```

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```

    return hpx::init(argc, argv, init_args);
}

```

The `hpx::init` function in `main()` starts the runtime system, and invokes `hpx_main()` as the first *HPX*-thread. The command line option `--n-value` is read in, a timer (`hpx::chrono::high_resolution_timer`) is set up to record the time it takes to do the computation, the `fibonacci` *action* is invoked synchronously, and the answer is printed out.

```

int hpx_main(hpx::program_options::variables_map& vm)
{
    // extract command line argument, i.e. fib(N)
    std::uint64_t n = vm["n-value"].as<std::uint64_t>();

    {
        // Keep track of the time required to execute.
        hpx::chrono::high_resolution_timer t;

        // Wait for fib() to return the value
        fibonacci_action fib;
        std::uint64_t r = fib(hpx::find_here(), n);

        char const* fmt = "fibonacci({1}) == {2}\\nelapsed time: {3} [s]\\n";
        hpx::util::format_to(std::cout, fmt, n, r, t.elapsed());
    }

    return hpx::finalize();    // Handles HPX shutdown
}

```

Upon a closer look we see that we've created a `std::uint64_t` to store the result of invoking our `fibonacci_action` `fib`. This *action* will launch synchronously (as the work done inside of the *action* will be asynchronous itself) and return the result of the Fibonacci sequence. But wait, what is an *action*? And what is this `fibonacci_action`? For starters, an *action* is a wrapper for a function. By wrapping functions, *HPX* can send packets of work to different processing units. These vehicles allow users to calculate work now, later, or on certain nodes. The first argument to our *action* is the location where the *action* should be run. In this case, we just want to run the *action* on the machine that we are currently on, so we use `hpx::find_here`. To further understand this we turn to the code to find where `fibonacci_action` was defined:

```

// forward declaration of the Fibonacci function
std::uint64_t fibonacci(std::uint64_t n);

// This is to generate the required boilerplate we need for the remote
// invocation to work.
HPX_PLAIN_ACTION(fibonacci, fibonacci_action)

```

A plain *action* is the most basic form of *action*. Plain *actions* wrap simple global functions which are not associated with any particular object (we will discuss other types of *actions* in *Components and actions*). In this block of code the function `fibonacci()` is declared. After the declaration, the function is wrapped in an *action* in the declaration `HPX_PLAIN_ACTION`. This function takes two arguments: the name of the function that is to be wrapped and the name of the *action* that you are creating.

This picture should now start making sense. The function `fibonacci()` is wrapped in an *action* `fibonacci_action`, which was run synchronously but created asynchronous work, then returns a `std::uint64_t` representing the result of the function `fibonacci()`. Now, let's look at the function `fibonacci()`:

```

std::uint64_t fibonacci(std::uint64_t n)
{
    if (n < 2)
        return n;

    // We restrict ourselves to execute the Fibonacci function locally.
    hpx::id_type const locality_id = hpx::find_here();

    // Invoking the Fibonacci algorithm twice is inefficient.
    // However, we intentionally demonstrate it this way to create some
    // heavy workload.

    fibonacci_action fib;
    hpx::future<std::uint64_t> n1 = hpx::async(fib, locality_id, n - 1);
    hpx::future<std::uint64_t> n2 = hpx::async(fib, locality_id, n - 2);

    return n1.get() +
        n2.get();    // wait for the Futures to return their values
}

```

This block of code is much more straightforward and should look familiar from the *previous example*. First, if ($n < 2$), meaning n is 0 or 1, then we return 0 or 1 (recall the first element of the Fibonacci sequence is 0 and the second is 1). If n is larger than 1 we spawn two tasks using `hpx::async`. Each of these futures represents an asynchronous, recursive call to `fibonacci`. As previously we wait for both futures to finish computing, get the results, add them together, and return that value as our result. The recursive call tree will continue until n is equal to 0 or 1, at which point the value can be returned because it is implicitly known. When this termination condition is reached, the futures can then be added up, producing the n -th value of the Fibonacci sequence.

2.2.4 Remote execution with actions

This program will print out a hello world message on every OS-thread on every *locality*. The output will look something like this:

```

hello world from OS-thread 1 on locality 0
hello world from OS-thread 1 on locality 1
hello world from OS-thread 0 on locality 0
hello world from OS-thread 0 on locality 1

```

Setup

The source code for this example can be found here: `hello_world_distributed.cpp`.

To compile this program, go to your *HPX* build directory (see *Building HPX* for information on configuring and building *HPX*) and enter:

```
$ make examples.quickstart.hello_world_distributed
```

To run the program type:

```
$ ./bin/hello_world_distributed
```

This should print:

```
hello world from OS-thread 0 on locality 0
```

To use more OS-threads use the command line option `--hpx:threads` and type the number of threads that you wish to use. For example, typing:

```
$ ./bin/hello_world_distributed --hpx:threads 2
```

will yield:

```
hello world from OS-thread 1 on locality 0
hello world from OS-thread 0 on locality 0
```

Notice how the ordering of the two print statements will change with subsequent runs. To run this program on multiple localities please see the section *How to use HPX applications with PBS*.

Walkthrough

Now that you have compiled and run the code, let's look at how the code works, beginning with `main()`:

```
// Here is the main entry point. By using the include 'hpx/hpx_main.hpp' HPX
// will invoke the plain old C-main() as its first HPX thread.
int main()
{
    // Get a list of all available localities.
    std::vector<hpx::id_type> localities = hpx::find_all_localities();

    // Reserve storage space for futures, one for each locality.
    std::vector<hpx::future<void>> futures;
    futures.reserve(localities.size());

    for (hpx::id_type const& node : localities)
    {
        // Asynchronously start a new task. The task is encapsulated in a
        // future, which we can query to determine if the task has
        // completed.
        typedef hello_world_foreman_action action_type;
        futures.push_back(hpx::async<action_type>(node));
    }

    // The non-callback version of hpx::wait_all takes a single parameter,
    // a vector of futures to wait on. hpx::wait_all only returns when
    // all of the futures have finished.
    hpx::wait_all(futures);
    return 0;
}
```

In this excerpt of the code we again see the use of futures. This time the futures are stored in a vector so that they can easily be accessed. `hpx::wait_all` is a family of functions that wait on for an `std::vector<>` of futures to become ready. In this piece of code, we are using the synchronous version of `hpx::wait_all`, which takes one argument (the `std::vector<>` of futures to wait on). This function will not return until all the futures in the vector have been executed.

In *Asynchronous execution with actions* we used `hpx::find_here` to specify the target of our actions. Here, we instead use `hpx::find_all_localities`, which returns an `std::vector<>` containing the identifiers of all the machines

in the system, including the one that we are on.

As in *Asynchronous execution with actions* our futures are set using `hpx::async<>`. The `hello_world_foreman_action` is declared here:

```
// Define the boilerplate code necessary for the function 'hello_world_foreman'
// to be invoked as an HPX action.
HPX_PLAIN_ACTION(hello_world_foreman, hello_world_foreman_action)
```

Another way of thinking about this wrapping technique is as follows: functions (the work to be done) are wrapped in actions, and actions can be executed locally or remotely (e.g. on another machine participating in the computation).

Now it is time to look at the `hello_world_foreman()` function which was wrapped in the action above:

```
void hello_world_foreman()
{
    // Get the number of worker OS-threads in use by this locality.
    std::size_t const os_threads = hpx::get_os_thread_count();

    // Populate a set with the OS-thread numbers of all OS-threads on this
    // locality. When the hello world message has been printed on a particular
    // OS-thread, we will remove it from the set.
    std::set<std::size_t> attendance;
    for (std::size_t os_thread = 0; os_thread < os_threads; ++os_thread)
        attendance.insert(os_thread);

    // As long as there are still elements in the set, we must keep scheduling
    // HPX-threads. Because HPX features work-stealing task schedulers, we have
    // no way of enforcing which worker OS-thread will actually execute
    // each HPX-thread.
    while (!attendance.empty())
    {
        // Each iteration, we create a task for each element in the set of
        // OS-threads that have not said "Hello world". Each of these tasks
        // is encapsulated in a future.
        std::vector<hpx::future<std::size_t>> futures;
        futures.reserve(attendance.size());

        for (std::size_t worker : attendance)
        {
            // Asynchronously start a new task. The task is encapsulated in a
            // future that we can query to determine if the task has completed.
            //
            // We give the task a hint to run on a particular worker thread
            // (core) and suggest binding the scheduled thread to the given
            // core, but no guarantees are given by the scheduler that the task
            // will actually run on that worker thread. It will however try as
            // hard as possible to place the new task on the given worker
            // thread.
            hpx::execution::parallel_executor exec(
                hpx::threads::thread_priority::bound);

            hpx::threads::thread_schedule_hint hint(
                hpx::threads::thread_schedule_hint_mode::thread,
                static_cast<std::int16_t>(worker));
```

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```

    futures.push_back(
        hpx::async(hpx::execution::experimental::with_hint(exec, hint),
            hello_world_worker, worker));
}

// Wait for all of the futures to finish. The callback version of the
// hpx::wait_each function takes two arguments: a vector of futures,
// and a binary callback. The callback takes two arguments; the first
// is the index of the future in the vector, and the second is the
// return value of the future. hpx::wait_each doesn't return until
// all the futures in the vector have returned.
hpx::spinlock mtx;
hpx::wait_each(hpx::unwrapping([&](std::size_t t) {
    if (std::size_t(-1) != t)
    {
        std::lock_guard<hpx::spinlock> lk(mtx);
        attendance.erase(t);
    }
})),
    futures);
}
}

```

Now, before we discuss `hello_world_foreman()`, let's talk about the `hpx::wait_each` function. The version of `hpx::wait_each` invokes a callback function provided by the user, supplying the callback function with the result of the future.

In `hello_world_foreman()`, an `std::set<>` called `attendance` keeps track of which OS-threads have printed out the hello world message. When the OS-thread prints out the statement, the future is marked as ready, and `hpx::wait_each` in `hello_world_foreman()`. If it is not executing on the correct OS-thread, it returns a value of -1, which causes `hello_world_foreman()` to leave the OS-thread id in `attendance`.

```

std::size_t hello_world_worker(std::size_t desired)
{
    // Returns the OS-thread number of the worker that is running this
    // HPX-thread.
    std::size_t current = hpx::get_worker_thread_num();
    if (current == desired)
    {
        // The HPX-thread has been run on the desired OS-thread.
        char const* msg = "hello world from OS-thread {1} on locality {2}\n";

        hpx::util::format_to(hpx::cout, msg, desired, hpx::get_locality_id())
            << std::flush;

        return desired;
    }

    // This HPX-thread has been run by the wrong OS-thread, make the foreman
    // try again by rescheduling it.
    return std::size_t(-1);
}

```

Because *HPX* features work stealing task schedulers, there is no way to guarantee that an action will be scheduled on a particular OS-thread. This is why we must use a guess-and-check approach.

2.2.5 Components and actions

The accumulator examples demonstrate the use of components. Components are C++ classes that expose methods as a type of *HPX* action. These actions are called component actions. There are three examples: - accumulator - template accumulator - template function accumulator

Components are globally named, meaning that a component action can be called remotely (e.g., from another machine). There are two accumulator examples in *HPX*.

In the *Asynchronous execution with actions* and the *Remote execution with actions*, we introduced plain actions, which wrapped global functions. The target of a plain action is an identifier which refers to a particular machine involved in the computation. For plain actions, the target is the machine where the action will be executed.

Component actions, however, do not target machines. Instead, they target component instances. The instance may live on the machine that we've invoked the component action from, or it may live on another machine.

The components in these examples expose three different functions:

- `reset()` - Resets the accumulator value to 0.
- `add(arg)` - Adds `arg` to the accumulators value.
- `query()` - Queries the value of the accumulator.

These examples create an instance of the (template or template function) accumulator, and then allow the user to enter commands at a prompt, which subsequently invoke actions on the accumulator instance.

Accumulator

Setup

The source code for this example can be found here: `accumulator_client.cpp`.

To compile this program, go to your *HPX* build directory (see *Building HPX* for information on configuring and building *HPX*) and enter:

```
$ make examples.accumulators.accumulator
```

To run the program type:

```
$ ./bin/accumulator_client
```

Once the program starts running, it will print the following prompt and then wait for input. An example session is given below:

```
commands: reset, add [amount], query, help, quit
> add 5
> add 10
> query
15
> add 2
> query
17
```

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```
> reset
> add 1
> query
1
> quit
```

Walkthrough

Now, let's take a look at the source code of the accumulator example. This example consists of two parts: an *HPX* component library (a library that exposes an *HPX* component) and a client application which uses the library. This walkthrough will cover the *HPX* component library. The code for the client application can be found here: `accumulator_client.cpp`.

An *HPX* component is represented by two C++ classes:

- **A server class** - The implementation of the component's functionality.
- **A client class** - A high-level interface that acts as a proxy for an instance of the component.

Typically, these two classes both have the same name, but the server class usually lives in different sub-namespaces (server). For example, the full names of the two classes in `accumulator` are:

- `examples::server::accumulator` (server class)
- `examples::accumulator` (client class)

The server class

The following code is from `server/accumulator.hpp`¹⁰.

All *HPX* component server classes must inherit publicly from the *HPX* component base class: `hpx::components::component_base`

The accumulator component inherits from `hpx::components::locking_hook`. This allows the runtime system to ensure that all action invocations are serialized. That means that the system ensures that no two actions are invoked at the same time on a given component instance. This makes the component thread safe and no additional locking has to be implemented by the user. Moreover, an accumulator component is a component because it also inherits from `hpx::components::component_base` (the template argument passed to `locking_hook` is used as its base class). The following snippet shows the corresponding code:

```
class accumulator
: public hpx::components::locking_hook<
  hpx::components::component_base<accumulator>>
```

Our accumulator class will need a data member to store its value in, so let's declare a data member:

```
argument_type value_;
```

The constructor for this class simply initializes `value_` to 0:

¹⁰ <http://github.com/STELLAR-GROUP/hpx/blob/8a3b7c1a4cb5693b2f7d9f587f759392ed0c51a0/examples/accumulators/server/accumulator.hpp>

```

    accumulator()
      : value_(0)
    {
    }

```

Next, let's look at the three methods of this component that we will be exposing as component actions:

Here are the action types. These types wrap the methods we're exposing. The wrapping technique is very similar to the one used in the *Asynchronous execution with actions* and the *Remote execution with actions*:

```

HPX_DEFINE_COMPONENT_ACTION(accumulator, reset)
HPX_DEFINE_COMPONENT_ACTION(accumulator, add)
HPX_DEFINE_COMPONENT_ACTION(accumulator, query)

```

The last piece of code in the server class header is the declaration of the action type registration code:

```

HPX_REGISTER_ACTION_DECLARATION(
    examples::server::accumulator::reset_action, accumulator_reset_action)

HPX_REGISTER_ACTION_DECLARATION(
    examples::server::accumulator::add_action, accumulator_add_action)

HPX_REGISTER_ACTION_DECLARATION(
    examples::server::accumulator::query_action, accumulator_query_action)

```

Note: The code above must be placed in the global namespace.

The rest of the registration code is in `accumulator.cpp`¹¹

```

////////////////////////////////////
// Add factory registration functionality.
HPX_REGISTER_COMPONENT_MODULE()

////////////////////////////////////
typedef hpx::components::component<examples::server::accumulator>
    accumulator_type;

HPX_REGISTER_COMPONENT(accumulator_type, accumulator)

////////////////////////////////////
// Serialization support for accumulator actions.
HPX_REGISTER_ACTION(
    accumulator_type::wrapped_type::reset_action, accumulator_reset_action)
HPX_REGISTER_ACTION(
    accumulator_type::wrapped_type::add_action, accumulator_add_action)
HPX_REGISTER_ACTION(
    accumulator_type::wrapped_type::query_action, accumulator_query_action)

```

Note: The code above must be placed in the global namespace.

¹¹ <http://github.com/STELLAR-GROUP/hpx/blob/8a3b7c1a4cb5693b2f7d9f587f759392ed0c51a0/examples/accumulators/accumulator.cpp>

The client class

The following code is from `accumulator.hpp`¹²

The client class is the primary interface to a component instance. Client classes are used to create components:

```
// Create a component on this locality.
examples::accumulator c = hpx::new_<examples::accumulator>(hpx::find_here());
```

and to invoke component actions:

```
c.add(hpx::launch::apply, 4);
```

Clients, like servers, need to inherit from a base class, this time, `hpx::components::client_base`:

```
class accumulator
: public hpx::components::client_base<accumulator, server::accumulator>
```

For readability, we typedef the base class like so:

```
typedef hpx::components::client_base<accumulator, server::accumulator>
base_type;
```

Here are examples of how to expose actions through a client class:

There are a few different ways of invoking actions:

- **Non-blocking:** For actions that don't have return types, or when we do not care about the result of an action, we can invoke the action using fire-and-forget semantics. This means that once we have asked *HPX* to compute the action, we forget about it completely and continue with our computation. We use `hpx::post` to invoke an action in a non-blocking fashion.

```
void reset(hpx::launch::apply_policy)
{
    HPX_ASSERT(this->get_id());

    typedef server::accumulator::reset_action action_type;
    hpx::post(action_type(), this->get_id());
}
```

- **Asynchronous:** Futures, as demonstrated in *Asynchronous execution*, *Asynchronous execution with actions*, and the *Remote execution with actions*, enable asynchronous action invocation. Here's an example from the accumulator client class:

```
hpx::future<argument_type> query(hpx::launch::async_policy)
{
    HPX_ASSERT(this->get_id());

    typedef server::accumulator::query_action action_type;
    return hpx::async(action_type(), this->get_id());
}
```

- **Synchronous:** To invoke an action in a fully synchronous manner, we can simply call `hpx::sync` which is semantically equivalent to `hpx::async().get()` (i.e., create a future and immediately wait on it to be ready). Here's an example from the accumulator client class:

¹² <http://github.com/STELLAR-GROUP/hpx/blob/8a3b7c1a4cb5693b2f7d9f587f759392ed0c51a0/examples/accumulators/accumulator.hpp>

```

void add(argument_type arg)
{
    HPX_ASSERT(this->get_id());

    typedef server::accumulator::add_action action_type;
    action_type()(this->get_id(), arg);
}

```

Note that `this->get_id()` references a data member of the `hpx::components::client_base` base class which identifies the server accumulator instance.

`hpx::id_type` is a type which represents a global identifier in *HPX*. This type specifies the target of an action. This is the type that is returned by `hpx::find_here` in which case it represents the *locality* the code is running on.

Template accumulator

Walkthrough

The server class

The following code is from `server/template_accumulator.hpp`¹³.

Similarly to the accumulator example, the component server class inherits publicly from `hpx::components::component_base` and from `hpx::components::locking_hook` ensuring thread-safe method invocations.

```

template <typename T>
class template_accumulator
: public hpx::components::locking_hook<
    hpx::components::component_base<template_accumulator<T>>>

```

The body of the template accumulator class remains mainly the same as the accumulator with the difference that it uses templates in the data types.

```

typedef T argument_type;

template_accumulator()
: value_(0)
{
}

////////////////////////////////////
// Exposed functionality of this component.

/// Reset the components value to 0.
void reset()
{
    // set value_ to 0.
    value_ = 0;
}

```

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¹³ http://github.com/STELLAR-GROUP/hpx/blob/8a3b7c1a4cb5693b2f7d9f587f759392ed0c51a0/examples/accumulators/server/template_accumulator.hpp

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```

    /// Add the given number to the accumulator.
    void add(argument_type arg)
    {
        // add value_ to arg, and store the result in value_.
        value_ += arg;
    }

    /// Return the current value to the caller.
    argument_type query() const
    {
        // Get the value of value_.
        return value_;
    }

    //////////////////////////////////////
    // Each of the exposed functions needs to be encapsulated into an
    // action type, generating all required boilerplate code for threads,
    // serialization, etc.
    HPX_DEFINE_COMPONENT_ACTION(template_accumulator, reset)
    HPX_DEFINE_COMPONENT_ACTION(template_accumulator, add)
    HPX_DEFINE_COMPONENT_ACTION(template_accumulator, query)

```

The last piece of code in the server class header is the declaration of the action type registration code. *REGISTER_TEMPLATE_ACCUMULATOR_DECLARATION*(*type*) declares actions for the specified type, while *REGISTER_TEMPLATE_ACCUMULATOR*(*type*) registers the actions and the component for the specified type, using macros to handle boilerplate code.

```

#define REGISTER_TEMPLATE_ACCUMULATOR_DECLARATION(type) \
    HPX_REGISTER_ACTION_DECLARATION( \
        examples::server::template_accumulator<type>::reset_action, \
        HPX_PP_CAT(__template_accumulator_reset_action_, type)) \
 \
    HPX_REGISTER_ACTION_DECLARATION( \
        examples::server::template_accumulator<type>::add_action, \
        HPX_PP_CAT(__template_accumulator_add_action_, type)) \
 \
    HPX_REGISTER_ACTION_DECLARATION( \
        examples::server::template_accumulator<type>::query_action, \
        HPX_PP_CAT(__template_accumulator_query_action_, type)) \
    /**/

#define REGISTER_TEMPLATE_ACCUMULATOR(type) \
    HPX_REGISTER_ACTION( \
        examples::server::template_accumulator<type>::reset_action, \
        HPX_PP_CAT(__template_accumulator_reset_action_, type)) \
 \
    HPX_REGISTER_ACTION( \
        examples::server::template_accumulator<type>::add_action, \
        HPX_PP_CAT(__template_accumulator_add_action_, type)) \
 \
    HPX_REGISTER_ACTION(

```

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```

examples::server::template_accumulator<type>::query_action,      \
HPX_PP_CAT(__template_accumulator_query_action_, type))          \
                                                                    \
typedef ::hpx::components::component<                            \
    examples::server::template_accumulator<type>>                \
    HPX_PP_CAT(__template_accumulator_, type);                    \
HPX_REGISTER_COMPONENT(HPX_PP_CAT(__template_accumulator_, type)) \
/**/

```

Note: The code above must be placed in the global namespace.

Finally, `HPX_REGISTER_COMPONENT_MODULE()` in file `server/template_accumulator.cpp`¹⁴ adds the factory registration functionality.

The client class

The client class of the template accumulator can be found in `template_accumulator.hpp`¹⁵ and is very similar to the client class of the accumulator with the only difference that it uses templates and hence can work with different types.

Template function accumulator

Walkthrough

The server class

The following code is from `server/template_function_accumulator.hpp`¹⁶.

The component server class inherits publicly from `hpx::components::component_base`.

```

class template_function_accumulator
: public hpx::components::component_base<template_function_accumulator>

```

`typedef hpx::spinlock mutex_type` defines a `mutex_type` as `hpx::spinlock` for thread safety, while the code that follows exposes the functionality of this component.

```

////////////////////////////////////
// Exposed functionality of this component.

/// Reset the value to 0.
void reset()
{
    // Atomically set value_ to 0.
    std::lock_guard<mutex_type> l(mtx_);

```

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¹⁴ http://github.com/STELLAR-GROUP/hpx/blob/8a3b7c1a4cb5693b2f7d9f587f759392ed0c51a0/examples/accumulators/server/template_accumulator.cpp

¹⁵ http://github.com/STELLAR-GROUP/hpx/blob/8a3b7c1a4cb5693b2f7d9f587f759392ed0c51a0/examples/accumulators/template_accumulator.hpp

¹⁶ http://github.com/STELLAR-GROUP/hpx/blob/8a3b7c1a4cb5693b2f7d9f587f759392ed0c51a0/examples/accumulators/server/template_function_accumulator.hpp

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```

    value_ = 0;
}

/// Add the given number to the accumulator.
template <typename T>
void add(T arg)
{
    // Atomically add value_ to arg, and store the result in value_.
    std::lock_guard<mutex_type> l(mtx_);
    value_ += static_cast<double>(arg);
}

/// Return the current value to the caller.
double query() const
{
    // Get the value of value_.
    std::lock_guard<mutex_type> l(mtx_);
    return value_;
}

```

- *reset()*: Resets the accumulator value to 0 in a thread-safe manner using *std::lock_guard*.
- *add()*: Adds a value to the accumulator, allowing any type *T* that can be cast to double.
- *query()*: Returns the current value of the accumulator in a thread-safe manner.

To define the actions for *reset()* and *query()* we can use the macro *HPX_DEFINE_COMPONENT_ACTION*. However, actions with template arguments require special type definitions. Therefore, we use *make_action()* to define *add()*.

```

////////////////////////////////////
// Each of the exposed functions needs to be encapsulated into an
// action type, generating all required boilerplate code for threads,
// serialization, etc.

HPX_DEFINE_COMPONENT_ACTION(template_function_accumulator, reset)
HPX_DEFINE_COMPONENT_ACTION(template_function_accumulator, query)

// Actions with template arguments (see add<>() above) require special
// type definitions. The simplest way to define such an action type is
// by deriving from the HPX facility make_action.
template <typename T>
struct add_action
    : hpx::actions::make_action<void (template_function_accumulator::*)(
        T),
        &template_function_accumulator::template add<T>,
        add_action<T>::type
    {
};

```

The last piece of code in the server class header is the action registration:

```

HPX_REGISTER_ACTION_DECLARATION(
    examples::server::template_function_accumulator::reset_action,
    managed_accumulator_reset_action)

```

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```
HPX_REGISTER_ACTION_DECLARATION(
    examples::server::template_function_accumulator::query_action,
    managed_accumulator_query_action)
```

Note: The code above must be placed in the global namespace.

The rest of the registration code is in `accumulator.cpp`¹⁷

```
////////////////////////////////////
// Add factory registration functionality.
HPX_REGISTER_COMPONENT_MODULE()

////////////////////////////////////
typedef hpx::components::component<
    examples::server::template_function_accumulator>
    accumulator_type;

HPX_REGISTER_COMPONENT(accumulator_type, template_function_accumulator)

////////////////////////////////////
// Serialization support for managed_accumulator actions.
HPX_REGISTER_ACTION(accumulator_type::wrapped_type::reset_action,
    managed_accumulator_reset_action)
HPX_REGISTER_ACTION(accumulator_type::wrapped_type::query_action,
    managed_accumulator_query_action)
```

Note: The code above must be placed in the global namespace.

The client class

The client class of the template accumulator can be found in `template_function_accumulator.hpp`¹⁸ and is very similar to the client class of the accumulator with the only difference that it uses templates and hence can work with different types.

¹⁷ <http://github.com/STELLAR-GROUP/hpx/blob/8a3b7c1a4cb5693b2f7d9f587f759392ed0c51a0/examples/accumulators/accumulator.cpp>

¹⁸ http://github.com/STELLAR-GROUP/hpx/blob/8a3b7c1a4cb5693b2f7d9f587f759392ed0c51a0/examples/accumulators/template_function_accumulator.hpp

2.2.6 Dataflow

HPX provides its users with several different tools to simply express parallel concepts. One of these tools is a *local control object (LCO)* called dataflow. An *LCO* is a type of component that can spawn a new thread when triggered. They are also distinguished from other components by a standard interface that allow users to understand and use them easily. A Dataflow, being an *LCO*, is triggered when the values it depends on become available. For instance, if you have a calculation X that depends on the results of three other calculations, you could set up a dataflow that would begin the calculation X as soon as the other three calculations have returned their values. Dataflows are set up to depend on other dataflows. It is this property that makes dataflow a powerful parallelization tool. If you understand the dependencies of your calculation, you can devise a simple algorithm that sets up a dependency tree to be executed. In this example, we calculate compound interest. To calculate compound interest, one must calculate the interest made in each compound period, and then add that interest back to the principal before calculating the interest made in the next period. A practical person would, of course, use the formula for compound interest:

$$F = P(1 + i)^n$$

where F is the future value, P is the principal value, i is the interest rate, and n is the number of compound periods.

However, for the sake of this example, we have chosen to manually calculate the future value by iterating:

$$I = Pi$$

and

$$P = P + I$$

Setup

The source code for this example can be found here: `interest_calculator.cpp`.

To compile this program, go to your *HPX* build directory (see *Building HPX* for information on configuring and building *HPX*) and enter:

```
$ make examples.quickstart.interest_calculator
```

To run the program type:

```
$ ./bin/interest_calculator --principal 100 --rate 5 --cp 6 --time 36
Final amount: 134.01
Amount made: 34.0096
```

Walkthrough

Let us begin with `main`. Here we can see that we again are using `Boost.Program_options` to set our command line variables (see *Asynchronous execution with actions* for more details). These options set the principal, rate, compound period, and time. It is important to note that the units of time for `cp` and `time` must be the same.

```
int main(int argc, char** argv)
{
    options_description cmdline("Usage: " HPX_APPLICATION_STRING " [options]");

    cmdline.add_options()("principal", value<double>()->default_value(1000),
        "The principal [$]")("rate", value<double>()->default_value(7),
```

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```

    "The interest rate [%]"("cp", value<int>()->default_value(12),
    "The compound period [months]"("time",
    value<int>()->default_value(12 * 30),
    "The time money is invested [months]");

    hpx::init_params init_args;
    init_args.desc_cmdline = cmdline;

    return hpx::init(argc, argv, init_args);
}

```

Next we look at hpx_main.

```

int hpx_main(variables_map& vm)
{
    {
        using hpx::dataflow;
        using hpx::make_ready_future;
        using hpx::shared_future;
        using hpx::unwrapping;
        hpx::id_type here = hpx::find_here();

        double init_principal =
            vm["principal"].as<double>();           //Initial principal
        double init_rate = vm["rate"].as<double>(); //Interest rate
        int cp = vm["cp"].as<int>();                //Length of a compound period
        int t = vm["time"].as<int>();              //Length of time money is invested

        init_rate /= 100; //Rate is a % and must be converted
        t /= cp; //Determine how many times to iterate interest calculation:
                //How many full compound periods can fit in the time invested

        // In non-dataflow terms the implemented algorithm would look like:
        //
        // int t = 5; // number of time periods to use
        // double principal = init_principal;
        // double rate = init_rate;
        //
        // for (int i = 0; i < t; ++i)
        // {
        //     double interest = calc(principal, rate);
        //     principal = add(principal, interest);
        // }
        //
        // Please note the similarity with the code below!

        shared_future<double> principal = make_ready_future(init_principal);
        shared_future<double> rate = make_ready_future(init_rate);

        for (int i = 0; i < t; ++i)
        {
            shared_future<double> interest =

```

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```

        dataflow(unwrapping(calc), principal, rate);
        principal = dataflow(unwrapping(add), principal, interest);
    }

    // wait for the dataflow execution graph to be finished calculating our
    // overall interest
    double result = principal.get();

    std::cout << "Final amount: " << result << std::endl;
    std::cout << "Amount made: " << result - init_principal << std::endl;
}

return hpx::finalize();
}

```

Here we find our command line variables read in, the rate is converted from a percent to a decimal, the number of calculation iterations is determined, and then our shared_futures are set up. Notice that we first place our principal and rate into shares futures by passing the variables `init_principal` and `init_rate` using `hpx::make_ready_future`.

In this way `hpx::shared_future<double>` `principal` and `rate` will be initialized to `init_principal` and `init_rate` when `hpx::make_ready_future<double>` returns a future containing those initial values. These shared futures then enter the for loop and are passed to `interest`. Next `principal` and `interest` are passed to the reassignment of `principal` using a `hpx::dataflow`. A dataflow will first wait for its arguments to be ready before launching any callbacks, so `add` in this case will not begin until both `principal` and `interest` are ready. This loop continues for each compound period that must be calculated. To see how `interest` and `principal` are calculated in the loop, let us look at `calc_action` and `add_action`:

```

// Calculate interest for one period
double calc(double principal, double rate)
{
    return principal * rate;
}

////////////////////////////////////
// Add the amount made to the principal
double add(double principal, double interest)
{
    return principal + interest;
}

```

After the shared future dependencies have been defined in `hpx_main`, we see the following statement:

```
double result = principal.get();
```

This statement calls `hpx::future::get` on the shared future `principal` which had its value calculated by our for loop. The program will wait here until the entire dataflow tree has been calculated and the value assigned to `result`. The program then prints out the final value of the investment and the amount of interest made by subtracting the final value of the investment from the initial value of the investment.

2.2.7 Local to remote

When developers write code they typically begin with a simple serial code and build upon it until all of the required functionality is present. The following set of examples were developed to demonstrate this iterative process of evolving a simple serial program to an efficient, fully-distributed *HPX* application. For this demonstration, we implemented a 1D heat distribution problem. This calculation simulates the diffusion of heat across a ring from an initialized state to some user-defined point in the future. It does this by breaking each portion of the ring into discrete segments and using the current segment's temperature and the temperature of the surrounding segments to calculate the temperature of the current segment in the next timestep as shown by Fig. 2.2 below.

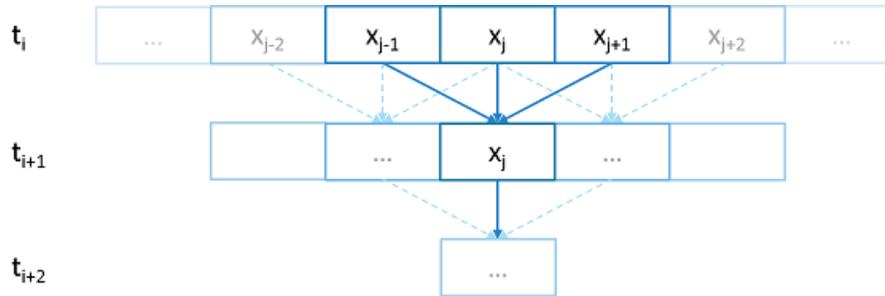


Fig. 2.2: Heat diffusion example program flow.

We parallelize this code over the following eight examples:

- Example 1
- Example 2
- Example 3
- Example 4
- Example 5
- Example 6
- Example 7
- Example 8

The first example is straight serial code. In this code we instantiate a vector *U* that contains two vectors of doubles as seen in the structure stepper.

```
struct stepper
{
    // Our partition type
    typedef double partition;

    // Our data for one time step
    typedef std::vector<partition> space;

    // Our operator
    static double heat(double left, double middle, double right)
    {
        return middle + (k * dt / (dx * dx)) * (left - 2 * middle + right);
    }
}
```

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```

// do all the work on 'nx' data points for 'nt' time steps
space do_work(std::size_t nx, std::size_t nt)
{
    // U[t][i] is the state of position i at time t.
    std::vector<space> U(2);
    for (space& s : U)
        s.resize(nx);

    // Initial conditions: f(0, i) = i
    for (std::size_t i = 0; i != nx; ++i)
        U[0][i] = double(i);

    // Actual time step loop
    for (std::size_t t = 0; t != nt; ++t)
    {
        space const& current = U[t % 2];
        space& next = U[(t + 1) % 2];

        next[0] = heat(current[nx - 1], current[0], current[1]);

        for (std::size_t i = 1; i != nx - 1; ++i)
            next[i] = heat(current[i - 1], current[i], current[i + 1]);

        next[nx - 1] = heat(current[nx - 2], current[nx - 1], current[0]);
    }

    // Return the solution at time-step 'nt'.
    return U[nt % 2];
}
};

```

Each element in the vector of doubles represents a single grid point. To calculate the change in heat distribution, the temperature of each grid point, along with its neighbors, is passed to the function `heat`. In order to improve readability, references named `current` and `next` are created which, depending on the time step, point to the first and second vector of doubles. The first vector of doubles is initialized with a simple heat ramp. After calling the `heat` function with the data in the `current` vector, the results are placed into the `next` vector.

In example 2 we employ a technique called futurization. Futurization is a method by which we can easily transform a code that is serially executed into a code that creates asynchronous threads. In the simplest case this involves replacing a variable with a future to a variable, a function with a future to a function, and adding a `.get()` at the point where a value is actually needed. The code below shows how this technique was applied to the `struct stepper`.

```

struct stepper
{
    // Our partition type
    typedef hpx::shared_future<double> partition;

    // Our data for one time step
    typedef std::vector<partition> space;

    // Our operator
    static double heat(double left, double middle, double right)
    {

```

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```

    return middle + (k * dt / (dx * dx)) * (left - 2 * middle + right);
}

// do all the work on 'nx' data points for 'nt' time steps
hpx::future<space> do_work(std::size_t nx, std::size_t nt)
{
    using hpx::dataflow;
    using hpx::unwrapping;

    // U[t][i] is the state of position i at time t.
    std::vector<space> U(2);
    for (space& s : U)
        s.resize(nx);

    // Initial conditions: f(0, i) = i
    for (std::size_t i = 0; i != nx; ++i)
        U[0][i] = hpx::make_ready_future(double(i));

    auto Op = unwrapping(&stepper::heat);

    // Actual time step loop
    for (std::size_t t = 0; t != nt; ++t)
    {
        space const& current = U[t % 2];
        space& next = U[(t + 1) % 2];

        // WHEN U[t][i-1], U[t][i], and U[t][i+1] have been computed, THEN we
        // can compute U[t+1][i]
        for (std::size_t i = 0; i != nx; ++i)
        {
            next[i] =
                dataflow(hpx::launch::async, Op, current[idx(i, -1, nx)],
                    current[i], current[idx(i, +1, nx)]);
        }
    }

    // Now the asynchronous computation is running; the above for-loop does not
    // wait on anything. There is no implicit waiting at the end of each timestep;
    // the computation of each U[t][i] will begin as soon as its dependencies
    // are ready and hardware is available.

    // Return the solution at time-step 'nt'.
    return hpx::when_all(U[nt % 2]);
}
};

```

In example 2, we redefine our partition type as a `shared_future` and, in `main`, create the object `result`, which is a future to a vector of partitions. We use `result` to represent the last vector in a string of vectors created for each timestep. In order to move to the next timestep, the values of a partition and its neighbors must be passed to `heat` once the futures that contain them are ready. In *HPX*, we have an LCO (Local Control Object) named `Dataflow` that assists the programmer in expressing this dependency. `Dataflow` allows us to pass the results of a set of futures to a specified function when the futures are ready. `Dataflow` takes three types of arguments, one which instructs the dataflow on how to perform the function call (`async` or `sync`), the function to call (in this case `Op`), and futures to the arguments that will

be passed to the function. When called, dataflow immediately returns a future to the result of the specified function. This allows users to string dataflows together and construct an execution tree.

After the values of the futures in dataflow are ready, the values must be pulled out of the future container to be passed to the function `heat`. In order to do this, we use the HPX facility `unwrapping`, which underneath calls `.get()` on each of the futures so that the function `heat` will be passed doubles and not futures to doubles.

By setting up the algorithm this way, the program will be able to execute as quickly as the dependencies of each future are met. Unfortunately, this example runs terribly slow. This increase in execution time is caused by the overheads needed to create a future for each data point. Because the work done within each call to `heat` is very small, the overhead of creating and scheduling each of the three futures is greater than that of the actual useful work! In order to amortize the overheads of our synchronization techniques, we need to be able to control the amount of work that will be done with each future. We call this amount of work per overhead grain size.

In example 3, we return to our serial code to figure out how to control the grain size of our program. The strategy that we employ is to create “partitions” of data points. The user can define how many partitions are created and how many data points are contained in each partition. This is accomplished by creating the struct `partition`, which contains a member object `data_`, a vector of doubles that holds the data points assigned to a particular instance of `partition`.

In example 4, we take advantage of the partition setup by redefining `space` to be a vector of shared_futures with each future representing a partition. In this manner, each future represents several data points. Because the user can define how many data points are in each partition, and, therefore, how many data points are represented by one future, a user can control the grain size of the simulation. The rest of the code is then futurized in the same manner as example 2. It should be noted how strikingly similar example 4 is to example 2.

Example 4 finally shows good results. This code scales equivalently to the OpenMP version. While these results are promising, there are more opportunities to improve the application’s scalability. Currently, this code only runs on one *locality*, but to get the full benefit of *HPX*, we need to be able to distribute the work to other machines in a cluster. We begin to add this functionality in example 5.

In order to run on a distributed system, a large amount of boilerplate code must be added. Fortunately, *HPX* provides us with the concept of a *component*, which saves us from having to write quite as much code. A component is an object that can be remotely accessed using its global address. Components are made of two parts: a server and a client class. While the client class is not required, abstracting the server behind a client allows us to ensure type safety instead of having to pass around pointers to global objects. Example 5 renames example 4’s struct `partition` to `partition_data` and adds serialization support. Next, we add the server side representation of the data in the structure `partition_server`. `Partition_server` inherits from `hpx::components::component_base`, which contains a server-side component boilerplate. The boilerplate code allows a component’s public members to be accessible anywhere on the machine via its Global Identifier (GID). To encapsulate the component, we create a client side helper class. This object allows us to create new instances of our component and access its members without having to know its GID. In addition, we are using the client class to assist us with managing our asynchrony. For example, our client class `partition`’s member function `get_data()` returns a future to `partition_data` `get_data()`. This struct inherits its boilerplate code from `hpx::components::client_base`.

In the structure `stepper`, we have also had to make some changes to accommodate a distributed environment. In order to get the data from a particular neighboring partition, which could be remote, we must retrieve the data from all of the neighboring partitions. These retrievals are asynchronous and the function `heat_part_data`, which, amongst other things, calls `heat`, should not be called unless the data from the neighboring partitions have arrived. Therefore, it should come as no surprise that we synchronize this operation with another instance of dataflow (found in `heat_part`). This dataflow receives futures to the data in the current and surrounding partitions by calling `get_data()` on each respective partition. When these futures are ready, dataflow passes them to the `unwrapping` function, which extracts the shared_array of doubles and passes them to the lambda. The lambda calls `heat_part_data` on the *locality*, which the middle partition is on.

Although this example could run distributed, it only runs on one *locality*, as it always uses `hpx::find_here()` as the target for the functions to run on.

In example 6, we begin to distribute the partition data on different nodes. This is accomplished in

stepper::do_work() by passing the GID of the *locality* where we wish to create the partition to the partition constructor.

```
for (std::size_t i = 0; i != np; ++i)
    U[0][i] = partition(localities[locidx(i, np, nl)], nx, double(i));
```

We distribute the partitions evenly based on the number of localities used, which is described in the function `locidx`. Because some of the data needed to update the partition in `heat_part` could now be on a new *locality*, we must devise a way of moving data to the *locality* of the middle partition. We accomplished this by adding a switch in the function `get_data()` that returns the end element of the buffer `data_` if it is from the left partition or the first element of the buffer if the data is from the right partition. In this way only the necessary elements, not the whole buffer, are exchanged between nodes. The reader should be reminded that this exchange of end elements occurs in the function `get_data()` and, therefore, is executed asynchronously.

Now that we have the code running in distributed, it is time to make some optimizations. The function `heat_part` spends most of its time on two tasks: retrieving remote data and working on the data in the middle partition. Because we know that the data for the middle partition is local, we can overlap the work on the middle partition with that of the possibly remote call of `get_data()`. This algorithmic change, which was implemented in example 7, can be seen below:

```
// The partitioned operator, it invokes the heat operator above on all elements
// of a partition.
static partition heat_part(
    partition const& left, partition const& middle, partition const& right)
{
    using hpx::dataflow;
    using hpx::unwrapping;

    hpx::shared_future<partition_data> middle_data =
        middle.get_data(partition_server::middle_partition);

    hpx::future<partition_data> next_middle = middle_data.then(
        unwrapping([middle](partition_data const& m) -> partition_data {
            HPX_UNUSED(middle);

            // All local operations are performed once the middle data of
            // the previous time step becomes available.
            std::size_t size = m.size();
            partition_data next(size);
            for (std::size_t i = 1; i != size - 1; ++i)
                next[i] = heat(m[i - 1], m[i], m[i + 1]);
            return next;
        }));

    return dataflow(hpx::launch::async,
        unwrapping([left, middle, right](partition_data next,
            partition_data const& l, partition_data const& m,
            partition_data const& r) -> partition {
            HPX_UNUSED(left);
            HPX_UNUSED(right);

            // Calculate the missing boundary elements once the
            // corresponding data has become available.
            std::size_t size = m.size();
```

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```

next[0] = heat(l[size - 1], m[0], m[1]);
next[size - 1] = heat(m[size - 2], m[size - 1], r[0]);

// The new partition_data will be allocated on the same locality
// as 'middle'.
return partition(middle.get_id(), std::move(next));
}),
std::move(next_middle),
left.get_data(partition_server::left_partition), middle_data,
right.get_data(partition_server::right_partition));
}

```

Example 8 completes the futurization process and utilizes the full potential of *HPX* by distributing the program flow to multiple localities, usually defined as nodes in a cluster. It accomplishes this task by running an instance of *HPX* main on each *locality*. In order to coordinate the execution of the program, the `struct stepper` is wrapped into a component. In this way, each *locality* contains an instance of `stepper` that executes its own instance of the function `do_work()`. This scheme does create an interesting synchronization problem that must be solved. When the program flow was being coordinated on the head node, the GID of each component was known. However, when we distribute the program flow, each partition has no notion of the GID of its neighbor if the next partition is on another *locality*. In order to make the GIDs of neighboring partitions visible to each other, we created two buffers to store the GIDs of the remote neighboring partitions on the left and right respectively. These buffers are filled by sending the GID of newly created edge partitions to the right and left buffers of the neighboring localities.

In order to finish the simulation, the solution vectors named `result` are then gathered together on *locality* 0 and added into a vector of spaces `overall_result` using the *HPX* functions `gather_id` and `gather_here`.

Example 8 completes this example series, which takes the serial code of example 1 and incrementally morphs it into a fully distributed parallel code. This evolution was guided by the simple principles of futurization, the knowledge of grainsize, and utilization of components. Applying these techniques easily facilitates the scalable parallelization of most applications.

2.2.8 Serializing user-defined types

In order to facilitate the sending and receiving of complex datatypes *HPX* provides a serialization abstraction.

Just like `boost`, `hpx` allows users to serialize user-defined types by either providing the serializer as a member function or defining the serialization as a free function.

Unlike Boost *HPX* doesn't acknowledge second unsigned int parameter, it is solely there to preserve API compatibility with Boost Serialization

This is tutorial was heavily inspired by [Boost's serialization concepts](https://www.boost.org/doc/libs/1_79_0/libs/serialization/doc/serialization.html)¹⁹.

¹⁹ https://www.boost.org/doc/libs/1_79_0/libs/serialization/doc/serialization.html

Setup

The source code for this example can be found here: `custom_serialization.cpp`.

To compile this program, go to your *HPX* build directory (see *Building HPX* for information on configuring and building *HPX*) and enter:

```
$ make examples.quickstart.custom_serialization
```

To run the program type:

```
$ ./bin/custom_serialization
```

This should print:

```
Rectangle(Point(x=0,y=0),Point(x=0,y=5))
gravity.g = 9.81%
```

Serialization Requirements

In order to serialize objects in HPX, at least one of the following criteria must be met:

In the case of default constructible objects:

- The object is an empty type.
- Has a serialization function as shown in this tutorial.
- All members are accessible publicly and they can be used in structured binding contexts.

Otherwise:

- They need to have special serialization support.

Member function serialization

```
struct point_member_serialization
{
    int x{0};
    int y{0};

    // Required when defining the serialization function as private
    // In this case it isn't
    // Provides serialization access to HPX
    friend class hpx::serialization::access;

    // Second argument exists solely for compatibility with boost serialize
    // it is NOT processed by HPX in any way.
    template <typename Archive>
    void serialize(Archive& ar, const unsigned int)
    {
        // clang-format off
        ar & x & y;
        // clang-format on
    }
}
```

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(continued from previous page)

```
};

// Allow bitwise serialization
HPX_IS_BITWISE_SERIALIZABLE(point_member_serialization)
```

Notice that `point_member_serialization` is defined as bitwise serializable (see *Bitwise serialization for bitwise copyable data* for more details). HPX is also able to recursively serialize composite classes and structs given that its members are serializable.

```
struct rectangle_member_serialization
{
    point_member_serialization top_left;
    point_member_serialization lower_right;

    template <typename Archive>
    void serialize(Archive& ar, const unsigned int)
    {
        // clang-format off
        ar & top_left & lower_right;
        // clang-format on
    }
};
```

Free function serialization

In order to decouple your models from HPX, HPX also allows for the definition of free function serializers.

```
struct rectangle_free
{
    point_member_serialization top_left;
    point_member_serialization lower_right;
};

template <typename Archive>
void serialize(Archive& ar, rectangle_free& pt, const unsigned int)
{
    // clang-format off
    ar & pt.lower_right & pt.top_left;
    // clang-format on
}
```

Even if you can't modify a class to befriend it, you can still be able to serialize your class provided that your class is default constructable and you are able to reconstruct it yourself.

```
class point_class
{
public:
    point_class(int x, int y)
        : x(x)
        , y(y)
    {
```

(continues on next page)

(continued from previous page)

```

    }

    point_class() = default;

    [[nodiscard]] int get_x() const noexcept
    {
        return x;
    }

    [[nodiscard]] int get_y() const noexcept
    {
        return y;
    }

private:
    int x;
    int y;
};

template <typename Archive>
void load(Archive& ar, point_class& pt, const unsigned int)
{
    int x, y;
    ar >> x >> y;
    pt = point_class(x, y);
}

template <typename Archive>
void save(Archive& ar, point_class const& pt, const unsigned int)
{
    ar << pt.get_x() << pt.get_y();
}

// This tells HPX that you have spilt your serialize function into
// load and save
HPX_SERIALIZATION_SPLIT_FREE(point_class)

```

Serializing non default constructable classes

Some classes don't provide any default constructor.

```

class planet_weight_calculator
{
public:
    explicit planet_weight_calculator(double g)
        : g(g)
    {
    }

    template <class Archive>
    friend void save_construct_data(

```

(continues on next page)

```

        Archive&, planet_weight_calculator const*, unsigned int);

    [[nodiscard]] double get_g() const
    {
        return g;
    }

private:
    // Provides serialization access to HPX
    friend class hpx::serialization::access;
    template <class Archive>
    void serialize(Archive&, const unsigned int)
    {
        // Serialization will be done in the save_construct_data
        // Still needs to be defined
    }

    double g;
};

```

In this case you have to define a `save_construct_data` and `load_construct_data` in which you do the serialization yourself.

```

template <class Archive>
inline void save_construct_data(Archive& ar,
    planet_weight_calculator const* weight_calc, const unsigned int)
{
    ar << weight_calc->g;    // Do all of your serialization here
}

template <class Archive>
inline void load_construct_data(
    Archive& ar, planet_weight_calculator* weight_calc, const unsigned int)
{
    double g;
    ar >> g;

    // ::new(ptr) construct new object at given address
    hpx::construct_at(weight_calc, g);
}

```

Bitwise serialization for bitwise copyable data

When sending non arithmetic types not defined by `std::is_arithmetic`²⁰, HPX has to (de)serialize each object separately. However, if the class you are trying to send consists only of bitwise copyable datatypes, you may mark your class as such. Then HPX will serialize your object bitwise instead of element wise. This has enormous benefits, especially when sending a vector/array of your class. To define your class as such you need to call `HPX_IS_BITWISE_SERIALIZABLE(T)` with your desired custom class.

²⁰ https://en.cppreference.com/w/cpp/types/is_arithmetic

```

struct point_member_serialization
{
    int x{0};
    int y{0};

    // Required when defining the serialization function as private
    // In this case it isn't
    // Provides serialization access to HPX
    friend class hpx::serialization::access;

    // Second argument exists solely for compatibility with boost serialize
    // it is NOT processed by HPX in any way.
    template <typename Archive>
    void serialize(Archive& ar, const unsigned int)
    {
        // clang-format off
        ar & x & y;
        // clang-format on
    }
};

// Allow bitwise serialization
HPX_IS_BITWISE_SERIALIZABLE(point_member_serialization)

```

2.3 Manual

The manual is your comprehensive guide to *HPX*. It contains detailed information on how to build and use *HPX* in different scenarios.

2.3.1 Prerequisites

Supported platforms

At this time, *HPX* supports the following platforms. Other platforms may work, but we do not test *HPX* with other platforms, so please be warned.

Table 2.1: Supported Platforms for *HPX*

Name	Minimum Version	Architectures
Linux	2.6	x86-32, x86-64, k1om
BlueGeneQ	V1R2M0	PowerPC A2
Windows	Any Windows system	x86-32, x86-64
Mac OSX	Any OSX system	x86-64
ARM	Any ARM system	Any architecture
RISC-V	Any RISC-V system	Any architecture

Supported compilers

The table below shows the supported compilers for *HPX*.

Table 2.2: Supported Compilers for *HPX*

Name	Minimum Version	Latest tested
GNU Compiler Collection (g++) ²¹	11.0	15.0
clang: a C language family frontend for LLVM ²²	16.0	20.0
Visual C++ ²³ (x64)	2019	2022

Software and libraries

The table below presents all the necessary prerequisites for building *HPX*.

Table 2.3: Software prerequisites for *HPX*

	Name	Minimum Version	Latest tested
Build System	CMake ²⁴	3.18	4.0
Required Libraries	Boost ²⁵	1.71.0	1.88.0
	Portable Hardware Locality (HWLOC) ²⁶	1.5	2.4

The most important dependencies are Boost²⁷ and Portable Hardware Locality (HWLOC)²⁸. The installation of Boost is described in detail in Boost's *Getting Started*²⁹ document. A recent version of hwloc is required in order to support thread pinning and NUMA awareness and can be found in *Hwloc Downloads*³⁰.

HPX is written in 99.99% Standard C++ (the remaining 0.01% is platform specific assembly code). As such, *HPX* is compatible with almost any standards compliant C++ compiler. The code base takes advantage of C++ language and standard library features when available.

Note: When building Boost using gcc, please note that it is required to specify a `cxxflags=-std=c++17` command line argument to `b2` (`bjam`).

Note: In most configurations, *HPX* depends only on header-only Boost. Boost.Filesystem is required if the standard library does not support filesystem. The following are not needed by default, but are required in certain configurations: Boost.Chrono, Boost.DateTime, Boost.Log, Boost.LogSetup, Boost.Regex, and Boost.Thread.

Depending on the options you chose while building and installing *HPX*, you will find that *HPX* may depend on several other libraries such as those listed below.

²¹ <https://gcc.gnu.org>

²² <https://clang.llvm.org/>

²³ <https://msdn.microsoft.com/en-us/visualc/default.aspx>

²⁴ <https://www.cmake.org>

²⁵ <https://www.boost.org/>

²⁶ <https://www.open-mpi.org/projects/hwloc/>

²⁷ <https://www.boost.org/>

²⁸ <https://www.open-mpi.org/projects/hwloc/>

²⁹ https://www.boost.org/more/getting_started/index.html

³⁰ <https://www.open-mpi.org/software/hwloc/v1.11>

Note: In order to use a high speed parcelport, we currently recommend configuring *HPX* to use MPI so that MPI can be used for communication between different localities. Please set the CMake variable `MPI_CXX_COMPILER` to your MPI C++ compiler wrapper if not detected automatically.

Table 2.4: Optional software prerequisites for *HPX*

Name	Minimum version
google-perftools ³¹	1.7.1
jemalloc ³²	2.1.0
mi-malloc ³³	1.0.0
Performance Application Programming Interface (PAPI)	

2.3.2 Getting *HPX*

Download a tarball of the latest release from [HPX Downloads](#)³⁴ and unpack it or clone the repository directly using `git`:

```
$ git clone https://github.com/STELLAR-GROUP/hpx.git
```

It is also recommended that you check out the latest stable tag:

```
$ cd hpx
```

```
$ git checkout v1.11.1
```

2.3.3 Building *HPX*

Basic information

The build system for *HPX* is based on [CMake](#)³⁵, a cross-platform build-generator tool which is not responsible for building the project but rather generates the files needed by your build tool (GNU make, Visual Studio, etc.) for building *HPX*. If CMake is not already installed in your system, you can download it and install it here: [CMake Downloads](#)³⁶.

Once [CMake](#)³⁷ has been run, the build process can be started. The build process consists of the following parts:

- The *HPX* core libraries (target `core`): This forms the basic set of *HPX* libraries.
- *HPX* Examples (target `examples`): This target is enabled by default and builds all *HPX* examples (disable by setting `HPX_WITH_EXAMPLES:BOOL=Off`). *HPX* examples are part of the `all` target and are included in the installation if enabled.
- *HPX* Tests (target `tests`): This target builds the *HPX* test suite and is enabled by default (disable by setting `HPX_WITH_TESTS:BOOL=Off`). They are not built by the `all` target and have to be built separately.
- *HPX* Documentation (target `docs`): This target builds the documentation, and is not enabled by default (enable by setting `HPX_WITH_DOCUMENTATION:BOOL=On`. For more information see [Documentation](#).

³¹ <https://code.google.com/p/gperftools>

³² <http://jemalloc.net>

³³ <http://microsoft.github.io/mimalloc/>

³⁴ <https://hpx.stellar-group.org/downloads/>

³⁵ <https://www.cmake.org>

³⁶ <https://www.cmake.org/cmake/resources/software.html>

³⁷ <https://www.cmake.org>

The *HPX* build process is highly configurable through [CMake](#)³⁸, and various [CMake](#)³⁹ variables influence the build process. A list with the most important [CMake](#)⁴⁰ variables can be found in the section that follows, while the complete list of available [CMake](#)⁴¹ variables is in *CMake options*. These variables can be used to refine the recipes that can be found at *Platform specific build recipes*, a section that shows some basic steps on how to build *HPX* for a specific platform.

In order to use *HPX*, only the core libraries are required. In order to use the optional libraries, you need to specify them as link dependencies in your build (See *Creating HPX projects*).

Most important CMake options

While building *HPX*, you are provided with multiple CMake options which correspond to different configurations. Below, there is a set of the most important and frequently used CMake options.

HPX_WITH_MALLOC

Use a custom allocator. Using a custom allocator tuned for multithreaded applications is very important for the performance of *HPX* applications. When debugging applications, it's useful to set this to `system`, as custom allocators can hide some memory-related bugs. Note that setting this to something other than `system` requires an external dependency.

HPX_WITH_CUDA

Enable support for CUDA. Use `CMAKE_CUDA_COMPILER` to set the CUDA compiler. This is a standard [CMake](#)⁴² variable, like `CMAKE_CXX_COMPILER`.

HPX_WITH_PARCELPOR_T_MPI

Enable the MPI parcelport. This enables the use of MPI for the networking operations in the *HPX* runtime. The default value is `OFF` because it's not available on all systems and/or requires another dependency. However, it is the recommended parcelport.

HPX_WITH_PARCELPOR_T_TCP

Enable the TCP parcelport. Enables the use of TCP for networking in the runtime. The default value is `ON`. However, it's only recommended for debugging purposes, as it is slower than the MPI parcelport.

HPX_WITH_PARCELPOR_T_LCI

Enable the LCI parcelport. This enables the use of LCI for the networking operations in the *HPX* runtime. The default value is `OFF` because it's not available on all systems and/or requires another dependency. However, this experimental parcelport may provide better performance than the MPI parcelport. Please refer to *Using the LCI parcelport* for more information about the LCI parcelport.

HPX_WITH_APEX

Enable APEX integration. [APEX](#)⁴³ can be used to profile *HPX* applications. In particular, it provides information about individual tasks in the *HPX* runtime.

HPX_WITH_GENERIC_CONTEXT_COROUTINES

Enable Boost. Context for task context switching. It must be enabled for non-x86 architectures such as ARM and Power.

HPX_WITH_MAX_CPU_COUNT

Set the maximum CPU count supported by *HPX*. The default value is 64, and should be set to a number at least as high as the number of cores on a system including virtual cores such as hyperthreads.

³⁸ <https://www.cmake.org>

³⁹ <https://www.cmake.org>

⁴⁰ <https://www.cmake.org>

⁴¹ <https://www.cmake.org>

⁴² <https://www.cmake.org>

⁴³ <https://uo-oaciss.github.io/apex/quickstarthpx/>

HPX_WITH_CXX_STANDARD

Set a specific C++ standard version e.g. `HPX_WITH_CXX_STANDARD=20`. The default and minimum value is 17.

HPX_WITH_EXAMPLES

Build examples.

HPX_WITH_TESTS

Build tests.

For a complete list of available [CMake](#)⁴⁴ variables that influence the build of *HPX*, see *CMake options*.

Build types

[CMake](#)⁴⁵ can be configured to generate project files suitable for builds that have enabled debugging support or for an optimized build (without debugging support). The [CMake](#)⁴⁶ variable used to set the build type is `CMAKE_BUILD_TYPE` (for more information see the [CMake Documentation](#)⁴⁷). Available build types are:

- **Debug:** Full debug symbols are available as well as additional assertions to help debugging. To enable the debug build type for the *HPX* API, the C++ Macro `HPX_DEBUG` is defined.
- **RelWithDebInfo:** Release build with debugging symbols. This is most useful for profiling applications
- **Release:** Release build. This disables assertions and enables default compiler optimizations.
- **RelMinSize:** Release build with optimizations for small binary sizes.

Important: We currently don't guarantee ABI compatibility between Debug and Release builds. Please make sure that applications built against *HPX* use the same build type as you used to build *HPX*. For CMake builds, this means that the `CMAKE_BUILD_TYPE` variables have to match and for projects not using [CMake](#)⁴⁸, the `HPX_DEBUG` macro has to be set in debug mode.

Platform specific build recipes**Unix variants**

Once you have the source code and the dependencies and assuming all your dependencies are in paths known to [CMake](#)⁴⁹, the following gets you started:

1. First, set up a separate build directory to configure the project:

```
$ mkdir build && cd build
```

2. To configure the project you have the following options:

- To build the core *HPX* libraries and examples, and install them to your chosen location (recommended):

```
$ cmake -DCMAKE_INSTALL_PREFIX=/install/path ..
```

⁴⁴ <https://www.cmake.org>

⁴⁵ <https://www.cmake.org>

⁴⁶ <https://www.cmake.org>

⁴⁷ https://cmake.org/cmake/help/latest/variable/CMAKE_BUILD_TYPE.html

⁴⁸ <https://www.cmake.org>

⁴⁹ <https://www.cmake.org>

Tip: If you want to change [CMake](#)⁵⁰ variables for your build, it is usually a good idea to start with a clean build directory to avoid configuration problems. It is especially important that you use a clean build directory when changing between Release and Debug modes.

- To install *HPX* to the default system folders, simply leave out the `CMAKE_INSTALL_PREFIX` option:

```
$ cmake ..
```

- If your dependencies are in custom locations, you may need to tell [CMake](#)⁵¹ where to find them by passing one or more options to [CMake](#)⁵² as shown below:

```
$ cmake -DBoost_ROOT=/path/to/boost
      -DHWloc_ROOT=/path/to/hwloc
      -DTcmalloc_ROOT=/path/to/tcmalloc
      -DJemalloc_ROOT=/path/to/jemalloc
      [other CMake variable definitions]
      /path/to/source/tree
```

For instance:

```
$ cmake -DBoost_ROOT=~/.packages/boost -DHWloc_ROOT=~/.packages/hwloc -DCMAKE_
↪INSTALL_PREFIX=~/.packages/hpx ~/downloads/hpx_1.5.1
```

- If you want to try *HPX* without using a custom allocator pass `-DHPX_WITH_MALLOC=system` to [CMake](#)⁵³:

```
$ cmake -DCMAKE_INSTALL_PREFIX=/install/path -DHPX_WITH_MALLOC=system ..
```

Note: Please pay special attention to the section about [HPX_WITH_MALLOC:STRING](#) as this is crucial for getting decent performance.

Important: If you are building *HPX* for a system with more than 64 processing units, you must change the [CMake](#)⁵⁴ variable `HPX_WITH_MAX_CPU_COUNT` (to a value at least as big as the number of (virtual) cores on your system). Note that the default value is 64.

Caution: Compiling and linking *HPX* needs a considerable amount of memory. It is advisable that at least 2 GB of memory per parallel process is available.

3. Once the configuration is complete, to build the project you run:

```
$ cmake --build . --target install
```

⁵⁰ <https://www.cmake.org>

⁵¹ <https://www.cmake.org>

⁵² <https://www.cmake.org>

⁵³ <https://www.cmake.org>

⁵⁴ <https://www.cmake.org>

Windows

Note: The following build recipes are mostly user-contributed and may be outdated. We always welcome updated and new build recipes.

To build *HPX* under Windows 10 x64 with Visual Studio 2015:

- Download the CMake V3.19 installer (or latest version) from [here](#)⁵⁵
- Download the hwloc V1.11.0 (or the latest version) from [here](#)⁵⁶ and unpack it.
- Download the latest Boost libraries from [here](#)⁵⁷ and unpack them.
- Build the Boost DLLs and LIBs by using these commands from Command Line (or PowerShell). Open CMD/PowerShell inside the Boost dir and type in:

```
.\bootstrap.bat
```

This batch file will set up everything needed to create a successful build. Now execute:

```
.\b2.exe link=shared variant=release,debug architecture=x86 address-model=64_
↪threading=multi --build-type=complete install
```

This command will start a (very long) build of all available Boost libraries. Please, be patient.

- Open CMake-GUI.exe and set up your source directory (input field ‘Where is the source code’) to the *base directory* of the source code you downloaded from *HPX*’s GitHub pages. Here’s an example of CMake path settings, which point to the Documents/GitHub/hpx folder:

Inside ‘Where is the source-code’ enter the base directory of your *HPX* source directory (do not enter the “src” sub-directory!). Inside ‘Where to build the binaries’ you should put in the path where all the building processes will happen. This is important because the building machinery will do an “out-of-tree” build. CMake will not touch or change the original source files in any way. Instead, it will generate Visual Studio Solution Files, which will build *HPX* packages out of the *HPX* source tree.

- Set new configuration variables (in CMake, not in Windows environment): Boost_ROOT, Hwloc_ROOT, Asio_ROOT, CMAKE_INSTALL_PREFIX. The meaning of these variables is as follows:
 - Boost_ROOT the *HPX* root directory of the unpacked Boost headers/cpp files.
 - Hwloc_ROOT the *HPX* root directory of the unpacked Portable Hardware Locality files.
 - Asio_ROOT the *HPX* root directory of the unpacked ASIO files. Alternatively use HPX_WITH_FETCH_ASIO with value True.
 - CMAKE_INSTALL_PREFIX the *HPX* root directory where the future builds of *HPX* should be installed.

Note: *HPX* is a very large software collection, so it is not recommended to use the default C:\Program Files\hpx. Many users may prefer to use simpler paths *without* whitespace, like C:\bin\hpx or D:\bin\hpx etc.

To insert new env-vars click on “Add Entry” and then insert the name inside “Name”, select PATH as Type and put the path-name in the “Path” text field. Repeat this for the first three variables.

This is how variable insertion will look:

⁵⁵ <https://blog.kitware.com/cmake-3-19-0-available-for-download/>

⁵⁶ <https://www.open-mpi.org/software/hwloc/v2.11/>

⁵⁷ <https://www.boost.org/users/download/>

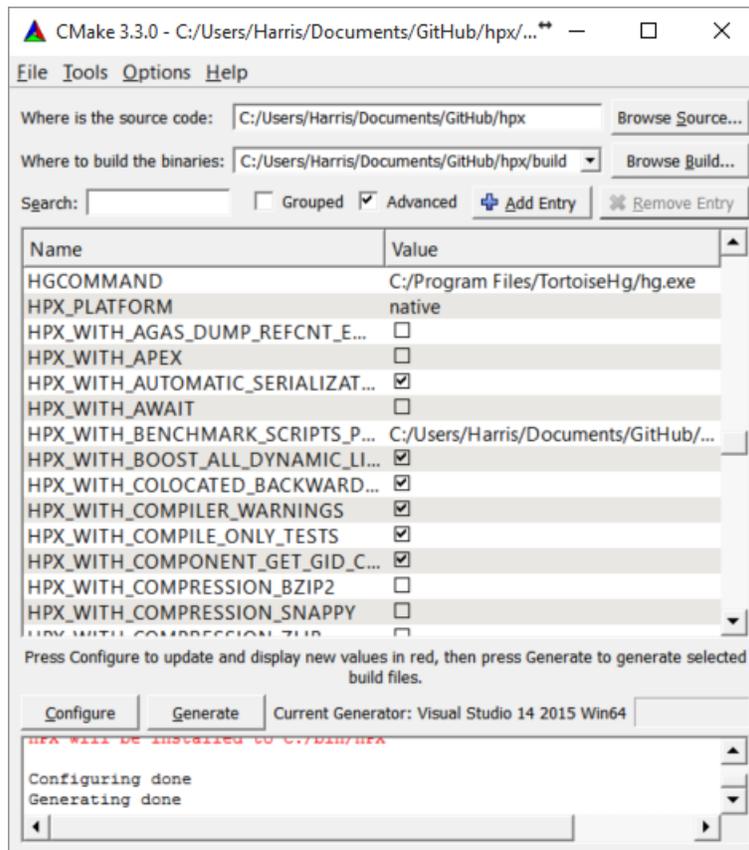


Fig. 2.3: Example CMake path settings.

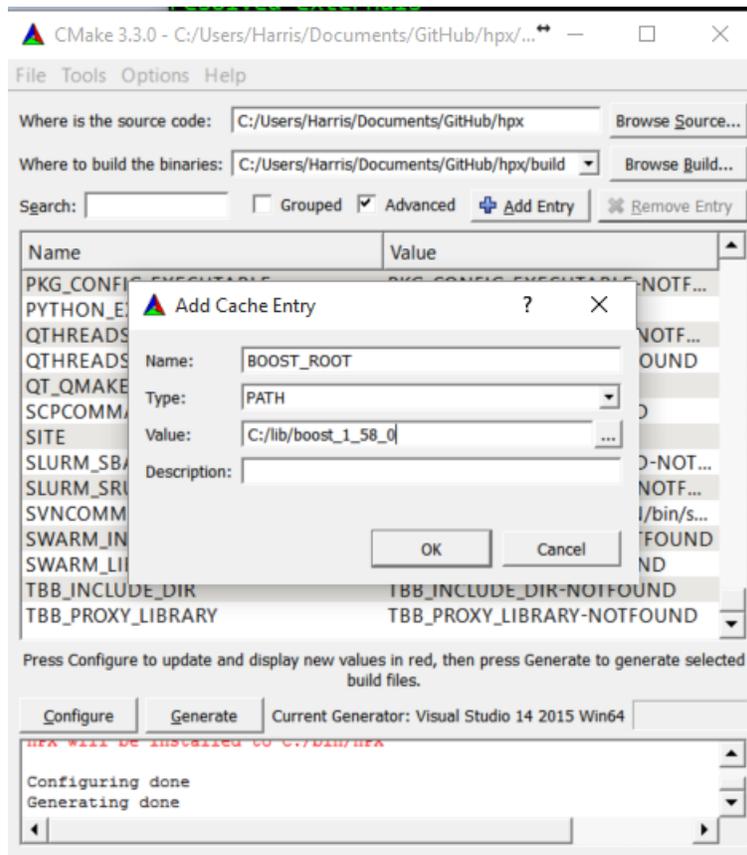


Fig. 2.4: Example CMake adding entry.

Alternatively, users could provide `Boost_LIBRARYDIR` instead of `Boost_ROOT`; the difference is that `Boost_LIBRARYDIR` should point to the subdirectory inside Boost root where all the compiled DLLs/LIBs are. For example, `Boost_LIBRARYDIR` may point to the `bin.v2` subdirectory under the Boost rootdir. It is important to keep the meanings of these two variables separated from each other: `Boost_DIR` points to the ROOT folder of the Boost library. `Boost_LIBRARYDIR` points to the subdir inside the Boost root folder where the compiled binaries are.

- Click the ‘Configure’ button of CMake-GUI. You will be immediately presented with a small window where you can select the C++ compiler to be used within Visual Studio. This has been tested using the latest v14 (a.k.a C++ 2015) but older versions should be sufficient too. Make sure to select the 64Bit compiler.
- After the generate process has finished successfully, click the ‘Generate’ button. Now, CMake will put new VS Solution files into the BUILD folder you selected at the beginning.
- Open Visual Studio and load the `HPX.sln` from your build folder.
- Go to `CMakePredefinedTargets` and build the `INSTALL` project:

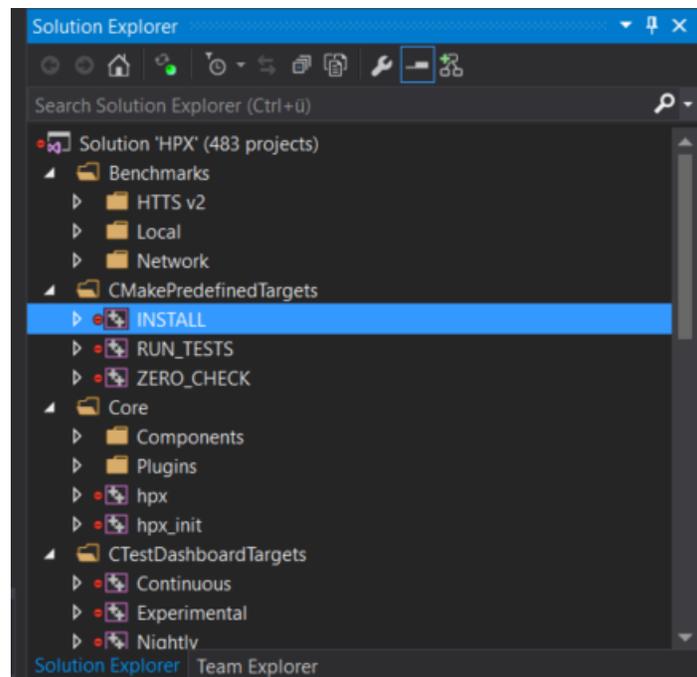
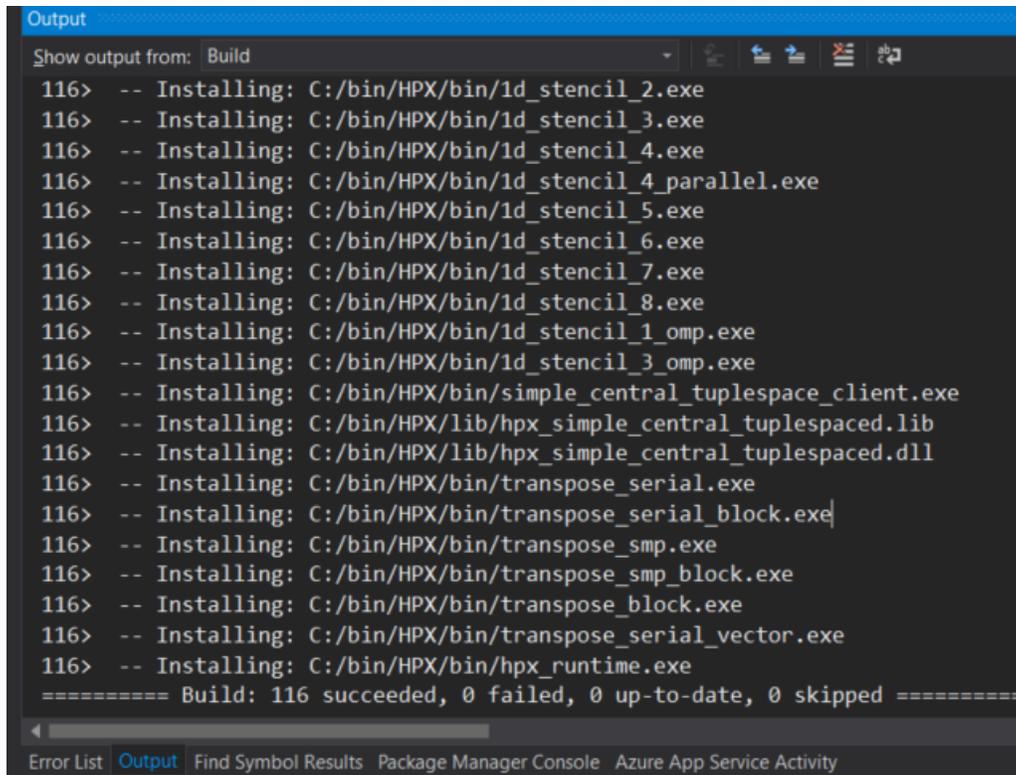


Fig. 2.5: Visual Studio INSTALL target.

It will take some time to compile everything, and in the end you should see an output similar to this one:

2.3.4 CMake options

In order to configure *HPX*, you can set a variety of options to allow CMake to generate your specific makefiles/project files. A list of the most important CMake options can be found in *Most important CMake options*, while this section includes the comprehensive list.



```
Output
Show output from: Build
116> -- Installing: C:/bin/HPX/bin/1d_stencil_2.exe
116> -- Installing: C:/bin/HPX/bin/1d_stencil_3.exe
116> -- Installing: C:/bin/HPX/bin/1d_stencil_4.exe
116> -- Installing: C:/bin/HPX/bin/1d_stencil_4_parallel.exe
116> -- Installing: C:/bin/HPX/bin/1d_stencil_5.exe
116> -- Installing: C:/bin/HPX/bin/1d_stencil_6.exe
116> -- Installing: C:/bin/HPX/bin/1d_stencil_7.exe
116> -- Installing: C:/bin/HPX/bin/1d_stencil_8.exe
116> -- Installing: C:/bin/HPX/bin/1d_stencil_1_omp.exe
116> -- Installing: C:/bin/HPX/bin/1d_stencil_3_omp.exe
116> -- Installing: C:/bin/HPX/bin/simple_central_tuplespace_client.exe
116> -- Installing: C:/bin/HPX/lib/hpx_simple_central_tuplespaced.lib
116> -- Installing: C:/bin/HPX/lib/hpx_simple_central_tuplespaced.dll
116> -- Installing: C:/bin/HPX/bin/transpose_serial.exe
116> -- Installing: C:/bin/HPX/bin/transpose_serial_block.exe
116> -- Installing: C:/bin/HPX/bin/transpose_smp.exe
116> -- Installing: C:/bin/HPX/bin/transpose_smp_block.exe
116> -- Installing: C:/bin/HPX/bin/transpose_block.exe
116> -- Installing: C:/bin/HPX/bin/transpose_serial_vector.exe
116> -- Installing: C:/bin/HPX/bin/hpx_runtime.exe
===== Build: 116 succeeded, 0 failed, 0 up-to-date, 0 skipped =====
```

Fig. 2.6: Visual Studio build output.

Variables that influence how *HPX* is built

The options are split into these categories:

- *Generic options*
- *Build Targets options*
- *Thread Manager options*
- *AGAS options*
- *Parcelport options*
- *Profiling options*
- *Debugging options*
- *Modules options*

Generic options

- `HPX_WITH_AUTOMATIC_SERIALIZATION_REGISTRATION:BOOL`
- `HPX_WITH_BENCHMARK_SCRIPTS_PATH:PATH`
- `HPX_WITH_BUILD_BINARY_PACKAGE:BOOL`
- `HPX_WITH_CHECK_MODULE_DEPENDENCIES:BOOL`
- `HPX_WITH_COMPILER_WARNINGS:BOOL`
- `HPX_WITH_COMPILER_WARNINGS_AS_ERRORS:BOOL`
- `HPX_WITH_COMPRESSION_BZIP2:BOOL`
- `HPX_WITH_COMPRESSION_SNAPPY:BOOL`
- `HPX_WITH_COMPRESSION_ZLIB:BOOL`
- `HPX_WITH_CUDA:BOOL`
- `HPX_WITH_CXX_STANDARD:STRING`
- `HPX_WITH_DATAPAR:BOOL`
- `HPX_WITH_DATAPAR_BACKEND:STRING`
- `HPX_WITH_DATAPAR_VC_NO_LIBRARY:BOOL`
- `HPX_WITH_DEPRECATION_WARNINGS:BOOL`
- `HPX_WITH_DISABLED_SIGNAL_EXCEPTION_HANDLERS:BOOL`
- `HPX_WITH_DYNAMIC_HPX_MAIN:BOOL`
- `HPX_WITH_FAULT_TOLERANCE:BOOL`
- `HPX_WITH_FULL_RPATH:BOOL`
- `HPX_WITH_GCC_VERSION_CHECK:BOOL`
- `HPX_WITH_GENERIC_CONTEXT_COROUTINES:BOOL`
- `HPX_WITH_HIDDEN_VISIBILITY:BOOL`
- `HPX_WITH_HIP:BOOL`
- `HPX_WITH_HIPSYCL:BOOL`
- `HPX_WITH_IGNORE_COMPILER_COMPATIBILITY:BOOL`
- `HPX_WITH_LOGGING:BOOL`
- `HPX_WITH_MALLOC:STRING`
- `HPX_WITH_MODULES_AS_STATIC_LIBRARIES:BOOL`
- `HPX_WITH_NICE_THREADLEVEL:BOOL`
- `HPX_WITH_PARCEL_COALESCING:BOOL`
- `HPX_WITH_PKGCONFIG:BOOL`
- `HPX_WITH_PRECOMPILED_HEADERS:BOOL`
- `HPX_WITH_RUN_MAIN_EVERYWHERE:BOOL`
- `HPX_WITH_STACKOVERFLOW_DETECTION:BOOL`
- `HPX_WITH_STATIC_LINKING:BOOL`

- *HPX_WITH_SUPPORT_NO_UNIQUE_ADDRESS_ATTRIBUTE:BOOL*
- *HPX_WITH_SYCL:BOOL*
- *HPX_WITH_SYCL_FLAGS:STRING*
- *HPX_WITH_UNITY_BUILD:BOOL*
- *HPX_WITH_VIM_YCM:BOOL*
- *HPX_WITH_ZERO_COPY_SERIALIZATION_THRESHOLD:STRING*

HPX_WITH_AUTOMATIC_SERIALIZATION_REGISTRATION:BOOL

Use automatic serialization registration for actions and functions. This affects compatibility between HPX applications compiled with different compilers (default ON)

HPX_WITH_BENCHMARK_SCRIPTS_PATH:PATH

Directory to place batch scripts in

HPX_WITH_BUILD_BINARY_PACKAGE:BOOL

Build HPX on the build infrastructure on any LINUX distribution (default: OFF).

HPX_WITH_CHECK_MODULE_DEPENDENCIES:BOOL

Verify that no modules are cross-referenced from a different module category (default: OFF)

HPX_WITH_COMPILER_WARNINGS:BOOL

Enable compiler warnings (default: ON)

HPX_WITH_COMPILER_WARNINGS_AS_ERRORS:BOOL

Turn compiler warnings into errors (default: OFF)

HPX_WITH_COMPRESSION_BZIP2:BOOL

Enable bzip2 compression for parcel data (default: OFF).

HPX_WITH_COMPRESSION_SNAPPY:BOOL

Enable snappy compression for parcel data (default: OFF).

HPX_WITH_COMPRESSION_ZLIB:BOOL

Enable zlib compression for parcel data (default: OFF).

HPX_WITH_CUDA:BOOL

Enable support for CUDA (default: OFF)

HPX_WITH_CXX_STANDARD:STRING

Set the C++ standard to use when compiling HPX itself. (default: 17)

HPX_WITH_DATAPAR:BOOL

Enable data parallel algorithm support using Vc library (default: ON)

HPX_WITH_DATAPAR_BACKEND:STRING

Define which vectorization library should be used. Options are: VC, EVE, STD_EXPERIMENTAL_SIMD, SVE; NONE

HPX_WITH_DATAPAR_VC_NO_LIBRARY:BOOL

Don't link with the Vc static library (default: OFF)

HPX_WITH_DEPRECATION_WARNINGS:BOOL

Enable warnings for deprecated facilities (default: ON).

HPX_WITH_DISABLED_SIGNAL_EXCEPTION_HANDLERS:BOOL

Disables the mechanism that produces debug output for caught signals and unhandled exceptions (default: OFF)

HPX_WITH_DYNAMIC_HPX_MAIN:BOOL

Enable dynamic overload of system main() (Linux and Apple only, default: ON)

HPX_WITH_FAULT_TOLERANCE:BOOL

Build HPX to tolerate failures of nodes, i.e. ignore errors in active communication channels (default: OFF)

HPX_WITH_FULL_RPATH:BOOL

Build and link HPX libraries and executables with full RPATHs (default: ON)

HPX_WITH_GCC_VERSION_CHECK:BOOL

Don't ignore version reported by gcc (default: ON)

HPX_WITH_GENERIC_CONTEXT_COROUTINES:BOOL

Use Boost.Context as the underlying coroutines context switch implementation.

HPX_WITH_HIDDEN_VISIBILITY:BOOL

Use -fvisibility=hidden for builds on platforms which support it (default OFF)

HPX_WITH_HIP:BOOL

Enable compilation with HIPCC (default: OFF)

HPX_WITH_HIPSYCL:BOOL

Use hipsycl cmake integration (default: OFF)

HPX_WITH_IGNORE_COMPILER_COMPATIBILITY:BOOL

Ignore compiler incompatibility in dependent projects (default: ON).

HPX_WITH_LOGGING:BOOL

Build HPX with logging enabled (default: ON).

HPX_WITH_MALLOC:STRING

Define which allocator should be linked in. Options are: system, tcmalloc, jemalloc, mimalloc, tbbmalloc, and custom (default is: tcmalloc)

HPX_WITH_MODULES_AS_STATIC_LIBRARIES:BOOL

Compile HPX modules as STATIC (whole-archive) libraries instead of OBJECT libraries (Default: ON)

HPX_WITH_NICE_THREADLEVEL:BOOL

Set HPX worker threads to have high NICE level (may impact performance) (default: OFF)

HPX_WITH_PARCEL_COALESCING:BOOL

Enable the parcel coalescing plugin (default: ON).

HPX_WITH_PKGCONFIG:BOOL

Enable generation of pkgconfig files (default: ON on Linux without CUDA/HIP, otherwise OFF)

HPX_WITH_PRECOMPILED_HEADERS:BOOL

Enable precompiled headers for certain build targets (experimental) (default OFF)

HPX_WITH_RUN_MAIN_EVERYWHERE:BOOL

Run hpx_main by default on all localities (default: OFF, deprecated, will be removed).

HPX_WITH_STACKOVERFLOW_DETECTION:BOOL

Enable stackoverflow detection for HPX threads/coroutines (default: OFF, debug: ON).

HPX_WITH_STATIC_LINKING:BOOL

Compile HPX statically linked libraries (Default: OFF)

HPX_WITH_SUPPORT_NO_UNIQUE_ADDRESS_ATTRIBUTE:BOOL

Enable the use of the `[[no_unique_address]]` attribute (default: ON)

HPX_WITH_SYCL:BOOL

Enable support for Sycl (default: OFF)

HPX_WITH_SYCL_FLAGS:STRING

Sycl compile flags for selecting specific targets (default: empty)

HPX_WITH_UNITY_BUILD:BOOL

Enable unity build for certain build targets (default OFF)

HPX_WITH_VIM_YCM:BOOL

Generate HPX completion file for VIM YouCompleteMe plugin

HPX_WITH_ZERO_COPY_SERIALIZATION_THRESHOLD:STRING

The threshold in bytes to when perform zero copy optimizations (default: 8192)

Build Targets options

- *HPX_WITH_ASIO_TAG:STRING*
- *HPX_WITH_COMPILE_ONLY_TESTS:BOOL*
- *HPX_WITH_DISTRIBUTED_RUNTIME:BOOL*
- *HPX_WITH_DOCUMENTATION:BOOL*
- *HPX_WITH_DOCUMENTATION_OUTPUT_FORMATS:STRING*
- *HPX_WITH_EXAMPLES:BOOL*
- *HPX_WITH_EXAMPLES_HDF5:BOOL*
- *HPX_WITH_EXAMPLES_OPENMP:BOOL*
- *HPX_WITH_EXAMPLES_QT4:BOOL*
- *HPX_WITH_EXAMPLES_QTHREADS:BOOL*
- *HPX_WITH_EXAMPLES_TBB:BOOL*
- *HPX_WITH_EXECUTABLE_PREFIX:STRING*
- *HPX_WITH_FAIL_COMPILE_TESTS:BOOL*
- *HPX_WITH_FETCH_APEX:BOOL*
- *HPX_WITH_FETCH_ASIO:BOOL*
- *HPX_WITH_FETCH_BOOST:BOOL*
- *HPX_WITH_FETCH_GASNET:BOOL*
- *HPX_WITH_FETCH_HWLOC:BOOL*
- *HPX_WITH_FETCH_LCI:BOOL*
- *HPX_WITH_IO_COUNTERS:BOOL*
- *HPX_WITH_LCI_TAG:STRING*

- *HPX_WITH_NANOBENCH:BOOL*
- *HPX_WITH_PARALLEL_LINK_JOBS:STRING*
- *HPX_WITH_TESTS:BOOL*
- *HPX_WITH_TESTS_BENCHMARKS:BOOL*
- *HPX_WITH_TESTS_EXAMPLES:BOOL*
- *HPX_WITH_TESTS_EXTERNAL_BUILD:BOOL*
- *HPX_WITH_TESTS_HEADERS:BOOL*
- *HPX_WITH_TESTS_REGRESSIONS:BOOL*
- *HPX_WITH_TESTS_UNIT:BOOL*
- *HPX_WITH_TOOLS:BOOL*

HPX_WITH_ASIO_TAG:STRING

Asio repository tag or branch

HPX_WITH_COMPILE_ONLY_TESTS:BOOL

Create build system support for compile time only HPX tests (default ON)

HPX_WITH_DISTRIBUTED_RUNTIME:BOOL

Enable the distributed runtime (default: ON). Turning off the distributed runtime completely disallows the creation and use of components and actions. Turning this option off is experimental!

HPX_WITH_DOCUMENTATION:BOOL

Build the HPX documentation (default OFF).

HPX_WITH_DOCUMENTATION_OUTPUT_FORMATS:STRING

List of documentation output formats to generate. Valid options are html;singlehtml;latexpdf;man. Multiple values can be separated with semicolons. (default html).

HPX_WITH_EXAMPLES:BOOL

Build the HPX examples (default ON)

HPX_WITH_EXAMPLES_HDF5:BOOL

Enable examples requiring HDF5 support (default: OFF).

HPX_WITH_EXAMPLES_OPENMP:BOOL

Enable examples requiring OpenMP support (default: OFF).

HPX_WITH_EXAMPLES_QT4:BOOL

Enable examples requiring Qt4 support (default: OFF).

HPX_WITH_EXAMPLES_QTHREADS:BOOL

Enable examples requiring QThreads support (default: OFF).

HPX_WITH_EXAMPLES_TBB:BOOL

Enable examples requiring TBB support (default: OFF).

HPX_WITH_EXECUTABLE_PREFIX:STRING

Executable prefix (default none), **‘hpx_’** useful for system install.

HPX_WITH_FAIL_COMPILE_TESTS:BOOL

Create build system support for fail compile HPX tests (default ON)

HPX_WITH_FETCH_APEX:BOOL

Use FetchContent to fetch APEX. By default an installed APEX will be used. (default: OFF)

HPX_WITH_FETCH_ASIO:BOOL

Use FetchContent to fetch Asio. By default an installed Asio will be used. (default: OFF)

HPX_WITH_FETCH_BOOST:BOOL

Use FetchContent to fetch Boost. By default an installed Boost will be used. (default: OFF)

HPX_WITH_FETCH_GASNET:BOOL

Use FetchContent to fetch GASNET. By default an installed GASNET will be used. (default: OFF).

HPX_WITH_FETCH_HWLOC:BOOL

Use FetchContent to fetch Hwloc. By default an installed Hwloc will be used. (default: OFF)

HPX_WITH_FETCH_LCI:BOOL

Use FetchContent to fetch LCI. By default an installed LCI will be used. (default: OFF)

HPX_WITH_IO_COUNTERS:BOOL

Enable IO counters (default: ON)

HPX_WITH_LCI_TAG:STRING

LCI repository tag or branch

HPX_WITH_NANOBENCH:BOOL

Use Nanobench for performance tests. Nanobench will be fetched using FetchContent (default: OFF)

HPX_WITH_PARALLEL_LINK_JOBS:STRING

Number of Parallel link jobs while building hpx (only for Ninja as generator) (default 2)

HPX_WITH_TESTS:BOOL

Build the HPX tests (default ON)

HPX_WITH_TESTS_BENCHMARKS:BOOL

Build HPX benchmark tests (default: ON)

HPX_WITH_TESTS_EXAMPLES:BOOL

Add HPX examples as tests (default: ON)

HPX_WITH_TESTS_EXTERNAL_BUILD:BOOL

Build external cmake build tests (default: ON)

HPX_WITH_TESTS_HEADERS:BOOL

Build HPX header tests (default: OFF)

HPX_WITH_TESTS_REGRESSIONS:BOOL

Build HPX regression tests (default: ON)

HPX_WITH_TESTS_UNIT:BOOL

Build HPX unit tests (default: ON)

HPX_WITH_TOOLS:BOOL

Build HPX tools (default: OFF)

Thread Manager options

- *HPX_COROUTINES_WITH_SWAP_CONTEXT_EMULATION:BOOL*
- *HPX_COROUTINES_WITH_THREAD_SCHEDULE_HINT_RUNS_AS_CHILD:BOOL*
- *HPX_WITH_COROUTINE_COUNTERS:BOOL*
- *HPX_WITH_IO_POOL:BOOL*
- *HPX_WITH_MAX_CPU_COUNT:STRING*
- *HPX_WITH_MAX_NUMA_DOMAIN_COUNT:STRING*
- *HPX_WITH_SCHEDULER_LOCAL_STORAGE:BOOL*
- *HPX_WITH_SPINLOCK_DEADLOCK_DETECTION:BOOL*
- *HPX_WITH_SPINLOCK_POOL_NUM:STRING*
- *HPX_WITH_STACKTRACES:BOOL*
- *HPX_WITH_STACKTRACES_DEMANGLE_SYMBOLS:BOOL*
- *HPX_WITH_STACKTRACES_STATIC_SYMBOLS:BOOL*
- *HPX_WITH_THREAD_BACKTRACE_DEPTH:STRING*
- *HPX_WITH_THREAD_BACKTRACE_ON_SUSPENSION:BOOL*
- *HPX_WITH_THREAD_CREATION_AND_CLEANUP_RATES:BOOL*
- *HPX_WITH_THREAD_CUMULATIVE_COUNTS:BOOL*
- *HPX_WITH_THREAD_IDLE_RATES:BOOL*
- *HPX_WITH_THREAD_LOCAL_STORAGE:BOOL*
- *HPX_WITH_THREAD_MANAGER_IDLE_BACKOFF:BOOL*
- *HPX_WITH_THREAD_QUEUE_WAITTIME:BOOL*
- *HPX_WITH_THREAD_STACK_MMAP:BOOL*
- *HPX_WITH_THREAD_STEALING_COUNTS:BOOL*
- *HPX_WITH_THREAD_TARGET_ADDRESS:BOOL*
- *HPX_WITH_TIMER_POOL:BOOL*
- *HPX_WITH_WORK_REQUESTING_SCHEDULERS:BOOL*

HPX_COROUTINES_WITH_SWAP_CONTEXT_EMULATION:BOOL

Emulate SwapContext API for coroutines (Windows only, default: OFF)

HPX_COROUTINES_WITH_THREAD_SCHEDULE_HINT_RUNS_AS_CHILD:BOOL

Futures attempt to run associated threads directly if those have not been started (default: OFF)

HPX_WITH_COROUTINE_COUNTERS:BOOL

Enable keeping track of coroutine creation and rebind counts (default: OFF)

HPX_WITH_IO_POOL:BOOL

Disable internal IO thread pool, do not change if not absolutely necessary (default: ON)

HPX_WITH_MAX_CPU_COUNT:STRING

HPX applications will not use more that this number of OS-Threads (empty string means dynamic) (default: “”)

HPX_WITH_MAX_NUMA_DOMAIN_COUNT:STRING

HPX applications will not run on machines with more NUMA domains (default: 8)

HPX_WITH_SCHEDULER_LOCAL_STORAGE:BOOL

Enable scheduler local storage for all HPX schedulers (default: OFF)

HPX_WITH_SPINLOCK_DEADLOCK_DETECTION:BOOL

Enable spinlock deadlock detection (default: OFF)

HPX_WITH_SPINLOCK_POOL_NUM:STRING

Number of elements a spinlock pool manages (default: 128)

HPX_WITH_STACKTRACES:BOOL

Attach backtraces to HPX exceptions (default: ON)

HPX_WITH_STACKTRACES_DEMANGLE_SYMBOLS:BOOL

Thread stack back trace symbols will be demangled (default: ON)

HPX_WITH_STACKTRACES_STATIC_SYMBOLS:BOOL

Thread stack back trace will resolve static symbols (default: OFF)

HPX_WITH_THREAD_BACKTRACE_DEPTH:STRING

Thread stack back trace depth being captured (default: 20)

HPX_WITH_THREAD_BACKTRACE_ON_SUSPENSION:BOOL

Enable thread stack back trace being captured on suspension (default: OFF)

HPX_WITH_THREAD_CREATION_AND_CLEANUP_RATES:BOOL

Enable measuring thread creation and cleanup times (default: OFF)

HPX_WITH_THREAD_CUMULATIVE_COUNTS:BOOL

Enable keeping track of cumulative thread counts in the schedulers (default: ON)

HPX_WITH_THREAD_IDLE_RATES:BOOL

Enable measuring the percentage of overhead times spent in the scheduler (default: OFF)

HPX_WITH_THREAD_LOCAL_STORAGE:BOOL

Enable thread local storage for all HPX threads (default: OFF)

HPX_WITH_THREAD_MANAGER_IDLE_BACKOFF:BOOL

HPX scheduler threads do exponential backoff on idle queues (default: ON)

HPX_WITH_THREAD_QUEUE_WAITTIME:BOOL

Enable collecting queue wait times for threads (default: OFF)

HPX_WITH_THREAD_STACK_MMAP:BOOL

Use mmap for stack allocation on appropriate platforms

HPX_WITH_THREAD_STEALING_COUNTS:BOOL

Enable keeping track of counts of thread stealing incidents in the schedulers (default: OFF)

HPX_WITH_THREAD_TARGET_ADDRESS:BOOL

Enable storing target address in thread for NUMA awareness (default: OFF)

HPX_WITH_TIMER_POOL:BOOL

Disable internal timer thread pool, do not change if not absolutely necessary (default: ON)

HPX_WITH_WORK_REQUESTING_SCHEDULERS:BOOL

Enable work requesting scheduler (default: ON)

AGAS options

- *HPX_WITH_AGAS_DUMP_REFCNT_ENTRIES:BOOL*

HPX_WITH_AGAS_DUMP_REFCNT_ENTRIES:BOOL

Enable dumps of the AGAS refcnt tables to logs (default: OFF)

Parcelport options

- *HPX_WITH_NETWORKING:BOOL*
- *HPX_WITH_PARCELPORT_ACTION_COUNTERS:BOOL*
- *HPX_WITH_PARCELPORT_COUNTERS:BOOL*
- *HPX_WITH_PARCELPORT_GASNET:BOOL*
- *HPX_WITH_PARCELPORT_LCI:BOOL*
- *HPX_WITH_PARCELPORT_LCI_LOG:STRING*
- *HPX_WITH_PARCELPORT_LCI_PCOUNTER:STRING*
- *HPX_WITH_PARCELPORT_LIBFABRIC:BOOL*
- *HPX_WITH_PARCELPORT_MPI:BOOL*
- *HPX_WITH_PARCELPORT_TCP:BOOL*
- *HPX_WITH_PARCEL_PROFILING:BOOL*

HPX_WITH_NETWORKING:BOOL

Enable support for networking and multi-node runs (default: ON)

HPX_WITH_PARCELPORT_ACTION_COUNTERS:BOOL

Enable performance counters reporting parcelport statistics on a per-action basis.

HPX_WITH_PARCELPORT_COUNTERS:BOOL

Enable performance counters reporting parcelport statistics.

HPX_WITH_PARCELPORT_GASNET:BOOL

Enable the GASNET based parcelport.

HPX_WITH_PARCELPORT_LCI:BOOL

Enable the LCI based parcelport.

HPX_WITH_PARCELPORT_LCI_LOG:STRING

Enable the LCI-parcelport-specific logger

HPX_WITH_PARCELPORT_LCI_PCOUNTER:STRING

Enable the LCI-parcelport-specific performance counter

HPX_WITH_PARCELPORT_LIBFABRIC:BOOL

Enable the libfabric based parcelport. This is currently an experimental feature

HPX_WITH_PARCELPORT_MPI:BOOL

Enable the MPI based parcelport.

HPX_WITH_PARCELPORT_TCP:BOOL

Enable the TCP based parcelport.

HPX_WITH_PARCEL_PROFILING:BOOL

Enable profiling data for parcels

Profiling options

- *HPX_WITH_APEX:BOOL*
- *HPX_WITH_ITTNOTIFY:BOOL*
- *HPX_WITH_PAPI:BOOL*

HPX_WITH_APEX:BOOL

Enable APEX instrumentation support.

HPX_WITH_ITTNOTIFY:BOOL

Enable Amplifier (ITT) instrumentation support.

HPX_WITH_PAPI:BOOL

Enable the PAPI based performance counter.

Debugging options

- *HPX_WITH_ATTACH_DEBUGGER_ON_TEST_FAILURE:BOOL*
- *HPX_WITH_PARALLEL_TESTS_BIND_NONE:BOOL*
- *HPX_WITH_SANITIZERS:BOOL*
- *HPX_WITH_TESTS_COMMAND_LINE:STRING*
- *HPX_WITH_TESTS_DEBUG_LOG:BOOL*
- *HPX_WITH_TESTS_DEBUG_LOG_DESTINATION:STRING*
- *HPX_WITH_TESTS_MAX_THREADS_PER_LOCALITY:STRING*
- *HPX_WITH_THREAD_DEBUG_INFO:BOOL*
- *HPX_WITH_THREAD_DESCRIPTION_FULL:BOOL*
- *HPX_WITH_THREAD_GUARD_PAGE:BOOL*
- *HPX_WITH_VALGRIND:BOOL*
- *HPX_WITH_VERIFY_LOCKS:BOOL*
- *HPX_WITH_VERIFY_LOCKS_BACKTRACE:BOOL*

HPX_WITH_ATTACH_DEBUGGER_ON_TEST_FAILURE:BOOL

Break the debugger if a test has failed (default: OFF)

HPX_WITH_PARALLEL_TESTS_BIND_NONE:BOOL

Pass `-hpx:bind=none` to tests that may run in parallel (cmake `-j` flag) (default: OFF)

HPX_WITH_SANITIZERS:BOOL

Configure with sanitizer instrumentation support.

HPX_WITH_TESTS_COMMAND_LINE:STRING

Add given command line options to all tests run

HPX_WITH_TESTS_DEBUG_LOG:BOOL

Turn on debug logs (`-hpx:debug-hpx-log`) for tests (default: OFF)

HPX_WITH_TESTS_DEBUG_LOG_DESTINATION:STRING

Destination for test debug logs (default: `cout`)

HPX_WITH_TESTS_MAX_THREADS_PER_LOCALITY:STRING

Maximum number of threads to use for tests (default: 0, use the number of threads specified by the test)

HPX_WITH_THREAD_DEBUG_INFO:BOOL

Enable thread debugging information (default: OFF, implicitly enabled in debug builds)

HPX_WITH_THREAD_DESCRIPTION_FULL:BOOL

Use function address for thread description (default: OFF)

HPX_WITH_THREAD_GUARD_PAGE:BOOL

Enable thread guard page (default: ON)

HPX_WITH_VALGRIND:BOOL

Enable Valgrind instrumentation support.

HPX_WITH_VERIFY_LOCKS:BOOL

Enable lock verification code (default: OFF, enabled in debug builds)

HPX_WITH_VERIFY_LOCKS_BACKTRACE:BOOL

Enable thread stack back trace being captured on lock registration (to be used in combination with `HPX_WITH_VERIFY_LOCKS=ON`, default: OFF)

Modules options

- *HPX_ALLOCATOR_SUPPORT_WITH_CACHING:BOOL*
- *HPX_COMMAND_LINE_HANDLING_LOCAL_WITH_JSON_CONFIGURATION_FILES:BOOL*
- *HPX_DATASTRUCTURES_WITH_ADAPT_STD_TUPLE:BOOL*
- *HPX_DATASTRUCTURES_WITH_ADAPT_STD_VARIANT:BOOL*
- *HPX_FILESYSTEM_WITH_BOOST_FILESYSTEM_COMPATIBILITY:BOOL*
- *HPX_ITERATOR_SUPPORT_WITH_BOOST_ITERATOR_TRAVERSAL_TAG_COMPATIBILITY:BOOL*
- *HPX_LOGGING_WITH_SEPARATE_DESTINATIONS:BOOL*
- *HPX_SERIALIZATION_WITH_ALLOW_CONST_TUPLE_MEMBERS:BOOL*
- *HPX_SERIALIZATION_WITH_ALLOW_RAW_POINTER_SERIALIZATION:BOOL*
- *HPX_SERIALIZATION_WITH_ALL_TYPES_ARE_BITWISE_SERIALIZABLE:BOOL*
- *HPX_SERIALIZATION_WITH_BOOST_TYPES:BOOL*
- *HPX_SERIALIZATION_WITH_SUPPORTS_ENDIANESS:BOOL*
- *HPX_TOPOLOGY_WITH_ADDITIONAL_HWLOC_TESTING:BOOL*
- *HPX_WITH_POWER_COUNTER:BOOL*

HPX_ALLOCATOR_SUPPORT_WITH_CACHING:BOOL

Enable caching allocator. (default: ON)

HPX_COMMAND_LINE_HANDLING_LOCAL_WITH_JSON_CONFIGURATION_FILES:BOOL

Enable reading JSON formatted configuration files on the command line.

(default: On)

HPX_DATASTRUCTURES_WITH_ADAPT_STD_TUPLE:BOOL

Enable compatibility of `hpx::get` with `std::tuple`. (default: ON)

HPX_DATASTRUCTURES_WITH_ADAPT_STD_VARIANT:BOOL

Enable compatibility of `hpx::get` with `std::variant`.

(default: OFF)

HPX_FILESYSTEM_WITH_BOOST_FILESYSTEM_COMPATIBILITY:BOOL

Enable `Boost.FileSystem` compatibility. (default: OFF)

HPX_ITERATOR_SUPPORT_WITH_BOOST_ITERATOR_TRAVERSAL_TAG_COMPATIBILITY:BOOL

Enable `Boost.Iterator` traversal tag compatibility. (default: OFF)

HPX_LOGGING_WITH_SEPARATE_DESTINATIONS:BOOL

Enable separate logging channels for AGAS, timing, and parcel transport. (default: ON)

HPX_SERIALIZATION_WITH_ALLOW_CONST_TUPLE_MEMBERS:BOOL

Enable serializing `std::tuple` with `const` members. (default: OFF)

HPX_SERIALIZATION_WITH_ALLOW_RAW_POINTER_SERIALIZATION:BOOL

Enable serializing raw pointers. (default: OFF)

HPX_SERIALIZATION_WITH_ALL_TYPES_ARE_BITWISE_SERIALIZABLE:BOOL

Assume all types are bitwise serializable. (default: OFF)

HPX_SERIALIZATION_WITH_BOOST_TYPES:BOOL

Enable serialization of certain Boost types. (default: OFF)

HPX_SERIALIZATION_WITH_SUPPORTS_ENDIANESS:BOOL

Support endian conversion on inout and output archives. (default: OFF)

HPX_TOPOLOGY_WITH_ADDITIONAL_HWLOC_TESTING:BOOL

Enable HWLOC filtering that makes it report no cores, this is purely an option supporting better testing - do not enable under normal circumstances. (default: OFF)

HPX_WITH_POWER_COUNTER:BOOL

Enable use of performance counters based on `pwr` library (default: OFF)

Additional tools and libraries used by HPX

Here is a list of additional libraries and tools that are either optionally supported by the build system or are optionally required for certain examples or tests. These libraries and tools can be detected by the *HPX* build system.

Each of the tools or libraries listed here will be automatically detected if they are installed in some standard location. If a tool or library is installed in a different location, you can specify its base directory by appending `_ROOT` to the variable name as listed below. For instance, to configure a custom directory for Boost, specify `Boost_ROOT=/custom/boost/root`.

Boost_ROOT:PATH

Specifies where to look for the Boost installation to be used for compiling *HPX*. Set this if CMake is not able to locate a suitable version of Boost. The directory specified here can be either the root of an installed Boost distribution or the directory where you unpacked and built Boost without installing it (with staged libraries).

Hwloc_ROOT:PATH

Specifies where to look for the hwloc library. Set this if CMake is not able to locate a suitable version of hwloc. Hwloc provides platform- independent support for extracting information about the used hardware architecture (number of cores, number of NUMA domains, hyperthreading, etc.). *HPX* utilizes this information if available.

Papi_ROOT:PATH

Specifies where to look for the PAPI library. The PAPI library is needed to compile a special component exposing PAPI hardware events and counters as *HPX* performance counters. This is not available on the Windows platform.

Amplifier_ROOT:PATH

Specifies where to look for one of the tools of the Intel Parallel Studio product, either Intel Amplifier or Intel Inspector. This should be set if the CMake variable `HPX_USE_ITT_NOTIFY` is set to ON. Enabling ITT support in *HPX* will integrate any application with the mentioned Intel tools, which customizes the generated information for your application and improves the generated diagnostics.

In addition, some of the examples may need the following variables:

Hdf5_ROOT:PATH

Specifies where to look for the Hierarchical Data Format V5 (HDF5) include files and libraries.

2.3.5 Migration guide

The Migration Guide serves as a valuable resource for developers seeking to transition their parallel computing applications from different APIs (i.e. OpenMP, Intel Threading Building Blocks (TBB), MPI) to *HPX*. *HPX*, an advanced C++ library, offers a versatile and high-performance platform for parallel and distributed computing, providing a wide range of features and capabilities. This guide aims to assist developers in understanding the key differences between different APIs and *HPX*, and it provides step-by-step instructions for converting code to *HPX* code effectively.

Some general steps that can be used to migrate code to *HPX* code are the following:

1. Install *HPX* using the [Quick start](#) guide.
2. Include the *HPX* header files:

Add the necessary header files for *HPX* at the beginning of your code, such as:

```
#include <hpx/init.hpp>
```

3. Replace your code with *HPX* code using the guide that follows.
4. Use *HPX*-specific features and APIs:

HPX provides additional features and APIs that can be used to take advantage of the library's capabilities. For example, you can use the *HPX* asynchronous execution to express fine-grained tasks and dependencies, or utilize *HPX*'s distributed computing features for distributed memory systems.

5. Compile and run the *HPX* code:

Compile the converted code with the *HPX* library and run it using the appropriate *HPX* runtime environment.

OpenMP

The OpenMP API supports multi-platform shared-memory parallel programming in C/C++. Typically it is used for loop-level parallelism, but it also supports function-level parallelism. Below are some examples on how to convert OpenMP to *HPX* code:

OpenMP parallel for loop

Parallel for loop

OpenMP code:

```
#pragma omp parallel for
for (int i = 0; i < n; ++i) {
    // loop body
}
```

HPX equivalent:

```
#include <hpx/algorithm.hpp>

hpx::experimental::for_loop(hpx::execution::par, 0, n, [&](int i) {
    // loop body
});
```

In the above code, the OpenMP `#pragma omp parallel for` directive is replaced with `hpx::experimental::for_loop` from the *HPX* library. The loop body within the lambda function will be executed in parallel for each iteration.

Private variables

OpenMP code:

```
int x = 0;

#pragma omp parallel for private(x)
for (int i = 0; i < n; ++i) {
    // loop body
}
```

HPX equivalent:

```
#include <hpx/algorithm.hpp>

hpx::experimental::for_loop(hpx::execution::par, 0, n, [&](int i) {
    int x = 0; // Declare 'x' as a local variable inside the loop body
    // loop body
});
```

The variable `x` is declared as a local variable inside the loop body, ensuring that it is private to each thread.

Shared variables

OpenMP code:

```
int x = 0;

#pragma omp parallel for shared(x)
for (int i = 0; i < n; ++i) {
    // loop body
}
```

HPX equivalent:

```
#include <hpx/algorithm.hpp>

std::atomic<int> x = 0; // Declare 'x' as a shared variable outside the loop

hpx::experimental::for_loop(hpx::execution::par, 0, n, [&](int i) {
    // loop body
});
```

To ensure variable *x* is shared among all threads, you simply have to declare it as an atomic variable outside the *for_loop*.

Number of threads

OpenMP code:

```
#pragma omp parallel for num_threads(2)
for (int i = 0; i < n; ++i) {
    // loop body
}
```

HPX equivalent:

```
#include <hpx/algorithm.hpp>
#include <hpx/execution.hpp>

hpx::execution::experimental::num_cores nc(2);

hpx::experimental::for_loop(hpx::execution::par.with(nc), 0, n, [&](int i) {
    // loop body
});
```

To declare the number of threads to be used for the parallel region, you can use `hpx::execution::experimental::num_cores` and pass the number of cores (*nc*) to `hpx::experimental::for_loop` using `hpx::execution::par.with(nc)`. This example uses 2 threads for the parallel loop.

Reduction

OpenMP code:

```
int s = 0;

#pragma omp parallel for reduction(+: s)
for (int i = 0; i < n; ++i) {
    s += i;
    // loop body
}
```

HPX equivalent:

```
#include <hpx/algorithm.hpp>
#include <hpx/execution.hpp>

int s = 0;

hpx::experimental::for_loop(hpx::execution::par, 0, n, reduction(s, 0, plus<>()), [&
->](int i, int& accum) {
    accum += i;
    // loop body
});
```

The reduction clause specifies that the variable *s* should be reduced across iterations using the *plus<>* operation. It initializes *s* to 0 at the beginning of the loop and accumulates the values of *s* from each iteration using the + operator. The lambda function representing the loop body takes two parameters: *i*, which represents the loop index, and *accum*, which is the reduction variable *s*. The lambda function is executed for each iteration of the loop. The reduction ensures that the *accum* value is correctly accumulated across different iterations and threads.

Schedule

OpenMP code:

```
int s = 0;

// static scheduling with chunk size 1000
#pragma omp parallel for schedule(static, 1000)
for (int i = 0; i < n; ++i) {
    // loop body
}
```

HPX equivalent:

```
#include <hpx/algorithm.hpp>
#include <hpx/execution.hpp>

hpx::execution::experimental::static_chunk_size cs(1000);

hpx::experimental::for_loop(hpx::execution::par.with(cs), 0, n, [&](int i) {
    // loop body
});
```

To define the scheduling type, you can use the corresponding execution policy from `hpx::execution::experimental`, define the chunk size (`cs`, here declared as 1000) and pass it to the to `hpx::experimental::for_loop` using `hpx::execution::par.with(cs)`.

Accordingly, other types of scheduling are available and can be used in a similar manner:

```
#include <hpx/execution.hpp>
hpx::execution::experimental::dynamic_chunk_size cs(1000);
```

```
#include <hpx/execution.hpp>
hpx::execution::experimental::guided_chunk_size cs(1000);
```

```
#include <hpx/execution.hpp>
hpx::execution::experimental::auto_chunk_size cs(1000);
```

OpenMP single thread

OpenMP code:

```
{ // parallel code
  #pragma omp single
  {
    // single-threaded code
  }
  // more parallel code
}
```

HPX equivalent:

```
#include <hpx/mutex.hpp>

hpx::mutex mtx;

{ // parallel code
  { // single-threaded code
    std::scoped_lock l(mtx);
  }
  // more parallel code
}
```

To make sure that only one thread accesses a specific code within a parallel section you can use `hpx::mutex` and `std::scoped_lock` to take ownership of the given mutex `mtx`. For more information about mutexes please refer to [Mutex](#).

OpenMP tasks

Simple tasks

OpenMP code:

```
// executed asynchronously by any available thread
#pragma omp task
{
    // task code
}
```

HPX equivalent:

```
#include <hpx/future.hpp>

auto future = hpx::async([](){
    // task code
});
```

or

```
#include <hpx/future.hpp>

hpx::post([](){
    // task code
}); // fire and forget
```

The tasks in *HPX* can be defined simply by using the `async` function and passing as argument the code you wish to run asynchronously. Another alternative is to use `post` which is a fire-and-forget method.

Tip: If you think you will like to synchronize your tasks later on, we suggest you use `hpx::async` which provides synchronization options, while `hpx::post` explicitly states that there is no return value or way to synchronize with the function execution. Synchronization options are listed below.

Task wait

OpenMP code:

```
#pragma omp task
{
    // task code
}

#pragma omp taskwait
// code after completion of task
```

HPX equivalent:

```
#include <hpx/future.hpp>
```

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```
hpx::async([]){
    // task code
}.get(); // wait for the task to complete

// code after completion of task
```

The `get()` function can be used to ensure that the task created with `hpx::async` is completed before the code continues executing beyond that point.

Multiple tasks synchronization

OpenMP code:

```
#pragma omp task
{
    // task 1 code
}

#pragma omp task
{
    // task 2 code
}

#pragma omp taskwait
// code after completion of both tasks 1 and 2
```

HPX equivalent:

```
#include <hpx/future.hpp>

auto future1 = hpx::async([]){
    // task 1 code
};

auto future2 = hpx::async([]){
    // task 2 code
};

auto future = hpx::when_all(future1, future2).then([](auto&&){
    // code after completion of both tasks 1 and 2
});
```

If you would like to synchronize multiple tasks, you can use the `hpx::when_all` function to define which futures have to be ready and the `then()` function to declare what should be executed once these futures are ready.

Dependencies

OpenMP code:

```
int a = 10;
int b = 20;
int c = 0;

#pragma omp task depend(in: a, b) depend(out: c)
{
    // task code
    c = 100;
}
```

HPX equivalent:

```
#include <hpx/future.hpp>

int a = 10;
int b = 20;
int c = 0;

// Create a future representing 'a'
auto future_a = hpx::make_ready_future(a);

// Create a future representing 'b'
auto future_b = hpx::make_ready_future(b);

// Create a task that depends on 'a' and 'b' and executes 'task_code'
auto future_c = hpx::dataflow(
    []() {
        // task code
        return 100;
    },
    future_a, future_b);

c = future_c.get();
```

If one of the arguments of `hpx::dataflow` is a future, then it will wait for the future to be ready to launch the thread. Hence, to define the dependencies of tasks you have to create futures representing the variables that create dependencies and pass them as arguments to `hpx::dataflow`. `get()` is used to save the result of the future to the desired variable.

Nested tasks

OpenMP code:

```
#pragma omp task
{
    // Outer task code
    #pragma omp task
    {
        // Inner task code
    }
}
```

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```

    }
}

```

HPX equivalent:

```

#include <hpx/future.hpp>

auto future_outer = hpx::async([]() {
    // Outer task code

    hpx::async([]() {
        // Inner task code
    });
});

```

or

```

#include <hpx/future.hpp>

auto future_outer = hpx::post([]() { // fire and forget
    // Outer task code

    hpx::post([]() { // fire and forget
        // Inner task code
    });
});

```

If you have nested tasks, you can simply use nested `hpx::async` or `hpx::post` calls. The implementation is similar if you want to take care of synchronization:

OpenMP code:

```

#pragma omp taskwait
{
    // Outer task code
    #pragma omp taskwait
    {
        // Inner task code
    }
}

```

HPX equivalent:

```

#include <hpx/future.hpp>

auto future_outer = hpx::async([]() {
    // Outer task code

    hpx::async([]() {
        // Inner task code
    }).get(); // Wait for the inner task to complete
});

future_outer.get(); // Wait for the outer task to complete

```

Task yield

OpenMP code:

```
#pragma omp task
{
    // code before yielding
    #pragma omp taskyield
    // code after yielding
}
```

HPX equivalent:

```
#include <hpx/future.hpp>
#include <hpx/thread.hpp>

auto future = hpx::async([]() {
    // code before yielding
});

// yield execution to potentially allow other tasks to run
hpx::this_thread::yield();

// code after yielding
```

After creating a task using `hpx::async`, `hpx::this_thread::yield` can be used to reschedule the execution of threads, allowing other threads to run.

Task group

OpenMP code:

```
#pragma omp taskgroup
{
    #pragma omp task
    {
        // task 1 code
    }

    #pragma omp task
    {
        // task 2 code
    }
}
```

HPX equivalent:

```
#include <hpx/task_group.hpp>

// Declare a task group
hpx::experimental::task_group tg;

// Run the tasks
```

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```
tg.run([]){
    // task 1 code
};
tg.run(
    // task 2 code
);

// Wait for the task group
tg.wait();
```

To create task groups, you can use `hpx::experimental::task_group`. The function `run()` can be used to run each task within the task group, while `wait()` can be used to achieve synchronization. If you do not care about waiting for the task group to complete its execution, you can simply remove the `wait()` function.

OpenMP sections

OpenMP code:

```
#pragma omp sections
{
    #pragma omp section
    // section 1 code
    #pragma omp section
    // section 2 code
} // implicit synchronization
```

HPX equivalent:

```
#include <hpx/future.hpp>

auto future_section1 = hpx::async([]){
    // section 1 code
};
auto future_section2 = hpx::async([]){
    // section 2 code
};

// synchronization: wait for both sections to complete
hpx::wait_all(future_section1, future_section2);
```

Unlike tasks, there is an implicit synchronization barrier at the end of each `sections` directive in OpenMP. This synchronization is achieved using `hpx::wait_all` function.

Note: If the `nowait` clause is used in the `sections` directive, then you can just remove the `hpx::wait_all` function while keeping the rest of the code as it is.

Intel Threading Building Blocks (TBB)

Intel Threading Building Blocks (TBB) provides a high-level interface for parallelism and concurrent programming using standard ISO C++ code. Below are some examples on how to convert Intel Threading Building Blocks (TBB) to *HPX* code:

parallel_for

Intel Threading Building Blocks (TBB) code:

```
auto values = std::vector<double>(10000);

tbb::parallel_for( tbb::blocked_range<int>(0, values.size()),
                  [&](tbb::blocked_range<int> r)
{
    for (int i=r.begin(); i<r.end(); ++i)
    {
        // loop body
    }
});
```

HPX equivalent:

```
#include <hpx/algorithm.hpp>

auto values = std::vector<double>(10000);

hpx::experimental::for_loop(hpx::execution::par, 0, values.size(), [&](int i) {
    // loop body
});
```

In the above code, *tbb::parallel_for* is replaced with *hpx::experimental::for_loop* from the *HPX* library. The loop body within the lambda function will be executed in parallel for each iteration.

parallel_for_each

Intel Threading Building Blocks (TBB) code:

```
auto values = std::vector<double>(10000);

tbb::parallel_for_each(values.begin(), values.end(), [&]() {
    // loop body
});
```

HPX equivalent:

```
#include <hpx/algorithm.hpp>

auto values = std::vector<double>(10000);

hpx::for_each(hpx::execution::par, values.begin(), values.end(), [&]() {
```

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```

    // loop body
});

```

By utilizing `hpx::for_each` and specifying a parallel execution policy with `hpx::execution::par`, it is possible to transform `tbb::parallel_for_each` into its equivalent counterpart in HPX.

parallel_invoke

Intel Threading Building Blocks (TBB) code:

```
tbb::parallel_invoke(task1, task2, task3);
```

HPX equivalent:

```

#include <hpx/future.hpp>

hpx::wait_all(hpx::async(task1), hpx::async(task2), hpx::async(task3));

```

To convert `tbb::parallel_invoke` to HPX, we use `hpx::async` to asynchronously execute each task, which returns a future representing the result of each task. We then pass these futures to `hpx::when_all`, which waits for all the futures to complete before returning.

parallel_pipeline

Intel Threading Building Blocks (TBB) code:

```

tbb::parallel_pipeline(4,
    tbb::make_filter<void, int>(tbb::filter::serial_in_order,
        [](tbb::flow_control& fc) -> int {
            // Generate numbers from 1 to 10
            static int i = 1;
            if (i <= 10) {
                return i++;
            }
            else {
                fc.stop();
                return 0;
            }
        }) &
    tbb::make_filter<int, int>(tbb::filter::parallel,
        [](int num) -> int {
            // Multiply each number by 2
            return num * 2;
        }) &
    tbb::make_filter<int, void>(tbb::filter::serial_in_order,
        [](int num) {
            // Print the results
            std::cout << num << " ";
        })
);

```

HPX equivalent:

```
#include <iostream>
#include <vector>
#include <ranges>
#include <hpx/algorithm.hpp>

// generate the values
auto range = std::views::iota(1) | std::views::take(10);

// materialize the output vector
std::vector<int> results(10);

// in parallel execution of pipeline and transformation
hpx::ranges::transform(
    hpx::execution::par, range, result.begin(), [](int i) { return 2 * i; });

// print the modified vector
for (int i : result)
{
    std::cout << i << " ";
}
std::cout << std::endl;
```

The line `auto range = std::views::iota(1) | std::views::take(10);` generates a range of values using the `std::views::iota` function. It starts from the value 1 and generates an infinite sequence of incrementing values. The `std::views::take(10)` function is then applied to limit the sequence to the first 10 values. The result is stored in the `range` variable.

Hint: A view is a lightweight object that represents a particular view of a sequence or range. It acts as a read-only interface to the original data, providing a way to query and traverse the elements without making any copies or modifications.

Views can be composed and chained together to form complex pipelines of operations. These operations are evaluated lazily, meaning that the actual computation is performed only when the result is needed or consumed.

Since views perform lazy evaluation, we use `std::vector<int> results(10);` to materialize the vector that will store the transformed values. The `hpx::ranges::transform` function is then used to perform a parallel transformation on the range. The transformed values will be written to the `results` vector.

Hint: Ranges enable loop fusion by combining multiple operations into a single parallel loop, eliminating waiting time and reducing overhead. Using ranges, you can express these operations as a pipeline of transformations on a sequence of elements. This pipeline is evaluated in a single pass, performing all the desired operations in parallel without the need to wait between them.

In addition, *HPX* enhances the benefits of range fusion by offering parallel execution policies, which can be used to optimize the execution of the fused loop across multiple threads.

parallel_reduce

Reduction

Intel Threading Building Blocks (TBB) code:

```

auto values = std::vector<double>{1,2,3,4,5,6,7,8,9};

auto total = tbb::parallel_reduce(
    tbb::blocked_range<int>(0, values.size()),
    0.0,
    [&](tbb::blocked_range<int> r, double running_total)
    {
        for (int i=r.begin(); i<r.end(); ++i)
        {
            running_total += values[i];
        }

        return running_total;
    },
    std::plus<double>());

```

HPX equivalent:

```

#include <hpx/numeric.hpp>

auto values = std::vector<double>{1,2,3,4,5,6,7,8,9};

auto total = hpx::reduce(
    hpx::execution::par, values.begin(), values.end(), 0, std::plus{});

```

By utilizing `hpx::reduce` and specifying a parallel execution policy with `hpx::execution::par`, it is possible to transform `tbb::parallel_reduce` into its equivalent counterpart in *HPX*. As demonstrated in the previous example, the management of intermediate results is seamlessly handled internally by *HPX*, eliminating the need for explicit consideration.

Transformation & Reduction

Intel Threading Building Blocks (TBB) code:

```

auto values = std::vector<double>{1,2,3,4,5,6,7,8,9};

auto transform_function(double current_value){
    // transformation code
}

auto total = tbb::parallel_reduce(
    tbb::blocked_range<int>(0, values.size()),
    0.0,
    [&](tbb::blocked_range<int> r, double transformed_val)
    {
        for (int i=r.begin(); i<r.end(); ++i)

```

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```

        {
            transformed_val += transform_function(values[i]);
        }
        return transformed_val;
    },
    std::plus<double>());

```

HPX equivalent:

```

#include <hpx/numeric.hpp>

auto values = std::vector<double>{1,2,3,4,5,6,7,8,9};

auto transform_function(double current_value)
{
    // transformation code
}

auto total = hpx::transform_reduce(hpx::execution::par, values.begin(),
    values.end(), 0, std::plus{}),
    [&](double current_value) { return transform_function(current_value); });

```

In situations where certain values require transformation before the reduction process, *HPX* provides a straightforward solution through `hpx::transform_reduce`. The `transform_function()` allows for the application of the desired transformation to each value.

parallel_scan

Intel Threading Building Blocks (TBB) code:

```

tbb::parallel_scan(tbb::blocked_range<size_t>(0, input.size()),
    0,
    [&input, &output](const tbb::blocked_range<size_t>& range, int& partial_sum, bool is_
↪final_scan) {
    for (size_t i = range.begin(); i != range.end(); ++i) {
        partial_sum += input[i];
        if (is_final_scan) {
            output[i] = partial_sum;
        }
    }
    return partial_sum;
},
    [](int left_sum, int right_sum) {
        return left_sum + right_sum;
    }
);

```

HPX equivalent:

```

#include <hpx/numeric.hpp>

hpx::inclusive_scan(hpx::execution::par, input.begin(), input.end(),

```

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```
output.begin(),
[](const int& left, const int& right) { return left + right; });
```

`hpx::inclusive_scan` with `hpx::execution::par` as execution policy can be used to perform a prefix scan in parallel. The management of intermediate results is seamlessly handled internally by *HPX*, eliminating the need for explicit consideration. `input.begin()` and `input.end()` refer to the beginning and end of the sequence of elements the algorithm will be applied to respectively. `output.begin()` refers to the beginning of the destination, while the last argument specifies the function which will be invoked for each of the values of the input sequence.

Apart from `hpx::inclusive_scan`, *HPX* provides its users with `hpx::exclusive_scan`. The key difference between inclusive scan and exclusive scan lies in the treatment of the current element during the scan operation. In an inclusive scan, each element in the output sequence includes the contribution of the corresponding element in the input sequence, while in an exclusive scan, the current element in the input sequence does not contribute to the corresponding element in the output sequence.

parallel_sort

Intel Threading Building Blocks (TBB) code:

```
std::vector<int> numbers = {9, 2, 7, 1, 5, 3};

tbb::parallel_sort(numbers.begin(), numbers.end());
```

HPX equivalent:

```
#include <hpx/algorithm.hpp>

std::vector<int> numbers = {9, 2, 7, 1, 5, 3};

hpx::sort(hpx::execution::par, numbers.begin(), numbers.end());
```

`hpx::sort` provides an equivalent functionality to `tbb::parallel_sort`. When given a parallel execution policy with `hpx::execution::par`, the algorithm employs parallel execution, allowing for efficient sorting across available threads.

task_group

Intel Threading Building Blocks (TBB) code:

```
// Declare a task group
tbb::task_group tg;

// Run the tasks
tg.run(task1);
tg.run(task2);

// Wait for the task group
tg.wait();
```

HPX equivalent:

```

#include <hpx/task_group.hpp>

// Declare a task group
hpx::experimental::task_group tg;

// Run the tasks
tg.run(task1);
tg.run(task2);

// Wait for the task group
tg.wait();

```

HPX drew inspiration from Intel Threading Building Blocks (TBB) to introduce the `hpx::experimental::task_group` feature. Therefore, utilizing `hpx::experimental::task_group` provides an equivalent functionality to `tbb::task_group`.

MPI

MPI is a standardized communication protocol and library that allows multiple processes or nodes in a parallel computing system to exchange data and coordinate their execution.

List of MPI-HPX functions

MPI function	HPX equivalent
<code>MPI_Allgather</code>	<code>hpx::collectives::all_gather</code>
<code>MPI_Allreduce</code>	<code>hpx::collectives::all_reduce</code>
<code>MPI_Alltoall</code>	<code>hpx::collectives::all_to_all</code>
<code>MPI_Barrier</code>	<code>hpx::distributed::barrier</code>
<code>MPI_Bcast</code>	<code>hpx::collectives::broadcast_to()</code> and <code>hpx::collectives::broadcast_from()</code> used with <code>get()</code>
<code>MPI_Comm_size</code>	<code>hpx::get_num_localities</code>
<code>MPI_Comm_rank</code>	<code>hpx::get_locality_id()</code>
<code>MPI_Exscan</code>	<code>hpx::collectives::exclusive_scan()</code> used with <code>get()</code>
<code>MPI_Gather</code>	<code>hpx::collectives::gather_here()</code> and <code>hpx::collectives::gather_there()</code> used with <code>get()</code>
<code>MPI_Irecv</code>	<code>hpx::collectives::get()</code>
<code>MPI_Isend</code>	<code>hpx::collectives::set()</code>
<code>MPI_Reduce</code>	<code>hpx::collectives::reduce_here</code> and <code>hpx::collectives::reduce_there</code> used with <code>get()</code>
<code>MPI_Scan</code>	<code>hpx::collectives::inclusive_scan()</code> used with <code>get()</code>
<code>MPI_Scatter</code>	<code>hpx::collectives::scatter_to()</code> and <code>hpx::collectives::scatter_from()</code>
<code>MPI_Wait</code>	<code>hpx::collectives::get()</code> used with a future i.e. <code>setf.get()</code>

MPI_Send & MPI_Recv

Let's assume we have the following simple message passing code where each process sends a message to the next process in a circular manner. The exchanged message is modified and printed to the console.

MPI code:

```
#include <cstddef>
#include <cstdint>
#include <iostream>
#include <mpi.h>
#include <vector>

constexpr int times = 2;

int main(int argc, char *argv[]) {
    MPI_Init(&argc, &argv);

    int num_localities;
    MPI_Comm_size(MPI_COMM_WORLD, &num_localities);

    int this_locality;
    MPI_Comm_rank(MPI_COMM_WORLD, &this_locality);

    int next_locality = (this_locality + 1) % num_localities;
    std::vector<int> msg_vec = {0, 1};

    int cnt = 0;
    int msg = msg_vec[this_locality];

    int recv_msg;
    MPI_Request request_send, request_recv;
    MPI_Status status;

    while (cnt < times) {
        cnt += 1;

        MPI_Isend(&msg, 1, MPI_INT, next_locality, cnt, MPI_COMM_WORLD,
                &request_send);
        MPI_Irecv(&recv_msg, 1, MPI_INT, next_locality, cnt, MPI_COMM_WORLD,
                &request_recv);

        MPI_Wait(&request_send, &status);
        MPI_Wait(&request_recv, &status);

        std::cout << "Time: " << cnt << ", Locality " << this_locality
                << " received msg: " << recv_msg << "\n";

        recv_msg += 10;
        msg = recv_msg;
    }

    MPI_Finalize();
```

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```
return 0;
}
```

HPX equivalent:

```
#include <hpx/config.hpp>

#if !defined(HPX_COMPUTE_DEVICE_CODE)
#include <hpx/algorithm.hpp>
#include <hpx/hpx_init.hpp>
#include <hpx/modules/collectives.hpp>

#include <cstddef>
#include <cstdint>
#include <iostream>
#include <utility>
#include <vector>

using namespace hpx::collectives;

constexpr char const* channel_communicator_name =
    "/example/channel_communicator/";

// the number of times
constexpr int times = 2;

int hpx_main()
{
    std::uint32_t num_localities = hpx::get_num_localities(hpx::launch::sync);
    std::uint32_t this_locality = hpx::get_locality_id();

    // allocate channel communicator
    auto comm = create_channel_communicator(hpx::launch::sync,
        channel_communicator_name, num_sites_arg(num_localities),
        this_site_arg(this_locality));

    std::uint32_t next_locality = (this_locality + 1) % num_localities;
    std::vector<int> msg_vec = {0, 1};

    int cnt = 0;
    int msg = msg_vec[this_locality];

    // send values to another locality
    auto setf = set(comm, that_site_arg(next_locality), msg, tag_arg(cnt));
    auto got_msg = get<int>(comm, that_site_arg(next_locality), tag_arg(cnt));

    setf.get();

    while (cnt < times)
    {
        cnt += 1;
    }
}
```

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```

    auto done_msg = got_msg.then([&](auto&& f) {
        int rec_msg = f.get();
        std::cout << "Time: " << cnt << ", Locality " << this_locality
            << " received msg: " << rec_msg << "\n";

        // change msg by adding 10
        rec_msg += 10;

        // start next round
        setf =
            set(comm, that_site_arg(next_locality), rec_msg, tag_arg(cnt));
        got_msg =
            get<int>(comm, that_site_arg(next_locality), tag_arg(cnt));
        setf.get();
    });

    done_msg.get();
}

return hpx::finalize();
}
#endif

int main(int argc, char* argv[])
{
#ifdef HPX_COMPUTE_DEVICE_CODE
    hpx::init_params params;
    params.cfg = {"--hpx:run-hpx-main"};
    return hpx::init(argc, argv, params);
#else
    (void) argc;
    (void) argv;
    return 0;
#endif
}

```

To perform message passing between different processes in *HPX* we can use a channel communicator. To understand this example, let's focus on the *hpx_main()* function:

- *hpx::get_num_localities(hpx::launch::sync)* retrieves the number of localities, while *hpx::get_locality_id()* returns the ID of the current locality.
- *create_channel_communicator* function is used to create a channel to serve the communication. This function takes several arguments, including the launch policy (*hpx::launch::sync*), the name of the communicator (*channel_communicator_name*), the number of localities, and the ID of the current locality.
- The communication follows a ring pattern, where each process (or locality) sends a message to its neighbor in a circular manner. This means that the messages circulate around the localities, ensuring that the communication wraps around when reaching the end of the locality sequence. To achieve this, the *next_locality* variable is calculated as the ID of the next locality in the ring.
- The initial values for the communication are set (*msg_vec*, *cnt*, *msg*).
- The *set()* function is called to send the message to the next locality in the ring. The message is sent asynchronously and is associated with a tag (*cnt*).

- The `get()` function is called to receive a message from the next locality. It is also associated with the same tag as the `set()` operation.
- The `setf.get()` call blocks until the message sending operation is complete.
- A continuation is set up using the function `then()` to handle the received message. Inside the continuation:
 - The received message value (`rec_msg`) is retrieved using `f.get()`.
 - The received message is printed to the console and then modified by adding 10.
 - The `set()` and `get()` operations are repeated to send and receive the modified message to the next locality.
 - The `setf.get()` call blocks until the new message sending operation is complete.
- The `done_msg.get()` call blocks until the continuation is complete for the current loop iteration.

Having said that, we conclude to the following table:

MPI_Gather

The following code gathers data from all processes to the root process and verifies the gathered data in the root process.

MPI code:

```
#include <iostream>
#include <mpi.h>
#include <numeric>
#include <vector>

int main(int argc, char *argv[]) {
    MPI_Init(&argc, &argv);

    int num_localities, this_locality;
    MPI_Comm_size(MPI_COMM_WORLD, &num_localities);
    MPI_Comm_rank(MPI_COMM_WORLD, &this_locality);

    std::vector<int> local_data; // Data to be gathered

    if (this_locality == 0) {
        local_data.resize(num_localities); // Resize the vector on the root process
    }

    // Each process calculates its local data value
    int my_data = 42 + this_locality;

    for (std::uint32_t i = 0; i != 10; ++i) {

        // Gather data from all processes to the root process (process 0)
        MPI_Gather(&my_data, 1, MPI_INT, local_data.data(), 1, MPI_INT, 0,
                 MPI_COMM_WORLD);

        // Only the root process (process 0) will print the gathered data
        if (this_locality == 0) {
            std::cout << "Gathered data on the root: ";
            for (int i = 0; i < num_localities; ++i) {
                std::cout << local_data[i] << " ";
            }
        }
    }
}
```

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```

    }
    std::cout << std::endl;
    }
}
std::cout << std::endl;

MPI_Finalize();
return 0;
}

```

HPX equivalent:

```

std::uint32_t num_localities = hpx::get_num_localities(hpx::launch::sync);
std::uint32_t this_locality = hpx::get_locality_id();

// test functionality based on immediate local result value
auto gather_direct_client = create_communicator(gather_direct_basename,
    num_sites_arg(num_localities), this_site_arg(this_locality));

for (std::uint32_t i = 0; i != 10; ++i)
{
    if (this_locality == 0)
    {
        hpx::future<std::vector<std::uint32_t>> overall_result =
            gather_here(gather_direct_client, std::uint32_t(42));

        std::vector<std::uint32_t> sol = overall_result.get();
        std::cout << "Gathered data on the root:";

        for (std::size_t j = 0; j != sol.size(); ++j)
        {
            HPX_TEST(j + 42 == sol[j]);
            std::cout << " " << sol[j];
        }
        std::cout << std::endl;
    }
    else
    {
        hpx::future<void> overall_result =
            gather_there(gather_direct_client, this_locality + 42);
        overall_result.get();
    }
}
}

```

This code will print 10 times the following message:

```
Gathered data on the root: 42 43
```

HPX uses two functions to implement the functionality of *MPI_Gather*: *gather_here* and *gather_there*. *gather_here* is gathering data from all localities to the locality with ID 0 (root locality). *gather_there* allows non-root localities to participate in the gather operation by sending data to the root locality. In more detail:

- *hpx::get_num_localities(hpx::launch::sync)* retrieves the number of localities, while *hpx::get_locality_id()* re-

turns the ID of the current locality.

- The function `create_communicator()` is used to create a communicator called `gather_direct_client`.
- If the current locality is the root (its ID is equal to 0):
 - The `gather_here` function is used to perform the gather operation. It collects data from all other localities into the `overall_result` future object. The function arguments provide the necessary information, such as the base name for the gather operation (`gather_direct_basename`), the value to be gathered (`value`), the number of localities (`num_localities`), the current locality ID (`this_locality`), and the generation number (related to the gather operation).
 - The `get()` member function of the `overall_result` future is used to retrieve the gathered data.
 - The `next_for` loop is used to verify the correctness of the gathered data (`sol`). `HPX_TEST` is a macro provided by the `HPX` testing utilities to perform similar testing with the Standard C++ macro `assert`.
- If the current locality is not the root:
 - The `gather_there` function is used to participate in the gather operation initiated by the root locality. It sends the data (in this case, the value `this_locality + 42`) to the root locality, indicating that it should be included in the gathering.
 - The `get()` member function of the `overall_result` future is used to wait for the gather operation to complete for this locality.

MPI_Scatter

The following code gathers data from all processes to the root process and verifies the gathered data in the root process.

MPI code:

```
#include <iostream>
#include <mpi.h>
#include <vector>

int main(int argc, char *argv[]) {
    MPI_Init(&argc, &argv);

    int num_localities, this_locality;
    MPI_Comm_size(MPI_COMM_WORLD, &num_localities);
    MPI_Comm_rank(MPI_COMM_WORLD, &this_locality);

    int num_localities = num_localities;
    std::vector<int> data(num_localities);

    if (this_locality == 0) {
        // Fill the data vector on the root locality (locality 0)
        for (int i = 0; i < num_localities; ++i) {
            data[i] = 42 + i;
        }
    }

    int local_data; // Variable to store the received data

    // Scatter data from the root locality to all other localities
    MPI_Scatter(&data[0], 1, MPI_INT, &local_data, 1, MPI_INT, 0, MPI_COMM_WORLD);
```

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```

// Now, each locality has its own local_data

// Print the local_data on each locality
std::cout << "Locality " << this_locality << " received " << local_data
          << std::endl;

MPI_Finalize();
return 0;
}

```

HPX equivalent:

```

std::uint32_t num_localities = hpx::get_num_localities(hpx::launch::sync);
HPX_TEST_LTE(std::uint32_t(2), num_localities);

std::uint32_t this_locality = hpx::get_locality_id();

auto scatter_direct_client =
    hpx::collectives::create_communicator(scatter_direct_basename,
        num_sites_arg(num_localities), this_site_arg(this_locality));

// test functionality based on immediate local result value
for (std::uint32_t i = 0; i != 10; ++i)
{
    if (this_locality == 0)
    {
        std::vector<std::uint32_t> data(num_localities);
        std::iota(data.begin(), data.end(), 42 + i);

        hpx::future<std::uint32_t> result =
            scatter_to(scatter_direct_client, std::move(data));

        HPX_TEST_EQ(i + 42 + this_locality, result.get());
    }
    else
    {
        hpx::future<std::uint32_t> result =
            scatter_from<std::uint32_t>(scatter_direct_client);

        HPX_TEST_EQ(i + 42 + this_locality, result.get());

        std::cout << "Locality " << this_locality << " received "
                  << i + 42 + this_locality << std::endl;
    }
}

```

For num_localities = 2 and since we run for 10 iterations this code will print the following message:

```

Locality 1 received 43
Locality 1 received 44
Locality 1 received 45

```

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```

Locality 1 received 46
Locality 1 received 47
Locality 1 received 48
Locality 1 received 49
Locality 1 received 50
Locality 1 received 51
Locality 1 received 52

```

HPX uses two functions to implement the functionality of *MPI_Scatter*: *hpx::scatter_to* and *hpx::scatter_from*. *hpx::scatter_to* is distributing the data from the locality with ID 0 (root locality) to all other localities. *hpx::scatter_from* allows non-root localities to receive the data from the root locality. In more detail:

- *hpx::get_num_localities(hpx::launch::sync)* retrieves the number of localities, while *hpx::get_locality_id()* returns the ID of the current locality.
- The function *hpx::collectives::create_communicator()* is used to create a communicator called *scatter_direct_client*.
- If the current locality is the root (its ID is equal to 0):
 - The data vector is filled with values ranging from $42 + i$ to $42 + i + \text{num_localities} - 1$.
 - The *hpx::scatter_to* function is used to perform the scatter operation using the communicator *scatter_direct_client*. This scatters the data vector to other localities and returns a future representing the result.
 - *HPX_TEST_EQ* is a macro provided by the HPX testing utilities to test the distributed values.
- If the current locality is not the root:
 - The *hpx::scatter_from* function is used to collect the data by the root locality.
 - *HPX_TEST_EQ* is a macro provided by the HPX testing utilities to test the collected values.

MPI_Allgather

The following code gathers data from all processes and sends the data to all processes.

MPI code:

```

#include <cstdint>
#include <iostream>
#include <mpi.h>
#include <vector>

int main(int argc, char **argv) {
    MPI_Init(&argc, &argv);

    int rank, size;
    MPI_Comm_rank(MPI_COMM_WORLD, &rank);
    MPI_Comm_size(MPI_COMM_WORLD, &size);

    // Get the number of MPI processes
    int num_localities = size;

    // Get the MPI process rank
    int here = rank;

```

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```

std::uint32_t value = here;

std::vector<std::uint32_t> r(num_localities);

// Perform an all-gather operation to gather values from all processes.
MPI_Allgather(&value, 1, MPI_UINT32_T, r.data(), 1, MPI_UINT32_T,
             MPI_COMM_WORLD);

// Print the result.
std::cout << "Locality " << here << " has values:";
for (size_t j = 0; j < r.size(); ++j) {
    std::cout << " " << r[j];
}
std::cout << std::endl;

MPI_Finalize();
return 0;
}

```

HPX equivalent:

```

std::uint32_t num_localities = hpx::get_num_localities(hpx::launch::sync);
std::uint32_t here = hpx::get_locality_id();

// test functionality based on immediate local result value
auto all_gather_direct_client =
    create_communicator(all_gather_direct_basename,
                       num_sites_arg(num_localities), this_site_arg(here));

std::uint32_t value = here;

hpx::future<std::vector<std::uint32_t>> overall_result =
    all_gather(all_gather_direct_client, value);

std::vector<std::uint32_t> r = overall_result.get();

std::cout << "Locality " << here << " has values:";
for (std::size_t j = 0; j != r.size(); ++j)
{
    std::cout << " " << j;
}
std::cout << std::endl;

```

For `num_localities = 2` this code will print the following message:

```

Locality 0 has values: 0 1
Locality 1 has values: 0 1

```

HPX uses the function `all_gather` to implement the functionality of `MPI_Allgather`. In more detail:

- `hpx::get_num_localities(hpx::launch::sync)` retrieves the number of localities, while `hpx::get_locality_id()` returns the ID of the current locality.

- The function `hpx::collectives::create_communicator()` is used to create a communicator called `all_gather_direct_client`.
- The values that the localities exchange with each other are equal to each locality's ID.
- The gather operation is performed using `all_gather`. The result is stored in an `hpx::future` object called `overall_result`, which represents a future result that can be retrieved later when needed.
- The `get()` function waits until the result is available and then stores it in the vector called `r`.

MPI_Allreduce

The following code combines values from all processes and distributes the result back to all processes.

MPI code:

```
#include <cstdint>
#include <iostream>
#include <mpi.h>

int main(int argc, char **argv) {
    MPI_Init(&argc, &argv);

    int rank, size;
    MPI_Comm_rank(MPI_COMM_WORLD, &rank);
    MPI_Comm_size(MPI_COMM_WORLD, &size);

    // Get the number of MPI processes
    int num_localities = size;

    // Get the MPI process rank
    int here = rank;

    // Create a communicator for the all reduce operation.
    MPI_Comm all_reduce_direct_client;
    MPI_Comm_split(MPI_COMM_WORLD, 0, rank, &all_reduce_direct_client);

    // Perform the all reduce operation to calculate the sum of 'here' values.
    std::uint32_t value = here;
    std::uint32_t res = 0;
    MPI_Allreduce(&value, &res, 1, MPI_UINT32_T, MPI_SUM,
                 all_reduce_direct_client);

    std::cout << "Locality " << rank << " has value: " << res << std::endl;

    MPI_Finalize();
    return 0;
}
```

HPX equivalent:

```
std::uint32_t const num_localities =
    hpx::get_num_localities(hpx::launch::sync);
std::uint32_t const here = hpx::get_locality_id();
```

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```

auto const all_reduce_direct_client =
    create_communicator(all_reduce_direct_basename,
        num_sites_arg(num_localities), this_site_arg(here));

std::uint32_t value = here;

hpx::future<std::uint32_t> overall_result =
    all_reduce(all_reduce_direct_client, value, std::plus<std::uint32_t>{});

std::uint32_t res = overall_result.get();
std::cout << "Locality " << here << " has value: " << res << std::endl;

```

For num_localities = 2 this code will print the following message:

```

Locality 0 has value: 1
Locality 1 has value: 1

```

HPX uses the function *all_reduce* to implement the functionality of *MPI_Allreduce*. In more detail:

- *hpx::get_num_localities(hpx::launch::sync)* retrieves the number of localities, while *hpx::get_locality_id()* returns the ID of the current locality.
- The function *hpx::collectives::create_communicator()* is used to create a communicator called *all_reduce_direct_client*.
- The value of each locality is equal to its ID.
- The reduce operation is performed using *all_reduce*. The result is stored in an *hpx::future* object called *overall_result*, which represents a future result that can be retrieved later when needed.
- The *get()* function waits until the result is available and then stores it in the variable *res*.

MPI_Alltoall

The following code gathers data from and scatters data to all processes.

MPI code:

```

#include <algorithm>
#include <cstdint>
#include <iostream>
#include <mpi.h>
#include <vector>

int main(int argc, char **argv) {
    MPI_Init(&argc, &argv);

    int rank, size;
    MPI_Comm_rank(MPI_COMM_WORLD, &rank);
    MPI_Comm_size(MPI_COMM_WORLD, &size);

    // Get the number of MPI processes
    int num_localities = size;

```

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```

// Get the MPI process rank
int this_locality = rank;

// Create a communicator for all-to-all operation.
MPI_Comm all_to_all_direct_client;
MPI_Comm_split(MPI_COMM_WORLD, 0, rank, &all_to_all_direct_client);

std::vector<std::uint32_t> values(num_localities);
std::fill(values.begin(), values.end(), this_locality);

// Create vectors to store received values.
std::vector<std::uint32_t> r(num_localities);

// Perform an all-to-all operation to exchange values with other localities.
MPI_Alltoall(values.data(), 1, MPI_UINT32_T, r.data(), 1, MPI_UINT32_T,
             all_to_all_direct_client);

// Print the results.
std::cout << "Locality " << this_locality << " has values:";
for (std::size_t j = 0; j != r.size(); ++j) {
    std::cout << " " << r[j];
}
std::cout << std::endl;

MPI_Finalize();
return 0;
}

```

HPX equivalent:

```

std::uint32_t num_localities = hpx::get_num_localities(hpx::launch::sync);
std::uint32_t this_locality = hpx::get_locality_id();

auto all_to_all_direct_client =
    create_communicator(all_to_all_direct_basename,
                       num_sites_arg(num_localities), this_site_arg(this_locality));

std::vector<std::uint32_t> values(num_localities);
std::fill(values.begin(), values.end(), this_locality);

hpx::future<std::vector<std::uint32_t>> overall_result =
    all_to_all(all_to_all_direct_client, std::move(values));

std::vector<std::uint32_t> r = overall_result.get();
std::cout << "Locality " << this_locality << " has values:";

for (std::size_t j = 0; j != r.size(); ++j)
{
    std::cout << " " << r[j];
}
std::cout << std::endl;

```

For num_localities = 2 this code will print the following message:

```
Locality 0 has values: 0 1
Locality 1 has values: 0 1
```

HPX uses the function `all_to_all` to implement the functionality of `MPI_Alltoall`. In more detail:

- `hpx::get_num_localities(hpx::launch::sync)` retrieves the number of localities, while `hpx::get_locality_id()` returns the ID of the current locality.
- The function `hpx::collectives::create_communicator()` is used to create a communicator called `all_to_all_direct_client`.
- The value each locality sends is equal to its ID.
- The all-to-all operation is performed using `all_to_all`. The result is stored in an `hpx::future` object called `overall_result`, which represents a future result that can be retrieved later when needed.
- The `get()` function waits until the result is available and then stores it in the variable `r`.

MPI Barrier

The following code shows how barrier is used to synchronize multiple processes.

MPI code:

```
#include <cstdlib>
#include <iostream>
#include <mpi.h>

int main(int argc, char **argv) {
    MPI_Init(&argc, &argv);

    std::size_t iterations = 5;

    int rank, size;
    MPI_Comm_rank(MPI_COMM_WORLD, &rank);
    MPI_Comm_size(MPI_COMM_WORLD, &size);

    for (std::size_t i = 0; i != iterations; ++i) {
        MPI_Barrier(MPI_COMM_WORLD);
        if (rank == 0) {
            std::cout << "Iteration " << i << " completed." << std::endl;
        }
    }

    MPI_Finalize();
    return 0;
}
```

HPX equivalent:

```
std::size_t iterations = 5;
std::uint32_t this_locality = hpx::get_locality_id();

char const* const barrier_test_name = "/test/barrier/multiple";
```

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```

hpx::distributed::barrier b(barrier_test_name);
for (std::size_t i = 0; i != iterations; ++i)
{
    b.wait();
    if (this_locality == 0)
    {
        std::cout << "Iteration " << i << " completed." << std::endl;
    }
}

```

This code will print the following message:

```

Iteration 0 completed.
Iteration 1 completed.
Iteration 2 completed.
Iteration 3 completed.
Iteration 4 completed.

```

HPX uses the function *barrier* to implement the functionality of *MPI_Barrier*. In more detail:

- After defining the number of iterations, we use *hpx::get_locality_id()* to get the ID of the current locality.
- *char const* const barrier_test_name = "/test/barrier/multiple"*: This line defines a constant character array as the name of the barrier. This name is used to identify the barrier across different localities. All participating threads that use this name will synchronize at this barrier.
- Using *hpx::distributed::barrier b(barrier_test_name)*, we create an instance of the distributed barrier with the previously defined name. This barrier will be used to synchronize the execution of threads across different localities.
- Running for all the desired iterations, we use *b.wait()* to synchronize the threads. Each thread waits until all other threads also reach this point before any of them can proceed further.

MPI_Bcast

The following code broadcasts data from one process to all other processes.

MPI code:

```

#include <iostream>
#include <mpi.h>

int main(int argc, char *argv[]) {
    MPI_Init(&argc, &argv);

    int num_localities;
    MPI_Comm_size(MPI_COMM_WORLD, &num_localities);

    int here;
    MPI_Comm_rank(MPI_COMM_WORLD, &here);

    int value;

    for (int i = 0; i < 5; ++i) {

```

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```

    if (here == 0) {
        value = i + 42;
    }

    // Broadcast the value from process 0 to all other processes
    MPI_Bcast(&value, 1, MPI_INT, 0, MPI_COMM_WORLD);

    if (here != 0) {
        std::cout << "Locality " << here << " received " << value << std::endl;
    }
}

MPI_Finalize();
return 0;
}

```

HPX equivalent:

```

std::uint32_t num_localities = hpx::get_num_localities(hpx::launch::sync);

std::uint32_t here = hpx::get_locality_id();

auto broadcast_direct_client =
    create_communicator(broadcast_direct_basename,
        num_sites_arg(num_localities), this_site_arg(here));

// test functionality based on immediate local result value
for (std::uint32_t i = 0; i != 5; ++i)
{
    if (here == 0)
    {
        hpx::future<std::uint32_t> result =
            broadcast_to(broadcast_direct_client, i + 42);

        result.get();
    }
    else
    {
        hpx::future<std::uint32_t> result =
            hpx::collectives::broadcast_from<std::uint32_t>(
                broadcast_direct_client);

        uint32_t r = result.get();

        std::cout << "Locality " << here << " received " << r << std::endl;
    }
}

```

For num_localities = 2 this code will print the following message:

```
Locality 1 received 42
```

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```

Locality 1 received 43
Locality 1 received 44
Locality 1 received 45
Locality 1 received 46

```

HPX uses two functions to implement the functionality of *MPI_Bcast*: *broadcast_to* and *broadcast_from*. *broadcast_to* is broadcasting the data from the root locality to all other localities. *broadcast_from* allows non-root localities to collect the data sent by the root locality. In more detail:

- *hpx::get_num_localities(hpx::launch::sync)* retrieves the number of localities, while *hpx::get_locality_id()* returns the ID of the current locality.
- The function *create_communicator()* is used to create a communicator called *broadcast_direct_client*.
- If the current locality is the root (its ID is equal to 0):
 - The *broadcast_to* function is used to perform the broadcast operation using the communicator *broadcast_direct_client*. This sends the data to other localities and returns a future representing the result.
 - The *get()* member function of the *result* future is used to wait for and retrieve the result.
- If the current locality is not the root:
 - The *broadcast_from* function is used to collect the data by the root locality.
 - The *get()* member function of the *result* future is used to wait for the result.

MPI_Exscan

The following code computes the exclusive scan (partial reductions) of data on a collection of processes.

MPI code:

```

#include <iostream>
#include <mpi.h>
#include <numeric>
#include <vector>

int main(int argc, char *argv[]) {
    MPI_Init(&argc, &argv);

    int num_localities;
    MPI_Comm_size(MPI_COMM_WORLD, &num_localities);

    int here;
    MPI_Comm_rank(MPI_COMM_WORLD, &here);

    // Calculate the value for this locality (here)
    int value = here;

    // Perform an exclusive scan
    std::vector<int> result(num_localities);
    MPI_Exscan(&value, &result[0], 1, MPI_INT, MPI_SUM, MPI_COMM_WORLD);

    if (here != 0) {
        int r = result[here - 1]; // Result is in the previous rank's slot
    }
}

```

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```
        std::cout << "Locality " << here << " has value " << r << std::endl;
    }

    MPI_Finalize();
    return 0;
}
```

HPX equivalent:

```
std::uint32_t num_localities = hpx::get_num_localities(hpx::launch::sync);
std::uint32_t here = hpx::get_locality_id();

auto exclusive_scan_client = create_communicator(exclusive_scan_basename,
    num_sites_arg(num_localities), this_site_arg(here));

// test functionality based on immediate local result value
std::uint32_t value = here;

hpx::future<std::uint32_t> overall_result = exclusive_scan(
    exclusive_scan_client, value, std::plus<std::uint32_t>{});

uint32_t r = overall_result.get();

if (here != 0)
{
    std::cout << "Locality " << here << " has value " << r << std::endl;
}
```

For num_localities = 2 this code will print the following message:

```
Locality 1 has value 0
```

HPX uses the function *exclusive_scan* to implement *MPI_Exscan*. In more detail:

- *hpx::get_num_localities(hpx::launch::sync)* retrieves the number of localities, while *hpx::get_locality_id()* returns the ID of the current locality.
- The function *create_communicator()* is used to create a communicator called *exclusive_scan_client*.
- The *exclusive_scan* function is used to perform the exclusive scan operation using the communicator *exclusive_scan_client*. *std::plus<std::uint32_t>{}* specifies the binary associative operator to use for the scan. In this case, it's addition for summing values.
- The *get()* member function of the *overall_result* future is used to wait for the result.

MPI_Scan

The following code Computes the inclusive scan (partial reductions) of data on a collection of processes.

MPI code:

```
#include <iostream>
#include <mpi.h>
#include <numeric>
#include <vector>

int main(int argc, char *argv[]) {
    MPI_Init(&argc, &argv);

    int num_localities;
    MPI_Comm_size(MPI_COMM_WORLD, &num_localities);

    int here;
    MPI_Comm_rank(MPI_COMM_WORLD, &here);

    // Calculate the value for this locality (here)
    int value = here;

    std::vector<int> result(num_localities);

    MPI_Scan(&value, &result[0], 1, MPI_INT, MPI_SUM, MPI_COMM_WORLD);

    std::cout << "Locality " << here << " has value " << result[0] << std::endl;

    MPI_Finalize();
    return 0;
}
```

HPX equivalent:

```
std::uint32_t num_localities = hpx::get_num_localities(hpx::launch::sync);
std::uint32_t here = hpx::get_locality_id();

auto inclusive_scan_client = create_communicator(inclusive_scan_basename,
    num_sites_arg(num_localities), this_site_arg(here));

std::uint32_t value = here;

hpx::future<std::uint32_t> overall_result = inclusive_scan(
    inclusive_scan_client, value, std::plus<std::uint32_t>{});

uint32_t r = overall_result.get();

std::cout << "Locality " << here << " has value " << r << std::endl;
```

For num_localities = 2 this code will print the following message:

```
Locality 0 has value 0
Locality 1 has value 1
```

HPX uses the function `inclusive_scan` to implement `MPI_Scan`. In more detail:

- `hpx::get_num_localities(hpx::launch::sync)` retrieves the number of localities, while `hpx::get_locality_id()` returns the ID of the current locality.
- The function `create_communicator()` is used to create a communicator called `inclusive_scan_client`.
- The `inclusive_scan` function is used to perform the exclusive scan operation using the communicator `inclusive_scan_client`. `std::plus<std::uint32_t>{}` specifies the binary associative operator to use for the scan. In this case, it's addition for summing values.
- The `get()` member function of the `overall_result` future is used to wait for the result.

MPI_Reduce

The following code performs a global reduce operation across all processes.

MPI code:

```
#include <iostream>
#include <mpi.h>

int main(int argc, char *argv[]) {
    MPI_Init(&argc, &argv);

    int num_processes;
    MPI_Comm_size(MPI_COMM_WORLD, &num_processes);

    int this_rank;
    MPI_Comm_rank(MPI_COMM_WORLD, &this_rank);

    int value = this_rank;

    int result = 0;

    // Perform the reduction operation
    MPI_Reduce(&value, &result, 1, MPI_INT, MPI_SUM, 0, MPI_COMM_WORLD);

    // Print the result for the root process (process 0)
    if (this_rank == 0) {
        std::cout << "Locality " << this_rank << " has value " << result
            << std::endl;
    }

    MPI_Finalize();
    return 0;
}
```

HPX equivalent:

```
std::uint32_t num_localities = hpx::get_num_localities(hpx::launch::sync);
std::uint32_t this_locality = hpx::get_locality_id();

auto reduce_direct_client = create_communicator(reduce_direct_basename,
    num_sites_arg(num_localities), this_site_arg(this_locality));
```

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```

std::uint32_t value = hpx::get_locality_id();

if (this_locality == 0)
{
    hpx::future<std::uint32_t> overall_result = reduce_here(
        reduce_direct_client, value, std::plus<std::uint32_t>{});

    uint32_t r = overall_result.get();

    std::cout << "Locality " << this_locality << " has value " << r
        << std::endl;
}
else
{
    hpx::future<void> overall_result =
        reduce_there(reduce_direct_client, std::move(value));
    overall_result.get();
}

```

This code will print the following message:

```
Locality 0 has value 1
```

HPX uses two functions to implement the functionality of *MPI_Reduce*: *reduce_here* and *reduce_there*. *reduce_here* is gathering data from all localities to the locality with ID 0 (root locality) and then performs the defined reduction operation. *reduce_there* allows non-root localities to participate in the reduction operation by sending data to the root locality. In more detail:

- *hpx::get_num_localities(hpx::launch::sync)* retrieves the number of localities, while *hpx::get_locality_id()* returns the ID of the current locality.
- The function *create_communicator()* is used to create a communicator called *reduce_direct_client*.
- If the current locality is the root (its ID is equal to 0):
 - The *reduce_here* function initiates a reduction operation with addition (*std::plus*) as the reduction operator. The result is stored in *overall_result*.
 - The *get()* member function of the *overall_result* future is used to wait for the result.
- If the current locality is not the root:
 - The *reduce_there* initiates a remote reduction operation.
 - The *get()* member function of the *overall_result* future is used to wait for the remote reduction operation to complete. This is done to ensure synchronization among localities.

2.3.6 Building tests and examples

Tests

To build the tests:

```
$ cmake --build . --target tests
```

To control which tests to run use `ctest`:

- To run single tests, for example a test for `for_loop`:

```
$ ctest --output-on-failure -R tests.unit.modules.algorithms.algorithms.for_loop
```

- To run a whole group of tests:

```
$ ctest --output-on-failure -R tests.unit
```

Examples

- To build (and install) all examples invoke:

```
$ cmake -DHPX_WITH_EXAMPLES=On .  
$ make examples  
$ make install
```

- To build the `hello_world_1` example run:

```
$ make hello_world_1
```

HPX executables end up in the `bin` directory in your build directory. You can now run `hello_world_1` and should see the following output:

```
$ ./bin/hello_world_1  
Hello World!
```

You've just run an example which prints `Hello World!` from the *HPX* runtime. The source for the example is in `examples/quickstart/hello_world_1.cpp`. The `hello_world_distributed` example (also available in the `examples/quickstart` directory) is a distributed hello world program, which is described in *Remote execution with actions*. It provides a gentle introduction to the distributed aspects of *HPX*.

Tip: Most build targets in *HPX* have two names: a simple name and a hierarchical name corresponding to what type of example or test the target is. If you are developing *HPX* it is often helpful to run `make help` to get a list of available targets. For example, `make help | grep hello_world` outputs the following:

```
... examples.quickstart.hello_world_2  
... hello_world_2  
... examples.quickstart.hello_world_1  
... hello_world_1  
... examples.quickstart.hello_world_distributed  
... hello_world_distributed
```

It is also possible to build, for instance, all quickstart examples using `make examples.quickstart`.

2.3.7 Creating *HPX* projects

Using *HPX* with pkg-config

How to build *HPX* applications with pkg-config

After you are done installing *HPX*, you should be able to build the following program. It prints Hello World! on the *locality* you run it on.

```
// Including 'hpx/hpx_main.hpp' instead of the usual 'hpx/hpx_init.hpp' enables
// to use the plain C-main below as the direct main HPX entry point.
#include <hpx/hpx_main.hpp>
#include <hpx/iostream.hpp>

int main()
{
    // Say hello to the world!
    hpx::cout << "Hello World!\n" << std::flush;
    return 0;
}
```

Copy the text of this program into a file called `hello_world.cpp`.

Now, in the directory where you put `hello_world.cpp`, issue the following commands (where `$HPX_LOCATION` is the build directory or `CMAKE_INSTALL_PREFIX` you used while building *HPX*):

```
$ export PKG_CONFIG_PATH=$PKG_CONFIG_PATH:$HPX_LOCATION/lib/pkgconfig
$ c++ -o hello_world hello_world.cpp \
    `pkg-config --cflags --libs hpx_application` \
    -lhpx_iostreams -DHPX_APPLICATION_NAME=hello_world
```

Important: When using `pkg-config` with *HPX*, the `pkg-config` flags must go after the `-o` flag.

Note: *HPX* libraries have different names in debug and release mode. If you want to link against a debug *HPX* library, you need to use the `_debug` suffix for the `pkg-config` name. That means instead of `hpx_application` or `hpx_component`, you will have to use `hpx_application_debug` or `hpx_component_debug`. Moreover, all referenced *HPX* components need to have an appended `d` suffix. For example, instead of `-lhpx_iostreams` you will need to specify `-lhpx_iostreamsd`.

Important: If the *HPX* libraries are in a path that is not found by the dynamic linker, you will need to add the path `$HPX_LOCATION/lib` to your linker search path (for example `LD_LIBRARY_PATH` on Linux).

To test the program, type:

```
$ ./hello_world
```

which should print Hello World! and exit.

How to build *HPX* components with pkg-config

Let's try a more complex example involving an *HPX* component. An *HPX* component is a class that exposes *HPX* actions. *HPX* components are compiled into dynamically loaded modules called component libraries. Here's the source code:

hello_world_component.cpp

```
#include <hpx/config.hpp>
#if !defined(HPX_COMPUTE_DEVICE_CODE)
#include <hpx/iostream.hpp>
#include "hello_world_component.hpp"

#include <iostream>

namespace examples { namespace server {
    void hello_world::invoke()
    {
        hpx::cout << "Hello HPX World!" << std::endl;
    }
}} // namespace examples::server

HPX_REGISTER_COMPONENT_MODULE()

typedef hpx::components::component<examples::server::hello_world>
    hello_world_type;

HPX_REGISTER_COMPONENT(hello_world_type, hello_world)

HPX_REGISTER_ACTION(
    examples::server::hello_world::invoke_action, hello_world_invoke_action)
#endif
```

hello_world_component.hpp

```
#pragma once

#include <hpx/config.hpp>
#if !defined(HPX_COMPUTE_DEVICE_CODE)
#include <hpx/hpx.hpp>
#include <hpx/include/actions.hpp>
#include <hpx/include/components.hpp>
#include <hpx/include/lcos.hpp>
#include <hpx/serialization.hpp>

#include <utility>

namespace examples { namespace server {
    struct HPX_COMPONENT_EXPORT hello_world
        : hpx::components::component_base<hello_world>
    {
        void invoke();
        HPX_DEFINE_COMPONENT_ACTION(hello_world, invoke)
    };
};
```

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```

}} // namespace examples::server

HPX_REGISTER_ACTION_DECLARATION(
    examples::server::hello_world::invoke_action, hello_world_invoke_action)

namespace examples {
    struct hello_world
    : hpx::components::client_base<hello_world, server::hello_world>
    {
        typedef hpx::components::client_base<hello_world, server::hello_world>
            base_type;

        hello_world(hpx::future<hpx::id_type>&& f)
            : base_type(std::move(f))
        {
        }

        hello_world(hpx::id_type&& f)
            : base_type(std::move(f))
        {
        }

        void invoke()
        {
            hpx::async<server::hello_world::invoke_action>(this->get_id())
                .get();
        }
    };
} // namespace examples

#endif

```

hello_world_client.cpp

```

#include <hpx/config.hpp>
#if defined(HPX_COMPUTE_HOST_CODE)
#include <hpx/wrap_main.hpp>

#include "hello_world_component.hpp"

int main()
{
    {
        // Create a single instance of the component on this locality.
        examples::hello_world client =
            hpx::new_<examples::hello_world>(hpx::find_here());

        // Invoke the component's action, which will print "Hello World!".
        client.invoke();
    }

    return 0;
}

```

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```
}  
#endif
```

Copy the three source files above into three files (called `hello_world_component.cpp`, `hello_world_component.hpp` and `hello_world_client.cpp`, respectively).

Now, in the directory where you put the files, run the following command to build the component library. (where `$HPX_LOCATION` is the build directory or `CMAKE_INSTALL_PREFIX` you used while building *HPX*):

```
$ export PKG_CONFIG_PATH=$PKG_CONFIG_PATH:$HPX_LOCATION/lib/pkgconfig  
$ c++ -o libhpx_hello_world.so hello_world_component.cpp \  
  `pkg-config --cflags --libs hpx_component` \  
  -lhpx_iostreams -DHPX_COMPONENT_NAME=hpx_hello_world
```

Now pick a directory in which to install your *HPX* component libraries. For this example, we'll choose a directory named `my_hpx_libs`:

```
$ mkdir ~/my_hpx_libs  
$ mv libhpx_hello_world.so ~/my_hpx_libs
```

Note: *HPX* libraries have different names in debug and release mode. If you want to link against a debug *HPX* library, you need to use the `_debug` suffix for the `pkg-config` name. That means instead of `hpx_application` or `hpx_component` you will have to use `hpx_application_debug` or `hpx_component_debug`. Moreover, all referenced *HPX* components need to have a appended `d` suffix, e.g. instead of `-lhpx_iostreams` you will need to specify `-lhpx_iostreamsd`.

Important: If the *HPX* libraries are in a path that is not found by the dynamic linker. You need to add the path `$HPX_LOCATION/lib` to your linker search path (for example `LD_LIBRARY_PATH` on Linux).

Now, to build the application that uses this component (`hello_world_client.cpp`), we do:

```
$ export PKG_CONFIG_PATH=$PKG_CONFIG_PATH:$HPX_LOCATION/lib/pkgconfig  
$ c++ -o hello_world_client hello_world_client.cpp \  
  `pkg-config --cflags --libs hpx_application` \  
  -L${HOME}/my_hpx_libs -lhpx_hello_world -lhpx_iostreams
```

Important: When using `pkg-config` with *HPX*, the `pkg-config` flags must go after the `-o` flag.

Finally, you'll need to set your `LD_LIBRARY_PATH` before you can run the program. To run the program, type:

```
$ export LD_LIBRARY_PATH="$LD_LIBRARY_PATH:$HOME/my_hpx_libs"  
$ ./hello_world_client
```

which should print `Hello HPX World!` and exit.

Using HPX with CMake-based projects

In addition to the pkg-config support discussed on the previous pages, *HPX* comes with full CMake support. In order to integrate *HPX* into existing or new CMakeLists.txt, you can leverage the `find_package`⁵⁸ command integrated into CMake. Following, is a Hello World component example using CMake.

Let's revisit what we have. We have three files that compose our example application:

- `hello_world_component.hpp`
- `hello_world_component.cpp`
- `hello_world_client.hpp`

The basic structure to include *HPX* into your CMakeLists.txt is shown here:

```
# Require a recent version of cmake
cmake_minimum_required(VERSION 3.18 FATAL_ERROR)

# This project is C++ based.
project(your_app CXX)

# Instruct cmake to find the HPX settings
find_package(HPX)
```

In order to have CMake find *HPX*, it needs to be told where to look for the `HPXConfig.cmake` file that is generated when *HPX* is built or installed. It is used by `find_package(HPX)` to set up all the necessary macros needed to use *HPX* in your project. The ways to achieve this are:

- Set the `HPX_DIR` CMake variable to point to the directory containing the `HPXConfig.cmake` script on the command line when you invoke CMake:

```
$ cmake -DHPX_DIR=$HPX_LOCATION/lib/cmake/HPX ...
```

where `$HPX_LOCATION` is the build directory or `CMAKE_INSTALL_PREFIX` you used when building/configuring *HPX*.

- Set the `CMAKE_PREFIX_PATH` variable to the root directory of your *HPX* build or install location on the command line when you invoke CMake:

```
$ cmake -DCMAKE_PREFIX_PATH=$HPX_LOCATION ...
```

The difference between `CMAKE_PREFIX_PATH` and `HPX_DIR` is that CMake will add common postfixes, such as `lib/cmake/<project`, to the `CMAKE_PREFIX_PATH` and search in these locations too. Note that if your project uses *HPX* as well as other CMake-managed projects, the paths to the locations of these multiple projects may be concatenated in the `CMAKE_PREFIX_PATH`.

- The variables above may be set in the CMake GUI or curses `ccmake` interface instead of the command line.

Additionally, if you wish to require *HPX* for your project, replace the `find_package(HPX)` line with `find_package(HPX REQUIRED)`.

You can check if *HPX* was successfully found with the `HPX_FOUND` CMake variable.

⁵⁸ https://www.cmake.org/cmake/help/latest/command/find_package.html

Using CMake targets

The recommended way of setting up your targets to use *HPX* is to link to the `HPX::hpx CMake`⁵⁹ target:

```
target_link_libraries(hello_world_component PUBLIC HPX::hpx)
```

This requires that you have already created the target like this:

```
add_library(hello_world_component SHARED hello_world_component.cpp)
target_include_directories(hello_world_component PUBLIC ${CMAKE_CURRENT_SOURCE_DIR})
```

When you link your library to the `HPX::hpx CMake`⁶⁰ target, you will be able use *HPX* functionality in your library. To use `main()` as the implicit entry point in your application you must additionally link your application to the CMake target `HPX::wrap_main`. This target is automatically linked to executables if you are using the macros described below (*Using macros to create new targets*). See *Re-use the main() function as the main HPX entry point* for more information on implicitly using `main()` as the entry point.

Creating a component requires setting two additional compile definitions:

```
target_compile_options(hello_world_component
  HPX_COMPONENT_NAME=hello_world
  HPX_COMPONENT_EXPORTS)
```

Instead of setting these definitions manually you may link to the `HPX::component` target, which sets `HPX_COMPONENT_NAME` to `hpx_<target_name>`, where `<target_name>` is the target name of your library. Note that these definitions should be `PRIVATE` to make sure these definitions are not propagated transitively to dependent targets.

In addition to making your library a component you can make it a plugin. To do so link to the `HPX::plugin` target. Similarly to `HPX::component` this will set `HPX_PLUGIN_NAME` to `hpx_<target_name>`. This definition should also be `PRIVATE`. Unlike regular shared libraries, plugins are loaded at runtime from certain directories and will not be found without additional configuration. Plugins should be installed into a directory containing only plugins. For example, the plugins created by *HPX* itself are installed into the `hpx` subdirectory in the library install directory (typically `lib` or `lib64`). When using the `HPX::plugin` target you need to install your plugins into an appropriate directory. You may also want to set the location of your plugin in the build directory with the `*_OUTPUT_DIRECTORY*` CMake target properties to be able to load the plugins in the build directory. Once you've set the install or output directory of your plugin you need to tell your executable where to find it at runtime. You can do this either by setting the environment variable `HPX_COMPONENT_PATHS` or the ini setting `hpx.component_paths` (see *--hpx:ini*) to the directory containing your plugin.

Using macros to create new targets

In addition to the targets described above, *HPX* provides convenience macros to hide optional boilerplate code that may be useful for your project. The link to the targets described above. We recommend that you use the targets directly whenever possible as they tend to compose better with other targets.

The macro for adding an *HPX* component is `add_hpx_component`. It can be used in your `CMakeLists.txt` file like this:

```
# build your application using HPX
add_hpx_component(hello_world
  SOURCES hello_world_component.cpp
```

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⁵⁹ <https://www.cmake.org>

⁶⁰ <https://www.cmake.org>

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```
HEADERS hello_world_component.hpp
COMPONENT_DEPENDENCIES iostreams)
```

Note: `add_hpx_component` adds a `_component` suffix to the target name. In the example above, a `hello_world_component` target will be created.

The available options to `add_hpx_component` are:

- `SOURCES`: The source files for that component
- `HEADERS`: The header files for that component
- `DEPENDENCIES`: Other libraries or targets this component depends on
- `COMPONENT_DEPENDENCIES`: The components this component depends on
- `PLUGIN`: Treats this component as a plugin-able library
- `COMPILE_FLAGS`: Additional compiler flags
- `LINK_FLAGS`: Additional linker flags
- `FOLDER`: Adds the headers and source files to this Source Group folder
- `EXCLUDE_FROM_ALL`: Do not build this component as part of the `all` target

After adding the component, the way you add the executable is as follows:

```
# build your application using HPX
add_hpx_executable(hello_world
  SOURCES hello_world_client.cpp
  COMPONENT_DEPENDENCIES hello_world)
```

Note: `add_hpx_executable` automatically adds a `_component` suffix to dependencies specified in `COMPONENT_DEPENDENCIES`, meaning you can directly use the name given when adding a component using `add_hpx_component`.

When you configure your application, all you need to do is set the `HPX_DIR` variable to point to the installation of `HPX`.

Note: All library targets built with `HPX` are exported and readily available to be used as arguments to `target_link_libraries`⁶¹ in your targets. The `HPX` include directories are available with the `HPX_INCLUDE_DIRS` CMake variable.

⁶¹ https://www.cmake.org/cmake/help/latest/command/target_link_libraries.html

Using the *HPX* compiler wrapper `hpxcxx`

The `hpxcxx` compiler wrapper helps to compile a *HPX* component, application, or object file, based on the arguments passed to it.

```
$ hpxcxx [--exe=<APPLICATION_NAME> | --comp=<COMPONENT_NAME> | -c] FLAGS FILES
```

The `hpxcxx` command **requires** that either an application or a component is built or `-c` flag is specified. If the build is against a debug build, the `-g` is to be specified while building.

Optional FLAGS

- `-l <LIBRARY>` | `-l<LIBRARY>`: Links `<LIBRARY>` to the build
- `-g`: Specifies that the application or component build is against a debug build
- `-rd`: Sets `release-with-debug-info` option
- `-mr`: Sets `minsize-release` option

All other flags (like `-o OUTPUT_FILE`) are directly passed to the underlying C++ compiler.

Using macros to set up existing targets to use *HPX*

In addition to the `add_hpx_component` and `add_hpx_executable`, you can use the `hpx_setup_target` macro to have an already existing target to be used with the *HPX* libraries:

```
hpx_setup_target(target)
```

Optional parameters are:

- `EXPORT`: Adds it to the CMake export list `HPXTargets`
- `INSTALL`: Generates an install rule for the target
- `PLUGIN`: Treats this component as a plugin-able library
- `TYPE`: The type can be: `EXECUTABLE`, `LIBRARY` or `COMPONENT`
- `DEPENDENCIES`: Other libraries or targets this component depends on
- `COMPONENT_DEPENDENCIES`: The components this component depends on
- `COMPILE_FLAGS`: Additional compiler flags
- `LINK_FLAGS`: Additional linker flags

If you do not use CMake, you can still build against *HPX*, but you should refer to the section on *How to build HPX components with pkg-config*.

Note: Since *HPX* relies on dynamic libraries, the dynamic linker needs to know where to look for them. If *HPX* isn't installed into a path that is configured as a linker search path, external projects need to either set `RPATH` or adapt `LD_LIBRARY_PATH` to point to where the *HPX* libraries reside. In order to set `RPATHs`, you can include `HPX_SetFullRPATH` in your project after all libraries you want to link against have been added. Please also consult the CMake documentation [here](https://cmake.org/doc/paths.html)⁶².

⁶² <https://gitlab.kitware.com/cmake/community/wikis/doc/cmake/RPATH-handling>

Using HPX with Makefile

A basic project building with *HPX* is through creating makefiles. The process of creating one can get complex depending upon the use of cmake parameter `HPX_WITH_HPX_MAIN` (which defaults to ON).

How to build *HPX* applications with makefile

If *HPX* is installed correctly, you should be able to build and run a simple Hello World program. It prints Hello World! on the *locality* you run it on.

```
// Including 'hpx/hpx_main.hpp' instead of the usual 'hpx/hpx_init.hpp' enables
// to use the plain C-main below as the direct main HPX entry point.
#include <hpx/hpx_main.hpp>
#include <hpx/iostream.hpp>

int main()
{
    // Say hello to the world!
    hpx::cout << "Hello World!\n" << std::flush;
    return 0;
}
```

Copy the content of this program into a file called `hello_world.cpp`.

Now, in the directory where you put `hello_world.cpp`, create a Makefile. Add the following code:

```
CXX=(CXX) # Add your favourite compiler here or let makefile choose default.

CXXFLAGS=-O3 -std=c++17

Boost_ROOT=/path/to/boost
Hwloc_ROOT=/path/to/hwloc
Tcmalloc_ROOT=/path/to/tcmalloc
HPX_ROOT=/path/to/hpx

INCLUDE_DIRECTIVES=$(HPX_ROOT)/include $(Boost_ROOT)/include $(Hwloc_ROOT)/include

LIBRARY_DIRECTIVES=-L$(HPX_ROOT)/lib $(HPX_ROOT)/lib/libhpx_init.a $(HPX_ROOT)/lib/
↪ libhpx.so $(Boost_ROOT)/lib/libboost_atomic-mt.so $(Boost_ROOT)/lib/libboost_
↪ filesystem-mt.so $(Boost_ROOT)/lib/libboost_program_options-mt.so $(Boost_ROOT)/lib/
↪ libboost_regex-mt.so $(Boost_ROOT)/lib/libboost_system-mt.so -lpthread $(Tcmalloc_
↪ ROOT)/libtcmalloc_minimal.so $(Hwloc_ROOT)/libhwloc.so -ldl -lrt

LINK_FLAGS=$(HPX_ROOT)/lib/libhpx_wrap.a -Wl,-wrap=main # should be left empty for HPX_
↪ WITH_HPX_MAIN=OFF

hello_world: hello_world.o
    $(CXX) $(CXXFLAGS) -o hello_world hello_world.o $(LIBRARY_DIRECTIVES) $(LINK_FLAGS)

hello_world.o:
    $(CXX) $(CXXFLAGS) -c -o hello_world.o hello_world.cpp $(INCLUDE_DIRECTIVES)
```

Important: `LINK_FLAGS` should be left empty if `HPX_WITH_HPX_MAIN` is set to OFF. Boost in the above example

is build with `--layout=tagged`. Actual Boost flags may vary on your build of Boost.

To build the program, type:

```
$ make
```

A successful build should result in `hello_world` binary. To test, type:

```
$ ./hello_world
```

How to build *HPX* components with makefile

Let's try a more complex example involving an *HPX* component. An *HPX* component is a class that exposes *HPX* actions. *HPX* components are compiled into dynamically-loaded modules called component libraries. Here's the source code:

hello_world_component.cpp

```
#include <hpx/config.hpp>
#if !defined(HPX_COMPUTE_DEVICE_CODE)
#include <hpx/iostream.hpp>
#include "hello_world_component.hpp"

#include <iostream>

namespace examples { namespace server {
    void hello_world::invoke()
    {
        hpx::cout << "Hello HPX World!" << std::endl;
    }
}} // namespace examples::server

HPX_REGISTER_COMPONENT_MODULE()

typedef hpx::components::component<examples::server::hello_world>
    hello_world_type;

HPX_REGISTER_COMPONENT(hello_world_type, hello_world)

HPX_REGISTER_ACTION(
    examples::server::hello_world::invoke_action, hello_world_invoke_action)
#endif
```

hello_world_component.hpp

```
#pragma once

#include <hpx/config.hpp>
#if !defined(HPX_COMPUTE_DEVICE_CODE)
#include <hpx/hpx.hpp>
#include <hpx/include/actions.hpp>
#include <hpx/include/components.hpp>
```

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```

#include <hpx/include/lcos.hpp>
#include <hpx/serialization.hpp>

#include <utility>

namespace examples { namespace server {
    struct HPX_COMPONENT_EXPORT hello_world
        : hpx::components::component_base<hello_world>
    {
        void invoke();
        HPX_DEFINE_COMPONENT_ACTION(hello_world, invoke)
    };
}} // namespace examples::server

HPX_REGISTER_ACTION_DECLARATION(
    examples::server::hello_world::invoke_action, hello_world_invoke_action)

namespace examples {
    struct hello_world
        : hpx::components::client_base<hello_world, server::hello_world>
    {
        typedef hpx::components::client_base<hello_world, server::hello_world>
            base_type;

        hello_world(hpx::future<hpx::id_type>&& f)
            : base_type(std::move(f))
        {
        }

        hello_world(hpx::id_type&& f)
            : base_type(std::move(f))
        {
        }

        void invoke()
        {
            hpx::async<server::hello_world::invoke_action>(this->get_id())
                .get();
        }
    };
} // namespace examples

#endif

```

hello_world_client.cpp

```

#include <hpx/config.hpp>
#if defined(HPX_COMPUTE_HOST_CODE)
#include <hpx/wrap_main.hpp>

#include "hello_world_component.hpp"

```

(continues on next page)

```

int main()
{
    {
        // Create a single instance of the component on this locality.
        examples::hello_world client =
            hpx::new_<examples::hello_world>(hpx::find_here());

        // Invoke the component's action, which will print "Hello World!".
        client.invoke();
    }

    return 0;
}
#endif

```

Now, in the directory, create a Makefile. Add the following code:

```

CXX=(CXX) # Add your favourite compiler here or let makefile choose default.

CXXFLAGS=-O3 -std=c++17

Boost_ROOT=/path/to/boost
Hwloc_ROOT=/path/to/hwloc
Tcmalloc_ROOT=/path/to/tcmalloc
HPX_ROOT=/path/to/hpx

INCLUDE_DIRECTIVES=$(HPX_ROOT)/include $(Boost_ROOT)/include $(Hwloc_ROOT)/include

LIBRARY_DIRECTIVES=-L$(HPX_ROOT)/lib $(HPX_ROOT)/lib/libhpx_init.a $(HPX_ROOT)/lib/
↪ libhpx.so $(Boost_ROOT)/lib/libboost_atomic-mt.so $(Boost_ROOT)/lib/libboost_
↪ filesystem-mt.so $(Boost_ROOT)/lib/libboost_program_options-mt.so $(Boost_ROOT)/lib/
↪ libboost_regex-mt.so $(Boost_ROOT)/lib/libboost_system-mt.so -lpthread $(Tcmalloc_
↪ ROOT)/libtcmalloc_minimal.so $(Hwloc_ROOT)/libhwloc.so -ldl -lrt

LINK_FLAGS=$(HPX_ROOT)/lib/libhpx_wrap.a -Wl,-wrap=main # should be left empty for HPX_
↪ WITH_HPX_MAIN=OFF

hello_world_client: libhpx_hello_world hello_world_client.o
    $(CXX) $(CXXFLAGS) -o hello_world_client $(LIBRARY_DIRECTIVES) libhpx_hello_world
↪ $(LINK_FLAGS)

hello_world_client.o: hello_world_client.cpp
    $(CXX) $(CXXFLAGS) -o hello_world_client.o hello_world_client.cpp $(INCLUDE_DIRECTIVES)

libhpx_hello_world: hello_world_component.o
    $(CXX) $(CXXFLAGS) -o libhpx_hello_world hello_world_component.o $(LIBRARY_DIRECTIVES)

hello_world_component.o: hello_world_component.cpp
    $(CXX) $(CXXFLAGS) -c -o hello_world_component.o hello_world_component.cpp $(INCLUDE_
↪ DIRECTIVES)

```

To build the program, type:

```
$ make
```

A successful build should result in `hello_world` binary. To test, type:

```
$ ./hello_world
```

Note: Due to high variations in CMake flags and library dependencies, it is recommended to build *HPX* applications and components with `pkg-config` or `CMakeLists.txt`. Writing Makefile may result in broken builds if due care is not taken. `pkg-config` files and CMake systems are configured with CMake build of *HPX*. Hence, they are stable when used together and provide better support overall.

2.3.8 Starting the *HPX* runtime

In order to write an application that uses services from the *HPX* runtime system, you need to initialize the *HPX* library by inserting certain calls into the code of your application. Depending on your use case, this can be done in 3 different ways:

- *Minimally invasive*: Re-use the `main()` function as the main *HPX* entry point.
- *Balanced use case*: Supply your own main *HPX* entry point while blocking the main thread.
- *Most flexibility*: Supply your own main *HPX* entry point while avoiding blocking the main thread.
- *Suspend and resume*: As above but suspend and resume the *HPX* runtime to allow for other runtimes to be used.

Re-use the `main()` function as the main *HPX* entry point

This method is the least intrusive to your code. However, it provides you with the smallest flexibility in terms of initializing the *HPX* runtime system. The following code snippet shows what a minimal *HPX* application using this technique looks like:

```
#include <hpx/hpx_main.hpp>

int main(int argc, char* argv[])
{
    return 0;
}
```

The only change to your code you have to make is to include the file `hpx/hpx_main.hpp`. In this case the function `main()` will be invoked as the first *HPX* thread of the application. The runtime system will be initialized behind the scenes before the function `main()` is executed and will automatically stop after `main()` has returned. For this method to work you must link your application to the CMake⁶³ target `HPX::wrap_main`. This is done automatically if you are using the provided macros (*Using macros to create new targets*) to set up your application, but must be done explicitly if you are using targets directly (*Using CMake targets*). All *HPX* API functions can be used from within the `main()` function now.

Note: The function `main()` does not need to expect receiving `argc` and `argv` as shown above, but could expose the signature `int main()`. This is consistent with the usually allowed prototypes for the function `main()` in C++ applications.

⁶³ <https://www.cmake.org>

All command line arguments specific to *HPX* will still be processed by the *HPX* runtime system as usual. However, those command line options will be removed from the list of values passed to `argc/argv` of the function `main()`. The list of values passed to `main()` will hold only the commandline options that are not recognized by the *HPX* runtime system (see the section *HPX Command Line Options* for more details on what options are recognized by *HPX*).

Note: In this mode all one-letter shortcuts that are normally available on the *HPX* command line are disabled (such as `-t` or `-l` see *HPX Command Line Options*). This is done to minimize any possible interaction between the command line options recognized by the *HPX* runtime system and any command line options defined by the application.

The value returned from the function `main()` as shown above will be returned to the operating system as usual.

Important: To achieve this seamless integration, the header file `hpx/hpx_main.hpp` defines a macro:

```
#define main hpx_startup::user_main
```

which could result in unexpected behavior.

Important: To achieve this seamless integration, we use different implementations for different operating systems. In case of Linux or macOS, the code present in `hpx_wrap.cpp` is put into action. We hook into the system function in case of Linux and provide alternate entry point in case of macOS. For other operating systems we rely on a macro:

```
#define main hpx_startup::user_main
```

provided in the header file `hpx/hpx_main.hpp`. This implementation can result in unexpected behavior.

Caution: We make use of an *override* variable `include_libhpx_wrap` in the header file `hpx/hpx_main.hpp` to swiftly choose the function call stack at runtime. Therefore, the header file should *only* be included in the main executable. Including it in the components will result in multiple definition of the variable.

Supply your own main *HPX* entry point while blocking the main thread

With this method you need to provide an explicit main-thread function named `hpx_main` at global scope. This function will be invoked as the main entry point of your *HPX* application on the console *locality* only (this function will be invoked as the first *HPX* thread of your application). All *HPX* API functions can be used from within this function.

The thread executing the function `hpx::init` will block waiting for the runtime system to exit. The value returned from `hpx_main` will be returned from `hpx::init` after the runtime system has stopped.

The function `hpx::finalize` has to be called on one of the *HPX* localities in order to signal that all work has been scheduled and the runtime system should be stopped after the scheduled work has been executed.

This method of invoking *HPX* has the advantage of the user being able to decide which version of `hpx::init` to call. This allows to pass additional configuration parameters while initializing the *HPX* runtime system.

```
#include <hpx/hpx_init.hpp>

int hpx_main(int argc, char* argv[])
{
    // Any HPX application logic goes here...
```

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```

    return hpx::finalize();
}

int main(int argc, char* argv[])
{
    // Initialize HPX, run hpx_main as the first HPX thread, and
    // wait for hpx::finalize being called.
    return hpx::init(argc, argv);
}

```

Note: The function `hpx_main` does not need to expect receiving `argc/argv` as shown above, but could expose one of the following signatures:

```

int hpx_main();
int hpx_main(int argc, char* argv[]);
int hpx_main(hpx::program_options::variables_map& vm);

```

This is consistent with (and extends) the usually allowed prototypes for the function `main()` in C++ applications.

The header file to include for this method of using *HPX* is `hpx/hpx_init.hpp`.

There are many additional overloads of `hpx::init` available, such as the ability to provide your own entry-point function instead of `hpx_main`. Please refer to the function documentation for more details (see: `hpx/hpx_init.hpp`).

Supply your own main *HPX* entry point while avoiding blocking the main thread

With this method you need to provide an explicit main thread function named `hpx_main` at global scope. This function will be invoked as the main entry point of your *HPX* application on the console *locality* only (this function will be invoked as the first *HPX* thread of your application). All *HPX* API functions can be used from within this function.

The thread executing the function `hpx::start` will *not* block waiting for the runtime system to exit, but will return immediately. The function `hpx::finalize` has to be called on one of the *HPX* localities in order to signal that all work has been scheduled and the runtime system should be stopped after the scheduled work has been executed.

This method of invoking *HPX* is useful for applications where the main thread is used for special operations, such a GUIs. The function `hpx::stop` can be used to wait for the *HPX* runtime system to exit and should at least be used as the last function called in `main()`. The value returned from `hpx_main` will be returned from `hpx::stop` after the runtime system has stopped.

```

#include <hpx/hpx_start.hpp>

int hpx_main(int argc, char* argv[])
{
    // Any HPX application logic goes here...
    return hpx::finalize();
}

int main(int argc, char* argv[])
{
    // Initialize HPX, run hpx_main.
    hpx::start(argc, argv);
}

```

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```
// ...Execute other code here...

// Wait for hpx::finalize being called.
return hpx::stop();
}
```

Note: The function `hpx_main` does not need to expect receiving `argc/argv` as shown above, but could expose one of the following signatures:

```
int hpx_main();
int hpx_main(int argc, char* argv[]);
int hpx_main(hpx::program_options::variables_map& vm);
```

This is consistent with (and extends) the usually allowed prototypes for the function `main()` in C++ applications.

The header file to include for this method of using *HPX* is `hpx/hpx_start.hpp`.

There are many additional overloads of `hpx::start` available, such as the option for users to provide their own entry point function instead of `hpx_main`. Please refer to the function documentation for more details (see: `hpx/hpx_start.hpp`).

Supply your own explicit startup function as the main *HPX* entry point

There is also a way to specify any function (besides `hpx_main`) to be used as the main entry point for your *HPX* application:

```
#include <hpx/hpx_init.hpp>

int application_entry_point(int argc, char* argv[])
{
    // Any HPX application logic goes here...
    return hpx::finalize();
}

int main(int argc, char* argv[])
{
    // Initialize HPX, run application_entry_point as the first HPX thread,
    // and wait for hpx::finalize being called.
    return hpx::init(&application_entry_point, argc, argv);
}
```

Note: The function supplied to `hpx::init` must have one of the following prototypes:

```
int application_entry_point(int argc, char* argv[]); int application_entry_point(hpx::program_options::variables_map&
vm);
```

Note: If `nullptr` is used as the function argument, *HPX* will not run any startup function on this locality.

Suspending and resuming the HPX runtime

In some applications it is required to combine *HPX* with other runtimes. To support this use case, *HPX* provides two functions: `hpx::suspend` and `hpx::resume`. `hpx::suspend` is a blocking call which will wait for all scheduled tasks to finish executing and then put the thread pool OS threads to sleep. `hpx::resume` simply wakes up the sleeping threads so that they are ready to accept new work. `hpx::suspend` and `hpx::resume` can be found in the header `hpx/hpx_suspend.hpp`.

```
#include <hpx/hpx_start.hpp>
#include <hpx/hpx_suspend.hpp>

int main(int argc, char* argv[])
{
    // Initialize HPX, don't run hpx_main
    hpx::start(nullptr, argc, argv);

    // Schedule a function on the HPX runtime
    hpx::post(&my_function, ...);

    // Wait for all tasks to finish, and suspend the HPX runtime
    hpx::suspend();

    // Execute non-HPX code here

    // Resume the HPX runtime
    hpx::resume();

    // Schedule more work on the HPX runtime

    // hpx::finalize has to be called from the HPX runtime before hpx::stop
    hpx::post([]() { hpx::finalize(); });
    return hpx::stop();
}
```

Note: `hpx::suspend` does not wait for `hpx::finalize` to be called. Only call `hpx::finalize` when you wish to fully stop the *HPX* runtime.

Warning:

`hpx::suspend` only waits for local tasks, i.e. tasks on the current locality, to finish executing. When using `hpx::suspend` in a multi-locality scenario the user is responsible for ensuring that any work required from other localities has also finished.

HPX also supports suspending individual thread pools and threads. For details on how to do that, see the documentation for `hpx::threads::thread_pool_base`.

Automatically suspending worker threads

The previous method guarantees that the worker threads are suspended when you ask for it and that they stay suspended. An alternative way to achieve the same effect is to tweak how quickly *HPX* suspends its worker threads when they run out of work. The following configuration values make sure that *HPX* idles very quickly:

```
hpx.max_idle_backoff_time = 1000
hpx.max_idle_loop_count = 0
```

They can be set on the command line using `--hpx:ini=hpx.max_idle_backoff_time=1000` and `--hpx:ini=hpx.max_idle_loop_count=0`. See *Launching and configuring HPX applications* for more details on how to set configuration parameters.

After setting idling parameters the previous example could now be written like this instead:

```
#include <hpx/hpx_start.hpp>

int main(int argc, char* argv[])
{
    // Initialize HPX, don't run hpx_main
    hpx::start(nullptr, argc, argv);

    // Schedule some functions on the HPX runtime
    // NOTE: run_as_hpx_thread blocks until completion.
    hpx::run_as_hpx_thread(&my_function, ...);
    hpx::run_as_hpx_thread(&my_other_function, ...);

    // hpx::finalize has to be called from the HPX runtime before hpx::stop
    hpx::post([]() { hpx::finalize(); });
    return hpx::stop();
}
```

In this example each call to `hpx::run_as_hpx_thread` acts as a “parallel region”.

Working of hpx_main.hpp

In order to initialize *HPX* from `main()`, we make use of linker tricks.

It is implemented differently for different operating systems. The method of implementation is as follows:

- *Linux*: Using linker `--wrap` option.
- *Mac OSX*: Using the linker `-e` option.
- *Windows*: Using `#define main hpx_startup::user_main`

Linux implementation

We make use of the Linux linker `ld`'s `--wrap` option to wrap the `main()` function. This way any calls to `main()` are redirected to our own implementation of `main`. It is here that we check for the existence of `hpx_main.hpp` by making use of a shadow variable `include_libhpx_wrap`. The value of this variable determines the function stack at runtime.

The implementation can be found in `libhpx_wrap.a`.

Important: It is necessary that `hpx_main.hpp` be not included more than once. Multiple inclusions can result in multiple definition of `include_libhpx_wrap`.

Mac OSX implementation

Here we make use of yet another linker option `-e` to change the entry point to our custom entry function `initialize_main`. We initialize the *HPX* runtime system from this function and call `main` from the initialized system. We determine the function stack at runtime by making use of the shadow variable `include_libhpx_wrap`.

The implementation can be found in `libhpx_wrap.a`.

Important: It is necessary that `hpx_main.hpp` be not included more than once. Multiple inclusions can result in multiple definition of `include_libhpx_wrap`.

Windows implementation

We make use of a macro `#define main hpx_startup::user_main` to take care of the initializations.

This implementation could result in unexpected behaviors.

2.3.9 Launching and configuring *HPX* applications

Configuring *HPX* applications

All *HPX* applications can be configured using special command line options and/or using special configuration files. This section describes the available options, the configuration file format, and the algorithm used to locate possible predefined configuration files. Additionally, this section describes the defaults assumed if no external configuration information is supplied.

During startup any *HPX* application applies a predefined search pattern to locate one or more configuration files. All found files will be read and merged in the sequence they are found into one single internal database holding all configuration properties. This database is used during the execution of the application to configure different aspects of the runtime system.

In addition to the ini files, any application can supply its own configuration files, which will be merged with the configuration database as well. Moreover, the user can specify additional configuration parameters on the command line when executing an application. The *HPX* runtime system will merge all command line configuration options (see the description of the `--hpx:ini`, `--hpx:config`, and `--hpx:app-config` command line options).

The HPX ini file format

All HPX applications can be configured using a special file format that is similar to the well-known [Windows INI file format](#)⁶⁴. This is a structured text format that allows users to group key/value pairs (properties) into sections. The basic element contained in an ini file is the property. Every property has a name and a value, delimited by an equal sign '='. The name appears to the left of the equal sign:

```
name=value
```

The value may contain equal signs as only the first '=' character is interpreted as the delimiter between name and value. Whitespace before the name, after the value and immediately before and after the delimiting equal sign is ignored. Whitespace inside the value is retained.

Properties may be grouped into arbitrarily named sections. The section name appears on a line by itself, in square brackets. All properties after the section declaration are associated with that section. There is no explicit “end of section” delimiter; sections end at the next section declaration or the end of the file:

```
[section]
```

In HPX sections can be nested. A nested section has a name composed of all section names it is embedded in. The section names are concatenated using a dot '.':

```
[outer_section.inner_section]
```

Here, `inner_section` is logically nested within `outer_section`.

It is possible to use the full section name concatenated with the property name to refer to a particular property. For example, in:

```
[a.b.c]  
d = e
```

the property value of `d` can be referred to as `a.b.c.d=e`.

In HPX ini files can contain comments. Hash signs '#' at the beginning of a line indicate a comment. All characters starting with '#' until the end of the line are ignored.

If a property with the same name is reused inside a section, the second occurrence of this property name will override the first occurrence (discard the first value). Duplicate sections simply merge their properties together, as if they occurred contiguously.

In HPX ini files a property value `${FOO:default}` will use the environmental variable `FOO` to extract the actual value if it is set and `default` otherwise. No default has to be specified. Therefore, `${FOO}` refers to the environmental variable `FOO`. If `FOO` is not set or empty, the overall expression will evaluate to an empty string. A property value `[$section.key:default]` refers to the value held by the property `section.key` if it exists and `default` otherwise. No default has to be specified. Therefore `[$section.key]` refers to the property `section.key`. If the property `section.key` is not set or empty, the overall expression will evaluate to an empty string.

Note: Any property `[$section.key:default]` is evaluated whenever it is queried and not when the configuration data is initialized. This allows for lazy evaluation and relaxes initialization order of different sections. The only exception are recursive property values, e.g., values referring to the very key they are associated with. Those property values are evaluated at initialization time to avoid infinite recursion.

⁶⁴ https://en.wikipedia.org/wiki/INI_file

Built-in default configuration settings

During startup any *HPX* application applies a predefined search pattern to locate one or more configuration files. All found files will be read and merged in the sequence they are found into one single internal data structure holding all configuration properties.

As a first step the internal configuration database is filled with a set of default configuration properties. Those settings are described on a section by section basis below.

Note: You can print the default configuration settings used for an executable by specifying the command line option `--hpx:dump-config`.

The system configuration section

```
[system]
pid = <process-id>
prefix = <current prefix path of core HPX library>
executable = <current prefix path of executable>
```

Property	Description
system.pid	This is initialized to store the current OS-process id of the application instance.
system.prefix	This is initialized to the base directory <i>HPX</i> has been loaded from.
system.executable_prefix	This is initialized to the base directory the current executable has been loaded from.

The *HPX* configuration section

```
[hpx]
location = ${HPX_LOCATION:[system.prefix]}
component_path = [hpx.location]/lib/hpx:[system.executable_prefix]/lib/hpx:[system.
↪executable_prefix]/../lib/hpx
master_ini_path = [hpx.location]/share/hpx-<version>:[system.executable_prefix]/share/
↪hpx-<version>:[system.executable_prefix]/../share/hpx-<version>
ini_path = [hpx.master_ini_path]/ini
os_threads = 1
cores = all
localities = 1
program_name =
cmd_line =
lock_detection = ${HPX_LOCK_DETECTION:0}
throw_on_held_lock = ${HPX_THROW_ON_HELD_LOCK:1}
minimal_deadlock_detection = <debug>
spinlock_deadlock_detection = <debug>
spinlock_deadlock_detection_limit = ${HPX_SPINLOCK_DEADLOCK_DETECTION_LIMIT:1000000}
max_background_threads = ${HPX_MAX_BACKGROUND_THREADS:[hpx.os_threads]}
max_idle_loop_count = ${HPX_MAX_IDLE_LOOP_COUNT:<hpx_idle_loop_count_max>}
max_busy_loop_count = ${HPX_MAX_BUSY_LOOP_COUNT:<hpx_busy_loop_count_max>}
max_idle_backoff_time = ${HPX_MAX_IDLE_BACKOFF_TIME:<hpx_idle_backoff_time_max>}
```

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```
exception_verbosity = ${HPX_EXCEPTION_VERBOSITY:2}
trace_depth = ${HPX_TRACE_DEPTH:20}
handle_signals = ${HPX_HANDLE_SIGNALS:1}
handle_failed_new = ${HPX_HANDLE_FAILED_NEW:1}
```

[hpx.stacks]

```
small_size = ${HPX_SMALL_STACK_SIZE:<hpx_small_stack_size>}
medium_size = ${HPX_MEDIUM_STACK_SIZE:<hpx_medium_stack_size>}
large_size = ${HPX_LARGE_STACK_SIZE:<hpx_large_stack_size>}
huge_size = ${HPX_HUGE_STACK_SIZE:<hpx_huge_stack_size>}
use_guard_pages = ${HPX_THREAD_GUARD_PAGE:1}
```


Property	Description
hpx.location	This is initialized to the id of the <i>locality</i> this application instance is running on.
hpx.component_path	Duplicates are discarded. This property can refer to a list of directories separated by ':' (Linux, Android, and MacOS) or by ';' (Windows).
hpx.master_ini_path	This is initialized to the list of default paths of the main hpx.ini configuration files. This property can refer to a list of directories separated by ':' (Linux, Android, and MacOS) or using ';' (Windows).
hpx.ini_path	This is initialized to the default path where <i>HPX</i> will look for more ini configuration files. This property can refer to a list of directories separated by ':' (Linux, Android, and MacOS) or using ';' (Windows).
hpx.os_threads	This setting reflects the number of OS threads used for running <i>HPX</i> threads. Defaults to number of detected cores (not hyperthreads/PUs).
hpx.cores	This setting reflects the number of cores used for running <i>HPX</i> threads. Defaults to number of detected cores (not hyperthreads/PUs).
hpx.localities	This setting reflects the number of localities the application is running on. Defaults to 1.
hpx.program_name	This setting reflects the program name of the application instance. Initialized from the command line <code>argv[0]</code> .
hpx.cmd_line	This setting reflects the actual command line used to launch this application instance.
hpx.lock_detection	This setting verifies that no locks are being held while a <i>HPX</i> thread is suspended. This setting is applicable only if <code>HPX_WITH_VERIFY_LOCKS</code> is set during configuration in CMake.
hpx.throw_on_hold	This setting causes an exception if during lock detection at least one lock is being held while a <i>HPX</i> thread is suspended. This setting is applicable only if <code>HPX_WITH_VERIFY_LOCKS</code> is set during configuration in CMake. This setting has no effect if <code>hpx.lock_detection=0</code> .
hpx.minimal_deadlock_detection	This setting enables support for minimal deadlock detection for <i>HPX</i> threads. By default this is set to 1 (for Debug builds) or to 0 (for Release, RelWithDebInfo, RelMinSize builds). This setting is effective only if <code>HPX_WITH_THREAD_DEADLOCK_DETECTION</code> is set during configuration in CMake.
hpx.spinlock_deadlock_detection	This setting verifies that spinlocks don't spin longer than specified using the <code>spinlock_deadlock_detection_limit</code> . This setting is applicable only if <code>HPX_WITH_SPINLOCK_DEADLOCK_DETECTION</code> is set during configuration in CMake. By default this is set to 1 (for Debug builds) or to 0 (for Release, RelWithDebInfo, RelMinSize builds).
hpx.spinlock_deadlock_detection_limit	This setting specifies the upper limit of the allowed number of spins that spinlocks are allowed to perform. This setting is applicable only if <code>HPX_WITH_SPINLOCK_DEADLOCK_DETECTION</code> is set during configuration in CMake. By default this is set to 1000000.
hpx.max_background_threads	This setting defines the number of threads in the scheduler, which are used to execute background work. By default this is the same as the number of cores used for the scheduler.
hpx.max_idle_loop_count	By default this is defined by the preprocessor constant <code>HPX_IDLE_LOOP_COUNT_MAX</code> . This is an internal setting that you should change only if you know exactly what you are doing.
hpx.max_busy_loop_count	This setting defines the maximum value of the busy-loop counter in the scheduler. By default this is defined by the preprocessor constant <code>HPX_BUSY_LOOP_COUNT_MAX</code> . This is an internal setting that you should change only if you know exactly what you are doing.
hpx.max_idle_backoff_time	This setting defines the maximum time (in milliseconds) for the scheduler to sleep after <code>hpx.max_idle_loop_count</code> iterations. This setting is applicable only if <code>HPX_WITH_THREAD_MANAGER_IDLE_BACKOFF</code> is set during configuration in CMake ⁶⁵ . By default this is defined by the preprocessor constant <code>HPX_IDLE_BACKOFF_TIME_MAX</code> . This is an internal setting that you should change only if you know exactly what you are doing.
hpx.exception_verbosity	This setting defines the verbosity of exceptions. Valid values are integers. A setting of 2 or higher prints all available information. A setting of 1 leaves out the build configuration and environment variables. A setting of 0 or lower prints only the description of the thrown exception and the file name, function, and line number where the exception was thrown. The default value is 2 or the value of the environment variable <code>HPX_EXCEPTION_VERBOSITY</code> .
hpx.trace_depth	This setting defines the number of stack-levels printed in generated stack backtraces. This defaults to 20, but can be changed using the cmake <code>HPX_WITH_THREAD_BACKTRACE_DEPTH</code> configuration setting.
hpx.handle_signals	This setting defines whether <i>HPX</i> will register signal handlers that will print the configuration information (stack backtrace, system information, etc.) whenever a signal is raised. The default is 1. Setting this value to 0 can be useful in cases when generating a core-dump on segmentation faults or similar signals is desired.

The `hpx.threadpools` configuration section

[`hpx.threadpools`]

```
io_pool_size = ${HPX_NUM_IO_POOL_SIZE:2}
parcel_pool_size = ${HPX_NUM_PARCEL_POOL_SIZE:2}
timer_pool_size = ${HPX_NUM_TIMER_POOL_SIZE:2}
```

Property	Description
<code>hpx.threadpools.io_pool_size</code>	The value of this property defines the number of OS threads created for the internal I/O thread pool.
<code>hpx.threadpools.parcel_pool_size</code>	The value of this property defines the number of OS threads created for the internal parcel thread pool.
<code>hpx.threadpools.timer_pool_size</code>	The value of this property defines the number of OS threads created for the internal timer thread pool.

The `hpx.thread_queue` configuration section

Important: These are the setting control internal values used by the thread scheduling queues in the *HPX* scheduler. You should not modify these settings unless you know exactly what you are doing.

[`hpx.thread_queue`]

```
min_tasks_to_steal_pending = ${HPX_THREAD_QUEUE_MIN_TASKS_TO_STEAL_PENDING:0}
min_tasks_to_steal_staged = ${HPX_THREAD_QUEUE_MIN_TASKS_TO_STEAL_STAGED:0}
min_add_new_count = ${HPX_THREAD_QUEUE_MIN_ADD_NEW_COUNT:10}
max_add_new_count = ${HPX_THREAD_QUEUE_MAX_ADD_NEW_COUNT:10}
max_delete_count = ${HPX_THREAD_QUEUE_MAX_DELETE_COUNT:1000}
```

Property	Description
<code>hpx.thread_queue.min_tasks_to_steal_pending</code>	The value of this property defines the number of pending <i>HPX</i> threads that have to be available before neighboring cores are allowed to steal work. The default is to allow stealing always.
<code>hpx.thread_queue.min_tasks_to_steal_staged</code>	The value of this property defines the number of staged <i>HPX</i> tasks that need to be available before neighboring cores are allowed to steal work. The default is to allow stealing always.
<code>hpx.thread_queue.min_add_new_count</code>	The value of this property defines the minimal number of tasks to be converted into <i>HPX</i> threads whenever the thread queues for a core have run empty.
<code>hpx.thread_queue.max_add_new_count</code>	The value of this property defines the maximal number of tasks to be converted into <i>HPX</i> threads whenever the thread queues for a core have run empty.
<code>hpx.thread_queue.max_delete_count</code>	The value of this property defines the number of terminated <i>HPX</i> threads to discard during each invocation of the corresponding function.

⁶⁵ <https://www.cmake.org>

The `hpx.components` configuration section

```
[hpx.components]
load_external = ${HPX_LOAD_EXTERNAL_COMPONENTS:1}
```

Property	Description
<code>hpx.components.load_external</code>	This entry defines whether external components will be loaded on this <i>locality</i> . This entry is normally set to 1, and usually there is no need to directly change this value. It is automatically set to 0 for a dedicated <i>AGAS</i> server <i>locality</i> .

Additionally, the section `hpx.components` will be populated with the information gathered from all found components. The information loaded for each of the components will contain at least the following properties:

```
[hpx.components.<component_instance_name>]
name = <component_name>
path = <full_path_of_the_component_module>
enabled = $[hpx.components.load_external]
```

Property	Description
<code>hpx.components.<component_instance_name></code>	This is the name of a component, usually the same as the second argument to the macro used while registering the component with <code>HPX_REGISTER_COMPONENT</code> . Set by the component factory.
<code>hpx.components.<component_instance_name>.path</code>	This is either the full path file name of the component module or the directory the component module is located in. In this case, the component module name will be derived from the property <code>hpx.components.<component_instance_name>.name</code> . Set by the component factory.
<code>hpx.components.<component_instance_name>.enabled</code>	This setting explicitly enables or disables the component. This is an optional property. <code>HPX</code> assumes that the component is enabled if it is not defined.

The value for `<component_instance_name>` is usually the same as for the corresponding name property. However, generally it can be defined to any arbitrary instance name. It is used to distinguish between different ini sections, one for each component.

The `hpx.parcel` configuration section

```
[hpx.parcel]
address = ${HPX_PARCEL_SERVER_ADDRESS:<hpx_initial_ip_address>}
port = ${HPX_PARCEL_SERVER_PORT:<hpx_initial_ip_port>}
bootstrap = ${HPX_PARCEL_BOOTSTRAP:<hpx_parcel_bootstrap>}
max_connections = ${HPX_PARCEL_MAX_CONNECTIONS:<hpx_parcel_max_connections>}
max_connections_per_locality = ${HPX_PARCEL_MAX_CONNECTIONS_PER_LOCALITY:<hpx_parcel_max_
↪connections_per_locality>}
max_message_size = ${HPX_PARCEL_MAX_MESSAGE_SIZE:<hpx_parcel_max_message_size>}
max_outbound_message_size = ${HPX_PARCEL_MAX_OUTBOUND_MESSAGE_SIZE:<hpx_parcel_max_
↪outbound_message_size>}
array_optimization = ${HPX_PARCEL_ARRAY_OPTIMIZATION:1}
zero_copy_optimization = ${HPX_PARCEL_ZERO_COPY_OPTIMIZATION:$[hpx.parcel.array_
↪optimization]}
zero_copy_receive_optimization = ${HPX_PARCEL_ZERO_COPY_RECEIVE_OPTIMIZATION:$[hpx.
↪parcel.array_optimization]}
```

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```
async_serialization = ${HPX_PARCEL_ASYNC_SERIALIZATION:1}
message_handlers = ${HPX_PARCEL_MESSAGE_HANDLERS:0}
```

Property	Description
hpx.parcel.address	This property defines the default IP address to be used for the <i>parcel</i> layer to listen to. This IP address will be used as long as no other values are specified (for instance, using the <code>--hpx:hpx</code> command line option). The expected format is any valid IP address or domain name format that can be resolved into an IP address. The default depends on the compile time preprocessor constant <code>HPX_INITIAL_IP_ADDRESS</code> ("127.0.0.1").
hpx.parcel.port	This property defines the default IP port to be used for the <i>parcel</i> layer to listen to. This IP port will be used as long as no other values are specified (for instance using the <code>--hpx:hpx</code> command line option). The default depends on the compile time preprocessor constant <code>HPX_INITIAL_IP_PORT</code> (7910).
hpx.parcel.bootstrap	This property defines which <i>parcelport</i> type should be used during application bootstrap. The default depends on the compile time preprocessor constant <code>HPX_PARCEL_BOOTSTRAP</code> ("tcp").
hpx.parcel.max_connections	This property defines how many network connections between different localities are overall kept alive by each <i>locality</i> . The default depends on the compile time preprocessor constant <code>HPX_PARCEL_MAX_CONNECTIONS</code> (512).
hpx.parcel.max_connections_per_locality	This property defines the maximum number of network connections that one <i>locality</i> will open to another <i>locality</i> . The default depends on the compile time preprocessor constant <code>HPX_PARCEL_MAX_CONNECTIONS_PER_LOCALITY</code> (4).
hpx.parcel.max_message_size	This property defines the maximum allowed message size that will be transferrable through the <i>parcel</i> layer. The default depends on the compile time preprocessor constant <code>HPX_PARCEL_MAX_MESSAGE_SIZE</code> (1000000000 bytes).
hpx.parcel.max_outbound_message_size	This property defines the maximum allowed outbound coalesced message size that will be transferrable through the <i>parcel</i> layer. The default depends on the compile time preprocessor constant <code>HPX_PARCEL_MAX_OUTBOUND_MESSAGE_SIZE</code> (1000000 bytes).
hpx.parcel.array_optimization	This property defines whether this <i>locality</i> is allowed to utilize array optimizations during serialization of <i>parcel</i> data. The default is 1.
hpx.parcel.zero_copy_optimization	This property defines whether this <i>locality</i> is allowed to utilize zero copy optimizations during serialization of <i>parcel</i> data. The default is the same value as set for <code>hpx.parcel.array_optimization</code> .
hpx.parcel.zero_copy_receive_optimization	This property defines whether this <i>locality</i> is allowed to utilize zero copy optimizations on the receiving end during de-serialization of <i>parcel</i> data. The default is the same value as set for <code>hpx.parcel.array_optimization</code> .
hpx.parcel.zero_copy_serialization_threshold	This property defines the threshold value (in bytes) starting at which the serialization layer will apply zero-copy optimizations for serialized entities. The default value is defined by the preprocessor constant <code>HPX_ZERO_COPY_SERIALIZATION_THRESHOLD</code> .
hpx.parcel.async_serialization	This property defines whether this <i>locality</i> is allowed to spawn a new thread for serialization (this is both for encoding and decoding parcels). The default is 1.
hpx.parcel.message_handlers	This property defines whether message handlers are loaded. The default is 0.
hpx.parcel.max_background_threads	This property defines how many cores should be used to perform background operations. The default is -1 (all cores).

The following settings relate to the TCP/IP *parcelport*.

```
[hpx.parcel.tcp]
enable = ${HPX_HAVE_PARCELPOR_TCP:${hpx.parcel.enabled}}
array_optimization = ${HPX_PARCEL_TCP_ARRAY_OPTIMIZATION:${hpx.parcel.array_
↳optimization}}
zero_copy_optimization = ${HPX_PARCEL_TCP_ZERO_COPY_OPTIMIZATION:${hpx.parcel.zero_copy_
↳optimization}}
zero_copy_receive_optimization = ${HPX_PARCEL_TCP_ZERO_COPY_RECEIVE_OPTIMIZATION:${hpx.
↳parcel.zero_copy_receive_optimization}}
zero_copy_serialization_threshold = ${HPX_PARCEL_TCP_ZERO_COPY_SERIALIZATION_THRESHOLD:
↳${hpx.parcel.zero_copy_serialization_threshold}}
async_serialization = ${HPX_PARCEL_TCP_ASYNC_SERIALIZATION:${hpx.parcel.async_
↳serialization}}
parcel_pool_size = ${HPX_PARCEL_TCP_PARCEL_POOL_SIZE:${hpx.threadpools.parcel_pool_size}}
max_connections = ${HPX_PARCEL_TCP_MAX_CONNECTIONS:${hpx.parcel.max_connections}}
max_connections_per_locality = ${HPX_PARCEL_TCP_MAX_CONNECTIONS_PER_LOCALITY:${hpx.
↳parcel.max_connections_per_locality}}
max_message_size = ${HPX_PARCEL_TCP_MAX_MESSAGE_SIZE:${hpx.parcel.max_message_size}}
max_outbound_message_size = ${HPX_PARCEL_TCP_MAX_OUTBOUND_MESSAGE_SIZE:${hpx.parcel.max_
↳outbound_message_size}}
max_background_threads = ${HPX_PARCEL_TCP_MAX_BACKGROUND_THREADS:${hpx.parcel.max_
↳background_threads}}
```

Property	Description
<code>hpx.parcel.tcp.enable</code>	Enables the use of the default TCP parcelport. Note that the initial bootstrap of the overall <i>HPX</i> application will be performed using the default TCP connections. This parcelport is enabled by default. This will be disabled only if MPI is enabled (see below).
<code>hpx.parcel.tcp.array_optimization</code>	This property defines whether this <i>locality</i> is allowed to utilize array optimizations in the TCP/IP parcelport during serialization of parcel data. The default is the same value as set for <code>hpx.parcel.array_optimization</code> .
<code>hpx.parcel.tcp.zero_copy_optimization</code>	This property defines whether this <i>locality</i> is allowed to utilize zero copy optimizations during serialization of parcel data. The default is the same value as set for <code>hpx.parcel.zero_copy_optimization</code> .
<code>hpx.parcel.tcp.zero_copy_receive_optimization</code>	This property defines whether this <i>locality</i> is allowed to utilize zero copy optimizations on the receiving end in the TCP/IP parcelport during de-serialization of <i>parcel</i> data. The default is the same value as set for <code>hpx.parcel.zero_copy_optimization</code> .
<code>hpx.parcel.tcp.zero_copy_serialization_threshold</code>	This property defines the threshold value (in bytes) starting at which the serialization layer will apply zero copy optimizations for serialized entities. The default is the same value as set for <code>hpx.parcel.zero_copy_serialization_threshold</code> .
<code>hpx.parcel.tcp.async_serialization</code>	This property defines whether this <i>locality</i> is allowed to spawn a new thread for serialization in the TCP/IP parcelport (this is both for encoding and decoding parcels). The default is the same value as set for <code>hpx.parcel.async_serialization</code> .
<code>hpx.parcel.tcp.parcel_pool_size</code>	The value of this property defines the number of OS threads created for the internal parcel thread pool of the TCP <i>parcel</i> port. The default is taken from <code>hpx.threadpools.parcel_pool_size</code> .
<code>hpx.parcel.tcp.max_connections</code>	This property defines how many network connections between different localities are overall kept alive by each <i>locality</i> . The default is taken from <code>hpx.parcel.max_connections</code> .
<code>hpx.parcel.tcp.max_connections_per_locality</code>	This property defines the maximum number of network connections that one <i>locality</i> will open to another <i>locality</i> . The default is taken from <code>hpx.parcel.max_connections_per_locality</code> .
<code>hpx.parcel.tcp.max_message_size</code>	This property defines the maximum allowed message size that will be transferrable through the <i>parcel</i> layer. The default is taken from <code>hpx.parcel.max_message_size</code> .
<code>hpx.parcel.tcp.max_outbound_message_size</code>	This property defines the maximum allowed outbound coalesced message size that will be transferrable through the <i>parcel</i> layer. The default is taken from <code>hpx.parcel.max_outbound_message_size</code> .
<code>hpx.parcel.tcp.max_background_threads</code>	This property defines how many cores should be used to perform background operations. The default is taken from <code>hpx.parcel.max_background_threads</code> .

The following settings relate to the MPI parcelport. These settings take effect only if the compile time constant `HPX_HAVE_PARCELPOR_T_MPI` is set (the equivalent CMake variable is `HPX_WITH_PARCELPOR_T_MPI` and has to be set to ON).

```
[hpx.parcel.mpi]
enable = ${HPX_HAVE_PARCELPOR_T_MPI:[hpx.parcel.enabled]}
env = ${HPX_HAVE_PARCELPOR_T_MPI_ENV:MV2_COMM_WORLD_RANK,PMI_RANK,OMPI_COMM_WORLD_SIZE,
↪ALPS_APP_PE,PALS_NODEID}
multithreaded = ${HPX_HAVE_PARCELPOR_T_MPI_MULTITHREADED:1}
rank = <MPI_rank>
processor_name = <MPI_processor_name>
array_optimization = ${HPX_HAVE_PARCEL_MPI_ARRAY_OPTIMIZATION:[hpx.parcel.array_
↪optimization]}
zero_copy_optimization = ${HPX_HAVE_PARCEL_MPI_ZERO_COPY_OPTIMIZATION:[hpx.parcel.zero_
↪copy_optimization]}
zero_copy_receive_optimization = ${HPX_HAVE_PARCEL_MPI_ZERO_COPY_RECEIVE_OPTIMIZATION:
↪[hpx.parcel.zero_copy_receive_optimization]}
```

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```
zero_copy_serialization_threshold = ${HPX_PARCEL_MPI_ZERO_COPY_SERIALIZATION_THRESHOLD:
↪${hpx.parcel.zero_copy_serialization_threshold]}
use_io_pool = ${HPX_HAVE_PARCEL_MPI_USE_IO_POOL:$1}
async_serialization = ${HPX_HAVE_PARCEL_MPI_ASYNC_SERIALIZATION:${hpx.parcel.async_
↪serialization]}
parcel_pool_size = ${HPX_HAVE_PARCEL_MPI_PARCEL_POOL_SIZE:${hpx.threadpools.parcel_pool_
↪size]}
max_connections = ${HPX_HAVE_PARCEL_MPI_MAX_CONNECTIONS:${hpx.parcel.max_connections}}
max_connections_per_locality = ${HPX_HAVE_PARCEL_MPI_MAX_CONNECTIONS_PER_LOCALITY:${hpx.
↪parcel.max_connections_per_locality]}
max_message_size = ${HPX_HAVE_PARCEL_MPI_MAX_MESSAGE_SIZE:${hpx.parcel.max_message_
↪size]}
max_outbound_message_size = ${HPX_HAVE_PARCEL_MPI_MAX_OUTBOUND_MESSAGE_SIZE:${hpx.
↪parcel.max_outbound_message_size]}
max_background_threads = ${HPX_PARCEL_MPI_MAX_BACKGROUND_THREADS:${hpx.parcel.max_
↪background_threads}}
```

Property	Description
<code>hpx.parcel.mpi.enable</code>	Enables the use of the MPI parcelport. <i>HPX</i> tries to detect if the application was started within a parallel MPI environment. If the detection was successful, the MPI parcelport is enabled by default. To explicitly disable the MPI parcelport, set to 0. Note that the initial bootstrap of the overall <i>HPX</i> application will be performed using MPI as well.
<code>hpx.parcel.mpi.env</code>	This property influences which environment variables (separated by commas) will be analyzed to find out whether the application was invoked by MPI.
<code>hpx.parcel.mpi.multithreaded</code>	This property is used to determine what threading mode to use when initializing MPI. If this setting is 0, <i>HPX</i> will initialize MPI with <code>MPI_THREAD_SINGLE</code> . If the value is not equal to 0, <i>HPX</i> will initialize MPI with <code>MPI_THREAD_MULTII</code> .
<code>hpx.parcel.mpi.rank</code>	This property will be initialized to the MPI rank of the <i>locality</i> .
<code>hpx.parcel.mpi.processor_name</code>	This property will be initialized to the MPI processor name of the <i>locality</i> .
<code>hpx.parcel.mpi.array_optimization</code>	This property defines whether this <i>locality</i> is allowed to utilize array optimizations in the MPI parcelport during serialization of <i>parcel</i> data. The default is the same value as set for <code>hpx.parcel.array_optimization</code> .
<code>hpx.parcel.mpi.zero_copy_optimization</code>	This property defines whether this <i>locality</i> is allowed to utilize zero copy optimizations in the MPI parcelport during serialization of <i>parcel</i> data. The default is the same value as set for <code>hpx.parcel.zero_copy_optimization</code> .
<code>hpx.parcel.mpi.zero_copy_reception_optimization</code>	This property defines whether this <i>locality</i> is allowed to utilize zero copy optimizations on the receiving end in the MPI parcelport during de-serialization of <i>parcel</i> data. The default is the same value as set for <code>hpx.parcel.zero_copy_optimization</code> .
<code>hpx.parcel.mpi.zero_copy_serialization_threshold</code>	This property defines the threshold value (in bytes) starting at which the serialization layer will apply zero-copy optimizations for serialized entities. The default is the same value as set for <code>hpx.parcel.zero_copy_serialization_threshold</code> .
<code>hpx.parcel.mpi.use_io_pool</code>	This property can be set to run the progress thread inside of <i>HPX</i> threads instead of a separate thread pool. The default is 1.
<code>hpx.parcel.mpi.async_serialization</code>	This property defines whether this <i>locality</i> is allowed to spawn a new thread for serialization in the MPI parcelport (this is both for encoding and decoding parcels). The default is the same value as set for <code>hpx.parcel.async_serialization</code> .
<code>hpx.parcel.mpi.parcel_pool_size</code>	The value of this property defines the number of OS threads created for the internal parcel thread pool of the MPI <i>parcel</i> port. The default is taken from <code>hpx.threadpools.parcel_pool_size</code> .
<code>hpx.parcel.mpi.max_connections</code>	This property defines how many network connections between different localities are overall kept alive by each <i>locality</i> . The default is taken from <code>hpx.parcel.max_connections</code> .
<code>hpx.parcel.mpi.max_connections_per_locality</code>	This property defines the maximum number of network connections that one <i>locality</i> will open to another <i>locality</i> . The default is taken from <code>hpx.parcel.max_connections_per_locality</code> .
<code>hpx.parcel.mpi.max_message_size</code>	This property defines the maximum allowed message size that will be transferrable through the <i>parcel</i> layer. The default is taken from <code>hpx.parcel.max_message_size</code> .
<code>hpx.parcel.mpi.max_outbound_message_size</code>	This property defines the maximum allowed outbound coalesced message size that will be transferrable through the <i>parcel</i> layer. The default is taken from <code>hpx.parcel.max_outbound_message_size</code> .
<code>hpx.parcel.mpi.max_background_threads</code>	This property defines how many cores should be used to perform background operations. The default is taken from <code>hpx.parcel.max_background_threads</code> .

The `hpx.agas` configuration section

```
[hpx.agas]
address = ${HPX_AGAS_SERVER_ADDRESS:<hpx_initial_ip_address>}
port = ${HPX_AGAS_SERVER_PORT:<hpx_initial_ip_port>}
service_mode = hosted
dedicated_server = 0
max_pending_refcnt_requests = ${HPX_AGAS_MAX_PENDING_REFCNT_REQUESTS:<hpx_initial_agas_
↳max_pending_refcnt_requests>}
use_caching = ${HPX_AGAS_USE_CACHING:1}
use_range_caching = ${HPX_AGAS_USE_RANGE_CACHING:1}
local_cache_size = ${HPX_AGAS_LOCAL_CACHE_SIZE:<hpx_agas_local_cache_size>}
```

Property	Description
<code>hpx.agas.address</code>	This property defines the default IP address to be used for the <i>AGAS</i> root server. This IP address will be used as long as no other values are specified (for instance, using the <code>--hpx:agas</code> command line option). The expected format is any valid IP address or domain name format that can be resolved into an IP address. The default depends on the compile time preprocessor constant <code>HPX_INITIAL_IP_ADDRESS</code> ("127.0.0.1").
<code>hpx.agas.port</code>	This property defines the default IP port to be used for the <i>AGAS</i> root server. This IP port will be used as long as no other values are specified (for instance, using the <code>--hpx:agas</code> command line option). The default depends on the compile time preprocessor constant <code>HPX_INITIAL_IP_PORT</code> (7009).
<code>hpx.agas.service_mode</code>	This property specifies what type of <i>AGAS</i> service is running on this <i>locality</i> . Currently, two modes exist. The <i>locality</i> that acts as the <i>AGAS</i> server runs in <code>bootstrap</code> mode. All other localities are in <code>hosted</code> mode.
<code>hpx.agas.dedicated_server</code>	This property specifies whether the <i>AGAS</i> server is exclusively running <i>AGAS</i> services and not hosting any application components. It is a boolean value. Set to 1 if <code>--hpx:run-agas-server-only</code> is used.
<code>hpx.agas.max_pending_refcnt_requests</code>	This property defines the number of reference counting requests (increments or decrements) to buffer. The default depends on the compile time preprocessor constant <code>HPX_AGAS_MAX_PENDING_REFCNT_REQUESTS</code> (4096).
<code>hpx.agas.use_caching</code>	This property specifies whether a software address translation cache is used. It is a boolean value. Defaults to 1.
<code>hpx.agas.use_range_caching</code>	This property specifies whether range-based caching is used by the software address translation cache. This property is ignored if <code>hpx.agas.use_caching</code> is false. It is a boolean value. Defaults to 1.
<code>hpx.agas.local_cache_size</code>	This property defines the size of the software address translation cache for <i>AGAS</i> services. This property is ignored if <code>hpx.agas.use_caching</code> is false. Note that if <code>hpx.agas.use_range_caching</code> is true, this size will refer to the maximum number of ranges stored in the cache, not the number of entries spanned by the cache. The default depends on the compile time preprocessor constant <code>HPX_AGAS_LOCAL_CACHE_SIZE</code> (4096).

The `hpx.commandline` configuration section

The following table lists the definition of all pre-defined command line option shortcuts. For more information about commandline options, see the section *HPX Command Line Options*.

```
[hpx.commandline]
aliasing = ${HPX_COMMANDLINE_ALIASING:1}
allow_unknown = ${HPX_COMMANDLINE_ALLOW_UNKNOWN:0}

[hpx.commandline.aliases]
-a = --hpx:agas
-c = --hpx:console
-h = --hpx:help
-I = --hpx:ini
-l = --hpx:localities
-p = --hpx:app-config
-q = --hpx:queuing
-r = --hpx:run-agas-server
-t = --hpx:threads
-v = --hpx:version
-w = --hpx:worker
-x = --hpx:hpx
-0 = --hpx:node=0
-1 = --hpx:node=1
-2 = --hpx:node=2
-3 = --hpx:node=3
-4 = --hpx:node=4
-5 = --hpx:node=5
-6 = --hpx:node=6
-7 = --hpx:node=7
-8 = --hpx:node=8
-9 = --hpx:node=9
```

Note: The short options listed above are disabled by default if the application is built using `#include <hpx/hpx_main.hpp>`. See *Re-use the `main()` function as the main HPX entry point* for more information. The rationale behind this is that in this case the user's application may handle its own command line options, since *HPX* passes all unknown options to `main()`. Short options like `-t` are prone to create ambiguities regarding what the application will support. Hence, the user should instead rely on the corresponding long options like `--hpx:threads` in such a case.

Property	Description
<code>hpx.commandline.aliases</code>	Enable command line aliases as defined in the section <code>hpx.commandline.aliases</code> (see below). Defaults to 1.
<code>hpx.commandline.allow_unknown</code>	Allow for unknown command line options to be passed through to <code>hpx_main()</code> Defaults to 0.
<code>hpx.commandline.aliases.-a</code>	On the commandline <code>-a</code> expands to: <code>--hpx:agas</code> .
<code>hpx.commandline.aliases.-c</code>	On the commandline <code>-c</code> expands to: <code>--hpx:console</code> .
<code>hpx.commandline.aliases.-h</code>	On the commandline <code>-h</code> expands to: <code>--hpx:help</code> .
<code>hpx.commandline.aliases.--help</code>	On the commandline <code>--help</code> expands to: <code>--hpx:help</code> .
<code>hpx.commandline.aliases.-I</code>	On the commandline <code>-I</code> expands to: <code>--hpx:ini</code> .
<code>hpx.commandline.aliases.-l</code>	On the commandline <code>-l</code> expands to: <code>--hpx:localities</code> .
<code>hpx.commandline.aliases.-p</code>	On the commandline <code>-p</code> expands to: <code>--hpx:app-config</code> .
<code>hpx.commandline.aliases.-q</code>	On the commandline <code>-q</code> expands to: <code>--hpx:queuing</code> .
<code>hpx.commandline.aliases.-r</code>	On the commandline <code>-r</code> expands to: <code>--hpx:run-agas-server</code> .
<code>hpx.commandline.aliases.-t</code>	On the commandline <code>-t</code> expands to: <code>--hpx:threads</code> .
<code>hpx.commandline.aliases.-v</code>	On the commandline <code>-v</code> expands to: <code>--hpx:version</code> .
<code>hpx.commandline.aliases.--version</code>	On the commandline <code>--version</code> expands to: <code>--hpx:version</code> .
<code>hpx.commandline.aliases.-w</code>	On the commandline <code>-w</code> expands to: <code>--hpx:worker</code> .
<code>hpx.commandline.aliases.-x</code>	On the commandline <code>-x</code> expands to: <code>--hpx:hpx</code> .
<code>hpx.commandline.aliases.-0</code>	On the commandline <code>-0</code> expands to: <code>--hpx:node=0</code> .
<code>hpx.commandline.aliases.-1</code>	On the commandline <code>-1</code> expands to: <code>--hpx:node=1</code> .
<code>hpx.commandline.aliases.-2</code>	On the commandline <code>-2</code> expands to: <code>--hpx:node=2</code> .
<code>hpx.commandline.aliases.-3</code>	On the commandline <code>-3</code> expands to: <code>--hpx:node=3</code> .
<code>hpx.commandline.aliases.-4</code>	On the commandline <code>-4</code> expands to: <code>--hpx:node=4</code> .
<code>hpx.commandline.aliases.-5</code>	On the commandline <code>-5</code> expands to: <code>--hpx:node=5</code> .
<code>hpx.commandline.aliases.-6</code>	On the commandline <code>-6</code> expands to: <code>--hpx:node=6</code> .
<code>hpx.commandline.aliases.-7</code>	On the commandline <code>-7</code> expands to: <code>--hpx:node=7</code> .
<code>hpx.commandline.aliases.-8</code>	On the commandline <code>-8</code> expands to: <code>--hpx:node=8</code> .
<code>hpx.commandline.aliases.-9</code>	On the commandline <code>-9</code> expands to: <code>--hpx:node=9</code> .

Loading INI files

During startup and after the internal database has been initialized as described in the section *Built-in default configuration settings*, *HPX* will try to locate and load additional ini files to be used as a source for configuration properties. This allows for a wide spectrum of additional customization possibilities by the user and system administrators. The sequence of locations where *HPX* will try loading the ini files is well defined and documented in this section. All ini files found are merged into the internal configuration database. The merge operation itself conforms to the rules as described in the section *The HPX ini file format*.

1. Load all component shared libraries found in the directories specified by the property `hpx.component_path` and retrieve their default configuration information (see section *Loading components* for more details). This property can refer to a list of directories separated by ':' (Linux, Android, and MacOS) or by ';' (Windows).
2. Load all files named `hpx.ini` in the directories referenced by the property `hpx.master_ini_path`. This property can refer to a list of directories separated by ':' (Linux, Android, and MacOS) or by ';' (Windows).
3. Load a file named `.hpx.ini` in the current working directory, e.g., the directory the application was invoked from.
4. Load a file referenced by the environment variable `HPX_INI`. This variable is expected to provide the full path name of the ini configuration file (if any).
5. Load a file named `/etc/hpx.ini`. This lookup is done on non-Windows systems only.
6. Load a file named `.hpx.ini` in the home directory of the current user, e.g., the directory referenced by the environment variable `HOME`.
7. Load a file named `.hpx.ini` in the directory referenced by the environment variable `PWD`.
8. Load the file specified on the command line using the option `--hpx:config`.
9. Load all properties specified on the command line using the option `--hpx:ini`. The properties will be added to the database in the same sequence as they are specified on the command line. The format for those options is, for instance, `--hpx:ini=hpx.default_stack_size=0x4000`. In addition to the explicit command line options, this will set the following properties as implied from other settings:
 - `hpx.parcel.address` and `hpx.parcel.port` as set by `--hpx:hpx`
 - `hpx.agas.address`, `hpx.agas.port` and `hpx.agas.service_mode` as set by `--hpx:agas`
 - `hpx.program_name` and `hpx.cmd_line` will be derived from the actual command line
 - **`hpx.os_threads` and `hpx.localities` as set by `--hpx:threads` and `--hpx:localities`**
 - `hpx.runtime_mode` will be derived from any explicit `--hpx:console`, `--hpx:worker`, or `--hpx:connect`, or it will be derived from other settings, such as `--hpx:node =0`, which implies `--hpx:console`.
10. Load files based on the pattern `*.ini` in all directories listed by the property `hpx.ini_path`. All files found during this search will be merged. The property `hpx.ini_path` can hold a list of directories separated by ':' (on Linux or Mac) or ';' (on Windows).
11. Load the file specified on the command line using the option `--hpx:app-config`. Note that this file will be merged as the content for a top level section `[application]`.

Note: Any changes made to the configuration database caused by one of the steps will influence the loading process for all subsequent steps. For instance, if one of the ini files loaded changes the property `hpx.ini_path`, this will influence the directories searched in step 9 as described above.

Important: The *HPX* core library will verify that all configuration settings specified on the command line (using the `--hpx:ini` option) will be checked for validity. That means that the library will accept only *known* configuration settings. This is to protect the user from unintentional typos while specifying those settings. This behavior can be overwritten by appending a '!' to the configuration key, thus forcing the setting to be entered into the configuration database. For instance: `--hpx:ini=hpx.foo! = 1`

If any of the environment variables or files listed above are not found, the corresponding loading step will be silently skipped.

Loading components

HPX relies on loading application specific components during the runtime of an application. Moreover, *HPX* comes with a set of preinstalled components supporting basic functionalities useful for almost every application. Any component in *HPX* is loaded from a shared library, where any of the shared libraries can contain more than one component type. During startup, *HPX* tries to locate all available components (e.g., their corresponding shared libraries) and creates an internal component registry for later use. This section describes the algorithm used by *HPX* to locate all relevant shared libraries on a system. As described, this algorithm is customizable by the configuration properties loaded from the ini files (see section *Loading INI files*).

Loading components is a two-stage process. First *HPX* tries to locate all component shared libraries, loads those, and generates a default configuration section in the internal configuration database for each component found. For each found component the following information is generated:

```
[hpx.components.<component_instance_name>]
name = <name_of_shared_library>
path = ${component_path}
enabled = ${hpx.components.load_external}
default = 1
```

The values in this section correspond to the expected configuration information for a component as described in the section *Built-in default configuration settings*.

In order to locate component shared libraries, *HPX* will try loading all shared libraries (files with the platform specific extension of a shared library, Linux: *.so, Windows: *.dll, MacOS: *.dylib found in the directory referenced by the ini property `hpx.component_path`).

This first step corresponds to step 1) during the process of filling the internal configuration database with default information as described in section *Loading INI files*.

After all of the configuration information has been loaded, *HPX* performs the second step in terms of loading components. During this step, *HPX* scans all existing configuration sections `[hpx.component.<some_component_instance_name>]` and instantiates a special factory object for each of the successfully located and loaded components. During the application's life time, these factory objects are responsible for creating new and discarding old instances of the component they are associated with. This step is performed after step 1) of the process of filling the internal configuration database with default information as described in section *Loading INI files*.

Application specific component example

This section assumes there is a simple application component that exposes one member function as a component action. The header file `app_server.hpp` declares the C++ type to be exposed as a component. This type has a member function `print_greeting()`, which is exposed as an action `print_greeting_action`. We assume the source files for this example are located in a directory referenced by `$APP_ROOT`:

```
// file: $APP_ROOT/app_server.hpp
#include <hpx/hpx.hpp>
#include <hpx/include/iostreams.hpp>

namespace app
{
    // Define a simple component exposing one action 'print_greeting'
    class HPX_COMPONENT_EXPORT server
    : public hpx::components::component_base<server>
    {
    public:
        void print_greeting ()
        {
            hpx::cout << "Hey, how are you?\n" << std::flush;
        }

        // Component actions need to be declared, this also defines the
        // type 'print_greeting_action' representing the action.
        HPX_DEFINE_COMPONENT_ACTION(server, print_greeting, print_greeting_action);
    };
}

// Declare boilerplate code required for each of the component actions.
HPX_REGISTER_ACTION_DECLARATION(app::server::print_greeting_action);
```

The corresponding source file contains mainly macro invocations that define the boilerplate code needed for *HPX* to function properly:

```
// file: $APP_ROOT/app_server.cpp
#include "app_server.hpp"

// Define boilerplate required once per component module.
HPX_REGISTER_COMPONENT_MODULE();

// Define factory object associated with our component of type 'app::server'.
HPX_REGISTER_COMPONENT(app::server, app_server);

// Define boilerplate code required for each of the component actions. Use the
// same argument as used for HPX_REGISTER_ACTION_DECLARATION above.
HPX_REGISTER_ACTION(app::server::print_greeting_action);
```

The following gives an example of how the component can be used. Here, one instance of the `app::server` component is created on the current *locality* and the exposed action `print_greeting_action` is invoked using the global id of the newly created instance. Note that no special code is required to delete the component instance after it is not needed anymore. It will be deleted automatically when its last reference goes out of scope (shown in the example below at the closing brace of the block surrounding the code):

```

// file: $APP_ROOT/use_app_server_example.cpp
#include <hpx/hpx_init.hpp>
#include "app_server.hpp"

int hpx_main()
{
    {
        // Create an instance of the app_server component on the current locality.
        hpx::naming::id_type app_server_instance =
            hpx::create_component<app::server>(hpx::find_here());

        // Create an instance of the action 'print_greeting_action'.
        app::server::print_greeting_action print_greeting;

        // Invoke the action 'print_greeting' on the newly created component.
        print_greeting(app_server_instance);
    }
    return hpx::finalize();
}

int main(int argc, char* argv[])
{
    return hpx::init(argc, argv);
}

```

In order to make sure that the application will be able to use the component `app::server`, special configuration information must be passed to *HPX*. The simplest way to allow *HPX* to ‘find’ the component is to provide special ini configuration files that add the necessary information to the internal configuration database. The component should have a special ini file containing the information specific to the component `app_server`.

```

# file: $APP_ROOT/app_server.ini
[hpx.components.app_server]
name = app_server
path = $APP_LOCATION/

```

Here, `$APP_LOCATION` is the directory where the (binary) component shared library is located. *HPX* will attempt to load the shared library from there. The section name `hpx.components.app_server` reflects the instance name of the component (`app_server` is an arbitrary, but unique name). The property value for `hpx.components.app_server.name` should be the same as used for the second argument to the macro `HPX_REGISTER_COMPONENT` above.

Additionally, a file `.hpx.ini`, which could be located in the current working directory (see step 3 as described in the section *Loading INI files*), can be used to add to the ini search path for components:

```

# file: $PWD/.hpx.ini
[hpx]
ini_path = ${hpx.ini_path}:$APP_ROOT/

```

This assumes that the above ini file specific to the component is located in the directory `$APP_ROOT`.

Note: It is possible to reference the defined property from inside its value. *HPX* will gracefully use the previous value of `hpx.ini_path` for the reference on the right hand side and assign the overall (now expanded) value to the property.

Logging

HPX uses a sophisticated logging framework, allowing users to follow in detail what operations have been performed inside the *HPX* library in what sequence. This information proves to be very useful for diagnosing problems or just for improving the understanding of what is happening in *HPX* as a consequence of invoking *HPX* API functionality.

Default logging

Enabling default logging is a simple process. The detailed description in the remainder of this section explains different ways to customize the defaults. Default logging can be enabled by using one of the following:

- A command line switch `--hpx:debug-hpx-log`, which will enable logging to the console terminal.
- The command line switch `--hpx:debug-hpx-log=<filename>`, which enables logging to a given file `<filename>`.
- Setting an environment variable `HPX_LOGLEVEL=<loglevel>` while running the *HPX* application. In this case `<loglevel>` should be a number between (or equal to) 1 and 5 where 1 means minimal logging and 5 causes all available messages to be logged. When setting the environment variable, the logs will be written to a file named `hpx.<PID>.lo` in the current working directory, where `<PID>` is the process id of the console instance of the application.

Customizing logging

Generally, logging can be customized either using environment variable settings or using by an ini configuration file. Logging is generated in several categories, each of which can be customized independently. All customizable configuration parameters have reasonable defaults, allowing for the use of logging without any additional configuration effort. The following table lists the available categories.

Table 2.5: Logging categories

Category	Category shortcut	Information to be generated	Environment variable
General	None	Logging information generated by different subsystems of <i>HPX</i> , such as thread-manager, parcel layer, LCOs, etc.	HPX_LOGLEVEL
<i>AGAS</i>	AGAS	Logging output generated by the <i>AGAS</i> subsystem	HPX_AGAS_LOGLEVEL
Application	APP	Logging generated by applications.	HPX_APP_LOGLEVEL

By default, all logging output is redirected to the console instance of an application, where it is collected and written to a file, one file for each logging category.

Each logging category can be customized at two levels. The parameters for each are stored in the ini configuration sections `hpx.logging.CATEGORY` and `hpx.logging.console.CATEGORY` (where `CATEGORY` is the category shortcut as listed in the table above). The former influences logging at the source *locality* and the latter modifies the logging behaviour for each of the categories at the console instance of an application.

Levels

All *HPX* logging output has seven different logging levels. These levels can be set explicitly or through environment variables in the main *HPX* ini file as shown below. The logging levels and their associated integral values are shown in the table below, ordered from most verbose to least verbose. By default, all *HPX* logs are set to 0, e.g., all logging output is disabled by default.

Table 2.6: Logging levels

Logging level	Integral value
<debug>	5
<info>	4
<warning>	3
<error>	2
<fatal>	1
No logging	0

Tip: The easiest way to enable logging output is to set the environment variable corresponding to the logging category to an integral value as described in the table above. For instance, setting `HPX_LOGLEVEL=5` will enable full logging output for the general category. Please note that the syntax and means of setting environment variables varies between operating systems.

Configuration

Logs will be saved to destinations as configured by the user. By default, logging output is saved on the console instance of an application to `hpx.<CATEGORY>.<PID>.lo` (where `CATEGORY` and `PID` are placeholders for the category shortcut and the OS process id). The output for the general logging category is saved to `hpx.<PID>.log`. The default settings for the general logging category are shown here (the syntax is described in the section *The HPX ini file format*):

```
[hpx.logging]
level = ${HPX_LOGLEVEL:0}
destination = ${HPX_LOGDESTINATION:console}
format = ${HPX_LOGFORMAT:(T%locality%/%hpxthread%.%hpxphase%/%hpxcomponent%) P%parentloc
↪%/%hpxparent%.%hpxparentphase% %time%($hh:$mm.$ss.$mili) [%idx%]|\\n}
```

The logging level is taken from the environment variable `HPX_LOGLEVEL` and defaults to zero, e.g., no logging. The default logging destination is read from the environment variable `HPX_LOGDESTINATION`. On any of the localities it defaults to `console`, which redirects all generated logging output to the console instance of an application. The following table lists the possible destinations for any logging output. It is possible to specify more than one destination separated by whitespace.

Table 2.7: Logging destinations

Logging destination	Description
<code>file(<filename>)</code>	Directs all output to a file with the given <code><filename></code> .
<code>cout</code>	Directs all output to the local standard output of the application instance on this <i>locality</i> .
<code>cerr</code>	Directs all output to the local standard error output of the application instance on this <i>locality</i> .
<code>console</code>	Directs all output to the console instance of the application. The console instance has its logging destinations configured separately.
<code>android_log</code>	Directs all output to the (Android) system log (available on Android systems only).

The logging format is read from the environment variable `HPX_LOGFORMAT`, and it defaults to a complex format description. This format consists of several placeholder fields (for instance `%locality%`), which will be replaced by concrete values when the logging output is generated. All other information is transferred verbatim to the output. The table below describes the available field placeholders. The separator character `|` separates the logging message prefix formatted as shown and the actual log message which will replace the separator.

Table 2.8: Available field placeholders

Name	Description
<i>locality</i>	The id of the <i>locality</i> on which the logging message was generated.
hpxthread	The id of the <i>HPX</i> thread generating this logging output.
hpxphase	The phase ⁶⁷ of the <i>HPX</i> thread generating this logging output.
hpxcomponent	The local virtual address of the component which the current <i>HPX</i> thread is accessing.
parentloc	The id of the <i>locality</i> where the <i>HPX</i> thread was running that initiated the current <i>HPX</i> thread. The current <i>HPX</i> thread is generating this logging output.
hpxparent	The id of the <i>HPX</i> thread that initiated the current <i>HPX</i> thread. The current <i>HPX</i> thread is generating this logging output.
hpxparentphase	The phase of the <i>HPX</i> thread when it initiated the current <i>HPX</i> thread. The current <i>HPX</i> thread is generating this logging output.
time	The time stamp for this logging outputline as generated by the source <i>locality</i> .
idx	The sequence number of the logging output line as generated on the source <i>locality</i> .
osthread	The sequence number of the OS thread that executes the current <i>HPX</i> thread.

Note: Not all of the field placeholder may be expanded for all generated logging output. If no value is available for a particular field, it is replaced with a sequence of '-' characters.

Here is an example line from a logging output generated by one of the *HPX* examples (please note that this is generated on a single line, without a line break):

```
(T000000000/0000000002d46f90.01/00000000009ebc10) P-----/0000000002d46f80.02 17:49.37.
↪320 [000000000000004d]
  <info> [RT] successfully created component {0000000100ff0001, 0000000000030002} of
↪type: component_barrier[7(3)]
```

The default settings for the general logging category on the console is shown here:

```
[hpx.logging.console]
level = ${HPX_LOGLEVEL:[hpx.logging.level]}
destination = ${HPX_CONSOLE_LOGDESTINATION:file(hpx.${system.pid}.log)}
format = ${HPX_CONSOLE_LOGFORMAT:|}
```

These settings define how the logging is customized once the logging output is received by the console instance of an application. The logging level is read from the environment variable `HPX_LOGLEVEL` (as set for the console instance of the application). The level defaults to the same values as the corresponding settings in the general logging configuration shown before. The destination on the console instance is set to be a file that's name is generated based on its OS process id. Setting the environment variable `HPX_CONSOLE_LOGDESTINATION` allows customization of the naming scheme for the output file. The logging format is set to leave the original logging output unchanged, as received from one of the localities the application runs on.

⁶⁷ The phase of a *HPX*-thread counts how often this thread has been activated.

HPX Command Line Options

The predefined command line options for any application using `hpx::init` are described in the following subsections.

HPX options (allowed on command line only)

--hpx:help

Print out program usage (default: this message). Possible values: `full` (additionally prints options from components).

--hpx:version

Print out *HPX* version and copyright information.

--hpx:info

Print out *HPX* configuration information.

--hpx:options-file arg

Specify a file containing command line options (alternatively: `@filepath`).

HPX options (additionally allowed in an options file)

--hpx:worker

Run this instance in worker mode.

--hpx:console

Run this instance in console mode.

--hpx:connect

Run this instance in worker mode, but connecting late.

--hpx:run-agas-server

Run *AGAS* server as part of this runtime instance.

--hpx:run-hpx-main

Run the `hpx_main` function, regardless of *locality* mode.

--hpx:hpx arg

The IP address the *HPX* parcellport is listening on, expected format: `address:port` (default: `127.0.0.1:7910`).

--hpx:agas arg

The IP address the *AGAS* root server is running on, expected format: `address:port` (default: `127.0.0.1:7910`).

--hpx:run-agas-server-only

Run only the *AGAS* server.

--hpx:nodefile arg

The file name of a node file to use (list of nodes, one node name per line and core).

--hpx:nodes arg

The (space separated) list of the nodes to use (usually this is extracted from a node file).

--hpx:endnodes

This can be used to end the list of nodes specified using the option `--hpx:nodes`.

--hpx:ifsuffix arg

Suffix to append to host names in order to resolve them to the proper network interconnect.

--hpx:ifprefix arg

Prefix to prepend to host names in order to resolve them to the proper network interconnect.

--hpx:iftransform arg

Sed-style search and replace (s/search/replace/) used to transform host names to the proper network interconnect.

--hpx:force_ipv4

Network hostnames will be resolved to ipv4 addresses instead of using the first resolved endpoint. This is especially useful on Windows where the local hostname will resolve to an ipv6 address while remote network hostnames are commonly resolved to ipv4 addresses.

--hpx:localities arg

The number of localities to wait for at application startup (default: 1).

--hpx:node arg

Number of the node this *locality* is run on (must be unique).

--hpx:ignore-batch-env

Ignore batch environment variables.

--hpx:expect-connecting-localities

This *locality* expects other localities to dynamically connect (this is implied if the number of initial localities is larger than 1).

--hpx:pu-offset

The first processing unit this instance of *HPX* should be run on (default: 0).

--hpx:pu-step

The step between used processing unit numbers for this instance of *HPX* (default: 1).

--hpx:threads arg

The number of operating system threads to spawn for this *HPX locality*. Possible values are: numeric values 1, 2, 3 and so on, *all* (which spawns one thread per processing unit, includes hyperthreads), or *cores* (which spawns one thread per core) (default: *cores*).

--hpx:cores arg

The number of cores to utilize for this *HPX locality* (default: *all*, i.e., the number of cores is based on the number of threads *--hpx:threads* assuming *--hpx:bind=compact*).

--hpx:affinity arg

The affinity domain the OS threads will be confined to, possible values: *pu*, *core*, *numa*, *machine* (default: *pu*).

--hpx:bind arg

he detailed affinity description for the OS threads, see *More details about HPX command line options* for a detailed description of possible values. Do not use with *--hpx:pu-step*, *--hpx:pu-offset* or *--hpx:affinity* options. Implies *--hpx:numa-sensitive* (*--hpx:bind=none*) disables defining thread affinities).

--hpx:use-process-mask

Use the process mask to restrict available hardware resources (implies *--hpx:ignore-batch-env*).

--hpx:print-bind

Print to the console the bit masks calculated from the arguments specified to all *--hpx:bind* options.

--hpx:queuing arg

The queue scheduling policy to use. Options are `local`, `local-priority-fifo`, `local-priority-lifo`, `static`, `static-priority`, `abp-priority-fifo`, `local-workrequesting-fifo`, `local-workrequesting-lifo`, `local-workrequesting-mc`, and `abp-priority-lifo` (default: `local-priority-fifo`).

--hpx:high-priority-threads arg

The number of operating system threads maintaining a high priority queue (default: number of OS threads), valid for `--hpx:queuing=abp-priority`, `--hpx:queuingstatic-priority` and `--hpx:queuinglocal-priority` only.

--hpx:numa-sensitive

Makes the scheduler NUMA sensitive.

HPX configuration options**--hpx:app-config arg**

Load the specified application configuration (ini) file.

--hpx:config arg

Load the specified *HPX* configuration (ini) file.

--hpx:ini arg

Add a configuration definition to the default runtime configuration.

--hpx:exit

Exit after configuring the runtime.

HPX debugging options**--hpx:list-symbolic-names**

List all registered symbolic names after startup.

--hpx:list-component-types

List all dynamic component types after startup.

--hpx:dump-config-initial

Print the initial runtime configuration.

--hpx:dump-config

Print the final runtime configuration.

--hpx:debug-hpx-log [arg]

Enable all messages on the *HPX* log channel and send all *HPX* logs to the target destination (default: `cout`).

--hpx:debug-agas-log [arg]

Enable all messages on the *AGAS* log channel and send all *AGAS* logs to the target destination (default: `cout`).

--hpx:debug-parcel-log [arg]

Enable all messages on the parcel transport log channel and send all parcel transport logs to the target destination (default: `cout`).

--hpx:debug-timing-log [arg]

Enable all messages on the timing log channel and send all timing logs to the target destination (default: `cout`).

--hpx:debug-app-log [arg]

Enable all messages on the application log channel and send all application logs to the target destination (default: cout).

--hpx:debug-clp

Debug command line processing.

--hpx:attach-debugger arg

Wait for a debugger to be attached, possible arg values: startup or exception (default: startup)

HPX options related to performance counters**--hpx:print-counter**

Print the specified performance counter either repeatedly and/or at the times specified by *--hpx:print-counter-at* (see also option *--hpx:print-counter-interval*).

--hpx:print-counter-reset

Print the specified performance counter either repeatedly and/or at the times specified by *--hpx:print-counter-at*. Reset the counter after the value is queried (see also option *--hpx:print-counter-interval*).

--hpx:print-counter-interval

Print the performance counter(s) specified with *--hpx:print-counter* repeatedly after the time interval (specified in milliseconds), (default: 0, which means print once at shutdown).

--hpx:print-counter-destination

Print the performance counter(s) specified with *--hpx:print-counter* to the given file (default: console).

--hpx:list-counters

List the names of all registered performance counters, possible values: minimal (prints counter name skeletons), full (prints all available counter names).

--hpx:list-counter-infos

List the description of all registered performance counters, possible values: minimal (prints info for counter name skeletons), full (prints all available counter infos).

--hpx:print-counter-format

Print the performance counter(s) specified with *--hpx:print-counter*. Possible formats in CSV include a format with a header or without any header (see option *--hpx:no-csv-header*). Possible values: csv (prints counter values in CSV format with full names as header), csv-short (prints counter values in CSV format with short names provided with *--hpx:print-counter* as *--hpx:print-counter* shortname, full-countername

--hpx:no-csv-header

Print the performance counter(s) specified with *--hpx:print-counter* and csv or csv-short format specified with *--hpx:print-counter-format* without header.

--hpx:print-counter-at arg

Print the performance counter(s) specified with *--hpx:print-counter* (or *--hpx:print-counter-reset*) at the given point in time, possible argument values: startup, shutdown (default), noshtutdown.

--hpx:reset-counters

Reset all performance counter(s) specified with *--hpx:print-counter* after they have been evaluated.

--hpx:print-counters-locally

Each *locality* prints only its own local counters. If this is used with `--hpx:print-counter-destination=<file>`, the code will append a "`.<locality_id>`" to the file name in order to avoid clashes between localities.

Command line argument shortcuts

Additionally, the following shortcuts are available from every *HPX* application.

Table 2.9: Predefined command line option shortcuts

Shortcut option	Equivalent long option
-a	<code>--hpx:agas</code>
-c	<code>--hpx:console</code>
-h	<code>--hpx:help</code>
-I	<code>--hpx:ini</code>
-l	<code>--hpx:localities</code>
-p	<code>--hpx:app-config</code>
-q	<code>--hpx:queuing</code>
-r	<code>--hpx:run-agas-server</code>
-t	<code>--hpx:threads</code>
-v	<code>--hpx:version</code>
-w	<code>--hpx:worker</code>
-x	<code>--hpx:hpx</code>
-0	<code>--hpx:node=0</code>
-1	<code>--hpx:node=1</code>
-2	<code>--hpx:node=2</code>
-3	<code>--hpx:node=3</code>
-4	<code>--hpx:node=4</code>
-5	<code>--hpx:node=5</code>
-6	<code>--hpx:node=6</code>
-7	<code>--hpx:node=7</code>
-8	<code>--hpx:node=8</code>
-9	<code>--hpx:node=9</code>

Note: The short options listed above are disabled by default if the application is built using `#include <hpx/hpx_main.hpp>`. See *Re-use the main() function as the main HPX entry point* for more information. The rationale behind this is that in this case the user's application may handle its own command line options, since *HPX* passes all unknown options to `main()`. Short options like `-t` are prone to create ambiguities regarding what the application will support. Hence, the user should instead rely on the corresponding long options like `--hpx:threads` in such a case.

It is possible to define your own shortcut options. In fact, all of the shortcuts listed above are pre-defined using the technique described here. Also, it is possible to redefine any of the pre-defined shortcuts to expand differently as well.

Shortcut options are obtained from the internal configuration database. They are stored as key-value properties in a special properties section named `hpx.commandline`. You can define your own shortcuts by adding the corresponding definitions to one of the ini configuration files as described in the section *Configuring HPX applications*. For instance, in order to define a command line shortcut `--p`, which should expand to `-hpx:print-counter`, the following configuration information needs to be added to one of the ini configuration files:

```
[hpx.commandline.aliases]
--pc = --hpx:print-counter
```

Note: Any arguments for shortcut options passed on the command line are retained and passed as arguments to the corresponding expanded option. For instance, given the definition above, the command line option:

```
--pc=/threads{locality#0/total}/count/cumulative
```

would be expanded to:

```
--hpx:print-counter=/threads{locality#0/total}/count/cumulative
```

Important: Any shortcut option should either start with a single '-' or with two '--' characters. Shortcuts starting with a single '-' are interpreted as short options (i.e., everything after the first character following the '-' is treated as the argument). Shortcuts starting with '--' are interpreted as long options. No other shortcut formats are supported.

Specifying options for single localities only

For runs involving more than one *locality*, it is sometimes desirable to supply specific command line options to single localities only. When the *HPX* application is launched using a scheduler (like PBS; for more details see section *How to use HPX applications with PBS*), specifying dedicated command line options for single localities may be desirable. For this reason all of the command line options that have the general format `--hpx:<some_key>` can be used in a more general form: `--hpx:<N>:<some_key>`, where `<N>` is the number of the *locality* this command line option will be applied to; all other localities will simply ignore the option. For instance, the following PBS script passes the option `--hpx:pu-offset=4` to the *locality* '1' only.

```
#!/bin/bash
#
#PBS -l nodes=2:ppn=4

APP_PATH=~/packages/hpx/bin/hello_world_distributed
APP_OPTIONS=

pbsdsh -u $APP_PATH $APP_OPTIONS --hpx:1:pu-offset=4 --hpx:nodes=`cat $PBS_NODEFILE`
```

Caution: If the first application specific argument (inside `$APP_OPTIONS`) is a non-option (i.e., does not start with a - or a --), then it must be placed before the option `--hpx:nodes`, which, in this case, should be the last option on the command line.

Alternatively, use the option `--hpx:endnodes` to explicitly mark the end of the list of node names:

```
$ pbsdsh -u $APP_PATH --hpx:1:pu-offset=4 --hpx:nodes=`cat $PBS_NODEFILE` --
↪hpx:endnodes $APP_OPTIONS
```

More details about *HPX* command line options

This section documents the following list of the command line options in more detail:

- *The command line option `--hpx:bind`*

The command line option `--hpx:bind`

This command line option allows one to specify the required affinity of the *HPX* worker threads to the underlying processing units. As a result the worker threads will run only on the processing units identified by the corresponding bind specification. The affinity settings are to be specified using `--hpx:bind=<BINDINGS>`, where `<BINDINGS>` have to be formatted as described below.

In addition to the syntax described below, one can use `--hpx:bind=none` to disable all binding of any threads to a particular core. This is mostly supported for debugging purposes.

The specified affinities refer to specific regions within a machine hardware topology. In order to understand the hardware topology of a particular machine, it may be useful to run the `lstopo` tool, which is part of Portable Hardware Locality (HWLOC), to see the reported topology tree. Seeing and understanding a topology tree will definitely help in understanding the concepts that are discussed below.

Affinities can be specified using hwloc tuples. Tuples of hwloc *objects* and associated *indexes* can be specified in the form `object:index`, `object:index-index` or `object:index,...,index`. Hwloc objects represent types of mapped items in a topology tree. Possible values for objects are `socket`, `numanode`, `core` and `pu` (processing unit). Indexes are non-negative integers that specify a unique physical object in a topology tree using its logical sequence number.

Chaining multiple tuples together in the more general form `object1:index1[.object2:index2[...]]` is permissible. While the first tuple's object may appear anywhere in the topology, the *N*th tuple's object must have a shallower topology depth than the (*N*+1)th tuple's object. Put simply: as you move right in a tuple chain, objects must go deeper in the topology tree. Indexes specified in chained tuples are relative to the scope of the parent object. For example, `socket:0.core:1` refers to the second core in the first socket (all indices are zero based).

Multiple affinities can be specified using several `--hpx:bind` command line options or by appending several affinities separated by a `' ; '`. By default, if multiple affinities are specified, they are added.

`"all"` is a special affinity consisting in the entire current topology.

Note: All "names" in an affinity specification, such as `thread`, `socket`, `numanode`, `pu` or `all`, can be abbreviated. Thus, the affinity specification `threads:0-3=socket:0.core:1.pu:1` is fully equivalent to its shortened form `t:0-3=s:0.c:1.p:1`.

Here is a full grammar describing the possible format of mappings:

```

mappings      ::=  distribution | mapping (";" mapping)*
distribution  ::=  "compact" | "scatter" | "balanced" | "numa-balanced"
mapping       ::=  thread_spec "=" pu_specs
thread_spec   ::=  "thread:" range_specs
pu_specs      ::=  pu_spec ("." pu_spec)*
pu_spec       ::=  type ":" range_specs | "~" pu_spec
range_specs   ::=  range_spec ("," range_spec)*
range_spec    ::=  int | int "-" int | "all"
type          ::=  "socket" | "numanode" | "core" | "pu"

```

The following example assumes a system with at least 4 cores, where each core has more than 1 processing unit (hardware threads). Running `hello_world_distributed` with 4 OS threads (on 4 processing units), where each of those threads is bound to the first processing unit of each of the cores, can be achieved by invoking:

```
$ hello_world_distributed -t4 --hpx:bind=thread:0-3=core:0-3.pu:0
```

Here, `thread:0-3` specifies the OS threads used to define affinity bindings, and `core:0-3.pu:0` defines that for each of the cores (`core:0-3`) only their first processing unit `pu:0` should be used.

Note: The command line option `--hpx:print-bind` can be used to print the bitmasks generated from the affinity mappings as specified with `--hpx:bind`. For instance, on a system with hyperthreading enabled (i.e. 2 processing units per core), the command line:

```
$ hello_world_distributed -t4 --hpx:bind=thread:0-3=core:0-3.pu:0 --hpx:print-bind
```

will cause this output to be printed:

```
0: PU L#0(P#0), Core L#0, Socket L#0, Node L#0(P#0)
1: PU L#2(P#2), Core L#1, Socket L#0, Node L#0(P#0)
2: PU L#4(P#4), Core L#2, Socket L#0, Node L#0(P#0)
3: PU L#6(P#6), Core L#3, Socket L#0, Node L#0(P#0)
```

where each bit in the bitmasks corresponds to a processing unit the listed worker thread will be bound to run on.

The difference between the four possible predefined distribution schemes (`compact`, `scatter`, `balanced` and `numa-balanced`) is best explained with an example. Imagine that we have a system with 4 cores and 4 hardware threads per core on 2 sockets. If we place 8 threads the assignments produced by the `compact`, `scatter`, `balanced` and `numa-balanced` types are shown in the figure below. Notice that `compact` does not fully utilize all the cores in the system. For this reason it is recommended that applications are run using the `scatter` or `balanced/numa-balanced` options in most cases.

In addition to the predefined distributions it is possible to restrict the resources used by *HPX* to the process CPU mask. The CPU mask is typically set by e.g. `MPI`⁶⁶ and batch environments. Using the command line option `--hpx:use-process-mask` makes *HPX* act as if only the processing units in the CPU mask are available for use by *HPX*. The number of threads is automatically determined from the CPU mask. The number of threads can still be changed manually using this option, but only to a number less than or equal to the number of processing units in the CPU mask. The option `--hpx:print-bind` is useful in conjunction with `--hpx:use-process-mask` to make sure threads are placed as expected.

2.3.10 Writing single-node applications

Being a C++ Standard Library for Concurrency and Parallelism, *HPX* implements all of the corresponding facilities as defined by the C++ Standard but also those which are proposed as part of the ongoing C++ standardization process. This section focuses on the features available in *HPX* for parallel and concurrent computation on a single node, although many of the features presented here are also implemented to work in the distributed case.

⁶⁶ https://en.wikipedia.org/wiki/Message_Passing_Interface

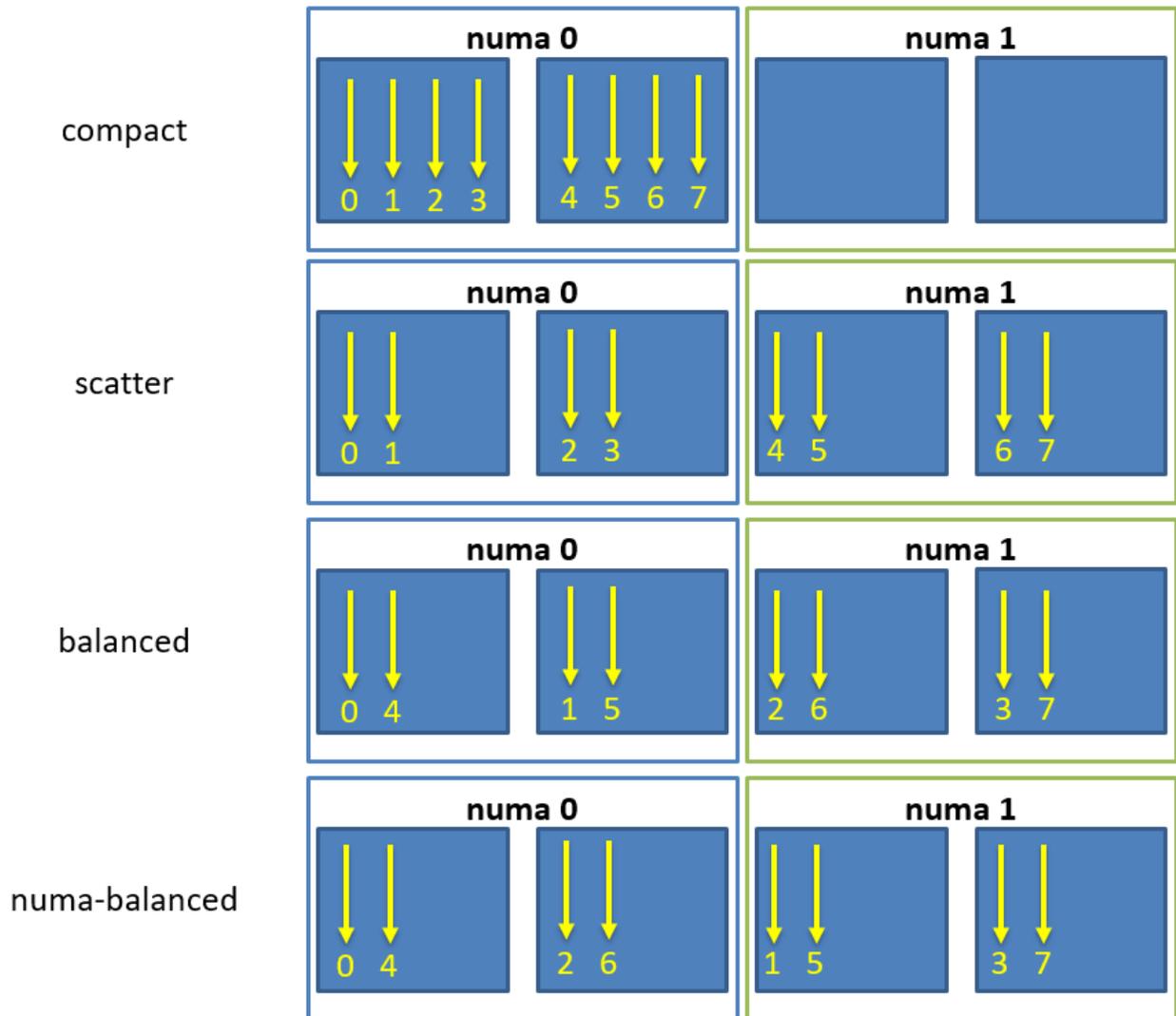


Fig. 2.7: Schematic of thread affinity type distributions.

Synchronization objects

The following objects are providing synchronization for *HPX* applications:

1. *Barrier*
2. *Condition variable*
3. *Latch*
4. *Mutex*
5. *Shared mutex*
6. *Semaphore*
7. *Composable guards*

Barrier

Barriers are used for synchronizing multiple threads. They provide a synchronization point, where all threads must wait until they have all reached the barrier, before they can continue execution. This allows multiple threads to work together to solve a common task, and ensures that no thread starts working on the next task until all threads have completed the current task. This ensures that all threads are in the same state before performing any further operations, leading to a more consistent and accurate computation.

Unlike latches, barriers are reusable: once the participating threads are released from a barrier's synchronization point, they can re-use the same barrier. It is thus useful for managing repeated tasks, or phases of a larger task, that are handled by multiple threads. The code below shows how barriers can be used to synchronize two threads:

```
#include <hpx/barrier.hpp>
#include <hpx/future.hpp>
#include <hpx/init.hpp>

#include <iostream>

int hpx_main()
{
    hpx::barrier b(2);

    hpx::future<void> f1 = hpx::async([&b]() {
        std::cout << "Thread 1 started." << std::endl;
        // Do some computation
        b.arrive_and_wait();
        // Continue with next task
        std::cout << "Thread 1 finished." << std::endl;
    });

    hpx::future<void> f2 = hpx::async([&b]() {
        std::cout << "Thread 2 started." << std::endl;
        // Do some computation
        b.arrive_and_wait();
        // Continue with next task
        std::cout << "Thread 2 finished." << std::endl;
    });
}
```

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```

    f1.get();
    f2.get();

    return hpx::local::finalize();
}

int main(int argc, char* argv[])
{
    return hpx::local::init(hpx_main, argc, argv);
}

```

In this example, two `hpx::future` objects are created, each representing a separate thread of execution. The `wait` function of the `hpx::barrier` object is called by each thread. The threads will wait at the barrier until both have reached it. Once both threads have reached the barrier, they can continue with their next task.

Condition variable

A *condition variable* is a synchronization primitive in *HPX* that allows a thread to wait for a specific condition to be satisfied before continuing execution. It is typically used in conjunction with a mutex or a lock to protect shared data that is being modified by multiple threads. Hence, it blocks one or more threads until another thread both modifies a shared variable (the condition) and notifies the `condition_variable`. The code below shows how two threads modifying the shared variable data can be synchronized using the `condition_variable`:

```

#include <hpx/condition_variable.hpp>
#include <hpx/init.hpp>
#include <hpx/mutex.hpp>
#include <hpx/thread.hpp>

#include <iostream>
#include <string>

hpx::condition_variable cv;
hpx::mutex m;
std::string data;
bool ready = false;
bool processed = false;

void worker_thread()
{
    // Wait until the main thread signals that data is ready
    std::unique_lock<hpx::mutex> lk(m);
    cv.wait(lk, [] { return ready; });

    // Access the shared resource
    std::cout << "Worker thread: Processing data...\n";
    data = "Test data after";

    // Send data back to the main thread
    processed = true;
    std::cout << "Worker thread: data processing is complete\n";
}

```

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```

// Manual unlocking is done before notifying, to avoid waking up
// the waiting thread only to block again
lk.unlock();
cv.notify_one();
}

int hpx_main()
{
    hpx::thread worker(worker_thread);

    // Do some work
    std::cout << "Main thread: Preparing data...\n";
    data = "Test data before";
    hpx::this_thread::sleep_for(std::chrono::seconds(1));
    std::cout << "Main thread: Data before processing = " << data << '\n';

    // Signal that data is ready and send data to worker thread
    {
        std::lock_guard<hpx::mutex> lk(m);
        ready = true;
        std::cout << "Main thread: Data is ready...\n";
    }
    cv.notify_one();

    // Wait for the worker thread to finish
    {
        std::unique_lock<hpx::mutex> lk(m);
        cv.wait(lk, [] { return processed; });
    }
    std::cout << "Main thread: Data after processing = " << data << '\n';
    worker.join();

    return hpx::local::finalize();
}

int main(int argc, char* argv[])
{
    return hpx::local::init(hpx_main, argc, argv);
}

```

The main thread of the code above starts by creating a worker thread and preparing the shared variable data. Once the data is ready, the main thread acquires a lock on the mutex `m` using `std::lock_guard<hpx::mutex> lk(m)` and sets the ready flag to true, then signals the worker thread to start processing by calling `cv.notify_one()`. The `cv.wait()` call in the main thread then blocks until the worker thread signals that processing is complete by setting the processed flag.

The worker thread starts by acquiring a lock on the mutex `m` to ensure exclusive access to the shared data. The `cv.wait()` call blocks the thread until the ready flag is set by the main thread. Once this is true, the worker thread accesses the shared data resource, processes it, and sets the processed flag to indicate completion. The mutex is then unlocked using `lk.unlock()` and the `cv.notify_one()` call signals the main thread to resume execution. Finally, the new data is printed by the main thread to the console.

Latch

A *latch* is a downward counter which can be used to synchronize threads. The value of the counter is initialized on creation. Threads may block on the latch until the counter is decremented to zero. There is no possibility to increase or reset the counter, which makes the latch a single-use barrier.

In *HPX*, a latch is implemented as a counting semaphore, which can be initialized with a specific count value and decremented each time a thread reaches the latch. When the count value reaches zero, all waiting threads are unblocked and allowed to continue execution. The code below shows how latch can be used to synchronize 16 threads:

```
std::ptrdiff_t num_threads = 16;

/////////////////////////////////////////////////////////////////
void wait_for_latch(hpx::latch& l)
{
    l.arrive_and_wait();
}

/////////////////////////////////////////////////////////////////
int hpx_main(hpx::program_options::variables_map& vm)
{
    num_threads = vm["num-threads"].as<std::ptrdiff_t>();

    hpx::latch l(num_threads + 1);

    std::vector<hpx::future<void>> results;
    for (std::ptrdiff_t i = 0; i != num_threads; ++i)
        results.push_back(hpx::async(&wait_for_latch, std::ref(l)));

    // Wait for all threads to reach this point.
    l.arrive_and_wait();

    hpx::wait_all(results);

    return hpx::local::finalize();
}
```

In the above code, the `hpx_main` function creates a latch object `l` with a count of `num_threads + 1` and `num_threads` number of threads using `hpx::async`. These threads call the `wait_for_latch` function and pass the reference to the latch object. In the `wait_for_latch` function, the thread calls the `arrive_and_wait` method on the latch, which decrements the count of the latch and causes the thread to wait until the count reaches zero. Finally, the main thread waits for all the threads to arrive at the latch by calling the `arrive_and_wait` method and then waits for all the threads to finish by calling the `hpx::wait_all` method.

Mutex

A *mutex* (short for “mutual exclusion”) is a synchronization primitive in *HPX* used to control access to a shared resource, ensuring that only one thread can access it at a time. A mutex is used to protect data structures from race conditions and other synchronization-related issues. When a thread acquires a mutex, other threads that try to access the same resource will be blocked until the mutex is released. The code below shows the basic use of mutexes:

```
#include <hpx/future.hpp>
#include <hpx/init.hpp>
#include <hpx/mutex.hpp>

#include <iostream>

int hpx_main()
{
    hpx::mutex m;

    hpx::future<void> f1 = hpx::async([&m]() {
        std::scoped_lock sl(m);
        std::cout << "Thread 1 acquired the mutex" << std::endl;
    });

    hpx::future<void> f2 = hpx::async([&m]() {
        std::scoped_lock sl(m);
        std::cout << "Thread 2 acquired the mutex" << std::endl;
    });

    hpx::wait_all(f1, f2);

    return hpx::local::finalize();
}

int main(int argc, char* argv[])
{
    return hpx::local::init(hpx_main, argc, argv);
}
```

In this example, two *HPX* threads created using `hpx::async` are acquiring a `hpx::mutex m`. `std::scoped_lock sl(m)` is used to take ownership of the given mutex `m`. When control leaves the scope in which the `scoped_lock` object was created, the `scoped_lock` is destructed and the mutex is released.

Attention: A common way to acquire and release mutexes is by using the function `m.lock()` before accessing the shared resource, and `m.unlock()` called after the access is complete. However, these functions may lead to deadlocks in case of exception(s). That is, if an exception happens when the mutex is locked then the code that unlocks the mutex will never be executed, the lock will remain held by the thread that acquired it, and other threads will be unable to access the shared resource. This can cause a deadlock if the other threads are also waiting to acquire the same lock. For this reason, we suggest you use `std::scoped_lock`, which prevents this issue by releasing the lock when control leaves the scope in which the `scoped_lock` object was created.

Shared mutex

A *shared mutex* is a synchronization primitive that can be used to protect shared data from being simultaneously accessed by multiple threads. In contrast to other mutex types which facilitate exclusive access, a `shared_mutex` has two levels of access:

- *Exclusive access* prevents any other thread from acquiring the mutex, just as with the normal mutex. It does not matter if the other thread tries to acquire shared or exclusive access.
- *Shared access* allows multiple threads to acquire the mutex, but all of them only in shared mode. Exclusive access is not granted until all of the previous shared holders have returned the mutex (typically, as long as an exclusive request is waiting, new shared ones are queued to be granted after the exclusive access).

Shared mutexes are especially useful when shared data can be safely read by any number of threads simultaneously, but a thread may only write the same data when no other thread is reading or writing at the same time. A typical scenario is a database: The data can be read simultaneously by different threads with no problem. However, modification of the database is critical: if some threads read data while another one is writing, the threads reading may receive inconsistent data. Hence, while a thread is writing, reading should not be allowed. After writing is complete, reads can occur simultaneously again. The code below shows how `shared_mutex` can be used to synchronize reads and writes:

```
int const writers = 3;
int const readers = 3;
int const cycles = 10;

using std::chrono::milliseconds;

int hpx_main()
{
    std::vector<hpx::thread> threads;
    std::atomic<bool> ready(false);
    hpx::shared_mutex stm;

    for (int i = 0; i < writers; ++i)
    {
        threads.emplace_back([&ready, &stm, i] {
            std::mt19937 urng(static_cast<std::uint32_t>(std::time(nullptr)));
            std::uniform_int_distribution<int> dist(1, 1000);

            while (!ready)
            { /*** wait... ***/
            }

            for (int j = 0; j < cycles; ++j)
            {
                // scope of unique_lock
                {
                    std::unique_lock<hpx::shared_mutex> ul(stm);

                    std::cout << "^^^ Writer " << i << " starting..."
                                << std::endl;
                    hpx::this_thread::sleep_for(milliseconds(dist(urng)));
                    std::cout << "vvv Writer " << i << " finished."
                                << std::endl;
                }
            }
        });
    }
}
```

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```

        hpx::this_thread::sleep_for(milliseconds(dist(urng)));
    }
    });
}

for (int i = 0; i < readers; ++i)
{
    int k = writers + i;
    threads.emplace_back([&ready, &stm, k, i] {
        HPX_UNUSED(k);
        std::mt19937 urng(static_cast<std::uint32_t>(std::time(nullptr)));
        std::uniform_int_distribution<int> dist(1, 1000);

        while (!ready)
        { /*** wait... ***/
        }

        for (int j = 0; j < cycles; ++j)
        {
            // scope of shared_lock
            {
                std::shared_lock<hpx::shared_mutex> sl(stm);

                std::cout << "Reader " << i << " starting..." << std::endl;
                hpx::this_thread::sleep_for(milliseconds(dist(urng)));
                std::cout << "Reader " << i << " finished." << std::endl;
            }
            hpx::this_thread::sleep_for(milliseconds(dist(urng)));
        }
    });
}

ready = true;
for (auto& t : threads)
    t.join();

return hpx::local::finalize();
}

```

The above code creates writers and readers threads, each of which will perform cycles of operations. Both the writer and reader threads use the `hpx::shared_mutex` object `stm` to synchronize access to a shared resource.

- For the writer threads, a `unique_lock` on the shared mutex is acquired before each write operation and is released after control leaves the scope in which the `unique_lock` object was created.
- For the reader threads, a `shared_lock` on the shared mutex is acquired before each read operation and is released after control leaves the scope in which the `shared_lock` object was created.

Before each operation, both the reader and writer threads sleep for a random time period, which is generated using a random number generator. The random time period simulates the processing time of the operation.

Semaphore

Semaphores are a synchronization mechanism used to control concurrent access to a shared resource. The two types of semaphores are:

- counting semaphore: it has a counter that is bigger than zero. The counter is initialized in the constructor. Acquiring the semaphore decreases the counter and releasing the semaphore increases the counter. If a thread tries to acquire the semaphore when the counter is zero, the thread will block until another thread increments the counter by releasing the semaphore. Unlike `hpx::mutex`, an `hpx::counting_semaphore` is not bound to a thread, which means that the acquire and release call of a semaphore can happen on different threads.
- binary semaphore: it is an alias for a `hpx::counting_semaphore<1>`. In this case, the least maximal value is 1. `hpx::binary_semaphore` can be used to implement locks.

```
#include <hpx/init.hpp>
#include <hpx/semaphore.hpp>
#include <hpx/thread.hpp>

#include <iostream>

// initialize the semaphore with a count of 3
hpx::counting_semaphore<> semaphore(3);

void worker()
{
    semaphore.acquire(); // decrement the semaphore's count
    std::cout << "Entering critical section" << std::endl;
    hpx::this_thread::sleep_for(std::chrono::seconds(1));
    semaphore.release(); // increment the semaphore's count
    std::cout << "Exiting critical section" << std::endl;
}

int hpx_main()
{
    hpx::thread t1(worker);
    hpx::thread t2(worker);
    hpx::thread t3(worker);
    hpx::thread t4(worker);
    hpx::thread t5(worker);

    t1.join();
    t2.join();
    t3.join();
    t4.join();
    t5.join();

    return hpx::local::finalize();
}

int main(int argc, char* argv[])
{
    return hpx::local::init(hpx_main, argc, argv);
}
```

In this example, the counting semaphore is initialized to the value of 3. This means that up to 3 threads can access the

critical section (the section of code inside the `worker()` function) at the same time. When a thread enters the critical section, it acquires the semaphore, which decrements the count, while when it exits the critical section, it releases the semaphore, incrementing thus the count. The `worker()` function simulates a critical section by acquiring the semaphore, sleeping for 1 second and then releasing the semaphore.

In the main function, 5 worker threads are created and started, each trying to enter the critical section. If the count of the semaphore is already 0, a worker will wait until another worker releases the semaphore (increasing its value).

Composable guards

Composable guards operate in a manner similar to locks, but are applied only to asynchronous functions. The guard (or guards) is automatically locked at the beginning of a specified task and automatically unlocked at the end. Because guards are never added to an existing task's execution context, the calling of guards is freely composable and can never deadlock.

To call an application with a single guard, simply declare the guard and call `run_guarded()` with a function (`task`):

```
hpx::lcos::local::guard gu;  
run_guarded(gu, task);
```

If a single method needs to run with multiple guards, use a guard set:

```
std::shared_ptr<hpx::lcos::local::guard> gu1(new hpx::lcos::local::guard());  
std::shared_ptr<hpx::lcos::local::guard> gu2(new hpx::lcos::local::guard());  
gs.add(*gu1);  
gs.add(*gu2);  
run_guarded(gs, task);
```

Guards use two atomic operations (which are not called repeatedly) to manage what they do, so overhead should be extremely low.

Execution control

The following objects are providing control of the execution in *HPX* applications:

1. *Futures*
2. *Channels*
3. *Task blocks*
4. *Task groups*
5. *Threads*

Futures

Futures are a mechanism to represent the result of a potentially asynchronous operation. A future is a type that represents a value that will become available at some point in the future, and it can be used to write asynchronous and parallel code. Futures can be returned from functions that perform time-consuming operations, allowing the calling code to continue executing while the function performs its work. The value of the future is set when the operation completes and can be accessed later. Futures are used in *HPX* to write asynchronous and parallel code. Below is an example demonstrating different features of futures:

```

#include <hpx/assert.hpp>
#include <hpx/future.hpp>
#include <hpx/hpx_main.hpp>
#include <hpx/tuple.hpp>

#include <iostream>
#include <utility>

int main()
{
    // Asynchronous execution with futures
    hpx::future<void> f1 = hpx::async(hpx::launch::async, []() {});
    hpx::shared_future<int> f2 =
        hpx::async(hpx::launch::async, []() { return 42; });
    hpx::future<int> f3 =
        f2.then([](hpx::shared_future<int>&& f) { return f.get() * 3; });

    hpx::promise<double> p;
    auto f4 = p.get_future();
    HPX_ASSERT(!f4.is_ready());
    p.set_value(123.45);
    HPX_ASSERT(f4.is_ready());

    hpx::packaged_task<int()> t([]() { return 43; });
    hpx::future<int> f5 = t.get_future();
    HPX_ASSERT(!f5.is_ready());
    t();
    HPX_ASSERT(f5.is_ready());

    // Fire-and-forget
    hpx::post([]() {
        std::cout << "This will be printed later\n" << std::flush;
    });

    // Synchronous execution
    hpx::sync([]() {
        std::cout << "This will be printed immediately\n" << std::flush;
    });

    // Combinators
    hpx::future<double> f6 = hpx::async([]() { return 3.14; });
    hpx::future<double> f7 = hpx::async([]() { return 42.0; });
    std::cout
        << hpx::when_all(f6, f7)
            .then([](hpx::future<
                hpx::tuple<hpx::future<double>, hpx::future<double>>>
                f) {
                hpx::tuple<hpx::future<double>, hpx::future<double>> t =
                    f.get();
                double pi = hpx::get<0>(t).get();
                double r = hpx::get<1>(t).get();
                return pi * r * r;
            })

```

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```

        .get()
    << std::endl;

    // Easier continuations with dataflow; it waits for all future or
    // shared_future arguments before executing the continuation, and also
    // accepts non-future arguments
    hpx::future<double> f8 = hpx::async([]() { return 3.14; });
    hpx::future<double> f9 = hpx::make_ready_future(42.0);
    hpx::shared_future<double> f10 = hpx::async([]() { return 123.45; });
    hpx::future<hpx::tuple<double, double>> f11 = hpx::dataflow(
        [](hpx::future<double> a, hpx::future<double> b,
            hpx::shared_future<double> c, double d) {
            return hpx::make_tuple<>(a.get() + b.get(), c.get() / d);
        },
        f8, f9, f10, -3.9);

    // split_future gives a tuple of futures from a future of tuple
    hpx::tuple<hpx::future<double>, hpx::future<double>> f12 =
        hpx::split_future(std::move(f11));
    std::cout << hpx::get<1>(f12).get() << std::endl;

    return 0;
}

```

The first section of the main function demonstrates how to use futures for asynchronous execution. The first two lines create two futures, one for void and another for an integer, using the `hpx::async()` function. These futures are executed *asynchronously* in separate threads using the `hpx::launch::async` launch policy. The third future is created by *chaining* the second future using the `then()` member function. This future multiplies the result of the second future by 3.

The next part of the code demonstrates how to use *promises* and *packaged* tasks, which are constructs used for communicating data between threads. The `promise` class is used to store a value that can be retrieved *later* using a future. The `packaged_task` class represents a task that can be executed *asynchronously*, and its result can be obtained using a future. The last three lines create a packaged task that returns an integer, obtain its future, execute the task, and check whether the future is ready or not.

The code then demonstrates how to use the `hpx::post()` and `hpx::sync()` functions for *fire-and-forget* and *synchronous* execution, respectively. The `hpx::post()` function executes a given function *asynchronously* and *returns immediately* without waiting for the result. The `hpx::sync()` function executes a given function *synchronously* and *waits* for the result before returning.

Next the code demonstrates the use of *combinators*, which are higher-order functions that combine two or more futures into a single future. The `hpx::when_all()` function is used to combine two futures, which return double values, into a tuple of futures. The `then()` member function is then used to compute the area of a circle using the values of the two futures. The `get()` member function is used to retrieve the result of the computation.

The last section demonstrates the use of `hpx::dataflow()`, which is a higher-order function that waits for all the future or `shared_future` arguments to be ready before executing the continuation. The `hpx::make_ready_future()` function is used to create a future with a given value. The `hpx::split_future()` function is used to split a future of a tuple into a tuple of futures. The last line retrieves the value of the second future in the tuple using `hpx::get()` and prints it to the console.

Extended facilities for futures

Concurrency is about both decomposing and composing the program from the parts that work well individually and together. It is in the composition of connected and multicore components where today's C++ libraries are still lacking.

The functionality of `std::future`⁶⁸ offers a partial solution. It allows for the separation of the initiation of an operation and the act of waiting for its result; however, the act of waiting is synchronous. In communication-intensive code this act of waiting can be unpredictable, inefficient and simply frustrating. The example below illustrates a possible synchronous wait using futures:

```
#include <future>
using namespace std;
int main()
{
    future<int> f = async([]() { return 123; });
    int result = f.get(); // might block
}
```

For this reason, *HPX* implements a set of extensions to `std::future`⁶⁹ (as proposed by N4313⁷⁰). This proposal introduces the following key asynchronous operations to `hpx::future`, `hpx::shared_future` and `hpx::async`, which enhance and enrich these facilities.

Table 2.11: Facilities extending `std::future`

Facility	Description
<code>hpx::future::then</code>	In asynchronous programming, it is very common for one asynchronous operation, on completion, to invoke a second operation and pass data to it. The current C++ standard does not allow one to register a continuation to a future. With <code>then</code> , instead of waiting for the result, a continuation is “attached” to the asynchronous operation, which is invoked when the result is ready. Continuations registered using <code>then</code> function will help to avoid blocking waits or wasting threads on polling, greatly improving the responsiveness and scalability of an application.
unwrapping constructor for <code>hpx::future</code>	In some scenarios, you might want to create a future that returns another future, resulting in nested futures. Although it is possible to write code to unwrap the outer future and retrieve the nested future and its result, such code is not easy to write because users must handle exceptions and it may cause a blocking call. Unwrapping can allow users to mitigate this problem by doing an asynchronous call to unwrap the outermost future.
<code>hpx::future::is_ready</code>	There are often situations where a <code>get()</code> call on a future may not be a blocking call, or is only a blocking call under certain circumstances. This function gives the ability to test for early completion and allows us to avoid associating a continuation, which needs to be scheduled with some non-trivial overhead and near-certain loss of cache efficiency.
<code>hpx::make_ready_future</code>	Some functions may know the value at the point of construction. In these cases the value is immediately available, but needs to be returned as a future. By using <code>hpx::make_ready_future</code> a future can be created that holds a pre-computed result in its shared state. In the current standard it is non-trivial to create a future directly from a value. First a promise must be created, then the promise is set, and lastly the future is retrieved from the promise. This can now be done with one operation.

The standard also omits the ability to compose multiple futures. This is a common pattern that is ubiquitous in other asynchronous frameworks and is absolutely necessary in order to make C++ a powerful asynchronous programming language. Not including these functions is synonymous to Boolean algebra without AND/OR.

⁶⁸ <http://en.cppreference.com/w/cpp/thread/future>

⁶⁹ <http://en.cppreference.com/w/cpp/thread/future>

⁷⁰ <http://wg21.link/n4313>

In addition to the extensions proposed by N4313⁷¹, HPX adds functions allowing users to compose several futures in a more flexible way.

Table 2.12: Facilities for composing `hpx::futures`

Facility	Description
<code>hpx::when_any</code> , <code>hpx::when_any_n</code>	Asynchronously wait for at least one of multiple future or <code>shared_future</code> objects to finish.
<code>hpx::wait_any</code> , <code>hpx::wait_any_n</code>	Synchronously wait for at least one of multiple future or <code>shared_future</code> objects to finish.
<code>hpx::when_all</code> , <code>hpx::when_all_n</code>	Asynchronously wait for all future and <code>shared_future</code> objects to finish.
<code>hpx::wait_all</code> , <code>hpx::wait_all_n</code>	Synchronously wait for all future and <code>shared_future</code> objects to finish.
<code>hpx::when_some</code> , <code>hpx::when_some_n</code>	Asynchronously wait for multiple future and <code>shared_future</code> objects to finish.
<code>hpx::wait_some</code> , <code>hpx::wait_some_n</code>	Synchronously wait for multiple future and <code>shared_future</code> objects to finish.
<code>hpx::when_each</code>	Asynchronously wait for multiple future and <code>shared_future</code> objects to finish and call a function for each of the future objects as soon as it becomes ready.
<code>hpx::wait_each</code> , <code>hpx::wait_each_n</code>	Synchronously wait for multiple future and <code>shared_future</code> objects to finish and call a function for each of the future objects as soon as it becomes ready.

Channels

Channels combine communication (the exchange of a value) with synchronization (guaranteeing that two calculations (tasks) are in a known state). A channel can transport any number of values of a given type from a sender to a receiver:

```
hpx::lcos::local::channel<int> c;
hpx::future<int> f = c.get();
HPX_ASSERT(!f.is_ready());
c.set(42);
HPX_ASSERT(f.is_ready());
std::cout << f.get() << std::endl;
```

Channels can be handed to another thread (or in case of channel components, to other localities), thus establishing a communication channel between two independent places in the program:

```
void do_something(hpx::lcos::local::receive_channel<int> c,
                hpx::lcos::local::send_channel<> done)
{
    // prints 43
    std::cout << c.get(hpx::launch::sync) << std::endl;
    // signal back
    done.set();
}

void send_receive_channel()
{
    hpx::lcos::local::channel<int> c;
    hpx::lcos::local::channel<> done;
```

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⁷¹ <http://wg21.link/n4313>

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```

hpx::post(&do_something, c, done);

// send some value
c.set(43);
// wait for thread to be done
done.get().wait();
}

```

Note how `hpx::lcos::local::channel::get` without any arguments returns a future which is ready when a value has been set on the channel. The launch policy `hpx::launch::sync` can be used to make `hpx::lcos::local::channel::get` block until a value is set and return the value directly.

A channel component is created on one *locality* and can be sent to another *locality* using an action. This example also demonstrates how a channel can be used as a range of values:

```

// channel components need to be registered for each used type (not needed
// for hpx::lcos::local::channel)
HPX_REGISTER_CHANNEL(double)

void channel_sender(hpx::lcos::channel<double> c)
{
    for (double d : c)
        hpx::cout << d << std::endl;
}
HPX_PLAIN_ACTION(channel_sender)

void channel()
{
    // create the channel on this locality
    hpx::lcos::channel<double> c(hpx::find_here());

    // pass the channel to a (possibly remote invoked) action
    hpx::post(channel_sender_action(), hpx::find_here(), c);

    // send some values to the receiver
    std::vector<double> v = {1.2, 3.4, 5.0};
    for (double d : v)
        c.set(d);

    // explicitly close the communication channel (implicit at destruction)
    c.close();
}

```

Task blocks

Task blocks in *HPX* provide a way to structure and organize the execution of tasks in a parallel program, making it easier to manage dependencies between tasks. A task block actually is a group of tasks that can be executed in parallel. Tasks in a task block can depend on other tasks in the same task block. The task block allows the runtime to optimize the execution of tasks, by scheduling them in an optimal order based on the dependencies between them.

The `define_task_block`, `run` and the `wait` functions implemented based on N4755⁷² are based on the `task_block` concept that is a part of the common subset of the *Microsoft Parallel Patterns Library (PPL)*⁷³ and the *Intel Threading Building Blocks (TBB)*⁷⁴ libraries.

These implementations adopt a simpler syntax than exposed by those libraries— one that is influenced by language-based concepts, such as `spawn` and `sync` from *Cilk++*⁷⁵ and `async` and `finish` from *X10*⁷⁶. They improve on existing practice in the following ways:

- The exception handling model is simplified and more consistent with normal C++ exceptions.
- Most violations of strict fork-join parallelism can be enforced at compile time (with compiler assistance, in some cases).
- The syntax allows scheduling approaches other than child stealing.

Consider an example of a parallel traversal of a tree, where a user-provided function `compute` is applied to each node of the tree, returning the sum of the results:

```
template <typename Func>
int traverse(node& n, Func && compute)
{
    int left = 0, right = 0;
    define_task_block(
        [&](task_block<>& tr) {
            if (n.left)
                tr.run([&] { left = traverse(*n.left, compute); });
            if (n.right)
                tr.run([&] { right = traverse(*n.right, compute); });
        });

    return compute(n) + left + right;
}
```

The example above demonstrates the use of two of the functions, `hpx::experimental::define_task_block` and the `hpx::experimental::task_block::run` member function of a `hpx::experimental::task_block`.

The `task_block` function delineates a region in a program code potentially containing invocations of threads spawned by the `run` member function of the `task_block` class. The `run` function spawns an *HPX* thread, a unit of work that is allowed to execute in parallel with respect to the caller. Any parallel tasks spawned by `run` within the task block are joined back to a single thread of execution at the end of the `define_task_block`. `run` takes a user-provided function object `f` and starts it asynchronously—i.e., it may return before the execution of `f` completes. The *HPX* scheduler may choose to run `f` immediately or delay running `f` until compute resources become available.

A `task_block` can be constructed only by `define_task_block` because it has no public constructors. Thus, `run` can be invoked directly or indirectly only from a user-provided function passed to `define_task_block`:

⁷² <http://wg21.link/n4755>

⁷³ <https://msdn.microsoft.com/en-us/library/dd492418.aspx>

⁷⁴ <https://www.threadingbuildingblocks.org/>

⁷⁵ <https://software.intel.com/en-us/articles/intel-cilk-plus/>

⁷⁶ <https://x10-lang.org/>

```

void g();

void f(task_block<>& tr)
{
    tr.run(g);          // OK, invoked from within task_block in h
}

void h()
{
    define_task_block(f);
}

int main()
{
    task_block<> tr;    // Error: no public constructor
    tr.run(g);         // No way to call run outside of a define_task_block
    return 0;
}

```

Extensions for task blocks

Using execution policies with task blocks

HPX implements some extensions for `task_block` beyond the actual standards proposal N4755⁷⁷. The main addition is that a `task_block` can be invoked with an execution policy as its first argument, very similar to the parallel algorithms.

An execution policy is an object that expresses the requirements on the ordering of functions invoked as a consequence of the invocation of a task block. Enabling passing an execution policy to `define_task_block` gives the user control over the amount of parallelism employed by the created `task_block`. In the following example the use of an explicit `par` execution policy makes the user's intent explicit:

```

template <typename Func>
int traverse(node *n, Func&& compute)
{
    int left = 0, right = 0;

    define_task_block(
        execution::par,          // execution::parallel_policy
        [&](task_block<>& tb) {
            if (n->left)
                tb.run([&] { left = traverse(n->left, compute); });
            if (n->right)
                tb.run([&] { right = traverse(n->right, compute); });
        });

    return compute(n) + left + right;
}

```

This also causes the `hpx::experimental::task_block` object to be a template in our implementation. The template argument is the type of the execution policy used to create the task block. The template argument defaults to `hpx::execution::parallel_policy`.

⁷⁷ <http://wg21.link/n4755>

HPX still supports calling `hpx::experimental::define_task_block` without an explicit execution policy. In this case the task block will run using the `hpx::execution::parallel_policy`.

HPX also adds the ability to access the execution policy that was used to create a given `task_block`.

Using executors to run tasks

Often, users want to be able to not only define an execution policy to use by default for all spawned tasks inside the task block, but also to customize the execution context for one of the tasks executed by `task_block::run`. Adding an optionally passed executor instance to that function enables this use case:

```
template <typename Func>
int traverse(node *n, Func&& compute)
{
    int left = 0, right = 0;

    define_task_block(
        execution::par,                // execution::parallel_policy
        [&](auto& tb) {
            if (n->left)
            {
                // use explicitly specified executor to run this task
                tb.run(my_executor(), [&] { left = traverse(n->left, compute); });
            }
            if (n->right)
            {
                // use the executor associated with the par execution policy
                tb.run([&] { right = traverse(n->right, compute); });
            }
        });

    return compute(n) + left + right;
}
```

HPX still supports calling `hpx::experimental::task_block::run` without an explicit executor object. In this case the task will be run using the executor associated with the execution policy that was used to call `hpx::experimental::define_task_block`.

Task groups

A *task group* in HPX is a synchronization primitive that allows you to execute a group of tasks concurrently and wait for their completion before continuing. The tasks in an `hpx::experimental::task_group` can be added dynamically. This is the HPX implementation of `tbb::task_group` of the Intel Threading Building Blocks (TBB)⁷⁸ library.

The example below shows that to use a task group, you simply create an `hpx::task_group` object and add tasks to it using the `run()` method. Once all the tasks have been added, you can call the `wait()` method to synchronize the tasks and wait for them to complete.

```
#include <hpx/experimental/task_group.hpp>
#include <hpx/init.hpp>
```

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⁷⁸ <https://www.threadingbuildingblocks.org/>

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```
#include <iostream>

void task1()
{
    std::cout << "Task 1 executed." << std::endl;
}

void task2()
{
    std::cout << "Task 2 executed." << std::endl;
}

int hpx_main()
{
    hpx::experimental::task_group tg;

    tg.run(task1);
    tg.run(task2);

    tg.wait();

    std::cout << "All tasks finished!" << std::endl;

    return hpx::local::finalize();
}

int main(int argc, char* argv[])
{
    return hpx::local::init(hpx_main, argc, argv);
}
```

Note: *task groups* and *task blocks* are both ways to group and synchronize parallel tasks, but *task groups* are used to group multiple tasks together as a single unit, while *task blocks* are used to execute a loop in parallel, with each iteration of the loop executing in a separate task. If the difference is not clear yet, continue reading.

A *task group* is a construct that allows multiple parallel tasks to be grouped together as a single unit. The task group provides a way to synchronize all the tasks in the group before continuing with the rest of the program.

A *task block*, on the other hand, is a parallel loop construct that allows you to execute a loop in parallel, with each iteration of the loop executing in a separate task. The loop iterations are executed in a block, meaning that the loop body is executed as a single task.

Threads

A thread in *HPX* refers to a sequence of instructions that can be executed concurrently with other such sequences in multithreading environments, while sharing a same address space. These threads can communicate with each other through various means, such as futures or shared data structures.

The example below demonstrates how to launch multiple threads and synchronize them using a `hpx::latch` object. It also shows how to query the state of threads and wait for futures to complete.

```
#include <hpx/future.hpp>
#include <hpx/init.hpp>
#include <hpx/thread.hpp>

#include <functional>
#include <iostream>
#include <vector>

int const num_threads = 10;

////////////////////////////////////
void wait_for_latch(hpx::latch& l)
{
    l.arrive_and_wait();
}

int hpx_main()
{
    // Spawn a couple of threads
    hpx::latch l(num_threads + 1);

    std::vector<hpx::future<void>> results;
    results.reserve(num_threads);

    for (int i = 0; i != num_threads; ++i)
        results.push_back(hpx::async(&wait_for_latch, std::ref(l)));

    // Allow spawned threads to reach latch
    hpx::this_thread::yield();

    // Enumerate all suspended threads
    hpx::threads::enumerate_threads(
        [](hpx::threads::thread_id_type id) -> bool {
            std::cout << "thread " << hpx::thread::id(id) << " is "
                << hpx::threads::get_thread_state_name(
                    hpx::threads::get_thread_state(id))
                << std::endl;
            return true; // always continue enumeration
        },
        hpx::threads::thread_schedule_state::suspended);

    // Wait for all threads to reach this point.
    l.arrive_and_wait();
}
```

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```
hpx::wait_all(results);

return hpx::local::finalize();
}

int main(int argc, char* argv[])
{
    return hpx::local::init(hpx_main, argc, argv);
}
```

In more detail, the `wait_for_latch()` function is a simple helper function that waits for a `hpx::latch` object to be released. At this point we remind that `hpx::latch` is a synchronization primitive that allows multiple threads to wait for a common event to occur.

In the `hpx_main()` function, an `hpx::latch` object is created with a count of `num_threads + 1`, indicating that `num_threads` threads need to arrive at the latch before the latch is released. The loop that follows launches `num_threads` asynchronous operations, each of which calls the `wait_for_latch` function. The resulting futures are added to the vector.

After the threads have been launched, `hpx::this_thread::yield()` is called to give them a chance to reach the latch before the program proceeds. Then, the `hpx::threads::enumerate_threads` function prints the state of each suspended thread, while the next call of `l.arrive_and_wait()` waits for all the threads to reach the latch. Finally, `hpx::wait_all` is called to wait for all the futures to complete.

Hint: An advantage of using `hpx::thread` over other threading libraries is that it is optimized for high-performance parallelism, with support for lightweight threads and task scheduling to minimize thread overhead and maximize parallelism. Additionally, `hpx::thread` integrates seamlessly with other features of *HPX* such as futures, promises, and task groups, making it a powerful tool for parallel programming.

Checkout the examples of *Shared mutex*, *Condition variable*, *Semaphore* to see how *HPX* threads are used in combination with other features.

High level parallel facilities

In preparation for the upcoming C++ Standards, there are currently several proposals targeting different facilities supporting parallel programming. *HPX* implements (and extends) some of those proposals. This is well aligned with our strategy to align the APIs exposed from *HPX* with current and future C++ Standards.

At this point, *HPX* implements several of the C++ Standardization working papers, most notably [N4409](http://wg21.link/n4409)⁷⁹ (Working Draft, Technical Specification for C++ Extensions for Parallelism), [N4755](http://wg21.link/n4755)⁸⁰ (Task Blocks), and [N4406](http://wg21.link/n4406)⁸¹ (Parallel Algorithms Need Executors).

⁷⁹ <http://wg21.link/n4409>

⁸⁰ <http://wg21.link/n4755>

⁸¹ <http://wg21.link/n4406>

Using parallel algorithms

A parallel algorithm is a function template declared in the namespace `hpx::parallel`.

All parallel algorithms are very similar in semantics to their sequential counterparts (as defined in the namespace `std`) with an additional formal template parameter named `ExecutionPolicy`. The execution policy is generally passed as the first argument to any of the parallel algorithms and describes the manner in which the execution of these algorithms may be parallelized and the manner in which they apply user-provided function objects.

The applications of function objects in parallel algorithms invoked with an execution policy object of type `hpx::execution::sequenced_policy` or `hpx::execution::sequenced_task_policy` execute in sequential order. For `hpx::execution::sequenced_policy` the execution happens in the calling thread.

The applications of function objects in parallel algorithms invoked with an execution policy object of type `hpx::execution::parallel_policy` or `hpx::execution::parallel_task_policy` are permitted to execute in an unordered fashion in unspecified threads, and are indeterminately sequenced within each thread.

Important: It is the caller's responsibility to ensure correctness, such as making sure that the invocation does not introduce data races or deadlocks.

The example below demonstrates how to perform a sequential and parallel `hpx::for_each` loop on a vector of integers.

```
#include <hpx/algorithm.hpp>
#include <hpx/execution.hpp>
#include <hpx/init.hpp>

#include <iostream>
#include <vector>

int hpx_main()
{
    std::vector<int> v{1, 2, 3, 4, 5};

    auto print = [](const int& n) { std::cout << n << ' '; };

    std::cout << "Print sequential: ";
    hpx::for_each(v.begin(), v.end(), print);
    std::cout << '\n';

    std::cout << "Print parallel: ";
    hpx::for_each(hpx::execution::par, v.begin(), v.end(), print);
    std::cout << '\n';

    return hpx::local::finalize();
}

int main(int argc, char* argv[])
{
    return hpx::local::init(hpx_main, argc, argv);
}
```

The above code uses `hpx::for_each` to print the elements of the vector `v{1, 2, 3, 4, 5}`. At first, `hpx::for_each()` is called without an execution policy, which means that it applies the lambda function `print` to each element in the vector sequentially. Hence, the elements are printed in order.

Next, `hpx::for_each()` is called with the `hpx::execution::par` execution policy, which applies the lambda function `print` to each element in the vector in parallel. Therefore, the output order of the elements in the vector is not deterministic and may vary from run to run.

Parallel exceptions

During the execution of a standard parallel algorithm, if temporary memory resources are required by any of the algorithms and no memory is available, the algorithm throws a `std::bad_alloc` exception.

During the execution of any of the parallel algorithms, if the application of a function object terminates with an uncaught exception, the behavior of the program is determined by the type of execution policy used to invoke the algorithm:

- If the execution policy object is of type `hpx::execution::parallel_unsequenced_policy`, `hpx::terminate` shall be called.
- If the execution policy object is of type `hpx::execution::sequenced_policy`, `hpx::execution::sequenced_task_policy`, `hpx::execution::parallel_policy`, or `hpx::execution::parallel_task_policy`, the execution of the algorithm terminates with an `hpx::exception_list` exception. All uncaught exceptions thrown during the application of user-provided function objects shall be contained in the `hpx::exception_list`.

For example, the number of invocations of the user-provided function object in `for_each` is unspecified. When `hpx::for_each` is executed sequentially, only one exception will be contained in the `hpx::exception_list` object.

These guarantees imply that, unless the algorithm has failed to allocate memory and terminated with `std::bad_alloc`, all exceptions thrown during the execution of the algorithm are communicated to the caller. It is unspecified whether an algorithm implementation will “forge ahead” after encountering and capturing a user exception.

The algorithm may terminate with the `std::bad_alloc` exception even if one or more user-provided function objects have terminated with an exception. For example, this can happen when an algorithm fails to allocate memory while creating or adding elements to the `hpx::exception_list` object.

Parallel algorithms

HPX provides implementations of the following parallel algorithms:

Table 2.13: Non-modifying parallel algorithms of header `hpx/algorithm.hpp`

Name	Description	C++ standard
<code>hpx::adjacent_find</code>	Computes the differences between adjacent elements in a range.	<code>adjacent_find</code> ⁸²
<code>hpx::all_of</code>	Checks if a predicate is <code>true</code> for all of the elements in a range.	<code>all_any_none_of</code> ⁸³
<code>hpx::any_of</code>	Checks if a predicate is <code>true</code> for any of the elements in a range.	<code>all_any_none_of</code> ⁸⁴
<code>hpx::count</code>	Returns the number of elements equal to a given value.	<code>count</code> ⁸⁵
<code>hpx::count_if</code>	Returns the number of elements satisfying a specific criteria.	<code>count_if</code> ⁸⁶
<code>hpx::equal</code>	Determines if two sets of elements are the same.	<code>equal</code> ⁸⁷
<code>hpx::find</code>	Finds the first element equal to a given value.	<code>find</code> ⁸⁸
<code>hpx::find_end</code>	Finds the last sequence of elements in a certain range.	<code>find_end</code> ⁸⁹
<code>hpx::find_first_of</code>	Searches for any one of a set of elements.	<code>find_first_of</code> ⁹⁰
<code>hpx::find_if</code>	Finds the first element satisfying a specific criteria.	<code>find_if</code> ⁹¹
<code>hpx::find_if_not</code>	Finds the first element not satisfying a specific criteria.	<code>find_if_not</code> ⁹²
<code>hpx::for_each</code>	Applies a function to a range of elements.	<code>for_each</code> ⁹³
<code>hpx::for_each_n</code>	Applies a function to a number of elements.	<code>for_each_n</code> ⁹⁴
<code>hpx::lexicographical_compare</code>	Checks if a range of values is lexicographically less than another range of values.	<code>lexicographical_compare</code> ⁹⁵
<code>hpx::mismatch</code>	Finds the first position where two ranges differ.	<code>mismatch</code> ⁹⁶
<code>hpx::none_of</code>	Checks if a predicate is <code>true</code> for none of the elements in a range.	<code>all_any_none_of</code> ⁹⁷
<code>hpx::search</code>	Searches for a range of elements.	<code>search</code> ⁹⁸
<code>hpx::search_n</code>	Searches for a number consecutive copies of an element in a range.	<code>search_n</code> ⁹⁹

⁸² http://en.cppreference.com/w/cpp/algorithm/adjacent_find⁸³ http://en.cppreference.com/w/cpp/algorithm/all_any_none_of⁸⁴ http://en.cppreference.com/w/cpp/algorithm/all_any_none_of⁸⁵ <http://en.cppreference.com/w/cpp/algorithm/count>⁸⁶ http://en.cppreference.com/w/cpp/algorithm/count_if⁸⁷ <http://en.cppreference.com/w/cpp/algorithm/equal>⁸⁸ <http://en.cppreference.com/w/cpp/algorithm/find>⁸⁹ http://en.cppreference.com/w/cpp/algorithm/find_end⁹⁰ http://en.cppreference.com/w/cpp/algorithm/find_first_of⁹¹ http://en.cppreference.com/w/cpp/algorithm/find_if⁹² http://en.cppreference.com/w/cpp/algorithm/find_if_not⁹³ http://en.cppreference.com/w/cpp/algorithm/for_each⁹⁴ http://en.cppreference.com/w/cpp/algorithm/for_each_n⁹⁵ http://en.cppreference.com/w/cpp/algorithm/lexicographical_compare⁹⁶ <http://en.cppreference.com/w/cpp/algorithm/mismatch>⁹⁷ http://en.cppreference.com/w/cpp/algorithm/all_any_none_of⁹⁸ <http://en.cppreference.com/w/cpp/algorithm/search>⁹⁹ http://en.cppreference.com/w/cpp/algorithm/search_n

Table 2.14: Modifying parallel algorithms of header `hpx/algorithm.hpp`

Name	Description	C++ standard
<code>hpx::copy</code>	Copies a range of elements to a new location.	<code>exclusive_scan</code> ¹⁰⁰
<code>hpx::copy_n</code>	Copies a number of elements to a new location.	<code>copy_n</code> ¹⁰¹
<code>hpx::copy_if</code>	Copies the elements from a range to a new location for which the given predicate is <code>true</code>	<code>copy</code> ¹⁰²
<code>hpx::move</code>	Moves a range of elements to a new location.	<code>move</code> ¹⁰³
<code>hpx::fill</code>	Assigns a range of elements a certain value.	<code>fill</code> ¹⁰⁴
<code>hpx::fill_n</code>	Assigns a value to a number of elements.	<code>fill_n</code> ¹⁰⁵
<code>hpx::generate</code>	Saves the result of a function in a range.	<code>generate</code> ¹⁰⁶
<code>hpx::generate_n</code>	Saves the result of N applications of a function.	<code>generate_n</code> ¹⁰⁷
<code>hpx::experimental::reduce_key</code>	Performs an inclusive scan on consecutive elements with matching keys, with a reduction to output only the final sum for each key. The key sequence <code>{1, 1, 1, 2, 3, 3, 3, 1}</code> and value sequence <code>{2, 3, 4, 5, 6, 7, 8, 9, 10}</code> would be reduced to <code>keys={1, 2, 3, 1}</code> , <code>values={9, 5, 30, 10}</code> .	
<code>hpx::remove</code>	Removes the elements from a range that are equal to the given value.	<code>remove</code> ¹⁰⁸
<code>hpx::remove_if</code>	Removes the elements from a range that are equal to the given predicate is <code>false</code>	<code>remove</code> ¹⁰⁹
<code>hpx::remove_copy</code>	Copies the elements from a range to a new location that are not equal to the given value.	<code>remove_copy</code> ¹¹⁰
<code>hpx::remove_copy_if</code>	Copies the elements from a range to a new location for which the given predicate is <code>false</code>	<code>remove_copy</code> ¹¹¹
<code>hpx::replace</code>	Replaces all values satisfying specific criteria with another value.	<code>replace</code> ¹¹²
<code>hpx::replace_if</code>	Replaces all values satisfying specific criteria with another value.	<code>replace</code> ¹¹³
<code>hpx::replace_copy</code>	Copies a range, replacing elements satisfying specific criteria with another value.	<code>replace_copy</code> ¹¹⁴
<code>hpx::replace_copy_if</code>	Copies a range, replacing elements satisfying specific criteria with another value.	<code>replace_copy</code> ¹¹⁵
<code>hpx::reverse</code>	Reverses the order elements in a range.	<code>reverse</code> ¹¹⁶
<code>hpx::reverse_copy</code>	Creates a copy of a range that is reversed.	<code>reverse_copy</code> ¹¹⁷
<code>hpx::rotate</code>	Rotates the order of elements in a range.	<code>rotate</code> ¹¹⁸
<code>hpx::rotate_copy</code>	Copies and rotates a range of elements.	<code>rotate_copy</code> ¹¹⁹
<code>hpx::shift_left</code>	Shifts the elements in the range left by <code>n</code> positions.	<code>shift_left</code> ¹²⁰
<code>hpx::shift_right</code>	Shifts the elements in the range right by <code>n</code> positions.	<code>shift_right</code> ¹²¹
<code>hpx::swap_ranges</code>	Swaps two ranges of elements.	<code>swap_ranges</code> ¹²²
<code>hpx::transform</code>	Applies a function to a range of elements.	<code>transform</code> ¹²³
<code>hpx::unique</code>	Eliminates all but the first element from every consecutive group of equivalent elements from a range.	<code>unique</code> ¹²⁴
<code>hpx::unique_copy</code>	Copies the elements from one range to another in such a way that there are no consecutive equal elements.	<code>unique_copy</code> ¹²⁵

Table 2.15: Set operations on sorted sequences of header `hpx/algorithm.hpp`

Name	Description	C++ standard
<code>hpx::merge</code>	Merges two sorted ranges.	<code>merge</code> ¹²⁶
<code>hpx::inplace_merge</code>	Merges two ordered ranges in-place.	<code>inplace_merge</code> ¹²⁷
<code>hpx::includes</code>	Returns true if one set is a subset of another.	<code>includes</code> ¹²⁸
<code>hpx::set_difference</code>	Computes the difference between two sets.	<code>set_difference</code> ¹²⁹
<code>hpx::set_intersection</code>	Computes the intersection of two sets.	<code>set_intersection</code> ¹³⁰
<code>hpx::set_symmetric_difference</code>	Computes the symmetric difference between two sets.	<code>set_symmetric_difference</code> ¹³¹
<code>hpx::set_union</code>	Computes the union of two sets.	<code>set_union</code> ¹³²

Table 2.16: Heap operations of header `hpx/algorithm.hpp`

Name	Description	C++ standard
<code>hpx::is_heap</code>	Returns true if the range is max heap.	<code>is_heap</code> ¹³³
<code>hpx::is_heap_until</code>	Returns the first element that breaks a max heap.	<code>is_heap_until</code> ¹³⁴
<code>hpx::make_heap</code>	Constructs a max heap in the range [first, last).	<code>make_heap</code> ¹³⁵

¹⁰⁰ http://en.cppreference.com/w/cpp/algorithm/exclusive_scan
¹⁰¹ http://en.cppreference.com/w/cpp/algorithm/copy_n
¹⁰² <http://en.cppreference.com/w/cpp/algorithm/copy>
¹⁰³ <http://en.cppreference.com/w/cpp/algorithm/move>
¹⁰⁴ <http://en.cppreference.com/w/cpp/algorithm/fill>
¹⁰⁵ http://en.cppreference.com/w/cpp/algorithm/fill_n
¹⁰⁶ <http://en.cppreference.com/w/cpp/algorithm/generate>
¹⁰⁷ http://en.cppreference.com/w/cpp/algorithm/generate_n
¹⁰⁸ <http://en.cppreference.com/w/cpp/algorithm/remove>
¹⁰⁹ http://en.cppreference.com/w/cpp/algorithm/remove_copy
¹¹⁰ http://en.cppreference.com/w/cpp/algorithm/remove_copy
¹¹¹ <http://en.cppreference.com/w/cpp/algorithm/replace>
¹¹² <http://en.cppreference.com/w/cpp/algorithm/replace>
¹¹³ <http://en.cppreference.com/w/cpp/algorithm/replace>
¹¹⁴ http://en.cppreference.com/w/cpp/algorithm/replace_copy
¹¹⁵ http://en.cppreference.com/w/cpp/algorithm/replace_copy
¹¹⁶ <http://en.cppreference.com/w/cpp/algorithm/reverse>
¹¹⁷ http://en.cppreference.com/w/cpp/algorithm/reverse_copy
¹¹⁸ <http://en.cppreference.com/w/cpp/algorithm/rotate>
¹¹⁹ http://en.cppreference.com/w/cpp/algorithm/rotate_copy
¹²⁰ http://en.cppreference.com/w/cpp/algorithm/shift_left
¹²¹ http://en.cppreference.com/w/cpp/algorithm/shift_right
¹²² http://en.cppreference.com/w/cpp/algorithm/swap_ranges
¹²³ <http://en.cppreference.com/w/cpp/algorithm/transform>
¹²⁴ <http://en.cppreference.com/w/cpp/algorithm/unique>
¹²⁵ http://en.cppreference.com/w/cpp/algorithm/unique_copy
¹²⁶ <http://en.cppreference.com/w/cpp/algorithm/merge>
¹²⁷ http://en.cppreference.com/w/cpp/algorithm/inplace_merge
¹²⁸ <http://en.cppreference.com/w/cpp/algorithm/includes>
¹²⁹ http://en.cppreference.com/w/cpp/algorithm/set_difference
¹³⁰ http://en.cppreference.com/w/cpp/algorithm/set_intersection
¹³¹ http://en.cppreference.com/w/cpp/algorithm/set_symmetric_difference
¹³² http://en.cppreference.com/w/cpp/algorithm/set_union

Table 2.17: Minimum/maximum operations of header `hpx/algorithm.hpp`

Name	Description	C++ standard
<code>hpx::max_element</code>	Returns the largest element in a range.	<code>max_element</code> ¹³⁶
<code>hpx::min_element</code>	Returns the smallest element in a range.	<code>min_element</code> ¹³⁷
<code>hpx::minmax_element</code>	Returns the smallest and the largest element in a range.	<code>minmax_element</code> ¹³⁸

Table 2.18: Partitioning Operations of header `hpx/algorithm.hpp`

Name	Description	C++ standard
<code>hpx::nth_element</code>	Partially sorts the given range making sure that it is partitioned by the given element	<code>nth_element</code> ¹³⁹
<code>hpx::is_partitioned</code>	Returns <code>true</code> if each true element for a predicate precedes the false elements in a range.	<code>is_partitioned</code> ¹⁴⁰
<code>hpx::partition</code>	Divides elements into two groups without preserving their relative order.	<code>partition</code> ¹⁴¹
<code>hpx::partition_copy</code>	Copies a range dividing the elements into two groups.	<code>partition_copy</code> ¹⁴²
<code>hpx::stable_partition</code>	Divides elements into two groups while preserving their relative order.	<code>stable_partition</code> ¹⁴³

Table 2.19: Sorting Operations of header `hpx/algorithm.hpp`

Name	Description	C++ standard
<code>hpx::is_sorted</code>	Returns <code>true</code> if each element in a range is sorted.	<code>is_sorted</code> ¹⁴⁴
<code>hpx::is_sorted_until</code>	Returns the first unsorted element.	<code>is_sorted_until</code> ¹⁴⁵
<code>hpx::sort</code>	Sorts the elements in a range.	<code>sort</code> ¹⁴⁶
<code>hpx::stable_sort</code>	Sorts the elements in a range, maintain sequence of equal elements.	<code>stable_sort</code> ¹⁴⁷
<code>hpx::partial_sort</code>	Sorts the first elements in a range.	<code>partial_sort</code> ¹⁴⁸
<code>hpx::partial_sort_copy</code>	Sorts the first elements in a range, storing the result in another range.	<code>partial_sort_copy</code> ¹⁴⁹
<code>hpx::experimental::sort</code>	Sorts a range of data using keys supplied in another range.	

¹³³ http://en.cppreference.com/w/cpp/algorithm/is_heap¹³⁴ http://en.cppreference.com/w/cpp/algorithm/is_heap_until¹³⁵ http://en.cppreference.com/w/cpp/algorithm/make_heap¹³⁶ http://en.cppreference.com/w/cpp/algorithm/max_element¹³⁷ http://en.cppreference.com/w/cpp/algorithm/min_element¹³⁸ http://en.cppreference.com/w/cpp/algorithm/minmax_element¹³⁹ http://en.cppreference.com/w/cpp/algorithm/nth_element¹⁴⁰ http://en.cppreference.com/w/cpp/algorithm/is_partitioned¹⁴¹ <http://en.cppreference.com/w/cpp/algorithm/partition>¹⁴² http://en.cppreference.com/w/cpp/algorithm/partition_copy¹⁴³ http://en.cppreference.com/w/cpp/algorithm/stable_partition

Table 2.20: Numeric Parallel Algorithms of header `hpx/numeric.hpp`

Name	Description	C++ standard
<code>hpx::adjacent_difference</code>	Calculates the difference between each element in an input range and the preceding element.	<code>adjacent_difference</code> ¹⁵⁰
<code>hpx::exclusive_scan</code>	Does an exclusive parallel scan over a range of elements.	<code>exclusive_scan</code> ¹⁵¹
<code>hpx::inclusive_scan</code>	Does an inclusive parallel scan over a range of elements.	<code>inclusive_scan</code> ¹⁵²
<code>hpx::reduce</code>	Sums up a range of elements.	<code>reduce</code> ¹⁵³
<code>hpx::transform_exclusive_scan</code>	Does an exclusive parallel scan over a range of elements after applying a function.	<code>transform_exclusive_scan</code> ¹⁵⁴
<code>hpx::transform_inclusive_scan</code>	Does an inclusive parallel scan over a range of elements after applying a function.	<code>transform_inclusive_scan</code> ¹⁵⁵
<code>hpx::transform_reduce</code>	Sums up a range of elements after applying a function. Also, accumulates the inner products of two input ranges.	<code>transform_reduce</code> ¹⁵⁶

¹⁴⁴ http://en.cppreference.com/w/cpp/algorithm/is_sorted

¹⁴⁵ http://en.cppreference.com/w/cpp/algorithm/is_sorted_until

¹⁴⁶ <http://en.cppreference.com/w/cpp/algorithm/sort>

¹⁴⁷ http://en.cppreference.com/w/cpp/algorithm/stable_sort

¹⁴⁸ http://en.cppreference.com/w/cpp/algorithm/partial_sort

¹⁴⁹ http://en.cppreference.com/w/cpp/algorithm/partial_sort_copy

¹⁵⁰ http://en.cppreference.com/w/cpp/algorithm/adjacent_difference

¹⁵¹ http://en.cppreference.com/w/cpp/algorithm/exclusive_scan

¹⁵² http://en.cppreference.com/w/cpp/algorithm/inclusive_scan

¹⁵³ <http://en.cppreference.com/w/cpp/algorithm/reduce>

¹⁵⁴ http://en.cppreference.com/w/cpp/algorithm/transform_exclusive_scan

¹⁵⁵ http://en.cppreference.com/w/cpp/algorithm/transform_inclusive_scan

¹⁵⁶ http://en.cppreference.com/w/cpp/algorithm/transform_reduce

Table 2.21: Dynamic Memory Management of header `hpx/memory.hpp`

Name	Description	C++ standard
<code>hpx::destroy</code>	Destroys a range of objects.	<code>destroy</code> ¹⁵⁷
<code>hpx::destroy_n</code>	Destroys a range of objects.	<code>destroy_n</code> ¹⁵⁸
<code>hpx::uninitialized_copy</code>	Copies a range of objects to an uninitialized area of memory.	<code>uninitialized_copy</code> ¹⁵⁹
<code>hpx::uninitialized_copy_n</code>	Copies a number of objects to an uninitialized area of memory.	<code>uninitialized_copy_n</code> ¹⁶⁰
<code>hpx::uninitialized_default_construct</code>	Copies a range of objects to an uninitialized area of memory.	<code>uninitialized_default_construct</code> ¹⁶¹
<code>hpx::uninitialized_default_construct_n</code>	Copies a number of objects to an uninitialized area of memory.	<code>uninitialized_default_construct_n</code> ¹⁶²
<code>hpx::uninitialized_fill</code>	Copies an object to an uninitialized area of memory.	<code>uninitialized_fill</code> ¹⁶³
<code>hpx::uninitialized_fill_n</code>	Copies an object to an uninitialized area of memory.	<code>uninitialized_fill_n</code> ¹⁶⁴
<code>hpx::uninitialized_move</code>	Moves a range of objects to an uninitialized area of memory.	<code>uninitialized_move</code> ¹⁶⁵
<code>hpx::uninitialized_move_n</code>	Moves a number of objects to an uninitialized area of memory.	<code>uninitialized_move_n</code> ¹⁶⁶
<code>hpx::uninitialized_value_construct</code>	Constructs objects in an uninitialized area of memory.	<code>uninitialized_value_construct</code> ¹⁶⁷
<code>hpx::uninitialized_value_construct_n</code>	Constructs objects in an uninitialized area of memory.	<code>uninitialized_value_construct_n</code> ¹⁶⁸

Table 2.22: Index-based for-loops of header `hpx/algorithm.hpp`

Name	Description
<code>hpx::experimental::for_loop</code>	Implements loop functionality over a range specified by integral or iterator bounds.
<code>hpx::experimental::for_loop_stride</code>	Implements loop functionality over a range specified by integral or iterator bounds.
<code>hpx::experimental::for_loop_n</code>	Implements loop functionality over a range specified by integral or iterator bounds.
<code>hpx::experimental::for_loop_n_stride</code>	Implements loop functionality over a range specified by integral or iterator bounds.

¹⁵⁷ <http://en.cppreference.com/w/cpp/memory/destroy>¹⁵⁸ http://en.cppreference.com/w/cpp/memory/destroy_n¹⁵⁹ http://en.cppreference.com/w/cpp/memory/uninitialized_copy¹⁶⁰ http://en.cppreference.com/w/cpp/memory/uninitialized_copy_n¹⁶¹ http://en.cppreference.com/w/cpp/memory/uninitialized_default_construct¹⁶² http://en.cppreference.com/w/cpp/memory/uninitialized_default_construct_n¹⁶³ http://en.cppreference.com/w/cpp/memory/uninitialized_fill¹⁶⁴ http://en.cppreference.com/w/cpp/memory/uninitialized_fill_n¹⁶⁵ http://en.cppreference.com/w/cpp/memory/uninitialized_move¹⁶⁶ http://en.cppreference.com/w/cpp/memory/uninitialized_move_n¹⁶⁷ http://en.cppreference.com/w/cpp/memory/uninitialized_value_construct¹⁶⁸ http://en.cppreference.com/w/cpp/memory/uninitialized_value_construct_n

Executor parameters and executor parameter traits

HPX introduces the notion of execution parameters and execution parameter traits. At this point, the only parameter that can be customized is the size of the chunks of work executed on a single *HPX* thread (such as the number of loop iterations combined to run as a single task).

An executor parameter object is responsible for exposing the calculation of the size of the chunks scheduled. It abstracts the (potentially platform-specific) algorithms of determining those chunk sizes.

The way executor parameters are implemented is aligned with the way executors are implemented. All functionalities of concrete executor parameter types are exposed and accessible through a corresponding customization point, e.g. `get_chunk_size()`.

With `executor_parameter_traits`, clients access all types of executor parameters uniformly, e.g.:

```
std::size_t chunk_size =
    hpx::execution::experimental::get_chunk_size(my_parameter, my_executor,
        num_cores, num_tasks);
```

This call synchronously retrieves the size of a single chunk of loop iterations (or similar) to combine for execution on a single *HPX* thread if the overall number of cores `num_cores` and tasks to schedule is given by `num_tasks`. The lambda function exposes a means of test-probing the execution of a single iteration for performance measurement purposes. The execution parameter type might dynamically determine the execution time of one or more tasks in order to calculate the chunk size; see `hpx::execution::experimental::auto_chunk_size` for an example of this executor parameter type.

Other functions in the interface exist to discover whether an executor parameter type should be invoked once (i.e., it returns a static chunk size; see `hpx::execution::experimental::static_chunk_size`) or whether it should be invoked for each scheduled chunk of work (i.e., it returns a variable chunk size; for an example, see `hpx::execution::experimental::guided_chunk_size`).

Although this interface appears to require executor parameter type authors to implement all different basic operations, none are required. In practice, all operations have sensible defaults. However, some executor parameter types will naturally specialize all operations for maximum efficiency.

HPX implements the following executor parameter types:

- `hpx::execution::experimental::auto_chunk_size`: Loop iterations are divided into pieces and then assigned to threads. The number of loop iterations combined is determined based on measurements of how long the execution of 1% of the overall number of iterations takes. This executor parameter type makes sure that as many loop iterations are combined as necessary to run for the amount of time specified.
- `hpx::execution::experimental::static_chunk_size`: Loop iterations are divided into pieces of a given size and then assigned to threads. If the size is not specified, the iterations are, if possible, evenly divided contiguously among the threads. This executor parameters type is equivalent to OpenMP's STATIC scheduling directive.
- `hpx::execution::experimental::dynamic_chunk_size`: Loop iterations are divided into pieces of a given size and then dynamically scheduled among the cores; when a core finishes one chunk, it is dynamically assigned another. If the size is not specified, the default chunk size is 1. This executor parameter type is equivalent to OpenMP's DYNAMIC scheduling directive.
- `hpx::execution::experimental::guided_chunk_size`: Iterations are dynamically assigned to cores in blocks as cores request them until no blocks remain to be assigned. This is similar to `dynamic_chunk_size` except that the block size decreases each time a number of loop iterations is given to a thread. The size of the initial block is proportional to `number_of_iterations / number_of_cores`. Subsequent blocks are proportional to `number_of_iterations_remaining / number_of_cores`. The optional chunk size parameter defines the minimum block size. The default minimal chunk size is 1. This executor parameter type is equivalent to OpenMP's GUIDED scheduling directive.

2.3.11 Writing distributed applications

This section focuses on the features of *HPX* needed to write distributed applications, namely the *Active Global Address Space (AGAS)*, remotely executable functions (i.e., *actions*), and distributed objects (i.e., *components*).

Global names

HPX implements an *Active Global Address Space (AGAS)* which exposes a single uniform address space spanning all localities an application runs on. AGAS is a fundamental component of the ParalleX execution model. Conceptually, there is no rigid demarcation of local or global memory in AGAS; all available memory is a part of the same address space. AGAS enables named objects to be moved (migrated) across localities without having to change the object's name; i.e., no references to migrated objects have to be ever updated. This feature has significance for dynamic load balancing and in applications where the workflow is highly dynamic, allowing work to be migrated from heavily loaded nodes to less loaded nodes. In addition, immutability of names ensures that AGAS does not have to keep extra indirections ("bread crumbs") when objects move, hence, minimizing complexity of code management for system developers as well as minimizing overheads in maintaining and managing aliases.

The AGAS implementation in *HPX* does not automatically expose every local address to the global address space. It is the responsibility of the programmer to explicitly define which of the objects have to be globally visible and which of the objects are purely local.

In *HPX* global addresses (global names) are represented using the `hpx::id_type` data type. This data type is conceptually very similar to `void*` pointers as it does not expose any type information of the object it is referring to.

The only predefined global addresses are assigned to all localities. The following *HPX* API functions allow one to retrieve the global addresses of localities:

- `hpx::find_here`: retrieves the global address of the *locality* this function is called on.
- `hpx::find_all_localities`: retrieves the global addresses of all localities available to this application (including the *locality* the function is being called on).
- `hpx::find_remote_localities`: retrieves the global addresses of all remote localities available to this application (not including the *locality* the function is being called on).
- `hpx::get_num_localities`: retrieves the number of localities available to this application.
- `hpx::find_locality`: retrieves the global address of any *locality* supporting the given component type.
- `hpx::get_colocation_id`: retrieves the global address of the *locality* currently hosting the object with the given global address.

Additionally, the global addresses of localities can be used to create new instances of components using the following *HPX* API function:

- `hpx::components::new_`: Creates a new instance of the given *Component* type on the specified *locality*.

Note: *HPX* does not expose any functionality to delete component instances. All global addresses (as represented using `hpx::id_type`) are automatically garbage collected. When the last (global) reference to a particular component instance goes out of scope, the corresponding component instance is automatically deleted.

Posting actions

Action type definition

Actions are special types used to describe possibly remote operations. For every global function and every member function which has to be invoked distantly, a special type must be defined. For any global function the special macro `HPX_PLAIN_ACTION` can be used to define the action type. Here is an example demonstrating this:

```
namespace app
{
    void some_global_function(double d)
    {
        cout << d;
    }
}

// This will define the action type 'some_global_action' which represents
// the function 'app::some_global_function'.
HPX_PLAIN_ACTION(app::some_global_function, some_global_action);
```

Important: The macro `HPX_PLAIN_ACTION` has to be placed in global namespace, even if the wrapped function is located in some other namespace. The newly defined action type is placed in the global namespace as well.

If the action type should be defined somewhere not in global namespace, the action type definition has to be split into two macro invocations (`HPX_DEFINE_PLAIN_ACTION` and `HPX_REGISTER_ACTION`) as shown in the next example:

```
namespace app
{
    void some_global_function(double d)
    {
        cout << d;
    }

    // On conforming compilers the following macro expands to:
    //
    //     typedef hpx::actions::make_action<
    //         decltype(&some_global_function), &some_global_function
    //     >::type some_global_action;
    //
    // This will define the action type 'some_global_action' which represents
    // the function 'some_global_function'.
    HPX_DEFINE_PLAIN_ACTION(some_global_function, some_global_action);
}

// The following macro expands to a series of definitions of global objects
// which are needed for proper serialization and initialization support
// enabling the remote invocation of the function `some_global_function`
HPX_REGISTER_ACTION(app::some_global_action, app_some_global_action);
```

The shown code defines an action type `some_global_action` inside the namespace `app`.

Important: If the action type definition is split between two macros as shown above, the name of the action type to

create has to be the same for both macro invocations (here `some_global_action`).

Important: The second argument passed to `HPX_REGISTER_ACTION` (`app_some_global_action`) has to comprise a globally unique C++ identifier representing the action. This is used for serialization purposes.

For member functions of objects which have been registered with AGAS (e.g., ‘components’), a different registration macro `HPX_DEFINE_COMPONENT_ACTION` has to be utilized. Any component needs to be declared in a header file and have some special support macros defined in a source file. Here is an example demonstrating this. The first snippet has to go into the header file:

```
namespace app
{
    struct some_component
        : hpx::components::component_base<some_component>
    {
        int some_member_function(std::string s)
        {
            return boost::lexical_cast<int>(s);
        }

        // This will define the action type 'some_member_action' which
        // represents the member function 'some_member_function' of the
        // object type 'some_component'.
        HPX_DEFINE_COMPONENT_ACTION(some_component, some_member_function,
            some_member_action);
    };
}

// Note: The second argument to the macro below has to be systemwide-unique
// C++ identifiers
HPX_REGISTER_ACTION_DECLARATION(app::some_component::some_member_action, some_component_
↪some_action);
```

The next snippet belongs in a source file (e.g., the main application source file) in the simplest case:

```
typedef hpx::components::component<app::some_component> component_type;
typedef app::some_component some_component;

HPX_REGISTER_COMPONENT(component_type, some_component);

// The parameters for this macro have to be the same as used in the corresponding
// HPX_REGISTER_ACTION_DECLARATION() macro invocation above
typedef some_component::some_member_action some_component_some_action;
HPX_REGISTER_ACTION(some_component_some_action);
```

While these macro invocations are a bit more complex than those for simple global functions, they should still be manageable.

The most important macro invocation is the `HPX_DEFINE_COMPONENT_ACTION` in the header file as this defines the action type we need to invoke the member function. For a complete example of a simple component action see `component_in_executable.cpp`.

Action invocation

The process of invoking a global function (or a member function of an object) with the help of the associated action is called ‘posting the action’. Actions can have arguments, which will be supplied while the action is applied. At the minimum, one parameter is required to `post` any action - the id of the *locality* the associated function should be invoked on (for global functions), or the id of the component instance (for member functions). Generally, *HPX* provides several ways to `post` an action, all of which are described in the following sections.

Generally, *HPX* actions are very similar to ‘normal’ C++ functions except that actions can be invoked remotely. Fig. 2.8 below shows an overview of the main API exposed by *HPX*. This shows the function invocation syntax as defined by the C++ language (dark gray), the additional invocation syntax as provided through C++ Standard Library features (medium gray), and the extensions added by *HPX* (light gray) where:

- `f` function to invoke,
- `p...`: (optional) arguments,
- `R`: return type of `f`,
- `action`: action type defined by, *HPX_DEFINE_PLAIN_ACTION* or *HPX_DEFINE_COMPONENT_ACTION* encapsulating `f`,
- `a`: an instance of the type `action`,
- `id`: the global address the action is applied to.

<code>R f(p...)</code>	Synchronous (return <code>R</code>)	Asynchronous (return <code>future<R></code>)	Fire & Forget (return <code>void</code>)
Functions (direct)	<code>f(p...)</code> C++	<code>async(f, p...)</code>	<code>post(f, p...)</code>
Functions (lazy)	<code>bind(f, p...)(...)</code>	<code>async(bind(f, p...), ...)</code> C++ Library	<code>post(bind(f, p...), ...)</code>
Actions (direct)	<code>HPX_ACTION(f, a)</code> <code>a(id, p...)</code>	<code>HPX_ACTION(f, a)</code> <code>async(a, id, p...)</code>	<code>HPX_ACTION(f, a)</code> <code>post(a, id, p...)</code>
Actions (lazy)	<code>HPX_ACTION(f, a)</code> <code>bind(a, id, p...)(...)</code>	<code>HPX_ACTION(f, a)</code> <code>async(bind(a, id, p...), ...)</code>	<code>HPX_ACTION(f, a)</code> <code>post(bind(a, id, p...), ...)</code> HPX

Fig. 2.8: Overview of the main API exposed by *HPX*.

This figure shows that *HPX* allows the user to `post` actions with a syntax similar to the C++ standard. In fact, all action types have an overloaded function operator allowing to synchronously `post` the action. Further, *HPX* implements `hpx::async` which semantically works similar to the way `std::async` works for plain C++ function.

Note: The similarity of posting an action to conventional function invocations extends even further. *HPX* implements `hpx::bind` and `hpx::function` two facilities which are semantically equivalent to the `std::bind` and `std::function` types as defined by the C++11 Standard. While `hpx::async` extends beyond the conventional semantics by supporting actions and conventional C++ functions, the *HPX* facilities `hpx::bind` and `hpx::function` extend beyond the conventional standard facilities too. The *HPX* facilities not only support conventional functions, but can be used for actions as well.

Additionally, *HPX* exposes `hpx::post` and `hpx::async_continue` both of which refine and extend the standard C++ facilities.

The different ways to invoke a function in *HPX* will be explained in more detail in the following sections.

Posting an action asynchronously without any synchronization

This method ('fire and forget') will make sure the function associated with the action is scheduled to run on the target *locality*. Posting the action does not wait for the function to start running, instead it is a fully asynchronous operation. The following example shows how to post the action as defined *in the previous section* on the local *locality* (the *locality* this code runs on):

```
some_global_action act;    // define an instance of some_global_action
hpx::post(act, hpx::find_here(), 2.0);
```

(the function `hpx::find_here()` returns the id of the local *locality*, i.e. the *locality* this code executes on).

Any component member function can be invoked using the same syntactic construct. Given that `id` is the global address for a component instance created earlier, this invocation looks like:

```
some_component_action act;    // define an instance of some_component_action
hpx::post(act, id, "42");
```

In this case any value returned from this action (e.g. in this case the integer 42 is ignored. Please look at *Action type definition* for the code defining the component action `some_component_action` used.

Posting an action asynchronously with synchronization

This method will make sure the action is scheduled to run on the target *locality*. Posting the action itself does not wait for the function to start running or to complete, instead this is a fully asynchronous operation similar to using `hpx::post` as described above. The difference is that this method will return an instance of a `hpx::future<>` encapsulating the result of the (possibly remote) execution. The future can be used to synchronize with the asynchronous operation. The following example shows how to post the action from above on the local *locality*:

```
some_global_action act;    // define an instance of some_global_action
hpx::future<void> f = hpx::async(act, hpx::find_here(), 2.0);
//
// ... other code can be executed here
//
f.get();    // this will possibly wait for the asynchronous operation to 'return'
```

(as before, the function `hpx::find_here()` returns the id of the local *locality* (the *locality* this code is executed on).

Note: The use of a `hpx::future<void>` allows the current thread to synchronize with any remote operation not returning any value.

Note: Any `std::future<>` returned from `std::async()` is required to block in its destructor if the value has not been set for this future yet. This is not true for `hpx::future<>` which will never block in its destructor, even if the value has not been returned to the future yet. We believe that consistency in the behavior of futures is more important than standards conformance in this case.

Any component member function can be invoked using the same syntactic construct. Given that `id` is the global address for a component instance created earlier, this invocation looks like:

```
some_component_action act;    // define an instance of some_component_action
hpx::future<int> f = hpx::async(act, id, "42");
//
// ... other code can be executed here
//
cout << f.get();    // this will possibly wait for the asynchronous operation to 'return'
↪42
```

Note: The invocation of `f.get()` will return the result immediately (without suspending the calling thread) if the result from the asynchronous operation has already been returned. Otherwise, the invocation of `f.get()` will suspend the execution of the calling thread until the asynchronous operation returns its result.

Posting an action synchronously

This method will schedule the function wrapped in the specified action on the target *locality*. While the invocation appears to be synchronous (as we will see), the calling thread will be suspended while waiting for the function to return. Invoking a plain action (e.g. a global function) synchronously is straightforward:

```
some_global_action act;    // define an instance of some_global_action
act(hpx::find_here(), 2.0);
```

While this call looks just like a normal synchronous function invocation, the function wrapped by the action will be scheduled to run on a new thread and the calling thread will be suspended. After the new thread has executed the wrapped global function, the waiting thread will resume and return from the synchronous call.

Equivalently, any action wrapping a component member function can be invoked synchronously as follows:

```
some_component_action act;    // define an instance of some_component_action
int result = act(id, "42");
```

The action invocation will either schedule a new thread locally to execute the wrapped member function (as before, `id` is the global address of the component instance the member function should be invoked on), or it will send a parcel to the remote *locality* of the component causing a new thread to be scheduled there. The calling thread will be suspended until the function returns its result. This result will be returned from the synchronous action invocation.

It is very important to understand that this ‘synchronous’ invocation syntax in fact conceals an asynchronous function call. This is beneficial as the calling thread is suspended while waiting for the outcome of a potentially remote operation. The *HPX* thread scheduler will schedule other work in the meantime, allowing the application to make further progress while the remote result is computed. This helps overlapping computation with communication and hiding communication latencies.

Note: The syntax of posting an action is always the same, regardless whether the target *locality* is remote to the invocation *locality* or not. This is a very important feature of *HPX* as it frees the user from the task of keeping track what actions have to be applied locally and which actions are remote. If the target for posting an action is local, a new thread is automatically created and scheduled. Once this thread is scheduled and run, it will execute the function encapsulated by that action. If the target is remote, *HPX* will send a parcel to the remote *locality* which encapsulates the action and its parameters. Once the parcel is received on the remote *locality* *HPX* will create and schedule a new thread there. Once this thread runs on the remote *locality*, it will execute the function encapsulated by the action.

Posting an action with a continuation but without any synchronization

This method is very similar to the method described in section *Posting an action asynchronously without any synchronization*. The difference is that it allows the user to chain a sequence of asynchronous operations, while handing the (intermediate) results from one step to the next step in the chain. Where `hpx::post` invokes a single function using ‘fire and forget’ semantics, `hpx::post_continue` asynchronously triggers a chain of functions without the need for the execution flow ‘to come back’ to the invocation site. Each of the asynchronous functions can be executed on a different *locality*.

Posting an action with a continuation and with synchronization

This method is very similar to the method described in section *Posting an action asynchronously with synchronization*. In addition to what `hpx::async` can do, the functions `hpx::async_continue` takes an additional function argument. This function will be called as the continuation of the executed action. It is expected to perform additional operations and to make sure that a result is returned to the original invocation site. This method chains operations asynchronously by providing a continuation operation which is automatically executed once the first action has finished executing.

As an example we chain two actions, where the result of the first action is forwarded to the second action and the result of the second action is sent back to the original invocation site:

```
// first action
std::int32_t action1(std::int32_t i)
{
    return i+1;
}
HPX_PLAIN_ACTION(action1);    // defines action1_type

// second action
std::int32_t action2(std::int32_t i)
{
    return i*2;
}
HPX_PLAIN_ACTION(action2);    // defines action2_type

// this code invokes 'action1' above and passes along a continuation
// function which will forward the result returned from 'action1' to
// 'action2'.
action1_type act1;           // define an instance of 'action1_type'
action2_type act2;           // define an instance of 'action2_type'
hpx::future<int> f =
    hpx::async_continue(act1, hpx::make_continuation(act2),
        hpx::find_here(), 42);
hpx::cout << f.get() << "\n";    // will print: 86 ((42 + 1) * 2)
```

By default, the continuation is executed on the same *locality* as `hpx::async_continue` is invoked from. If you want to specify the *locality* where the continuation should be executed, the code above has to be written as:

```
// this code invokes 'action1' above and passes along a continuation
// function which will forward the result returned from 'action1' to
// 'action2'.
action1_type act1;           // define an instance of 'action1_type'
action2_type act2;           // define an instance of 'action2_type'
hpx::future<int> f =
```

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```
hpx::async_continue(act1, hpx::make_continuation(act2, hpx::find_here()),
    hpx::find_here(), 42);
hpx::cout << f.get() << "\n"; // will print: 86 ((42 + 1) * 2)
```

Similarly, it is possible to chain more than 2 operations:

```
action1_type act1; // define an instance of 'action1_type'
action2_type act2; // define an instance of 'action2_type'
hpx::future<int> f =
    hpx::async_continue(act1,
        hpx::make_continuation(act2, hpx::make_continuation(act1)),
        hpx::find_here(), 42);
hpx::cout << f.get() << "\n"; // will print: 87 ((42 + 1) * 2 + 1)
```

The function `hpx::make_continuation` creates a special function object which exposes the following prototype:

```
struct continuation
{
    template <typename Result>
    void operator()(hpx::id_type id, Result&& result) const
    {
        ...
    }
};
```

where the parameters passed to the overloaded function operator `operator()()` are:

- the `id` is the global id where the final result of the asynchronous chain of operations should be sent to (in most cases this is the id of the `hpx::future` returned from the initial call to `hpx::async_continue`. Any custom continuation function should make sure this `id` is forwarded to the last operation in the chain.
- the `result` is the result value of the current operation in the asynchronous execution chain. This value needs to be forwarded to the next operation.

Note: All of those operations are implemented by the predefined continuation function object which is returned from `hpx::make_continuation`. Any (custom) function object used as a continuation should conform to the same interface.

Action error handling

Like in any other asynchronous invocation scheme it is important to be able to handle error conditions occurring while the asynchronous (and possibly remote) operation is executed. In *HPX* all error handling is based on standard C++ exception handling. Any exception thrown during the execution of an asynchronous operation will be transferred back to the original invocation *locality*, where it is rethrown during synchronization with the calling thread.

Important: Exceptions thrown during asynchronous execution can be transferred back to the invoking thread only for the synchronous and the asynchronous case with synchronization. Like with any other unhandled exception, any exception thrown during the execution of an asynchronous action *without* synchronization will result in calling `hpx::terminate` causing the running application to exit immediately.

Note: Even if error handling internally relies on exceptions, most of the API functions exposed by *HPX* can be used without throwing an exception. Please see *Working with exceptions* for more information.

As an example, we will assume that the following remote function will be executed:

```
namespace app
{
    void some_function_with_error(int arg)
    {
        if (arg < 0) {
            HPX_THROW_EXCEPTION(hpx::error::bad_parameter,
                               "some_function_with_error",
                               "some really bad error happened");
        }
        // do something else...
    }
}

// This will define the action type 'some_error_action' which represents
// the function 'app::some_function_with_error'.
HPX_PLAIN_ACTION(app::some_function_with_error, some_error_action);
```

The use of *HPX_THROW_EXCEPTION* to report the error encapsulates the creation of a *hpx::exception* which is initialized with the error code *hpx::error::bad_parameter*. Additionally it carries the passed strings, the information about the file name, line number, and call stack of the point the exception was thrown from.

We invoke this action using the synchronous syntax as described before:

```
// note: wrapped function will throw hpx::exception
some_error_action act;           // define an instance of some_error_action
try {
    act(hpx::find_here(), -3);    // exception will be rethrown from here
}
catch (hpx::exception const& e) {
    // prints: 'some really bad error happened: HPX(bad parameter)'
    cout << e.what();
}
```

If this action is invoked asynchronously with synchronization, the exception is propagated to the waiting thread as well and is re-thrown from the future's function *get()*:

```
// note: wrapped function will throw hpx::exception
some_error_action act;           // define an instance of some_error_action
hpx::future<void> f = hpx::async(act, hpx::find_here(), -3);
try {
    f.get();                      // exception will be rethrown from here
}
catch (hpx::exception const& e) {
    // prints: 'some really bad error happened: HPX(bad parameter)'
    cout << e.what();
}
```

For more information about error handling please refer to the section *Working with exceptions*. There we also explain how to handle error conditions without having to rely on exception.

Writing components

A component in *HPX* is a C++ class which can be created remotely and for which its member functions can be invoked remotely as well. The following sections highlight how components can be defined, created, and used.

Defining components

In order for a C++ class type to be managed remotely in *HPX*, the type must be derived from the `hpx::components::component_base` template type. We call such C++ class types ‘components’.

Note that the component type itself is passed as a template argument to the base class:

```
// header file some_component.hpp

#include <hpx/include/components.hpp>

namespace app
{
    // Define a new component type 'some_component'
    struct some_component
        : hpx::components::component_base<some_component>
    {
        // This member function is has to be invoked remotely
        int some_member_function(std::string const& s)
        {
            return boost::lexical_cast<int>(s);
        }

        // This will define the action type 'some_member_action' which
        // represents the member function 'some_member_function' of the
        // object type 'some_component'.
        HPX_DEFINE_COMPONENT_ACTION(some_component, some_member_function, some_member_
        ↪action);
    };
}

// This will generate the necessary boiler-plate code for the action allowing
// it to be invoked remotely. This declaration macro has to be placed in the
// header file defining the component itself.
//
// Note: The second argument to the macro below has to be systemwide-unique
//       C++ identifiers
//
HPX_REGISTER_ACTION_DECLARATION(app::some_component::some_member_action, some_component_
↪some_action);
```

There is more boiler plate code which has to be placed into a source file in order for the component to be usable. Every component type is required to have macros placed into its source file, one for each component type and one macro for each of the actions defined by the component type.

For instance:

```
// source file some_component.cpp
```

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```

#include "some_component.hpp"

// The following code generates all necessary boiler plate to enable the
// remote creation of 'app::some_component' instances with 'hpx::new_<>()'
//
using some_component = app::some_component;
using some_component_type = hpx::components::component<some_component>;

// Please note that the second argument to this macro must be a
// (system-wide) unique C++-style identifier (without any namespaces)
//
HPX_REGISTER_COMPONENT(some_component_type, some_component);

// The parameters for this macro have to be the same as used in the corresponding
// HPX_REGISTER_ACTION_DECLARATION() macro invocation in the corresponding
// header file.
//
// Please note that the second argument to this macro must be a
// (system-wide) unique C++-style identifier (without any namespaces)
//
HPX_REGISTER_ACTION(app::some_component::some_member_action, some_component_some_action);

```

Defining client side representation classes

Often it is very convenient to define a separate type for a component which can be used on the client side (from where the component is instantiated and used). This step might seem as unnecessary duplicating code, however it significantly increases the type safety of the code.

A possible implementation of such a client side representation for the component described in the previous section could look like:

```

#include <hpx/include/components.hpp>

namespace app
{
    // Define a client side representation type for the component type
    // 'some_component' defined in the previous section.
    //
    struct some_component_client
    : hpx::components::client_base<some_component_client, some_component>
    {
        using base_type = hpx::components::client_base<
            some_component_client, some_component>;

        some_component_client(hpx::future<hpx::id_type> && id)
        : base_type(std::move(id))
        {}

        hpx::future<int> some_member_function(std::string const& s)
        {
            some_component::some_member_action act;

```

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```

        return hpx::async(act, get_id(), s);
    }
};
}

```

A client side object stores the global id of the component instance it represents. This global id is accessible by calling the function `client_base<>::get_id()`. The special constructor which is provided in the example allows to create this client side object directly using the API function `hpx::new_`.

Creating component instances

Instances of defined component types can be created in two different ways. If the component to create has a defined client side representation type, then this can be used, otherwise use the server type.

The following examples assume that `some_component_type` is the type of the server side implementation of the component to create. All additional arguments (see `, ...` notation below) are passed through to the corresponding constructor calls of those objects:

```

// create one instance on the given locality
hpx::id_type here = hpx::find_here();
hpx::future<hpx::id_type> f =
    hpx::new_<some_component_type>(here, ...);

// create one instance using the given distribution
// policy (here: hpx::colocating_distribution_policy)
hpx::id_type here = hpx::find_here();
hpx::future<hpx::id_type> f =
    hpx::new_<some_component_type>(hpx::colocated(here), ...);

// create multiple instances on the given locality
hpx::id_type here = find_here();
hpx::future<std::vector<hpx::id_type>> f =
    hpx::new_<some_component_type[]>(here, num, ...);

// create multiple instances using the given distribution
// policy (here: hpx::binpacking_distribution_policy)
hpx::future<std::vector<hpx::id_type>> f = hpx::new_<some_component_type[]>(
    hpx::binpacking(hpx::find_all_localities()), num, ...);

```

The examples below demonstrate the use of the same API functions for creating client side representation objects (instead of just plain ids). These examples assume that `client_type` is the type of the client side representation of the component type to create. As above, all additional arguments (see `, ...` notation below) are passed through to the corresponding constructor calls of the server side implementation objects corresponding to the `client_type`:

```

// create one instance on the given locality
hpx::id_type here = hpx::find_here();
client_type c = hpx::new_<client_type>(here, ...);

// create one instance using the given distribution
// policy (here: hpx::colocating_distribution_policy)
hpx::id_type here = hpx::find_here();
client_type c = hpx::new_<client_type>(hpx::colocated(here), ...);

```

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```

// create multiple instances on the given locality
hpx::id_type here = hpx::find_here();
hpx::future<std::vector<client_type>> f =
    hpx::new_<client_type[]>(here, num, ...);

// create multiple instances using the given distribution
// policy (here: hpx::binpacking_distribution_policy)
hpx::future<std::vector<client_type>> f = hpx::new_<client_type[]>(
    hpx::binpacking(hpx::find_all_localities()), num, ...);

```

Using component instances

After having created the component instances as described above, we can simply use them as indicated below:

```

#include <hpx/include/components.hpp>
#include <iostream>
#include <vector>

// Define a simple component
struct some_component : hpx::components::component_base<some_component>
{
    void print() const
    {
        std::cout << "Hello from component instance!" << std::endl;
    }
    HPX_DEFINE_COMPONENT_ACTION(some_component, print, print_action);
};

typedef some_component::print_action print_action;

// Create one instance on the given locality
hpx::id_type here = hpx::find_here();
hpx::future<hpx::id_type> f1 =
    hpx::new_<some_component>(here);

// Get the future value
hpx::id_type instance_id = f1.get();

// Invoke action on the instance
hpx::async<print_action>(instance_id).get();

// Create multiple instances on the given locality
int num = 3;
hpx::future<std::vector<hpx::id_type>> f2 =
    hpx::new_<some_component[]>(here, num);

// Get the future value
std::vector<hpx::id_type> instance_ids = f2.get();

// Invoke action on each instance

```

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```
for (const auto& id : instance_ids)
{
    hpx::async<print_action>(id).get();
}
```

We can use the component instances with distribution policies the same way.

Segmented containers

In parallel programming, there is now a plethora of solutions aimed at implementing “partially contiguous” or segmented data structures, whether on shared memory systems or distributed memory systems. *HPX* implements such structures by drawing inspiration from Standard C++ containers.

Using segmented containers

A segmented container is a template class that is described in the namespace `hpx`. All segmented containers are very similar semantically to their sequential counterpart (defined in namespace `std` but with an additional template parameter named `DistPolicy`). The distribution policy is an optional parameter that is passed last to the segmented container constructor (after the container size when no default value is given, after the default value if not). The distribution policy describes the manner in which a container is segmented and the placement of each segment among the available runtime localities.

However, only a part of the `std` container member functions were reimplemented:

- (constructor), (destructor), `operator=`
- `operator[]`
- `begin`, `cbegin`, `end`, `cend`
- `size`

An example of how to use the `partitioned_vector` container would be:

```
#include <hpx/include/partitioned_vector.hpp>

// The following code generates all necessary boiler plate to enable the
// remote creation of 'partitioned_vector' segments
//
HPX_REGISTER_PARTITIONED_VECTOR(double);

// By default, the number of segments is equal to the current number of
// localities
//
hpx::partitioned_vector<double> va(50);
hpx::partitioned_vector<double> vb(50, 0.0);
```

An example of how to use the `partitioned_vector` container with distribution policies would be:

```
#include <hpx/include/partitioned_vector.hpp>
#include <hpx/runtime_distributed/find_localities.hpp>

// The following code generates all necessary boiler plate to enable the
// remote creation of 'partitioned_vector' segments
```

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```

//
HPX_REGISTER_PARTITIONED_VECTOR(double);

std::size_t num_segments = 10;
std::vector<hpx::id_type> locs = hpx::find_all_localities();

auto layout =
    hpx::container_layout( num_segments, locs );

// The number of segments is 10 and those segments are spread across the
// localities collected in the variable locs in a Round-Robin manner
//
hpx::partitioned_vector<double> va(50, layout);
hpx::partitioned_vector<double> vb(50, 0.0, layout);

```

By definition, a segmented container must be accessible from any thread although its construction is synchronous only for the thread who has called its constructor. To overcome this problem, it is possible to assign a symbolic name to the segmented container:

```

#include <hpx/include/partitioned_vector.hpp>

// The following code generates all necessary boiler plate to enable the
// remote creation of 'partitioned_vector' segments
//
HPX_REGISTER_PARTITIONED_VECTOR(double);

hpx::future<void> fserver = hpx::async(
    []() {
        hpx::partitioned_vector<double> v(50);

        // Register the 'partitioned_vector' with the name "some_name"
        //
        v.register_as("some_name");

        /* Do some code */
    });

hpx::future<void> fclient =
    hpx::async(
        []() {
            // Naked 'partitioned_vector'
            //
            hpx::partitioned_vector<double> v;

            // Now the variable v points to the same 'partitioned_vector' that has
            // been registered with the name "some_name"
            //
            v.connect_to("some_name");

            /* Do some code */
        });

```

Segmented containers

HPX provides the following segmented containers:

Table 2.23: Sequence containers

Name	Description	In header	C++ standard
<code>hpx::partitioned_vector</code>	Dynamic segmented contiguous array.	<code><hpx/include/partitioned_vector.hpp></code>	<code>vector</code> ¹⁶⁹

Table 2.24: Unordered associative containers

Name	Description	In header	C++ standard
<code>hpx::unordered_map</code>	Segmented collection of key-value pairs, hashed by keys, keys are unique.	<code><hpx/include/unordered_map.hpp></code>	<code>unordered_map</code> ¹⁷⁰

Segmented iterators and segmented iterator traits

The basic iterator used in the STL library is only suitable for one-dimensional structures. The iterators we use in HPX must adapt to the segmented format of our containers. Our iterators are then able to know when incrementing themselves if the next element of type T is in the same data segment or in another segment. In this second case, the iterator will automatically point to the beginning of the next segment.

Note: Note that the dereference operation operator `*` does not directly return a reference of type T& but an intermediate object wrapping this reference. When this object is used as an l-value, a remote write operation is performed; When this object is used as an r-value, implicit conversion to T type will take care of performing remote read operation.

It is sometimes useful not only to iterate element by element, but also segment by segment, or simply get a local iterator in order to avoid additional construction costs at each dereferencing operations. To mitigate this need, the `hpx::traits::segmented_iterator_traits` are used.

With `segmented_iterator_traits` users can uniformly get the iterators which specifically iterates over segments (by providing a segmented iterator as a parameter), or get the local begin/end iterators of the nearest local segment (by providing a per-segment iterator as a parameter):

```
#include <hpx/include/partitioned_vector.hpp>

// The following code generates all necessary boiler plate to enable the
// remote creation of 'partitioned_vector' segments
//
HPX_REGISTER_PARTITIONED_VECTOR(double);

using iterator = hpx::partitioned_vector<T>::iterator;
using traits    = hpx::traits::segmented_iterator_traits<iterator>;

hpx::partitioned_vector<T> v;
std::size_t count = 0;
```

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¹⁶⁹ <http://en.cppreference.com/w/cpp/container/vector>

¹⁷⁰ http://en.cppreference.com/w/cpp/container/unordered_map

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```

auto seg_begin = traits::segment(v.begin());
auto seg_end   = traits::segment(v.end());

// Iterate over segments
for (auto seg_it = seg_begin; seg_it != seg_end; ++seg_it)
{
    auto loc_begin = traits::begin(seg_it);
    auto loc_end   = traits::end(seg_it);

    // Iterate over elements inside segments
    for (auto lit = loc_begin; lit != loc_end; ++lit, ++count)
    {
        *lit = count;
    }
}

```

Which is equivalent to:

```

hpx::partitioned_vector<T> v;
std::size_t count = 0;

auto begin = v.begin();
auto end   = v.end();

for (auto it = begin; it != end; ++it, ++count)
{
    *it = count;
}

```

Using views

The use of multidimensional arrays is quite common in the numerical field whether to perform dense matrix operations or to process images. It exist many libraries which implement such object classes overloading their basic operators (e.g. +, -, *, (), etc.). However, such operation becomes more delicate when the underlying data layout is segmented or when it is mandatory to use optimized linear algebra subroutines (i.e. BLAS subroutines).

Our solution is thus to relax the level of abstraction by allowing the user to work not directly on n-dimensionnal data, but on “n-dimensionnal collections of 1-D arrays”. The use of well-accepted techniques on contiguous data is thus preserved at the segment level, and the composability of the segments is made possible thanks to multidimensional array-inspired access mode.

Preface: Why SPMD?

Although *HPX* refutes by design this programming model, the *locality* plays a dominant role when it comes to implementing vectorized code. To maximize local computations and avoid unneeded data transfers, a parallel section (or Single Programming Multiple Data section) is required. Because the use of global variables is prohibited, this parallel section is created via the RAII idiom.

To define a parallel section, simply write an action taking a `spmd_block` variable as a first parameter:

```
#include <hpx/collectives/spmd_block.hpp>

void bulk_function(hpx::lcos::spmd_block block /* , arg0, arg1, ... */)
{
    // Parallel section

    /* Do some code */
}
HPX_PLAIN_ACTION(bulk_function, bulk_action);
```

Note: In the following paragraphs, we will use the term “image” several times. An image is defined as a lightweight process whose entry point is a function provided by the user. It’s an “image of the function”.

The `spmd_block` class contains the following methods:

- Team information: `get_num_images`, `this_image`, `images_per_locality`
- Control statements: `sync_all`, `sync_images`

Here is a sample code summarizing the features offered by the `spmd_block` class:

```
#include <hpx/collectives/spmd_block.hpp>

void bulk_function(hpx::lcos::spmd_block block /* , arg0, arg1, ... */)
{
    std::size_t num_images = block.get_num_images();
    std::size_t this_image = block.this_image();
    std::size_t images_per_locality = block.images_per_locality();

    /* Do some code */

    // Synchronize all images in the team
    block.sync_all();

    /* Do some code */

    // Synchronize image 0 and image 1
    block.sync_images(0,1);

    /* Do some code */

    std::vector<std::size_t> vec_images = {2,3,4};

    // Synchronize images 2, 3 and 4
    block.sync_images(vec_images);
```

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```

// Alternative call to synchronize images 2, 3 and 4
block.sync_images(vec_images.begin(), vec_images.end());

/* Do some code */

// Non-blocking version of sync_all()
hpx::future<void> event =
    block.sync_all(hpx::launch::async);

// Callback waiting for 'event' to be ready before being scheduled
hpx::future<void> cb =
    event.then(
        [](hpx::future<void>)
        {

            /* Do some code */

        });

// Finally wait for the execution tree to be finished
cb.get();
}
HPX_PLAIN_ACTION(bulk_test_function, bulk_test_action);

```

Then, in order to invoke the parallel section, call the function `define_spmdd_block` specifying an arbitrary symbolic name and indicating the number of images per *locality* to create:

```

void bulk_function(hpx::lcos::spmd_block block, /* , arg0, arg1, ... */)
{
}
HPX_PLAIN_ACTION(bulk_test_function, bulk_test_action);

int main()
{
    /* std::size_t arg0, arg1, ...; */

    bulk_action act;
    std::size_t images_per_locality = 4;

    // Instantiate the parallel section
    hpx::lcos::define_spmdd_block(
        "some_name", images_per_locality, std::move(act) /*, arg0, arg1, ... */);

    return 0;
}

```

Note: In principle, the user should never call the `spmd_block` constructor. The `define_spmdd_block` function is responsible of instantiating `spmd_block` objects and broadcasting them to each created image.

SPMD multidimensional views

Some classes are defined as “container views” when the purpose is to observe and/or modify the values of a container using another perspective than the one that characterizes the container. For example, the values of an `std::vector` object can be accessed via the expression `[i]`. Container views can be used, for example, when it is desired for those values to be “viewed” as a 2D matrix that would have been flattened in a `std::vector`. The values would be possibly accessible via the expression `vv(i, j)` which would call internally the expression `v[k]`.

By default, the `partitioned_vector` class integrates 1-D views of its segments:

```
#include <hpx/include/partitioned_vector.hpp>

// The following code generates all necessary boiler plate to enable the
// remote creation of 'partitioned_vector' segments
//
HPX_REGISTER_PARTITIONED_VECTOR(double);

using iterator = hpx::partitioned_vector<double>::iterator;
using traits = hpx::traits::segmented_iterator_traits<iterator>;

hpx::partitioned_vector<double> v;

// Create a 1-D view of the vector of segments
auto vv = traits::segment(v.begin());

// Access segment i
std::vector<double> v = vv[i];
```

Our views are called “multidimensional” in the sense that they generalize to N dimensions the purpose of `segmented_iterator_traits::segment()` in the 1-D case. Note that in a parallel section, the 2-D expression `a(i, j) = b(i, j)` is quite confusing because without convention, each of the images invoked will race to execute the statement. For this reason, our views are not only multidimensional but also “spmd-aware”.

Note: SPMD-awareness: The convention is simple. If an assignment statement contains a view subscript as an l-value, it is only and only the image holding the r-value who is evaluating the statement. (In MPI sense, it is called a Put operation).

Subscript-based operations

Here are some examples of using subscripts in the 2-D view case:

```
#include <hpx/components/containers/partitioned_vector/partitioned_vector_view.hpp>
#include <hpx/include/partitioned_vector.hpp>

// The following code generates all necessary boiler plate to enable the
// remote creation of 'partitioned_vector' segments
//
HPX_REGISTER_PARTITIONED_VECTOR(double);

using Vec = hpx::partitioned_vector<double>;
using View_2D = hpx::partitioned_vector_view<double, 2>;
```

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```

/* Do some code */

Vec v;

// Parallel section (suppose 'block' an spmd_block instance)
{
    std::size_t height, width;

    // Instantiate the view
    View_2D vv(block, v.begin(), v.end(), {height,width});

    // The l-value is a view subscript, the image that owns vv(1,0)
    // evaluates the assignment.
    vv(0,1) = vv(1,0);

    // The l-value is a view subscript, the image that owns the r-value
    // (result of expression 'std::vector<double>(4,1.0)') evaluates the
    // assignment : oops! race between all participating images.
    vv(2,3) = std::vector<double>(4,1.0);
}

```

Iterator-based operations

Here are some examples of using iterators in the 3-D view case:

```

#include <hpx/components/containers/partitioned_vector/partitioned_vector_view.hpp>
#include <hpx/include/partitioned_vector.hpp>

// The following code generates all necessary boiler plate to enable the
// remote creation of 'partitioned_vector' segments
//
HPX_REGISTER_PARTITIONED_VECTOR(int);

using Vec = hpx::partitioned_vector<int>;
using View_3D = hpx::partitioned_vector_view<int,3>;

/* Do some code */

Vec v1, v2;

// Parallel section (suppose 'block' an spmd_block instance)
{
    std::size_t size_x, size_y, size_z;

    // Instantiate the views
    View_3D vv1(block, v1.begin(), v1.end(), {size_x,size_y,size_z});
    View_3D vv2(block, v2.begin(), v2.end(), {size_x,size_y,size_z});

    // Save previous segments covered by vv1 into segments covered by vv2
    auto vv2_it = vv2.begin();

```

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```

auto vv1_it = vv1.cbegin();

for(; vv2_it != vv2.end(); vv2_it++, vv1_it++)
{
    // It's a Put operation
    *vv2_it = *vv1_it;
}

// Ensure that all images have performed their Put operations
block.sync_all();

// Ensure that only one image is putting updated data into the different
// segments covered by vv1
if(block.this_image() == 0)
{
    int idx = 0;

    // Update all the segments covered by vv1
    for(auto i = vv1.begin(); i != vv1.end(); i++)
    {
        // It's a Put operation
        *i = std::vector<float>(elt_size,idx++);
    }
}
}

```

Here is an example that shows how to iterate only over segments owned by the current image:

```

#include <hpx/components/containers/partitioned_vector/partitioned_vector_view.hpp>
#include <hpx/components/containers/partitioned_vector/partitioned_vector_local_view.hpp>
#include <hpx/include/partitioned_vector.hpp>

// The following code generates all necessary boiler plate to enable the
// remote creation of 'partitioned_vector' segments
//
HPX_REGISTER_PARTITIONED_VECTOR(float);

using Vec = hpx::partitioned_vector<float>;
using View_1D = hpx::partitioned_vector_view<float,1>;

/* Do some code */

Vec v;

// Parallel section (suppose 'block' an spmd_block instance)
{
    std::size_t num_segments;

    // Instantiate the view
    View_1D vv(block, v.begin(), v.end(), {num_segments});

    // Instantiate the local view from the view

```

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```

auto local_vv = hpx::local_view(vv);

for ( auto i = local_vv.begin(); i != local_vv.end(); i++ )
{
    std::vector<float> & segment = *i;

    /* Do some code */
}
}

```

Instantiating sub-views

It is possible to construct views from other views: we call it sub-views. The constraint nevertheless for the subviews is to retain the dimension and the value type of the input view. Here is an example showing how to create a sub-view:

```

#include <hpx/components/containers/partitioned_vector/partitioned_vector_view.hpp>
#include <hpx/include/partitioned_vector.hpp>

// The following code generates all necessary boiler plate to enable the
// remote creation of 'partitioned_vector' segments
//
HPX_REGISTER_PARTITIONED_VECTOR(float);

using Vec = hpx::partitioned_vector<float>;
using View_2D = hpx::partitioned_vector_view<float,2>;

/* Do some code */

Vec v;

// Parallel section (suppose 'block' an spmd_block instance)
{
    std::size_t N = 20;
    std::size_t tileSize = 5;

    // Instantiate the view
    View_2D vv(block, v.begin(), v.end(), {N,N});

    // Instantiate the subview
    View_2D svv(
        block,&vv(tileSize,0),&vv(2*tileSize-1,tileSize-1),{tileSize,tileSize},{N,N});

    if(block.this_image() == 0)
    {
        // Equivalent to 'vv(tileSize,0) = 2.0f'
        svv(0,0) = 2.0f;

        // Equivalent to 'vv(2*tileSize-1,tileSize-1) = 3.0f'
        svv(tileSize-1,tileSize-1) = 3.0f;
    }
}

```

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}

Note: The last parameter of the subview constructor is the size of the original view. If one would like to create a subview of the subview and so on, this parameter should stay unchanged. {N,N} for the above example).

C++ co-arrays

Fortran has extended its scalar element indexing approach to reference each segment of a distributed array. In this extension, a segment is attributed a ?co-index? and lives in a specific *locality*. A co-index provides the application with enough information to retrieve the corresponding data reference. In C++, containers present themselves as a ?smarter? alternative of Fortran arrays but there are still no corresponding standardized features similar to the Fortran co-indexing approach. We present here an implementation of such features in *HPX*.

Preface: co-array, a segmented container tied to a SPMD multidimensional views

As mentioned before, a co-array is a distributed array whose segments are accessible through an array-inspired access mode. We have previously seen that it is possible to reproduce such access mode using the concept of views. Nevertheless, the user must pre-create a segmented container to instantiate this view. We illustrate below how a single constructor call can perform those two operations:

```
#include <hpx/components/containers/coarray/coarray.hpp>
#include <hpx/collectives/spmd_block.hpp>

// The following code generates all necessary boiler plate to enable the
// co-creation of 'coarray'
//
HPX_REGISTER_COARRAY(double);

// Parallel section (suppose 'block' an spmd_block instance)
{
    using hpx::container::placeholders::_;

    std::size_t height=32, width=4, segment_size=10;

    hpx::coarray<double,3> a(block, "a", {height,width,_}, segment_size);

    /* Do some code */
}
```

Unlike segmented containers, a co-array object can only be instantiated within a parallel section. Here is the description of the parameters to provide to the coarray constructor:

Table 2.25: Parameters of coarray constructor

Parameter	Description
<code>block</code>	Reference to a <code>smpd_block</code> object
<code>"a"</code>	Symbolic name of type <code>std::string</code>
<code>{height,width, _}</code>	Dimensions of the coarray object
<code>segment_size</code>	Size of a co-indexed element (i.e. size of the object referenced by the expression <code>a(i, j, k)</code>)

Note that the “last dimension size” cannot be set by the user. It only accepts the constexpr variable `hpx::container::placeholders::_`. This size, which is considered private, is equal to the number of current images (value returned by `block.get_num_images()`).

Note: An important constraint to remember about coarray objects is that all segments sharing the same “last dimension index” are located in the same image.

Using co-arrays

The member functions owned by the coarray objects are exactly the same as those of `smpd` multidimensional views. These are:

- * Subscript-based operations
- * Iterator-based operations

However, one additional functionality is provided. Knowing that the element `a(i, j, k)` is in the memory of the `k`th image, the use of local subscripts is possible.

Note: For `smpd` multidimensional views, subscripts are only global as it still involves potential remote data transfers.

Here is an example of using local subscripts:

```
#include <hpx/components/containers/coarray/coarray.hpp>
#include <hpx/collectives/smpd_block.hpp>

// The following code generates all necessary boiler plate to enable the
// co-creation of 'coarray'
//
HPX_REGISTER_COARRAY(double);

// Parallel section (suppose 'block' an smpd_block instance)
{
    using hpx::container::placeholders::_;

    std::size_t height=32, width=4, segment_size=10;

    hpx::coarray<double,3> a(block, "a", {height,width,_}, segment_size);

    double idx = block.this_image()*height*width;

    for (std::size_t j = 0; j<width; j++)
```

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```

for (std::size_t i = 0; i<height; i++)
{
    // Local write operation performed via the use of local subscript
    a(i,j,_) = std::vector<double>(elt_size,idx);
    idx++;
}

block.sync_all();
}

```

Note: When the “last dimension index” of a subscript is equal to `hpx::container::placeholders::_`, local subscript (and not global subscript) is used. It is equivalent to a global subscript used with a “last dimension index” equal to the value returned by `block.this_image()`.

2.3.12 Running on batch systems

This section walks you through launching *HPX* applications on various batch systems.

How to use *HPX* applications with PBS

Most *HPX* applications are executed on parallel computers. These platforms typically provide integrated job management services that facilitate the allocation of computing resources for each parallel program. *HPX* includes support for one of the most common job management systems, the Portable Batch System (PBS).

All PBS jobs require a script to specify the resource requirements and other parameters associated with a parallel job. The PBS script is basically a shell script with PBS directives placed within commented sections at the beginning of the file. The remaining (not commented-out) portions of the file executes just like any other regular shell script. While the description of all available PBS options is outside the scope of this tutorial (the interested reader may refer to in-depth [documentation](#)¹⁷¹ for more information), below is a minimal example to illustrate the approach. The following test application will use the multithreaded `hello_world_distributed` program, explained in the section *Remote execution with actions*.

```

#!/bin/bash
#
#PBS -l nodes=2:ppn=4

APP_PATH=~/.packages/hpx/bin/hello_world_distributed
APP_OPTIONS=

pbsdsh -u $APP_PATH $APP_OPTIONS --hpx:nodes=`cat $PBS_NODEFILE`

```

Caution: If the first application specific argument (inside `$APP_OPTIONS`) is a non-option (i.e., does not start with a `-` or a `--`), then the argument has to be placed before the option `--hpx:nodes`, which, in this case, should be the last option on the command line.

Alternatively, use the option `--hpx:endnodes` to explicitly mark the end of the list of node names:

```
$ pbsdsh -u $APP_PATH --hpx:nodes`cat $PBS_NODEFILE` --hpx:endnodes $APP_OPTIONS
```

¹⁷¹ <http://www.clusterresources.com/torquedocs21/>

The `#PBS -l nodes=2:ppn=4` directive will cause two compute nodes to be allocated for the application, as specified in the option `nodes`. Each of the nodes will dedicate four cores to the program, as per the option `ppn`, short for “processors per node” (PBS does not distinguish between processors and cores). Note that requesting more cores per node than physically available is pointless and may prevent PBS from accepting the script.

On newer PBS versions the PBS command syntax might be different. For instance, the PBS script above would look like:

```
#!/bin/bash
#
#PBS -l select=2:ncpus=4

APP_PATH=~/packages/hpx/bin/hello_world_distributed
APP_OPTIONS=

pbsdsh -u $APP_PATH $APP_OPTIONS --hpx:nodes=`cat $PBS_NODEFILE`
```

`APP_PATH` and `APP_OPTIONS` are shell variables that respectively specify the correct path to the executable (`hello_world_distributed` in this case) and the command line options. Since the `hello_world_distributed` application doesn't need any command line options, `APP_OPTIONS` has been left empty. Unlike in other execution environments, there is no need to use the `--hpx:threads` option to indicate the required number of OS threads per node; the `HPX` library will derive this parameter automatically from PBS.

Finally, `pbsdsh` is a PBS command that starts tasks to the resources allocated to the current job. It is recommended to leave this line as shown and modify only the PBS options and shell variables as needed for a specific application.

Important: A script invoked by `pbsdsh` starts in a very basic environment: the user's `$HOME` directory is defined and is the current directory, the `LANG` variable is set to `C` and the `PATH` is set to the basic `/usr/local/bin:/usr/bin:/bin` as defined in a system-wide file `pbs_environment`. Nothing that would normally be set up by a system shell profile or user shell profile is defined, unlike the environment for the main job script.

Another choice is for the `pbsdsh` command in your main job script to invoke your program via a shell, like `sh` or `bash`, so that it gives an initialized environment for each instance. Users can create a small script `runme.sh`, which is used to invoke the program:

```
#!/bin/bash
# Small script which invokes the program based on what was passed on its
# command line.
#
# This script is executed by the bash shell which will initialize all
# environment variables as usual.
$@
```

Now, the script is invoked using the `pbsdsh` tool:

```
#!/bin/bash
#
#PBS -l nodes=2:ppn=4

APP_PATH=~/packages/hpx/bin/hello_world_distributed
APP_OPTIONS=
```

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```
pbsdsh -u runme.sh $APP_PATH $APP_OPTIONS --hpx:nodes=`cat $PBS_NODEFILE`
```

All that remains now is submitting the job to the queuing system. Assuming that the contents of the PBS script were saved in the file `pbs_hello_world.sh` in the current directory, this is accomplished by typing:

```
$ qsub ./pbs_hello_world_pbs.sh
```

If the job is accepted, `qsub` will print out the assigned job ID, which may look like:

```
$ 42.supercomputer.some.university.edu
```

To check the status of your job, issue the following command:

```
$ qstat 42.supercomputer.some.university.edu
```

and look for a single-letter job status symbol. The common cases include:

- *Q* - signifies that the job is queued and awaiting its turn to be executed.
- *R* - indicates that the job is currently running.
- *C* - means that the job has completed.

The example `qstat` output below shows a job waiting for execution resources to become available:

Job id	Name	User	Time Use	S	Queue
42.supercomputer	...ello_world.sh	joe_user	0	Q	batch

After the job completes, PBS will place two files, `pbs_hello_world.sh.o42` and `pbs_hello_world.sh.e42`, in the directory where the job was submitted. The first contains the standard output and the second contains the standard error from all the nodes on which the application executed. In our example, the error output file should be empty and the standard output file should contain something similar to:

```
hello world from OS-thread 3 on locality 0
hello world from OS-thread 2 on locality 0
hello world from OS-thread 1 on locality 1
hello world from OS-thread 0 on locality 0
hello world from OS-thread 3 on locality 1
hello world from OS-thread 2 on locality 1
hello world from OS-thread 1 on locality 0
hello world from OS-thread 0 on locality 1
```

Congratulations! You have just run your first distributed *HPX* application!

How to use HPX applications with SLURM

Just like PBS (described in section *How to use HPX applications with PBS*), SLURM is a job management system which is widely used on large supercomputing systems. Any HPX application can easily be run using SLURM. This section describes how this can be done.

The easiest way to run an HPX application using SLURM is to utilize the command line tool `srun`, which interacts with the SLURM batch scheduling system:

```
$ srun -p <partition> -N <number-of-nodes> hpx-application <application-arguments>
```

Here, `<partition>` is one of the node partitions existing on the target machine (consult the machine's documentation to get a list of existing partitions) and `<number-of-nodes>` is the number of compute nodes that should be used. By default, the HPX application is started with one *locality* per node and uses all available cores on a node. You can change the number of localities started per node (for example, to account for NUMA effects) by specifying the `-n` option of `srun`. The number of cores per *locality* can be set by `-c`. The `<application-arguments>` are any application specific arguments that need to be passed on to the application.

Note: There is no need to use any of the HPX command line options related to the number of localities, number of threads, or related to networking ports. All of this information is automatically extracted from the SLURM environment by the HPX startup code.

Important: The `srun` documentation explicitly states: “If `-c` is specified without `-n`, as many tasks will be allocated per node as possible while satisfying the `-c` restriction. For instance on a cluster with 8 CPUs per node, a job request for 4 nodes and 3 CPUs per task may be allocated 3 or 6 CPUs per node (1 or 2 tasks per node) depending upon resource consumption by other jobs.” For this reason, it's recommended to always specify `-n <number-of-instances>`, even if `<number-of-instances>` is equal to one (1).

Interactive shells

To get an interactive development shell on one of the nodes, users can issue the following command:

```
$ srun -p <node-type> -N <number-of-nodes> --pty /bin/bash -l
```

After the shell has been opened, users can run their HPX application. By default, it uses all available cores. Note that if you requested one node, you don't need to do `srun` again. However, if you requested more than one node, and want to run your distributed application, you can use `srun` again to start up the distributed HPX application. It will use the resources that have been requested for the interactive shell.

Scheduling batch jobs

The above mentioned method of running HPX applications is fine for development purposes. The disadvantage that comes with `srun` is that it only returns once the application is finished. This might not be appropriate for longer-running applications (for example, benchmarks or larger scale simulations). In order to cope with that limitation, users can use the `sbatch` command.

The `sbatch` command expects a script that it can run once the requested resources are available. In order to request resources, users need to add `#SBATCH` comments in their script or provide the necessary parameters to `sbatch` directly. The parameters are the same as with `run`. The commands you need to execute are the same you would need to start your application as if you were in an interactive shell.

2.3.13 Debugging HPX applications

Using a debugger with HPX applications

Using a debugger such as `gdb` with *HPX* applications is no problem. However, there are some things to keep in mind to make the experience somewhat more productive.

Call stacks in *HPX* can often be quite unwieldy as the library is heavily templated and the call stacks can be very deep. For this reason it is sometimes a good idea compile *HPX* in `RelWithDebInfo` mode, which applies some optimizations but keeps debugging symbols. This can often compress call stacks significantly. On the other hand, stepping through the code can also be more difficult because of statements being reordered and variables being optimized away. Also, note that because *HPX* implements user-space threads and context switching, call stacks may not always be complete in a debugger.

HPX launches not only worker threads but also a few helper threads. The first thread is the main thread, which typically does no work in an *HPX* application, except at startup and shutdown. If using the default settings, *HPX* will spawn six additional threads (used for service thread pools). The first worker thread is usually the eighth thread, and most user codes will be run on these worker threads. The last thread is a helper thread used for *HPX* shutdown.

Finally, since *HPX* is a multi-threaded runtime, the following `gdb` options can be helpful:

```
set pagination off
set non-stop on
```

Non-stop mode allows users to have a single thread stop on a breakpoint without stopping all other threads as well.

Using sanitizers with HPX applications

Warning: Not all parts of *HPX* are sanitizer clean. This means that users may end up with false positives from *HPX* itself when using sanitizers for their applications.

To use sanitizers with *HPX*, turn on `HPX_WITH_SANITIZERS` and turn off `HPX_WITH_STACKOVERFLOW_DETECTION` during `CMake`¹⁷² configuration. It's recommended to also build Boost with the same sanitizers that will be used for *HPX*. The appropriate sanitizers can then be enabled using `CMake` by appending `-fsanitize=address` `-fno-omit-frame-pointer` to `CMAKE_CXX_FLAGS` and `-fsanitize=address` to `CMAKE_EXE_LINKER_FLAGS`. Replace `address` with the sanitizer that you want to use.

Debugging applications using core files

For *HPX* to generate useful core files, *HPX* has to be compiled without signal and exception handlers `HPX_WITH_DISABLED_SIGNAL_EXCEPTION_HANDLERS:BOOL`. If this option is not specified, the signal handlers change the application state. For example, after a segmentation fault the stack trace will show the signal handler. Similarly, unhandled exceptions are also caught by these handlers and the stack trace will not point to the location where the unhandled exception was thrown.

In general, core files are a helpful tool to inspect the state of the application at the moment of the crash (post-mortem debugging), without the need of attaching a debugger beforehand. This approach to debugging is especially useful if the error cannot be reliably reproduced, as only a single crashed application run is required to gain potentially helpful information like a stacktrace.

To debug with core files, the operating system first has to be told to actually write them. On most Unix systems this can be done by calling:

¹⁷² <https://www.cmake.org>

```
$ ulimit -c unlimited
```

in the shell. Now the debugger can be started up with:

```
$ gdb <application> <core file name>
```

The debugger should now display the last state of the application. The default file name for core files is `core`.

2.3.14 Optimizing HPX applications

Performance counters

Performance counters in *HPX* are used to provide information as to how well the runtime system or an application is performing. The counter data can help determine system bottlenecks, and fine-tune system and application performance. The *HPX* runtime system, its networking, and other layers provide counter data that an application can consume to provide users with information about how well the application is performing.

Applications can also use counter data to determine how much system resources to consume. For example, an application that transfers data over the network could consume counter data from a network switch to determine how much data to transfer without competing for network bandwidth with other network traffic. The application could use the counter data to adjust its transfer rate as the bandwidth usage from other network traffic increases or decreases.

Performance counters are *HPX* parallel processes that expose a predefined interface. *HPX* exposes special API functions that allow one to create, manage, and read the counter data, and release instances of performance counters. Performance Counter instances are accessed by name, and these names have a predefined structure which is described in the section *Performance counter names*. The advantage of this is that any Performance Counter can be accessed remotely (from a different *locality*) or locally (from the same *locality*). Moreover, since all counters expose their data using the same API, any code consuming counter data can be utilized to access arbitrary system information with minimal effort.

Counter data may be accessed in real time. More information about how to consume counter data can be found in the section *Consuming performance counter data*.

All *HPX* applications provide command line options related to performance counters, such as the ability to list available counter types, or periodically query specific counters to be printed to the screen or save them in a file. For more information, please refer to the section *HPX Command Line Options*.

Performance counter names

All Performance Counter instances have a name uniquely identifying each instance. This name can be used to access the counter, retrieve all related meta data, and to query the counter data (as described in the section *Consuming performance counter data*). Counter names are strings with a predefined structure. The general form of a countername is:

```
/objectname{full_instancename}/countername@parameters
```

where `full_instancename` could be either another (full) counter name or a string formatted as:

```
parentinstancename#parentindex/instancename#instanceindex
```

Each separate part of a countername (e.g., `objectname`, `countername`, `parentinstancename`, `instancename`, and `parameters`) should start with a letter ('a'...'z', 'A'...'Z') or an underscore character ('_'), optionally followed by letters, digits ('0'...'9'), hyphen ('-'), or underscore characters. Whitespace is not allowed inside a counter name. The characters '/', '{', '}', '#', and '@' have a special meaning and are used to delimit the different parts of the counter name.

The parts `parentinstanceindex` and `instanceindex` are integers. If an index is not specified, *HPX* will assume a default of `-1`.

Two counter name examples

This section gives examples of both simple counter names and aggregate counter names. For more information on simple and aggregate counter names, please see *Performance counter instances*.

An example of a well-formed (and meaningful) simple counter name would be:

```
/threads{locality#0/total}/count/cumulative
```

This counter returns the current cumulative number of executed (retired) *HPX* threads for the *locality* `0`. The counter type of this counter is `/threads/count/cumulative` and the full instance name is `locality#0/total`. This counter type does not require an `instanceindex` or `parameters` to be specified.

In this case, the `parentindex` (the `'0'`) designates the *locality* for which the counter instance is created. The counter will return the number of *HPX* threads retired on that particular *locality*.

Another example for a well formed (aggregate) counter name is:

```
/statistics{/threads{locality#0/total}/count/cumulative}/average@500
```

This counter takes the simple counter from the first example, samples its values every `500` milliseconds, and returns the average of the value samples whenever it is queried. The counter type of this counter is `/statistics/average` and the instance name is the full name of the counter for which the values have to be averaged. In this case, the `parameters` (the `'500'`) specify the sampling interval for the averaging to take place (in milliseconds).

Performance counter types

Every performance counter belongs to a specific performance counter type which classifies the counters into groups of common semantics. The type of a counter is identified by the `objectname` and the `countername` parts of the name.

```
/objectname/countername
```

When an application starts *HPX* will register all available counter types on each of the localities. These counter types are held in a special performance counter registration database, which can be used to retrieve the meta data related to a counter type and to create counter instances based on a given counter instance name.

Performance counter instances

The `full_instancename` distinguishes different counter instances of the same counter type. The formatting of the `full_instancename` depends on the counter type. There are two types of counters: simple counters, which usually generate the counter values based on direct measurements, and aggregate counters, which take another counter and transform its values before generating their own counter values. An example for a simple counter is given *above*: counting retired *HPX* threads. An aggregate counter is shown as an example *above* as well: calculating the average of the underlying counter values sampled at constant time intervals.

While simple counters use instance names formatted as `parentinstancename#parentindex/instancename#instanceindex`, most aggregate counters have the full counter name of the embedded counter as their instance name.

Not all simple counter types require specifying all four elements of a full counter instance name; some of the parts (`parentinstancename`, `parentindex`, `instancename`, and `instanceindex`) are optional for specific counters.

Please refer to the documentation of a particular counter for more information about the formatting requirements for the name of this counter (see *Existing HPX performance counters*).

The `parameters` are used to pass additional information to a counter at creation time. They are optional, and they fully depend on the concrete counter. Even if a specific counter type allows additional parameters to be given, those usually are not required as sensible defaults will be chosen. Please refer to the documentation of a particular counter for more information about what parameters are supported, how to specify them, and what default values are assumed (see also *Existing HPX performance counters*).

Every *locality* of an application exposes its own set of performance counter types and performance counter instances. The set of exposed counters is determined dynamically at application start based on the execution environment of the application. For instance, this set is influenced by the current hardware environment for the *locality* (such as whether the *locality* has access to accelerators), and the software environment of the application (such as the number of OS threads used to execute *HPX* threads).

Using wildcards in performance counter names

It is possible to use wildcard characters when specifying performance counter names. Performance counter names can contain two types of wildcard characters:

- Wildcard characters in the performance counter type
- Wildcard characters in the performance counter instance name

A wildcard character has a meaning which is very close to usual file name wildcard matching rules implemented by common shells (like bash).

Table 2.26: Wildcard characters in the performance counter type

Wild-card	Description
*	This wildcard character matches any number (zero or more) of arbitrary characters.
?	This wildcard character matches any single arbitrary character.
[. . .]	This wildcard character matches any single character from the list of specified within the square brackets.

Table 2.27: Wildcard characters in the performance counter instance name

Wild-card	Description
*	This wildcard character matches any <i>locality</i> or any thread, depending on whether it is used for <code>locality#*</code> or <code>worker-thread#*</code> . No other wildcards are allowed in counter instance names.

Consuming performance counter data

You can consume performance data using either the command line interface, the *HPX* application or the *HPX* API. The command line interface is easier to use, but it is less flexible and does not allow one to adjust the behaviour of your application at runtime. The command line interface provides a convenience abstraction but simplified abstraction for querying and logging performance counter data for a set of performance counters.

Consuming performance counter data from the command line

HPX provides a set of predefined command line options for every application that uses `hpx::init` for its initialization. While there are many more command line options available (see *HPX Command Line Options*), the set of options related to performance counters allows one to list existing counters, and query existing counters once at application termination or repeatedly after a constant time interval.

The following table summarizes the available command line options:

Table 2.28: HPX Command Line Options Related to Performance Counters

Command line option	Description
<code>--hpx:print-counter</code>	Prints the specified performance counter either repeatedly and/or at the times specified by <code>--hpx:print-counter-at</code> (see also option <code>--hpx:print-counter-interval</code>).
<code>--hpx:print-counter-reset</code>	Prints the specified performance counter either repeatedly and/or at the times specified by <code>--hpx:print-counter-at</code> . Reset the counter after the value is queried (see also option <code>--hpx:print-counter-interval</code>).
<code>--hpx:print-counter-interval</code>	Prints the performance counter(s) specified with <code>--hpx:print-counter</code> repeatedly after the time interval (specified in milliseconds) (default:0 which means print once at shutdown).
<code>--hpx:print-counter-destination</code>	Prints the performance counter(s) specified with <code>--hpx:print-counter</code> to the given file (default: console).
<code>--hpx:list-counters</code>	List the names of all registered performance counters.
<code>--hpx:list-counter-infos</code>	List the description of all registered performance counters.
<code>--hpx:print-counter-format</code>	Prints the performance counter(s) specified with <code>--hpx:print-counter</code> . Possible formats in CSV format with header or without any header (see option <code>--hpx:no-csv-header</code>), possible values: <code>csv</code> (prints counter values in CSV format with full names as header) <code>csv-short</code> (prints counter values in CSV format with shortnames provided with <code>--hpx:print-counter</code> as <code>--hpx:print-counter-shortname, full-countername</code>).
<code>--hpx:no-csv-header</code>	Prints the performance counter(s) specified with <code>--hpx:print-counter</code> and <code>csv</code> or <code>csv-short</code> format specified with <code>--hpx:print-counter-format</code> without header.
<code>--hpx:print-counter-at arg</code>	Prints the performance counter(s) specified with <code>--hpx:print-counter</code> (or <code>--hpx:print-counter-reset</code>) at the given point in time. Possible argument values: <code>startup</code> , <code>shutdown</code> (default), <code>noshutdown</code> .
<code>--hpx:reset-counters</code>	Resets the performance counter(s) specified with <code>--hpx:print-counter</code> after they have been evaluated.
<code>--hpx:print-counter-type</code>	Append counter type description to generated output.
<code>--hpx:print-color</code>	Prints color in its own local counters.

While the options `--hpx:list-counters` and `--hpx:list-counter-infos` give a short list of all available counters, the full documentation for those can be found in the section *Existing HPX performance counters*.

A simple example

All of the commandline options mentioned above can be tested using the `hello_world_distributed` example.

Listing all available counters `hello_world_distributed --hpx:list-counters` yields:

```
List of available counter instances (replace * below with the appropriate
sequence number)
-----
/agas/count/allocate /agas/count/bind /agas/count/bind_gid
/agas/count/bind_name ... /threads{locality#*/allocator#*/count/objects
/threads{locality#*/total}/count/stack-recycles
/threads{locality#*/total}/idle-rate
/threads{locality#*/worker-thread#*/idle-rate
```

Providing more information about all available counters, `hello_world_distributed --hpx:list-counter-infos` yields:

```
Information about available counter instances (replace * below with the
appropriate sequence number)
-----
fullname: /agas/count/allocate helptext: returns the number of invocations of
the AGAS service 'allocate' type: counter_type::raw version: 1.0.0
-----
-----
fullname: /agas/count/bind helptext: returns the number of invocations of the
AGAS service 'bind' type: counter_type::raw version: 1.0.0
-----
-----
fullname: /agas/count/bind_gid helptext: returns the number of invocations of
the AGAS service 'bind_gid' type: counter_type::raw version: 1.0.0
-----
-----
...

```

This command will not only list the counter names but also a short description of the data exposed by this counter.

Note: The list of available counters may differ depending on the concrete execution environment (hardware or software) of your application.

Requesting the counter data for one or more performance counters can be achieved by invoking `hello_world_distributed` with a list of counter names:

```
$ hello_world_distributed \
  --hpx:print-counter=/threads{locality#0/total}/count/cumulative \
  --hpx:print-counter=/agas{locality#0/total}/count/bind
```

which yields for instance:

```
hello world from OS-thread 0 on locality 0
/threads{locality#0/total}/count/cumulative,1,0.212527,[s],33
/agas{locality#0/total}/count/bind,1,0.212790,[s],11
```

The first line is the normal output generated by `hello_world_distributed` and has no relation to the counter data listed. The last two lines contain the counter data as gathered at application shutdown. These lines have six fields, the counter name, the sequence number of the counter invocation, the time stamp at which this information has been sampled, the unit of measure for the time stamp, the actual counter value and an optional unit of measure for the counter value.

Note: The command line option `--hpx:print-counter-types` will append a seventh field to the generated output. This field will hold an abbreviated counter type.

The actual counter value can be represented by a single number (for counters returning singular values) or a list of numbers separated by `' '` (for counters returning an array of values, like for instance a histogram).

Note: The name of the performance counter will be enclosed in double quotes `''` if it contains one or more commas `,`.

Requesting to query the counter data once after a constant time interval with this command line:

```
$ hello_world_distributed \
  --hpx:print-counter=/threads{locality#0/total}/count/cumulative \
  --hpx:print-counter=/agas{locality#0/total}/count/bind \
  --hpx:print-counter-interval=20
```

yields for instance (leaving off the actual console output of the `hello_world_distributed` example for brevity):

```
threads{locality#0/total}/count/cumulative,1,0.002409,[s],22
agas{locality#0/total}/count/bind,1,0.002542,[s],9
threads{locality#0/total}/count/cumulative,2,0.023002,[s],41
agas{locality#0/total}/count/bind,2,0.023557,[s],10
threads{locality#0/total}/count/cumulative,3,0.037514,[s],46
agas{locality#0/total}/count/bind,3,0.038679,[s],10
```

The command `--hpx:print-counter-destination=<file>` will redirect all counter data gathered to the specified file name, which avoids cluttering the console output of your application.

The command line option `--hpx:print-counter` supports using a limited set of wildcards for a (very limited) set of use cases. In particular, all occurrences of `#*` as in `locality#*` and in `worker-thread#*` will be automatically expanded to the proper set of performance counter names representing the actual environment for the executed program. For instance, if your program is utilizing four worker threads for the execution of *HPX* threads (see command line option `--hpx:threads`) the following command line

```
$ hello_world_distributed \
  --hpx:threads=4 \
  --hpx:print-counter=/threads{locality#0/worker-thread#*}/count/cumulative
```

will print the value of the performance counters monitoring each of the worker threads:

```
hello world from OS-thread 1 on locality 0
hello world from OS-thread 0 on locality 0
hello world from OS-thread 3 on locality 0
hello world from OS-thread 2 on locality 0
/threads{locality#0/worker-thread#0}/count/cumulative,1,0.0025214,[s],27
/threads{locality#0/worker-thread#1}/count/cumulative,1,0.0025453,[s],33
```

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```
/threads{locality#0/worker-thread#2}/count/cumulative,1,0.0025683,[s],29
/threads{locality#0/worker-thread#3}/count/cumulative,1,0.0025904,[s],33
```

The command `--hpx:print-counter-format` takes values `csv` and `csv-short` to generate CSV formatted counter values with a header.

With format as `csv`:

```
$ hello_world_distributed \
  --hpx:threads=2 \
  --hpx:print-counter-format csv \
  --hpx:print-counter /threads{locality#*/total}/count/cumulative \
  --hpx:print-counter /threads{locality#*/total}/count/cumulative-phases
```

will print the values of performance counters in CSV format with the full countername as a header:

```
hello world from OS-thread 1 on locality 0
hello world from OS-thread 0 on locality 0
/threads{locality#*/total}/count/cumulative,/threads{locality#*/total}/count/cumulative-
↪phases
39,93
```

With format `csv-short`:

```
$ hello_world_distributed \
  --hpx:threads 2 \
  --hpx:print-counter-format csv-short \
  --hpx:print-counter cumulative,/threads{locality#*/total}/count/cumulative \
  --hpx:print-counter phases,/threads{locality#*/total}/count/cumulative-phases
```

will print the values of performance counters in CSV format with the short countername as a header:

```
hello world from OS-thread 1 on locality 0
hello world from OS-thread 0 on locality 0
cumulative,phases
39,93
```

With format `csv` and `csv-short` when used with `--hpx:print-counter-interval`:

```
$ hello_world_distributed \
  --hpx:threads 2 \
  --hpx:print-counter-format csv-short \
  --hpx:print-counter cumulative,/threads{locality#*/total}/count/cumulative \
  --hpx:print-counter phases,/threads{locality#*/total}/count/cumulative-phases \
  --hpx:print-counter-interval 5
```

will print the header only once repeating the performance counter value(s) repeatedly:

```
cum,phases
25,42
hello world from OS-thread 1 on locality 0
hello world from OS-thread 0 on locality 0
44,95
```

The command `--hpx:no-csv-header` can be used with `--hpx:print-counter-format` to print performance counter values in CSV format without any header:

```
$ hello_world_distributed \  
--hpx:threads 2 \  
--hpx:print-counter-format csv-short \  
--hpx:print-counter cumulative,/threads{locality#*/total}/count/cumulative \  
--hpx:print-counter phases,/threads{locality#*/total}/count/cumulative-phases \  
--hpx:no-csv-header
```

will print:

```
hello world from OS-thread 1 on locality 0  
hello world from OS-thread 0 on locality 0  
37,91
```

Consuming performance counter data using the HPX API

HPX provides an API that allows users to discover performance counters and to retrieve the current value of any existing performance counter from any application.

Discover existing performance counters

Retrieve the current value of any performance counter

Performance counters are specialized *HPX* components. In order to retrieve a counter value, the performance counter needs to be instantiated. *HPX* exposes a client component object for this purpose:

```
hpx::performance_counters::performance_counter counter(std::string const& name);
```

Instantiating an instance of this type will create the performance counter identified by the given name. Only the first invocation for any given counter name will create a new instance of that counter. All following invocations for a given counter name will reference the initially created instance. This ensures that at any point in time there is never more than one active instance of any of the existing performance counters.

In order to access the counter value (or to invoke any of the other functionality related to a performance counter, like `start`, `stop` or `reset`) member functions of the created client component instance should be called:

```
// print the current number of threads created on locality 0  
hpx::performance_counters::performance_counter count(  
    "/threads{locality#0/total}/count/cumulative");  
hpx::cout << count.get_value<int>().get() << std::endl;
```

For more information about the client component type, see `hpx::performance_counters::performance_counter`

Note: In the above example `count.get_value()` returns a future. In order to print the result we must append `.get()` to retrieve the value. You could write the above example like this for more clarity:

```
// print the current number of threads created on locality 0  
hpx::performance_counters::performance_counter count(  
    "/threads{locality#0/total}/count/cumulative");
```

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```
hpx::future<int> result = count.get_value<int>();
hpx::cout << result.get() << std::endl;
```

Providing performance counter data

HPX offers several ways by which you may provide your own data as a performance counter. This has the benefit of exposing additional, possibly application-specific information using the existing Performance Counter framework, unifying the process of gathering data about your application.

An application that wants to provide counter data can implement a performance counter to provide the data. When a consumer queries performance data, the *HPX* runtime system calls the provider to collect the data. The runtime system uses an internal registry to determine which provider to call.

Generally, there are two ways of exposing your own performance counter data: a simple, function-based way and a more complex, but more powerful way of implementing a full performance counter. Both alternatives are described in the following sections.

Exposing performance counter data using a simple function

The simplest way to expose arbitrary numeric data is to write a function which will then be called whenever a consumer queries this counter. Currently, this type of performance counter can only be used to expose integer values. The expected signature of this function is:

```
std::int64_t some_performance_data(bool reset);
```

The argument `bool reset` (which is supplied by the runtime system when the function is invoked) specifies whether the counter value should be reset after evaluating the current value (if applicable).

For instance, here is such a function returning how often it was invoked:

```
// The atomic variable 'counter' ensures the thread safety of the counter.
boost::atomic<std::int64_t> counter(0);

std::int64_t some_performance_data(bool reset)
{
    std::int64_t result = ++counter;
    if (reset)
        counter = 0;
    return result;
}
```

This example function exposes a linearly-increasing value as our performance data. The value is incremented on each invocation, i.e., each time a consumer requests the counter data of this performance counter.

The next step in exposing this counter to the runtime system is to register the function as a new raw counter type using the *HPX* API function `hpx::performance_counters::install_counter_type`. A counter type represents certain common characteristics of counters, like their counter type name and any associated description information. The following snippet shows an example of how to register the function `some_performance_data`, which is shown above, for a counter type named `"/test/data"`. This registration has to be executed before any consumer instantiates, and queries an instance of this counter type:

```

#include <hpx/include/performance_counters.hpp>

void register_counter_type()
{
    // Call the HPX API function to register the counter type.
    hpx::performance_counters::install_counter_type(
        "/test/data", // counter type name
        &some_performance_data, // function providing counter_
↪data
        "returns a linearly increasing counter value" // description text (optional)
        "" // unit of measure (optional)
    );
}

```

Now it is possible to instantiate a new counter instance based on the naming scheme `"/test{locality#*/total}/data"` where `*` is a zero-based integer index identifying the *locality* for which the counter instance should be accessed. The function `hpx::performance_counters::install_counter_type` enables users to instantiate exactly one counter instance for each *locality*. Repeated requests to instantiate such a counter will return the same instance, i.e., the instance created for the first request.

If this counter needs to be accessed using the standard *HPX* command line options, the registration has to be performed during application startup, before `hpx_main` is executed. The best way to achieve this is to register an *HPX* startup function using the API function `hpx::register_startup_function` before calling `hpx::init` to initialize the runtime system:

```

int main(int argc, char* argv[])
{
    // By registering the counter type we make it available to any consumer
    // who creates and queries an instance of the type "/test/data".
    //
    // This registration should be performed during startup. The
    // function 'register_counter_type' should be executed as an HPX thread right
    // before hpx_main is executed.
    hpx::register_startup_function(&register_counter_type);

    // Initialize and run HPX.
    return hpx::init(argc, argv);
}

```

Please see the code in `simplest_performance_counter.cpp` for a full example demonstrating this functionality.

Implementing a full performance counter

Sometimes, the simple way of exposing a single value as a performance counter is not sufficient. For that reason, *HPX* provides a means of implementing full performance counters which support:

- Retrieving the descriptive information about the performance counter
- Retrieving the current counter value
- Resetting the performance counter (value)
- Starting the performance counter
- Stopping the performance counter

- Setting the (initial) value of the performance counter

Every full performance counter will implement a predefined interface:

```
// Copyright (c) 2007-2023 Hartmut Kaiser
//
// SPDX-License-Identifier: BSL-1.0
// Distributed under the Boost Software License, Version 1.0. (See accompanying
// file LICENSE_1_0.txt or copy at http://www.boost.org/LICENSE_1_0.txt)

#pragma once

#include <hpx/config.hpp>
#include <hpx/async_base/launch_policy.hpp>
#include <hpx/components/client_base.hpp>
#include <hpx/functional/bind_front.hpp>
#include <hpx/futures/future.hpp>
#include <hpx/modules/execution.hpp>

#include <hpx/performance_counters/counters_fwd.hpp>
#include <hpx/performance_counters/server/base_performance_counter.hpp>

#include <string>
#include <utility>
#include <vector>

#include <hpx/config/warnings_prefix.hpp>

////////////////////////////////////////////////////////////////////////////////////////////////////////////////////////////////
namespace hpx::performance_counters {
    //////////////////////////////////////////////////////////////////////////////////////////////////////////////////////////////////
    struct HPX_EXPORT performance_counter
        : components::client_base<performance_counter,
          server::base_performance_counter>
    {
        using base_type = components::client_base<performance_counter,
          server::base_performance_counter>;

        performance_counter() = default;

        explicit performance_counter(std::string const& name);

        performance_counter(
            std::string const& name, hpx::id_type const& locality);

        performance_counter(id_type const& id)
            : base_type(id)
        {
        }

        performance_counter(future<id_type>&& id)
            : base_type(HPX_MOVE(id))
        {
        }
    }
}
```

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```

}

performance_counter(hpx::future<performance_counter>&& c)
    : base_type(HPX_MOVE(c))
{
}

////////////////////////////////////
future<counter_info> get_info() const;
counter_info get_info(
    launch::sync_policy, error_code& ec = throws) const;

future<counter_value> get_counter_value(bool reset) const;
counter_value get_counter_value(
    launch::sync_policy, bool reset, error_code& ec = throws) const;

future<counter_value> get_counter_value() const;
counter_value get_counter_value(
    launch::sync_policy, error_code& ec = throws) const;

future<counter_values_array> get_counter_values_array(bool reset) const;
counter_values_array get_counter_values_array(
    launch::sync_policy, bool reset, error_code& ec = throws) const;

future<counter_values_array> get_counter_values_array() const;
counter_values_array get_counter_values_array(
    launch::sync_policy, error_code& ec = throws) const;

////////////////////////////////////
future<bool> start() const;
bool start(launch::sync_policy, error_code& ec = throws) const;

future<bool> stop() const;
bool stop(launch::sync_policy, error_code& ec = throws) const;

future<void> reset() const;
void reset(launch::sync_policy, error_code& ec = throws) const;

future<void> reinit(bool reset = true) const;
void reinit(launch::sync_policy, bool reset = true,
    error_code& ec = throws) const;

////////////////////////////////////
future<std::string> get_name() const;
std::string get_name(
    launch::sync_policy, error_code& ec = throws) const;

private:
    template <typename T>
    static T extract_value(future<counter_value>&& value)
    {
        return value.get().get_value<T>();
    }

```

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```

    }

    public:
        template <typename T>
        future<T> get_value(bool reset = false)
        {
            return get_counter_value(reset).then(hpx::launch::sync,
                hpx::bind_front(&performance_counter::extract_value<T>));
        }
        template <typename T>
        T get_value(
            launch::sync_policy, bool reset = false, error_code& ec = throws)
        {
            return get_counter_value(launch::sync, reset).get_value<T>(ec);
        }

        template <typename T>
        future<T> get_value() const
        {
            return get_counter_value(false).then(hpx::launch::sync,
                hpx::bind_front(&performance_counter::extract_value<T>));
        }
        template <typename T>
        T get_value(launch::sync_policy, error_code& ec = throws) const
        {
            return get_counter_value(launch::sync, false).get_value<T>(ec);
        }
    };

    // Return all counters matching the given name (with optional wild cards).
    HPX_EXPORT std::vector<performance_counter> discover_counters(
        std::string const& name, error_code& ec = throws);
} // namespace hpx::performance_counters

#include <hpx/config/warnings_suffix.hpp>

```

In order to implement a full performance counter, you have to create an *HPX* component exposing this interface. To simplify this task, *HPX* provides a ready-made base class which handles all the boiler plate of creating a component for you. The remainder of this section will explain the process of creating a full performance counter based on the *Sine* example, which you can find in the directory `examples/performance_counters/sine/`.

The base class is defined in the header file `base_performance_counter.hpp` as:

```

// Copyright (c) 2007-2023 Hartmut Kaiser
//
// SPDX-License-Identifier: BSL-1.0
// Distributed under the Boost Software License, Version 1.0. (See accompanying
// file LICENSE_1_0.txt or copy at http://www.boost.org/LICENSE_1_0.txt)

#pragma once

#include <hpx/config.hpp>
#include <hpx/actions_base/component_action.hpp>

```

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```

#include <hpx/components_base/component_type.hpp>
#include <hpx/components_base/server/component_base.hpp>
#include <hpx/performance_counters/counters.hpp>
#include <hpx/performance_counters/server/base_performance_counter.hpp>
#include <hpx/runtime_local/get_locality_id.hpp>

/////////////////////////////////////////////////////////////////
//[performance_counter_base_class
namespace hpx::performance_counters {

    template <typename Derived>
    class base_performance_counter;
} // namespace hpx::performance_counters
//]

/////////////////////////////////////////////////////////////////
namespace hpx::performance_counters {

    template <typename Derived>
    class base_performance_counter
        : public hpx::performance_counters::server::base_performance_counter
        , public hpx::components::component_base<Derived>
    {
    private:
        using base_type = hpx::components::component_base<Derived>;

    public:
        using type_holder = Derived;
        using base_type_holder =
            hpx::performance_counters::server::base_performance_counter;

        base_performance_counter() = default;

        explicit base_performance_counter(
            hpx::performance_counters::counter_info const& info)
            : base_type_holder(info)
        {
        }

        // Disambiguate finalize() which is implemented in both base classes
        void finalize()
        {
            base_type_holder::finalize();
            base_type::finalize();
        }

        hpx::naming::address get_current_address() const
        {
            return hpx::naming::address(
                hpx::naming::get_gid_from_locality_id(hpx::get_locality_id()),
                hpx::components::get_component_type<Derived>(),
                const_cast<Derived*>(static_cast<Derived const*>(this)));
        }
    };
}

```

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```

    }
};
} // namespace hpx::performance_counters

```

The single template parameter is expected to receive the type of the derived class implementing the performance counter. In the Sine example this looks like:

```

// Copyright (c) 2007-2012 Hartmut Kaiser
//
// SPDX-License-Identifier: BSL-1.0
// Distributed under the Boost Software License, Version 1.0. (See accompanying
// file LICENSE_1_0.txt or copy at http://www.boost.org/LICENSE_1_0.txt)

#pragma once

#include <hpx/config.hpp>
#if !defined(HPX_COMPUTE_DEVICE_CODE)
#include <hpx/hpx.hpp>
#include <hpx/include/lcos_local.hpp>
#include <hpx/include/performance_counters.hpp>
#include <hpx/include/util.hpp>

#include <cstdint>

namespace performance_counters { namespace sine { namespace server {
///////////////////////////////////////////////////////////////////
//[sine_counter_definition
class sine_counter
: public hpx::performance_counters::base_performance_counter<sine_counter>
//]
{
public:
    sine_counter()
        : current_value_(0)
        , evaluated_at_(0)
    {
    }
    explicit sine_counter(
        hpx::performance_counters::counter_info const& info);

    /// This function will be called in order to query the current value of
    /// this performance counter
    hpx::performance_counters::counter_value get_counter_value(bool reset);

    /// The functions below will be called to start and stop collecting
    /// counter values from this counter.
    bool start();
    bool stop();

    /// finalize() will be called just before the instance gets destructed
    void finalize();

```

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```
protected:
    bool evaluate();

private:
    typedef hpx::spinlock mutex_type;

    mutable mutex_type mtx_;
    double current_value_;
    std::uint64_t evaluated_at_;

    hpx::util::interval_timer timer_;
};
}}} // namespace performance_counters::sine::server
#endif
```

i.e., the type `sine_counter` is derived from the base class passing the type as a template argument (please see `simplest_performance_counter.cpp` for the full source code of the counter definition). For more information about this technique (called Curiously Recurring Template Pattern - CRTP), please see for instance the corresponding [Wikipedia article](http://en.wikipedia.org/wiki/Curiously_recurring_template_pattern)¹⁷³. This base class itself is derived from the `performance_counter` interface described above.

Additionally, a full performance counter implementation not only exposes the actual value but also provides information about:

- The point in time a particular value was retrieved.
- A (sequential) invocation count.
- The actual counter value.
- An optional scaling coefficient.
- Information about the counter status.

Existing HPX performance counters

The *HPX* runtime system exposes a wide variety of predefined performance counters. These counters expose critical information about different modules of the runtime system. They can help determine system bottlenecks and fine-tune system and application performance.

¹⁷³ http://en.wikipedia.org/wiki/Curiously_recurring_template_pattern

Table 2.29: AGAS performance counter `/agas/count/<agas_service>`

Counter type	<code>/agas/count/<agas_service></code> where <code><agas_service></code> is one of the following: <i>primary namespace services:</i> <code>route</code> , <code>bind_gid</code> , <code>resolve_gid</code> , <code>unbind_gid</code> , <code>increment_credit</code> , <code>decrement_credit</code> , <code>allocate</code> , <code>begin_migration</code> , <code>end_migration</code> <i>component namespace services:</i> <code>bind_prefix</code> , <code>bind_name</code> , <code>resolve_id</code> , <code>unbind_name</code> , <code>iterate_types</code> , <code>get_component_typename</code> , <code>num_localities_type</code> <i>locality namespace services:</i> <code>free</code> , <code>localities</code> , <code>num_localities</code> , <code>num_threads</code> , <code>resolve_locality</code> , <code>resolved_localities</code> <i>symbol namespace services:</i> <code>bind</code> , <code>resolve</code> , <code>unbind</code> , <code>iterate_names</code> , <code>on_symbol_namespace_event</code>
Counter instance formatting	<code><agas_instance>/total</code> where <code><agas_instance></code> is the name of the <i>AGAS</i> service to query. Currently, this value will be <code>locality#0</code> where <code>0</code> is the root <i>locality</i> (the id of the <i>locality</i> hosting the <i>AGAS</i> service). The value for <code>*</code> can be any <i>locality</i> id for the following <code><agas_service></code> : <code>route</code> , <code>bind_gid</code> , <code>resolve_gid</code> , <code>unbind_gid</code> , <code>increment_credit</code> , <code>decrement_credit</code> , <code>bin</code> , <code>resolve</code> , <code>unbind</code> , and <code>iterate_names</code> (only the primary and symbol <i>AGAS</i> service components live on all localities, whereas all other <i>AGAS</i> services are available on <code>locality#0</code> only).
Description	Returns the total number of invocations of the specified <i>AGAS</i> service since its creation.

Table 2.30: AGAS performance counter `/agas/<agas_service_category>/count`

Counter type	<code>/agas/<agas_service_category>/count</code> where <code><agas_service_category></code> is one of the following: <code>primary</code> , <code>locality</code> , <code>component</code> or <code>symbol</code>
Counter instance formatting	<code><agas_instance>/total</code> where <code><agas_instance></code> is the name of the <i>AGAS</i> service to query. Currently, this value will be <code>locality#0</code> where <code>0</code> is the root <i>locality</i> (the id of the <i>locality</i> hosting the <i>AGAS</i> service). Except for <code><agas_service_category></code> , <code>primary</code> or <code>symbol</code> for which the value for <code>*</code> can be any <i>locality</i> id (only the primary and symbol <i>AGAS</i> service components live on all localities, whereas all other <i>AGAS</i> services are available on <code>locality#0</code> only).
Description	Returns the overall total number of invocations of all <i>AGAS</i> services provided by the given <i>AGAS</i> service category since its creation.

Table 2.31: AGAS performance counter `/agas/<agas_service_category>/count`

Counter type	<code>/agas/<agas_service_category>/count</code> where <code><agas_service_category></code> is one of the following: <code>primary</code> , <code>locality</code> , <code>component</code> or <code>symbol</code>
Counter instance formatting	<code><agas_instance>/total</code> where <code><agas_instance></code> is the name of the <i>AGAS</i> service to query. Currently, this value will be <code>locality#0</code> where <code>0</code> is the root <i>locality</i> (the id of the <i>locality</i> hosting the <i>AGAS</i> service). Except for <code><agas_service_category></code> , <code>primary</code> or <code>symbol</code> for which the value for <code>*</code> can be any <i>locality</i> id (only the primary and symbol <i>AGAS</i> service components live on all localities, whereas all other <i>AGAS</i> services are available on <code>locality#0</code> only).
Description	Returns the overall total number of invocations of all <i>AGAS</i> services provided by the given <i>AGAS</i> service category since its creation.

Table 2.32: AGAS performance counter `agas/time/<agas_service>`

Counter type	<code>agas/time/<agas_service></code> where <code><agas_service></code> is one of the following: <i>primary namespace services:</i> <code>route, bind_gid, resolve_gid, unbind_gid, increment_credit, decrement_credit, allocate begin_migration, end_migration</code> <i>component namespace services:</i> <code>bind_prefix, bind_name, resolve_id, unbind_name, iterate_types, get_component_typename, num_localities_type</code> <i>locality namespace services:</i> <code>free, localities, num_localities, num_threads, resolve_locality, resolved_localities</code> <i>symbol namespace services:</i> <code>bind, resolve, unbind, iterate_names, on_symbol_namespace_event</code>
Counter instance formatting	<code><agas_instance>/total</code> where <code><agas_instance></code> is the name of the <i>AGAS</i> service to query. Currently, this value will be <code>locality#0</code> where <code>0</code> is the root <i>locality</i> (the id of the <i>locality</i> hosting the <i>AGAS</i> service). The value for <code>*</code> can be any <i>locality</i> id for the following <code><agas_service></code> : <code>route, bind_gid, resolve_gid, unbind_gid, increment_credit, decrement_credit, bin, resolve, unbind, and iterate_names</code> (only the primary and symbol <i>AGAS</i> service components live on all localities, whereas all other <i>AGAS</i> services are available on <code>locality#0</code> only).
Description	Returns the overall execution time of the specified <i>AGAS</i> service since its creation (in nanoseconds).

Table 2.33: AGAS performance counter `/agas/<agas_service_category>/time``

Counter type	<code>/agas/<agas_service_category>/time`</code> where <code><agas_service_category></code> is one of the following: <code>primary, locality, component or symbol</code>
Counter instance formatting	<code><agas_instance>/total</code> where <code><agas_instance></code> is the name of the <i>AGAS</i> service to query. Currently, this value will be <code>locality#0</code> where <code>0</code> is the root <i>locality</i> (the id of the <i>locality</i> hosting the <i>AGAS</i> service). Except for <code><agas_service_category></code> <code>primary</code> or <code>symbol</code> for which the value for <code>*</code> can be any <i>locality</i> id (only the primary and symbol <i>AGAS</i> service components live on all localities, whereas all other <i>AGAS</i> services are available on <code>locality#0</code> only).
Description	Returns the overall execution time of all <i>AGAS</i> services provided by the given <i>AGAS</i> service category since its creation (in nanoseconds).

Table 2.34: AGAS performance counter `/agas/count/entries`

Counter type	<code>/agas/count/entries</code>
Counter instance formatting	<code>locality#*/total</code> where <code>*</code> is the <i>locality</i> id of the <i>locality</i> the <i>AGAS</i> cache should be queried. The <i>locality</i> id is a (zero based) number identifying the <i>locality</i> .
Description	Returns the number of cache entries resident in the <i>AGAS</i> cache of the specified <i>locality</i> (see <code><cache_statistics></code>).

Table 2.35: AGAS performance counter /agas/count/<cache_statistics>

Counter type	/agas/count/<cache_statistics> where <cache_statistics> is one of the following: cache/evictions, cache/hits, cache/insertions, cache/misses
Counter instance formatting	locality#*/total where * is the <i>locality</i> id of the <i>locality</i> the <i>AGAS</i> cache should be queried. The <i>locality</i> id is a (zero based) number identifying the <i>locality</i>
Description	Returns the number of cache events (evictions, hits, inserts, and misses) in the <i>AGAS</i> cache of the specified <i>locality</i> (see <cache_statistics>).

Table 2.36: AGAS performance counter /agas/count/<full_cache_statistics>

Counter type	/agas/count/<full_cache_statistics> where <full_cache_statistics> is one of the following: cache/get_entry, cache/insert_entry, cache/update_entry, cache/erase_entry
Counter instance formatting	locality#*/total where * is the <i>locality</i> id of the <i>locality</i> the <i>AGAS</i> cache should be queried. The <i>locality</i> id is a (zero based) number identifying the <i>locality</i> .
Description	Returns the number of invocations of the specified cache API function of the <i>AGAS</i> cache.

Table 2.37: AGAS performance counter /agas/time/<full_cache_statistics>

Counter type	/agas/time/<full_cache_statistics> where <full_cache_statistics> is one of the following: cache/get_entry, cache/insert_entry, cache/update_entry, cache/erase_entry
Counter instance formatting	locality#*/total where * is the <i>locality</i> id of the <i>locality</i> the <i>AGAS</i> cache should be queried. The <i>locality</i> id is a (zero based) number identifying the <i>locality</i> .
Description	Returns the overall time spent executing of the specified API function of the <i>AGAS</i> cache.

Table 2.38: Parcel layer performance counter `/data/count/<connection_type>/<operation>`

Counter type	<code>/data/count/<connection_type>/<operation></code> where: <code><operation></code> is one of the following: <code>sent</code> , <code>received</code> <code><connection_type></code> is one of the following: <code>tcp</code> , <code>mpi</code>
Counter instance formatting	<code>locality#*/total</code> where <code>*</code> is the <i>locality</i> id of the <i>locality</i> the overall number of transmitted bytes should be queried for. The <i>locality</i> id is a (zero based) number identifying the <i>locality</i> .
Description	Returns the overall number of raw (uncompressed) bytes sent or received (see <code><operation></code> , e.g. <code>sent</code> or <code>received</code>) for the specified <code><connection_type></code> . The performance counters are available only if the compile time constant <code>HPX_HAVE_PARCELPORNT_COUNTERS</code> was defined while compiling the <i>HPX</i> core library (which is not defined by default). The corresponding cmake configuration constant is <code>HPX_WITH_PARCELPORNT_COUNTERS</code> . The performance counters for the connection type <code>mpi</code> are available only if the compile time constant <code>HPX_HAVE_PARCELPORNT_MPI</code> was defined while compiling the <i>HPX</i> core library (which is not defined by default). The corresponding cmake configuration constant is <code>HPX_WITH_PARCELPORNT_MPI</code> . Please see <i>CMake options</i> for more details.

Table 2.39: Parcel layer performance counter `/data/time/<connection_type>/<operation>`

Counter type	<code>/data/time/<connection_type>/<operation></code> where: <code><operation></code> is one of the following: <code>sent</code> , <code>received</code> <code><connection_type></code> is one of the following: <code>tcp</code> , <code>mpi</code>
Counter instance formatting	<code>locality#*/total</code> where <code>*</code> is the <i>locality</i> id of the <i>locality</i> the total transmission time should be queried for. The <i>locality</i> id is a (zero based) number identifying the <i>locality</i> .
Description	Returns the total time (in nanoseconds) between the start of each asynchronous transmission operation and the end of the corresponding operation for the specified <code><connection_type></code> the given <i>locality</i> (see <code><operation></code> , e.g. <code>sent</code> or <code>received</code>). The performance counters are available only if the compile time constant <code>HPX_HAVE_PARCELPORNT_COUNTERS</code> was defined while compiling the <i>HPX</i> core library (which is not defined by default). The corresponding cmake configuration constant is <code>HPX_WITH_PARCELPORNT_COUNTERS</code> . The performance counters for the connection type <code>mpi</code> are available only if the compile time constant <code>HPX_HAVE_PARCELPORNT_MPI</code> was defined while compiling the <i>HPX</i> core library (which is not defined by default). The corresponding cmake configuration constant is <code>HPX_WITH_PARCELPORNT_MPI</code> . Please see <i>CMake options</i> for more details.

Table 2.40: Parcel layer performance counter `/serialize/count/<connection_type>/<operation>`

Counter type	<code>/serialize/count/<connection_type>/<operation></code> where: <operation> is one of the following: <code>sent</code> , <code>received</code> <connection_type> is one of the following: <code>tcp</code> , <code>mpi</code>
Counter instance formatting	<code>locality#*/total</code> where * is the <i>locality</i> id of the <i>locality</i> the overall number of transmitted bytes should be queried for. The <i>locality</i> id is a (zero based) number identifying the <i>locality</i> .
Description	Returns the overall number of bytes transferred (see <operation>, e.g. <code>sent</code> or <code>received</code> possibly compressed) for the specified <connection_type> by the given <i>locality</i> . The performance counters are available only if the compile time constant <code>HPX_HAVE_PARCELPORNT_COUNTERS</code> was defined while compiling the <i>HPX</i> core library (which is not defined by default). The corresponding cmake configuration constant is <code>HPX_WITH_PARCELPORNT_COUNTERS</code> . The performance counters for the connection type <code>mpi</code> are available only if the compile time constant <code>HPX_HAVE_PARCELPORNT_MPI</code> was defined while compiling the <i>HPX</i> core library (which is not defined by default). The corresponding cmake configuration constant is <code>HPX_WITH_PARCELPORNT_MPI</code> . Please see <i>CMake options</i> for more details.
Description	If the configure-time option <code>-DHPX_WITH_PARCELPORNT_ACTION_COUNTERS=On</code> was specified, this counter allows one to specify an optional action name as its parameter. In this case the counter will report the number of bytes transmitted for the given action only.

Table 2.41: Parcel layer performance counter `/serialize/time/<connection_type>/<operation>`

Counter type	<code>/serialize/time/<connection_type>/<operation></code> where: <operation> is one of the following: <code>sent</code> , <code>received</code> <connection_type> is one of the following: <code>tcp</code> , <code>mpi</code>
Counter instance formatting	<code>locality#*/total</code> where * is the <i>locality</i> id of the <i>locality</i> the serialization time should be queried for. The <i>locality</i> id is a (zero based) number identifying the <i>locality</i> .
Description	Returns the overall time spent performing outgoing data serialization for the specified <connection_type> on the given <i>locality</i> (see <operation>, e.g. <code>sent</code> or <code>received</code>). The performance counters are available only if the compile time constant <code>HPX_HAVE_PARCELPORNT_COUNTERS</code> was defined while compiling the <i>HPX</i> core library (which is not defined by default). The corresponding cmake configuration constant is <code>HPX_WITH_PARCELPORNT_COUNTERS</code> . The performance counters for the connection type <code>mpi</code> are available only if the compile time constant <code>HPX_HAVE_PARCELPORNT_MPI</code> was defined while compiling the <i>HPX</i> core library (which is not defined by default). The corresponding cmake configuration constant is <code>HPX_WITH_PARCELPORNT_MPI</code> . Please see <i>CMake options</i> for more details.
Parameters	If the configure-time option <code>-DHPX_WITH_PARCELPORNT_ACTION_COUNTERS=On</code> was specified, this counter allows one to specify an optional action name as its parameter. In this case the counter will report the serialization time for the given action only.

Table 2.42: Parcel layer performance counter `/parcels/count/routed`

Counter type	<code>/parcels/count/routed</code>
Counter instance formatting	<code>locality#*/total</code> where * is the <i>locality</i> id of the <i>locality</i> the number of routed parcels should be queried for. The <i>locality</i> id is a (zero based) number identifying the <i>locality</i> .
Description	Returns the overall number of routed (outbound) parcels transferred by the given <i>locality</i> . Routed parcels are those which cannot directly be delivered to its destination as the local <i>AGAS</i> is not able to resolve the destination address. In this case a parcel is sent to the <i>AGAS</i> service component which is responsible for creating the destination GID (and is responsible for resolving the destination address). This <i>AGAS</i> service component will deliver the parcel to its final target.
Parameters	If the configure-time option <code>-DHPX_WITH_PARCELPOR_ACTION_COUNTERS=On</code> was specified, this counter allows one to specify an optional action name as its parameter. In this case the counter will report the number of parcels for the given action only.

Table 2.43: Parcel layer performance counter `/parcels/count/<connection_type>/<operation>`

Counter type	<code>/parcels/count/<connection_type>/<operation></code> where: <code><operation></code> is one of the following: <code>sent</code> , <code>received</code> <code><connection_type></code> is one of the following: <code>tcp</code> , <code>mpi</code>
Counter instance formatting	<code>locality#*/total</code> where * is the <i>locality</i> id of the <i>locality</i> the number of parcels should be queried for. The <i>locality</i> id is a (zero based) number identifying the <i>locality</i> .
Description	Returns the overall number of parcels transferred using the specified <code><connection_type></code> by the given <i>locality</i> (see <code><operation></code> , e.g. <code>sent</code> or <code>received</code>). The performance counters are available only if the compile time constant <code>HPX_HAVE_PARCELPOR_COUNTERS</code> was defined while compiling the <i>HPX</i> core library (which is not defined by default). The corresponding cmake configuration constant is <code>HPX_WITH_PARCELPOR_COUNTERS</code> . The performance counters for the connection type <code>mpi</code> are available only if the compile time constant <code>HPX_HAVE_PARCELPOR_MPI</code> was defined while compiling the <i>HPX</i> core library (which is not defined by default). The corresponding cmake configuration constant is <code>HPX_WITH_PARCELPOR_MPI</code> . Please see <i>CMake options</i> for more details.

Table 2.44: Parcel layer performance counter `/messages/count/<connection_type>/<operation>`

Counter type	<code>/messages/count/<connection_type>/<operation></code> where: <code><operation></code> is one of the following: <code>sent</code> , <code>received</code> <code><connection_type></code> is one of the following: <code>tcp</code> , <code>mpi</code>
Counter instance formatting	<code>locality#*/total</code> where <code>*</code> is the <i>locality</i> id of the <i>locality</i> the number of messages should be queried for. The <i>locality</i> id is a (zero based) number identifying the <i>locality</i> .
Description	Returns the overall number of messages ¹⁷⁴ transferred using the specified <code><connection_type></code> by the given <i>locality</i> (see <code><operation></code> , e.g. <code>sent</code> or <code>received</code>) The performance counters are available only if the compile time constant <code>HPX_HAVE_PARCELPORNT_COUNTERS</code> was defined while compiling the <i>HPX</i> core library (which is not defined by default). The corresponding cmake configuration constant is <code>HPX_WITH_PARCELPORNT_COUNTERS</code> . The performance counters for the connection type <code>mpi</code> are available only if the compile time constant <code>HPX_HAVE_PARCELPORNT_MPI</code> was defined while compiling the <i>HPX</i> core library (which is not defined by default). The corresponding cmake configuration constant is <code>HPX_WITH_PARCELPORNT_MPI</code> . Please see <i>CMake options</i> for more details.

Table 2.45: Parcel layer performance counter `/parcelport/count/<connection_type>/zero_copy_chunks/<operation>`

Counter type	<code>/parcelport/count/<connection_type>/zero_copy_chunks/<operation></code> where: <code><operation></code> is one of the following: <code>sent</code> , <code>received</code> <code><connection_type></code> is one of the following: <code>tcp</code> , <code>mpi</code>
Counter instance formatting	<code>locality#*/total</code> where <code>*</code> is the <i>locality</i> id of the <i>locality</i> the overall number of transmitted bytes should be queried for. The <i>locality</i> id is a (zero based) number identifying the <i>locality</i> .
Description	Returns the overall number of zero-copy chunks sent or received (see <code><operation></code> , e.g. <code>sent</code> or <code>received</code>) for the specified <code><connection_type></code> . The performance counters are available only if the compile time constant <code>HPX_HAVE_PARCELPORNT_COUNTERS</code> was defined while compiling the <i>HPX</i> core library (which is not defined by default). The corresponding cmake configuration constant is <code>HPX_WITH_PARCELPORNT_COUNTERS</code> . The performance counters for the connection type <code>mpi</code> are available only if the compile time constant <code>HPX_HAVE_PARCELPORNT_MPI</code> was defined while compiling the <i>HPX</i> core library (which is not defined by default). The corresponding cmake configuration constant is <code>HPX_WITH_PARCELPORNT_MPI</code> . Please see <i>CMake options</i> for more details.

¹⁷⁴ A message can potentially consist of more than one *parcel*.

Table 2.46: Parcel layer performance counter `/parcelport/count-max/<connection_type>/zero_copy_chunks/<operation>`

Counter type	<code>/parcelport/count-max/<connection_type>/zero_copy_chunks/<operation></code> where: <operation> is one of the following: <code>sent</code> , <code>received</code> <connection_type> is one of the following: <code>tcp</code> , <code>mpi</code>
Counter instance formatting	<code>locality#*/total</code> where * is the <i>locality</i> id of the <i>locality</i> the overall number of transmitted bytes should be queried for. The <i>locality</i> id is a (zero based) number identifying the <i>locality</i> .
Description	Returns the maximum number of zero-copy chunks sent or received per message (see <operation>, e.g. <code>sent</code> or <code>received</code>) for the specified <connection_type>. The performance counters are available only if the compile time constant <code>HPX_HAVE_PARCELPORNT_COUNTERS</code> was defined while compiling the <i>HPX</i> core library (which is not defined by default). The corresponding cmake configuration constant is <code>HPX_WITH_PARCELPORNT_COUNTERS</code> . The performance counters for the connection type <code>mpi</code> are available only if the compile time constant <code>HPX_HAVE_PARCELPORNT_MPI</code> was defined while compiling the <i>HPX</i> core library (which is not defined by default). The corresponding cmake configuration constant is <code>HPX_WITH_PARCELPORNT_MPI</code> . Please see <i>CMake options</i> for more details.

Table 2.47: Parcel layer performance counter `/parcelport/size/<connection_type>/zero_copy_chunks/<operation>`

Counter type	<code>/parcelport/size/<connection_type>/zero_copy_chunks/<operation></code> where: <operation> is one of the following: <code>sent</code> , <code>received</code> <connection_type> is one of the following: <code>tcp</code> , <code>mpi</code>
Counter instance formatting	<code>locality#*/total</code> where * is the <i>locality</i> id of the <i>locality</i> the overall number of transmitted bytes should be queried for. The <i>locality</i> id is a (zero based) number identifying the <i>locality</i> .
Description	Returns the overall size of zero-copy chunks sent or received (see <operation>, e.g. <code>sent</code> or <code>received</code>) for the specified <connection_type>. The performance counters are available only if the compile time constant <code>HPX_HAVE_PARCELPORNT_COUNTERS</code> was defined while compiling the <i>HPX</i> core library (which is not defined by default). The corresponding cmake configuration constant is <code>HPX_WITH_PARCELPORNT_COUNTERS</code> . The performance counters for the connection type <code>mpi</code> are available only if the compile time constant <code>HPX_HAVE_PARCELPORNT_MPI</code> was defined while compiling the <i>HPX</i> core library (which is not defined by default). The corresponding cmake configuration constant is <code>HPX_WITH_PARCELPORNT_MPI</code> . Please see <i>CMake options</i> for more details.

Table 2.48: Parcel layer performance counter `/parcelport/size-max/<connection_type>/zero_copy_chunks/<operation>`

Counter type	<code>/parcelport/size-max/<connection_type>/zero_copy_chunks/<operation></code> where: <operation> is one of the following: sent, received <connection_type> is one of the following: tcp, mpi
Counter instance formatting	<code>locality#*/total</code> where * is the <i>locality</i> id of the <i>locality</i> the overall number of transmitted bytes should be queried for. The <i>locality</i> id is a (zero based) number identifying the <i>locality</i> .
Description	Returns the maximum size of zero-copy chunks sent or received (see <operation>, e.g. sent or received) for the specified <connection_type>. The performance counters are available only if the compile time constant <code>HPX_HAVE_PARCELPорт_COUNTERS</code> was defined while compiling the <i>HPX</i> core library (which is not defined by default). The corresponding cmake configuration constant is <code>HPX_WITH_PARCELPорт_COUNTERS</code> . The performance counters for the connection type <code>mpi</code> are available only if the compile time constant <code>HPX_HAVE_PARCELPорт_MPI</code> was defined while compiling the <i>HPX</i> core library (which is not defined by default). The corresponding cmake configuration constant is <code>HPX_WITH_PARCELPорт_MPI</code> . Please see <i>CMake options</i> for more details.

Table 2.49: Parcel layer performance counter `/parcelport/count/<connection_type>/<cache_statistics>`

Counter type	<code>/parcelport/count/<connection_type>/<cache_statistics></code> where: <cache_statistics> is one of the following: cache/insertions, cache/evictions, cache/hits, cache/misses <connection_type> is one of the following: tcp, mpi
Counter instance formatting	<code>locality#*/total</code> where * is the <i>locality</i> id of the <i>locality</i> the number of messages should be queried for. The <i>locality</i> id is a (zero based) number identifying the <i>locality</i> .
Description	Returns the overall number cache events (evictions, hits, inserts, misses, and reclaims) for the connection cache of the given connection type on the given <i>locality</i> (see <cache_statistics, e.g. ache/insertions, cache/evictions, cache/hits, cache/misses or ``cache/reclaims``). The performance counters for the connection type <code>mpi</code> are available only if the compile time constant <code>HPX_HAVE_PARCELPорт_MPI</code> was defined while compiling the <i>HPX</i> core library (which is not defined by default). The corresponding cmake configuration constant is <code>HPX_WITH_PARCELPорт_MPI</code> . Please see <i>CMake options</i> for more details.

Table 2.50: Parcel layer performance counter `/parcelqueue/length/<operation>`

Counter type	<code>/parcelqueue/length/<operation></code> where <operation> is one of the following: sent, receive
Counter instance formatting	<code>locality#*/total</code> where * is the <i>locality</i> id of the <i>locality</i> the <i>parcel</i> queue should be queried. The <i>locality</i> id is a (zero based) number identifying the <i>locality</i> .
Description	Returns the current number of parcels stored in the <i>parcel</i> queue (see <operation> for which queue to query, e.g. sent or received).

Table 2.51: Thread manager performance counter `/threads/count/cumulative`

Counter type	<code>/threads/count/cumulative</code>
Counter instance formatting	<p><code>locality#*/total</code> or <code>locality#*/worker-thread#*</code> or <code>locality#*/pool#*/worker-thread#*</code> where: <code>locality#*</code> is defining the <i>locality</i> for which the overall number of retired <i>HPX</i>-threads should be queried for. The <i>locality</i> id (given by the <code>*</code>) is a (zero based) number identifying the <i>locality</i>. pool#* is defining the pool for which the current value of the idle-loop counter should be queried for. worker-thread#* is defining the worker thread for which the overall number of retired <i>HPX</i>-threads should be queried for. The worker thread number (given by the <code>*</code>) is a (zero based) number identifying the worker thread. The number of available worker threads is usually specified on the command line for the application using the option <code>--hpx:threads</code>. If no pool-name is specified the counter refers to the 'default' pool.</p>
Description	<p>Returns the overall number of executed (retired) <i>HPX</i>-threads on the given <i>locality</i> since application start. If the instance name is <code>total</code> the counter returns the accumulated number of retired <i>HPX</i>-threads for all worker threads (cores) on that <i>locality</i>. If the instance name is <code>worker-thread#*</code> the counter will return the overall number of retired <i>HPX</i>-threads for all worker threads separately. This counter is available only if the configuration time constant <code>HPX_WITH_THREAD_CUMULATIVE_COUNTS</code> is set to <code>ON</code> (default: <code>ON</code>).</p>

Table 2.52: Thread manager performance counter `/threads/time/average`

Counter type	<code>/threads/time/average</code>
Counter instance formatting	<p><code>locality#*/total</code> or <code>locality#*/worker-thread#*</code> or <code>locality#*/pool#*/worker-thread#*</code> where: <code>locality#*</code> is defining the <i>locality</i> for which the average time spent executing one <i>HPX</i>-thread should be queried for. The <i>locality</i> id (given by the <code>*</code>) is a (zero based) number identifying the <i>locality</i>. <code>pool#*</code> is defining the pool for which the current value of the idle-loop counter should be queried for. <code>worker-thread#*</code> is defining the worker thread for which the average time spent executing one <i>HPX</i>-thread should be queried for. The worker thread number (given by the <code>*</code>) is a (zero based) number identifying the worker thread. The number of available worker threads is usually specified on the command line for the application using the option <code>--hpx:threads</code>. If no pool-name is specified the counter refers to the 'default' pool.</p>
Description	<p>Returns the average time spent executing one <i>HPX</i>-thread on the given <i>locality</i> since application start. If the instance name is <code>total</code> the counter returns the average time spent executing one <i>HPX</i>-thread for all worker threads (cores) on that <i>locality</i>. If the instance name is <code>worker-thread#*</code> the counter will return the average time spent executing one <i>HPX</i>-thread for all worker threads separately. This counter is available only if the configuration time constants <code>HPX_WITH_THREAD_CUMULATIVE_COUNTS</code> (default: <code>ON</code>) and <code>HPX_WITH_THREAD_IDLE_RATES</code> are set to <code>ON</code> (default: <code>OFF</code>). The unit of measure for this counter is nanosecond [ns].</p>

Table 2.53: Thread manager performance counter `/threads/time/average-overhead`

Counter type	<code>/threads/time/average-overhead</code>
Counter instance formatting	<p><code>locality#*/total</code> or <code>locality#*/worker-thread#*</code> or <code>locality#*/pool#*/worker-thread#*</code></p> <p>where: <code>locality#*</code> is defining the <i>locality</i> for which the average overhead spent executing one <i>HPX</i>-thread should be queried for. The <i>locality</i> id (given by the <code>*</code>) is a (zero based) number identifying the <i>locality</i>. <code>pool#*</code> is defining the pool for which the current value of the idle-loop counter should be queried for. <code>worker-thread#*</code> is defining the worker thread for which the average overhead spent executing one <i>HPX</i>-thread should be queried for. The worker thread number (given by the <code>*</code>) is a (zero based) number identifying the worker thread. The number of available worker threads is usually specified on the command line for the application using the option <code>--hpx:threads</code>. If no pool-name is specified the counter refers to the 'default' pool.</p>
Description	<p>Returns the average time spent on overhead while executing one <i>HPX</i>-thread on the given <i>locality</i> since application start. If the instance name is <code>total</code> the counter returns the average time spent on overhead while executing one <i>HPX</i>-thread for all worker threads (cores) on that <i>locality</i>. If the instance name is <code>worker-thread#*</code> the counter will return the average time spent on overhead executing one <i>HPX</i>-thread for all worker threads separately. This counter is available only if the configuration time constants <code>HPX_WITH_THREAD_CUMULATIVE_COUNTS</code> (default: ON) and <code>HPX_WITH_THREAD_IDLE_RATES</code> are set to ON (default: OFF). The unit of measure for this counter is nanosecond [ns].</p>

Table 2.54: Thread manager performance counter `/threads/count/cumulative-phases`

Counter type	<code>/threads/count/cumulative-phases</code>
Counter instance formatting	<p><code>locality#*/total</code> or <code>locality#*/worker-thread#*</code> or <code>locality#*/pool#*/worker-thread#*</code></p> <p>where: <code>locality#*</code> is defining the <i>locality</i> for which the overall number of executed <i>HPX</i>-thread phases (invocations) should be queried for. The <i>locality</i> id (given by the <code>*</code>) is a (zero based) number identifying the <i>locality</i>. <code>pool#*</code> is defining the pool for which the current value of the idle-loop counter should be queried for. <code>worker-thread#*</code> is defining the worker thread for which the overall number of executed <i>HPX</i>-thread phases (invocations) should be queried for. The worker thread number (given by the <code>*</code>) is a (zero based) number identifying the worker thread. The number of available worker threads is usually specified on the command line for the application using the option <code>--hpx:threads</code>. If no pool-name is specified the counter refers to the 'default' pool.</p>
Description	<p>Returns the overall number of executed <i>HPX</i>-thread phases (invocations) on the given <i>locality</i> since application start. If the instance name is <code>total</code> the counter returns the accumulated number of executed <i>HPX</i>-thread phases (invocations) for all worker threads (cores) on that <i>locality</i>. If the instance name is <code>worker-thread#*</code> the counter will return the overall number of executed <i>HPX</i>-thread phases for all worker threads separately. This counter is available only if the configuration time constant <code>HPX_WITH_THREAD_CUMULATIVE_COUNTS</code> is set to ON (default: ON). The unit of measure for this counter is nanosecond [ns].</p>

Table 2.55: Thread manager performance counter `/threads/time/average-phase`

Counter type	<code>/threads/time/average-phase</code>
Counter instance formatting	<p><code>locality#*/total</code> or <code>locality#*/worker-thread#*</code> or <code>locality#*/pool#*/worker-thread#*</code></p> <p>where: <code>locality#*</code> is defining the <i>locality</i> for which the average time spent executing one <i>HPX</i>-thread phase (invocation) should be queried for. The <i>locality</i> id (given by the <code>*</code>) is a (zero based) number identifying the <i>locality</i>. <code>pool#*</code> is defining the pool for which the current value of the idle-loop counter should be queried for. <code>worker-thread#*</code> is defining the worker thread for which the average time executing one <i>HPX</i>-thread phase (invocation) should be queried for. The worker thread number (given by the <code>*</code>) is a (zero based) number identifying the worker thread. The number of available worker threads is usually specified on the command line for the application using the option <code>--hpx:threads</code>. If no pool-name is specified the counter refers to the 'default' pool.</p>
Description	<p>Returns the average time spent executing one <i>HPX</i>-thread phase (invocation) on the given <i>locality</i> since application start. If the instance name is <code>total</code> the counter returns the average time spent executing one <i>HPX</i>-thread phase (invocation) for all worker threads (cores) on that <i>locality</i>. If the instance name is <code>worker-thread#*</code> the counter will return the average time spent executing one <i>HPX</i>-thread phase for all worker threads separately. This counter is available only if the configuration time constants <code>HPX_WITH_THREAD_CUMULATIVE_COUNTS</code> (default: ON) and <code>HPX_WITH_THREAD_IDLE_RATES</code> are set to ON (default: OFF). The unit of measure for this counter is nanosecond [ns].</p>

Table 2.56: Thread manager performance counter `/threads/time/average-phase-overhead`

Counter type	<code>/threads/time/average-phase-overhead</code>
Counter instance formatting	<p><code>locality#*/total</code> or <code>locality#*/worker-thread#*</code> or <code>locality#*/pool#*/worker-thread#*</code></p> <p>where: <code>locality#*</code> is defining the <i>locality</i> for which the average time overhead executing one <i>HPX</i>-thread phase (invocation) should be queried for. The <i>locality</i> id (given by the <code>*</code>) is a (zero based) number identifying the <i>locality</i>. <code>pool#*</code> is defining the pool for which the current value of the idle-loop counter should be queried for. <code>worker-thread#*</code> is defining the worker thread for which the average overhead executing one <i>HPX</i>-thread phase (invocation) should be queried for. The worker thread number (given by the <code>*</code>) is a (zero based) number identifying the worker thread. The number of available worker threads is usually specified on the command line for the application using the option <code>--hpx:threads</code>. If no pool-name is specified the counter refers to the 'default' pool.</p>
Description	<p>Returns the average time spent on overhead executing one <i>HPX</i>-thread phase (invocation) on the given <i>locality</i> since application start. If the instance name is <code>total</code> the counter returns the average time spent on overhead while executing one <i>HPX</i>-thread phase (invocation) for all worker threads (cores) on that <i>locality</i>. If the instance name is <code>worker-thread#*</code> the counter will return the average time spent on overhead executing one <i>HPX</i>-thread phase for all worker threads separately. This counter is available only if the configuration time constants <code>HPX_WITH_THREAD_CUMULATIVE_COUNTS</code> (default: ON) and <code>HPX_WITH_THREAD_IDLE_RATES</code> are set to ON (default: OFF). The unit of measure for this counter is nanosecond [ns].</p>

Table 2.57: Thread manager performance counter `/threads/time/overall`

Counter type	<code>/threads/time/overall</code>
Counter instance formatting	<p><code>locality#*/total</code> or <code>locality#*/worker-thread#*</code> or <code>locality#*/pool#*/worker-thread#*</code></p> <p>where: <code>locality#*</code> is defining the <i>locality</i> for which the overall time spent running the scheduler should be queried for. The <i>locality</i> id (given by the <code>*</code>) is a (zero based) number identifying the <i>locality</i>. <code>pool#*</code> is defining the pool for which the current value of the idle-loop counter should be queried for. <code>worker-thread#*</code> is defining the worker thread for which the overall time spent running the scheduler should be queried for. The worker thread number (given by the <code>*</code>) is a (zero based) number identifying the worker thread. The number of available worker threads is usually specified on the command line for the application using the option <code>--hpx:threads</code>. If no pool-name is specified the counter refers to the 'default' pool.</p>
Description	<p>Returns the overall time spent running the scheduler on the given <i>locality</i> since application start. If the instance name is <code>total</code> the counter returns the overall time spent running the scheduler for all worker threads (cores) on that <i>locality</i>. If the instance name is <code>worker-thread#*</code> the counter will return the overall time spent running the scheduler for all worker threads separately. This counter is available only if the configuration time constant <code>HPX_WITH_THREAD_IDLE_RATES</code> is set to ON (default: OFF). The unit of measure for this counter is nanosecond [ns].</p>

Table 2.58: Thread manager performance counter `/threads/time/cumulative`

Counter type	<code>/threads/time/cumulative</code>
Counter instance formatting	<p><code>locality#*/total</code> or <code>locality#*/worker-thread#*</code> or <code>locality#*/pool#*/worker-thread#*</code> where: <code>locality#*</code> is defining the <i>locality</i> for which the overall time spent executing all <i>HPX</i>-threads should be queried for. The <i>locality</i> id (given by the <code>*</code>) is a (zero based) number identifying the <i>locality</i>. <code>pool#*</code> is defining the pool for which the current value of the idle-loop counter should be queried for. <code>worker-thread#*</code> is defining the worker thread for which the overall time spent executing all <i>HPX</i>-threads should be queried for. The worker thread number (given by the <code>*</code>) is a (zero based) number identifying the worker thread. The number of available worker threads is usually specified on the command line for the application using the option <code>--hpx:threads</code>. If no pool-name is specified the counter refers to the 'default' pool.</p>
Description	<p>Returns the overall time spent executing all <i>HPX</i>-threads on the given <i>locality</i> since application start. If the instance name is <code>total</code> the counter returns the overall time spent executing all <i>HPX</i>-threads for all worker threads (cores) on that <i>locality</i>. If the instance name is <code>worker-thread#*</code> the counter will return the overall time spent executing all <i>HPX</i>-threads for all worker threads separately. This counter is available only if the configuration time constants <code>HPX_THREAD_MAINTAIN_CUMULATIVE_COUNTS</code> (default: ON) and <code>HPX_THREAD_MAINTAIN_IDLE_RATES</code> are set to ON (default: OFF).</p>

Table 2.59: Thread manager performance counter `/threads/time/cumulative-overheads`

Counter type	<code>/threads/time/cumulative-overheads</code>
Counter instance formatting	<p><code>locality#*/total</code> or <code>locality#*/worker-thread#*</code> or <code>locality#*/pool#*/worker-thread#*</code> where: <code>locality#*</code> is defining the <i>locality</i> for which the overall overhead time incurred by executing all <i>HPX</i>-threads should be queried for. The <i>locality</i> id (given by the <code>*</code>) is a (zero based) number identifying the <i>locality</i>. <code>pool#*</code> is defining the pool for which the current value of the idle-loop counter should be queried for. <code>worker-thread#*</code> is defining the worker thread for which the the overall overhead time incurred by executing all <i>HPX</i>-threads should be queried for. The worker thread number (given by the <code>*</code>) is a (zero based) number identifying the worker thread. The number of available worker threads is usually specified on the command line for the application using the option <code>--hpx:threads</code>. If no pool-name is specified the counter refers to the 'default' pool.</p>
Description	<p>Returns the overall overhead time incurred executing all <i>HPX</i>-threads on the given <i>locality</i> since application start. If the instance name is <code>total</code> the counter returns the overall overhead time incurred executing all <i>HPX</i>-threads for all worker threads (cores) on that <i>locality</i>. If the instance name is <code>worker-thread#*</code> the counter will return the overall overhead time incurred executing all <i>HPX</i>-threads for all worker threads separately. This counter is available only if the configuration time constants <code>HPX_THREAD_MAINTAIN_CUMULATIVE_COUNTS</code> (default: ON) and <code>HPX_THREAD_MAINTAIN_IDLE_RATES</code> are set to ON (default: OFF). The unit of measure for this counter is nanosecond [ns].</p>

Table 2.60: Thread manager performance counter threads/count/instantaneous/<thread-state>

Counter type	threads/count/instantaneous/<thread-state> where: <thread-state> is one of the following: all, active, pending, suspended, terminated, staged
Counter instance formatting	locality#*/total or locality#*/worker-thread#* or locality#*/pool#*/worker-thread#* where: locality#* is defining the <i>locality</i> for which the current number of threads with the given state should be queried for. The <i>locality</i> id (given by the *) is a (zero based) number identifying the <i>locality</i> . pool#* is defining the pool for which the current value of the idle-loop counter should be queried for. worker-thread#* is defining the worker thread for which the current number of threads with the given state should be queried for. The worker thread number (given by the *) is a (zero based) number identifying the worker thread. The number of available worker threads is usually specified on the command line for the application using the option <code>--hpx:threads</code> . If no pool-name is specified the counter refers to the 'default' pool. The staged thread state refers to registered tasks before they are converted to thread objects.
Description	Returns the current number of <i>HPX</i> -threads having the given thread state on the given <i>locality</i> . If the instance name is <code>total</code> the counter returns the current number of <i>HPX</i> -threads of the given state for all worker threads (cores) on that <i>locality</i> . If the instance name is <code>worker-thread#*</code> the counter will return the current number of <i>HPX</i> -threads in the given state for all worker threads separately.

Table 2.61: Thread manager performance counter threads/
wait-time/<thread-state>

Counter type	threads/wait-time/<thread-state> where: <thread-state> is one of the following: pending staged
Counter instance formatting	locality#*/total or locality#*/worker-thread#* or locality#*/pool#*/worker-thread#* where: locality#* is defining the <i>locality</i> for which the average wait time of <i>HPX</i> -threads (pending) or thread descriptions (staged) with the given state should be queried for. The <i>locality</i> id (given by * is a (zero based) number identifying the <i>locality</i> . pool#* is defining the pool for which the current value of the idle-loop counter should be queried for. worker-thread#* is defining the worker thread for which the average wait time for the given state should be queried for. The worker thread number (given by the *) is a (zero based) number identifying the worker thread. The number of available worker threads is usually specified on the command line for the application using the option <code>--hpx:threads</code> . If no pool-name is specified the counter refers to the 'default' pool. The <i>staged</i> thread state refers to the wait time of registered tasks before they are converted into thread objects, while the <i>pending</i> thread state refers to the wait time of threads in any of the scheduling queues.
Description	Returns the average wait time of <i>HPX</i> -threads (if the thread state is <i>pending</i> or of task descriptions (if the thread state is <i>staged</i> on the given <i>locality</i> since application start. If the instance name is <code>total</code> the counter returns the wait time of <i>HPX</i> -threads of the given state for all worker threads (cores) on that <i>locality</i> . If the instance name is <code>worker-thread#*</code> the counter will return the wait time of <i>HPX</i> -threads in the given state for all worker threads separately. These counters are available only if the compile time constant <code>HPX_WITH_THREAD_QUEUE_WAITTIME</code> was defined while compiling the <i>HPX</i> core library (default: OFF). The unit of measure for this counter is nanosecond [ns].

Table 2.62: Thread manager performance counter `/threads/idle-rate`

Counter type	<code>/threads/idle-rate</code>
Counter instance formatting	<code>locality#*/total</code> or <code>locality#*/worker-thread#*</code> or <code>locality#*/pool#*/worker-thread#*</code> where: <code>locality#*</code> is defining the <i>locality</i> for which the average idle rate of all (or one) worker threads should be queried for. The <i>locality</i> id (given by the <code>*</code>) is a (zero based) number identifying the <i>locality</i> <code>pool#*</code> is defining the pool for which the current value of the idle-loop counter should be queried for. <code>worker-thread#*</code> is defining the worker thread for which the averaged idle rate should be queried for. The worker thread number (given by the <code>*</code>) is a (zero based) number identifying the worker thread. The number of available worker threads is usually specified on the command line for the application using the option <code>--hpx:threads</code> . If no pool-name is specified the counter refers to the 'default' pool.
Description	Returns the average idle rate for the given worker thread(s) on the given <i>locality</i> . The idle rate is defined as the ratio of the time spent on scheduling and management tasks and the overall time spent executing work since the application started. This counter is available only if the configuration time constant <code>HPX_WITH_THREAD_IDLE_RATES</code> is set to ON (default: OFF).

Table 2.63: Thread manager performance counter `/threads/creation-idle-rate`

Counter type	<code>/threads/creation-idle-rate</code>
Counter instance formatting	<code>locality#*/total</code> or <code>locality#*/worker-thread#*</code> or <code>locality#*/pool#*/worker-thread#*</code> where: <code>locality#*</code> is defining the <i>locality</i> for which the average creation idle rate of all (or one) worker threads should be queried for. The <i>locality</i> id (given by the <code>*</code>) is a (zero based) number identifying the <i>locality</i> . <code>pool#*</code> is defining the pool for which the current value of the idle-loop counter should be queried for. <code>worker-thread#*</code> is defining the worker thread for which the averaged idle rate should be queried for. The worker thread number (given by the <code>*</code>) is a (zero based) number identifying the worker thread. The number of available worker threads is usually specified on the command line for the application using the option <code>--hpx:threads</code> . If no pool-name is specified the counter refers to the 'default' pool.
Description	Returns the average idle rate for the given worker thread(s) on the given <i>locality</i> which is caused by creating new threads. The creation idle rate is defined as the ratio of the time spent on creating new threads and the overall time spent executing work since the application started. This counter is available only if the configuration time constants <code>HPX_WITH_THREAD_IDLE_RATES</code> (default: OFF) and <code>HPX_WITH_THREAD_CREATION_AND_CLEANUP_RATES</code> are set to ON.

Table 2.64: Thread manager performance counter `/threads/cleanup-idle-rate`

Counter type	<code>/threads/cleanup-idle-rate</code>
Counter instance formatting	<p><code>locality#*/total</code> or <code>locality#*/worker-thread#*</code> or <code>locality#*/pool#*/worker-thread#*</code> where: <code>locality#*</code> is defining the <i>locality</i> for which the average cleanup idle rate of all (or one) worker threads should be queried for. The <i>locality</i> id (given by the <code>*</code>) is a (zero based) number identifying the <i>locality</i>. <code>pool#*</code> is defining the pool for which the current value of the idle-loop counter should be queried for. <code>worker-thread#*</code> is defining the worker thread for which the averaged cleanup idle rate should be queried for. The worker thread number (given by the <code>*</code>) is a (zero based) number identifying the worker thread. The number of available worker threads is usually specified on the command line for the application using the option <code>--hpx:threads</code>. If no pool-name is specified the counter refers to the 'default' pool.</p>
Description	<p>Returns the average idle rate for the given worker thread(s) on the given <i>locality</i> which is caused by cleaning up terminated threads. The cleanup idle rate is defined as the ratio of the time spent on cleaning up terminated thread objects and the overall time spent executing work since the application started. This counter is available only if the configuration time constants <code>HPX_WITH_THREAD_IDLE_RATES</code> (default: <code>OFF</code>) and <code>HPX_WITH_THREAD_CREATION_AND_CLEANUP_RATES</code> are set to <code>ON</code>.</p>

Table 2.65: Thread manager performance counter `/threadqueue/length`

Counter type	<code>/threadqueue/length</code>
Counter instance formatting	<p><code>locality#*/total</code> or <code>locality#*/worker-thread#*</code> or <code>locality#*/pool#*/worker-thread#*</code> where: <code>locality#*</code> is defining the <i>locality</i> for which the current length of all thread queues in the scheduler for all (or one) worker threads should be queried for. The <i>locality</i> id (given by the <code>*</code>) is a (zero based) number identifying the <i>locality</i>. <code>pool#*</code> is defining the pool for which the current value of the idle-loop counter should be queried for. <code>worker-thread#*</code> is defining the worker thread for which the current length of all thread queues in the scheduler should be queried for. The worker thread number (given by the <code>*</code>) is a (zero based) number identifying the worker thread. The number of available worker threads is usually specified on the command line for the application using the option <code>--hpx:threads</code>. If no pool-name is specified the counter refers to the 'default' pool.</p>
Description	<p>Returns the overall length of all queues for the given worker thread(s) on the given <i>locality</i>.</p>

Table 2.66: Thread manager performance counter `/threads/count/stack-unbinds`

Counter type	<code>/threads/count/stack-unbinds</code>
Counter instance formatting	<code>locality#*/total</code> where: * is the <i>locality</i> id of the <i>locality</i> the unbind (madvise) operations should be queried for. The <i>locality</i> id is a (zero based) number identifying the <i>locality</i> .
Description	Returns the total number of <i>HPX</i> -thread unbind (madvise) operations performed for the referenced <i>locality</i> . Note that this counter is not available on Windows based platforms.

Table 2.67: Thread manager performance counter `/threads/count/stack-recycles`

Counter type	<code>/threads/count/stack-recycles</code>
Counter instance formatting	<code>locality#*/total</code> where: * is the <i>locality</i> id of the <i>locality</i> the recycling operations should be queried for. The <i>locality</i> id is a (zero based) number identifying the <i>locality</i> .
Description	Returns the total number of <i>HPX</i> -thread recycling operations performed.

Table 2.68: Thread manager performance counter `/threads/count/stolen-from-pending`

Counter type	<code>/threads/count/stolen-from-pending</code>
Counter instance formatting	<code>locality#*/total</code> where: * is the <i>locality</i> id of the <i>locality</i> the number of 'stole' threads should be queried for. The <i>locality</i> id is a (zero based) number identifying the <i>locality</i> .
Description	Returns the total number of <i>HPX</i> -threads 'stolen' from the pending thread queue by a neighboring thread worker thread (these threads are executed by a different worker thread than they were initially scheduled on). This counter is available only if the configuration time constant <code>HPX_WITH_THREAD_STEALING_COUNTS</code> is set to ON (default: ON).

Table 2.69: Thread manager performance counter `/threads/count/pending-misses`

Counter type	<code>/threads/count/pending-misses</code>
Counter instance formatting	<p><code>locality#*/total</code> or <code>locality#*/worker-thread#*</code> or <code>locality#*/pool#*/worker-thread#*</code> where: <code>locality#*</code> is defining the <i>locality</i> for which the number of pending queue misses of all (or one) worker threads should be queried for. The <i>locality</i> id (given by the <code>*</code>) is a (zero based) number identifying the <i>locality</i> <code>pool#*</code> is defining the pool for which the current value of the idle-loop counter should be queried for. <code>worker-thread#*</code> is defining the worker thread for which the number of pending queue misses should be queried for. The worker thread number (given by the <code>*</code>) is a (zero based) number identifying the worker thread. The number of available worker threads is usually specified on the command line for the application using the option <code>--hpx:threads</code>. If no pool-name is specified the counter refers to the ‘default’ pool.</p>
Description	Returns the total number of times that the referenced worker-thread on the referenced <i>locality</i> failed to find pending <i>HPX</i> -threads in its associated queue. This counter is available only if the configuration time constant <code>HPX_WITH_THREAD_STEALING_COUNTS</code> is set to <code>ON</code> (default: <code>ON</code>).

Table 2.70: Thread manager performance counter `/threads/count/pending-accesses`

Counter type	<code>/threads/count/pending-accesses</code>
Counter instance formatting	<p><code>locality#*/total</code> or <code>locality#*/worker-thread#*</code> or <code>locality#*/pool#*/worker-thread#*</code> where: <code>locality#*</code> is defining the <i>locality</i> for which the number of pending queue accesses of all (or one) worker threads should be queried for. The <i>locality</i> id (given by the <code>*</code>) is a (zero based) number identifying the <i>locality</i> <code>pool#*</code> is defining the pool for which the current value of the idle-loop counter should be queried for. <code>worker-thread#*</code> is defining the worker thread for which the number of pending queue accesses should be queried for. The worker thread number (given by the <code>*</code>) is a (zero based) number identifying the worker thread. The number of available worker threads is usually specified on the command line for the application using the option <code>--hpx:threads</code>. If no pool-name is specified the counter refers to the ‘default’ pool.</p>
Description	Returns the total number of times that the referenced worker-thread on the referenced <i>locality</i> looked for pending <i>HPX</i> -threads in its associated queue. This counter is available only if the configuration time constant <code>HPX_WITH_THREAD_STEALING_COUNTS</code> is set to <code>ON</code> (default: <code>ON</code>).

Table 2.71: Thread manager performance counter `/threads/count/stolen-from-staged`

Counter type	<code>/threads/count/stolen-from-staged</code>
Counter instance formatting	<code>locality#*/total</code> or <code>locality#*/worker-thread#*</code> or <code>locality#*/pool#*/worker-thread#*</code> where: <code>locality#*</code> is defining the <i>locality</i> for which the number of <i>HPX</i> -threads stolen from the staged queue of all (or one) worker threads should be queried for. The <i>locality</i> id (given by the <code>*</code>) is a (zero based) number identifying the <i>locality</i> . <code>pool#*</code> is defining the pool for which the current value of the idle-loop counter should be queried for. <code>worker-thread#*</code> is defining the worker thread for which the number of <i>HPX</i> -threads stolen from the staged queue should be queried for. The worker thread number (given by the <code>*</code>) is a (zero based) number identifying the worker thread. The number of available worker threads is usually specified on the command line for the application using the option <code>--hpx:threads</code> . If no pool-name is specified the counter refers to the 'default' pool.
Description	Returns the total number of <i>HPX</i> -threads 'stolen' from the staged thread queue by a neighboring worker thread (these threads are executed by a different worker thread than they were initially scheduled on). This counter is available only if the configuration time constant <code>HPX_WITH_THREAD_STEALING_COUNTS</code> is set to ON (default: ON).

Table 2.72: Thread manager performance counter `/threads/count/stolen-to-pending`

Counter type	<code>/threads/count/stolen-to-pending</code>
Counter instance formatting	<code>locality#*/total</code> or <code>locality#*/worker-thread#*</code> or <code>locality#*/pool#*/worker-thread#*</code> where: <code>locality#*</code> is defining the <i>locality</i> for which the number of <i>HPX</i> -threads stolen to the pending queue of all (or one) worker threads should be queried for. The <i>locality</i> id (given by the <code>*</code>) is a (zero based) number identifying the <i>locality</i> . <code>pool#*</code> is defining the pool for which the current value of the idle-loop counter should be queried for. <code>worker-thread#*</code> is defining the worker thread for which the number of <i>HPX</i> -threads stolen to the pending queue should be queried for. The worker thread number (given by the <code>*</code>) is a (zero based) number identifying the worker thread. The number of available worker threads is usually specified on the command line for the application using the option <code>--hpx:threads</code> . If no pool-name is specified the counter refers to the 'default' pool.
Description	Returns the total number of <i>HPX</i> -threads 'stolen' to the pending thread queue of the worker thread (these threads are executed by a different worker thread than they were initially scheduled on). This counter is available only if the configuration time constant <code>HPX_WITH_THREAD_STEALING_COUNTS</code> is set to ON (default: ON).

Table 2.73: Thread manager performance counter `/threads/count/stolen-to-staged`

Counter type	<code>/threads/count/stolen-to-staged</code>
Counter instance formatting	<p><code>locality#*/total</code> or <code>locality#*/worker-thread#*</code> or <code>locality#*/pool#*/worker-thread#*</code> where: <code>locality#*</code> is defining the <i>locality</i> for which the number of <i>HPX</i>-threads stolen to the staged queue of all (or one) worker threads should be queried for. The <i>locality</i> id (given by <code>*</code>) is a (zero based) number identifying the <i>locality</i>. <code>pool#*</code> is defining the pool for which the current value of the idle-loop counter should be queried for. <code>worker-thread#*</code> is defining the worker thread for which the number of <i>HPX</i>-threads stolen to the staged queue should be queried for. The worker thread number (given by the <code>*</code>) is a (zero based) worker thread number (given by the <code>*</code>) is a (zero based) number identifying the worker thread. The number of available worker threads is usually specified on the command line for the application using the option <code>--hpx:threads</code>. If no pool-name is specified the counter refers to the 'default' pool.</p>
Description	Returns the total number of <i>HPX</i> -threads 'stolen' to the staged thread queue of a neighboring worker thread (these threads are executed by a different worker thread than they were initially scheduled on). This counter is available only if the configuration time constant <code>HPX_WITH_THREAD_STEALING_COUNTS</code> is set to ON (default: ON).

Table 2.74: Thread manager performance counter `/threads/count/objects`

Counter type	<code>/threads/count/objects</code>
Counter instance formatting	<p><code>locality#*/total</code> or <code>locality#*/allocator#*</code> where: <code>locality#*</code> is defining the <i>locality</i> for which the current (cumulative) number of all created <i>HPX</i>-thread objects should be queried for. The <i>locality</i> id (given by <code>*</code>) is a (zero based) number identifying the <i>locality</i>. <code>allocator#*</code> is defining the number of the allocator instance using which the threads have been created. <i>HPX</i> uses a varying number of allocators to create (and recycle) <i>HPX</i>-thread objects, most likely these counters are of use for debugging purposes only. The allocator id (given by <code>*</code>) is a (zero based) number identifying the allocator to query.</p>
Description	Returns the total number of <i>HPX</i> -thread objects created. Note that thread objects are reused to improve system performance, thus this number does not reflect the number of actually executed (retired) <i>HPX</i> -threads.

Table 2.75: Thread manager performance counter `/scheduler/`
`utilization/instantaneous`

Counter type	<code>/scheduler/utilization/instantaneous</code>
Counter instance formatting	<code>locality#*/total</code> where: <code>locality#*</code> is defining the <i>locality</i> for which the current (instantaneous) scheduler utilization queried for. The <i>locality</i> id (given by <code>*</code>) is a (zero based) number identifying the <i>locality</i> .
Description	Returns the total (instantaneous) scheduler utilization. This is the current percentage of scheduler threads executing <i>HPX</i> threads.
Parameters	Percent

Table 2.76: Thread manager performance counter `/threads/`
`idle-loop-count/instantaneous`

Counter type	<code>/threads/idle-loop-count/instantaneous</code>
Counter instance formatting	<code>locality#*/worker-thread#*</code> or <code>locality#*/pool#*/worker-thread#*</code> where: <code>locality#*</code> is defining the <i>locality</i> for which the current current accumulated value of all idle-loop counters of all worker threads should be queried. The <i>locality</i> id (given by the <code>*</code>) is a (zero based) number identifying the <i>locality</i> . <code>pool#*</code> is defining the pool for which the current value of the idle-loop counter should be queried for. <code>worker-thread#*</code> is defining the worker thread for which the current value of the idle-loop counter should be queried for. The worker thread number (given by the <code>*</code>) is a (zero based) worker thread number (given by the <code>*</code>) is a (zero based) number identifying the worker thread. The number of available worker threads is usually specified on the command line for the application using the option <code>--hpx:threads</code> . If no pool-name is specified the counter refers to the 'default' pool.
Description	Returns the current (instantaneous) idle-loop count for the given <i>HPX</i> - worker thread or the accumulated value for all worker threads.

Table 2.77: Thread manager performance counter `/threads/busy-loop-count/instantaneous`

Counter type	<code>/threads/busy-loop-count/instantaneous</code>
Counter instance formatting	<p><code>locality#*/worker-thread#*</code> or <code>locality#*/pool#*/worker-thread#*</code> where: <code>locality#*</code> is defining the <i>locality</i> for which the current current accumulated value of all busy-loop counters of all worker threads should be queried. The <i>locality</i> id (given by the <code>*</code>) is a (zero based) number identifying the <i>locality</i>. <code>pool#*</code> is defining the pool for which the current value of the idle-loop counter should be queried for. <code>worker-thread#*</code> is defining the worker thread for which the current value of the busy-loop counter should be queried for. The worker thread number (given by the <code>*</code>) is a (zero based) worker thread number (given by the <code>*</code>) is a (zero based) number identifying the worker thread. The number of available worker threads is usually specified on the command line for the application using the option <code>--hpx:threads</code>. If no pool-name is specified the counter refers to the 'default' pool.</p>
Description	Returns the current (instantaneous) busy-loop count for the given <i>HPX</i> - worker thread or the accumulated value for all worker threads.

Table 2.78: Thread manager performance counter `/threads/time/background-work-duration`

Counter type	<code>/threads/time/background-work-duration</code>
Counter instance formatting	<p><code>locality#*/total</code> or <code>locality#*/worker-thread#*</code> where: <code>locality#*</code> is defining the locality for which the overall time spent performing background work should be queried for. The locality id (given by <code>*</code>) is a (zero based) number identifying the locality. <code>worker-thread#*</code> is defining the worker thread for which the overall time spent performing background work should be queried for. The worker thread number (given by the <code>*</code>) is a (zero based) number identifying the worker thread. The number of available worker threads is usually specified on the command line for the application using the option <code>--hpx:threads</code>.</p>
Description	Returns the overall time spent performing background work on the given locality since application start. If the instance name is <code>total</code> the counter returns the overall time spent performing background work for all worker threads (cores) on that locality. If the instance name is <code>worker-thread#*</code> the counter will return the overall time spent performing background work for all worker threads separately. This counter is available only if the configuration time constants <code>HPX_WITH_BACKGROUND_THREAD_COUNTERS</code> (default: OFF) and <code>HPX_WITH_THREAD_IDLE_RATES</code> are set to ON (default: OFF). The unit of measure for this counter is nanosecond [ns].

Table 2.79: Thread manager performance counter `/threads/background-overhead`

Counter type	<code>/threads/background-overhead</code>
Counter instance formatting	<code>locality#*/total</code> or <code>locality#*/worker-thread#*</code> where: <code>locality#*</code> is defining the locality for which the background overhead should be queried for. The locality id (given by <code>*</code>) is a (zero based) number identifying the locality. <code>worker-thread#*</code> is defining the worker thread for which the background overhead should be queried for. The worker thread number (given by the <code>*</code>) is a (zero based) number identifying the worker thread. The number of available worker threads is usually specified on the command line for the application using the option <code>--hpx:threads</code> .
Description	Returns the background overhead on the given locality since application start. If the instance name is <code>total</code> the counter returns the background overhead for all worker threads (cores) on that locality. If the instance name is <code>worker-thread#*</code> the counter will return background overhead for all worker threads separately. This counter is available only if the configuration time constants <code>HPX_WITH_BACKGROUND_THREAD_COUNTERS</code> (default: OFF) and <code>HPX_WITH_THREAD_IDLE_RATES</code> are set to ON (default: OFF). The unit of measure displayed for this counter is 0.1%.

Table 2.80: Thread manager performance counter `/threads/time/background-send-duration`

Counter type	<code>/threads/time/background-send-duration</code>
Counter instance formatting	<code>locality#*/total</code> or <code>locality#*/worker-thread#*</code> where: <code>locality#*</code> is defining the locality for which the overall time spent performing background work related to sending parcels should be queried for. The locality id (given by <code>*</code>) is a (zero based) number identifying the locality. <code>worker-thread#*</code> is defining the worker thread for which the overall time spent performing background work related to sending parcels should be queried for. The worker thread number (given by the <code>*</code>) is a (zero based) number identifying the worker thread. The number of available worker threads is usually specified on the command line for the application using the option <code>--hpx:threads</code> .
Description	Returns the overall time spent performing background work related to sending parcels on the given locality since application start. If the instance name is <code>total</code> the counter returns the overall time spent performing background work for all worker threads (cores) on that locality. If the instance name is <code>worker-thread#*</code> the counter will return the overall time spent performing background work for all worker threads separately. This counter is available only if the configuration time constants <code>HPX_WITH_BACKGROUND_THREAD_COUNTERS</code> (default: OFF) and <code>HPX_WITH_THREAD_IDLE_RATES</code> are set to ON (default: OFF). The unit of measure for this counter is nanosecond [ns]. This counter will currently return meaningful values for the MPI parcelport only.

Table 2.81: Thread manager performance counter `/threads/background-send-overhead`

Counter type	<code>/threads/background-send-overhead</code>
Counter instance formatting	<p><code>locality#*/total</code> or <code>locality#*/worker-thread#*</code></p> <p>where:</p> <p><code>locality#*</code> is defining the locality for which the background overhead related to sending parcels should be queried for. The locality id (given by <code>*</code>) is a (zero based) number identifying the locality.</p> <p><code>worker-thread#*</code> is defining the worker thread for which the background overhead related to sending parcels should be queried for. The worker thread number (given by the <code>*</code>) is a (zero based) number identifying the worker thread. The number of available worker threads is usually specified on the command line for the application using the option <code>--hpx:threads</code>.</p>
Description	<p>Returns the background overhead related to sending parcels on the given locality since application start. If the instance name is <code>total</code> the counter returns the background overhead for all worker threads (cores) on that locality. If the instance name is <code>worker-thread#*</code> the counter will return background overhead for all worker threads separately. This counter is available only if the configuration time constants <code>HPX_WITH_BACKGROUND_THREAD_COUNTERS</code> (default: <code>OFF</code>) and <code>HPX_WITH_THREAD_IDLE_RATES</code> are set to <code>ON</code> (default: <code>OFF</code>). The unit of measure displayed for this counter is 0.1%.</p> <p>This counter will currently return meaningful values for the MPI parcellport only.</p>

Table 2.82: Thread manager performance counter `/threads/time/background-receive-duration`

Counter type	<code>/threads/time/background-receive-duration</code>
Counter instance formatting	<p><code>locality#*/total</code> or <code>locality#*/worker-thread#*</code></p> <p>where:</p> <p><code>locality#*</code> is defining the locality for which the overall time spent performing background work related to receiving parcels should be queried for. The locality id (given by <code>*</code>) is a (zero based) number identifying the locality.</p> <p><code>worker-thread#*</code> is defining the worker thread for which the overall time spent performing background work related to receiving parcels should be queried for. The worker thread number (given by the <code>*</code>) is a (zero based) number identifying the worker thread. The number of available worker threads is usually specified on the command line for the application using the option <code>--hpx:threads</code>.</p>
Description	<p>Returns the overall time spent performing background work related to receiving parcels on the given locality since application start. If the instance name is <code>total</code> the counter returns the overall time spent performing background work for all worker threads (cores) on that locality. If the instance name is <code>worker-thread#*</code> the counter will return the overall time spent performing background work for all worker threads separately. This counter is available only if the configuration time constants <code>HPX_WITH_BACKGROUND_THREAD_COUNTERS</code> (default: <code>OFF</code>) and <code>HPX_WITH_THREAD_IDLE_RATES</code> are set to <code>ON</code> (default: <code>OFF</code>). The unit of measure for this counter is nanosecond [ns].</p> <p>This counter will currently return meaningful values for the MPI parcellport only.</p>

Table 2.83: Thread manager performance counter `/threads/background-receive-overhead`

Counter type	<code>/threads/background-receive-overhead</code>
Counter instance formatting	<code>locality#*/total</code> or <code>locality#*/worker-thread#*</code> where: <code>locality#*</code> is defining the locality for which the background overhead related to receiving should be queried for. The locality id (given by <code>*</code>) is a (zero based) number identifying the locality. <code>worker-thread#*</code> is defining the worker thread for which the background overhead related to receiving parcels should be queried for. The worker thread number (given by the <code>*</code>) is a (zero based) number identifying the worker thread. The number of available worker threads is usually specified on the command line for the application using the option <code>--hpx:threads</code> .
Description	Returns the background overhead related to receiving parcels on the given locality since application start. If the instance name is <code>total</code> the counter returns the background overhead for all worker threads (cores) on that locality. If the instance name is <code>worker-thread#*</code> the counter will return background overhead for all worker threads separately. This counter is available only if the configuration time constants <code>HPX_WITH_BACKGROUND_THREAD_COUNTERS</code> (default: <code>OFF</code>) and <code>HPX_WITH_THREAD_IDLE_RATES</code> are set to <code>ON</code> (default: <code>OFF</code>). The unit of measure displayed for this counter is 0.1%. This counter will currently return meaningful values for the MPI parcolport only.

Table 2.84: General performance counter `/runtime/count/component`

Counter type	<code>/runtime/count/component</code>
Counter instance formatting	<code>locality#*/total</code> where: <code>*</code> is the <i>locality</i> id of the <i>locality</i> the number of components should be queried. The <i>locality</i> id is a (zero based) number identifying the <i>locality</i> .
Description	Returns the overall number of currently active components of the specified type on the given <i>locality</i> .
Parameters	The type of the component. This is the string which has been used while registering the component with <code>HPX</code> , e.g. which has been passed as the second parameter to the macro <code>HPX_REGISTER_COMPONENT</code> .

Table 2.85: General performance counter `/runtime/count/action-invocation`

Counter type	<code>/runtime/count/action-invocation</code>
Counter instance formatting	<code>locality#*/total</code> where: <code>*</code> is the <i>locality</i> id of the locality the number of action invocations should be queried. The <i>locality</i> id is a (zero based) number identifying the <i>locality</i> .
Description	Returns the overall (local) invocation count of the specified action type on the given <i>locality</i> .
Parameters	The action type. This is the string which has been used while registering the action with <code>HPX</code> , e.g. which has been passed as the second parameter to the macro <code>HPX_REGISTER_ACTION</code> or <code>HPX_REGISTER_ACTION_ID</code> .

Table 2.86: General performance counter `/runtime/count/remote-action-invocation`

Counter type	<code>/runtime/count/remote-action-invocation</code>
Counter instance formatting	<code>locality#*/total</code> where: * is the <i>locality</i> id of the <i>locality</i> the number of action invocations should be queried. The <i>locality</i> id is a (zero based) number identifying the <i>locality</i> .
Description	Returns the overall (remote) invocation count of the specified action type on the given <i>locality</i> .
Parameters	The action type. This is the string which has been used while registering the action with <i>HPX</i> , e.g. which has been passed as the second parameter to the macro <code>HPX_REGISTER_ACTION</code> or <code>HPX_REGISTER_ACTION_ID</code> .

Table 2.87: General performance counter `/runtime/uptime`

Counter type	<code>/runtime/uptime</code>
Counter instance formatting	<code>locality#*/total</code> where: * is the <i>locality</i> id of the <i>locality</i> the system uptime should be queried. The <i>locality</i> id is a (zero based) number identifying the <i>locality</i> .
Description	Returns the overall time since application start on the given <i>locality</i> in nanoseconds.

Table 2.88: General performance counter `/runtime/memory/virtual`

Counter type	<code>/runtime/memory/virtual</code>
Counter instance formatting	<code>locality#*/total</code> where: * is the <i>locality</i> id of the <i>locality</i> the allocated virtual memory should be queried. The <i>locality</i> id is a (zero based) number identifying the <i>locality</i> .
Description	Returns the amount of virtual memory currently allocated by the referenced <i>locality</i> (in bytes).

Table 2.89: General performance counter `/runtime/memory/resident`

Counter type	<code>/runtime/memory/resident</code>
Counter instance formatting	<code>locality#*/total</code> where: * is the <i>locality</i> id of the <i>locality</i> the allocated resident memory should be queried. The <i>locality</i> id is a (zero based) number identifying the <i>locality</i> .
Description	Returns the amount of resident memory currently allocated by the referenced <i>locality</i> (in bytes).

Table 2.90: General performance counter `/runtime/memory/total`

Counter type	<code>/runtime/memory/total</code>
Counter instance formatting	<code>locality#*/total</code> where: * is the <i>locality</i> id of the <i>locality</i> the total available memory should be queried. The <i>locality</i> id is a (zero based) number identifying the <i>locality</i> . Note: only supported in Linux.
Description	Returns the total available memory for use by the referenced <i>locality</i> (in bytes). This counter is available on Linux and Windows systems only.

Table 2.91: General performance counter `/runtime/io/read_bytes_issued`

Counter type	<code>/runtime/io/read_bytes_issued</code>
Counter instance formatting	<code>locality#*/total</code> where: * is the <i>locality</i> id of the <i>locality</i> the number of bytes read should be queried. The <i>locality</i> id is a (zero based) number identifying the <i>locality</i> .
Description	Returns the number of bytes read by the process (aggregate of count arguments passed to <code>read()</code> call or its analogues). This performance counter is available only on systems which expose the related data through the <code>/proc</code> file system.

Table 2.92: General performance counter `/runtime/io/write_bytes_issued`

Counter type	<code>/runtime/io/write_bytes_issued</code>
Counter instance formatting	<code>locality#*/total</code> where: * is the <i>locality</i> id of the <i>locality</i> the number of bytes written should be queried. The <i>locality</i> id is a (zero based) number identifying the <i>locality</i> .
Description	Returns the number of bytes written by the process (aggregate of count arguments passed to <code>write()</code> call or its analogues). This performance counter is available only on systems which expose the related data through the <code>/proc</code> file system.

Table 2.93: General performance counter `/runtime/io/read_syscalls`

Counter type	<code>/runtime/io/read_syscalls</code>
Counter instance formatting	<code>locality#*/total</code> where: * is the <i>locality</i> id of the <i>locality</i> the number of system calls should be queried. The <i>locality</i> id is a (zero based) number identifying the <i>locality</i> .
Description	Returns the number of system calls that perform I/O reads. This performance counter is available only on systems which expose the related data through the <code>/proc</code> file system.

Table 2.94: General performance counter `/runtime/io/write_syscalls`

Counter type	<code>/runtime/io/write_syscalls</code>
Counter instance formatting	<code>locality#*/total</code> where: * is the <i>locality</i> id of the <i>locality</i> the number of system calls should be queried. The <i>locality</i> id is a (zero based) number identifying the <i>locality</i> .
Description	Returns the number of system calls that perform I/O writes. This performance counter is available only on systems which expose the related data through the <code>/proc</code> file system.

Table 2.95: General performance counter `/runtime/io/read_bytes_transferred`

Counter type	<code>/runtime/io/read_bytes_transferred</code>
Counter instance formatting	<code>locality#*/total</code> where: * is the <i>locality</i> id of the <i>locality</i> the number of bytes transferred should be queried. The <i>locality</i> id is a (zero based) number identifying the <i>locality</i> .
Description	Returns the number of bytes retrieved from storage by I/O operations. This performance counter is available only on systems which expose the related data through the <code>/proc</code> file system.

Table 2.96: General performance counter `/runtime/io/write_bytes_transferred`

Counter type	<code>/runtime/io/write_bytes_transferred</code>
Counter instance formatting	<code>locality#*/total</code> where: * is the <i>locality</i> id of the <i>locality</i> the number of bytes transferred should be queried. The <i>locality</i> id is a (zero based) number identifying the <i>locality</i> .
Description	Returns the number of bytes retrieved from storage by I/O operations. This performance counter is available only on systems which expose the related data through the <code>/proc</code> file system.

Table 2.97: General performance counter `/runtime/io/write_bytes_cancelled`

Counter type	<code>/runtime/io/write_bytes_cancelled</code>
Counter instance formatting	<code>locality#*/total</code> where: * is the <i>locality</i> id of the <i>locality</i> the number of bytes not being transferred should be queried. The <i>locality</i> id is a (zero based) number identifying the <i>locality</i> .
Description	Returns the number of bytes accounted by <code>write_bytes_transferred</code> that has not been ultimately stored due to truncation or deletion. This performance counter is available only on systems which expose the related data through the <code>/proc</code> file system.

Table 2.98: Performance counter /papi/<papi_event>

Counter type	/papi/<papi_event> where: <papi_event> is the name of the PAPI event to expose as a performance counter (such as PAPI_SR_INS). Note that the list of available PAPI events changes depending on the used architecture. For a full list of available PAPI events and their (short) description use the <code>--hpx:list-counters</code> and <code>--hpx:papi-event-info=all</code> command line options.
Counter instance formatting	locality#*/total or locality#*/worker-thread#* where: locality#* is defining the <i>locality</i> for which the current current accumulated value of all busy-loop counters of all worker threads should be queried. The <i>locality</i> id (given by *) is a (zero based) number identifying the <i>locality</i> . worker-thread#* is defining the worker thread for which the current value of the busy-loop counter should be queried for. The worker thread number (given by the *) is a (zero based) worker thread number (given by the *) is a (zero based) number identifying the worker thread. The number of available worker threads is usually specified on the command line for the application using the option <code>--hpx:threads</code> .
Description	Returns the current count of occurrences of the specified PAPI event. This counter is available only if the configuration time constant HPX_WITH_PAPI is set to ON (default: OFF).

Table 2.99: Performance counter /statistics/average

Counter type	/statistics/average
Counter instance formatting	Any full performance counter name. The referenced performance counter is queried at fixed time intervals as specified by the first parameter.
Description	Returns the current average (mean) value calculated based on the values queried from the underlying counter (the one specified as the instance name).
Parameters	Any parameter will be interpreted as a list of up to two comma separated (integer) values, where the first is the time interval (in milliseconds) at which the underlying counter should be queried. If no value is specified, the counter will assume 1000 [ms] as the default. The second value can be either 0 or 1 and specifies whether the underlying counter should be reset during evaluation 1 or not 0. The default value is 0.

Table 2.100: Performance counter /statistics/rolling_average

Counter type	/statistics/rolling_average
Counter instance formatting	Any full performance counter name. The referenced performance counter is queried at fixed time intervals as specified by the first parameter.
Description	Returns the current rolling average (mean) value calculated based on the values queried from the underlying counter (the one specified as the instance name).
Parameters	Any parameter will be interpreted as a list of up to three comma separated (integer) values, where the first is the time interval (in milliseconds) at which the underlying counter should be queried. If no value is specified, the counter will assume 1000 [ms] as the default. The second value will be interpreted as the size of the rolling window (the number of latest values to use to calculate the rolling average). The default value for this is 10. The third value can be either 0 or 1 and specifies whether the underlying counter should be reset during evaluation 1 or not 0. The default value is 0.

Table 2.101: Performance counter `/statistics/stddev`

Counter type	<code>/statistics/stddev</code>
Counter instance formatting	Any full performance counter name. The referenced performance counter is queried at fixed time intervals as specified by the first parameter.
Description	Returns the current standard deviation (stddev) value calculated based on the values queried from the underlying counter (the one specified as the instance name).
Parameters	Any parameter will be interpreted as a list of up to two comma separated (integer) values, where the first is the time interval (in milliseconds) at which the underlying counter should be queried. If no value is specified, the counter will assume 1000 [ms] as the default. The second value can be either 0 or 1 and specifies whether the underlying counter should be reset during evaluation 1 or not 0. The default value is 0.

Table 2.102: Performance counter `/statistics/rolling_stddev`

Counter type	<code>/statistics/rolling_stddev</code>
Counter instance formatting	Any full performance counter name. The referenced performance counter is queried at fixed time intervals as specified by the first parameter.
Description	Returns the current rolling variance (stddev) value calculated based on the values queried from the underlying counter (the one specified as the instance name).
Parameters	Any parameter will be interpreted as a list of up to three comma separated (integer) values, where the first is the time interval (in milliseconds) at which the underlying counter should be queried. If no value is specified, the counter will assume 1000 [ms] as the default. The second value will be interpreted as the size of the rolling window (the number of latest values to use to calculate the rolling average). The default value for this is 10. The third value can be either 0 or 1 and specifies whether the underlying counter should be reset during evaluation 1 or not 0. The default value is 0.

Table 2.103: Performance counter `/statistics/median`

Counter type	<code>/statistics/median</code>
Counter instance formatting	Any full performance counter name. The referenced performance counter is queried at fixed time intervals as specified by the first parameter.
Description	Returns the current (statistically estimated) median value calculated based on the values queried from the underlying counter (the one specified as the instance name).
Parameters	Any parameter will be interpreted as a list of up to two comma separated (integer) values, where the first is the time interval (in milliseconds) at which the underlying counter should be queried. If no value is specified, the counter will assume 1000 [ms] as the default. The second value can be either 0 or 1 and specifies whether the underlying counter should be reset during evaluation 1 or not 0. The default value is 0.

Table 2.104: Performance counter `/statistics/max`

Counter type	<code>/statistics/max</code>
Counter instance formatting	Any full performance counter name. The referenced performance counter is queried at fixed time intervals as specified by the first parameter.
Description	Returns the current maximum value calculated based on the values queried from the underlying counter (the one specified as the instance name).
Parameters	Any parameter will be interpreted as a list of up to two comma separated (integer) values, where the first is the time interval (in milliseconds) at which the underlying counter should be queried. If no value is specified, the counter will assume 1000 [ms] as the default. The second value can be either 0 or 1 and specifies whether the underlying counter should be reset during evaluation 1 or not 0. The default value is 0.

Table 2.105: Performance counter `/statistics/rolling_max`

Counter type	<code>/statistics/rolling_max</code>
Counter instance formatting	Any full performance counter name. The referenced performance counter is queried at fixed time intervals as specified by the first parameter.
Description	Returns the current rolling maximum value calculated based on the values queried from the underlying counter (the one specified as the instance name).
Parameters	Any parameter will be interpreted as a list of up to three comma separated (integer) values, where the first is the time interval (in milliseconds) at which the underlying counter should be queried. If no value is specified, the counter will assume 1000 [ms] as the default. The second value will be interpreted as the size of the rolling window (the number of latest values to use to calculate the rolling average). The default value for this is 10. The third value can be either 0 or 1 and specifies whether the underlying counter should be reset during evaluation 1 or not 0. The default value is 0.

Table 2.106: Performance counter `/statistics/min`

Counter type	<code>/statistics/min</code>
Counter instance formatting	Any full performance counter name. The referenced performance counter is queried at fixed time intervals as specified by the first parameter.
Description	Returns the current minimum value calculated based on the values queried from the underlying counter (the one specified as the instance name).
Parameters	Any parameter will be interpreted as a list of up to two comma separated (integer) values, where the first is the time interval (in milliseconds) at which the underlying counter should be queried. If no value is specified, the counter will assume 1000 [ms] as the default. The second value can be either 0 or 1 and specifies whether the underlying counter should be reset during evaluation 1 or not 0. The default value is 0.

Table 2.107: Performance counter `/statistics/rolling_min`

Counter type	<code>/statistics/rolling_min</code>
Counter instance formatting	Any full performance counter name. The referenced performance counter is queried at fixed time intervals as specified by the first parameter.
Description	Returns the current rolling minimum value calculated based on the values queried from the underlying counter (the one specified as the instance name).
Parameters	Any parameter will be interpreted as a list of up to three comma separated (integer) values, where the first is the time interval (in milliseconds) at which the underlying counter should be queried. If no value is specified, the counter will assume 1000 [ms] as the default. The second value will be interpreted as the size of the rolling window (the number of latest values to use to calculate the rolling average). The default value for this is 10. The third value can be either 0 or 1 and specifies whether the underlying counter should be reset during evaluation 1 or not 0. The default value is 0.

Table 2.108: Performance counter `/arithmetics/add`

Counter type	<code>/arithmetics/add</code>
Description	Returns the sum calculated based on the values queried from the underlying counters (the ones specified as the parameters).
Parameters	The parameter will be interpreted as a comma separated list of full performance counter names which are queried whenever this counter is accessed. Any wildcards in the counter names will be expanded.

Table 2.109: Performance counter `/arithmetics/subtract`

Counter type	<code>/arithmetics/subtract</code>
Description	Returns the difference calculated based on the values queried from the underlying counters (the ones specified as the parameters).
Parameters	The parameter will be interpreted as a comma separated list of full performance counter names which are queried whenever this counter is accessed. Any wildcards in the counter names will be expanded.

Table 2.110: Performance counter `/arithmetics/multiply`

Counter type	<code>/arithmetics/multiply</code>
Description	Returns the product calculated based on the values queried from the underlying counters (the ones specified as the parameters).
Parameters	The parameter will be interpreted as a comma separated list of full performance counter names which are queried whenever this counter is accessed. Any wildcards in the counter names will be expanded.

Table 2.111: Performance counter `/arithmetics/divide`

Counter type	<code>/arithmetics/divide</code>
Description	Returns the result of division of the values queried from the underlying counters (the ones specified as the parameters).
Parameters	The parameter will be interpreted as a comma separated list of full performance counter names which are queried whenever this counter is accessed. Any wildcards in the counter names will be expanded.

Table 2.112: Performance counter `/arithmetics/mean`

Counter type	<code>/arithmetics/mean</code>
Description	Returns the average value of all values queried from the underlying counters (the ones specified as the parameters).
Parameters	The parameter will be interpreted as a comma separated list of full performance counter names which are queried whenever this counter is accessed. Any wildcards in the counter names will be expanded.

Table 2.113: Performance counter `/arithmetics/variance`

Counter type	<code>/arithmetics/variance</code>
Description	Returns the standard deviation of all values queried from the underlying counters (the ones specified as the parameters).
Parameters	The parameter will be interpreted as a comma separated list of full performance counter names which are queried whenever this counter is accessed. Any wildcards in the counter names will be expanded.

Table 2.114: Performance counter `/arithmetics/median`

Counter type	<code>/arithmetics/median</code>
Description	Returns the median value of all values queried from the underlying counters (the ones specified as the parameters).
Parameters	The parameter will be interpreted as a comma separated list of full performance counter names which are queried whenever this counter is accessed. Any wildcards in the counter names will be expanded.

Table 2.115: Performance counter `/arithmetics/min`

Counter type	<code>/arithmetics/min</code>
Description	Returns the minimum value of all values queried from the underlying counters (the ones specified as the parameters).
Parameters	The parameter will be interpreted as a comma separated list of full performance counter names which are queried whenever this counter is accessed. Any wildcards in the counter names will be expanded.

Table 2.116: Performance counter `/arithmetics/max`

Counter type	<code>/arithmetics/max</code>
Description	Returns the maximum value of all values queried from the underlying counters (the ones specified as the parameters).
Parameters	The parameter will be interpreted as a comma separated list of full performance counter names which are queried whenever this counter is accessed. Any wildcards in the counter names will be expanded.

Table 2.117: Performance counter `/arithmetics/count`

Counter type	<code>/arithmetics/count</code>
Description	Returns the count value of all values queried from the underlying counters (the ones specified as the parameters).
Parameters	The parameter will be interpreted as a comma separated list of full performance counter names which are queried whenever this counter is accessed. Any wildcards in the counter names will be expanded.

Note: The `/arithmetics` counters can consume an arbitrary number of other counters. For this reason those have to be specified as parameters (a comma separated list of counters appended after a '@'). For instance:

```
$ ./bin/hello_world_distributed -t2 \
  --hpx:print-counter=/threads{locality#0/worker-thread#*}/count/cumulative \
  --hpx:print-counter=/arithmetics/add@/threads{locality#0/worker-thread#*}/count/
↪cumulative
hello world from OS-thread 0 on locality 0
hello world from OS-thread 1 on locality 0
/threads{locality#0/worker-thread#0}/count/cumulative,1,0.515640,[s],25
/threads{locality#0/worker-thread#1}/count/cumulative,1,0.515520,[s],36
/arithmetics/add@/threads{locality#0/worker-thread#*}/count/cumulative,1,0.516445,[s],64
```

Since all wildcards in the parameters are expanded, this example is fully equivalent to specifying both counters separately to `/arithmetics/add`:

```
$ ./bin/hello_world_distributed -t2 \
  --hpx:print-counter=/threads{locality#0/worker-thread#*}/count/cumulative \
  --hpx:print-counter=/arithmetics/add@
  /threads{locality#0/worker-thread#0}/count/cumulative,\
  /threads{locality#0/worker-thread#1}/count/cumulative
```

Table 2.118: Performance counter /coalescing/count/parcels

Counter type	/coalescing/count/parcels
Counter instance formatting	locality#*/total where: * is the <i>locality</i> id of the <i>locality</i> the number of parcels for the given action should be queried for. The <i>locality</i> id is a (zero based) number identifying the <i>locality</i> .
Description	Returns the number of parcels handled by the message handler associated with the action which is given by the counter parameter.
Parameters	The action type. This is the string which has been used while registering the action with <i>HPX</i> , e.g. which has been passed as the second parameter to the macro <i>HPX_REGISTER_ACTION</i> or <i>HPX_REGISTER_ACTION_ID</i> .

Table 2.119: Performance counter /coalescing/count/messages

Counter type	/coalescing/count/messages
Counter instance formatting	locality#*/total where: * is the <i>locality</i> id of the <i>locality</i> the number of messages for the given action should be queried for. The <i>locality</i> id is a (zero based) number identifying the <i>locality</i> .
Description	Returns the number of messages generated by the message handler associated with the action which is given by the counter parameter.
Parameters	The action type. This is the string which has been used while registering the action with <i>HPX</i> , e.g. which has been passed as the second parameter to the macro <i>HPX_REGISTER_ACTION</i> or <i>HPX_REGISTER_ACTION_ID</i> .

Table 2.120: Performance counter /coalescing/count/average-parcels-per-message

Counter type	/coalescing/count/average-parcels-per-message
Counter instance formatting	locality#*/total where: * is the <i>locality</i> id of the <i>locality</i> the number of messages for the given action should be queried for. The <i>locality</i> id is a (zero based) number identifying the <i>locality</i> .
Description	Returns the average number of parcels sent in a message generated by the message handler associated with the action which is given by the counter parameter.
Parameters	The action type. This is the string which has been used while registering the action with <i>HPX</i> , e.g. which has been passed as the second parameter to the macro <i>HPX_REGISTER_ACTION</i> or <i>HPX_REGISTER_ACTION_ID</i> .

Table 2.121: Performance counter /coalescing/time/average-parcel-arrival

Counter type	/coalescing/time/average-parcel-arrival
Counter instance formatting	locality#*/total where: * is the <i>locality</i> id of the <i>locality</i> the average time between parcels for the given action should be queried for. The <i>locality</i> id is a (zero based) number identifying the <i>locality</i> .
Description	Returns the average time between arriving parcels for the action which is given by the counter parameter.
Parameters	The action type. This is the string which has been used while registering the action with <i>HPX</i> , e.g. which has been passed as the second parameter to the macro <i>HPX_REGISTER_ACTION</i> or <i>HPX_REGISTER_ACTION_ID</i> .

Table 2.122: Performance counter /coalescing/time/parcel-arrival-histogram

Counter type	/coalescing/time/parcel-arrival-histogram
Counter instance formatting	locality#*/total where: * is the <i>locality</i> id of the <i>locality</i> the average time between parcels for the given action should be queried for. The <i>locality</i> id is a (zero based) number identifying the <i>locality</i> .
Description	Returns a histogram representing the times between arriving parcels for the action which is given by the counter parameter. This counter returns an array of values, where the first three values represent the three parameters used for the histogram followed by one value for each of the histogram buckets. The first unit of measure displayed for this counter [ns] refers to the lower and upper boundary values in the returned histogram data only. The second unit of measure displayed [0.1%] refers to the actual histogram data. For each bucket the counter shows a value between 0 and 1000 which corresponds to a percentage value between 0% and 100%.
Parameters	The action type and optional histogram parameters. The action type is the string which has been used while registering the action with <i>HPX</i> , e.g. which has been passed as the second parameter to the macro <i>HPX_REGISTER_ACTION</i> or <i>HPX_REGISTER_ACTION_ID</i> . The action type may be followed by a comma separated list of up-to three numbers: the lower and upper boundaries for the collected histogram, and the number of buckets for the histogram to generate. By default these three numbers will be assumed to be 0 ([ns], lower bound), 1000000 ([ns], upper bound), and 20 (number of buckets to generate).

Note: The performance counters related to *parcel* coalescing are available only if the configuration time constant `HPX_WITH_PARCEL_COALESCING` is set to `ON` (default: `ON`). However, even in this case it will be available only for actions that are enabled for parcel coalescing (see the macros `HPX_ACTION_USES_MESSAGE_COALESCING` and `HPX_ACTION_USES_MESSAGE_COALESCING_NOTHROW`).

APEX integration

HPX provides integration with *APEX*¹⁷⁵, which is a framework for application profiling using task timers and various performance counters Huck *et al.*¹⁸³. It can be added as a git submodule by turning on the option `HPX_WITH_APEX:BOOL` during *CMake*¹⁷⁶ configuration. *TAU*¹⁷⁷ is an optional dependency when using *APEX*.

To build *HPX* with *APEX*¹⁷⁸, add `HPX_WITH_APEX=ON`, and, optionally, `Tau_ROOT=$PATH_TO_TAU` to your *CMake*¹⁷⁹ configuration. In addition, you can override the tag used for *APEX*¹⁸⁰ with the `HPX_WITH_APEX_TAG` option. Please see the *APEX HPX documentation*¹⁸¹ for detailed instructions on using *APEX*¹⁸² with *HPX*.

¹⁷⁵ <http://uo-oaciss.github.io/apex>

¹⁸³ K. A. Huck, A. Porterfield, N Chaimov, H. Kaiser, A. D. Malony, T. Sterling, and R. Fowler. *An autonomic performance environment for exascale*. Supercomputing Frontiers and Innovations, 2015.

¹⁷⁶ <https://www.cmake.org>

¹⁷⁷ <https://www.cs.uoregon.edu/research/tau/home.php>

¹⁷⁸ <http://uo-oaciss.github.io/apex>

¹⁷⁹ <https://www.cmake.org>

¹⁸⁰ <http://uo-oaciss.github.io/apex>

¹⁸¹ <https://uo-oaciss.github.io/apex/usage/#hpx-louisiana-state-university>

¹⁸² <http://uo-oaciss.github.io/apex>

References

2.3.15 Using the LCI parcelport

Basic information

The [Lightweight Communication Interface](#)¹⁸⁴ (LCI) is an ongoing research project aiming to provide efficient support for applications with irregular and asynchronous communication patterns such as graph analysis, sparse linear algebra, and task-based runtime on modern parallel architectures. Its features include (a) support for more communication primitives such as two-sided send/rcv and one-sided (dynamic or direct) remote put/get (b) better multi-threaded performance (c) explicit user control of communication resource (d) flexible signaling mechanisms such as synchronizer, completion queue, and active message handler. It is designed to be a low-level communication library used by high-level libraries and frameworks.

The LCI parcelport is an experimental parcelport. It aims to provide the best possible communication performance on high-performance computation platforms. Compared to the MPI parcelport, it uses much fewer messages and memory copies to transfer an *HPX* parcel over the network. Its message transmission path involves minimum synchronization points and is almost lock-free. It is expected to be much faster than the MPI parcelport.

Build *HPX* with the LCI parcelport

While building *HPX*, you can specify a set of [CMake](#)¹⁸⁵ variables to enable and configure the LCI parcelport. Below, there is a set of the most important and frequently used CMake variables.

HPX_WITH_PARCELPOR_T_LCI

Enable the LCI parcelport. This enables the use of LCI for networking operations in the *HPX* runtime. The default value is `OFF` because it's not available on all systems and/or requires another dependency. However, this experimental parcelport may provide better performance than the MPI parcelport. You must set this variable to `ON` in order to use the LCI parcelport. All the following variables only make sense when this variable is set to `ON`.

HPX_WITH_FETCH_LCI

Use `FetchContent` to fetch LCI. The default value is `OFF`. If this option is set to `OFF`. You need to install your own LCI library and *HPX* will try to find it using [CMake](#)¹⁸⁶ `find_package`. You can specify the location of the LCI installation by the environmental variable `LCI_ROOT`. Refer to the [LCI README](#)¹⁸⁷ for how to install LCI. If this option is set to `ON`. *HPX* will fetch and build LCI for you. You can use the following [CMake](#)¹⁸⁸ variables to configure this behavior for your platform.

HPX_WITH_LCI_TAG

This variable only takes effect when `HPX_WITH_FETCH_LCI` is set to `ON` and `FETCHCONTENT_SOURCE_DIR_LCI` is not set. *HPX* will fetch LCI from its github repository. This variable controls the branch/tag LCI will be fetched.

FETCHCONTENT_SOURCE_DIR_LCI

This variable only takes effect when `HPX_WITH_FETCH_LCI` is set to `ON`. When it is defined, `HPX_WITH_LCI_TAG` will be ignored. It accepts a path to a local version of LCI source code and *HPX* will fetch and build LCI from there. The default value is set conservatively for the stability of *HPX*, but users are welcome to set this variable to `master` for potentially better performance.

¹⁸⁴ <https://github.com/uiuc-hpc/lci>

¹⁸⁵ <https://www.cmake.org>

¹⁸⁶ <https://www.cmake.org>

¹⁸⁷ <https://github.com/uiuc-hpc/lci#readme>

¹⁸⁸ <https://www.cmake.org>

Run HPX with the LCI parcelport

We use the same mechanisms as MPI to launch LCI, so you can use the same way you run MPI parcelport to run LCI parcelport. Typically, it would be `hpxrun.py`, `mpirun`, or `srun`.

`hpxrun.py` serves as a wrapper for `mpirun` and `srun`. If you are using `hpxrun.py`, pass `-p lci` to the scripts. You also need to pass either `-r mpi` or `-r srun` to select the correct run wrapper according to the platform.

If you are using `mpirun` or `srun`, you can just pass `--hpx:ini=hpx.parcel.lci.priority=1000`, `--hpx:ini=hpx.parcel.lci.enable=1`, and `--hpx:ini=hpx.parcel.bootstrap=lci` to the *HPX* applications.

The `hpxrun.py` argument `-r none` (the default option for the run wrapper) and its corresponding *HPX* arguments `--hpx:hpx` and `--hpx:agas` do not work for the MPI or the LCI parcelport.

Performance tuning of the LCI parcelport

We encourage users to set the following environmental variables when using the LCI parcelport to get better performance.

```
$ export LCI_SERVER_MAX_SENDS=1024
$ export LCI_SERVER_MAX_RECVS=4096
$ export LCI_SERVER_NUM_PKTS=65536
$ export LCI_SERVER_MAX_CQES=65536
$ export LCI_PACKET_SIZE=12288
```

This setting needs roughly 800MB memory per process. The memory consumption mainly comes from the packets, which can be calculated using $LCI_SERVER_NUM_PKTS \times LCI_PACKET_SIZE$.

In addition, users can tune the following command-line options when using the LCI parcelport to get better performance.

`--hpx:ini=hpx.parcel.lci.ndevices=<int>`

The number of LCI devices to use. The default value is 2. An LCI device represents a collection of network resources. More devices lead to lower thread contention, but too many devices may lead to load imbalance or hardware overhead.

`--hpx:ini=hpx.parcel.lci.progress_type=<worker|rp>`

The way to progress the LCI device. The default value is `worker`. The `worker` option uses all worker threads to progress the LCI devices. The `rp` option uses dedicated pinned threads to progress the LCI devices. Normally, the `worker` option gives better performance, but the `rp` option has been observed with better performance on some clusters with prior generation of InfiniBand hardware.

2.3.16 HPX runtime and resources

HPX thread scheduling policies

The *HPX* runtime has six thread scheduling policies: `local-priority`, `static-priority`, `local`, `static`, `local-workrequesting-fifo`, and `abp-priority`. These policies can be specified from the command line using the command line option `--hpx:queuing`. In order to use a particular scheduling policy, the runtime system must be built with the appropriate scheduler flag turned on (e.g. `cmake -DHPX_THREAD_SCHEDULERS=local`, see *CMake options* for more information).

Priority local scheduling policy (default policy)

The priority local scheduling policy maintains one queue per operating system (OS) thread. The OS thread pulls its work from this queue. By default the number of high priority queues is equal to the number of OS threads; the number of high priority queues can be specified on the command line using `--hpx:high-priority-threads`. High priority threads are executed by any of the OS threads before any other work is executed. When a queue is empty, work will be taken from high priority queues first. There is one low priority queue from which threads will be scheduled only when there is no other work.

For this scheduling policy there is an option to turn on NUMA sensitivity using the command line option `--hpx:numa-sensitive`. When NUMA sensitivity is turned on, work stealing is done from queues associated with the same NUMA domain first, only after that work is stolen from other NUMA domains.

This scheduler is enabled at build time by default using the FIFO (first-in-first-out) queueing policy. This policy can be invoked using `--hpx:queuinglocal-priority-fifo`. The scheduler can also be enabled using the LIFO (last-in-first-out) policy. This is not the default policy and must be invoked using the command line option `--hpx:queuinglocal-priority-lifo`.

Static priority scheduling policy

- invoke using: `--hpx:queuingstatic-priority` (or `-qs`)

The static scheduling policy maintains one queue per OS thread from which each OS thread pulls its tasks (user threads). Threads are distributed in a round robin fashion. There is no thread stealing in this policy.

Local scheduling policy

- invoke using: `--hpx:queuinglocal` (or `-ql`)
- flag to turn on for build: `HPX_THREAD_SCHEDULERS=all` or `HPX_THREAD_SCHEDULERS=local`

The local scheduling policy maintains one queue per OS thread from which each OS thread pulls its tasks (user threads).

Static scheduling policy

- invoke using: `--hpx:queuingstatic`
- flag to turn on for build: `HPX_THREAD_SCHEDULERS=all` or `HPX_THREAD_SCHEDULERS=static`

The static scheduling policy maintains one queue per OS thread from which each OS thread pulls its tasks (user threads). Threads are distributed in a round robin fashion. There is no thread stealing in this policy.

Priority ABP scheduling policy

- invoke using: `--hpx:queuingabp-priority-fifo`
- flag to turn on for build: `HPX_THREAD_SCHEDULERS=all` or `HPX_THREAD_SCHEDULERS=abp-priority`

Priority ABP policy maintains a double ended lock free queue for each OS thread. By default the number of high priority queues is equal to the number of OS threads; the number of high priority queues can be specified on the command line using `--hpx:high-priority-threads`. High priority threads are executed by the first OS threads before any other work is executed. When a queue is empty work will be taken from high priority queues first. There is one low priority queue from which threads will be scheduled only when there is no other work. For this scheduling policy there is an option to turn on NUMA sensitivity using the command line option `--hpx:numa-sensitive`. When

NUMA sensitivity is turned on work stealing is done from queues associated with the same NUMA domain first, only after that work is stolen from other NUMA domains.

This scheduler can be used with two underlying queuing policies (FIFO: first-in-first-out, and LIFO: last-in-first-out). In order to use the LIFO policy use the command line option `--hpx:queuingabp-priority-lifo`.

Work requesting scheduling policies

- invoke using: `--hpx:queuinglocal-workrequesting-fifo`, using `--hpx:queuinglocal-workrequesting-lifo`, or using `--hpx:queuinglocal-workrequesting-mc`

The work-requesting policies rely on a different mechanism of balancing work between cores (compared to the other policies listed above). Instead of actively trying to steal work from other cores, requesting work relies on a less disruptive mechanism. If a core runs out of work, instead of actively looking at the queues of neighboring cores, in this case a request is posted to another core. This core now (whenever it is not busy with other work) either responds to the original core by sending back work or passes the request on to the next possible core in the system. In general, this scheme avoids contention on the work queues as those are always accessed by their own cores only.

The HPX resource partitioner

The *HPX* resource partitioner lets you take the execution resources available on a system—processing units, cores, and numa domains—and assign them to thread pools. By default *HPX* creates a single thread pool name `default`. While this is good for most use cases, the resource partitioner lets you create multiple thread pools with custom resources and options.

Creating custom thread pools is useful for cases where you have tasks which absolutely need to run without interference from other tasks. An example of this is when using [MPI](https://en.wikipedia.org/wiki/Message_Passing_Interface)¹⁸⁹ for distribution instead of the built-in mechanisms in *HPX* (useful in legacy applications). In this case one can create a thread pool containing a single thread for MPI communication. MPI tasks will then always run on the same thread, instead of potentially being stuck in a queue behind other threads.

Note that *HPX* thread pools are completely independent from each other in the sense that task stealing will never happen between different thread pools. However, tasks running on a particular thread pool can schedule tasks on another thread pool.

Note: It is simpler in some situations to schedule important tasks with high priority instead of using a separate thread pool.

Using the resource partitioner

The `hpx::resource::partitioner` is now created during *HPX* runtime initialization without explicit action needed from the user. To specify some of the initialization parameters you can use the `hpx::init_params`.

The resource partitioner callback is the interface to add thread pools to the *HPX* runtime and to assign resources to the thread pools. In order to create custom thread pools you can specify the resource partitioner callback `hpx::init_params::rp_callback` which will be called once the resource partitioner will be created, see the example below. You can also specify other parameters, see `hpx::init_params`.

To add a thread pool use the `hpx::resource::partitioner::create_thread_pool` method. If you simply want to use the default scheduler and scheduler options, it is enough to call `rp.create_thread_pool("my-thread-pool")`.

¹⁸⁹ https://en.wikipedia.org/wiki/Message_Passing_Interface

Then, to add resources to the thread pool you can use the `hpx::resource::partitioner::add_resource` method. The resource partitioner exposes the hardware topology retrieved using [Portable Hardware Locality \(HWLOC\)](#)¹⁹⁰ and lets you iterate through the topology to add the wanted processing units to the thread pool. Below is an example of adding all processing units from the first NUMA domain to a custom thread pool, unless there is only one NUMA domain in which case we leave the first processing unit for the default thread pool:

Note: Whatever processing units are not assigned to a thread pool by the time `hpx::init` is called will be added to the default thread pool. It is also possible to explicitly add processing units to the default thread pool, and to create the default thread pool manually (in order to e.g. set the scheduler type).

Tip: The command line option `--hpx:print-bind` is useful for checking that the thread pools have been set up the way you expect.

Difference between the old and new version

In the old version, you had to create an instance of the `resource_partitioner` with `argc` and `argv`.

```
int main(int argc, char** argv)
{
    hpx::resource::partitioner rp(argc, argv);
    hpx::init();
}
```

From *HPX* 1.5.0 onwards, you just pass `argc` and `argv` to `hpx::init()` or `hpx::start()` for the binding options to be parsed by the resource partitioner.

```
int main(int argc, char** argv)
{
    hpx::init_params init_args;
    hpx::init(argc, argv, init_args);
}
```

In the old version, when creating a custom thread pool, you just called the utilities on the resource partitioner instantiated previously.

```
int main(int argc, char** argv)
{
    hpx::resource::partitioner rp(argc, argv);

    rp.create_thread_pool("my-thread-pool");

    bool one_numa_domain = rp.numa_domains().size() == 1;
    bool skipped_first_pu = false;

    hpx::resource::numa_domain const& d = rp.numa_domains()[0];

    for (const hpx::resource::core& c : d.cores())
    {
```

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¹⁹⁰ <https://www.open-mpi.org/projects/hwloc/>

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```

    for (const hpx::resource::pu& p : c.pus())
    {
        if (one_numa_domain && !skipped_first_pu)
        {
            skipped_first_pu = true;
            continue;
        }

        rp.add_resource(p, "my-thread-pool");
    }
}

hpx::init();
}

```

You now specify the resource partitioner callback which will tie the resources to the resource partitioner created during runtime initialization.

```

void init_resource_partitioner_handler(hpx::resource::partitioner& rp)
{
    rp.create_thread_pool("my-thread-pool");

    bool one_numa_domain = rp.numa_domains().size() == 1;
    bool skipped_first_pu = false;

    hpx::resource::numa_domain const& d = rp.numa_domains()[0];

    for (const hpx::resource::core& c : d.cores())
    {
        for (const hpx::resource::pu& p : c.pus())
        {
            if (one_numa_domain && !skipped_first_pu)
            {
                skipped_first_pu = true;
                continue;
            }

            rp.add_resource(p, "my-thread-pool");
        }
    }
}

int main(int argc, char* argv[])
{
    hpx::init_params init_args;
    init_args.rp_callback = &init_resource_partitioner_handler;

    hpx::init(argc, argv, init_args);
}

```

Advanced usage

It is possible to customize the built in schedulers by passing scheduler options to `hpx::resource::partitioner::create_thread_pool`. It is also possible to create and use custom schedulers.

Note: It is not recommended to create your own scheduler. The *HPX* developers use this to experiment with new scheduler designs before making them available to users via the standard mechanisms of choosing a scheduler (command line options). If you would like to experiment with a custom scheduler the resource partitioner example `shared_priority_queue_scheduler.cpp` contains a fully implemented scheduler with logging, etc. to make exploration easier.

To choose a scheduler and custom mode for a thread pool, pass additional options when creating the thread pool like this:

```
rp.create_thread_pool("my-thread-pool",
    hpx::resource::policies::local_priority_lifo,
    hpx::policies::scheduler_mode(
        hpx::policies::scheduler_mode::default |
        hpx::policies::scheduler_mode::enable_elasticity));
```

The available schedulers are documented here: `hpx::resource::scheduling_policy`, and the available scheduler modes here: `hpx::threads::policies::scheduler_mode`. Also see the examples folder for examples of advanced resource partitioner usage: `simple_resource_partitioner.cpp` and `oversubscribing_resource_partitioner.cpp`.

2.3.17 Miscellaneous

Error handling

Like in any other asynchronous invocation scheme, it is important to be able to handle error conditions occurring while the asynchronous (and possibly remote) operation is executed. In *HPX* all error handling is based on standard C++ exception handling. Any exception thrown during the execution of an asynchronous operation will be transferred back to the original invocation *locality*, where it will be rethrown during synchronization with the calling thread.

The source code for this example can be found here: `error_handling.cpp`.

Working with exceptions

For the following description assume that the function `raise_exception()` is executed by invoking the plain action `raise_exception_type`.

```
#include <hpx/iostream.hpp>
#include <hpx/modules/runtime_local.hpp>

//[error_handling_raise_exception
void raise_exception()
```

The exception is thrown using the macro `HPX_THROW_EXCEPTION`. The type of the thrown exception is `hpx::exception`. This associates additional diagnostic information with the exception, such as file name and line number, *locality* id and thread id, and stack backtrace from the point where the exception was thrown.

Any exception thrown during the execution of an action is transferred back to the (asynchronous) invocation site. It will be rethrown in this context when the calling thread tries to wait for the result of the action by invoking either `future<>::get()` or the synchronous action invocation wrapper as shown here:

```
{
  {
    //////////////////////////////////////
    // Error reporting using exceptions
    //[exception_diagnostic_information
    hpx::cout << "Error reporting using exceptions\n";
    try
    {
      // invoke raise_exception() which throws an exception
      raise_exception_action do_it;
      do_it(hpx::find_here());
    }
    catch (hpx::exception const& e)
    {
      // Print just the essential error information.
      hpx::cout << "caught exception: " << e.what() << "\n\n";
    }
  }
}
```

Note: The exception is transferred back to the invocation site even if it is executed on a different *locality*.

Additionally, this example demonstrates how an exception thrown by an (possibly remote) action can be handled. It shows the use of `hpx::diagnostic_information`, which retrieves all available diagnostic information from the exception as a formatted string. This includes, for instance, the name of the source file and line number, the sequence number of the OS thread and the *HPX* thread id, the *locality* id and the stack backtrace of the point where the original exception was thrown.

Under certain circumstances it is desirable to output only some of the diagnostics, or to output those using different formatting. For this case, *HPX* exposes a set of lower-level functions as demonstrated in the following code snippet:

```

    << hpx::diagnostic_information(e) << "\n";
  }
  hpx::cout << std::flush;
  //]

  // Detailed error reporting using exceptions
  //[exception_diagnostic_elements
  hpx::cout << "Detailed error reporting using exceptions\n";
  try
  {
    // Invoke raise_exception() which throws an exception.
    raise_exception_action do_it;
    do_it(hpx::find_here());
  }
  catch (hpx::exception const& e)
  {
    // Print the elements of the diagnostic information separately.
    hpx::cout << "{what}: " << hpx::get_error_what(e) << "\n";
    hpx::cout << "{locality-id}: " << hpx::get_error_locality_id(e)
      << "\n";
    hpx::cout << "{hostname}: " << hpx::get_error_host_name(e) << "\n";
  }
}
```

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```

hpx::cout << "{pid}: " << hpx::get_error_process_id(e) << "\n";
hpx::cout << "{function}: " << hpx::get_error_function_name(e)
    << "\n";
hpx::cout << "{file}: " << hpx::get_error_file_name(e) << "\n";
hpx::cout << "{line}: " << hpx::get_error_line_number(e) << "\n";

```

Working with error codes

Most of the API functions exposed by *HPX* can be invoked in two different modes. By default those will throw an exception on error as described above. However, sometimes it is desirable not to throw an exception in case of an error condition. In this case an object instance of the `hpx::error_code` type can be passed as the last argument to the API function. In case of an error, the error condition will be returned in that `hpx::error_code` instance. The following example demonstrates extracting the full diagnostic information without exception handling:

```

    << "\n";
    hpx::cout << "{stack-trace}: " << hpx::get_error_backtrace(e)
        << "\n";
    hpx::cout << "{env}: " << hpx::get_error_env(e) << "\n";
}
hpx::cout << std::flush;
//]

////////////////////////////////////
// Error reporting using error code
{
    // [error_handling_diagnostic_information
    hpx::cout << "Error reporting using error code\n";

    // Create a new error_code instance.
    hpx::error_code ec;

    // If an instance of an error_code is passed as the last argument while
    // invoking the action, the function will not throw in case of an error
    // but store the error information in this error_code instance instead.
    raise_exception_action do_it;
    do_it(hpx::find_here(), ec);
}

```

Note: The error information is transferred back to the invocation site even if it is executed on a different *locality*.

This example shows how an error can be handled without having to resolve to exceptions and that the returned `hpx::error_code` instance can be used in a very similar way as the `hpx::exception` type above. Simply pass it to the `hpx::diagnostic_information`, which retrieves all available diagnostic information from the error code instance as a formatted string.

As for handling exceptions, when working with error codes, under certain circumstances it is desirable to output only some of the diagnostics, or to output those using different formatting. For this case, *HPX* exposes a set of lower-level functions usable with error codes as demonstrated in the following code snippet:

```

    // Print all of the available diagnostic information as stored with
    // the exception.

```

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```

        hpx::cout << "diagnostic information:"
                << hpx::diagnostic_information(ec) << "\n";
    }

    hpx::cout << std::flush;
    //]
}

// Detailed error reporting using error code
{
    // [error_handling_diagnostic_elements
    hpx::cout << "Detailed error reporting using error code\n";

    // Create a new error_code instance.
    hpx::error_code ec;

    // If an instance of an error_code is passed as the last argument while
    // invoking the action, the function will not throw in case of an error
    // but store the error information in this error_code instance instead.
    raise_exception_action do_it;
    do_it(hpx::find_here(), ec);

    if (ec)
    {
        // Print the elements of the diagnostic information separately.
        hpx::cout << "{what}: " << hpx::get_error_what(ec) << "\n";
        hpx::cout << "{locality-id}: " << hpx::get_error_locality_id(ec)
                << "\n";
        hpx::cout << "{hostname}: " << hpx::get_error_host_name(ec)
                << "\n";
        hpx::cout << "{pid}: " << hpx::get_error_process_id(ec) << "\n";
    }
}

```

For more information please refer to the documentation of `hpx::get_error_what`, `hpx::get_error_locality_id`, `hpx::get_error_host_name`, `hpx::get_error_process_id`, `hpx::get_error_function_name`, `hpx::get_error_file_name`, `hpx::get_error_line_number`, `hpx::get_error_os_thread`, `hpx::get_error_thread_id`, `hpx::get_error_thread_description`, `hpx::get_error_backtrace`, `hpx::get_error_env`, and `hpx::get_error_state`.

Lightweight error codes

Sometimes it is not desirable to collect all the ambient information about the error at the point where it happened as this might impose too much overhead for simple scenarios. In this case, *HPX* provides a lightweight error code facility that will hold the error code only. The following snippet demonstrates its use:

```

        << "\n";
    hpx::cout << "{thread-id}: " << std::hex
            << hpx::get_error_thread_id(ec) << "\n";
    hpx::cout << "{thread-description}: "
            << hpx::get_error_thread_description(ec) << "\n\n";
    hpx::cout << "{state}: " << std::hex << hpx::get_error_state(ec)
            << "\n";
}

```

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```

        hpx::cout << "{stack-trace}: " << hpx::get_error_backtrace(ec)
            << "\n";
        hpx::cout << "{env}: " << hpx::get_error_env(ec) << "\n";
    }

    hpx::cout << std::flush;
    //]
}

// Error reporting using lightweight error code
{
    //[[lightweight_error_handling_diagnostic_information
    hpx::cout << "Error reporting using an lightweight error code\n";
}

```

All functions that retrieve other diagnostic elements from the `hpx::error_code` will fail if called with a lightweight `error_code` instance.

Utilities in HPX

In order to ease the burden of programming, *HPX* provides several utilities to users. The following section documents those facilities.

Checkpoint

See *checkpoint*.

The HPX I/O-streams component

The *HPX* I/O-streams subsystem extends the standard C++ output streams `std::cout` and `std::cerr` to work in the distributed setting of an *HPX* application. All of the output streamed to `hpx::cout` will be dispatched to `std::cout` on the console *locality*. Likewise, all output generated from `hpx::cerr` will be dispatched to `std::cerr` on the console *locality*.

Note: All existing standard manipulators can be used in conjunction with `hpx::cout` and `hpx::cerr`.

In order to use either `hpx::cout` or `hpx::cerr`, application codes need to `#include <hpx/include/iostreams.hpp>`. For an example, please see the following ‘Hello world’ program:

```

// Copyright (c) 2007-2012 Hartmut Kaiser
//
// SPDX-License-Identifier: BSL-1.0
// Distributed under the Boost Software License, Version 1.0. (See accompanying
// file LICENSE_1_0.txt or copy at http://www.boost.org/LICENSE_1_0.txt)
//
//
// The purpose of this example is to execute a HPX-thread printing
// "Hello World!" once. That's all.
//
//[[hello_world_1_getting_started

```

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```
// Including 'hpx/hpx_main.hpp' instead of the usual 'hpx/hpx_init.hpp' enables
// to use the plain C-main below as the direct main HPX entry point.
#include <hpx/hpx_main.hpp>
#include <hpx/iostream.hpp>

int main()
{
    // Say hello to the world!
    hpx::cout << "Hello World!\n" << std::flush;
    return 0;
}
//]
```

Additionally, those applications need to link with the iostreams component. When using CMake this can be achieved by using the COMPONENT_DEPENDENCIES parameter; for instance:

```
include(HPX_AddExecutable)

add_hpx_executable(
    hello_world
    SOURCES hello_world.cpp
    COMPONENT_DEPENDENCIES iostreams
)
```

Note: The `hpx::cout` and `hpx::cerr` streams buffer all output locally until a `std::endl` or `std::flush` is encountered. That means that no output will appear on the console as long as either of these is explicitly used.

2.3.18 Troubleshooting

Common issues

This section contains commonly encountered problems when compiling or using HPX.

See also the closed issues on [GitHub](https://github.com/STELLAR-GROUP/hpx/issues?q=is%3Aissue+is%3Aclosed)¹⁹¹ to find out how other people resolved a similar problem. If nothing of that works, you can also open a new issue on [GitHub](https://github.com/STELLAR-GROUP/hpx/issues)¹⁹² or contact us using one of the options found in [Support for deploying and using HPX](#)¹⁹³.

¹⁹¹ <https://github.com/STELLAR-GROUP/hpx/issues?q=is%3Aissue+is%3Aclosed>

¹⁹² <https://github.com/STELLAR-GROUP/hpx/issues>

¹⁹³ <https://github.com/STELLAR-GROUP/hpx/blob/master/.github/SUPPORT.md>

HPX::iostreams_component" target not found

You may see a [CMake](#)¹⁹⁴ error message that looks a bit like this:

```
error: `HPX::iostreams_component` target not found
```

Simply ensure that *HPX* is installed with `HPX_WITH_DISTRIBUTED_RUNTIME=ON` to prevent encountering such error(s). This is required if you want to use `hpx::cout`.

Undefined reference to hpx::cout

You may see a linker error message that looks a bit like this:

```
hello_world.cpp:(.text+0x5aa): undefined reference to `hpx::cout'
```

This usually happens if you are trying to use *HPX* iostreams functionality such as `hpx::cout` but are not linking against it. The iostreams functionality is not part of the core *HPX* library, and must be linked to explicitly. Typically this can be solved by adding `COMPONENT_DEPENDENCIES iostreams` to a call to `add_hpx_library/add_hpx_executable/hpx_setup_target` if using [CMake](#)¹⁹⁵. See [Creating HPX projects](#) for more details.

Fail compiling for examples with hpx::future and co_await

You may see an error message that looks a bit like this:

```
error: coroutines require a traits template; cannot find 'std::coroutine_traits'
```

This can be resolved by using `-DHPX_WITH_CXX_STANDARD=20` to the cmake command line. Note that a compiler that supports C++20 is needed.

See also the corresponding closed [Issue #5784](#)¹⁹⁶.

Build fails with ASIO error

You may see an error message that looks a bit like this:

```
Cannot open include file asio/io_context.hpp
```

This can be resolved by using `-DHPX_WITH_FETCH_ASIO=ON` to the cmake command line.

See also the corresponding closed [Issue #5404](#)¹⁹⁷ for more information.

¹⁹⁴ <https://www.cmake.org>

¹⁹⁵ <https://www.cmake.org>

¹⁹⁶ <https://github.com/STELLAR-GROUP/hpx/issues/5784>

¹⁹⁷ <https://github.com/STELLAR-GROUP/hpx/issues/5404>

Build fails with TCMalloc error

You may see an error message that looks a bit like this:

```
Could NOT find TCMalloc (missing: Tcmalloc_LIBRARY Tcmalloc_INCLUDE_DIR)
ERROR: HPX_WITH_MALLOC was set to tcmalloc, but tcmalloc could not be
found. Valid options for HPX_WITH_MALLOC are: system, tcmalloc, jemalloc,
mimalloc, tbbmalloc, and custom
```

This can be resolved either by defining `HPX_WITH_MALLOC=system` or by installing TCMalloc. This error occurs when users don't specify an option for `HPX_WITH_MALLOC`; in that case, *HPX* will be looking `tcmalloc`, which is the default value.

Useful suggestions

Reducing compilation time

If you want to significantly reduce compilation time, you can just use the local part of *HPX* for parallelism by disabling the distributed functionality. Moreover, you can avoid compiling examples. These can be done with the following flags:

```
-DHPX_WITH_NETWORKING=OFF
-DHPX_WITH_DISTRIBUTED_RUNTIME=OFF
-DHPX_WITH_EXAMPLES=OFF
-DHPX_WITH_TESTS=OFF
```

Linking *HPX* to your application

If you want to avoid installing and linking *HPX*, you can just build *HPX* and then use the following flag on your *HPX* application CMake configuration:

```
-DHPX_DIR=<build_dir>/lib/cmake/HPX
```

Note: For this to work you need not to specify `-DCMAKE_INSTALL_PREFIX` when building *HPX*.

HPX-application build type conformance

Your application's build type should align with the *HPX* build type. For example, if you specified `-DCMAKE_BUILD_TYPE=Debug` during the *HPX* compilation, then your application needs to be compiled with the same flag. We recommend keeping a separate build folder for different build types and just point accordingly to the type you want by using `-DHPX_DIR=<build_dir>/lib/cmake/HPX`.

2.4 Terminology

This section gives definitions for some of the terms used throughout the *HPX* documentation and source code.

Locality A locality in *HPX* describes a synchronous domain of execution, or the domain of bounded upper response time. This normally is just a single node in a cluster or a NUMA domain in a SMP machine.

Active Global Address Space

AGAS *HPX* incorporates a global address space. Any executing thread can access any object within the domain of the parallel application with the caveat that it must have appropriate access privileges. The model does not assume that global addresses are cache coherent; all loads and stores will deal directly with the site of the target object. All global addresses within a Synchronous Domain are assumed to be cache coherent for those processor cores that incorporate transparent caches. The Active Global Address Space used by *HPX* differs from research *PGAS*¹⁹⁸ models. Partitioned Global Address Space is passive in their means of address translation. Copy semantics, distributed compound operations, and affinity relationships are some of the global functionality supported by AGAS.

Process The concept of the “process” in *HPX* is extended beyond that of either sequential execution or communicating sequential processes. While the notion of process suggests action (as do “function” or “subroutine”) it has a further responsibility of context, that is, the logical container of program state. It is this aspect of operation that process is employed in *HPX*. Furthermore, referring to “parallel processes” in *HPX* designates the presence of parallelism within the context of a given process, as well as the coarse grained parallelism achieved through concurrency of multiple processes of an executing user job. *HPX* processes provide a hierarchical name space within the framework of the active global address space and support multiple means of internal state access from external sources.

Parcel The Parcel is a component in *HPX* that communicates data, invokes an action at a distance, and distributes flow-control through the migration of continuations. Parcels bridge the gap of asynchrony between synchronous domains while maintaining symmetry of semantics between local and global execution. Parcels enable message-driven computation and may be seen as a form of “active messages”. Other important forms of message-driven computation predating active messages include *dataflow tokens*¹⁹⁹, the *J-machine*’s²⁰⁰ support for remote method instantiation, and at the coarse grained variations of Unix remote procedure calls, among others. This enables work to be moved to the data as well as performing the more common action of bringing data to the work. A parcel can cause actions to occur remotely and asynchronously, among which are the creation of threads at different system nodes or synchronous domains.

Local Control Object

Lightweight Control Object

LCO A local control object (sometimes called a lightweight control object) is a general term for the synchronization mechanisms used in *HPX*. Any object implementing a certain concept can be seen as an LCO. This concepts encapsulates the ability to be triggered by one or more events which when taking the object into a predefined state will cause a thread to be executed. This could either create a new thread or resume an existing thread.

The LCO is a family of synchronization functions potentially representing many classes of synchronization constructs, each with many possible variations and multiple instances. The LCO is sufficiently general that it can subsume the functionality of conventional synchronization primitives such as spinlocks, mutexes, semaphores, and global barriers. However due to the rich concept an LCO can represent powerful synchronization and control functionality not widely employed, such as dataflow and futures (among others), which open up enormous opportunities for rich diversity of distributed control and operation.

See *lcos* for more details on how to use LCOs in *HPX*.

¹⁹⁸ <https://www.pgas.org/>

¹⁹⁹ http://en.wikipedia.org/wiki/Dataflow_architecture

²⁰⁰ <http://en.wikipedia.org/wiki/J%E2%80%93Machine>

Action An action is a function that can be invoked remotely. In *HPX* a plain function can be made into an action using a macro. See `applying_actions` for details on how to use actions in *HPX*.

Component A component is a C++ object which can be accessed remotely. A component can also contain member functions which can be invoked remotely. These are referred to as component actions. See *Writing components* for details on how to use components in *HPX*.

2.5 Why HPX?

Current advances in high performance computing (HPC) continue to suffer from the issues plaguing parallel computation. These issues include, but are not limited to, ease of programming, inability to handle dynamically changing workloads, scalability, and efficient utilization of system resources. Emerging technological trends such as multi-core processors further highlight limitations of existing parallel computation models. To mitigate the aforementioned problems, it is necessary to rethink the approach to parallelization models. ParalleX contains mechanisms such as multi-threading, *parcels*, *global name space* support, percolation and *local control objects (LCO)*. By design, ParalleX overcomes limitations of current models of parallelism by alleviating contention, latency, overhead and starvation. With ParalleX, it is further possible to increase performance by at least an order of magnitude on challenging parallel algorithms, e.g., dynamic directed graph algorithms and adaptive mesh refinement methods for astrophysics. An additional benefit of ParalleX is fine-grained control of power usage, enabling reductions in power consumption.

2.5.1 ParalleX—a new execution model for future architectures

ParalleX is a new parallel execution model that offers an alternative to the conventional computation models, such as message passing. ParalleX distinguishes itself by:

- Split-phase transaction model
- Message-driven
- Distributed shared memory (not cache coherent)
- Multi-threaded
- Futures synchronization
- *Local Control Objects (LCOs)*
- Synchronization for anonymous producer-consumer scenarios
- Percolation (pre-staging of task data)

The ParalleX model is intrinsically latency hiding, delivering an abundance of variable-grained parallelism within a hierarchical namespace environment. The goal of this innovative strategy is to enable future systems delivering very high efficiency, increased scalability and ease of programming. ParalleX can contribute to significant improvements in the design of all levels of computing systems and their usage from application algorithms and their programming languages to system architecture and hardware design together with their supporting compilers and operating system software.

2.5.2 What is HPX?

High Performance ParalleX (*HPX*) is the first runtime system implementation of the ParalleX execution model. The *HPX* runtime software package is a modular, feature-complete, and performance-oriented representation of the ParalleX execution model targeted at conventional parallel computing architectures, such as SMP nodes and commodity clusters. It is academically developed and freely available under an open source license. We provide *HPX* to the community for experimentation and application to achieve high efficiency and scalability for dynamic adaptive and irregular computational problems. *HPX* is a C++ library that supports a set of critical mechanisms for dynamic adaptive resource management and lightweight task scheduling within the context of a global address space. It is solidly based on many years of experience in writing highly parallel applications for HPC systems.

The two-decade success of the communicating sequential processes (CSP) execution model and its message passing interface (MPI) programming model have been seriously eroded by challenges of power, processor core complexity, multi-core sockets, and heterogeneous structures of GPUs. Both efficiency and scalability for some current (strong scaled) applications and future Exascale applications demand new techniques to expose new sources of algorithm parallelism and exploit unused resources through adaptive use of runtime information.

The ParalleX execution model replaces CSP to provide a new computing paradigm embodying the governing principles for organizing and conducting highly efficient scalable computations greatly exceeding the capabilities of today's problems. *HPX* is the first practical, reliable, and performance-oriented runtime system incorporating the principal concepts of the ParalleX model publicly provided in open source release form.

HPX is designed by the STE||AR²⁰¹ Group (Systems Technology, Emergent Parallelism, and Algorithm Research) at Louisiana State University (LSU)²⁰²'s Center for Computation and Technology (CCT)²⁰³ to enable developers to exploit the full processing power of many-core systems with an unprecedented degree of parallelism. STE||AR²⁰⁴ is a research group focusing on system software solutions and scientific application development for hybrid and many-core hardware architectures.

For more information about the STE||AR²⁰⁵ Group, see *People*.

2.5.3 What makes our systems slow?

Estimates say that we currently run our computers at well below 100% efficiency. The theoretical peak performance (usually measured in FLOPS²⁰⁶—floating point operations per second) is much higher than any practical peak performance reached by any application. This is particularly true for highly parallel hardware. The more hardware parallelism we provide to an application, the better the application must scale in order to efficiently use all the resources of the machine. Roughly speaking, we distinguish two forms of scalability: strong scaling (see Amdahl's Law²⁰⁷) and weak scaling (see Gustafson's Law²⁰⁸). Strong scaling is defined as how the solution time varies with the number of processors for a fixed **total** problem size. It gives an estimate of how much faster we can solve a particular problem by throwing more resources at it. Weak scaling is defined as how the solution time varies with the number of processors for a fixed problem size **per processor**. In other words, it defines how much more data can we process by using more hardware resources.

In order to utilize as much hardware parallelism as possible an application must exhibit excellent strong and weak scaling characteristics, which requires a high percentage of work executed in parallel, i.e., using multiple threads of execution. Optimally, if you execute an application on a hardware resource with N processors it either runs N times faster or it can handle N times more data. Both cases imply 100% of the work is executed on all available processors in parallel. However, this is just a theoretical limit. Unfortunately, there are more things that limit scalability, mostly

²⁰¹ <https://stellar-group.org>

²⁰² <https://www.lsu.edu>

²⁰³ <https://www.cct.lsu.edu>

²⁰⁴ <https://stellar-group.org>

²⁰⁵ <https://stellar-group.org>

²⁰⁶ <http://en.wikipedia.org/wiki/FLOPS>

²⁰⁷ http://en.wikipedia.org/wiki/Amdahl%27s_law

²⁰⁸ http://en.wikipedia.org/wiki/Gustafson%27s_law

inherent to the hardware architectures and the programming models we use. We break these limitations into four fundamental factors that make our systems *SLOW*:

- **Starvation** occurs when there is insufficient concurrent work available to maintain high utilization of all resources.
- **Latencies** are imposed by the time-distance delay intrinsic to accessing remote resources and services.
- **Overhead** is work required for the management of parallel actions and resources on the critical execution path, which is not necessary in a sequential variant.
- **Waiting for contention resolution** is the delay due to the lack of availability of oversubscribed shared resources.

Each of those four factors manifests itself in multiple and different ways; each of the hardware architectures and programming models expose specific forms. However, the interesting part is that all of them are limiting the scalability of applications no matter what part of the hardware jungle we look at. Hand-helds, PCs, supercomputers, or the cloud, all suffer from the reign of the 4 horsemen: **Starvation**, **Latency**, **Overhead**, and **Contention**. This realization is very important as it allows us to derive the criteria for solutions to the scalability problem from first principles, and it allows us to focus our analysis on very concrete patterns and measurable metrics. Moreover, any derived results will be applicable to a wide variety of targets.

2.5.4 Technology demands new response

Today's computer systems are designed based on the initial ideas of [John von Neumann](#)²⁰⁹, as published back in 1945, and later extended by the [Harvard architecture](#)²¹⁰. These ideas form the foundation, the execution model, of computer systems we use currently. However, a new response is required in the light of the demands created by today's technology.

So, what are the overarching objectives for designing systems allowing for applications to scale as they should? In our opinion, the main objectives are:

- **Performance**: as previously mentioned, scalability and efficiency are the main criteria people are interested in.
- **Fault tolerance**: the low expected mean time between failures ([MTBF](#)²¹¹) of future systems requires embracing faults, not trying to avoid them.
- **Power**: minimizing energy consumption is a must as it is one of the major cost factors today, and will continue to rise in the future.
- **Generality**: any system should be usable for a broad set of use cases.
- **Programmability**: for programmer this is a very important objective, ensuring long term platform stability and portability.

What needs to be done to meet those objectives, to make applications scale better on tomorrow's architectures? Well, the answer is almost obvious: we need to devise a new execution model—a set of governing principles for the holistic design of future systems—targeted at minimizing the effect of the outlined **SLOW** factors. Everything we create for future systems, every design decision we make, every criteria we apply, have to be validated against this single, uniform metric. This includes changes in the hardware architecture we prevalently use today, and it certainly involves new ways of writing software, starting from the operating system, runtime system, compilers, and at the application level. However, the key point is that all those layers have to be co-designed; they are interdependent and cannot be seen as separate facets. The systems we have today have been evolving for over 50 years now. All layers function in a certain way, relying on the other layers to do so. But we do not have the time to wait another 50 years for a new coherent system to evolve. The new paradigms are needed now—therefore, co-design is the key.

²⁰⁹ <http://qss.stanford.edu/~godfrey/vonNeumann/vnedvac.pdf>

²¹⁰ http://en.wikipedia.org/wiki/Harvard_architecture

²¹¹ http://en.wikipedia.org/wiki/Mean_time_between_failures

2.5.5 Governing principles applied while developing HPX

As it turns out, we do not have to start from scratch. Not everything has to be invented and designed anew. Many of the ideas needed to combat the 4 horsemen already exist, many for more than 30 years. All it takes is to gather them into a coherent approach. We'll highlight some of the derived principles we think to be crucial for defeating **SLOW**. Some of those are focused on high-performance computing, others are more general.

Focus on latency hiding instead of latency avoidance

It is impossible to design a system exposing zero latencies. In an effort to come as close as possible to this goal many optimizations are mainly targeted towards minimizing latencies. Examples for this can be seen everywhere, such as low latency network technologies like [InfiniBand](#)²¹², caching memory hierarchies in all modern processors, the constant optimization of existing [MPI](#)²¹³ implementations to reduce related latencies, or the data transfer latencies intrinsic to the way we use [GPGPUs](#)²¹⁴ today. It is important to note that existing latencies are often tightly related to some resource having to wait for the operation to be completed. At the same time it would be perfectly fine to do some other, unrelated work in the meantime, allowing the system to hide the latencies by filling the idle-time with useful work. Modern systems already employ similar techniques (pipelined instruction execution in the processor cores, asynchronous input/output operations, and many more). What we propose is to go beyond anything we know today and to make latency hiding an intrinsic concept of the operation of the whole system stack.

Embrace fine-grained parallelism instead of heavyweight threads

If we plan to hide latencies even for very short operations, such as fetching the contents of a memory cell from main memory (if it is not already cached), we need to have very lightweight threads with extremely short context switching times, optimally executable within one cycle. Granted, for mainstream architectures, this is not possible today (even if we already have special machines supporting this mode of operation, such as the [Cray XMT](#)²¹⁵). For conventional systems, however, the smaller the overhead of a context switch and the finer the granularity of the threading system, the better will be the overall system utilization and its efficiency. For today's architectures we already see a flurry of libraries providing exactly this type of functionality: non-pre-emptive, task-queue based parallelization solutions, such as [Intel Threading Building Blocks \(TBB\)](#)²¹⁶, [Microsoft Parallel Patterns Library \(PPL\)](#)²¹⁷, [Cilk++](#)²¹⁸, and many others. The possibility to suspend a current task if some preconditions for its execution are not met (such as waiting for I/O or the result of a different task), seamlessly switching to any other task which can continue, and to reschedule the initial task after the required result has been calculated, which makes the implementation of latency hiding almost trivial.

Rediscover constraint-based synchronization to replace global barriers

The code we write today is riddled with implicit (and explicit) global barriers. By "global barriers," we mean the synchronization of the control flow between several (very often all) threads (when using [OpenMP](#)²¹⁹) or processes ([MPI](#)²²⁰). For instance, an implicit global barrier is inserted after each loop parallelized using [OpenMP](#)²²¹ as the system synchronizes the threads used to execute the different iterations in parallel. In [MPI](#)²²² each of the communication steps imposes an explicit barrier onto the execution flow as (often all) nodes have to be synchronized. Each of those barriers

²¹² <http://en.wikipedia.org/wiki/InfiniBand>

²¹³ https://en.wikipedia.org/wiki/Message_Passing_Interface

²¹⁴ <http://en.wikipedia.org/wiki/GPGPU>

²¹⁵ http://en.wikipedia.org/wiki/Cray_XMT

²¹⁶ <https://www.threadingbuildingblocks.org/>

²¹⁷ <https://msdn.microsoft.com/en-us/library/dd492418.aspx>

²¹⁸ <https://software.intel.com/en-us/articles/intel-cilk-plus/>

²¹⁹ <https://openmp.org/wp/>

²²⁰ https://en.wikipedia.org/wiki/Message_Passing_Interface

²²¹ <https://openmp.org/wp/>

²²² https://en.wikipedia.org/wiki/Message_Passing_Interface

is like the eye of a needle the overall execution is forced to be squeezed through. Even minimal fluctuations in the execution times of the parallel threads (jobs) causes them to wait. Additionally, it is often only one of the executing threads that performs the actual reduce operation, which further impedes parallelism. A closer analysis of a couple of key algorithms used in science applications reveals that these global barriers are not always necessary. In many cases it is sufficient to synchronize a small subset of the threads. Any operation should proceed whenever the preconditions for its execution are met, and only those. Usually there is no need to wait for iterations of a loop to finish before you can continue calculating other things; all you need is to complete the iterations that produce the required results for the next operation. Good bye global barriers, hello constraint based synchronization! People have been trying to build this type of computing (and even computers) since the 1970s. The theory behind what they did is based on ideas around static and dynamic dataflow. There are certain attempts today to get back to those ideas and to incorporate them with modern architectures. For instance, a lot of work is being done in the area of constructing dataflow-oriented execution trees. Our results show that employing dataflow techniques in combination with the other ideas, as outlined herein, considerably improves scalability for many problems.

Adaptive locality control instead of static data distribution

While this principle seems to be a given for single desktop or laptop computers (the operating system is your friend), it is everything but ubiquitous on modern supercomputers, which are usually built from a large number of separate nodes (i.e., Beowulf clusters), tightly interconnected by a high-bandwidth, low-latency network. Today's prevalent programming model for those is MPI, which does not directly help with proper data distribution, leaving it to the programmer to decompose the data to all of the nodes the application is running on. There are a couple of specialized languages and programming environments based on PGAS²²³ (Partitioned Global Address Space) designed to overcome this limitation, such as Chapel²²⁴, X10²²⁵, UPC²²⁶, or Fortress²²⁷. However, all systems based on PGAS rely on static data distribution. This works fine as long as this static data distribution does not result in heterogeneous workload distributions or other resource utilization imbalances. In a distributed system these imbalances can be mitigated by migrating part of the application data to different localities (nodes). The only framework supporting (limited) migration today is Charm++²²⁸. The first attempts towards solving related problem go back decades as well, a good example is the Linda coordination language²²⁹. Nevertheless, none of the other mentioned systems support data migration today, which forces the users to either rely on static data distribution and live with the related performance hits or to implement everything themselves, which is very tedious and difficult. We believe that the only viable way to flexibly support dynamic and adaptive *locality* control is to provide a global, uniform address space to the applications, even on distributed systems.

Prefer moving work to the data over moving data to the work

For the best performance it seems obvious to minimize the amount of bytes transferred from one part of the system to another. This is true on all levels. At the lowest level we try to take advantage of processor memory caches, thus, minimizing memory latencies. Similarly, we try to amortize the data transfer time to and from GPGPUs²³⁰ as much as possible. At high levels we try to minimize data transfer between different nodes of a cluster or between different virtual machines on the cloud. Our experience (well, it's almost common wisdom) shows that the amount of bytes necessary to encode a certain operation is very often much smaller than the amount of bytes encoding the data the operation is performed upon. Nevertheless, we still often transfer the data to a particular place where we execute the operation just to bring the data back to where it came from afterwards. As an example let's look at the way we usually write our applications for clusters using MPI. This programming model is all about data transfer between nodes. MPI is the prevalent programming model for clusters, and it is fairly straightforward to understand and to use. Therefore,

²²³ <https://www.pgas.org/>

²²⁴ <https://chapel.cray.com/>

²²⁵ <https://x10-lang.org/>

²²⁶ <https://upc.lbl.gov/>

²²⁷ <https://labs.oracle.com/projects/plrg/Publications/index.html>

²²⁸ <https://charm.cs.uiuc.edu/>

²²⁹ [http://en.wikipedia.org/wiki/Linda_\(coordination_language\)](http://en.wikipedia.org/wiki/Linda_(coordination_language))

²³⁰ <http://en.wikipedia.org/wiki/GPGPU>

we often write applications in a way that accommodates this model, centered around data transfer. These applications usually work well for smaller problem sizes and for regular data structures. The larger the amount of data we have to churn and the more irregular the problem domain becomes, the worse the overall machine utilization and the (strong) scaling characteristics become. While it is not impossible to implement more dynamic, data driven, and asynchronous applications using MPI, it is somewhat difficult to do so. At the same time, if we look at applications that prefer to execute the code close to the *locality* where the data was placed, i.e., utilizing active messages (for instance based on Charm++²³¹), we see better asynchrony, simpler application codes, and improved scaling.

Favor message driven computation over message passing

Today's prevalently used programming model on parallel (multi-node) systems is MPI. It is based on message passing, as the name implies, which means that the receiver has to be aware of a message about to come in. Both codes, the sender and the receiver, have to synchronize in order to perform the communication step. Even the newer, asynchronous interfaces require explicitly coding the algorithms around the required communication scheme. As a result, everything but the most trivial MPI applications spends a considerable amount of time waiting for incoming messages, thus, causing starvation and latencies to impede full resource utilization. The more complex and more dynamic the data structures and algorithms become, the larger the adverse effects. The community discovered message-driven and data-driven methods of implementing algorithms a long time ago, and systems such as Charm++²³² have already integrated active messages demonstrating the validity of the concept. Message-driven computation allows for sending messages without requiring the receiver to actively wait for them. Any incoming message is handled asynchronously and triggers the encoded action by passing along arguments and—possibly—continuations. *HPX* combines this scheme with work-queue based scheduling as described above, which allows the system to almost completely overlap any communication with useful work, thereby minimizing latencies.

2.6 Additional material

- 2-day workshop held at CSCS in 2016
 - Recorded lectures²³³
 - Slides²³⁴
- Tutorials repository²³⁵
- STE||AR Group blog posts²³⁶
- Basic *HPX* recipes
 - Exporting a free function from a shared library which lives in a namespace, to use as Action²³⁷
 - Turning a struct or class into a component and use it's methods²³⁸
 - Creating and referencing components in hpx²³⁹

²³¹ <https://charm.cs.uiuc.edu/>

²³² <https://charm.cs.uiuc.edu/>

²³³ <https://www.youtube.com/playlist?list=PL1tk5lGm7zvSXfS-sqOOmIJ0lFNjKze18>

²³⁴ <https://github.com/STELLAR-GROUP/tutorials/tree/master/cscs2016>

²³⁵ <https://github.com/STELLAR-GROUP/tutorials>

²³⁶ <http://stellar-group.org/blog/>

²³⁷ <https://gitlab.com/-/snippets/1821389>

²³⁸ <https://gitlab.com/-/snippets/1822983>

²³⁹ <https://gitlab.com/-/snippets/1828131>

2.7 Overview

HPX is organized into different sub-libraries and those in turn into modules. The libraries and modules are independent, with clear dependencies and no cycles. As an end-user, the use of these libraries is completely transparent. If you use e.g. `add_hpx_executable` to create a target in your project you will automatically get all modules as dependencies. See below for a list of the available libraries and modules. Currently these are nothing more than an internal grouping and do not affect usage. They cannot be consumed individually at the moment.

Note: There is a dependency report that displays useful information about the structure of the code. It is available for each commit at [HPX Dependency report](#).

2.7.1 Core modules

affinity

The affinity module contains helper functionality for mapping worker threads to hardware resources.

See the [API reference](#) of the module for more details.

algorithms

The algorithms module exposes the full set of algorithms defined by the C++ standard. There is also partial support for C++ ranges.

See the [API reference](#) of the module for more details.

allocator_support

This module provides utilities for allocators. It contains `hpx::util::internal_allocator` which directly forwards allocation calls to `jemalloc`. This utility is mainly useful on Windows.

See the [API reference](#) of the module for more details.

asio

The asio module is a thin wrapper around the [Boost.Asio](#)²⁴⁰ library, providing a few additional helper functions.

See the [API reference](#) of the module for more details.

²⁴⁰ https://www.boost.org/doc/libs/release/doc/html/boost_asio.html

assertion

The assertion library implements the macros `HPX_ASSERT` and `HPX_ASSERT_MSG`. Those two macros can be used to implement assertions which are turned off during a release build.

By default, the location and function where the assert has been called from are displayed when the assertion fires. This behavior can be modified by using `hpx::assertion::set_assertion_handler`. When HPX initializes, it uses this function to specify a more elaborate assertion handler. If your application needs to customize this, it needs to do so before calling `hpx::init`, `hpx_main` or using the C-main wrappers.

See the *API reference* of the module for more details.

async_base

The `async_base` module defines the basic functionality for spawning tasks on thread pools. This module does not implement any functionality on its own, but is extended by `async_local` and `async_distributed` with implementations for the local and distributed cases.

See the *API reference* of this module for more details.

async_combinators

This module contains combinators for futures. The `when_*` functions allow you to turn multiple futures into a single future which is ready when all, any, some, or each of the given futures are ready. The `wait_*` combinators are equivalent to the `when_*` functions except that they do not return a future. Those wait for all futures to become ready before returning to the user. Note that the `wait_*` functions will rethrow one of the exceptions from exceptional futures. The `wait_*_nothrow` combinators are equivalent to the `wait_*` functions except that they do not throw if one of the futures has become exceptional.

The `split_future` combinator takes a single future of a container (e.g. `tuple`) and turns it into a container of futures.

See *lcos_local*, *synchronization*, and *async_distributed* for other synchronization facilities.

See the *API reference* of this module for more details.

async_cuda

This library adds a simple API that enables the user to retrieve a future from a `CUDA`²⁴¹ stream. Typically, a user may launch one or more kernels and then get a future from the stream that will become ready when those kernels have completed. It is important to note that multiple kernels may be launched without fetching a future, and multiple futures may be obtained from the helper. Please refer to the unit tests and examples for further examples.

See the *API reference* of this module for more details.

²⁴¹ https://www.nvidia.com/object/cuda_home_new.html

async_local

This module extends *async_base* to provide local implementations of *hpx::async*, *hpx::post*, *hpx::sync*, and *hpx::dataflow*. The *async_distributed* module extends the functionality in this module to work with *actions*.

See the API reference of this module for more details.

async_mpi

The MPI library is intended to simplify the process of integrating MPI²⁴² based codes with the *HPX* runtime. Any MPI function that is asynchronous and uses an *MPI_Request* may be converted into an *hpx::future*. The syntax is designed to allow a simple replacement of the MPI call with a futurized async version that accepts an executor instead of a communicator, and returns a future instead of assigning a request. Typically, an MPI call of the form

```
int MPI_Isend(buf, count, datatype, rank, tag, comm, request);
```

becomes

```
hpx::future<int> f = hpx::async(executor, MPI_Isend, buf, count, datatype, rank, tag);
```

When the MPI operation is complete, the future will become ready. This allows communication to be integrated cleanly with the rest of *HPX*, in particular the continuation style of programming may be used to build up more complex code. Consider the following example, that chains user processing, sends and receives using continuations...

```
// create an executor for MPI dispatch
hpx::mpi::experimental::executor exec(MPI_COMM_WORLD);

// post an asynchronous receive using MPI_Irecv
hpx::future<int> f_recv = hpx::async(
    exec, MPI_Irecv, &data, rank, MPI_INT, rank_from, i);

// attach a continuation to run when the recv completes,
f_recv.then([=, &tokens, &counter](auto&&)
{
    // call an application specific function
    msg_recv(rank, size, rank_to, rank_from, tokens[i], i);

    // send a new message
    hpx::future<int> f_send = hpx::async(
        exec, MPI_Isend, &tokens[i], 1, MPI_INT, rank_to, i);

    // when that send completes
    f_send.then([=, &tokens, &counter](auto&&)
    {
        // call an application specific function
        msg_send(rank, size, rank_to, rank_from, tokens[i], i);
    });
});
```

The example above makes use of *MPI_Isend* and *MPI_Irecv*, but *any* MPI function that uses requests may be futurized in this manner. The following is a (non exhaustive) list of MPI functions that *should* be supported, though not all have been tested at the time of writing (please report any problems to the issue tracker).

²⁴² https://en.wikipedia.org/wiki/Message_Passing_Interface

```
int MPI_Isend(...);
int MPI_Ibsend(...);
int MPI_Issend(...);
int MPI_Irsend(...);
int MPI_Irecv(...);
int MPI_Imrecv(...);
int MPI_Ibarrier(...);
int MPI_Ibcast(...);
int MPI_Igather(...);
int MPI_Igatherv(...);
int MPI_Iscatter(...);
int MPI_Iscatterv(...);
int MPI_Iallgather(...);
int MPI_Iallgatherv(...);
int MPI_Ialltoall(...);
int MPI_Ialltoallv(...);
int MPI_Ialltoallw(...);
int MPI_Ireduce(...);
int MPI_Iallreduce(...);
int MPI_Ireduce_scatter(...);
int MPI_Ireduce_scatter_block(...);
int MPI_Iscan(...);
int MPI_Iexscan(...);
int MPI_Ineighbor_allgather(...);
int MPI_Ineighbor_allgatherv(...);
int MPI_Ineighbor_alltoall(...);
int MPI_Ineighbor_alltoallv(...);
int MPI_Ineighbor_alltoallw(...);
```

Note that the *HPX* mpi futurization wrapper should work with *any* asynchronous MPI call, as long as the function signature has the last two arguments `MPI_xxx(..., MPI_Comm comm, MPI_Request *request)` - internally these two parameters will be substituted by the executor and future data parameters that are supplied by template instantiations inside the `hpx::mpi` code.

See the API reference of this module for more details.

async_sycl

This module allows creating HPX futures using SYCL²⁴³ events, effectively integrating asynchronous SYCL kernels and memory transfers with HPX. Building on this integration, this module also contains a SYCL executor. This executor encapsulates a SYCL queue. When SYCL queue member functions are launched with this executor, the user can automatically obtain the HPX futures associated with them.

The creation of the HPX futures using SYCL events is based on the same event polling mechanism that the CUDA HPX integration uses. Each registered event gets an associated callback and gets inserted into a callback vector to be polled by the scheduler in between tasks. Once the polling reveals the event is complete, the callback will be called, which in turn sets the future to ready (see `sycl_event_callback.cpp`). There are multiple adaptations for HipSYCL for this: To keep the runtime alive (avoiding the repeated on-the-fly creation of the runtime during the polling), we keep a default queue. Furthermore, we flush the internal SYCL DAG to ensure that the launched SYCL function is actually being executed.

The SYCL executor offers the usual `post` and `async_execute` functions. Additionally, it contains two `get_future` functions. One expects a pre-existing SYCL event to return a future, the other one does not but will launch an empty SYCL kernel instead, to obtain an event (causing higher overhead for the sake of being more convenient). The `post` and

²⁴³ <https://en.wikipedia.org/wiki/SYCL>

async_execute implementations here are actually different for HipSYCL and OneAPI, since the `sycl::queue` in OneAPI uses a different interface (using a `code_location` parameter) which requires some adaptations here.

To make this module compile, we use the `-fno-sycl` and `-fsycl` compiler parameters for the OneAPI use-case (requiring HPX to be compiled with `dpcpp`). For HipSYCL we use its `cmake` integration instead (requiring HPX to be compiled with `clang++` and including HipSYCL as a library).

To build with OneAPI, use the CMake Variable `HPX_WITH_SYCL=ON`. To build with HipSYCL, use `HPX_WITH_SYCL=ON` and `HPX_WITH_HIPSYCL=ON` (and make sure `find_package` will find HipSYCL).

Lastly, the module contains three tests/examples. All three implement a simple vector add example. The first one obtains a future using the free method `get_future`, the second one uses a single SYCL executor and the last one is using multiple executors called from multiple host threads.

To build the tests, use `make tests.unit.modules.async_sycl` To run the tests, use `ctest -R sycl`.

NOTE: Theoretically, this module could work with other SYCL implementations, but was only tested using OneAPI and HipSYCL so far.

See the API reference of this module for more details.

batch_environments

This module allows for the detection of execution as batch jobs, a series of programs executed without user intervention. All data is preselected and will be executed according to preset parameters, such as date or completion of another task. Batch environments are especially useful for executing repetitive tasks.

HPX supports the creation of batch jobs through the Portable Batch System (PBS) and SLURM.

For more information on batch environments, see *Running on batch systems* and the API reference for the module.

cache

This module provides two cache data structures:

- `hpx::util::cache::local_cache`
- `hpx::util::cache::lru_cache`

See the *API reference* of the module for more details.

concepts

This module provides helpers for emulating concepts. It provides the following macros:

- `HPX_CONCEPT_REQUIRES`
- `HPX_HAS_MEMBER_XXX_TRAIT_DEF`
- `HPX_HAS_XXX_TRAIT_DEF`

See the API reference of the module for more details.

concurrency

This module provides concurrency primitives useful for multi-threaded programming such as:

- `hpx::barrier`
- `hpx::util::cache_line_data` and `hpx::util::cache_aligned_data`: wrappers for aligning and padding data to cache lines.
- various lockfree queue data structures

See the API reference of the module for more details.

config

The config module contains various configuration options, typically hidden behind macros that choose the correct implementation based on the compiler and other available options. It also contains platform independent macros to control inlining, export sets and more.

See the *API reference* of the module for more details.

config_registry

The config_registry module is a low level module providing helper functionality for registering configuration entries to a global registry from other modules. The `hpx::config_registry::add_module_config` function is used to add configuration options, and `hpx::config_registry::get_module_configs` can be used to retrieve configuration entries registered so far. `add_module_config_helper` can be used to register configuration entries through static global options.

See the API reference of this module for more details.

coroutines

The coroutines module provides coroutine (user-space thread) implementations for different platforms.

See the *API reference* of the module for more details.

datastructures

The datastructures module provides basic data structures (typically provided for compatibility with older C++ standards):

- `hpx::detail::small_vector`
- `hpx::util::basic_any`
- `hpx::util::member_pack`
- `hpx::optional`
- `hpx::tuple`
- `hpx::variant`

See the *API reference* of the module for more details.

debugging

This module provides helpers for demangling symbol names.

See the *API reference* of the module for more details.

errors

This module provides support for exceptions and error codes:

- `hpx::exception`
- `hpx::error_code`
- `hpx::error`

See the *API reference* of the module for more details.

execution

This library implements executors and execution policies for use with parallel algorithms and other facilities related to managing the execution of tasks.

See the *API reference* of the module for more details.

execution_base

The basic execution module is the main entry point to implement parallel and concurrent operations. It is modeled after P0443²⁴⁴ with some additions and implementations for the described concepts. Most notably, it provides an abstraction for execution resources, execution contexts and execution agents in such a way, that it provides customization points that those aforementioned concepts can be replaced and combined with ease.

For that purpose, three virtual base classes are provided to be able to provide implementations with different properties:

- **resource_base:** **This is the abstraction for execution resources, that is** for example CPU cores or an accelerator.
- **context_base:** **An execution context uses execution resources and is able** to spawn new execution agents, as new threads of executions on the available resources.
- **agent_base:** **The execution agent represents the thread of execution, and** can be used to yield, suspend, resume or abort a thread of execution.

executors

The executors module exposes executors and execution policies. Most importantly, it exposes the following classes and constants:

- `hpx::execution::sequenced_executor`
- `hpx::execution::parallel_executor`
- `hpx::execution::sequenced_policy`
- `hpx::execution::parallel_policy`
- `hpx::execution::parallel_unsequenced_policy`

²⁴⁴ <http://wg21.link/p0443>

- `hpx::execution::sequenced_task_policy`
- `hpx::execution::parallel_task_policy`
- `hpx::execution::seq`
- `hpx::execution::par`
- `hpx::execution::par_unseq`
- `hpx::execution::task`

See the *API reference* of this module for more details.

filesystem

This module provides a compatibility layer for the C++17 filesystem library. If the filesystem library is available this module will simply forward its contents into the `hpx::filesystem` namespace. If the library is not available it will fall back to Boost.Filesystem instead.

See the *API reference* of the module for more details.

format

The format module exposes the `format` and `format_to` functions for formatting strings.

See the *API reference* of the module for more details.

functional

This module provides function wrappers and helpers for managing functions and their arguments.

- `hpx::function`
- `hpx::function_ref`
- `hpx::move_only_function`
- `hpx::bind`
- `hpx::bind_back`
- `hpx::bind_front`
- `hpx::util::deferred_call`
- `hpx::invoke`
- `hpx::invoke_r`
- `hpx::invoke_fused`
- `hpx::invoke_fused_r`
- `hpx::mem_fn`
- `hpx::util::one_shot`
- `hpx::util::protect`
- `hpx::util::result_of`
- `hpx::placeholders::_1`

- `hpx::placeholders::_2`
- ...
- `hpx::placeholders::_9`

See the *API reference* of the module for more details.

futures

This module defines the `hpx::future` and `hpx::shared_future` classes corresponding to the C++ standard library classes `std::future`²⁴⁵ and `std::shared_future`²⁴⁶. Note that the specializations of `hpx::future::then` for executors and execution policies are defined in the *execution* module.

See the *API reference* of this module for more details.

hardware

The hardware module abstracts away hardware specific details of timestamps and CPU features.

See the API reference of the module for more details.

hashing

The hashing module provides two hashing implementations:

- `hpx::util::fibhash`
- `hpx::util::jenkins_hash`

See the API reference of the module for more details.

include_local

This module provides no functionality in itself. Instead it provides headers that group together other headers that often appear together. This module provides local-only headers.

See the API reference of this module for more details.

io_service

This module provides an abstraction over Boost.ASIO, combining multiple `asio::io_contexts` into a single pool. `hpx::util::io_service_pool` provides a simple pool of `asio::io_contexts` with an API similar to `asio::io_context`. `hpx::threads::detail::io_service_thread_pool` wraps `hpx::util::io_service_pool` into an interface derived from `hpx::threads::detail::thread_pool_base`.

See the *API reference* of this module for more details.

²⁴⁵ <http://en.cppreference.com/w/cpp/thread/future>

²⁴⁶ http://en.cppreference.com/w/cpp/thread/shared_future

iterator_support

This module provides helpers for iterators. It provides `hpx::util::iterator_facade` and `hpx::util::iterator_adaptor` for creating new iterators, and the trait `hpx::util::is_iterator` along with more specific iterator traits.

See the API reference of the module for more details.

itt_notify

This module provides support for profiling with Intel VTune²⁴⁷.

See the API reference of this module for more details.

lci_base

This module provides helper functionality for detecting LCI environments.

See the API reference of this module for more details.

lcos_local

This module provides the following local *LCOs*:

- `hpx::lcos::local::and_gate`
- `hpx::lcos::local::channel`
- `hpx::lcos::local::one_element_channel`
- `hpx::lcos::local::receive_channel`
- `hpx::lcos::local::send_channel`
- `hpx::lcos::local::guard`
- `hpx::lcos::local::guard_set`
- `hpx::lcos::local::run_guarded`
- `hpx::lcos::local::conditional_trigger`
- `hpx::packaged_task`
- `hpx::promise`
- `hpx::lcos::local::receive_buffer`
- `hpx::lcos::local::trigger`

See *lcos_distributed* for distributed LCOs. Basic synchronization primitives for use in *HPX* threads can be found in *synchronization*. *async_combinators* contains useful utility functions for combining futures.

See the *API reference* of this module for more details.

²⁴⁷ <https://software.intel.com/content/www/us/en/develop/tools/vtune-profiler.html>

lock_registration

This module contains functionality for registering locks to detect when they are locked and unlocked on different threads.

See the API reference of this module for more details.

logging

This module provides useful macros for logging information.

See the API reference of the module for more details.

memory

Part of this module is a forked version of `boost::intrusive_ptr` from `Boost.SmartPtr`²⁴⁸.

See the API reference of the module for more details.

mpi_base

This module provides helper functionality for detecting `MPI`²⁴⁹ environments.

See the API reference of this module for more details.

pack_traversal

This module exposes the basic functionality for traversing various packs, both synchronously and asynchronously: `hpx::util::traverse_pack` and `hpx::util::traverse_pack_async`. It also exposes the higher level functionality of unwrapping nested futures: `hpx::util::unwrap` and its function object form `hpx::util::functional::unwrap`.

See the *API reference* of this module for more details.

plugin

This module provides base utilities for creating plugins.

See the API reference of the module for more details.

prefix

This module provides utilities for handling the prefix of an *HPX* application, i.e. the paths used for searching components and plugins.

See the API reference of this module for more details.

²⁴⁸ https://www.boost.org/doc/libs/release/libs/smart_ptr/doc/html/smart_ptr.html

²⁴⁹ https://en.wikipedia.org/wiki/Message_Passing_Interface

preprocessor

This library contains useful preprocessor macros:

- `HPX_PP_CAT`: Concatenate two tokens
- `HPX_PP_EXPAND`: Expands a preprocessor token
- `HPX_PP_NARGS`: Determines the number of arguments passed to a variadic macro
- `HPX_PP_STRINGIZE`: Turns a token into a string
- `HPX_PP_STRIP_PARENS`: Strips parenthesis from a token

See the *API reference* of the module for more details.

program_options

The module `program_options` is a direct fork of the `Boost.Program_options`²⁵⁰ library (Boost V1.70.0²⁵¹). In order to be included as an *HPX* module, the `Boost.Program_options` library has been moved to the namespace `hpx::program_options`. We have also replaced all Boost facilities the library depends on with either the equivalent facilities from the standard library or from *HPX*. As a result, the *HPX* `program_options` module is fully interface compatible with `Boost.Program_options` (sans the `hpx` namespace and the `#include <hpx/modules/program_options.hpp>` changes that need to be applied to all code relying on this library).

All credit goes to Vladimir Prus, the author of the excellent `Boost.Program_options` library. All bugs have been introduced by us.

See the *API reference* of the module for more details.

properties

This module implements the `prefer` customization point for properties in terms of `P2220`²⁵². This differs from `P1393`²⁵³ in that it relies fully on `tag_invoke` overloads and fewer base customization points. Actual properties are defined in modules. All functionality is experimental and can be accessed through the `hpx::experimental` namespace.

See the *API reference* of this module for more details.

resiliency

In *HPX*, a program failure is a manifestation of a failing task. This module exposes several APIs that allow users to manage failing tasks in a convenient way by either replaying a failed task or by replicating a specific task.

Task replay is analogous to the Checkpoint/Restart mechanism found in conventional execution models. The key difference being localized fault detection. When the runtime detects an error, it replays the failing task as opposed to completely rolling back the entire program to the previous checkpoint.

Task replication is designed to provide reliability enhancements by replicating a set of tasks and evaluating their results to determine a consensus among them. This technique is most effective in situations where there are few tasks in the critical path of the DAG which leaves the system underutilized or where hardware or software failures may result in an incorrect result instead of an error. However, the drawback of this method is the additional computational cost incurred by repeating a task multiple times.

²⁵⁰ https://www.boost.org/doc/html/program_options.html

²⁵¹ https://www.boost.org/doc/libs/1_70_0/doc/html/program_options.html

²⁵² <https://wg21.link/p2220>

²⁵³ <http://wg21.link/p1393>

The following API functions are exposed:

- `hpx::resiliency::experimental::async_replay`: This version of task replay will catch user-defined exceptions and automatically reschedule the task N times before throwing an `hpx::resiliency::experimental::abort_replay_exception` if no task is able to complete execution without an exception.
- `hpx::resiliency::experimental::async_replay_validate`: This version of replay adds an argument to async replay which receives a user-provided validation function to test the result of the task against. If the task's output is validated, the result is returned. If the output fails the check or an exception is thrown, the task is replayed until no errors are encountered or the number of specified retries has been exceeded.
- `hpx::resiliency::experimental::async_replicate`: This is the most basic implementation of the task replication. The API returns the first result that runs without detecting any errors.
- `hpx::resiliency::experimental::async_replicate_validate`: This API additionally takes a validation function which evaluates the return values produced by the threads. The first task to compute a valid result is returned.
- `hpx::resiliency::experimental::async_replicate_vote`: This API adds a vote function to the basic replicate function. Many hardware or software failures are silent errors which do not interrupt program flow. In order to detect errors of this kind, it is necessary to run the task several times and compare the values returned by every version of the task. In order to determine which return value is "correct", the API allows the user to provide a custom consensus function to properly form a consensus. This voting function then returns the "correct" answer.
- `hpx::resiliency::experimental::async_replicate_vote_validate`: This combines the features of the previously discussed replicate set. Replicate vote validate allows a user to provide a validation function to filter results. Additionally, as described in replicate vote, the user can provide a "voting function" which returns the consensus formed by the voting logic.
- `hpx::resiliency::experimental::dataflow_replay`: This version of dataflow replay will catch user-defined exceptions and automatically reschedules the task N times before throwing an `hpx::resiliency::experimental::abort_replay_exception` if no task is able to complete execution without an exception. Any arguments for the executed task that are futures will cause the task invocation to be delayed until all of those futures have become ready.
- `hpx::resiliency::experimental::dataflow_replay_validate`: This version of replay adds an argument to dataflow replay which receives a user-provided validation function to test the result of the task against. If the task's output is validated, the result is returned. If the output fails the check or an exception is thrown, the task is replayed until no errors are encountered or the number of specified retries have been exceeded. Any arguments for the executed task that are futures will cause the task invocation to be delayed until all of those futures have become ready.
- `hpx::resiliency::experimental::dataflow_replicate`: This is the most basic implementation of the task replication. The API returns the first result that runs without detecting any errors. Any arguments for the executed task that are futures will cause the task invocation to be delayed until all of those futures have become ready.
- `hpx::resiliency::experimental::dataflow_replicate_validate`: This API additionally takes a validation function which evaluates the return values produced by the threads. The first task to compute a valid result is returned. Any arguments for the executed task that are futures will cause the task invocation to be delayed until all of those futures have become ready.
- `hpx::resiliency::experimental::dataflow_replicate_vote`: This API adds a vote function to the basic replicate function. Many hardware or software failures are silent errors which do not interrupt program flow. In order to detect errors of this kind, it is necessary to run the task several times and compare the values returned by every version of the task. In order to determine which return value is "correct", the API allows the user to provide a custom consensus function to properly form a consensus. This voting function then returns

the “correct” answer. Any arguments for the executed task that are futures will cause the task invocation to be delayed until all of those futures have become ready.

- `hpx::resiliency::experimental::dataflow_replicate_vote_validate`: This combines the features of the previously discussed replicate set. Replicate vote validate allows a user to provide a validation function to filter results. Additionally, as described in replicate vote, the user can provide a “voting function” which returns the consensus formed by the voting logic. Any arguments for the executed task that are futures will cause the task invocation to be delayed until all of those futures have become ready.

See the *API reference* of the module for more details.

resource_partitioner

The `resource_partitioner` module defines `hpx::resource::partitioner`, the class used by the runtime and users to partition available hardware resources into thread pools. See *Using the resource partitioner* for more details on using the resource partitioner in applications.

See the API reference of this module for more details.

runtime_configuration

This module handles the configuration options required by the runtime.

See the *API reference* of this module for more details.

schedulers

This module provides schedulers used by thread pools in the *thread_pools* module. There are currently three main schedulers:

- `hpx::threads::policies::local_priority_queue_scheduler`
- `hpx::threads::policies::static_priority_queue_scheduler`
- `hpx::threads::policies::shared_priority_queue_scheduler`

Other schedulers are specializations or variations of the above schedulers. See the examples of the *resource_partitioner* module for examples of specifying a custom scheduler for a thread pool.

See the API reference of this module for more details.

serialization

This module provides serialization primitives and support for all built-in types as well as all C++ Standard Library collection and utility types. This list is extended by *HPX* vocabulary types with proper support for global reference counting. *HPX*'s mode of serialization is derived from Boost's *serialization model*²⁵⁴ and, as such, is mostly interface compatible with its Boost counterpart.

The purest form of serializing data is to copy the content of the payload bit by bit; however, this method is impractical for generic C++ types, which might be composed of more than just regular built-in types. Instead, *HPX*'s approach to serialization is derived from the Boost Serialization library, and is geared towards allowing the programmer of a given class explicit control and syntax of what to serialize. It is based on operator overloading of two special archive types that hold a buffer or stream to store the serialized data and is responsible for dispatching the serialization mechanism to the intrusive or non-intrusive version. The serialization process is recursive. Each member that needs to be serialized must be specified explicitly. The advantage of this approach is that the serialization code is written in C++ and

²⁵⁴ https://www.boost.org/doc/libs/1_72_0/libs/serialization/doc/index.html

leverages all necessary programming techniques. The generic, user-facing interface allows for effective application of the serialization process without obstructing the algorithms that need special code for packing and unpacking. It also allows for optimizations in the implementation of the archives.

See the *API reference* of the module for more details.

static_reinit

This module provides a simple wrapper around static variables that can be reinitialized.

See the *API reference* of this module for more details.

string_util

This module contains string utilities inspired by the Boost String Algorithms Library.

See the *API reference* of this module for more details.

synchronization

This module provides synchronization primitives that should be used rather than the C++ standard ones in *HPX* threads:

- `hpx::barrier`
- `hpx::binary_semaphore`
- `hpx::call_once`
- `hpx::condition_variable`
- `hpx::condition_variable_any`
- `hpx::counting_semaphore`
- `hpx::lcos::local::event`
- `hpx::latch`
- `hpx::mutex`
- `hpx::no_mutex`
- `hpx::once_flag`
- `hpx::recursive_mutex`
- `hpx::shared_mutex`
- `hpx::sliding_semaphore`
- `hpx::spinlock` (`std::mutex` compatible spinlock)
- `hpx::spinlock_no_backoff` (`boost::mutex` compatible spinlock)
- `hpx::spinlock_pool`
- `hpx::stop_callback`
- `hpx::stop_source`
- `hpx::stop_token`
- `hpx::in_place_stop_token`

- `hpx::timed_mutex`
- `hpx::upgrade_to_unique_lock`
- `hpx::upgrade_lock`

See *lcos_local*, *async_combinators*, and *async_distributed* for higher level synchronization facilities.

See the *API reference* of this module for more details.

testing

The testing module contains useful macros for testing. The results of tests can be printed with `hpx::util::report_errors`. The following macros are provided:

- `HPX_TEST`
- `HPX_TEST_MSG`
- `HPX_TEST_EQ`
- `HPX_TEST_NEQ`
- `HPX_TEST_LT`
- `HPX_TEST_LTE`
- `HPX_TEST_RANGE`
- `HPX_TEST_EQ_MSG`
- `HPX_TEST_NEQ_MSG`
- `HPX_SANITY`
- `HPX_SANITY_MSG`
- `HPX_SANITY_EQ`
- `HPX_SANITY_NEQ`
- `HPX_SANITY_LT`
- `HPX_SANITY_LTE`
- `HPX_SANITY_RANGE`
- `HPX_SANITY_EQ_MSG`

See the API reference of the module for more details.

thread_pool_util

This module contains helper functions for asynchronously suspending and resuming thread pools and their worker threads.

See the *API reference* of this module for more details.

thread_pools

This module defines the thread pools and utilities used by the *HPX* runtime. The only thread pool implementation provided by this module is `hpx::threads::detail::scheduled_thread_pool`, which is derived from `hpx::threads::detail::thread_pool_base` defined in the *threading_base* module.

See the *API reference* of this module for more details.

thread_support

This module provides miscellaneous utilities for threading and concurrency.

See the *API reference* of the module for more details.

threading

This module provides the equivalents of `std::thread` and `std::jthread` for lightweight *HPX* threads:

- `hpx::thread`
- `hpx::jthread`

See the *API reference* of this module for more details.

threading_base

This module contains the base class definition required for threads. The base class `hpx::threads::thread_data` is inherited by two specializations for stackful and stackless threads: `hpx::threads::thread_data_stackful` and `hpx::threads::thread_data_stackless`. In addition, the module defines the base classes for schedulers and thread pools: `hpx::threads::policies::scheduler_base` and `hpx::threads::thread_pool_base`.

See the *API reference* of this module for more details.

thread_manager

This module defines the `hpx::threads::threadmanager` class. This is used by the runtime to manage the creation and destruction of thread pools. The *resource_partitioner* module handles the partitioning of resources into thread pools, but not the creation of thread pools.

See the *API reference* of this module for more details.

timed_execution

This module provides extensions to the executor interfaces defined in the *execution* module that allow timed submission of tasks on thread pools (at or after a specified time).

See the *API reference* of this module for more details.

timing

This module provides the timing utilities (clocks and timers).

See the *API reference* of the module for more details.

topology

This module provides the class `hpx::threads::topology` which represents the hardware resources available on a node. The class is a light wrapper around the [Portable Hardware Locality \(HWLOC\)²⁵⁵](#) library. The `hpx::threads::cpu_mask` is a small companion class that represents a set of resources on a node.

See the *API reference* of the module for more details.

type_support

This module provides helper facilities related to types.

See the *API reference* of the module for more details.

util

The util module provides miscellaneous standalone utilities.

See the *API reference* of the module for more details.

version

This module macros and functions for accessing version information about *HPX* and its dependencies.

See the *API reference* of this module for more details.

2.7.2 Main HPX modules

actions

TODO: High-level description of the library.

See the *API reference* of this module for more details.

actions_base

TODO: High-level description of the library.

See the *API reference* of this module for more details.

²⁵⁵ <https://www.open-mpi.org/projects/hwloc/>

agas

TODO: High-level description of the module.

See the *API reference* of this module for more details.

agas_base

This module holds the implementation of the four AGAS services: primary namespace, locality namespace, component namespace, and symbol namespace.

See the *API reference* of this module for more details.

async_colocated

TODO: High-level description of the module.

See the *API reference* of this module for more details.

async_distributed

This module contains functionality for asynchronously launching work on remote localities: `hpx::async`, `hpx::post`. This module extends the local-only functions in `libs_async_local`.

See the API reference of this module for more details.

checkpoint

A common need of users is to periodically backup an application. This practice provides resiliency and potential restart points in code. HPX utilizes the concept of a `checkpoint` to support this use case.

Found in `hpx/util/checkpoint.hpp`, checkpoints are defined as objects that hold a serialized version of an object or set of objects at a particular moment in time. This representation can be stored in memory for later use or it can be written to disk for storage and/or recovery at a later point. In order to create and fill this object with data, users must use a function called `save_checkpoint`. In code the function looks like this:

```
hpx::future<hpx::util::checkpoint> hpx::util::save_checkpoint(a, b, c, ...);
```

`save_checkpoint` takes arbitrary data containers, such as `int`, `double`, `float`, `vector`, and `future`, and serializes them into a newly created `checkpoint` object. This function returns a `future` to a `checkpoint` containing the data. Here's an example of a simple use case:

```
using hpx::util::checkpoint;
using hpx::util::save_checkpoint;

std::vector<int> vec{1,2,3,4,5};
hpx::future<checkpoint> save_checkpoint(vec);
```

Once the future is ready, the checkpoint object will contain the vector `vec` and its five elements.

`prepare_checkpoint` takes arbitrary data containers (same as for `save_checkpoint`), , such as `int`, `double`, `float`, `vector`, and `future`, and calculates the necessary buffer space for the checkpoint that would be created if `save_checkpoint` was called with the same arguments. This function returns a `future` to a `checkpoint` that is appropriately initialized. Here's an example of a simple use case:

```
using hpx::util::checkpoint;
using hpx::util::prepare_checkpoint;

std::vector<int> vec{1,2,3,4,5};
hpx::future<checkpoint> prepare_checkpoint(vec);
```

Once the future is ready, the checkpoint object will be initialized with an appropriately sized internal buffer.

It is also possible to modify the launch policy used by `save_checkpoint`. This is accomplished by passing a launch policy as the first argument. It is important to note that passing `hpx::launch::sync` will cause `save_checkpoint` to return a checkpoint instead of a future to a checkpoint. All other policies passed to `save_checkpoint` will return a future to a checkpoint.

Sometimes checkpoints must be declared before they are used. `save_checkpoint` allows users to move pre-created checkpoints into the function as long as they are the first container passing into the function (In the case where a launch policy is used, the checkpoint will immediately follow the launch policy). An example of these features can be found below:

```
char character = 'd';
int integer = 10;
float flt = 10.01f;
bool boolean = true;
std::string str = "I am a string of characters";
std::vector<char> vec(str.begin(), str.end());
checkpoint archive;

// Test 1
// test basic functionality
hpx::shared_future<checkpoint> f_archive = save_checkpoint(
    std::move(archive), character, integer, flt, boolean, str, vec);
```

Once users can create checkpoints they must now be able to restore the objects they contain into memory. This is accomplished by the function `restore_checkpoint`. This function takes a checkpoint and fills its data into the containers it is provided. It is important to remember that the containers must be ordered in the same way they were placed into the checkpoint. For clarity see the example below:

```
char character2;
int integer2;
float flt2;
bool boolean2;
std::string str2;
std::vector<char> vec2;

restore_checkpoint(data, character2, integer2, flt2, boolean2, str2, vec2);
```

The core utility of `checkpoint` is in its ability to make certain data persistent. Often, this means that the data needs to be stored in an object, such as a file, for later use. *HPX* has two solutions for these issues: stream operator overloads and access iterators.

HPX contains two stream overloads, `operator<<` and `operator>>`, to stream data out of and into `checkpoint`. Here is an example of the overloads in use below:

```
double a9 = 1.0, b9 = 1.1, c9 = 1.2;
std::ofstream test_file_9("test_file_9.txt");
hpx::future<checkpoint> f_9 = save_checkpoint(a9, b9, c9);
```

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```

test_file_9 << f_9.get();
test_file_9.close();

double a9_1, b9_1, c9_1;
std::ifstream test_file_9_1("test_file_9.txt");
checkpoint archive9;
test_file_9_1 >> archive9;
restore_checkpoint(archive9, a9_1, b9_1, c9_1);

```

This is the primary way to move data into and out of a checkpoint. It is important to note, however, that users should be cautious when using a stream operator to load data and another function to remove it (or vice versa). Both `operator<<` and `operator>>` rely on a `.write()` and a `.read()` function respectively. In order to know how much data to read from the `std::istream`, the `operator<<` will write the size of the checkpoint before writing the checkpoint data. Correspondingly, the `operator>>` will read the size of the stored data before reading the data into a new instance of checkpoint. As long as the user employs the `operator<<` and `operator>>` to stream the data, this detail can be ignored.

Important: Be careful when mixing `operator<<` and `operator>>` with other facilities to read and write to a checkpoint. `operator<<` writes an extra variable, and `operator>>` reads this variable back separately. Used together the user will not encounter any issues and can safely ignore this detail.

Users may also move the data into and out of a checkpoint using the exposed `.begin()` and `.end()` iterators. An example of this use case is illustrated below.

```

std::ofstream test_file_7("checkpoint_test_file.txt");
std::vector<float> vec7{1.02f, 1.03f, 1.04f, 1.05f};
hpx::future<checkpoint> fut_7 = save_checkpoint(vec7);
checkpoint archive7 = fut_7.get();
std::copy(archive7.begin(),      // Write data to ofstream
          archive7.end(),        // ie. the file
          std::ostream_iterator<char>(test_file_7));
test_file_7.close();

std::vector<float> vec7_1;
std::vector<char> char_vec;
std::ifstream test_file_7_1("checkpoint_test_file.txt");
if (test_file_7_1)
{
    test_file_7_1.seekg(0, test_file_7_1.end);
    auto length = test_file_7_1.tellg();
    test_file_7_1.seekg(0, test_file_7_1.beg);
    char_vec.resize(length);
    test_file_7_1.read(char_vec.data(), length);
}
checkpoint archive7_1(std::move(char_vec)); // Write data to checkpoint
restore_checkpoint(archive7_1, vec7_1);

```

Checkpointing components

`save_checkpoint` and `restore_checkpoint` are also able to store components inside checkpoints. This can be done in one of two ways. First a client of the component can be passed to `save_checkpoint`. When the user wishes to resurrect the component she can pass a client instance to `restore_checkpoint`.

This technique is demonstrated below:

```
// Try to checkpoint and restore a component with a client
std::vector<int> vec3{10, 10, 10, 10, 10};

// Create a component instance through client constructor
data_client D(hpx::find_here(), std::move(vec3));
hpx::future<checkpoint> f3 = save_checkpoint(D);

// Create a new client
data_client E;

// Restore server inside client instance
restore_checkpoint(f3.get(), E);
```

The second way a user can save a component is by passing a `shared_ptr` to the component to `save_checkpoint`. This component can be resurrected by creating a new instance of the component type and passing a `shared_ptr` to the new instance to `restore_checkpoint`.

This technique is demonstrated below:

```
// test checkpoint a component using a shared_ptr
std::vector<int> vec{1, 2, 3, 4, 5};
data_client A(hpx::find_here(), std::move(vec));

// Checkpoint Server
hpx::id_type old_id = A.get_id();

hpx::future<std::shared_ptr<data_server>> f_a_ptr =
    hpx::get_ptr<data_server>(A.get_id());
std::shared_ptr<data_server> a_ptr = f_a_ptr.get();
hpx::future<checkpoint> f = save_checkpoint(a_ptr);
auto&& data = f.get();

// test prepare_checkpoint API
checkpoint c = prepare_checkpoint(hpx::launch::sync, a_ptr);
HPX_TEST(c.size() == data.size());

// Restore Server
// Create a new server instance
std::shared_ptr<data_server> b_server;
restore_checkpoint(data, b_server);
```

checkpoint_base

The `checkpoint_base` module contains lower level facilities that wrap simple check-pointing capabilities. This module does not implement special handling for futures or components, but simply serializes all arguments to or from a given container.

This module exposes the `hpx::util::save_checkpoint_data`, `hpx::util::restore_checkpoint_data`, and `hpx::util::prepare_checkpoint_data` APIs. These functions encapsulate the basic serialization functionalities necessary to save/restore a variadic list of arguments to/from a given data container.

See the *API reference* of this module for more details.

collectives

The `collectives` module exposes a set of distributed collective operations. Those can be used to exchange data between participating sites in a coordinated way. At this point the module exposes the following collective primitives:

- `hpx::collectives::all_gather`: receives a set of values from all participating sites.
- `hpx::collectives::all_reduce`: performs a reduction on data from each participating site to each participating site.
- `hpx::collectives::all_to_all`: each participating site provides its element of the data to collect while all participating sites receive the data from every other site.
- `hpx::collectives::broadcast_to` and `hpx::collectives::broadcast_from`: performs a broadcast operation from a root site to all participating sites.
- **cpp:func:hpx::collectives::exclusive_scan** performs an exclusive scan operation on a set of values received from all call sites operating on the given base name.
- `hpx::collectives::gather_here` and `hpx::collectives::gather_there`: gathers values from all participating sites.
- **cpp:func:hpx::collectives::inclusive_scan** performs an inclusive scan operation on a set of values received from all call sites operating on the given base name.
- `hpx::collectives::reduce_here` and `hpx::collectives::reduce_there`: performs a reduction on data from each participating site to a root site.
- `hpx::collectives::scatter_to` and `hpx::collectives::scatter_from`: receives an element of a set of values operating on the given base name.
- `hpx::lcos::broadcast`: performs a given action on all given global identifiers.
- `hpx::distributed::barrier`: distributed barrier.
- `hpx::lcos::fold`: performs a fold with a given action on all given global identifiers.
- `hpx::distributed::latch`: distributed latch.
- `hpx::lcos::reduce`: performs a reduction on data from each given global identifiers.
- `hpx::lcos::smd_block`: performs the same operation on a local image while providing handles to the other images.

See the *API reference* of the module for more details.

command_line_handling

The `command_line_handling` module defines and handles the command-line options required by the *HPX* runtime, combining them with configuration options defined by the *runtime_configuration* module. The actual parsing of command line options is handled by the *program_options* module.

See the API reference of the module for more details.

components

TODO: High-level description of the module.

See the *API reference* of this module for more details.

components_base

TODO: High-level description of the library.

See the *API reference* of this module for more details.

compute

The `compute` module provides utilities for handling task and memory affinity on host systems.

See the *API reference* of the module for more details.

distribution_policies

TODO: High-level description of the module.

See the *API reference* of this module for more details.

executors_distributed

This module provides the executor `hpx::parallel::execution::distribution_policy_executor`. It allows one to create work that is implicitly distributed over multiple localities.

See the *API reference* of this module for more details.

include

This module provides no functionality in itself. Instead it provides headers that group together other headers that often appear together.

See the API reference of this module for more details.

init_runtime

TODO: High-level description of the library.

See the *API reference* of this module for more details.

lcos_distributed

This module contains distributed *LCOs*. Currently the only LCO provided is `:cpp:class::hpx::lcos::channel`, a construct for sending values from one *locality* to another. See `libs_lcos_local` for local LCOs.

See the API reference of this module for more details.

naming

TODO: High-level description of the module.

See the API reference of this module for more details.

naming_base

This module provides a forward declaration of *address_type*, *component_type* and *invalid_locality_id*.

See the *API reference* of this module for more details.

parcelport_lci

TODO: High-level description of the module.

See the API reference of this module for more details.

parcelport_mpi

TODO: High-level description of the module.

See the API reference of this module for more details.

parcelport_tcp

TODO: High-level description of the module.

See the API reference of this module for more details.

parcelset

TODO: High-level description of the module.

See the *API reference* of this module for more details.

parcelset_base

TODO: High-level description of the module.

See the *API reference* of this module for more details.

performance_counters

This module provides the basic functionality required for defining performance counters. See *Performance counters* for more information about performance counters.

See the *API reference* of this module for more details.

plugin_factories

TODO: High-level description of the module.

See the *API reference* of this module for more details.

resiliency_distributed

Software resiliency features of *HPX* were introduced in the *resiliency module*. This module extends the APIs to run on distributed-memory systems allowing the user to invoke the failing task on other localities at runtime. This is useful in cases where a node is identified to fail more often (e.g., for certain ALU computes) as the task can now be replayed or replicated among different localities. The API exposed allows for an easy integration with the local only resiliency APIs as well.

Distributed software resilience APIs have a similar function signature and lives under the same namespace of *hpx::resiliency::experimental*. The difference arises in the formal parameters where distributed APIs takes the localities as the first argument, and an action as opposed to a function or a function object. The localities signify the order in which the API will either schedule (in case of Task Replay) tasks in a round robin fashion or replicate the tasks onto the list of localities.

The list of APIs exposed by distributed resiliency modules is the same as those defined in *local resiliency module*.

See the API reference of this module for more details.

runtime_components

TODO: High-level description of the module.

See the *API reference* of this module for more details.

runtime_distributed

TODO: High-level description of the module.

See the *API reference* of this module for more details.

segmented_algorithms

Segmented algorithms extend the usual parallel *algorithms* by providing overloads that work with distributed containers, such as partitioned vectors.

See the *API reference* of the module for more details.

statistics

This module provide some statistics utilities like rolling min/max and histogram.

See the API reference of the module for more details.

2.8 API reference

HPX follows a versioning scheme with three numbers: `major.minor.patch`. We guarantee no breaking changes in the API for patch releases. Minor releases may remove or break existing APIs, but only after a deprecation period of at least two minor releases. In rare cases do we outright remove old and unused functionality without a deprecation period.

We do not provide any ABI compatibility guarantees between any versions, debug and release builds, and builds with different C++ standards.

The public API of *HPX* is presented below. Clicking on a name brings you to the full documentation for the class or function. Including the header specified in a heading brings in the features listed under that heading.

Note: Names listed here are guaranteed stable with respect to semantic versioning. However, at the moment the list is incomplete and certain unlisted features are intended to be in the public API. While we work on completing the list, if you're unsure about whether a particular unlisted name is part of the public API you can get into contact with us or open an issue and we'll clarify the situation.

2.8.1 Public API

Our API is semantically conforming; hence, the reader is highly encouraged to refer to the corresponding facility in the *C++ Standard*²⁵⁶ if needed. All names below are also available in the top-level `hpx` namespace unless otherwise noted. The names in `hpx` should be preferred. The names in sub-namespaces will eventually be removed.

`hpx/algorithm.hpp`

The header `hpx/algorithm.hpp`²⁵⁷ corresponds to the C++ standard library header `algorithm`²⁵⁸. See *Using parallel algorithms* for more information about the parallel algorithms.

²⁵⁶ <https://en.cppreference.com/w/cpp/header>

²⁵⁷ <http://github.com/STELLAR-GROUP/hpx/blob/8a3b7c1a4cb5693b2f7d9f587f759392ed0c51a0/libs/full/include/include/hpx/algorithm.hpp>

²⁵⁸ <http://en.cppreference.com/w/cpp/header/algorithm>

Classes

Table 2.123: Classes of header `hpx/algorithm.hpp`

Class	C++ standard
<code>hpx::experimental::reduction</code>	N4808 ²⁵⁹
<code>hpx::experimental::induction</code>	N4808 ²⁶⁰

Functions

Table 2.124: *hpx* functions of header `hpx/algorithm.hpp`

<i>hpx</i> function	C++ standard
<code>hpx::adjacent_find</code>	<code>std::adjacent_find</code> ²⁶¹
<code>hpx::all_of</code>	<code>std::all_of</code> ²⁶²
<code>hpx::any_of</code>	<code>std::any_of</code> ²⁶³
<code>hpx::copy</code>	<code>std::copy</code> ²⁶⁴
<code>hpx::copy_if</code>	<code>std::copy_if</code> ²⁶⁵
<code>hpx::copy_n</code>	<code>std::copy_n</code> ²⁶⁶
<code>hpx::count</code>	<code>std::count</code> ²⁶⁷
<code>hpx::count_if</code>	<code>std::count_if</code> ²⁶⁸
<code>hpx::ends_with</code>	<code>std::ends_with</code> ²⁶⁹
<code>hpx::equal</code>	<code>std::equal</code> ²⁷⁰
<code>hpx::fill</code>	<code>std::fill</code> ²⁷¹
<code>hpx::fill_n</code>	<code>std::fill_n</code> ²⁷²
<code>hpx::find</code>	<code>std::find</code> ²⁷³
<code>hpx::find_end</code>	<code>std::find_end</code> ²⁷⁴
<code>hpx::find_first_of</code>	<code>std::find_first_of</code> ²⁷⁵
<code>hpx::find_if</code>	<code>std::find_if</code> ²⁷⁶
<code>hpx::find_if_not</code>	<code>std::find_if_not</code> ²⁷⁷
<code>hpx::for_each</code>	<code>std::for_each</code> ²⁷⁸
<code>hpx::for_each_n</code>	<code>std::for_each_n</code> ²⁷⁹
<code>hpx::generate</code>	<code>std::generate</code> ²⁸⁰
<code>hpx::generate_n</code>	<code>std::generate_n</code> ²⁸¹
<code>hpx::includes</code>	<code>std::includes</code> ²⁸²
<code>hpx::inplace_merge</code>	<code>std::inplace_merge</code> ²⁸³
<code>hpx::is_heap</code>	<code>std::is_heap</code> ²⁸⁴
<code>hpx::is_heap_until</code>	<code>std::is_heap_until</code> ²⁸⁵
<code>hpx::is_partitioned</code>	<code>std::is_partitioned</code> ²⁸⁶
<code>hpx::is_sorted</code>	<code>std::is_sorted</code> ²⁸⁷
<code>hpx::is_sorted_until</code>	<code>std::is_sorted_until</code> ²⁸⁸
<code>hpx::lexicographical_compare</code>	<code>std::lexicographical_compare</code> ²⁸⁹
<code>hpx::make_heap</code>	<code>std::make_heap</code> ²⁹⁰
<code>hpx::max_element</code>	<code>std::max_element</code> ²⁹¹
<code>hpx::merge</code>	<code>std::merge</code> ²⁹²
<code>hpx::min_element</code>	<code>std::min_element</code> ²⁹³
<code>hpx::minmax_element</code>	<code>std::minmax_element</code> ²⁹⁴

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²⁵⁹ <http://wg21.link/n4808>

²⁶⁰ <http://wg21.link/n4808>

Table 2.124 – continued from previous page

<i>hpx</i> function	C++ standard
<i>hpx::mismatch</i>	std::mismatch ²⁹⁵
<i>hpx::move</i>	std::move ²⁹⁶
<i>hpx::none_of</i>	std::none_of ²⁹⁷
<i>hpx::nth_element</i>	std::nth_element ²⁹⁸
<i>hpx::partial_sort</i>	std::partial_sort ²⁹⁹
<i>hpx::partial_sort_copy</i>	std::partial_sort_copy ³⁰⁰
<i>hpx::partition</i>	std::partition ³⁰¹
<i>hpx::partition_copy</i>	std::partition_copy ³⁰²
<i>hpx::experimental::reduce_by_key</i>	reduce_by_key ³⁰³
<i>hpx::remove</i>	std::remove ³⁰⁴
<i>hpx::remove_copy</i>	std::remove_copy ³⁰⁵
<i>hpx::remove_copy_if</i>	std::remove_copy_if ³⁰⁶
<i>hpx::remove_if</i>	std::remove_if ³⁰⁷
<i>hpx::replace</i>	std::replace ³⁰⁸
<i>hpx::replace_copy</i>	std::replace_copy ³⁰⁹
<i>hpx::replace_copy_if</i>	std::replace_copy_if ³¹⁰
<i>hpx::replace_if</i>	std::replace_if ³¹¹
<i>hpx::reverse</i>	std::reverse ³¹²
<i>hpx::reverse_copy</i>	std::reverse_copy ³¹³
<i>hpx::rotate</i>	std::rotate ³¹⁴
<i>hpx::rotate_copy</i>	std::rotate_copy ³¹⁵
<i>hpx::search</i>	std::search ³¹⁶
<i>hpx::search_n</i>	std::search_n ³¹⁷
<i>hpx::set_difference</i>	std::set_difference ³¹⁸
<i>hpx::set_intersection</i>	std::set_intersection ³¹⁹
<i>hpx::set_symmetric_difference</i>	std::set_symmetric_difference ³²⁰
<i>hpx::set_union</i>	std::set_union ³²¹
<i>hpx::shift_left</i>	std::shift_left ³²²
<i>hpx::shift_right</i>	std::shift_right ³²³
<i>hpx::sort</i>	std::sort ³²⁴
<i>hpx::experimental::sort_by_key</i>	sort_by_key ³²⁵
<i>hpx::stable_partition</i>	std::stable_partition ³²⁶
<i>hpx::stable_sort</i>	std::stable_sort ³²⁷
<i>hpx::starts_with</i>	std::starts_with ³²⁸
<i>hpx::swap_ranges</i>	std::swap_ranges ³²⁹
<i>hpx::transform</i>	std::transform ³³⁰
<i>hpx::unique</i>	std::unique ³³¹
<i>hpx::unique_copy</i>	std::unique_copy ³³²
<i>hpx::experimental::for_loop</i>	N4808 ³³³
<i>hpx::experimental::for_loop_strided</i>	N4808 ³³⁴
<i>hpx::experimental::for_loop_n</i>	N4808 ³³⁵
<i>hpx::experimental::for_loop_n_strided</i>	N4808 ³³⁶

261 http://en.cppreference.com/w/cpp/algorithm/adjacent_find
 262 http://en.cppreference.com/w/cpp/algorithm/all_any_none_of
 263 http://en.cppreference.com/w/cpp/algorithm/all_any_none_of
 264 <http://en.cppreference.com/w/cpp/algorithm/copy>
 265 <http://en.cppreference.com/w/cpp/algorithm/copy>
 266 http://en.cppreference.com/w/cpp/algorithm/copy_n
 267 <http://en.cppreference.com/w/cpp/algorithm/count>
 268 <http://en.cppreference.com/w/cpp/algorithm/count>
 269 http://en.cppreference.com/w/cpp/algorithm/ranges/ends_with
 270 <http://en.cppreference.com/w/cpp/algorithm/equal>
 271 <http://en.cppreference.com/w/cpp/algorithm/fill>
 272 http://en.cppreference.com/w/cpp/algorithm/fill_n
 273 <http://en.cppreference.com/w/cpp/algorithm/find>
 274 http://en.cppreference.com/w/cpp/algorithm/find_end
 275 http://en.cppreference.com/w/cpp/algorithm/find_first_of
 276 <http://en.cppreference.com/w/cpp/algorithm/find>
 277 <http://en.cppreference.com/w/cpp/algorithm/find>
 278 http://en.cppreference.com/w/cpp/algorithm/for_each
 279 http://en.cppreference.com/w/cpp/algorithm/for_each_n
 280 <http://en.cppreference.com/w/cpp/algorithm/generate>
 281 http://en.cppreference.com/w/cpp/algorithm/generate_n
 282 <http://en.cppreference.com/w/cpp/algorithm/includes>
 283 http://en.cppreference.com/w/cpp/algorithm/inplace_merge
 284 http://en.cppreference.com/w/cpp/algorithm/is_heap
 285 http://en.cppreference.com/w/cpp/algorithm/is_heap_until
 286 http://en.cppreference.com/w/cpp/algorithm/is_partitioned
 287 http://en.cppreference.com/w/cpp/algorithm/is_sorted
 288 http://en.cppreference.com/w/cpp/algorithm/is_sorted_until
 289 http://en.cppreference.com/w/cpp/algorithm/lexicographical_compare
 290 http://en.cppreference.com/w/cpp/algorithm/make_heap
 291 http://en.cppreference.com/w/cpp/algorithm/max_element
 292 <http://en.cppreference.com/w/cpp/algorithm/merge>
 293 http://en.cppreference.com/w/cpp/algorithm/min_element
 294 http://en.cppreference.com/w/cpp/algorithm/minmax_element
 295 <http://en.cppreference.com/w/cpp/algorithm/mismatch>
 296 <http://en.cppreference.com/w/cpp/algorithm/move>
 297 http://en.cppreference.com/w/cpp/algorithm/all_any_none_of
 298 http://en.cppreference.com/w/cpp/algorithm/nth_element
 299 http://en.cppreference.com/w/cpp/algorithm/partial_sort
 300 http://en.cppreference.com/w/cpp/algorithm/partial_sort_copy
 301 <http://en.cppreference.com/w/cpp/algorithm/partition>
 302 http://en.cppreference.com/w/cpp/algorithm/partition_copy
 303 https://thrust.github.io/doc/group__reductions_gad5623f203f9b3fdcab72481c3913f0e0.html
 304 <http://en.cppreference.com/w/cpp/algorithm/remove>
 305 http://en.cppreference.com/w/cpp/algorithm/remove_copy
 306 http://en.cppreference.com/w/cpp/algorithm/remove_copy
 307 <http://en.cppreference.com/w/cpp/algorithm/remove>
 308 <http://en.cppreference.com/w/cpp/algorithm/replace>
 309 http://en.cppreference.com/w/cpp/algorithm/replace_copy
 310 http://en.cppreference.com/w/cpp/algorithm/replace_copy
 311 <http://en.cppreference.com/w/cpp/algorithm/replace>
 312 <http://en.cppreference.com/w/cpp/algorithm/reverse>
 313 http://en.cppreference.com/w/cpp/algorithm/reverse_copy
 314 <http://en.cppreference.com/w/cpp/algorithm/rotate>
 315 http://en.cppreference.com/w/cpp/algorithm/rotate_copy
 316 <http://en.cppreference.com/w/cpp/algorithm/search>
 317 http://en.cppreference.com/w/cpp/algorithm/search_n
 318 http://en.cppreference.com/w/cpp/algorithm/set_difference
 319 http://en.cppreference.com/w/cpp/algorithm/set_intersection
 320 http://en.cppreference.com/w/cpp/algorithm/set_symmetric_difference
 321 http://en.cppreference.com/w/cpp/algorithm/set_union
 322 <http://en.cppreference.com/w/cpp/algorithm/shift>
 323 <http://en.cppreference.com/w/cpp/algorithm/shift>
 324 <http://en.cppreference.com/w/cpp/algorithm/sort>
 325 https://thrust.github.io/doc/group__sorting_gabe038d6107f7c824cf74120500ef45ea.html
 326 http://en.cppreference.com/w/cpp/algorithm/stable_partition
 327 http://en.cppreference.com/w/cpp/algorithm/stable_sort
 328 http://en.cppreference.com/w/cpp/algorithm/ranges/starts_with
 329 http://en.cppreference.com/w/cpp/algorithm/swap_ranges
 330 <http://en.cppreference.com/w/cpp/algorithm/transform>
 331 <http://en.cppreference.com/w/cpp/algorithm/unique>
 332 http://en.cppreference.com/w/cpp/algorithm/unique_copy
 333 <http://wg21.link/n4808>
 334 <http://wg21.link/n4808>

Table 2.125: *hpx::ranges* functions of header `hpx/algorithm.hpp`

<i>hpx::ranges</i> function	C++ standard
<i>hpx::ranges::adjacent_find</i>	<code>std::adjacent_find</code> ³³⁷
<i>hpx::ranges::all_of</i>	<code>std::all_of</code> ³³⁸
<i>hpx::ranges::any_of</i>	<code>std::any_of</code> ³³⁹
<i>hpx::ranges::copy</i>	<code>std::copy</code> ³⁴⁰
<i>hpx::ranges::copy_if</i>	<code>std::copy_if</code> ³⁴¹
<i>hpx::ranges::copy_n</i>	<code>std::copy_n</code> ³⁴²
<i>hpx::ranges::count</i>	<code>std::count</code> ³⁴³
<i>hpx::ranges::count_if</i>	<code>std::count_if</code> ³⁴⁴
<i>hpx::ranges::ends_with</i>	<code>std::ends_with</code> ³⁴⁵
<i>hpx::ranges::equal</i>	<code>std::equal</code> ³⁴⁶
<i>hpx::ranges::fill</i>	<code>std::fill</code> ³⁴⁷
<i>hpx::ranges::fill_n</i>	<code>std::fill_n</code> ³⁴⁸
<i>hpx::ranges::find</i>	<code>std::find</code> ³⁴⁹
<i>hpx::ranges::find_end</i>	<code>std::find_end</code> ³⁵⁰
<i>hpx::ranges::find_first_of</i>	<code>std::find_first_of</code> ³⁵¹
<i>hpx::ranges::find_if</i>	<code>std::find_if</code> ³⁵²
<i>hpx::ranges::find_if_not</i>	<code>std::find_if_not</code> ³⁵³
<i>hpx::ranges::for_each</i>	<code>std::for_each</code> ³⁵⁴
<i>hpx::ranges::for_each_n</i>	<code>std::for_each_n</code> ³⁵⁵
<i>hpx::ranges::generate</i>	<code>std::generate</code> ³⁵⁶
<i>hpx::ranges::generate_n</i>	<code>std::generate_n</code> ³⁵⁷
<i>hpx::ranges::includes</i>	<code>std::includes</code> ³⁵⁸
<i>hpx::ranges::inplace_merge</i>	<code>std::inplace_merge</code> ³⁵⁹
<i>hpx::ranges::is_heap</i>	<code>std::is_heap</code> ³⁶⁰
<i>hpx::ranges::is_heap_until</i>	<code>std::is_heap_until</code> ³⁶¹
<i>hpx::ranges::is_partitioned</i>	<code>std::is_partitioned</code> ³⁶²
<i>hpx::ranges::is_sorted</i>	<code>std::is_sorted</code> ³⁶³
<i>hpx::ranges::is_sorted_until</i>	<code>std::is_sorted_until</code> ³⁶⁴
<i>hpx::ranges::make_heap</i>	<code>std::make_heap</code> ³⁶⁵
<i>hpx::ranges::max_element</i>	<code>std::max_element</code> ³⁶⁶
<i>hpx::ranges::merge</i>	<code>std::merge</code> ³⁶⁷
<i>hpx::ranges::min_element</i>	<code>std::min_element</code> ³⁶⁸
<i>hpx::ranges::minmax_element</i>	<code>std::minmax_element</code> ³⁶⁹
<i>hpx::ranges::mismatch</i>	<code>std::mismatch</code> ³⁷⁰
<i>hpx::ranges::move</i>	<code>std::move</code> ³⁷¹
<i>hpx::ranges::none_of</i>	<code>std::none_of</code> ³⁷²
<i>hpx::ranges::nth_element</i>	<code>std::nth_element</code> ³⁷³
<i>hpx::ranges::partial_sort</i>	<code>std::partial_sort</code> ³⁷⁴
<i>hpx::ranges::partial_sort_copy</i>	<code>std::partial_sort_copy</code> ³⁷⁵
<i>hpx::ranges::partition</i>	<code>std::partition</code> ³⁷⁶
<i>hpx::ranges::partition_copy</i>	<code>std::partition_copy</code> ³⁷⁷
<i>hpx::ranges::set_difference</i>	<code>std::set_difference</code> ³⁷⁸
<i>hpx::ranges::set_intersection</i>	<code>std::set_intersection</code> ³⁷⁹
<i>hpx::ranges::set_symmetric_difference</i>	<code>std::set_symmetric_difference</code> ³⁸⁰
<i>hpx::ranges::set_union</i>	<code>std::set_union</code> ³⁸¹
<i>hpx::ranges::shift_left</i>	P2440 ³⁸²
<i>hpx::ranges::shift_right</i>	P2440 ³⁸³
<i>hpx::ranges::sort</i>	<code>std::sort</code> ³⁸⁴

continues on next page

Table 2.125 – continued from previous page

<i>hpx::ranges</i> function	C++ standard
<i>hpx::ranges::stable_partition</i>	std::stable_partition ³⁸⁵
<i>hpx::ranges::stable_sort</i>	std::stable_sort ³⁸⁶
<i>hpx::ranges::starts_with</i>	std::starts_with ³⁸⁷
<i>hpx::ranges::swap_ranges</i>	std::swap_ranges ³⁸⁸
<i>hpx::ranges::transform</i>	std::transform ³⁸⁹
<i>hpx::ranges::unique</i>	std::unique ³⁹⁰
<i>hpx::ranges::unique_copy</i>	std::unique_copy ³⁹¹
<i>hpx::ranges::experimental::for_loop</i>	N4808 ³⁹²
<i>hpx::ranges::experimental::for_loop_strided</i>	N4808 ³⁹³

hpx/any.hpp

The header `hpx/any.hpp`³⁹⁴ corresponds to the C++ standard library header `any`³⁹⁵.

`hpx::any` is compatible with `std::any`.

```

337 http://en.cppreference.com/w/cpp/algorithm/ranges/adjacent\_find
338 http://en.cppreference.com/w/cpp/algorithm/ranges/all\_any\_none\_of
339 http://en.cppreference.com/w/cpp/algorithm/ranges/all\_any\_none\_of
340 http://en.cppreference.com/w/cpp/algorithm/ranges/copy
341 http://en.cppreference.com/w/cpp/algorithm/ranges/copy
342 http://en.cppreference.com/w/cpp/algorithm/ranges/copy\_n
343 http://en.cppreference.com/w/cpp/algorithm/ranges/count
344 http://en.cppreference.com/w/cpp/algorithm/ranges/count
345 http://en.cppreference.com/w/cpp/algorithm/ranges/ends\_with
346 http://en.cppreference.com/w/cpp/algorithm/ranges/equal
347 http://en.cppreference.com/w/cpp/algorithm/ranges/fill
348 http://en.cppreference.com/w/cpp/algorithm/ranges/fill\_n
349 http://en.cppreference.com/w/cpp/algorithm/ranges/find
350 http://en.cppreference.com/w/cpp/algorithm/ranges/find\_end
351 http://en.cppreference.com/w/cpp/algorithm/ranges/find\_first\_of
352 http://en.cppreference.com/w/cpp/algorithm/ranges/find
353 http://en.cppreference.com/w/cpp/algorithm/ranges/find
354 http://en.cppreference.com/w/cpp/algorithm/ranges/for\_each
355 http://en.cppreference.com/w/cpp/algorithm/ranges/for\_each\_n
356 http://en.cppreference.com/w/cpp/algorithm/ranges/generate
357 http://en.cppreference.com/w/cpp/algorithm/ranges/generate\_n
358 http://en.cppreference.com/w/cpp/algorithm/ranges/includes
359 http://en.cppreference.com/w/cpp/algorithm/ranges/inplace\_merge
360 http://en.cppreference.com/w/cpp/algorithm/ranges/is\_heap
361 http://en.cppreference.com/w/cpp/algorithm/ranges/is\_heap\_until
362 http://en.cppreference.com/w/cpp/algorithm/ranges/is\_partitioned
363 http://en.cppreference.com/w/cpp/algorithm/ranges/is\_sorted
364 http://en.cppreference.com/w/cpp/algorithm/ranges/is\_sorted\_until
365 http://en.cppreference.com/w/cpp/algorithm/ranges/make\_heap
366 http://en.cppreference.com/w/cpp/algorithm/ranges/max\_element
367 http://en.cppreference.com/w/cpp/algorithm/ranges/merge
368 http://en.cppreference.com/w/cpp/algorithm/ranges/min\_element
369 http://en.cppreference.com/w/cpp/algorithm/ranges/minmax\_element
370 http://en.cppreference.com/w/cpp/algorithm/ranges/mismatch
371 http://en.cppreference.com/w/cpp/algorithm/ranges/move
372 http://en.cppreference.com/w/cpp/algorithm/ranges/all\_any\_none\_of
373 http://en.cppreference.com/w/cpp/algorithm/ranges/nth\_element
374 http://en.cppreference.com/w/cpp/algorithm/ranges/partial\_sort
375 http://en.cppreference.com/w/cpp/algorithm/ranges/partial\_sort\_copy
376 http://en.cppreference.com/w/cpp/algorithm/ranges/partition
377 http://en.cppreference.com/w/cpp/algorithm/ranges/partition\_copy
378 http://en.cppreference.com/w/cpp/algorithm/ranges/set\_difference
379 http://en.cppreference.com/w/cpp/algorithm/ranges/set\_intersection
380 http://en.cppreference.com/w/cpp/algorithm/ranges/set\_symmetric\_difference
381 http://en.cppreference.com/w/cpp/algorithm/ranges/set\_union
382 https://wg21.link/p2440
383 https://wg21.link/p2440
384 http://en.cppreference.com/w/cpp/algorithm/ranges/sort
385 http://en.cppreference.com/w/cpp/algorithm/ranges/stable\_partition
386 http://en.cppreference.com/w/cpp/algorithm/ranges/stable\_sort
387 http://en.cppreference.com/w/cpp/algorithm/ranges/starts\_with
388 http://en.cppreference.com/w/cpp/algorithm/ranges/swap\_ranges
389 http://en.cppreference.com/w/cpp/algorithm/ranges/transform
390 http://en.cppreference.com/w/cpp/algorithm/ranges/unique
391 http://en.cppreference.com/w/cpp/algorithm/ranges/unique\_copy
392 http://wg21.link/n4808
393 http://wg21.link/n4808
394 http://github.com/STELLAR-GROUP/hpx/blob/8a3b7c1a4cb5693b2f7d9f587f759392ed0c51a0/libs/core/include\_local/include/hpx/any.hpp
395 http://en.cppreference.com/w/cpp/header/any

```

Classes

Table 2.126: Classes of header `hpx/any.hpp`

Class	C++ standard
<code>hpx::any</code>	<code>std::any</code> ³⁹⁶
<code>hpx::any_nonser</code>	
<code>hpx::bad_any_cast</code>	<code>std::bad_any_cast</code> ³⁹⁷
<code>hpx::unique_any_nonser</code>	

Functions

Table 2.127: Functions of header `hpx/any.hpp`

Function	C++ standard
<code>hpx::any_cast</code>	<code>std::any_cast</code> ³⁹⁸
<code>hpx::make_any</code>	<code>std::make_any</code> ³⁹⁹
<code>hpx::make_any_nonser</code>	
<code>hpx::make_unique_any_nonser</code>	

`hpx/assert.hpp`

The header `hpx/assert.hpp`⁴⁰⁰ corresponds to the C++ standard library header `cassert`⁴⁰¹.

`HPX_ASSERT` is the *HPX* equivalent to `assert` in `cassert`. `HPX_ASSERT` can also be used in CUDA device code.

Macros

Table 2.128: Macros of header `hpx/assert.hpp`

Macro
<code>HPX_ASSERT</code>
<code>HPX_ASSERT_MSG</code>

³⁹⁶ <http://en.cppreference.com/w/cpp/utility/any>

³⁹⁷ http://en.cppreference.com/w/cpp/utility/any/bad_any_cast

³⁹⁸ http://en.cppreference.com/w/cpp/utility/any/any_cast

³⁹⁹ http://en.cppreference.com/w/cpp/utility/any/make_any

⁴⁰⁰ <http://github.com/STELLAR-GROUP/hpx/blob/8a3b7c1a4cb5693b2f7d9f587f759392ed0c51a0/libs/core/assertion/include/hpx/assert.hpp>

⁴⁰¹ <http://en.cppreference.com/w/cpp/header/cassert>

hpx/barrier.hpp

The header `hpx/barrier.hpp`⁴⁰² corresponds to the C++ standard library header `barrier`⁴⁰³ and contains a distributed barrier implementation. This functionality is also exposed through the `hpx::distributed` namespace. The name in `hpx::distributed` should be preferred.

Classes

Table 2.129: Classes of header `hpx/barrier.hpp`

Class	C++ standard
<code>hpx::barrier</code>	<code>std::barrier</code> ⁴⁰⁴

Table 2.130: Distributed implementation of classes of header `hpx/barrier.hpp`

Class
<code>hpx::distributed::barrier</code>

hpx/channel.hpp

The header `hpx/channel.hpp`⁴⁰⁵ contains a local and a distributed channel implementation. This functionality is also exposed through the `hpx::distributed` namespace. The name in `hpx::distributed` should be preferred.

Classes

Table 2.131: Classes of header `hpx/channel.hpp`

Class
<code>hpx::channel</code>

Table 2.132: Distributed implementation of classes of header `hpx/channel.hpp`

Class
<code>hpx::distributed::channel</code>

⁴⁰² <http://github.com/STELLAR-GROUP/hpx/blob/8a3b7c1a4cb5693b2f7d9f587f759392ed0c51a0/libs/full/include/include/hpx/barrier.hpp>

⁴⁰³ <http://en.cppreference.com/w/cpp/header/barrier>

⁴⁰⁴ <http://en.cppreference.com/w/cpp/thread/barrier>

⁴⁰⁵ <http://github.com/STELLAR-GROUP/hpx/blob/8a3b7c1a4cb5693b2f7d9f587f759392ed0c51a0/libs/full/include/include/hpx/channel.hpp>

hpx/chrono.hpp

The header `hpx/chrono.hpp`⁴⁰⁶ corresponds to the C++ standard library header `chrono`⁴⁰⁷. The following replacements and extensions are provided compared to `chrono`⁴⁰⁸.

Classes

Table 2.133: Classes of header `hpx/chrono.hpp`

Class	C++ standard
<code>hpx::chrono::high_resolution_clock</code>	<code>std::high_resolution_clock</code> ⁴⁰⁹
<code>hpx::chrono::high_resolution_timer</code>	
<code>hpx::chrono::steady_time_point</code>	<code>std::time_point</code> ⁴¹⁰

hpx/condition_variable.hpp

The header `hpx/condition_variable.hpp`⁴¹¹ corresponds to the C++ standard library header `condition_variable`⁴¹².

Classes

Table 2.134: Classes of header `hpx/condition_variable.hpp`

Class	C++ standard
<code>hpx::condition_variable</code>	<code>std::condition_variable</code> ⁴¹³
<code>hpx::condition_variable_any</code>	<code>std::condition_variable_any</code> ⁴¹⁴
<code>hpx::cv_status</code>	<code>std::cv_status</code> ⁴¹⁵

hpx/exception.hpp

The header `hpx/exception.hpp`⁴¹⁶ corresponds to the C++ standard library header `exception`⁴¹⁷. `hpx::exception` extends `std::exception` and is the base class for all exceptions thrown in *HPX*. `HPX_THROW_EXCEPTION` can be used to throw *HPX* exceptions with file and line information attached to the exception.

⁴⁰⁶ http://github.com/STELLAR-GROUP/hpx/blob/8a3b7c1a4cb5693b2f7d9f587f759392ed0c51a0/libs/core/include_local/include/hpx/chrono.hpp

⁴⁰⁷ <http://en.cppreference.com/w/cpp/header/chrono>

⁴⁰⁸ <http://en.cppreference.com/w/cpp/header/chrono>

⁴⁰⁹ http://en.cppreference.com/w/cpp/chrono/high_resolution_clock

⁴¹⁰ http://en.cppreference.com/w/cpp/chrono/time_point

⁴¹¹ http://github.com/STELLAR-GROUP/hpx/blob/8a3b7c1a4cb5693b2f7d9f587f759392ed0c51a0/libs/core/include_local/include/hpx/condition_variable.hpp

⁴¹² http://en.cppreference.com/w/cpp/header/condition_variable

⁴¹³ http://en.cppreference.com/w/cpp/thread/condition_variable

⁴¹⁴ http://en.cppreference.com/w/cpp/thread/condition_variable_any

⁴¹⁵ http://en.cppreference.com/w/cpp/thread/cv_status

⁴¹⁶ http://github.com/STELLAR-GROUP/hpx/blob/8a3b7c1a4cb5693b2f7d9f587f759392ed0c51a0/libs/core/include_local/include/hpx/exception.hpp

⁴¹⁷ <http://en.cppreference.com/w/cpp/header/exception>

Macros

- `HPX_THROW_EXCEPTION`

Classes

Table 2.135: Classes of header `hpx/exception.hpp`

Class	C++ standard
<code>hpx::exception</code>	<code>std::exception</code> ⁴¹⁸

`hpx/execution.hpp`

The header `hpx/execution.hpp`⁴¹⁹ corresponds to the C++ standard library header `execution`⁴²⁰. See *High level parallel facilities*, *Using parallel algorithms* and *Executor parameters and executor parameter traits* for more information about execution policies and executor parameters.

Note: These names are only available in the `hpx::execution` namespace, not in the top-level `hpx` namespace.

Constants

Table 2.136: Constants of header `hpx/execution.hpp`

Constant	C++ standard
<code>hpx::execution::seq</code>	<code>std::execution_policy_tag</code> ⁴²¹
<code>hpx::execution::par</code>	<code>std::execution_policy_tag</code> ⁴²²
<code>hpx::execution::par_unseq</code>	<code>std::execution_policy_tag</code> ⁴²³
<code>hpx::execution::task</code>	

⁴¹⁸ <http://en.cppreference.com/w/cpp/error/exception>

⁴¹⁹ http://github.com/STELLAR-GROUP/hpx/blob/8a3b7c1a4cb5693b2f7d9f587f759392ed0c51a0/libs/core/include_local/include/hpx/execution.hpp

⁴²⁰ <http://en.cppreference.com/w/cpp/header/execution>

⁴²¹ http://en.cppreference.com/w/cpp/algorithm/execution_policy_tag

⁴²² http://en.cppreference.com/w/cpp/algorithm/execution_policy_tag

⁴²³ http://en.cppreference.com/w/cpp/algorithm/execution_policy_tag

Classes

Table 2.137: Classes of header `hpx/execution.hpp`

Class	C++ standard
<code>hpx::execution::sequenced_policy</code>	<code>std::execution_policy_tag_t</code> ⁴²⁴
<code>hpx::execution::parallel_policy</code>	<code>std::execution_policy_tag_t</code> ⁴²⁵
<code>hpx::execution::parallel_unsequenced_policy</code>	<code>std::execution_policy_tag_t</code> ⁴²⁶
<code>hpx::execution::sequenced_task_policy</code>	
<code>hpx::execution::parallel_task_policy</code>	
<code>hpx::execution::experimental::auto_chunk_size</code>	
<code>hpx::execution::experimental::dynamic_chunk_size</code>	
<code>hpx::execution::experimental::guided_chunk_size</code>	
<code>hpx::execution::experimental::persistent_auto_chunk_size</code>	
<code>hpx::execution::experimental::static_chunk_size</code>	
<code>hpx::execution::experimental::num_cores</code>	

`hpx/functional.hpp`

The header `hpx/functional.hpp`⁴²⁷ corresponds to the C++ standard library header `functional`⁴²⁸. `hpx::function` is a more efficient and serializable replacement for `std::function`.

Constants

The following constants correspond to the C++ standard `std::placeholders`⁴²⁹

Table 2.138: Constants of header `hpx/functional.hpp`

Constant
<code>hpx::placeholders::_1</code>
<code>hpx::placeholders::_2</code>
...
<code>hpx::placeholders::_9</code>

⁴²⁴ http://en.cppreference.com/w/cpp/algorithm/execution_policy_tag_t

⁴²⁵ http://en.cppreference.com/w/cpp/algorithm/execution_policy_tag_t

⁴²⁶ http://en.cppreference.com/w/cpp/algorithm/execution_policy_tag_t

⁴²⁷ http://github.com/STELLAR-GROUP/hpx/blob/8a3b7c1a4cb5693b2f7d9f587f759392ed0c51a0/libs/core/include_local/include/hpx/functional.hpp

⁴²⁸ <http://en.cppreference.com/w/cpp/header/functional>

⁴²⁹ <http://en.cppreference.com/w/cpp/utility/functional/placeholders>

Classes

Table 2.139: Classes of header `hpx/functional.hpp`

Class	C++ standard
<code>hpx::function</code>	<code>std::function</code> ⁴³⁰
<code>hpx::function_ref</code>	P0792 ⁴³¹
<code>hpx::move_only_function</code>	<code>std::move_only_function</code> ⁴³²
<code>hpx::is_bind_expression</code>	<code>std::is_bind_expression</code> ⁴³³
<code>hpx::is_placeholder</code>	<code>std::is_placeholder</code> ⁴³⁴
<code>hpx::scoped_annotation</code>	

Functions

Table 2.140: Functions of header `hpx/functional.hpp`

Function	C++ standard
<code>hpx::annotated_function</code>	
<code>hpx::bind</code>	<code>std::bind</code> ⁴³⁵
<code>hpx::bind_back</code>	<code>std::bind_front</code> ⁴³⁶
<code>hpx::bind_front</code>	<code>std::bind_front</code> ⁴³⁷
<code>hpx::invoke</code>	<code>std::invoke</code> ⁴³⁸
<code>hpx::invoke_fused</code>	<code>std::apply</code> ⁴³⁹
<code>hpx::invoke_fused_r</code>	
<code>hpx::mem_fn</code>	<code>std::mem_fn</code> ⁴⁴⁰

`hpx/future.hpp`

The header `hpx/future.hpp`⁴⁴¹ corresponds to the C++ standard library header `future`⁴⁴². See *Extended facilities for futures* for more information about extensions to futures compared to the C++ standard library.

This header file also contains overloads of `hpx::async`, `hpx::post`, `hpx::sync`, and `hpx::dataflow` that can be used with actions. See *Action invocation* for more information about invoking actions.

⁴³⁰ <http://en.cppreference.com/w/cpp/utility/functional/function>

⁴³¹ <http://wg21.link/p0792>

⁴³² http://en.cppreference.com/w/cpp/utility/functional/move_only_function

⁴³³ http://en.cppreference.com/w/cpp/utility/functional/is_bind_expression

⁴³⁴ http://en.cppreference.com/w/cpp/utility/functional/is_placeholder

⁴³⁵ <http://en.cppreference.com/w/cpp/utility/functional/bind>

⁴³⁶ http://en.cppreference.com/w/cpp/utility/functional/bind_front

⁴³⁷ http://en.cppreference.com/w/cpp/utility/functional/bind_front

⁴³⁸ <http://en.cppreference.com/w/cpp/utility/functional/invoke>

⁴³⁹ <http://en.cppreference.com/w/cpp/utility/apply>

⁴⁴⁰ http://en.cppreference.com/w/cpp/utility/functional/mem_fn

⁴⁴¹ <http://github.com/STELLAR-GROUP/hpx/blob/8a3b7c1a4cb5693b2f7d9f587f759392ed0c51a0/libs/full/include/include/hpx/future.hpp>

⁴⁴² <http://en.cppreference.com/w/cpp/header/future>

Classes

Table 2.141: Classes of header `hpx/future.hpp`

Class	C++ standard
<code>hpx::future</code>	<code>std::future</code> ⁴⁴³
<code>hpx::shared_future</code>	<code>std::shared_future</code> ⁴⁴⁴
<code>hpx::promise</code>	<code>std::promise</code> ⁴⁴⁵
<code>hpx::launch</code>	<code>std::launch</code> ⁴⁴⁶
<code>hpx::packaged_task</code>	<code>std::packaged_task</code> ⁴⁴⁷

Note: All names except `hpx::promise` are also available in the top-level `hpx` namespace. `hpx::promise` refers to `hpx::distributed::promise`, a distributed variant of `hpx::promise`, but will eventually refer to `hpx::promise` after a deprecation period.

Table 2.142: Distributed implementation of classes of header `hpx/future.hpp`

Class
<code>hpx::distributed::promise</code>

Functions

Table 2.143: Functions of header `hpx/future.hpp`

Function	C++ standard
<code>hpx::async</code>	<code>std::async</code> ⁴⁴⁸
<code>hpx::post</code>	
<code>hpx::sync</code>	
<code>hpx::dataflow</code>	
<code>hpx::make_future</code>	
<code>hpx::make_shared_future</code>	
<code>hpx::make_ready_future</code>	P0159 ⁴⁴⁹
<code>hpx::make_ready_future_alloc</code>	
<code>hpx::make_ready_future_at</code>	
<code>hpx::make_ready_future_after</code>	
<code>hpx::make_exceptional_future</code>	P0159 ⁴⁵⁰
<code>hpx::when_all</code>	P0159 ⁴⁵¹
<code>hpx::when_any</code>	P0159 ⁴⁵²
<code>hpx::when_some</code>	
<code>hpx::when_each</code>	
<code>hpx::wait_all</code>	
<code>hpx::wait_any</code>	
<code>hpx::wait_some</code>	
<code>hpx::wait_each</code>	

⁴⁴³ <http://en.cppreference.com/w/cpp/thread/future>

⁴⁴⁴ http://en.cppreference.com/w/cpp/thread/shared_future

⁴⁴⁵ <http://en.cppreference.com/w/cpp/thread/promise>

⁴⁴⁶ <http://en.cppreference.com/w/cpp/thread/launch>

⁴⁴⁷ http://en.cppreference.com/w/cpp/thread/packaged_task

hpx/init.hpp

The header `hpx/init.hpp`⁴⁵³ contains functionality for starting, stopping, suspending, and resuming the *HPX* runtime. This is the main way to explicitly start the *HPX* runtime. See *Starting the HPX runtime* for more details on starting the *HPX* runtime.

Classes

Table 2.144: Classes of header `hpx/init.hpp`

Class
<code>hpx::init_params</code>
<code>hpx::runtime_mode</code>

Functions

Table 2.145: Functions of header `hpx/init.hpp`

Function
<code>hpx::init</code>
<code>hpx::start</code>
<code>hpx::finalize</code>
<code>hpx::disconnect</code>
<code>hpx::suspend</code>
<code>hpx::resume</code>

hpx/latch.hpp

The header `hpx/latch.hpp`⁴⁵⁴ corresponds to the C++ standard library header `latch`⁴⁵⁵. It contains a local and a distributed latch implementation. This functionality is also exposed through the `hpx::distributed` namespace. The name in `hpx::distributed` should be preferred.

Classes

Table 2.146: Classes of header `hpx/latch.hpp`

Class	C++ standard
<code>hpx::latch</code>	<code>std::latch</code> ⁴⁵⁶

⁴⁴⁸ <http://en.cppreference.com/w/cpp/thread/async>

⁴⁴⁹ <http://wg21.link/p0159>

⁴⁵⁰ <http://wg21.link/p0159>

⁴⁵¹ <http://wg21.link/p0159>

⁴⁵² <http://wg21.link/p0159>

⁴⁵³ http://github.com/STELLAR-GROUP/hpx/blob/8a3b7c1a4cb5693b2f7d9f587f759392ed0c51a0/libs/full/init_runtime/include/hpx/init.hpp

⁴⁵⁴ <http://github.com/STELLAR-GROUP/hpx/blob/8a3b7c1a4cb5693b2f7d9f587f759392ed0c51a0/libs/full/include/include/hpx/latch.hpp>

⁴⁵⁵ <http://en.cppreference.com/w/cpp/header/latch>

⁴⁵⁶ <http://en.cppreference.com/w/cpp/thread/latch>

Table 2.147: Distributed implementation of classes of header `hpx/latch.hpp`

Class
<code>hpx::distributed::latch</code>

`hpx/mutex.hpp`

The header `hpx/mutex.hpp`⁴⁵⁷ corresponds to the C++ standard library header `mutex`⁴⁵⁸.

Classes

Table 2.148: Classes of header `hpx/mutex.hpp`

Class	C++ standard
<code>hpx::mutex</code>	<code>std::mutex</code> ⁴⁵⁹
<code>hpx::no_mutex</code>	
<code>hpx::once_flag</code>	<code>std::once_flag</code> ⁴⁶⁰
<code>hpx::recursive_mutex</code>	<code>std::recursive_mutex</code> ⁴⁶¹
<code>hpx::spinlock</code>	
<code>hpx::timed_mutex</code>	<code>std::timed_mutex</code> ⁴⁶²
<code>hpx::unlock_guard</code>	

Functions

Table 2.149: Functions of header `hpx/mutex.hpp`

Class	C++ standard
<code>hpx::call_once</code>	<code>std::call_once</code> ⁴⁶³

`hpx/memory.hpp`

The header `hpx/memory.hpp`⁴⁶⁴ corresponds to the C++ standard library header `memory`⁴⁶⁵. It contains parallel versions of the copy, fill, move, and construct helper functions in `memory`⁴⁶⁶. See *Using parallel algorithms* for more information about the parallel algorithms.

⁴⁵⁷ http://github.com/STELLAR-GROUP/hpx/blob/8a3b7c1a4cb5693b2f7d9f587f759392ed0c51a0/libs/core/include_local/include/hpx/mutex.hpp

hpp

⁴⁵⁸ <http://en.cppreference.com/w/cpp/header/mutex>

⁴⁵⁹ <http://en.cppreference.com/w/cpp/thread/mutex>

⁴⁶⁰ http://en.cppreference.com/w/cpp/thread/once_flag

⁴⁶¹ http://en.cppreference.com/w/cpp/thread/recursive_mutex

⁴⁶² http://en.cppreference.com/w/cpp/thread/timed_mutex

⁴⁶³ http://en.cppreference.com/w/cpp/thread/call_once

⁴⁶⁴ http://github.com/STELLAR-GROUP/hpx/blob/8a3b7c1a4cb5693b2f7d9f587f759392ed0c51a0/libs/core/include_local/include/hpx/memory.hpp

hpp

⁴⁶⁵ <http://en.cppreference.com/w/cpp/header/memory>

⁴⁶⁶ <http://en.cppreference.com/w/cpp/header/memory>

Functions

Table 2.150: *hpx* functions of header `hpx/memory.hpp`

<i>hpx</i> function	C++ standard
<code>hpx::uninitialized_copy</code>	<code>std::uninitialized_copy</code> ⁴⁶⁷
<code>hpx::uninitialized_copy_n</code>	<code>std::uninitialized_copy_n</code> ⁴⁶⁸
<code>hpx::uninitialized_default_construct</code>	<code>std::uninitialized_default_construct</code> ⁴⁶⁹
<code>hpx::uninitialized_default_construct_n</code>	<code>std::uninitialized_default_construct_n</code> ⁴⁷⁰
<code>hpx::uninitialized_fill</code>	<code>std::uninitialized_fill</code> ⁴⁷¹
<code>hpx::uninitialized_fill_n</code>	<code>std::uninitialized_fill_n</code> ⁴⁷²
<code>hpx::uninitialized_move</code>	<code>std::uninitialized_move</code> ⁴⁷³
<code>hpx::uninitialized_move_n</code>	<code>std::uninitialized_move_n</code> ⁴⁷⁴
<code>hpx::uninitialized_value_construct</code>	<code>std::uninitialized_value_construct</code> ⁴⁷⁵
<code>hpx::uninitialized_value_construct_n</code>	<code>std::uninitialized_value_construct_n</code> ⁴⁷⁶

Table 2.151: *hpx::ranges* functions of header `hpx/memory.hpp`

<i>hpx::ranges</i> function	C++ standard
<code>hpx::ranges::uninitialized_copy</code>	<code>std::uninitialized_copy</code> ⁴⁷⁷
<code>hpx::ranges::uninitialized_copy_n</code>	<code>std::uninitialized_copy_n</code> ⁴⁷⁸
<code>hpx::ranges::uninitialized_default_construct</code>	<code>std::uninitialized_default_construct</code> ⁴⁷⁹
<code>hpx::ranges::uninitialized_default_construct_n</code>	<code>std::uninitialized_default_construct_n</code> ⁴⁸⁰
<code>hpx::ranges::uninitialized_fill</code>	<code>std::uninitialized_fill</code> ⁴⁸¹
<code>hpx::ranges::uninitialized_fill_n</code>	<code>std::uninitialized_fill_n</code> ⁴⁸²
<code>hpx::ranges::uninitialized_move</code>	<code>std::uninitialized_move</code> ⁴⁸³
<code>hpx::ranges::uninitialized_move_n</code>	<code>std::uninitialized_move_n</code> ⁴⁸⁴
<code>hpx::ranges::uninitialized_value_construct</code>	<code>std::uninitialized_value_construct</code> ⁴⁸⁵
<code>hpx::ranges::uninitialized_value_construct_n</code>	<code>std::uninitialized_value_construct_n</code> ⁴⁸⁶

⁴⁶⁷ http://en.cppreference.com/w/cpp/memory/uninitialized_copy⁴⁶⁸ http://en.cppreference.com/w/cpp/memory/uninitialized_copy_n⁴⁶⁹ http://en.cppreference.com/w/cpp/memory/uninitialized_default_construct⁴⁷⁰ http://en.cppreference.com/w/cpp/memory/uninitialized_default_construct_n⁴⁷¹ http://en.cppreference.com/w/cpp/memory/uninitialized_fill⁴⁷² http://en.cppreference.com/w/cpp/memory/uninitialized_fill_n⁴⁷³ http://en.cppreference.com/w/cpp/memory/uninitialized_move⁴⁷⁴ http://en.cppreference.com/w/cpp/memory/uninitialized_move_n⁴⁷⁵ http://en.cppreference.com/w/cpp/memory/uninitialized_value_construct⁴⁷⁶ http://en.cppreference.com/w/cpp/memory/uninitialized_value_construct_n⁴⁷⁷ http://en.cppreference.com/w/cpp/memory/ranges/uninitialized_copy⁴⁷⁸ http://en.cppreference.com/w/cpp/memory/ranges/uninitialized_copy_n⁴⁷⁹ http://en.cppreference.com/w/cpp/memory/ranges/uninitialized_default_construct⁴⁸⁰ http://en.cppreference.com/w/cpp/memory/ranges/uninitialized_default_construct_n⁴⁸¹ http://en.cppreference.com/w/cpp/memory/ranges/uninitialized_fill⁴⁸² http://en.cppreference.com/w/cpp/memory/ranges/uninitialized_fill_n⁴⁸³ http://en.cppreference.com/w/cpp/memory/ranges/uninitialized_move⁴⁸⁴ http://en.cppreference.com/w/cpp/memory/ranges/uninitialized_move_n⁴⁸⁵ http://en.cppreference.com/w/cpp/memory/ranges/uninitialized_value_construct⁴⁸⁶ http://en.cppreference.com/w/cpp/memory/ranges/uninitialized_value_construct_n

hpx/numeric.hpp

The header `hpx/numeric.hpp`⁴⁸⁷ corresponds to the C++ standard library header `numeric`⁴⁸⁸. See *Using parallel algorithms* for more information about the parallel algorithms.

Functions

Table 2.152: *hpx* functions of header `hpx/numeric.hpp`

<i>hpx</i> function	C++ standard
<code>hpx::adjacent_difference</code>	<code>std::adjacent_difference</code> ⁴⁸⁹
<code>hpx::exclusive_scan</code>	<code>std::exclusive_scan</code> ⁴⁹⁰
<code>hpx::inclusive_scan</code>	<code>std::inclusive_scan</code> ⁴⁹¹
<code>hpx::reduce</code>	<code>std::reduce</code> ⁴⁹²
<code>hpx::transform_exclusive_scan</code>	<code>std::transform_exclusive_scan</code> ⁴⁹³
<code>hpx::transform_inclusive_scan</code>	<code>std::transform_inclusive_scan</code> ⁴⁹⁴
<code>hpx::transform_reduce</code>	<code>std::transform_reduce</code> ⁴⁹⁵

Table 2.153: *hpx::ranges* functions of header `hpx/numeric.hpp`

<i>hpx::ranges</i> function
<code>hpx::ranges::adjacent_difference</code>
<code>hpx::ranges::exclusive_scan</code>
<code>hpx::ranges::inclusive_scan</code>
<code>hpx::ranges::reduce</code>
<code>hpx::ranges::transform_exclusive_scan</code>
<code>hpx::ranges::transform_inclusive_scan</code>
<code>hpx::ranges::transform_reduce</code>

hpx/optional.hpp

The header `hpx/optional.hpp`⁴⁹⁶ corresponds to the C++ standard library header `optional`⁴⁹⁷. `hpx::optional` is compatible with `std::optional`.

⁴⁸⁷ http://github.com/STELLAR-GROUP/hpx/blob/8a3b7c1a4cb5693b2f7d9f587f759392ed0c51a0/libs/core/include_local/include/hpx/numeric.hpp

⁴⁸⁸ <http://en.cppreference.com/w/cpp/header/numeric>

⁴⁸⁹ http://en.cppreference.com/w/cpp/algorithm/adjacent_difference

⁴⁹⁰ http://en.cppreference.com/w/cpp/algorithm/exclusive_scan

⁴⁹¹ http://en.cppreference.com/w/cpp/algorithm/inclusive_scan

⁴⁹² <http://en.cppreference.com/w/cpp/algorithm/reduce>

⁴⁹³ http://en.cppreference.com/w/cpp/algorithm/transform_exclusive_scan

⁴⁹⁴ http://en.cppreference.com/w/cpp/algorithm/transform_inclusive_scan

⁴⁹⁵ http://en.cppreference.com/w/cpp/algorithm/transform_reduce

⁴⁹⁶ http://github.com/STELLAR-GROUP/hpx/blob/8a3b7c1a4cb5693b2f7d9f587f759392ed0c51a0/libs/core/include_local/include/hpx/optional.hpp

⁴⁹⁷ <http://en.cppreference.com/w/cpp/header/optional>

Constants

- `hpx::nullopt`

Classes

Table 2.154: Classes of header `hpx/optional.hpp`

Class	C++ standard
<code>hpx::optional</code>	<code>std::optional</code> ⁴⁹⁸
<code>hpx::nullopt_t</code>	<code>std::nullopt_t</code> ⁴⁹⁹
<code>hpx::bad_optional_access</code>	<code>std::bad_optional_access</code> ⁵⁰⁰

`hpx/runtime.hpp`

The header `hpx/runtime.hpp`⁵⁰¹ contains functions for accessing local and distributed runtime information.

Typedefs

Table 2.155: Typedefs of header `hpx/runtime.hpp`

Typedef
<code>hpx::startup_function_type</code>
<code>hpx::shutdown_function_type</code>

Functions

Table 2.156: Functions of header `hpx/runtime.hpp`

Function
<code>hpx::find_root_locality</code>
<code>hpx::find_all_localities</code>
<code>hpx::find_remote_localities</code>
<code>hpx::find_locality</code>
<code>hpx::get_colocation_id</code>
<code>hpx::get_locality_id</code>
<code>hpx::get_num_worker_threads</code>
<code>hpx::get_worker_thread_num</code>
<code>hpx::get_thread_name</code>
<code>hpx::register_pre_startup_function</code>
<code>hpx::register_startup_function</code>
<code>hpx::register_pre_shutdown_function</code>
<code>hpx::register_shutdown_function</code>
<code>hpx::get_num_localities</code>
<code>hpx::get_locality_name</code>

⁴⁹⁸ <http://en.cppreference.com/w/cpp/utility/optional>

⁴⁹⁹ http://en.cppreference.com/w/cpp/utility/nullopt_t

⁵⁰⁰ http://en.cppreference.com/w/cpp/utility/optional/bad_optional_access

⁵⁰¹ <http://github.com/STELLAR-GROUP/hpx/blob/8a3b7c1a4cb5693b2f7d9f587f759392ed0c51a0/libs/full/include/include/hpx/runtime.hpp>

hpx/experimental/scope.hpp

The header `hpx/experimental/scope.hpp`⁵⁰² corresponds to the C++ standard library header `experimental/scope`⁵⁰³.

Classes

Table 2.157: Classes of header `hpx/scope.hpp`

Class	C++ standard
<code>hpx::experimental::scope_exit</code>	<code>std::scope_exit</code> ⁵⁰⁴
<code>hpx::experimental::scope_fail</code>	<code>std::scope_fail</code> ⁵⁰⁵
<code>hpx::experimental::scope_success</code>	<code>std::scope_success</code> ⁵⁰⁶

hpx/semaphore.hpp

The header `hpx/semaphore.hpp`⁵⁰⁷ corresponds to the C++ standard library header `semaphore`⁵⁰⁸.

Classes

Table 2.158: Classes of header `hpx/semaphore.hpp`

Class	C++ standard
<code>hpx::binary_semaphore</code>	<code>std::counting_semaphore</code> ⁵⁰⁹
<code>hpx::counting_semaphore</code>	<code>std::counting_semaphore</code> ⁵¹⁰

hpx/shared_mutex.hpp

The header `hpx/shared_mutex.hpp`⁵¹¹ corresponds to the C++ standard library header `shared_mutex`⁵¹².

⁵⁰² http://github.com/STELLAR-GROUP/hpx/blob/8a3b7c1a4cb5693b2f7d9f587f759392ed0c51a0/libs/core/include_local/include/hpx/experimental/scope.hpp

⁵⁰³ <http://en.cppreference.com/w/cpp/header/experimental/scope>

⁵⁰⁴ http://en.cppreference.com/w/cpp/experimental/scope_exit

⁵⁰⁵ http://en.cppreference.com/w/cpp/experimental/scope_fail

⁵⁰⁶ http://en.cppreference.com/w/cpp/experimental/scope_success

⁵⁰⁷ http://github.com/STELLAR-GROUP/hpx/blob/8a3b7c1a4cb5693b2f7d9f587f759392ed0c51a0/libs/core/include_local/include/hpx/semaphore.hpp

⁵⁰⁸ <http://en.cppreference.com/w/cpp/header/semaphore>

⁵⁰⁹ http://en.cppreference.com/w/cpp/thread/counting_semaphore

⁵¹⁰ http://en.cppreference.com/w/cpp/thread/counting_semaphore

⁵¹¹ http://github.com/STELLAR-GROUP/hpx/blob/8a3b7c1a4cb5693b2f7d9f587f759392ed0c51a0/libs/core/include_local/include/hpx/shared_mutex.hpp

⁵¹² http://en.cppreference.com/w/cpp/header/shared_mutex

Classes

Table 2.159: Classes of header `hpx/shared_mutex.hpp`

Class	C++ standard
<code>hpx::shared_mutex</code>	<code>std::shared_mutex</code> ⁵¹³

`hpx/source_location.hpp`

The header `hpx/source_location.hpp`⁵¹⁴ corresponds to the C++ standard library header `source_location`⁵¹⁵.

Classes

Table 2.160: Classes of header `hpx/system_error.hpp`

Class	C++ standard
<code>hpx::source_location</code>	<code>std::source_location</code> ⁵¹⁶

`hpx/stop_token.hpp`

The header `hpx/stop_token.hpp`⁵¹⁷ corresponds to the C++ standard library header `stop_token`⁵¹⁸.

Constants

Table 2.161: Constants of header `hpx/stop_token.hpp`

Constant	C++ standard
<code>hpx::nostreamstate</code>	<code>std::nostreamstate</code> ⁵¹⁹

Classes

Table 2.162: Classes of header `hpx/stop_token.hpp`

Class	C++ standard
<code>hpx::stop_callback</code>	<code>std::stop_callback</code> ⁵²⁰
<code>hpx::stop_source</code>	<code>std::stop_source</code> ⁵²¹
<code>hpx::stop_token</code>	<code>std::stop_token</code> ⁵²²
<code>hpx::nostreamstate_t</code>	<code>std::nostreamstate_t</code> ⁵²³

⁵¹³ http://en.cppreference.com/w/cpp/thread/shared_mutex

⁵¹⁴ http://github.com/STELLAR-GROUP/hpx/blob/8a3b7c1a4cb5693b2f7d9f587f759392ed0c51a0/libs/core/include_local/include/hpx/source_location.hpp

⁵¹⁵ http://en.cppreference.com/w/cpp/header/source_location

⁵¹⁶ http://en.cppreference.com/w/cpp/utility/source_location

⁵¹⁷ http://github.com/STELLAR-GROUP/hpx/blob/8a3b7c1a4cb5693b2f7d9f587f759392ed0c51a0/libs/core/include_local/include/hpx/stop_token.hpp

⁵¹⁸ http://en.cppreference.com/w/cpp/header/stop_token

⁵¹⁹ http://en.cppreference.com/w/cpp/thread/stop_source/nostreamstate

hpx/system_error.hpp

The header `hpx/system_error.hpp`⁵²⁴ corresponds to the C++ standard library header `system_error`⁵²⁵.

Classes

Table 2.163: Classes of header `hpx/system_error.hpp`

Class	C++ standard
<code>hpx::error_code</code>	<code>std::error_code</code> ⁵²⁶

hpx/task_block.hpp

The header `hpx/task_block.hpp`⁵²⁷ corresponds to the `task_block` feature in N4755⁵²⁸. See `using_task_block` for more details on using task blocks.

Classes

Table 2.164: Classes of header `hpx/task_block.hpp`

Class
<code>hpx::experimental::task_canceled_exception</code>
<code>hpx::experimental::task_block</code>

Functions

Table 2.165: Functions of header `hpx/task_block.hpp`

Function
<code>hpx::experimental::define_task_block</code>
<code>hpx::experimental::define_task_block_restore_thread</code>

⁵²⁰ http://en.cppreference.com/w/cpp/thread/stop_callback
⁵²¹ http://en.cppreference.com/w/cpp/thread/stop_source
⁵²² http://en.cppreference.com/w/cpp/thread/stop_token
⁵²³ http://en.cppreference.com/w/cpp/thread/stop_source/nostopstate_t
⁵²⁴ http://github.com/STELLAR-GROUP/hpx/blob/8a3b7c1a4cb5693b2f7d9f587f759392ed0c51a0/libs/core/include_local/include/hpx/system_error.hpp
⁵²⁵ http://en.cppreference.com/w/cpp/header/system_error
⁵²⁶ http://en.cppreference.com/w/cpp/error/error_code
⁵²⁷ http://github.com/STELLAR-GROUP/hpx/blob/8a3b7c1a4cb5693b2f7d9f587f759392ed0c51a0/libs/core/include_local/include/hpx/task_block.hpp
⁵²⁸ <http://wg21.link/n4755>

hpx/experimental/task_group.hpp

The header `hpx/experimental/task_group.hpp`⁵²⁹ corresponds to the `task_group` feature in oneAPI Threading Building Blocks (oneTBB)⁵³⁰.

Classes

Table 2.166: Classes of header `hpx/experimental/task_group.hpp`

Class
<code>hpx::experimental::task_group</code>

hpx/thread.hpp

The header `hpx/thread.hpp`⁵³¹ corresponds to the C++ standard library header `thread`⁵³². The functionality in this header is equivalent to the standard library thread functionality, with the exception that the *HPX* equivalents are implemented on top of lightweight threads and the *HPX* runtime.

Classes

Table 2.167: Classes of header `hpx/thread.hpp`

Class	C++ standard
<code>hpx::thread</code>	<code>std::thread</code> ⁵³³
<code>hpx::jthread</code>	<code>std::jthread</code> ⁵³⁴

Functions

Table 2.168: Functions of header `hpx/thread.hpp`

Function	C++ standard
<code>hpx::this_thread::yield</code>	<code>std::yield</code> ⁵³⁵
<code>hpx::this_thread::get_id</code>	<code>std::get_id</code> ⁵³⁶
<code>hpx::this_thread::sleep_for</code>	<code>std::sleep_for</code> ⁵³⁷
<code>hpx::this_thread::sleep_until</code>	<code>std::sleep_until</code> ⁵³⁸

⁵²⁹ http://github.com/STELLAR-GROUP/hpx/blob/8a3b7c1a4cb5693b2f7d9f587f759392ed0c51a0/libs/core/include_local/include/hpx/experimental/task_group.hpp

⁵³⁰ https://spec.oneapi.io/versions/1.0-rev-3/elements/oneTBB/source/task_scheduler/task_group/task_group_cls.html

⁵³¹ http://github.com/STELLAR-GROUP/hpx/blob/8a3b7c1a4cb5693b2f7d9f587f759392ed0c51a0/libs/core/include_local/include/hpx/thread.hpp

⁵³² <http://en.cppreference.com/w/cpp/header/thread>

⁵³³ <http://en.cppreference.com/w/cpp/thread/thread>

⁵³⁴ <http://en.cppreference.com/w/cpp/thread/jthread>

⁵³⁵ <http://en.cppreference.com/w/cpp/thread/yield>

⁵³⁶ http://en.cppreference.com/w/cpp/thread/get_id

⁵³⁷ http://en.cppreference.com/w/cpp/thread/sleep_for

⁵³⁸ http://en.cppreference.com/w/cpp/thread/sleep_until

hpx/tuple.hpp

The header `hpx/tuple.hpp`⁵³⁹ corresponds to the C++ standard library header `tuple`⁵⁴⁰. `hpx::tuple` can be used in CUDA device code, unlike `std::tuple`.

Constants

Table 2.169: Constants of header `hpx/tuple.hpp`

Constant	C++ standard
<code>hpx::ignore</code>	<code>std::ignore</code> ⁵⁴¹

Classes

Table 2.170: Classes of header `hpx/tuple.hpp`

Class	C++ standard
<code>hpx::tuple</code>	<code>std::tuple</code> ⁵⁴²
<code>hpx::tuple_size</code>	<code>std::tuple_size</code> ⁵⁴³
<code>hpx::tuple_element</code>	<code>std::tuple_element</code> ⁵⁴⁴

Functions

Table 2.171: Functions of header `hpx/tuple.hpp`

Function	C++ standard
<code>hpx::make_tuple</code>	<code>std::tuple_element</code> ⁵⁴⁵
<code>hpx::tie</code>	<code>std::tie</code> ⁵⁴⁶
<code>hpx::forward_as_tuple</code>	<code>std::forward_as_tuple</code> ⁵⁴⁷
<code>hpx::tuple_cat</code>	<code>std::tuple_cat</code> ⁵⁴⁸
<code>hpx::get</code>	<code>std::get</code> ⁵⁴⁹

⁵³⁹ http://github.com/STELLAR-GROUP/hpx/blob/8a3b7c1a4cb5693b2f7d9f587f759392ed0c51a0/libs/core/include_local/include/hpx/tuple.hpp

⁵⁴⁰ <http://en.cppreference.com/w/cpp/header/tuple>

⁵⁴¹ <http://en.cppreference.com/w/cpp/utility/tuple/ignore>

⁵⁴² <http://en.cppreference.com/w/cpp/utility/tuple>

⁵⁴³ http://en.cppreference.com/w/cpp/utility/tuple_size

⁵⁴⁴ http://en.cppreference.com/w/cpp/utility/tuple_element

⁵⁴⁵ http://en.cppreference.com/w/cpp/utility/tuple/tuple_element

⁵⁴⁶ <http://en.cppreference.com/w/cpp/utility/tuple/tie>

⁵⁴⁷ http://en.cppreference.com/w/cpp/utility/tuple/forward_as_tuple

⁵⁴⁸ http://en.cppreference.com/w/cpp/utility/tuple/tuple_cat

⁵⁴⁹ <http://en.cppreference.com/w/cpp/utility/tuple/get>

hpx/type_traits.hpp

The header `hpx/type_traits.hpp`⁵⁵⁰ corresponds to the C++ standard library header `type_traits`⁵⁵¹.

Classes

Table 2.172: Classes of header `hpx/type_traits.hpp`

Class	C++ standard
<code>hpx::is_invocable</code>	<code>std::is_invocable</code> ⁵⁵²
<code>hpx::is_invocable_r</code>	<code>std::is_invocable</code> ⁵⁵³

hpx/unwrap.hpp

The header `hpx/unwrap.hpp`⁵⁵⁴ contains utilities for unwrapping futures.

Classes

Table 2.173: Classes of header `hpx/unwrap.hpp`

Class
<code>hpx::functional::unwrap</code>
<code>hpx::functional::unwrap_n</code>
<code>hpx::functional::unwrap_all</code>

Functions

Table 2.174: Functions of header `hpx/unwrap.hpp`

Function
<code>hpx::unwrap</code>
<code>hpx::unwrap_n</code>
<code>hpx::unwrap_all</code>
<code>hpx::unwrapping</code>
<code>hpx::unwrapping_n</code>
<code>hpx::unwrapping_all</code>

⁵⁵⁰ http://github.com/STELLAR-GROUP/hpx/blob/8a3b7c1a4cb5693b2f7d9f587f759392ed0c51a0/libs/core/include_local/include/hpx/type_traits.hpp

⁵⁵¹ http://en.cppreference.com/w/cpp/header/type_traits

⁵⁵² http://en.cppreference.com/w/cpp/types/is_invocable

⁵⁵³ http://en.cppreference.com/w/cpp/types/is_invocable

⁵⁵⁴ http://github.com/STELLAR-GROUP/hpx/blob/8a3b7c1a4cb5693b2f7d9f587f759392ed0c51a0/libs/core/include_local/include/hpx/unwrap.hpp

hpx/version.hpp

The header `hpx/version.hpp`⁵⁵⁵ provides version information about *HPX*.

Macros

Table 2.175: Macros of header `hpx/version.hpp`

Macro
<code>HPX_VERSION_MAJOR</code>
<code>HPX_VERSION_MINOR</code>
<code>HPX_VERSION_SUBMINOR</code>
<code>HPX_VERSION_FULL</code>
<code>HPX_VERSION_DATE</code>
<code>HPX_VERSION_TAG</code>
<code>HPX_AGAS_VERSION</code>

Functions

Table 2.176: Functions of header `hpx/version.hpp`

Function
<code>hpx::major_version</code>
<code>hpx::minor_version</code>
<code>hpx::subminor_version</code>
<code>hpx::full_version</code>
<code>hpx::full_version_as_string</code>
<code>hpx::tag</code>
<code>hpx::agas_version</code>
<code>hpx::build_type</code>
<code>hpx::build_date_time</code>

hpx/wrap_main.hpp

The header `hpx/wrap_main.hpp`⁵⁵⁶ does not provide any direct functionality but is used for implicitly using `main` as the runtime entry point. See *Re-use the `main()` function as the main HPX entry point* for more details on implicitly starting the *HPX* runtime.

⁵⁵⁵ <http://github.com/STELLAR-GROUP/hpx/blob/8a3b7c1a4cb5693b2f7d9f587f759392ed0c51a0/libs/core/version/include/hpx/version.hpp>

⁵⁵⁶ http://github.com/STELLAR-GROUP/hpx/blob/8a3b7c1a4cb5693b2f7d9f587f759392ed0c51a0/wrap/include/hpx/wrap_main.hpp

2.8.2 Public distributed API

Our Public Distributed API offers a rich set of tools and functions that enable developers to harness the full potential of distributed computing. Here, you'll find a comprehensive list of header files, classes and functions for various distributed computing features provided by *HPX*.

`hpx/barrier.hpp`

The header `hpx/barrier.hpp`⁵⁵⁷ includes a distributed barrier implementation. For information regarding the C++ standard library header `barrier`⁵⁵⁸, see *Public API*.

Classes

Table 2.177: Distributed implementation of classes of header `hpx/barrier.hpp`

Class
<code>hpx::distributed::barrier</code>

Functions

Table 2.178: *hpx* functions of header `hpx/barrier.hpp`

Function
<code>hpx::distributed::wait</code>
<code>hpx::distributed::synchronize</code>

`hpx/collectives.hpp`

The header `hpx/collectives.hpp`⁵⁵⁹ contains definitions and implementations related to the collectives operations.

Classes

Table 2.179: *hpx* classes of header `hpx/collectives.hpp`

Class
<code>hpx::collectives::num_sites_arg</code>
<code>hpx::collectives::this_site_arg</code>
<code>hpx::collectives::that_site_arg</code>
<code>hpx::collectives::generation_arg</code>
<code>hpx::collectives::root_site_arg</code>
<code>hpx::collectives::tag_arg</code>
<code>hpx::collectives::arity_arg</code>
<code>hpx::collectives::communicator</code>
<code>hpx::collectives::channel_communicator</code>

⁵⁵⁷ <http://github.com/STELLAR-GROUP/hpx/blob/8a3b7c1a4cb5693b2f7d9f587f759392ed0c51a0/libs/full/include/include/hpx/barrier.hpp>

⁵⁵⁸ <http://en.cppreference.com/w/cpp/header/barrier>

⁵⁵⁹ <http://github.com/STELLAR-GROUP/hpx/blob/8a3b7c1a4cb5693b2f7d9f587f759392ed0c51a0/libs/full/include/include/hpx/collectives.hpp>

Functions

Table 2.180: *hpx* functions of header `hpx/collectives.hpp`

Function
<code>hpx::collectives::all_gather</code>
<code>hpx::collectives::all_reduce</code>
<code>hpx::collectives::all_to_all</code>
<code>hpx::collectives::broadcast_to</code>
<code>hpx::collectives::broadcast_from</code>
<code>hpx::collectives::create_channel_communicator</code>
<code>hpx::collectives::set</code>
<code>hpx::collectives::get</code>
<code>hpx::collectives::create_communication_set</code>
<code>hpx::collectives::create_communicator</code>
<code>hpx::collectives::create_local_communicator</code>
<code>hpx::collectives::communicator::set_info</code>
<code>hpx::collectives::communicator::get_info</code>
<code>hpx::collectives::communicator::is_root</code>
<code>hpx::collectives::exclusive_scan</code>
<code>hpx::collectives::gather_here</code>
<code>hpx::collectives::gather_there</code>
<code>hpx::collectives::inclusive_scan</code>
<code>hpx::collectives::reduce_here</code>
<code>hpx::collectives::reduce_there</code>
<code>hpx::collectives::scatter_from</code>
<code>hpx::collectives::scatter_to</code>

`hpx/latch.hpp`

The header `hpx/latch.hpp`⁵⁶⁰ includes a distributed latch implementation. For information regarding the C++ standard library header `latch`⁵⁶¹, see *Public API*.

⁵⁶⁰ <http://github.com/STELLAR-GROUP/hpx/blob/8a3b7c1a4cb5693b2f7d9f587f759392ed0c51a0/libs/full/include/include/hpx/latch.hpp>

⁵⁶¹ <http://en.cppreference.com/w/cpp/header/latch>

Classes

Table 2.181: Distributed implementation of classes of header `hpx/latch.hpp`

Class
<code>hpx::distributed::latch</code>

Member functions

Table 2.182: *hpx* functions of class `hpx::distributed::latch` from header `hpx/latch.hpp`

Function
<code>hpx::distributed::latch::count_down_and_wait</code>
<code>hpx::distributed::latch::arrive_and_wait</code>
<code>hpx::distributed::latch::count_down</code>
<code>hpx::distributed::latch::is_ready</code>
<code>hpx::distributed::latch::try_wait</code>
<code>hpx::distributed::latch::wait</code>

`hpx/async.hpp`

The header `hpx/async.hpp`⁵⁶² includes distributed implementations of `hpx::async`, `hpx::post`, `hpx::sync`, and `hpx::dataflow`. For information regarding the C++ standard library header, see *Public API*.

Functions

Table 2.183: Distributed implementation of functions of header `hpx/async.hpp`

Functions
<code>hpx::async (distributed)</code>
<code>hpx::sync (distributed)</code>
<code>hpx::post (distributed)</code>
<code>hpx::dataflow (distributed)</code>

⁵⁶² http://github.com/STELLAR-GROUP/hpx/blob/8a3b7c1a4cb5693b2f7d9f587f759392ed0c51a0/libs/full/async_distributed/include/hpx/async.hpp

hpx/components.hpp

The header `hpx/include/components.hpp`⁵⁶³ includes the components implementation. A component in *hpx* is a C++ class which can be created remotely and for which its member functions can be invoked remotely as well. More information about how components can be defined, created, and used can be found in *Writing components*. *Components and actions* includes examples on the accumulator, template accumulator and template function accumulator.

Macros

Table 2.184: *hpx* macros of header `hpx/components.hpp`

Macro
<code>HPX_DEFINE_COMPONENT_ACTION</code>
<code>HPX_REGISTER_ACTION_DECLARATION</code>
<code>HPX_REGISTER_ACTION</code>
<code>HPX_REGISTER_COMMANDLINE_MODULE</code>
<code>HPX_REGISTER_COMPONENT</code>
<code>HPX_REGISTER_COMPONENT_MODULE</code>
<code>HPX_REGISTER_STARTUP_MODULE</code>

Classes

Table 2.185: *hpx* classes of header `hpx/components.hpp`

Class
<code>hpx::components::client</code>
<code>hpx::components::client_base</code>
<code>hpx::components::component</code>
<code>hpx::components::component_base</code>
<code>hpx::components::component_commandline_base</code>

Functions

Table 2.186: *hpx* functions of header `hpx/components.hpp`

Function
<code>hpx::new_</code>

⁵⁶³ <http://github.com/STELLAR-GROUP/hpx/blob/8a3b7c1a4cb5693b2f7d9f587f759392ed0c51a0/libs/full/include/include/hpx/include/components.hpp>

2.8.3 Full API

The full API of *HPX* is presented below. The listings for the public API above refer to the full documentation below.

Note: Most names listed in the full API reference are implementation details or considered unstable. They are listed mostly for completeness. If there is a particular feature you think deserves being in the public API we may consider promoting it. In general we prioritize making sure features corresponding to C++ standard library features are stable and complete.

algorithms

See *Public API* for a list of names and headers that are part of the public *HPX* API.

`hpx::experimental::run_on_all`

Defined in header `hpx/task_block.hpp`⁵⁶⁴.

See *Public API* for a list of names and headers that are part of the public *HPX* API.

namespace **hpx**

namespace **experimental**

Top-level namespace.

Functions

```
template<typename ExPolicy, typename T, typename ...Ts>
decltype(auto) run_on_all(ExPolicy &&policy, T &&t, Ts&&... ts)
```

Run a function on all available worker threads with reduction support using the given execution policy

Template Parameters

- **ExPolicy** – The execution policy type
- **T** – The first type in a list of reduction types and the function type to invoke (last argument)
- **Ts** – The list of reduction types and the function type to invoke (last argument)

Parameters

- **policy** – The execution policy to use
- **t** – The first in a list of reductions and the function to invoke (last argument)
- **ts** – The list of reductions and the function to invoke (last argument)

```
template<typename T, typename ...Ts>
decltype(auto) run_on_all(T &&t, Ts&&... ts)
```

Run a function on all available worker threads with reduction support using the `hpx::execution::par` execution policy

Template Parameters

- **T** – The first type in a list of reduction types and the function type to invoke (last argument)
- **Ts** – The list of reduction types and the function type to invoke (last argument)

Parameters

- **t** – The first in a list of reductions and the function to invoke (last argument)
- **ts** – The list of reductions and the function to invoke (last argument)

⁵⁶⁴ http://github.com/STELLAR-GROUP/hpx/blob/8a3b7c1a4cb5693b2f7d9f587f759392ed0c51a0/libs/core/include_local/include/hpx/task_block.hpp

hpx::experimental::task_canceled_exception, **hpx::experimental::task_block,**
hpx::experimental::define_task_block, **hpx::experimental::define_task_block_restore_thread**

Defined in header `hpx/task_block.hpp`⁵⁶⁵.

See *Public API* for a list of names and headers that are part of the public *HPX* API.

namespace **hpx**

namespace **experimental**

Top-level namespace.

Functions

```
template<typename ExPolicy, typename F>  
decltype(auto) define_task_block(ExPolicy &&policy, F &&f)
```

Constructs a `task_block`, *tr*, using the given execution policy *policy*, and invokes the expression *f(tr)* on the user-provided object, *f*.

Postcondition: All tasks spawned from *f* have finished execution. A call to `define_task_block` may return on a different thread than that on which it was called.

Note: It is expected (but not mandated) that *f* will (directly or indirectly) call `tr.run(callable_object)`.

Template Parameters

- **ExPolicy** – The type of the execution policy to use (deduced). It describes the manner in which the execution of the task block may be parallelized.
- **F** – The type of the user defined function to invoke inside the `define_task_block` (deduced). *F* shall be `MoveConstructible`.

Parameters

- **policy** – The execution policy to use for the scheduling of the iterations.
- **f** – The user defined function to invoke inside the task block. Given an lvalue *tr* of type `task_block`, the expression, `(void)f(tr)`, shall be well-formed.

Throws *exception_list* – specified in Exception Handling.

```
template<typename F>  
void define_task_block(F &&f)
```

Constructs a `task_block`, *tr*, and invokes the expression *f(tr)* on the user-provided object, *f*. This version uses *parallel_policy* for task scheduling.

Postcondition: All tasks spawned from *f* have finished execution. A call to `define_task_block` may return on a different thread than that on which it was called.

Note: It is expected (but not mandated) that *f* will (directly or indirectly) call `tr.run(callable_object)`.

⁵⁶⁵ http://github.com/STELLAR-GROUP/hpx/blob/8a3b7c1a4cb5693b2f7d9f587f759392ed0c51a0/libs/core/include_local/include/hpx/task_block.hpp

Template Parameters **F** – The type of the user defined function to invoke inside the `define_task_block` (deduced). *F* shall be `MoveConstructible`.

Parameters **f** – The user defined function to invoke inside the task block. Given an lvalue *tr* of type `task_block`, the expression, `(void)f(tr)`, shall be well-formed.

Throws `exception_list` – specified in Exception Handling.

```
template<typename ExPolicy, typename F>
hpx::parallel::util::detail::algorithm_result_t<ExPolicy> define_task_block_restore_thread(ExPolicy
                                                                                               &&pol-
                                                                                               icy,
                                                                                               F
                                                                                               &&f)
```

Constructs a `task_block`, *tr*, and invokes the expression *f(tr)* on the user-provided object, *f*.

Postcondition: All tasks spawned from *f* have finished execution. A call to `define_task_block_restore_thread` always returns on the same thread as that on which it was called.

Note: It is expected (but not mandated) that *f* will (directly or indirectly) call `tr.run(callable_object)`.

Template Parameters

- **ExPolicy** – The type of the execution policy to use (deduced). It describes the manner in which the execution of the task block may be parallelized.
- **F** – The type of the user defined function to invoke inside the `define_task_block` (deduced). *F* shall be `MoveConstructible`.

Parameters

- **policy** – The execution policy to use for the scheduling of the iterations.
- **f** – The user defined function to invoke inside the `define_task_block`. Given an lvalue *tr* of type `task_block`, the expression, `(void)f(tr)`, shall be well-formed.

Throws `exception_list` – specified in Exception Handling.

```
template<typename F>
void define_task_block_restore_thread(F &&f)
```

Constructs a `task_block`, *tr*, and invokes the expression *f(tr)* on the user-provided object, *f*. This version uses `parallel_policy` for task scheduling.

Postcondition: All tasks spawned from *f* have finished execution. A call to `define_task_block_restore_thread` always returns on the same thread as that on which it was called.

Note: It is expected (but not mandated) that *f* will (directly or indirectly) call `tr.run(callable_object)`.

Template Parameters **F** – The type of the user defined function to invoke inside the `define_task_block` (deduced). *F* shall be `MoveConstructible`.

Parameters **f** – The user defined function to invoke inside the `define_task_block`. Given an lvalue *tr* of type `task_block`, the expression, `(void)f(tr)`, shall be well-formed.

Throws `exception_list` – specified in Exception Handling.

```
template<typename ExPolicy = hpx::execution::parallel_policy>
```

```
class task_block
```

```
    #include <task_block.hpp> The class task_block defines an interface for forking and joining paral-
```

lel tasks. The `define_task_block` and `define_task_block_restore_thread` function templates create an object of type `task_block` and pass a reference to that object to a user-provided callable object.

An object of class `task_block` cannot be constructed, destroyed, copied, or moved except by the implementation of the task region library. Taking the address of a `task_block` object via operator`&` or `addressof` is ill formed. The result of obtaining its address by any other means is unspecified.

A `task_block` is active if it was created by the nearest enclosing task block, where “task block” refers to an invocation of `define_task_block` or `define_task_block_restore_thread` and “nearest

enclosing” means the most recent invocation that has not yet completed. Code designated for execution in another thread by means other than the facilities in this section (e.g., using `thread` or `async`) are not enclosed in the task region and a `task_block` passed to (or captured by) such code is not active within that code. Performing any operation on a `task_block` that is not active results in undefined behavior.

The `task_block` that is active before a specific call to the `run` member function is not active within the asynchronous function that invoked `run`. (The invoked function should not, therefore, capture the `task_block` from the surrounding block.)

Example:

```
define_task_block([&](auto& tr) {
    tr.run([&] {
        tr.run([] { f(); });           // Error: tr is not active
        define_task_block([&](auto& tr) { // Nested task block
            tr.run(f);                 // OK: inner tr is active
            /// ...
        });
    }); /// ...
});
```

Template Parameters `ExPolicy` – The execution policy an instance of a `task_block` was created with. This defaults to `parallel_policy`.

Public Types

using `execution_policy` = `ExPolicy`

Refers to the type of the execution policy used to create the `task_block`.

Public Functions

inline constexpr `execution_policy` const &`get_execution_policy`() const noexcept

Return the execution policy instance used to create this `task_block`

template<typename `F`, typename ...`Ts`>

inline void `run`(`F` &&`f`, `Ts`&&... `ts`)

Causes the expression `f()` to be invoked asynchronously. The invocation of `f` is permitted to run on an unspecified thread in an unordered fashion relative to the sequence of operations following the call to `run(f)` (the continuation), or indeterminately sequenced within the same thread as the continuation.

The call to `run` synchronizes with the invocation of `f`. The completion of `f()` synchronizes with the next invocation of `wait` on the same `task_block` or completion of the nearest enclosing task block (i.e., the `define_task_block` or `define_task_block_restore_thread` that created this task block).

Requires: F shall be MoveConstructible. The expression, (void)f(), shall be well-formed.

Precondition: this shall be the active *task_block*.

Postconditions: A call to run may return on a different thread than that on which it was called.

Note: The call to *run* is sequenced before the continuation as if *run* returns on the same thread. The invocation of the user-supplied callable object f may be immediate or may be delayed until compute resources are available. *run* might or might not return before invocation of f completes.

Throws *task_canceled_exception* – described in Exception Handling.

```
template<typename Executor, typename F, typename ...Ts>
inline void run(Executor &&exec, F &&f, Ts&&... ts)
```

Causes the expression f() to be invoked asynchronously using the given executor. The invocation of f is permitted to run on an unspecified thread associated with the given executor and in an unordered fashion relative to the sequence of operations following the call to run(exec, f) (the continuation), or indeterminately sequenced within the same thread as the continuation.

The call to *run* synchronizes with the invocation of f. The completion of f() synchronizes with the next invocation of wait on the same *task_block* or completion of the nearest enclosing task block (i.e., the *define_task_block* or *define_task_block_restore_thread* that created this task block).

Requires: Executor shall be a type modeling the Executor concept. F shall be MoveConstructible. The expression, (void)f(), shall be well-formed.

Precondition: this shall be the active *task_block*.

Postconditions: A call to run may return on a different thread than that on which it was called.

Note: The call to *run* is sequenced before the continuation as if *run* returns on the same thread. The invocation of the user-supplied callable object f may be immediate or may be delayed until compute resources are available. *run* might or might not return before invocation of f completes.

Throws *task_canceled_exception* – described in Exception Handling. The function will also throw an *exception_list* holding all exceptions that were caught while executing the tasks.

```
inline void wait()
```

Blocks until the tasks spawned using this *task_block* have finished.

Precondition: this shall be the active *task_block*.

Postcondition: All tasks spawned by the nearest enclosing task region have finished. A call to wait may return on a different thread than that on which it was called.

Example:

```
define_task_block([&](auto& tr) {
    tr.run([&]{ process(a, w, x); }); // Process a[w] through a[x]
    if (y < x) tr.wait(); // Wait if overlap between [w, x) and [y,
    ↪z)
    process(a, y, z); // Process a[y] through a[z]
});
```

Note: The call to *wait* is sequenced before the continuation as if *wait* returns on the same thread.

Throws This – function may throw `task_canceled_exception`, as described in Exception Handling. The function will also throw a *exception_list* holding all exceptions that were caught while executing the tasks.

inline *ExPolicy* &**policy**() noexcept

Returns a reference to the execution policy used to construct this object.

Precondition: this shall be the active *task_block*.

inline constexpr *ExPolicy* const &**policy**() const noexcept

Returns a reference to the execution policy used to construct this object.

Precondition: this shall be the active *task_block*.

Private Members

hpx::experimental::task_group **tasks_**

threads::thread_id_type **id_**

ExPolicy **policy_**

class **task_canceled_exception** : public *exception*

#include <task_block.hpp> The class `task_canceled_exception` defines the type of objects thrown by *task_block::run* or *task_block::wait* if they detect that an exception is pending within the current parallel region.

Public Functions

inline **task_canceled_exception**() noexcept

namespace **parallel**

Typedefs

typedef *hpx::experimental::task_canceled_exception* **instead**

Functions

```
template<typename ExPolicy, typename F> HPX_DEPRECATED_V (1, 9,
"hp::parallel:v2::define_task_block is deprecated,
use " "hp::experimental::define_task_block instead") hp
```

```
template<typename ExPolicy, typename F> HPX_DEPRECATED_V (1, 9,
"hp::parallel:v2::define_task_block is deprecated,
use " "hp::experimental::define_task_block instead") void define_task_block(ExPolicy &&policy
```

```
template<typename F> HPX_DEPRECATED_V (1, 9,
"hp::parallel:v2::define_task_block is deprecated,
use " "hp::experimental::define_task_block instead") void define_task_block(F &&f)
```

Variables

```
F && f {return hp::experimental::define_task_block(policy, f)
```

hp::experimental::task_group

Defined in header `hp/experimental/task_group.hpp`⁵⁶⁶.

See *Public API* for a list of names and headers that are part of the public *HPX* API.

```
namespace hp
```

```
namespace execution
```

```
namespace experimental
```

Typedefs

```
using instead = hp::experimental::task_group
```

```
namespace experimental
```

Top-level namespace.

```
class task_group
```

#include <task_group.hpp> A *task_group* represents concurrent execution of a group of tasks. Tasks can be dynamically added to the group while it is executing.

⁵⁶⁶ http://github.com/STELLAR-GROUP/hpx/blob/8a3b7c1a4cb5693b2f7d9f587f759392ed0c51a0/libs/core/include_local/include/hpx/experimental/task_group.hpp

Public Functions

task_group()

~task_group()

task_group(*task_group* const&) = delete

task_group(*task_group*&&) = delete

task_group &**operator**=(*task_group* const&) = delete

task_group &**operator**=(*task_group*&&) = delete

template<typename **Executor**, typename **F**, typename ...**Ts**>

inline void **run**(*Executor* &&exec, *F* &&f, *Ts*&&... ts)

Adds a task to compute *f*() and returns immediately.

Template Parameters

- **Executor** – The type of the executor to associate with this execution policy.
- **F** – The type of the user defined function to invoke.
- **Ts** – The type of additional arguments used to invoke *f*() .

Parameters

- **exec** – The executor to use for the execution of the parallel algorithm the returned execution policy is used with.
- **f** – The user defined function to invoke inside the task group.
- **ts** – Additional arguments to use to invoke *f*() .

template<typename **F**, typename ...**Ts**>

inline void **run**(*F* &&f, *Ts*&&... ts)

Adds a task to compute *f*() and returns immediately.

Template Parameters

- **F** – The type of the user defined function to invoke.
- **Ts** – The type of additional arguments used to invoke *f*() .

Parameters

- **f** – The user defined function to invoke inside the task group.
- **ts** – Additional arguments to use to invoke *f*() .

void **wait**()

Waits for all tasks in the group to complete or be cancelled.

void **add_exception**(*std::exception_ptr* p)

Adds an exception to this *task_group*.

Private Types

using **shared_state_type** = *lcos::detail::future_data*<void>

Private Functions

void **serialize**(*serialization::output_archive*&, unsigned const)

Private Members

hpx::lcos::local::latch **latch_**

hpx::intrusive_ptr<shared_state_type> **state_**

hpx::exception_list **errors_**

std::atomic<bool> **has_arrived_**

Private Static Functions

static inline constexpr void **serialize**(*serialization::input_archive*&, unsigned const) noexcept

Friends

friend class *serialization::access*

hpx::adjacent_difference

Defined in header *hpx/algorithm.hpp*⁵⁶⁷.

See *Public API* for a list of names and headers that are part of the public *HPX* API.

namespace **hpx**

Functions

template<typename **FwdIter1**, typename **FwdIter2**>
FwdIter2 **adjacent_difference**(*FwdIter1* first, *FwdIter1* last, *FwdIter2* dest)

Assigns each value in the range given by result its corresponding element in the range [first, last] and the one preceding it except *result, which is assigned *first.

Note: Complexity: Exactly (last - first) - 1 application of the binary operator and (last - first) assignments.

Template Parameters

- **FwdIter1** – The type of the source iterators used for the input range (deduced). This iterator type must meet the requirements of a forward iterator.

⁵⁶⁷ <http://github.com/STELLAR-GROUP/hpx/blob/8a3b7c1a4cb5693b2f7d9f587f759392ed0c51a0/libs/full/include/include/hpx/algorithm.hpp>

- **FwdIter2** – The type of the source iterators used for the output range (deduced). This iterator type must meet the requirements of a forward iterator.

Parameters

- **first** – Refers to the beginning of the sequence of elements of the range the algorithm will be applied to.
- **last** – Refers to the end of the sequence of elements of the range the algorithm will be applied to.
- **dest** – Refers to the beginning of the sequence of elements the results will be assigned to.

Returns The *adjacent_difference* algorithm returns a *FwdIter2*. The *adjacent_difference* algorithm returns an iterator to the element past the last element written.

```
template<typename ExPolicy, typename FwdIter1, typename FwdIter2>
hpx::parallel::util::detail::algorithm_result_t<ExPolicy, FwdIter2> adjacent_difference(ExPolicy
                                                                                       &&policy,
                                                                                       FwdIter1 first,
                                                                                       FwdIter1 last,
                                                                                       FwdIter2 dest)
```

Assigns each value in the range given by result its corresponding element in the range [first, last] and the one preceding it except *result, which is assigned *first. Executed according to the policy.

The difference operations in the parallel *adjacent_difference* invoked with an execution policy object of type *sequenced_policy* execute in sequential order in the calling thread.

The difference operations in the parallel *adjacent_difference* invoked with an execution policy object of type *parallel_policy* or *parallel_task_policy* are permitted to execute in an unordered fashion in unspecified threads, and indeterminately sequenced within each thread.

Note: Complexity: Exactly (last - first) - 1 application of the binary operator and (last - first) assignments.

Template Parameters

- **ExPolicy** – The type of the execution policy to use (deduced). It describes the manner in which the execution of the algorithm may be parallelized and the manner in which it executes the assignments.
- **FwdIter1** – The type of the source iterators used for the input range (deduced). This iterator type must meet the requirements of a forward iterator.
- **FwdIter2** – The type of the source iterators used for the output range (deduced). This iterator type must meet the requirements of a forward iterator.

Parameters

- **policy** – The execution policy to use for the scheduling of the iterations.
- **first** – Refers to the beginning of the sequence of elements of the range the algorithm will be applied to.
- **last** – Refers to the end of the sequence of elements of the range the algorithm will be applied to.
- **dest** – Refers to the beginning of the sequence of elements the results will be assigned to.

Returns The *adjacent_difference* algorithm returns a *hpx::future<FwdIter2>* if the execution policy is of type *sequenced_task_policy* or *parallel_task_policy* and returns *FwdIter2* otherwise. The *adjacent_difference* algorithm returns an iterator to the element past the last element written.

```
template<typename FwdIter1, typename FwdIter2, typename Op>
FwdIter2 adjacent_difference(FwdIter1 first, FwdIter1 last, FwdIter2 dest, Op &&op)
```

Assigns each value in the range given by result its corresponding element in the range [first, last] and the one preceding it except *result, which is assigned *first

Note: Complexity: Exactly (last - first) - 1 application of the binary operator and (last - first) assignments.

Template Parameters

- **FwdIter1** – The type of the source iterators used for the input range (deduced). This iterator type must meet the requirements of a forward iterator.
- **FwdIter2** – The type of the source iterators used for the output range (deduced). This iterator type must meet the requirements of a forward iterator.
- **Op** – The type of the function/function object to use (deduced). Unlike its sequential form, the parallel overload of *adjacent_difference* requires *Op* to meet the requirements of *Copy-Constructible*.

Parameters

- **first** – Refers to the beginning of the sequence of elements of the range the algorithm will be applied to.
- **last** – Refers to the end of the sequence of elements of the range the algorithm will be applied to.
- **dest** – Refers to the beginning of the sequence of elements the results will be assigned to.
- **op** – The binary operator which returns the difference of elements. The signature should be equivalent to the following:

```
bool op(const Type1 &a, const Type1 &b);
```

The signature does not need to have const &, but the function must not modify the objects passed to it. The types *Type1* must be such that objects of type *FwdIter1* can be dereferenced and then implicitly converted to the dereferenced type of *dest*.

Returns The *adjacent_difference* algorithm returns *FwdIter2*. The *adjacent_difference* algorithm returns an iterator to the element past the last element written.

```
template<typename ExPolicy, typename FwdIter1, typename FwdIter2, typename Op>
hpx::parallel::util::detail::algorithm_result_t<ExPolicy, FwdIter2> adjacent_difference(ExPolicy
                                                                                       &&policy,
                                                                                       FwdIter1 first,
                                                                                       FwdIter1 last,
                                                                                       FwdIter2 dest,
                                                                                       Op &&op)
```

Assigns each value in the range given by result its corresponding element in the range [first, last] and the one preceding it except *result, which is assigned *first

The difference operations in the parallel *adjacent_difference* invoked with an execution policy object of type *sequenced_policy* execute in sequential order in the calling thread.

The difference operations in the parallel *adjacent_difference* invoked with an execution policy object of type *parallel_policy* or *parallel_task_policy* are permitted to execute in an unordered fashion in unspecified threads, and indeterminately sequenced within each thread.

Note: Complexity: Exactly (last - first) - 1 application of the binary operator and (last - first) assignments.

Template Parameters

- **ExPolicy** – The type of the execution policy to use (deduced). It describes the manner in which the execution of the algorithm may be parallelized and the manner in which it executes the assignments.
- **FwdIter1** – The type of the source iterators used for the input range (deduced). This iterator type must meet the requirements of a forward iterator.
- **FwdIter2** – The type of the source iterators used for the output range (deduced). This iterator type must meet the requirements of a forward iterator.
- **Op** – The type of the function/function object to use (deduced). Unlike its sequential form, the parallel overload of *adjacent_difference* requires *Op* to meet the requirements of *Copy-Constructible*.

Parameters

- **policy** – The execution policy to use for the scheduling of the iterations.
- **first** – Refers to the beginning of the sequence of elements of the range the algorithm will be applied to.
- **last** – Refers to the end of the sequence of elements of the range the algorithm will be applied to.
- **dest** – Refers to the beginning of the sequence of elements the results will be assigned to.
- **op** – The binary operator which returns the difference of elements. The signature should be equivalent to the following:

```
bool op(const Type1 &a, const Type1 &b);
```

The signature does not need to have `const &`, but the function must not modify the objects passed to it. The types *Type1* must be such that objects of type *FwdIter1* can be dereferenced and then implicitly converted to the dereferenced type of *dest*.

Returns The *adjacent_difference* algorithm returns a *hpx::future<FwdIter2>* if the execution policy is of type *sequenced_task_policy* or *parallel_task_policy* and returns *FwdIter2* otherwise. The *adjacent_difference* algorithm returns an iterator to the element past the last element written.

hpx::adjacent_find

Defined in header `hpx/algorithm.hpp`⁵⁶⁸.

See *Public API* for a list of names and headers that are part of the public *HPX* API.

namespace **hpx**

Functions

```
template<typename InIter, typename Pred = hpx::parallel::detail::equal_to>
InIter adjacent_find(InIter first, InIter last, Pred &&pred = Pred())
```

Searches the range [first, last) for two consecutive identical elements.

Note: Complexity: Exactly the smaller of $(result - first) + 1$ and $(last - first) - 1$ application of the predicate where *result* is the value returned

Template Parameters

- **InIter** – The type of the source iterators used for the range (deduced). This iterator type must meet the requirements of an input iterator.
- **Pred** – The type of an optional function/function object to use.

Parameters

- **first** – Refers to the beginning of the sequence of elements of the range the algorithm will be applied to.
- **last** – Refers to the end of the sequence of elements of the range the algorithm will be applied to.
- **pred** – The binary predicate which returns *true* if the elements should be treated as equal. The signature should be equivalent to the following:

```
bool pred(const Type1 &a, const Type1 &b);
```

The signature does not need to have `const &`, but the function must not modify the objects passed to it. The types *Type1* must be such that objects of type *InIter* can be dereferenced and then implicitly converted to *Type1*.

Returns The *adjacent_find* algorithm returns an iterator to the first of the identical elements. If no such elements are found, *last* is returned.

```
template<typename ExPolicy, typename FwdIter, typename Pred = hpx::parallel::detail::equal_to>
hpx::parallel::util::detail::algorithm_result_t<ExPolicy, FwdIter> adjacent_find(ExPolicy &&policy,
                                                                              FwdIter first, FwdIter
                                                                              last, Pred &&pred =
                                                                              Pred())
```

Searches the range [first, last) for two consecutive identical elements. This version uses the given binary predicate *pred*

⁵⁶⁸ <http://github.com/STELLAR-GROUP/hpx/blob/8a3b7c1a4cb5693b2f7d9f587f759392ed0c51a0/libs/full/include/include/hpx/algorithm.hpp>

The comparison operations in the parallel *adjacent_find* invoked with an execution policy object of type *sequenced_policy* execute in sequential order in the calling thread.

The comparison operations in the parallel *adjacent_find* invoked with an execution policy object of type *parallel_policy* or *parallel_task_policy* are permitted to execute in an unordered fashion in unspecified threads, and indeterminately sequenced within each thread.

This overload of *adjacent_find* is available if the user decides to provide their algorithm their own binary predicate *pred*.

Note: Complexity: Exactly the smaller of $(result - first) + 1$ and $(last - first) - 1$ application of the predicate where *result* is the value returned

Template Parameters

- **ExPolicy** – The type of the execution policy to use (deduced). It describes the manner in which the execution of the algorithm may be parallelized and the manner in which it executes the assignments.
- **FwdIter** – The type of the source iterators used for the range (deduced). This iterator type must meet the requirements of a forward iterator.
- **Pred** – The type of an optional function/function object to use. Unlike its sequential form, the parallel overload of *adjacent_find* requires *Pred* to meet the requirements of *CopyConstructible*. This defaults to `std::equal_to<>`

Parameters

- **policy** – The execution policy to use for the scheduling of the iterations.
- **first** – Refers to the beginning of the sequence of elements of the range the algorithm will be applied to.
- **last** – Refers to the end of the sequence of elements of the range the algorithm will be applied to.
- **pred** – The binary predicate which returns *true* if the elements should be treated as equal. The signature should be equivalent to the following:

```
bool pred(const Type1 &a, const Type1 &b);
```

The signature does not need to have `const &`, but the function must not modify the objects passed to it. The types *Type1* must be such that objects of type *FwdIter* can be dereferenced and then implicitly converted to *Type1*.

Returns The *adjacent_find* algorithm returns a *hpx::future<FwdIter>* if the execution policy is of type *sequenced_task_policy* or *parallel_task_policy* and returns *FwdIter* otherwise. The *adjacent_find* algorithm returns an iterator to the first of the identical elements. If no such elements are found, *last* is returned.

hpx::all_of, hpx::any_of, hpx::none_of

Defined in header `hpx/algorithm.hpp`⁵⁶⁹.

See *Public API* for a list of names and headers that are part of the public HPX API.

namespace **hpx**

Functions

```
template<typename ExPolicy, typename FwdIter, typename F>
util::detail::algorithm_result_t<ExPolicy, bool> none_of(ExPolicy &&policy, FwdIter first, FwdIter last, F
&&f)
```

Checks if unary predicate *f* returns true for no elements in the range [first, last).

The application of function objects in parallel algorithm invoked with an execution policy object of type *sequenced_policy* execute in sequential order in the calling thread.

The application of function objects in parallel algorithm invoked with an execution policy object of type *parallel_policy* or *parallel_task_policy* are permitted to execute in an unordered fashion in unspecified threads, and indeterminately sequenced within each thread.

Note: Complexity: At most *last - first* applications of the predicate *f*

Template Parameters

- **ExPolicy** – The type of the execution policy to use (deduced). It describes the manner in which the execution of the algorithm may be parallelized and the manner in which it applies user-provided function objects.
- **FwdIter** – The type of the source iterators used (deduced). This iterator type must meet the requirements of an forward iterator.
- **F** – The type of the function/function object to use (deduced). Unlike its sequential form, the parallel overload of *none_of* requires *F* to meet the requirements of *CopyConstructible*.

Parameters

- **policy** – The execution policy to use for the scheduling of the iterations.
- **first** – Refers to the beginning of the sequence of elements the algorithm will be applied to.
- **last** – Refers to the end of the sequence of elements the algorithm will be applied to.
- **f** – Specifies the function (or function object) which will be invoked for each of the elements in the sequence specified by [first, last). The signature of this predicate should be equivalent to:

```
bool pred(const Type &a);
```

⁵⁶⁹ <http://github.com/STELLAR-GROUP/hpx/blob/8a3b7c1a4cb5693b2f7d9f587f759392ed0c51a0/libs/full/include/include/hpx/algorithm.hpp>

The signature does not need to have `const&`, but the function must not modify the objects passed to it. The type *Type* must be such that an object of type *FwdIter* can be dereferenced and then implicitly converted to *Type*.

Returns The *none_of* algorithm returns a *hpx::future<bool>* if the execution policy is of type *sequenced_task_policy* or *parallel_task_policy* and returns *bool* otherwise. The *none_of* algorithm returns true if the unary predicate *f* returns true for no elements in the range, false otherwise. It returns true if the range is empty.

```
template<typename InIter, typename F>
bool none_of(InIter first, InIter last, F &&f)
```

Checks if unary predicate *f* returns true for no elements in the range [first, last).

Note: Complexity: At most *last - first* applications of the predicate *f*

Template Parameters

- **InIter** – The type of the source iterators used (deduced). This iterator type must meet the requirements of an input iterator.
- **F** – The type of the function/function object to use (deduced). Unlike its sequential form, the parallel overload of *none_of* requires *F* to meet the requirements of *CopyConstructible*.

Parameters

- **first** – Refers to the beginning of the sequence of elements the algorithm will be applied to.
- **last** – Refers to the end of the sequence of elements the algorithm will be applied to.
- **f** – Specifies the function (or function object) which will be invoked for each of the elements in the sequence specified by [first, last). The signature of this predicate should be equivalent to:

```
bool pred(const Type &a);
```

The signature does not need to have `const&`, but the function must not modify the objects passed to it. The type *Type* must be such that an object of type *InIter* can be dereferenced and then implicitly converted to *Type*.

Returns The *none_of* algorithm returns a *bool*. The *none_of* algorithm returns true if the unary predicate *f* returns true for no elements in the range, false otherwise. It returns true if the range is empty.

```
template<typename ExPolicy, typename FwdIter, typename F>
util::detail::algorithm_result_t<ExPolicy, bool> any_of(ExPolicy &&policy, FwdIter first, FwdIter last, F &&f)
```

Checks if unary predicate *f* returns true for at least one element in the range [first, last).

The application of function objects in parallel algorithm invoked with an execution policy object of type *sequenced_policy* execute in sequential order in the calling thread.

The application of function objects in parallel algorithm invoked with an execution policy object of type *parallel_policy* or *parallel_task_policy* are permitted to execute in an unordered fashion in unspecified threads, and indeterminately sequenced within each thread.

Note: Complexity: At most *last - first* applications of the predicate *f*

Template Parameters

- **ExPolicy** – The type of the execution policy to use (deduced). It describes the manner in which the execution of the algorithm may be parallelized and the manner in which it applies user-provided function objects.
- **FwdIter** – The type of the source iterators used (deduced). This iterator type must meet the requirements of an forward iterator.
- **F** – The type of the function/function object to use (deduced). Unlike its sequential form, the parallel overload of *any_of* requires *F* to meet the requirements of *CopyConstructible*.

Parameters

- **policy** – The execution policy to use for the scheduling of the iterations.
- **first** – Refers to the beginning of the sequence of elements the algorithm will be applied to.
- **last** – Refers to the end of the sequence of elements the algorithm will be applied to.
- **f** – Specifies the function (or function object) which will be invoked for each of the elements in the sequence specified by [first, last). The signature of this predicate should be equivalent to:

```
bool pred(const Type &a);
```

The signature does not need to have const&, but the function must not modify the objects passed to it. The type *Type* must be such that an object of type *FwdIter* can be dereferenced and then implicitly converted to *Type*.

Returns The *any_of* algorithm returns a *hpx::future<bool>* if the execution policy is of type *sequenced_task_policy* or *parallel_task_policy* and returns *bool* otherwise. The *any_of* algorithm returns true if the unary predicate *f* returns true for at least one element in the range, false otherwise. It returns false if the range is empty.

```
template<typename InIter, typename F>
bool any_of(InIter first, InIter last, F &&f)
```

Checks if unary predicate *f* returns true for at least one element in the range [first, last).

Note: Complexity: At most *last - first* applications of the predicate *f*

Template Parameters

- **InIter** – The type of the source iterators used (deduced). This iterator type must meet the requirements of an input iterator.
- **F** – The type of the function/function object to use (deduced). Unlike its sequential form, the parallel overload of *any_of* requires *F* to meet the requirements of *CopyConstructible*.

Parameters

- **first** – Refers to the beginning of the sequence of elements the algorithm will be applied to.

- **last** – Refers to the end of the sequence of elements the algorithm will be applied to.
- **f** – Specifies the function (or function object) which will be invoked for each of the elements in the sequence specified by [first, last). The signature of this predicate should be equivalent to:

```
bool pred(const Type &a);
```

The signature does not need to have const&, but the function must not modify the objects passed to it. The type *Type* must be such that an object of type *InIter* can be dereferenced and then implicitly converted to *Type*.

Returns The *any_of* algorithm returns a *bool*. The *any_of* algorithm returns true if the unary predicate *f* returns true for at least one element in the range, false otherwise. It returns false if the range is empty.

```
template<typename ExPolicy, typename FwdIter, typename F>
util::detail::algorithm_result_t<ExPolicy, bool> all_of(ExPolicy &&policy, FwdIter first, FwdIter last, F
&&f)
```

Checks if unary predicate *f* returns true for all elements in the range [first, last).

The application of function objects in parallel algorithm invoked with an execution policy object of type *sequenced_policy* execute in sequential order in the calling thread.

The application of function objects in parallel algorithm invoked with an execution policy object of type *parallel_policy* or *parallel_task_policy* are permitted to execute in an unordered fashion in unspecified threads, and indeterminately sequenced within each thread.

Note: Complexity: At most *last - first* applications of the predicate *f*

Template Parameters

- **ExPolicy** – The type of the execution policy to use (deduced). It describes the manner in which the execution of the algorithm may be parallelized and the manner in which it applies user-provided function objects.
- **FwdIter** – The type of the source iterators used (deduced). This iterator type must meet the requirements of an forward iterator.
- **F** – The type of the function/function object to use (deduced). Unlike its sequential form, the parallel overload of *all_of* requires *F* to meet the requirements of *CopyConstructible*.

Parameters

- **policy** – The execution policy to use for the scheduling of the iterations.
- **first** – Refers to the beginning of the sequence of elements the algorithm will be applied to.
- **last** – Refers to the end of the sequence of elements the algorithm will be applied to.
- **f** – Specifies the function (or function object) which will be invoked for each of the elements in the sequence specified by [first, last). The signature of this predicate should be equivalent to:

```
bool pred(const Type &a);
```

The signature does not need to have `const&`, but the function must not modify the objects passed to it. The type *Type* must be such that an object of type *FwdIter* can be dereferenced and then implicitly converted to *Type*.

Returns The *all_of* algorithm returns a `hpx::future<bool>` if the execution policy is of type *sequenced_task_policy* or *parallel_task_policy* and returns *bool* otherwise. The *all_of* algorithm returns true if the unary predicate *f* returns true for all elements in the range, false otherwise. It returns true if the range is empty.

```
template<typename ExPolicy, typename InIter, typename F>
bool all_of(InIter first, InIter last, F &&f)
```

Checks if unary predicate *f* returns true for all elements in the range [first, last).

Note: Complexity: At most *last - first* applications of the predicate *f*

Template Parameters

- **InIter** – The type of the source iterators used (deduced). This iterator type must meet the requirements of an input iterator.
- **F** – The type of the function/function object to use (deduced). Unlike its sequential form, the parallel overload of *all_of* requires *F* to meet the requirements of *CopyConstructible*.

Parameters

- **first** – Refers to the beginning of the sequence of elements the algorithm will be applied to.
- **last** – Refers to the end of the sequence of elements the algorithm will be applied to.
- **f** – Specifies the function (or function object) which will be invoked for each of the elements in the sequence specified by [first, last). The signature of this predicate should be equivalent to:

```
bool pred(const Type &a);
```

The signature does not need to have `const&`, but the function must not modify the objects passed to it. The type *Type* must be such that an object of type *InIter* can be dereferenced and then implicitly converted to *Type*.

Returns The *all_of* algorithm returns a *bool*. The *all_of* algorithm returns true if the unary predicate *f* returns true for all elements in the range, false otherwise. It returns true if the range is empty.

hpx::copy, hpx::copy_n, hpx::copy_if

Defined in header `hpx/algorithm.hpp`⁵⁷⁰.

See *Public API* for a list of names and headers that are part of the public HPX API.

namespace **hpx**

⁵⁷⁰ <http://github.com/STELLAR-GROUP/hpx/blob/8a3b7c1a4cb5693b2f7d9f587f759392ed0c51a0/libs/full/include/include/hpx/algorithm.hpp>

Functions

```
template<typename ExPolicy, typename FwdIter1, typename FwdIter2>  
hpx::parallel::util::detail::algorithm_result_t<ExPolicy, FwdIter2> copy(ExPolicy &&policy, FwdIter1 first,  
FwdIter1 last, FwdIter2 dest)
```

Copies the elements in the range, defined by [first, last), to another range beginning at *dest*. Executed according to the policy.

The assignments in the parallel *copy* algorithm invoked with an execution policy object of type *sequenced_policy* execute in sequential order in the calling thread.

The assignments in the parallel *copy* algorithm invoked with an execution policy object of type *parallel_policy* or *parallel_task_policy* are permitted to execute in an unordered fashion in unspecified threads, and indeterminately sequenced within each thread.

Note: Complexity: Performs exactly *last - first* assignments.

Template Parameters

- **ExPolicy** – The type of the execution policy to use (deduced). It describes the manner in which the execution of the algorithm may be parallelized and the manner in which it executes the assignments.
- **FwdIter1** – The type of the source iterators used (deduced). This iterator type must meet the requirements of an forward iterator.
- **FwdIter2** – The type of the iterator representing the destination range (deduced). This iterator type must meet the requirements of an forward iterator.

Parameters

- **policy** – The execution policy to use for the scheduling of the iterations.
- **first** – Refers to the beginning of the sequence of elements the algorithm will be applied to.
- **last** – Refers to the end of the sequence of elements the algorithm will be applied to.
- **dest** – Refers to the beginning of the destination range.

Returns The *copy* algorithm returns a *hpx::future*<*FwdIter2*> if the execution policy is of type *sequenced_task_policy* or *parallel_task_policy* and returns *FwdIter2* otherwise. The *copy* algorithm returns the pair of the input iterator *last* and the output iterator to the element in the destination range, one past the last element copied.

```
template<typename FwdIter1, typename FwdIter2>  
FwdIter2 copy(FwdIter1 first, FwdIter1 last, FwdIter2 dest)
```

Copies the elements in the range, defined by [first, last), to another range beginning at *dest*.

Note: Complexity: Performs exactly *last - first* assignments.

Template Parameters

- **FwdIter1** – The type of the source iterators used (deduced). This iterator type must meet the requirements of an forward iterator.

- **FwdIter2** – The type of the iterator representing the destination range (deduced). This iterator type must meet the requirements of an forward iterator.

Parameters

- **first** – Refers to the beginning of the sequence of elements the algorithm will be applied to.
- **last** – Refers to the end of the sequence of elements the algorithm will be applied to.
- **dest** – Refers to the beginning of the destination range.

Returns The *copy* algorithm returns a *FwdIter2*. The *copy* algorithm returns the pair of the input iterator *last* and the output iterator to the element in the destination range, one past the last element copied.

```
template<typename ExPolicy, typename FwdIter1, typename Size, typename FwdIter2>
hpx::parallel::util::detail::algorithm_result_t<ExPolicy, FwdIter2> copy_n(ExPolicy &&policy, FwdIter1
first, Size count, FwdIter2 dest)
```

Copies the elements in the range [first, first + count), starting from first and proceeding to first + count - 1., to another range beginning at dest. Executed according to the policy.

The assignments in the parallel *copy_n* algorithm invoked with an execution policy object of type *sequenced_policy* execute in sequential order in the calling thread.

The assignments in the parallel *copy_n* algorithm invoked with an execution policy object of type *parallel_policy* or *parallel_task_policy* are permitted to execute in an unordered fashion in unspecified threads, and indeterminately sequenced within each thread.

Note: Complexity: Performs exactly *count* assignments, if count > 0, no assignments otherwise.

Template Parameters

- **ExPolicy** – The type of the execution policy to use (deduced). It describes the manner in which the execution of the algorithm may be parallelized and the manner in which it executes the assignments.
- **FwdIter1** – The type of the source iterators used (deduced). This iterator type must meet the requirements of an forward iterator.
- **Size** – The type of the argument specifying the number of elements to apply *f* to.
- **FwdIter2** – The type of the iterator representing the destination range (deduced). This iterator type must meet the requirements of an forward iterator.

Parameters

- **policy** – The execution policy to use for the scheduling of the iterations.
- **first** – Refers to the beginning of the sequence of elements the algorithm will be applied to.
- **count** – Refers to the number of elements starting at *first* the algorithm will be applied to.
- **dest** – Refers to the beginning of the destination range.

Returns The *copy_n* algorithm returns a *hpx::future<FwdIter2>* if the execution policy is of type *sequenced_task_policy* or *parallel_task_policy* and returns *FwdIter2* otherwise. The *copy_n*

algorithm returns Iterator in the destination range, pointing past the last element copied if count>0 or result otherwise.

```
template<typename FwdIter1, typename Size, typename FwdIter2>  
FwdIter2 copy_n(FwdIter1 first, Size count, FwdIter2 dest)
```

Copies the elements in the range [first, first + count), starting from first and proceeding to first + count - 1., to another range beginning at dest.

Note: Complexity: Performs exactly *count* assignments, if count > 0, no assignments otherwise.

Template Parameters

- **FwdIter1** – The type of the source iterators used (deduced). This iterator type must meet the requirements of an forward iterator.
- **Size** – The type of the argument specifying the number of elements to apply *f* to.
- **FwdIter2** – The type of the iterator representing the destination range (deduced). This iterator type must meet the requirements of an forward iterator.

Parameters

- **first** – Refers to the beginning of the sequence of elements the algorithm will be applied to.
- **count** – Refers to the number of elements starting at *first* the algorithm will be applied to.
- **dest** – Refers to the beginning of the destination range.

Returns The *copy_n* algorithm returns a *FwdIter2* . The *copy_n* algorithm returns Iterator in the destination range, pointing past the last element copied if count>0 or result otherwise.

```
template<typename ExPolicy, typename FwdIter1, typename FwdIter2, typename Pred>  
hpx::parallel::util::detail::algorithm_result_t<ExPolicy, FwdIter2> copy_if(ExPolicy &&policy, FwdIter1  
first, FwdIter1 last, FwdIter2  
dest, Pred &&pred)
```

Copies the elements in the range, defined by [first, last), to another range beginning at *dest*. Copies only the elements for which the predicate *f* returns true. The order of the elements that are not removed is preserved. Executed according to the policy.

The assignments in the parallel *copy_if* algorithm invoked with an execution policy object of type *sequenced_policy* execute in sequential order in the calling thread.

The assignments in the parallel *copy_if* algorithm invoked with an execution policy object of type *parallel_policy* or *parallel_task_policy* are permitted to execute in an unordered fashion in unspecified threads, and indeterminately sequenced within each thread.

Note: Complexity: Performs not more than *last - first* assignments, exactly *last - first* applications of the predicate *f*.

Template Parameters

- **ExPolicy** – The type of the execution policy to use (deduced). It describes the manner in which the execution of the algorithm may be parallelized and the manner in which it executes the assignments.
- **FwdIter1** – The type of the source iterators used (deduced). This iterator type must meet the requirements of an forward iterator.
- **FwdIter2** – The type of the iterator representing the destination range (deduced). This iterator type must meet the requirements of an forward iterator.
- **Pred** – The type of the function/function object to use (deduced). Unlike its sequential form, the parallel overload of *copy_if* requires *F* to meet the requirements of *CopyConstructible*.

Parameters

- **policy** – The execution policy to use for the scheduling of the iterations.
- **first** – Refers to the beginning of the sequence of elements the algorithm will be applied to.
- **last** – Refers to the end of the sequence of elements the algorithm will be applied to.
- **dest** – Refers to the beginning of the destination range.
- **pred** – Specifies the function (or function object) which will be invoked for each of the elements in the sequence specified by [first, last). This is an unary predicate which returns *true* for the required elements. The signature of this predicate should be equivalent to:

```
bool pred(const Type &a);
```

The signature does not need to have `const&`, but the function must not modify the objects passed to it. The type *Type* must be such that an object of type *FwdIter1* can be dereferenced and then implicitly converted to *Type*.

Returns The *copy_if* algorithm returns a `hpx::future<FwdIter2>` if the execution policy is of type *sequenced_task_policy* or *parallel_task_policy* and returns *FwdIter2* otherwise. The *copy_if* algorithm returns output iterator to the element in the destination range, one past the last element copied.

```
template<typename FwdIter1, typename FwdIter2, typename Pred>
FwdIter2 copy_if(FwdIter1 first, FwdIter1 last, FwdIter2 dest, Pred &&pred)
```

Copies the elements in the range, defined by [first, last), to another range beginning at *dest*. Copies only the elements for which the predicate *f* returns true. The order of the elements that are not removed is preserved.

Note: Complexity: Performs not more than *last - first* assignments, exactly *last - first* applications of the predicate *f*.

Template Parameters

- **FwdIter1** – The type of the source iterators used (deduced). This iterator type must meet the requirements of an forward iterator.
- **FwdIter2** – The type of the iterator representing the destination range (deduced). This iterator type must meet the requirements of an forward iterator.
- **Pred** – The type of the function/function object to use (deduced). Unlike its sequential form, the parallel overload of *copy_if* requires *F* to meet the requirements of *CopyConstructible*.

Parameters

- **first** – Refers to the beginning of the sequence of elements the algorithm will be applied to.
- **last** – Refers to the end of the sequence of elements the algorithm will be applied to.
- **dest** – Refers to the beginning of the destination range.
- **pred** – Specifies the function (or function object) which will be invoked for each of the elements in the sequence specified by [first, last). This is a unary predicate which returns *true* for the required elements. The signature of this predicate should be equivalent to:

```
bool pred(const Type &a);
```

The signature does not need to have `const&`, but the function must not modify the objects passed to it. The type *Type* must be such that an object of type *FwdIter1* can be dereferenced and then implicitly converted to *Type*.

Returns The *copy_if* algorithm returns a *FwdIter2*. The *copy_if* algorithm returns output iterator to the element in the destination range, one past the last element copied.

hpx::count, hpx::count_if

Defined in header `hpx/algorithm.hpp`⁵⁷¹.

See *Public API* for a list of names and headers that are part of the public *HPX* API.

namespace **hpx**

Functions

```
template<typename ExPolicy, typename FwdIter, typename T>
util::detail::algorithm_result<ExPolicy, typename std::iterator_traits<FwdIter>::difference_type>::type count(ExPolicy
&&policy,
FwdIter
first,
FwdIter
last,
T
const
&value)
```

Returns the number of elements in the range [first, last) satisfying a specific criteria. This version counts the elements that are equal to the given *value*. Executed according to the policy.

The comparisons in the parallel *count* algorithm invoked with an execution policy object of type *sequenced_policy* execute in sequential order in the calling thread.

Note: Complexity: Performs exactly *last - first* comparisons.

⁵⁷¹ <http://github.com/STELLAR-GROUP/hpx/blob/8a3b7c1a4cb5693b2f7d9f587f759392ed0c51a0/libs/full/include/include/hpx/algorithm.hpp>

Note: The comparisons in the parallel *count* algorithm invoked with an execution policy object of type *parallel_policy* or *parallel_task_policy* are permitted to execute in an unordered fashion in unspecified threads, and indeterminately sequenced within each thread.

Template Parameters

- **ExPolicy** – The type of the execution policy to use (deduced). It describes the manner in which the execution of the algorithm may be parallelized and the manner in which it executes the comparisons.
- **FwdIter** – The type of the source iterator used (deduced). This iterator type must meet the requirements of an forward iterator.
- **T** – The type of the value to search for (deduced).

Parameters

- **policy** – The execution policy to use for the scheduling of the iterations.
- **first** – Refers to the beginning of the sequence of elements the algorithm will be applied to.
- **last** – Refers to the end of the sequence of elements the algorithm will be applied to.
- **value** – The value to search for.

Returns The *count* algorithm returns a *hpx::future<difference_type>* if the execution policy is of type *sequenced_task_policy* or *parallel_task_policy* and returns *difference_type* otherwise (where *difference_type* is defined by *std::iterator_traits<FwdIterB>::difference_type*. The *count* algorithm returns the number of elements satisfying the given criteria.

```
template<typename InIter, typename T>
std::iterator_traits<InIter>::difference_type count(InIter first, InIter last, T const &value)
```

Returns the number of elements in the range [first, last) satisfying a specific criteria. This version counts the elements that are equal to the given *value*.

Note: Complexity: Performs exactly *last - first* comparisons.

Template Parameters

- **InIter** – The type of the source iterator used (deduced). This iterator type must meet the requirements of an input iterator.
- **T** – The type of the value to search for (deduced).

Parameters

- **first** – Refers to the beginning of the sequence of elements the algorithm will be applied to.
- **last** – Refers to the end of the sequence of elements the algorithm will be applied to.
- **value** – The value to search for.

Returns The *count* algorithm returns a *difference_type* (where *difference_type* is defined by *std::iterator_traits<InIter>::difference_type*. The *count* algorithm returns the number of elements satisfying the given criteria.

```
template<typename ExPolicy, typename FwdIter, typename F>
util::detail::algorithm_result<ExPolicy, typename std::iterator_traits<FwdIter>::difference_type>::type count_if(ExPolicy
&&pol-
icy,
FwdIter
first,
FwdIter
last,
F
&&f)
```

Returns the number of elements in the range [first, last) satisfying a specific criteria. This version counts elements for which predicate *f* returns true. Executed according to the policy.

Note: Complexity: Performs exactly *last - first* applications of the predicate.

Note: The assignments in the parallel *count_if* algorithm invoked with an execution policy object of type *sequenced_policy* execute in sequential order in the calling thread.

Note: The assignments in the parallel *count_if* algorithm invoked with an execution policy object of type *parallel_policy* or *parallel_task_policy* are permitted to execute in an unordered fashion in unspecified threads, and indeterminately sequenced within each thread.

Template Parameters

- **ExPolicy** – The type of the execution policy to use (deduced). It describes the manner in which the execution of the algorithm may be parallelized and the manner in which it executes the comparisons.
- **FwdIter** – The type of the source begin iterator used (deduced). This iterator type must meet the requirements of an forward iterator.
- **F** – The type of the function/function object to use (deduced). Unlike its sequential form, the parallel overload of *count_if* requires *F* to meet the requirements of *CopyConstructible*.

Parameters

- **policy** – The execution policy to use for the scheduling of the iterations.
- **first** – Refers to the beginning of the sequence of elements the algorithm will be applied to.
- **last** – Refers to the end of the sequence of elements the algorithm will be applied to.
- **f** – Specifies the function (or function object) which will be invoked for each of the elements in the sequence specified by [first, last). This is a unary predicate which returns *true* for the required elements. The signature of this predicate should be equivalent to:

```
bool pred(const Type &a);
```

The signature does not need to have *const&*, but the function must not modify the objects passed to it. The type *Type* must be such that an object of type *FwdIter* can be dereferenced and then implicitly converted to *Type*.

Returns The *count_if* algorithm returns *hpx::future<difference_type>* if the execution policy is of type *sequenced_task_policy* or *parallel_task_policy* and returns *difference_type* otherwise (where *difference_type* is defined by *std::iterator_traits<FwdIter>::difference_type*). The *count* algorithm returns the number of elements satisfying the given criteria.

```
template<typename InIter, typename F>
std::iterator_traits<InIter>::difference_type count_if(InIter first, InIter last, F &&f)
```

Returns the number of elements in the range [first, last) satisfying a specific criteria. This version counts elements for which predicate *f* returns true.

Note: Complexity: Performs exactly *last - first* applications of the predicate.

Template Parameters

- **InIter** – The type of the source begin iterator used (deduced). This iterator type must meet the requirements of an input iterator.
- **F** – The type of the function/function object to use (deduced). Unlike its sequential form, the parallel overload of *count_if* requires *F* to meet the requirements of *CopyConstructible*.

Parameters

- **first** – Refers to the beginning of the sequence of elements the algorithm will be applied to.
- **last** – Refers to the end of the sequence of elements the algorithm will be applied to.
- **f** – Specifies the function (or function object) which will be invoked for each of the elements in the sequence specified by [first, last). This is a unary predicate which returns *true* for the required elements. The signature of this predicate should be equivalent to:

```
bool pred(const Type &a);
```

The signature does not need to have *const&*, but the function must not modify the objects passed to it. The type *Type* must be such that an object of type *InIter* can be dereferenced and then implicitly converted to *Type*.

Returns The *count_if* algorithm returns *difference_type* (where a *difference_type* is defined by *std::iterator_traits<InIter>::difference_type*). The *count* algorithm returns the number of elements satisfying the given criteria.

hpx::destroy, hpx::destroy_n

Defined in header `hpx/algorithm.hpp`⁵⁷².

See *Public API* for a list of names and headers that are part of the public *HPX* API.

namespace **hpx**

⁵⁷² <http://github.com/STELLAR-GROUP/hpx/blob/8a3b7c1a4cb5693b2f7d9f587f759392ed0c51a0/libs/full/include/include/hpx/algorithm.hpp>

Functions

```
template<typename ExPolicy, typename FwdIter>  
util::detail::algorithm_result_t<ExPolicy> destroy(ExPolicy &&policy, FwdIter first, FwdIter last)
```

Destroys objects of type `typename iterator_traits<ForwardIt>::value_type` in the range `[first, last)`. Executed according to the policy.

The operations in the parallel *destroy* algorithm invoked with an execution policy object of type *sequenced_policy* execute in sequential order in the calling thread.

The operations in the parallel *destroy* algorithm invoked with an execution policy object of type *parallel_policy* or *parallel_task_policy* are permitted to execute in an unordered fashion in unspecified threads, and indeterminately sequenced within each thread.

Note: Complexity: Performs exactly *last - first* operations.

Template Parameters

- **ExPolicy** – The type of the execution policy to use (deduced). It describes the manner in which the execution of the algorithm may be parallelized and the manner in which it executes the assignments.
- **FwdIter** – The type of the source iterators used (deduced). This iterator type must meet the requirements of an forward iterator.

Parameters

- **policy** – The execution policy to use for the scheduling of the iterations.
- **first** – Refers to the beginning of the sequence of elements the algorithm will be applied to.
- **last** – Refers to the end of the sequence of elements the algorithm will be applied to.

Returns The *destroy* algorithm returns a *hpx::future<void>*, if the execution policy is of type *sequenced_task_policy* or *parallel_task_policy* and returns *void* otherwise.

```
template<typename FwdIter>  
void destroy(FwdIter first, FwdIter last)
```

Destroys objects of type `typename iterator_traits<ForwardIt>::value_type` in the range `[first, last)`.

Note: Complexity: Performs exactly *last - first* operations.

Template Parameters **FwdIter** – The type of the source iterators used (deduced). This iterator type must meet the requirements of an forward iterator.

Parameters

- **first** – Refers to the beginning of the sequence of elements the algorithm will be applied to.
- **last** – Refers to the end of the sequence of elements the algorithm will be applied to.

Returns The *destroy* algorithm returns a *void*

```
template<typename ExPolicy, typename FwdIter, typename Size>
util::detail::algorithm_result_t<ExPolicy, FwdIter> destroy_n(ExPolicy &&policy, FwdIter first, Size count)
```

Destroys objects of type `typename iterator_traits<ForwardIt>::value_type` in the range `[first, first + count)`. Executed according to the policy.

The operations in the parallel `destroy_n` algorithm invoked with an execution policy object of type `sequenced_policy` execute in sequential order in the calling thread.

The operations in the parallel `destroy_n` algorithm invoked with an execution policy object of type `parallel_policy` or `parallel_task_policy` are permitted to execute in an unordered fashion in unspecified threads, and indeterminately sequenced within each thread.

Note: Complexity: Performs exactly `count` operations, if `count > 0`, no assignments otherwise.

Template Parameters

- **ExPolicy** – The type of the execution policy to use (deduced). It describes the manner in which the execution of the algorithm may be parallelized and the manner in which it executes the assignments.
- **FwdIter** – The type of the source iterators used (deduced). This iterator type must meet the requirements of an forward iterator.
- **Size** – The type of the argument specifying the number of elements to apply this algorithm to.

Parameters

- **policy** – The execution policy to use for the scheduling of the iterations.
- **first** – Refers to the beginning of the sequence of elements the algorithm will be applied to.
- **count** – Refers to the number of elements starting at `first` the algorithm will be applied to.

Returns The `destroy_n` algorithm returns a `hpx::future<FwdIter>` if the execution policy is of type `sequenced_task_policy` or `parallel_task_policy` and returns `FwdIter` otherwise. The `destroy_n` algorithm returns the iterator to the element in the source range, one past the last element constructed.

```
template<typename FwdIter, typename Size>
FwdIter destroy_n(FwdIter first, Size count)
```

Destroys objects of type `typename iterator_traits<ForwardIt>::value_type` in the range `[first, first + count)`.

Note: Complexity: Performs exactly `count` operations, if `count > 0`, no assignments otherwise.

Template Parameters

- **FwdIter** – The type of the source iterators used (deduced). This iterator type must meet the requirements of an forward iterator.
- **Size** – The type of the argument specifying the number of elements to apply this algorithm to.

Parameters

- **first** – Refers to the beginning of the sequence of elements the algorithm will be applied to.
- **count** – Refers to the number of elements starting at *first* the algorithm will be applied to.

Returns The *destroy_n* algorithm returns a *FwdIter*. The *destroy_n* algorithm returns the iterator to the element in the source range, one past the last element constructed.

hpx::ends_with

Defined in header `hpx/algorithm.hpp`⁵⁷³.

See *Public API* for a list of names and headers that are part of the public *HPX* API.

namespace **hpx**

Functions

```
template<typename InIter1, typename InIter2, typename Pred>  
bool ends_with(InIter1 first1, InIter1 last1, InIter2 first2, InIter2 last2, Pred &&pred)
```

Checks whether the second range defined by [first1, last1) matches the suffix of the first range defined by [first2, last2)

The assignments in the parallel *ends_with* algorithm invoked without an execution policy object execute in sequential order in the calling thread.

Note: Complexity: Linear: at most min(N1, N2) applications of the predicate and both projections.

Template Parameters

- **InIter1** – The type of the begin source iterators used (deduced). This iterator type must meet the requirements of an input iterator.
- **InIter2** – The type of the begin destination iterators used (deduced). This iterator type must meet the requirements of an input iterator.
- **Pred** – The binary predicate that compares the projected elements.

Parameters

- **first1** – Refers to the beginning of the source range.
- **last1** – Refers to the end of the source range.
- **first2** – Refers to the beginning of the destination range.
- **last2** – Refers to the end of the destination range.
- **pred** – Specifies the binary predicate function (or function object) which will be invoked for comparison of the elements in the in two ranges projected by proj1 and proj2 respectively.

Returns The *ends_with* algorithm returns *bool*. The *ends_with* algorithm returns a boolean with the value true if the second range matches the suffix of the first range, false otherwise.

⁵⁷³ <http://github.com/STELLAR-GROUP/hpx/blob/8a3b7c1a4cb5693b2f7d9f587f759392ed0c51a0/libs/full/include/include/hpx/algorithm.hpp>

```
template<typename ExPolicy, typename FwdIter1, typename FwdIter2, typename Pred>
hpx::parallel::util::detail::algorithm_result<ExPolicy, bool>::type ends_with(ExPolicy &&policy, FwdIter1
first1, FwdIter1 last1, FwdIter2
first2, FwdIter2 last2, Pred
&&pred)
```

Checks whether the second range defined by [first1, last1) matches the suffix of the first range defined by [first2, last2). Executed according to the policy.

The assignments in the parallel *ends_with* algorithm invoked with an execution policy object of type *sequenced_policy* execute in sequential order in the calling thread.

The assignments in the parallel *ends_with* algorithm invoked with an execution policy object of type *parallel_policy* or *parallel_task_policy* are permitted to execute in an unordered fashion in unspecified threads, and indeterminately sequenced within each thread.

Note: Complexity: Linear: at most min(N1, N2) applications of the predicate and both projections.

Template Parameters

- **ExPolicy** – The type of the execution policy to use (deduced). It describes the manner in which the execution of the algorithm may be parallelized and the manner in which it executes the assignments.
- **FwdIter1** – The type of the begin source iterators used (deduced). This iterator type must meet the requirements of an forward iterator.
- **FwdIter2** – The type of the begin destination iterators used (deduced). This iterator type must meet the requirements of a forward iterator.
- **Pred** – The binary predicate that compares the projected elements.

Parameters

- **policy** – The execution policy to use for the scheduling of the iterations.
- **first1** – Refers to the beginning of the source range.
- **last1** – Refers to the end of the source range.
- **first2** – Refers to the beginning of the destination range.
- **last2** – Refers to the end of the destination range.
- **pred** – Specifies the binary predicate function (or function object) which will be invoked for

Returns The *ends_with* algorithm returns a *hpx::future<bool>* if the execution policy is of type *sequenced_task_policy* or *parallel_task_policy* and returns *bool* otherwise. The *ends_with* algorithm returns a boolean with the value true if the second range matches the suffix of the first range, false otherwise.

hpx::equal

Defined in header `hpx/algorithm.hpp`⁵⁷⁴.

See *Public API* for a list of names and headers that are part of the public HPX API.

namespace **hpx**

Functions

```
template<typename ExPolicy, typename FwdIter1, typename FwdIter2, typename Pred = detail::equal_to>  
util::detail::algorithm_result_t<ExPolicy, bool> equal(ExPolicy &&policy, FwdIter1 first1, FwdIter1 last1,  
                                                    FwdIter2 first2, FwdIter2 last2, Pred &&op = Pred())
```

Returns true if the range [first1, last1) is equal to the range [first2, last2), and false otherwise. Executed according to the policy.

The comparison operations in the parallel *equal* algorithm invoked with an execution policy object of type *sequenced_policy* execute in sequential order in the calling thread.

The comparison operations in the parallel *equal* algorithm invoked with an execution policy object of type *parallel_policy* or *parallel_task_policy* are permitted to execute in an unordered fashion in unspecified threads, and indeterminately sequenced within each thread.

Note: Complexity: $O(\min(\textit{last1} - \textit{first1}, \textit{last2} - \textit{first2}))$ applications of the predicate *op*.

Note: The two ranges are considered equal if, for every iterator *i* in the range [first1, last1), **i* equals $*(\textit{first2} + (i - \textit{first1}))$. This overload of *equal* uses operator== to determine if two elements are equal.

Template Parameters

- **ExPolicy** – The type of the execution policy to use (deduced). It describes the manner in which the execution of the algorithm may be parallelized and the manner in which it executes the assignments.
- **FwdIter1** – The type of the source iterators used for the first range (deduced). This iterator type must meet the requirements of an forward iterator.
- **FwdIter2** – The type of the source iterators used for the second range (deduced). This iterator type must meet the requirements of an forward iterator.
- **Pred** – The type of an optional function/function object to use. Unlike its sequential form, the parallel overload of *equal* requires *Pred* to meet the requirements of *CopyConstructible*. This defaults to `std::equal_to<>`

Parameters

- **policy** – The execution policy to use for the scheduling of the iterations.
- **first1** – Refers to the beginning of the sequence of elements of the first range the algorithm will be applied to.

⁵⁷⁴ <http://github.com/STELLAR-GROUP/hpx/blob/8a3b7c1a4cb5693b2f7d9f587f759392ed0c51a0/libs/full/include/include/hpx/algorithm.hpp>

- **last1** – Refers to the end of the sequence of elements of the first range the algorithm will be applied to.
- **first2** – Refers to the beginning of the sequence of elements of the second range the algorithm will be applied to.
- **last2** – Refers to the end of the sequence of elements of the second range the algorithm will be applied to.
- **op** – The binary predicate which returns true if the elements should be treated as equal. The signature of the predicate function should be equivalent to the following:

```
bool pred(const Type1 &a, const Type2 &b);
```

The signature does not need to have `const &`, but the function must not modify the objects passed to it. The types *Type1* and *Type2* must be such that objects of types *FwdIter1* and *FwdIter2* can be dereferenced and then implicitly converted to *Type1* and *Type2* respectively

Returns The *equal* algorithm returns a *hpx::future<bool>* if the execution policy is of type *sequenced_task_policy* or *parallel_task_policy* and returns *bool* otherwise. The *equal* algorithm returns true if the elements in the two ranges are equal, otherwise it returns false. If the length of the range [first1, last1) does not equal the length of the range [first2, last2), it returns false.

```
template<typename ExPolicy, typename FwdIter1, typename FwdIter2>
util::detail::algorithm_result_t<ExPolicy, bool> equal(ExPolicy &&policy, FwdIter1 first1, FwdIter1 last1,
                                                    FwdIter2 first2, FwdIter2 last2)
```

Returns true if the range [first1, last1) is equal to the range [first2, last2), and false otherwise. Executed according to policy.

The comparison operations in the parallel *equal* algorithm invoked with an execution policy object of type *sequenced_policy* execute in sequential order in the calling thread.

The comparison operations in the parallel *equal* algorithm invoked with an execution policy object of type *parallel_policy* or *parallel_task_policy* are permitted to execute in an unordered fashion in unspecified threads, and indeterminately sequenced within each thread.

Note: Complexity: $O(\min(\text{last1} - \text{first1}, \text{last2} - \text{first2}))$ applications of the predicate *std::equal_to*.

Note: The two ranges are considered equal if, for every iterator *i* in the range [first1, last1), **i* equals **(first2 + (i - first1))*. This overload of *equal* uses operator`==` to determine if two elements are equal.

Template Parameters

- **ExPolicy** – The type of the execution policy to use (deduced). It describes the manner in which the execution of the algorithm may be parallelized and the manner in which it executes the assignments.
- **FwdIter1** – The type of the source iterators used for the first range (deduced). This iterator type must meet the requirements of an forward iterator.
- **FwdIter2** – The type of the source iterators used for the second range (deduced). This iterator type must meet the requirements of an forward iterator.

Parameters

- **policy** – The execution policy to use for the scheduling of the iterations.
- **first1** – Refers to the beginning of the sequence of elements of the first range the algorithm will be applied to.
- **last1** – Refers to the end of the sequence of elements of the first range the algorithm will be applied to.
- **first2** – Refers to the beginning of the sequence of elements of the second range the algorithm will be applied to.
- **last2** – Refers to the end of the sequence of elements of the second range the algorithm will be applied to.

Returns The *equal* algorithm returns a *hpx::future<bool>* if the execution policy is of type *sequenced_task_policy* or *parallel_task_policy* and returns *bool* otherwise. The *equal* algorithm returns true if the elements in the two ranges are equal, otherwise it returns false. If the length of the range [first1, last1) does not equal the length of the range [first2, last2), it returns false.

```
template<typename ExPolicy, typename FwdIter1, typename FwdIter2, typename Pred = detail::equal_to>
util::detail::algorithm_result_t<ExPolicy, bool> equal(ExPolicy &&policy, FwdIter1 first1, FwdIter1 last1,
                                                    FwdIter2 first2, Pred &&op = Pred())
```

Returns true if the range [first1, last1) is equal to the range starting at first2, and false otherwise. Executed according to policy.

The comparison operations in the parallel *equal* algorithm invoked with an execution policy object of type *sequenced_policy* execute in sequential order in the calling thread.

The comparison operations in the parallel *equal* algorithm invoked with an execution policy object of type *parallel_policy* or *parallel_task_policy* are permitted to execute in an unordered fashion in unspecified threads, and indeterminately sequenced within each thread.

Note: Complexity: $O(\min(\textit{last1} - \textit{first1}, \textit{last2} - \textit{first2}))$ applications of the predicate *op*.

Note: The two ranges are considered equal if, for every iterator *i* in the range [first1, last1), **i* equals $*(\textit{first2} + (i - \textit{first1}))$. This overload of *equal* uses operator== to determine if two elements are equal.

Template Parameters

- **ExPolicy** – The type of the execution policy to use (deduced). It describes the manner in which the execution of the algorithm may be parallelized and the manner in which it executes the assignments.
- **FwdIter1** – The type of the source iterators used for the first range (deduced). This iterator type must meet the requirements of an forward iterator.
- **FwdIter2** – The type of the source iterators used for the second range (deduced). This iterator type must meet the requirements of an forward iterator.
- **Pred** – The type of an optional function/function object to use. Unlike its sequential form, the parallel overload of *equal* requires *Pred* to meet the requirements of *CopyConstructible*. This defaults to `std::equal_to<>`

Parameters

- **policy** – The execution policy to use for the scheduling of the iterations.
- **first1** – Refers to the beginning of the sequence of elements of the first range the algorithm will be applied to.
- **last1** – Refers to the end of the sequence of elements of the first range the algorithm will be applied to.
- **first2** – Refers to the beginning of the sequence of elements of the second range the algorithm will be applied to.
- **op** – The binary predicate which returns true if the elements should be treated as equal. The signature of the predicate function should be equivalent to the following:

```
bool pred(const Type1 &a, const Type2 &b);
```

The signature does not need to have `const &`, but the function must not modify the objects passed to it. The types *Type1* and *Type2* must be such that objects of types *FwdIter1* and *FwdIter2* can be dereferenced and then implicitly converted to *Type1* and *Type2* respectively

Returns The *equal* algorithm returns a *hpx::future<bool>* if the execution policy is of type *sequenced_task_policy* or *parallel_task_policy* and returns *bool* otherwise. The *equal* algorithm returns true if the elements in the two ranges are equal, otherwise it returns false.

```
template<typename ExPolicy, typename FwdIter1, typename FwdIter2>
util::detail::algorithm_result_t<ExPolicy, bool> equal(ExPolicy &&policy, FwdIter1 first1, FwdIter1 last1,
                                                    FwdIter2 first2)
```

Returns true if the range [first1, last1) is equal to the range [first2, last2), and false otherwise. Executed according to policy.

The comparison operations in the parallel *equal* algorithm invoked with an execution policy object of type *sequenced_policy* execute in sequential order in the calling thread.

The comparison operations in the parallel *equal* algorithm invoked with an execution policy object of type *parallel_policy* or *parallel_task_policy* are permitted to execute in an unordered fashion in unspecified threads, and indeterminately sequenced within each thread.

Note: Complexity: At most *last1 - first1* applications of the predicate *op*.

Note: The two ranges are considered equal if, for every iterator *i* in the range [first1, last1), **i* equals **(first2 + (i - first1))*. This overload of *equal* uses `operator==` to determine if two elements are equal.

Template Parameters

- **ExPolicy** – The type of the execution policy to use (deduced). It describes the manner in which the execution of the algorithm may be parallelized and the manner in which it executes the assignments.
- **FwdIter1** – The type of the source iterators used for the first range (deduced). This iterator type must meet the requirements of an forward iterator.

- **FwdIter2** – The type of the source iterators used for the second range (deduced). This iterator type must meet the requirements of an forward iterator.

Parameters

- **policy** – The execution policy to use for the scheduling of the iterations.
- **first1** – Refers to the beginning of the sequence of elements of the first range the algorithm will be applied to.
- **last1** – Refers to the end of the sequence of elements of the first range the algorithm will be applied to.
- **first2** – Refers to the beginning of the sequence of elements of the second range the algorithm will be applied to.

Returns The *equal* algorithm returns a *hpx::future<bool>* if the execution policy is of type *sequenced_task_policy* or *parallel_task_policy* and returns *bool* otherwise. The *equal* algorithm returns true if the elements in the two ranges are equal, otherwise it returns false. If the length of the range [first1, last1) does not equal the length of the range [first2, last2), it returns false.

```
template<typename FwdIter1, typename FwdIter2, typename Pred = detail::equal_to>  
bool equal(FwdIter1 first1, FwdIter1 last1, FwdIter2 first2, FwdIter2 last2, Pred &&op = Pred())
```

Returns true if the range [first1, last1) is equal to the range [first2, last2), and false otherwise.

Note: Complexity: At most $\min(\text{last1} - \text{first1}, \text{last2} - \text{first2})$ applications of the predicate *op*.

Note: The two ranges are considered equal if, for every iterator *i* in the range [first1,last1), **i* equals **(first2 + (i - first1))*. This overload of *equal* uses *operator==* to determine if two elements are equal.

Template Parameters

- **FwdIter1** – The type of the source iterators used for the first range (deduced). This iterator type must meet the requirements of an forward iterator.
- **FwdIter2** – The type of the source iterators used for the second range (deduced). This iterator type must meet the requirements of an forward iterator.
- **Pred** – The type of an optional function/function object to use. Unlike its sequential form, the parallel overload of *equal* requires *Pred* to meet the requirements of *CopyConstructible*. This defaults to `std::equal_to<>`

Parameters

- **first1** – Refers to the beginning of the sequence of elements of the first range the algorithm will be applied to.
- **last1** – Refers to the end of the sequence of elements of the first range the algorithm will be applied to.
- **first2** – Refers to the beginning of the sequence of elements of the second range the algorithm will be applied to.
- **last2** – Refers to the end of the sequence of elements of the second range the algorithm will be applied to.

- **op** – The binary predicate which returns true if the elements should be treated as equal. The signature of the predicate function should be equivalent to the following:

```
bool pred(const Type1 &a, const Type2 &b);
```

The signature does not need to have `const &`, but the function must not modify the objects passed to it. The types *Type1* and *Type2* must be such that objects of types *FwdIter1* and *FwdIter2* can be dereferenced and then implicitly converted to *Type1* and *Type2* respectively

Returns The *equal* algorithm returns a *bool*. The *equal* algorithm returns true if the elements in the two ranges are equal, otherwise it returns false. If the length of the range [first1, last1) does not equal the length of the range [first2, last2), it returns false.

```
template<typename FwdIter1, typename FwdIter2>
bool equal(FwdIter1 first1, FwdIter1 last1, FwdIter2 first2, FwdIter2 last2)
```

Returns true if the range [first1, last1) is equal to the range [first2, last2), and false otherwise.

Note: Complexity: At most $\min(\text{last1} - \text{first1}, \text{last2} - \text{first2})$ applications of the predicate `std::equal_to`.

Note: The two ranges are considered equal if, for every iterator *i* in the range [first1, last1), **i* equals **(first2 + (i - first1))*. This overload of `equal` uses `operator==` to determine if two elements are equal.

Template Parameters

- **FwdIter1** – The type of the source iterators used for the first range (deduced). This iterator type must meet the requirements of an forward iterator.
- **FwdIter2** – The type of the source iterators used for the second range (deduced). This iterator type must meet the requirements of an forward iterator.

Parameters

- **first1** – Refers to the beginning of the sequence of elements of the first range the algorithm will be applied to.
- **last1** – Refers to the end of the sequence of elements of the first range the algorithm will be applied to.
- **first2** – Refers to the beginning of the sequence of elements of the second range the algorithm will be applied to.
- **last2** – Refers to the end of the sequence of elements of the second range the algorithm will be applied to.

Returns The *equal* algorithm returns a *bool*. The *equal* algorithm returns true if the elements in the two ranges are equal, otherwise it returns false. If the length of the range [first1, last1) does not equal the length of the range [first2, last2), it returns false.

```
template<typename FwdIter1, typename FwdIter2, typename Pred = detail::equal_to>
bool equal(FwdIter1 first1, FwdIter1 last1, FwdIter2 first2, Pred &&op = Pred())
```

Returns true if the range [first1, last1) is equal to the range [first2, first2 + (last1 - first1)), and false otherwise.

Note: Complexity: At most *last1 - first1* applications of the predicate *op*.

Note: The two ranges are considered equal if, for every iterator i in the range $[first1, last1)$, $*i$ equals $*(first2 + (i - first1))$. This overload of `equal` uses operator`==` to determine if two elements are equal.

Template Parameters

- **FwdIter1** – The type of the source iterators used for the first range (deduced). This iterator type must meet the requirements of an forward iterator.
- **FwdIter2** – The type of the source iterators used for the second range (deduced). This iterator type must meet the requirements of an forward iterator.
- **Pred** – The type of an optional function/function object to use. Unlike its sequential form, the parallel overload of `equal` requires `Pred` to meet the requirements of `CopyConstructible`. This defaults to `std::equal_to<>`

Parameters

- **first1** – Refers to the beginning of the sequence of elements of the first range the algorithm will be applied to.
- **last1** – Refers to the end of the sequence of elements of the first range the algorithm will be applied to.
- **first2** – Refers to the beginning of the sequence of elements of the second range the algorithm will be applied to.
- **op** – The binary predicate which returns true if the elements should be treated as equal. The signature of the predicate function should be equivalent to the following:

```
bool pred(const Type1 &a, const Type2 &b);
```

The signature does not need to have `const &`, but the function must not modify the objects passed to it. The types `Type1` and `Type2` must be such that objects of types `FwdIter1` and `FwdIter2` can be dereferenced and then implicitly converted to `Type1` and `Type2` respectively

Returns The `equal` algorithm returns a `bool`. The `equal` algorithm returns true if the elements in the two ranges are equal, otherwise it returns false. If the length of the range $[first1, last1)$ does not equal the length of the range $[first2, last2)$, it returns false.

hpx::exclusive_scan

Defined in header `hpx/algorithm.hpp`⁵⁷⁵.

See *Public API* for a list of names and headers that are part of the public *HPX* API.

namespace **hpx**

⁵⁷⁵ <http://github.com/STELLAR-GROUP/hpx/blob/8a3b7c1a4cb5693b2f7d9f587f759392ed0c51a0/libs/full/include/include/hpx/algorithm.hpp>

Functions

```
template<typename InIter, typename OutIter, typename T>
OutIter exclusive_scan(InIter first, InIter last, OutIter dest, T init)
```

Assigns through each iterator i in $[\text{result}, \text{result} + (\text{last} - \text{first}))$ the value of `GENERALIZED_NONCOMMUTATIVE_SUM(+, init, *first, ..., *(first + (i - result) - 1))`

The reduce operations in the parallel *exclusive_scan* algorithm invoked without an execution policy object will execute in sequential order in the calling thread.

The difference between *exclusive_scan* and *inclusive_scan* is that *inclusive_scan* includes the i th input element in the i th sum.

Note: Complexity: $O(\text{last} - \text{first})$ applications of the predicate `std::plus<T>`.

Note: `GENERALIZED_NONCOMMUTATIVE_SUM(+, a1, ..., aN)` is defined as:

- a_1 when N is 1
 - `GENERALIZED_NONCOMMUTATIVE_SUM(+, a1, ..., aK)`
 - `GENERALIZED_NONCOMMUTATIVE_SUM(+, aM, ..., aN)` where $1 < K+1 = M \leq N$.
-

Template Parameters

- **InIter** – The type of the source iterators used (deduced). This iterator type must meet the requirements of an input iterator.
- **OutIter** – The type of the iterator representing the destination range (deduced). This iterator type must meet the requirements of an output iterator.
- **T** – The type of the value to be used as initial (and intermediate) values (deduced).

Parameters

- **first** – Refers to the beginning of the sequence of elements the algorithm will be applied to.
- **last** – Refers to the end of the sequence of elements the algorithm will be applied to.
- **dest** – Refers to the beginning of the destination range.
- **init** – The initial value for the generalized sum.

Returns The *exclusive_scan* algorithm returns *OutIter*. The *exclusive_scan* algorithm returns the output iterator to the element in the destination range, one past the last element copied.

```
template<typename ExPolicy, typename FwdIter1, typename FwdIter2, typename T>
util::detail::algorithm_result_t<ExPolicy, FwdIter2> exclusive_scan(ExPolicy &&policy, FwdIter1 first,
                                                                    FwdIter1 last, FwdIter2 dest, T init)
```

Assigns through each iterator i in $[\text{result}, \text{result} + (\text{last} - \text{first}))$ the value of `GENERALIZED_NONCOMMUTATIVE_SUM(+, init, *first, ..., *(first + (i - result) - 1))`

The reduce operations in the parallel *exclusive_scan* algorithm invoked with an execution policy object of type *sequenced_policy* execute in sequential order in the calling thread.

The reduce operations in the parallel *exclusive_scan* algorithm invoked with an execution policy object of type *parallel_policy* or *parallel_task_policy* are permitted to execute in an unordered fashion in unspecified threads, and indeterminately sequenced within each thread.

The difference between *exclusive_scan* and *inclusive_scan* is that *inclusive_scan* includes the *i*th input element in the *i*th sum.

Note: Complexity: $O(\text{last} - \text{first})$ applications of the predicate *std::plus<T>*.

Note: GENERALIZED_NONCOMMUTATIVE_SUM(+, a1, ..., aN) is defined as:

- a1 when N is 1
 - GENERALIZED_NONCOMMUTATIVE_SUM(+, a1, ..., aK)
 - GENERALIZED_NONCOMMUTATIVE_SUM(+, aM, ..., aN) where $1 < K+1 = M \leq N$.
-

Template Parameters

- **ExPolicy** – The type of the execution policy to use (deduced). It describes the manner in which the execution of the algorithm may be parallelized and the manner in which it executes the assignments.
- **FwdIter1** – The type of the source iterators used (deduced). This iterator type must meet the requirements of an forward iterator.
- **FwdIter2** – The type of the iterator representing the destination range (deduced). This iterator type must meet the requirements of an forward iterator.
- **T** – The type of the value to be used as initial (and intermediate) values (deduced).

Parameters

- **policy** – The execution policy to use for the scheduling of the iterations.
- **first** – Refers to the beginning of the sequence of elements the algorithm will be applied to.
- **last** – Refers to the end of the sequence of elements the algorithm will be applied to.
- **dest** – Refers to the beginning of the destination range.
- **init** – The initial value for the generalized sum.

Returns The *exclusive_scan* algorithm returns a *hpx::future<FwdIter2>* if the execution policy is of type *sequenced_task_policy* or *parallel_task_policy* and returns *FwdIter2* otherwise. The *exclusive_scan* algorithm returns the output iterator to the element in the destination range, one past the last element copied.

```
template<typename InIter, typename OutIter, typename T, typename Op>  
OutIter exclusive_scan(InIter first, InIter last, OutIter dest, T init, Op &&op)
```

Assigns through each iterator *i* in [result, result + (last - first)) the value of GENERALIZED_NONCOMMUTATIVE_SUM(binary_op, init, *first, ..., *(first + (i - result) - 1)).

The reduce operations in the parallel *exclusive_scan* algorithm invoked without an execution policy object will execute in sequential order in the calling thread.

The difference between *exclusive_scan* and *inclusive_scan* is that *inclusive_scan* includes the *i*th input element in the *i*th sum. If *op* is not mathematically associative, the behavior of *inclusive_scan* may be non-deterministic.

Note: Complexity: $O(\text{last} - \text{first})$ applications of the predicate *op*.

Note: GENERALIZED_NONCOMMUTATIVE_SUM(*op*, *a*₁, ..., *a*_N) is defined as:

- *a*₁ when *N* is 1
 - *op*(GENERALIZED_NONCOMMUTATIVE_SUM(*op*, *a*₁, ..., *a*_K), GENERALIZED_NONCOMMUTATIVE_SUM(*op*, *a*_M, ..., *a*_N)) where $1 < K+1 = M \leq N$.
-

Template Parameters

- **InIter** – The type of the source iterators used (deduced). This iterator type must meet the requirements of an input iterator.
- **OutIter** – The type of the iterator representing the destination range (deduced). This iterator type must meet the requirements of an output iterator.
- **T** – The type of the value to be used as initial (and intermediate) values (deduced).
- **Op** – The type of the binary function object used for the reduction operation.

Parameters

- **first** – Refers to the beginning of the sequence of elements the algorithm will be applied to.
- **last** – Refers to the end of the sequence of elements the algorithm will be applied to.
- **dest** – Refers to the beginning of the destination range.
- **init** – The initial value for the generalized sum.
- **op** – Specifies the function (or function object) which will be invoked for each of the values of the input sequence. This is a binary predicate. The signature of this predicate should be equivalent to:

```
Ret fun(const Type1 &a, const Type1 &b);
```

The signature does not need to have `const&`, but the function must not modify the objects passed to it. The types *Type1* and *Ret* must be such that an object of a type as given by the input sequence can be implicitly converted to any of those types.

Returns The *exclusive_scan* algorithm returns *OutIter*. The *exclusive_scan* algorithm returns the output iterator to the element in the destination range, one past the last element copied.

```
template<typename ExPolicy, typename FwdIter1, typename FwdIter2, typename Op, typename T>
util::detail::algorithm_result_t<ExPolicy, FwdIter2> exclusive_scan(ExPolicy &&policy, FwdIter1 first,
                                                                    FwdIter1 last, FwdIter2 dest, T init,
                                                                    Op &&op)
```

Assigns through each iterator i in $[\text{result}, \text{result} + (\text{last} - \text{first}))$ the value of `GENERALIZED_NONCOMMUTATIVE_SUM(binary_op, init, *first, ..., *(first + (i - result) - 1))`.

The reduce operations in the parallel `exclusive_scan` algorithm invoked with an execution policy object of type `sequenced_policy` execute in sequential order in the calling thread.

The reduce operations in the parallel `exclusive_scan` algorithm invoked with an execution policy object of type `parallel_policy` or `parallel_task_policy` are permitted to execute in an unordered fashion in unspecified threads, and indeterminately sequenced within each thread.

The difference between `exclusive_scan` and `inclusive_scan` is that `inclusive_scan` includes the i th input element in the i th sum. If op is not mathematically associative, the behavior of `inclusive_scan` may be non-deterministic.

Note: Complexity: $O(\text{last} - \text{first})$ applications of the predicate op .

Note: `GENERALIZED_NONCOMMUTATIVE_SUM(op, a1, ..., aN)` is defined as:

- a_1 when N is 1
 - $op(\text{GENERALIZED_NONCOMMUTATIVE_SUM}(op, a_1, \dots, a_K), \text{GENERALIZED_NONCOMMUTATIVE_SUM}(op, a_{K+1}, \dots, a_N))$ where $1 < K+1 = M \leq N$.
-

Template Parameters

- **ExPolicy** – The type of the execution policy to use (deduced). It describes the manner in which the execution of the algorithm may be parallelized and the manner in which it executes the assignments.
- **FwdIter1** – The type of the source iterators used (deduced). This iterator type must meet the requirements of an forward iterator.
- **FwdIter2** – The type of the iterator representing the destination range (deduced). This iterator type must meet the requirements of an forward iterator.
- **Op** – The type of the binary function object used for the reduction operation.
- **T** – The type of the value to be used as initial (and intermediate) values (deduced).

Parameters

- **policy** – The execution policy to use for the scheduling of the iterations.
- **first** – Refers to the beginning of the sequence of elements the algorithm will be applied to.
- **last** – Refers to the end of the sequence of elements the algorithm will be applied to.
- **dest** – Refers to the beginning of the destination range.
- **init** – The initial value for the generalized sum.
- **op** – Specifies the function (or function object) which will be invoked for each of the values of the input sequence. This is a binary predicate. The signature of this predicate should be equivalent to:

```
Ret fun(const Type1 &a, const Type1 &b);
```

The signature does not need to have `const&`, but the function must not modify the objects passed to it. The types *Type1* and *Ret* must be such that an object of a type as given by the input sequence can be implicitly converted to any of those types.

Returns The *exclusive_scan* algorithm returns a `hpx::future<OutIter>` if the execution policy is of type *sequenced_task_policy* or *parallel_task_policy* and returns *OutIter* otherwise. The *exclusive_scan* algorithm returns the output iterator to the element in the destination range, one past the last element copied.

hpx::fill, hpx::fill_n

Defined in header `hpx/algorithm.hpp`⁵⁷⁶.

See *Public API* for a list of names and headers that are part of the public HPX API.

namespace **hpx**

Functions

```
template<typename ExPolicy, typename FwdIter, typename T>
util::detail::algorithm_result_t<ExPolicy> fill(ExPolicy &&policy, FwdIter first, FwdIter last, T value)
```

Assigns the given value to the elements in the range [first, last). Executed according to the policy.

The comparisons in the parallel *fill* algorithm invoked with an execution policy object of type *sequenced_policy* execute in sequential order in the calling thread.

The comparisons in the parallel *fill* algorithm invoked with an execution policy object of type *parallel_policy* or *parallel_task_policy* are permitted to execute in an unordered fashion in unspecified threads, and indeterminately sequenced within each thread.

Note: Complexity: Performs exactly *last - first* assignments.

Template Parameters

- **ExPolicy** – The type of the execution policy to use (deduced). It describes the manner in which the execution of the algorithm may be parallelized and the manner in which it executes the assignments.
- **FwdIter** – The type of the source iterators used (deduced). This iterator type must meet the requirements of an forward iterator.
- **T** – The type of the value to be assigned (deduced).

Parameters

- **policy** – The execution policy to use for the scheduling of the iterations.
- **first** – Refers to the beginning of the sequence of elements the algorithm will be applied to.

⁵⁷⁶ <http://github.com/STELLAR-GROUP/hpx/blob/8a3b7c1a4cb5693b2f7d9f587f759392ed0c51a0/libs/full/include/include/hpx/algorithm.hpp>

- **last** – Refers to the end of the sequence of elements the algorithm will be applied to.
- **value** – The value to be assigned.

Returns The *fill* algorithm returns a *hpx::future<void>* if the execution policy is of type *sequenced_task_policy* or *parallel_task_policy* and returns *difference_type* otherwise (where *difference_type* is defined by *void*).

```
template<typename FwdIter, typename T>  
void fill(FwdIter first, FwdIter last, T value)
```

Assigns the given value to the elements in the range [first, last).

Note: Complexity: Performs exactly *last - first* assignments.

Template Parameters

- **FwdIter** – The type of the source iterators used (deduced). This iterator type must meet the requirements of an forward iterator.
- **T** – The type of the value to be assigned (deduced).

Parameters

- **first** – Refers to the beginning of the sequence of elements the algorithm will be applied to.
- **last** – Refers to the end of the sequence of elements the algorithm will be applied to.
- **value** – The value to be assigned.

Returns The *fill* algorithm returns a *void*.

```
template<typename ExPolicy, typename FwdIter, typename Size, typename T>  
util::detail::algorithm_result_t<ExPolicy, FwdIter> fill_n(ExPolicy &&policy, FwdIter first, Size count, T  
value)
```

Assigns the given value value to the first count elements in the range beginning at first if count > 0. Does nothing otherwise. Executed according to the policy.

The comparisons in the parallel *fill_n* algorithm invoked with an execution policy object of type *sequenced_policy* execute in sequential order in the calling thread.

The comparisons in the parallel *fill_n* algorithm invoked with an execution policy object of type *parallel_policy* or *parallel_task_policy* are permitted to execute in an unordered fashion in unspecified threads, and indeterminately sequenced within each thread.

Note: Complexity: Performs exactly *count* assignments, for count > 0.

Template Parameters

- **ExPolicy** – The type of the execution policy to use (deduced). It describes the manner in which the execution of the algorithm may be parallelized and the manner in which it executes the assignments.
- **FwdIter** – The type of the source iterators used (deduced). This iterator type must meet the requirements of a forward iterator.

- **Size** – The type of the argument specifying the number of elements to apply *f* to.
- **T** – The type of the value to be assigned (deduced).

Parameters

- **policy** – The execution policy to use for the scheduling of the iterations.
- **first** – Refers to the beginning of the sequence of elements the algorithm will be applied to.
- **count** – Refers to the number of elements starting at *first* the algorithm will be applied to.
- **value** – The value to be assigned.

Returns The *fill_n* algorithm returns a *hpx::future<void>* if the execution policy is of type *sequenced_task_policy* or *parallel_task_policy* and returns *difference_type* otherwise (where *difference_type* is defined by *void*).

```
template<typename FwdIter, typename Size, typename T>
FwdIter fill_n(FwdIter first, Size count, T value)
```

Assigns the given value *value* to the first *count* elements in the range beginning at *first* if *count* > 0. Does nothing otherwise.

Note: Complexity: Performs exactly *count* assignments, for *count* > 0.

Template Parameters

- **FwdIter** – The type of the source iterators used (deduced). This iterator type must meet the requirements of a forward iterator.
- **Size** – The type of the argument specifying the number of elements to apply *f* to.
- **T** – The type of the value to be assigned (deduced).

Parameters

- **first** – Refers to the beginning of the sequence of elements the algorithm will be applied to.
- **count** – Refers to the number of elements starting at *first* the algorithm will be applied to.
- **value** – The value to be assigned.

Returns The *fill_n* algorithm returns a *FwdIter*.

hpx::find, hpx::find_if, hpx::find_if_not, hpx::find_end, hpx::find_first_of

Defined in header `hpx/algorithm.hpp`⁵⁷⁷.

See *Public API* for a list of names and headers that are part of the public *HPX* API.

namespace **hpx**

⁵⁷⁷ <http://github.com/STELLAR-GROUP/hpx/blob/8a3b7c1a4cb5693b2f7d9f587f759392ed0c51a0/libs/full/include/include/hpx/algorithm.hpp>

Functions

```
template<typename ExPolicy, typename FwdIter, typename T>
util::detail::algorithm_result_t<ExPolicy, FwdIter> find(ExPolicy &&policy, FwdIter first, FwdIter last, T
const &val)
```

Returns the first element in the range [first, last) that is equal to value. Executed according to the policy.

The comparison operations in the parallel *find* algorithm invoked with an execution policy object of type *sequenced_policy* execute in sequential order in the calling thread.

The comparison operations in the parallel *find* algorithm invoked with an execution policy object of type *parallel_policy* or *parallel_task_policy* are permitted to execute in an unordered fashion in unspecified threads, and indeterminately sequenced within each thread.

Note: Complexity: At most last - first applications of the operator==().

Template Parameters

- **ExPolicy** – The type of the execution policy to use (deduced). It describes the manner in which the execution of the algorithm may be parallelized and the manner in which it executes the assignments.
- **FwdIter** – The type of the source iterators used for the first range (deduced). This iterator type must meet the requirements of an forward iterator.
- **T** – The type of the value to find (deduced).

Parameters

- **policy** – The execution policy to use for the scheduling of the iterations.
- **first** – Refers to the beginning of the sequence of elements of the first range the algorithm will be applied to.
- **last** – Refers to the end of the sequence of elements of the first range the algorithm will be applied to.
- **val** – the value to compare the elements to

Returns The *find* algorithm returns a *hpx::future<FwdIter>* if the execution policy is of type *sequenced_task_policy* or *parallel_task_policy* and returns *FwdIter* otherwise. The *find* algorithm returns the first element in the range [first,last) that is equal to *val*. If no such element in the range of [first,last) is equal to *val*, then the algorithm returns *last*.

```
template<typename InIter, typename T>
InIter find(InIter first, InIter last, T const &val)
```

Returns the first element in the range [first, last) that is equal to value. Executed according to the policy.

Note: Complexity: At most last - first applications of the operator==().

Template Parameters

- **InIter** – The type of the source iterators used for the first range (deduced). This iterator type must meet the requirements of an input iterator.

- **T** – The type of the value to find (deduced).

Parameters

- **first** – Refers to the beginning of the sequence of elements of the first range the algorithm will be applied to.
- **last** – Refers to the end of the sequence of elements of the first range the algorithm will be applied to.
- **val** – the value to compare the elements to

Returns The *find* algorithm returns a *InIter*. The *find* algorithm returns the first element in the range [first,last) that is equal to *val*. If no such element in the range of [first,last) is equal to *val*, then the algorithm returns *last*.

```
template<typename ExPolicy, typename FwdIter, typename F>
util::detail::algorithm_result_t<ExPolicy, FwdIter> find_if(ExPolicy &&policy, FwdIter first, FwdIter last,
                                                         F &&f)
```

Returns the first element in the range [first, last) for which predicate *f* returns true. Executed according to the policy.

The comparison operations in the parallel *find_if* algorithm invoked with an execution policy object of type *sequenced_policy* execute in sequential order in the calling thread.

The comparison operations in the parallel *find_if* algorithm invoked with an execution policy object of type *parallel_policy* or *parallel_task_policy* are permitted to execute in an unordered fashion in unspecified threads, and indeterminately sequenced within each thread.

Note: Complexity: At most last - first applications of the predicate.

Template Parameters

- **ExPolicy** – The type of the execution policy to use (deduced). It describes the manner in which the execution of the algorithm may be parallelized and the manner in which it executes the assignments.
- **FwdIter** – The type of the source iterators used for the first range (deduced). This iterator type must meet the requirements of a forward iterator.
- **F** – The type of the function/function object to use (deduced). Unlike its sequential form, the parallel overload of *equal* requires *F* to meet the requirements of *CopyConstructible*.

Parameters

- **policy** – The execution policy to use for the scheduling of the iterations.
- **first** – Refers to the beginning of the sequence of elements of the first range the algorithm will be applied to.
- **last** – Refers to the end of the sequence of elements of the first range the algorithm will be applied to.
- **f** – The unary predicate which returns true for the required element. The signature of the predicate should be equivalent to:

```
bool pred(const Type &a);
```

The signature does not need to have `const &`, but the function must not modify the objects passed to it. The type *Type* must be such that objects of type *FwdIter* can be dereferenced and then implicitly converted to *Type*.

Returns The *find_if* algorithm returns a *hpx::future<FwdIter>* if the execution policy is of type *sequenced_task_policy* or *parallel_task_policy* and returns *FwdIter* otherwise. The *find_if* algorithm returns the first element in the range `[first,last)` that satisfies the predicate *f*. If no such element exists that satisfies the predicate *f*, the algorithm returns *last*.

```
template<typename InIter, typename F>
InIter find_if(InIter first, InIter last, F &&f)
```

Returns the first element in the range `[first, last)` for which predicate *f* returns true.

Note: Complexity: At most last - first applications of the predicate.

Template Parameters

- **InIter** – The type of the source iterators used for the first range (deduced). This iterator type must meet the requirements of an input iterator.
- **F** – The type of the function/function object to use (deduced). Unlike its sequential form, the parallel overload of *equal* requires *F* to meet the requirements of *CopyConstructible*.

Parameters

- **first** – Refers to the beginning of the sequence of elements of the first range the algorithm will be applied to.
- **last** – Refers to the end of the sequence of elements of the first range the algorithm will be applied to.
- **f** – The unary predicate which returns true for the required element. The signature of the predicate should be equivalent to:

```
bool pred(const Type &a);
```

The signature does not need to have `const &`, but the function must not modify the objects passed to it. The type *Type* must be such that objects of type *InIter* can be dereferenced and then implicitly converted to *Type*.

Returns The *find_if* algorithm returns a *InIter*. The *find_if* algorithm returns the first element in the range `[first,last)` that satisfies the predicate *f*. If no such element exists that satisfies the predicate *f*, the algorithm returns *last*.

```
template<typename ExPolicy, typename FwdIter, typename F>
util::detail::algorithm_result_t<ExPolicy, FwdIter> find_if_not(ExPolicy &&policy, FwdIter first, FwdIter
last, F &&f)
```

Returns the first element in the range `[first, last)` for which predicate *f* returns false. Executed according to the policy.

The comparison operations in the parallel *find_if_not* algorithm invoked with an execution policy object of type *sequenced_policy* execute in sequential order in the calling thread.

The comparison operations in the parallel *find_if_not* algorithm invoked with an execution policy object of type *parallel_policy* or *parallel_task_policy* are permitted to execute in an unordered fashion in unspecified threads, and indeterminately sequenced within each thread.

Note: Complexity: At most last - first applications of the predicate.

Template Parameters

- **ExPolicy** – The type of the execution policy to use (deduced). It describes the manner in which the execution of the algorithm may be parallelized and the manner in which it executes the assignments.
- **FwdIter** – The type of the source iterators used for the first range (deduced). This iterator type must meet the requirements of a forward iterator.
- **F** – The type of the function/function object to use (deduced). Unlike its sequential form, the parallel overload of *equal* requires *F* to meet the requirements of *CopyConstructible*.

Parameters

- **policy** – The execution policy to use for the scheduling of the iterations.
- **first** – Refers to the beginning of the sequence of elements of the first range the algorithm will be applied to.
- **last** – Refers to the end of the sequence of elements of the first range the algorithm will be applied to.
- **f** – The unary predicate which returns false for the required element. The signature of the predicate should be equivalent to:

```
bool pred(const Type &a);
```

The signature does not need to have `const &`, but the function must not modify the objects passed to it. The type *Type* must be such that objects of type *FwdIter* can be dereferenced and then implicitly converted to *Type*.

Returns The *find_if_not* algorithm returns a *hpx::future<FwdIter>* if the execution policy is of type *sequenced_task_policy* or *parallel_task_policy* and returns *FwdIter* otherwise. The *find_if_not* algorithm returns the first element in the range [first, last) that does **not** satisfy the predicate *f*. If no such element exists that does not satisfy the predicate *f*, the algorithm returns *last*.

```
template<typename FwdIter, typename F>
FwdIter find_if_not(FwdIter first, FwdIter last, F &&f)
```

Returns the first element in the range [first, last) for which predicate *f* returns false.

Note: Complexity: At most last - first applications of the predicate.

Template Parameters

- **FwdIter** – The type of the source iterators used for the first range (deduced). This iterator type must meet the requirements of a forward iterator.
- **F** – The type of the function/function object to use (deduced). Unlike its sequential form, the parallel overload of *equal* requires *F* to meet the requirements of *CopyConstructible*.

Parameters

- **first** – Refers to the beginning of the sequence of elements of the first range the algorithm will be applied to.

- **last** – Refers to the end of the sequence of elements of the first range the algorithm will be applied to.
- **f** – The unary predicate which returns false for the required element. The signature of the predicate should be equivalent to:

```
bool pred(const Type &a);
```

The signature does not need to have `const &`, but the function must not modify the objects passed to it. The type *Type* must be such that objects of type *FwdIter* can be dereferenced and then implicitly converted to *Type*.

Returns The *find_if_not* algorithm returns a *FwdIter*. The *find_if_not* algorithm returns the first element in the range [first, last) that does **not** satisfy the predicate *f*. If no such element exists that does not satisfy the predicate *f*, the algorithm returns *last*.

```
template<typename ExPolicy, typename FwdIter1, typename FwdIter2, typename Pred = detail::equal_to>
util::detail::algorithm_result_t<ExPolicy, FwdIter1> find_end(ExPolicy &&policy, FwdIter1 first1, FwdIter1
    last1, FwdIter2 first2, FwdIter2 last2, Pred
    &&op = Pred())
```

Returns the last subsequence of elements [first2, last2) found in the range [first, last) using the given predicate *op* to compare elements. Executed according to the policy.

The comparison operations in the parallel *find_end* algorithm invoked with an execution policy object of type *sequenced_policy* execute in sequential order in the calling thread.

The comparison operations in the parallel *find_end* algorithm invoked with an execution policy object of type *parallel_policy* or *parallel_task_policy* are permitted to execute in an unordered fashion in unspecified threads, and indeterminately sequenced within each thread.

This overload of *find_end* is available if the user decides to provide the algorithm their own predicate *op*.

Note: Complexity: at most $S \cdot (N - S + 1)$ comparisons where $S = \text{distance}(\text{first2}, \text{last2})$ and $N = \text{distance}(\text{first1}, \text{last1})$.

Template Parameters

- **ExPolicy** – The type of the execution policy to use (deduced). It describes the manner in which the execution of the algorithm may be parallelized and the manner in which it executes the assignments.
- **FwdIter1** – The type of the source iterators used for the first range (deduced). This iterator type must meet the requirements of an forward iterator.
- **FwdIter2** – The type of the source iterators used for the second range (deduced). This iterator type must meet the requirements of an forward iterator.
- **Pred** – The type of an optional function/function object to use. Unlike its sequential form, the parallel overload of *replace* requires *Pred* to meet the requirements of *CopyConstructible*. This defaults to `std::equal_to<>`

Parameters

- **policy** – The execution policy to use for the scheduling of the iterations.

- **first1** – Refers to the beginning of the sequence of elements of the first range the algorithm will be applied to.
- **last1** – Refers to the end of the sequence of elements of the first range the algorithm will be applied to.
- **first2** – Refers to the beginning of the sequence of elements the algorithm will be searching for.
- **last2** – Refers to the end of the sequence of elements of the algorithm will be searching for.
- **op** – The binary predicate which returns *true* if the elements should be treated as equal. The signature should be equivalent to the following:

```
bool pred(const Type1 &a, const Type2 &b);
```

The signature does not need to have `const &`, but the function must not modify the objects passed to it. The types *Type1* and *Type2* must be such that objects of types *FwdIter1* and *FwdIter2* can be dereferenced and then implicitly converted to *Type1* and *Type2* respectively.

Returns The *find_end* algorithm returns a *hpx::future<FwdIter>* if the execution policy is of type *sequenced_task_policy* or *parallel_task_policy* and returns *FwdIter* otherwise. The *find_end* algorithm returns an iterator to the beginning of the last subsequence [*first2*, *last2*) in range [*first*, *last*). If the length of the subsequence [*first2*, *last2*) is greater than the length of the range [*first1*, *last1*), *last1* is returned. Additionally if the size of the subsequence is empty or no subsequence is found, *last1* is also returned.

```
template<typename ExPolicy, typename FwdIter1, typename FwdIter2>
util::detail::algorithm_result_t<ExPolicy, FwdIter1> find_end(ExPolicy &&policy, FwdIter1 first1, FwdIter1
last1, FwdIter2 first2, FwdIter2 last2)
```

Returns the last subsequence of elements [*first2*, *last2*) found in the range [*first*, *last*). Elements are compared using *operator==*. Executed according to the policy.

The comparison operations in the parallel *find_end* algorithm invoked with an execution policy object of type *sequenced_policy* execute in sequential order in the calling thread.

The comparison operations in the parallel *find_end* algorithm invoked with an execution policy object of type *parallel_policy* or *parallel_task_policy* are permitted to execute in an unordered fashion in unspecified threads, and indeterminately sequenced within each thread.

Note: Complexity: at most $S \cdot (N - S + 1)$ comparisons where $S = \text{distance}(\text{first2}, \text{last2})$ and $N = \text{distance}(\text{first1}, \text{last1})$.

Template Parameters

- **ExPolicy** – The type of the execution policy to use (deduced). It describes the manner in which the execution of the algorithm may be parallelized and the manner in which it executes the assignments.
- **FwdIter1** – The type of the source iterators used for the first range (deduced). This iterator type must meet the requirements of an forward iterator.
- **FwdIter2** – The type of the source iterators used for the second range (deduced). This iterator type must meet the requirements of an forward iterator.

Parameters

- **policy** – The execution policy to use for the scheduling of the iterations.
- **first1** – Refers to the beginning of the sequence of elements of the first range the algorithm will be applied to.
- **last1** – Refers to the end of the sequence of elements of the first range the algorithm will be applied to.
- **first2** – Refers to the beginning of the sequence of elements the algorithm will be searching for.
- **last2** – Refers to the end of the sequence of elements of the algorithm will be searching for.

Returns The *find_end* algorithm returns a *hpx::future<FwdIter>* if the execution policy is of type *sequenced_task_policy* or *parallel_task_policy* and returns *FwdIter* otherwise. The *find_end* algorithm returns an iterator to the beginning of the last subsequence [first2, last2) in range [first, last). If the length of the subsequence [first2, last2) is greater than the length of the range [first1, last1), *last1* is returned. Additionally if the size of the subsequence is empty or no subsequence is found, *last1* is also returned.

```
template<typename FwdIter1, typename FwdIter2, typename Pred = detail::equal_to>  
FwdIter1 find_end(FwdIter1 first1, FwdIter1 last1, FwdIter2 first2, FwdIter2 last2, Pred &&op = Pred())
```

Returns the last subsequence of elements [first2, last2) found in the range [first, last) using the given predicate *op* to compare elements.

This overload of *find_end* is available if the user decides to provide the algorithm their own predicate *op*.

Note: Complexity: at most $S \cdot (N - S + 1)$ comparisons where $S = \text{distance}(\text{first2}, \text{last2})$ and $N = \text{distance}(\text{first1}, \text{last1})$.

Template Parameters

- **FwdIter1** – The type of the source iterators used for the first range (deduced). This iterator type must meet the requirements of an forward iterator.
- **FwdIter2** – The type of the source iterators used for the second range (deduced). This iterator type must meet the requirements of an forward iterator.
- **Pred** – The type of an optional function/function object to use. Unlike its sequential form, the parallel overload of *replace* requires *Pred* to meet the requirements of *CopyConstructible*. This defaults to `std::equal_to<>`

Parameters

- **first1** – Refers to the beginning of the sequence of elements of the first range the algorithm will be applied to.
- **last1** – Refers to the end of the sequence of elements of the first range the algorithm will be applied to.
- **first2** – Refers to the beginning of the sequence of elements the algorithm will be searching for.
- **last2** – Refers to the end of the sequence of elements of the algorithm will be searching for.

- **op** – The binary predicate which returns *true* if the elements should be treated as equal. The signature should be equivalent to the following:

```
bool pred(const Type1 &a, const Type2 &b);
```

The signature does not need to have `const &`, but the function must not modify the objects passed to it. The types *Type1* and *Type2* must be such that objects of types *FwdIter1* and *FwdIter2* can be dereferenced and then implicitly converted to *Type1* and *Type2* respectively.

Returns The *find_end* algorithm returns a *FwdIter1*. The *find_end* algorithm returns an iterator to the beginning of the last subsequence [first2, last2) in range [first, last). If the length of the subsequence [first2, last2) is greater than the length of the range [first1, last1), *last1* is returned. Additionally if the size of the subsequence is empty or no subsequence is found, *last1* is also returned.

```
template<typename FwdIter1, typename FwdIter2>
FwdIter1 find_end(FwdIter1 first1, FwdIter1 last1, FwdIter2 first2, FwdIter2 last2)
```

Returns the last subsequence of elements [first2, last2) found in the range [first, last). Elements are compared using *operator==*.

Note: Complexity: at most $S \cdot (N - S + 1)$ comparisons where $S = \text{distance}(\text{first2}, \text{last2})$ and $N = \text{distance}(\text{first1}, \text{last1})$.

Template Parameters

- **FwdIter1** – The type of the source iterators used for the first range (deduced). This iterator type must meet the requirements of an forward iterator.
- **FwdIter2** – The type of the source iterators used for the second range (deduced). This iterator type must meet the requirements of an forward iterator.

Parameters

- **first1** – Refers to the beginning of the sequence of elements of the first range the algorithm will be applied to.
- **last1** – Refers to the end of the sequence of elements of the first range the algorithm will be applied to.
- **first2** – Refers to the beginning of the sequence of elements the algorithm will be searching for.
- **last2** – Refers to the end of the sequence of elements of the algorithm will be searching for.

Returns The *find_end* algorithm returns a *FwdIter1*. The *find_end* algorithm returns an iterator to the beginning of the last subsequence [first2, last2) in range [first, last). If the length of the subsequence [first2, last2) is greater than the length of the range [first1, last1), *last1* is returned. Additionally if the size of the subsequence is empty or no subsequence is found, *last1* is also returned.

```
template<typename ExPolicy, typename FwdIter1, typename FwdIter2, typename Pred = detail::equal_to>
util::detail::algorithm_result_t<ExPolicy, FwdIter1> find_first_of(ExPolicy &&policy, FwdIter1 first,
                                                                FwdIter1 last, FwdIter2 s_first,
                                                                FwdIter2 s_last, Pred &&op = Pred())
```

Searches the range [first, last) for any elements in the range [s_first, s_last). Uses binary predicate *op* to compare elements. Executed according to the policy.

The comparison operations in the parallel *find_first_of* algorithm invoked with an execution policy object of type *sequenced_policy* execute in sequential order in the calling thread.

The comparison operations in the parallel *find_first_of* algorithm invoked with an execution policy object of type *parallel_policy* or *parallel_task_policy* are permitted to execute in an unordered fashion in unspecified threads, and indeterminately sequenced within each thread.

This overload of *find_first_of* is available if the user decides to provide the algorithm their own predicate *op*.

Note: Complexity: at most $(S*N)$ comparisons where $S = \text{distance}(s_first, s_last)$ and $N = \text{distance}(first, last)$.

Template Parameters

- **ExPolicy** – The type of the execution policy to use (deduced). It describes the manner in which the execution of the algorithm may be parallelized and the manner in which it executes the assignments.
- **FwdIter1** – The type of the source iterators used for the first range (deduced). This iterator type must meet the requirements of an forward iterator.
- **FwdIter2** – The type of the source iterators used for the second range (deduced). This iterator type must meet the requirements of an forward iterator.
- **Pred** – The type of an optional function/function object to use. Unlike its sequential form, the parallel overload of *equal* requires *Pred* to meet the requirements of *CopyConstructible*. This defaults to `std::equal_to<>`

Parameters

- **policy** – The execution policy to use for the scheduling of the iterations.
- **first** – Refers to the beginning of the sequence of elements of the first range the algorithm will be applied to.
- **last** – Refers to the end of the sequence of elements of the first range the algorithm will be applied to.
- **s_first** – Refers to the beginning of the sequence of elements the algorithm will be searching for.
- **s_last** – Refers to the end of the sequence of elements of the algorithm will be searching for.
- **op** – The binary predicate which returns *true* if the elements should be treated as equal. The signature should be equivalent to the following:

```
bool pred(const Type1 &a, const Type2 &b);
```

The signature does not need to have `const &`, but the function must not modify the objects passed to it. The types *Type1* and *Type2* must be such that objects of types *FwdIter1* and

FwdIter2 can be dereferenced and then implicitly converted to *Type1* and *Type2* respectively.

Returns The *find_first_of* algorithm returns a *hpx::future<FwdIter1>* if the execution policy is of type *sequenced_task_policy* or *parallel_task_policy* and returns *FwdIter1* otherwise. The *find_first_of* algorithm returns an iterator to the first element in the range [first, last) that is equal to an element from the range [s_first, s_last). If the length of the subsequence [s_first, s_last) is greater than the length of the range [first, last), *last* is returned. Additionally if the size of the subsequence is empty or no subsequence is found, *last* is also returned.

```
template<typename ExPolicy, typename FwdIter1, typename FwdIter2>
util::detail::algorithm_result_t<ExPolicy, FwdIter1> find_first_of(ExPolicy &&policy, FwdIter1 first,
                                                                FwdIter1 last, FwdIter2 s_first,
                                                                FwdIter2 s_last)
```

Searches the range [first, last) for any elements in the range [s_first, s_last). Elements are compared using *operator==*. Executed according to the policy.

The comparison operations in the parallel *find_first_of* algorithm invoked with an execution policy object of type *sequenced_policy* execute in sequential order in the calling thread.

The comparison operations in the parallel *find_first_of* algorithm invoked with an execution policy object of type *parallel_policy* or *parallel_task_policy* are permitted to execute in an unordered fashion in unspecified threads, and indeterminately sequenced within each thread.

Note: Complexity: at most ($S \cdot N$) comparisons where $S = \text{distance}(s_first, s_last)$ and $N = \text{distance}(first, last)$.

Template Parameters

- **ExPolicy** – The type of the execution policy to use (deduced). It describes the manner in which the execution of the algorithm may be parallelized and the manner in which it executes the assignments.
- **FwdIter1** – The type of the source iterators used for the first range (deduced). This iterator type must meet the requirements of an forward iterator.
- **FwdIter2** – The type of the source iterators used for the second range (deduced). This iterator type must meet the requirements of an forward iterator.

Parameters

- **policy** – The execution policy to use for the scheduling of the iterations.
- **first** – Refers to the beginning of the sequence of elements of the first range the algorithm will be applied to.
- **last** – Refers to the end of the sequence of elements of the first range the algorithm will be applied to.
- **s_first** – Refers to the beginning of the sequence of elements the algorithm will be searching for.
- **s_last** – Refers to the end of the sequence of elements of the algorithm will be searching for.

Returns The *find_first_of* algorithm returns a *hpx::future<FwdIter1>* if the execution policy is of type *sequenced_task_policy* or *parallel_task_policy* and returns *FwdIter1* otherwise. The

find_first_of algorithm returns an iterator to the first element in the range [first, last) that is equal to an element from the range [s_first, s_last). If the length of the subsequence [s_first, s_last) is greater than the length of the range [first, last), *last* is returned. Additionally if the size of the subsequence is empty or no subsequence is found, *last* is also returned.

```
template<typename FwdIter1, typename FwdIter2, typename Pred = detail::equal_to>
FwdIter1 find_first_of(FwdIter1 first, FwdIter1 last, FwdIter2 s_first, FwdIter2 s_last, Pred &&op =
    Pred())
```

Searches the range [first, last) for any elements in the range [s_first, s_last). Uses binary predicate *op* to compare elements.

This overload of *find_first_of* is available if the user decides to provide the algorithm their own predicate *op*.

Note: Complexity: at most ($S \cdot N$) comparisons where $S = \text{distance}(s_first, s_last)$ and $N = \text{distance}(first, last)$.

Template Parameters

- **FwdIter1** – The type of the source iterators used for the first range (deduced). This iterator type must meet the requirements of an forward iterator.
- **FwdIter2** – The type of the source iterators used for the second range (deduced). This iterator type must meet the requirements of an forward iterator.
- **Pred** – The type of an optional function/function object to use. Unlike its sequential form, the parallel overload of *equal* requires *Pred* to meet the requirements of *CopyConstructible*. This defaults to `std::equal_to<>`

Parameters

- **first** – Refers to the beginning of the sequence of elements of the first range the algorithm will be applied to.
- **last** – Refers to the end of the sequence of elements of the first range the algorithm will be applied to.
- **s_first** – Refers to the beginning of the sequence of elements the algorithm will be searching for.
- **s_last** – Refers to the end of the sequence of elements of the algorithm will be searching for.
- **op** – The binary predicate which returns *true* if the elements should be treated as equal. The signature should be equivalent to the following:

```
bool pred(const Type1 &a, const Type2 &b);
```

The signature does not need to have `const &`, but the function must not modify the objects passed to it. The types *Type1* and *Type2* must be such that objects of types *FwdIter1* and *FwdIter2* can be dereferenced and then implicitly converted to *Type1* and *Type2* respectively.

Returns The *find_first_of* algorithm returns a *FwdIter1*. The *find_first_of* algorithm returns an iterator to the first element in the range [first, last) that is equal to an element from the range [s_first, s_last). If the length of the subsequence [s_first, s_last) is greater than the length of

the range [first, last), *last* is returned. Additionally if the size of the subsequence is empty or no subsequence is found, *last* is also returned.

```
template<typename FwdIter1, typename FwdIter2>
FwdIter1 find_first_of(FwdIter1 first, FwdIter1 last, FwdIter2 s_first, FwdIter2 s_last)
```

Searches the range [first, last) for any elements in the range [s_first, s_last). Elements are compared using *operator==*.

Note: Complexity: at most ($S \cdot N$) comparisons where $S = \text{distance}(s_first, s_last)$ and $N = \text{distance}(first, last)$.

Template Parameters

- **FwdIter1** – The type of the source iterators used for the first range (deduced). This iterator type must meet the requirements of an forward iterator.
- **FwdIter2** – The type of the source iterators used for the second range (deduced). This iterator type must meet the requirements of an forward iterator.

Parameters

- **first** – Refers to the beginning of the sequence of elements of the first range the algorithm will be applied to.
- **last** – Refers to the end of the sequence of elements of the first range the algorithm will be applied to.
- **s_first** – Refers to the beginning of the sequence of elements the algorithm will be searching for.
- **s_last** – Refers to the end of the sequence of elements of the algorithm will be searching for.

Returns The *find_first_of* algorithm returns a *FwdIter1*. The *find_first_of* algorithm returns an iterator to the first element in the range [first, last) that is equal to an element from the range [s_first, s_last). If the length of the subsequence [s_first, s_last) is greater than the length of the range [first, last), *last* is returned. Additionally if the size of the subsequence is empty or no subsequence is found, *last* is also returned.

hpx::for_each, hpx::for_each_n

Defined in header `hpx/algorithm.hpp`⁵⁷⁸.

See *Public API* for a list of names and headers that are part of the public *HPX* API.

namespace **hpx**

⁵⁷⁸ <http://github.com/STELLAR-GROUP/hpx/blob/8a3b7c1a4cb5693b2f7d9f587f759392ed0c51a0/libs/full/include/include/hpx/algorithm.hpp>

Functions

```
template<typename InIter, typename F>  
F for_each(InIter first, InIter last, F &&f)
```

Applies *f* to the result of dereferencing every iterator in the range [first, last).

If *f* returns a result, the result is ignored.

If the type of *first* satisfies the requirements of a mutable iterator, *f* may apply non-constant functions through the dereferenced iterator.

Note: Complexity: Applies *f* exactly *last - first* times.

Template Parameters

- **InIter** – The type of the source begin and end iterator used (deduced). This iterator type must meet the requirements of an input iterator.
- **F** – The type of the function/function object to use (deduced). *F* must meet requirements of *MoveConstructible*.

Parameters

- **first** – Refers to the beginning of the sequence of elements the algorithm will be applied to.
- **last** – Refers to the end of the sequence of elements the algorithm will be applied to.
- **f** – Specifies the function (or function object) which will be invoked for each of the elements in the sequence specified by [first, last). The signature of this predicate should be equivalent to:

```
<ignored> pred(const Type &a);
```

The signature does not need to have const&. The type *Type* must be such that an object of type *InIter* can be dereferenced and then implicitly converted to *Type*.

Returns *f*.

```
template<typename ExPolicy, typename FwdIter, typename F>  
util::detail::algorithm_result_t<ExPolicy, void> for_each(ExPolicy &&policy, FwdIter first, FwdIter last, F  
&&f)
```

Applies *f* to the result of dereferencing every iterator in the range [first, last). Executed according to the policy.

If *f* returns a result, the result is ignored.

If the type of *first* satisfies the requirements of a mutable iterator, *f* may apply non-constant functions through the dereferenced iterator.

Unlike its sequential form, the parallel overload of *for_each* does not return a copy of its *Function* parameter, since parallelization may not permit efficient state accumulation.

The application of function objects in parallel algorithm invoked with an execution policy object of type *sequenced_policy* execute in sequential order in the calling thread.

The application of function objects in parallel algorithm invoked with an execution policy object of type *parallel_policy* or *parallel_task_policy* are permitted to execute in an unordered fashion in unspecified threads, and indeterminately sequenced within each thread.

Note: Complexity: Applies *f* exactly *last - first* times.

Template Parameters

- **ExPolicy** – The type of the execution policy to use (deduced). It describes the manner in which the execution of the algorithm may be parallelized and the manner in which it applies user-provided function objects.
- **FwdIter** – The type of the source begin and end iterator used (deduced). This iterator type must meet the requirements of a forward iterator.
- **F** – The type of the function/function object to use (deduced). Unlike its sequential form, the parallel overload of *for_each* requires *F* to meet the requirements of *CopyConstructible*.

Parameters

- **policy** – The execution policy to use for the scheduling of the iterations.
- **first** – Refers to the beginning of the sequence of elements the algorithm will be applied to.
- **last** – Refers to the end of the sequence of elements the algorithm will be applied to.
- **f** – Specifies the function (or function object) which will be invoked for each of the elements in the sequence specified by [first, last). The signature of this predicate should be equivalent to:

```
<ignored> pred(const Type &a);
```

The signature does not need to have const&. The type *Type* must be such that an object of type *FwdIter* can be dereferenced and then implicitly converted to *Type*.

Returns The *for_each* algorithm returns a *hpx::future<void>* if the execution policy is of type *sequenced_task_policy* or *parallel_task_policy* and returns void otherwise.

```
template<typename InIter, typename Size, typename F>
InIter for_each_n(InIter first, Size count, F &&f)
```

Applies *f* to the result of dereferencing every iterator in the range [first, first + count), starting from first and proceeding to first + count - 1.

If *f* returns a result, the result is ignored.

If the type of *first* satisfies the requirements of a mutable iterator, *f* may apply non-constant functions through the dereferenced iterator.

Note: Complexity: Applies *f* exactly *count* times.

Template Parameters

- **InIter** – The type of the source begin and end iterator used (deduced). This iterator type must meet the requirements of an input iterator.
- **Size** – The type of the argument specifying the number of elements to apply *f* to.
- **F** – The type of the function/function object to use (deduced). *F* must meet requirements of *MoveConstructible*.

Parameters

- **first** – Refers to the beginning of the sequence of elements the algorithm will be applied to.
- **count** – Refers to the number of elements starting at *first* the algorithm will be applied to.
- **f** – Specifies the function (or function object) which will be invoked for each of the elements in the sequence specified by [first, last). The signature of this predicate should be equivalent to:

```
<ignored> pred(const Type &a);
```

The signature does not need to have `const&`. The type *Type* must be such that an object of type *InIter* can be dereferenced and then implicitly converted to *Type*.

Returns *first* + *count* for non-negative values of *count* and *first* for negative values.

```
template<typename ExPolicy, typename FwdIter, typename Size, typename F>  
util::detail::algorithm_result_t<ExPolicy, FwdIter> for_each_n(ExPolicy &&policy, FwdIter first, Size  
count, F &&f)
```

Applies *f* to the result of dereferencing every iterator in the range [first, first + count), starting from first and proceeding to first + count - 1. Executed according to the policy.

If *f* returns a result, the result is ignored.

If the type of *first* satisfies the requirements of a mutable iterator, *f* may apply non-constant functions through the dereferenced iterator.

Unlike its sequential form, the parallel overload of *for_each_n* does not return a copy of its *Function* parameter, since parallelization may not permit efficient state accumulation.

The application of function objects in parallel algorithm invoked with an execution policy object of type *sequenced_policy* execute in sequential order in the calling thread.

The application of function objects in parallel algorithm invoked with an execution policy object of type *parallel_policy* or *parallel_task_policy* are permitted to execute in an unordered fashion in unspecified threads, and indeterminately sequenced within each thread.

Note: Complexity: Applies *f* exactly *count* times.

Template Parameters

- **ExPolicy** – The type of the execution policy to use (deduced). It describes the manner in which the execution of the algorithm may be parallelized and the manner in which it applies user-provided function objects.

- **FwdIter** – The type of the source iterators used (deduced). This iterator type must meet the requirements of an forward iterator.
- **Size** – The type of the argument specifying the number of elements to apply *f* to.
- **F** – The type of the function/function object to use (deduced). Unlike its sequential form, the parallel overload of *for_each_n* requires *F* to meet the requirements of *CopyConstructible*.

Parameters

- **policy** – The execution policy to use for the scheduling of the iterations.
- **first** – Refers to the beginning of the sequence of elements the algorithm will be applied to.
- **count** – Refers to the number of elements starting at *first* the algorithm will be applied to.
- **f** – Specifies the function (or function object) which will be invoked for each of the elements in the sequence specified by [first, last). The signature of this predicate should be equivalent to:

```
<ignored> pred(const Type &a);
```

The signature does not need to have `const&`. The type *Type* must be such that an object of type *FwdIter* can be dereferenced and then implicitly converted to *Type*.

Returns The *for_each_n* algorithm returns a *hpx::future<FwdIter>* if the execution policy is of type *sequenced_task_policy* or *parallel_task_policy* and returns *FwdIter* otherwise. It returns *first + count* for non-negative values of *count* and *first* for negative values.

hpx::experimental::for_loop, hpx::experimental::for_loop_strided, hpx::experimental::for_loop_n, hpx::experimental::for_loop_n_strided

Defined in header `hpx/algorithm.hpp`⁵⁷⁹.

See *Public API* for a list of names and headers that are part of the public *HPX* API.

namespace **hpx**

namespace **experimental**

Top-level namespace.

Functions

```
template<typename I, typename ...Args>
void for_loop(std::decay_t<I> first, I last, Args&&... args)
```

The `for_loop` implements loop functionality over a range specified by integral or iterator bounds. For the iterator case, these algorithms resemble `for_each` from the Parallelism TS, but leave to the programmer when and if to dereference the iterator.

The execution of `for_loop` without specifying an execution policy is equivalent to specifying *hpx::execution::seq* as the execution policy.

⁵⁷⁹ <http://github.com/STELLAR-GROUP/hpx/blob/8a3b7c1a4cb5693b2f7d9f587f759392ed0c51a0/libs/full/include/include/hpx/algorithm.hpp>

Requires: I shall be an integral type or meet the requirements of an input iterator type. The $args$ parameter pack shall have at least one element, comprising objects returned by invocations of *reduction* and/or *induction* function templates followed by exactly one element invocable element-access function, f . f shall meet the requirements of *MoveConstructible*.

Effects: Applies f to each element in the input sequence, with additional arguments corresponding to the reductions and inductions in the $args$ parameter pack. The length of the input sequence is *last - first*.

The first element in the input sequence is specified by *first*. Each subsequent element is generated by incrementing the previous element.

Along with an element from the input sequence, for each member of the $args$ parameter pack excluding f , an additional argument is passed to each application of f as follows:

If the pack member is an object returned by a call to a reduction function listed in section, then the additional argument is a reference to a view of that reduction object. If the pack member is an object returned by a call to induction, then the additional argument is the induction value for that induction object corresponding to the position of the application of f in the input sequence.

Complexity: Applies f exactly once for each element of the input sequence.

Remarks: If f returns a result, the result is ignored.

Note: As described in the C++ standard, arithmetic on non-random-access iterators is performed using *advance* and *distance*.

Note: The order of the elements of the input sequence is important for determining ordinal position of an application of f , even though the applications themselves may be unordered.

Template Parameters

- **I** – The type of the iteration variable. This could be an (forward) iterator type or an integral type.
- **Args** – A parameter pack, it's last element is a function object to be invoked for each iteration, the others have to be either conforming to the induction or reduction concept.

Parameters

- **first** – Refers to the beginning of the sequence of elements the algorithm will be applied to.
- **last** – Refers to the end of the sequence of elements the algorithm will be applied to.
- **args** – The last element of this parameter pack is the function (object) to invoke, while the remaining elements of the parameter pack are instances of either induction or reduction objects. The function (or function object) which will be invoked for each of the elements in the sequence specified by [*first*, *last*) should expose a signature equivalent to:

```
<ignored> pred(I const& a, ...);
```

The signature does not need to have `const&`. It will receive the current value of the iteration variable and one argument for each of the induction or reduction objects passed to the algorithms, representing their current values.

```
template<typename ExPolicy, typename I, typename...  
Args> < unspecified > for_loop (ExPolicy &&policy, std::decay_t< I > first,  
I last, Args &&... args)
```

The `for_loop` implements loop functionality over a range specified by integral or iterator bounds. For the iterator case, these algorithms resemble `for_each` from the Parallelism TS, but leave to the programmer when and if to dereference the iterator. Executed according to the policy.

Requires: *I* shall be an integral type or meet the requirements of an input iterator type. The *args* parameter pack shall have at least one element, comprising objects returned by invocations of *reduction* and/or *induction* function templates followed by exactly one element invocable element-access function, *f*. *f* shall meet the requirements of *MoveConstructible*.

Effects: Applies *f* to each element in the input sequence, with additional arguments corresponding to the reductions and inductions in the *args* parameter pack. The length of the input sequence is *last - first*.

The first element in the input sequence is specified by *first*. Each subsequent element is generated by incrementing the previous element.

Along with an element from the input sequence, for each member of the *args* parameter pack excluding *f*, an additional argument is passed to each application of *f* as follows:

If the pack member is an object returned by a call to a reduction function listed in section, then the additional argument is a reference to a view of that reduction object. If the pack member is an object returned by a call to induction, then the additional argument is the induction value for that induction object corresponding to the position of the application of *f* in the input sequence.

Complexity: Applies *f* exactly once for each element of the input sequence.

Remarks: If *f* returns a result, the result is ignored.

Note: As described in the C++ standard, arithmetic on non-random-access iterators is performed using `advance` and `distance`.

Note: The order of the elements of the input sequence is important for determining ordinal position of an application of *f*, even though the applications themselves may be unordered.

Template Parameters

- **ExPolicy** – The type of the execution policy to use (deduced). It describes the manner in which the execution of the algorithm may be parallelized and the manner in which it applies user-provided function objects.
- **I** – The type of the iteration variable. This could be an (forward) iterator type or an integral type.
- **Args** – A parameter pack, it's last element is a function object to be invoked for each iteration, the others have to be either conforming to the induction or reduction concept.

Parameters

- **policy** – The execution policy to use for the scheduling of the iterations.
- **first** – Refers to the beginning of the sequence of elements the algorithm will be applied to.
- **last** – Refers to the end of the sequence of elements the algorithm will be applied to.
- **args** – The last element of this parameter pack is the function (object) to invoke, while the remaining elements of the parameter pack are instances of either induction or reduction objects. The function (or function object) which will be invoked for each of the elements in the sequence specified by [`first`, `last`) should expose a signature equivalent to:

```
<ignored> pred(I const& a, ...);
```

The signature does not need to have `const&`. It will receive the current value of the iteration variable and one argument for each of the induction or reduction objects passed to the algorithms, representing their current values.

Returns The `for_loop` algorithm returns a `hpx::future<void>` if the execution policy is of type `hpx::execution::sequenced_task_policy` or `hpx::execution::parallel_task_policy` and returns `void` otherwise.

```
template<typename I, typename S, typename ...Args>  
void for_loop_strided(std::decay_t<I> first, I last, S stride, Args&&... args)
```

The `for_loop_strided` implements loop functionality over a range specified by integral or iterator bounds. For the iterator case, these algorithms resemble `for_each` from the Parallelism TS, but leave to the programmer when and if to dereference the iterator.

The execution of `for_loop` without specifying an execution policy is equivalent to specifying `hpx::execution::seq` as the execution policy.

Requires: *I* shall be an integral type or meet the requirements of an input iterator type. The *args* parameter pack shall have at least one element, comprising objects returned by invocations of *reduction* and/or *induction* function templates followed by exactly one element invocable element-access function, *f*. *f* shall meet the requirements of *MoveConstructible*.

Effects: Applies *f* to each element in the input sequence, with additional arguments corresponding to the reductions and inductions in the *args* parameter pack. The length of the input sequence is *last - first*.

The first element in the input sequence is specified by *first*. Each subsequent element is generated by incrementing the previous element.

Along with an element from the input sequence, for each member of the *args* parameter pack excluding *f*, an additional argument is passed to each application of *f* as follows:

If the pack member is an object returned by a call to a reduction function listed in section, then the additional argument is a reference to a view of that reduction object. If the pack member is an object returned by a call to induction, then the additional argument is the induction value for that induction object corresponding to the position of the application of *f* in the input sequence.

Complexity: Applies *f* exactly once for each element of the input sequence.

Remarks: If *f* returns a result, the result is ignored.

Note: As described in the C++ standard, arithmetic on non-random-access iterators is performed using `advance` and `distance`.

Note: The order of the elements of the input sequence is important for determining ordinal position of an application of *f*, even though the applications themselves may be unordered.

Template Parameters

- **I** – The type of the iteration variable. This could be an (forward) iterator type or an integral type.
- **S** – The type of the stride variable. This should be an integral type.

- **Args** – A parameter pack, it's last element is a function object to be invoked for each iteration, the others have to be either conforming to the induction or reduction concept.

Parameters

- **first** – Refers to the beginning of the sequence of elements the algorithm will be applied to.
- **last** – Refers to the end of the sequence of elements the algorithm will be applied to.
- **stride** – Refers to the stride of the iteration steps. This shall have non-zero value and shall be negative only if I has integral type or meets the requirements of a bidirectional iterator.
- **args** – The last element of this parameter pack is the function (object) to invoke, while the remaining elements of the parameter pack are instances of either induction or reduction objects. The function (or function object) which will be invoked for each of the elements in the sequence specified by [first, last) should expose a signature equivalent to:

```
<ignored> pred(I const& a, ...);
```

The signature does not need to have const&. It will receive the current value of the iteration variable and one argument for each of the induction or reduction objects passed to the algorithms, representing their current values.

```
template<typename ExPolicy, typename I, typename S, typename...
Args> < unspecified > for_loop_strided (ExPolicy &&policy,
std::decay_t< I > first, I last, S stride, Args &&... args)
```

The `for_loop_strided` implements loop functionality over a range specified by integral or iterator bounds. For the iterator case, these algorithms resemble `for_each` from the Parallelism TS, but leave to the programmer when and if to dereference the iterator. Executed according to the policy.

Requires: *I* shall be an integral type or meet the requirements of an input iterator type. The *args* parameter pack shall have at least one element, comprising objects returned by invocations of *reduction* and/or *induction* function templates followed by exactly one element invocable element-access function, *f*. *f* shall meet the requirements of *MoveConstructible*.

Effects: Applies *f* to each element in the input sequence, with additional arguments corresponding to the reductions and inductions in the *args* parameter pack. The length of the input sequence is *last - first*.

The first element in the input sequence is specified by *first*. Each subsequent element is generated by incrementing the previous element.

Along with an element from the input sequence, for each member of the *args* parameter pack excluding *f*, an additional argument is passed to each application of *f* as follows:

If the pack member is an object returned by a call to a reduction function listed in section, then the additional argument is a reference to a view of that reduction object. If the pack member is an object returned by a call to induction, then the additional argument is the induction value for that induction object corresponding to the position of the application of *f* in the input sequence.

Complexity: Applies *f* exactly once for each element of the input sequence.

Remarks: If *f* returns a result, the result is ignored.

Note: As described in the C++ standard, arithmetic on non-random-access iterators is performed using `advance` and `distance`.

Note: The order of the elements of the input sequence is important for determining ordinal position of an application of f , even though the applications themselves may be unordered.

Template Parameters

- **ExPolicy** – The type of the execution policy to use (deduced). It describes the manner in which the execution of the algorithm may be parallelized and the manner in which it applies user-provided function objects.
- **I** – The type of the iteration variable. This could be an (forward) iterator type or an integral type.
- **S** – The type of the stride variable. This should be an integral type.
- **Args** – A parameter pack, it's last element is a function object to be invoked for each iteration, the others have to be either conforming to the induction or reduction concept.

Parameters

- **policy** – The execution policy to use for the scheduling of the iterations.
- **first** – Refers to the beginning of the sequence of elements the algorithm will be applied to.
- **last** – Refers to the end of the sequence of elements the algorithm will be applied to.
- **stride** – Refers to the stride of the iteration steps. This shall have non-zero value and shall be negative only if I has integral type or meets the requirements of a bidirectional iterator.
- **args** – The last element of this parameter pack is the function (object) to invoke, while the remaining elements of the parameter pack are instances of either induction or reduction objects. The function (or function object) which will be invoked for each of the elements in the sequence specified by [first, last) should expose a signature equivalent to:

```
<ignored> pred(I const& a, ...);
```

The signature does not need to have `const&`. It will receive the current value of the iteration variable and one argument for each of the induction or reduction objects passed to the algorithms, representing their current values.

Returns The `for_loop_strided` algorithm returns a `hpx::future<void>` if the execution policy is of type `hpx::execution::sequenced_task_policy` or `hpx::execution::parallel_task_policy` and returns `void` otherwise.

```
template<typename I, typename Size, typename ...Args>
void for_loop_n(I first, Size size, Args&&... args)
```

The `for_loop_n` implements loop functionality over a range specified by integral or iterator bounds. For the iterator case, these algorithms resemble `for_each` from the Parallelism TS, but leave to the programmer when and if to dereference the iterator.

The execution of `for_loop_n` without specifying an execution policy is equivalent to specifying `hpx::execution::seq` as the execution policy.

Requires: I shall be an integral type or meet the requirements of an input iterator type. The $args$ parameter pack shall have at least one element, comprising objects returned by invocations of *reduction* and/or *induction* function templates followed by exactly one element invocable element-access function, f . f shall meet the requirements of *MoveConstructible*.

Effects: Applies f to each element in the input sequence, with additional arguments corresponding to the reductions and inductions in the $args$ parameter pack. The length of the input sequence is $last - first$.

The first element in the input sequence is specified by $first$. Each subsequent element is generated by

incrementing the previous element.

Along with an element from the input sequence, for each member of the *args* parameter pack excluding *f*, an additional argument is passed to each application of *f* as follows:

If the pack member is an object returned by a call to a reduction function listed in section, then the additional argument is a reference to a view of that reduction object. If the pack member is an object returned by a call to induction, then the additional argument is the induction value for that induction object corresponding to the position of the application of *f* in the input sequence.

Complexity: Applies *f* exactly once for each element of the input sequence.

Remarks: If *f* returns a result, the result is ignored.

Note: As described in the C++ standard, arithmetic on non-random-access iterators is performed using *advance* and *distance*.

Note: The order of the elements of the input sequence is important for determining ordinal position of an application of *f*, even though the applications themselves may be unordered.

Template Parameters

- **I** – The type of the iteration variable. This could be an (forward) iterator type or an integral type.
- **Size** – The type of a non-negative integral value specifying the number of items to iterate over.
- **Args** – A parameter pack, it's last element is a function object to be invoked for each iteration, the others have to be either conforming to the induction or reduction concept.

Parameters

- **first** – Refers to the beginning of the sequence of elements the algorithm will be applied to.
- **size** – Refers to the number of items the algorithm will be applied to.
- **args** – The last element of this parameter pack is the function (object) to invoke, while the remaining elements of the parameter pack are instances of either induction or reduction objects. The function (or function object) which will be invoked for each of the elements in the sequence specified by [first, last) should expose a signature equivalent to:

```
<ignored> pred(I const& a, ...);
```

The signature does not need to have `const&`. It will receive the current value of the iteration variable and one argument for each of the induction or reduction objects passed to the algorithms, representing their current values.

```
template<typename ExPolicy, typename I, typename Size, typename...
Args> < unspecified > for_loop_n (ExPolicy &&policy, I first, Size size,
Args &&... args)
```

The `for_loop_n` implements loop functionality over a range specified by integral or iterator bounds. For the iterator case, these algorithms resemble `for_each` from the Parallelism TS, but leave to the programmer when and if to dereference the iterator. Executed according to the policy.

Requires: *I* shall be an integral type or meet the requirements of an input iterator type. The *args* parameter pack shall have at least one element, comprising objects returned by invocations of *reduc-*

tion and/or *induction* function templates followed by exactly one element invocable element-access function, *f*. *f* shall meet the requirements of *MoveConstructible*.

Effects: Applies *f* to each element in the input sequence, with additional arguments corresponding to the reductions and inductions in the *args* parameter pack. The length of the input sequence is *last - first*.

The first element in the input sequence is specified by *first*. Each subsequent element is generated by incrementing the previous element.

Along with an element from the input sequence, for each member of the *args* parameter pack excluding *f*, an additional argument is passed to each application of *f* as follows:

If the pack member is an object returned by a call to a reduction function listed in section, then the additional argument is a reference to a view of that reduction object. If the pack member is an object returned by a call to induction, then the additional argument is the induction value for that induction object corresponding to the position of the application of *f* in the input sequence.

Complexity: Applies *f* exactly once for each element of the input sequence.

Remarks: If *f* returns a result, the result is ignored.

Note: As described in the C++ standard, arithmetic on non-random-access iterators is performed using *advance* and *distance*.

Note: The order of the elements of the input sequence is important for determining ordinal position of an application of *f*, even though the applications themselves may be unordered.

Template Parameters

- **ExPolicy** – The type of the execution policy to use (deduced). It describes the manner in which the execution of the algorithm may be parallelized and the manner in which it applies user-provided function objects.
- **I** – The type of the iteration variable. This could be an (forward) iterator type or an integral type.
- **Size** – The type of a non-negative integral value specifying the number of items to iterate over.
- **Args** – A parameter pack, it's last element is a function object to be invoked for each iteration, the others have to be either conforming to the induction or reduction concept.

Parameters

- **policy** – The execution policy to use for the scheduling of the iterations.
- **first** – Refers to the beginning of the sequence of elements the algorithm will be applied to.
- **size** – Refers to the number of items the algorithm will be applied to.
- **args** – The last element of this parameter pack is the function (object) to invoke, while the remaining elements of the parameter pack are instances of either induction or reduction objects. The function (or function object) which will be invoked for each of the elements in the sequence specified by [*first*, *last*) should expose a signature equivalent to:

```
<ignored> pred(I const& a, ...);
```

The signature does not need to have `const&`. It will receive the current value of the iteration variable and one argument for each of the induction or reduction objects passed to the algorithms, representing their current values.

Returns The `for_loop_n` algorithm returns a `hpx::future<void>` if the execution policy is of type `hpx::execution::sequenced_task_policy` or `hpx::execution::parallel_task_policy` and returns `void` otherwise.

```
template<typename I, typename Size, typename S, typename ...Args>
void for_loop_n_strided(I first, Size size, S stride, Args&&... args)
```

The `for_loop_n_strided` implements loop functionality over a range specified by integral or iterator bounds. For the iterator case, these algorithms resemble `for_each` from the Parallelism TS, but leave to the programmer when and if to dereference the iterator.

The execution of `for_loop` without specifying an execution policy is equivalent to specifying `hpx::execution::seq` as the execution policy.

Requires: *I* shall be an integral type or meet the requirements of an input iterator type. The *args* parameter pack shall have at least one element, comprising objects returned by invocations of *reduction* and/or *induction* function templates followed by exactly one element invocable element-access function, *f*. *f* shall meet the requirements of *MoveConstructible*.

Effects: Applies *f* to each element in the input sequence, with additional arguments corresponding to the reductions and inductions in the *args* parameter pack. The length of the input sequence is *last - first*.

The first element in the input sequence is specified by *first*. Each subsequent element is generated by incrementing the previous element.

Along with an element from the input sequence, for each member of the *args* parameter pack excluding *f*, an additional argument is passed to each application of *f* as follows:

If the pack member is an object returned by a call to a reduction function listed in section, then the additional argument is a reference to a view of that reduction object. If the pack member is an object returned by a call to induction, then the additional argument is the induction value for that induction object corresponding to the position of the application of *f* in the input sequence.

Complexity: Applies *f* exactly once for each element of the input sequence.

Remarks: If *f* returns a result, the result is ignored.

Note: As described in the C++ standard, arithmetic on non-random-access iterators is performed using `advance` and `distance`.

Note: The order of the elements of the input sequence is important for determining ordinal position of an application of *f*, even though the applications themselves may be unordered.

Template Parameters

- **I** – The type of the iteration variable. This could be an (forward) iterator type or an integral type.
- **Size** – The type of a non-negative integral value specifying the number of items to iterate over.
- **S** – The type of the stride variable. This should be an integral type.
- **Args** – A parameter pack, its last element is a function object to be invoked for each iteration, the others have to be either conforming to the induction or reduction concept.

Parameters

- **first** – Refers to the beginning of the sequence of elements the algorithm will be applied to.
- **size** – Refers to the number of items the algorithm will be applied to.
- **stride** – Refers to the stride of the iteration steps. This shall have non-zero value and shall be negative only if *I* has integral type or meets the requirements of a bidirectional iterator.
- **args** – The last element of this parameter pack is the function (object) to invoke, while the remaining elements of the parameter pack are instances of either induction or reduction objects. The function (or function object) which will be invoked for each of the elements in the sequence specified by [*first*, *last*) should expose a signature equivalent to:

```
<ignored> pred(I const& a, ...);
```

The signature does not need to have `const&`. It will receive the current value of the iteration variable and one argument for each of the induction or reduction objects passed to the algorithms, representing their current values.

```
template<typename ExPolicy, typename I, typename Size, typename S, typename...  
Args> < unspecified > for_loop_n_strided (ExPolicy &&policy, I first, Size size,  
S stride, Args &&... args)
```

The `for_loop_n_strided` implements loop functionality over a range specified by integral or iterator bounds. For the iterator case, these algorithms resemble `for_each` from the Parallelism TS, but leave to the programmer when and if to dereference the iterator. Executed according to the policy.

Requires: *I* shall be an integral type or meet the requirements of an input iterator type. The *args* parameter pack shall have at least one element, comprising objects returned by invocations of *reduction* and/or *induction* function templates followed by exactly one element invocable element-access function, *f*. *f* shall meet the requirements of *MoveConstructible*.

Effects: Applies *f* to each element in the input sequence, with additional arguments corresponding to the reductions and inductions in the *args* parameter pack. The length of the input sequence is *last - first*.

The first element in the input sequence is specified by *first*. Each subsequent element is generated by incrementing the previous element.

Along with an element from the input sequence, for each member of the *args* parameter pack excluding *f*, an additional argument is passed to each application of *f* as follows:

If the pack member is an object returned by a call to a reduction function listed in section, then the additional argument is a reference to a view of that reduction object. If the pack member is an object returned by a call to induction, then the additional argument is the induction value for that induction object corresponding to the position of the application of *f* in the input sequence.

Complexity: Applies *f* exactly once for each element of the input sequence.

Remarks: If *f* returns a result, the result is ignored.

Note: As described in the C++ standard, arithmetic on non-random-access iterators is performed using `advance` and `distance`.

Note: The order of the elements of the input sequence is important for determining ordinal position

of an application of f , even though the applications themselves may be unordered.

Template Parameters

- **ExPolicy** – The type of the execution policy to use (deduced). It describes the manner in which the execution of the algorithm may be parallelized and the manner in which it applies user-provided function objects.
- **I** – The type of the iteration variable. This could be an (forward) iterator type or an integral type.
- **Size** – The type of a non-negative integral value specifying the number of items to iterate over.
- **S** – The type of the stride variable. This should be an integral type.
- **Args** – A parameter pack, it's last element is a function object to be invoked for each iteration, the others have to be either conforming to the induction or reduction concept.

Parameters

- **policy** – The execution policy to use for the scheduling of the iterations.
- **first** – Refers to the beginning of the sequence of elements the algorithm will be applied to.
- **size** – Refers to the number of items the algorithm will be applied to.
- **stride** – Refers to the stride of the iteration steps. This shall have non-zero value and shall be negative only if I has integral type or meets the requirements of a bidirectional iterator.
- **args** – The last element of this parameter pack is the function (object) to invoke, while the remaining elements of the parameter pack are instances of either induction or reduction objects. The function (or function object) which will be invoked for each of the elements in the sequence specified by [first, last) should expose a signature equivalent to:

```
<ignored> pred(I const& a, ...);
```

The signature does not need to have `const&`. It will receive the current value of the iteration variable and one argument for each of the induction or reduction objects passed to the algorithms, representing their current values.

Returns The *for_loop_n_strided* algorithm returns a `hpx::future<void>` if the execution policy is of type `hpx::execution::sequenced_task_policy` or `hpx::execution::parallel_task_policy` and returns `void` otherwise.

hpx::experimental::induction

Defined in header `hpx/algorithm.hpp`⁵⁸⁰.

See *Public API* for a list of names and headers that are part of the public HPX API.

namespace **hpx**

namespace **experimental**

Top-level namespace.

⁵⁸⁰ <http://github.com/STELLAR-GROUP/hpx/blob/8a3b7c1a4cb5693b2f7d9f587f759392ed0c51a0/libs/full/include/include/hpx/algorithm.hpp>

Functions

```
template<typename T>
constexpr hpx::parallel::detail::induction_stride_helper<T> induction(T &&value, std::size_t stride)
```

The function template returns an induction object of unspecified type having a value type and encapsulating an initial *value* of that type and, optionally, a stride.

For each element in the input range, a looping algorithm over input sequence *S* computes an induction value from an induction variable and ordinal position *p* within *S* by the formula $i + p * \text{stride}$ if a stride was specified or $i + p$ otherwise. This induction value is passed to the element access function.

If the *value* argument to *induction* is a non-const lvalue, then that lvalue becomes the live-out object for the returned induction object. For each induction object that has a live-out object, the looping algorithm assigns the value of $i + n * \text{stride}$ to the live-out object upon return, where *n* is the number of elements in the input range.

Template Parameters **T** – The value type to be used by the induction object.

Parameters

- **value** – [in] The initial value to use for the induction object
- **stride** – [in] The (optional) stride to use for the induction object (default: 1)

Returns This returns an induction object with value type *T*, initial *value*, and (if specified) *stride*. If *T* is a lvalue of non-const type, *value* is used as the live-out object for the induction object; otherwise there is no live-out object.

```
template<typename T>
constexpr hpx::parallel::detail::induction_helper<T> induction(T &&value)
```

`hpx::experimental::reduction`

Defined in header `hpx/algorithm.hpp`⁵⁸¹.

See *Public API* for a list of names and headers that are part of the public HPX API.

```
namespace hpx
```

```
namespace experimental
```

```
    Top-level namespace.
```

Functions

```
template<typename T, typename Op>
constexpr hpx::parallel::detail::reduction_helper<T, std::decay_t<Op>> reduction(T &var, T const
                                                                                   &identity, Op
                                                                                   &&combiner)
```

The function template returns a reduction object of unspecified type having a value type and encapsulating an identity value for the reduction, a combiner function object, and a live-out object from which the initial value is obtained and into which the final value is stored.

A parallel algorithm uses reduction objects by allocating an unspecified number of instances, called views, of the reduction's value type. Each view is initialized with the reduction object's identity value, except that the live-out object (which was initialized by the caller) comprises one of the views. The algorithm passes a reference to a view to each application of an element-access function, ensuring that

⁵⁸¹ <http://github.com/STELLAR-GROUP/hpx/blob/8a3b7c1a4cb5693b2f7d9f587f759392ed0c51a0/libs/full/include/include/hpx/algorithm.hpp>

no two concurrently-executing invocations share the same view. A view can be shared between two applications that do not execute concurrently, but initialization is performed only once per view.

Modifications to the view by the application of element access functions accumulate as partial results. At some point before the algorithm returns, the partial results are combined, two at a time, using the reduction object's combiner operation until a single value remains, which is then assigned back to the live-out object.

T shall meet the requirements of *CopyConstructible* and *MoveAssignable*. The expression

```
var = combiner(var, var)
```

shall be well-formed.

Note: In order to produce useful results, modifications to the view should be limited to commutative operations closely related to the combiner operation. For example if the combiner is `plus<T>`, incrementing the view would be consistent with the combiner but doubling it or assigning to it would not.

Template Parameters

- **T** – The value type to be used by the induction object.
- **Op** – The type of the binary function (object) used to perform the reduction operation.

Parameters

- **var** – [in,out] The live-out value to use for the reduction object. This will hold the reduced value after the algorithm is finished executing.
- **identity** – [in] The identity value to use for the reduction operation. This argument is optional and defaults to a copy of *var*.
- **combiner** – [in] The binary function (object) used to perform a pairwise reduction on the elements.

Returns This returns a reduction object of unspecified type having a value type of *T*. When the return value is used by an algorithm, the reference to *var* is used as the live-out object, new views are initialized to a copy of identity, and views are combined by invoking the copy of combiner, passing it the two views to be combined.

```
template<typename T, typename Op>
constexpr hpx::parallel::detail::reduction_helper<T, std::decay_t<Op>> reduction(T &var, Op
&&combiner)
```

hpx::experimental::reduction_bit_and

Defined in header `hpx/algorithm.hpp`⁵⁸².

See *Public API* for a list of names and headers that are part of the public *HPX* API.

```
namespace hpx
```

```
    namespace experimental
```

```
        Top-level namespace.
```

⁵⁸² <http://github.com/STELLAR-GROUP/hpx/blob/8a3b7c1a4cb5693b2f7d9f587f759392ed0c51a0/libs/full/include/include/hpx/algorithm.hpp>

Functions

```
template<typename T>
constexpr hpx::parallel::detail::reduction_helper<T, std::bit_and<T>> reduction_bit_and(T &var)
```

The function template *reduction_bit_and* returns a reduction object of unspecified type having a value type and encapsulating an identity value for the reduction, it uses *std::bit_and*{ } as its combiner function, and a live-out object from which the initial value is obtained and into which the final value is stored.

A parallel algorithm uses the *reduction_bit_and* object by allocating an unspecified number of instances, called views, of the reduction's value type. Each view is initialized with the reduction object's identity value, except that the live-out object (which was initialized by the caller) comprises one of the views. The algorithm passes a reference to a view to each application of an element-access function, ensuring that no two concurrently-executing invocations share the same view. A view can be shared between two applications that do not execute concurrently, but initialization is performed only once per view.

Modifications to the view by the application of element access functions accumulate as partial results. At some point before the algorithm returns, the partial results are combined, two at a time, using the *std::bit_and*{ } operation until a single value remains, which is then assigned back to the live-out object.

T shall meet the requirements of *CopyConstructible* and *MoveAssignable*.

Note: In order to produce useful results, modifications to the view should be limited to commutative operations closely related to the combiner operation.

Template Parameters

- **T** – The value type to be used by the induction object.
- **Op** – The type of the binary function (object) used to perform the reduction operation.

Parameters

- **var** – [in,out] The live-out value to use for the reduction object. This will hold the reduced value after the algorithm is finished executing.
- **identity** – [in] The identity value to use for the reduction operation. This argument is optional and defaults to a copy of *var*.

Returns This returns a reduction object of unspecified type having a value type of *T*. When the return value is used by an algorithm, the reference to *var* is used as the live-out object, new views are initialized to a copy of identity, and views are combined by invoking the copy of combiner, passing it the two views to be combined.

```
template<typename T>
constexpr hpx::parallel::detail::reduction_helper<T, std::bit_and<T>> reduction_bit_and(T &var, T
                                                                    const
                                                                    &iden-
                                                                    tity)
```

hpx::experimental::reduction_bit_or

Defined in header `hpx/algorithm.hpp`⁵⁸³.

See *Public API* for a list of names and headers that are part of the public *HPX* API.

```
namespace hpx
```

```
    namespace experimental
```

```
        Top-level namespace.
```

Functions

```
template<typename T>
```

```
constexpr hpx::parallel::detail::reduction_helper<T, std::bit_or<T>> reduction_bit_or(T &var)
```

The function template `reduction_bit_or` returns a reduction object of unspecified type having a value type and encapsulating an identity value for the reduction, it uses `std::bit_or{ }` as its combiner function, and a live-out object from which the initial value is obtained and into which the final value is stored.

A parallel algorithm uses the `reduction_bit_or` object by allocating an unspecified number of instances, called views, of the reduction's value type. Each view is initialized with the reduction object's identity value, except that the live-out object (which was initialized by the caller) comprises one of the views. The algorithm passes a reference to a view to each application of an element-access function, ensuring that no two concurrently-executing invocations share the same view. A view can be shared between two applications that do not execute concurrently, but initialization is performed only once per view.

Modifications to the view by the application of element access functions accumulate as partial results. At some point before the algorithm returns, the partial results are combined, two at a time, using the `std::bit_or{ }` operation until a single value remains, which is then assigned back to the live-out object.

T shall meet the requirements of *CopyConstructible* and *MoveAssignable*.

Note: In order to produce useful results, modifications to the view should be limited to commutative operations closely related to the combiner operation.

Template Parameters

- **T** – The value type to be used by the induction object.
- **Op** – The type of the binary function (object) used to perform the reduction operation.

Parameters

- **var** – [in,out] The live-out value to use for the reduction object. This will hold the reduced value after the algorithm is finished executing.
- **identity** – [in] The identity value to use for the reduction operation. This argument is optional and defaults to a copy of *var*.

Returns This returns a reduction object of unspecified type having a value type of *T*. When the return value is used by an algorithm, the reference to *var* is used as the live-out object, new views are initialized to a copy of *identity*, and views are combined by invoking the copy of combiner, passing it the two views to be combined.

```
template<typename T>
```

⁵⁸³ <http://github.com/STELLAR-GROUP/hpx/blob/8a3b7c1a4cb5693b2f7d9f587f759392ed0c51a0/libs/full/include/include/hpx/algorithm.hpp>

```
constexpr hpx::parallel::detail::reduction_helper<T, std::bit_or<T>> reduction_bit_or(T &var, T
                                                                    const
                                                                    &identity)
```

hpx::experimental::reduction_bit_xor

Defined in header `hpx/algorithm.hpp`⁵⁸⁴.

See *Public API* for a list of names and headers that are part of the public *HPX* API.

namespace **hpx**

namespace **experimental**

Top-level namespace.

Functions

```
template<typename T>
constexpr hpx::parallel::detail::reduction_helper<T, std::bit_xor<T>> reduction_bit_xor(T &var)
```

The function template `reduction_bit_xor` returns a reduction object of unspecified type having a value type and encapsulating an identity value for the reduction, it uses `std::bit_xor{ }` as its combiner function, and a live-out object from which the initial value is obtained and into which the final value is stored.

A parallel algorithm uses the `reduction_bit_xor` object by allocating an unspecified number of instances, called views, of the reduction's value type. Each view is initialized with the reduction object's identity value, except that the live-out object (which was initialized by the caller) comprises one of the views. The algorithm passes a reference to a view to each application of an element-access function, ensuring that no two concurrently-executing invocations share the same view. A view can be shared between two applications that do not execute concurrently, but initialization is performed only once per view.

Modifications to the view by the application of element access functions accumulate as partial results. At some point before the algorithm returns, the partial results are combined, two at a time, using the `std::bit_xor{ }` operation until a single value remains, which is then assigned back to the live-out object.

T shall meet the requirements of *CopyConstructible* and *MoveAssignable*.

Note: In order to produce useful results, modifications to the view should be limited to commutative operations closely related to the combiner operation.

Template Parameters

- **T** – The value type to be used by the induction object.
- **Op** – The type of the binary function (object) used to perform the reduction operation.

Parameters

- **var** – [in,out] The life-out value to use for the reduction object. This will hold the reduced value after the algorithm is finished executing.
- **identity** – [in] The identity value to use for the reduction operation. This argument is optional and defaults to a copy of *var*.

⁵⁸⁴ <http://github.com/STELLAR-GROUP/hpx/blob/8a3b7c1a4cb5693b2f7d9f587f759392ed0c51a0/libs/full/include/include/hpx/algorithm.hpp>

Returns This returns a reduction object of unspecified type having a value type of T . When the return value is used by an algorithm, the reference to var is used as the live-out object, new views are initialized to a copy of identity, and views are combined by invoking the copy of combiner, passing it the two views to be combined.

```
template<typename T>
constexpr hpx::parallel::detail::reduction_helper<T, std::bit_xor<T>> reduction_bit_xor(T &var, T
const
&identity)
```

hpx::experimental::reduction_max

Defined in header `hpx/algorithm.hpp`⁵⁸⁵.

See *Public API* for a list of names and headers that are part of the public *HPX* API.

```
namespace hpx
```

```
namespace experimental
```

Top-level namespace.

Functions

```
template<typename T>
constexpr hpx::parallel::detail::reduction_helper<T, hpx::parallel::detail::max_of<T>> reduction_max(T
&var)
```

The function template `reduction_max` returns a reduction object of unspecified type having a value type and encapsulating an identity value for the reduction, it uses `std::max_of{ }` as its combiner function, and a live-out object from which the initial value is obtained and into which the final value is stored.

A parallel algorithm uses the `reduction_max` object by allocating an unspecified number of instances, called views, of the reduction's value type. Each view is initialized with the reduction object's identity value, except that the live-out object (which was initialized by the caller) comprises one of the views. The algorithm passes a reference to a view to each application of an element-access function, ensuring that no two concurrently-executing invocations share the same view. A view can be shared between two applications that do not execute concurrently, but initialization is performed only once per view.

Modifications to the view by the application of element access functions accumulate as partial results. At some point before the algorithm returns, the partial results are combined, two at a time, using the `std::max_of{ }` operation until a single value remains, which is then assigned back to the live-out object.

T shall meet the requirements of *CopyConstructible* and *MoveAssignable*.

Note: In order to produce useful results, modifications to the view should be limited to commutative operations closely related to the combiner operation.

Template Parameters

- **T** – The value type to be used by the induction object.
- **Op** – The type of the binary function (object) used to perform the reduction operation.

⁵⁸⁵ <http://github.com/STELLAR-GROUP/hpx/blob/8a3b7c1a4cb5693b2f7d9f587f759392ed0c51a0/libs/full/include/include/hpx/algorithm.hpp>

Parameters

- **var** – [in,out] The live-out value to use for the reduction object. This will hold the reduced value after the algorithm is finished executing.
- **identity** – [in] The identity value to use for the reduction operation. This argument is optional and defaults to a copy of *var*.

Returns This returns a reduction object of unspecified type having a value type of *T*. When the return value is used by an algorithm, the reference to *var* is used as the live-out object, new views are initialized to a copy of *identity*, and views are combined by invoking the copy of combiner, passing it the two views to be combined.

```
template<typename T>
constexpr hpx::parallel::detail::reduction_helper<T, hpx::parallel::detail::max_of<T>> reduction_max(T
                                                                                                     &var,
                                                                                                     T
                                                                                                     const
                                                                                                     &iden-
                                                                                                     tity)
```

`hpx::experimental::reduction_min`

Defined in header `hpx/algorithm.hpp`⁵⁸⁶.

See *Public API* for a list of names and headers that are part of the public *HPX* API.

```
namespace hpx
```

```
namespace experimental
```

Top-level namespace.

Functions

```
template<typename T>
constexpr hpx::parallel::detail::reduction_helper<T, hpx::parallel::detail::min_of<T>> reduction_min(T
                                                                                                     &var)
```

The function template *reduction_min* returns a reduction object of unspecified type having a value type and encapsulating an identity value for the reduction, it uses `std::min_of{ }` as its combiner function, and a live-out object from which the initial value is obtained and into which the final value is stored.

A parallel algorithm uses the *reduction_min* object by allocating an unspecified number of instances, called views, of the reduction's value type. Each view is initialized with the reduction object's identity value, except that the live-out object (which was initialized by the caller) comprises one of the views. The algorithm passes a reference to a view to each application of an element-access function, ensuring that no two concurrently-executing invocations share the same view. A view can be shared between two applications that do not execute concurrently, but initialization is performed only once per view.

Modifications to the view by the application of element access functions accumulate as partial results. At some point before the algorithm returns, the partial results are combined, two at a time, using the `std::min_of{ }` operation until a single value remains, which is then assigned back to the live-out object.

T shall meet the requirements of *CopyConstructible* and *MoveAssignable*.

⁵⁸⁶ <http://github.com/STELLAR-GROUP/hpx/blob/8a3b7c1a4cb5693b2f7d9f587f759392ed0c51a0/libs/full/include/include/hpx/algorithm.hpp>

Note: In order to produce useful results, modifications to the view should be limited to commutative operations closely related to the combiner operation.

Template Parameters

- **T** – The value type to be used by the induction object.
- **Op** – The type of the binary function (object) used to perform the reduction operation.

Parameters

- **var** – [in,out] The live-out value to use for the reduction object. This will hold the reduced value after the algorithm is finished executing.
- **identity** – [in] The identity value to use for the reduction operation. This argument is optional and defaults to a copy of *var*.

Returns This returns a reduction object of unspecified type having a value type of *T*. When the return value is used by an algorithm, the reference to *var* is used as the live-out object, new views are initialized to a copy of *identity*, and views are combined by invoking the copy of *combiner*, passing it the two views to be combined.

```
template<typename T>
constexpr hpx::parallel::detail::reduction_helper<T, hpx::parallel::detail::min_of<T>> reduction_min(T
                                                                    &var,
                                                                    T
                                                                    const
                                                                    &iden-
                                                                    tity)
```

hpx::experimental::reduction_multiplies

Defined in header `hpx/algorithm.hpp`⁵⁸⁷.

See *Public API* for a list of names and headers that are part of the public *HPX* API.

```
namespace hpx
```

```
    namespace experimental
```

```
        Top-level namespace.
```

Functions

```
template<typename T>
constexpr hpx::parallel::detail::reduction_helper<T, std::multiplies<T>> reduction_multiplies(T
                                                                                                    &var)
```

The function template *reduction_multiplies* returns a reduction object of unspecified type having a value type and encapsulating an identity value for the reduction, it uses `std::multiplies{ }` as its combiner function, and a live-out object from which the initial value is obtained and into which the final value is stored.

A parallel algorithm uses the *reduction_multiplies* object by allocating an unspecified number of instances, called views, of the reduction's value type. Each view is initialized with the reduction object's identity value, except that the live-out object (which was initialized by the caller) comprises one of the views. The algorithm passes a reference to a view to each application of an element-access function,

⁵⁸⁷ <http://github.com/STELLAR-GROUP/hpx/blob/8a3b7c1a4cb5693b2f7d9f587f759392ed0c51a0/libs/full/include/include/hpx/algorithm.hpp>

ensuring that no two concurrently-executing invocations share the same view. A view can be shared between two applications that do not execute concurrently, but initialization is performed only once per view.

Modifications to the view by the application of element access functions accumulate as partial results. At some point before the algorithm returns, the partial results are combined, two at a time, using the `std::multiplies{}` operation until a single value remains, which is then assigned back to the live-out object.

`T` shall meet the requirements of *CopyConstructible* and *MoveAssignable*.

Note: In order to produce useful results, modifications to the view should be limited to commutative operations closely related to the combiner operation.

Template Parameters

- **T** – The value type to be used by the induction object.
- **Op** – The type of the binary function (object) used to perform the reduction operation.

Parameters

- **var** – [in,out] The live-out value to use for the reduction object. This will hold the reduced value after the algorithm is finished executing.
- **identity** – [in] The identity value to use for the reduction operation. This argument is optional and defaults to a copy of *var*.

Returns This returns a reduction object of unspecified type having a value type of *T*. When the return value is used by an algorithm, the reference to *var* is used as the live-out object, new views are initialized to a copy of *identity*, and views are combined by invoking the copy of *combiner*, passing it the two views to be combined.

```
template<typename T>
constexpr hpx::parallel::detail::reduction_helper<T, std::multiplies<T>> reduction_multiplies(T
                                                                    &var,
                                                                    T
                                                                    const
                                                                    &iden-
                                                                    tity)
```

`hpx::experimental::reduction_plus`

Defined in header `hpx/algorithm.hpp`⁵⁸⁸.

See *Public API* for a list of names and headers that are part of the public *HPX* API.

```
namespace hpx
```

```
    namespace experimental
```

```
        Top-level namespace.
```

⁵⁸⁸ <http://github.com/STELLAR-GROUP/hpx/blob/8a3b7c1a4cb5693b2f7d9f587f759392ed0c51a0/libs/full/include/include/hpx/algorithm.hpp>

Functions

```
template<typename T>
constexpr hpx::parallel::detail::reduction_helper<T, std::plus<T>> reduction_plus(T &var)
```

The function template *reduction_plus* returns a reduction object of unspecified type having a value type and encapsulating an identity value for the reduction, it uses *std::plus*{ } as its combiner function, and a live-out object from which the initial value is obtained and into which the final value is stored.

A parallel algorithm uses the *reduction_plus* object by allocating an unspecified number of instances, called views, of the reduction's value type. Each view is initialized with the reduction object's identity value, except that the live-out object (which was initialized by the caller) comprises one of the views. The algorithm passes a reference to a view to each application of an element-access function, ensuring that no two concurrently-executing invocations share the same view. A view can be shared between two applications that do not execute concurrently, but initialization is performed only once per view.

Modifications to the view by the application of element access functions accumulate as partial results. At some point before the algorithm returns, the partial results are combined, two at a time, using the *std::plus*{ } operation until a single value remains, which is then assigned back to the live-out object.

T shall meet the requirements of *CopyConstructible* and *MoveAssignable*.

Note: In order to produce useful results, modifications to the view should be limited to commutative operations closely related to the combiner operation.

Template Parameters

- **T** – The value type to be used by the induction object.
- **Op** – The type of the binary function (object) used to perform the reduction operation.

Parameters

- **var** – [in,out] The live-out value to use for the reduction object. This will hold the reduced value after the algorithm is finished executing.
- **identity** – [in] The identity value to use for the reduction operation. This argument is optional and defaults to a copy of *var*.

Returns This returns a reduction object of unspecified type having a value type of *T*. When the return value is used by an algorithm, the reference to *var* is used as the live-out object, new views are initialized to a copy of identity, and views are combined by invoking the copy of combiner, passing it the two views to be combined.

```
template<typename T>
constexpr hpx::parallel::detail::reduction_helper<T, std::plus<T>> reduction_plus(T &var, T const
&identity)
```

hpx::generate, hpx::generate_n

Defined in header *hpx/algorithm.hpp*⁵⁸⁹.

See *Public API* for a list of names and headers that are part of the public HPX API.

namespace **hpx**

⁵⁸⁹ <http://github.com/STELLAR-GROUP/hpx/blob/8a3b7c1a4cb5693b2f7d9f587f759392ed0c51a0/libs/full/include/include/hpx/algorithm.hpp>

Functions

```
template<typename ExPolicy, typename FwdIter, typename F>  
hpx::parallel::util::detail::algorithm_result_t<ExPolicy, FwdIter> generate(ExPolicy &&policy, FwdIter  
first, FwdIter last, F &&f)
```

Assign each element in range [*first*, *last*) a value generated by the given function object *f*. Executed according to the policy.

The assignments in the parallel *generate* algorithm invoked with an execution policy object of type *sequenced_policy* execute in sequential order in the calling thread.

The assignments in the parallel *generate* algorithm invoked with an execution policy object of type *parallel_policy* or *parallel_task_policy* are permitted to execute in an unordered fashion in unspecified threads, and indeterminately sequenced within each thread.

Note: Complexity: Exactly *distance(first, last)* invocations of *f* and assignments.

Template Parameters

- **ExPolicy** – The type of the execution policy to use (deduced). It describes the manner in which the execution of the algorithm may be parallelized and the manner in which it executes the assignments.
- **FwdIter** – The type of the source iterators used (deduced). This iterator type must meet the requirements of a forward iterator.
- **F** – The type of the function/function object to use (deduced). Unlike its sequential form, the parallel overload of *equal* requires *F* to meet the requirements of *CopyConstructible*.

Parameters

- **policy** – The execution policy to use for the scheduling of the iterations.
- **first** – Refers to the beginning of the sequence of elements the algorithm will be applied to.
- **last** – Refers to the end of the sequence of elements the algorithm will be applied to.
- **f** – generator function that will be called. signature of function should be equivalent to the following:

```
Ret fun();
```

The type *Ret* must be such that an object of type *FwdIter* can be dereferenced and assigned a value of type *Ret*.

Returns The *generate* algorithm returns a *hpx::future*<*FwdIter*> if the execution policy is of type *sequenced_task_policy* or *parallel_task_policy* and returns *FwdIter* otherwise.

```
template<typename FwdIter, typename F>  
FwdIter generate(FwdIter first, FwdIter last, F &&f)
```

Assign each element in range [*first*, *last*) a value generated by the given function object *f*.

Note: Complexity: Exactly *distance(first, last)* invocations of *f* and assignments.

Template Parameters

- **FwdIter** – The type of the source iterators used (deduced). This iterator type must meet the requirements of a forward iterator.
- **F** – The type of the function/function object to use (deduced). Unlike its sequential form, the parallel overload of *equal* requires *F* to meet the requirements of *CopyConstructible*.

Parameters

- **first** – Refers to the beginning of the sequence of elements the algorithm will be applied to.
- **last** – Refers to the end of the sequence of elements the algorithm will be applied to.
- **f** – generator function that will be called. signature of function should be equivalent to the following:

```
Ret fun();
```

The type *Ret* must be such that an object of type *FwdIter* can be dereferenced and assigned a value of type *Ret*.

Returns The *generate* algorithm returns a *FwdIter*.

```
template<typename ExPolicy, typename FwdIter, typename Size, typename F>
hpx::parallel::util::detail::algorithm_result_t<ExPolicy, FwdIter> generate_n(ExPolicy &&policy, FwdIter
first, Size count, F &&f)
```

Assigns each element in range $[first, first+)$ a value generated by the given function object *f*. Executed according to the policy.

The assignments in the parallel *generate_n* algorithm invoked with an execution policy object of type *sequenced_policy* execute in sequential order in the calling thread.

The assignments in the parallel *generate_n* algorithm invoked with an execution policy object of type *parallel_policy* or *parallel_task_policy* are permitted to execute in an unordered fashion in unspecified threads, and indeterminately sequenced within each thread.

Note: Complexity: Exactly *count* invocations of *f* and assignments, for count > 0.

Template Parameters

- **ExPolicy** – The type of the execution policy to use (deduced). It describes the manner in which the execution of the algorithm may be parallelized and the manner in which it executes the assignments.
- **Size** – The type of a non-negative integral value specifying the number of items to iterate over.
- **FwdIter** – The type of the source iterators used (deduced). This iterator type must meet the requirements of an forward iterator.
- **F** – The type of the function/function object to use (deduced). Unlike its sequential form, the parallel overload of *equal* requires *F* to meet the requirements of *CopyConstructible*.

Parameters

- **policy** – The execution policy to use for the scheduling of the iterations.

- **first** – Refers to the beginning of the sequence of elements the algorithm will be applied to.
- **count** – Refers to the number of elements in the sequence the algorithm will be applied to.
- **f** – Refers to the generator function object that will be called. The signature of the function should be equivalent to

```
Ret fun();
```

The type *Ret* must be such that an object of type *OutputIt* can be dereferenced and assigned a value of type *Ret*.

Returns The *generate_n* algorithm returns a *hpx::future<FwdIter>* if the execution policy is of type *sequenced_task_policy* or *parallel_task_policy* and returns *FwdIter* otherwise. *generate_n* algorithm returns iterator one past the last element assigned if *count*>0, *first* otherwise.

```
template<typename FwdIter, typename Size, typename F>  
FwdIter generate_n(FwdIter first, Size count, F &&f)
```

Assigns each element in range [*first*, *first*+) a value generated by the given function object *f*.

Note: Complexity: Exactly *count* invocations of *f* and assignments, for *count* > 0.

Template Parameters

- **Size** – The type of a non-negative integral value specifying the number of items to iterate over.
- **FwdIter** – The type of the source iterators used (deduced). This iterator type must meet the requirements of an forward iterator.
- **F** – The type of the function/function object to use (deduced). Unlike its sequential form, the parallel overload of *equal* requires *F* to meet the requirements of *CopyConstructible*.

Parameters

- **first** – Refers to the beginning of the sequence of elements the algorithm will be applied to.
- **count** – Refers to the number of elements in the sequence the algorithm will be applied to.
- **f** – Refers to the generator function object that will be called. The signature of the function should be equivalent to

```
Ret fun();
```

The type *Ret* must be such that an object of type *OutputIt* can be dereferenced and assigned a value of type *Ret*.

Returns The *generate_n* algorithm returns a *FwdIter*. *generate_n* algorithm returns iterator one past the last element assigned if *count*>0, *first* otherwise.

hpx::includes

Defined in header `hpx/algorithm.hpp`⁵⁹⁰.

See *Public API* for a list of names and headers that are part of the public HPX API.

namespace **hpx**

Functions

```
template<typename ExPolicy, typename FwdIter1, typename FwdIter2, typename Pred =
    hpx::parallel::detail::less>
hpx::parallel::util::detail::algorithm_result_t<ExPolicy, bool>::type includes(ExPolicy &&policy, FwdIter1
    first1, FwdIter1 last1,
    FwdIter2 first2, FwdIter2
    last2, Pred &&op = Pred())
```

Returns true if every element from the sorted range $[first2, last2)$ is found within the sorted range $[first1, last1)$. Also returns true if $[first2, last2)$ is empty. The version expects both ranges to be sorted with the user supplied binary predicate f . Executed according to the policy.

The comparison operations in the parallel *includes* algorithm invoked with an execution policy object of type *sequenced_policy* execute in sequential order in the calling thread.

The comparison operations in the parallel *includes* algorithm invoked with an execution policy object of type *parallel_policy* or *parallel_task_policy* are permitted to execute in an unordered fashion in unspecified threads, and indeterminately sequenced within each thread.

Note: At most $2*(N1+N2-1)$ comparisons, where $N1 = \text{std::distance}(first1, last1)$ and $N2 = \text{std::distance}(first2, last2)$.

Template Parameters

- **ExPolicy** – The type of the execution policy to use (deduced). It describes the manner in which the execution of the algorithm may be parallelized and the manner in which it executes the assignments.
- **FwdIter1** – The type of the source iterators used for the first range (deduced). This iterator type must meet the requirements of an forward iterator.
- **FwdIter2** – The type of the source iterators used for the second range (deduced). This iterator type must meet the requirements of an forward iterator.
- **Pred** – The type of an optional function/function object to use. Unlike its sequential form, the parallel overload of *includes* requires *Pred* to meet the requirements of *Copy-Constructible*. This defaults to `std::less<>`

Parameters

- **policy** – The execution policy to use for the scheduling of the iterations.
- **first1** – Refers to the beginning of the sequence of elements of the first range the algorithm will be applied to.

⁵⁹⁰ <http://github.com/STELLAR-GROUP/hpx/blob/8a3b7c1a4cb5693b2f7d9f587f759392ed0c51a0/libs/full/include/include/hpx/algorithm.hpp>

- **last1** – Refers to the end of the sequence of elements of the first range the algorithm will be applied to.
- **first2** – Refers to the beginning of the sequence of elements of the second range the algorithm will be applied to.
- **last2** – Refers to the end of the sequence of elements of the second range the algorithm will be applied to.
- **op** – The binary predicate which returns true if the elements should be treated as includes. The signature of the predicate function should be equivalent to the following:

```
bool pred(const Type1 &a, const Type2 &b);
```

The signature does not need to have `const &`, but the function must not modify the objects passed to it. The types *Type1* and *Type2* must be such that objects of types *FwdIter1* and *FwdIter2* can be dereferenced and then implicitly converted to *Type1* and *Type2* respectively

Returns The *includes* algorithm returns a *hpx::future<bool>* if the execution policy is of type *sequenced_task_policy* or *parallel_task_policy* and returns *bool* otherwise. The *includes* algorithm returns true every element from the sorted range [*first2*, *last2*) is found within the sorted range [*first1*, *last1*). Also returns true if [*first2*, *last2*) is empty.

```
template<typename FwdIter1, typename FwdIter2, typename Pred = hpx::parallel::detail::less>
bool includes(FwdIter1 first1, FwdIter1 last1, FwdIter2 first2, FwdIter2 last2, Pred &&op = Pred())
```

Returns true if every element from the sorted range [*first2*, *last2*) is found within the sorted range [*first1*, *last1*). Also returns true if [*first2*, *last2*) is empty. The version expects both ranges to be sorted with the user supplied binary predicate *f*.

Note: At most $2 \cdot (N1 + N2 - 1)$ comparisons, where $N1 = \text{std::distance}(\text{first1}, \text{last1})$ and $N2 = \text{std::distance}(\text{first2}, \text{last2})$.

Template Parameters

- **FwdIter1** – The type of the source iterators used for the first range (deduced). This iterator type must meet the requirements of an forward iterator.
- **FwdIter2** – The type of the source iterators used for the second range (deduced). This iterator type must meet the requirements of an forward iterator.
- **Pred** – The type of an optional function/function object to use. Unlike its sequential form, the parallel overload of *includes* requires *Pred* to meet the requirements of *CopyConstructible*. This defaults to `std::less<>`

Parameters

- **first1** – Refers to the beginning of the sequence of elements of the first range the algorithm will be applied to.
- **last1** – Refers to the end of the sequence of elements of the first range the algorithm will be applied to.
- **first2** – Refers to the beginning of the sequence of elements of the second range the algorithm will be applied to.
- **last2** – Refers to the end of the sequence of elements of the second range the algorithm will be applied to.

- **op** – The binary predicate which returns true if the elements should be treated as includes. The signature of the predicate function should be equivalent to the following:

```
bool pred(const Type1 &a, const Type2 &b);
```

The signature does not need to have `const &`, but the function must not modify the objects passed to it. The types *Type1* and *Type2* must be such that objects of types *FwdIter1* and *FwdIter2* can be dereferenced and then implicitly converted to *Type1* and *Type2* respectively.

Returns The *includes* algorithm returns a *bool*. The *includes* algorithm returns true every element from the sorted range [*first2*, *last2*) is found within the sorted range [*first1*, *last1*). Also returns true if [*first2*, *last2*) is empty.

hpx::inclusive_scan

Defined in header `hpx/algorithm.hpp`⁵⁹¹.

See *Public API* for a list of names and headers that are part of the public *HPX* API.

namespace **hpx**

Functions

```
template<typename InIter, typename OutIter>
OutIter inclusive_scan(InIter first, InIter last, OutIter dest)
```

Assigns through each iterator *i* in [*result*, *result* + (*last* - *first*)) the value of GENERALIZED_NONCOMMUTATIVE_SUM(+, **first*, ..., *(*first* + (*i* - *result*))).

The reduce operations in the parallel *inclusive_scan* algorithm invoked without an execution policy object will execute in sequential order in the calling thread.

The difference between *exclusive_scan* and *inclusive_scan* is that *inclusive_scan* includes the *i*th input element in the *i*th sum.

Note: Complexity: $O(\textit{last} - \textit{first})$ applications of the predicate *op*, here `std::plus<>()`.

Note: GENERALIZED_NONCOMMUTATIVE_SUM(+, *a1*, ..., *aN*) is defined as:

- *a1* when *N* is 1
 - GENERALIZED_NONCOMMUTATIVE_SUM(+, *a1*, ..., *aK*)
 - GENERALIZED_NONCOMMUTATIVE_SUM(+, *aM*, ..., *aN*) where $1 < K+1 = M \leq N$.
-

Template Parameters

⁵⁹¹ <http://github.com/STELLAR-GROUP/hpx/blob/8a3b7c1a4cb5693b2f7d9f587f759392ed0c51a0/libs/full/include/include/hpx/algorithm.hpp>

- **InIter** – The type of the source iterators used (deduced). This iterator type must meet the requirements of an input iterator.
- **OutIter** – The type of the iterator representing the destination range (deduced). This iterator type must meet the requirements of an output iterator.

Parameters

- **first** – Refers to the beginning of the sequence of elements the algorithm will be applied to.
- **last** – Refers to the end of the sequence of elements the algorithm will be applied to.
- **dest** – Refers to the beginning of the destination range.

Returns The *inclusive_scan* algorithm returns *OutIter*. The *inclusive_scan* algorithm returns the output iterator to the element in the destination range, one past the last element copied.

```
template<typename ExPolicy, typename FwdIter1, typename FwdIter2>  
hpx::parallel::util::detail::algorithm_result_t<ExPolicy, FwdIter2> inclusive_scan(ExPolicy &&policy,  
                                         FwdIter1 first,  
                                         FwdIter1 last, FwdIter2  
                                         dest)
```

Assigns through each iterator *i* in [result, result + (last - first)) the value of GENERALIZED_NONCOMMUTATIVE_SUM(+, *first, ..., *(first + (i - result))). Executed according to the policy.

The reduce operations in the parallel *inclusive_scan* algorithm invoked with an execution policy object of type *sequenced_policy* execute in sequential order in the calling thread.

The reduce operations in the parallel *inclusive_scan* algorithm invoked with an execution policy object of type *parallel_policy* or *parallel_task_policy* are permitted to execute in an unordered fashion in unspecified threads, and indeterminately sequenced within each thread.

The difference between *exclusive_scan* and *inclusive_scan* is that *inclusive_scan* includes the *i*th input element in the *i*th sum.

Note: Complexity: $O(\text{last} - \text{first})$ applications of the predicate *op*, here `std::plus<>()`.

Note: GENERALIZED_NONCOMMUTATIVE_SUM(+, a1, ..., aN) is defined as:

- a1 when N is 1
 - GENERALIZED_NONCOMMUTATIVE_SUM(+, a1, ..., aK)
 - GENERALIZED_NONCOMMUTATIVE_SUM(+, aM, ..., aN) where $1 < K+1 = M \leq N$.
-

Template Parameters

- **ExPolicy** – The type of the execution policy to use (deduced). It describes the manner in which the execution of the algorithm may be parallelized and the manner in which it executes the assignments.
- **FwdIter1** – The type of the source iterators used (deduced). This iterator type must meet the requirements of an forward iterator.

- **FwdIter2** – The type of the iterator representing the destination range (deduced). This iterator type must meet the requirements of an forward iterator.

Parameters

- **policy** – The execution policy to use for the scheduling of the iterations.
- **first** – Refers to the beginning of the sequence of elements the algorithm will be applied to.
- **last** – Refers to the end of the sequence of elements the algorithm will be applied to.
- **dest** – Refers to the beginning of the destination range.

Returns The *inclusive_scan* algorithm returns a `hpx::future<FwdIter2>` if the execution policy is of type *sequenced_task_policy* or *parallel_task_policy* and returns *FwdIter2* otherwise. The *inclusive_scan* algorithm returns the output iterator to the element in the destination range, one past the last element copied.

```
template<typename InIter, typename OutIter, typename Op>
OutIter inclusive_scan(InIter first, InIter last, OutIter dest, Op &&op)
```

Assigns through each iterator *i* in `[result, result + (last - first))` the value of `GENERALIZED_NONCOMMUTATIVE_SUM(op, *first, ..., *(first + (i - result)))`.

The reduce operations in the parallel *inclusive_scan* algorithm invoked without an execution policy object will execute in sequential order in the calling thread.

The difference between *exclusive_scan* and *inclusive_scan* is that *inclusive_scan* includes the *i*th input element in the *i*th sum.

Note: Complexity: $O(\text{last} - \text{first})$ applications of the predicate *op*.

Note: `GENERALIZED_NONCOMMUTATIVE_SUM(+, a1, ..., aN)` is defined as:

- `a1` when `N` is 1
 - `GENERALIZED_NONCOMMUTATIVE_SUM(+, a1, ..., aK)`
– `GENERALIZED_NONCOMMUTATIVE_SUM(+, aM, ..., aN)` where $1 < K+1 = M \leq N$.
-

Template Parameters

- **InIter** – The type of the source iterators used (deduced). This iterator type must meet the requirements of an input iterator.
- **OutIter** – The type of the iterator representing the destination range (deduced). This iterator type must meet the requirements of an output iterator.
- **Op** – The type of the binary function object used for the reduction operation.

Parameters

- **first** – Refers to the beginning of the sequence of elements the algorithm will be applied to.
- **last** – Refers to the end of the sequence of elements the algorithm will be applied to.

- **dest** – Refers to the beginning of the destination range.
- **op** – Specifies the function (or function object) which will be invoked for each of the values of the input sequence. This is a binary predicate. The signature of this predicate should be equivalent to:

```
Ret fun(const Type1 &a, const Type1 &b);
```

The signature does not need to have `const&`, but the function must not modify the objects passed to it. The types *Type1* and *Ret* must be such that an object of a type as given by the input sequence can be implicitly converted to any of those types.

Returns The *inclusive_scan* algorithm returns *OutIter*. The *inclusive_scan* algorithm returns the output iterator to the element in the destination range, one past the last element copied.

```
template<typename ExPolicy, typename FwdIter1, typename FwdIter2, typename Op>
hpx::parallel::util::detail::algorithm_result_t<ExPolicy, FwdIter2> inclusive_scan(ExPolicy &&policy,
                                          FwdIter1 first,
                                          FwdIter1 last, FwdIter2
                                          dest, Op &&op)
```

Assigns through each iterator *i* in `[result, result + (last - first))` the value of `GENERALIZED_NONCOMMUTATIVE_SUM(op, *first, ..., *(first + (i - result)))`. Executed according to the policy.

The reduce operations in the parallel *inclusive_scan* algorithm invoked with an execution policy object of type *sequenced_policy* execute in sequential order in the calling thread.

The reduce operations in the parallel *inclusive_scan* algorithm invoked with an execution policy object of type *parallel_policy* or *parallel_task_policy* are permitted to execute in an unordered fashion in unspecified threads, and indeterminately sequenced within each thread.

The difference between *exclusive_scan* and *inclusive_scan* is that *inclusive_scan* includes the *i*th input element in the *i*th sum.

Note: Complexity: $O(\text{last} - \text{first})$ applications of the predicate *op*.

Note: `GENERALIZED_NONCOMMUTATIVE_SUM(+, a1, ..., aN)` is defined as:

- `a1` when *N* is 1
 - `GENERALIZED_NONCOMMUTATIVE_SUM(op, a1, ..., aK)`
 - `GENERALIZED_NONCOMMUTATIVE_SUM(+, aM, ..., aN)` where $1 < K+1 = M \leq N$.
-

Template Parameters

- **ExPolicy** – The type of the execution policy to use (deduced). It describes the manner in which the execution of the algorithm may be parallelized and the manner in which it executes the assignments.
- **FwdIter1** – The type of the source iterators used (deduced). This iterator type must meet the requirements of an forward iterator.

- **FwdIter2** – The type of the iterator representing the destination range (deduced). This iterator type must meet the requirements of an forward iterator.
- **Op** – The type of the binary function object used for the reduction operation.

Parameters

- **policy** – The execution policy to use for the scheduling of the iterations.
- **first** – Refers to the beginning of the sequence of elements the algorithm will be applied to.
- **last** – Refers to the end of the sequence of elements the algorithm will be applied to.
- **dest** – Refers to the beginning of the destination range.
- **op** – Specifies the function (or function object) which will be invoked for each of the values of the input sequence. This is a binary predicate. The signature of this predicate should be equivalent to:

```
Ret fun(const Type1 &a, const Type1 &b);
```

The signature does not need to have const&, but the function must not modify the objects passed to it. The types *Type1* and *Ret* must be such that an object of a type as given by the input sequence can be implicitly converted to any of those types.

Returns The *inclusive_scan* algorithm returns a `hpx::future<FwdIter2>` if the execution policy is of type *sequenced_task_policy* or *parallel_task_policy* and returns *FwdIter2* otherwise. The *inclusive_scan* algorithm returns the output iterator to the element in the destination range, one past the last element copied.

```
template<typename InIter, typename OutIter, typename Op, typename T>
```

```
OutIter inclusive_scan(InIter first, InIter last, OutIter dest, Op &&op, T init)
```

Assigns through each iterator *i* in `[result, result + (last - first))` the value of `GENERALIZED_NONCOMMUTATIVE_SUM(op, init, *first, ..., *(first + (i - result)))`.

The reduce operations in the parallel *inclusive_scan* algorithm invoked without an execution policy object will execute in sequential order in the calling thread.

The difference between *exclusive_scan* and *inclusive_scan* is that *inclusive_scan* includes the *i*th input element in the *i*th sum. If *op* is not mathematically associative, the behavior of *inclusive_scan* may be non-deterministic.

Note: Complexity: $O(\text{last} - \text{first})$ applications of the predicate *op*.

Note: `GENERALIZED_NONCOMMUTATIVE_SUM(op, a1, ..., aN)` is defined as:

- `a1` when `N` is 1
 - `op(GENERALIZED_NONCOMMUTATIVE_SUM(op, a1, ..., aK), GENERALIZED_NONCOMMUTATIVE_SUM(op, aM, ..., aN))` where $1 < K+1 = M \leq N$.
-

Template Parameters

- **InIter** – The type of the source iterators used (deduced). This iterator type must meet the requirements of an input iterator.
- **OutIter** – The type of the iterator representing the destination range (deduced). This iterator type must meet the requirements of an output iterator.
- **Op** – The type of the binary function object used for the reduction operation.
- **T** – The type of the value to be used as initial (and intermediate) values (deduced).

Parameters

- **first** – Refers to the beginning of the sequence of elements the algorithm will be applied to.
- **last** – Refers to the end of the sequence of elements the algorithm will be applied to.
- **dest** – Refers to the beginning of the destination range.
- **op** – Specifies the function (or function object) which will be invoked for each of the values of the input sequence. This is a binary predicate. The signature of this predicate should be equivalent to:

```
Ret fun(const Type1 &a, const Type1 &b);
```

The signature does not need to have `const&`, but the function must not modify the objects passed to it. The types *Type1* and *Ret* must be such that an object of a type as given by the input sequence can be implicitly converted to any of those types.

- **init** – The initial value for the generalized sum.

Returns The *inclusive_scan* algorithm returns *OutIter*. The *inclusive_scan* algorithm returns the output iterator to the element in the destination range, one past the last element copied.

```
template<typename ExPolicy, typename FwdIter1, typename FwdIter2, typename Op, typename T>
hpx::parallel::util::detail::algorithm_result_t<ExPolicy, FwdIter2> inclusive_scan(ExPolicy &&policy,
                                         FwdIter1 first,
                                         FwdIter1 last, FwdIter2
                                         dest, Op &&op, T init)
```

Assigns through each iterator *i* in `[result, result + (last - first))` the value of GENERALIZED_NONCOMMUTATIVE_SUM(`op, init, *first, ..., *(first + (i - result))`). Executed according to the policy.

The reduce operations in the parallel *inclusive_scan* algorithm invoked with an execution policy object of type *sequenced_policy* execute in sequential order in the calling thread.

The reduce operations in the parallel *inclusive_scan* algorithm invoked with an execution policy object of type *parallel_policy* or *parallel_task_policy* are permitted to execute in an unordered fashion in unspecified threads, and indeterminately sequenced within each thread.

The difference between *exclusive_scan* and *inclusive_scan* is that *inclusive_scan* includes the *i*th input element in the *i*th sum. If *op* is not mathematically associative, the behavior of *inclusive_scan* may be non-deterministic.

Note: Complexity: $O(\text{last} - \text{first})$ applications of the predicate *op*.

Note: GENERALIZED_NONCOMMUTATIVE_SUM(op, a1, ..., aN) is defined as:

- a1 when N is 1
 - op(GENERALIZED_NONCOMMUTATIVE_SUM(op, a1, ..., aK), GENERALIZED_NONCOMMUTATIVE_SUM(op, aM, ..., aN)) where $1 < K+1 = M \leq N$.
-

Template Parameters

- **ExPolicy** – The type of the execution policy to use (deduced). It describes the manner in which the execution of the algorithm may be parallelized and the manner in which it executes the assignments.
- **FwdIter1** – The type of the source iterators used (deduced). This iterator type must meet the requirements of an forward iterator.
- **FwdIter2** – The type of the iterator representing the destination range (deduced). This iterator type must meet the requirements of an forward iterator.
- **Op** – The type of the binary function object used for the reduction operation.
- **T** – The type of the value to be used as initial (and intermediate) values (deduced).

Parameters

- **policy** – The execution policy to use for the scheduling of the iterations.
- **first** – Refers to the beginning of the sequence of elements the algorithm will be applied to.
- **last** – Refers to the end of the sequence of elements the algorithm will be applied to.
- **dest** – Refers to the beginning of the destination range.
- **op** – Specifies the function (or function object) which will be invoked for each of the values of the input sequence. This is a binary predicate. The signature of this predicate should be equivalent to:

```
Ret fun(const Type1 &a, const Type1 &b);
```

The signature does not need to have const&, but the function must not modify the objects passed to it. The types *Type1* and *Ret* must be such that an object of a type as given by the input sequence can be implicitly converted to any of those types.

- **init** – The initial value for the generalized sum.

Returns The *inclusive_scan* algorithm returns a *hpx::future<FwdIter2>* if the execution policy is of type *sequenced_task_policy* or *parallel_task_policy* and returns *FwdIter2* otherwise. The *inclusive_scan* algorithm returns the output iterator to the element in the destination range, one past the last element copied.

hpx::is_heap, hpx::is_heap_until

Defined in header `hpx/algorithm.hpp`⁵⁹².

See *Public API* for a list of names and headers that are part of the public HPX API.

namespace **hpx**

Functions

```
template<typename ExPolicy, typename RandIter, typename Comp = hpx::parallel::detail::less>  
hpx::parallel::util::detail::algorithm_result_t<ExPolicy, bool> is_heap(ExPolicy &&policy, RandIter first,  
                                RandIter last, Comp &&comp =  
                                Comp())
```

Returns whether the range is max heap. That is, true if the range is max heap, false otherwise. The function uses the given comparison function object *comp* (defaults to using operator<()). Executed according to the policy.

comp has to induce a strict weak ordering on the values.

The application of function objects in parallel algorithm invoked with an execution policy object of type *sequenced_policy* execute in sequential order in the calling thread.

The application of function objects in parallel algorithm invoked with an execution policy object of type *parallel_policy* or *parallel_task_policy* are permitted to execute in an unordered fashion in unspecified threads, and indeterminately sequenced within each thread.

Note: Complexity: Linear in the distance between *first* and *last*.

Template Parameters

- **ExPolicy** – The type of the execution policy to use (deduced). It describes the manner in which the execution of the algorithm may be parallelized and the manner in which it executes the assignments.
- **RandIter** – The type of the source iterators used (deduced). This iterator type must meet the requirements of a random access iterator.
- **Comp** – The type of the function/function object to use (deduced).

Parameters

- **policy** – The execution policy to use for the scheduling of the iterations.
- **first** – Refers to the beginning of the sequence of elements the algorithm will be applied to.
- **last** – Refers to the end of the sequence of elements the algorithm will be applied to.
- **comp** – *comp* is a callable object. The return value of the INVOKE operation applied to an object of type *Comp*, when contextually converted to bool, yields true if the first argument of the call is less than the second, and false otherwise. It is assumed that *comp* will not apply any non-constant function through the dereferenced iterator.

⁵⁹² <http://github.com/STELLAR-GROUP/hpx/blob/8a3b7c1a4cb5693b2f7d9f587f759392ed0c51a0/libs/full/include/include/hpx/algorithm.hpp>

Returns The *is_heap* algorithm returns a *hpx::future<bool>* if the execution policy is of type *sequenced_task_policy* or *parallel_task_policy* and returns *bool* otherwise. The *is_heap* algorithm returns whether the range is max heap. That is, true if the range is max heap, false otherwise.

```
template<typename RandIter, typename Comp = hpx::parallel::detail::less>
bool is_heap(RandIter first, RandIter last, Comp &&comp = Comp())
```

Returns whether the range is max heap. That is, true if the range is max heap, false otherwise. The function uses the given comparison function object *comp* (defaults to using *operator<()*).

comp has to induce a strict weak ordering on the values.

Note: Complexity: Linear in the distance between *first* and *last*.

Template Parameters

- **RandIter** – The type of the source iterators used (deduced). This iterator type must meet the requirements of a random access iterator.
- **Comp** – The type of the function/function object to use (deduced).

Parameters

- **first** – Refers to the beginning of the sequence of elements the algorithm will be applied to.
- **last** – Refers to the end of the sequence of elements the algorithm will be applied to.
- **comp** – *comp* is a callable object. The return value of the INVOKE operation applied to an object of type *Comp*, when contextually converted to *bool*, yields true if the first argument of the call is less than the second, and false otherwise. It is assumed that *comp* will not apply any non-constant function through the dereferenced iterator.

Returns The *is_heap* a *bool*. The *is_heap* algorithm returns whether the range is max heap. That is, true if the range is max heap, false otherwise.

```
template<typename ExPolicy, typename RandIter, typename Comp = hpx::parallel::detail::less>
hpx::parallel::util::detail::algorithm_result_t<ExPolicy, RandIter> is_heap_until(ExPolicy &&policy,
                                                                              RandIter first, RandIter
                                                                              last, Comp &&comp =
                                                                              Comp())
```

Returns the upper bound of the largest range beginning at *first* which is a max heap. That is, the last iterator *it* for which range [first, it) is a max heap. The function uses the given comparison function object *comp* (defaults to using *operator<()*). Executed according to the policy.

comp has to induce a strict weak ordering on the values.

The application of function objects in parallel algorithm invoked with an execution policy object of type *sequenced_policy* execute in sequential order in the calling thread.

The application of function objects in parallel algorithm invoked with an execution policy object of type *parallel_policy* or *parallel_task_policy* are permitted to execute in an unordered fashion in unspecified threads, and indeterminately sequenced within each thread.

Note: Complexity: Linear in the distance between *first* and *last*.

Template Parameters

- **ExPolicy** – The type of the execution policy to use (deduced). It describes the manner in which the execution of the algorithm may be parallelized and the manner in which it executes the assignments.
- **RandIter** – The type of the source iterators used (deduced). This iterator type must meet the requirements of a random access iterator.
- **Comp** – The type of the function/function object to use (deduced).

Parameters

- **policy** – The execution policy to use for the scheduling of the iterations.
- **first** – Refers to the beginning of the sequence of elements the algorithm will be applied to.
- **last** – Refers to the end of the sequence of elements the algorithm will be applied to.
- **comp** – *comp* is a callable object. The return value of the INVOKE operation applied to an object of type *Comp*, when contextually converted to bool, yields true if the first argument of the call is less than the second, and false otherwise. It is assumed that *comp* will not apply any non-constant function through the dereferenced iterator.

Returns The *is_heap_until* algorithm returns a *hpx::future<RandIter>* if the execution policy is of type *sequenced_task_policy* or *parallel_task_policy* and returns *RandIter* otherwise. The *is_heap_until* algorithm returns the upper bound of the largest range beginning at *first* which is a max heap. That is, the last iterator *it* for which range [first, it) is a max heap.

```
template<typename RandIter, typename Comp = hpx::parallel::detail::less>  
RandIter is_heap_until(RandIter first, RandIter last, Comp &&comp = Comp())
```

Returns the upper bound of the largest range beginning at *first* which is a max heap. That is, the last iterator *it* for which range [first, it) is a max heap. The function uses the given comparison function object *comp* (defaults to using operator<()).

comp has to induce a strict weak ordering on the values.

Note: Complexity: Linear in the distance between *first* and *last*.

Template Parameters

- **RandIter** – The type of the source iterators used (deduced). This iterator type must meet the requirements of a random access iterator.
- **Comp** – The type of the function/function object to use (deduced).

Parameters

- **first** – Refers to the beginning of the sequence of elements the algorithm will be applied to.
- **last** – Refers to the end of the sequence of elements the algorithm will be applied to.
- **comp** – *comp* is a callable object. The return value of the INVOKE operation applied to an object of type *Comp*, when contextually converted to bool, yields true if the first argument of the call is less than the second, and false otherwise. It is assumed that *comp* will not apply any non-constant function through the dereferenced iterator.

Returns The *is_heap_until* algorithm returns a *RandIter*. The *is_heap_until* algorithm returns the upper bound of the largest range beginning at first which is a max heap. That is, the last iterator *it* for which range [first, it) is a max heap.

hpx::is_partitioned

Defined in header `hpx/algorithm.hpp`⁵⁹³.

See *Public API* for a list of names and headers that are part of the public HPX API.

namespace **hpx**

Functions

```
template<typename FwdIter, typename Pred>
bool is_partitioned(FwdIter first, FwdIter last, Pred &&pred)
    Determines if the range [first, last) is partitioned.
```

Note: Complexity: at most (N) predicate evaluations where $N = \text{distance}(\text{first}, \text{last})$.

Template Parameters

- **FwdIter** – The type of the source iterators used for the This iterator type must meet the requirements of a forward iterator.
- **Pred** – The type of the function/function object to use (deduced).

Parameters

- **first** – Refers to the beginning of the sequence of elements of that the algorithm will be applied to.
- **last** – Refers to the end of the sequence of elements of that the algorithm will be applied to.
- **pred** – Refers to the unary predicate which returns true for elements expected to be found in the beginning of the range. The signature of the function should be equivalent to

```
bool pred(const Type &a);
```

The signature does not need to have `const &`, but the function must not modify the objects passed to it. The type *Type* must be such that objects of types *FwdIter* can be dereferenced and then implicitly converted to *Type*.

Returns The *is_partitioned* algorithm returns *bool*. The *is_partitioned* algorithm returns true if each element in the sequence for which *pred* returns true precedes those for which *pred* returns false. Otherwise *is_partitioned* returns false. If the range [first, last) contains less than two elements, the function is always true.

```
template<typename ExPolicy, typename FwdIter, typename Pred>
```

⁵⁹³ <http://github.com/STELLAR-GROUP/hpx/blob/8a3b7c1a4cb5693b2f7d9f587f759392ed0c51a0/libs/full/include/include/hpx/algorithm.hpp>

```
hpx::parallel::util::detail::algorithm_result_t<ExPolicy, bool> is_partitioned(ExPolicy &&policy, FwdIter
first, FwdIter last, Pred
&&pred)
```

Determines if the range [first, last) is partitioned. Executed according to the policy.

The predicate operations in the parallel *is_partitioned* algorithm invoked with an execution policy object of type *sequenced_policy* executes in sequential order in the calling thread.

The comparison operations in the parallel *is_partitioned* algorithm invoked with an execution policy object of type *parallel_policy* or *parallel_task_policy* are permitted to execute in an unordered fashion in unspecified threads, and indeterminately sequenced within each thread.

Note: Complexity: at most (N) predicate evaluations where $N = \text{distance}(\text{first}, \text{last})$.

Template Parameters

- **ExPolicy** – The type of the execution policy to use (deduced). It describes the manner in which the execution of the algorithm may be parallelized and the manner in which it executes the assignments.
- **FwdIter** – The type of the source iterators used for the This iterator type must meet the requirements of a forward iterator.
- **Pred** – The type of the function/function object to use (deduced). *Pred* must be *CopyConstructible* when using a parallel policy.

Parameters

- **policy** – The execution policy to use for the scheduling of the iterations.
- **first** – Refers to the beginning of the sequence of elements of that the algorithm will be applied to.
- **last** – Refers to the end of the sequence of elements of that the algorithm will be applied to.
- **pred** – Refers to the unary predicate which returns true for elements expected to be found in the beginning of the range. The signature of the function should be equivalent to

```
bool pred(const Type &a);
```

The signature does not need to have const &, but the function must not modify the objects passed to it. The type *Type* must be such that objects of types *FwdIter* can be dereferenced and then implicitly converted to *Type*.

Returns The *is_partitioned* algorithm returns a *hpx::future<bool>* if the execution policy is of type *task_execution_policy* and returns *bool* otherwise. The *is_partitioned* algorithm returns true if each element in the sequence for which *pred* returns true precedes those for which *pred* returns false. Otherwise *is_partitioned* returns false. If the range [first, last) contains less than two elements, the function is always true.

hpx::is_sorted, hpx::is_sorted_until

Defined in header `hpx/algorithm.hpp`⁵⁹⁴.

See *Public API* for a list of names and headers that are part of the public HPX API.

namespace **hpx**

Functions

```
template<typename FwdIter, typename Pred = hpx::parallel::detail::less>
bool is_sorted(FwdIter first, FwdIter last, Pred &&pred = Pred())
```

Determines if the range [first, last) is sorted. Uses pred to compare elements.

The comparison operations in the parallel *is_sorted* algorithm executes in sequential order in the calling thread.

Note: Complexity: at most $(N+S-1)$ comparisons where N = distance(first, last). S = number of partitions

Template Parameters

- **FwdIter** – The type of the source iterators used for the This iterator type must meet the requirements of a forward iterator.
- **Pred** – The type of an optional function/function object to use.

Parameters

- **first** – Refers to the beginning of the sequence of elements of that the algorithm will be applied to.
- **last** – Refers to the end of the sequence of elements of that the algorithm will be applied to.
- **pred** – Refers to the binary predicate which returns true if the first argument should be treated as less than the second argument. The signature of the function should be equivalent to

```
bool pred(const Type &a, const Type &b);
```

The signature does not need to have const &, but the function must not modify the objects passed to it. The type *Type* must be such that objects of types *FwdIter* can be dereferenced and then implicitly converted to *Type*.

Returns The *is_sorted* algorithm returns a *bool*. The *is_sorted* algorithm returns true if each element in the sequence [first, last) satisfies the predicate passed. If the range [first, last) contains less than two elements, the function always returns true.

```
template<typename ExPolicy, typename FwdIter, typename Pred = hpx::parallel::detail::less>
```

⁵⁹⁴ <http://github.com/STELLAR-GROUP/hpx/blob/8a3b7c1a4cb5693b2f7d9f587f759392ed0c51a0/libs/full/include/include/hpx/algorithm.hpp>

```
hpx::parallel::util::detail::algorithm_result_t<ExPolicy, bool> is_sorted(ExPolicy &&policy, FwdIter first,
                                                                    FwdIter last, Pred &&pred =
                                                                    Pred())
```

Determines if the range [first, last) is sorted. Uses pred to compare elements. Executed according to the policy.

The comparison operations in the parallel *is_sorted* algorithm invoked with an execution policy object of type *sequenced_policy* executes in sequential order in the calling thread.

The comparison operations in the parallel *is_sorted* algorithm invoked with an execution policy object of type *parallel_policy* or *parallel_task_policy* are permitted to execute in an unordered fashion in unspecified threads, and indeterminately sequenced within each thread.

Note: Complexity: at most $(N+S-1)$ comparisons where N = distance(first, last). S = number of partitions

Template Parameters

- **ExPolicy** – The type of the execution policy to use (deduced). It describes the manner in which the execution of the algorithm may be parallelized and the manner in which it executes the assignments.
- **FwdIter** – The type of the source iterators used for the This iterator type must meet the requirements of a forward iterator.
- **Pred** – The type of an optional function/function object to use. Unlike its sequential form, the parallel overload of *is_sorted* requires *Pred* to meet the requirements of *CopyConstructible*. This defaults to `std::less<>`

Parameters

- **policy** – The execution policy to use for the scheduling of the iterations.
- **first** – Refers to the beginning of the sequence of elements of that the algorithm will be applied to.
- **last** – Refers to the end of the sequence of elements of that the algorithm will be applied to.
- **pred** – Refers to the binary predicate which returns true if the first argument should be treated as less than the second argument. The signature of the function should be equivalent to

```
bool pred(const Type &a, const Type &b);
```

The signature does not need to have `const &`, but the function must not modify the objects passed to it. The type *Type* must be such that objects of types *FwdIter* can be dereferenced and then implicitly converted to *Type*.

Returns The *is_sorted* algorithm returns a *hpx::future<bool>* if the execution policy is of type *task_execution_policy* and returns *bool* otherwise. The *is_sorted* algorithm returns a *bool* if each element in the sequence [first, last) satisfies the predicate passed. If the range [first, last) contains less than two elements, the function always returns true.

```
template<typename FwdIter, typename Pred = hpx::parallel::detail::less>
```

FwdIter **is_sorted_until**(*FwdIter* first, *FwdIter* last, *Pred* &&pred = *Pred*())

Returns the first element in the range [first, last) that is not sorted. Uses a predicate to compare elements or the less than operator.

The comparison operations in the parallel *is_sorted_until* algorithm execute in sequential order in the calling thread.

Note: Complexity: at most $(N+S-1)$ comparisons where N = distance(first, last). S = number of partitions

Template Parameters

- **FwdIter** – The type of the source iterators used for the This iterator type must meet the requirements of a forward iterator.
- **Pred** – The type of an optional function/function object to use.

Parameters

- **first** – Refers to the beginning of the sequence of elements of that the algorithm will be applied to.
- **last** – Refers to the end of the sequence of elements of that the algorithm will be applied to.
- **pred** – Refers to the binary predicate which returns true if the first argument should be treated as less than the second argument. The signature of the function should be equivalent to

```
bool pred(const Type &a, const Type &b);
```

The signature does not need to have const &, but the function must not modify the objects passed to it. The type *Type* must be such that objects of types *FwdIter* can be dereferenced and then implicitly converted to *Type*.

Returns The *is_sorted_until* algorithm returns a *FwdIter*. The *is_sorted_until* algorithm returns the first unsorted element. If the sequence has less than two elements or the sequence is sorted, last is returned.

```
template<typename ExPolicy, typename FwdIter, typename Pred = hpx::parallel::detail::less>
hpx::parallel::util::detail::algorithm_result<ExPolicy, FwdIter>::type is_sorted_until(ExPolicy &&policy,
                                          FwdIter first,
                                          FwdIter last, Pred
                                          &&pred = Pred())
```

Returns the first element in the range [first, last) that is not sorted. Uses a predicate to compare elements or the less than operator. Executed according to the policy.

The comparison operations in the parallel *is_sorted_until* algorithm invoked with an execution policy object of type *sequenced_policy* executes in sequential order in the calling thread.

The comparison operations in the parallel *is_sorted_until* algorithm invoked with an execution policy object of type *parallel_policy* or *parallel_task_policy* are permitted to execute in an unordered fashion in unspecified threads, and indeterminately sequenced within each thread.

Note: Complexity: at most $(N+S-1)$ comparisons where $N = \text{distance}(\text{first}, \text{last})$. $S = \text{number of partitions}$

Template Parameters

- **ExPolicy** – The type of the execution policy to use (deduced). It describes the manner in which the execution of the algorithm may be parallelized and the manner in which it executes the assignments.
- **FwdIter** – The type of the source iterators used for the This iterator type must meet the requirements of a forward iterator.
- **Pred** – The type of an optional function/function object to use. Unlike its sequential form, the parallel overload of *is_sorted_until* requires *Pred* to meet the requirements of *Copy-Constructible*. This defaults to `std::less<>`

Parameters

- **policy** – The execution policy to use for the scheduling of the iterations.
- **first** – Refers to the beginning of the sequence of elements of that the algorithm will be applied to.
- **last** – Refers to the end of the sequence of elements of that the algorithm will be applied to.
- **pred** – Refers to the binary predicate which returns true if the first argument should be treated as less than the second argument. The signature of the function should be equivalent to

```
bool pred(const Type &a, const Type &b);
```

The signature does not need to have `const &`, but the function must not modify the objects passed to it. The type *Type* must be such that objects of types *FwdIter* can be dereferenced and then implicitly converted to *Type*.

Returns The *is_sorted_until* algorithm returns a *hpx::future<FwdIter>* if the execution policy is of type *task_execution_policy* and returns *FwdIter* otherwise. The *is_sorted_until* algorithm returns the first unsorted element. If the sequence has less than two elements or the sequence is sorted, *last* is returned.

hpx::lexicographical_compare

Defined in header `hpx/algorithm.hpp`⁵⁹⁵.

See *Public API* for a list of names and headers that are part of the public *HPX* API.

namespace **hpx**

⁵⁹⁵ <http://github.com/STELLAR-GROUP/hpx/blob/8a3b7c1a4cb5693b2f7d9f587f759392ed0c51a0/libs/full/include/include/hpx/algorithm.hpp>

Functions

```
template<typename InIter1, typename InIter2, typename Pred = hpx::parallel::detail::less>
bool lexicographical_compare(InIter1 first1, InIter1 last1, InIter2 first2, InIter2 last2, Pred &&pred)
```

Checks if the first range [first1, last1) is lexicographically less than the second range [first2, last2). uses a provided predicate to compare elements.

The comparison operations in the parallel *lexicographical_compare* algorithm invoked without an execution policy object execute in sequential order in the calling thread.

Note: Complexity: At most $2 * \min(N1, N2)$ applications of the comparison operation, where $N1 = \text{std::distance}(\text{first1}, \text{last})$ and $N2 = \text{std::distance}(\text{first2}, \text{last2})$.

Note: Lexicographical comparison is an operation with the following properties

- Two ranges are compared element by element
 - The first mismatching element defines which range is lexicographically *less* or *greater* than the other
 - If one range is a prefix of another, the shorter range is lexicographically *less* than the other
 - If two ranges have equivalent elements and are of the same length, then the ranges are lexicographically *equal*
 - An empty range is lexicographically *less* than any non-empty range
 - Two empty ranges are lexicographically *equal*
-

Template Parameters

- **InIter1** – The type of the source iterators used for the first range (deduced). This iterator type must meet the requirements of an input iterator.
- **InIter2** – The type of the source iterators used for the second range (deduced). This iterator type must meet the requirements of an input iterator.
- **Pred** – The type of an optional function/function object to use. Unlike its sequential form, the parallel overload of *lexicographical_compare* requires *Pred* to meet the requirements of *CopyConstructible*. This defaults to `std::less<>`

Parameters

- **first1** – Refers to the beginning of the sequence of elements of the first range the algorithm will be applied to.
- **last1** – Refers to the end of the sequence of elements of the first range the algorithm will be applied to.
- **first2** – Refers to the beginning of the sequence of elements of the second range the algorithm will be applied to.
- **last2** – Refers to the end of the sequence of elements of the second range the algorithm will be applied to.
- **pred** – Refers to the comparison function that the first and second ranges will be applied to

Returns The *lexicographically_compare* algorithm returns a *bool* if the execution policy object is not passed in. The *lexicographically_compare* algorithm returns true if the first range is lexicographically less, otherwise it returns false. *range* [first2, last2), it returns false.

```
template<typename ExPolicy, typename FwdIter1, typename FwdIter2, typename Pred =  
hpx::parallel::detail::less>  
hpx::parallel::util::detail::algorithm_result_t<ExPolicy, bool> lexicographical_compare(ExPolicy  
                                                &&policy,  
                                                FwdIter1 first1,  
                                                FwdIter1 last1,  
                                                FwdIter2 first2,  
                                                FwdIter2 last2,  
                                                Pred &&pred)
```

Checks if the first range [first1, last1) is lexicographically less than the second range [first2, last2). uses a provided predicate to compare elements.

The comparison operations in the parallel *lexicographical_compare* algorithm invoked with an execution policy object of type *sequenced_policy* execute in sequential order in the calling thread.

The comparison operations in the parallel *lexicographical_compare* algorithm invoked with an execution policy object of type *parallel_policy* or *parallel_task_policy* are permitted to execute in an unordered fashion in unspecified threads, and indeterminately sequenced within each thread.

Note: Complexity: At most $2 * \min(N1, N2)$ applications of the comparison operation, where $N1 = \text{std::distance}(\text{first1}, \text{last})$ and $N2 = \text{std::distance}(\text{first2}, \text{last2})$.

Note: Lexicographical comparison is an operation with the following properties

- Two ranges are compared element by element
 - The first mismatching element defines which range is lexicographically *less* or *greater* than the other
 - If one range is a prefix of another, the shorter range is lexicographically *less* than the other
 - If two ranges have equivalent elements and are of the same length, then the ranges are lexicographically *equal*
 - An empty range is lexicographically *less* than any non-empty range
 - Two empty ranges are lexicographically *equal*
-

Template Parameters

- **ExPolicy** – The type of the execution policy to use (deduced). It describes the manner in which the execution of the algorithm may be parallelized and the manner in which it executes the assignments.
- **FwdIter1** – The type of the source iterators used for the first range (deduced). This iterator type must meet the requirements of an forward iterator.
- **FwdIter2** – The type of the source iterators used for the second range (deduced). This iterator type must meet the requirements of an forward iterator.

- **Pred** – The type of an optional function/function object to use. Unlike its sequential form, the parallel overload of *lexicographical_compare* requires *Pred* to meet the requirements of *CopyConstructible*. This defaults to `std::less<>`

Parameters

- **policy** – The execution policy to use for the scheduling of the iterations.
- **first1** – Refers to the beginning of the sequence of elements of the first range the algorithm will be applied to.
- **last1** – Refers to the end of the sequence of elements of the first range the algorithm will be applied to.
- **first2** – Refers to the beginning of the sequence of elements of the second range the algorithm will be applied to.
- **last2** – Refers to the end of the sequence of elements of the second range the algorithm will be applied to.
- **pred** – Refers to the comparison function that the first and second ranges will be applied to

Returns The *lexicographically_compare* algorithm returns a *hpx::future<bool>* if the execution policy is of type *sequenced_task_policy* or *parallel_task_policy* and returns *bool* otherwise. The *lexicographically_compare* algorithm returns true if the first range is lexicographically less, otherwise it returns false. range [first2, last2), it returns false.

hpx::make_heap

Defined in header `hpx/algorithm.hpp`⁵⁹⁶.

See *Public API* for a list of names and headers that are part of the public *HPX* API.

namespace **hpx**

Functions

```
template<typename ExPolicy, typename RndIter, typename Comp>
hpx::parallel::util::detail::algorithm_result_t<ExPolicy> make_heap(ExPolicy &&policy, RndIter first,
                                                                    RndIter last, Comp &&comp)
```

Constructs a *max heap* in the range [first, last). Executed according to the policy.

The predicate operations in the parallel *make_heap* algorithm invoked with an execution policy object of type *sequential_execution_policy* executes in sequential order in the calling thread.

The comparison operations in the parallel *make_heap* algorithm invoked with an execution policy object of type *parallel_execution_policy* or *parallel_task_execution_policy* are permitted to execute in an unordered fashion in unspecified threads, and indeterminately sequenced within each thread.

Note: Complexity: at most (3*N) comparisons where *N* = distance(first, last).

⁵⁹⁶ <http://github.com/STELLAR-GROUP/hpx/blob/8a3b7c1a4cb5693b2f7d9f587f759392ed0c51a0/libs/full/include/include/hpx/algorithm.hpp>

Template Parameters

- **ExPolicy** – The type of the execution policy to use (deduced). It describes the manner in which the execution of the algorithm may be parallelized and the manner in which it executes the assignments.
- **RndIter** – The type of the source iterators used for algorithm. This iterator must meet the requirements for a random access iterator.
- **Comp** – Comparison function object (i.e. an object that satisfies the requirements of Compare) which returns true if the first argument is less than the second. The signature of the comparison function should be equivalent to the following:

```
bool cmp(const Type1 &a, const Type2 &b);
```

While the signature does not need to have `const &`, the function must not modify the objects passed to it and must be able to accept all values of type (possibly *const*) *Type1* and *Type2* regardless of value category (thus, *Type1 &* is not allowed, nor is *Type1* unless for *Type1* a move is equivalent to a copy. The types *Type1* and *Type2* must be such that an object of type *RandomIt* can be dereferenced and then implicitly converted to both of them.

Parameters

- **policy** – The execution policy to use for the scheduling of the iterations.
- **first** – Refers to the beginning of the sequence of elements of that the algorithm will be applied to.
- **last** – Refers to the end of the sequence of elements of that the algorithm will be applied to.
- **comp** – Refers to the binary predicate which returns true if the first argument should be treated as less than the second. The signature of the function should be equivalent to

```
bool comp(const Type &a, const Type &b);
```

The signature does not need to have `const &`, but the function must not modify the objects passed to it. The type *Type* must be such that objects of types *RndIter* can be dereferenced and then implicitly converted to *Type*.

Returns The *make_heap* algorithm returns a *hpx::future<void>* if the execution policy is of type *task_execution_policy* and returns *void* otherwise.

```
template<typename ExPolicy, typename RndIter>  
hpx::parallel::util::detail::algorithm_result_t<ExPolicy> make_heap(ExPolicy &&policy, RndIter first,  
                                                                    RndIter last)
```

Constructs a *max heap* in the range [first, last). Uses the operator < for comparisons. Executed according to the policy.

The predicate operations in the parallel *make_heap* algorithm invoked with an execution policy object of type *sequential_execution_policy* executes in sequential order in the calling thread.

The comparison operations in the parallel *make_heap* algorithm invoked with an execution policy object of type *parallel_execution_policy* or *parallel_task_execution_policy* are permitted to execute in an unordered fashion in unspecified threads, and indeterminately sequenced within each thread.

Note: Complexity: at most (3*N) comparisons where *N* = distance(first, last).

Template Parameters

- **ExPolicy** – The type of the execution policy to use (deduced). It describes the manner in which the execution of the algorithm may be parallelized and the manner in which it executes the assignments.
- **RndIter** – The type of the source iterators used for algorithm. This iterator must meet the requirements for a random access iterator.

Parameters

- **policy** – The execution policy to use for the scheduling of the iterations.
- **first** – Refers to the beginning of the sequence of elements of that the algorithm will be applied to.
- **last** – Refers to the end of the sequence of elements of that the algorithm will be applied to.

Returns The *make_heap* algorithm returns a *hpx::future<void>* if the execution policy is of type *task_execution_policy* and returns *void* otherwise.

```
template<typename RndIter, typename Comp>
void make_heap(RndIter first, RndIter last, Comp &&comp)
```

Constructs a *max heap* in the range [first, last).

Note: Complexity: at most (3*N) comparisons where *N* = distance(first, last).

Template Parameters

- **RndIter** – The type of the source iterators used for algorithm. This iterator must meet the requirements for a random access iterator.
- **Comp** – Comparison function object (i.e. an object that satisfies the requirements of Compare) which returns true if the first argument is less than the second. The signature of the comparison function should be equivalent to the following:

```
bool cmp(const Type1 &a, const Type2 &b);
```

While the signature does not need to have `const &`, the function must not modify the objects passed to it and must be able to accept all values of type (possibly *const*) *Type1* and *Type2* regardless of value category (thus, *Type1 &* is not allowed, nor is *Type1* unless for *Type1* a move is equivalent to a copy. The types *Type1* and *Type2* must be such that an object of type *RandomIt* can be dereferenced and then implicitly converted to both of them.

Parameters

- **first** – Refers to the beginning of the sequence of elements of that the algorithm will be applied to.
- **last** – Refers to the end of the sequence of elements of that the algorithm will be applied to.
- **comp** – Refers to the binary predicate which returns true if the first argument should be treated as less than the second. The signature of the function should be equivalent to

```
bool comp(const Type &a, const Type &b);
```

The signature does not need to have `const &`, but the function must not modify the objects passed to it. The type *Type* must be such that objects of types *RndIter* can be dereferenced and then implicitly converted to *Type*.

Returns The *make_heap* algorithm returns a *void*.

```
template<typename RndIter>
void make_heap(RndIter first, RndIter last)
    Constructs a max heap in the range [first, last).
```

Note: Complexity: at most (3*N) comparisons where *N* = distance(first, last).

Template Parameters **RndIter** – The type of the source iterators used for algorithm. This iterator must meet the requirements for a random access iterator.

Parameters

- **first** – Refers to the beginning of the sequence of elements of that the algorithm will be applied to.
- **last** – Refers to the end of the sequence of elements of that the algorithm will be applied to.

Returns The *make_heap* algorithm returns a *void*.

hpx::merge, hpx::inplace_merge

Defined in header `hpx/algorithm.hpp`⁵⁹⁷.

See *Public API* for a list of names and headers that are part of the public *HPX* API.

```
namespace hpx
```

Functions

```
template<typename ExPolicy, typename RandIter1, typename RandIter2, typename RandIter3,
typename Comp = hpx::parallel::detail::less>
hpx::parallel::util::detail::algorithm_result_t<ExPolicy, RandIter3> merge(ExPolicy &&policy, RandIter1
    first1, RandIter1 last1, RandIter2
    first2, RandIter2 last2, RandIter3
    dest, Comp &&comp = Comp())
```

Merges two sorted ranges [first1, last1) and [first2, last2) into one sorted range beginning at *dest*. The order of equivalent elements in the each of original two ranges is preserved. For equivalent elements in the original two ranges, the elements from the first range precede the elements from the second range. The destination range cannot overlap with either of the input ranges. Executed according to the policy.

The assignments in the parallel *merge* algorithm invoked with an execution policy object of type *sequenced_policy* execute in sequential order in the calling thread.

⁵⁹⁷ <http://github.com/STELLAR-GROUP/hpx/blob/8a3b7c1a4cb5693b2f7d9f587f759392ed0c51a0/libs/full/include/include/hpx/algorithm.hpp>

The assignments in the parallel *merge* algorithm invoked with an execution policy object of type *parallel_policy* or *parallel_task_policy* are permitted to execute in an unordered fashion in unspecified threads, and indeterminately sequenced within each thread.

Note: Complexity: Performs $O(\text{std::distance}(\text{first1}, \text{last1}) + \text{std::distance}(\text{first2}, \text{last2}))$ applications of the comparison *comp* and the each projection.

Template Parameters

- **ExPolicy** – The type of the execution policy to use (deduced). It describes the manner in which the execution of the algorithm may be parallelized and the manner in which it executes the assignments.
- **RandIter1** – The type of the source iterators used (deduced) representing the first sorted range. This iterator type must meet the requirements of a random access iterator.
- **RandIter2** – The type of the source iterators used (deduced) representing the second sorted range. This iterator type must meet the requirements of a random access iterator.
- **RandIter3** – The type of the iterator representing the destination range (deduced). This iterator type must meet the requirements of a random access iterator.
- **Comp** – The type of the function/function object to use (deduced). Unlike its sequential form, the parallel overload of *merge* requires *Comp* to meet the requirements of *CopyConstructible*. This defaults to `std::less<>`

Parameters

- **policy** – The execution policy to use for the scheduling of the iterations.
- **first1** – Refers to the beginning of the first range of elements the algorithm will be applied to.
- **last1** – Refers to the end of the first range of elements the algorithm will be applied to.
- **first2** – Refers to the beginning of the second range of elements the algorithm will be applied to.
- **last2** – Refers to the end of the second range of elements the algorithm will be applied to.
- **dest** – Refers to the beginning of the destination range.
- **comp** – *comp* is a callable object which returns true if the first argument is less than the second, and false otherwise. The signature of this comparison should be equivalent to:

```
bool comp(const Type1 &a, const Type2 &b);
```

The signature does not need to have `const&`, but the function must not modify the objects passed to it. The types *Type1* and *Type2* must be such that objects of types *RandIter1* and *RandIter2* can be dereferenced and then implicitly converted to both *Type1* and *Type2*

Returns The *merge* algorithm returns a `hpx::future<RandIter3>` if the execution policy is of type *sequenced_task_policy* or *parallel_task_policy* and returns *RandIter3* otherwise. The *merge* algorithm returns the destination iterator to the end of the *dest* range.

```
template<typename RandIter1, typename RandIter2, typename RandIter3, typename Comp =
hpx::parallel::detail::less>
```

RandIter3 **merge**(*RandIter1* first1, *RandIter1* last1, *RandIter2* first2, *RandIter2* last2, *RandIter3* dest, *Comp* &&comp = *Comp*())

Merges two sorted ranges [first1, last1) and [first2, last2) into one sorted range beginning at *dest*. The order of equivalent elements in the each of original two ranges is preserved. For equivalent elements in the original two ranges, the elements from the first range precede the elements from the second range. The destination range cannot overlap with either of the input ranges.

Note: Complexity: Performs $O(\text{std::distance}(\text{first1}, \text{last1}) + \text{std::distance}(\text{first2}, \text{last2}))$ applications of the comparison *comp* and the each projection.

Template Parameters

- **RandIter1** – The type of the source iterators used (deduced) representing the first sorted range. This iterator type must meet the requirements of a random access iterator.
- **RandIter2** – The type of the source iterators used (deduced) representing the second sorted range. This iterator type must meet the requirements of a random access iterator.
- **RandIter3** – The type of the iterator representing the destination range (deduced). This iterator type must meet the requirements of a random access iterator.
- **Comp** – The type of the function/function object to use (deduced). Unlike its sequential form, the parallel overload of *merge* requires *Comp* to meet the requirements of *CopyConstructible*. This defaults to `std::less<>`

Parameters

- **first1** – Refers to the beginning of the first range of elements the algorithm will be applied to.
- **last1** – Refers to the end of the first range of elements the algorithm will be applied to.
- **first2** – Refers to the beginning of the second range of elements the algorithm will be applied to.
- **last2** – Refers to the end of the second range of elements the algorithm will be applied to.
- **dest** – Refers to the beginning of the destination range.
- **comp** – *comp* is a callable object which returns true if the first argument is less than the second, and false otherwise. The signature of this comparison should be equivalent to:

```
bool comp(const Type1 &a, const Type2 &b);
```

The signature does not need to have `const&`, but the function must not modify the objects passed to it. The types *Type1* and *Type2* must be such that objects of types *RandIter1* and *RandIter2* can be dereferenced and then implicitly converted to both *Type1* and *Type2*

Returns The *merge* algorithm returns a *RandIter3*. The *merge* algorithm returns the destination iterator to the end of the *dest* range.

```
template<typename ExPolicy, typename RandIter, typename Comp = hpx::parallel::detail::less>
hpx::parallel::util::detail::algorithm_result_t<ExPolicy> inplace_merge(ExPolicy &&policy, RandIter first,
    RandIter middle, RandIter last,
    Comp &&comp = Comp())
```

Merges two consecutive sorted ranges [first, middle) and [middle, last) into one sorted range [first, last). The order of equivalent elements in the each of original two ranges is preserved. For equivalent elements

in the original two ranges, the elements from the first range precede the elements from the second range. Executed according to the policy.

The assignments in the parallel *inplace_merge* algorithm invoked with an execution policy object of type *sequenced_policy* execute in sequential order in the calling thread.

The assignments in the parallel *inplace_merge* algorithm invoked with an execution policy object of type *parallel_policy* or *parallel_task_policy* are permitted to execute in an unordered fashion in unspecified threads, and indeterminately sequenced within each thread.

Note: Complexity: Performs $O(\text{std::distance}(\text{first}, \text{last}))$ applications of the comparison *comp* and the each projection.

Template Parameters

- **ExPolicy** – The type of the execution policy to use (deduced). It describes the manner in which the execution of the algorithm may be parallelized and the manner in which it executes the assignments.
- **RandIter** – The type of the source iterators used (deduced). This iterator type must meet the requirements of a random access iterator.
- **Comp** – The type of the function/function object to use (deduced). Unlike its sequential form, the parallel overload of *inplace_merge* requires *Comp* to meet the requirements of *CopyConstructible*. This defaults to `std::less<>`

Parameters

- **policy** – The execution policy to use for the scheduling of the iterations.
- **first** – Refers to the beginning of the first sorted range the algorithm will be applied to.
- **middle** – Refers to the end of the first sorted range and the beginning of the second sorted range the algorithm will be applied to.
- **last** – Refers to the end of the second sorted range the algorithm will be applied to.
- **comp** – *comp* is a callable object which returns true if the first argument is less than the second, and false otherwise. The signature of this comparison should be equivalent to:

```
bool comp(const Type1 &a, const Type2 &b);
```

The signature does not need to have `const&`, but the function must not modify the objects passed to it. The types *Type1* and *Type2* must be such that objects of types *RandIter* can be dereferenced and then implicitly converted to both *Type1* and *Type2*

Returns The *inplace_merge* algorithm returns a `hpx::future<void>` if the execution policy is of type *sequenced_task_policy* or *parallel_task_policy* and returns void otherwise. The *inplace_merge* algorithm returns the source iterator *last*.

```
template<typename RandIter, typename Comp = hpx::parallel::detail::less>
void inplace_merge(RandIter first, RandIter middle, RandIter last, Comp &&comp = Comp())
```

Merges two consecutive sorted ranges [first, middle) and [middle, last) into one sorted range [first, last). The order of equivalent elements in the each of original two ranges is preserved. For equivalent elements in the original two ranges, the elements from the first range precede the elements from the second range.

Note: Complexity: Performs $O(\text{std::distance}(\text{first}, \text{last}))$ applications of the comparison *comp* and the each projection.

Template Parameters

- **RandIter** – The type of the source iterators used (deduced). This iterator type must meet the requirements of a random access iterator.
- **Comp** – The type of the function/function object to use (deduced). Unlike its sequential form, the parallel overload of *inplace_merge* requires *Comp* to meet the requirements of *CopyConstructible*. This defaults to `std::less<>`

Parameters

- **first** – Refers to the beginning of the first sorted range the algorithm will be applied to.
- **middle** – Refers to the end of the first sorted range and the beginning of the second sorted range the algorithm will be applied to.
- **last** – Refers to the end of the second sorted range the algorithm will be applied to.
- **comp** – *comp* is a callable object which returns true if the first argument is less than the second, and false otherwise. The signature of this comparison should be equivalent to:

```
bool comp(const Type1 &a, const Type2 &b);
```

The signature does not need to have `const&`, but the function must not modify the objects passed to it. The types *Type1* and *Type2* must be such that objects of types *RandIter* can be dereferenced and then implicitly converted to both *Type1* and *Type2*

Returns The *inplace_merge* algorithm returns a *void*. The *inplace_merge* algorithm returns the source iterator *last*.

hpx::min_element, hpx::max_element, hpx::minmax_element

Defined in header `hpx/algorithm.hpp`⁵⁹⁸.

See *Public API* for a list of names and headers that are part of the public *HPX* API.

namespace **hpx**

Functions

```
template<typename FwdIter, typename F = hpx::parallel::detail::less>  
FwdIter min_element(FwdIter first, FwdIter last, F &&f)
```

Finds the smallest element in the range `[first, last)` using the given comparison function *f*.

The comparisons in the parallel *min_element* algorithm execute in sequential order in the calling thread.

Note: Complexity: Exactly $\max(N-1, 0)$ comparisons, where $N = \text{std::distance}(\text{first}, \text{last})$.

⁵⁹⁸ <http://github.com/STELLAR-GROUP/hpx/blob/8a3b7c1a4cb5693b2f7d9f587f759392ed0c51a0/libs/full/include/include/hpx/algorithm.hpp>

Template Parameters

- **FwdIter** – The type of the source iterators used (deduced). This iterator type must meet the requirements of a forward iterator.
- **F** – The type of the function/function object to use (deduced).

Parameters

- **first** – Refers to the beginning of the sequence of elements the algorithm will be applied to.
- **last** – Refers to the end of the sequence of elements the algorithm will be applied to.
- **f** – The binary predicate which returns true if the the left argument is less than the right element. The signature of the predicate function should be equivalent to the following:

```
bool pred(const Type1 &a, const Type1 &b);
```

The signature does not need to have `const &`, but the function must not modify the objects passed to it. The type *Type1* must be such that objects of type *FwdIter* can be dereferenced and then implicitly converted to *Type1*.

Returns The *min_element* algorithm returns *FwdIter*. The *min_element* algorithm returns the iterator to the smallest element in the range [first, last). If several elements in the range are equivalent to the smallest element, returns the iterator to the first such element. Returns last if the range is empty.

```
template<typename ExPolicy, typename FwdIter, typename F = hpx::parallel::detail::less>
hpx::parallel::util::detail::algorithm_result_t<ExPolicy, FwdIter> min_element(ExPolicy &&policy, FwdIter
first, FwdIter last, F &&f)
```

Finds the smallest element in the range [first, last) using the given comparison function *f*. Executed according to the policy.

The comparisons in the parallel *min_element* algorithm invoked with an execution policy object of type *sequenced_policy* execute in sequential order in the calling thread.

The comparisons in the parallel *min_element* algorithm invoked with an execution policy object of type *parallel_policy* or *parallel_task_policy* are permitted to execute in an unordered fashion in unspecified threads, and indeterminately sequenced within each thread.

Note: Complexity: Exactly $\max(N-1, 0)$ comparisons, where $N = \text{std::distance}(\text{first}, \text{last})$.

Template Parameters

- **ExPolicy** – The type of the execution policy to use (deduced). It describes the manner in which the execution of the algorithm may be parallelized and the manner in which it executes the assignments.
- **FwdIter** – The type of the source iterators used (deduced). This iterator type must meet the requirements of a forward iterator.
- **F** – The type of the function/function object to use (deduced). Unlike its sequential form, the parallel overload of *min_element* requires *F* to meet the requirements of *CopyConstructible*.

Parameters

- **policy** – The execution policy to use for the scheduling of the iterations.
- **first** – Refers to the beginning of the sequence of elements the algorithm will be applied to.
- **last** – Refers to the end of the sequence of elements the algorithm will be applied to.
- **f** – The binary predicate which returns true if the the left argument is less than the right element. The signature of the predicate function should be equivalent to the following:

```
bool pred(const Type1 &a, const Type1 &b);
```

The signature does not need to have `const &`, but the function must not modify the objects passed to it. The type *Type1* must be such that objects of type *FwdIter* can be dereferenced and then implicitly converted to *Type1*.

Returns The *min_element* algorithm returns a `hpx::future<FwdIter>` if the execution policy is of type *sequenced_task_policy* or *parallel_task_policy* and returns *FwdIter* otherwise. The *min_element* algorithm returns the iterator to the smallest element in the range [first, last). If several elements in the range are equivalent to the smallest element, returns the iterator to the first such element. Returns last if the range is empty.

```
template<typename FwdIter, typename F = hpx::parallel::detail::less>  
FwdIter max_element(FwdIter first, FwdIter last, F &&f)
```

Finds the largest element in the range [first, last) using the given comparison function *f*.

The comparisons in the parallel *min_element* algorithm execute in sequential order in the calling thread.

Note: Complexity: Exactly $\max(N-1, 0)$ comparisons, where $N = \text{std::distance}(\text{first}, \text{last})$.

Template Parameters

- **FwdIter** – The type of the source iterators used (deduced). This iterator type must meet the requirements of a forward iterator.
- **F** – The type of the function/function object to use (deduced).

Parameters

- **first** – Refers to the beginning of the sequence of elements the algorithm will be applied to.
- **last** – Refers to the end of the sequence of elements the algorithm will be applied to.
- **f** – The binary predicate which returns true if the This argument is optional and defaults to `std::less`. the left argument is less than the right element. The signature of the predicate function should be equivalent to the following:

```
bool pred(const Type1 &a, const Type1 &b);
```

The signature does not need to have `const &`, but the function must not modify the objects passed to it. The type *Type1* must be such that objects of type *FwdIter* can be dereferenced and then implicitly converted to *Type1*.

Returns The *max_element* algorithm returns *FwdIter*. The *max_element* algorithm returns the iterator to the smallest element in the range [first, last). If several elements in the range are

equivalent to the smallest element, returns the iterator to the first such element. Returns last if the range is empty.

```
template<typename ExPolicy, typename FwdIter, typename F = hpx::parallel::detail::less>
hpx::parallel::util::detail::algorithm_result<ExPolicy, FwdIter>::type max_element(ExPolicy &&policy,
                                                                    FwdIter first, FwdIter
                                                                    last, F &&f)
```

Removes all elements satisfying specific criteria from the range Finds the largest element in the range [first, last) using the given comparison function *f*. Executed according to the policy.

The comparisons in the parallel *max_element* algorithm invoked with an execution policy object of type *sequenced_policy* execute in sequential order in the calling thread.

The comparisons in the parallel *max_element* algorithm invoked with an execution policy object of type *parallel_policy* or *parallel_task_policy* are permitted to execute in an unordered fashion in unspecified threads, and indeterminately sequenced within each thread.

Note: Complexity: Exactly $\max(N-1, 0)$ comparisons, where $N = \text{std::distance}(\text{first}, \text{last})$.

Template Parameters

- **ExPolicy** – The type of the execution policy to use (deduced). It describes the manner in which the execution of the algorithm may be parallelized and the manner in which it executes the assignments.
- **FwdIter** – The type of the source iterators used (deduced). This iterator type must meet the requirements of a forward iterator.
- **F** – The type of the function/function object to use (deduced). Unlike its sequential form, the parallel overload of *max_element* requires *F* to meet the requirements of *CopyConstructible*.

Parameters

- **policy** – The execution policy to use for the scheduling of the iterations.
- **first** – Refers to the beginning of the sequence of elements the algorithm will be applied to.
- **last** – Refers to the end of the sequence of elements the algorithm will be applied to.
- **f** – The binary predicate which returns true if the This argument is optional and defaults to `std::less`. the left argument is less than the right element. The signature of the predicate function should be equivalent to the following:

```
bool pred(const Type1 &a, const Type1 &b);
```

The signature does not need to have `const &`, but the function must not modify the objects passed to it. The type *Type1* must be such that objects of type *FwdIter* can be dereferenced and then implicitly converted to *Type1*.

Returns The *max_element* algorithm returns a *hpx::future*<*FwdIter*> if the execution policy is of type *sequenced_task_policy* or *parallel_task_policy* and returns *FwdIter* otherwise. The *max_element* algorithm returns the iterator to the smallest element in the range [first, last). If several elements in the range are equivalent to the smallest element, returns the iterator to the first such element. Returns last if the range is empty.

```
template<typename FwdIter, typename F = hpx::parallel::detail::less>
minmax_element_result<FwdIter> minmax_element(FwdIter first, FwdIter last, F &&f)
```

Finds the largest element in the range [first, last) using the given comparison function *f*.

The comparisons in the parallel *minmax_element* algorithm execute in sequential order in the calling thread.

Note: Complexity: At most $\max(\text{floor}(3/2*(N-1)), 0)$ applications of the predicate, where $N = \text{std::distance}(\text{first}, \text{last})$.

Template Parameters

- **FwdIter** – The type of the source iterators used (deduced). This iterator type must meet the requirements of a forward iterator.
- **F** – The type of the function/function object to use (deduced).

Parameters

- **first** – Refers to the beginning of the sequence of elements the algorithm will be applied to.
- **last** – Refers to the end of the sequence of elements the algorithm will be applied to.
- **f** – The binary predicate which returns true if the the left argument is less than the right element. This argument is optional and defaults to `std::less`. The signature of the predicate function should be equivalent to the following:

```
bool pred(const Type1 &a, const Type1 &b);
```

The signature does not need to have `const &`, but the function must not modify the objects passed to it. The type *Type1* must be such that objects of type *FwdIter* can be dereferenced and then implicitly converted to *Type1*.

Returns The *minmax_element* algorithm returns a *minmax_element_result<FwdIter>* The *minmax_element* algorithm returns a pair consisting of an iterator to the smallest element as the min element and an iterator to the largest element as the max element. Returns *minmax_element_result<FwdIter>{first,first}* if the range is empty. If several elements are equivalent to the smallest element, the iterator to the first such element is returned. If several elements are equivalent to the largest element, the iterator to the last such element is returned.

```
template<typename ExPolicy, typename FwdIter, typename F = hpx::parallel::detail::less>
hpx::parallel::util::detail::algorithm_result_t<ExPolicy, minmax_element_result<FwdIter>> minmax_element(ExPolicy
&&pol-
icy,
FwdIter
first,
FwdIter
last,
F
&&f)
```

Finds the largest element in the range [first, last) using the given comparison function *f*.

The comparisons in the parallel *minmax_element* algorithm invoked with an execution policy object of type *sequenced_policy* execute in sequential order in the calling thread.

The comparisons in the parallel *minmax_element* algorithm invoked with an execution policy object of type *parallel_policy* or *parallel_task_policy* are permitted to execute in an unordered fashion in unspecified threads, and indeterminately sequenced within each thread.

Note: Complexity: At most $\max(\text{floor}(3/2*(N-1)), 0)$ applications of the predicate, where $N = \text{std::distance}(\text{first}, \text{last})$.

Template Parameters

- **ExPolicy** – The type of the execution policy to use (deduced). It describes the manner in which the execution of the algorithm may be parallelized and the manner in which it executes the assignments.
- **FwdIter** – The type of the source iterators used (deduced). This iterator type must meet the requirements of a forward iterator.
- **F** – The type of the function/function object to use (deduced). Unlike its sequential form, the parallel overload of *minmax_element* requires *F* to meet the requirements of *CopyConstructible*.

Parameters

- **policy** – The execution policy to use for the scheduling of the iterations.
- **first** – Refers to the beginning of the sequence of elements the algorithm will be applied to.
- **last** – Refers to the end of the sequence of elements the algorithm will be applied to.
- **f** – The binary predicate which returns true if the the left argument is less than the right element. This argument is optional and defaults to `std::less`. The signature of the predicate function should be equivalent to the following:

```
bool pred(const Type1 &a, const Type1 &b);
```

The signature does not need to have `const &`, but the function must not modify the objects passed to it. The type *Type1* must be such that objects of type *FwdIter* can be dereferenced and then implicitly converted to *Type1*.

Returns The *minmax_element* algorithm returns a `hpx::future<minmax_element_result<FwdIter>>` if the execution policy is of type *sequenced_task_policy* or *parallel_task_policy* and returns `minmax_element_result<FwdIter>` otherwise. The *minmax_element* algorithm returns a pair consisting of an iterator to the smallest element as the min element and an iterator to the largest element as the max element. Returns `std::make_pair(first,first)` if the range is empty. If several elements are equivalent to the smallest element, the iterator to the first such element is returned. If several elements are equivalent to the largest element, the iterator to the last such element is returned.

hpx::mismatch

Defined in header `hpx/algorithm.hpp`⁵⁹⁹.

See *Public API* for a list of names and headers that are part of the public *HPX* API.

namespace **hpx**

Functions

```
template<typename ExPolicy, typename FwdIter1, typename FwdIter2, typename Pred>  
hpx::parallel::util::detail::algorithm_result_t<ExPolicy, std::pair<FwdIter1, FwdIter2>> mismatch(ExPolicy  
                                                                                               &&pol-  
                                                                                               icy,  
                                                                                               FwdIter1  
                                                                                               first1,  
                                                                                               FwdIter1  
                                                                                               last1,  
                                                                                               FwdIter2  
                                                                                               first2,  
                                                                                               FwdIter2  
                                                                                               last2,  
                                                                                               Pred  
                                                                                               &&op)
```

Returns the first mismatching pair of elements from two ranges: one defined by [first1, last1) and another defined by [first2,last2). If last2 is not provided, it denotes first2 + (last1 - first1). Executed according to the policy.

The comparison operations in the parallel *mismatch* algorithm invoked with an execution policy object of type *sequenced_policy* execute in sequential order in the calling thread.

The comparison operations in the parallel *mismatch* algorithm invoked with an execution policy object of type *parallel_policy* or *parallel_task_policy* are permitted to execute in an unordered fashion in unspecified threads, and indeterminately sequenced within each thread.

Note: Complexity: At most $\min(\text{last1} - \text{first1}, \text{last2} - \text{first2})$ applications of the predicate *op* or *operator==*. If *FwdIter1* and *FwdIter2* meet the requirements of *RandomAccessIterator* and $(\text{last1} - \text{first1}) \neq (\text{last2} - \text{first2})$ then no applications of the predicate *op* or *operator==* are made.

Note: The two ranges are considered mismatch if, for every iterator *i* in the range [first1,last1), **i* mismatches **(first2 + (i - first1))*. This overload of *mismatch* uses *operator==* to determine if two elements are mismatch.

Template Parameters

- **ExPolicy** – The type of the execution policy to use (deduced). It describes the manner in which the execution of the algorithm may be parallelized and the manner in which it executes the assignments.

⁵⁹⁹ <http://github.com/STELLAR-GROUP/hpx/blob/8a3b7c1a4cb5693b2f7d9f587f759392ed0c51a0/libs/full/include/include/hpx/algorithm.hpp>

- **FwdIter1** – The type of the source iterators used for the first range (deduced). This iterator type must meet the requirements of an forward iterator.
- **FwdIter2** – The type of the source iterators used for the second range (deduced). This iterator type must meet the requirements of an forward iterator.
- **Pred** – The type of an optional function/function object to use. Unlike its sequential form, the parallel overload of *mismatch* requires *Pred* to meet the requirements of *CopyConstructible*. This defaults to `std::equal_to<>`

Parameters

- **policy** – The execution policy to use for the scheduling of the iterations.
- **first1** – Refers to the beginning of the sequence of elements of the first range the algorithm will be applied to.
- **last1** – Refers to the end of the sequence of elements of the first range the algorithm will be applied to.
- **first2** – Refers to the beginning of the sequence of elements of the second range the algorithm will be applied to.
- **last2** – Refers to the end of the sequence of elements of the second range the algorithm will be applied to.
- **op** – The binary predicate which returns true if the elements should be treated as mismatch. The signature of the predicate function should be equivalent to the following:

```
bool pred(const Type1 &a, const Type2 &b);
```

The signature does not need to have `const &`, but the function must not modify the objects passed to it. The types *Type1* and *Type2* must be such that objects of types *FwdIter1* and *FwdIter2* can be dereferenced and then implicitly converted to *Type1* and *Type2* respectively

Returns The *mismatch* algorithm returns a `hpx::future<std::pair<FwdIter1,FwdIter2>>` if the execution policy is of type *sequenced_task_policy* or *parallel_task_policy* and returns `std::pair<FwdIter1,FwdIter2>` otherwise. If no mismatches are found when the comparison reaches `last1` or `last2`, whichever happens first, the pair holds the end iterator and the corresponding iterator from the other range.

```
template<typename ExPolicy, typename FwdIter1, typename FwdIter2>
hpx::parallel::util::detail::algorithm_result_t<ExPolicy, std::pair<FwdIter1, FwdIter2>> mismatch(ExPolicy
&&policy,
FwdIter1
first1,
FwdIter1
last1,
FwdIter2
first2,
FwdIter2
last2)
```

Returns the first mismatching pair of elements from two ranges: one defined by [`first1`, `last1`) and another defined by [`first2`,`last2`). If `last2` is not provided, it denotes `first2 + (last1 - first1)`. Executed according to the policy.

The comparison operations in the parallel *mismatch* algorithm invoked with an execution policy object of type *sequenced_policy* execute in sequential order in the calling thread.

The comparison operations in the parallel *mismatch* algorithm invoked with an execution policy object of type *parallel_policy* or *parallel_task_policy* are permitted to execute in an unordered fashion in unspecified threads, and indeterminately sequenced within each thread.

Note: Complexity: At most $\min(\text{last1} - \text{first1}, \text{last2} - \text{first2})$ applications of *operator==*. If *FwdIter1* and *FwdIter2* meet the requirements of *RandomAccessIterator* and $(\text{last1} - \text{first1}) \neq (\text{last2} - \text{first2})$ then no applications of *operator==* are made.

Note: The two ranges are considered mismatch if, for every iterator *i* in the range $[\text{first1}, \text{last1})$, **i* mismatches $*(\text{first2} + (i - \text{first1}))$. This overload of *mismatch* uses *operator==* to determine if two elements are mismatch.

Template Parameters

- **ExPolicy** – The type of the execution policy to use (deduced). It describes the manner in which the execution of the algorithm may be parallelized and the manner in which it executes the assignments.
- **FwdIter1** – The type of the source iterators used for the first range (deduced). This iterator type must meet the requirements of an forward iterator.
- **FwdIter2** – The type of the source iterators used for the second range (deduced). This iterator type must meet the requirements of an forward iterator.

Parameters

- **policy** – The execution policy to use for the scheduling of the iterations.
- **first1** – Refers to the beginning of the sequence of elements of the first range the algorithm will be applied to.
- **last1** – Refers to the end of the sequence of elements of the first range the algorithm will be applied to.
- **first2** – Refers to the beginning of the sequence of elements of the second range the algorithm will be applied to.
- **last2** – Refers to the end of the sequence of elements of the second range the algorithm will be applied to.

Returns The *mismatch* algorithm returns a `hpx::future<std::pair<FwdIter1, FwdIter2>>` if the execution policy is of type *sequenced_task_policy* or *parallel_task_policy* and returns `std::pair<FwdIter1, FwdIter2>` otherwise. If no mismatches are found when the comparison reaches *last1* or *last2*, whichever happens first, the pair holds the end iterator and the corresponding iterator from the other range.

```
template<typename ExPolicy, typename FwdIter1, typename FwdIter2, typename Pred>
```

```

hpx::parallel::util::detail::algorithm_result_t<ExPolicy, std::pair<FwdIter1, FwdIter2>> mismatch(ExPolicy
&&pol-
icy,
FwdIter1
first1,
FwdIter1
last1,
FwdIter2
first2,
Pred
&&op)

```

Returns the first mismatching pair of elements from two ranges: one defined by [first1, last1) and another defined by [first2,last2). If last2 is not provided, it denotes first2 + (last1 - first1). Executed according to the policy.

The comparison operations in the parallel *mismatch* algorithm invoked with an execution policy object of type *sequenced_policy* execute in sequential order in the calling thread.

The comparison operations in the parallel *mismatch* algorithm invoked with an execution policy object of type *parallel_policy* or *parallel_task_policy* are permitted to execute in an unordered fashion in unspecified threads, and indeterminately sequenced within each thread.

Note: Complexity: At most last1 - first1 applications of the predicate *op* or *operator==*. If *FwdIter1* and *FwdIter2* meet the requirements of *RandomAccessIterator* and (last1 - first1) != (last2 - first2) then no applications of the predicate *op* or *operator==* are made.

Note: The two ranges are considered mismatch if, for every iterator *i* in the range [first1,last1), **i* mismatches *(first2 + (i - first1)). This overload of *mismatch* uses *operator==* to determine if two elements are mismatch.

Template Parameters

- **ExPolicy** – The type of the execution policy to use (deduced). It describes the manner in which the execution of the algorithm may be parallelized and the manner in which it executes the assignments.
- **FwdIter1** – The type of the source iterators used for the first range (deduced). This iterator type must meet the requirements of an forward iterator.
- **FwdIter2** – The type of the source iterators used for the second range (deduced). This iterator type must meet the requirements of an forward iterator.
- **Pred** – The type of an optional function/function object to use. Unlike its sequential form, the parallel overload of *mismatch* requires *Pred* to meet the requirements of *CopyConstructible*. This defaults to `std::equal_to<>`

Parameters

- **policy** – The execution policy to use for the scheduling of the iterations.
- **first1** – Refers to the beginning of the sequence of elements of the first range the algorithm will be applied to.

- **last1** – Refers to the end of the sequence of elements of the first range the algorithm will be applied to.
- **first2** – Refers to the beginning of the sequence of elements of the second range the algorithm will be applied to.
- **op** – The binary predicate which returns true if the elements should be treated as mismatch. The signature of the predicate function should be equivalent to the following:

```
bool pred(const Type1 &a, const Type2 &b);
```

The signature does not need to have `const &`, but the function must not modify the objects passed to it. The types *Type1* and *Type2* must be such that objects of types *FwdIter1* and *FwdIter2* can be dereferenced and then implicitly converted to *Type1* and *Type2* respectively

Returns The *mismatch* algorithm returns a `hpx::future<std::pair<FwdIter1,FwdIter2>>` if the execution policy is of type *sequenced_task_policy* or *parallel_task_policy* and returns `std::pair<FwdIter1,FwdIter2>` otherwise. If no mismatches are found when the comparison reaches `last1` or `last2`, whichever happens first, the pair holds the end iterator and the corresponding iterator from the other range.

```
template<typename ExPolicy, typename FwdIter1, typename FwdIter2>
hpx::parallel::util::detail::algorithm_result_t<ExPolicy, std::pair<FwdIter1, FwdIter2>> mismatch(ExPolicy
&&policy,
FwdIter1
first1,
FwdIter1
last1,
FwdIter2
first2)
```

Returns the first mismatching pair of elements from two ranges: one defined by [`first1`, `last1`) and another defined by [`first2`,`last2`). If `last2` is not provided, it denotes `first2 + (last1 - first1)`. Executed according to the policy.

The comparison operations in the parallel *mismatch* algorithm invoked with an execution policy object of type *sequenced_policy* execute in sequential order in the calling thread.

The comparison operations in the parallel *mismatch* algorithm invoked with an execution policy object of type *parallel_policy* or *parallel_task_policy* are permitted to execute in an unordered fashion in unspecified threads, and indeterminately sequenced within each thread.

Note: Complexity: At most `last1 - first1` applications of *operator==*. If *FwdIter1* and *FwdIter2* meet the requirements of *RandomAccessIterator* and `(last1 - first1) != (last2 - first2)` then no applications of *operator==* are made.

Note: The two ranges are considered mismatch if, for every iterator *i* in the range [`first1`,`last1`), **i* mismatches **(first2 + (i - first1))*. This overload of *mismatch* uses *operator==* to determine if two elements are mismatch.

Template Parameters

- **ExPolicy** – The type of the execution policy to use (deduced). It describes the manner in which the execution of the algorithm may be parallelized and the manner in which it executes the assignments.
- **FwdIter1** – The type of the source iterators used for the first range (deduced). This iterator type must meet the requirements of an forward iterator.
- **FwdIter2** – The type of the source iterators used for the second range (deduced). This iterator type must meet the requirements of an forward iterator.
- **Pred** – The type of an optional function/function object to use. Unlike its sequential form, the parallel overload of *mismatch* requires *Pred* to meet the requirements of *CopyConstructible*. This defaults to `std::equal_to<>`

Parameters

- **policy** – The execution policy to use for the scheduling of the iterations.
- **first1** – Refers to the beginning of the sequence of elements of the first range the algorithm will be applied to.
- **last1** – Refers to the end of the sequence of elements of the first range the algorithm will be applied to.
- **first2** – Refers to the beginning of the sequence of elements of the second range the algorithm will be applied to.

Returns The *mismatch* algorithm returns a `hpx::future<std::pair<FwdIter1,FwdIter2>>` if the execution policy is of type *sequenced_task_policy* or *parallel_task_policy* and returns `std::pair<FwdIter1,FwdIter2>` otherwise. If no mismatches are found when the comparison reaches last1 or last2, whichever happens first, the pair holds the end iterator and the corresponding iterator from the other range.

```
template<typename FwdIter1, typename FwdIter2, typename Pred>
std::pair<FwdIter1, FwdIter2> mismatch(FwdIter1 first1, FwdIter1 last1, FwdIter2 first2, FwdIter2 last2,
                                     Pred &&op)
```

Returns the first mismatching pair of elements from two ranges: one defined by [first1, last1) and another defined by [first2, last2). If last2 is not provided, it denotes first2 + (last1 - first1).

Note: Complexity: At most $\min(\text{last1} - \text{first1}, \text{last2} - \text{first2})$ applications of the predicate *op* or *operator==*. If *FwdIter1* and *FwdIter2* meet the requirements of *RandomAccessIterator* and $(\text{last1} - \text{first1}) \neq (\text{last2} - \text{first2})$ then no applications of the predicate *op* or *operator==* are made.

Note: The two ranges are considered mismatch if, for every iterator *i* in the range [first1, last1), **i* mismatches $*(\text{first2} + (i - \text{first1}))$. This overload of *mismatch* uses *operator==* to determine if two elements are mismatch.

Template Parameters

- **FwdIter1** – The type of the source iterators used for the first range (deduced). This iterator type must meet the requirements of an forward iterator.
- **FwdIter2** – The type of the source iterators used for the second range (deduced). This iterator type must meet the requirements of an forward iterator.

- **Pred** – The type of an optional function/function object to use. Unlike its sequential form, the parallel overload of *mismatch* requires *Pred* to meet the requirements of *CopyConstructible*. This defaults to `std::equal_to<>`

Parameters

- **first1** – Refers to the beginning of the sequence of elements of the first range the algorithm will be applied to.
- **last1** – Refers to the end of the sequence of elements of the first range the algorithm will be applied to.
- **first2** – Refers to the beginning of the sequence of elements of the second range the algorithm will be applied to.
- **last2** – Refers to the end of the sequence of elements of the second range the algorithm will be applied to.
- **op** – The binary predicate which returns true if the elements should be treated as mismatch. The signature of the predicate function should be equivalent to the following:

```
bool pred(const Type1 &a, const Type2 &b);
```

The signature does not need to have `const &`, but the function must not modify the objects passed to it. The types *Type1* and *Type2* must be such that objects of types *FwdIter1* and *FwdIter2* can be dereferenced and then implicitly converted to *Type1* and *Type2* respectively

Returns The *mismatch* algorithm returns a `std::pair<FwdIter1,FwdIter2>`. If no mismatches are found when the comparison reaches `last1` or `last2`, whichever happens first, the pair holds the end iterator and the corresponding iterator from the other range.

```
template<typename FwdIter1, typename FwdIter2>  
std::pair<FwdIter1, FwdIter2> mismatch(FwdIter1 first1, FwdIter1 last1, FwdIter2 first2, FwdIter2 last2)
```

Returns the first mismatching pair of elements from two ranges: one defined by `[first1, last1)` and another defined by `[first2,last2)`. If `last2` is not provided, it denotes `first2 + (last1 - first1)`.

Note: Complexity: At most $\min(\text{last1} - \text{first1}, \text{last2} - \text{first2})$ applications of `operator==`. If *FwdIter1* and *FwdIter2* meet the requirements of *RandomAccessIterator* and $(\text{last1} - \text{first1}) \neq (\text{last2} - \text{first2})$ then no applications of `operator==` are made.

Note: The two ranges are considered mismatch if, for every iterator *i* in the range `[first1,last1)`, `*i` mismatches `*(first2 + (i - first1))`. This overload of *mismatch* uses `operator==` to determine if two elements are mismatch.

Template Parameters

- **FwdIter1** – The type of the source iterators used for the first range (deduced). This iterator type must meet the requirements of an forward iterator.
- **FwdIter2** – The type of the source iterators used for the second range (deduced). This iterator type must meet the requirements of an forward iterator.

Parameters

- **first1** – Refers to the beginning of the sequence of elements of the first range the algorithm will be applied to.
- **last1** – Refers to the end of the sequence of elements of the first range the algorithm will be applied to.
- **first2** – Refers to the beginning of the sequence of elements of the second range the algorithm will be applied to.
- **last2** – Refers to the end of the sequence of elements of the second range the algorithm will be applied to.

Returns The *mismatch* algorithm returns a `std::pair<FwdIter1,FwdIter2>`. If no mismatches are found when the comparison reaches `last1` or `last2`, whichever happens first, the pair holds the end iterator and the corresponding iterator from the other range.

```
template<typename FwdIter1, typename FwdIter2, typename Pred>
std::pair<FwdIter1, FwdIter2> mismatch(FwdIter1 first1, FwdIter1 last1, FwdIter2 first2, Pred &&op)
```

Returns the first mismatching pair of elements from two ranges: one defined by `[first1, last1)` and another defined by `[first2, last2)`. If `last2` is not provided, it denotes `first2 + (last1 - first1)`.

Note: Complexity: At most `last1 - first1` applications of the predicate *op* or *operator==*. If *FwdIter1* and *FwdIter2* meet the requirements of *RandomAccessIterator* and `(last1 - first1) != (last2 - first2)` then no applications of the predicate *op* or *operator==* are made.

Note: The two ranges are considered mismatch if, for every iterator *i* in the range `[first1, last1)`, **i* mismatches `*(first2 + (i - first1))`. This overload of *mismatch* uses *operator==* to determine if two elements are mismatch.

Template Parameters

- **FwdIter1** – The type of the source iterators used for the first range (deduced). This iterator type must meet the requirements of an forward iterator.
- **FwdIter2** – The type of the source iterators used for the second range (deduced). This iterator type must meet the requirements of an forward iterator.
- **Pred** – The type of an optional function/function object to use. Unlike its sequential form, the parallel overload of *mismatch* requires *Pred* to meet the requirements of *CopyConstructible*. This defaults to `std::equal_to<>`

Parameters

- **first1** – Refers to the beginning of the sequence of elements of the first range the algorithm will be applied to.
- **last1** – Refers to the end of the sequence of elements of the first range the algorithm will be applied to.
- **first2** – Refers to the beginning of the sequence of elements of the second range the algorithm will be applied to.
- **op** – The binary predicate which returns true if the elements should be treated as mismatch. The signature of the predicate function should be equivalent to the following:

```
bool pred(const Type1 &a, const Type2 &b);
```

The signature does not need to have `const &`, but the function must not modify the objects passed to it. The types *Type1* and *Type2* must be such that objects of types *FwdIter1* and *FwdIter2* can be dereferenced and then implicitly converted to *Type1* and *Type2* respectively

Returns The *mismatch* algorithm returns a `std::pair<FwdIter1,FwdIter2>`. If no mismatches are found when the comparison reaches `last1` or `last2`, whichever happens first, the pair holds the end iterator and the corresponding iterator from the other range.

```
template<typename FwdIter1, typename FwdIter2>
std::pair<FwdIter1, FwdIter2> mismatch(FwdIter1 first1, FwdIter1 last1, FwdIter2 first2)
```

Returns the first mismatching pair of elements from two ranges: one defined by `[first1, last1)` and another defined by `[first2, last2)`. If `last2` is not provided, it denotes `first2 + (last1 - first1)`.

Note: Complexity: At most `last1 - first1` applications of `operator==`. If *FwdIter1* and *FwdIter2* meet the requirements of *RandomAccessIterator* and `(last1 - first1) != (last2 - first2)` then no applications of `operator==` are made.

Note: The two ranges are considered mismatch if, for every iterator *i* in the range `[first1, last1)`, **i* mismatches `*(first2 + (i - first1))`. This overload of *mismatch* uses `operator==` to determine if two elements are mismatch.

Template Parameters

- **FwdIter1** – The type of the source iterators used for the first range (deduced). This iterator type must meet the requirements of an forward iterator.
- **FwdIter2** – The type of the source iterators used for the second range (deduced). This iterator type must meet the requirements of an forward iterator.
- **Pred** – The type of an optional function/function object to use. Unlike its sequential form, the parallel overload of *mismatch* requires *Pred* to meet the requirements of *CopyConstructible*. This defaults to `std::equal_to<>`

Parameters

- **first1** – Refers to the beginning of the sequence of elements of the first range the algorithm will be applied to.
- **last1** – Refers to the end of the sequence of elements of the first range the algorithm will be applied to.
- **first2** – Refers to the beginning of the sequence of elements of the second range the algorithm will be applied to.

Returns The *mismatch* algorithm returns a `std::pair<FwdIter1,FwdIter2>`. If no mismatches are found when the comparison reaches `last1` or `last2`, whichever happens first, the pair holds the end iterator and the corresponding iterator from the other range.

hpx::move

Defined in header `hpx/algorithm.hpp`⁶⁰⁰.

See *Public API* for a list of names and headers that are part of the public HPX API.

namespace **hpx**

Functions

```
template<typename ExPolicy, typename FwdIter1, typename FwdIter2>
hpx::parallel::util::detail::algorithm_result_t<ExPolicy, FwdIter2> move(ExPolicy &&policy, FwdIter1 first,
FwdIter1 last, FwdIter2 dest)
```

Moves the elements in the range `[first, last)`, to another range beginning at `dest`. After this operation the elements in the moved-from range will still contain valid values of the appropriate type, but not necessarily the same values as before the move. Executed according to the policy.

The move assignments in the parallel *move* algorithm invoked with an execution policy object of type *sequenced_policy* execute in sequential order in the calling thread.

The move assignments in the parallel *move* algorithm invoked with an execution policy object of type *parallel_policy* or *parallel_task_policy* are permitted to execute in an unordered fashion in unspecified threads, and indeterminately sequenced within each thread.

Note: Complexity: Performs exactly *last - first* move assignments.

Template Parameters

- **ExPolicy** – The type of the execution policy to use (deduced). It describes the manner in which the execution of the algorithm may be parallelized and the manner in which it executes the move assignments.
- **FwdIter1** – The type of the source iterators used (deduced). This iterator type must meet the requirements of an forward iterator.
- **FwdIter2** – The type of the iterator representing the destination range (deduced). This iterator type must meet the requirements of an forward iterator.

Parameters

- **policy** – The execution policy to use for the scheduling of the iterations.
- **first** – Refers to the beginning of the sequence of elements the algorithm will be applied to.
- **last** – Refers to the end of the sequence of elements the algorithm will be applied to.
- **dest** – Refers to the beginning of the destination range.

Returns The *move* algorithm returns a `hpx::future<FwdIter2>>` if the execution policy is of type *sequenced_task_policy* or *parallel_task_policy* and returns `FwdIter2` otherwise. The *move* algorithm returns the output iterator to the element in the destination range, one past the last element moved.

⁶⁰⁰ <http://github.com/STELLAR-GROUP/hpx/blob/8a3b7c1a4cb5693b2f7d9f587f759392ed0c51a0/libs/full/include/include/hpx/algorithm.hpp>

```
template<typename FwdIter1, typename FwdIter2>  
FwdIter2 move(FwdIter1 first, FwdIter1 last, FwdIter2 dest)
```

Moves the elements in the range [first, last), to another range beginning at *dest*. After this operation the elements in the moved-from range will still contain valid values of the appropriate type, but not necessarily the same values as before the move.

Note: Complexity: Performs exactly *last - first* move assignments.

Template Parameters

- **FwdIter1** – The type of the source iterators used (deduced). This iterator type must meet the requirements of an forward iterator.
- **FwdIter2** – The type of the iterator representing the destination range (deduced). This iterator type must meet the requirements of an forward iterator.

Parameters

- **first** – Refers to the beginning of the sequence of elements the algorithm will be applied to.
- **last** – Refers to the end of the sequence of elements the algorithm will be applied to.
- **dest** – Refers to the beginning of the destination range.

Returns The *move* algorithm returns a *FwdIter2*. The *move* algorithm returns the output iterator to the element in the destination range, one past the last element moved.

hpx::nth_element

Defined in header `hpx/algorithm.hpp`⁶⁰¹.

See *Public API* for a list of names and headers that are part of the public *HPX* API.

namespace **hpx**

Functions

```
template<typename RandomIt, typename Pred = hpx::parallel::detail::less>  
void nth_element(RandomIt first, RandomIt nth, RandomIt last, Pred &&pred = Pred())
```

nth_element is a partial sorting algorithm that rearranges elements in [first, last) such that the element pointed at by *nth* is changed to whatever element would occur in that position if [first, last) were sorted and all of the elements before this new *nth* element are less than or equal to the elements after the new *nth* element. Executed according to the policy.

The comparison operations in the parallel *nth_element* algorithm invoked without an execution policy object execute in sequential order in the calling thread.

Note: Complexity: Linear in `std::distance(first, last)` on average. $O(N)$ applications of the predicate, and $O(N \log N)$ swaps, where $N = last - first$.

⁶⁰¹ <http://github.com/STELLAR-GROUP/hpx/blob/8a3b7c1a4cb5693b2f7d9f587f759392ed0c51a0/libs/full/include/include/hpx/algorithm.hpp>

Template Parameters

- **RandomIt** – The type of the source begin, nth, and end iterators used (deduced). This iterator type must meet the requirements of a random access iterator.
- **Pred** – Comparison function object which returns true if the first argument is less than the second. This defaults to `std::less<>`.

Parameters

- **first** – Refers to the beginning of the sequence of elements the algorithm will be applied to.
- **nth** – Refers to the iterator defining the sort partition point
- **last** – Refers to the end of the sequence of elements the algorithm will be applied to.
- **pred** – Specifies the comparison function object which returns true if the first argument is less than (i.e. is ordered before) the second. The signature of this comparison function should be equivalent to:

```
bool cmp(const Type1 &a, const Type2 &b);
```

The signature does not need to have `const&`, but the function must not modify the objects passed to it. The type must be such that an object of type *randomIt* can be dereferenced and then implicitly converted to *Type*. This defaults to `std::less<>`.

Returns The *nth_element* algorithms returns nothing.

```
template<typename ExPolicy, typename RandomIt, typename Pred = hpx::parallel::detail::less>
void nth_element(ExPolicy &&policy, RandomIt first, RandomIt nth, RandomIt last, Pred &&pred =
    Pred())
```

nth_element is a partial sorting algorithm that rearranges elements in `[first, last)` such that the element pointed at by *nth* is changed to whatever element would occur in that position if `[first, last)` were sorted and all of the elements before this new *nth* element are less than or equal to the elements after the new *nth* element.

The comparison operations in the parallel *nth_element* invoked with an execution policy object of type *sequenced_policy* execute in sequential order in the calling thread.

The assignments in the parallel *nth_element* algorithm invoked with an execution policy object of type *parallel_policy* or *parallel_task_policy* are permitted to execute in an unordered fashion in unspecified threads, and indeterminately sequenced within each thread.

Note: Complexity: Linear in `std::distance(first, last)` on average. $O(N)$ applications of the predicate, and $O(N \log N)$ swaps, where $N = last - first$.

Template Parameters

- **ExPolicy** – The type of the execution policy to use (deduced). It describes the manner in which the execution of the algorithm may be parallelized and the manner in which it executes the assignments.
- **RandomIt** – The type of the source begin, nth, and end iterators used (deduced). This iterator type must meet the requirements of a random access iterator.

- **Pred** – Comparison function object which returns true if the first argument is less than the second. This defaults to `std::less<>`.

Parameters

- **policy** – The execution policy to use for the scheduling of the iterations.
- **first** – Refers to the beginning of the sequence of elements the algorithm will be applied to.
- **nth** – Refers to the iterator defining the sort partition point
- **last** – Refers to the end of the sequence of elements the algorithm will be applied to.
- **pred** – Specifies the comparison function object which returns true if the first argument is less than (i.e. is ordered before) the second. The signature of this comparison function should be equivalent to:

```
bool cmp(const Type1 &a, const Type2 &b);
```

The signature does not need to have `const&`, but the function must not modify the objects passed to it. The type must be such that an object of type *randomIt* can be dereferenced and then implicitly converted to *Type*. This defaults to `std::less<>`.

Returns The *nth_element* algorithms returns nothing.

hpx::partial_sort

Defined in header `hpx/algorithm.hpp`⁶⁰².

See *Public API* for a list of names and headers that are part of the public *HPX* API.

namespace **hpx**

Functions

```
template<typename RandIter, typename Comp = hpx::parallel::detail::less>  
RandIter partial_sort(RandIter first, RandIter middle, RandIter last, Comp &&comp = Comp())
```

Places the first middle - first elements from the range [first, last) as sorted with respect to *comp* into the range [first, middle). The rest of the elements in the range [middle, last) are placed in an unspecified order.

Note: Complexity: Approximately $(last - first) * \log(middle - first)$ comparisons.

Template Parameters

- **RandIter** – The type of the source begin, middle, and end iterators used (deduced). This iterator type must meet the requirements of a random access iterator.
- **Comp** – The type of the function/function object to use (deduced). *Comp* defaults to `detail::less`.

Parameters

- **first** – Refers to the beginning of the sequence of elements the algorithm will be applied to.

⁶⁰² <http://github.com/STELLAR-GROUP/hpx/blob/8a3b7c1a4cb5693b2f7d9f587f759392ed0c51a0/libs/full/include/include/hpx/algorithm.hpp>

- **middle** – Refers to the middle of the sequence of elements the algorithm will be applied to.
- **last** – Refers to the end of the sequence of elements the algorithm will be applied to.
- **comp** – comp is a callable object. The return value of the INVOKE operation applied to an object of type Comp, when contextually converted to bool, yields true if the first argument of the call is less than the second, and false otherwise. It is assumed that comp will not apply any non-constant function through the dereferenced iterator. It defaults to detail::less.

Returns The *partial_sort* algorithm returns a *RandIter* that refers to *last*.

```
template<typename ExPolicy, typename RandIter, typename Comp = hpx::parallel::detail::less>
parallel::util::detail::algorithm_result_t<ExPolicy, RandIter> partial_sort(ExPolicy &&policy, RandIter
    first, RandIter middle, RandIter
    last, Comp &&comp =
    Comp())
```

Places the first middle - first elements from the range [first, last) as sorted with respect to comp into the range [first, middle). The rest of the elements in the range [middle, last) are placed in an unspecified order.

Note: Complexity: Approximately (last - first) * log(middle - first) comparisons.

Template Parameters

- **ExPolicy** – The type of the execution policy to use (deduced). It describes the manner in which the execution of the algorithm may be parallelized and the manner in which it applies user-provided function objects.
- **RandIter** – The type of the source begin, middle, and end iterators used (deduced). This iterator type must meet the requirements of a random access iterator.
- **Comp** – The type of the function/function object to use (deduced). Comp defaults to detail::less.

Parameters

- **policy** – The execution policy to use for the scheduling of the iterations.
- **first** – Refers to the beginning of the sequence of elements the algorithm will be applied to.
- **middle** – Refers to the middle of the sequence of elements the algorithm will be applied to.
- **last** – Refers to the end of the sequence of elements the algorithm will be applied to.
- **comp** – comp is a callable object. The return value of the INVOKE operation applied to an object of type Comp, when contextually converted to bool, yields true if the first argument of the call is less than the second, and false otherwise. It is assumed that comp will not apply any non-constant function through the dereferenced iterator. It defaults to detail::less.

Returns The *partial_sort* algorithm returns a *hpx::future*<*RandIter*> if the execution policy is of type *sequenced_task_policy* or *parallel_task_policy* and returns *RandIter* otherwise. The iterator returned refers to *last*.

hpx::partial_sort_copy

Defined in header `hpx/algorithm.hpp`⁶⁰³.

See *Public API* for a list of names and headers that are part of the public HPX API.

namespace **hpx**

Functions

```
template<typename InIter, typename RandIter, typename Comp = hpx::parallel::detail::less>  
RandIter partial_sort_copy(InIter first, InIter last, RandIter d_first, RandIter d_last, Comp &&comp =  
    Comp())
```

Sorts some of the elements in the range `[first, last)` in ascending order, storing the result in the range `[d_first, d_last)`. At most `d_last - d_first` of the elements are placed sorted to the range `[d_first, d_first + n)` where `n` is the number of elements to sort (`n = min(last - first, d_last - d_first)`).

The application of function objects in parallel algorithm invoked with an execution policy object of type *sequenced_policy* execute in sequential order in the calling thread.

The application of function objects in parallel algorithm invoked with an execution policy object of type *parallel_policy* or *parallel_task_policy* are permitted to execute in an unordered fashion in unspecified threads, and indeterminately sequenced within each thread.

Note: Complexity: $O(N \log(\min(D, N)))$, where $N = \text{std::distance}(\text{first}, \text{last})$ and $D = \text{std::distance}(\text{d_first}, \text{d_last})$ comparisons.

Template Parameters

- **InIter** – The type of the source iterators used (deduced). This iterator type must meet the requirements of an input iterator.
- **RandIter** – The type of the destination iterators used (deduced). This iterator type must meet the requirements of a random iterator.
- **Comp** – The type of the function/function object to use (deduced). `Comp` defaults to `detail::less`.

Parameters

- **first** – Refers to the beginning of the sequence of elements the algorithm will be applied to.
- **last** – Refers to the end of the sequence of elements the algorithm will be applied to.
- **d_first** – Refers to the beginning of the destination range.
- **d_last** – Refers to the end of the destination range.
- **comp** – `comp` is a callable object. The return value of the INVOKE operation applied to an object of type `Comp`, when contextually converted to `bool`, yields `true` if the first argument of the call is less than the second, and `false` otherwise. It is assumed that `comp` will not apply any non-constant function through the dereferenced iterator. This defaults to `detail::less`.

⁶⁰³ <http://github.com/STELLAR-GROUP/hpx/blob/8a3b7c1a4cb5693b2f7d9f587f759392ed0c51a0/libs/full/include/include/hpx/algorithm.hpp>

Returns The *partial_sort_copy* algorithm returns a *RandomIt*. The algorithm returns an iterator to the element defining the upper boundary of the sorted range i.e. $d_first + \min(\text{last} - \text{first}, d_last - d_first)$

```
template<typename ExPolicy, typename FwdIter, typename RandIter, typename Comp =
    hpx::parallel::detail::less>
parallel::util::detail::algorithm_result_t<ExPolicy, RandIter> partial_sort_copy(ExPolicy &&policy,
    FwdIter first, FwdIter
    last, RandIter d_first,
    RandIter d_last, Comp
    &&comp = Comp())
```

Sorts some of the elements in the range [first, last) in ascending order, storing the result in the range [d_first, d_last). At most $d_last - d_first$ of the elements are placed sorted to the range [d_first, d_first + n) where n is the number of elements to sort ($n = \min(\text{last} - \text{first}, d_last - d_first)$). Executed according to the policy.

The application of function objects in parallel algorithm invoked with an execution policy object of type *sequenced_policy* execute in sequential order in the calling thread.

The application of function objects in parallel algorithm invoked with an execution policy object of type *parallel_policy* or *parallel_task_policy* are permitted to execute in an unordered fashion in unspecified threads, and indeterminately sequenced within each thread.

Note: Complexity: $O(N \log(\min(D, N)))$, where $N = \text{std::distance}(\text{first}, \text{last})$ and $D = \text{std::distance}(d_first, d_last)$ comparisons.

Template Parameters

- **ExPolicy** – The type of the execution policy to use (deduced). It describes the manner in which the execution of the algorithm may be parallelized and the manner in which it executes the assignments.
- **FwdIter** – The type of the source iterators used (deduced). This iterator type must meet the requirements of an forward iterator.
- **RandIter** – The type of the destination iterators used(deduced) This iterator type must meet the requirements of an random iterator.
- **Comp** – The type of the function/function object to use (deduced). Comp defaults to *detail::less*.

Parameters

- **policy** – The execution policy to use for the scheduling of the iterations.
- **first** – Refers to the beginning of the sequence of elements the algorithm will be applied to.
- **last** – Refers to the end of the sequence of elements the algorithm will be applied to.
- **d_first** – Refers to the beginning of the destination range.
- **d_last** – Refers to the end of the destination range.
- **comp** – comp is a callable object. The return value of the INVOKE operation applied to an object of type Comp, when contextually converted to bool, yields true if the first argument of the call is less than the second, and false otherwise. It is assumed that comp will not apply any non-constant function through the dereferenced iterator. This defaults to *detail::less*.

Returns The *partial_sort_copy* algorithm returns a *hpx::future<RandomIt>* if the execution policy is of type *sequenced_task_policy* or *parallel_task_policy* and returns *RandomIt* otherwise. The algorithm returns an iterator to the element defining the upper boundary of the sorted range i.e. $d_first + \min(\text{last} - \text{first}, d_last - d_first)$

hpx::partition, hpx::stable_partition, hpx::partition_copy

Defined in header `hpx/algorithm.hpp`⁶⁰⁴.

See *Public API* for a list of names and headers that are part of the public HPX API.

namespace **hpx**

Functions

```
template<typename FwdIter, typename Pred, typename Proj = hpx::identity>  
FwdIter partition(FwdIter first, FwdIter last, Pred &&pred, Proj &&proj = Proj())
```

Reorders the elements in the range `[first, last)` in such a way that all elements for which the predicate *pred* returns true precede the elements for which the predicate *pred* returns false. Relative order of the elements is not preserved.

The assignments in the parallel *partition* algorithm invoked without an execution policy object execute in sequential order in the calling thread.

Note: Complexity: At most $2 * (\text{last} - \text{first})$ swaps. Exactly *last - first* applications of the predicate and projection.

Template Parameters

- **FwdIter** – The type of the source iterators used (deduced). This iterator type must meet the requirements of a forward iterator.
- **Pred** – The type of the function/function object to use (deduced). Unlike its sequential form, the parallel overload of *partition* requires *Pred* to meet the requirements of *Copy-Constructible*.
- **Proj** – The type of an optional projection function. This defaults to *hpx::identity*

Parameters

- **first** – Refers to the beginning of the sequence of elements the algorithm will be applied to.
- **last** – Refers to the end of the sequence of elements the algorithm will be applied to.
- **pred** – Specifies the function (or function object) which will be invoked for each of the elements in the sequence specified by `[first, last)`. This is an unary predicate for partitioning the source iterators. The signature of this predicate should be equivalent to:

```
bool pred(const Type &a);
```

⁶⁰⁴ <http://github.com/STELLAR-GROUP/hpx/blob/8a3b7c1a4cb5693b2f7d9f587f759392ed0c51a0/libs/full/include/include/hpx/algorithm.hpp>

The signature does not need to have `const&`, but the function must not modify the objects passed to it. The type *Type* must be such that an object of type *FwdIter* can be dereferenced and then implicitly converted to *Type*.

- **proj** – Specifies the function (or function object) which will be invoked for each of the elements as a projection operation before the actual predicate *is* invoked.

Returns The *partition* algorithm returns returns *FwdIter*. The *partition* algorithm returns the iterator to the first element of the second group.

```
template<typename ExPolicy, typename FwdIter, typename Pred, typename Proj = hpx::identity>
parallel::util::detail::algorithm_result_t<ExPolicy, FwdIter> partition(ExPolicy &&policy, FwdIter first,
                                                                    FwdIter last, Pred &&pred, Proj
                                                                    &&proj = Proj())
```

Reorders the elements in the range [first, last) in such a way that all elements for which the predicate *pred* returns true precede the elements for which the predicate *pred* returns false. Relative order of the elements is not preserved.

The assignments in the parallel *partition* algorithm invoked with an execution policy object of type *sequenced_policy* execute in sequential order in the calling thread.

The assignments in the parallel *partition* algorithm invoked with an execution policy object of type *parallel_policy* or *parallel_task_policy* are permitted to execute in an unordered fashion in unspecified threads, and indeterminately sequenced within each thread.

Note: Complexity: At most $2 * (\text{last} - \text{first})$ swaps. Exactly *last - first* applications of the predicate and projection.

Template Parameters

- **ExPolicy** – The type of the execution policy to use (deduced). It describes the manner in which the execution of the algorithm may be parallelized and the manner in which it executes the assignments.
- **FwdIter** – The type of the source iterators used (deduced). This iterator type must meet the requirements of an forward iterator.
- **Pred** – The type of the function/function object to use (deduced). Unlike its sequential form, the parallel overload of *partition* requires *Pred* to meet the requirements of *CopyConstructible*.
- **Proj** – The type of an optional projection function. This defaults to *hpx::identity*

Parameters

- **policy** – The execution policy to use for the scheduling of the iterations.
- **first** – Refers to the beginning of the sequence of elements the algorithm will be applied to.
- **last** – Refers to the end of the sequence of elements the algorithm will be applied to.
- **pred** – Specifies the function (or function object) which will be invoked for each of the elements in the sequence specified by [first, last). This is an unary predicate for partitioning the source iterators. The signature of this predicate should be equivalent to:

```
bool pred(const Type &a);
```

The signature does not need to have `const&`, but the function must not modify the objects passed to it. The type *Type* must be such that an object of type *FwdIter* can be dereferenced and then implicitly converted to *Type*.

- **proj** – Specifies the function (or function object) which will be invoked for each of the elements as a projection operation before the actual predicate *is* invoked.

Returns The *partition* algorithm returns a `hpx::future<FwdIter>` if the execution policy is of type *parallel_task_policy* and returns *FwdIter* otherwise. The *partition* algorithm returns the iterator to the first element of the second group.

```
template<typename BidirIter, typename F, typename Proj = hpx::identity>
BidirIter stable_partition(BidirIter first, BidirIter last, F &&f, Proj &&proj = Proj())
```

Permutes the elements in the range `[first, last)` such that there exists an iterator *i* such that for every iterator *j* in the range `[first, i)` `INVOKE(f, INVOKE(proj, *j)) != false`, and for every iterator *k* in the range `[i, last)`, `INVOKE(f, INVOKE(proj, *k)) == false`

The invocations of *f* in the parallel *stable_partition* algorithm invoked without an execution policy object executes in sequential order in the calling thread.

Note: Complexity: At most $(last - first) * \log(last - first)$ swaps, but only linear number of swaps if there is enough extra memory. Exactly *last - first* applications of the predicate and projection.

Template Parameters

- **BidirIter** – The type of the source iterators used (deduced). This iterator type must meet the requirements of a bidirectional iterator.
- **F** – The type of the function/function object to use (deduced). Unlike its sequential form, the parallel overload of *transform* requires *F* to meet the requirements of *CopyConstructible*.
- **Proj** – The type of an optional projection function. This defaults to `hpx::identity`

Parameters

- **first** – Refers to the beginning of the sequence of elements the algorithm will be applied to.
- **last** – Refers to the end of the sequence of elements the algorithm will be applied to.
- **f** – Unary predicate which returns true if the element should be ordered before other elements. Specifies the function (or function object) which will be invoked for each of the elements in the sequence specified by `[first, last)`. The signature of this predicate should be equivalent to:

```
bool fun(const Type &a);
```

The signature does not need to have `const&`. The type *Type* must be such that an object of type *BidirIter* can be dereferenced and then implicitly converted to *Type*.

- **proj** – Specifies the function (or function object) which will be invoked for each of the elements as a projection operation before the actual predicate *f* is invoked.

Returns The *stable_partition* algorithm returns an iterator *i* such that for every iterator *j* in the range $[first, i)$, $f(*j) \neq \text{false}$ INVOKE(*f*, INVOKE(*proj*, **j*)) $\neq \text{false}$, and for every iterator *k* in the range $[i, last)$, $f(*k) == \text{false}$ INVOKE(*f*, INVOKE(*proj*, **k*)) $== \text{false}$. The relative order of the elements in both groups is preserved.

```
template<typename ExPolicy, typename BidirIter, typename F, typename Proj = hpx::identity>
parallel::util::detail::algorithm_result_t<ExPolicy, BidirIter> stable_partition(ExPolicy &&policy,
                                                                    BidirIter first, BidirIter
                                                                    last, F &&f, Proj &&proj
                                                                    = Proj())
```

Permutes the elements in the range $[first, last)$ such that there exists an iterator *i* such that for every iterator *j* in the range $[first, i)$ INVOKE(*f*, INVOKE(*proj*, **j*)) $\neq \text{false}$, and for every iterator *k* in the range $[i, last)$, INVOKE(*f*, INVOKE(*proj*, **k*)) $== \text{false}$

The invocations of *f* in the parallel *stable_partition* algorithm invoked with an execution policy object of type *sequenced_policy* executes in sequential order in the calling thread.

The invocations of *f* in the parallel *stable_partition* algorithm invoked with an execution policy object of type *parallel_policy* or *parallel_task_policy* are permitted to execute in an unordered fashion in unspecified threads, and indeterminately sequenced within each thread.

Note: Complexity: At most $(last - first) * \log(last - first)$ swaps, but only linear number of swaps if there is enough extra memory. Exactly *last - first* applications of the predicate and projection.

Template Parameters

- **ExPolicy** – The type of the execution policy to use (deduced). It describes the manner in which the execution of the algorithm may be parallelized and the manner in which it executes the invocations of *f*.
- **BidirIter** – The type of the source iterators used (deduced). This iterator type must meet the requirements of a bidirectional iterator.
- **F** – The type of the function/function object to use (deduced). Unlike its sequential form, the parallel overload of *transform* requires *F* to meet the requirements of *CopyConstructible*.
- **Proj** – The type of an optional projection function. This defaults to *hpx::identity*

Parameters

- **policy** – The execution policy to use for the scheduling of the iterations.
- **first** – Refers to the beginning of the sequence of elements the algorithm will be applied to.
- **last** – Refers to the end of the sequence of elements the algorithm will be applied to.
- **f** – Unary predicate which returns true if the element should be ordered before other elements. Specifies the function (or function object) which will be invoked for each of the elements in the sequence specified by $[first, last)$. The signature of this predicate should be equivalent to:

```
bool fun(const Type &a);
```

The signature does not need to have `const&`. The type *Type* must be such that an object of type *BidirIter* can be dereferenced and then implicitly converted to *Type*.

- **proj** – Specifies the function (or function object) which will be invoked for each of the elements as a projection operation before the actual predicate *f* is invoked.

Returns The *stable_partition* algorithm returns an iterator *i* such that for every iterator *j* in the range [*first*, *i*), $f(*j) \neq \text{false}$ INVOKE(*f*, INVOKE(*proj*, **j*)) $\neq \text{false}$, and for every iterator *k* in the range [*i*, *last*), $f(*k) == \text{false}$ INVOKE(*f*, INVOKE(*proj*, **k*)) $== \text{false}$. The relative order of the elements in both groups is preserved. If the execution policy is of type *parallel_task_policy* the algorithm returns a *future*<> referring to this iterator.

```
template<typename FwdIter1, typename FwdIter2, typename FwdIter3, typename Pred, typename Proj =
hpx::identity>
std::pair<FwdIter2, FwdIter3> partition_copy(FwdIter1 first, FwdIter1 last, FwdIter2 dest_true, FwdIter3
dest_false, Pred &&pred, Proj &&proj = Proj())
```

Copies the elements in the range, defined by [*first*, *last*), to two different ranges depending on the value returned by the predicate *pred*. The elements, that satisfy the predicate *pred* are copied to the range beginning at *dest_true*. The rest of the elements are copied to the range beginning at *dest_false*. The order of the elements is preserved.

The assignments in the parallel *partition_copy* algorithm invoked without an execution policy object execute in sequential order in the calling thread.

Note: Complexity: Performs not more than *last - first* assignments, exactly *last - first* applications of the predicate *pred*.

Template Parameters

- **FwdIter1** – The type of the source iterators used (deduced). This iterator type must meet the requirements of an forward iterator.
- **FwdIter2** – The type of the iterator representing the destination range for the elements that satisfy the predicate *pred* (deduced). This iterator type must meet the requirements of an forward iterator.
- **FwdIter3** – The type of the iterator representing the destination range for the elements that don't satisfy the predicate *pred* (deduced). This iterator type must meet the requirements of an forward iterator.
- **Pred** – The type of the function/function object to use (deduced). Unlike its sequential form, the parallel overload of *partition_copy* requires *Pred* to meet the requirements of *CopyConstructible*.
- **Proj** – The type of an optional projection function. This defaults to *hpx::identity*

Parameters

- **first** – Refers to the beginning of the sequence of elements the algorithm will be applied to.
- **last** – Refers to the end of the sequence of elements the algorithm will be applied to.
- **dest_true** – Refers to the beginning of the destination range for the elements that satisfy the predicate *pred*
- **dest_false** – Refers to the beginning of the destination range for the elements that don't satisfy the predicate *pred*.

- **pred** – Specifies the function (or function object) which will be invoked for each of the elements in the sequence specified by [first, last). This is an unary predicate for partitioning the source iterators. The signature of this predicate should be equivalent to:

```
bool pred(const Type &a);
```

The signature does not need to have const&, but the function must not modify the objects passed to it. The type *Type* must be such that an object of type *FwdIter1* can be dereferenced and then implicitly converted to *Type*.

- **proj** – Specifies the function (or function object) which will be invoked for each of the elements as a projection operation before the actual predicate *is* invoked.

Returns The *partition_copy* algorithm returns *std::pair<OutIter1, OutIter2>*. The *partition_copy* algorithm returns the pair of the destination iterator to the end of the *dest_true* range, and the destination iterator to the end of the *dest_false* range.

```
template<typename ExPolicy, typename FwdIter1, typename FwdIter2, typename FwdIter3, typename
Pred, typename Proj = hpx::identity>
parallel::util::detail::algorithm_result_t<ExPolicy, std::pair<FwdIter2, FwdIter3>> partition_copy(ExPolicy
&&policy,
FwdIter1
first,
FwdIter1
last,
FwdIter2
dest_true,
FwdIter3
dest_false,
Pred
&&pred,
Proj
&&proj
=
Proj())
```

Copies the elements in the range, defined by [first, last), to two different ranges depending on the value returned by the predicate *pred*. The elements, that satisfy the predicate *pred*, are copied to the range beginning at *dest_true*. The rest of the elements are copied to the range beginning at *dest_false*. The order of the elements is preserved.

The assignments in the parallel *partition_copy* algorithm invoked with an execution policy object of type *sequenced_policy* execute in sequential order in the calling thread.

The assignments in the parallel *partition_copy* algorithm invoked with an execution policy object of type *parallel_policy* or *parallel_task_policy* are permitted to execute in an unordered fashion in unspecified threads, and indeterminately sequenced within each thread.

Note: Complexity: Performs not more than *last - first* assignments, exactly *last - first* applications of the predicate *pred*.

Template Parameters

- **ExPolicy** – The type of the execution policy to use (deduced). It describes the manner in which the execution of the algorithm may be parallelized and the manner in which it executes the assignments.
- **FwdIter1** – The type of the source iterators used (deduced). This iterator type must meet the requirements of an forward iterator.
- **FwdIter2** – The type of the iterator representing the destination range for the elements that satisfy the predicate *pred* (deduced). This iterator type must meet the requirements of an forward iterator.
- **FwdIter3** – The type of the iterator representing the destination range for the elements that don't satisfy the predicate *pred* (deduced). This iterator type must meet the requirements of an forward iterator.
- **Pred** – The type of the function/function object to use (deduced). Unlike its sequential form, the parallel overload of *partition_copy* requires *Pred* to meet the requirements of *CopyConstructible*.
- **Proj** – The type of an optional projection function. This defaults to *hpx::identity*

Parameters

- **policy** – The execution policy to use for the scheduling of the iterations.
- **first** – Refers to the beginning of the sequence of elements the algorithm will be applied to.
- **last** – Refers to the end of the sequence of elements the algorithm will be applied to.
- **dest_true** – Refers to the beginning of the destination range for the elements that satisfy the predicate *pred*
- **dest_false** – Refers to the beginning of the destination range for the elements that don't satisfy the predicate *pred*.
- **pred** – Specifies the function (or function object) which will be invoked for each of the elements in the sequence specified by [first, last). This is an unary predicate for partitioning the source iterators. The signature of this predicate should be equivalent to:

```
bool pred(const Type &a);
```

The signature does not need to have `const&`, but the function must not modify the objects passed to it. The type *Type* must be such that an object of type *FwdIter1* can be dereferenced and then implicitly converted to *Type*.

- **proj** – Specifies the function (or function object) which will be invoked for each of the elements as a projection operation before the actual predicate *is* invoked.

Returns The *partition_copy* algorithm returns a *hpx::future<std::pair<OutIter1, OutIter2>>* if the execution policy is of type *parallel_task_policy* and returns *std::pair<OutIter1, OutIter2>* otherwise. The *partition_copy* algorithm returns the pair of the destination iterator to the end of the *dest_true* range, and the destination iterator to the end of the *dest_false* range.

hpx::reduce

Defined in header `hpx/algorithm.hpp`⁶⁰⁵.

See *Public API* for a list of names and headers that are part of the public HPX API.

namespace **hpx**

Functions

```
template<typename ExPolicy, typename FwdIter, typename F, typename T = typename
std::iterator_traits<FwdIter>::value_type>
hpx::parallel::util::detail::algorithm_result_t<ExPolicy, T> reduce(ExPolicy &&policy, FwdIter first,
FwdIter last, T init, F &&f)
```

Returns GENERALIZED_SUM(f, init, *first, ..., *(first + (last - first) - 1)). Executed according to the policy.

The reduce operations in the parallel *reduce* algorithm invoked with an execution policy object of type *sequenced_policy* execute in sequential order in the calling thread.

The reduce operations in the parallel *copy_if* algorithm invoked with an execution policy object of type *parallel_policy* or *parallel_task_policy* are permitted to execute in an unordered fashion in unspecified threads, and indeterminately sequenced within each thread.

The difference between *reduce* and *accumulate* is that the behavior of reduce may be non-deterministic for non-associative or non-commutative binary predicate.

Note: Complexity: $O(\text{last} - \text{first})$ applications of the predicate *f*.

Note: GENERALIZED_SUM(op, a1, ..., aN) is defined as follows:

- a1 when N is 1
 - op(GENERALIZED_SUM(op, b1, ..., bK), GENERALIZED_SUM(op, bM, ..., bN)), where:
 - b1, ..., bN may be any permutation of a1, ..., aN and
 - $1 < K+1 = M \leq N$.
-

Template Parameters

- **ExPolicy** – The type of the execution policy to use (deduced). It describes the manner in which the execution of the algorithm may be parallelized and the manner in which it executes the assignments.
- **FwdIter** – The type of the source begin and end iterators used (deduced). This iterator type must meet the requirements of a forward iterator.
- **F** – The type of the function/function object to use (deduced). Unlike its sequential form, the parallel overload of *reduce* requires *F* to meet the requirements of *CopyConstructible*.

⁶⁰⁵ <http://github.com/STELLAR-GROUP/hpx/blob/8a3b7c1a4cb5693b2f7d9f587f759392ed0c51a0/libs/full/include/include/hpx/algorithm.hpp>

- **T** – The type of the value to be used as initial (and intermediate) values (deduced).

Parameters

- **policy** – The execution policy to use for the scheduling of the iterations.
- **first** – Refers to the beginning of the sequence of elements the algorithm will be applied to.
- **last** – Refers to the end of the sequence of elements the algorithm will be applied to.
- **init** – The initial value for the generalized sum.
- **f** – Specifies the function (or function object) which will be invoked for each of the elements in the sequence specified by [first, last). This is a binary predicate. The signature of this predicate should be equivalent to:

```
Ret fun(const Type1 &a, const Type1 &b);
```

The signature does not need to have const&. The types *Type1 Ret* must be such that an object of type *FwdIter* can be dereferenced and then implicitly converted to any of those types.

Returns The *reduce* algorithm returns a *hpx::future<T>* if the execution policy is of type *sequenced_task_policy* or *parallel_task_policy* and returns *T* otherwise. The *reduce* algorithm returns the result of the generalized sum over the elements given by the input range [first, last).

```
template<typename ExPolicy, typename FwdIter, typename T = typename
std::iterator_traits<FwdIter>::value_type>
util::detail::algorithm_result_t<ExPolicy, T> reduce(ExPolicy &&policy, FwdIter first, FwdIter last, T init)
```

Returns GENERALIZED_SUM(+, init, *first, ..., *(first + (last - first) - 1)). Executed according to the policy.

The reduce operations in the parallel *reduce* algorithm invoked with an execution policy object of type *sequenced_policy* execute in sequential order in the calling thread.

The reduce operations in the parallel *copy_if* algorithm invoked with an execution policy object of type *parallel_policy* or *parallel_task_policy* are permitted to execute in an unordered fashion in unspecified threads, and indeterminately sequenced within each thread.

The difference between *reduce* and *accumulate* is that the behavior of reduce may be non-deterministic for non-associative or non-commutative binary predicate.

Note: Complexity: $O(\textit{last} - \textit{first})$ applications of the operator+().

Note: GENERALIZED_SUM(+, a1, ..., aN) is defined as follows:

- a1 when N is 1
 - op(GENERALIZED_SUM(+, b1, ..., bK), GENERALIZED_SUM(+, bM, ..., bN)), where:
 - b1, ..., bN may be any permutation of a1, ..., aN and
 - $1 < K+1 = M \leq N$.
-

Template Parameters

- **ExPolicy** – The type of the execution policy to use (deduced). It describes the manner in which the execution of the algorithm may be parallelized and the manner in which it executes the assignments.
- **FwdIter** – The type of the source begin and end iterators used (deduced). This iterator type must meet the requirements of a forward iterator.
- **T** – The type of the value to be used as initial (and intermediate) values (deduced).

Parameters

- **policy** – The execution policy to use for the scheduling of the iterations.
- **first** – Refers to the beginning of the sequence of elements the algorithm will be applied to.
- **last** – Refers to the end of the sequence of elements the algorithm will be applied to.
- **init** – The initial value for the generalized sum.

Returns The *reduce* algorithm returns a *hpx::future<T>* if the execution policy is of type *sequenced_task_policy* or *parallel_task_policy* and returns *T* otherwise. The *reduce* algorithm returns the result of the generalized sum (applying operator+()) over the elements given by the input range [first, last).

```
template<typename ExPolicy, typename FwdIter>
hpx::parallel::util::detail::algorithm_result<ExPolicy, typename std::iterator_traits<FwdIter>::value_type>::type reduce(ExPol
&&po
icy,
FwdIt
first,
FwdIt
last)
```

Returns GENERALIZED_SUM(+, T(), *first, ..., *(first + (last - first) - 1)). Executed according to the policy.

The reduce operations in the parallel *reduce* algorithm invoked with an execution policy object of type *sequenced_policy* execute in sequential order in the calling thread.

The reduce operations in the parallel *reduce* algorithm invoked with an execution policy object of type *parallel_policy* or *parallel_task_policy* are permitted to execute in an unordered fashion in unspecified threads, and indeterminately sequenced within each thread.

The difference between *reduce* and *accumulate* is that the behavior of reduce may be non-deterministic for non-associative or non-commutative binary predicate.

Note: Complexity: $O(\text{last} - \text{first})$ applications of the operator+().

Note: The type of the initial value (and the result type) *T* is determined from the value_type of the used *FwdIter*.

Note: GENERALIZED_SUM(+, a1, ..., aN) is defined as follows:

- a1 when N is 1
 - op(GENERALIZED_SUM(+, b1, ..., bK), GENERALIZED_SUM(+, bM, ..., bN)), where:
 - b1, ..., bN may be any permutation of a1, ..., aN and
 - $1 < K+1 = M \leq N$.
-

Template Parameters

- **ExPolicy** – The type of the execution policy to use (deduced). It describes the manner in which the execution of the algorithm may be parallelized and the manner in which it executes the assignments.
- **FwdIter** – The type of the source begin and end iterators used (deduced). This iterator type must meet the requirements of a forward iterator.

Parameters

- **policy** – The execution policy to use for the scheduling of the iterations.
- **first** – Refers to the beginning of the sequence of elements the algorithm will be applied to.
- **last** – Refers to the end of the sequence of elements the algorithm will be applied to.

Returns The *reduce* algorithm returns a `hpx::future<T>` if the execution policy is of type *sequenced_task_policy* or *parallel_task_policy* and returns T otherwise (where T is the value_type of *FwdIter*). The *reduce* algorithm returns the result of the generalized sum (applying operator+) over the elements given by the input range [first, last).

```
template<typename FwdIter, typename F, typename T = typename std::iterator_traits<FwdIter>::value_type>
T reduce(FwdIter first, FwdIter last, T init, F &&f)
```

Returns GENERALIZED_SUM(f, init, *first, ..., *(first + (last - first) - 1)). Executed according to the policy.

The difference between *reduce* and *accumulate* is that the behavior of *reduce* may be non-deterministic for non-associative or non-commutative binary predicate.

Note: Complexity: $O(\text{last} - \text{first})$ applications of the predicate *f*.

Note: GENERALIZED_SUM(op, a1, ..., aN) is defined as follows:

- a1 when N is 1
 - op(GENERALIZED_SUM(op, b1, ..., bK), GENERALIZED_SUM(op, bM, ..., bN)), where:
 - b1, ..., bN may be any permutation of a1, ..., aN and
 - $1 < K+1 = M \leq N$.
-

Template Parameters

- **FwdIter** – The type of the source begin and end iterators used (deduced). This iterator type must meet the requirements of an input iterator.
- **F** – The type of the function/function object to use (deduced). Unlike its sequential form, the parallel overload of *reduce* requires *F* to meet the requirements of *CopyConstructible*.
- **T** – The type of the value to be used as initial (and intermediate) values (deduced).

Parameters

- **first** – Refers to the beginning of the sequence of elements the algorithm will be applied to.
- **last** – Refers to the end of the sequence of elements the algorithm will be applied to.
- **init** – The initial value for the generalized sum.
- **f** – Specifies the function (or function object) which will be invoked for each of the elements in the sequence specified by [first, last). This is a binary predicate. The signature of this predicate should be equivalent to:

```
Ret fun(const Type1 &a, const Type1 &b);
```

The signature does not need to have const&. The types *Type1* *Ret* must be such that an object of type *InIter* can be dereferenced and then implicitly converted to any of those types.

Returns The *reduce* algorithm returns *T*. The *reduce* algorithm returns the result of the generalized sum over the elements given by the input range [first, last).

```
template<typename FwdIter, typename T = typename std::iterator_traits<FwdIter>::value_type>
T reduce(FwdIter first, FwdIter last, T init)
```

Returns GENERALIZED_SUM(+, init, *first, ..., *(first + (last - first) - 1)). Executed according to the policy.

The difference between *reduce* and *accumulate* is that the behavior of reduce may be non-deterministic for non-associative or non-commutative binary predicate.

Note: Complexity: $O(\text{last} - \text{first})$ applications of the operator+().

Note: GENERALIZED_SUM(+, a1, ..., aN) is defined as follows:

- a1 when N is 1
 - op(GENERALIZED_SUM(+, b1, ..., bK), GENERALIZED_SUM(+, bM, ..., bN)), where:
 - b1, ..., bN may be any permutation of a1, ..., aN and
 - $1 < K+1 = M \leq N$.
-

Template Parameters

- **FwdIter** – The type of the source begin and end iterators used (deduced). This iterator type must meet the requirements of an input iterator.
- **T** – The type of the value to be used as initial (and intermediate) values (deduced).

Parameters

- **first** – Refers to the beginning of the sequence of elements the algorithm will be applied to.
- **last** – Refers to the end of the sequence of elements the algorithm will be applied to.
- **init** – The initial value for the generalized sum.

Returns The *reduce* algorithm returns a *T*. The *reduce* algorithm returns the result of the generalized sum (applying operator+()) over the elements given by the input range [first, last).

```
template<typename FwdIter>  
std::iterator_traits<FwdIter>::value_type reduce(FwdIter first, FwdIter last)
```

Returns GENERALIZED_SUM(+, T(), *first, ..., *(first + (last - first) - 1)). Executed according to the policy.

The difference between *reduce* and *accumulate* is that the behavior of reduce may be non-deterministic for non-associative or non-commutative binary predicate.

Note: Complexity: $O(\text{last} - \text{first})$ applications of the operator+().

Note: The type of the initial value (and the result type) *T* is determined from the value_type of the used *FwdIter*.

Note: GENERALIZED_SUM(+, a1, ..., aN) is defined as follows:

- a1 when N is 1
 - op(GENERALIZED_SUM(+, b1, ..., bK), GENERALIZED_SUM(+, bM, ..., bN)), where:
 - b1, ..., bN may be any permutation of a1, ..., aN and
 - $1 < K+1 = M \leq N$.
-

Template Parameters **FwdIter** – The type of the source begin and end iterators used (deduced). This iterator type must meet the requirements of an input iterator.

Parameters

- **first** – Refers to the beginning of the sequence of elements the algorithm will be applied to.
- **last** – Refers to the end of the sequence of elements the algorithm will be applied to.

Returns The *reduce* algorithm returns *T* (where T is the value_type of *FwdIter*). The *reduce* algorithm returns the result of the generalized sum (applying operator+()) over the elements given by the input range [first, last).

hpx::reduce_by_key

Defined in header `hpx/algorithm.hpp`⁶⁰⁶.

See *Public API* for a list of names and headers that are part of the public *HPX* API.

namespace **hpx**

namespace **experimental**

Top-level namespace.

Functions

```

template<typename ExPolicy, typename RanIter, typename RanIter2, typename FwdIter1,
typename FwdIter2, typename Compare = std::equal_to<typename
std::iterator_traits<RanIter>::value_type>, typename Func = std::plus<typename
std::iterator_traits<RanIter2>::value_type>>
util::detail::algorithm_result<ExPolicy, util::in_out_result<FwdIter1, FwdIter2>>::type reduce_by_key(ExPolicy
&&pol-
icy,
Ran-
Iter
key_first,
Ran-
Iter
key_last,
Ran-
Iter2
val-
ues_first,
FwdIter1
keys_output,
FwdIter2
val-
ues_output,
Com-
pare
&&comp
=
Com-
pare()
Func
&&func
=
Func())

```

Reduce by Key performs an inclusive scan reduction operation on elements supplied in key/value pairs. The algorithm produces a single output value for each set of equal consecutive keys in [key_first, key_last). the value being the GENERALIZED_NONCOMMUTATIVE_SUM(op, init, *first, ..., *(first + (i - result))). for the run of consecutive matching keys. The number of keys supplied must match the number of values.

⁶⁰⁶ <http://github.com/STELLAR-GROUP/hpx/blob/8a3b7c1a4cb5693b2f7d9f587f759392ed0c51a0/libs/full/include/include/hpx/algorithm.hpp>

comp has to induce a strict weak ordering on the values.

The application of function objects in parallel algorithm invoked with an execution policy object of type *sequenced_policy* execute in sequential order in the calling thread.

The application of function objects in parallel algorithm invoked with an execution policy object of type *parallel_policy* or *parallel_task_policy* are permitted to execute in an unordered fashion in unspecified threads, and indeterminately sequenced within each thread.

Note: Complexity: $O(\textit{last} - \textit{first})$ applications of the predicate *op*.

Template Parameters

- **ExPolicy** – The type of the execution policy to use (deduced). It describes the manner in which the execution of the algorithm may be parallelized and the manner in which it applies user-provided function objects.
- **RanIter** – The type of the key iterators used (deduced). This iterator type must meet the requirements of a random access iterator.
- **RanIter2** – The type of the value iterators used (deduced). This iterator type must meet the requirements of a random access iterator.
- **FwdIter1** – The type of the iterator representing the destination key range (deduced). This iterator type must meet the requirements of a forward iterator.
- **FwdIter2** – The type of the iterator representing the destination value range (deduced). This iterator type must meet the requirements of a forward iterator.
- **Compare** – The type of the optional function/function object to use to compare keys (deduced). Assumed to be `std::equal_to` otherwise.
- **Func** – The type of the function/function object to use (deduced). Unlike its sequential form, the parallel overload of *reduce_by_key* requires *Func* to meet the requirements of *CopyConstructible*.

Parameters

- **policy** – The execution policy to use for the scheduling of the iterations.
- **key_first** – Refers to the beginning of the sequence of key elements the algorithm will be applied to.
- **key_last** – Refers to the end of the sequence of key elements the algorithm will be applied to.
- **values_first** – Refers to the beginning of the sequence of value elements the algorithm will be applied to.
- **keys_output** – Refers to the start output location for the keys produced by the algorithm.
- **values_output** – Refers to the start output location for the values produced by the algorithm.
- **comp** – *comp* is a callable object. The return value of the INVOKE operation applied to an object of type *Comp*, when contextually converted to `bool`, yields `true` if the first argument of the call is less than the second, and `false` otherwise. It is assumed that *comp* will not apply any non-constant function through the dereferenced iterator.
- **func** – Specifies the function (or function object) which will be invoked for each of the elements in the sequence specified by [*first*, *last*). This is a binary predicate. The signature of this predicate should be equivalent to:

```
Ret fun(const Type1 &a, const Type1 &b);
```

The signature does not need to have `const&`. The types *Type1* *Ret* must be such that an object of type *FwdIter* can be dereferenced and then implicitly converted to any of those types.

Returns The *reduce_by_key* algorithm returns a `hpx::future<pair<Iter1,Iter2>>` if the execution policy is of type *sequenced_task_policy* or *parallel_task_policy* and returns

pair<Iter1,Iter2> otherwise.

hpx::reduce_deterministic

Defined in header `hpx/algorithm.hpp`⁶⁰⁷.

See *Public API* for a list of names and headers that are part of the public HPX API.

namespace **hpx**

Functions

```
template<typename ExPolicy, typename FwdIter, typename F, typename T = typename
std::iterator_traits<FwdIter>::value_type>
hpx::parallel::util::detail::algorithm_result_t<ExPolicy, T> reduce_deterministic(ExPolicy &&policy,
FwdIter first, FwdIter
last, T init, F &&f)
```

Returns GENERALIZED_SUM(f, init, *first, ..., *(first + (last - first) - 1)). Executed according to the policy.

The reduce operations in the parallel *reduce* algorithm invoked with an execution policy object of type *sequenced_policy* execute in sequential order in the calling thread.

The reduce operations in the parallel *copy_if* algorithm invoked with an execution policy object of type *parallel_policy* or *parallel_task_policy* are permitted to execute in an unordered fashion in unspecified threads, and indeterminately sequenced within each thread.

The difference between *reduce* and *accumulate* is that the behavior of reduce may be non-deterministic for non-associative or non-commutative binary predicate.

Note: Complexity: $O(\text{last} - \text{first})$ applications of the predicate *f*.

Note: GENERALIZED_SUM(op, a1, ..., aN) is defined as follows:

- a1 when N is 1
 - op(GENERALIZED_SUM(op, b1, ..., bK), GENERALIZED_SUM(op, bM, ..., bN)), where:
 - b1, ..., bN may be any permutation of a1, ..., aN and
 - $1 < K+1 = M \leq N$.
-

Template Parameters

- **ExPolicy** – The type of the execution policy to use (deduced). It describes the manner in which the execution of the algorithm may be parallelized and the manner in which it executes the assignments.

⁶⁰⁷ <http://github.com/STELLAR-GROUP/hpx/blob/8a3b7c1a4cb5693b2f7d9f587f759392ed0c51a0/libs/full/include/include/hpx/algorithm.hpp>

- **FwdIter** – The type of the source begin and end iterators used (deduced). This iterator type must meet the requirements of a forward iterator.
- **F** – The type of the function/function object to use (deduced). Unlike its sequential form, the parallel overload of *reduce* requires *F* to meet the requirements of *CopyConstructible*.
- **T** – The type of the value to be used as initial (and intermediate) values (deduced).

Parameters

- **policy** – The execution policy to use for the scheduling of the iterations.
- **first** – Refers to the beginning of the sequence of elements the algorithm will be applied to.
- **last** – Refers to the end of the sequence of elements the algorithm will be applied to.
- **init** – The initial value for the generalized sum.
- **f** – Specifies the function (or function object) which will be invoked for each of the elements in the sequence specified by [first, last). This is a binary predicate. The signature of this predicate should be equivalent to:

```
Ret fun(const Type1 &a, const Type1 &b);
```

The signature does not need to have const&. The types *Type1 Ret* must be such that an object of type *FwdIter* can be dereferenced and then implicitly converted to any of those types.

Returns The *reduce* algorithm returns a *hpx::future<T>* if the execution policy is of type *sequenced_task_policy* or *parallel_task_policy* and returns *T* otherwise. The *reduce* algorithm returns the result of the generalized sum over the elements given by the input range [first, last).

```
template<typename ExPolicy, typename FwdIter, typename T = typename
std::iterator_traits<FwdIter>::value_type>
util::detail::algorithm_result_t<ExPolicy, T> reduce_deterministic(ExPolicy &&policy, FwdIter first,
FwdIter last, T init)
```

Returns GENERALIZED_SUM(+, init, *first, ..., *(first + (last - first) - 1)). Executed according to the policy.

The reduce operations in the parallel *reduce* algorithm invoked with an execution policy object of type *sequenced_policy* execute in sequential order in the calling thread.

The reduce operations in the parallel *copy_if* algorithm invoked with an execution policy object of type *parallel_policy* or *parallel_task_policy* are permitted to execute in an unordered fashion in unspecified threads, and indeterminately sequenced within each thread.

The difference between *reduce* and *accumulate* is that the behavior of reduce may be non-deterministic for non-associative or non-commutative binary predicate.

Note: Complexity: $O(\text{last} - \text{first})$ applications of the operator+().

Note: GENERALIZED_SUM(+, a1, ..., aN) is defined as follows:

- a1 when N is 1

- $op(\text{GENERALIZED_SUM}(+, b_1, \dots, b_K), \text{GENERALIZED_SUM}(+, b_M, \dots, b_N))$, where:
 - b_1, \dots, b_N may be any permutation of a_1, \dots, a_N and
 - $1 < K+1 = M \leq N$.

Template Parameters

- **ExPolicy** – The type of the execution policy to use (deduced). It describes the manner in which the execution of the algorithm may be parallelized and the manner in which it executes the assignments.
- **FwdIter** – The type of the source begin and end iterators used (deduced). This iterator type must meet the requirements of a forward iterator.
- **T** – The type of the value to be used as initial (and intermediate) values (deduced).

Parameters

- **policy** – The execution policy to use for the scheduling of the iterations.
- **first** – Refers to the beginning of the sequence of elements the algorithm will be applied to.
- **last** – Refers to the end of the sequence of elements the algorithm will be applied to.
- **init** – The initial value for the generalized sum.

Returns The *reduce* algorithm returns a `hpx::future<T>` if the execution policy is of type *sequenced_task_policy* or *parallel_task_policy* and returns *T* otherwise. The *reduce* algorithm returns the result of the generalized sum (applying operator+()) over the elements given by the input range [first, last).

```
template<typename ExPolicy, typename FwdIter>
hpx::parallel::util::detail::algorithm_result<ExPolicy, typename std::iterator_traits<FwdIter>::value_type>::type reduce_deter
```

Returns $\text{GENERALIZED_SUM}(+, T(), *first, \dots, *(first + (last - first) - 1))$. Executed according to the policy.

The reduce operations in the parallel *reduce* algorithm invoked with an execution policy object of type *sequenced_policy* execute in sequential order in the calling thread.

The reduce operations in the parallel *reduce* algorithm invoked with an execution policy object of type *parallel_policy* or *parallel_task_policy* are permitted to execute in an unordered fashion in unspecified threads, and indeterminately sequenced within each thread.

The difference between *reduce* and *accumulate* is that the behavior of reduce may be non-deterministic for non-associative or non-commutative binary predicate.

Note: Complexity: $O(\text{last} - \text{first})$ applications of the operator+().

Note: The type of the initial value (and the result type) T is determined from the `value_type` of the used `FwdIter`.

Note: `GENERALIZED_SUM(+, a1, ..., aN)` is defined as follows:

- a_1 when N is 1
 - `op(GENERALIZED_SUM(+, b1, ..., bK), GENERALIZED_SUM(+, bM, ..., bN))`, where:
 - b_1, \dots, b_N may be any permutation of a_1, \dots, a_N and
 - $1 < K+1 = M \leq N$.
-

Template Parameters

- **ExPolicy** – The type of the execution policy to use (deduced). It describes the manner in which the execution of the algorithm may be parallelized and the manner in which it executes the assignments.
- **FwdIter** – The type of the source begin and end iterators used (deduced). This iterator type must meet the requirements of a forward iterator.

Parameters

- **policy** – The execution policy to use for the scheduling of the iterations.
- **first** – Refers to the beginning of the sequence of elements the algorithm will be applied to.
- **last** – Refers to the end of the sequence of elements the algorithm will be applied to.

Returns The *reduce* algorithm returns a `hpx::future<T>` if the execution policy is of type `sequenced_task_policy` or `parallel_task_policy` and returns T otherwise (where T is the `value_type` of `FwdIter`). The *reduce* algorithm returns the result of the generalized sum (applying operator`+`) over the elements given by the input range `[first, last)`.

```
template<typename FwdIter, typename F, typename T = typename std::iterator_traits<FwdIter>::value_type>
T reduce_deterministic(FwdIter first, FwdIter last, T init, F &&f)
```

Returns `GENERALIZED_SUM(f, init, *first, ..., *(first + (last - first) - 1))`. Executed according to the policy.

The difference between *reduce* and *accumulate* is that the behavior of *reduce* may be non-deterministic for non-associative or non-commutative binary predicate.

Note: Complexity: $O(\text{last} - \text{first})$ applications of the predicate f .

Note: `GENERALIZED_SUM(op, a1, ..., aN)` is defined as follows:

- a_1 when N is 1
- `op(GENERALIZED_SUM(op, b1, ..., bK), GENERALIZED_SUM(op, bM, ..., bN))`, where:
 - b_1, \dots, b_N may be any permutation of a_1, \dots, a_N and
 - $1 < K+1 = M \leq N$.

Template Parameters

- **FwdIter** – The type of the source begin and end iterators used (deduced). This iterator type must meet the requirements of an input iterator.
- **F** – The type of the function/function object to use (deduced). Unlike its sequential form, the parallel overload of *reduce* requires *F* to meet the requirements of *CopyConstructible*.
- **T** – The type of the value to be used as initial (and intermediate) values (deduced).

Parameters

- **first** – Refers to the beginning of the sequence of elements the algorithm will be applied to.
- **last** – Refers to the end of the sequence of elements the algorithm will be applied to.
- **init** – The initial value for the generalized sum.
- **f** – Specifies the function (or function object) which will be invoked for each of the elements in the sequence specified by [first, last). This is a binary predicate. The signature of this predicate should be equivalent to:

```
Ret fun(const Type1 &a, const Type1 &b);
```

The signature does not need to have const&. The types *Type1 Ret* must be such that an object of type *InIter* can be dereferenced and then implicitly converted to any of those types.

Returns The *reduce* algorithm returns *T*. The *reduce* algorithm returns the result of the generalized sum over the elements given by the input range [first, last).

```
template<typename FwdIter, typename T = typename std::iterator_traits<FwdIter>::value_type>
T reduce_deterministic(FwdIter first, FwdIter last, T init)
```

Returns GENERALIZED_SUM(+, init, *first, ..., *(first + (last - first) - 1)). Executed according to the policy.

The difference between *reduce* and *accumulate* is that the behavior of reduce may be non-deterministic for non-associative or non-commutative binary predicate.

Note: Complexity: $O(\text{last} - \text{first})$ applications of the operator+().

Note: GENERALIZED_SUM(+, a1, ..., aN) is defined as follows:

- a1 when N is 1
 - op(GENERALIZED_SUM(+, b1, ..., bK), GENERALIZED_SUM(+, bM, ..., bN)), where:
 - b1, ..., bN may be any permutation of a1, ..., aN and
 - $1 < K+1 = M \leq N$.
-

Template Parameters

- **FwdIter** – The type of the source begin and end iterators used (deduced). This iterator type must meet the requirements of an input iterator.
- **T** – The type of the value to be used as initial (and intermediate) values (deduced).

Parameters

- **first** – Refers to the beginning of the sequence of elements the algorithm will be applied to.
- **last** – Refers to the end of the sequence of elements the algorithm will be applied to.
- **init** – The initial value for the generalized sum.

Returns The *reduce* algorithm returns a *T*. The *reduce* algorithm returns the result of the generalized sum (applying operator+()) over the elements given by the input range [first, last).

```
template<typename FwdIter>  
std::iterator_traits<FwdIter>::value_type reduce_deterministic(FwdIter first, FwdIter last)
```

Returns GENERALIZED_SUM(+, T(), *first, ..., *(first + (last - first) - 1)). Executed according to the policy.

The difference between *reduce* and *accumulate* is that the behavior of reduce may be non-deterministic for non-associative or non-commutative binary predicate.

Note: Complexity: $O(\text{last} - \text{first})$ applications of the operator+().

Note: The type of the initial value (and the result type) *T* is determined from the value_type of the used *FwdIter*.

Note: GENERALIZED_SUM(+, a1, ..., aN) is defined as follows:

- a1 when N is 1
 - op(GENERALIZED_SUM(+, b1, ..., bK), GENERALIZED_SUM(+, bM, ..., bN)), where:
 - b1, ..., bN may be any permutation of a1, ..., aN and
 - $1 < K+1 = M \leq N$.
-

Template Parameters **FwdIter** – The type of the source begin and end iterators used (deduced). This iterator type must meet the requirements of an input iterator.

Parameters

- **first** – Refers to the beginning of the sequence of elements the algorithm will be applied to.
- **last** – Refers to the end of the sequence of elements the algorithm will be applied to.

Returns The *reduce* algorithm returns *T* (where T is the value_type of *FwdIter*). The *reduce* algorithm returns the result of the generalized sum (applying operator+()) over the elements given by the input range [first, last).

hpx::remove, hpx::remove_if

Defined in header `hpx/algorithm.hpp`⁶⁰⁸.

See *Public API* for a list of names and headers that are part of the public HPX API.

namespace **hpx**

Functions

```
template<typename FwdIter, typename T = typename std::iterator_traits<FwdIter>::value_type>
FwdIter remove(FwdIter first, FwdIter last, T const &value)
```

Removes all elements satisfying specific criteria from the range [first, last) and returns a past-the-end iterator for the new end of the range. This version removes all elements that are equal to *value*.

The assignments in the parallel *remove* algorithm execute in sequential order in the calling thread.

Note: Complexity: Performs not more than *last - first* assignments, exactly *last - first* applications of the operator==().

Template Parameters

- **FwdIter** – The type of the source iterators used (deduced). This iterator type must meet the requirements of an forward iterator.
- **T** – The type of the value to remove (deduced). This value type must meet the requirements of *CopyConstructible*.

Parameters

- **first** – Refers to the beginning of the sequence of elements the algorithm will be applied to.
- **last** – Refers to the end of the sequence of elements the algorithm will be applied to.
- **value** – Specifies the value of elements to remove.

Returns The *remove* algorithm returns a *FwdIter*. The *remove* algorithm returns the iterator to the new end of the range.

```
template<typename ExPolicy, typename FwdIter, typename T = typename
std::iterator_traits<FwdIter>::value_type>
hpx::parallel::util::detail::algorithm_result_t<ExPolicy, FwdIter> remove(ExPolicy &&policy, FwdIter first,
FwdIter last, T const &value)
```

Removes all elements satisfying specific criteria from the range [first, last) and returns a past-the-end iterator for the new end of the range. This version removes all elements that are equal to *value*. Executed according to the policy.

The assignments in the parallel *remove* algorithm invoked with an execution policy object of type *sequenced_policy* execute in sequential order in the calling thread.

⁶⁰⁸ <http://github.com/STELLAR-GROUP/hpx/blob/8a3b7c1a4cb5693b2f7d9f587f759392ed0c51a0/libs/full/include/include/hpx/algorithm.hpp>

The assignments in the parallel *remove* algorithm invoked with an execution policy object of type *parallel_policy* or *parallel_task_policy* are permitted to execute in an unordered fashion in unspecified threads, and indeterminately sequenced within each thread.

Note: Complexity: Performs not more than *last - first* assignments, exactly *last - first* applications of the operator `==()`.

Template Parameters

- **ExPolicy** – The type of the execution policy to use (deduced). It describes the manner in which the execution of the algorithm may be parallelized and the manner in which it executes the assignments.
- **FwdIter** – The type of the source iterators used (deduced). This iterator type must meet the requirements of an forward iterator.
- **T** – The type of the value to remove (deduced). This value type must meet the requirements of *CopyConstructible*.

Parameters

- **policy** – The execution policy to use for the scheduling of the iterations.
- **first** – Refers to the beginning of the sequence of elements the algorithm will be applied to.
- **last** – Refers to the end of the sequence of elements the algorithm will be applied to.
- **value** – Specifies the value of elements to remove.

Returns The *remove* algorithm returns a *hpx::future<FwdIter>* if the execution policy is of type *sequenced_task_policy* or *parallel_task_policy* and returns *FwdIter* otherwise. The *remove* algorithm returns the iterator to the new end of the range.

```
template<typename FwdIter, typename Pred>  
FwdIter remove_if(FwdIter first, FwdIter last, Pred &&pred)
```

Removes all elements satisfying specific criteria from the range [first, last) and returns a past-the-end iterator for the new end of the range. This version removes all elements for which predicate *pred* returns true.

The assignments in the parallel *remove_if* algorithm execute in sequential order in the calling thread.

Note: Complexity: Performs not more than *last - first* assignments, exactly *last - first* applications of the predicate *pred*.

Template Parameters

- **FwdIter** – The type of the source iterators used (deduced). This iterator type must meet the requirements of an forward iterator.
- **Pred** – The type of the function/function object to use (deduced). Unlike its sequential form, the parallel overload of *remove_if* requires *Pred* to meet the requirements of *CopyConstructible*.

Parameters

- **first** – Refers to the beginning of the sequence of elements the algorithm will be applied to.
- **last** – Refers to the end of the sequence of elements the algorithm will be applied to.
- **pred** – Specifies the function (or function object) which will be invoked for each of the elements in the sequence specified by [first, last). This is a unary predicate which returns *true* for the required elements. The signature of this predicate should be equivalent to:

```
bool pred(const Type &a);
```

The signature does not need to have `const&`, but the function must not modify the objects passed to it. The type *Type* must be such that an object of type *FwdIter* can be dereferenced and then implicitly converted to *Type*.

Returns The *remove_if* algorithm returns a *FwdIter*. The *remove_if* algorithm returns the iterator to the new end of the range.

```
template<typename ExPolicy, typename FwdIter, typename Pred>
hpx::parallel::util::detail::algorithm_result_t<ExPolicy, FwdIter> remove_if(ExPolicy &&policy, FwdIter
first, FwdIter last, Pred
&&pred)
```

Removes all elements satisfying specific criteria from the range [first, last) and returns a past-the-end iterator for the new end of the range. This version removes all elements for which predicate *pred* returns true. Executed according to the policy.

The assignments in the parallel *remove_if* algorithm invoked with an execution policy object of type *sequenced_policy* execute in sequential order in the calling thread.

The assignments in the parallel *remove_if* algorithm invoked with an execution policy object of type *parallel_policy* or *parallel_task_policy* are permitted to execute in an unordered fashion in unspecified threads, and indeterminately sequenced within each thread.

Note: Complexity: Performs not more than *last - first* assignments, exactly *last - first* applications of the predicate *pred*.

Template Parameters

- **ExPolicy** – The type of the execution policy to use (deduced). It describes the manner in which the execution of the algorithm may be parallelized and the manner in which it executes the assignments.
- **FwdIter** – The type of the source iterators used (deduced). This iterator type must meet the requirements of an forward iterator.
- **Pred** – The type of the function/function object to use (deduced). Unlike its sequential form, the parallel overload of *remove_if* requires *Pred* to meet the requirements of *CopyConstructible*.

Parameters

- **policy** – The execution policy to use for the scheduling of the iterations.
- **first** – Refers to the beginning of the sequence of elements the algorithm will be applied to.
- **last** – Refers to the end of the sequence of elements the algorithm will be applied to.

- **pred** – Specifies the function (or function object) which will be invoked for each of the elements in the sequence specified by [first, last). This is a unary predicate which returns *true* for the required elements. The signature of this predicate should be equivalent to:

```
bool pred(const Type &a);
```

The signature does not need to have `const&`, but the function must not modify the objects passed to it. The type *Type* must be such that an object of type *FwdIter* can be dereferenced and then implicitly converted to *Type*.

Returns The *remove_if* algorithm returns a `hpx::future<FwdIter>` if the execution policy is of type *sequenced_task_policy* or *parallel_task_policy* and returns *FwdIter* otherwise. The *remove_if* algorithm returns the iterator to the new end of the range.

hpx::remove_copy, hpx::remove_copy_if

Defined in header `hpx/algorithm.hpp`⁶⁰⁹.

See *Public API* for a list of names and headers that are part of the public *HPX* API.

namespace **hpx**

Functions

```
template<typename InIter, typename OutIter, typename T = typename  
std::iterator_traits<InIter>::value_type>
```

```
OutIter remove_copy(InIter first, InIter last, OutIter dest, T const &value)
```

Copies the elements in the range, defined by [first, last), to another range beginning at *dest*. Copies only the elements for which the comparison operator returns false when compare to value. The order of the elements that are not removed is preserved.

Effects: Copies all the elements referred to by the iterator it in the range [first,last) for which the following corresponding conditions do not hold: `*it == value`

The assignments in the parallel *remove_copy* algorithm execute in sequential order in the calling thread.

Note: Complexity: Performs not more than *last - first* assignments, exactly *last - first* applications of the predicate *pred*, here comparison operator.

Template Parameters

- **InIter** – The type of the source iterators used (deduced). This iterator type must meet the requirements of an input iterator.
- **OutIter** – The type of the iterator representing the destination range (deduced). This iterator type must meet the requirements of an output iterator.
- **T** – The type that the result of dereferencing *FwdIter1* is compared to.

Parameters

⁶⁰⁹ <http://github.com/STELLAR-GROUP/hpx/blob/8a3b7c1a4cb5693b2f7d9f587f759392ed0c51a0/libs/full/include/include/hpx/algorithm.hpp>

- **first** – Refers to the beginning of the sequence of elements the algorithm will be applied to.
- **last** – Refers to the end of the sequence of elements the algorithm will be applied to.
- **dest** – Refers to the beginning of the destination range.
- **value** – Value to be removed.

Returns The *remove_copy* algorithm returns an *OutIter*. The *remove_copy* algorithm returns the iterator to the element past the last element copied.

```
template<typename ExPolicy, typename FwdIter1, typename FwdIter2, typename T = typename
std::iterator_traits<InIter>::value_type>
hpx::parallel::util::detail::algorithm_result_t<ExPolicy, FwdIter2> remove_copy(ExPolicy &&policy,
                                         FwdIter1 first, FwdIter1
                                         last, FwdIter2 dest, T const
                                         &value)
```

Copies the elements in the range, defined by [first, last), to another range beginning at *dest*. Copies only the elements for which the comparison operator returns false when compare to value. The order of the elements that are not removed is preserved. Executed according to the policy.

Effects: Copies all the elements referred to by the iterator it in the range [first,last) for which the following corresponding conditions do not hold: *it == value

The assignments in the parallel *remove_copy* algorithm invoked with an execution policy object of type *sequenced_policy* execute in sequential order in the calling thread.

The assignments in the parallel *remove_copy* algorithm invoked with an execution policy object of type *parallel_policy* or *parallel_task_policy* are permitted to execute in an unordered fashion in unspecified threads, and indeterminately sequenced within each thread.

Note: Complexity: Performs not more than *last - first* assignments, exactly *last - first* applications of the predicate *pred*, here comparison operator.

Template Parameters

- **ExPolicy** – The type of the execution policy to use (deduced). It describes the manner in which the execution of the algorithm may be parallelized and the manner in which it executes the assignments.
- **FwdIter1** – The type of the source iterators used (deduced). This iterator type must meet the requirements of an forward iterator.
- **FwdIter2** – The type of the iterator representing the destination range (deduced). This iterator type must meet the requirements of an forward iterator.
- **T** – The type that the result of dereferencing FwdIter1 is compared to.

Parameters

- **policy** – The execution policy to use for the scheduling of the iterations.
- **first** – Refers to the beginning of the sequence of elements the algorithm will be applied to.
- **last** – Refers to the end of the sequence of elements the algorithm will be applied to.

- **dest** – Refers to the beginning of the destination range.
- **value** – Value to be removed.

Returns The *remove_copy* algorithm returns a *hpx::future<FwdIter2>* if the execution policy is of type *sequenced_task_policy* or *parallel_task_policy* and returns *FwdIter2* otherwise. The *remove_copy* algorithm returns the iterator to the element past the last element copied.

```
template<typename InIter, typename OutIter, typename Pred>  
OutIter remove_copy_if(InIter first, InIter last, OutIter dest, Pred &&pred)
```

Copies the elements in the range, defined by [first, last), to another range beginning at *dest*. Copies only the elements for which the predicate *pred* returns false. The order of the elements that are not removed is preserved.

Effects: Copies all the elements referred to by the iterator it in the range [first,last) for which the following corresponding conditions do not hold: INVOKE(pred, *it) != false.

The assignments in the parallel *remove_copy_if* algorithm execute in sequential order in the calling thread.

Note: Complexity: Performs not more than *last - first* assignments, exactly *last - first* applications of the predicate *pred*.

Template Parameters

- **InIter** – The type of the source iterators used (deduced). This iterator type must meet the requirements of an input iterator.
- **OutIter** – The type of the iterator representing the destination range (deduced). This iterator type must meet the requirements of an output iterator.
- **Pred** – The type of the function/function object to use (deduced).

Parameters

- **first** – Refers to the beginning of the sequence of elements the algorithm will be applied to.
- **last** – Refers to the end of the sequence of elements the algorithm will be applied to.
- **dest** – Refers to the beginning of the destination range.
- **pred** – Specifies the function (or function object) which will be invoked for each of the elements in the sequence specified by [first, last). This is a unary predicate which returns *true* for the elements to be removed. The signature of this predicate should be equivalent to:

```
bool pred(const Type &a);
```

The signature does not need to have *const&*, but the function must not modify the objects passed to it. The type *Type* must be such that an object of type *InIter* can be dereferenced and then implicitly converted to *Type*.

Returns The *remove_copy_if* algorithm returns an *OutIter* The *remove_copy_if* algorithm returns the iterator to the element past the last element copied.

```
template<typename ExPolicy, typename FwdIter1, typename FwdIter2, typename Pred>
```

```

hpx::parallel::util::detail::algorithm_result_t<ExPolicy, FwdIter2> remove_copy_if(ExPolicy &&policy,
                                                                                   FwdIter1 first,
                                                                                   FwdIter1 last, FwdIter2
                                                                                   dest, Pred &&pred)

```

Copies the elements in the range, defined by [first, last), to another range beginning at *dest*. Copies only the elements for which the predicate *pred* returns false. The order of the elements that are not removed is preserved. Executed according to the policy.

Effects: Copies all the elements referred to by the iterator *it* in the range [first,last) for which the following corresponding conditions do not hold: INVOKE(pred, *it) != false.

The assignments in the parallel *remove_copy_if* algorithm invoked with an execution policy object of type *sequenced_policy* execute in sequential order in the calling thread.

The assignments in the parallel *remove_copy_if* algorithm invoked with an execution policy object of type *parallel_policy* or *parallel_task_policy* are permitted to execute in an unordered fashion in unspecified threads, and indeterminately sequenced within each thread.

Note: Complexity: Performs not more than *last - first* assignments, exactly *last - first* applications of the predicate *pred*.

Template Parameters

- **ExPolicy** – The type of the execution policy to use (deduced). It describes the manner in which the execution of the algorithm may be parallelized and the manner in which it executes the assignments.
- **FwdIter1** – The type of the source iterators used (deduced). This iterator type must meet the requirements of an forward iterator.
- **FwdIter2** – The type of the iterator representing the destination range (deduced). This iterator type must meet the requirements of an forward iterator.
- **Pred** – The type of the function/function object to use (deduced). Unlike its sequential form, the parallel overload of *remove_copy_if* requires *Pred* to meet the requirements of *CopyConstructible*.

Parameters

- **policy** – The execution policy to use for the scheduling of the iterations.
- **first** – Refers to the beginning of the sequence of elements the algorithm will be applied to.
- **last** – Refers to the end of the sequence of elements the algorithm will be applied to.
- **dest** – Refers to the beginning of the destination range.
- **pred** – Specifies the function (or function object) which will be invoked for each of the elements in the sequence specified by [first, last). This is a unary predicate which returns *true* for the elements to be removed. The signature of this predicate should be equivalent to:

```
bool pred(const Type &a);
```

The signature does not need to have `const&`, but the function must not modify the objects passed to it. The type *Type* must be such that an object of type *FwdIter1* can be dereferenced and then implicitly converted to *Type*.

Returns The *remove_copy_if* algorithm returns a `hpx::future<FwdIter2>` if the execution policy is of type *sequenced_task_policy* or *parallel_task_policy* and returns *FwdIter2* otherwise. The *remove_copy_if* algorithm returns the iterator to the element past the last element copied.

`hpx::replace`, `hpx::replace_if`, `hpx::replace_copy`, `hpx::replace_copy_if`

Defined in header `hpx/algorithm.hpp`⁶¹⁰.

See *Public API* for a list of names and headers that are part of the public *HPX* API.

namespace **hpx**

Functions

```
template<typename InIter, typename T = typename std::iterator_traits<InIter>::value_type>
void replace(InIter first, InIter last, T const &old_value, T const &new_value)
```

Replaces all elements satisfying specific criteria with *new_value* in the range [first, last).

Effects: Substitutes elements referred by the iterator *it* in the range [first, last) with *new_value*, when the following corresponding conditions hold: **it == old_value*

The assignments in the parallel *replace* algorithm execute in sequential order in the calling thread.

Note: Complexity: Performs exactly *last - first* assignments.

Template Parameters

- **InIter** – The type of the source iterators used (deduced). This iterator type must meet the requirements of an input iterator.
- **T** – The type of the old and new values to replace (deduced).

Parameters

- **first** – Refers to the beginning of the sequence of elements the algorithm will be applied to.
- **last** – Refers to the end of the sequence of elements the algorithm will be applied to.
- **old_value** – Refers to the old value of the elements to replace.
- **new_value** – Refers to the new value to use as the replacement.

Returns The *replace* algorithm returns a *void*.

```
template<typename ExPolicy, typename FwdIter, typename T = typename
std::iterator_traits<FwdIter>::value_type>
```

⁶¹⁰ <http://github.com/STELLAR-GROUP/hpx/blob/8a3b7c1a4cb5693b2f7d9f587f759392ed0c51a0/libs/full/include/include/hpx/algorithm.hpp>

```
hpx::parallel::util::detail::algorithm_result_t<ExPolicy, void> replace(ExPolicy &&policy, FwdIter first,
                                                                    FwdIter last, T const &old_value, T
                                                                    const &new_value)
```

Replaces all elements satisfying specific criteria with *new_value* in the range [first, last). Executed according to the policy.

Effects: Substitutes elements referred by the iterator *it* in the range [first, last) with *new_value*, when the following corresponding conditions hold: **it == old_value*

The assignments in the parallel *replace* algorithm invoked with an execution policy object of type *sequenced_policy* execute in sequential order in the calling thread.

The assignments in the parallel *replace* algorithm invoked with an execution policy object of type *parallel_policy* or *parallel_task_policy* are permitted to execute in an unordered fashion in unspecified threads, and indeterminately sequenced within each thread.

Note: Complexity: Performs exactly *last - first* assignments.

Template Parameters

- **ExPolicy** – The type of the execution policy to use (deduced). It describes the manner in which the execution of the algorithm may be parallelized and the manner in which it executes the assignments.
- **FwdIter** – The type of the source iterators used (deduced). This iterator type must meet the requirements of a forward iterator.
- **T** – The type of the old and new values to replace (deduced).

Parameters

- **policy** – The execution policy to use for the scheduling of the iterations.
- **first** – Refers to the beginning of the sequence of elements the algorithm will be applied to.
- **last** – Refers to the end of the sequence of elements the algorithm will be applied to.
- **old_value** – Refers to the old value of the elements to replace.
- **new_value** – Refers to the new value to use as the replacement.

Returns The *replace* algorithm returns a *hpx::future<void>* if the execution policy is of type *sequenced_task_policy* or *parallel_task_policy* and returns *void* otherwise.

```
template<typename Iter, typename Pred, typename T = typename std::iterator_traits<Iter>::value_type>
void replace_if(Iter first, Iter last, Pred &&pred, T const &new_value)
```

Replaces all elements satisfying specific criteria (for which predicate *pred* returns true) with *new_value* in the range [first, last).

Effects: Substitutes elements referred by the iterator *it* in the range [first, last) with *new_value*, when the following corresponding conditions hold: *INVOKE(f, *it) != false*

The assignments in the parallel *replace_if* algorithm execute in sequential order in the calling thread.

Note: Complexity: Performs exactly *last - first* applications of the predicate.

Template Parameters

- **Iter** – The type of the source iterators used (deduced). This iterator type must meet the requirements of an input iterator.
- **Pred** – The type of the function/function object to use (deduced). Unlike its sequential form, the parallel overload of *equal* requires *Pred* to meet the requirements of *CopyConstructible*. (deduced).
- **T** – The type of the new values to replace (deduced).

Parameters

- **first** – Refers to the beginning of the sequence of elements the algorithm will be applied to.
- **last** – Refers to the end of the sequence of elements the algorithm will be applied to.
- **pred** – Specifies the function (or function object) which will be invoked for each of the elements in the sequence specified by [first, last). This is an unary predicate which returns *true* for the elements which need to be replaced. The signature of this predicate should be equivalent to:

```
bool pred(const Type &a);
```

The signature does not need to have `const&`, but the function must not modify the objects passed to it. The type *Type* must be such that an object of type *InIter* can be dereferenced and then implicitly converted to *Type*.

- **new_value** – Refers to the new value to use as the replacement.

Returns The *replace_if* algorithm returns *void*.

```
template<typename ExPolicy, typename FwdIter, typename Pred, typename T = typename
std::iterator_traits<FwdIter>::value_type>
hpx::parallel::util::detail::algorithm_result_t<ExPolicy, void> replace_if(ExPolicy &&policy, FwdIter first,
FwdIter last, Pred &&pred, T
const &new_value)
```

Replaces all elements satisfying specific criteria (for which predicate *f* returns true) with *new_value* in the range [first, last). Executed according to the policy.

Effects: Substitutes elements referred by the iterator *it* in the range [first, last) with *new_value*, when the following corresponding conditions hold: `INVOKE(f, *it) != false`

The assignments in the parallel *replace_if* algorithm invoked with an execution policy object of type *sequenced_policy* execute in sequential order in the calling thread.

The assignments in the parallel *replace_if* algorithm invoked with an execution policy object of type *parallel_policy* or *parallel_task_policy* are permitted to execute in an unordered fashion in unspecified threads, and indeterminately sequenced within each thread.

Note: Complexity: Performs exactly *last - first* applications of the predicate.

Template Parameters

- **ExPolicy** – The type of the execution policy to use (deduced). It describes the manner in which the execution of the algorithm may be parallelized and the manner in which it executes the assignments.
- **FwdIter** – The type of the source iterators used (deduced). This iterator type must meet the requirements of a forward iterator.
- **Pred** – The type of the function/function object to use (deduced). Unlike its sequential form, the parallel overload of *equal* requires *Pred* to meet the requirements of *CopyConstructible*. (deduced).
- **T** – The type of the new values to replace (deduced).

Parameters

- **policy** – The execution policy to use for the scheduling of the iterations.
- **first** – Refers to the beginning of the sequence of elements the algorithm will be applied to.
- **last** – Refers to the end of the sequence of elements the algorithm will be applied to.
- **pred** – Specifies the function (or function object) which will be invoked for each of the elements in the sequence specified by [first, last). This is an unary predicate which returns *true* for the elements which need to be replaced. The signature of this predicate should be equivalent to:

```
bool pred(const Type &a);
```

The signature does not need to have `const&`, but the function must not modify the objects passed to it. The type *Type* must be such that an object of type *FwdIter* can be dereferenced and then implicitly converted to *Type*.

- **new_value** – Refers to the new value to use as the replacement.

Returns The *replace_if* algorithm returns a *hpx::future<void>* if the execution policy is of type *sequenced_task_policy* or *parallel_task_policy* and returns *void* otherwise.

```
template<typename InIter, typename OutIter, typename T = typename
std::iterator_traits<OutIter>::value_type>
```

```
OutIter replace_copy(InIter first, InIter last, OutIter dest, T const &old_value, T const &new_value)
```

Copies the all elements from the range [first, last) to another range beginning at *dest* replacing all elements satisfying a specific criteria with *new_value*.

Effects: Assigns to every iterator it in the range [result, result + (last - first)) either *new_value* or $*(first + (it - result))$ depending on whether the following corresponding condition holds: $*(first + (i - result)) == old_value$

The assignments in the parallel *replace_copy* algorithm execute in sequential order in the calling thread.

Note: Complexity: Performs exactly *last - first* applications of the predicate.

Template Parameters

- **InIter** – The type of the source iterators used (deduced). This iterator type must meet the requirements of an input iterator.

- **OutIter** – The type of the iterator representing the destination range (deduced). This iterator type must meet the requirements of an output iterator.
- **T** – The type of the old and new values (deduced).

Parameters

- **first** – Refers to the beginning of the sequence of elements the algorithm will be applied to.
- **last** – Refers to the end of the sequence of elements the algorithm will be applied to.
- **dest** – Refers to the beginning of the destination range.
- **old_value** – Refers to the old value of the elements to replace.
- **new_value** – Refers to the new value to use as the replacement.

Returns The *replace_copy* algorithm returns an *OutIter* The *replace_copy* algorithm returns the Iterator to the element past the last element copied.

```
template<typename ExPolicy, typename FwdIter1, typename FwdIter2, typename T = typename
std::iterator_traits<FwdIter2>::value_type>
hpx::parallel::util::detail::algorithm_result_t<ExPolicy, FwdIter2> replace_copy(ExPolicy &&policy,
                                        FwdIter1 first, FwdIter1
                                        last, FwdIter2 dest, T
                                        const &old_value, T const
                                        &new_value)
```

Copies the all elements from the range [first, last) to another range beginning at *dest* replacing all elements satisfying a specific criteria with *new_value*. Executed according to the policy.

Effects: Assigns to every iterator it in the range [result, result + (last - first)) either *new_value* or $*(first + (it - result))$ depending on whether the following corresponding condition holds: $*(first + (i - result)) == old_value$

The assignments in the parallel *replace_copy* algorithm invoked with an execution policy object of type *sequenced_policy* execute in sequential order in the calling thread.

The assignments in the parallel *replace_copy* algorithm invoked with an execution policy object of type *parallel_policy* or *parallel_task_policy* are permitted to execute in an unordered fashion in unspecified threads, and indeterminately sequenced within each thread.

Note: Complexity: Performs exactly *last - first* applications of the predicate.

Template Parameters

- **ExPolicy** – The type of the execution policy to use (deduced). It describes the manner in which the execution of the algorithm may be parallelized and the manner in which it executes the assignments.
- **FwdIter1** – The type of the source iterators used (deduced). This iterator type must meet the requirements of an forward iterator.
- **FwdIter2** – The type of the iterator representing the destination range (deduced). This iterator type must meet the requirements of an forward iterator.
- **T** – The type of the old and new values (deduced).

Parameters

- **policy** – The execution policy to use for the scheduling of the iterations.
- **first** – Refers to the beginning of the sequence of elements the algorithm will be applied to.
- **last** – Refers to the end of the sequence of elements the algorithm will be applied to.
- **dest** – Refers to the beginning of the destination range.
- **old_value** – Refers to the old value of the elements to replace.
- **new_value** – Refers to the new value to use as the replacement.

Returns The *replace_copy* algorithm returns a *hpx::future<FwdIter2>* if the execution policy is of type *sequenced_task_policy* or *parallel_task_policy* and returns *FwdIter2* otherwise. The *replace_copy* algorithm returns the Iterator to the element past the last element copied.

```
template<typename InIter, typename OutIter, typename Pred, typename T = typename
std::iterator_traits<OutIter>::value_type>
OutIter replace_copy_if(InIter first, InIter last, OutIter dest, Pred &&pred, T const &new_value)
```

Copies the all elements from the range [first, last) to another range beginning at *dest* replacing all elements satisfying a specific criteria with *new_value*.

Effects: Assigns to every iterator it in the range [result, result + (last - first)) either *new_value* or $*(first + (it - result))$ depending on whether the following corresponding condition holds: $INVOKE(f, *(first + (i - result))) \neq false$

The assignments in the parallel *replace_copy_if* algorithm execute in sequential order in the calling thread.

Note: Complexity: Performs exactly *last - first* applications of the predicate.

Template Parameters

- **InIter** – The type of the source iterators used (deduced). This iterator type must meet the requirements of an input iterator.
- **OutIter** – The type of the iterator representing the destination range (deduced). This iterator type must meet the requirements of an output iterator.
- **Pred** – The type of the function/function object to use (deduced). Unlike its sequential form, the parallel overload of *equal* requires *Pred* to meet the requirements of *CopyConstructible*. (deduced).
- **T** – The type of the new values to replace (deduced).

Parameters

- **first** – Refers to the beginning of the sequence of elements the algorithm will be applied to.
- **last** – Refers to the end of the sequence of elements the algorithm will be applied to.
- **dest** – Refers to the beginning of the destination range.
- **pred** – Specifies the function (or function object) which will be invoked for each of the elements in the sequence specified by [first, last). This is a unary predicate which returns *true* for the elements which need to be replaced. The signature of this predicate should be equivalent to:

```
bool pred(const Type &a);
```

The signature does not need to have `const&`, but the function must not modify the objects passed to it. The type *Type* must be such that an object of type *InIter* can be dereferenced and then implicitly converted to *Type*.

- **new_value** – Refers to the new value to use as the replacement.

Returns The *replace_copy_if* algorithm returns an *OutIter*. The *replace_copy_if* algorithm returns the output iterator to the element in the destination range, one past the last element copied.

```
template<typename ExPolicy, typename FwdIter1, typename FwdIter2, typename Pred, typename T =
typename std::iterator_traits<FwdIter2>::value_type>
hpx::parallel::util::detail::algorithm_result_t<ExPolicy, FwdIter2> replace_copy_if(ExPolicy &&policy,
                                          FwdIter1 first,
                                          FwdIter1 last,
                                          FwdIter2 dest, Pred
                                          &&pred, T const
                                          &new_value)
```

Copies the all elements from the range [first, last) to another range beginning at *dest* replacing all elements satisfying a specific criteria with *new_value*.

Effects: Assigns to every iterator *it* in the range [result, result + (last - first)) either *new_value* or **(first + (it - result))* depending on whether the following corresponding condition holds: `INVOKE(f, *(first + (i - result))) != false`

The assignments in the parallel *replace_copy_if* algorithm invoked with an execution policy object of type *sequenced_policy* execute in sequential order in the calling thread.

The assignments in the parallel *replace_copy_if* algorithm invoked with an execution policy object of type *parallel_policy* or *parallel_task_policy* are permitted to execute in an unordered fashion in unspecified threads, and indeterminately sequenced within each thread.

Note: Complexity: Performs exactly *last - first* applications of the predicate.

Template Parameters

- **ExPolicy** – The type of the execution policy to use (deduced). It describes the manner in which the execution of the algorithm may be parallelized and the manner in which it executes the assignments.
- **FwdIter1** – The type of the source iterators used (deduced). This iterator type must meet the requirements of a forward iterator.
- **FwdIter2** – The type of the iterator representing the destination range (deduced). This iterator type must meet the requirements of a forward iterator.
- **Pred** – The type of the function/function object to use (deduced). Unlike its sequential form, the parallel overload of *replace_copy_if* requires *Pred* to meet the requirements of *CopyConstructible*. (deduced).
- **T** – The type of the new values to replace (deduced).

Parameters

- **policy** – The execution policy to use for the scheduling of the iterations.
- **first** – Refers to the beginning of the sequence of elements the algorithm will be applied to.
- **last** – Refers to the end of the sequence of elements the algorithm will be applied to.
- **dest** – Refers to the beginning of the destination range.
- **pred** – Specifies the function (or function object) which will be invoked for each of the elements in the sequence specified by [first, last). This is a unary predicate which returns *true* for the elements which need to be replaced. The signature of this predicate should be equivalent to:

```
bool pred(const Type &a);
```

The signature does not need to have `const&`, but the function must not modify the objects passed to it. The type *Type* must be such that an object of type *FwdIter1* can be dereferenced and then implicitly converted to *Type*.

- **new_value** – Refers to the new value to use as the replacement.

Returns The `replace_copy_if` algorithm returns a `hpx::future<FwdIter2>` if the execution policy is of type `sequenced_task_policy` or `parallel_task_policy` and returns `FwdIter2` otherwise. The `replace_copy_if` algorithm returns the iterator to the element in the destination range, one past the last element copied.

hpx::reverse, hpx::reverse_copy

Defined in header `hpx/algorithm.hpp`⁶¹¹.

See *Public API* for a list of names and headers that are part of the public *HPX* API.

namespace **hpx**

Functions

```
template<typename BidirIter>
void reverse(BidirIter first, BidirIter last)
```

Reverses the order of the elements in the range [first, last). Behaves as if applying `std::iter_swap` to every pair of iterators `first+i`, `(last-i) - 1` for each non-negative `i < (last-first)/2`.

The assignments in the parallel `reverse` algorithm execute in sequential order in the calling thread.

Note: Complexity: Linear in the distance between *first* and *last*.

Template Parameters **BidirIter** – The type of the source iterators used (deduced). This iterator type must meet the requirements of a bidirectional iterator.

Parameters

⁶¹¹ <http://github.com/STELLAR-GROUP/hpx/blob/8a3b7c1a4cb5693b2f7d9f587f759392ed0c51a0/libs/full/include/include/hpx/algorithm.hpp>

- **first** – Refers to the beginning of the sequence of elements the algorithm will be applied to.
- **last** – Refers to the end of the sequence of elements the algorithm will be applied to.

Returns The *reverse* algorithm returns *void*.

```
template<typename ExPolicy, typename BidirIter>  
hpx::parallel::util::detail::algorithm_result_t<ExPolicy, void> reverse(ExPolicy &&policy, BidirIter first,  
                                     BidirIter last)
```

Reverses the order of the elements in the range [first, last). Behaves as if applying *std::iter_swap* to every pair of iterators first+i, (last-i) - 1 for each non-negative i < (last-first)/2. Executed according to the policy.

The assignments in the parallel *reverse* algorithm invoked with an execution policy object of type *sequenced_policy* execute in sequential order in the calling thread.

The assignments in the parallel *reverse* algorithm invoked with an execution policy object of type *parallel_policy* or *parallel_task_policy* are permitted to execute in an unordered fashion in unspecified threads, and indeterminately sequenced within each thread.

Note: Complexity: Linear in the distance between *first* and *last*.

Template Parameters

- **ExPolicy** – The type of the execution policy to use (deduced). It describes the manner in which the execution of the algorithm may be parallelized and the manner in which it executes the assignments.
- **BidirIter** – The type of the source iterators used (deduced). This iterator type must meet the requirements of a bidirectional iterator.

Parameters

- **policy** – The execution policy to use for the scheduling of the iterations.
- **first** – Refers to the beginning of the sequence of elements the algorithm will be applied to.
- **last** – Refers to the end of the sequence of elements the algorithm will be applied to.

Returns The *reverse* algorithm returns a *hpx::future<void>* if the execution policy is of type *sequenced_task_policy* or *parallel_task_policy* and returns *void* otherwise.

```
template<typename BidirIter, typename OutIter>  
OutIter reverse_copy(BidirIter first, BidirIter last, OutIter dest)
```

Copies the elements from the range [first, last) to another range beginning at dest in such a way that the elements in the new range are in reverse order. Behaves as if by executing the assignment $*(dest + (last - first) - 1 - i) = *(first + i)$ once for each non-negative i < (last - first) If the source and destination ranges (that is, [first, last) and [dest, dest+(last-first)) respectively) overlap, the behavior is undefined.

The assignments in the parallel *reverse_copy* algorithm execute in sequential order in the calling thread.

Note: Complexity: Performs exactly *last - first* assignments.

Template Parameters

- **BidirIter** – The type of the source iterators used (deduced). This iterator type must meet the requirements of a bidirectional iterator.
- **OutIter** – The type of the iterator representing the destination range (deduced). This iterator type must meet the requirements of an output iterator.

Parameters

- **first** – Refers to the beginning of the sequence of elements the algorithm will be applied to.
- **last** – Refers to the end of the sequence of elements the algorithm will be applied to.
- **dest** – Refers to the begin of the destination range.

Returns The *reverse_copy* algorithm returns an *OutIter*. The *reverse_copy* algorithm returns the output iterator to the element in the destination range, one past the last element copied.

```
template<typename ExPolicy, typename BidirIter, typename FwdIter>
hpx::parallel::util::detail::algorithm_result_t<ExPolicy, FwdIter> reverse_copy(ExPolicy &&policy,
                                          BidirIter first, BidirIter
                                          last, FwdIter dest)
```

Copies the elements from the range [first, last) to another range beginning at dest in such a way that the elements in the new range are in reverse order. Behaves as if by executing the assignment $*(dest + (last - first) - 1 - i) = *(first + i)$ once for each non-negative $i < (last - first)$. If the source and destination ranges (that is, [first, last) and [dest, dest+(last-first)) respectively) overlap, the behavior is undefined. Executed according to the policy.

The assignments in the parallel *reverse_copy* algorithm invoked with an execution policy object of type *sequenced_policy* execute in sequential order in the calling thread.

The assignments in the parallel *reverse_copy* algorithm invoked with an execution policy object of type *parallel_policy* or *parallel_task_policy* are permitted to execute in an unordered fashion in unspecified threads, and indeterminately sequenced within each thread.

Note: Complexity: Performs exactly *last - first* assignments.

Template Parameters

- **ExPolicy** – The type of the execution policy to use (deduced). It describes the manner in which the execution of the algorithm may be parallelized and the manner in which it executes the assignments.
- **BidirIter** – The type of the source iterators used (deduced). This iterator type must meet the requirements of a bidirectional iterator.
- **FwdIter** – The type of the iterator representing the destination range (deduced). This iterator type must meet the requirements of a forward iterator.

Parameters

- **policy** – The execution policy to use for the scheduling of the iterations.
- **first** – Refers to the beginning of the sequence of elements the algorithm will be applied to.
- **last** – Refers to the end of the sequence of elements the algorithm will be applied to.

- **dest** – Refers to the begin of the destination range.

Returns The *reverse_copy* algorithm returns a *hpx::future<FwdIter>* if the execution policy is of type *sequenced_task_policy* or *parallel_task_policy* and returns *FwdIter* otherwise. The *reverse_copy* algorithm returns the output iterator to the element in the destination range, one past the last element copied.

hpx::rotate, hpx::rotate_copy

Defined in header `hpx/algorithm.hpp`⁶¹².

See *Public API* for a list of names and headers that are part of the public HPX API.

namespace **hpx**

Functions

template<typename **FwdIter**>
FwdIter **rotate**(*FwdIter* first, *FwdIter* new_first, *FwdIter* last)

Performs a left rotation on a range of elements. Specifically, *rotate* swaps the elements in the range [first, last) in such a way that the element new_first becomes the first element of the new range and new_first - 1 becomes the last element.

The assignments in the parallel *rotate* algorithm execute in sequential order in the calling thread.

Note: Complexity: Linear in the distance between *first* and *last*.

Note: The type of dereferenced *FwdIter* must meet the requirements of *MoveAssignable* and *MoveConstructible*.

Template Parameters **FwdIter** – The type of the source iterators used (deduced). This iterator type must meet the requirements of a forward iterator.

Parameters

- **first** – Refers to the beginning of the sequence of elements the algorithm will be applied to.
- **new_first** – Refers to the element that should appear at the beginning of the rotated range.
- **last** – Refers to the end of the sequence of elements the algorithm will be applied to.

Returns The *rotate* algorithm returns a *FwdIter*. The *rotate* algorithm returns the iterator to the new location of the element pointed by first, equal to first + (last - new_first).

template<typename **ExPolicy**, typename **FwdIter**>

⁶¹² <http://github.com/STELLAR-GROUP/hpx/blob/8a3b7c1a4cb5693b2f7d9f587f759392ed0c51a0/libs/full/include/include/hpx/algorithm.hpp>

```
hpx::parallel::util::detail::algorithm_result_t<ExPolicy, FwdIter> rotate(ExPolicy &&policy, FwdIter first,
                                                                    FwdIter new_first, FwdIter last)
```

Performs a left rotation on a range of elements. Specifically, *rotate* swaps the elements in the range [first, last) in such a way that the element *new_first* becomes the first element of the new range and *new_first* - 1 becomes the last element. Executed according to the policy.

The assignments in the parallel *rotate* algorithm invoked with an execution policy object of type *sequenced_policy* execute in sequential order in the calling thread.

The assignments in the parallel *rotate* algorithm invoked with an execution policy object of type *parallel_policy* or *parallel_task_policy* are permitted to execute in an unordered fashion in unspecified threads, and indeterminately sequenced within each thread.

Note: Complexity: Linear in the distance between *first* and *last*.

Note: The type of dereferenced *FwdIter* must meet the requirements of *MoveAssignable* and *MoveConstructible*.

Template Parameters

- **ExPolicy** – The type of the execution policy to use (deduced). It describes the manner in which the execution of the algorithm may be parallelized and the manner in which it executes the assignments.
- **FwdIter** – The type of the source iterators used (deduced). This iterator type must meet the requirements of a forward iterator.

Parameters

- **policy** – The execution policy to use for the scheduling of the iterations.
- **first** – Refers to the beginning of the sequence of elements the algorithm will be applied to.
- **new_first** – Refers to the element that should appear at the beginning of the rotated range.
- **last** – Refers to the end of the sequence of elements the algorithm will be applied to.

Returns The *rotate* algorithm returns a *hpx::future<FwdIter>* if the execution policy is of type *sequenced_task_policy* or *parallel_task_policy* and returns *FwdIter* otherwise. The *rotate* algorithm returns the iterator equal to *first* + (*last* - *new_first*).

```
template<typename FwdIter, typename OutIter>
OutIter rotate_copy(FwdIter first, FwdIter new_first, FwdIter last, OutIter dest_first)
```

Copies the elements from the range [first, last), to another range beginning at *dest_first* in such a way, that the element *new_first* becomes the first element of the new range and *new_first* - 1 becomes the last element.

The assignments in the parallel *rotate_copy* algorithm execute in sequential order in the calling thread.

Note: Complexity: Performs exactly *last* - *first* assignments.

Template Parameters

- **FwdIter** – The type of the source iterators used (deduced). This iterator type must meet the requirements of a forward iterator.
- **OutIter** – The type of the source iterators used (deduced). This iterator type must meet the requirements of an output iterator.

Parameters

- **first** – Refers to the beginning of the sequence of elements the algorithm will be applied to.
- **new_first** – Refers to the element that should appear at the beginning of the rotated range.
- **last** – Refers to the end of the sequence of elements the algorithm will be applied to.
- **dest_first** – Refers to the begin of the destination range.

Returns The *rotate_copy* algorithm returns an output iterator, The *rotate_copy* algorithm returns the output iterator to the element past the last element copied.

```
template<typename ExPolicy, typename FwdIter1, typename FwdIter2>  
hpx::parallel::util::detail::algorithm_result_t<ExPolicy, FwdIter2> rotate_copy(ExPolicy &&policy,  
                                     FwdIter1 first, FwdIter1  
                                     new_first, FwdIter1 last,  
                                     FwdIter2 dest_first)
```

Copies the elements from the range [first, last), to another range beginning at *dest_first* in such a way, that the element *new_first* becomes the first element of the new range and *new_first* - 1 becomes the last element. Executed according to the policy.

The assignments in the parallel *rotate_copy* algorithm execute in sequential order in the calling thread.

The assignments in the parallel *rotate_copy* algorithm execute in an unordered fashion in unspecified threads, and indeterminately sequenced within each thread.

Note: Complexity: Performs exactly *last - first* assignments.

Template Parameters

- **ExPolicy** – The type of the execution policy to use (deduced). It describes the manner in which the execution of the algorithm may be parallelized and the manner in which it executes the assignments.
- **FwdIter1** – The type of the source iterators used (deduced). This iterator type must meet the requirements of a forward iterator.
- **FwdIter2** – The type of the iterator representing the destination range (deduced). This iterator type must meet the requirements of a forward iterator.

Parameters

- **policy** – The execution policy to use for the scheduling of the iterations.
- **first** – Refers to the beginning of the sequence of elements the algorithm will be applied to.
- **new_first** – Refers to the element that should appear at the beginning of the rotated range.
- **last** – Refers to the end of the sequence of elements the algorithm will be applied to.

- **dest_first** – Refers to the begin of the destination range.

Returns The *rotate_copy* algorithm returns a `hpx::future<FwdIter2>` if the execution policy is of type *parallel_task_policy* and returns `FwdIter2` otherwise. The *rotate_copy* algorithm returns the output iterator to the element past the last element copied.

hpx::search, hpx::search_n

Defined in header `hpx/algorithm.hpp`⁶¹³.

See *Public API* for a list of names and headers that are part of the public HPX API.

namespace **hpx**

Functions

```
template<typename FwdIter, typename FwdIter2, typename Pred = parallel::detail::equal_to>
FwdIter search(FwdIter first, FwdIter last, FwdIter2 s_first, FwdIter2 s_last, Pred &&op = Pred())
```

Searches the range [first, last) for any elements in the range [s_first, s_last). Uses a provided predicate to compare elements.

The comparison operations in the parallel *search* algorithm execute in sequential order in the calling thread.

Note: Complexity: at most (S*N) comparisons where $S = \text{distance}(s_first, s_last)$ and $N = \text{distance}(first, last)$.

Template Parameters

- **FwdIter** – The type of the source iterators used for the first range (deduced). This iterator type must meet the requirements of a forward iterator.
- **FwdIter2** – The type of the source iterators used for the second range (deduced). This iterator type must meet the requirements of a forward iterator.
- **Pred** – The type of an optional function/function object to use. Unlike its sequential form, the parallel overload of *search* requires *Pred* to meet the requirements of *CopyConstructible*. This defaults to `std::equal_to<>`

Parameters

- **first** – Refers to the beginning of the sequence of elements of the first range the algorithm will be applied to.
- **last** – Refers to the end of the sequence of elements of the first range the algorithm will be applied to.
- **s_first** – Refers to the beginning of the sequence of elements the algorithm will be searching for.
- **s_last** – Refers to the end of the sequence of elements of the algorithm will be searching for.

⁶¹³ <http://github.com/STELLAR-GROUP/hpx/blob/8a3b7c1a4cb5693b2f7d9f587f759392ed0c51a0/libs/full/include/include/hpx/algorithm.hpp>

- **op** – Refers to the binary predicate which returns true if the elements should be treated as equal. the signature of the function should be equivalent to

```
bool pred(const Type1 &a, const Type2 &b);
```

The signature does not need to have `const &`, but the function must not modify the objects passed to it. The types *Type1* and *Type2* must be such that objects of types *FwdIter1* and *FwdIter2* can be dereferenced and then implicitly converted to *Type1* and *Type2* respectively

Returns The *search* algorithm returns a *hpx::future<FwdIter>* if the execution policy is of type *task_execution_policy* and returns *FwdIter* otherwise. The *search* algorithm returns an iterator to the beginning of the first subsequence [s_first, s_last) in range [first, last). If the length of the subsequence [s_first, s_last) is greater than the length of the range [first, last), *last* is returned. Additionally if the size of the subsequence is empty *first* is returned. If no subsequence is found, *last* is returned.

```
template<typename ExPolicy, typename FwdIter, typename FwdIter2, typename Pred =
parallel::detail::equal_to>
hpx::parallel::util::detail::algorithm_result_t<ExPolicy, FwdIter> search(ExPolicy &&policy, FwdIter first,
FwdIter last, FwdIter2 s_first,
FwdIter2 s_last, Pred &&op =
Pred())
```

Searches the range [first, last) for any elements in the range [s_first, s_last). Uses a provided predicate to compare elements. Executed according to the policy.

The comparison operations in the parallel *search* algorithm invoked with an execution policy object of type *sequenced_policy* execute in sequential order in the calling thread.

The comparison operations in the parallel *search* algorithm invoked with an execution policy object of type *parallel_policy* or *parallel_task_policy* are permitted to execute in an unordered fashion in unspecified threads, and indeterminately sequenced within each thread.

Note: Complexity: at most (S*N) comparisons where *S* = distance(s_first, s_last) and *N* = distance(first, last).

Template Parameters

- **ExPolicy** – The type of the execution policy to use (deduced). It describes the manner in which the execution of the algorithm may be parallelized and the manner in which it executes the assignments.
- **FwdIter** – The type of the source iterators used for the first range (deduced). This iterator type must meet the requirements of a forward iterator.
- **FwdIter2** – The type of the source iterators used for the second range (deduced). This iterator type must meet the requirements of a forward iterator.
- **Pred** – The type of an optional function/function object to use. Unlike its sequential form, the parallel overload of *search* requires *Pred* to meet the requirements of *CopyConstructible*. This defaults to *std::equal_to<>*.

Parameters

- **policy** – The execution policy to use for the scheduling of the iterations.

- **first** – Refers to the beginning of the sequence of elements of the first range the algorithm will be applied to.
- **last** – Refers to the end of the sequence of elements of the first range the algorithm will be applied to.
- **s_first** – Refers to the beginning of the sequence of elements the algorithm will be searching for.
- **s_last** – Refers to the end of the sequence of elements of the algorithm will be searching for.
- **op** – Refers to the binary predicate which returns true if the elements should be treated as equal. the signature of the function should be equivalent to

```
bool pred(const Type1 &a, const Type2 &b);
```

The signature does not need to have `const &`, but the function must not modify the objects passed to it. The types *Type1* and *Type2* must be such that objects of types *FwdIter1* and *FwdIter2* can be dereferenced and then implicitly converted to *Type1* and *Type2* respectively

Returns The *search* algorithm returns a `hpx::future<FwdIter>` if the execution policy is of type *task_execution_policy* and returns *FwdIter* otherwise. The *search* algorithm returns an iterator to the beginning of the first subsequence [s_first, s_last) in range [first, last). If the length of the subsequence [s_first, s_last) is greater than the length of the range [first, last), *last* is returned. Additionally if the size of the subsequence is empty *first* is returned. If no subsequence is found, *last* is returned.

```
template<typename FwdIter, typename FwdIter2, typename Pred = parallel::detail::equal_to>
FwdIter search_n(FwdIter first, std::size_t count, FwdIter2 s_first, FwdIter2 s_last, Pred &&op = Pred())
```

Searches the range [first, last) for any elements in the range [s_first, s_last). Uses a provided predicate to compare elements.

The comparison operations in the parallel *search_n* algorithm execute in sequential order in the calling thread.

Note: Complexity: at most (S*N) comparisons where *S* = distance(s_first, s_last) and *N* = count.

Template Parameters

- **FwdIter** – The type of the source iterators used for the first range (deduced). This iterator type must meet the requirements of a forward iterator.
- **FwdIter2** – The type of the source iterators used for the second range (deduced). This iterator type must meet the requirements of a forward iterator.
- **Pred** – The type of an optional function/function object to use. Unlike its sequential form, the parallel overload of *search_n* requires *Pred* to meet the requirements of *CopyConstructible*. This defaults to `std::equal_to<>`

Parameters

- **first** – Refers to the beginning of the sequence of elements of the first range the algorithm will be applied to.
- **count** – Refers to the range of elements of the first range the algorithm will be applied to.

- **s_first** – Refers to the beginning of the sequence of elements the algorithm will be searching for.
- **s_last** – Refers to the end of the sequence of elements of the algorithm will be searching for.
- **op** – Refers to the binary predicate which returns true if the elements should be treated as equal. the signature of the function should be equivalent to

```
bool pred(const Type1 &a, const Type2 &b);
```

The signature does not need to have `const &`, but the function must not modify the objects passed to it. The types *Type1* and *Type2* must be such that objects of types *FwdIter1* and *FwdIter2* can be dereferenced and then implicitly converted to *Type1* and *Type2* respectively

Returns The *search_n* algorithm returns *FwdIter*. The *search_n* algorithm returns an iterator to the beginning of the last subsequence [s_first, s_last) in range [first, first+count). If the length of the subsequence [s_first, s_last) is greater than the length of the range [first, first+count), *first* is returned. Additionally if the size of the subsequence is empty or no subsequence is found, *first* is also returned.

```
template<typename ExPolicy, typename FwdIter, typename FwdIter2, typename Pred =
parallel::detail::equal_to>
hpx::parallel::util::detail::algorithm_result_t<ExPolicy, FwdIter> search_n(ExPolicy &&policy, FwdIter
first, std::size_t count, FwdIter2
s_first, FwdIter2 s_last, Pred
&&op = Pred())
```

Searches the range [first, last) for any elements in the range [s_first, s_last). Uses a provided predicate to compare elements. Executed according to the policy.

The comparison operations in the parallel *search_n* algorithm invoked with an execution policy object of type *sequenced_policy* execute in sequential order in the calling thread.

The comparison operations in the parallel *search_n* algorithm invoked with an execution policy object of type *parallel_policy* or *parallel_task_policy* are permitted to execute in an unordered fashion in unspecified threads, and indeterminately sequenced within each thread.

Note: Complexity: at most (S*N) comparisons where *S* = distance(s_first, s_last) and *N* = count.

Template Parameters

- **ExPolicy** – The type of the execution policy to use (deduced). It describes the manner in which the execution of the algorithm may be parallelized and the manner in which it executes the assignments.
- **FwdIter** – The type of the source iterators used for the first range (deduced). This iterator type must meet the requirements of a forward iterator.
- **FwdIter2** – The type of the source iterators used for the second range (deduced). This iterator type must meet the requirements of a forward iterator.
- **Pred** – The type of an optional function/function object to use. Unlike its sequential form, the parallel overload of *search_n* requires *Pred* to meet the requirements of *CopyConstructible*. This defaults to `std::equal_to<>`

Parameters

- **policy** – The execution policy to use for the scheduling of the iterations.
- **first** – Refers to the beginning of the sequence of elements of the first range the algorithm will be applied to.
- **count** – Refers to the range of elements of the first range the algorithm will be applied to.
- **s_first** – Refers to the beginning of the sequence of elements the algorithm will be searching for.
- **s_last** – Refers to the end of the sequence of elements of the algorithm will be searching for.
- **op** – Refers to the binary predicate which returns true if the elements should be treated as equal. the signature of the function should be equivalent to

```
bool pred(const Type1 &a, const Type2 &b);
```

The signature does not need to have `const &`, but the function must not modify the objects passed to it. The types *Type1* and *Type2* must be such that objects of types *FwdIter1* and *FwdIter2* can be dereferenced and then implicitly converted to *Type1* and *Type2* respectively

Returns The *search_n* algorithm returns a *hpx::future<FwdIter>* if the execution policy is of type *task_execution_policy* and returns *FwdIter* otherwise. The *search_n* algorithm returns an iterator to the beginning of the last subsequence [s_first, s_last) in range [first, first+count). If the length of the subsequence [s_first, s_last) is greater than the length of the range [first, first+count), *first* is returned. Additionally if the size of the subsequence is empty or no subsequence is found, *first* is also returned.

hpx::set_difference

Defined in header `hpx/algorithm.hpp`⁶¹⁴.

See *Public API* for a list of names and headers that are part of the public *HPX* API.

namespace **hpx**

Functions

```
template<typename ExPolicy, typename FwdIter1, typename FwdIter2, typename FwdIter3, typename
Pred = hpx::parallel::detail::less>
hpx::parallel::util::detail::algorithm_result_t<ExPolicy, FwdIter3> set_difference(ExPolicy &&policy,
FwdIter1 first1,
FwdIter1 last1,
FwdIter2 first2,
FwdIter2 last2,
FwdIter3 dest, Pred
&&op = Pred())
```

Constructs a sorted range beginning at *dest* consisting of all elements present in the range [first1, last1) and not present in the range [first2, last2). This algorithm expects both input ranges to be sorted with the given binary predicate *pred*. Executed according to the policy.

⁶¹⁴ <http://github.com/STELLAR-GROUP/hpx/blob/8a3b7c1a4cb5693b2f7d9f587f759392ed0c51a0/libs/full/include/include/hpx/algorithm.hpp>

Equivalent elements are treated individually, that is, if some element is found m times in $[first1, last1)$ and n times in $[first2, last2)$, it will be copied to *dest* exactly $\text{std::max}(m-n, 0)$ times. The resulting range cannot overlap with either of the input ranges.

The resulting range cannot overlap with either of the input ranges.

The application of function objects in parallel algorithm invoked with a sequential execution policy object execute in sequential order in the calling thread (*sequenced_policy*) or in a single new thread spawned from the current thread (for *sequenced_task_policy*).

The application of function objects in parallel algorithm invoked with an execution policy object of type *parallel_policy* or *parallel_task_policy* are permitted to execute in an unordered fashion in unspecified threads, and indeterminately sequenced within each thread.

Note: Complexity: At most $2*(N1 + N2 - 1)$ comparisons, where $N1$ is the length of the first sequence and $N2$ is the length of the second sequence.

Template Parameters

- **ExPolicy** – The type of the execution policy to use (deduced). It describes the manner in which the execution of the algorithm may be parallelized and the manner in which it applies user-provided function objects.
- **FwdIter1** – The type of the source iterators used (deduced) representing the first sequence. This iterator type must meet the requirements of a forward iterator.
- **FwdIter2** – The type of the source iterators used (deduced) representing the first sequence. This iterator type must meet the requirements of a forward iterator.
- **FwdIter3** – The type of the iterator representing the destination range (deduced). This iterator type must meet the requirements of a output iterator.
- **Pred** – The type of an optional function/function object to use. Unlike its sequential form, the parallel overload of *set_difference* requires *Pred* to meet the requirements of *CopyConstructible*. This defaults to `std::less<>`

Parameters

- **policy** – The execution policy to use for the scheduling of the iterations.
- **first1** – Refers to the beginning of the sequence of elements of the first range the algorithm will be applied to.
- **last1** – Refers to the end of the sequence of elements of the first range the algorithm will be applied to.
- **first2** – Refers to the beginning of the sequence of elements of the second range the algorithm will be applied to.
- **last2** – Refers to the end of the sequence of elements of the second range the algorithm will be applied to.
- **dest** – Refers to the beginning of the destination range.
- **op** – The binary predicate which returns true if the elements should be treated as equal. The signature of the predicate function should be equivalent to the following:

```
bool pred(const Type1 &a, const Type1 &b);
```

The signature does not need to have `const &`, but the function must not modify the objects passed to it. The type *Type1* must be such that objects of type *FwdIter* can be dereferenced and then implicitly converted to *Type1*.

Returns The *set_difference* algorithm returns a `hpx::future<FwdIter3>` if the execution policy is of type *sequenced_task_policy* or *parallel_task_policy* and returns *FwdIter3* otherwise. The *set_difference* algorithm returns the output iterator to the element in the destination range, one past the last element copied.

```
template<typename FwdIter1, typename FwdIter2, typename FwdIter3, typename Pred =
hpx::parallel::detail::less>
FwdIter3 set_difference(FwdIter1 first1, FwdIter1 last1, FwdIter2 first2, FwdIter2 last2, FwdIter3 dest,
Pred &&op = Pred())
```

Constructs a sorted range beginning at *dest* consisting of all elements present in the range `[first1, last1)` and not present in the range `[first2, last2)`. This algorithm expects both input ranges to be sorted with the given binary predicate *pred*.

Equivalent elements are treated individually, that is, if some element is found *m* times in `[first1, last1)` and *n* times in `[first2, last2)`, it will be copied to *dest* exactly `std::max(m-n, 0)` times. The resulting range cannot overlap with either of the input ranges.

The resulting range cannot overlap with either of the input ranges.

Note: Complexity: At most $2 \cdot (N1 + N2 - 1)$ comparisons, where *N1* is the length of the first sequence and *N2* is the length of the second sequence.

Template Parameters

- **FwdIter1** – The type of the source iterators used (deduced) representing the first sequence. This iterator type must meet the requirements of a forward iterator.
- **FwdIter2** – The type of the source iterators used (deduced) representing the first sequence. This iterator type must meet the requirements of a forward iterator.
- **FwdIter3** – The type of the iterator representing the destination range (deduced). This iterator type must meet the requirements of an output iterator.
- **Pred** – The type of an optional function/function object to use. Unlike its sequential form, the parallel overload of *set_difference* requires *Pred* to meet the requirements of *CopyConstructible*. This defaults to `std::less<>`

Parameters

- **first1** – Refers to the beginning of the sequence of elements of the first range the algorithm will be applied to.
- **last1** – Refers to the end of the sequence of elements of the first range the algorithm will be applied to.
- **first2** – Refers to the beginning of the sequence of elements of the second range the algorithm will be applied to.
- **last2** – Refers to the end of the sequence of elements of the second range the algorithm will be applied to.

- **dest** – Refers to the beginning of the destination range.
- **op** – The binary predicate which returns true if the elements should be treated as equal. The signature of the predicate function should be equivalent to the following:

```
bool pred(const Type1 &a, const Type1 &b);
```

The signature does not need to have `const &`, but the function must not modify the objects passed to it. The type *Type1* must be such that objects of type *FwdIter* can be dereferenced and then implicitly converted to *Type1*.

Returns The *set_difference* algorithm returns a *FwdIter3*. The *set_difference* algorithm returns the output iterator to the element in the destination range, one past the last element copied.

hpx::set_intersection

Defined in header `hpx/algorithm.hpp`⁶¹⁵.

See *Public API* for a list of names and headers that are part of the public *HPX* API.

namespace **hpx**

Functions

```
template<typename ExPolicy, typename FwdIter1, typename FwdIter2, typename FwdIter3, typename
Pred = hpx::parallel::detail::less>
hpx::parallel::util::detail::algorithm_result_t<ExPolicy, FwdIter3> set_intersection(ExPolicy &&policy,
                                          FwdIter1 first1,
                                          FwdIter1 last1,
                                          FwdIter2 first2,
                                          FwdIter2 last2,
                                          FwdIter3 dest, Pred
                                          &&op = Pred())
```

Constructs a sorted range beginning at *dest* consisting of all elements present in both sorted ranges [*first1*, *last1*) and [*first2*, *last2*). This algorithm expects both input ranges to be sorted with the given binary predicate *pred*. Executed according to the policy.

If some element is found *m* times in [*first1*, *last1*) and *n* times in [*first2*, *last2*), the first `std::min(m, n)` elements will be copied from the first range to the destination range. The order of equivalent elements is preserved. The resulting range cannot overlap with either of the input ranges.

The resulting range cannot overlap with either of the input ranges.

The application of function objects in parallel algorithm invoked with a sequential execution policy object execute in sequential order in the calling thread (*sequenced_policy*) or in a single new thread spawned from the current thread (for *sequenced_task_policy*).

The application of function objects in parallel algorithm invoked with an execution policy object of type *parallel_policy* or *parallel_task_policy* are permitted to execute in an unordered fashion in unspecified threads, and indeterminately sequenced within each thread.

⁶¹⁵ <http://github.com/STELLAR-GROUP/hpx/blob/8a3b7c1a4cb5693b2f7d9f587f759392ed0c51a0/libs/full/include/include/hpx/algorithm.hpp>

Note: Complexity: At most $2*(N1 + N2 - 1)$ comparisons, where $N1$ is the length of the first sequence and $N2$ is the length of the second sequence.

Template Parameters

- **ExPolicy** – The type of the execution policy to use (deduced). It describes the manner in which the execution of the algorithm may be parallelized and the manner in which it applies user-provided function objects.
- **FwdIter1** – The type of the source iterators used (deduced) representing the first sequence. This iterator type must meet the requirements of a forward iterator.
- **FwdIter2** – The type of the source iterators used (deduced) representing the first sequence. This iterator type must meet the requirements of a forward iterator.
- **FwdIter3** – The type of the iterator representing the destination range (deduced). This iterator type must meet the requirements of a forward iterator or output iterator with sequential execution.
- **Pred** – The type of an optional function/function object to use. Unlike its sequential form, the parallel overload of *set_intersection* requires *Pred* to meet the requirements of *CopyConstructible*. This defaults to `std::less<>`

Parameters

- **policy** – The execution policy to use for the scheduling of the iterations.
- **first1** – Refers to the beginning of the sequence of elements of the first range the algorithm will be applied to.
- **last1** – Refers to the end of the sequence of elements of the first range the algorithm will be applied to.
- **first2** – Refers to the beginning of the sequence of elements of the second range the algorithm will be applied to.
- **last2** – Refers to the end of the sequence of elements of the second range the algorithm will be applied to.
- **dest** – Refers to the beginning of the destination range.
- **op** – The binary predicate which returns true if the elements should be treated as equal. The signature of the predicate function should be equivalent to the following:

```
bool pred(const Type1 &a, const Type1 &b);
```

The signature does not need to have `const &`, but the function must not modify the objects passed to it. The type *Type1* must be such that objects of type *FwdIter* can be dereferenced and then implicitly converted to *Type1*

Returns The *set_intersection* algorithm returns a `hpx::future<FwdIter3>` if the execution policy is of type *sequenced_task_policy* or *parallel_task_policy* and returns *FwdIter3* otherwise. The *set_intersection* algorithm returns the output iterator to the element in the destination range, one past the last element copied.

```
template<typename FwdIter1, typename FwdIter2, typename FwdIter3, typename Pred =
    hpx::parallel::detail::less>
```

```
FwdIter3 set_intersection(FwdIter1 first1, FwdIter1 last1, FwdIter2 first2, FwdIter2 last2, FwdIter3 dest,
                          Pred &&op = Pred())
```

Constructs a sorted range beginning at *dest* consisting of all elements present in both sorted ranges [*first1*, *last1*) and [*first2*, *last2*). This algorithm expects both input ranges to be sorted with the given binary predicate *pred*.

If some element is found *m* times in [*first1*, *last1*) and *n* times in [*first2*, *last2*), the first `std::min(m, n)` elements will be copied from the first range to the destination range. The order of equivalent elements is preserved. The resulting range cannot overlap with either of the input ranges.

The resulting range cannot overlap with either of the input ranges.

Note: Complexity: At most $2 \cdot (N1 + N2 - 1)$ comparisons, where *N1* is the length of the first sequence and *N2* is the length of the second sequence.

Template Parameters

- **FwdIter1** – The type of the source iterators used (deduced) representing the first sequence. This iterator type must meet the requirements of a forward iterator.
- **FwdIter2** – The type of the source iterators used (deduced) representing the first sequence. This iterator type must meet the requirements of a forward iterator.
- **FwdIter3** – The type of the iterator representing the destination range (deduced). This iterator type must meet the requirements of a forward iterator or output iterator with sequential execution.
- **Pred** – The type of an optional function/function object to use. Unlike its sequential form, the parallel overload of *set_intersection* requires *Pred* to meet the requirements of *CopyConstructible*. This defaults to `std::less<>`

Parameters

- **first1** – Refers to the beginning of the sequence of elements of the first range the algorithm will be applied to.
- **last1** – Refers to the end of the sequence of elements of the first range the algorithm will be applied to.
- **first2** – Refers to the beginning of the sequence of elements of the second range the algorithm will be applied to.
- **last2** – Refers to the end of the sequence of elements of the second range the algorithm will be applied to.
- **dest** – Refers to the beginning of the destination range.
- **op** – The binary predicate which returns true if the elements should be treated as equal. The signature of the predicate function should be equivalent to the following:

```
bool pred(const Type1 &a, const Type1 &b);
```

The signature does not need to have `const &`, but the function must not modify the objects passed to it. The type *Type1* must be such that objects of type *FwdIter* can be dereferenced and then implicitly converted to *Type1*

Returns The *set_intersection* algorithm returns a *FwdIter3*. The *set_intersection* algorithm returns the output iterator to the element in the destination range, one past the last element copied.

hpx::set_symmetric_difference

Defined in header `hpx/algorithm.hpp`⁶¹⁶.

See *Public API* for a list of names and headers that are part of the public HPX API.

namespace **hpx**

Functions

```
template<typename ExPolicy, typename FwdIter1, typename FwdIter2, typename FwdIter3, typename
Pred = hpx::parallel::detail::less>
hpx::parallel::util::detail::algorithm_result<ExPolicy, FwdIter3>::type set_symmetric_difference(ExPolicy
&&pol-
icy,
FwdIter1
first1,
FwdIter1
last1,
FwdIter2
first2,
FwdIter2
last2,
FwdIter3
dest,
Pred
&&op
=
Pred())
```

Constructs a sorted range beginning at *dest* consisting of all elements present in either of the sorted ranges $[first1, last1)$ and $[first2, last2)$, but not in both of them are copied to the range beginning at *dest*. The resulting range is also sorted. This algorithm expects both input ranges to be sorted with the given binary predicate *pred*. Executed according to the policy.

If some element is found *m* times in $[first1, last1)$ and *n* times in $[first2, last2)$, it will be copied to *dest* exactly $\text{std::abs}(m-n)$ times. If $m > n$, then the last $m-n$ of those elements are copied from $[first1, last1)$, otherwise the last $n-m$ elements are copied from $[first2, last2)$. The resulting range cannot overlap with either of the input ranges.

The resulting range cannot overlap with either of the input ranges.

The application of function objects in parallel algorithm invoked with a sequential execution policy object execute in sequential order in the calling thread (*sequenced_policy*) or in a single new thread spawned from the current thread (for *sequenced_task_policy*).

⁶¹⁶ <http://github.com/STELLAR-GROUP/hpx/blob/8a3b7c1a4cb5693b2f7d9f587f759392ed0c51a0/libs/full/include/include/hpx/algorithm.hpp>

The application of function objects in parallel algorithm invoked with an execution policy object of type *parallel_policy* or *parallel_task_policy* are permitted to execute in an unordered fashion in unspecified threads, and indeterminately sequenced within each thread.

Note: Complexity: At most $2*(N1 + N2 - 1)$ comparisons, where $N1$ is the length of the first sequence and $N2$ is the length of the second sequence.

Template Parameters

- **ExPolicy** – The type of the execution policy to use (deduced). It describes the manner in which the execution of the algorithm may be parallelized and the manner in which it applies user-provided function objects.
- **FwdIter1** – The type of the source iterators used (deduced) representing the first sequence. This iterator type must meet the requirements of a forward iterator.
- **FwdIter2** – The type of the source iterators used (deduced) representing the first sequence. This iterator type must meet the requirements of a forward iterator.
- **FwdIter3** – The type of the iterator representing the destination range (deduced). This iterator type must meet the requirements of a forward iterator or output iterator and sequential execution.
- **Pred** – The type of an optional function/function object to use. Unlike its sequential form, the parallel overload of *set_symmetric_difference* requires *Pred* to meet the requirements of *CopyConstructible*. This defaults to `std::less<>`

Parameters

- **policy** – The execution policy to use for the scheduling of the iterations.
- **first1** – Refers to the beginning of the sequence of elements of the first range the algorithm will be applied to.
- **last1** – Refers to the end of the sequence of elements of the first range the algorithm will be applied to.
- **first2** – Refers to the beginning of the sequence of elements of the second range the algorithm will be applied to.
- **last2** – Refers to the end of the sequence of elements of the second range the algorithm will be applied to.
- **dest** – Refers to the beginning of the destination range.
- **op** – The binary predicate which returns true if the elements should be treated as equal. The signature of the predicate function should be equivalent to the following:

```
bool pred(const Type1 &a, const Type1 &b);
```

The signature does not need to have `const &`, but the function must not modify the objects passed to it. The type *Type1* must be such that objects of type *FwdIter* can be dereferenced and then implicitly converted to *Type1*

Returns The *set_symmetric_difference* algorithm returns a `hpx::future<FwdIter3>` if the execution policy is of type *sequenced_task_policy* or *parallel_task_policy* and returns *FwdIter3* otherwise. The *set_symmetric_difference* algorithm returns the output iterator to the element in the destination range, one past the last element copied.

```
template<typename FwdIter1, typename FwdIter2, typename FwdIter3, typename Pred =
    hpx::parallel::detail::less>
FwdIter3 set_symmetric_difference(FwdIter1 first1, FwdIter1 last1, FwdIter2 first2, FwdIter2 last2,
    FwdIter3 dest, Pred &&op = Pred())
```

Constructs a sorted range beginning at *dest* consisting of all elements present in either of the sorted ranges $[first1, last1)$ and $[first2, last2)$, but not in both of them are copied to the range beginning at *dest*. The resulting range is also sorted. This algorithm expects both input ranges to be sorted with the given binary predicate *pred*.

If some element is found m times in $[first1, last1)$ and n times in $[first2, last2)$, it will be copied to *dest* exactly $\text{std::abs}(m-n)$ times. If $m > n$, then the last $m-n$ of those elements are copied from $[first1, last1)$, otherwise the last $n-m$ elements are copied from $[first2, last2)$. The resulting range cannot overlap with either of the input ranges.

The resulting range cannot overlap with either of the input ranges.

Note: Complexity: At most $2 \cdot (N1 + N2 - 1)$ comparisons, where $N1$ is the length of the first sequence and $N2$ is the length of the second sequence.

Template Parameters

- **FwdIter1** – The type of the source iterators used (deduced) representing the first sequence. This iterator type must meet the requirements of a forward iterator.
- **FwdIter2** – The type of the source iterators used (deduced) representing the first sequence. This iterator type must meet the requirements of a forward iterator.
- **FwdIter3** – The type of the iterator representing the destination range (deduced). This iterator type must meet the requirements of a forward iterator or output iterator and sequential execution.
- **Pred** – The type of an optional function/function object to use. Unlike its sequential form, the parallel overload of *set_symmetric_difference* requires *Pred* to meet the requirements of *CopyConstructible*. This defaults to `std::less<>`

Parameters

- **first1** – Refers to the beginning of the sequence of elements of the first range the algorithm will be applied to.
- **last1** – Refers to the end of the sequence of elements of the first range the algorithm will be applied to.
- **first2** – Refers to the beginning of the sequence of elements of the second range the algorithm will be applied to.
- **last2** – Refers to the end of the sequence of elements of the second range the algorithm will be applied to.
- **dest** – Refers to the beginning of the destination range.
- **op** – The binary predicate which returns true if the elements should be treated as equal. The signature of the predicate function should be equivalent to the following:

```
bool pred(const Type1 &a, const Type1 &b);
```

The signature does not need to have `const &`, but the function must not modify the objects passed to it. The type *Type1* must be such that objects of type *FwdIter* can be dereferenced and then implicitly converted to *Type1*

Returns The *set_symmetric_difference* algorithm returns a *FwdIter3*. The *set_symmetric_difference* algorithm returns the output iterator to the element in the destination range, one past the last element copied.

hpx::set_union

Defined in header `hpx/algorithm.hpp`⁶¹⁷.

See *Public API* for a list of names and headers that are part of the public HPX API.

namespace **hpx**

Functions

```
template<typename ExPolicy, typename FwdIter1, typename FwdIter2, typename FwdIter3, typename  
Pred = hpx::parallel::detail::less>  
hpx::parallel::util::detail::algorithm_result_t<ExPolicy, FwdIter3> set_union(ExPolicy &&policy, FwdIter1  
first1, FwdIter1 last1,  
FwdIter2 first2, FwdIter2  
last2, FwdIter3 dest, Pred  
&&op = Pred())
```

Constructs a sorted range beginning at *dest* consisting of all elements present in one or both sorted ranges $[first1, last1)$ and $[first2, last2)$. This algorithm expects both input ranges to be sorted with the given binary predicate *pred*. Executed according to the policy.

If some element is found *m* times in $[first1, last1)$ and *n* times in $[first2, last2)$, then all *m* elements will be copied from $[first1, last1)$ to *dest*, preserving order, and then exactly `std::max(n-m, 0)` elements will be copied from $[first2, last2)$ to *dest*, also preserving order.

The resulting range cannot overlap with either of the input ranges.

The application of function objects in parallel algorithm invoked with a sequential execution policy object execute in sequential order in the calling thread (*sequenced_policy*) or in a single new thread spawned from the current thread (for *sequenced_task_policy*).

The application of function objects in parallel algorithm invoked with an execution policy object of type *parallel_policy* or *parallel_task_policy* are permitted to execute in an unordered fashion in unspecified threads, and indeterminately sequenced within each thread.

Note: Complexity: At most $2*(N1 + N2 - 1)$ comparisons, where *N1* is the length of the first sequence and *N2* is the length of the second sequence.

Template Parameters

⁶¹⁷ <http://github.com/STELLAR-GROUP/hpx/blob/8a3b7c1a4cb5693b2f7d9f587f759392ed0c51a0/libs/full/include/include/hpx/algorithm.hpp>

- **ExPolicy** – The type of the execution policy to use (deduced). It describes the manner in which the execution of the algorithm may be parallelized and the manner in which it applies user-provided function objects.
- **FwdIter1** – The type of the source iterators used (deduced) representing the first sequence. This iterator type must meet the requirements of a forward iterator.
- **FwdIter2** – The type of the source iterators used (deduced) representing the first sequence. This iterator type must meet the requirements of a forward iterator.
- **FwdIter3** – The type of the iterator representing the destination range (deduced). This iterator type must meet the requirements of a forward iterator or output iterator and sequential execution.
- **Op** – The type of an optional function/function object to use. Unlike its sequential form, the parallel overload of *set_union* requires *Pred* to meet the requirements of *CopyConstructible*. This defaults to `std::less<>`

Parameters

- **policy** – The execution policy to use for the scheduling of the iterations.
- **first1** – Refers to the beginning of the sequence of elements of the first range the algorithm will be applied to.
- **last1** – Refers to the end of the sequence of elements of the first range the algorithm will be applied to.
- **first2** – Refers to the beginning of the sequence of elements of the second range the algorithm will be applied to.
- **last2** – Refers to the end of the sequence of elements of the second range the algorithm will be applied to.
- **dest** – Refers to the beginning of the destination range.
- **op** – The binary predicate which returns true if the elements should be treated as equal. The signature of the predicate function should be equivalent to the following:

```
bool pred(const Type1 &a, const Type1 &b);
```

The signature does not need to have `const &`, but the function must not modify the objects passed to it. The type *Type1* must be such that objects of type *FwdIter* can be dereferenced and then implicitly converted to *Type1*

Returns The *set_union* algorithm returns a *hpx::future<FwdIter3>* if the execution policy is of type *sequenced_task_policy* or *parallel_task_policy* and returns *FwdIter3* otherwise. The *set_union* algorithm returns the output iterator to the element in the destination range, one past the last element copied.

```
template<typename FwdIter1, typename FwdIter2, typename FwdIter3, typename Pred =
hpx::parallel::detail::less>
FwdIter3 set_union(FwdIter1 first1, FwdIter1 last1, FwdIter2 first2, FwdIter2 last2, FwdIter3 dest, Pred
&&op = Pred())
```

Constructs a sorted range beginning at *dest* consisting of all elements present in one or both sorted ranges *[first1, last1)* and *[first2, last2)*. This algorithm expects both input ranges to be sorted with the given binary predicate *pred*. Executed according to the policy.

If some element is found m times in $[first1, last1)$ and n times in $[first2, last2)$, then all m elements will be copied from $[first1, last1)$ to `dest`, preserving order, and then exactly `std::max(n-m, 0)` elements will be copied from $[first2, last2)$ to `dest`, also preserving order.

The resulting range cannot overlap with either of the input ranges.

Note: Complexity: At most $2*(N1 + N2 - 1)$ comparisons, where $N1$ is the length of the first sequence and $N2$ is the length of the second sequence.

Template Parameters

- **FwdIter1** – The type of the source iterators used (deduced) representing the first sequence. This iterator type must meet the requirements of a forward iterator.
- **FwdIter2** – The type of the source iterators used (deduced) representing the first sequence. This iterator type must meet the requirements of a forward iterator.
- **FwdIter3** – The type of the iterator representing the destination range (deduced). This iterator type must meet the requirements of a forward iterator or output iterator and sequential execution.
- **Op** – The type of an optional function/function object to use. Unlike its sequential form, the parallel overload of `set_union` requires `Pred` to meet the requirements of `CopyConstructible`. This defaults to `std::less<>`

Parameters

- **first1** – Refers to the beginning of the sequence of elements of the first range the algorithm will be applied to.
- **last1** – Refers to the end of the sequence of elements of the first range the algorithm will be applied to.
- **first2** – Refers to the beginning of the sequence of elements of the second range the algorithm will be applied to.
- **last2** – Refers to the end of the sequence of elements of the second range the algorithm will be applied to.
- **dest** – Refers to the beginning of the destination range.
- **op** – The binary predicate which returns true if the elements should be treated as equal. The signature of the predicate function should be equivalent to the following:

```
bool pred(const Type1 &a, const Type1 &b);
```

The signature does not need to have `const &`, but the function must not modify the objects passed to it. The type `Type1` must be such that objects of type `FwdIter` can be dereferenced and then implicitly converted to `Type1`

Returns The `set_union` algorithm returns a `FwdIter3`. The `set_union` algorithm returns the output iterator to the element in the destination range, one past the last element copied.

hpx::shift_left

Defined in header `hpx/algorithm.hpp`⁶¹⁸.

See *Public API* for a list of names and headers that are part of the public HPX API.

namespace **hpx**

Functions

```
template<typename FwdIter, typename Size>
FwdIter shift_left(FwdIter first, FwdIter last, Size n)
```

Shifts the elements in the range [first, last) by n positions towards the beginning of the range. For every integer i in [0, last - first

- n), moves the element originally at position first + n + i to position first + i.

The assignment operations in the parallel *shift_left* algorithm invoked without an execution policy object will execute in sequential order in the calling thread.

Note: Complexity: At most (last - first) - n assignments.

Note: The type of dereferenced *FwdIter* must meet the requirements of *MoveAssignable*.

Template Parameters

- **FwdIter** – The type of the source iterators used (deduced). This iterator type must meet the requirements of a forward iterator.
- **Size** – The type of the argument specifying the number of positions to shift by.

Parameters

- **first** – Refers to the beginning of the sequence of elements the algorithm will be applied to.
- **last** – Refers to the end of the sequence of elements the algorithm will be applied to.
- **n** – Refers to the number of positions to shift.

Returns The *shift_left* algorithm returns *FwdIter*. The *shift_left* algorithm returns an iterator to the end of the resulting range.

```
template<typename ExPolicy, typename FwdIter, typename Size>
hpx::parallel::util::detail::algorithm_result<ExPolicy, FwdIter> shift_left(ExPolicy &&policy, FwdIter
first, FwdIter last, Size n)
```

Shifts the elements in the range [first, last) by n positions towards the beginning of the range. For every integer i in [0, last - first

- n), moves the element originally at position first + n + i to position first + i. Executed according to the policy.

⁶¹⁸ <http://github.com/STELLAR-GROUP/hpx/blob/8a3b7c1a4cb5693b2f7d9f587f759392ed0c51a0/libs/full/include/include/hpx/algorithm.hpp>

The assignment operations in the parallel *shift_left* algorithm invoked with an execution policy object of type *sequenced_policy* execute in sequential order in the calling thread.

The assignment operations in the parallel *shift_left* algorithm invoked with an execution policy object of type *parallel_policy* or *parallel_task_policy* are permitted to execute in an unordered fashion in unspecified threads, and indeterminately sequenced within each thread.

Note: Complexity: At most (last - first) - n assignments.

Note: The type of dereferenced *FwdIter* must meet the requirements of *MoveAssignable*.

Template Parameters

- **ExPolicy** – The type of the execution policy to use (deduced). It describes the manner in which the execution of the algorithm may be parallelized and the manner in which it executes the assignments.
- **FwdIter** – The type of the source iterators used (deduced). This iterator type must meet the requirements of a forward iterator.
- **Size** – The type of the argument specifying the number of positions to shift by.

Parameters

- **policy** – The execution policy to use for the scheduling of the iterations.
- **first** – Refers to the beginning of the sequence of elements the algorithm will be applied to.
- **last** – Refers to the end of the sequence of elements the algorithm will be applied to.
- **n** – Refers to the number of positions to shift.

Returns The *shift_left* algorithm returns a *hpx::future<FwdIter>* if the execution policy is of type *sequenced_task_policy* or *parallel_task_policy* and returns *FwdIter* otherwise. The *shift_left* algorithm returns an iterator to the end of the resulting range.

hpx::shift_right

Defined in header `hpx/algorithm.hpp`⁶¹⁹.

See *Public API* for a list of names and headers that are part of the public *HPX* API.

namespace **hpx**

⁶¹⁹ <http://github.com/STELLAR-GROUP/hpx/blob/8a3b7c1a4cb5693b2f7d9f587f759392ed0c51a0/libs/full/include/include/hpx/algorithm.hpp>

Functions

```
template<typename FwdIter, typename Size>
FwdIter shift_right(FwdIter first, FwdIter last, Size n)
```

Shifts the elements in the range [first, last) by n positions towards the end of the range. For every integer i in [0, last - first - n), moves the element originally at position first + i to position first

- n + i.

The assignment operations in the parallel *shift_right* algorithm invoked without an execution policy object will execute in sequential order in the calling thread.

Note: Complexity: At most (last - first) - n assignments.

Note: The type of dereferenced *FwdIter* must meet the requirements of *MoveAssignable*.

Template Parameters

- **FwdIter** – The type of the source iterators used (deduced). This iterator type must meet the requirements of a forward iterator.
- **Size** – The type of the argument specifying the number of positions to shift by.

Parameters

- **first** – Refers to the beginning of the sequence of elements the algorithm will be applied to.
- **last** – Refers to the end of the sequence of elements the algorithm will be applied to.
- **n** – Refers to the number of positions to shift.

Returns The *shift_right* algorithm returns *FwdIter*. The *shift_right* algorithm returns an iterator to the end of the resulting range.

```
template<typename ExPolicy, typename FwdIter, typename Size>
hpx::parallel::util::detail::algorithm_result<ExPolicy, FwdIter> shift_right(ExPolicy &&policy, FwdIter
first, FwdIter last, Size n)
```

Shifts the elements in the range [first, last) by n positions towards the end of the range. For every integer i in [0, last - first - n), moves the element originally at position first + i to position first

- n + i. Executed according to the policy.

The assignment operations in the parallel *shift_right* algorithm invoked with an execution policy object of type *sequenced_policy* execute in sequential order in the calling thread.

The assignment operations in the parallel *shift_right* algorithm invoked with an execution policy object of type *parallel_policy* or *parallel_task_policy* are permitted to execute in an unordered fashion in unspecified threads, and indeterminately sequenced within each thread.

Note: Complexity: At most (last - first) - n assignments.

Note: The type of dereferenced *FwdIter* must meet the requirements of *MoveAssignable*.

Template Parameters

- **ExPolicy** – The type of the execution policy to use (deduced). It describes the manner in which the execution of the algorithm may be parallelized and the manner in which it executes the assignments.
- **FwdIter** – The type of the source iterators used (deduced). This iterator type must meet the requirements of a forward iterator.
- **Size** – The type of the argument specifying the number of positions to shift by.

Parameters

- **policy** – The execution policy to use for the scheduling of the iterations.
- **first** – Refers to the beginning of the sequence of elements the algorithm will be applied to.
- **last** – Refers to the end of the sequence of elements the algorithm will be applied to.
- **n** – Refers to the number of positions to shift.

Returns The *shift_right* algorithm returns a *hpx::future<FwdIter>* if the execution policy is of type *sequenced_task_policy* or *parallel_task_policy* and returns *FwdIter* otherwise. The *shift_right* algorithm returns an iterator to the end of the resulting range.

hpx::sort

Defined in header `hpx/algorithm.hpp`⁶²⁰.

See *Public API* for a list of names and headers that are part of the public HPX API.

namespace **hpx**

Functions

```
template<typename RandomIt, typename Comp = hpx::parallel::detail::less, typename Proj = hpx::identity>  
void sort(RandomIt first, RandomIt last, Comp &&comp, Proj &&proj = Proj())
```

Sorts the elements in the range [first, last) in ascending order. The order of equal elements is not guaranteed to be preserved. The function uses the given comparison function object comp (defaults to using operator<()).

A sequence is sorted with respect to a comparator *comp* and a projection *proj* if for every iterator *i* pointing to the sequence and every non-negative integer *n* such that *i + n* is a valid iterator pointing to an element of the sequence, and `INVOKE(comp, INVOKE(proj, *(i + n)), INVOKE(proj, *i)) == false`.

comp has to induce a strict weak ordering on the values.

The assignments in the parallel *sort* algorithm invoked without an execution policy object execute in sequential order in the calling thread.

⁶²⁰ <http://github.com/STELLAR-GROUP/hpx/blob/8a3b7c1a4cb5693b2f7d9f587f759392ed0c51a0/libs/full/include/include/hpx/algorithm.hpp>

Note: Complexity: $O(N \log(N))$, where $N = \text{std::distance}(\text{first}, \text{last})$ comparisons.

Template Parameters

- **RandomIt** – The type of the source iterators used (deduced). This iterator type must meet the requirements of a random access iterator.
- **Comp** – The type of the function/function object to use (deduced).
- **Proj** – The type of an optional projection function. This defaults to `hpx::identity`.

Parameters

- **first** – Refers to the beginning of the sequence of elements the algorithm will be applied to.
- **last** – Refers to the end of the sequence of elements the algorithm will be applied to.
- **comp** – `comp` is a callable object. The return value of the INVOKE operation applied to an object of type `Comp`, when contextually converted to `bool`, yields `true` if the first argument of the call is less than the second, and `false` otherwise. It is assumed that `comp` will not apply any non-constant function through the dereferenced iterator.
- **proj** – Specifies the function (or function object) which will be invoked for each pair of elements as a projection operation before the actual predicate `comp` is invoked.

Returns The `sort` algorithm returns `void`.

```
template<typename ExPolicy, typename RandomIt, typename Comp = hpx::parallel::detail::less, typename
Proj = hpx::identity>
hpx::parallel::util::detail::algorithm_result_t<ExPolicy> sort(ExPolicy &&policy, RandomIt first, RandomIt
last, Comp &&comp, Proj &&proj)
```

Sorts the elements in the range `[first, last)` in ascending order. The order of equal elements is not guaranteed to be preserved. The function uses the given comparison function object `comp` (defaults to using `operator<()`). Executed according to the policy.

A sequence is sorted with respect to a comparator `comp` and a projection `proj` if for every iterator `i` pointing to the sequence and every non-negative integer `n` such that `i + n` is a valid iterator pointing to an element of the sequence, and `INVOKE(comp, INVOKE(proj, *(i + n)), INVOKE(proj, *i)) == false`.

`comp` has to induce a strict weak ordering on the values.

The application of function objects in parallel algorithm invoked with an execution policy object of type `sequenced_policy` execute in sequential order in the calling thread.

The application of function objects in parallel algorithm invoked with an execution policy object of type `parallel_policy` or `parallel_task_policy` are permitted to execute in an unordered fashion in unspecified threads, and indeterminately sequenced within each thread.

Note: Complexity: $O(N \log(N))$, where $N = \text{std::distance}(\text{first}, \text{last})$ comparisons.

Template Parameters

- **ExPolicy** – The type of the execution policy to use (deduced). It describes the manner in which the execution of the algorithm may be parallelized and the manner in which it applies user-provided function objects.

- **RandomIt** – The type of the source iterators used (deduced). This iterator type must meet the requirements of a random access iterator.
- **Comp** – The type of the function/function object to use (deduced).
- **Proj** – The type of an optional projection function. This defaults to *hpx::identity*.

Parameters

- **policy** – The execution policy to use for the scheduling of the iterations.
- **first** – Refers to the beginning of the sequence of elements the algorithm will be applied to.
- **last** – Refers to the end of the sequence of elements the algorithm will be applied to.
- **comp** – `comp` is a callable object. The return value of the INVOKE operation applied to an object of type *Comp*, when contextually converted to `bool`, yields `true` if the first argument of the call is less than the second, and `false` otherwise. It is assumed that `comp` will not apply any non-constant function through the dereferenced iterator.
- **proj** – Specifies the function (or function object) which will be invoked for each pair of elements as a projection operation before the actual predicate *comp* is invoked.

Returns The *sort* algorithm returns a *hpx::future<void>* if the execution policy is of type *sequenced_task_policy* or *parallel_task_policy* and returns *void* otherwise.

hpx::experimental::sort_by_key

Defined in header `hpx/algorithm.hpp`⁶²¹.

See *Public API* for a list of names and headers that are part of the public *HPX* API.

namespace **hpx**

namespace **experimental**

Top-level namespace.

Functions

```
template<typename ExPolicy, typename KeyIter, typename ValueIter, typename Compare =  
detail::less>
```

⁶²¹ <http://github.com/STELLAR-GROUP/hpx/blob/8a3b7c1a4cb5693b2f7d9f587f759392ed0c51a0/libs/full/include/include/hpx/algorithm.hpp>

```

util::detail::algorithm_result_t<ExPolicy, sort_by_key_result<KeyIter, ValueIter>> sort_by_key(ExPolicy
&&pol-
icy,
KeyIter
key_first,
KeyIter
key_last,
Val-
ueIter
value_first,
Com-
pare
&&comp
=
Com-
pare())

```

Sorts one range of data using keys supplied in another range. The key elements in the range [key_first, key_last) are sorted in ascending order with the corresponding elements in the value range moved to follow the sorted order. The algorithm is not stable, the order of equal elements is not guaranteed to be preserved. The function uses the given comparison function object comp (defaults to using operator<()). Executed according to the policy.

A sequence is sorted with respect to a comparator *comp* if for every iterator *i* pointing to the sequence and every non-negative integer *n* such that *i + n* is a valid iterator pointing to an element of the sequence, and INVOKE(comp, *(i + n), *i) == false.

comp has to induce a strict weak ordering on the values.

The application of function objects in parallel algorithm invoked with an execution policy object of type *sequenced_policy* execute in sequential order in the calling thread.

The application of function objects in parallel algorithm invoked with an execution policy object of type *parallel_policy* or *parallel_task_policy* are permitted to execute in an unordered fashion in unspecified threads, and indeterminately sequenced within each thread.

Note: Complexity: $O(N \log(N))$, where $N = \text{std::distance}(\text{first}, \text{last})$ comparisons.

Template Parameters

- **ExPolicy** – The type of the execution policy to use (deduced). It describes the manner in which the execution of the algorithm may be parallelized and the manner in which it applies user-provided function objects.
- **KeyIter** – The type of the key iterators used (deduced). This iterator type must meet the requirements of a random access iterator.
- **ValueIter** – The type of the value iterators used (deduced). This iterator type must meet the requirements of a random access iterator.
- **Compare** – The type of the function/function object to use (deduced).

Parameters

- **policy** – The execution policy to use for the scheduling of the iterations.
- **key_first** – Refers to the beginning of the sequence of key elements the algorithm will be applied to.
- **key_last** – Refers to the end of the sequence of key elements the algorithm will be applied to.

- **value_first** – Refers to the beginning of the sequence of value elements the algorithm will be applied to, the range of elements must match [key_first, key_last)
- **comp** – comp is a callable object. The return value of the INVOKE operation applied to an object of type Comp, when contextually converted to bool, yields true if the first argument of the call is less than the second, and false otherwise. It is assumed that comp will not apply any non-constant function through the dereferenced iterator.

Returns The *sort_by_key* algorithm returns a `hpx::future<sort_by_key_result<KeyIter, ValueIter>>` if the execution policy is of type *sequenced_task_policy* or *parallel_task_policy* and returns *otherwise*. The algorithm returns a pair holding an iterator pointing to the first element after the last element in the input key sequence and an iterator pointing to the first element after the last element in the input value sequence.

hpx::stable_sort

Defined in header `hpx/algorithm.hpp`⁶²².

See *Public API* for a list of names and headers that are part of the public HPX API.

namespace **hpx**

Functions

```
template<typename RandomIt, typename Comp = hpx::parallel::detail::less, typename Proj = hpx::identity>  
void stable_sort(RandomIt first, RandomIt last, Comp &&comp = Comp(), Proj &&proj = Proj())
```

Sorts the elements in the range [first, last) in ascending order. The relative order of equal elements is preserved. The function uses the given comparison function object comp (defaults to using operator<()).

A sequence is sorted with respect to a comparator *comp* and a projection *proj* if for every iterator *i* pointing to the sequence and every non-negative integer *n* such that *i + n* is a valid iterator pointing to an element of the sequence, and `INVOKE(comp, INVOKE(proj, *(i + n)), INVOKE(proj, *i)) == false`.

comp has to induce a strict weak ordering on the values.

The assignments in the parallel *stable_sort* algorithm invoked without an execution policy object execute in sequential order in the calling thread.

Note: Complexity: $O(N \log(N))$, where $N = \text{std::distance}(\text{first}, \text{last})$ comparisons.

Template Parameters

- **RandomIt** – The type of the source iterators used (deduced). This iterator type must meet the requirements of a random access iterator.
- **Comp** – The type of the function/function object to use (deduced).
- **Proj** – The type of an optional projection function. This defaults to `hpx::identity`.

Parameters

- **first** – Refers to the beginning of the sequence of elements the algorithm will be applied to.

⁶²² <http://github.com/STELLAR-GROUP/hpx/blob/8a3b7c1a4cb5693b2f7d9f587f759392ed0c51a0/libs/full/include/include/hpx/algorithm.hpp>

- **last** – Refers to the end of the sequence of elements the algorithm will be applied to.
- **comp** – `comp` is a callable object. The return value of the INVOKE operation applied to an object of type `Comp`, when contextually converted to `bool`, yields `true` if the first argument of the call is less than the second, and `false` otherwise. It is assumed that `comp` will not apply any non-constant function through the dereferenced iterator.
- **proj** – Specifies the function (or function object) which will be invoked for each pair of elements as a projection operation before the actual predicate `comp` is invoked.

Returns The `stable_sort` algorithm returns `void`.

```
template<typename ExPolicy, typename RandomIt, typename Comp = hpx::parallel::detail::less, typename
Proj = hpx::identity>
hpx::parallel::util::detail::algorithm_result_t<ExPolicy> stable_sort(ExPolicy &&policy, RandomIt first,
                                                                    RandomIt last, Comp &&comp =
                                                                    Comp(), Proj &&proj = Proj())
```

Sorts the elements in the range `[first, last)` in ascending order. The relative order of equal elements is preserved. The function uses the given comparison function object `comp` (defaults to using `operator<()`). Executed according to the policy.

A sequence is sorted with respect to a comparator `comp` and a projection `proj` if for every iterator `i` pointing to the sequence and every non-negative integer `n` such that `i + n` is a valid iterator pointing to an element of the sequence, and `INVOKE(comp, INVOKE(proj, *(i + n)), INVOKE(proj, *i)) == false`.

`comp` has to induce a strict weak ordering on the values.

The application of function objects in parallel algorithm invoked with an execution policy object of type `sequenced_policy` execute in sequential order in the calling thread.

The application of function objects in parallel algorithm invoked with an execution policy object of type `parallel_policy` or `parallel_task_policy` are permitted to execute in an unordered fashion in unspecified threads, and indeterminately sequenced within each thread.

Note: Complexity: $O(N \log(N))$, where $N = \text{std::distance}(\text{first}, \text{last})$ comparisons.

Template Parameters

- **ExPolicy** – The type of the execution policy to use (deduced). It describes the manner in which the execution of the algorithm may be parallelized and the manner in which it applies user-provided function objects.
- **RandomIt** – The type of the source iterators used (deduced). This iterator type must meet the requirements of a random access iterator.
- **Comp** – The type of the function/function object to use (deduced).
- **Proj** – The type of an optional projection function. This defaults to `hpx::identity`.

Parameters

- **policy** – The execution policy to use for the scheduling of the iterations.
- **first** – Refers to the beginning of the sequence of elements the algorithm will be applied to.
- **last** – Refers to the end of the sequence of elements the algorithm will be applied to.

- **comp** – `comp` is a callable object. The return value of the INVOKE operation applied to an object of type `Comp`, when contextually converted to `bool`, yields `true` if the first argument of the call is less than the second, and `false` otherwise. It is assumed that `comp` will not apply any non-constant function through the dereferenced iterator.
- **proj** – Specifies the function (or function object) which will be invoked for each pair of elements as a projection operation before the actual predicate `comp` is invoked.

Returns The `stable_sort` algorithm returns a `hpx::future<void>` if the execution policy is of type `sequenced_task_policy` or `parallel_task_policy` and returns `void` otherwise.

hpx::starts_with

Defined in header `hpx/algorithm.hpp`⁶²³.

See *Public API* for a list of names and headers that are part of the public HPX API.

namespace **hpx**

Functions

```
template<typename InIter1, typename InIter2, typename Pred = hpx::parallel::detail::equal_to, typename Proj1 = hpx::identity, typename Proj2 = hpx::identity>
bool starts_with(InIter1 first1, InIter1 last1, InIter2 first2, InIter2 last2, Pred &&pred = Pred(), Proj1 &&proj1 = Proj1(), Proj2 &&proj2 = Proj2())
```

Checks whether the second range defined by `[first1, last1)` matches the prefix of the first range defined by `[first2, last2)`

The assignments in the parallel `starts_with` algorithm invoked without an execution policy object execute in sequential order in the calling thread.

Note: Complexity: Linear: at most $\min(N1, N2)$ applications of the predicate and both projections.

Template Parameters

- **InIter1** – The type of the source iterators used (deduced). This iterator type must meet the requirements of an input iterator.
- **InIter2** – The type of the destination iterators used (deduced). This iterator type must meet the requirements of an input iterator.
- **Pred** – The binary predicate that compares the projected elements. This defaults to `hpx::parallel::detail::equal_to`.
- **Proj1** – The type of an optional projection function for the source range. This defaults to `hpx::identity`.
- **Proj2** – The type of an optional projection function for the destination range. This defaults to `hpx::identity`.

Parameters

⁶²³ <http://github.com/STELLAR-GROUP/hpx/blob/8a3b7c1a4cb5693b2f7d9f587f759392ed0c51a0/libs/full/include/include/hpx/algorithm.hpp>

- **first1** – Refers to the beginning of the source range.
- **last1** – Sentinel value referring to the end of the source range.
- **first2** – Refers to the beginning of the destination range.
- **last2** – Sentinel value referring to the end of the destination range.
- **pred** – Specifies the binary predicate function (or function object) which will be invoked for comparison of the elements in the in two ranges projected by *proj1* and *proj2* respectively.
- **proj1** – Specifies the function (or function object) which will be invoked for each of the elements in the source range as a projection operation before the actual predicate *pred* is invoked.
- **proj2** – Specifies the function (or function object) which will be invoked for each of the elements in the destination range as a projection operation before the actual predicate *pred* is invoked.

Returns The *starts_with* algorithm returns *bool*. The *starts_with* algorithm returns a boolean with the value true if the second range matches the prefix of the first range, false otherwise.

```
template<typename ExPolicy, typename InIter1, typename InIter2, typename Pred =
    hpx::parallel::detail::equal_to, typename Proj1 = hpx::identity, typename Proj2 = hpx::identity>
hpx::parallel::util::detail::algorithm_result_t<ExPolicy, bool> starts_with(ExPolicy &&policy, InIter1
    first1, InIter1 last1, InIter2
    first2, InIter2 last2, Pred
    &&pred = Pred(), Proj1
    &&proj1 = Proj1(), Proj2
    &&proj2 = Proj2())
```

Checks whether the second range defined by [first1, last1) matches the prefix of the first range defined by [first2, last2). Executed according to the policy.

The assignments in the parallel *starts_with* algorithm invoked without an execution policy object execute in sequential order in the calling thread.

Note: Complexity: Linear: at most min(N1, N2) applications of the predicate and both projections.

Template Parameters

- **ExPolicy** – The type of the execution policy to use (deduced). It describes the manner in which the execution of the algorithm may be parallelized and the manner in which it executes the assignments.
- **InIter1** – The type of the source iterators used (deduced). This iterator type must meet the requirements of an input iterator.
- **InIter2** – The type of the destination iterators used (deduced). This iterator type must meet the requirements of an input iterator.
- **Pred** – The binary predicate that compares the projected elements. This defaults to *hpx::parallel::detail::equal_to*.
- **Proj1** – The type of an optional projection function for the source range. This defaults to *hpx::identity*.
- **Proj2** – The type of an optional projection function for the destination range. This defaults to *hpx::identity*.

Parameters

- **policy** – The execution policy to use for the scheduling of the iterations.
- **first1** – Refers to the beginning of the source range.
- **last1** – Sentinel value referring to the end of the source range.
- **first2** – Refers to the beginning of the destination range.
- **last2** – Sentinel value referring to the end of the destination range.
- **pred** – Specifies the binary predicate function (or function object) which will be invoked for comparison of the elements in the in two ranges projected by *proj1* and *proj2* respectively.
- **proj1** – Specifies the function (or function object) which will be invoked for each of the elements in the source range as a projection operation before the actual predicate *pred* is invoked.
- **proj2** – Specifies the function (or function object) which will be invoked for each of the elements in the destination range as a projection operation before the actual predicate *pred* is invoked.

Returns The *starts_with* algorithm returns a *hpx::future<bool>* if the execution policy is of type *sequenced_task_policy* or *parallel_task_policy* and returns *bool* otherwise. The *starts_with* algorithm returns a boolean with the value true if the second range matches the prefix of the first range, false otherwise.

hpx::swap_ranges

Defined in header `hpx/algorithm.hpp`⁶²⁴.

See *Public API* for a list of names and headers that are part of the public HPX API.

namespace **hpx**

Functions

```
template<typename FwdIter1, typename FwdIter2>  
FwdIter2 swap_ranges(FwdIter1 first1, FwdIter1 last1, FwdIter2 first2)
```

Exchanges elements between range [first1, last1) and another range starting at *first2*.

The swap operations in the parallel *swap_ranges* algorithm invoked without an execution policy object execute in sequential order in the calling thread.

Note: Complexity: Linear in the distance between *first1* and *last1*.

Template Parameters

- **FwdIter1** – The type of the first range of iterators to swap (deduced). This iterator type must meet the requirements of a forward iterator.
- **FwdIter2** – The type of the second range of iterators to swap (deduced). This iterator type must meet the requirements of a forward iterator.

⁶²⁴ <http://github.com/STELLAR-GROUP/hpx/blob/8a3b7c1a4cb5693b2f7d9f587f759392ed0c51a0/libs/full/include/include/hpx/algorithm.hpp>

Parameters

- **first1** – Refers to the beginning of the first sequence of elements the algorithm will be applied to.
- **last1** – Refers to the end of the first sequence of elements the algorithm will be applied to.
- **first2** – Refers to the beginning of the second sequence of elements the algorithm will be applied to.

Returns The *swap_ranges* algorithm returns *FwdIter2*. The *swap_ranges* algorithm returns iterator to the element past the last element exchanged in the range beginning with *first2*.

```
template<typename ExPolicy, typename FwdIter1, typename FwdIter2>
hpx::parallel::util::detail::algorithm_result_t<ExPolicy, FwdIter2> swap_ranges(ExPolicy &&policy,
                                         FwdIter1 first1, FwdIter1
                                         last1, FwdIter2 first2)
```

Exchanges elements between range [first1, last1) and another range starting at *first2*. Executed according to the policy.

The swap operations in the parallel *swap_ranges* algorithm invoked with an execution policy object of type *sequenced_policy* execute in sequential order in the calling thread.

The swap operations in the parallel *swap_ranges* algorithm invoked with an execution policy object of type *parallel_policy* or *parallel_task_policy* are permitted to execute in an unordered fashion in unspecified threads, and indeterminately sequenced within each thread.

Note: Complexity: Linear in the distance between *first1* and *last1*.

Template Parameters

- **ExPolicy** – The type of the execution policy to use (deduced). It describes the manner in which the execution of the algorithm may be parallelized and the manner in which it executes the swap operations.
- **FwdIter1** – The type of the first range of iterators to swap (deduced). This iterator type must meet the requirements of a forward iterator.
- **FwdIter2** – The type of the second range of iterators to swap (deduced). This iterator type must meet the requirements of a forward iterator.

Parameters

- **policy** – The execution policy to use for the scheduling of the iterations.
- **first1** – Refers to the beginning of the first sequence of elements the algorithm will be applied to.
- **last1** – Refers to the end of the first sequence of elements the algorithm will be applied to.
- **first2** – Refers to the beginning of the second sequence of elements the algorithm will be applied to.

Returns The *swap_ranges* algorithm returns a *hpx::future<FwdIter2>* if the execution policy is of type *parallel_task_policy* and returns *FwdIter2* otherwise. The *swap_ranges* algorithm

returns iterator to the element past the last element exchanged in the range beginning with *first2*.

hpx::transform

Defined in header `hpx/algorithm.hpp`⁶²⁵.

See *Public API* for a list of names and headers that are part of the public HPX API.

namespace **hpx**

Functions

```
template<typename FwdIter1, typename FwdIter2, typename F>  
FwdIter2 transform(FwdIter1 first, FwdIter1 last, FwdIter2 dest, F &&f)
```

Applies the given function *f* to the range [first, last) and stores the result in another range, beginning at dest.

Note: Complexity: Exactly *last - first* applications of *f*

Template Parameters

- **FwdIter1** – The type of the source iterators used (deduced). This iterator type must meet the requirements of a forward iterator.
- **FwdIter2** – The type of the iterator representing the destination range (deduced). This iterator type must meet the requirements of a forward iterator.
- **F** – The type of the function/function object to use (deduced). Unlike its sequential form, the parallel overload of *transform* requires *F* to meet the requirements of *CopyConstructible*.

Parameters

- **first** – Refers to the beginning of the sequence of elements the algorithm will be applied to.
- **last** – Refers to the end of the sequence of elements the algorithm will be applied to.
- **dest** – Refers to the beginning of the destination range.
- **f** – Specifies the function (or function object) which will be invoked for each of the elements in the sequence specified by [first, last). This is an unary predicate. The signature of this predicate should be equivalent to:

```
Ret fun(const Type &a);
```

The signature does not need to have `const&`. The type *Type* must be such that an object of type *FwdIter1* can be dereferenced and then implicitly converted to *Type*. The type *Ret* must be such that an object of type *FwdIter2* can be dereferenced and assigned a value of type *Ret*.

Returns The *transform* algorithm returns a *FwdIter2*. The *transform* algorithm returns a tuple holding an iterator referring to the first element after the input sequence and the output iterator to the element in the destination range, one past the last element copied.

⁶²⁵ <http://github.com/STELLAR-GROUP/hpx/blob/8a3b7c1a4cb5693b2f7d9f587f759392ed0c51a0/libs/full/include/include/hpx/algorithm.hpp>

```
template<typename ExPolicy, typename FwdIter1, typename FwdIter2, typename F>
parallel::util::detail::algorithm_result_t<ExPolicy, FwdIter2> transform(ExPolicy &&policy, FwdIter1 first,
                                                                    FwdIter1 last, FwdIter2 dest, F
                                                                    &&f)
```

Applies the given function f to the range $[first, last)$ and stores the result in another range, beginning at $dest$. Executed according to the policy.

The invocations of f in the parallel *transform* algorithm invoked with an execution policy object of type *sequenced_policy* execute in sequential order in the calling thread.

The invocations of f in the parallel *transform* algorithm invoked with an execution policy object of type *parallel_policy* or *parallel_task_policy* are permitted to execute in an unordered fashion in unspecified threads, and indeterminately sequenced within each thread.

Note: Complexity: Exactly *last - first* applications of f

Template Parameters

- **ExPolicy** – The type of the execution policy to use (deduced). It describes the manner in which the execution of the algorithm may be parallelized and the manner in which it executes the invocations of f .
- **FwdIter1** – The type of the source iterators used (deduced). This iterator type must meet the requirements of a forward iterator.
- **FwdIter2** – The type of the iterator representing the destination range (deduced). This iterator type must meet the requirements of a forward iterator.
- **F** – The type of the function/function object to use (deduced). Unlike its sequential form, the parallel overload of *transform* requires F to meet the requirements of *CopyConstructible*.

Parameters

- **policy** – The execution policy to use for the scheduling of the iterations.
- **first** – Refers to the beginning of the sequence of elements the algorithm will be applied to.
- **last** – Refers to the end of the sequence of elements the algorithm will be applied to.
- **dest** – Refers to the beginning of the destination range.
- **f** – Specifies the function (or function object) which will be invoked for each of the elements in the sequence specified by $[first, last)$. This is a unary predicate. The signature of this predicate should be equivalent to:

```
Ret fun(const Type &a);
```

The signature does not need to have `const&`. The type *Type* must be such that an object of type *FwdIter1* can be dereferenced and then implicitly converted to *Type*. The type *Ret* must be such that an object of type *FwdIter2* can be dereferenced and assigned a value of type *Ret*.

Returns The *transform* algorithm returns a `hpx::future<FwdIter2>` if the execution policy is of type *parallel_task_policy* and returns *FwdIter2* otherwise. The *transform* algorithm returns a tuple holding an iterator referring to the first element after the input sequence and the output iterator to the element in the destination range, one past the last element copied.

```
template<typename FwdIter1, typename FwdIter2, typename FwdIter3, typename F>
FwdIter3 transform(FwdIter1 first1, FwdIter1 last1, FwdIter2 first2, FwdIter3 dest, F &&f)
```

Applies the given function f to pairs of elements from two ranges: one defined by $[first1, last1)$ and the other beginning at $first2$, and stores the result in another range, beginning at $dest$.

Note: Complexity: Exactly *last - first* applications of f

Template Parameters

- **FwdIter1** – The type of the source iterators for the first range used (deduced). This iterator type must meet the requirements of a forward iterator.
- **FwdIter2** – The type of the source iterators for the second range used (deduced). This iterator type must meet the requirements of a forward iterator.
- **FwdIter3** – The type of the iterator representing the destination range (deduced). This iterator type must meet the requirements of a forward iterator.
- **F** – The type of the function/function object to use (deduced). Unlike its sequential form, the parallel overload of *transform* requires F to meet the requirements of *CopyConstructible*.

Parameters

- **first1** – Refers to the beginning of the first sequence of elements the algorithm will be applied to.
- **last1** – Refers to the end of the first sequence of elements the algorithm will be applied to.
- **first2** – Refers to the beginning of the second sequence of elements the algorithm will be applied to.
- **dest** – Refers to the beginning of the destination range.
- **f** – Specifies the function (or function object) which will be invoked for each of the elements in the sequence specified by $[first, last)$. This is a binary predicate. The signature of this predicate should be equivalent to:

```
Ret fun(const Type1 &a, const Type2 &b);
```

The signature does not need to have `const&`. The types *Type1* and *Type2* must be such that objects of types *FwdIter1* and *FwdIter2* can be dereferenced and then implicitly converted to *Type1* and *Type2* respectively. The type *Ret* must be such that an object of type *FwdIter3* can be dereferenced and assigned a value of type *Ret*.

Returns The *transform* algorithm returns a *FwdIter3*. The *transform* algorithm returns a tuple holding an iterator referring to the first element after the first input sequence, an iterator referring to the first element after the second input sequence, and the output iterator referring to the element in the destination range, one past the last element copied.

```
template<typename ExPolicy, typename FwdIter1, typename FwdIter2, typename FwdIter3, typename F>
parallel::util::detail::algorithm_result_t<ExPolicy, FwdIter3> transform(ExPolicy &&policy, FwdIter1
first1, FwdIter1 last1, FwdIter2
first2, FwdIter3 dest, F &&f)
```

Applies the given function f to pairs of elements from two ranges: one defined by $[first1, last1)$ and the other beginning at $first2$, and stores the result in another range, beginning at $dest$. Executed according to the policy.

The invocations of f in the parallel *transform* algorithm invoked with an execution policy object of type *sequenced_policy* execute in sequential order in the calling thread.

The invocations of f in the parallel *transform* algorithm invoked with an execution policy object of type *parallel_policy* or *parallel_task_policy* are permitted to execute in an unordered fashion in unspecified threads, and indeterminately sequenced within each thread.

Note: Complexity: Exactly *last - first* applications of f

Template Parameters

- **ExPolicy** – The type of the execution policy to use (deduced). It describes the manner in which the execution of the algorithm may be parallelized and the manner in which it executes the invocations of f .
- **FwdIter1** – The type of the source iterators for the first range used (deduced). This iterator type must meet the requirements of a forward iterator.
- **FwdIter2** – The type of the source iterators for the second range used (deduced). This iterator type must meet the requirements of a forward iterator.
- **FwdIter3** – The type of the iterator representing the destination range (deduced). This iterator type must meet the requirements of a forward iterator.
- **F** – The type of the function/function object to use (deduced). Unlike its sequential form, the parallel overload of *transform* requires F to meet the requirements of *CopyConstructible*.

Parameters

- **policy** – The execution policy to use for the scheduling of the iterations.
- **first1** – Refers to the beginning of the first sequence of elements the algorithm will be applied to.
- **last1** – Refers to the end of the first sequence of elements the algorithm will be applied to.
- **first2** – Refers to the beginning of the second sequence of elements the algorithm will be applied to.
- **dest** – Refers to the beginning of the destination range.
- **f** – Specifies the function (or function object) which will be invoked for each of the elements in the sequence specified by [first, last). This is a binary predicate. The signature of this predicate should be equivalent to:

```
Ret fun(const Type1 &a, const Type2 &b);
```

The signature does not need to have `const&`. The types *Type1* and *Type2* must be such that objects of types *FwdIter1* and *FwdIter2* can be dereferenced and then implicitly converted to *Type1* and *Type2* respectively. The type *Ret* must be such that an object of type *FwdIter3* can be dereferenced and assigned a value of type *Ret*.

Returns The *transform* algorithm returns a `hpx::future<FwdIter3>` if the execution policy is of type *parallel_task_policy* and returns *FwdIter3* otherwise. The *transform* algorithm returns a tuple holding an iterator referring to the first element after the first input sequence, an iterator referring to the first element after the second input sequence, and the output iterator referring to the element in the destination range, one past the last element copied.

hpx::transform_exclusive_scan

Defined in header `hpx/algorithm.hpp`⁶²⁶.

See *Public API* for a list of names and headers that are part of the public HPX API.

namespace **hpx**

Functions

```
template<typename InIter, typename OutIter, typename BinOp, typename UnOp, typename T = typename
std::iterator_traits<InIter>::value_type>
OutIter transform_exclusive_scan(InIter first, InIter last, OutIter dest, T init, BinOp &&binary_op,
                                UnOp &&unary_op)
```

Transforms each element in the range `[first, last)` with `unary_op`, then computes an exclusive prefix sum operation using `binary_op` over the resulting range, with `init` as the initial value, and writes the results to the range beginning at `dest`. “exclusive” means that the *i*-th input element is not included in the *i*-th sum. Formally, assigns through each iterator *i* in `[dest, dest + (last - first))` the value of the generalized noncommutative sum of `init`, `unary_op(*j)`... for every *j* in `[first, first + (i - first))` over `binary_op`, where generalized noncommutative sum `GNSUM(op, a1, ..., aN)` is defined as follows:

- if $N=1$, `a1`
- if $N > 1$, `op(GNSUM(op, a1, ..., aK), GNSUM(op, aM, ..., aN))` for any K where $1 < K+1 = M \leq N$. In other words, the summation operations may be performed in arbitrary order, and the behavior is nondeterministic if `binary_op` is not associative.

The reduce operations in the parallel `transform_exclusive_scan` algorithm invoked without an execution policy object execute in sequential order in the calling thread.

Neither `unary_op` nor `binary_op` shall invalidate iterators or sub-ranges, or modify elements in the ranges `[first,last)` or `[result,result + (last - first))`.

The behavior of `transform_exclusive_scan` may be non-deterministic for a non-associative predicate.

Note: Complexity: $O(\text{last} - \text{first})$ applications of each of `binary_op` and `unary_op`.

Note: `GENERALIZED_NONCOMMUTATIVE_SUM(op, a1, ..., aN)` is defined as:

- `a1` when N is 1
 - `op(GENERALIZED_NONCOMMUTATIVE_SUM(op, a1, ..., aK), GENERALIZED_NONCOMMUTATIVE_SUM(op, aM, ..., aN))` where $1 < K+1 = M \leq N$.
-

Template Parameters

- **InIter** – The type of the source iterators used (deduced). This iterator type must meet the requirements of an input iterator.

⁶²⁶ <http://github.com/STELLAR-GROUP/hpx/blob/8a3b7c1a4cb5693b2f7d9f587f759392ed0c51a0/libs/full/include/include/hpx/algorithm.hpp>

- **OutIter** – The type of the iterator representing the destination range (deduced). This iterator type must meet the requirements of an output iterator.
- **BinOp** – The type of *binary_op*.
- **UnOp** – The type of *unary_op*.
- **T** – The type of the value to be used as initial (and intermediate) values (deduced).

Parameters

- **first** – Refers to the beginning of the sequence of elements the algorithm will be applied to.
- **last** – Refers to the end of the sequence of elements the algorithm will be applied to.
- **dest** – Refers to the beginning of the destination range.
- **init** – The initial value for the generalized sum.
- **binary_op** – Binary *FunctionObject* that will be applied to the result of *unary_op*, the results of other *binary_op*, and *init*.
- **unary_op** – Unary *FunctionObject* that will be applied to each element of the input range. The return type must be acceptable as input to *binary_op*.

Returns The *transform_exclusive_scan* algorithm returns a returns *OutIter*. The *transform_exclusive_scan* algorithm returns the output iterator to the element in the destination range, one past the last element copied.

```
template<typename ExPolicy, typename FwdIter1, typename FwdIter2, typename BinOp, typename UnOp,
typename T = typename std::iterator_traits<FwdIter1>::value_type>
parallel::util::detail::algorithm_result<ExPolicy, FwdIter2>::type transform_exclusive_scan(ExPolicy
                                                                                               &&policy,
                                                                                               FwdIter1
                                                                                               first,
                                                                                               FwdIter1
                                                                                               last,
                                                                                               FwdIter2
                                                                                               dest, T init,
                                                                                               BinOp
                                                                                               &&bi-
                                                                                               nary_op,
                                                                                               UnOp
                                                                                               &&unary_op)
```

Assigns through each iterator *i* in [result, result + (last - first)) the value of GENERALIZED_NONCOMMUTATIVE_SUM(binary_op, init, conv(*first), ..., conv(*(first + (i - result) - 1))). Executed according to the policy.

The reduce operations in the parallel *transform_exclusive_scan* algorithm invoked with an execution policy object of type *sequenced_policy* execute in sequential order in the calling thread.

The reduce operations in the parallel *transform_exclusive_scan* algorithm invoked with an execution policy object of type *parallel_policy* or *parallel_task_policy* are permitted to execute in an unordered fashion in unspecified threads, and indeterminately sequenced within each thread.

Neither *unary_op* nor *binary_op* shall invalidate iterators or sub-ranges, or modify elements in the ranges [first,last) or [result,result + (last - first)).

The behavior of `transform_exclusive_scan` may be non-deterministic for a non-associative predicate.

Note: Complexity: $O(\text{last} - \text{first})$ applications of each of *binary_op* and *unary_op*.

Note: `GENERALIZED_NONCOMMUTATIVE_SUM(op, a1, ..., aN)` is defined as:

- `a1` when `N` is 1
 - `op(GENERALIZED_NONCOMMUTATIVE_SUM(op, a1, ..., aK), GENERALIZED_NONCOMMUTATIVE_SUM(op, aM, ..., aN))` where $1 < K+1 = M \leq N$.
-

Template Parameters

- **ExPolicy** – The type of the execution policy to use (deduced). It describes the manner in which the execution of the algorithm may be parallelized and the manner in which it executes the assignments.
- **FwdIter1** – The type of the source iterators used (deduced). This iterator type must meet the requirements of an forward iterator.
- **FwdIter2** – The type of the iterator representing the destination range (deduced). This iterator type must meet the requirements of an forward iterator.
- **BinOp** – The type of *binary_op*.
- **UnOp** – The type of *unary_op*.
- **T** – The type of the value to be used as initial (and intermediate) values (deduced).

Parameters

- **policy** – The execution policy to use for the scheduling of the iterations.
- **first** – Refers to the beginning of the sequence of elements the algorithm will be applied to.
- **last** – Refers to the end of the sequence of elements the algorithm will be applied to.
- **dest** – Refers to the beginning of the destination range.
- **init** – The initial value for the generalized sum.
- **binary_op** – Binary *FunctionObject* that will be applied in to the result of *unary_op*, the results of other *binary_op*, and *init*.
- **unary_op** – Unary *FunctionObject* that will be applied to each element of the input range. The return type must be acceptable as input to *binary_op*.

Returns The `transform_exclusive_scan` algorithm returns a `hpx::future<FwdIter2>` if the execution policy is of type `sequenced_task_policy` or `parallel_task_policy` and returns `FwdIter2` otherwise. The `transform_exclusive_scan` algorithm returns the output iterator to the element in the destination range, one past the last element copied.

hpx::transform_inclusive_scan

Defined in header `hpx/algorithm.hpp`⁶²⁷.

See *Public API* for a list of names and headers that are part of the public HPX API.

namespace **hpx**

Functions

```
template<typename InIter, typename OutIter, typename BinOp, typename UnOp>
OutIter transform_inclusive_scan(InIter first, InIter last, OutIter dest, BinOp &&binary_op, UnOp
&&unary_op)
```

Assigns through each iterator i in $[result, result + (last - first))$ the value of GENERALIZED_NONCOMMUTATIVE_SUM($op, conv(*first), \dots, conv(*(first + (i - result)))$).

The reduce operations in the parallel *transform_inclusive_scan* algorithm invoked without an execution policy object execute in sequential order in the calling thread.

Neither *binary_op* nor *unary_op* shall invalidate iterators or sub-ranges, or modify elements in the ranges $[first, last)$ or $[result, result + (last - first))$.

The difference between *inclusive_scan* and *transform_inclusive_scan* is that *transform_inclusive_scan* includes the i th input element in the i th sum.

Note: Complexity: $O(last - first)$ applications of each of *binary_op* and *unary_op*.

Note: GENERALIZED_NONCOMMUTATIVE_SUM(op, a_1, \dots, a_N) is defined as:

- a_1 when N is 1
 - $op(GENERALIZED_NONCOMMUTATIVE_SUM(op, a_1, \dots, a_K), GENERALIZED_NONCOMMUTATIVE_SUM(op, a_M, \dots, a_N))$ where $1 < K+1 = M \leq N$.
-

Template Parameters

- **InIter** – The type of the source iterators used (deduced). This iterator type must meet the requirements of an input iterator.
- **OutIter** – The type of the iterator representing the destination range (deduced). This iterator type must meet the requirements of an output iterator.
- **BinOp** – The type of *binary_op*.
- **UnOp** – The type of *unary_op*.

Parameters

- **first** – Refers to the beginning of the sequence of elements the algorithm will be applied to.

⁶²⁷ <http://github.com/STELLAR-GROUP/hpx/blob/8a3b7c1a4cb5693b2f7d9f587f759392ed0c51a0/libs/full/include/include/hpx/algorithm.hpp>

- **last** – Refers to the end of the sequence of elements the algorithm will be applied to.
- **dest** – Refers to the beginning of the destination range.
- **binary_op** – Binary *FunctionObject* that will be applied in to the result of *unary_op*, the results of other *binary_op*, and *init* if provided.
- **unary_op** – Unary *FunctionObject* that will be applied to each element of the input range. The return type must be acceptable as input to *binary_op*.

Returns The *transform_inclusive_scan* algorithm returns a returns *OutIter*. The *transform_inclusive_scan* algorithm returns the output iterator to the element in the destination range, one past the last element copied.

```
template<typename ExPolicy, typename FwdIter1, typename FwdIter2, typename BinOp, typename UnOp>
parallel::util::detail::algorithm_result<ExPolicy, FwdIter2>::type transform_inclusive_scan(ExPolicy
                                                                                               &&policy,
                                                                                               FwdIter1
                                                                                               first,
                                                                                               FwdIter1
                                                                                               last,
                                                                                               FwdIter2
                                                                                               dest, BinOp
                                                                                               &&bi-
                                                                                               nary_op,
                                                                                               UnOp
                                                                                               &&unary_op)
```

Assigns through each iterator *i* in [result, result + (last - first)) the value of GENERALIZED_NONCOMMUTATIVE_SUM(op, conv(*first), ..., conv(*(first + (i - result)))). Executed according to the policy.

The reduce operations in the parallel *transform_inclusive_scan* algorithm invoked with an execution policy object of type *sequenced_policy* execute in sequential order in the calling thread.

The reduce operations in the parallel *transform_inclusive_scan* algorithm invoked with an execution policy object of type *parallel_policy* or *parallel_task_policy* are permitted to execute in an unordered fashion in unspecified threads, and indeterminately sequenced within each thread.

Neither *binary_op* nor *unary_op* shall invalidate iterators or sub-ranges, or modify elements in the ranges [first,last) or [result,result + (last - first)).

The difference between *inclusive_scan* and *transform_inclusive_scan* is that *transform_inclusive_scan* includes the *i*th input element in the *i*th sum.

Note: Complexity: O(last - first) applications of each of *binary_op* and *unary_op*.

Note: GENERALIZED_NONCOMMUTATIVE_SUM(op, a1, ..., aN) is defined as:

- a1 when N is 1
 - op(GENERALIZED_NONCOMMUTATIVE_SUM(op, a1, ..., aK), GENERALIZED_NONCOMMUTATIVE_SUM(op, aM, ..., aN)) where 1 < K+1 = M <= N.
-

Template Parameters

- **ExPolicy** – The type of the execution policy to use (deduced). It describes the manner in which the execution of the algorithm may be parallelized and the manner in which it executes the assignments.
- **FwdIter1** – The type of the source iterators used (deduced). This iterator type must meet the requirements of a forward iterator.
- **FwdIter2** – The type of the iterator representing the destination range (deduced). This iterator type must meet the requirements of a forward iterator.
- **BinOp** – The type of *binary_op*.
- **UnOp** – The type of *unary_op*.

Parameters

- **policy** – The execution policy to use for the scheduling of the iterations.
- **first** – Refers to the beginning of the sequence of elements the algorithm will be applied to.
- **last** – Refers to the end of the sequence of elements the algorithm will be applied to.
- **dest** – Refers to the beginning of the destination range.
- **binary_op** – Binary *FunctionObject* that will be applied in to the result of *unary_op*, the results of other *binary_op*, and *init* if provided.
- **unary_op** – Unary *FunctionObject* that will be applied to each element of the input range. The return type must be acceptable as input to *binary_op*.

Returns The *transform_inclusive_scan* algorithm returns a *hpx::future<FwdIter2>* if the execution policy is of type *sequenced_task_policy* or *parallel_task_policy* and returns *FwdIter2* otherwise. The *transform_inclusive_scan* algorithm returns the output iterator to the element in the destination range, one past the last element copied.

```
template<typename InIter, typename OutIter, typename BinOp, typename UnOp, typename T = typename
std::iterator_traits<InIter>::value_type>
OutIter transform_inclusive_scan(InIter first, InIter last, OutIter dest, BinOp &&binary_op, UnOp
&&unary_op, T init)
```

Assigns through each iterator *i* in [result, result + (last - first)) the value of GENERALIZED_NONCOMMUTATIVE_SUM(op, init, conv(*first), ..., conv>(*first + (i - result))).

The reduce operations in the parallel *transform_inclusive_scan* algorithm invoked without an execution policy object execute in sequential order in the calling thread.

Neither *binary_op* nor *unary_op* shall invalidate iterators or sub-ranges, or modify elements in the ranges [first,last) or [result,result + (last - first)).

The difference between *inclusive_scan* and *transform_inclusive_scan* is that *transform_inclusive_scan* includes the *i*th input element in the *i*th sum. If *binary_op* is not mathematically associative, the behavior of *transform_inclusive_scan* may be non-deterministic.

Note: Complexity: O(last - first) applications of each of *binary_op* and *unary_op*.

Note: GENERALIZED_NONCOMMUTATIVE_SUM(*op*, *a*1, ..., *a*N) is defined as:

- *a*1 when *N* is 1
 - *op*(GENERALIZED_NONCOMMUTATIVE_SUM(*op*, *a*1, ..., *a*K), GENERALIZED_NONCOMMUTATIVE_SUM(*op*, *a*M, ..., *a*N)) where 1 < K+1 = M <= N.
-

Template Parameters

- **InIter** – The type of the source iterators used (deduced). This iterator type must meet the requirements of an input iterator.
- **OutIter** – The type of the iterator representing the destination range (deduced). This iterator type must meet the requirements of an output iterator.
- **BinOp** – The type of *binary_op*.
- **UnOp** – The type of *unary_op*.
- **T** – The type of the value to be used as initial (and intermediate) values (deduced).

Parameters

- **first** – Refers to the beginning of the sequence of elements the algorithm will be applied to.
- **last** – Refers to the end of the sequence of elements the algorithm will be applied to.
- **dest** – Refers to the beginning of the destination range.
- **binary_op** – Binary *FunctionObject* that will be applied in to the result of *unary_op*, the results of other *binary_op*, and *init* if provided.
- **unary_op** – Unary *FunctionObject* that will be applied to each element of the input range. The return type must be acceptable as input to *binary_op*.
- **init** – The initial value for the generalized sum.

Returns The *transform_inclusive_scan* algorithm returns a returns *OutIter*. The *transform_inclusive_scan* algorithm returns the output iterator to the element in the destination range, one past the last element copied.

```
template<typename ExPolicy, typename FwdIter1, typename FwdIter2, typename BinOp, typename UnOp,
typename T = typename std::iterator_traits<FwdIter1>::value_type>
parallel::util::detail::algorithm_result<ExPolicy, FwdIter2>::type transform_inclusive_scan(ExPolicy
&&policy,
FwdIter1
first,
FwdIter1
last,
FwdIter2
dest, BinOp
&&bi-
nary_op,
UnOp
&&unary_op,
T init)
```

Assigns through each iterator i in $[\text{result}, \text{result} + (\text{last} - \text{first}))$ the value of `GENERALIZED_NONCOMMUTATIVE_SUM(op, init, conv(*first), ..., conv(*(first + (i - result))))`. Executed according to the policy.

The reduce operations in the parallel `transform_inclusive_scan` algorithm invoked with an execution policy object of type `sequenced_policy` execute in sequential order in the calling thread.

The reduce operations in the parallel `transform_inclusive_scan` algorithm invoked with an execution policy object of type `parallel_policy` or `parallel_task_policy` are permitted to execute in an unordered fashion in unspecified threads, and indeterminately sequenced within each thread.

Neither `binary_op` nor `unary_op` shall invalidate iterators or sub-ranges, or modify elements in the ranges $[\text{first}, \text{last})$ or $[\text{result}, \text{result} + (\text{last} - \text{first}))$.

The difference between `inclusive_scan` and `transform_inclusive_scan` is that `transform_inclusive_scan` includes the i th input element in the i th sum. If `binary_op` is not mathematically associative, the behavior of `transform_inclusive_scan` may be non-deterministic.

Note: Complexity: $O(\text{last} - \text{first})$ applications of each of `binary_op` and `unary_op`.

Note: `GENERALIZED_NONCOMMUTATIVE_SUM(op, a1, ..., aN)` is defined as:

- a_1 when N is 1
 - $\text{op}(\text{GENERALIZED_NONCOMMUTATIVE_SUM}(\text{op}, a_1, \dots, a_K), \text{GENERALIZED_NONCOMMUTATIVE_SUM}(\text{op}, a_{K+1}, \dots, a_N))$ where $1 < K+1 = M \leq N$.
-

Template Parameters

- **ExPolicy** – The type of the execution policy to use (deduced). It describes the manner in which the execution of the algorithm may be parallelized and the manner in which it executes the assignments.
- **FwdIter1** – The type of the source iterators used (deduced). This iterator type must meet the requirements of an forward iterator.
- **FwdIter2** – The type of the iterator representing the destination range (deduced). This iterator type must meet the requirements of an forward iterator.
- **BinOp** – The type of `binary_op`.
- **UnOp** – The type of `unary_op`.
- **T** – The type of the value to be used as initial (and intermediate) values (deduced).

Parameters

- **policy** – The execution policy to use for the scheduling of the iterations.
- **first** – Refers to the beginning of the sequence of elements the algorithm will be applied to.
- **last** – Refers to the end of the sequence of elements the algorithm will be applied to.
- **dest** – Refers to the beginning of the destination range.

- **binary_op** – Binary *FunctionObject* that will be applied in to the result of *unary_op*, the results of other *binary_op*, and *init* if provided.
- **unary_op** – Unary *FunctionObject* that will be applied to each element of the input range. The return type must be acceptable as input to *binary_op*.
- **init** – The initial value for the generalized sum.

Returns The *transform_inclusive_scan* algorithm returns a `hpx::future<FwdIter2>` if the execution policy is of type *sequenced_task_policy* or *parallel_task_policy* and returns *FwdIter2* otherwise. The *transform_inclusive_scan* algorithm returns the output iterator to the element in the destination range, one past the last element copied.

hpx::transform_reduce

Defined in header `hpx/algorithm.hpp`⁶²⁸.

See *Public API* for a list of names and headers that are part of the public HPX API.

namespace **hpx**

Functions

```
template<typename ExPolicy, typename FwdIter, typename T, typename Reduce, typename Convert>
hpx::parallel::util::detail::algorithm_result_t<ExPolicy, T> transform_reduce(ExPolicy &&policy, FwdIter
                                                                    first, FwdIter last, T init,
                                                                    Reduce &&red_op, Convert
                                                                    &&conv_op)
```

Returns GENERALIZED_SUM(red_op, init, conv_op(*first), ..., conv_op(*(first + (last - first) - 1))). Executed according to the policy.

The reduce operations in the parallel *transform_reduce* algorithm invoked with an execution policy object of type *sequenced_policy* execute in sequential order in the calling thread.

The reduce operations in the parallel *transform_reduce* algorithm invoked with an execution policy object of type *parallel_policy* or *parallel_task_policy* are permitted to execute in an unordered fashion in unspecified threads, and indeterminately sequenced within each thread.

The difference between *transform_reduce* and *accumulate* is that the behavior of *transform_reduce* may be non-deterministic for non-associative or non-commutative binary predicate.

Note: Complexity: $O(\text{last} - \text{first})$ applications of the predicates *red_op* and *conv_op*.

Note: GENERALIZED_SUM(op, a1, ..., aN) is defined as follows:

- a1 when N is 1
- op(GENERALIZED_SUM(op, b1, ..., bK), GENERALIZED_SUM(op, bM, ..., bN)), where:
 - b1, ..., bN may be any permutation of a1, ..., aN and

⁶²⁸ <http://github.com/STELLAR-GROUP/hpx/blob/8a3b7c1a4cb5693b2f7d9f587f759392ed0c51a0/libs/full/include/include/hpx/algorithm.hpp>

– $1 < K+1 = M \leq N$.

Template Parameters

- **ExPolicy** – The type of the execution policy to use (deduced). It describes the manner in which the execution of the algorithm may be parallelized and the manner in which it executes the assignments.
- **FwdIter** – The type of the source iterators used (deduced). This iterator type must meet the requirements of a forward iterator.
- **T** – The type of the value to be used as initial (and intermediate) values (deduced).
- **Reduce** – The type of the binary function object used for the reduction operation.
- **Convert** – The type of the unary function object used to transform the elements of the input sequence before invoking the reduce function.

Parameters

- **policy** – The execution policy to use for the scheduling of the iterations.
- **first** – Refers to the beginning of the sequence of elements the algorithm will be applied to.
- **last** – Refers to the end of the sequence of elements the algorithm will be applied to.
- **init** – The initial value for the generalized sum.
- **red_op** – Specifies the function (or function object) which will be invoked for each of the values returned from the invocation of *conv_op*. This is a binary predicate. The signature of this predicate should be equivalent to:

```
Ret fun(const Type1 &a, const Type2 &b);
```

The signature does not need to have `const&`, but the function must not modify the objects passed to it. The types *Type1*, *Type2*, and *Ret* must be such that an object of a type as returned from *conv_op* can be implicitly converted to any of those types.

- **conv_op** – Specifies the function (or function object) which will be invoked for each of the elements in the sequence specified by [first, last). This is a unary predicate. The signature of this predicate should be equivalent to:

```
R fun(const Type &a);
```

The signature does not need to have `const&`, but the function must not modify the objects passed to it. The type *Type* must be such that an object of type *FwdIter* can be dereferenced and then implicitly converted to *Type*. The type *R* must be such that an object of this type can be implicitly converted to *T*.

Returns The *transform_reduce* algorithm returns a *hpx::future<T>* if the execution policy is of type *parallel_task_policy* and returns *T* otherwise. The *transform_reduce* algorithm returns the result of the generalized sum over the values returned from *conv_op* when applied to the elements given by the input range [first, last).

```
template<typename InIter, typename T, typename Reduce, typename Convert>
T transform_reduce(InIter first, InIter last, T init, Reduce &&red_op, Convert &&conv_op)
```

Returns GENERALIZED_SUM(red_op, init, conv_op(*first), ..., conv_op(*(first + (last - first) - 1))).

The difference between *transform_reduce* and *accumulate* is that the behavior of *transform_reduce* may be non-deterministic for non-associative or non-commutative binary predicate.

Note: Complexity: $O(\text{last} - \text{first})$ applications of the predicates *red_op* and *conv_op*.

Note: GENERALIZED_SUM(op, a1, ..., aN) is defined as follows:

- a1 when N is 1
 - op(GENERALIZED_SUM(op, b1, ..., bK), GENERALIZED_SUM(op, bM, ..., bN)), where:
 - b1, ..., bN may be any permutation of a1, ..., aN and
 - $1 < K+1 = M \leq N$.
-

Template Parameters

- **InIter** – The type of the source iterators used (deduced). This iterator type must meet the requirements of an input iterator.
- **T** – The type of the value to be used as initial (and intermediate) values (deduced).
- **Reduce** – The type of the binary function object used for the reduction operation.
- **Convert** – The type of the unary function object used to transform the elements of the input sequence before invoking the reduce function.

Parameters

- **first** – Refers to the beginning of the sequence of elements the algorithm will be applied to.
- **last** – Refers to the end of the sequence of elements the algorithm will be applied to.
- **init** – The initial value for the generalized sum.
- **red_op** – Specifies the function (or function object) which will be invoked for each of the values returned from the invocation of *conv_op*. This is a binary predicate. The signature of this predicate should be equivalent to:

```
Ret fun(const Type1 &a, const Type2 &b);
```

The signature does not need to have const&, but the function must not modify the objects passed to it. The types *Type1*, *Type2*, and *Ret* must be such that an object of a type as returned from *conv_op* can be implicitly converted to any of those types.

- **conv_op** – Specifies the function (or function object) which will be invoked for each of the elements in the sequence specified by [first, last). This is a unary predicate. The signature of this predicate should be equivalent to:

```
R fun(const Type &a);
```

The signature does not need to have const&, but the function must not modify the objects passed to it. The type *Type* must be such that an object of type *InIter* can be dereferenced and then implicitly converted to *Type*. The type *R* must be such that an object of this type can be implicitly converted to *T*.

Returns The *transform_reduce* algorithm returns a *T*. The *transform_reduce* algorithm returns the result of the generalized sum over the values returned from *conv_op* when applied to the elements given by the input range [first, last).

```
template<typename ExPolicy, typename FwdIter1, typename FwdIter2, typename T>
hpx::parallel::util::detail::algorithm_result_t<ExPolicy, T> transform_reduce(ExPolicy &&policy,
                                                                    FwdIter1 first1, FwdIter1
                                                                    last1, FwdIter2 first2, T init)
```

Returns the result of accumulating *init* with the inner products of the pairs formed by the elements of two ranges starting at *first1* and *first2*. Executed according to the policy.

The operations in the parallel *transform_reduce* algorithm invoked with an execution policy object of type *sequenced_policy* execute in sequential order in the calling thread.

The operations in the parallel *transform_reduce* algorithm invoked with an execution policy object of type *parallel_policy* or *parallel_task_policy* are permitted to execute in an unordered fashion in unspecified threads, and indeterminately sequenced within each thread.

Note: Complexity: $O(\text{last} - \text{first})$ applications each of *reduce* and *transform*.

Template Parameters

- **ExPolicy** – The type of the execution policy to use (deduced). It describes the manner in which the execution of the algorithm may be parallelized and the manner in which it executes the assignments.
- **FwdIter1** – The type of the first source iterators used (deduced). This iterator type must meet the requirements of a forward iterator.
- **FwdIter2** – The type of the second source iterators used (deduced). This iterator type must meet the requirements of a forward iterator.
- **T** – The type of the value to be used as return) values (deduced).

Parameters

- **policy** – The execution policy to use for the scheduling of the iterations.
- **first1** – Refers to the beginning of the first sequence of elements the result will be calculated with.
- **last1** – Refers to the end of the first sequence of elements the algorithm will be applied to.
- **first2** – Refers to the beginning of the second sequence of elements the result will be calculated with.
- **init** – The initial value for the sum.

Returns The *transform_reduce* algorithm returns a *hpx::future<T>* if the execution policy is of type *sequenced_task_policy* or *parallel_task_policy* and returns *T* otherwise.

```
template<typename InIter1, typename InIter2, typename T>
T transform_reduce(InIter1 first1, InIter1 last1, InIter2 first2, T init)
```

Returns the result of accumulating *init* with the inner products of the pairs formed by the elements of two ranges starting at *first1* and *first2*.

Note: Complexity: $O(\textit{last} - \textit{first})$ applications each of *reduce* and *transform*.

Template Parameters

- **InIter1** – The type of the first source iterators used (deduced). This iterator type must meet the requirements of an input iterator.
- **InIter2** – The type of the second source iterators used (deduced). This iterator type must meet the requirements of an input iterator.
- **T** – The type of the value to be used as return) values (deduced).

Parameters

- **first1** – Refers to the beginning of the first sequence of elements the result will be calculated with.
- **last1** – Refers to the end of the first sequence of elements the algorithm will be applied to.
- **first2** – Refers to the beginning of the second sequence of elements the result will be calculated with.
- **init** – The initial value for the sum.

Returns The *transform_reduce* algorithm returns a *T*.

```
template<typename ExPolicy, typename FwdIter1, typename FwdIter2, typename T, typename Reduce,
typename Convert>
hpx::parallel::util::detail::algorithm_result_t<ExPolicy, T> transform_reduce(ExPolicy &&policy,
                                                                    FwdIter1 first1, FwdIter1
                                                                    last1, FwdIter2 first2, T init,
                                                                    Reduce &&red_op, Convert
                                                                    &&conv_op)
```

Returns the result of accumulating *init* with the inner products of the pairs formed by the elements of two ranges starting at *first1* and *first2*. Executed according to the policy.

The operations in the parallel *transform_reduce* algorithm invoked with an execution policy object of type *sequenced_policy* execute in sequential order in the calling thread.

The operations in the parallel *transform_reduce* algorithm invoked with an execution policy object of type *parallel_policy* or *parallel_task_policy* are permitted to execute in an unordered fashion in unspecified threads, and indeterminately sequenced within each thread.

Note: Complexity: $O(\textit{last} - \textit{first})$ applications each of *reduce* and *transform*.

Template Parameters

- **ExPolicy** – The type of the execution policy to use (deduced). It describes the manner in which the execution of the algorithm may be parallelized and the manner in which it executes the assignments.
- **FwdIter1** – The type of the first source iterators used (deduced). This iterator type must meet the requirements of a forward iterator.

- **FwdIter2** – The type of the second source iterators used (deduced). This iterator type must meet the requirements of a forward iterator.
- **T** – The type of the value to be used as return) values (deduced).
- **Reduce** – The type of the binary function object used for the multiplication operation.
- **Convert** – The type of the unary function object used to transform the elements of the input sequence before invoking the reduce function.

Parameters

- **policy** – The execution policy to use for the scheduling of the iterations.
- **first1** – Refers to the beginning of the first sequence of elements the result will be calculated with.
- **last1** – Refers to the end of the first sequence of elements the algorithm will be applied to.
- **first2** – Refers to the beginning of the second sequence of elements the result will be calculated with.
- **init** – The initial value for the sum.
- **red_op** – Specifies the function (or function object) which will be invoked for the initial value and each of the return values of *conv_op*. This is a binary predicate. The signature of this predicate should be equivalent to should be equivalent to:

```
Ret fun(const Type1 &a, const Type1 &b);
```

The signature does not need to have `const&`, but the function must not modify the objects passed to it. The type *Ret* must be such that it can be implicitly converted to a type of *T*.

- **conv_op** – Specifies the function (or function object) which will be invoked for each of the input values of the sequence. This is a binary predicate. The signature of this predicate should be equivalent to

```
Ret fun(const Type1 &a, const Type2 &b);
```

The signature does not need to have `const&`, but the function must not modify the objects passed to it. The type *Ret* must be such that it can be implicitly converted to an object for the second argument type of *red_op*.

Returns The *transform_reduce* algorithm returns a *hpx::future<T>* if the execution policy is of type *sequenced_task_policy* or *parallel_task_policy* and returns *T* otherwise.

```
template<typename InIter1, typename InIter2, typename T, typename Reduce, typename Convert>
T transform_reduce(ExPolicy &&policy, InIter1 first1, InIter1 last1, InIter2 first2, T init, Reduce
&&red_op, Convert &&conv_op)
```

Returns the result of accumulating *init* with the inner products of the pairs formed by the elements of two ranges starting at *first1* and *first2*.

Note: Complexity: $O(\text{last} - \text{first})$ applications each of *reduce* and *transform*.

Template Parameters

- **InIter1** – The type of the first source iterators used (deduced). This iterator type must meet the requirements of an input iterator.

- **InIter2** – The type of the second source iterators used (deduced). This iterator type must meet the requirements of an input iterator.
- **T** – The type of the value to be used as return) values (deduced).
- **Reduce** – The type of the binary function object used for the multiplication operation.
- **Convert** – The type of the unary function object used to transform the elements of the input sequence before invoking the reduce function.

Parameters

- **first1** – Refers to the beginning of the first sequence of elements the result will be calculated with.
- **last1** – Refers to the end of the first sequence of elements the algorithm will be applied to.
- **first2** – Refers to the beginning of the second sequence of elements the result will be calculated with.
- **init** – The initial value for the sum.
- **red_op** – Specifies the function (or function object) which will be invoked for the initial value and each of the return values of *conv_op*. This is a binary predicate. The signature of this predicate should be equivalent to should be equivalent to:

```
Ret fun(const Type1 &a, const Type1 &b);
```

The signature does not need to have `const&`, but the function must not modify the objects passed to it. The type *Ret* must be such that it can be implicitly converted to a type of *T*.

- **conv_op** – Specifies the function (or function object) which will be invoked for each of the input values of the sequence. This is a binary predicate. The signature of this predicate should be equivalent to

```
Ret fun(const Type1 &a, const Type2 &b);
```

The signature does not need to have `const&`, but the function must not modify the objects passed to it. The type *Ret* must be such that it can be implicitly converted to an object for the second argument type of *red_op*.

Returns The *transform_reduce* algorithm returns a *T*.

hpx/parallel/algorithms/transform_reduce_binary.hpp

Defined in header `hpx/parallel/algorithms/transform_reduce_binary.hpp`.

See *Public API* for a list of names and headers that are part of the public *HPX* API.

hpx::uninitialized_copy, hpx::uninitialized_copy_n

Defined in header `hpx/algorithm.hpp`⁶²⁹.

See *Public API* for a list of names and headers that are part of the public *HPX* API.

namespace **hpx**

Functions

```
template<typename InIter, typename FwdIter>
FwdIter uninitialized_copy(InIter first, InIter last, FwdIter dest)
```

Copies the elements in the range, defined by [first, last), to an uninitialized memory area beginning at *dest*. If an exception is thrown during the copy operation, the function has no effects.

The assignments in the parallel *uninitialized_copy* algorithm invoked without an execution policy object will execute in sequential order in the calling thread.

Note: Complexity: Performs exactly *last - first* assignments.

Template Parameters

- **InIter** – The type of the source iterators used (deduced). This iterator type must meet the requirements of an input iterator.
- **FwdIter** – The type of the iterator representing the destination range (deduced). This iterator type must meet the requirements of a forward iterator.

Parameters

- **first** – Refers to the beginning of the sequence of elements the algorithm will be applied to.
- **last** – Refers to the end of the sequence of elements the algorithm will be applied to.
- **dest** – Refers to the beginning of the destination range.

Returns The *uninitialized_copy* algorithm returns *FwdIter*. The *uninitialized_copy* algorithm returns the output iterator to the element in the destination range, one past the last element copied.

```
template<typename ExPolicy, typename FwdIter1, typename FwdIter2>
hpx::parallel::util::detail::algorithm_result_t<ExPolicy, FwdIter2> uninitialized_copy(ExPolicy
                                                                                               &&policy,
                                                                                               FwdIter1 first,
                                                                                               FwdIter1 last,
                                                                                               FwdIter2 dest)
```

Copies the elements in the range, defined by [first, last), to an uninitialized memory area beginning at *dest*. If an exception is thrown during the copy operation, the function has no effects. Executed according to the policy.

⁶²⁹ <http://github.com/STELLAR-GROUP/hpx/blob/8a3b7c1a4cb5693b2f7d9f587f759392ed0c51a0/libs/full/include/include/hpx/algorithm.hpp>

The assignments in the parallel *uninitialized_copy* algorithm invoked with an execution policy object of type *sequenced_policy* execute in sequential order in the calling thread.

The assignments in the parallel *uninitialized_copy* algorithm invoked with an execution policy object of type *parallel_policy* or *parallel_task_policy* are permitted to execute in an unordered fashion in unspecified threads, and indeterminately sequenced within each thread.

Note: Complexity: Performs exactly *last - first* assignments.

Template Parameters

- **ExPolicy** – The type of the execution policy to use (deduced). It describes the manner in which the execution of the algorithm may be parallelized and the manner in which it executes the assignments.
- **FwdIter1** – The type of the source iterators used (deduced). This iterator type must meet the requirements of an forward iterator.
- **FwdIter2** – The type of the iterator representing the destination range (deduced). This iterator type must meet the requirements of a forward iterator.

Parameters

- **policy** – The execution policy to use for the scheduling of the iterations.
- **first** – Refers to the beginning of the sequence of elements the algorithm will be applied to.
- **last** – Refers to the end of the sequence of elements the algorithm will be applied to.
- **dest** – Refers to the beginning of the destination range.

Returns The *uninitialized_copy* algorithm returns a *hpx::future<FwdIter2>*, if the execution policy is of type *sequenced_task_policy* or *parallel_task_policy* and returns *FwdIter2* otherwise. The *uninitialized_copy* algorithm returns the output iterator to the element in the destination range, one past the last element copied.

```
template<typename InIter, typename Size, typename FwdIter>  
FwdIter uninitialized_copy_n(InIter first, Size count, FwdIter dest)
```

Copies the elements in the range [first, first + count), starting from first and proceeding to first + count - 1., to another range beginning at dest. If an exception is thrown during the copy operation, the function has no effects.

The assignments in the parallel *uninitialized_copy_n* algorithm invoked without an execution policy object execute in sequential order in the calling thread.

Note: Complexity: Performs exactly *count* assignments, if count > 0, no assignments otherwise.

Template Parameters

- **InIter** – The type of the source iterators used (deduced). This iterator type must meet the requirements of an input iterator.
- **Size** – The type of the argument specifying the number of elements to apply *f* to.

- **FwdIter** – The type of the iterator representing the destination range (deduced). This iterator type must meet the requirements of a forward iterator.

Parameters

- **first** – Refers to the beginning of the sequence of elements the algorithm will be applied to.
- **count** – Refers to the number of elements starting at *first* the algorithm will be applied to.
- **dest** – Refers to the beginning of the destination range.

Returns The *uninitialized_copy_n* algorithm returns a returns *FwdIter*. The *uninitialized_copy_n* algorithm returns the output iterator to the element in the destination range, one past the last element copied.

```
template<typename ExPolicy, typename FwdIter1, typename Size, typename FwdIter2>
hpx::parallel::util::detail::algorithm_result_t<ExPolicy, FwdIter2> uninitialized_copy_n(ExPolicy
&&policy,
FwdIter1 first,
Size count,
FwdIter2 dest)
```

Copies the elements in the range [first, first + count), starting from first and proceeding to first + count - 1., to another range beginning at dest. If an exception is thrown during the copy operation, the function has no effects.

The assignments in the parallel *uninitialized_copy_n* algorithm invoked with an execution policy object of type *sequenced_policy* execute in sequential order in the calling thread.

The assignments in the parallel *uninitialized_copy_n* algorithm invoked with an execution policy object of type *parallel_policy* or *parallel_task_policy* are permitted to execute in an unordered fashion in unspecified threads, and indeterminately sequenced within each thread.

Note: Complexity: Performs exactly *count* assignments, if count > 0, no assignments otherwise.

Template Parameters

- **ExPolicy** – The type of the execution policy to use (deduced). It describes the manner in which the execution of the algorithm may be parallelized and the manner in which it executes the assignments.
- **FwdIter1** – The type of the source iterators used (deduced). This iterator type must meet the requirements of a forward iterator.
- **Size** – The type of the argument specifying the number of elements to apply *f* to.
- **FwdIter2** – The type of the iterator representing the destination range (deduced). This iterator type must meet the requirements of a forward iterator.

Parameters

- **policy** – The execution policy to use for the scheduling of the iterations.
- **first** – Refers to the beginning of the sequence of elements the algorithm will be applied to.
- **count** – Refers to the number of elements starting at *first* the algorithm will be applied to.
- **dest** – Refers to the beginning of the destination range.

Returns The *uninitialized_copy_n* algorithm returns a *hpx::future<FwdIter2>* if the execution policy is of type *sequenced_task_policy* or *parallel_task_policy* and returns *FwdIter2* otherwise. The *uninitialized_copy_n* algorithm returns the output iterator to the element in the destination range, one past the last element copied.

hpx::uninitialized_default_construct, hpx::uninitialized_default_construct_n

Defined in header [hpx/algorithm.hpp](#)⁶³⁰.

See *Public API* for a list of names and headers that are part of the public *HPX* API.

namespace **hpx**

Functions

```
template<typename FwdIter>
void uninitialized_default_construct(FwdIter first, FwdIter last)
```

Constructs objects of type `typename iterator_traits<ForwardIt> ::value_type` in the uninitialized storage designated by the range by default-initialization. If an exception is thrown during the initialization, the function has no effects.

The assignments in the parallel *uninitialized_default_construct* algorithm invoked without an execution policy object will execute in sequential order in the calling thread.

Note: Complexity: Performs exactly *last - first* assignments.

Template Parameters **FwdIter** – The type of the source iterators used (deduced). This iterator type must meet the requirements of a forward iterator.

Parameters

- **first** – Refers to the beginning of the sequence of elements the algorithm will be applied to.
- **last** – Refers to the end of the sequence of elements the algorithm will be applied to.

Returns The *uninitialized_default_construct* algorithm returns nothing

```
template<typename ExPolicy, typename FwdIter>
hpx::parallel::util::detail::algorithm_result_t<ExPolicy> uninitialized_default_construct(ExPolicy
                                                                                          &&policy,
                                                                                          FwdIter
                                                                                          first,
                                                                                          FwdIter
                                                                                          last)
```

Constructs objects of type `typename iterator_traits<ForwardIt> ::value_type` in the uninitialized storage designated by the range by default-initialization. If an exception is thrown during the initialization, the function has no effects. Executed according to the policy.

⁶³⁰ <http://github.com/STELLAR-GROUP/hpx/blob/8a3b7c1a4cb5693b2f7d9f587f759392ed0c51a0/libs/full/include/include/hpx/algorithm.hpp>

The assignments in the parallel *uninitialized_default_construct* algorithm invoked with an execution policy object of type *sequenced_policy* execute in sequential order in the calling thread.

The assignments in the parallel *uninitialized_default_construct* algorithm invoked with an execution policy object of type *parallel_policy* or *parallel_task_policy* are permitted to execute in an unordered fashion in unspecified threads, and indeterminately sequenced within each thread.

Note: Complexity: Performs exactly *last - first* assignments.

Template Parameters

- **ExPolicy** – The type of the execution policy to use (deduced). It describes the manner in which the execution of the algorithm may be parallelized and the manner in which it executes the assignments.
- **FwdIter** – The type of the source iterators used (deduced). This iterator type must meet the requirements of a forward iterator.

Parameters

- **policy** – The execution policy to use for the scheduling of the iterations.
- **first** – Refers to the beginning of the sequence of elements the algorithm will be applied to.
- **last** – Refers to the end of the sequence of elements the algorithm will be applied to.

Returns The *uninitialized_default_construct* algorithm returns a *hpx::future<void>*, if the execution policy is of type *sequenced_task_policy* or *parallel_task_policy* and returns nothing otherwise.

```
template<typename FwdIter, typename Size>
FwdIter uninitialized_default_construct_n(FwdIter first, Size count)
```

Constructs objects of type `typename iterator_traits<ForwardIt>::value_type` in the uninitialized storage designated by the range `[first, first + count)` by default-initialization. If an exception is thrown during the initialization, the function has no effects.

Note: Complexity: Performs exactly *count* assignments, if *count* > 0, no assignments otherwise.

Template Parameters

- **FwdIter** – The type of the source iterators used (deduced). This iterator type must meet the requirements of a forward iterator.
- **Size** – The type of the argument specifying the number of elements to apply *f* to.

Parameters

- **first** – Refers to the beginning of the sequence of elements the algorithm will be applied to.
- **count** – Refers to the number of elements starting at *first* the algorithm will be applied to.

Returns The *uninitialized_default_construct_n* algorithm returns a *FwdIter*. The *uninitialized_default_construct_n* algorithm returns the iterator to the element in the source range, one past the last element constructed.

```
template<typename ExPolicy, typename FwdIter, typename Size>
```

hpx::parallel::util::detail::algorithm_result_t<ExPolicy, FwdIter> uninitialized_default_construct_n(ExPolicy &&policy, FwdIter first, Size count)

Constructs objects of type `typename iterator_traits<ForwardIt> ::value_type` in the uninitialized storage designated by the range `[first, first + count)` by default-initialization. If an exception is thrown during the initialization, the function has no effects. Executed according to the policy.

The assignments in the parallel *uninitialized_default_construct_n* algorithm invoked with an execution policy object of type *sequenced_policy* execute in sequential order in the calling thread.

The assignments in the parallel *uninitialized_default_construct_n* algorithm invoked with an execution policy object of type *parallel_policy* or *parallel_task_policy* are permitted to execute in an unordered fashion in unspecified threads, and indeterminately sequenced within each thread.

Note: Complexity: Performs exactly *count* assignments, if *count* > 0, no assignments otherwise.

Template Parameters

- **ExPolicy** – The type of the execution policy to use (deduced). It describes the manner in which the execution of the algorithm may be parallelized and the manner in which it executes the assignments.
- **FwdIter** – The type of the source iterators used (deduced). This iterator type must meet the requirements of an forward iterator.
- **Size** – The type of the argument specifying the number of elements to apply *f* to.

Parameters

- **policy** – The execution policy to use for the scheduling of the iterations.
- **first** – Refers to the beginning of the sequence of elements the algorithm will be applied to.
- **count** – Refers to the number of elements starting at *first* the algorithm will be applied to.

Returns The *uninitialized_default_construct_n* algorithm returns a *hpx::future<FwdIter>* if the execution policy is of type *sequenced_task_policy* or *parallel_task_policy* and returns *FwdIter* otherwise. The *uninitialized_default_construct_n* algorithm returns the iterator to the element in the source range, one past the last element constructed.

hpx::uninitialized_fill, hpx::uninitialized_fill_n

Defined in header `hpx/algorithm.hpp`⁶³¹.

See *Public API* for a list of names and headers that are part of the public HPX API.

namespace **hpx**

⁶³¹ <http://github.com/STELLAR-GROUP/hpx/blob/8a3b7c1a4cb5693b2f7d9f587f759392ed0c51a0/libs/full/include/include/hpx/algorithm.hpp>

Functions

```
template<typename FwdIter, typename T>
void uninitialized_fill(FwdIter first, FwdIter last, T const &value)
```

Copies the given *value* to an uninitialized memory area, defined by the range [first, last). If an exception is thrown during the initialization, the function has no effects.

Note: Complexity: Linear in the distance between *first* and *last*

Template Parameters

- **FwdIter** – The type of the source iterators used (deduced). This iterator type must meet the requirements of a forward iterator.
- **T** – The type of the value to be assigned (deduced).

Parameters

- **first** – Refers to the beginning of the sequence of elements the algorithm will be applied to.
- **last** – Refers to the end of the sequence of elements the algorithm will be applied to.
- **value** – The value to be assigned.

Returns The *uninitialized_fill* algorithm returns nothing

```
template<typename ExPolicy, typename FwdIter, typename T>
hpx::parallel::util::detail::algorithm_result_t<ExPolicy> uninitialized_fill(ExPolicy &&policy, FwdIter
                                                                 first, FwdIter last, T const
                                                                 &value)
```

Copies the given *value* to an uninitialized memory area, defined by the range [first, last). If an exception is thrown during the initialization, the function has no effects. Executed according to the policy.

The initializations in the parallel *uninitialized_fill* algorithm invoked with an execution policy object of type *sequenced_policy* execute in sequential order in the calling thread.

The initializations in the parallel *uninitialized_fill* algorithm invoked with an execution policy object of type *parallel_policy* or *parallel_task_policy* are permitted to execute in an unordered fashion in unspecified threads, and indeterminately sequenced within each thread.

Note: Complexity: Linear in the distance between *first* and *last*

Template Parameters

- **ExPolicy** – The type of the execution policy to use (deduced). It describes the manner in which the execution of the algorithm may be parallelized and the manner in which it executes the assignments.
- **FwdIter** – The type of the source iterators used (deduced). This iterator type must meet the requirements of a forward iterator.
- **T** – The type of the value to be assigned (deduced).

Parameters

- **policy** – The execution policy to use for the scheduling of the iterations.
- **first** – Refers to the beginning of the sequence of elements the algorithm will be applied to.
- **last** – Refers to the end of the sequence of elements the algorithm will be applied to.
- **value** – The value to be assigned.

Returns The *uninitialized_fill* algorithm returns a *hpx::future<void>*, if the execution policy is of type *sequenced_task_policy* or *parallel_task_policy* and returns nothing otherwise.

```
template<typename FwdIter, typename Size, typename T>  
FwdIter uninitialized_fill_n(FwdIter first, Size count, T const &value)
```

Copies the given *value* value to the first count elements in an uninitialized memory area beginning at first. If an exception is thrown during the initialization, the function has no effects.

Note: Complexity: Performs exactly *count* assignments, if count > 0, no assignments otherwise.

Template Parameters

- **FwdIter** – The type of the source iterators used (deduced). This iterator type must meet the requirements of a forward iterator.
- **Size** – The type of the argument specifying the number of elements to apply *f* to.
- **T** – The type of the value to be assigned (deduced).

Parameters

- **first** – Refers to the beginning of the sequence of elements the algorithm will be applied to.
- **count** – Refers to the number of elements starting at *first* the algorithm will be applied to.
- **value** – The value to be assigned.

Returns The *uninitialized_fill_n* algorithm returns a *FwdIter*. The *uninitialized_fill_n* algorithm returns the output iterator to the element in the range, one past the last element copied.

```
template<typename ExPolicy, typename FwdIter, typename Size, typename T>  
hpx::parallel::util::detail::algorithm_result_t<ExPolicy, FwdIter> uninitialized_fill_n(ExPolicy  
                                                                                   &&policy,  
                                                                                   FwdIter first,  
                                                                                   Size count, T  
                                                                                   const &value)
```

Copies the given *value* value to the first count elements in an uninitialized memory area beginning at first. If an exception is thrown during the initialization, the function has no effects. Executed according to the policy.

The initializations in the parallel *uninitialized_fill_n* algorithm invoked with an execution policy object of type *sequenced_policy* execute in sequential order in the calling thread.

The initializations in the parallel *uninitialized_fill_n* algorithm invoked with an execution policy object of type *parallel_policy* or *parallel_task_policy* are permitted to execute in an unordered fashion in unspecified threads, and indeterminately sequenced within each thread.

Note: Complexity: Performs exactly *count* assignments, if *count* > 0, no assignments otherwise.

Template Parameters

- **ExPolicy** – The type of the execution policy to use (deduced). It describes the manner in which the execution of the algorithm may be parallelized and the manner in which it executes the assignments.
- **FwdIter** – The type of the source iterators used (deduced). This iterator type must meet the requirements of a forward iterator.
- **Size** – The type of the argument specifying the number of elements to apply *f* to.
- **T** – The type of the value to be assigned (deduced).

Parameters

- **policy** – The execution policy to use for the scheduling of the iterations.
- **first** – Refers to the beginning of the sequence of elements the algorithm will be applied to.
- **count** – Refers to the number of elements starting at *first* the algorithm will be applied to.
- **value** – The value to be assigned.

Returns The *uninitialized_fill_n* algorithm returns a *hpx::future<FwdIter>*, if the execution policy is of type *sequenced_task_policy* or *parallel_task_policy* and returns *FwdIter* otherwise. The *uninitialized_fill_n* algorithm returns the output iterator to the element in the range, one past the last element copied.

hpx::uninitialized_move, hpx::uninitialized_move_n

Defined in header [hpx/algorithm.hpp](#)⁶³².

See *Public API* for a list of names and headers that are part of the public *HPX* API.

namespace **hpx**

Functions

```
template<typename InIter, typename FwdIter>
FwdIter uninitialized_move(InIter first, InIter last, FwdIter dest)
```

Moves the elements in the range, defined by [*first*, *last*), to an uninitialized memory area beginning at *dest*. If an exception is thrown during the initialization, some objects in [*first*, *last*) are left in a valid but unspecified state.

Note: Complexity: Performs exactly *last - first* assignments.

Template Parameters

- **InIter** – The type of the source iterators used (deduced). This iterator type must meet the requirements of an input iterator.

⁶³² <http://github.com/STELLAR-GROUP/hpx/blob/8a3b7c1a4cb5693b2f7d9f587f759392ed0c51a0/libs/full/include/include/hpx/algorithm.hpp>

- **FwdIter** – The type of the iterator representing the destination range (deduced). This iterator type must meet the requirements of a forward iterator.

Parameters

- **first** – Refers to the beginning of the sequence of elements the algorithm will be applied to.
- **last** – Refers to the end of the sequence of elements the algorithm will be applied to.
- **dest** – Refers to the beginning of the destination range.

Returns The *uninitialized_move* algorithm returns *FwdIter*. The *uninitialized_move* algorithm returns the output iterator to the element in the destination range, one past the last element moved.

```
template<typename ExPolicy, typename FwdIter1, typename FwdIter2>  
hpx::parallel::util::detail::algorithm_result_t<ExPolicy, FwdIter2> uninitialized_move(ExPolicy  
                                          &&policy,  
                                          FwdIter1 first,  
                                          FwdIter1 last,  
                                          FwdIter2 dest)
```

Moves the elements in the range, defined by [first, last), to an uninitialized memory area beginning at *dest*. If an exception is thrown during the initialization, some objects in [first, last) are left in a valid but unspecified state. Executed according to the policy.

The assignments in the parallel *uninitialized_move* algorithm invoked with an execution policy object of type *sequenced_policy* execute in sequential order in the calling thread.

The assignments in the parallel *uninitialized_move* algorithm invoked with an execution policy object of type *parallel_policy* or *parallel_task_policy* are permitted to execute in an unordered fashion in unspecified threads, and indeterminately sequenced within each thread.

Note: Complexity: Performs exactly *last - first* assignments.

Template Parameters

- **ExPolicy** – The type of the execution policy to use (deduced). It describes the manner in which the execution of the algorithm may be parallelized and the manner in which it executes the assignments.
- **FwdIter1** – The type of the source iterators used (deduced). This iterator type must meet the requirements of a forward iterator.
- **FwdIter2** – The type of the iterator representing the destination range (deduced). This iterator type must meet the requirements of a forward iterator.

Parameters

- **policy** – The execution policy to use for the scheduling of the iterations.
- **first** – Refers to the beginning of the sequence of elements the algorithm will be applied to.
- **last** – Refers to the end of the sequence of elements the algorithm will be applied to.
- **dest** – Refers to the beginning of the destination range.

Returns The *uninitialized_move* algorithm returns a *hpx::future<FwdIter2>*, if the execution policy is of type *sequenced_task_policy* or *parallel_task_policy* and returns *FwdIter2* otherwise. The *uninitialized_move* algorithm returns the output iterator to the element in the destination range, one past the last element moved.

```
template<typename InIter, typename Size, typename FwdIter>
std::pair<InIter, FwdIter> uninitialized_move_n(InIter first, Size count, FwdIter dest)
```

Moves the elements in the range [first, first + count), starting from first and proceeding to first + count - 1., to another range beginning at dest. If an exception is thrown during the initialization, some objects in [first, first + count) are left in a valid but unspecified state.

Note: Complexity: Performs exactly *count* movements, if count > 0, no move operations otherwise.

Template Parameters

- **InIter** – The type of the source iterators used (deduced). This iterator type must meet the requirements of an input iterator.
- **Size** – The type of the argument specifying the number of elements to apply *f* to.
- **FwdIter** – The type of the iterator representing the destination range (deduced). This iterator type must meet the requirements of a forward iterator.

Parameters

- **first** – Refers to the beginning of the sequence of elements the algorithm will be applied to.
- **count** – Refers to the number of elements starting at *first* the algorithm will be applied to.
- **dest** – Refers to the beginning of the destination range.

Returns The *uninitialized_move_n* algorithm returns a returns *std::pair<InIter,FwdIter>*. The *uninitialized_move_n* algorithm returns A pair whose first element is an iterator to the element past the last element moved in the source range, and whose second element is an iterator to the element past the last element moved in the destination range.

```
template<typename ExPolicy, typename FwdIter1, typename Size, typename FwdIter2>
parallel::util::detail::algorithm_result<ExPolicy, std::pair<FwdIter1, FwdIter2>>::type uninitialized_move_n(ExPolicy
&&policy,
FwdIter1
first,
Size
count,
FwdIter2
dest)
```

Moves the elements in the range [first, first + count), starting from first and proceeding to first + count - 1., to another range beginning at dest. If an exception is thrown during the initialization, some objects in [first, first + count) are left in a valid but unspecified state. Executed according to the policy.

The assignments in the parallel *uninitialized_move_n* algorithm invoked with an execution policy object of type *sequenced_policy* execute in sequential order in the calling thread.

The assignments in the parallel *uninitialized_move_n* algorithm invoked with an execution policy object of type *parallel_policy* or *parallel_task_policy* are permitted to execute in an unordered fashion in unspecified threads, and indeterminately sequenced within each thread.

Note: Complexity: Performs exactly *count* movements, if *count* > 0, no move operations otherwise.

Template Parameters

- **ExPolicy** – The type of the execution policy to use (deduced). It describes the manner in which the execution of the algorithm may be parallelized and the manner in which it executes the assignments.
- **FwdIter1** – The type of the source iterators used (deduced). This iterator type must meet the requirements of a forward iterator.
- **Size** – The type of the argument specifying the number of elements to apply *f* to.
- **FwdIter2** – The type of the iterator representing the destination range (deduced). This iterator type must meet the requirements of a forward iterator.

Parameters

- **policy** – The execution policy to use for the scheduling of the iterations.
- **first** – Refers to the beginning of the sequence of elements the algorithm will be applied to.
- **count** – Refers to the number of elements starting at *first* the algorithm will be applied to.
- **dest** – Refers to the beginning of the destination range.

Returns The *uninitialized_move_n* algorithm returns a `hpx::future<std::pair<FwdIter1,FwdIter2>>` if the execution policy is of type *sequenced_task_policy* or *parallel_task_policy* and returns `std::pair<FwdIter1,FwdIter2>` otherwise. The *uninitialized_move_n* algorithm returns A pair whose first element is an iterator to the element past the last element moved in the source range, and whose second element is an iterator to the element past the last element moved in the destination range.

`hpx::uninitialized_relocate`, `hpx::uninitialized_relocate_n`

Defined in header `hpx/algorithm.hpp`⁶³³.

See *Public API* for a list of names and headers that are part of the public HPX API.

namespace **hpx**

⁶³³ <http://github.com/STELLAR-GROUP/hpx/blob/8a3b7c1a4cb5693b2f7d9f587f759392ed0c51a0/libs/full/include/include/hpx/algorithm.hpp>

Functions

```
template<typename InIter1, typename InIter2, typename FwdIter>
FwdIter uninitialized_relocate(InIter1 first, InIter2 last, FwdIter dest)
```

Relocates the elements in the range, defined by [first, last), to an uninitialized memory area beginning at *dest*. If an exception is thrown during the move-construction of an element, all elements left in the input range, as well as all objects already constructed in the destination range are destroyed. After this algorithm completes, the source range should be freed or reused without destroying the objects.

The assignments in the parallel *uninitialized_relocate* algorithm invoked without an execution policy object will execute in sequential order in the calling thread.

Note: Complexity: time: $O(n)$, space: $O(1)$ 1) For “trivially relocatable” underlying types (T) and a contiguous iterator range [first, last): $\text{std::distance}(\text{first}, \text{last}) * \text{sizeof}(T)$ bytes are copied. 2) For “trivially relocatable” underlying types (T) and a non-contiguous iterator range [first, last): $\text{std::distance}(\text{first}, \text{last})$ memory copies of $\text{sizeof}(T)$ bytes each are performed. 3) For “non-trivially relocatable” underlying types (T): $\text{std::distance}(\text{first}, \text{last})$ move assignments and destructions are performed.

Note: Declare a type as “trivially relocatable” using the `HPX_DECLARE_TRIVIALY_RELOCATABLE` macros found in `<hpx/type_support/is_trivially_relocatable.hpp>`.

Template Parameters

- **InIter1** – The type of the source iterator first (deduced). This iterator type must meet the requirements of an input iterator.
- **InIter2** – The type of the source iterator last (deduced). This iterator type must meet the requirements of an input iterator.
- **FwdIter** – The type of the iterator representing the destination range (deduced). This iterator type must meet the requirements of a forward iterator.

Parameters

- **first** – Refers to the beginning of the sequence of elements the algorithm will be applied to.
- **last** – Refers to the end of the sequence of elements the algorithm will be applied to.
- **dest** – Refers to the beginning of the destination range.

Returns The *uninitialized_relocate* algorithm returns *FwdIter*. The *uninitialized_relocate* algorithm returns the output iterator to the element in the destination range, one past the last element relocated.

```
template<typename ExPolicy, typename InIter1, typename InIter2, typename FwdIter>
hpx::parallel::util::detail::algorithm_result_t<ExPolicy, FwdIter> uninitialized_relocate(ExPolicy
                                                                                               &&policy,
                                                                                               InIter1 first,
                                                                                               InIter2 last,
                                                                                               FwdIter dest)
```

Relocates the elements in the range defined by [first, last), to an uninitialized memory area beginning at *dest*. If an exception is thrown during the move-construction of an element, all elements left in the input

range, as well as all objects already constructed in the destination range are destroyed. After this algorithm completes, the source range should be freed or reused without destroying the objects.

The assignments in the parallel *uninitialized_relocate* algorithm invoked with an execution policy object of type *parallel_policy* or *parallel_task_policy* are permitted to execute in an unordered fashion in unspecified threads, and indeterminately sequenced within each thread.

Note: Complexity: time: $O(n)$, space: $O(1)$ 1) For “trivially relocatable” underlying types (T) and a contiguous iterator range [first, last): $\text{std::distance}(\text{first}, \text{last}) * \text{sizeof}(\text{T})$ bytes are copied. 2) For “trivially relocatable” underlying types (T) and a non-contiguous iterator range [first, last): $\text{std::distance}(\text{first}, \text{last})$ memory copies of $\text{sizeof}(\text{T})$ bytes each are performed. 3) For “non-trivially relocatable” underlying types (T): $\text{std::distance}(\text{first}, \text{last})$ move assignments and destructions are performed.

Note: Declare a type as “trivially relocatable” using the `HPX_DECLARE_TRIVIALY_RELOCATABLE` macros found in `<hpx/type_support/is_trivially_relocatable.hpp>`.

Template Parameters

- **ExPolicy** – The type of the execution policy to use (deduced). It describes the manner in which the execution of the algorithm may be parallelized and the manner in which it executes the assignments.
- **InIter1** – The type of the source iterator first (deduced). This iterator type must meet the requirements of an input iterator.
- **InIter2** – The type of the source iterator last (deduced). This iterator type must meet the requirements of an input iterator.
- **FwdIter** – The type of the iterator representing the destination range (deduced). This iterator type must meet the requirements of a forward iterator.

Parameters

- **policy** – The execution policy to use for the scheduling of the iterations.
- **first** – Refers to the beginning of the sequence of elements the algorithm will be applied to.
- **last** – Refers to the end of the sequence of elements the algorithm will be applied to.
- **dest** – Refers to the beginning of the destination range. The assignments in the parallel *uninitialized_relocate_n* algorithm invoked with an execution policy object of type *sequenced_policy* execute in sequential order in the calling thread.

Returns The *uninitialized_relocate* algorithm returns a `hpx::future<FwdIter>`, if the execution policy is of type *sequenced_task_policy* or *parallel_task_policy* and returns `FwdIter` otherwise. The *uninitialized_relocate* algorithm returns the output iterator to the element in the destination range, one past the last element relocated.

```
template<typename BiIter1, typename BiIter2>
```

```
BiIter2 uninitialized_relocate_backward(BiIter1 first, BiIter1 last, BiIter2 dest_last)
```

Relocates the elements in the range, defined by [first, last), to an uninitialized memory area ending at *dest_last*. The objects are processed in reverse order. If an exception is thrown during the the move-construction of an element, all elements left in the input range, as well as all objects already constructed

in the destination range are destroyed. After this algorithm completes, the source range should be freed or reused without destroying the objects.

The assignments in the parallel *uninitialized_relocate* algorithm invoked without an execution policy object will execute in sequential order in the calling thread.

Note: Complexity: time: $O(n)$, space: $O(1)$ 1) For “trivially relocatable” underlying types (T) and a contiguous iterator range [first, last): $\text{std::distance}(\text{first}, \text{last}) * \text{sizeof}(T)$ bytes are copied. 2) For “trivially relocatable” underlying types (T) and a non-contiguous iterator range [first, last): $\text{std::distance}(\text{first}, \text{last})$ memory copies of $\text{sizeof}(T)$ bytes each are performed. 3) For “non-trivially relocatable” underlying types (T): $\text{std::distance}(\text{first}, \text{last})$ move assignments and destructions are performed.

Note: Declare a type as “trivially relocatable” using the `HPX_DECLARE_TRIVIALY_RELOCATABLE` macros found in `<hpx/type_support/is_trivially_relocatable.hpp>`.

Template Parameters

- **BiIter1** – The type of the source range (deduced). This iterator type must meet the requirements of a Bidirectional iterator.
- **BiIter2** – The type of the iterator representing the destination range (deduced). This iterator type must meet the requirements of a Bidirectional iterator.

Parameters

- **first** – Refers to the beginning of the sequence of elements the algorithm will be applied to.
- **last** – Refers to the end of the sequence of elements the algorithm will be applied to.
- **dest_last** – Refers to the beginning of the destination range.

Returns The *uninitialized_relocate_backward* algorithm returns *BiIter2*. The *uninitialized_relocate_backward* algorithm returns the bidirectional iterator to the first element in the destination range.

```
template<typename ExPolicy, typename BiIter1, typename BiIter2>
hpx::parallel::util::detail::algorithm_result<ExPolicy, BiIter2> uninitialized_relocate_backward(ExPolicy
&&pol-
icy,
Bi-
Iter1
first,
Bi-
Iter1
last,
Bi-
Iter2
dest_last)
```

Relocates the elements in the range, defined by [first, last), to an uninitialized memory area ending at *dest_last*. The order of the relocation of the objects depends on the execution policy. If an exception is thrown during the the move-construction of an element, all elements left in the input range, as well as

all objects already constructed in the destination range are destroyed. After this algorithm completes, the source range should be freed or reused without destroying the objects.

The assignments in the parallel *uninitialized_relocate_backward* algorithm invoked with an execution policy object of type *parallel_policy* or *parallel_task_policy* are permitted to execute in an unordered fashion in unspecified threads, and indeterminately sequenced within each thread.

Note: Using the *uninitialized_relocate_backward* algorithm with the with a non-sequenced execution policy, will not guarantee the order of the relocation of the objects.

Note: Complexity: time: $O(n)$, space: $O(1)$ 1) For “trivially relocatable” underlying types (T) and a contiguous iterator range [first, last): $\text{std::distance}(\text{first}, \text{last}) * \text{sizeof}(T)$ bytes are copied. 2) For “trivially relocatable” underlying types (T) and a non-contiguous iterator range [first, last): $\text{std::distance}(\text{first}, \text{last})$ memory copies of $\text{sizeof}(T)$ bytes each are performed. 3) For “non-trivially relocatable” underlying types (T): $\text{std::distance}(\text{first}, \text{last})$ move assignments and destructions are performed.

Note: Declare a type as “trivially relocatable” using the `HPX_DECLARE_TRIVIALY_RELOCATABLE` macros found in `<hpx/type_support/is_trivially_relocatable.hpp>`.

Template Parameters

- **ExPolicy** – The type of the execution policy to use (deduced). It describes the manner in which the execution of the algorithm may be parallelized and the manner in which it executes the assignments.
- **BiIter1** – The type of the source range (deduced). This iterator type must meet the requirements of a Bidirectional iterator.
- **BiIter2** – The type of the iterator representing the destination range (deduced). This iterator type must meet the requirements of a Bidirectional iterator.

Parameters

- **policy** – The execution policy to use for the scheduling of the iterations.
- **first** – Refers to the beginning of the sequence of elements the algorithm will be applied to.
- **last** – Refers to the end of the sequence of elements the algorithm will be applied to.
- **dest_last** – Refers to the end of the destination range.

Returns The *uninitialized_relocate_backward* algorithm returns a `hpx::future<FwdIter>`, if the execution policy is of type *sequenced_task_policy* or *parallel_task_policy* and returns *BiIter2* otherwise. The *uninitialized_relocate_backward* algorithm returns the bidirectional iterator to the first element in the destination range.

```
template<typename InIter, typename Size, typename FwdIter>  
FwdIter uninitialized_relocate_n(InIter first, Size count, FwdIter dest)
```

Relocates the elements in the range, defined by [first, last), to an uninitialized memory area beginning at *dest*. If an exception is thrown during the move-construction of an element, all elements left in the input range, as well as all objects already constructed in the destination range are destroyed. After this algorithm completes, the source range should be freed or reused without destroying the objects.

The assignments in the parallel `uninitialized_relocate_n` algorithm invoked without an execution policy object will execute in sequential order in the calling thread.

Note: Complexity: time: $O(n)$, space: $O(1)$ 1) For “trivially relocatable” underlying types (T) and a contiguous iterator range [first, first+count): `count*sizeof(T)` bytes are copied. 2) For “trivially relocatable” underlying types (T) and a non-contiguous iterator range [first, first+count): `count` memory copies of `sizeof(T)` bytes each are performed. 3) For “non-trivially relocatable” underlying types (T): `count` move assignments and destructions are performed.

Note: Declare a type as “trivially relocatable” using the `HPX_DECLARE_TRIVIALY_RELOCATABLE` macros found in `<hpx/type_support/is_trivially_relocatable.hpp>`.

Template Parameters

- **InIter** – The type of the source iterator first (deduced). This iterator type must meet the requirements of an input iterator.
- **Size** – The type of the argument specifying the number of elements to relocate.
- **FwdIter** – The type of the iterator representing the destination range (deduced). This iterator type must meet the requirements of a forward iterator.

Parameters

- **first** – Refers to the beginning of the sequence of elements the algorithm will be applied to.
- **count** – Refers to the number of elements starting at *first* the algorithm will be applied to.
- **dest** – Refers to the beginning of the destination range.

Returns The `uninitialized_relocate_n` algorithm returns `FwdIter`. The `uninitialized_relocate_n` algorithm returns the output iterator to the element in the destination range, one past the last element relocated.

```
template<typename ExPolicy, typename InIter, typename Size, typename FwdIter>
hpx::parallel::util::detail::algorithm_result_t<ExPolicy, FwdIter> uninitialized_relocate_n(ExPolicy
&&policy,
InIter first,
Size count,
FwdIter
dest)
```

Relocates the elements in the range, defined by [first, last), to an uninitialized memory area beginning at *dest*. If an exception is thrown during the move-construction of an element, all elements left in the input range, as well as all objects already constructed in the destination range are destroyed. After this algorithm completes, the source range should be freed or reused without destroying the objects.

The assignments in the parallel `uninitialized_relocate_n` algorithm invoked with an execution policy object of type `sequenced_policy` execute in sequential order in the calling thread.

The assignments in the parallel `uninitialized_relocate_n` algorithm invoked with an execution policy object of type `parallel_policy` or `parallel_task_policy` are permitted to execute in an unordered fashion in unspecified threads, and indeterminately sequenced within each thread.

Note: Complexity: time: $O(n)$, space: $O(1)$ 1) For “trivially relocatable” underlying types (T) and a contiguous iterator range [first, first+count): `count * sizeof(T)` bytes are copied. 2) For “trivially relocatable” underlying types (T) and a non-contiguous iterator range [first, first+count): `count` memory copies of `sizeof(T)` bytes each are performed. 3) For “non-trivially relocatable” underlying types (T): `count` move assignments and destructions are performed.

Note: Declare a type as “trivially relocatable” using the `HPX_DECLARE_TRIVIALY_RELOCATABLE` macros found in `<hpx/type_support/is_trivially_relocatable.hpp>`.

Template Parameters

- **ExPolicy** – The type of the execution policy to use (deduced). It describes the manner in which the execution of the algorithm may be parallelized and the manner in which it executes the assignments.
- **InIter** – The type of the source iterator first (deduced). This iterator type must meet the requirements of an input iterator.
- **Size** – The type of the argument specifying the number of elements to relocate.
- **FwdIter** – The type of the iterator representing the destination range (deduced). This iterator type must meet the requirements of a forward iterator.

Parameters

- **policy** – The execution policy to use for the scheduling of the iterations.
- **first** – Refers to the beginning of the sequence of elements the algorithm will be applied to.
- **count** – Refers to the number of elements starting at *first* the algorithm will be applied to.
- **dest** – Refers to the beginning of the destination range.

Returns The `uninitialized_relocate_n` algorithm returns a `hpx::future<FwdIter>` if the execution policy is of type `sequenced_task_policy` or `parallel_task_policy` and returns `FwdIter` otherwise. The `uninitialized_relocate_n` algorithm returns the output iterator to the element in the destination range, one past the last element relocated.

`hpx::uninitialized_value_construct`, `hpx::uninitialized_value_construct_n`

Defined in header `hpx/algorithm.hpp`⁶³⁴.

See *Public API* for a list of names and headers that are part of the public *HPX* API.

namespace **hpx**

⁶³⁴ <http://github.com/STELLAR-GROUP/hpx/blob/8a3b7c1a4cb5693b2f7d9f587f759392ed0c51a0/libs/full/include/include/hpx/algorithm.hpp>

Functions

```
template<typename FwdIter>
void uninitialized_value_construct(FwdIter first, FwdIter last)
```

Constructs objects of type `typename iterator_traits<ForwardIt> ::value_type` in the uninitialized storage designated by the range by value-initialization. If an exception is thrown during the initialization, the function has no effects.

Note: Complexity: Performs exactly *last - first* assignments.

Template Parameters **FwdIter** – The type of the source iterators used (deduced). This iterator type must meet the requirements of a forward iterator.

Parameters

- **first** – Refers to the beginning of the sequence of elements the algorithm will be applied to.
- **last** – Refers to the end of the sequence of elements the algorithm will be applied to.

Returns The *uninitialized_value_construct* algorithm returns nothing

```
template<typename ExPolicy, typename FwdIter>
hpx::parallel::util::detail::algorithm_result_t<ExPolicy> uninitialized_value_construct(ExPolicy
                                                                                       &&policy,
                                                                                       FwdIter first,
                                                                                       FwdIter last)
```

Constructs objects of type `typename iterator_traits<ForwardIt> ::value_type` in the uninitialized storage designated by the range by value-initialization. If an exception is thrown during the initialization, the function has no effects. Executed according to the policy.

The assignments in the parallel *uninitialized_value_construct* algorithm invoked with an execution policy object of type *sequenced_policy* execute in sequential order in the calling thread.

The assignments in the parallel *uninitialized_value_construct* algorithm invoked with an execution policy object of type *parallel_policy* or *parallel_task_policy* are permitted to execute in an unordered fashion in unspecified threads, and indeterminately sequenced within each thread.

Note: Complexity: Performs exactly *last - first* assignments.

Template Parameters

- **ExPolicy** – The type of the execution policy to use (deduced). It describes the manner in which the execution of the algorithm may be parallelized and the manner in which it executes the assignments.
- **FwdIter** – The type of the source iterators used (deduced). This iterator type must meet the requirements of a forward iterator.

Parameters

- **policy** – The execution policy to use for the scheduling of the iterations.

- **first** – Refers to the beginning of the sequence of elements the algorithm will be applied to.
- **last** – Refers to the end of the sequence of elements the algorithm will be applied to.

Returns The *uninitialized_value_construct* algorithm returns a *hpx::future<void>*, if the execution policy is of type *sequenced_task_policy* or *parallel_task_policy* and returns nothing otherwise.

```
template<typename FwdIter, typename Size>  
FwdIter uninitialized_value_construct_n(FwdIter first, Size count)
```

Constructs objects of type *typename iterator_traits<ForwardIt> ::value_type* in the uninitialized storage designated by the range [first, first + count) by value-initialization. If an exception is thrown during the initialization, the function has no effects.

Note: Complexity: Performs exactly *count* assignments, if *count* > 0, no assignments otherwise.

Template Parameters

- **FwdIter** – The type of the source iterators used (deduced). This iterator type must meet the requirements of a forward iterator.
- **Size** – The type of the argument specifying the number of elements to apply *f* to.

Parameters

- **first** – Refers to the beginning of the sequence of elements the algorithm will be applied to.
- **count** – Refers to the number of elements starting at *first* the algorithm will be applied to.

Returns The *uninitialized_value_construct_n* algorithm returns a *FwdIter*. The *uninitialized_value_construct_n* algorithm returns the iterator to the element in the source range, one past the last element constructed.

```
template<typename ExPolicy, typename FwdIter, typename Size>  
hpx::parallel::util::detail::algorithm_result_t<ExPolicy, FwdIter> uninitialized_value_construct_n(ExPolicy  
&&pol-  
icy,  
FwdIter  
first,  
Size  
count)
```

Constructs objects of type *typename iterator_traits<ForwardIt> ::value_type* in the uninitialized storage designated by the range [first, first + count) by value-initialization. If an exception is thrown during the initialization, the function has no effects.

The assignments in the parallel *uninitialized_value_construct_n* algorithm invoked with an execution policy object of type *sequenced_policy* execute in sequential order in the calling thread.

The assignments in the parallel *uninitialized_value_construct_n* algorithm invoked with an execution policy object of type *parallel_policy* or *parallel_task_policy* are permitted to execute in an unordered fashion in unspecified threads, and indeterminately sequenced within each thread.

Note: Complexity: Performs exactly *count* assignments, if *count* > 0, no assignments otherwise.

Template Parameters

- **ExPolicy** – The type of the execution policy to use (deduced). It describes the manner in which the execution of the algorithm may be parallelized and the manner in which it executes the assignments.
- **FwdIter** – The type of the source iterators used (deduced). This iterator type must meet the requirements of a forward iterator.
- **Size** – The type of the argument specifying the number of elements to apply *f* to.

Parameters

- **policy** – The execution policy to use for the scheduling of the iterations.
- **first** – Refers to the beginning of the sequence of elements the algorithm will be applied to.
- **count** – Refers to the number of elements starting at *first* the algorithm will be applied to.

Returns The *uninitialized_value_construct_n* algorithm returns a *hpx::future<FwdIter>* if the execution policy is of type *sequenced_task_policy* or *parallel_task_policy* and returns *FwdIter* otherwise. The *uninitialized_value_construct_n* algorithm returns the iterator to the element in the source range, one past the last element constructed.

hpx::unique, hpx::unique_copy

Defined in header [hpx/algorithm.hpp](#)⁶³⁵.

See *Public API* for a list of names and headers that are part of the public HPX API.

namespace **hpx**

Functions

```
template<typename FwdIter, typename Pred = hpx::parallel::detail::equal_to, typename Proj =
hpx::identity>
```

```
FwdIter unique(FwdIter first, FwdIter last, Pred &&pred = Pred(), Proj &&proj = Proj())
```

Eliminates all but the first element from every consecutive group of equivalent elements from the range [first, last) and returns a past-the-end iterator for the new logical end of the range.

Note: Complexity: Performs not more than *last - first* assignments, exactly *last - first - 1* applications of the predicate *pred* and no more than twice as many applications of the projection *proj*.

Template Parameters

- **FwdIter** – The type of the source iterators used (deduced). This iterator type must meet the requirements of a forward iterator.

⁶³⁵ <http://github.com/STELLAR-GROUP/hpx/blob/8a3b7c1a4cb5693b2f7d9f587f759392ed0c51a0/libs/full/include/include/hpx/algorithm.hpp>

- **Pred** – The type of the function/function object to use (deduced). Unlike its sequential form, the parallel overload of *unique* requires *Pred* to meet the requirements of *CopyConstructible*. This defaults to `std::equal_to<>`
- **Proj** – The type of an optional projection function. This defaults to `hpx::identity`.

Parameters

- **first** – Refers to the beginning of the sequence of elements the algorithm will be applied to.
- **last** – Refers to the end of the sequence of elements the algorithm will be applied to.
- **pred** – Specifies the function (or function object) which will be invoked for each of the elements in the sequence specified by [first, last). This is a binary predicate which returns *true* for the required elements. The signature of this predicate should be equivalent to:

```
bool pred(const Type1 &a, const Type2 &b);
```

The signature does not need to have `const&`, but the function must not modify the objects passed to it. The types *Type1* and *Type2* must be such that objects of types *FwdIter* can be dereferenced and then implicitly converted to both *Type1* and *Type2*

- **proj** – Specifies the function (or function object) which will be invoked for each of the elements as a projection operation before the actual predicate *pred* is invoked.

Returns The *unique* algorithm returns *FwdIter*. The *unique* algorithm returns the iterator to the new end of the range.

```
template<typename ExPolicy, typename FwdIter, typename Pred = hpx::parallel::detail::equal_to,  
typename Proj = hpx::identity>  
parallel::util::detail::algorithm_result<ExPolicy, FwdIter>::type unique(ExPolicy &&policy, FwdIter first,  
                                FwdIter last, Pred &&pred =  
                                Pred(), Proj &&proj = Proj())
```

Eliminates all but the first element from every consecutive group of equivalent elements from the range [first, last) and returns a past-the-end iterator for the new logical end of the range. Executed according to the policy.

The assignments in the parallel *unique* algorithm invoked with an execution policy object of type *sequenced_policy* execute in sequential order in the calling thread.

The assignments in the parallel *unique* algorithm invoked with an execution policy object of type *parallel_policy* or *parallel_task_policy* are permitted to execute in an unordered fashion in unspecified threads, and indeterminately sequenced within each thread.

Note: Complexity: Performs not more than *last - first* assignments, exactly *last - first - 1* applications of the predicate *pred* and no more than twice as many applications of the projection *proj*.

Template Parameters

- **ExPolicy** – The type of the execution policy to use (deduced). It describes the manner in which the execution of the algorithm may be parallelized and the manner in which it executes the assignments.
- **FwdIter** – The type of the source iterators used (deduced). This iterator type must meet the requirements of a forward iterator.

- **Pred** – The type of the function/function object to use (deduced). Unlike its sequential form, the parallel overload of *unique* requires *Pred* to meet the requirements of *CopyConstructible*. This defaults to `std::equal_to<>`
- **Proj** – The type of an optional projection function. This defaults to `hpx::identity`.

Parameters

- **policy** – The execution policy to use for the scheduling of the iterations.
- **first** – Refers to the beginning of the sequence of elements the algorithm will be applied to.
- **last** – Refers to the end of the sequence of elements the algorithm will be applied to.
- **pred** – Specifies the function (or function object) which will be invoked for each of the elements in the sequence specified by [first, last). This is a binary predicate which returns *true* for the required elements. The signature of this predicate should be equivalent to:

```
bool pred(const Type1 &a, const Type2 &b);
```

The signature does not need to have `const&`, but the function must not modify the objects passed to it. The types *Type1* and *Type2* must be such that objects of types *FwdIter* can be dereferenced and then implicitly converted to both *Type1* and *Type2*

- **proj** – Specifies the function (or function object) which will be invoked for each of the elements as a projection operation before the actual predicate *pred* is invoked.

Returns The *unique* algorithm returns a `hpx::future<FwdIter>` if the execution policy is of type *sequenced_task_policy* or *parallel_task_policy* and returns *FwdIter* otherwise. The *unique* algorithm returns the iterator to the new end of the range.

```
template<typename InIter, typename OutIter, typename Pred = hpx::parallel::detail::equal_to, typename Proj = hpx::identity>
```

```
OutIter unique_copy(InIter first, InIter last, OutIter dest, Pred &&pred = Pred(), Proj &&proj = Proj())
```

Copies the elements from the range [first, last), to another range beginning at *dest* in such a way that there are no consecutive equal elements. Only the first element of each group of equal elements is copied.

Note: Complexity: Performs not more than *last - first* assignments, exactly *last - first - 1* applications of the predicate *pred* and no more than twice as many applications of the projection *proj*

Template Parameters

- **InIter** – The type of the source iterators used (deduced). This iterator type must meet the requirements of an input iterator.
- **OutIter** – The type of the iterator representing the destination range (deduced). This iterator type must meet the requirements of an output iterator.
- **Pred** – The type of the function/function object to use (deduced). Unlike its sequential form, the parallel overload of *unique_copy* requires *Pred* to meet the requirements of *CopyConstructible*. This defaults to `std::equal_to<>`
- **Proj** – The type of an optional projection function. This defaults to `hpx::identity`

Parameters

- **first** – Refers to the beginning of the sequence of elements the algorithm will be applied to.

- **last** – Refers to the end of the sequence of elements the algorithm will be applied to.
- **dest** – Refers to the beginning of the destination range.
- **pred** – Specifies the function (or function object) which will be invoked for each of the elements in the sequence specified by [first, last). This is a binary predicate which returns *true* for the required elements. The signature of this predicate should be equivalent to:

```
bool pred(const Type &a, const Type &b);
```

The signature does not need to have const&, but the function must not modify the objects passed to it. The type *Type* must be such that an object of type *FwdIter* can be dereferenced and then implicitly converted to *Type*.

- **proj** – Specifies the function (or function object) which will be invoked for each of the elements as a projection operation before the actual predicate *pred* is invoked.

Returns The *unique_copy* algorithm returns a returns *OutIter*. The *unique_copy* algorithm returns the destination iterator to the end of the *dest* range.

```
template<typename ExPolicy, typename FwdIter1, typename FwdIter2, typename Pred =
hpx::parallel::detail::equal_to, typename Proj = hpx::identity>
parallel::util::detail::algorithm_result<ExPolicy, FwdIter2>::type unique_copy(ExPolicy &&policy,
FwdIter1 first, FwdIter1 last,
FwdIter2 dest, Pred &&pred
= Pred(), Proj &&proj =
Proj())
```

Copies the elements from the range [first, last), to another range beginning at *dest* in such a way that there are no consecutive equal elements. Only the first element of each group of equal elements is copied. Executed according to the policy.

The assignments in the parallel *unique_copy* algorithm invoked with an execution policy object of type *sequenced_policy* execute in sequential order in the calling thread.

The assignments in the parallel *unique_copy* algorithm invoked with an execution policy object of type *parallel_policy* or *parallel_task_policy* are permitted to execute in an unordered fashion in unspecified threads, and indeterminately sequenced within each thread.

Note: Complexity: Performs not more than *last - first* assignments, exactly *last - first - 1* applications of the predicate *pred* and no more than twice as many applications of the projection *proj*

Template Parameters

- **ExPolicy** – The type of the execution policy to use (deduced). It describes the manner in which the execution of the algorithm may be parallelized and the manner in which it executes the assignments.
- **FwdIter1** – The type of the source iterators used (deduced). This iterator type must meet the requirements of a forward iterator.
- **FwdIter2** – The type of the iterator representing the destination range (deduced). This iterator type must meet the requirements of a forward iterator.
- **Pred** – The type of the function/function object to use (deduced). Unlike its sequential form, the parallel overload of *unique_copy* requires *Pred* to meet the requirements of *CopyConstructible*. This defaults to `std::equal_to<>`

- **Proj** – The type of an optional projection function. This defaults to `hpx::identity`.

Parameters

- **policy** – The execution policy to use for the scheduling of the iterations.
- **first** – Refers to the beginning of the sequence of elements the algorithm will be applied to.
- **last** – Refers to the end of the sequence of elements the algorithm will be applied to.
- **dest** – Refers to the beginning of the destination range.
- **pred** – Specifies the function (or function object) which will be invoked for each of the elements in the sequence specified by [first, last). This is a binary predicate which returns `true` for the required elements. The signature of this predicate should be equivalent to:

```
bool pred(const Type &a, const Type &b);
```

The signature does not need to have `const&`, but the function must not modify the objects passed to it. The type `Type` must be such that an object of type `FwdIter1` can be dereferenced and then implicitly converted to `Type`.

- **proj** – Specifies the function (or function object) which will be invoked for each of the elements as a projection operation before the actual predicate `pred` is invoked.

Returns The `unique_copy` algorithm returns a `hpx::future<FwdIter2>` if the execution policy is of type `sequenced_task_policy` or `parallel_task_policy` and returns `FwdIter2` otherwise. The `unique_copy` algorithm returns the pair of the source iterator to `last`, and the destination iterator to the end of the `dest` range.

hpx::ranges::adjacent_difference

Defined in header `hpx/algorithm.hpp`⁶³⁶.

See *Public API* for a list of names and headers that are part of the public *HPX* API.

namespace **hpx**

namespace **ranges**

Functions

```
template<typename FwdIter1, typename FwdIter2, typename Sent>
FwdIter2 adjacent_difference(FwdIter1 first, Sent last, FwdIter2 dest)
```

Searches the range [first, last) for two consecutive identical elements.

Note: Complexity: Exactly the smaller of $(result - first) + 1$ and $(last - first) - 1$ application of the predicate where `result` is the value returned

Template Parameters

- **FwdIter1** – The type of the source iterators used for the range (deduced). This iterator type must meet the requirements of an forward iterator.

⁶³⁶ <http://github.com/STELLAR-GROUP/hpx/blob/8a3b7c1a4cb5693b2f7d9f587f759392ed0c51a0/libs/full/include/include/hpx/algorithm.hpp>

- **FwdIter2** – The type of the source iterators used for the range (deduced). This iterator type must meet the requirements of an forward iterator.
- **Sent** – The type of the source sentinel (deduced). This sentinel type must be a sentinel for InIter.

Parameters

- **first** – Refers to the beginning of the sequence of elements of the range the algorithm will be applied to.
- **last** – Refers to the end of the sequence of elements of the range the algorithm will be applied to.
- **dest** – Refers to the beginning of the destination range.

Returns The *adjacent_difference* algorithm returns an iterator to the first of the identical elements. If no such elements are found, *last* is returned.

```
template<typename Rng, typename FwdIter2>
FwdIter2 adjacent_difference(Rng &&rng, FwdIter2 dest)
```

Searches the *rng* for two consecutive identical elements.

Note: Complexity: Exactly the smaller of (result - first) + 1 and (last - first) - 1 application of the predicate where *result* is the value returned

Template Parameters

- **FwdIter2** – The type of the source iterators used for the range (deduced). This iterator type must meet the requirements of an forward iterator.
- **Rng** – The type of the source range used (deduced). The iterators extracted from this range type must meet the requirements of an input iterator.

Parameters

- **rng** – Refers to the sequence of elements the algorithm will be applied to.
- **dest** – Refers to the beginning of the destination range.

Returns The *adjacent_difference* algorithm returns an iterator to the first of the identical elements.

```
template<typename ExPolicy, typename FwdIter1, typename Sent, typename FwdIter2>
hpx::parallel::util::detail::algorithm_result_t<ExPolicy, FwdIter2> adjacent_difference(ExPolicy
                                                                                       &&policy,
                                                                                       FwdIter1
                                                                                       first, Sent
                                                                                       last,
                                                                                       FwdIter2
                                                                                       dest)
```

Searches the range [first, last) for two consecutive identical elements.

Note: Complexity: Exactly the smaller of (result - first) + 1 and (last - first) - 1 application of the predicate where *result* is the value returned

Template Parameters

- **ExPolicy** – The type of the execution policy to use (deduced). It describes the manner in which the execution of the algorithm may be parallelized and the manner in which it executes the assignments.
- **FwdIter1** – The type of the source iterators used for the range (deduced). This iterator type must meet the requirements of an forward iterator.
- **FwdIter2** – The type of the source iterators used for the range (deduced). This iterator type must meet the requirements of an forward iterator.

- **Sent** – The type of the source sentinel (deduced). This sentinel type must be a sentinel for `InIter`.

Parameters

- **policy** – The execution policy to use for the scheduling of the iterations.
- **first** – Refers to the beginning of the sequence of elements of the range the algorithm will be applied to.
- **last** – Refers to the end of the sequence of elements of the range the algorithm will be applied to.
- **dest** – Refers to the beginning of the destination range.

Returns The *adjacent_difference* algorithm returns an iterator to the first of the identical elements. If no such elements are found, *last* is returned.

```
template<typename ExPolicy, typename Rng, typename FwdIter2>
hpx::parallel::util::detail::algorithm_result_t<ExPolicy, FwdIter2> adjacent_difference(ExPolicy
                                                                                       &&policy,
                                                                                       Rng
                                                                                       &&rng,
                                                                                       FwdIter2
                                                                                       dest)
```

Searches the *rng* for two consecutive identical elements.

Note: Complexity: Exactly the smaller of $(result - first) + 1$ and $(last - first) - 1$ application of the predicate where *result* is the value returned

Template Parameters

- **ExPolicy** – The type of the execution policy to use (deduced). It describes the manner in which the execution of the algorithm may be parallelized and the manner in which it executes the assignments.
- **FwdIter2** – The type of the source iterators used for the range (deduced). This iterator type must meet the requirements of an forward iterator.
- **Rng** – The type of the source range used (deduced). The iterators extracted from this range type must meet the requirements of an input iterator.

Parameters

- **policy** – The execution policy to use for the scheduling of the iterations.
- **rng** – Refers to the sequence of elements the algorithm will be applied to.
- **dest** – Refers to the beginning of the destination range.

Returns The *adjacent_difference* algorithm returns an iterator to the first of the identical elements.

```
template<typename FwdIter1, typename Sent, typename FwdIter2, typename Op>
FwdIter2 adjacent_difference(FwdIter1 first, Sent last, FwdIter2 dest, Op &&op)
```

Searches the range [first, last) for two consecutive identical elements.

Note: Complexity: Exactly the smaller of $(result - first) + 1$ and $(last - first) - 1$ application of the predicate where *result* is the value returned

Template Parameters

- **FwdIter1** – The type of the source iterators used for the range (deduced). This iterator type must meet the requirements of an forward iterator.
- **FwdIter2** – The type of the source iterators used for the range (deduced). This iterator type must meet the requirements of an forward iterator.

- **Sent** – The type of the source sentinel (deduced). This sentinel type must be a sentinel for `InIter`.
- **Op** – The type of the function/function object to use (deduced). Unlike its sequential form, the parallel overload of `adjacent_difference` requires `Op` to meet the requirements of `CopyConstructible`.

Parameters

- **first** – Refers to the beginning of the sequence of elements of the range the algorithm will be applied to.
- **last** – Refers to the end of the sequence of elements of the range the algorithm will be applied to.
- **dest** – Refers to the beginning of the destination range.
- **op** – Binary operation function object that will be applied. The signature of the function should be equivalent to the following:

```
Ret fun(const Type1 &a, const Type2 &b);
```

The signature does not need to have `const &`. The types `Type1` and `Type2` must be such that an object of type `iterator_traits<InputIt>::value_type` can be implicitly converted to both of them. The type `Ret` must be such that an object of type `OutputIt` can be dereferenced and assigned a value of type `Ret`.

Returns The `adjacent_difference` algorithm returns an iterator to the first of the identical elements. If no such elements are found, `last` is returned.

```
template<typename Rng, typename FwdIter2, typename Op>
FwdIter2 adjacent_difference(Rng &&rng, FwdIter2 dest, Op &&op)
```

Searches the `rng` for two consecutive identical elements.

Template Parameters

- **FwdIter2** – The type of the source iterators used for the range (deduced). This iterator type must meet the requirements of an forward iterator.
- **Rng** – The type of the source range used (deduced). The iterators extracted from this range type must meet the requirements of an input iterator.
- **Op** – The type of the function/function object to use (deduced). Unlike its sequential form, the parallel overload of `adjacent_difference` requires `Op` to meet the requirements of `CopyConstructible`.

Parameters

- **rng** – Refers to the sequence of elements the algorithm will be applied to.
- **dest** – Refers to the beginning of the destination range.
- **op** – Binary operation function object that will be applied. The signature of the function should be equivalent to the following:

```
Ret fun(const Type1 &a, const Type2 &b);
```

The signature does not need to have `const &`. The types `Type1` and `Type2` must be such that an object of type `iterator_traits<InputIt>::value_type` can be implicitly converted to both of them. The type `Ret` must be such that an object of type `OutputIt` can be dereferenced and assigned a value of type `Ret`.

Returns The `adjacent_difference` algorithm returns an iterator to the first of the identical elements.

```
template<typename ExpPolicy, typename FwdIter1, typename Sent, typename FwdIter2, typename Op>
```

hpx::parallel::util::detail::algorithm_result_t<ExPolicy, FwdIter2> **adjacent_difference**(*ExPolicy* &&policy, *FwdIter1* first, *Sent* last, *FwdIter2* dest, *Op* &&op)

Searches the range [first, last) for two consecutive identical elements.

Note: Complexity: Exactly the smaller of (result - first) + 1 and (last - first) - 1 application of the predicate where *result* is the value returned

Template Parameters

- **ExPolicy** – The type of the execution policy to use (deduced). It describes the manner in which the execution of the algorithm may be parallelized and the manner in which it executes the assignments.
- **FwdIter1** – The type of the source iterators used for the range (deduced). This iterator type must meet the requirements of an forward iterator.
- **FwdIter2** – The type of the source iterators used for the range (deduced). This iterator type must meet the requirements of an forward iterator.
- **Sent** – The type of the source sentinel (deduced). This sentinel type must be a sentinel for *InIter*.
- **Op** – The type of the function/function object to use (deduced). Unlike its sequential form, the parallel overload of *adjacent_difference* requires *Op* to meet the requirements of *CopyConstructible*.

Parameters

- **policy** – The execution policy to use for the scheduling of the iterations.
- **first** – Refers to the beginning of the sequence of elements of the range the algorithm will be applied to.
- **last** – Refers to the end of the sequence of elements of the range the algorithm will be applied to.
- **dest** – Refers to the beginning of the destination range.
- **op** – Binary operation function object that will be applied. The signature of the function should be equivalent to the following:

```
Ret fun(const Type1 &a, const Type2 &b);
```

The signature does not need to have `const &`. The types *Type1* and *Type2* must be such that an object of type *iterator_traits<InputIt>::value_type* can be implicitly converted to both of them. The type *Ret* must be such that an object of type *OutputIt* can be dereferenced and assigned a value of type *Ret*.

Returns The *adjacent_difference* algorithm returns an iterator to the first of the identical elements. If no such elements are found, *last* is returned.

```
template<typename ExPolicy, typename Rng, typename FwdIter2, typename Op>
hpx::parallel::util::detail::algorithm_result_t<ExPolicy, FwdIter2> adjacent_difference(ExPolicy &&policy,
Rng &&rng,
FwdIter2 dest, Op &&op)
```

Searches the *rng* for two consecutive identical elements.

Note: Complexity: Exactly the smaller of $(\text{result} - \text{first}) + 1$ and $(\text{last} - \text{first}) - 1$ application of the predicate where *result* is the value returned

Template Parameters

- **ExPolicy** – The type of the execution policy to use (deduced). It describes the manner in which the execution of the algorithm may be parallelized and the manner in which it executes the assignments.
- **FwdIter2** – The type of the source iterators used for the range (deduced). This iterator type must meet the requirements of an forward iterator.
- **Rng** – The type of the source range used (deduced). The iterators extracted from this range type must meet the requirements of an input iterator.
- **Op** – The type of the function/function object to use (deduced). Unlike its sequential form, the parallel overload of *adjacent_difference* requires *Op* to meet the requirements of *CopyConstructible*.

Parameters

- **policy** – The execution policy to use for the scheduling of the iterations.
- **rng** – Refers to the sequence of elements the algorithm will be applied to.
- **dest** – Refers to the beginning of the destination range.
- **op** – Binary operation function object that will be applied. The signature of the function should be equivalent to the following:

```
Ret fun(const Type1 &a, const Type2 &b);
```

The signature does not need to have `const &`. The types *Type1* and *Type2* must be such that an object of type *iterator_traits<InputIt>::value_type* can be implicitly converted to both of them. The type *Ret* must be such that an object of type *OutputIt* can be dereferenced and assigned a value of type *Ret*.

Returns The *adjacent_difference* algorithm returns an iterator to the first of the identical elements.

hpx::ranges::adjacent_find

Defined in header `hpx/algorithm.hpp`⁶³⁷.

See *Public API* for a list of names and headers that are part of the public *HPX* API.

namespace **hpx**

namespace **ranges**

⁶³⁷ <http://github.com/STELLAR-GROUP/hpx/blob/8a3b7c1a4cb5693b2f7d9f587f759392ed0c51a0/libs/full/include/include/hpx/algorithm.hpp>

Functions

```
template<typename FwdIter, typename Sent, typename Proj = hpx::identity, typename Pred =
detail::equal_to>
```

```
FwdIter adjacent_find(FwdIter first, Sent last, Pred &&pred = Pred(), Proj &&proj = Proj())
```

Searches the range [first, last) for two consecutive identical elements.

Note: Complexity: Exactly the smaller of (result - first) + 1 and (last - first) - 1 application of the predicate where *result* is the value returned

Template Parameters

- **FwdIter** – The type of the source iterators used for the range (deduced). This iterator type must meet the requirements of an forward iterator.
- **Sent** – The type of the source sentinel (deduced). This sentinel type must be a sentinel for *InIter*.
- **Proj** – The type of an optional projection function. This defaults to *hpx::identity*
- **Pred** – The type of an optional function/function object to use.

Parameters

- **first** – Refers to the beginning of the sequence of elements of the range the algorithm will be applied to.
- **last** – Refers to the end of the sequence of elements of the range the algorithm will be applied to.
- **pred** – The binary predicate which returns *true* if the elements should be treated as equal. The signature should be equivalent to the following:

```
bool pred(const Type1 &a, const Type1 &b);
```

The signature does not need to have `const &`, but the function must not modify the objects passed to it. The types *Type1* must be such that objects of type *FwdIter* can be dereferenced and then implicitly converted to *Type1*.

- **proj** – Specifies the function (or function object) which will be invoked for each of the elements as a projection operation before the actual predicate *is* invoked.

Returns The *adjacent_find* algorithm returns an iterator to the first of the identical elements. If no such elements are found, *last* is returned.

```
template<typename ExPolicy, typename FwdIter, typename Sent, typename Proj = hpx::identity,
typename Pred = detail::equal_to>
```

```
parallel::util::detail::algorithm_result<ExPolicy, FwdIter>::type adjacent_find(ExPolicy &&policy,
FwdIter first, Sent
last, Pred &&pred =
Pred(), Proj &&proj
= Proj())
```

Searches the range [first, last) for two consecutive identical elements. This version uses the given binary predicate `pred`

The comparison operations in the parallel *adjacent_find* invoked with an execution policy object of type *sequenced_policy* execute in sequential order in the calling thread.

The comparison operations in the parallel *adjacent_find* invoked with an execution policy object of type *parallel_policy* or *parallel_task_policy* are permitted to execute in an unordered fashion in unspecified threads, and indeterminately sequenced within each thread.

This overload of *adjacent_find* is available if the user decides to provide their algorithm their own binary predicate *pred*.

Note: Complexity: Exactly the smaller of $(\text{result} - \text{first}) + 1$ and $(\text{last} - \text{first}) - 1$ application of the predicate where *result* is the value returned

Template Parameters

- **ExPolicy** – The type of the execution policy to use (deduced). It describes the manner in which the execution of the algorithm may be parallelized and the manner in which it executes the assignments.
- **FwdIter** – The type of the source iterators used for the range (deduced). This iterator type must meet the requirements of an forward iterator.
- **Sent** – The type of the source sentinel (deduced). This sentinel type must be a sentinel for *InIter*.
- **Proj** – The type of an optional projection function. This defaults to *hpx::identity*
- **Pred** – The type of an optional function/function object to use. Unlike its sequential form, the parallel overload of *adjacent_find* requires *Pred* to meet the requirements of *CopyConstructible*. This defaults to `std::equal_to<>`

Parameters

- **policy** – The execution policy to use for the scheduling of the iterations.
- **first** – Refers to the beginning of the sequence of elements of the range the algorithm will be applied to.
- **last** – Refers to the end of the sequence of elements of the range the algorithm will be applied to.
- **pred** – The binary predicate which returns *true* if the elements should be treated as equal. The signature should be equivalent to the following:

```
bool pred(const Type1 &a, const Type1 &b);
```

The signature does not need to have `const &`, but the function must not modify the objects passed to it. The types *Type1* must be such that objects of type *FwdIter* can be dereferenced and then implicitly converted to *Type1*.

- **proj** – Specifies the function (or function object) which will be invoked for each of the elements as a projection operation before the actual predicate *is* invoked.

Returns The *adjacent_find* algorithm returns a *hpx::future<InIter>* if the execution policy is of type *sequenced_task_policy* or *parallel_task_policy* and returns *InIter* otherwise. The *adjacent_find* algorithm returns an iterator to the first of the identical elements. If no such elements are found, *last* is returned.

```
template<typename Rng, typename Proj = hpx::identity, typename Pred = detail::equal_to>
hpx::traits::range_traits<Rng>::iterator_type adjacent_find(Rng &&rng, Pred &&pred = Pred(), Proj
&&proj = Proj())
```

Searches the range *rng* for two consecutive identical elements.

Note: Complexity: Exactly the smaller of $(\text{result} - \text{std::begin}(\text{rng})) + 1$ and $(\text{std::begin}(\text{rng}) - \text{std::end}(\text{rng})) - 1$ applications of the predicate where *result* is the value returned

Template Parameters

- **Rng** – The type of the source range used (deduced). The iterators extracted from this range type must meet the requirements of an forward iterator.
- **Proj** – The type of an optional projection function. This defaults to *hpx::identity*
- **Pred** – The type of an optional function/function object to use.

Parameters

- **rng** – Refers to the sequence of elements the algorithm will be applied to.
- **pred** – The binary predicate which returns *true* if the elements should be treated as equal. The signature should be equivalent to the following:

```
bool pred(const Type1 &a, const Type1 &b);
```

The signature does not need to have `const &`, but the function must not modify the objects passed to it. The types *Type1* must be such that objects of type *FwdIter* can be dereferenced and then implicitly converted to *Type1*.

- **proj** – Specifies the function (or function object) which will be invoked for each of the elements as a projection operation before the actual predicate *is* invoked.

Returns The *adjacent_find* algorithm returns an iterator to the first of the identical elements.

If no such elements are found, *last* is returned.

```
template<typename ExPolicy, typename Rng, typename Proj = hpx::identity, typename Pred =  
detail::equal_to>  
parallel::util::detail::algorithm_result<ExPolicy, typename hpx::traits::range_traits<Rng>::iterator_type>::type adjacent_
```

Searches the range *rng* for two consecutive identical elements.

The comparison operations in the parallel *adjacent_find* invoked with an execution policy object of type *sequenced_policy* execute in sequential order in the calling thread.

The comparison operations in the parallel *adjacent_find* invoked with an execution policy object of type *parallel_policy* or *parallel_task_policy* are permitted to execute in an unordered fashion in unspecified threads, and indeterminately sequenced within each thread.

This overload of *adjacent_find* is available if the user decides to provide their algorithm their own binary predicate *pred*.

Note: Complexity: Exactly the smaller of $(\text{result} - \text{std::begin}(\text{rng})) + 1$ and $(\text{std::begin}(\text{rng}) - \text{std::end}(\text{rng})) - 1$ applications of the predicate where *result* is the value returned

Template Parameters

- **ExPolicy** – The type of the execution policy to use (deduced). It describes the manner in which the execution of the algorithm may be parallelized and the manner in which it executes the assignments.
- **Rng** – The type of the source range used (deduced). The iterators extracted from this range type must meet the requirements of an forward iterator.
- **Proj** – The type of an optional projection function. This defaults to *hpx::identity*

- **Pred** – The type of an optional function/function object to use. Unlike its sequential form, the parallel overload of *adjacent_find* requires *Pred* to meet the requirements of *CopyConstructible*. This defaults to `std::equal_to<>`

Parameters

- **policy** – The execution policy to use for the scheduling of the iterations.
- **rng** – Refers to the sequence of elements the algorithm will be applied to.
- **pred** – The binary predicate which returns *true* if the elements should be treated as equal. The signature should be equivalent to the following:

```
bool pred(const Type1 &a, const Type1 &b);
```

The signature does not need to have `const &`, but the function must not modify the objects passed to it. The types *Type1* must be such that objects of type *FwdIter* can be dereferenced and then implicitly converted to *Type1*.

- **proj** – Specifies the function (or function object) which will be invoked for each of the elements as a projection operation before the actual predicate *is* invoked.

Returns The *adjacent_find* algorithm returns a *hpx::future<InIter>* if the execution policy is of type *sequenced_task_policy* or *parallel_task_policy* and returns *InIter* otherwise. The *adjacent_find* algorithm returns an iterator to the first of the identical elements. If no such elements are found, *last* is returned.

hpx::ranges::all_of, hpx::ranges::any_of, hpx::ranges::none_of

Defined in header `hpx/algorithm.hpp`⁶³⁸.

See *Public API* for a list of names and headers that are part of the public *HPX* API.

namespace **hpx**

namespace **ranges**

Functions

```
template<typename ExPolicy, typename Rng, typename F, typename Proj = hpx::identity>
hpx::parallel::util::detail::algorithm_result_t<ExPolicy, bool> none_of(ExPolicy &&policy, Rng
&&rng, F &&f, Proj &&proj =
Proj())
```

Checks if unary predicate *f* returns true for no elements in the range *rng*.

The application of function objects in parallel algorithm invoked with an execution policy object of type *sequenced_policy* execute in sequential order in the calling thread.

The application of function objects in parallel algorithm invoked with an execution policy object of type *parallel_policy* or *parallel_task_policy* are permitted to execute in an unordered fashion in unspecified threads, and indeterminately sequenced within each thread.

Note: Complexity: At most `std::distance(begin(rng), end(rng))` applications of the predicate *f*

Template Parameters

⁶³⁸ <http://github.com/STELLAR-GROUP/hpx/blob/8a3b7c1a4cb5693b2f7d9f587f759392ed0c51a0/libs/full/include/include/hpx/algorithm.hpp>

- **ExPolicy** – The type of the execution policy to use (deduced). It describes the manner in which the execution of the algorithm may be parallelized and the manner in which it applies user-provided function objects.
- **Rng** – The type of the source range used (deduced). The iterators extracted from this range type must meet the requirements of an input iterator.
- **F** – The type of the function/function object to use (deduced). Unlike its sequential form, the parallel overload of *none_of* requires *F* to meet the requirements of *CopyConstructible*.
- **Proj** – The type of an optional projection function. This defaults to *hpx::identity*

Parameters

- **policy** – The execution policy to use for the scheduling of the iterations.
- **rng** – Refers to the sequence of elements the algorithm will be applied to.
- **f** – Specifies the function (or function object) which will be invoked for each of the elements in the sequence specified by [first, last). The signature of this predicate should be equivalent to:

```
bool pred(const Type &a);
```

The signature does not need to have `const&`, but the function must not modify the objects passed to it. The type *Type* must be such that an object of type *FwdIter* can be dereferenced and then implicitly converted to *Type*.

- **proj** – Specifies the function (or function object) which will be invoked for each of the elements as a projection operation before the actual predicate *is* invoked.

Returns The *none_of* algorithm returns a *hpx::future<bool>* if the execution policy is of type *sequenced_task_policy* or *parallel_task_policy* and returns *bool* otherwise. The *none_of* algorithm returns true if the unary predicate *f* returns true for no elements in the range, false otherwise. It returns true if the range is empty.

```
template<typename ExPolicy, typename Iter, typename Sent, typename F, typename Proj =
hpx::identity>
hpx::parallel::util::detail::algorithm_result_t<ExPolicy, bool> none_of(ExPolicy &&policy, Iter first,
Sent last, F &&f, Proj &&proj
= Proj())
```

Checks if unary predicate *f* returns true for no elements in the range [first, last).

The application of function objects in parallel algorithm invoked with an execution policy object of type *sequenced_policy* execute in sequential order in the calling thread.

The application of function objects in parallel algorithm invoked with an execution policy object of type *parallel_policy* or *parallel_task_policy* are permitted to execute in an unordered fashion in unspecified threads, and indeterminately sequenced within each thread.

Note: Complexity: At most *last - first* applications of the predicate *f*

Template Parameters

- **ExPolicy** – The type of the execution policy to use (deduced). It describes the manner in which the execution of the algorithm may be parallelized and the manner in which it applies user-provided function objects.
- **Iter** – The type of the source iterators used for the range (deduced).
- **Sent** – The type of the source sentinel (deduced). This sentinel type must be a sentinel for *InIter*.
- **F** – The type of the function/function object to use (deduced). Unlike its sequential

form, the parallel overload of *none_of* requires *F* to meet the requirements of *Copy-Constructible*.

- **Proj** – The type of an optional projection function. This defaults to *hpx::identity*

Parameters

- **policy** – The execution policy to use for the scheduling of the iterations.
- **first** – Refers to the beginning of the sequence of elements of the range the algorithm will be applied to.
- **last** – Refers to the end of the sequence of elements of the range the algorithm will be applied to.
- **f** – Specifies the function (or function object) which will be invoked for each of the elements in the sequence specified by [first, last). The signature of this predicate should be equivalent to:

```
bool pred(const Type &a);
```

The signature does not need to have `const&`, but the function must not modify the objects passed to it. The type *Type* must be such that an object of type *FwdIter* can be dereferenced and then implicitly converted to *Type*.

- **proj** – Specifies the function (or function object) which will be invoked for each of the elements as a projection operation before the actual predicate *is* invoked.

Returns The *none_of* algorithm returns a *hpx::future<bool>* if the execution policy is of type *sequenced_task_policy* or *parallel_task_policy* and returns *bool* otherwise. The *none_of* algorithm returns true if the unary predicate *f* returns true for no elements in the range, false otherwise. It returns true if the range is empty.

```
template<typename Rng, typename F, typename Proj = hpx::identity>
bool none_of(Rng &&rng, F &&f, Proj &&proj = Proj())
```

Checks if unary predicate *f* returns true for no elements in the range *rng*.

Note: Complexity: At most `std::distance(begin(rng), end(rng))` applications of the predicate *f*

Template Parameters

- **Rng** – The type of the source range used (deduced). The iterators extracted from this range type must meet the requirements of an input iterator.
- **F** – The type of the function/function object to use (deduced). Unlike its sequential form, the parallel overload of *none_of* requires *F* to meet the requirements of *Copy-Constructible*.
- **Proj** – The type of an optional projection function. This defaults to *hpx::identity*

Parameters

- **rng** – Refers to the sequence of elements the algorithm will be applied to.
- **f** – Specifies the function (or function object) which will be invoked for each of the elements in the sequence specified by [first, last). The signature of this predicate should be equivalent to:

```
bool pred(const Type &a);
```

The signature does not need to have `const&`, but the function must not modify the objects passed to it. The type *Type* must be such that an object of type *FwdIter* can be dereferenced and then implicitly converted to *Type*.

- **proj** – Specifies the function (or function object) which will be invoked for each of the elements as a projection operation before the actual predicate *is* invoked.

Returns The *none_of* algorithm returns true if the unary predicate *f* returns true for no elements in the range, false otherwise. It returns true if the range is empty.

```
template<typename Iter, typename Sent, typename F, typename Proj = hpx::identity>
bool none_of(Iter first, Sent last, F &&f, Proj &&proj = Proj())
```

Checks if unary predicate f returns true for no elements in the range $[first, last)$.

Note: Complexity: At most *last - first* applications of the predicate f

Template Parameters

- **Iter** – The type of the source iterators used for the range (deduced).
- **Sent** – The type of the source sentinel (deduced). This sentinel type must be a sentinel for *InIter*.
- **F** – The type of the function/function object to use (deduced). Unlike its sequential form, the parallel overload of *none_of* requires F to meet the requirements of *CopyConstructible*.
- **Proj** – The type of an optional projection function. This defaults to *hpx::identity*

Parameters

- **first** – Refers to the beginning of the sequence of elements of the range the algorithm will be applied to.
- **last** – Refers to the end of the sequence of elements of the range the algorithm will be applied to.
- **f** – Specifies the function (or function object) which will be invoked for each of the elements in the sequence specified by $[first, last)$. The signature of this predicate should be equivalent to:

```
bool pred(const Type &a);
```

The signature does not need to have `const&`, but the function must not modify the objects passed to it. The type *Type* must be such that an object of type *FwdIter* can be dereferenced and then implicitly converted to *Type*.

- **proj** – Specifies the function (or function object) which will be invoked for each of the elements as a projection operation before the actual predicate *is* invoked.

Returns The *none_of* algorithm returns true if the unary predicate f returns true for no elements in the range, false otherwise. It returns true if the range is empty.

```
template<typename ExPolicy, typename Rng, typename F, typename Proj = hpx::identity>
hpx::parallel::util::detail::algorithm_result_t<ExPolicy, bool> any_of(ExPolicy &&policy, Rng &&rng,
F &&f, Proj &&proj = Proj())
```

Checks if unary predicate f returns true for at least one element in the range rng .

The application of function objects in parallel algorithm invoked with an execution policy object of type *sequenced_policy* execute in sequential order in the calling thread.

The application of function objects in parallel algorithm invoked with an execution policy object of type *parallel_policy* or *parallel_task_policy* are permitted to execute in an unordered fashion in unspecified threads, and indeterminately sequenced within each thread.

Note: Complexity: At most `std::distance(begin(rng), end(rng))` applications of the predicate f

Template Parameters

- **ExPolicy** – The type of the execution policy to use (deduced). It describes the manner in which the execution of the algorithm may be parallelized and the manner in which it applies user-provided function objects.

- **Rng** – The type of the source range used (deduced). The iterators extracted from this range type must meet the requirements of an input iterator.
- **F** – The type of the function/function object to use (deduced). Unlike its sequential form, the parallel overload of *none_of* requires *F* to meet the requirements of *Copy-Constructible*.
- **Proj** – The type of an optional projection function. This defaults to *hpx::identity*

Parameters

- **policy** – The execution policy to use for the scheduling of the iterations.
- **rng** – Refers to the sequence of elements the algorithm will be applied to.
- **f** – Specifies the function (or function object) which will be invoked for each of the elements in the sequence specified by [first, last). The signature of this predicate should be equivalent to:

```
bool pred(const Type &a);
```

The signature does not need to have `const&`, but the function must not modify the objects passed to it. The type *Type* must be such that an object of type *FwdIter* can be dereferenced and then implicitly converted to *Type*.

- **proj** – Specifies the function (or function object) which will be invoked for each of the elements as a projection operation before the actual predicate *is* invoked.

Returns The *any_of* algorithm returns a *hpx::future<bool>* if the execution policy is of type *sequenced_task_policy* or *parallel_task_policy* and returns *bool* otherwise. The *any_of* algorithm returns true if the unary predicate *f* returns true for at least one element in the range, false otherwise. It returns false if the range is empty.

```
template<typename ExPolicy, typename Iter, typename Sent, typename F, typename Proj =
hpx::identity>
hpx::parallel::util::detail::algorithm_result_t<ExPolicy, bool> any_of(ExPolicy &&policy, Iter first,
Sent last, F &&f, Proj &&proj =
Proj())
```

Checks if unary predicate *f* returns true for at least one element in the range *rng*.

The application of function objects in parallel algorithm invoked with an execution policy object of type *sequenced_policy* execute in sequential order in the calling thread.

The application of function objects in parallel algorithm invoked with an execution policy object of type *parallel_policy* or *parallel_task_policy* are permitted to execute in an unordered fashion in unspecified threads, and indeterminately sequenced within each thread.

Note: Complexity: At most `std::distance(begin(rng), end(rng))` applications of the predicate *f*

Template Parameters

- **ExPolicy** – The type of the execution policy to use (deduced). It describes the manner in which the execution of the algorithm may be parallelized and the manner in which it applies user-provided function objects.
- **Iter** – The type of the source iterators used for the range (deduced).
- **Sent** – The type of the source sentinel (deduced). This sentinel type must be a sentinel for *InIter*.
- **F** – The type of the function/function object to use (deduced). Unlike its sequential form, the parallel overload of *none_of* requires *F* to meet the requirements of *Copy-Constructible*.
- **Proj** – The type of an optional projection function. This defaults to *hpx::identity*

Parameters

- **policy** – The execution policy to use for the scheduling of the iterations.
- **first** – Refers to the beginning of the sequence of elements of the range the algorithm will be applied to.
- **last** – Refers to the end of the sequence of elements of the range the algorithm will be applied to.
- **f** – Specifies the function (or function object) which will be invoked for each of the elements in the sequence specified by [first, last). The signature of this predicate should be equivalent to:

```
bool pred(const Type &a);
```

The signature does not need to have const&, but the function must not modify the objects passed to it. The type *Type* must be such that an object of type *FwdIter* can be dereferenced and then implicitly converted to *Type*.

- **proj** – Specifies the function (or function object) which will be invoked for each of the elements as a projection operation before the actual predicate *is* invoked.

Returns The *any_of* algorithm returns a *hpx::future<bool>* if the execution policy is of type *sequenced_task_policy* or *parallel_task_policy* and returns *bool* otherwise. The *any_of* algorithm returns true if the unary predicate *f* returns true for at least one element in the range, false otherwise. It returns false if the range is empty.

```
template<typename Rng, typename F, typename Proj = hpx::identity>
bool any_of(Rng &&rng, F &&f, Proj &&proj = Proj())
```

Checks if unary predicate *f* returns true for at least one element in the range *rng*.

Note: Complexity: At most `std::distance(begin(rng), end(rng))` applications of the predicate *f*

Template Parameters

- **Rng** – The type of the source range used (deduced). The iterators extracted from this range type must meet the requirements of an input iterator.
- **F** – The type of the function/function object to use (deduced). Unlike its sequential form, the parallel overload of *none_of* requires *F* to meet the requirements of *CopyConstructible*.
- **Proj** – The type of an optional projection function. This defaults to *hpx::identity*

Parameters

- **rng** – Refers to the sequence of elements the algorithm will be applied to.
- **f** – Specifies the function (or function object) which will be invoked for each of the elements in the sequence specified by [first, last). The signature of this predicate should be equivalent to:

```
bool pred(const Type &a);
```

The signature does not need to have const&, but the function must not modify the objects passed to it. The type *Type* must be such that an object of type *FwdIter* can be dereferenced and then implicitly converted to *Type*.

- **proj** – Specifies the function (or function object) which will be invoked for each of the elements as a projection operation before the actual predicate *is* invoked.

Returns The *any_of* algorithm returns true if the unary predicate *f* returns true for at least one element in the range, false otherwise. It returns false if the range is empty.

```
template<typename Iter, typename Sent, typename F, typename Proj = hpx::identity>
bool any_of(Iter first, Sent last, F &&f, Proj &&proj = Proj())
```

Checks if unary predicate *f* returns true for at least one element in the range *rng*.

Note: Complexity: At most `std::distance(begin(rng), end(rng))` applications of the predicate *f*

Template Parameters

- **Iter** – The type of the source iterators used for the range (deduced).
- **Sent** – The type of the source sentinel (deduced). This sentinel type must be a sentinel for `InIter`.
- **F** – The type of the function/function object to use (deduced). Unlike its sequential form, the parallel overload of *none_of* requires *F* to meet the requirements of *Copy-Constructible*.
- **Proj** – The type of an optional projection function. This defaults to `hpx::identity`

Parameters

- **first** – Refers to the beginning of the sequence of elements of the range the algorithm will be applied to.
- **last** – Refers to the end of the sequence of elements of the range the algorithm will be applied to.
- **f** – Specifies the function (or function object) which will be invoked for each of the elements in the sequence specified by [first, last). The signature of this predicate should be equivalent to:

```
bool pred(const Type &a);
```

The signature does not need to have `const&`, but the function must not modify the objects passed to it. The type *Type* must be such that an object of type *FwdIter* can be dereferenced and then implicitly converted to *Type*.

- **proj** – Specifies the function (or function object) which will be invoked for each of the elements as a projection operation before the actual predicate *is* invoked.

Returns The *any_of* algorithm returns true if the unary predicate *f* returns true for at least one element in the range, false otherwise. It returns false if the range is empty.

```
template<typename ExPolicy, typename Rng, typename F, typename Proj = hpx::identity>
hpx::parallel::util::detail::algorithm_result_t<ExPolicy, bool> all_of(ExPolicy &&policy, Rng &&rng,
                                                                    F &&f, Proj &&proj = Proj())
```

Checks if unary predicate *f* returns true for all elements in the range *rng*.

The application of function objects in parallel algorithm invoked with an execution policy object of type *sequenced_policy* execute in sequential order in the calling thread.

The application of function objects in parallel algorithm invoked with an execution policy object of type *parallel_policy* or *parallel_task_policy* are permitted to execute in an unordered fashion in unspecified threads, and indeterminately sequenced within each thread.

Note: Complexity: At most `std::distance(begin(rng), end(rng))` applications of the predicate *f*

Template Parameters

- **ExPolicy** – The type of the execution policy to use (deduced). It describes the manner in which the execution of the algorithm may be parallelized and the manner in which it applies user-provided function objects.
- **Rng** – The type of the source range used (deduced). The iterators extracted from this range type must meet the requirements of an input iterator.
- **F** – The type of the function/function object to use (deduced). Unlike its sequential form, the parallel overload of *none_of* requires *F* to meet the requirements of *Copy-*

Constructible.

- **Proj** – The type of an optional projection function. This defaults to `hpx::identity`

Parameters

- **policy** – The execution policy to use for the scheduling of the iterations.
- **rng** – Refers to the sequence of elements the algorithm will be applied to.
- **f** – Specifies the function (or function object) which will be invoked for each of the elements in the sequence specified by [first, last). The signature of this predicate should be equivalent to:

```
bool pred(const Type &a);
```

The signature does not need to have `const&`, but the function must not modify the objects passed to it. The type *Type* must be such that an object of type *FwdIter* can be dereferenced and then implicitly converted to *Type*.

- **proj** – Specifies the function (or function object) which will be invoked for each of the elements as a projection operation before the actual predicate *is* invoked.

Returns The *all_of* algorithm returns a `hpx::future<bool>` if the execution policy is of type *sequenced_task_policy* or *parallel_task_policy* and returns *bool* otherwise. The *all_of* algorithm returns true if the unary predicate *f* returns true for all elements in the range, false otherwise. It returns true if the range is empty.

```
template<typename ExPolicy, typename Iter, typename Sent, typename F, typename Proj =
hpx::identity>
hpx::parallel::util::detail::algorithm_result_t<ExPolicy, bool> all_of(ExPolicy &&policy, Iter first,
Sent last, F &&f, Proj &&proj =
Proj())
```

Checks if unary predicate *f* returns true for all elements in the range *rng*.

The application of function objects in parallel algorithm invoked with an execution policy object of type *sequenced_policy* execute in sequential order in the calling thread.

The application of function objects in parallel algorithm invoked with an execution policy object of type *parallel_policy* or *parallel_task_policy* are permitted to execute in an unordered fashion in unspecified threads, and indeterminately sequenced within each thread.

Note: Complexity: At most `std::distance(begin(rng), end(rng))` applications of the predicate *f*

Template Parameters

- **ExPolicy** – The type of the execution policy to use (deduced). It describes the manner in which the execution of the algorithm may be parallelized and the manner in which it applies user-provided function objects.
- **Iter** – The type of the source iterators used for the range (deduced).
- **Sent** – The type of the source sentinel (deduced). This sentinel type must be a sentinel for *InIter*.
- **F** – The type of the function/function object to use (deduced). Unlike its sequential form, the parallel overload of *none_of* requires *F* to meet the requirements of *Copy-Constructible*.
- **Proj** – The type of an optional projection function. This defaults to `hpx::identity`

Parameters

- **policy** – The execution policy to use for the scheduling of the iterations.
- **first** – Refers to the beginning of the sequence of elements of the range the algorithm will be applied to.

- **last** – Refers to the end of the sequence of elements of the range the algorithm will be applied to.
- **f** – Specifies the function (or function object) which will be invoked for each of the elements in the sequence specified by [first, last). The signature of this predicate should be equivalent to:

```
bool pred(const Type &a);
```

The signature does not need to have `const&`, but the function must not modify the objects passed to it. The type *Type* must be such that an object of type *FwdIter* can be dereferenced and then implicitly converted to *Type*.

- **proj** – Specifies the function (or function object) which will be invoked for each of the elements as a projection operation before the actual predicate *is* invoked.

Returns The *all_of* algorithm returns a `hpx::future<bool>` if the execution policy is of type *sequenced_task_policy* or *parallel_task_policy* and returns *bool* otherwise. The *all_of* algorithm returns true if the unary predicate *f* returns true for all elements in the range, false otherwise. It returns true if the range is empty.

```
template<typename Rng, typename F, typename Proj = hpx::identity>
bool all_of(Rng &&rng, F &&f, Proj &&proj = Proj())
```

Checks if unary predicate *f* returns true for all elements in the range *rng*.

Note: Complexity: At most `std::distance(begin(rng), end(rng))` applications of the predicate *f*

Template Parameters

- **Rng** – The type of the source range used (deduced). The iterators extracted from this range type must meet the requirements of an input iterator.
- **F** – The type of the function/function object to use (deduced). Unlike its sequential form, the parallel overload of *none_of* requires *F* to meet the requirements of *Copy-Constructible*.
- **Proj** – The type of an optional projection function. This defaults to `hpx::identity`

Parameters

- **rng** – Refers to the sequence of elements the algorithm will be applied to.
- **f** – Specifies the function (or function object) which will be invoked for each of the elements in the sequence specified by [first, last). The signature of this predicate should be equivalent to:

```
bool pred(const Type &a);
```

The signature does not need to have `const&`, but the function must not modify the objects passed to it. The type *Type* must be such that an object of type *FwdIter* can be dereferenced and then implicitly converted to *Type*.

- **proj** – Specifies the function (or function object) which will be invoked for each of the elements as a projection operation before the actual predicate *is* invoked.

Returns The *all_of* algorithm returns true if the unary predicate *f* returns true for all elements in the range, false otherwise. It returns true if the range is empty.

```
template<typename Iter, typename Sent, typename F, typename Proj = hpx::identity>
bool all_of(Iter first, Sent last, F &&f, Proj &&proj = Proj())
```

Checks if unary predicate *f* returns true for all elements in the range *rng*.

Note: Complexity: At most `std::distance(begin(rng), end(rng))` applications of the predicate *f*

Template Parameters

- **Iter** – The type of the source iterators used for the range (deduced).
- **Sent** – The type of the source sentinel (deduced). This sentinel type must be a sentinel for `InIter`.
- **F** – The type of the function/function object to use (deduced). Unlike its sequential form, the parallel overload of `none_of` requires `F` to meet the requirements of `CopyConstructible`.
- **Proj** – The type of an optional projection function. This defaults to `hpx::identity`

Parameters

- **first** – Refers to the beginning of the sequence of elements of the range the algorithm will be applied to.
- **last** – Refers to the end of the sequence of elements of the range the algorithm will be applied to.
- **f** – Specifies the function (or function object) which will be invoked for each of the elements in the sequence specified by [first, last). The signature of this predicate should be equivalent to:

```
bool pred(const Type &a);
```

The signature does not need to have `const&`, but the function must not modify the objects passed to it. The type `Type` must be such that an object of type `FwdIter` can be dereferenced and then implicitly converted to `Type`.

- **proj** – Specifies the function (or function object) which will be invoked for each of the elements as a projection operation before the actual predicate `is` is invoked.

Returns The `all_of` algorithm returns true if the unary predicate `f` returns true for all elements in the range, false otherwise. It returns true if the range is empty.

hpx::ranges::copy, hpx::ranges::copy_n, hpx::ranges::copy_if

Defined in header `hpx/algorithm.hpp`⁶³⁹.

See *Public API* for a list of names and headers that are part of the public *HPX* API.

namespace **hpx**

namespace **ranges**

Functions

```
template<typename ExPolicy, typename FwdIter1, typename Sent1, typename FwdIter>
parallel::util::detail::algorithm_result<ExPolicy, ranges::copy_result<FwdIter1, FwdIter>>::type copy(ExPolicy
&&pol-
icy,
FwdIter1
iter,
Sent1
sent,
FwdIter
dest)
```

Copies the elements in the range, defined by [first, last), to another range beginning at `dest`.

⁶³⁹ <http://github.com/STELLAR-GROUP/hpx/blob/8a3b7c1a4cb5693b2f7d9f587f759392ed0c51a0/libs/full/include/include/hpx/algorithm.hpp>

The assignments in the parallel *copy* algorithm invoked with an execution policy object of type *sequenced_policy* execute in sequential order in the calling thread.

The assignments in the parallel *copy* algorithm invoked with an execution policy object of type *parallel_policy* or *parallel_task_policy* are permitted to execute in an unordered fashion in unspecified threads, and indeterminately sequenced within each thread.

Note: Complexity: Performs exactly *last - first* assignments.

Template Parameters

- **ExPolicy** – The type of the execution policy to use (deduced). It describes the manner in which the execution of the algorithm may be parallelized and the manner in which it executes the assignments.
- **FwdIter1** – The type of the begin source iterators used (deduced). This iterator type must meet the requirements of an forward iterator.
- **Sent1** – The type of the end source iterators used (deduced). This iterator type must meet the requirements of an sentinel for Iter1.
- **FwdIter** – The type of the iterator representing the destination range (deduced). This iterator type must meet the requirements of an forward iterator.

Parameters

- **policy** – The execution policy to use for the scheduling of the iterations.
- **iter** – Refers to the beginning of the sequence of elements the algorithm will be applied to.
- **sent** – Refers to the end of the sequence of elements the algorithm will be applied to.
- **dest** – Refers to the beginning of the destination range.

Returns The *copy* algorithm returns a `hpx::future<ranges::copy_result<FwdIter1, FwdIter>>` if the execution policy is of type *sequenced_task_policy* or *parallel_task_policy* and returns `ranges::copy_result<FwdIter1, FwdIter>` otherwise. The *copy* algorithm returns the pair of the input iterator *last* and the output iterator to the element in the destination range, one past the last element copied.

```
template<typename ExPolicy, typename Rng, typename FwdIter>  
parallel::util::detail::algorithm_result<ExPolicy, ranges::copy_result<typename hpx::traits::range_traits<Rng>::iterator_type
```

Copies the elements in the range *rng* to another range beginning at *dest*.

The assignments in the parallel *copy* algorithm invoked with an execution policy object of type *sequenced_policy* execute in sequential order in the calling thread.

The assignments in the parallel *copy* algorithm invoked with an execution policy object of type *parallel_policy* or *parallel_task_policy* are permitted to execute in an unordered fashion in unspecified threads, and indeterminately sequenced within each thread.

Note: Complexity: Performs exactly `std::distance(begin(rng), end(rng))` assignments.

Template Parameters

- **ExPolicy** – The type of the execution policy to use (deduced). It describes the manner in which the execution of the algorithm may be parallelized and the manner in which it executes the assignments.
- **Rng** – The type of the source range used (deduced). The iterators extracted from this range type must meet the requirements of an input iterator.
- **FwdIter** – The type of the iterator representing the destination range (deduced). This iterator type must meet the requirements of an forward iterator.

Parameters

- **policy** – The execution policy to use for the scheduling of the iterations.
- **rng** – Refers to the sequence of elements the algorithm will be applied to.
- **dest** – Refers to the beginning of the destination range.

Returns The *copy* algorithm returns a `hpx::future<ranges::copy_result<iterator_t<Rng>, FwdIter2>>` if the execution policy is of type *sequenced_task_policy* or *parallel_task_policy* and returns `ranges::copy_result<iterator_t<Rng>, FwdIter2>` otherwise. The *copy* algorithm returns the pair of the input iterator *last* and the output iterator to the element in the destination range, one past the last element copied.

```
template<typename FwdIter1, typename Sent1, typename FwdIter>
ranges::copy_result<FwdIter1, FwdIter> copy(FwdIter1 iter, Sent1 sent, FwdIter dest)
```

Copies the elements in the range, defined by [first, last), to another range beginning at *dest*.

Note: Complexity: Performs exactly *last - first* assignments.

Template Parameters

- **FwdIter1** – The type of the begin source iterators used (deduced). This iterator type must meet the requirements of an forward iterator.
- **Sent1** – The type of the end source iterators used (deduced). This iterator type must meet the requirements of an sentinel for Iter1.
- **FwdIter** – The type of the iterator representing the destination range (deduced). This iterator type must meet the requirements of an forward iterator.

Parameters

- **iter** – Refers to the beginning of the sequence of elements the algorithm will be applied to.
- **sent** – Refers to the end of the sequence of elements the algorithm will be applied to.
- **dest** – Refers to the beginning of the destination range.

Returns The *copy* algorithm returns the pair of the input iterator *last* and the output iterator to the element in the destination range, one past the last element copied.

```
template<typename Rng, typename FwdIter>
ranges::copy_result<typename hpx::traits::range_traits<Rng>::iterator_type, FwdIter> copy(Rng
                                                                                       &&rng,
                                                                                       FwdIter
                                                                                       dest)
```

Copies the elements in the range *rng* to another range beginning at *dest*.

Note: Complexity: Performs exactly `std::distance(begin(rng), end(rng))` assignments.

Template Parameters

- **Rng** – The type of the source range used (deduced). The iterators extracted from this range type must meet the requirements of an input iterator.
- **FwdIter** – The type of the iterator representing the destination range (deduced). This iterator type must meet the requirements of an forward iterator.

Parameters

- **rng** – Refers to the sequence of elements the algorithm will be applied to.
- **dest** – Refers to the beginning of the destination range.

Returns The *copy* algorithm returns the pair of the input iterator *last* and the output iterator to the element in the destination range, one past the last element copied.

```
template<typename ExPolicy, typename FwdIter1, typename Size, typename FwdIter2>
hpx::parallel::util::detail::algorithm_result<ExPolicy, ranges::copy_n_result<FwdIter1, FwdIter2>>::type copy_n(ExPolic
&&pol-
icy,
FwdIter
first,
Size
count,
FwdIter
dest)
```

Copies the elements in the range [first, first + count), starting from first and proceeding to first + count - 1., to another range beginning at dest.

The assignments in the parallel *copy_n* algorithm invoked with an execution policy object of type *sequenced_policy* execute in sequential order in the calling thread.

The assignments in the parallel *copy_n* algorithm invoked with an execution policy object of type *parallel_policy* or *parallel_task_policy* are permitted to execute in an unordered fashion in unspecified threads, and indeterminately sequenced within each thread.

Note: Complexity: Performs exactly *count* assignments, if count > 0, no assignments otherwise.

Template Parameters

- **ExPolicy** – The type of the execution policy to use (deduced). It describes the manner in which the execution of the algorithm may be parallelized and the manner in which it executes the assignments.
- **FwdIter1** – The type of the source iterators used (deduced). This iterator type must meet the requirements of an forward iterator.
- **Size** – The type of the argument specifying the number of elements to apply *f* to.
- **FwdIter2** – The type of the iterator representing the destination range (deduced). This iterator type must meet the requirements of an forward iterator.

Parameters

- **policy** – The execution policy to use for the scheduling of the iterations.
- **first** – Refers to the beginning of the sequence of elements the algorithm will be applied to.
- **count** – Refers to the number of elements starting at *first* the algorithm will be applied to.
- **dest** – Refers to the beginning of the destination range.

Returns The *copy_n* algorithm returns a *hpx::future*<*ranges::copy_n_result*<*FwdIter1*, *FwdIter2*>> if the execution policy is of type *sequenced_task_policy* or *parallel_task_policy* and returns *ranges::copy_n_result*<*FwdIter1*, *FwdIter2*> otherwise. The *copy* algorithm returns the pair of the input iterator forwarded to the first element after the last in the input sequence and the output iterator to the element in the destination range, one past the last element copied.

```
template<typename FwdIter1, typename Size, typename FwdIter2>
```

ranges::copy_n_result<FwdIter1, FwdIter2> **copy_n**(*FwdIter1* first, *Size* count, *FwdIter2* dest)

Copies the elements in the range [first, first + count), starting from first and proceeding to first + count - 1., to another range beginning at dest.

Note: Complexity: Performs exactly *count* assignments, if count > 0, no assignments otherwise.

Template Parameters

- **FwdIter1** – The type of the source iterators used (deduced). This iterator type must meet the requirements of an forward iterator.
- **Size** – The type of the argument specifying the number of elements to apply *f* to.
- **FwdIter2** – The type of the iterator representing the destination range (deduced). This iterator type must meet the requirements of an forward iterator.

Parameters

- **first** – Refers to the beginning of the sequence of elements the algorithm will be applied to.
- **count** – Refers to the number of elements starting at *first* the algorithm will be applied to.
- **dest** – Refers to the beginning of the destination range.

Returns The *copy* algorithm returns the pair of the input iterator forwarded to the first element after the last in the input sequence and the output iterator to the element in the destination range, one past the last element copied.

```
template<typename ExPolicy, typename FwdIter1, typename Sent1, typename FwdIter, typename Pred, typename Proj = hpx::identity>
```

```
hpx::parallel::util::detail::algorithm_result<ExPolicy, ranges::copy_if_result<FwdIter1, FwdIter>>::type copy_if(ExPolicy
&&pol-
icy,
FwdIter
iter,
Sent1
sent,
FwdIter
dest,
Pred
&&pre-
Proj
&&pro-
=
Proj())
```

Copies the elements in the range, defined by [first, last) to another range beginning at *dest*. The order of the elements that are not removed is preserved.

The assignments in the parallel *copy_if* algorithm invoked with an execution policy object of type *sequenced_policy* execute in sequential order in the calling thread.

The assignments in the parallel *copy_if* algorithm invoked with an execution policy object of type *parallel_policy* or *parallel_task_policy* are permitted to execute in an unordered fashion in unspecified threads, and indeterminately sequenced within each thread.

Template Parameters

- **ExPolicy** – The type of the execution policy to use (deduced). It describes the manner in which the execution of the algorithm may be parallelized and the manner in which it executes the assignments.

- **FwdIter1** – The type of the begin source iterators used (deduced). This iterator type must meet the requirements of an forward iterator.
- **Sent1** – The type of the end source iterators used (deduced). This iterator type must meet the requirements of an sentinel for FwdIter1.
- **FwdIter** – The type of the iterator representing the destination range (deduced). This iterator type must meet the requirements of an output iterator.
- **Pred** – The type of an optional function/function object to use.
- **Proj** – The type of an optional projection function. This defaults to `hpx::identity`

Parameters

- **policy** – The execution policy to use for the scheduling of the iterations.
- **iter** – Refers to the beginning of the sequence of elements the algorithm will be applied to.
- **sent** – Refers to the end of the sequence of elements the algorithm will be applied to.
- **dest** – Refers to the beginning of the destination range.
- **pred** – The binary predicate which returns `true` if the elements should be treated as equal. The signature should be equivalent to the following:

```
bool pred(const Type1 &a, const Type1 &b);
```

The signature does not need to have `const &`, but the function must not modify the objects passed to it. The types `Type1` must be such that objects of type `FwdIter` can be dereferenced and then implicitly converted to `Type1`.

- **proj** – Specifies the function (or function object) which will be invoked for each of the elements as a projection operation before the actual predicate *is* invoked.

Returns The `copy_if` algorithm returns a `hpx::future<ranges::copy_if_result<iterator_t<Rng>, FwdIter2>>` if the execution policy is of type `sequenced_task_policy` or `parallel_task_policy` and returns `ranges::copy_if_result<iterator_t<Rng>, FwdIter2>` otherwise. The `copy_if` algorithm returns the pair of the input iterator `last` and the output iterator to the element in the destination range, one past the last element copied.

```
template<typename ExPolicy, typename Rng, typename FwdIter, typename Pred, typename Proj =
hpx::identity>
hpx::parallel::util::detail::algorithm_result<ExPolicy, ranges::copy_if_result<typename hpx::traits::range_traits<Rng>::iter
```

Copies the elements in the range, defined by `rng` to another range beginning at `dest`. The order of the elements that are not removed is preserved.

The assignments in the parallel `copy_if` algorithm invoked with an execution policy object of type `sequenced_policy` execute in sequential order in the calling thread.

The assignments in the parallel `copy_if` algorithm invoked with an execution policy object of type `parallel_policy` or `parallel_task_policy` are permitted to execute in an unordered fashion in unspecified threads, and indeterminately sequenced within each thread.

Template Parameters

- **ExPolicy** – The type of the execution policy to use (deduced). It describes the manner in which the execution of the algorithm may be parallelized and the manner in which it executes the assignments.
- **Rng** – The type of the source range used (deduced). The iterators extracted from this range type must meet the requirements of an forward iterator.
- **FwdIter** – The type of the iterator representing the destination range (deduced). This iterator type must meet the requirements of an output iterator.
- **Pred** – The type of an optional function/function object to use.
- **Proj** – The type of an optional projection function. This defaults to `hpx::identity`

Parameters

- **policy** – The execution policy to use for the scheduling of the iterations.
- **rng** – Refers to the sequence of elements the algorithm will be applied to.
- **dest** – Refers to the beginning of the destination range.
- **pred** – The binary predicate which returns `true` if the elements should be treated as equal. The signature should be equivalent to the following:

```
bool pred(const Type1 &a, const Type1 &b);
```

The signature does not need to have `const &`, but the function must not modify the objects passed to it. The types `Type1` must be such that objects of type `FwdIter` can be dereferenced and then implicitly converted to `Type1`.

- **proj** – Specifies the function (or function object) which will be invoked for each of the elements as a projection operation before the actual predicate `is` invoked.

Returns The `copy_if` algorithm returns a `hpx::future<ranges::copy_if_result<iterator_1<Rng>, FwdIter2>>` if the execution policy is of type `sequenced_task_policy` or `parallel_task_policy` and returns `ranges::copy_if_result<iterator_1<Rng>, FwdIter2>` otherwise. The `copy_if` algorithm returns the pair of the input iterator `last` and the output iterator to the element in the destination range, one past the last element copied.

```
template<typename FwdIter1, typename Sent1, typename FwdIter, typename Pred, typename Proj = hpx::identity>
ranges::copy_if_result<FwdIter1, FwdIter> copy_if(FwdIter1 iter, Sent1 sent, FwdIter dest, Pred
&&pred, Proj &&proj = Proj())
```

Copies the elements in the range, defined by `[first, last)` to another range beginning at `dest`. The order of the elements that are not removed is preserved.

Template Parameters

- **FwdIter1** – The type of the begin source iterators used (deduced). This iterator type must meet the requirements of an forward iterator.
- **Sent1** – The type of the end source iterators used (deduced). This iterator type must meet the requirements of an sentinel for `FwdIter1`.
- **FwdIter** – The type of the iterator representing the destination range (deduced). This iterator type must meet the requirements of an output iterator.
- **Pred** – The type of an optional function/function object to use.
- **Proj** – The type of an optional projection function. This defaults to `hpx::identity`

Parameters

- **iter** – Refers to the beginning of the sequence of elements the algorithm will be applied to.
- **sent** – Refers to the end of the sequence of elements the algorithm will be applied to.
- **dest** – Refers to the beginning of the destination range.
- **pred** – The binary predicate which returns `true` if the elements should be treated as equal. The signature should be equivalent to the following:

```
bool pred(const Type1 &a, const Type1 &b);
```

The signature does not need to have `const &`, but the function must not modify the objects passed to it. The types *Type1* must be such that objects of type *FwdIter* can be dereferenced and then implicitly converted to *Type1*.

- **proj** – Specifies the function (or function object) which will be invoked for each of the elements as a projection operation before the actual predicate *is* invoked.

Returns The *copy_if* algorithm returns the pair of the input iterator *last* and the output iterator to the element in the destination range, one past the last element copied.

```
template<typename Rng, typename FwdIter, typename Pred, typename Proj = hpx::identity>
ranges::copy_if_result<typename hpx::traits::range_traits<Rng>::iterator_type, FwdIter> copy_if(Rng
                                                                                               &&rng,
                                                                                               FwdIter
                                                                                               dest,
                                                                                               Pred
                                                                                               &&pred,
                                                                                               Proj
                                                                                               &&proj
                                                                                               =
                                                                                               Proj())
```

Copies the elements in the range, defined by *rng* to another range beginning at *dest*. The order of the elements that are not removed is preserved.

Template Parameters

- **Rng** – The type of the source range used (deduced). The iterators extracted from this range type must meet the requirements of an forward iterator.
- **FwdIter** – The type of the iterator representing the destination range (deduced). This iterator type must meet the requirements of an output iterator.
- **Pred** – The type of an optional function/function object to use.
- **Proj** – The type of an optional projection function. This defaults to *hpx::identity*

Parameters

- **rng** – Refers to the sequence of elements the algorithm will be applied to.
- **dest** – Refers to the beginning of the destination range.
- **pred** – The binary predicate which returns *true* if the elements should be treated as equal. The signature should be equivalent to the following:

```
bool pred(const Type1 &a, const Type1 &b);
```

The signature does not need to have `const &`, but the function must not modify the objects passed to it. The types *Type1* must be such that objects of type *FwdIter* can be dereferenced and then implicitly converted to *Type1*.

- **proj** – Specifies the function (or function object) which will be invoked for each of the elements as a projection operation before the actual predicate *is* invoked.

Returns The *copy_if* algorithm returns the pair of the input iterator *last* and the output iterator to the element in the destination range, one past the last element copied.

hpx::ranges::count, hpx::ranges::count_if

Defined in header `hpx/algorithm.hpp`⁶⁴⁰.

See *Public API* for a list of names and headers that are part of the public *HPX* API.

```
namespace hpx
```

```
    namespace ranges
```

Functions

```
template<typename ExPolicy, typename Rng, typename Proj = hpx::identity, typename T = typename
hpx::parallel::traits::projected<hpx::traits::range_iterator_t<Rng>, Proj>::value_type>
hpx::parallel::util::detail::algorithm_result<ExPolicy, typename std::iterator_traits<typename hpx::traits::range_traits<Rng>
```

Returns the number of elements in the range [first, last) satisfying a specific criteria. This version counts the elements that are equal to the given *value*.

The comparisons in the parallel *count* algorithm invoked with an execution policy object of type *sequenced_policy* execute in sequential order in the calling thread.

Note: Complexity: Performs exactly *last - first* comparisons.

Note: The comparisons in the parallel *count* algorithm invoked with an execution policy object of type *parallel_policy* or *parallel_task_policy* are permitted to execute in an unordered fashion in unspecified threads, and indeterminately sequenced within each thread.

Template Parameters

- **ExPolicy** – The type of the execution policy to use (deduced). It describes the manner in which the execution of the algorithm may be parallelized and the manner in which it executes the comparisons.
- **Rng** – The type of the source range used (deduced). The iterators extracted from this range type must meet the requirements of an input iterator.
- **T** – The type of the value to search for (deduced).
- **Proj** – The type of an optional projection function. This defaults to *hpx::identity*

Parameters

⁶⁴⁰ <http://github.com/STELLAR-GROUP/hpx/blob/8a3b7c1a4cb5693b2f7d9f587f759392ed0c51a0/libs/full/include/include/hpx/algorithm.hpp>

- **policy** – The execution policy to use for the scheduling of the iterations.
- **rng** – Refers to the sequence of elements the algorithm will be applied to.
- **value** – The value to search for.
- **proj** – Specifies the function (or function object) which will be invoked for each of the elements as a projection operation before the actual predicate *is* invoked.

Returns The *count* algorithm returns a `hpx::future<difference_type>` if the execution policy is of type `sequenced_task_policy` or `parallel_task_policy` and returns `difference_type` otherwise (where `difference_type` is defined by `std::iterator_traits<FwdIter>::difference_type`). The *count* algorithm returns the number of elements satisfying the given criteria.

```
template<typename ExPolicy, typename Iter, typename Sent, typename Proj = hpx::identity,
typename T = typename hpx::parallel::traits::projected<Iter, Proj>::value_type>
hpx::parallel::util::detail::algorithm_result<ExPolicy, typename std::iterator_traits<Iter>::difference_type>::type count (Ex
```

Returns the number of elements in the range [first, last) satisfying a specific criteria. This version counts the elements that are equal to the given *value*.

The comparisons in the parallel *count* algorithm invoked with an execution policy object of type *sequenced_policy* execute in sequential order in the calling thread.

Note: Complexity: Performs exactly *last - first* comparisons.

Note: The comparisons in the parallel *count* algorithm invoked with an execution policy object of type *parallel_policy* or *parallel_task_policy* are permitted to execute in an unordered fashion in unspecified threads, and indeterminately sequenced within each thread.

Template Parameters

- **ExPolicy** – The type of the execution policy to use (deduced). It describes the manner in which the execution of the algorithm may be parallelized and the manner in which it executes the comparisons.
- **Iter** – The type of the source iterators used for the range (deduced).
- **Sent** – The type of the source sentinel (deduced). This sentinel type must be a sentinel for `InIter`.
- **T** – The type of the value to search for (deduced).
- **Proj** – The type of an optional projection function. This defaults to `hpx::identity`

Parameters

- **policy** – The execution policy to use for the scheduling of the iterations.
- **first** – Refers to the beginning of the sequence of elements the algorithm will be applied to.

- **last** – Refers to the end of the sequence of elements the algorithm will be applied to.
- **value** – The value to search for.
- **proj** – Specifies the function (or function object) which will be invoked for each of the elements as a projection operation before the actual predicate *is* invoked.

Returns The *count* algorithm returns a *hpx::future<difference_type>* if the execution policy is of type *sequenced_task_policy* or *parallel_task_policy* and returns *difference_type* otherwise (where *difference_type* is defined by *std::iterator_traits<FwdIter>::difference_type*). The *count* algorithm returns the number of elements satisfying the given criteria.

```
template<typename Rng, typename Proj = hpx::identity, typename T = typename
hpx::parallel::traits::projected<hpx::traits::range_iterator_t<Rng>, Proj>::value_type>
std::iterator_traits<typename hpx::traits::range_traits<Rng>::iterator_type>::difference_type count(Rng
&&rng,
T
const
&value,
Proj
&&proj
=
Proj())
```

Returns the number of elements in the range [first, last) satisfying a specific criteria. This version counts the elements that are equal to the given *value*.

Note: Complexity: Performs exactly *last - first* comparisons.

Template Parameters

- **Rng** – The type of the source range used (deduced). The iterators extracted from this range type must meet the requirements of an input iterator.
- **T** – The type of the value to search for (deduced).
- **Proj** – The type of an optional projection function. This defaults to *hpx::identity*

Parameters

- **rng** – Refers to the sequence of elements the algorithm will be applied to.
- **value** – The value to search for.
- **proj** – Specifies the function (or function object) which will be invoked for each of the elements as a projection operation before the actual predicate *is* invoked.

Returns The *count* algorithm returns the number of elements satisfying the given criteria.

```
template<typename Iter, typename Sent, typename Proj = hpx::identity, typename T = typename
hpx::parallel::traits::projected<Iter, Proj>::value_type>
std::iterator_traits<Iter>::difference_type count(Iter first, Sent last, T const &value, Proj &&proj =
Proj())
```

Returns the number of elements in the range [first, last) satisfying a specific criteria. This version counts the elements that are equal to the given *value*.

Note: Complexity: Performs exactly *last - first* comparisons.

Template Parameters

- **Iter** – The type of the source iterators used for the range (deduced).
- **Sent** – The type of the source sentinel (deduced). This sentinel type must be a sentinel for *InIter*.
- **T** – The type of the value to search for (deduced).
- **Proj** – The type of an optional projection function. This defaults to *hpx::identity*

Parameters

- **first** – Refers to the beginning of the sequence of elements the algorithm will be applied to.
- **last** – Refers to the end of the sequence of elements the algorithm will be applied to.
- **value** – The value to search for.
- **proj** – Specifies the function (or function object) which will be invoked for each of the elements as a projection operation before the actual predicate *is* invoked.

Returns The *count* algorithm returns the number of elements satisfying the given criteria.

```
template<typename ExPolicy, typename Rng, typename F, typename Proj = hpx::identity>  
hpx::parallel::util::detail::algorithm_result<ExPolicy, typename std::iterator_traits<typename hpx::traits::range_traits<Rng
```

Returns the number of elements in the range [first, last) satisfying a specific criteria. This version counts elements for which predicate *f* returns true.

Note: Complexity: Performs exactly *last - first* applications of the predicate.

Note: The assignments in the parallel *count_if* algorithm invoked with an execution policy object of type *sequenced_policy* execute in sequential order in the calling thread.

Note: The assignments in the parallel *count_if* algorithm invoked with an execution policy object of type *parallel_policy* or *parallel_task_policy* are permitted to execute in an unordered fashion in unspecified threads, and indeterminately sequenced within each thread.

Template Parameters

- **ExPolicy** – The type of the execution policy to use (deduced). It describes the manner in which the execution of the algorithm may be parallelized and the manner in which it executes the comparisons.
- **Rng** – The type of the source range used (deduced). The iterators extracted from this range type must meet the requirements of an input iterator.
- **F** – The type of the function/function object to use (deduced). Unlike its sequential form, the parallel overload of *count_if* requires *F* to meet the requirements of *Copy-Constructible*.
- **Proj** – The type of an optional projection function. This defaults to *hpx::identity*

Parameters

- **policy** – The execution policy to use for the scheduling of the iterations.
- **rng** – Refers to the sequence of elements the algorithm will be applied to.
- **f** – Specifies the function (or function object) which will be invoked for each of the elements in the sequence specified by [first, last). This is a unary predicate which returns *true* for the required elements. The signature of this predicate should be equivalent to:

```
bool pred(const Type &a);
```

The signature does not need to have `const&`, but the function must not modify the objects passed to it. The type *Type* must be such that an object of type *FwdIter* can be dereferenced and then implicitly converted to *Type*.

- **proj** – Specifies the function (or function object) which will be invoked for each of the elements as a projection operation before the actual predicate *is* invoked.

Returns The *count_if* algorithm returns *hpx::future<difference_type>* if the execution policy is of type *sequenced_task_policy* or *parallel_task_policy* and returns *difference_type* otherwise (where *difference_type* is defined by *std::iterator_traits<FwdIter>::difference_type*). The *count* algorithm returns the number of elements satisfying the given criteria.

```
template<typename ExPolicy, typename Iter, typename Sent, typename F, typename Proj =
hpx::identity>
hpx::parallel::util::detail::algorithm_result<ExPolicy, typename std::iterator_traits<Iter>::difference_type>::type count_if
```

Returns the number of elements in the range [first, last) satisfying a specific criteria. This version counts elements for which predicate *f* returns true.

Note: Complexity: Performs exactly *last - first* applications of the predicate.

Note: The assignments in the parallel *count_if* algorithm invoked with an execution policy object of type *sequenced_policy* execute in sequential order in the calling thread.

Note: The assignments in the parallel *count_if* algorithm invoked with an execution policy object of type *parallel_policy* or *parallel_task_policy* are permitted to execute in an unordered fashion in unspecified threads, and indeterminately sequenced within each thread.

Template Parameters

- **ExPolicy** – The type of the execution policy to use (deduced). It describes the manner in which the execution of the algorithm may be parallelized and the manner in which it executes the comparisons.
- **Iter** – The type of the source iterators used for the range (deduced).
- **Sent** – The type of the source sentinel (deduced). This sentinel type must be a sentinel for *Iter*.
- **F** – The type of the function/function object to use (deduced). Unlike its sequential form, the parallel overload of *count_if* requires *F* to meet the requirements of *Copy-*

Constructible.

- **Proj** – The type of an optional projection function. This defaults to `hpx::identity`

Parameters

- **policy** – The execution policy to use for the scheduling of the iterations.
- **first** – Refers to the beginning of the sequence of elements the algorithm will be applied to.
- **last** – Refers to the end of the sequence of elements the algorithm will be applied to.
- **f** – Specifies the function (or function object) which will be invoked for each of the elements in the sequence specified by [first, last). This is an unary predicate which returns *true* for the required elements. The signature of this predicate should be equivalent to:

```
bool pred(const Type &a);
```

The signature does not need to have `const&`, but the function must not modify the objects passed to it. The type *Type* must be such that an object of type *FwdIter* can be dereferenced and then implicitly converted to *Type*.

- **proj** – Specifies the function (or function object) which will be invoked for each of the elements as a projection operation before the actual predicate *is* invoked.

Returns The *count_if* algorithm returns `hpx::future<difference_type>` if the execution policy is of type *sequenced_task_policy* or *parallel_task_policy* and returns *difference_type* otherwise (where *difference_type* is defined by `std::iterator_traits<FwdIter>::difference_type`. The *count* algorithm returns the number of elements satisfying the given criteria.

```
template<typename Rng, typename F, typename Proj = hpx::identity>
std::iterator_traits<typename hpx::traits::range_traits<Rng>::iterator_type>::difference_type count_if(Rng
&&rng,
F
&&f,
Proj
&&proj
=
Proj())
```

Returns the number of elements in the range [first, last) satisfying a specific criteria. This version counts elements for which predicate *f* returns true.

Note: Complexity: Performs exactly *last - first* applications of the predicate.

Template Parameters

- **Rng** – The type of the source range used (deduced). The iterators extracted from this range type must meet the requirements of an input iterator.
- **F** – The type of the function/function object to use (deduced). Unlike its sequential form, the parallel overload of *count_if* requires *F* to meet the requirements of *Copy-Constructible*.
- **Proj** – The type of an optional projection function. This defaults to `hpx::identity`

Parameters

- **rng** – Refers to the sequence of elements the algorithm will be applied to.
- **f** – Specifies the function (or function object) which will be invoked for each of the elements in the sequence specified by [first, last). This is an unary predicate which returns *true* for the required elements. The signature of this predicate should be equivalent to:

```
bool pred(const Type &a);
```

The signature does not need to have `const&`, but the function must not modify the ob-

jects passed to it. The type *Type* must be such that an object of type *FwdIter* can be dereferenced and then implicitly converted to *Type*.

- **proj** – Specifies the function (or function object) which will be invoked for each of the elements as a projection operation before the actual predicate *is* invoked.

Returns The *count* algorithm returns the number of elements satisfying the given criteria.

```
template<typename Iter, typename Sent, typename F, typename Proj = hpx::identity>
std::iterator_traits<Iter>::difference_type count_if(Iter first, Sent last, F &&f, Proj &&proj = Proj())
```

Returns the number of elements in the range [first, last) satisfying a specific criteria. This version counts elements for which predicate *f* returns true.

Note: Complexity: Performs exactly *last - first* applications of the predicate.

Template Parameters

- **Iter** – The type of the source iterators used for the range (deduced).
- **Sent** – The type of the source sentinel (deduced). This sentinel type must be a sentinel for *InIter*.
- **F** – The type of the function/function object to use (deduced). Unlike its sequential form, the parallel overload of *count_if* requires *F* to meet the requirements of *CopyConstructible*.
- **Proj** – The type of an optional projection function. This defaults to *hpx::identity*

Parameters

- **first** – Refers to the beginning of the sequence of elements the algorithm will be applied to.
- **last** – Refers to the end of the sequence of elements the algorithm will be applied to.
- **f** – Specifies the function (or function object) which will be invoked for each of the elements in the sequence specified by [first, last). This is an unary predicate which returns *true* for the required elements. The signature of this predicate should be equivalent to:

```
bool pred(const Type &a);
```

The signature does not need to have *const&*, but the function must not modify the objects passed to it. The type *Type* must be such that an object of type *FwdIter* can be dereferenced and then implicitly converted to *Type*.

- **proj** – Specifies the function (or function object) which will be invoked for each of the elements as a projection operation before the actual predicate *is* invoked.

Returns The *count* algorithm returns the number of elements satisfying the given criteria.

hpx::ranges::destroy, hpx::ranges::destroy_n

Defined in header `hpx/algorithm.hpp`⁶⁴¹.

See *Public API* for a list of names and headers that are part of the public *HPX* API.

```
namespace hpx
```

```
    namespace ranges
```

⁶⁴¹ <http://github.com/STELLAR-GROUP/hpx/blob/8a3b7c1a4cb5693b2f7d9f587f759392ed0c51a0/libs/full/include/include/hpx/algorithm.hpp>

Functions

```
template<typename ExPolicy, typename Rng>
hpx::parallel::util::detail::algorithm_result<ExPolicy, hpx::traits::range_iterator_t<Rng>> destroy(ExPolicy
&&pol-
icy,
Rng
&&rng)
```

Destroys objects of type `typename iterator_traits<ForwardIt>::value_type` in the range `[first, last)`.

The operations in the parallel *destroy* algorithm invoked with an execution policy object of type *sequenced_policy* execute in sequential order in the calling thread.

The operations in the parallel *destroy* algorithm invoked with an execution policy object of type *parallel_policy* or *parallel_task_policy* are permitted to execute in an unordered fashion in unspecified threads, and indeterminately sequenced within each thread.

Note: Complexity: Performs exactly *last - first* operations.

Template Parameters

- **ExPolicy** – The type of the execution policy to use (deduced). It describes the manner in which the execution of the algorithm may be parallelized and the manner in which it executes the assignments.
- **Rng** – The type of the source range used (deduced). The iterators extracted from this range type must meet the requirements of an input iterator.

Parameters

- **policy** – The execution policy to use for the scheduling of the iterations.
- **rng** – Refers to the sequence of elements the algorithm will be applied to.

Returns The *destroy* algorithm returns a `hpx::future<void>`, if the execution policy is of type *sequenced_task_policy* or *parallel_task_policy* and returns *void* otherwise.

```
template<typename ExPolicy, typename Iter, typename Sent>
hpx::parallel::util::detail::algorithm_result_t<ExPolicy, Iter> destroy(ExPolicy &&policy, Iter first,
Sent last)
```

Destroys objects of type `typename iterator_traits<ForwardIt>::value_type` in the range `[first, last)`.

The operations in the parallel *destroy* algorithm invoked with an execution policy object of type *sequenced_policy* execute in sequential order in the calling thread.

The operations in the parallel *destroy* algorithm invoked with an execution policy object of type *parallel_policy* or *parallel_task_policy* are permitted to execute in an unordered fashion in unspecified threads, and indeterminately sequenced within each thread.

Note: Complexity: Performs exactly *last - first* operations.

Template Parameters

- **ExPolicy** – The type of the execution policy to use (deduced). It describes the manner in which the execution of the algorithm may be parallelized and the manner in which it executes the assignments.
- **Iter** – The type of the source iterators used for the range (deduced).

- **Sent** – The type of the source sentinel (deduced). This sentinel type must be a sentinel for `InIter`.

Parameters

- **policy** – The execution policy to use for the scheduling of the iterations.
- **first** – Refers to the beginning of the sequence of elements the algorithm will be applied to.
- **last** – Refers to the end of the sequence of elements the algorithm will be applied to.

Returns The *destroy* algorithm returns a `hpx::future<void>`, if the execution policy is of type `sequenced_task_policy` or `parallel_task_policy` and returns `void` otherwise.

```
template<typename Rng>
```

```
hpx::traits::range_iterator<Rng>::type destroy(Rng &&rng)
```

Destroys objects of type `typename iterator_traits<ForwardIt>::value_type` in the range [first, last).

Note: Complexity: Performs exactly *last - first* operations.

Template Parameters **Rng** – The type of the source range used (deduced). The iterators extracted from this range type must meet the requirements of an input iterator.

Parameters **rng** – Refers to the sequence of elements the algorithm will be applied to.

Returns The *destroy* algorithm returns `void`.

```
template<typename Iter, typename Sent>
```

```
Iter destroy(Iter first, Sent last)
```

Destroys objects of type `typename iterator_traits<ForwardIt>::value_type` in the range [first, last).

Note: Complexity: Performs exactly *last - first* operations.

Template Parameters

- **Iter** – The type of the source iterators used for the range (deduced).
- **Sent** – The type of the source sentinel (deduced). This sentinel type must be a sentinel for `InIter`.

Parameters

- **first** – Refers to the beginning of the sequence of elements the algorithm will be applied to.
- **last** – Refers to the end of the sequence of elements the algorithm will be applied to.

Returns The *destroy* algorithm returns `void`.

```
template<typename ExPolicy, typename FwdIter, typename Size>
```

```
hpx::parallel::util::detail::algorithm_result<ExPolicy, FwdIter>::type destroy_n(ExPolicy &&policy,  
FwdIter first, Size  
count)
```

Destroys objects of type `typename iterator_traits<ForwardIt>::value_type` in the range [first, first + count).

The operations in the parallel *destroy_n* algorithm invoked with an execution policy object of type `sequenced_policy` execute in sequential order in the calling thread.

The operations in the parallel *destroy_n* algorithm invoked with an execution policy object of type `parallel_policy` or `parallel_task_policy` are permitted to execute in an unordered fashion in unspecified threads, and indeterminately sequenced within each thread.

Note: Complexity: Performs exactly *count* operations, if *count* > 0, no assignments otherwise.

Template Parameters

- **ExPolicy** – The type of the execution policy to use (deduced). It describes the manner in which the execution of the algorithm may be parallelized and the manner in which it executes the assignments.
- **FwdIter** – The type of the source iterators used (deduced). This iterator type must meet the requirements of an forward iterator.
- **Size** – The type of the argument specifying the number of elements to apply this algorithm to.

Parameters

- **policy** – The execution policy to use for the scheduling of the iterations.
- **first** – Refers to the beginning of the sequence of elements the algorithm will be applied to.
- **count** – Refers to the number of elements starting at *first* the algorithm will be applied to.

Returns The *destroy_n* algorithm returns a *hpx::future<FwdIter>* if the execution policy is of type *sequenced_task_policy* or *parallel_task_policy* and returns *FwdIter* otherwise. The *destroy_n* algorithm returns the iterator to the element in the source range, one past the last element constructed.

```
template<typename FwdIter, typename Size>  
FwdIter destroy_n(FwdIter first, Size count)
```

Destroys objects of type `typename iterator_traits<ForwardIt>::value_type` in the range `[first, first + count)`.

Note: Complexity: Performs exactly *count* operations, if *count* > 0, no assignments otherwise.

Template Parameters

- **FwdIter** – The type of the source iterators used (deduced). This iterator type must meet the requirements of an forward iterator.
- **Size** – The type of the argument specifying the number of elements to apply this algorithm to.

Parameters

- **first** – Refers to the beginning of the sequence of elements the algorithm will be applied to.
- **count** – Refers to the number of elements starting at *first* the algorithm will be applied to.

Returns The *destroy_n* algorithm returns the iterator to the element in the source range, one past the last element constructed.

hpx::ranges::ends_with

Defined in header `hpx/algorithm.hpp`⁶⁴².

See *Public API* for a list of names and headers that are part of the public *HPX* API.

namespace **hpx**

⁶⁴² <http://github.com/STELLAR-GROUP/hpx/blob/8a3b7c1a4cb5693b2f7d9f587f759392ed0c51a0/libs/full/include/include/hpx/algorithm.hpp>

namespace **ranges**

Functions

```
template<typename Iter1, typename Sent1, typename Iter2, typename Sent2, typename Pred =
ranges::equal_to, typename Proj1 = hpx::identity, typename Proj2 = hpx::identity>
bool ends_with(Iter1 first1, Sent1 last1, Iter2 first2, Sent2 last2, Pred &&pred = Pred(), Proj1 &&proj1
= Proj1(), Proj2 &&proj2 = Proj2())
```

Checks whether the second range defined by [first1, last1) matches the suffix of the first range defined by [first2, last2)

The assignments in the parallel *ends_with* algorithm invoked without an execution policy object execute in sequential order in the calling thread.

Note: Complexity: Linear: at most min(N1, N2) applications of the predicate and both projections.

Template Parameters

- **Iter1** – The type of the begin source iterators used (deduced). This iterator type must meet the requirements of an input iterator.
- **Sent1** – The type of the end source iterators used (deduced). This iterator type must meet the requirements of an sentinel for *Iter1*.
- **Iter2** – The type of the begin destination iterators used (deduced). This iterator type must meet the requirements of an input iterator.
- **Sent2** – The type of the end destination iterators used (deduced). This iterator type must meet the requirements of an sentinel for *Iter2*.
- **Pred** – The binary predicate that compares the projected elements.
- **Proj1** – The type of an optional projection function for the source range. This defaults to *hpx::identity*
- **Proj2** – The type of an optional projection function for the destination range. This defaults to *hpx::identity*

Parameters

- **first1** – Refers to the beginning of the source range.
- **last1** – Sentinel value referring to the end of the source range.
- **first2** – Refers to the beginning of the destination range.
- **last2** – Sentinel value referring to the end of the destination range.
- **pred** – Specifies the binary predicate function (or function object) which will be invoked for comparison of the elements in the in two ranges projected by *proj1* and *proj2* respectively.
- **proj1** – Specifies the function (or function object) which will be invoked for each of the elements in the source range as a projection operation before the actual predicate *is* invoked.
- **proj2** – Specifies the function (or function object) which will be invoked for each of the elements in the destination range as a projection operation before the actual predicate *is* invoked.

Returns The *ends_with* algorithm returns *bool*. The *ends_with* algorithm returns a boolean with the value true if the second range matches the suffix of the first range, false otherwise.

```
template<typename ExPolicy, typename FwdIter1, typename Sent1, typename FwdIter2, typename
Sent2, typename Pred = ranges::equal_to, typename Proj1 = hpx::identity, typename Proj2 =
hpx::identity>
```

```

parallel::util::detail::algorithm_result<ExPolicy, bool>::type ends_with(ExPolicy &&policy, FwdIter1
                                                                    first1, Sent1 last1, FwdIter2
                                                                    first2, Sent2 last2, Pred
                                                                    &&pred = Pred(), Proj1
                                                                    &&proj1 = Proj1(), Proj2
                                                                    &&proj2 = Proj2())

```

Checks whether the second range defined by [first1, last1) matches the suffix of the first range defined by [first2, last2)

The assignments in the parallel *ends_with* algorithm invoked with an execution policy object of type *sequenced_policy* execute in sequential order in the calling thread.

The assignments in the parallel *ends_with* algorithm invoked with an execution policy object of type *parallel_policy* or *parallel_task_policy* are permitted to execute in an unordered fashion in unspecified threads, and indeterminately sequenced within each thread.

Note: Complexity: Linear: at most min(N1, N2) applications of the predicate and both projections.

Template Parameters

- **ExPolicy** – The type of the execution policy to use (deduced). It describes the manner in which the execution of the algorithm may be parallelized and the manner in which it executes the assignments.
- **FwdIter1** – The type of the begin source iterators used (deduced). This iterator type must meet the requirements of an forward iterator.
- **Sent1** – The type of the end source iterators used (deduced). This iterator type must meet the requirements of an sentinel for Iter1.
- **FwdIter2** – The type of the begin destination iterators used (deduced). This iterator type must meet the requirements of a forward iterator.
- **Sent2** – The type of the end destination iterators used (deduced). This iterator type must meet the requirements of an sentinel for Iter2.
- **Pred** – The binary predicate that compares the projected elements.
- **Proj1** – The type of an optional projection function for the source range. This defaults to *hpx::identity*
- **Proj2** – The type of an optional projection function for the destination range. This defaults to *hpx::identity*

Parameters

- **policy** – The execution policy to use for the scheduling of the iterations.
- **first1** – Refers to the beginning of the source range.
- **last1** – Sentinel value referring to the end of the source range.
- **first2** – Refers to the beginning of the destination range.
- **last2** – Sentinel value referring to the end of the destination range.
- **pred** – Specifies the binary predicate function (or function object) which will be invoked for comparison of the elements in the in two ranges projected by proj1 and proj2 respectively.
- **proj1** – Specifies the function (or function object) which will be invoked for each of the elements in the source range as a projection operation before the actual predicate is invoked.
- **proj2** – Specifies the function (or function object) which will be invoked for each of the elements in the destination range as a projection operation before the actual predicate is invoked.

Returns The *ends_with* algorithm returns a *hpx::future<bool>* if the execution policy is of type *sequenced_task_policy* or *parallel_task_policy* and returns *bool* otherwise. The

ends_with algorithm returns a boolean with the value true if the second range matches the suffix of the first range, false otherwise.

```
template<typename Rng1, typename Rng2, typename Pred = ranges::equal_to, typename Proj1 =
hpx::identity, typename Proj2 = hpx::identity>
bool ends_with(Rng1 &&rng1, Rng2 &&rng2, Pred &&pred = Pred(), Proj1 &&proj1 = Proj1(),
Proj2 &&proj2 = Proj2())
```

Checks whether the second range *rng2* matches the suffix of the first range *rng1*.

The assignments in the parallel *ends_with* algorithm invoked without an execution policy object execute in sequential order in the calling thread.

Note: Complexity: Linear: at most min(N1, N2) applications of the predicate and both projections.

Template Parameters

- **Rng1** – The type of the source range used (deduced). The iterators extracted from this range type must meet the requirements of an forward iterator.
- **Rng2** – The type of the destination range used (deduced). The iterators extracted from this range type must meet the requirements of an forward iterator.
- **Pred** – The binary predicate that compares the projected elements.
- **Proj1** – The type of an optional projection function for the source range. This defaults to *hpx::identity*
- **Proj2** – The type of an optional projection function for the destination range. This defaults to *hpx::identity*

Parameters

- **rng1** – Refers to the source range.
- **rng2** – Refers to the destination range.
- **pred** – Specifies the binary predicate function (or function object) which will be invoked for comparison of the elements in the in two ranges projected by proj1 and proj2 respectively.
- **proj1** – Specifies the function (or function object) which will be invoked for each of the elements in the source range as a projection operation before the actual predicate *is* invoked.
- **proj2** – Specifies the function (or function object) which will be invoked for each of the elements in the destination range as a projection operation before the actual predicate *is* invoked.

Returns The *ends_with* algorithm returns *bool*. The *ends_with* algorithm returns a boolean with the value true if the second range matches the suffix of the first range, false otherwise.

```
template<typename ExPolicy, typename Rng1, typename Rng2, typename Pred = ranges::equal_to,
typename Proj1 = hpx::identity, typename Proj2 = hpx::identity>
hpx::parallel::util::detail::algorithm_result<ExPolicy, bool>::type ends_with(ExPolicy &&policy, Rng1
&&rng1, Rng2 &&rng2,
Pred &&pred = Pred(),
Proj1 &&proj1 = Proj1(),
Proj2 &&proj2 =
Proj2())
```

Checks whether the second range *rng2* matches the suffix of the first range *rng1*.

The assignments in the parallel *ends_with* algorithm invoked with an execution policy object of type *sequenced_policy* execute in sequential order in the calling thread.

The assignments in the parallel *ends_with* algorithm invoked with an execution policy object of type *parallel_policy* or *parallel_task_policy* are permitted to execute in an unordered fashion in unspecified threads, and indeterminately sequenced within each thread.

Note: Complexity: Linear: at most $\min(N1, N2)$ applications of the predicate and both projections.

Template Parameters

- **ExPolicy** – The type of the execution policy to use (deduced). It describes the manner in which the execution of the algorithm may be parallelized and the manner in which it executes the assignments.
- **Rng1** – The type of the source range used (deduced). The iterators extracted from this range type must meet the requirements of an forward iterator.
- **Rng2** – The type of the destination range used (deduced). The iterators extracted from this range type must meet the requirements of an forward iterator.
- **Pred** – The binary predicate that compares the projected elements.
- **Proj1** – The type of an optional projection function for the source range. This defaults to *hpx::identity*
- **Proj2** – The type of an optional projection function for the destination range. This defaults to *hpx::identity*

Parameters

- **policy** – The execution policy to use for the scheduling of the iterations.
- **rng1** – Refers to the source range.
- **rng2** – Refers to the destination range.
- **pred** – Specifies the binary predicate function (or function object) which will be invoked for comparison of the elements in the in two ranges projected by proj1 and proj2 respectively.
- **proj1** – Specifies the function (or function object) which will be invoked for each of the elements in the source range as a projection operation before the actual predicate *is* invoked.
- **proj2** – Specifies the function (or function object) which will be invoked for each of the elements in the destination range as a projection operation before the actual predicate *is* invoked.

Returns The *ends_with* algorithm returns a *hpx::future<bool>* if the execution policy is of type *sequenced_task_policy* or *parallel_task_policy* and returns *bool* otherwise. The *ends_with* algorithm returns a boolean with the value true if the second range matches the suffix of the first range, false otherwise.

hpx::ranges::equal

Defined in header [hpx/algorithm.hpp](#)⁶⁴³.

See *Public API* for a list of names and headers that are part of the public *HPX* API.

```
namespace hpx
```

```
    namespace ranges
```

⁶⁴³ <http://github.com/STELLAR-GROUP/hpx/blob/8a3b7c1a4cb5693b2f7d9f587f759392ed0c51a0/libs/full/include/include/hpx/algorithm.hpp>

Functions

```
template<typename ExPolicy, typename Iter1, typename Sent1, typename Iter2, typename Sent2,
typename Pred = equal_to, typename Proj1 = hpx::identity, typename Proj2 = hpx::identity>
hpx::parallel::util::detail::algorithm_result_t<ExPolicy, bool> equal (ExPolicy &&policy, Iter1 first1,
                                                                    Sent1 last1, Iter2 first2, Sent2
                                                                    last2, Pred &&op = Pred(), Proj1
                                                                    &&proj1 = Proj1(), Proj2
                                                                    &&proj2 = Proj2())
```

Returns true if the range [first1, last1) is equal to the range [first2, last2), and false otherwise.

The comparison operations in the parallel *equal* algorithm invoked with an execution policy object of type *sequenced_policy* execute in sequential order in the calling thread.

The comparison operations in the parallel *equal* algorithm invoked with an execution policy object of type *parallel_policy* or *parallel_task_policy* are permitted to execute in an unordered fashion in unspecified threads, and indeterminately sequenced within each thread.

Note: Complexity: At most $\min(\text{last1} - \text{first1}, \text{last2} - \text{first2})$ applications of the predicate *f*.

Note: The two ranges are considered equal if, for every iterator *i* in the range [first1, last1), **i* equals $*(\text{first2} + (i - \text{first1}))$. This overload of *equal* uses operator== to determine if two elements are equal.

Template Parameters

- **ExPolicy** – The type of the execution policy to use (deduced). It describes the manner in which the execution of the algorithm may be parallelized and the manner in which it executes the assignments.
- **Iter1** – The type of the source iterators used for the first range (deduced). This iterator type must meet the requirements of an forward iterator.
- **Sent1** – The type of the source iterators used for the end of the first range (deduced).
- **Iter2** – The type of the source iterators used for the second range (deduced). This iterator type must meet the requirements of an forward iterator.
- **Sent2** – The type of the source iterators used for the end of the second range (deduced).
- **Pred** – The type of an optional function/function object to use. Unlike its sequential form, the parallel overload of *equal* requires *Pred* to meet the requirements of *CopyConstructible*. This defaults to `std::equal_to<>`
- **Proj1** – The type of an optional projection function applied to the first range. This defaults to *hpx::identity*
- **Proj2** – The type of an optional projection function applied to the second range. This defaults to *hpx::identity*

Parameters

- **policy** – The execution policy to use for the scheduling of the iterations.
- **first1** – Refers to the beginning of the sequence of elements of the first range the algorithm will be applied to.
- **last1** – Refers to the end of the sequence of elements of the first range the algorithm will be applied to.
- **first2** – Refers to the beginning of the sequence of elements of the second range the algorithm will be applied to.
- **last2** – Refers to the end of the sequence of elements of the second range the algorithm will be applied to.

- **op** – The binary predicate which returns true if the elements should be treated as equal. The signature of the predicate function should be equivalent to the following:

```
bool pred(const Type1 &a, const Type2 &b);
```

The signature does not need to have `const &`, but the function must not modify the objects passed to it. The types *Type1* and *Type2* must be such that objects of types *FwdIter1* and *FwdIter2* can be dereferenced and then implicitly converted to *Type1* and *Type2* respectively

- **proj1** – Specifies the function (or function object) which will be invoked for each of the elements of the first range as a projection operation before the actual predicate *is* invoked.
- **proj2** – Specifies the function (or function object) which will be invoked for each of the elements of the second range as a projection operation before the actual predicate *is* invoked.

Returns The *equal* algorithm returns a `hpx::future<bool>` if the execution policy is of type *sequenced_task_policy* or *parallel_task_policy* and returns `bool` otherwise. The *equal* algorithm returns true if the elements in the two ranges are equal, otherwise it returns false. If the length of the range [first1, last1) does not equal the length of the range [first2, last2), it returns false.

```
template<typename ExPolicy, typename Rng1, typename Rng2, typename Pred = equal_to, typename
Proj1 = hpx::identity, typename Proj2 = hpx::identity>
hpx::parallel::util::detail::algorithm_result_t<ExPolicy, bool> equal(ExPolicy &&policy, Rng1
&&rng1, Rng2 &&rng2, Pred
&&op = Pred(), Proj1 &&proj1 =
Proj1(), Proj2 &&proj2 = Proj2())
```

Returns true if the range [first1, last1) is equal to the range starting at first2, and false otherwise.

The comparison operations in the parallel *equal* algorithm invoked with an execution policy object of type *sequenced_policy* execute in sequential order in the calling thread.

The comparison operations in the parallel *equal* algorithm invoked with an execution policy object of type *parallel_policy* or *parallel_task_policy* are permitted to execute in an unordered fashion in unspecified threads, and indeterminately sequenced within each thread.

Note: Complexity: At most *last1 - first1* applications of the predicate *f*.

Note: The two ranges are considered equal if, for every iterator *i* in the range [first1,last1), **i* equals **(first2 + (i - first1))*. This overload of *equal* uses operator`==` to determine if two elements are equal.

Template Parameters

- **ExPolicy** – The type of the execution policy to use (deduced). It describes the manner in which the execution of the algorithm may be parallelized and the manner in which it executes the assignments.
- **Rng1** – The type of the first source range used (deduced). The iterators extracted from this range type must meet the requirements of an forward iterator.
- **Rng2** – The type of the second source range used (deduced). The iterators extracted from this range type must meet the requirements of an forward iterator.
- **Pred** – The type of an optional function/function object to use. Unlike its sequential form, the parallel overload of *equal* requires *Pred* to meet the requirements of *CopyConstructible*. This defaults to `std::equal_to<>`

- **Proj1** – The type of an optional projection function applied to the first range. This defaults to `hpx::identity`
- **Proj2** – The type of an optional projection function applied to the second range. This defaults to `hpx::identity`

Parameters

- **policy** – The execution policy to use for the scheduling of the iterations.
- **rng1** – Refers to the first sequence of elements the algorithm will be applied to.
- **rng2** – Refers to the second sequence of elements the algorithm will be applied to.
- **op** – The binary predicate which returns true if the elements should be treated as equal. The signature of the predicate function should be equivalent to the following:

```
bool pred(const Type1 &a, const Type2 &b);
```

The signature does not need to have `const &`, but the function must not modify the objects passed to it. The types `Type1` and `Type2` must be such that objects of types `FwdIter1` and `FwdIter2` can be dereferenced and then implicitly converted to `Type1` and `Type2` respectively

- **proj1** – Specifies the function (or function object) which will be invoked for each of the elements of the first range as a projection operation before the actual predicate `is` is invoked.
- **proj2** – Specifies the function (or function object) which will be invoked for each of the elements of the second range as a projection operation before the actual predicate `is` is invoked.

Returns The `equal` algorithm returns a `hpx::future<bool>` if the execution policy is of type `sequenced_task_policy` or `parallel_task_policy` and returns `bool` otherwise. The `equal` algorithm returns true if the elements in the two ranges are equal, otherwise it returns false.

```
template<typename Iter1, typename Sent1, typename Iter2, typename Sent2, typename Pred =
equal_to, typename Proj1 = hpx::identity, typename Proj2 = hpx::identity>
bool equal(Iter1 first1, Sent1 last1, Iter2 first2, Sent2 last2, Pred &&op = Pred(), Proj1 &&proj1 =
Proj1(), Proj2 &&proj2 = Proj2())
```

Returns true if the range `[first1, last1)` is equal to the range `[first2, last2)`, and false otherwise.

Note: Complexity: At most $\min(\text{last1} - \text{first1}, \text{last2} - \text{first2})$ applications of the predicate `f`.

Note: The two ranges are considered equal if, for every iterator `i` in the range `[first1, last1)`, `*i` equals `*(first2 + (i - first1))`. This overload of `equal` uses operator`==` to determine if two elements are equal.

Template Parameters

- **Iter1** – The type of the source iterators used for the first range (deduced). This iterator type must meet the requirements of an forward iterator.
- **Sent1** – The type of the source iterators used for the end of the first range (deduced).
- **Iter2** – The type of the source iterators used for the second range (deduced). This iterator type must meet the requirements of an forward iterator.
- **Sent2** – The type of the source iterators used for the end of the second range (deduced).
- **Pred** – The type of an optional function/function object to use. Unlike its sequential form, the parallel overload of `equal` requires `Pred` to meet the requirements of `CopyConstructible`. This defaults to `std::equal_to<>`
- **Proj1** – The type of an optional projection function applied to the first range. This defaults to `hpx::identity`
- **Proj2** – The type of an optional projection function applied to the second range. This defaults to `hpx::identity`

Parameters

- **first1** – Refers to the beginning of the sequence of elements of the first range the algorithm will be applied to.
- **last1** – Refers to the end of the sequence of elements of the first range the algorithm will be applied to.
- **first2** – Refers to the beginning of the sequence of elements of the second range the algorithm will be applied to.
- **last2** – Refers to the end of the sequence of elements of the second range the algorithm will be applied to.
- **op** – The binary predicate which returns true if the elements should be treated as equal. The signature of the predicate function should be equivalent to the following:

```
bool pred(const Type1 &a, const Type2 &b);
```

The signature does not need to have `const &`, but the function must not modify the objects passed to it. The types *Type1* and *Type2* must be such that objects of types *FwdIter1* and *FwdIter2* can be dereferenced and then implicitly converted to *Type1* and *Type2* respectively

- **proj1** – Specifies the function (or function object) which will be invoked for each of the elements of the first range as a projection operation before the actual predicate *is* invoked.
- **proj2** – Specifies the function (or function object) which will be invoked for each of the elements of the second range as a projection operation before the actual predicate *is* invoked.

Returns The *equal* algorithm returns true if the elements in the two ranges are equal, otherwise it returns false. If the length of the range [first1, last1) does not equal the length of the range [first2, last2), it returns false.

```
template<typename Rng1, typename Rng2, typename Pred = equal_to, typename Proj1 = hpx::identity,
        typename Proj2 = hpx::identity>
bool equal(Rng1 &&rng1, Rng2 &&rng2, Pred &&op = Pred(), Proj1 &&proj1 = Proj1(), Proj2
        &&proj2 = Proj2())
```

Returns true if the range [first1, last1) is equal to the range starting at first2, and false otherwise.

Note: Complexity: At most *last1 - first1* applications of the predicate *f*.

Note: The two ranges are considered equal if, for every iterator *i* in the range [first1,last1), **i* equals **(first2 + (i - first1))*. This overload of *equal* uses operator`==` to determine if two elements are equal.

Template Parameters

- **Rng1** – The type of the first source range used (deduced). The iterators extracted from this range type must meet the requirements of an forward iterator.
- **Rng2** – The type of the second source range used (deduced). The iterators extracted from this range type must meet the requirements of an forward iterator.
- **Pred** – The type of an optional function/function object to use. Unlike its sequential form, the parallel overload of *equal* requires *Pred* to meet the requirements of *CopyConstructible*. This defaults to `std::equal_to<>`
- **Proj1** – The type of an optional projection function applied to the first range. This defaults to `hpx::identity`
- **Proj2** – The type of an optional projection function applied to the second range. This defaults to `hpx::identity`

Parameters

- **rng1** – Refers to the first sequence of elements the algorithm will be applied to.
- **rng2** – Refers to the second sequence of elements the algorithm will be applied to.

- **op** – The binary predicate which returns true if the elements should be treated as equal. The signature of the predicate function should be equivalent to the following:

```
bool pred(const Type1 &a, const Type2 &b);
```

The signature does not need to have `const &`, but the function must not modify the objects passed to it. The types *Type1* and *Type2* must be such that objects of types *FwdIter1* and *FwdIter2* can be dereferenced and then implicitly converted to *Type1* and *Type2* respectively

- **proj1** – Specifies the function (or function object) which will be invoked for each of the elements of the first range as a projection operation before the actual predicate *is* invoked.
- **proj2** – Specifies the function (or function object) which will be invoked for each of the elements of the second range as a projection operation before the actual predicate *is* invoked.

Returns The *equal* algorithm returns true if the elements in the two ranges are equal, otherwise it returns false.

hpx::ranges::exclusive_scan

Defined in header `hpx/algorithm.hpp`⁶⁴⁴.

See *Public API* for a list of names and headers that are part of the public HPX API.

namespace **hpx**

namespace **ranges**

Functions

```
template<typename InIter, typename Sent, typename OutIter, typename T = typename
std::iterator_traits<InIter>::value_type, typename Op = std::plus<T>>
exclusive_scan_result<InIter, OutIter> exclusive_scan(InIter first, Sent last, OutIter dest, T init, Op
&&op = Op())
```

Assigns through each iterator *i* in `[result, result + (last - first))` the value of GENERALIZED_NONCOMMUTATIVE_SUM(binary_op, init, *first, ..., *(first + (i - result) - 1)).

The difference between *exclusive_scan* and *inclusive_scan* is that *inclusive_scan* includes the *i*th input element in the *i*th sum. If *op* is not mathematically associative, the behavior of *inclusive_scan* may be non-deterministic.

Note: Complexity: $O(\text{last} - \text{first})$ applications of the predicate *op*.

Note: GENERALIZED_NONCOMMUTATIVE_SUM(*op*, *a*₁, ..., *a*_N) is defined as:

- *a*₁ when *N* is 1
 - *op*(GENERALIZED_NONCOMMUTATIVE_SUM(*op*, *a*₁, ..., *a*_K), GENERALIZED_NONCOMMUTATIVE_SUM(*op*, *a*_M, ..., *a*_N)) where $1 < K+1 = M \leq N$.
-

⁶⁴⁴ <http://github.com/STELLAR-GROUP/hpx/blob/8a3b7c1a4cb5693b2f7d9f587f759392ed0c51a0/libs/full/include/include/hpx/algorithm.hpp>

Template Parameters

- **FwdIter1** – The type of the source iterators used (deduced). This iterator type must meet the requirements of an forward iterator.
- **Sent** – The type of the source sentinel (deduced). This sentinel type must be a sentinel for FwdIter1.
- **FwdIter2** – The type of the iterator representing the destination range (deduced). This iterator type must meet the requirements of an forward iterator.
- **T** – The type of the value to be used as initial (and intermediate) values (deduced).
- **Op** – The type of the binary function object used for the reduction operation.

Parameters

- **first** – Refers to the beginning of the sequence of elements the algorithm will be applied to.
- **last** – Refers to sentinel value denoting the end of the sequence of elements the algorithm will be applied.
- **dest** – Refers to the beginning of the destination range.
- **init** – The initial value for the generalized sum.
- **op** – Specifies the function (or function object) which will be invoked for each of the values of the input sequence. This is a binary predicate. The signature of this predicate should be equivalent to:

```
Ret fun(const Type1 &a, const Type1 &b);
```

The signature does not need to have const&, but the function must not modify the objects passed to it. The types *Type1* and *Ret* must be such that an object of a type as given by the input sequence can be implicitly converted to any of those types.

Returns The *exclusive_scan* algorithm returns an input iterator to the point denoted by the sentinel and an output iterator to the element in the destination range, one past the last element copied.

```
template<typename ExPolicy, typename FwdIter1, typename Sent, typename FwdIter2, typename T
= typename std::iterator_traits<FwdIter1>::value_type, typename Op = std::plus<T>>
parallel::util::detail::algorithm_result<ExPolicy, exclusive_scan_result<FwdIter1, FwdIter2>>::type exclusive_scan(Ex
```

Assigns through each iterator *i* in [result, result + (last - first)) the value of GENERALIZED_NONCOMMUTATIVE_SUM(binary_op, init, *first, ..., *(first + (i - result) - 1)).

The reduce operations in the parallel *exclusive_scan* algorithm invoked with an execution policy object of type *sequenced_policy* execute in sequential order in the calling thread.

The reduce operations in the parallel *exclusive_scan* algorithm invoked with an execution policy object of type *parallel_policy* or *parallel_task_policy* are permitted to execute in an unordered fashion in

unspecified threads, and indeterminately sequenced within each thread.

The difference between *exclusive_scan* and *inclusive_scan* is that *inclusive_scan* includes the *i*th input element in the *i*th sum. If *op* is not mathematically associative, the behavior of *inclusive_scan* may be non-deterministic.

Note: Complexity: $O(\text{last} - \text{first})$ applications of the predicate *op*.

Note: GENERALIZED_NONCOMMUTATIVE_SUM(*op*, *a*₁, ..., *a*_N) is defined as:

- *a*₁ when *N* is 1
 - *op*(GENERALIZED_NONCOMMUTATIVE_SUM(*op*, *a*₁, ..., *a*_K), GENERALIZED_NONCOMMUTATIVE_SUM(*op*, *a*_M, ..., *a*_N)) where $1 < K+1 = M \leq N$.
-

Template Parameters

- **ExPolicy** – The type of the execution policy to use (deduced). It describes the manner in which the execution of the algorithm may be parallelized and the manner in which it executes the assignments.
- **FwdIter1** – The type of the source iterators used (deduced). This iterator type must meet the requirements of an forward iterator.
- **Sent** – The type of the source sentinel (deduced). This sentinel type must be a sentinel for *FwdIter1*.
- **FwdIter2** – The type of the iterator representing the destination range (deduced). This iterator type must meet the requirements of an forward iterator.
- **T** – The type of the value to be used as initial (and intermediate) values (deduced).
- **Op** – The type of the binary function object used for the reduction operation.

Parameters

- **policy** – The execution policy to use for the scheduling of the iterations.
- **first** – Refers to the beginning of the sequence of elements the algorithm will be applied to.
- **last** – Refers to sentinel value denoting the end of the sequence of elements the algorithm will be applied.
- **dest** – Refers to the beginning of the destination range.
- **init** – The initial value for the generalized sum.
- **op** – Specifies the function (or function object) which will be invoked for each of the values of the input sequence. This is a binary predicate. The signature of this predicate should be equivalent to:

```
Ret fun(const Type1 &a, const Type1 &b);
```

The signature does not need to have `const&`, but the function must not modify the objects passed to it. The types *Type1* and *Ret* must be such that an object of a type as given by the input sequence can be implicitly converted to any of those types.

Returns The *exclusive_scan* algorithm returns a `hpx::future<util::in_out_result<FwdIter1, FwdIter2>>` if the execution policy is of type *sequenced_task_policy* or *parallel_task_policy* and returns `util::in_out_result<FwdIter1, FwdIter2>` otherwise. The *exclusive_scan* algorithm returns an input iterator to the point denoted by the sentinel and an output iterator to the element in the destination range, one past the last element copied.

```
template<typename Rng, typename O, typename T = typename
std::iterator_traits<hpx::traits::range_iterator_t<Rng>>::value_type, typename Op = std::plus<T>>
exclusive_scan_result<traits::range_iterator_t<Rng>, O> exclusive_scan(Rng &&rng, O dest, T init,
Op &&op = Op())
```

Assigns through each iterator i in $[\text{result}, \text{result} + (\text{last} - \text{first}))$ the value of GENERALIZED_NONCOMMUTATIVE_SUM(+, init, *first, ..., *(first + (i - result) - 1))

The difference between *exclusive_scan* and *inclusive_scan* is that *inclusive_scan* includes the i th input element in the i th sum.

Note: Complexity: $O(\text{last} - \text{first})$ applications of the predicate `std::plus<T>`.

Note: GENERALIZED_NONCOMMUTATIVE_SUM(+, a1, ..., aN) is defined as:

- a1 when N is 1
 - GENERALIZED_NONCOMMUTATIVE_SUM(+, a1, ..., aK)
 - GENERALIZED_NONCOMMUTATIVE_SUM(+, aM, ..., aN) where $1 < K+1 = M \leq N$.
-

Template Parameters

- **Rng** – The type of the source range used (deduced). The iterators extracted from this range type must meet the requirements of an forward iterator.
- **O** – The type of the iterator representing the destination range (deduced). This iterator type must meet the requirements of an forward iterator.
- **T** – The type of the value to be used as initial (and intermediate) values (deduced).
- **Op** – The type of the binary function object used for the reduction operation.

Parameters

- **rng** – Refers to the sequence of elements the algorithm will be applied to.
- **dest** – Refers to the beginning of the destination range.
- **init** – The initial value for the generalized sum.
- **op** – Specifies the function (or function object) which will be invoked for each of the values of the input sequence. This is a binary predicate. The signature of this predicate should be equivalent to:

```
Ret fun(const Type1 &a, const Type1 &b);
```

The signature does not need to have `const&`, but the function must not modify the objects passed to it. The types *Type1* and *Ret* must be such that an object of a type as given by the input sequence can be implicitly converted to any of those types.

Returns The *exclusive_scan* algorithm returns an input iterator to the point denoted by the sentinel and an output iterator to the element in the destination range, one past the last element copied.

```
template<typename ExPolicy, typename Rng, typename O, typename T = typename
std::iterator_traits<hpx::traits::range_iterator_t<Rng>>::value_type, typename Op = std::plus<T>>
```

`parallel::util::detail::algorithm_result<ExPolicy, exclusive_scan_result<traits::range_iterator_t<Rng>, O>> exclusive_sc`

Assigns through each iterator i in $[\text{result}, \text{result} + (\text{last} - \text{first})]$ the value of GENERALIZED_NONCOMMUTATIVE_SUM(+, init, *first, ..., *(first + (i - result) - 1))

The reduce operations in the parallel `exclusive_scan` algorithm invoked with an execution policy object of type `sequenced_policy` execute in sequential order in the calling thread.

The reduce operations in the parallel `exclusive_scan` algorithm invoked with an execution policy object of type `parallel_policy` or `parallel_task_policy` are permitted to execute in an unordered fashion in unspecified threads, and indeterminately sequenced within each thread.

The difference between `exclusive_scan` and `inclusive_scan` is that `inclusive_scan` includes the i th input element in the i th sum.

Note: Complexity: $O(\text{last} - \text{first})$ applications of the predicate `std::plus<T>`.

Note: GENERALIZED_NONCOMMUTATIVE_SUM(+, a1, ..., aN) is defined as:

- a1 when N is 1
 - GENERALIZED_NONCOMMUTATIVE_SUM(+, a1, ..., aK)
 - GENERALIZED_NONCOMMUTATIVE_SUM(+, aM, ..., aN) where $1 < K+1 = M \leq N$.
-

Template Parameters

- **ExPolicy** – The type of the execution policy to use (deduced). It describes the manner in which the execution of the algorithm may be parallelized and the manner in which it executes the assignments.
- **Rng** – The type of the source range used (deduced). The iterators extracted from this range type must meet the requirements of an forward iterator.
- **O** – The type of the iterator representing the destination range (deduced). This iterator type must meet the requirements of an forward iterator.
- **T** – The type of the value to be used as initial (and intermediate) values (deduced).
- **Op** – The type of the binary function object used for the reduction operation.

Parameters

- **policy** – The execution policy to use for the scheduling of the iterations.
- **rng** – Refers to the sequence of elements the algorithm will be applied to.
- **dest** – Refers to the beginning of the destination range.
- **init** – The initial value for the generalized sum.
- **op** – Specifies the function (or function object) which will be invoked for each of the values of the input sequence. This is a binary predicate. The signature of this predicate

should be equivalent to:

```
Ret fun(const Type1 &a, const Type1 &b);
```

The signature does not need to have `const&`, but the function must not modify the objects passed to it. The types *Type1* and *Ret* must be such that an object of a type as given by the input sequence can be implicitly converted to any of those types.

Returns The *exclusive_scan* algorithm returns a *hpx::future<util::in_out_result<traits::range_iterator_t<Rng>, O>>* if the execution policy is of type *sequenced_task_policy* or *parallel_task_policy* and returns *util::in_out_result<traits::range_iterator_t<Rng>, O>* otherwise. The *exclusive_scan* algorithm returns an input iterator to the point denoted by the sentinel and an output iterator to the element in the destination range, one past the last element copied.

hpx::ranges::fill, hpx::ranges::fill_n

Defined in header `hpx/algorithm.hpp`⁶⁴⁵.

See *Public API* for a list of names and headers that are part of the public *HPX* API.

namespace **hpx**

namespace **ranges**

Functions

```
template<typename ExPolicy, typename Rng, typename T = typename  
std::iterator_traits<hpx::traits::range_iterator_t<Rng>>::value_type>  
hpx::parallel::util::detail::algorithm_result<ExPolicy, typename hpx::traits::range_traits<Rng>::iterator_type>::type fill(C
```

Assigns the given value to the elements in the range [first, last).

The comparisons in the parallel *fill* algorithm invoked with an execution policy object of type *sequenced_policy* execute in sequential order in the calling thread.

The comparisons in the parallel *fill* algorithm invoked with an execution policy object of type *parallel_policy* or *parallel_task_policy* are permitted to execute in an unordered fashion in unspecified threads, and indeterminately sequenced within each thread.

Note: Complexity: Performs exactly *last - first* assignments.

Template Parameters

⁶⁴⁵ <http://github.com/STELLAR-GROUP/hpx/blob/8a3b7c1a4cb5693b2f7d9f587f759392ed0c51a0/libs/full/include/include/hpx/algorithm.hpp>

- **ExPolicy** – The type of the execution policy to use (deduced). It describes the manner in which the execution of the algorithm may be parallelized and the manner in which it executes the assignments.
- **Rng** – The type of the source range used (deduced). The iterators extracted from this range type must meet the requirements of an input iterator.
- **T** – The type of the value to be assigned (deduced).

Parameters

- **policy** – The execution policy to use for the scheduling of the iterations.
- **rng** – Refers to the sequence of elements the algorithm will be applied to.
- **value** – The value to be assigned.

Returns The *fill* algorithm returns a *hpx::future<void>* if the execution policy is of type *sequenced_task_policy* or *parallel_task_policy* and returns *difference_type* otherwise (where *difference_type* is defined by *void*).

```
template<typename ExPolicy, typename Iter, typename Sent, typename T = typename
std::iterator_traits<Iter>::value_type>
hpx::parallel::util::detail::algorithm_result<ExPolicy, Iter>::type fill(ExPolicy &&policy, Iter first,
Sent last, T const &value)
```

Assigns the given value to the elements in the range [first, last).

The comparisons in the parallel *fill* algorithm invoked with an execution policy object of type *sequenced_policy* execute in sequential order in the calling thread.

The comparisons in the parallel *fill* algorithm invoked with an execution policy object of type *parallel_policy* or *parallel_task_policy* are permitted to execute in an unordered fashion in unspecified threads, and indeterminately sequenced within each thread.

Note: Complexity: Performs exactly *last - first* assignments.

Template Parameters

- **ExPolicy** – The type of the execution policy to use (deduced). It describes the manner in which the execution of the algorithm may be parallelized and the manner in which it executes the assignments.
- **Iter** – The type of the source iterators used for the range (deduced).
- **Sent** – The type of the source sentinel (deduced). This sentinel type must be a sentinel for *InIter*.
- **T** – The type of the value to be assigned (deduced).

Parameters

- **policy** – The execution policy to use for the scheduling of the iterations.
- **first** – Refers to the beginning of the sequence of elements of the range the algorithm will be applied to.
- **last** – Refers to the end of the sequence of elements of the range the algorithm will be applied to.
- **value** – The value to be assigned.

Returns The *fill* algorithm returns a *hpx::future<void>* if the execution policy is of type *sequenced_task_policy* or *parallel_task_policy* and returns *difference_type* otherwise (where *difference_type* is defined by *void*).

```
template<typename Rng, typename T = typename
std::iterator_traits<hpx::traits::range_iterator_t<Rng>>::value_type>
hpx::traits::range_iterator_t<Rng> fill(Rng &&rng, T const &value)
```

Assigns the given value to the elements in the range [first, last).

Note: Complexity: Performs exactly *last - first* assignments.

Template Parameters

- **Rng** – The type of the source range used (deduced). The iterators extracted from this range type must meet the requirements of an input iterator.
- **T** – The type of the value to be assigned (deduced).

Parameters

- **rng** – Refers to the sequence of elements the algorithm will be applied to.
- **value** – The value to be assigned.

Returns The *fill* algorithm returns *void*.

```
template<typename Iter, typename Sent, typename T = typename
std::iterator_traits<Iter>::value_type>
Iter fill(Iter first, Sent last, T const &value)
```

Assigns the given value to the elements in the range [first, last).

Note: Complexity: Performs exactly *last - first* assignments.

Template Parameters

- **Iter** – The type of the source iterators used for the range (deduced).
- **Sent** – The type of the source sentinel (deduced). This sentinel type must be a sentinel for *InIter*.
- **T** – The type of the value to be assigned (deduced).

Parameters

- **first** – Refers to the beginning of the sequence of elements of the range the algorithm will be applied to.
- **last** – Refers to the end of the sequence of elements of the range the algorithm will be applied to.
- **value** – The value to be assigned.

Returns The *fill* algorithm returns *void*.

```
template<typename ExPolicy, typename Rng, typename T = typename
std::iterator_traits<hpx::traits::range_iterator_t<Rng>>::value_type>
hpx::parallel::util::detail::algorithm_result_t<ExPolicy, hpx::traits::range_iterator_t<Rng>> fill_n(ExPolicy
&&pol-
icy,
Rng
&&rng,
T
const
&value)
```

Assigns the given value value to the first count elements in the range beginning at first if count > 0. Does nothing otherwise.

The comparisons in the parallel *fill_n* algorithm invoked with an execution policy object of type *sequenced_policy* execute in sequential order in the calling thread.

The comparisons in the parallel *fill_n* algorithm invoked with an execution policy object of type *parallel_policy* or *parallel_task_policy* are permitted to execute in an unordered fashion in unspecified threads, and indeterminately sequenced within each thread.

Template Parameters

- **ExPolicy** – The type of the execution policy to use (deduced). It describes the manner in which the execution of the algorithm may be parallelized and the manner in which it executes the assignments.
- **Rng** – The type of the source range used (deduced). The iterators extracted from this range type must meet the requirements of an input iterator.
- **T** – The type of the value to be assigned (deduced).

Parameters

- **policy** – The execution policy to use for the scheduling of the iterations.
- **rng** – Refers to the sequence of elements the algorithm will be applied to.
- **value** – The value to be assigned.

Returns The *fill_n* algorithm returns a *hpx::future<void>* if the execution policy is of type *sequenced_task_policy* or *parallel_task_policy* and returns *difference_type* otherwise (where *difference_type* is defined by *void*).

```
template<typename ExPolicy, typename FwdIter, typename Size, typename T = typename
std::iterator_traits<FwdIter>::value_type>
hpx::parallel::util::detail::algorithm_result<ExPolicy, FwdIter>::type fill_n(ExPolicy &&policy,
FwdIter first, Size count,
T const &value)
```

Assigns the given value value to the first count elements in the range beginning at first if count > 0. Does nothing otherwise.

The comparisons in the parallel *fill_n* algorithm invoked with an execution policy object of type *sequenced_policy* execute in sequential order in the calling thread.

The comparisons in the parallel *fill_n* algorithm invoked with an execution policy object of type *parallel_policy* or *parallel_task_policy* are permitted to execute in an unordered fashion in unspecified threads, and indeterminately sequenced within each thread.

Note: Complexity: Performs exactly *count* assignments, for count > 0.

Template Parameters

- **ExPolicy** – The type of the execution policy to use (deduced). It describes the manner in which the execution of the algorithm may be parallelized and the manner in which it executes the assignments.
- **FwdIter** – The type of the source iterators used for the range (deduced). This iterator type must meet the requirements of an forward iterator.
- **Size** – The type of the argument specifying the number of elements to apply *f* to.
- **T** – The type of the value to be assigned (deduced).

Parameters

- **policy** – The execution policy to use for the scheduling of the iterations.
- **first** – Refers to the beginning of the sequence of elements the algorithm will be applied to.
- **count** – Refers to the number of elements starting at *first* the algorithm will be applied to.
- **value** – The value to be assigned.

Returns The *fill_n* algorithm returns a *hpx::future<void>* if the execution policy is of type *sequenced_task_policy* or *parallel_task_policy* and returns *difference_type* otherwise (where *difference_type* is defined by *void*).

```
template<typename Rng, typename T = typename
std::iterator_traits<hpx::traits::range_iterator_t<Rng>>::value_type>
```

hpx::traits::range_traits<Rng>::iterator_type **fill_n**(*Rng* &&rng, *T* const &value)

Assigns the given value value to the first count elements in the range beginning at first if count > 0. Does nothing otherwise.

Template Parameters

- **Rng** – The type of the source range used (deduced). The iterators extracted from this range type must meet the requirements of an input iterator.
- **T** – The type of the value to be assigned (deduced).

Parameters

- **rng** – Refers to the sequence of elements the algorithm will be applied to.
- **value** – The value to be assigned.

Returns The *fill_n* algorithm returns an output iterator that compares equal to last.

template<typename **FwdIter**, typename **Size**, typename **T** = typename

std::iterator_traits<FwdIter>::value_type>

FwdIter **fill_n**(Iterator first, *Size* count, *T* const &value)

Assigns the given value value to the first count elements in the range beginning at first if count > 0. Does nothing otherwise.

Note: Complexity: Performs exactly *count* assignments, for count > 0.

Template Parameters

- **Iterator** – The type of the source range used (deduced). The iterators extracted from this range type must meet the requirements of an forward iterator.
- **Size** – The type of the argument specifying the number of elements to apply *f* to.
- **T** – The type of the value to be assigned (deduced).

Parameters

- **first** – Refers to the beginning of the sequence of elements the algorithm will be applied to.
- **count** – Refers to the number of elements starting at *first* the algorithm will be applied to.
- **value** – The value to be assigned.

Returns The *fill_n* algorithm returns an output iterator that compares equal to last.

hpx::ranges::find, **hpx::ranges::find_if**, **hpx::ranges::find_if_not**, **hpx::ranges::find_end**,
hpx::ranges::find_first_of

Defined in header [hpx/algorithm.hpp](#)⁶⁴⁶.

See *Public API* for a list of names and headers that are part of the public *HPX* API.

namespace **hpx**

namespace **ranges**

⁶⁴⁶ <http://github.com/STELLAR-GROUP/hpx/blob/8a3b7c1a4cb5693b2f7d9f587f759392ed0c51a0/libs/full/include/include/hpx/algorithm.hpp>

Functions

```
template<typename ExPolicy, typename Iter, typename Sent, typename Proj = hpx::identity,
typename T = typename hpx::parallel::traits::projected<Iter, Proj>::value_type>
hpx::parallel::util::detail::algorithm_result_t<ExPolicy, Iter> find(ExPolicy &&policy, Iter first, Sent
last, T const &val, Proj &&proj =
Proj())
```

Returns the first element in the range [first, last) that is equal to value

The comparison operations in the parallel *find* algorithm invoked with an execution policy object of type *sequenced_policy* execute in sequential order in the calling thread.

The comparison operations in the parallel *find* algorithm invoked with an execution policy object of type *parallel_policy* or *parallel_task_policy* are permitted to execute in an unordered fashion in unspecified threads, and indeterminately sequenced within each thread.

Note: Complexity: At most last - first applications of the operator==().

Template Parameters

- **ExPolicy** – The type of the execution policy to use (deduced). It describes the manner in which the execution of the algorithm may be parallelized and the manner in which it executes the assignments.
- **Iter** – The type of the begin source iterators used (deduced). This iterator type must meet the requirements of an forward iterator.
- **Sent** – The type of the end source iterators used (deduced). This iterator type must meet the requirements of an sentinel for *Iter*.
- **T** – The type of the value to find (deduced).
- **Proj** – The type of an optional projection function. This defaults to *hpx::identity*

Parameters

- **policy** – The execution policy to use for the scheduling of the iterations.
- **first** – Refers to the beginning of the sequence of elements of the first range the algorithm will be applied to.
- **last** – Refers to the end of the sequence of elements of the first range the algorithm will be applied to.
- **val** – the value to compare the elements to
- **proj** – Specifies the function (or function object) which will be invoked for each of the elements as a projection operation before the actual predicate *is* invoked.

Returns The *find* algorithm returns a *hpx::future*<*FwdIter*> if the execution policy is of type *sequenced_task_policy* or *parallel_task_policy* and returns *FwdIter* otherwise. The *find* algorithm returns the first element in the range [first,last) that is equal to *val*. If no such element in the range of [first,last) is equal to *val*, then the algorithm returns *last*.

```
template<typename ExPolicy, typename Rng, typename Proj = hpx::identity, typename T = typename
hpx::parallel::traits::projected<hpx::traits::range_iterator_t<Rng>, Proj>::value_type>
```

```

hpx::parallel::util::detail::algorithm_result<ExPolicy, hpx::traits::range_iterator_t<Rng>> find(ExPolicy
&&pol-
icy, Rng
&&rng,
T const
&val,
Proj
&&proj
=
Proj())

```

Returns the first element in the range [first, last) that is equal to value

The comparison operations in the parallel *find* algorithm invoked with an execution policy object of type *sequenced_policy* execute in sequential order in the calling thread.

The comparison operations in the parallel *find* algorithm invoked with an execution policy object of type *parallel_policy* or *parallel_task_policy* are permitted to execute in an unordered fashion in unspecified threads, and indeterminately sequenced within each thread.

Note: Complexity: At most last - first applications of the operator==().

Template Parameters

- **ExPolicy** – The type of the execution policy to use (deduced). It describes the manner in which the execution of the algorithm may be parallelized and the manner in which it executes the assignments.
- **Rng** – The type of the source range used (deduced). The iterators extracted from this range type must meet the requirements of an input iterator.
- **T** – The type of the value to find (deduced).
- **Proj** – The type of an optional projection function. This defaults to *hpx::identity*

Parameters

- **policy** – The execution policy to use for the scheduling of the iterations.
- **rng** – Refers to the sequence of elements the algorithm will be applied to.
- **val** – the value to compare the elements to
- **proj** – Specifies the function (or function object) which will be invoked for each of the elements as a projection operation before the actual predicate *is* invoked.

Returns The *find* algorithm returns a *hpx::future<FwdIter>* if the execution policy is of type *sequenced_task_policy* or *parallel_task_policy* and returns *FwdIter* otherwise. The *find* algorithm returns the first element in the range [first,last) that is equal to *val*. If no such element in the range of [first,last) is equal to *val*, then the algorithm returns *last*.

```

template<typename Iter, typename Sent, typename Proj = hpx::identity, typename T = typename
hpx::parallel::traits::projected<Iter, Proj>::value_type>

```

```

Iter find(Iter first, Sent last, T const &val, Proj &&proj = Proj())

```

Returns the first element in the range [first, last) that is equal to value

Note: Complexity: At most last - first applications of the operator==().

Template Parameters

- **Iter** – The type of the begin source iterators used (deduced). This iterator type must meet the requirements of an forward iterator.

- **Sent** – The type of the end source iterators used (deduced). This iterator type must meet the requirements of an sentinel for `Iter`.
- **T** – The type of the value to find (deduced).
- **Proj** – The type of an optional projection function. This defaults to `hpx::identity`

Parameters

- **first** – Refers to the beginning of the sequence of elements of the first range the algorithm will be applied to.
- **last** – Refers to the end of the sequence of elements of the first range the algorithm will be applied to.
- **val** – the value to compare the elements to
- **proj** – Specifies the function (or function object) which will be invoked for each of the elements as a projection operation before the actual predicate *is* invoked.

Returns The *find* algorithm returns the first element in the range [first,last) that is equal to *val*. If no such element in the range of [first,last) is equal to *val*, then the algorithm returns *last*.

```
template<typename Rng, typename Proj = hpx::identity, typename T = typename
hpx::parallel::traits::projected<hpx::traits::range_iterator_t<Rng>, Proj>::value_type>
hpx::traits::range_iterator_t<Rng> find(Rng &&rng, T const &val, Proj &&proj = Proj())
```

Returns the first element in the range [first, last) that is equal to value

The comparison operations in the parallel *find* algorithm invoked with an execution policy object of type *sequenced_policy* execute in sequential order in the calling thread.

The comparison operations in the parallel *find* algorithm invoked with an execution policy object of type *parallel_policy* or *parallel_task_policy* are permitted to execute in an unordered fashion in unspecified threads, and indeterminately sequenced within each thread.

Note: Complexity: At most last - first applications of the operator==().

Template Parameters

- **Rng** – The type of the source range used (deduced). The iterators extracted from this range type must meet the requirements of an input iterator.
- **T** – The type of the value to find (deduced).
- **Proj** – The type of an optional projection function. This defaults to `hpx::identity`

Parameters

- **rng** – Refers to the sequence of elements the algorithm will be applied to.
- **val** – the value to compare the elements to
- **proj** – Specifies the function (or function object) which will be invoked for each of the elements as a projection operation before the actual predicate *is* invoked.

Returns The *find* algorithm returns a `hpx::future<FwdIter>` if the execution policy is of type *sequenced_task_policy* or *parallel_task_policy* and returns *FwdIter* otherwise. The *find* algorithm returns the first element in the range [first,last) that is equal to *val*. If no such element in the range of [first,last) is equal to *val*, then the algorithm returns *last*.

```
template<typename ExPolicy, typename Iter, typename Sent, typename Pred, typename Proj =
hpx::identity>
hpx::parallel::util::detail::algorithm_result_t<ExPolicy, Iter> find_if(ExPolicy &&policy, Iter first,
Sent last, Pred &&pred, Proj
&&proj = Proj())
```

Returns the first element in the range [first, last) for which predicate *pred* returns true

The comparison operations in the parallel *find_if* algorithm invoked with an execution policy object of type *sequenced_policy* execute in sequential order in the calling thread.

The comparison operations in the parallel *find_if* algorithm invoked with an execution policy object of type *parallel_policy* or *parallel_task_policy* are permitted to execute in an unordered fashion in unspecified threads, and indeterminately sequenced within each thread.

Note: Complexity: At most last - first applications of the predicate.

Template Parameters

- **ExPolicy** – The type of the execution policy to use (deduced). It describes the manner in which the execution of the algorithm may be parallelized and the manner in which it executes the assignments.
- **Iter** – The type of the source iterators used for the first range (deduced). This iterator type must meet the requirements of a forward iterator.
- **Sent** – The type of the end source iterators used (deduced). This iterator type must meet the requirements of a sentinel for Iter.
- **Pred** – The type of the function/function object to use (deduced). Unlike its sequential form, the parallel overload of *equal* requires *F* to meet the requirements of *CopyConstructible*.
- **Proj** – The type of an optional projection function. This defaults to *hpx::identity*

Parameters

- **policy** – The execution policy to use for the scheduling of the iterations.
- **first** – Refers to the beginning of the sequence of elements of the first range the algorithm will be applied to.
- **last** – Refers to the end of the sequence of elements of the first range the algorithm will be applied to.
- **pred** – The unary predicate which returns true for the required element. The signature of the predicate should be equivalent to:

```
bool pred(const Type &a);
```

The signature does not need to have `const &`, but the function must not modify the objects passed to it. The type *Type* must be such that objects of type *FwdIter* can be dereferenced and then implicitly converted to *Type*.

- **proj** – Specifies the function (or function object) which will be invoked for each of the elements as a projection operation before the actual predicate *is* invoked.

Returns The *find_if* algorithm returns a *hpx::future<FwdIter>* if the execution policy is of type *sequenced_task_policy* or *parallel_task_policy* and returns *FwdIter* otherwise. The *find_if* algorithm returns the first element in the range [first,last) that satisfies the predicate *f*. If no such element exists that satisfies the predicate *f*, the algorithm returns *last*.

```
template<typename ExPolicy, typename Rng, typename Pred, typename Proj = hpx::identity>
hpx::parallel::util::detail::algorithm_result<ExPolicy, hpx::traits::range_iterator_t<Rng>> find_if(ExPolicy
&&pol-
icy,
Rng
&&rng,
Pred
&&pred,
Proj
&&proj
=
Proj())
```

Returns the first element in the range *rng* for which predicate *pred* returns true

The comparison operations in the parallel *find_if* algorithm invoked with an execution policy object of type *sequenced_policy* execute in sequential order in the calling thread.

The comparison operations in the parallel *find_if* algorithm invoked with an execution policy object of type *parallel_policy* or *parallel_task_policy* are permitted to execute in an unordered fashion in unspecified threads, and indeterminately sequenced within each thread.

Note: Complexity: At most last - first applications of the predicate.

Template Parameters

- **ExPolicy** – The type of the execution policy to use (deduced). It describes the manner in which the execution of the algorithm may be parallelized and the manner in which it executes the assignments.
- **Rng** – The type of the source range used (deduced). The iterators extracted from this range type must meet the requirements of an input iterator.
- **Pred** – The type of the function/function object to use (deduced). Unlike its sequential form, the parallel overload of *equal* requires *F* to meet the requirements of *CopyConstructible*.
- **Proj** – The type of an optional projection function. This defaults to *hpx::identity*

Parameters

- **policy** – The execution policy to use for the scheduling of the iterations.
- **rng** – Refers to the sequence of elements the algorithm will be applied to.
- **pred** – The unary predicate which returns true for the required element. The signature of the predicate should be equivalent to:

```
bool pred(const Type &a);
```

The signature does not need to have `const &`, but the function must not modify the objects passed to it. The type *Type* must be such that objects of type *FwdIter* can be dereferenced and then implicitly converted to *Type*.

- **proj** – Specifies the function (or function object) which will be invoked for each of the elements as a projection operation before the actual predicate *is* invoked.

Returns The *find_if* algorithm returns a *hpx::future<FwdIter>* if the execution policy is of type *sequenced_task_policy* or *parallel_task_policy* and returns *FwdIter* otherwise. The *find_if* algorithm returns the first element in the range [first,last) that satisfies the predicate *f*. If no such element exists that satisfies the predicate *f*, the algorithm returns *last*.

```
template<typename Iter, typename Sent, typename Pred, typename Proj = hpx::identity>
Iter find_if(Iter first, Sent last, Pred &&pred, Proj &&proj = Proj())
```

Returns the first element in the range [first, last) for which predicate *pred* returns true

Note: Complexity: At most last - first applications of the predicate.

Template Parameters

- **Iter** – The type of the source iterators used for the first range (deduced). This iterator type must meet the requirements of a forward iterator.
- **Sent** – The type of the end source iterators used (deduced). This iterator type must meet the requirements of an sentinel for *Iter*.

- **Pred** – The type of the function/function object to use (deduced). Unlike its sequential form, the parallel overload of *equal* requires *F* to meet the requirements of *CopyConstructible*.
- **Proj** – The type of an optional projection function. This defaults to *hpx::identity*

Parameters

- **first** – Refers to the beginning of the sequence of elements of the first range the algorithm will be applied to.
- **last** – Refers to the end of the sequence of elements of the first range the algorithm will be applied to.
- **pred** – The unary predicate which returns true for the required element. The signature of the predicate should be equivalent to:

```
bool pred(const Type &a);
```

The signature does not need to have `const &`, but the function must not modify the objects passed to it. The type *Type* must be such that objects of type *FwdIter* can be dereferenced and then implicitly converted to *Type*.

- **proj** – Specifies the function (or function object) which will be invoked for each of the elements as a projection operation before the actual predicate *is* invoked.

Returns The *find_if* algorithm returns the first element in the range [first,last) that satisfies the predicate *f*. If no such element exists that satisfies the predicate *f*, the algorithm returns *last*.

```
template<typename Rng, typename Pred, typename Proj = hpx::identity>
hpx::traits::range_iterator_t<Rng> find_if(Rng &&rng, Pred &&pred, Proj &&proj = Proj())
```

Returns the first element in the range *rng* for which predicate *pred* returns true

Note: Complexity: At most last - first applications of the predicate.

Template Parameters

- **Rng** – The type of the source range used (deduced). The iterators extracted from this range type must meet the requirements of an input iterator.
- **Pred** – The type of the function/function object to use (deduced). Unlike its sequential form, the parallel overload of *equal* requires *F* to meet the requirements of *CopyConstructible*.
- **Proj** – The type of an optional projection function. This defaults to *hpx::identity*

Parameters

- **rng** – Refers to the sequence of elements the algorithm will be applied to.
- **pred** – The unary predicate which returns true for the required element. The signature of the predicate should be equivalent to:

```
bool pred(const Type &a);
```

The signature does not need to have `const &`, but the function must not modify the objects passed to it. The type *Type* must be such that objects of type *FwdIter* can be dereferenced and then implicitly converted to *Type*.

- **proj** – Specifies the function (or function object) which will be invoked for each of the elements as a projection operation before the actual predicate *is* invoked.

Returns The *find_if* algorithm returns the first element in the range [first,last) that satisfies the predicate *f*. If no such element exists that satisfies the predicate *f*, the algorithm returns *last*.

```
template<typename ExPolicy, typename Iter, typename Sent, typename Pred, typename Proj =
hpx::identity>
```

```

hpx::parallel::util::detail::algorithm_result<ExPolicy, Iter>::type find_if_not(ExPolicy &&policy,
                                                                              Iter first, Sent last, Pred
                                                                              &&pred, Proj &&proj
                                                                              = Proj())

```

Returns the first element in the range [first, last) for which predicate *f* returns false

The comparison operations in the parallel *find_if_not* algorithm invoked with an execution policy object of type *sequenced_policy* execute in sequential order in the calling thread.

The comparison operations in the parallel *find_if_not* algorithm invoked with an execution policy object of type *parallel_policy* or *parallel_task_policy* are permitted to execute in an unordered fashion in unspecified threads, and indeterminately sequenced within each thread.

Note: Complexity: At most last - first applications of the predicate.

Template Parameters

- **ExPolicy** – The type of the execution policy to use (deduced). It describes the manner in which the execution of the algorithm may be parallelized and the manner in which it executes the assignments.
- **Iter** – The type of the source iterators used for the first range (deduced). This iterator type must meet the requirements of a forward iterator.
- **Sent** – The type of the end source iterators used (deduced). This iterator type must meet the requirements of an sentinel for Iter.
- **Pred** – The type of the function/function object to use (deduced). Unlike its sequential form, the parallel overload of *equal* requires *F* to meet the requirements of *CopyConstructible*.
- **Proj** – The type of an optional projection function. This defaults to *hpx::identity*

Parameters

- **policy** – The execution policy to use for the scheduling of the iterations.
- **first** – Refers to the beginning of the sequence of elements of the first range the algorithm will be applied to.
- **last** – Refers to the end of the sequence of elements of the first range the algorithm will be applied to.
- **pred** – The unary predicate which returns false for the required element. The signature of the predicate should be equivalent to:

```
bool pred(const Type &a);
```

The signature does not need to have `const &`, but the function must not modify the objects passed to it. The type *Type* must be such that objects of type *FwdIter* can be dereferenced and then implicitly converted to *Type*.

- **proj** – Specifies the function (or function object) which will be invoked for each of the elements as a projection operation before the actual predicate *is* invoked.

Returns The *find_if_not* algorithm returns a *hpx::future<FwdIter>* if the execution policy is of type *sequenced_task_policy* or *parallel_task_policy* and returns *FwdIter* otherwise. The *find_if_not* algorithm returns the first element in the range [first, last) that does **not** satisfy the predicate *f*. If no such element exists that does not satisfy the predicate *f*, the algorithm returns *last*.

```
template<typename ExPolicy, typename Rng, typename Pred, typename Proj = hpx::identity>
```

hpx::parallel::util::detail::algorithm_result<*ExPolicy*, *hpx::traits::range_iterator_t*<*Rng*>> **find_if_not**(*ExPolicy* &&policy, *Rng* &&rng, *Pred* &&pred, *Proj* &&proj = *Proj*())

Returns the first element in the range *rng* for which predicate *f* returns false

The comparison operations in the parallel *find_if_not* algorithm invoked with an execution policy object of type *sequenced_policy* execute in sequential order in the calling thread.

The comparison operations in the parallel *find_if_not* algorithm invoked with an execution policy object of type *parallel_policy* or *parallel_task_policy* are permitted to execute in an unordered fashion in unspecified threads, and indeterminately sequenced within each thread.

Note: Complexity: At most last - first applications of the predicate.

Template Parameters

- **ExPolicy** – The type of the execution policy to use (deduced). It describes the manner in which the execution of the algorithm may be parallelized and the manner in which it executes the assignments.
- **Rng** – The type of the source range used (deduced). The iterators extracted from this range type must meet the requirements of an input iterator.
- **Pred** – The type of the function/function object to use (deduced). Unlike its sequential form, the parallel overload of *equal* requires *F* to meet the requirements of *CopyConstructible*.
- **Proj** – The type of an optional projection function. This defaults to *hpx::identity*

Parameters

- **policy** – The execution policy to use for the scheduling of the iterations.
- **rng** – Refers to the sequence of elements the algorithm will be applied to.
- **pred** – The unary predicate which returns false for the required element. The signature of the predicate should be equivalent to:

```
bool pred(const Type &a);
```

The signature does not need to have `const &`, but the function must not modify the objects passed to it. The type *Type* must be such that objects of type *FwdIter* can be dereferenced and then implicitly converted to *Type*.

- **proj** – Specifies the function (or function object) which will be invoked for each of the elements as a projection operation before the actual predicate *is* invoked.

Returns The *find_if_not* algorithm returns a *hpx::future*<*FwdIter*> if the execution policy is of type *sequenced_task_policy* or *parallel_task_policy* and returns *FwdIter* otherwise. The *find_if_not* algorithm returns the first element in the range [first, last) that does **not** satisfy the predicate *f*. If no such element exists that does not satisfy the predicate *f*, the algorithm returns *last*.

```
template<typename Iter, typename Sent, typename Pred, typename Proj = hpx::identity>
```

Iter **find_if_not**(*Iter* first, *Sent* last, *Pred* &&pred, *Proj* &&proj = *Proj*())

Returns the first element in the range [first, last) for which predicate *f* returns false

Note: Complexity: At most last - first applications of the predicate.

Template Parameters

- **Iter** – The type of the source iterators used for the first range (deduced). This iterator type must meet the requirements of a forward iterator.
- **Sent** – The type of the end source iterators used (deduced). This iterator type must meet the requirements of an sentinel for *Iter*.
- **Pred** – The type of the function/function object to use (deduced). Unlike its sequential form, the parallel overload of *equal* requires *F* to meet the requirements of *CopyConstructible*.
- **Proj** – The type of an optional projection function. This defaults to *hpx::identity*

Parameters

- **first** – Refers to the beginning of the sequence of elements of the first range the algorithm will be applied to.
- **last** – Refers to the end of the sequence of elements of the first range the algorithm will be applied to.
- **pred** – The unary predicate which returns false for the required element. The signature of the predicate should be equivalent to:

```
bool pred(const Type &a);
```

The signature does not need to have `const &`, but the function must not modify the objects passed to it. The type *Type* must be such that objects of type *FwdIter* can be dereferenced and then implicitly converted to *Type*.

- **proj** – Specifies the function (or function object) which will be invoked for each of the elements as a projection operation before the actual predicate *is* invoked.

Returns The *find_if_not* algorithm returns the first element in the range [first, last) that does **not** satisfy the predicate *f*. If no such element exists that does not satisfy the predicate *f*, the algorithm returns *last*.

```
template<typename Rng, typename Pred, typename Proj = hpx::identity>
hpx::traits::range_iterator_t<Rng> find_if_not(Rng &&rng, Pred &&pred, Proj &&proj = Proj())
```

Returns the first element in the range *rng* for which predicate *f* returns false

Note: Complexity: At most last - first applications of the predicate.

Template Parameters

- **Rng** – The type of the source range used (deduced). The iterators extracted from this range type must meet the requirements of an input iterator.
- **Pred** – The type of the function/function object to use (deduced). Unlike its sequential form, the parallel overload of *equal* requires *F* to meet the requirements of *CopyConstructible*.
- **Proj** – The type of an optional projection function. This defaults to *hpx::identity*

Parameters

- **rng** – Refers to the sequence of elements the algorithm will be applied to.
- **pred** – The unary predicate which returns false for the required element. The signature of the predicate should be equivalent to:

```
bool pred(const Type &a);
```

The signature does not need to have `const &`, but the function must not modify the objects passed to it. The type *Type* must be such that objects of type *FwdIter* can be dereferenced and then implicitly converted to *Type*.

- **proj** – Specifies the function (or function object) which will be invoked for each of the elements as a projection operation before the actual predicate *is* invoked.

Returns The *find_if_not* algorithm returns the first element in the range [first, last) that does **not** satisfy the predicate *f*. If no such element exists that does not satisfy the predicate *f*, the algorithm returns *last*.

```
template<typename ExPolicy, typename Rng1, typename Rng2, typename Pred = equal_to, typename
Proj1 = hpx::identity, typename Proj2 = hpx::identity>
hpx::parallel::util::detail::algorithm_result<ExPolicy, hpx::traits::range_iterator_t<Rng1>> find_end(ExPolicy
&&pol-
icy,
Rng1
&&rng1,
Rng2
&&rng2,
Pred
&&op
=
Pred(),
Proj1
&&proj1
=
Proj1(),
Proj2
&&proj2
=
Proj2())
```

Returns the last subsequence of elements *rng2* found in the range *rng* using the given predicate *f* to compare elements.

The comparison operations in the parallel *find_end* algorithm invoked with an execution policy object of type *sequenced_policy* execute in sequential order in the calling thread.

The comparison operations in the parallel *find_end* algorithm invoked with an execution policy object of type *parallel_policy* or *parallel_task_policy* are permitted to execute in an unordered fashion in unspecified threads, and indeterminately sequenced within each thread.

This overload of *find_end* is available if the user decides to provide the algorithm their own predicate *op*.

Note: Complexity: at most $S \cdot (N - S + 1)$ comparisons where $S = \text{distance}(\text{begin}(\text{rng2}), \text{end}(\text{rng2}))$ and $N = \text{distance}(\text{begin}(\text{rng}), \text{end}(\text{rng}))$.

Template Parameters

- **ExPolicy** – The type of the execution policy to use (deduced). It describes the manner in which the execution of the algorithm may be parallelized and the manner in which it

executes the assignments.

- **Rng1** – The type of the first source range (deduced). The iterators extracted from this range type must meet the requirements of a forward iterator.
- **Rng2** – The type of the second source range (deduced). The iterators extracted from this range type must meet the requirements of a forward iterator.
- **Pred** – The type of an optional function/function object to use. Unlike its sequential form, the parallel overload of *replace* requires *Pred* to meet the requirements of *CopyConstructible*. This defaults to `std::equal_to<>`
- **Proj1** – The type of an optional projection function applied to the first sequence. This defaults to `hpx::identity`
- **Proj2** – The type of an optional projection function applied to the second sequence. This defaults to `hpx::identity`

Parameters

- **policy** – The execution policy to use for the scheduling of the iterations.
- **rng1** – Refers to the first sequence of elements the algorithm will be applied to.
- **rng2** – Refers to the second sequence of elements the algorithm will be applied to.
- **op** – The binary predicate which returns *true* if the elements should be treated as equal. The signature should be equivalent to the following:

```
bool pred(const Type1 &a, const Type2 &b);
```

The signature does not need to have `const &`, but the function must not modify the objects passed to it. The types *Type1* and *Type2* must be such that objects of types *iterator_t<Rng>* and *iterator_t<Rng2>* can be dereferenced and then implicitly converted to *Type1* and *Type2* respectively.

- **proj1** – Specifies the function (or function object) which will be invoked for each of the elements of the first range of type dereferenced *iterator_t<Rng1>* as a projection operation before the function *op* is invoked.
- **proj2** – Specifies the function (or function object) which will be invoked for each of the elements of the second range of type dereferenced *iterator_t<Rng2>* as a projection operation before the function *op* is invoked.

Returns The *find_end* algorithm returns a `hpx::future<iterator_t<Rng>` > if the execution policy is of type *sequenced_task_policy* or *parallel_task_policy* and returns *iterator_t<Rng>* otherwise. The *find_end* algorithm returns an iterator to the beginning of the last subsequence *rng2* in range *rng*. If the length of the subsequence *rng2* is greater than the length of the range *rng*, *end(rng)* is returned. Additionally if the size of the subsequence is empty or no subsequence is found, *end(rng)* is also returned.

```
template<typename ExPolicy, typename Iter1, typename Sent1, typename Iter2, typename Sent2,
typename Pred = equal_to, typename Proj1 = hpx::identity, typename Proj2 = hpx::identity>
hpx::parallel::util::detail::algorithm_result_t<ExPolicy, Iter1> find_end(ExPolicy &&policy, Iter1
    first1, Sent1 last1, Iter2 first2,
    Sent2 last2, Pred &&op =
    Pred(), Proj1 &&proj1 =
    Proj1(), Proj2 &&proj2 =
    Proj2())
```

Returns the last subsequence of elements [first2, last2) found in the range [first1, last1) using the given predicate *f* to compare elements.

The comparison operations in the parallel *find_end* algorithm invoked with an execution policy object of type *sequenced_policy* execute in sequential order in the calling thread.

The comparison operations in the parallel *find_end* algorithm invoked with an execution policy object of type *parallel_policy* or *parallel_task_policy* are permitted to execute in an unordered fashion in

unspecified threads, and indeterminately sequenced within each thread.

This overload of `find_end` is available if the user decides to provide the algorithm their own predicate `op`.

Note: Complexity: at most $S*(N-S+1)$ comparisons where $S = \text{distance}(\text{first2}, \text{last2})$ and $N = \text{distance}(\text{first1}, \text{last1})$.

Template Parameters

- **ExPolicy** – The type of the execution policy to use (deduced). It describes the manner in which the execution of the algorithm may be parallelized and the manner in which it executes the assignments.
- **Iter1** – The type of the begin source iterators for the first sequence used (deduced). This iterator type must meet the requirements of an forward iterator.
- **Sent1** – The type of the end source iterators for the first sequence used (deduced). This iterator type must meet the requirements of an sentinel for Iter1.
- **Iter2** – The type of the begin source iterators for the second sequence used (deduced). This iterator type must meet the requirements of an forward iterator.
- **Sent2** – The type of the end source iterators for the second sequence used (deduced). This iterator type must meet the requirements of an sentinel for Iter2.
- **Pred** – The type of an optional function/function object to use. Unlike its sequential form, the parallel overload of `replace` requires `Pred` to meet the requirements of `CopyConstructible`. This defaults to `std::equal_to<>`
- **Proj1** – The type of an optional projection function applied to the first sequence. This defaults to `hpx::identity`
- **Proj2** – The type of an optional projection function applied to the second sequence. This defaults to `hpx::identity`

Parameters

- **policy** – The execution policy to use for the scheduling of the iterations.
- **first1** – Refers to the beginning of the first sequence of elements the algorithm will be applied to.
- **last1** – Refers to the end of the first sequence of elements the algorithm will be applied to.
- **first2** – Refers to the beginning of the second sequence of elements the algorithm will be applied to.
- **last2** – Refers to the end of the second sequence of elements the algorithm will be applied to.
- **op** – The binary predicate which returns `true` if the elements should be treated as equal. The signature should be equivalent to the following:

```
bool pred(const Type1 &a, const Type2 &b);
```

The signature does not need to have `const &`, but the function must not modify the objects passed to it. The types `Type1` and `Type2` must be such that objects of types `iterator_t<Rng>` and `iterator_t<Rng2>` can be dereferenced and then implicitly converted to `Type1` and `Type2` respectively.

- **proj1** – Specifies the function (or function object) which will be invoked for each of the elements of the first range of type dereferenced `iterator_t<Rng1>` as a projection operation before the function `op` is invoked.
- **proj2** – Specifies the function (or function object) which will be invoked for each of the elements of the second range of type dereferenced `iterator_t<Rng2>` as a projection operation before the function `op` is invoked.

Returns The *find_end* algorithm returns a `hpx::future<iterator_t<Rng> >` if the execution policy is of type *sequenced_task_policy* or *parallel_task_policy* and returns *iterator_t<Rng>* otherwise. The *find_end* algorithm returns an iterator to the beginning of the last subsequence *rng2* in range *rng*. If the length of the subsequence *rng2* is greater than the length of the range *rng*, *end(rng)* is returned. Additionally if the size of the subsequence is empty or no subsequence is found, *end(rng)* is also returned.

```
template<typename Rng1, typename Rng2, typename Pred = equal_to, typename Proj1 = hpx::identity,
typename Proj2 = hpx::identity>
hpx::traits::range_iterator_t<Rng1> find_end(Rng1 &&rng1, Rng2 &&rng2, Pred &&op = Pred(),
                                           Proj1 &&proj1 = Proj1(), Proj2 &&proj2 = Proj2())
```

Returns the last subsequence of elements *rng2* found in the range *rng* using the given predicate *f* to compare elements.

This overload of *find_end* is available if the user decides to provide the algorithm their own predicate *op*.

Note: Complexity: at most $S \cdot (N - S + 1)$ comparisons where $S = \text{distance}(\text{begin}(\text{rng2}), \text{end}(\text{rng2}))$ and $N = \text{distance}(\text{begin}(\text{rng}), \text{end}(\text{rng}))$.

Template Parameters

- **Rng1** – The type of the first source range (deduced). The iterators extracted from this range type must meet the requirements of a forward iterator.
- **Rng2** – The type of the second source range (deduced). The iterators extracted from this range type must meet the requirements of a forward iterator.
- **Pred** – The type of an optional function/function object to use. Unlike its sequential form, the parallel overload of *replace* requires *Pred* to meet the requirements of *Copy-Constructible*. This defaults to `std::equal_to<>`
- **Proj1** – The type of an optional projection function applied to the first sequence. This defaults to `hpx::identity`
- **Proj2** – The type of an optional projection function applied to the second sequence. This defaults to `hpx::identity`

Parameters

- **rng1** – Refers to the first sequence of elements the algorithm will be applied to.
- **rng2** – Refers to the second sequence of elements the algorithm will be applied to.
- **op** – The binary predicate which returns *true* if the elements should be treated as equal. The signature should be equivalent to the following:

```
bool pred(const Type1 &a, const Type2 &b);
```

The signature does not need to have `const &`, but the function must not modify the objects passed to it. The types *Type1* and *Type2* must be such that objects of types *iterator_t<Rng>* and *iterator_t<Rng2>* can be dereferenced and then implicitly converted to *Type1* and *Type2* respectively.

- **proj1** – Specifies the function (or function object) which will be invoked for each of the elements of the first range of type dereferenced *iterator_t<Rng1>* as a projection operation before the function *op* is invoked.
- **proj2** – Specifies the function (or function object) which will be invoked for each of the elements of the second range of type dereferenced *iterator_t<Rng2>* as a projection operation before the function *op* is invoked.

Returns The *find_end* algorithm returns an iterator to the beginning of the last subsequence *rng2* in range *rng*. If the length of the subsequence *rng2* is greater than the length of the

range *rng*, *end(rng)* is returned. Additionally if the size of the subsequence is empty or no subsequence is found, *end(rng)* is also returned.

```
template<typename Iter1, typename Sent1, typename Iter2, typename Sent2, typename Pred =
equal_to, typename Proj1 = hpx::identity, typename Proj2 = hpx::identity>
Iter1 find_end(Iter1 first1, Sent1 last1, Iter2 first2, Sent2 last2, Pred &&op = Pred(), Proj1 &&proj1 =
Proj1(), Proj2 &&proj2 = Proj2())
```

Returns the last subsequence of elements [first2, last2) found in the range [first1, last1) using the given predicate *f* to compare elements.

This overload of *find_end* is available if the user decides to provide the algorithm their own predicate *op*.

Note: Complexity: at most $S \cdot (N - S + 1)$ comparisons where $S = \text{distance}(\text{first2}, \text{last2})$ and $N = \text{distance}(\text{first1}, \text{last1})$.

Template Parameters

- **Iter1** – The type of the begin source iterators for the first sequence used (deduced). This iterator type must meet the requirements of an forward iterator.
- **Sent1** – The type of the end source iterators for the first sequence used (deduced). This iterator type must meet the requirements of an sentinel for *Iter1*.
- **Iter2** – The type of the begin source iterators for the second sequence used (deduced). This iterator type must meet the requirements of an forward iterator.
- **Sent2** – The type of the end source iterators for the second sequence used (deduced). This iterator type must meet the requirements of an sentinel for *Iter2*.
- **Pred** – The type of an optional function/function object to use. Unlike its sequential form, the parallel overload of *replace* requires *Pred* to meet the requirements of *Copy-Constructible*. This defaults to `std::equal_to<>`
- **Proj1** – The type of an optional projection function applied to the first sequence. This defaults to `hpx::identity`
- **Proj2** – The type of an optional projection function applied to the second sequence. This defaults to `hpx::identity`

Parameters

- **first1** – Refers to the beginning of the first sequence of elements the algorithm will be applied to.
- **last1** – Refers to the end of the first sequence of elements the algorithm will be applied to.
- **first2** – Refers to the beginning of the second sequence of elements the algorithm will be applied to.
- **last2** – Refers to the end of the second sequence of elements the algorithm will be applied to.
- **op** – The binary predicate which returns *true* if the elements should be treated as equal. The signature should be equivalent to the following:

```
bool pred(const Type1 &a, const Type2 &b);
```

The signature does not need to have `const &`, but the function must not modify the objects passed to it. The types *Type1* and *Type2* must be such that objects of types *iterator_t<Rng>* and *iterator_t<Rng2>* can be dereferenced and then implicitly converted to *Type1* and *Type2* respectively.

- **proj1** – Specifies the function (or function object) which will be invoked for each of the elements of the first range of type dereferenced *iterator_t<Rng1>* as a projection

operation before the function *op* is invoked.

- **proj2** – Specifies the function (or function object) which will be invoked for each of the elements of the second range of type dereferenced *iterator_t*<*Rng2*> as a projection operation before the function *op* is invoked.

Returns The *find_end* algorithm returns an iterator to the beginning of the last subsequence *rng2* in range *rng*. If the length of the subsequence *rng2* is greater than the length of the range *rng*, *end(rng)* is returned. Additionally if the size of the subsequence is empty or no subsequence is found, *end(rng)* is also returned.

```
template<typename ExPolicy, typename Rng1, typename Rng2, typename Pred = equal_to, typename
Proj1 = hpx::identity, typename Proj2 = hpx::identity>
```

```
hpx::parallel::util::detail::algorithm_result<ExPolicy, hpx::traits::range_iterator_t<Rng1>> find_first_of(ExPolicy
&&pol-
icy,
Rng1
&&rng1,
Rng2
&&rng2,
Pred
&&op
=
Pred(),
Proj1
&&proj1
=
Proj1(),
Proj2
&&proj2
=
Proj2())
```

Searches the range *rng1* for any elements in the range *rng2*. Uses binary predicate *p* to compare elements

The comparison operations in the parallel *find_first_of* algorithm invoked with an execution policy object of type *sequenced_policy* execute in sequential order in the calling thread.

The comparison operations in the parallel *find_first_of* algorithm invoked with an execution policy object of type *parallel_policy* or *parallel_task_policy* are permitted to execute in an unordered fashion in unspecified threads, and indeterminately sequenced within each thread.

This overload of *find_first_of* is available if the user decides to provide the algorithm their own predicate *op*.

Note: Complexity: at most (*S***N*) comparisons where *S* = distance(begin(*rng2*), end(*rng2*)) and *N* = distance(begin(*rng1*), end(*rng1*)).

Template Parameters

- **ExPolicy** – The type of the execution policy to use (deduced). It describes the manner in which the execution of the algorithm may be parallelized and the manner in which it executes the assignments.
- **Rng1** – The type of the first source range (deduced). The iterators extracted from this range type must meet the requirements of a forward iterator.

- **Rng2** – The type of the second source range (deduced). The iterators extracted from this range type must meet the requirements of a forward iterator.
- **Pred** – The type of an optional function/function object to use. Unlike its sequential form, the parallel overload of *replace* requires *Pred* to meet the requirements of *CopyConstructible*. This defaults to `std::equal_to<>`
- **Proj1** – The type of an optional projection function. This defaults to `hpx::identity` and is applied to the elements in *rng1*.
- **Proj2** – The type of an optional projection function. This defaults to `hpx::identity` and is applied to the elements in *rng2*.

Parameters

- **policy** – The execution policy to use for the scheduling of the iterations.
- **rng1** – Refers to the first sequence of elements the algorithm will be applied to.
- **rng2** – Refers to the second sequence of elements the algorithm will be applied to.
- **op** – The binary predicate which returns *true* if the elements should be treated as equal. The signature should be equivalent to the following:

```
bool pred(const Type1 &a, const Type2 &b);
```

The signature does not need to have `const &`, but the function must not modify the objects passed to it. The types *Type1* and *Type2* must be such that objects of types *iterator_t<Rng1>* and *iterator_t<Rng2>* can be dereferenced and then implicitly converted to *Type1* and *Type2* respectively.

- **proj1** – Specifies the function (or function object) which will be invoked for each of the elements of type dereferenced *iterator_t<Rng1>* before the function *op* is invoked.
- **proj2** – Specifies the function (or function object) which will be invoked for each of the elements of type dereferenced *iterator_t<Rng2>* before the function *op* is invoked.

Returns The *find_end* algorithm returns a `hpx::future<iterator_t<Rng1> >` if the execution policy is of type *sequenced_task_policy* or *parallel_task_policy* and returns *iterator_t<Rng1>* otherwise. The *find_first_of* algorithm returns an iterator to the first element in the range *rng1* that is equal to an element from the range *rng2*. If the length of the subsequence *rng2* is greater than the length of the range *rng1*, *end(rng1)* is returned. Additionally if the size of the subsequence is empty or no subsequence is found, *end(rng1)* is also returned.

```
template<typename ExPolicy, typename Iter1, typename Sent1, typename Iter2, typename Sent2,
typename Pred = equal_to, typename Proj1 = hpx::identity, typename Proj2 = hpx::identity>
hpx::parallel::util::detail::algorithm_result_t<ExPolicy, Iter1> find_first_of(ExPolicy &&policy,
Iter1 first1, Sent1 last1,
Iter2 first2, Sent2 last2,
Pred &&op = Pred(),
Proj1 &&proj1 =
Proj1(), Proj2 &&proj2
= Proj2())
```

Searches the range [first1, last1) for any elements in the range [first2, last2). Uses binary predicate *p* to compare elements

The comparison operations in the parallel *find_first_of* algorithm invoked with an execution policy object of type *sequenced_policy* execute in sequential order in the calling thread.

The comparison operations in the parallel *find_first_of* algorithm invoked with an execution policy object of type *parallel_policy* or *parallel_task_policy* are permitted to execute in an unordered fashion in unspecified threads, and indeterminately sequenced within each thread.

This overload of *find_first_of* is available if the user decides to provide the algorithm their own predicate *op*.

Note: Complexity: at most $(S*N)$ comparisons where $S = \text{distance}(\text{first2}, \text{last2})$ and $N = \text{distance}(\text{first1}, \text{last1})$.

Template Parameters

- **ExPolicy** – The type of the execution policy to use (deduced). It describes the manner in which the execution of the algorithm may be parallelized and the manner in which it executes the assignments.
- **Iter1** – The type of the begin source iterators for the first sequence used (deduced). This iterator type must meet the requirements of an forward iterator.
- **Sent1** – The type of the end source iterators for the first sequence used (deduced). This iterator type must meet the requirements of an sentinel for Iter1.
- **Iter2** – The type of the begin source iterators for the second sequence used (deduced). This iterator type must meet the requirements of an forward iterator.
- **Sent2** – The type of the end source iterators for the second sequence used (deduced). This iterator type must meet the requirements of an sentinel for Iter2.
- **Pred** – The type of an optional function/function object to use. Unlike its sequential form, the parallel overload of *replace* requires *Pred* to meet the requirements of *CopyConstructible*. This defaults to `std::equal_to<>`
- **Proj1** – The type of an optional projection function. This defaults to `hpx::identity` and is applied to the elements in *rng1*.
- **Proj2** – The type of an optional projection function. This defaults to `hpx::identity` and is applied to the elements in *rng2*.

Parameters

- **policy** – The execution policy to use for the scheduling of the iterations.
- **first1** – Refers to the beginning of the first sequence of elements the algorithm will be applied to.
- **last1** – Refers to the end of the first sequence of elements the algorithm will be applied to.
- **first2** – Refers to the beginning of the second sequence of elements the algorithm will be applied to.
- **last2** – Refers to the end of the second sequence of elements the algorithm will be applied to.
- **op** – The binary predicate which returns *true* if the elements should be treated as equal. The signature should be equivalent to the following:

```
bool pred(const Type1 &a, const Type2 &b);
```

The signature does not need to have `const &`, but the function must not modify the objects passed to it. The types *Type1* and *Type2* must be such that objects of types *iterator_t<Rng1>* and *iterator_t<Rng2>* can be dereferenced and then implicitly converted to *Type1* and *Type2* respectively.

- **proj1** – Specifies the function (or function object) which will be invoked for each of the elements of type dereferenced *iterator_t<Rng1>* before the function *op* is invoked.
- **proj2** – Specifies the function (or function object) which will be invoked for each of the elements of type dereferenced *iterator_t<Rng2>* before the function *op* is invoked.

Returns The *find_end* algorithm returns a `hpx::future<iterator_t<Rng1> >` if the execution policy is of type *sequenced_task_policy* or *parallel_task_policy* and returns *iterator_t<Rng1>* otherwise. The *find_first_of* algorithm returns an iterator to the first element in the range *rng1* that is equal to an element from the range *rng2*. If the length of the subsequence *rng2* is greater than the length of the range *rng1*, *end(rng1)* is returned. Ad-

ditionally if the size of the subsequence is empty or no subsequence is found, `end(rng1)` is also returned.

```
template<typename Rng1, typename Rng2, typename Pred = equal_to, typename Proj1 = hpx::identity,
typename Proj2 = hpx::identity>
hpx::traits::range_iterator_t<Rng1> find_first_of(Rng1 &&rng1, Rng2 &&rng2, Pred &&op =
Pred(), Proj1 &&proj1 = Proj1(), Proj2 &&proj2
= Proj2())
```

Searches the range `rng1` for any elements in the range `rng2`. Uses binary predicate `p` to compare elements

This overload of `find_first_of` is available if the user decides to provide the algorithm their own predicate `op`.

Note: Complexity: at most $(S*N)$ comparisons where $S = \text{distance}(\text{begin}(\text{rng2}), \text{end}(\text{rng2}))$ and $N = \text{distance}(\text{begin}(\text{rng1}), \text{end}(\text{rng1}))$.

Template Parameters

- **Rng1** – The type of the first source range (deduced). The iterators extracted from this range type must meet the requirements of a forward iterator.
- **Rng2** – The type of the second source range (deduced). The iterators extracted from this range type must meet the requirements of a forward iterator.
- **Pred** – The type of an optional function/function object to use. Unlike its sequential form, the parallel overload of `replace` requires `Pred` to meet the requirements of `CopyConstructible`. This defaults to `std::equal_to<>`
- **Proj1** – The type of an optional projection function. This defaults to `hpx::identity` and is applied to the elements in `rng1`.
- **Proj2** – The type of an optional projection function. This defaults to `hpx::identity` and is applied to the elements in `rng2`.

Parameters

- **rng1** – Refers to the first sequence of elements the algorithm will be applied to.
- **rng2** – Refers to the second sequence of elements the algorithm will be applied to.
- **op** – The binary predicate which returns `true` if the elements should be treated as equal. The signature should be equivalent to the following:

```
bool pred(const Type1 &a, const Type2 &b);
```

The signature does not need to have `const &`, but the function must not modify the objects passed to it. The types `Type1` and `Type2` must be such that objects of types `iterator_t<Rng1>` and `iterator_t<Rng2>` can be dereferenced and then implicitly converted to `Type1` and `Type2` respectively.

- **proj1** – Specifies the function (or function object) which will be invoked for each of the elements of type dereferenced `iterator_t<Rng1>` before the function `op` is invoked.
- **proj2** – Specifies the function (or function object) which will be invoked for each of the elements of type dereferenced `iterator_t<Rng2>` before the function `op` is invoked.

Returns The `find_first_of` algorithm returns an iterator to the first element in the range `rng1` that is equal to an element from the range `rng2`. If the length of the subsequence `rng2` is greater than the length of the range `rng1`, `end(rng1)` is returned. Additionally if the size of the subsequence is empty or no subsequence is found, `end(rng1)` is also returned.

```
template<typename Iter1, typename Sent1, typename Iter2, typename Sent2, typename Pred =
equal_to, typename Proj1 = hpx::identity, typename Proj2 = hpx::identity>
```

Iter1 **find_first_of**(*Iter1* first1, *Sent1* last1, *Iter2* first2, *Sent2* last2, *Pred* &&op = *Pred*(), *Proj1* &&proj1 = *Proj1*(), *Proj2* &&proj2 = *Proj2*())

Searches the range [first1, last1) for any elements in the range [first2, last2). Uses binary predicate *p* to compare elements

This overload of *find_first_of* is available if the user decides to provide the algorithm their own predicate *op*.

Note: Complexity: at most ($S*N$) comparisons where S = distance(first2, last2) and N = distance(first1, last1).

Template Parameters

- **Iter1** – The type of the begin source iterators for the first sequence used (deduced). This iterator type must meet the requirements of an forward iterator.
- **Sent1** – The type of the end source iterators for the first sequence used (deduced). This iterator type must meet the requirements of an sentinel for Iter1.
- **Iter2** – The type of the begin source iterators for the second sequence used (deduced). This iterator type must meet the requirements of an forward iterator.
- **Sent2** – The type of the end source iterators for the second sequence used (deduced). This iterator type must meet the requirements of an sentinel for Iter2.
- **Pred** – The type of an optional function/function object to use. Unlike its sequential form, the parallel overload of *replace* requires *Pred* to meet the requirements of *Copy-Constructible*. This defaults to `std::equal_to<>`
- **Proj1** – The type of an optional projection function. This defaults to `hpx::identity` and is applied to the elements in *rng1*.
- **Proj2** – The type of an optional projection function. This defaults to `hpx::identity` and is applied to the elements in *rng2*.

Parameters

- **first1** – Refers to the beginning of the first sequence of elements the algorithm will be applied to.
- **last1** – Refers to the end of the first sequence of elements the algorithm will be applied to.
- **first2** – Refers to the beginning of the second sequence of elements the algorithm will be applied to.
- **last2** – Refers to the end of the second sequence of elements the algorithm will be applied to.
- **op** – The binary predicate which returns *true* if the elements should be treated as equal. The signature should be equivalent to the following:

```
bool pred(const Type1 &a, const Type2 &b);
```

The signature does not need to have `const &`, but the function must not modify the objects passed to it. The types *Type1* and *Type2* must be such that objects of types *iterator_t<Rng1>* and *iterator_t<Rng2>* can be dereferenced and then implicitly converted to *Type1* and *Type2* respectively.

- **proj1** – Specifies the function (or function object) which will be invoked for each of the elements of type dereferenced *iterator_t<Rng1>* before the function *op* is invoked.
- **proj2** – Specifies the function (or function object) which will be invoked for each of the elements of type dereferenced *iterator_t<Rng2>* before the function *op* is invoked.

Returns The *find_first_of* algorithm returns an iterator to the first element in the range *rng1* that is equal to an element from the range *rng2*. If the length of the subsequence *rng2* is greater than the length of the range *rng1*, *end(rng1)* is returned. Additionally if the size of

the subsequence is empty or no subsequence is found, *end(rng1)* is also returned.

hpx::ranges::for_each, hpx::ranges::for_each_n

Defined in header `hpx/algorithm.hpp`⁶⁴⁷.

See *Public API* for a list of names and headers that are part of the public HPX API.

namespace **hpx**

namespace **ranges**

Functions

```
template<typename InIter, typename Sent, typename F, typename Proj = hpx::identity>  
for_each_result<InIter, F> for_each(InIter first, Sent last, F &&f, Proj &&proj = Proj())
```

Applies *f* to the result of dereferencing every iterator in the range [first, last).

If *f* returns a result, the result is ignored.

If the type of *first* satisfies the requirements of a mutable iterator, *f* may apply non-constant functions through the dereferenced iterator.

Note: Complexity: Applies *f* exactly *last - first* times.

Template Parameters

- **InIter** – The type of the source begin iterator used (deduced). This iterator type must meet the requirements of an input iterator.
- **Sent** – The type of the source sentinel (deduced). This sentinel type must be a sentinel for *InIter*.
- **F** – The type of the function/function object to use (deduced). Unlike its sequential form, the parallel overload of *for_each* requires *F* to meet the requirements of *Copy-Constructible*.
- **Proj** – The type of an optional projection function. This defaults to *hpx::identity*

Parameters

- **first** – Refers to the beginning of the sequence of elements the algorithm will be applied to.
- **last** – Refers to the end of the sequence of elements the algorithm will be applied to.
- **f** – Specifies the function (or function object) which will be invoked for each of the elements in the sequence specified by [first, last). The signature of this predicate should be equivalent to:

```
<ignored> pred(const Type &a);
```

The signature does not need to have `const&`. The type *Type* must be such that an object of type *InIter* can be dereferenced and then implicitly converted to *Type*.

- **proj** – Specifies the function (or function object) which will be invoked for each of the elements as a projection operation before the actual predicate *is* invoked.

⁶⁴⁷ <http://github.com/STELLAR-GROUP/hpx/blob/8a3b7c1a4cb5693b2f7d9f587f759392ed0c51a0/libs/full/include/include/hpx/algorithm.hpp>

Returns {last, HPX_MOVE(f)} where last is the iterator corresponding to the input sentinel last.

```
template<typename Rng, typename F, typename Proj = hpx::identity>
for_each_result<hpx::traits::range_iterator_t<Rng>, F> for_each(Rng &&rng, F &&f, Proj &&proj =
    Proj())
```

Applies *f* to the result of dereferencing every iterator in the given range *rng*.

If *f* returns a result, the result is ignored.

If the type of *first* satisfies the requirements of a mutable iterator, *f* may apply non-constant functions through the dereferenced iterator.

Note: Complexity: Applies *f* exactly *size(rng)* times.

Template Parameters

- **Rng** – The type of the source range used (deduced). The iterators extracted from this range type must meet the requirements of an input iterator.
- **F** – The type of the function/function object to use (deduced). Unlike its sequential form, the parallel overload of *for_each* requires *F* to meet the requirements of *CopyConstructible*.
- **Proj** – The type of an optional projection function. This defaults to *hpx::identity*

Parameters

- **rng** – Refers to the sequence of elements the algorithm will be applied to.
- **f** – Specifies the function (or function object) which will be invoked for each of the elements in the sequence specified by [first, last). The signature of this predicate should be equivalent to:

```
<ignored> pred(const Type &a);
```

The signature does not need to have const&. The type *Type* must be such that an object of type *InIter* can be dereferenced and then implicitly converted to *Type*.

- **proj** – Specifies the function (or function object) which will be invoked for each of the elements as a projection operation before the actual predicate *is* invoked.

Returns {std::end(rng), HPX_MOVE(f)}

```
template<typename ExPolicy, typename FwdIter, typename Sent, typename F, typename Proj =
    hpx::identity>
hpx::parallel::util::detail::algorithm_result_t<ExPolicy, FwdIter> for_each(ExPolicy &&policy,
    FwdIter first, Sent last, F
    &&f, Proj &&proj =
    Proj())
```

Applies *f* to the result of dereferencing every iterator in the range [first, last).

If *f* returns a result, the result is ignored.

If the type of *first* satisfies the requirements of a mutable iterator, *f* may apply non-constant functions through the dereferenced iterator.

Unlike its sequential form, the parallel overload of *for_each* does not return a copy of its *Function* parameter, since parallelization may not permit efficient state accumulation.

The application of function objects in parallel algorithm invoked with an execution policy object of type *sequenced_policy* execute in sequential order in the calling thread.

The application of function objects in parallel algorithm invoked with an execution policy object of type *parallel_policy* or *parallel_task_policy* are permitted to execute in an unordered fashion in unspecified threads, and indeterminately sequenced within each thread.

Note: Complexity: Applies *f* exactly *last - first* times.

Template Parameters

- **ExPolicy** – The type of the execution policy to use (deduced). It describes the manner in which the execution of the algorithm may be parallelized and the manner in which it applies user-provided function objects.
- **FwdIter** – The type of the source begin iterator used (deduced). This iterator type must meet the requirements of an forward iterator.
- **Sent** – The type of the source sentinel (deduced). This sentinel type must be a sentinel for *InIter*.
- **F** – The type of the function/function object to use (deduced). Unlike its sequential form, the parallel overload of *for_each* requires *F* to meet the requirements of *CopyConstructible*.
- **Proj** – The type of an optional projection function. This defaults to *hpx::identity*

Parameters

- **policy** – The execution policy to use for the scheduling of the iterations.
- **first** – Refers to the beginning of the sequence of elements the algorithm will be applied to.
- **last** – Refers to the end of the sequence of elements the algorithm will be applied to.
- **f** – Specifies the function (or function object) which will be invoked for each of the elements in the sequence specified by [first, last). The signature of this predicate should be equivalent to:

```
<ignored> pred(const Type &a);
```

The signature does not need to have `const&`. The type *Type* must be such that an object of type *InIter* can be dereferenced and then implicitly converted to *Type*.

- **proj** – Specifies the function (or function object) which will be invoked for each of the elements as a projection operation before the actual predicate *is* invoked.

Returns The *for_each* algorithm returns a *hpx::future<FwdIter>* if the execution policy is of type *sequenced_task_policy* or *parallel_task_policy* and returns *FwdIter* otherwise. It returns *last*.

```
template<typename ExPolicy, typename Rng, typename F, typename Proj = hpx::identity>
hpx::parallel::util::detail::algorithm_result<ExPolicy, hpx::traits::range_iterator_t<Rng>>> for_each(ExPolicy
&&pol-
icy,
Rng
&&rng,
F
&&f,
Proj
&&proj
=
Proj())
```

Applies *f* to the result of dereferencing every iterator in the given range *rng*.

If f returns a result, the result is ignored.

If the type of $first$ satisfies the requirements of a mutable iterator, f may apply non-constant functions through the dereferenced iterator.

Unlike its sequential form, the parallel overload of for_each does not return a copy of its *Function* parameter, since parallelization may not permit efficient state accumulation.

The application of function objects in parallel algorithm invoked with an execution policy object of type *sequenced_policy* execute in sequential order in the calling thread.

The application of function objects in parallel algorithm invoked with an execution policy object of type *parallel_policy* or *parallel_task_policy* are permitted to execute in an unordered fashion in unspecified threads, and indeterminately sequenced within each thread.

Note: Complexity: Applies f exactly $size(rng)$ times.

Template Parameters

- **ExPolicy** – The type of the execution policy to use (deduced). It describes the manner in which the execution of the algorithm may be parallelized and the manner in which it applies user-provided function objects.
- **Rng** – The type of the source range used (deduced). The iterators extracted from this range type must meet the requirements of an input iterator.
- **F** – The type of the function/function object to use (deduced). Unlike its sequential form, the parallel overload of for_each requires F to meet the requirements of *CopyConstructible*.
- **Proj** – The type of an optional projection function. This defaults to $hpx::identity$

Parameters

- **policy** – The execution policy to use for the scheduling of the iterations.
- **rng** – Refers to the sequence of elements the algorithm will be applied to.
- **f** – Specifies the function (or function object) which will be invoked for each of the elements in the sequence specified by [first, last). The signature of this predicate should be equivalent to:

```
<ignored> pred(const Type &a);
```

The signature does not need to have `const&`. The type *Type* must be such that an object of type *InIter* can be dereferenced and then implicitly converted to *Type*.

- **proj** – Specifies the function (or function object) which will be invoked for each of the elements as a projection operation before the actual predicate *is* invoked.

Returns The for_each algorithm returns a $hpx::future<FwdIter>$ if the execution policy is of type *sequenced_task_policy* or *parallel_task_policy* and returns *FwdIter* otherwise. It returns *last*.

```
template<typename InIter, typename Size, typename F, typename Proj = hpx::identity>
for_each_n_result<InIter, F> for_each_n(InIter first, Size count, F &&f, Proj &&proj = Proj())
```

Applies f to the result of dereferencing every iterator in the range [first, first + count), starting from first and proceeding to first + count - 1.

If f returns a result, the result is ignored.

If the type of *first* satisfies the requirements of a mutable iterator, *f* may apply non-constant functions through the dereferenced iterator.

Unlike its sequential form, the parallel overload of *for_each* does not return a copy of its *Function* parameter, since parallelization may not permit efficient state accumulation.

Note: Complexity: Applies *f* exactly *count* times.

Template Parameters

- **InIter** – The type of the source begin iterator used (deduced). This iterator type must meet the requirements of an input iterator.
- **Size** – The type of the argument specifying the number of elements to apply *f* to.
- **F** – The type of the function/function object to use (deduced). Unlike its sequential form, the parallel overload of *for_each* requires *F* to meet the requirements of *CopyConstructible*.
- **Proj** – The type of an optional projection function. This defaults to *hpx::identity*

Parameters

- **first** – Refers to the beginning of the sequence of elements the algorithm will be applied to.
- **count** – Refers to the number of elements starting at *first* the algorithm will be applied to.
- **f** – Specifies the function (or function object) which will be invoked for each of the elements in the sequence specified by [first, last). The signature of this predicate should be equivalent to:

```
<ignored> pred(const Type &a);
```

The signature does not need to have `const&`. The type *Type* must be such that an object of type *InIter* can be dereferenced and then implicitly converted to *Type*.

- **proj** – Specifies the function (or function object) which will be invoked for each of the elements as a projection operation before the actual predicate *is* invoked.

Returns It returns *last*.

```
template<typename ExPolicy, typename FwdIter, typename Size, typename F, typename Proj =
    hpx::identity>
hpx::parallel::util::detail::algorithm_result<ExPolicy, FwdIter>::type for_each_n(ExPolicy &&policy,
    FwdIter first, Size
    count, F &&f, Proj
    &&proj = Proj())
```

Applies *f* to the result of dereferencing every iterator in the range [first, first + count), starting from first and proceeding to first + count - 1.

If *f* returns a result, the result is ignored.

If the type of *first* satisfies the requirements of a mutable iterator, *f* may apply non-constant functions through the dereferenced iterator.

Unlike its sequential form, the parallel overload of *for_each* does not return a copy of its *Function* parameter, since parallelization may not permit efficient state accumulation.

The application of function objects in parallel algorithm invoked with an execution policy object of type *sequenced_policy* execute in sequential order in the calling thread.

The application of function objects in parallel algorithm invoked with an execution policy object of type *parallel_policy* or *parallel_task_policy* are permitted to execute in an unordered fashion in unspecified threads, and indeterminately sequenced within each thread.

Note: Complexity: Applies *f* exactly *count* times.

Template Parameters

- **ExPolicy** – The type of the execution policy to use (deduced). It describes the manner in which the execution of the algorithm may be parallelized and the manner in which it applies user-provided function objects.
- **FwdIter** – The type of the source begin iterator used (deduced). This iterator type must meet the requirements of an forward iterator.
- **Size** – The type of the argument specifying the number of elements to apply *f* to.
- **F** – The type of the function/function object to use (deduced). Unlike its sequential form, the parallel overload of *for_each* requires *F* to meet the requirements of *CopyConstructible*.
- **Proj** – The type of an optional projection function. This defaults to *hpx::identity*

Parameters

- **policy** – The execution policy to use for the scheduling of the iterations.
- **first** – Refers to the beginning of the sequence of elements the algorithm will be applied to.
- **count** – Refers to the number of elements starting at *first* the algorithm will be applied to.
- **f** – Specifies the function (or function object) which will be invoked for each of the elements in the sequence specified by [first, last). The signature of this predicate should be equivalent to:

```
<ignored> pred(const Type &a);
```

The signature does not need to have `const&`. The type *Type* must be such that an object of type *InIter* can be dereferenced and then implicitly converted to *Type*.

- **proj** – Specifies the function (or function object) which will be invoked for each of the elements as a projection operation before the actual predicate *is* invoked.

Returns The *for_each* algorithm returns a *hpx::future<FwdIter>* if the execution policy is of type *sequenced_task_policy* or *parallel_task_policy* and returns *FwdIter* otherwise. It returns *last*.

hpx::ranges::experimental::for_loop, **hpx::ranges::experimental::for_loop_strided**,
hpx::ranges::experimental::for_loop_n, **hpx::ranges::experimental::for_loop_n_strided**

Defined in header `hpx/algorithm.hpp`⁶⁴⁸.

See *Public API* for a list of names and headers that are part of the public *HPX* API.

namespace **hpx**

namespace **ranges**

namespace **experimental**

⁶⁴⁸ <http://github.com/STELLAR-GROUP/hpx/blob/8a3b7c1a4cb5693b2f7d9f587f759392ed0c51a0/libs/full/include/include/hpx/algorithm.hpp>

Functions

```
template<typename ExPolicy, typename Iter, typename Sent, typename ...Args>  
hpx::parallel::util::detail::algorithm_result<ExPolicy>::type for_loop(ExPolicy &&policy, Iter  
first, Sent last, Args&&...  
args)
```

The `for_loop` implements loop functionality over a range specified by iterator bounds. These algorithms resemble `for_each` from the Parallelism TS, but leave to the programmer when and if to dereference the iterator.

Requires: *Iter* shall meet the requirements of a forward iterator type. The *args* parameter pack shall have at least one element, comprising objects returned by invocations of *reduction* and/or *induction* function templates followed by exactly one element invocable element-access function, *f*. *f* shall meet the requirements of `MoveConstructible`.

Effects: Applies *f* to each element in the input sequence, with additional arguments corresponding to the reductions and inductions in the *args* parameter pack. The length of the input sequence is `last - first`.

The first element in the input sequence is specified by *first*. Each subsequent element is generated by incrementing the previous element.

Along with an element from the input sequence, for each member of the *args* parameter pack excluding *f*, an additional argument is passed to each application of *f* as follows:

If the pack member is an object returned by a call to a reduction function listed in section, then the additional argument is a reference to a view of that reduction object. If the pack member is an object returned by a call to induction, then the additional argument is the induction value for that induction object corresponding to the position of the application of *f* in the input sequence.

Complexity: Applies *f* exactly once for each element of the input sequence.

Remarks: If *f* returns a result, the result is ignored.

Note: As described in the C++ standard, arithmetic on non-random-access iterators is performed using `advance` and `distance`.

Note: The order of the elements of the input sequence is important for determining ordinal position of an application of *f*, even though the applications themselves may be unordered.

Template Parameters

- **ExPolicy** – The type of the execution policy to use (deduced). It describes the manner in which the execution of the algorithm may be parallelized and the manner in which it applies user-provided function objects.
- **Iter** – The type of the iteration variable (forward iterator).
- **Sent** – The type of the source sentinel (deduced). This sentinel type must be a sentinel for `Iter`.
- **Args** – A parameter pack, its last element is a function object to be invoked for each iteration, the others have to be either conforming to the induction or reduction concept.

Parameters

- **policy** – The execution policy to use for the scheduling of the iterations.

- **first** – Refers to the beginning of the sequence of elements the algorithm will be applied to.
- **last** – Refers to the end of the sequence of elements the algorithm will be applied to.
- **args** – The last element of this parameter pack is the function (object) to invoke, while the remaining elements of the parameter pack are instances of either induction or reduction objects. The function (or function object) which will be invoked for each of the elements in the sequence specified by [first, last) should expose a signature equivalent to:

```
<ignored> pred(Iter const& a, ...);
```

The signature does not need to have `const&`. It will receive the current value of the iteration variable and one argument for each of the induction or reduction objects passed to the algorithms, representing their current values.

Returns The `for_loop` algorithm returns a `hpx::future<void>` if the execution policy is of type `hpx::execution::sequenced_task_policy` or `hpx::execution::parallel_task_policy` and returns `void` otherwise.

```
template<typename Iter, typename Sent, typename ...Args>
void for_loop(Iter first, Sent last, Args&&... args)
```

The `for_loop` implements loop functionality over a range specified by iterator bounds. These algorithms resemble `for_each` from the Parallelism TS, but leave to the programmer when and if to dereference the iterator.

The execution of `for_loop` without specifying an execution policy is equivalent to specifying `hpx::execution::seq` as the execution policy.

Requires: *Iter* shall meet the requirements of an input iterator type. The *args* parameter pack shall have at least one element, comprising objects returned by invocations of *reduction* and/or *induction* function templates followed by exactly one element invocable element-access function, *f*. *f* shall meet the requirements of `MoveConstructible`.

Effects: Applies *f* to each element in the input sequence, with additional arguments corresponding to the reductions and inductions in the *args* parameter pack. The length of the input sequence is `last - first`.

The first element in the input sequence is specified by *first*. Each subsequent element is generated by incrementing the previous element.

Along with an element from the input sequence, for each member of the *args* parameter pack excluding *f*, an additional argument is passed to each application of *f* as follows:

If the pack member is an object returned by a call to a reduction function listed in section, then the additional argument is a reference to a view of that reduction object. If the pack member is an object returned by a call to induction, then the additional argument is the induction value for that induction object corresponding to the position of the application of *f* in the input sequence.

Complexity: Applies *f* exactly once for each element of the input sequence.

Remarks: If *f* returns a result, the result is ignored.

Note: As described in the C++ standard, arithmetic on non-random-access iterators is performed using `advance` and `distance`.

Note: The order of the elements of the input sequence is important for determining ordinal position of an application of f , even though the applications themselves may be unordered.

Template Parameters

- **Iter** – The type of the iteration variable (input iterator).
- **Sent** – The type of the source sentinel (deduced). This sentinel type must be a sentinel for Iter.
- **Args** – A parameter pack, it's last element is a function object to be invoked for each iteration, the others have to be either conforming to the induction or reduction concept.

Parameters

- **first** – Refers to the beginning of the sequence of elements the algorithm will be applied to.
- **last** – Refers to the end of the sequence of elements the algorithm will be applied to.
- **args** – The last element of this parameter pack is the function (object) to invoke, while the remaining elements of the parameter pack are instances of either induction or reduction objects. The function (or function object) which will be invoked for each of the elements in the sequence specified by [first, last) should expose a signature equivalent to:

```
<ignored> pred(Iter const& a, ...);
```

The signature does not need to have `const&`. It will receive the current value of the iteration variable and one argument for each of the induction or reduction objects passed to the algorithms, representing their current values.

```
template<typename ExPolicy, typename R, typename ...Args>
hpx::parallel::util::detail::algorithm_result<ExPolicy>::type for_loop(ExPolicy &&policy, R
&&rng, Args&&... args)
```

The `for_loop` implements loop functionality over a range specified by a range. These algorithms resemble `for_each` from the Parallelism TS, but leave to the programmer when and if to dereference the iterator.

Requires: `Rng::iterator` shall meet the requirements of a forward iterator type. The `args` parameter pack shall have at least one element, comprising objects returned by invocations of *reduction* and/or *induction* function templates followed by exactly one element invocable element-access function, f . f shall meet the requirements of `MoveConstructible`.

Effects: Applies f to each element in the input sequence, with additional arguments corresponding to the reductions and inductions in the `args` parameter pack. The length of the input sequence is `last - first`.

The first element in the input sequence is specified by *first*. Each subsequent element is generated by incrementing the previous element.

Along with an element from the input sequence, for each member of the `args` parameter pack excluding f , an additional argument is passed to each application of f as follows:

If the pack member is an object returned by a call to a reduction function listed in section, then the additional argument is a reference to a view of that reduction object. If the pack member is an object returned by a call to induction, then the additional argument is the induction value for that induction object corresponding to the position of the application of f in the input sequence.

Complexity: Applies f exactly once for each element of the input sequence.

Remarks: If f returns a result, the result is ignored.

Note: As described in the C++ standard, arithmetic on non-random-access iterators is performed using `advance` and `distance`.

Note: The order of the elements of the input sequence is important for determining ordinal position of an application of f , even though the applications themselves may be unordered.

Template Parameters

- **ExPolicy** – The type of the execution policy to use (deduced). It describes the manner in which the execution of the algorithm may be parallelized and the manner in which it applies user-provided function objects.
- **R** – The type of the source range used (deduced). The iterators extracted from this range type must meet the requirements of an input iterator.
- **Args** – A parameter pack, its last element is a function object to be invoked for each iteration, the others have to be either conforming to the induction or reduction concept.

Parameters

- **policy** – The execution policy to use for the scheduling of the iterations.
- **rng** – Refers to the sequence of elements the algorithm will be applied to.
- **args** – The last element of this parameter pack is the function (object) to invoke, while the remaining elements of the parameter pack are instances of either induction or reduction objects. The function (or function object) which will be invoked for each of the elements in the sequence specified by [first, last) should expose a signature equivalent to:

```
<ignored> pred(Rng::iterator const& a, ...);
```

The signature does not need to have `const&`. It will receive the current value of the iteration variable and one argument for each of the induction or reduction objects passed to the algorithms, representing their current values.

Returns The `for_loop` algorithm returns a `hpx::future<void>` if the execution policy is of type `hpx::execution::sequenced_task_policy` or `hpx::execution::parallel_task_policy` and returns `void` otherwise.

```
template<typename Rng, typename ...Args>
void for_loop(Rng &&rng, Args&&... args)
```

The `for_loop` implements loop functionality over a range specified by a range. These algorithms resemble `for_each` from the Parallelism TS, but leave to the programmer when and if to dereference the iterator.

The execution of `for_loop` without specifying an execution policy is equivalent to specifying `hpx::execution::seq` as the execution policy.

Requires: `Rng::iterator` shall meet the requirements of an input iterator type. The `args` parameter pack shall have at least one element, comprising objects returned by invocations of *reduction* and/or *induction* function templates followed by exactly one invocable element-access function, f . f shall meet the requirements of `MoveConstructible`.

Effects: Applies f to each element in the input sequence, with additional arguments corresponding to the reductions and inductions in the `args` parameter pack. The length of the input sequence is `last - first`.

The first element in the input sequence is specified by *first*. Each subsequent element is generated by incrementing the previous element.

Along with an element from the input sequence, for each member of the *args* parameter pack excluding *f*, an additional argument is passed to each application of *f* as follows:

If the pack member is an object returned by a call to a reduction function listed in section, then the additional argument is a reference to a view of that reduction object. If the pack member is an object returned by a call to induction, then the additional argument is the induction value for that induction object corresponding to the position of the application of *f* in the input sequence.

Complexity: Applies *f* exactly once for each element of the input sequence.

Remarks: If *f* returns a result, the result is ignored.

Note: As described in the C++ standard, arithmetic on non-random-access iterators is performed using *advance* and *distance*.

Note: The order of the elements of the input sequence is important for determining ordinal position of an application of *f*, even though the applications themselves may be unordered.

Template Parameters

- **Rng** – The type of the source range used (deduced). The iterators extracted from this range type must meet the requirements of an input iterator.
- **Args** – A parameter pack, its last element is a function object to be invoked for each iteration, the others have to be either conforming to the induction or reduction concept.

Parameters

- **rng** – Refers to the of the sequence of elements the algorithm will be applied to.
- **args** – The last element of this parameter pack is the function (object) to invoke, while the remaining elements of the parameter pack are instances of either induction or reduction objects. The function (or function object) which will be invoked for each of the elements in the sequence specified by [*first*, *last*) should expose a signature equivalent to:

```
<ignored> pred(Rng::iterator const& a, ...);
```

The signature does not need to have `const&`. It will receive the current value of the iteration variable and one argument for each of the induction or reduction objects passed to the algorithms, representing their current values.

```
template<typename ExPolicy, typename Iter, typename Sent, typename S, typename ...Args>
hpx::parallel::util::detail::algorithm_result_t<ExPolicy> for_loop_strided(ExPolicy &&policy,
                                                                    Iter first, Sent last, S
                                                                    stride, Args&&...
                                                                    args)
```

The `for_loop_strided` implements loop functionality over a range specified by iterator bounds. These algorithms resemble `for_each` from the Parallelism TS, but leave to the programmer when and if to dereference the iterator.

Requires: *Iter* shall meet the requirements of a forward iterator type. The *args* parameter pack shall have at least one element, comprising objects returned by invocations of *reduction* and/or

induction function templates followed by exactly one element invocable element-access function, *f*. *f* shall meet the requirements of MoveConstructible.

Effects: Applies *f* to each element in the input sequence, with additional arguments corresponding to the reductions and inductions in the *args* parameter pack. The length of the input sequence is last - first.

The first element in the input sequence is specified by *first*. Each subsequent element is generated by incrementing the previous element.

Along with an element from the input sequence, for each member of the *args* parameter pack excluding *f*, an additional argument is passed to each application of *f* as follows:

If the pack member is an object returned by a call to a reduction function listed in section, then the additional argument is a reference to a view of that reduction object. If the pack member is an object returned by a call to induction, then the additional argument is the induction value for that induction object corresponding to the position of the application of *f* in the input sequence.

Complexity: Applies *f* exactly once for each element of the input sequence.

Remarks: If *f* returns a result, the result is ignored.

Note: As described in the C++ standard, arithmetic on non-random-access iterators is performed using advance and distance.

Note: The order of the elements of the input sequence is important for determining ordinal position of an application of *f*, even though the applications themselves may be unordered.

Template Parameters

- **ExPolicy** – The type of the execution policy to use (deduced). It describes the manner in which the execution of the algorithm may be parallelized and the manner in which it applies user-provided function objects.
- **Iter** – The type of the iteration variable (forward iterator).
- **Sent** – The type of the source sentinel (deduced). This sentinel type must be a sentinel for Iter.
- **S** – The type of the stride variable. This should be an integral type.
- **Args** – A parameter pack, its last element is a function object to be invoked for each iteration, the others have to be either conforming to the induction or reduction concept.

Parameters

- **policy** – The execution policy to use for the scheduling of the iterations.
- **first** – Refers to the beginning of the sequence of elements the algorithm will be applied to.
- **last** – Refers to the end of the sequence of elements the algorithm will be applied to.
- **stride** – Refers to the stride of the iteration steps. This shall have non-zero value and shall be negative only if Iter meets the requirements a bidirectional iterator.
- **args** – The last element of this parameter pack is the function (object) to invoke, while the remaining elements of the parameter pack are instances of either induction or reduction objects. The function (or function object) which will be invoked for each of the elements in the sequence specified by [first, last) should expose a signature equivalent to:

```
<ignored> pred(Iter const& a, ...);
```

The signature does not need to have `const&`. It will receive the current value of the iteration variable and one argument for each of the induction or reduction objects passed to the algorithms, representing their current values.

Returns The `for_loop_strided` algorithm returns a `hpx::future<void>` if the execution policy is of type `hpx::execution::sequenced_task_policy` or `hpx::execution::parallel_task_policy` and returns `void` otherwise.

```
template<typename Iter, typename Sent, typename S, typename ...Args>  
void for_loop_strided(Iter first, Sent last, S stride, Args&&... args)
```

The `for_loop_strided` implements loop functionality over a range specified by iterator bounds. These algorithms resemble `for_each` from the Parallelism TS, but leave to the programmer when and if to dereference the iterator.

The execution of `for_loop_strided` without specifying an execution policy is equivalent to specifying `hpx::execution::seq` as the execution policy.

Requires: *Iter* shall meet the requirements of an input iterator type. The *args* parameter pack shall have at least one element, comprising objects returned by invocations of *reduction* and/or *induction* function templates followed by exactly one element invocable element-access function, *f*. *f* shall meet the requirements of `MoveConstructible`.

Effects: Applies *f* to each element in the input sequence, with additional arguments corresponding to the reductions and inductions in the *args* parameter pack. The length of the input sequence is `last - first`.

The first element in the input sequence is specified by *first*. Each subsequent element is generated by incrementing the previous element.

Along with an element from the input sequence, for each member of the *args* parameter pack excluding *f*, an additional argument is passed to each application of *f* as follows:

If the pack member is an object returned by a call to a reduction function listed in section, then the additional argument is a reference to a view of that reduction object. If the pack member is an object returned by a call to induction, then the additional argument is the induction value for that induction object corresponding to the position of the application of *f* in the input sequence.

Complexity: Applies *f* exactly once for each element of the input sequence.

Remarks: If *f* returns a result, the result is ignored.

Note: As described in the C++ standard, arithmetic on non-random-access iterators is performed using `advance` and `distance`.

Note: The order of the elements of the input sequence is important for determining ordinal position of an application of *f*, even though the applications themselves may be unordered.

Template Parameters

- **Iter** – The type of the iteration variable (input iterator).
- **Sent** – The type of the source sentinel (deduced). This sentinel type must be a sentinel for *Iter*.
- **S** – The type of the stride variable. This should be an integral type.
- **Args** – A parameter pack, its last element is a function object to be invoked for each iteration, the others have to be either conforming to the induction or reduction concept.

Parameters

- **first** – Refers to the beginning of the sequence of elements the algorithm will be applied to.
- **last** – Refers to the end of the sequence of elements the algorithm will be applied to.
- **stride** – Refers to the stride of the iteration steps. This shall have non-zero value and shall be negative only if *Iter* meets the requirements a bidirectional iterator.
- **args** – The last element of this parameter pack is the function (object) to invoke, while the remaining elements of the parameter pack are instances of either induction or reduction objects. The function (or function object) which will be invoked for each of the elements in the sequence specified by $[first, last)$ should expose a signature equivalent to:

```
<ignored> pred(Iter const& a, ...);
```

The signature does not need to have `const&`. It will receive the current value of the iteration variable and one argument for each of the induction or reduction objects passed to the algorithms, representing their current values.

```
template<typename ExPolicy, typename Rng, typename S, typename ...Args>
hpx::parallel::util::detail::algorithm_result_t<ExPolicy> for_loop_strided(ExPolicy &&policy,
                                                                    Rng &&rng, S stride,
                                                                    Args&&... args)
```

The `for_loop_strided` implements loop functionality over a range specified by a range. These algorithms resemble `for_each` from the Parallelism TS, but leave to the programmer when and if to dereference the iterator.

Requires: *Rng::iterator* shall meet the requirements of a forward iterator type. The *args* parameter pack shall have at least one element, comprising objects returned by invocations of *reduction* and/or *induction* function templates followed by exactly one element invocable element-access function, *f*. *f* shall meet the requirements of `MoveConstructible`.

Effects: Applies *f* to each element in the input sequence, with additional arguments corresponding to the reductions and inductions in the *args* parameter pack. The length of the input sequence is `last - first`.

The first element in the input sequence is specified by *first*. Each subsequent element is generated by incrementing the previous element.

Along with an element from the input sequence, for each member of the *args* parameter pack excluding *f*, an additional argument is passed to each application of *f* as follows:

If the pack member is an object returned by a call to a reduction function listed in section, then the additional argument is a reference to a view of that reduction object. If the pack member is an object returned by a call to induction, then the additional argument is the induction value for that induction object corresponding to the position of the application of *f* in the input sequence.

Complexity: Applies *f* exactly once for each element of the input sequence.

Remarks: If *f* returns a result, the result is ignored.

Note: As described in the C++ standard, arithmetic on non-random-access iterators is performed using `advance` and `distance`.

Note: The order of the elements of the input sequence is important for determining ordinal position of an application of f , even though the applications themselves may be unordered.

Template Parameters

- **ExPolicy** – The type of the execution policy to use (deduced). It describes the manner in which the execution of the algorithm may be parallelized and the manner in which it applies user-provided function objects.
- **Rng** – The type of the source range used (deduced). The iterators extracted from this range type must meet the requirements of an input iterator.
- **S** – The type of the stride variable. This should be an integral type.
- **Args** – A parameter pack, its last element is a function object to be invoked for each iteration, the others have to be either conforming to the induction or reduction concept.

Parameters

- **policy** – The execution policy to use for the scheduling of the iterations.
- **rng** – Refers to theof the sequence of elements the algorithm will be applied to.
- **stride** – Refers to the stride of the iteration steps. This shall have non-zero value and shall be negative only if `Rng::iterator` meets the requirements a bidirectional iterator.
- **args** – The last element of this parameter pack is the function (object) to invoke, while the remaining elements of the parameter pack are instances of either induction or reduction objects. The function (or function object) which will be invoked for each of the elements in the sequence specified by [first, last) should expose a signature equivalent to:

```
<ignored> pred(Rng::iterator const& a, ...);
```

The signature does not need to have `const&`. It will receive the current value of the iteration variable and one argument for each of the induction or reduction objects passed to the algorithms, representing their current values.

Returns The `for_loop_strided` algorithm returns a `hpx::future<void>` if the execution policy is of type `hpx::execution::sequenced_task_policy` or `hpx::execution::parallel_task_policy` and returns `void` otherwise.

```
template<typename Rng, typename S, typename ...Args>
void for_loop_strided(Rng &&rng, S stride, Args&&... args)
```

The `for_loop_strided` implements loop functionality over a range specified by a range. These algorithms resemble `for_each` from the Parallelism TS, but leave to the programmer when and if to dereference the iterator.

The execution of `for_loop_strided` without specifying an execution policy is equivalent to specifying `hpx::execution::seq` as the execution policy.

Requires: `Rng::iterator` shall meet the requirements of an input iterator type. The `args` parameter pack shall have at least one element, comprising objects returned by invocations of *reduction* and/or *induction* function templates followed by exactly one element invocable element-access function, f . f shall meet the requirements of `MoveConstructible`.

Effects: Applies f to each element in the input sequence, with additional arguments corresponding to the reductions and inductions in the `args` parameter pack. The length of the input sequence is `last - first`.

The first element in the input sequence is specified by *first*. Each subsequent element is generated by incrementing the previous element.

Along with an element from the input sequence, for each member of the *args* parameter pack excluding *f*, an additional argument is passed to each application of *f* as follows:

If the pack member is an object returned by a call to a reduction function listed in section, then the additional argument is a reference to a view of that reduction object. If the pack member is an object returned by a call to induction, then the additional argument is the induction value for that induction object corresponding to the position of the application of *f* in the input sequence.

Complexity: Applies *f* exactly once for each element of the input sequence.

Remarks: If *f* returns a result, the result is ignored.

Note: As described in the C++ standard, arithmetic on non-random-access iterators is performed using `advance` and `distance`.

Note: The order of the elements of the input sequence is important for determining ordinal position of an application of *f*, even though the applications themselves may be unordered.

Template Parameters

- **Rng** – The type of the source range used (deduced). The iterators extracted from this range type must meet the requirements of an input iterator.
- **S** – The type of the stride variable. This should be an integral type.
- **Args** – A parameter pack, it's last element is a function object to be invoked for each iteration, the others have to be either conforming to the induction or reduction concept.

Parameters

- **rng** – Refers to theof the sequence of elements the algorithm will be applied to.
- **stride** – Refers to the stride of the iteration steps. This shall have non-zero value and shall be negative only if `Rng::iterator` meets the requirements a bidirectional iterator.
- **args** – The last element of this parameter pack is the function (object) to invoke, while the remaining elements of the parameter pack are instances of either induction or reduction objects. The function (or function object) which will be invoked for each of the elements in the sequence specified by `[first, last)` should expose a signature equivalent to:

```
<ignored> pred(Rng::iterator const& a, ...);
```

The signature does not need to have `const&`. It will receive the current value of the iteration variable and one argument for each of the induction or reduction objects passed to the algorithms, representing their current values.

`hpx::ranges::generate`, `hpx::ranges::generate_n`

Defined in header `hpx/algorithm.hpp`⁶⁴⁹.

See *Public API* for a list of names and headers that are part of the public *HPX* API.

namespace **hpx**

namespace **ranges**

⁶⁴⁹ <http://github.com/STELLAR-GROUP/hpx/blob/8a3b7c1a4cb5693b2f7d9f587f759392ed0c51a0/libs/full/include/include/hpx/algorithm.hpp>

Functions

```
template<typename ExPolicy, typename Rng, typename F>
hpx::parallel::util::detail::algorithm_result<ExPolicy, hpx::traits::range_iterator_t<Rng>> generate(ExPolicy
&&pol-
icy,
Rng
&&rng,
F
&&f)
```

Assign each element in range [first, last) a value generated by the given function object *f*

The assignments in the parallel *generate* algorithm invoked with an execution policy object of type *sequenced_policy* execute in sequential order in the calling thread.

The assignments in the parallel *generate* algorithm invoked with an execution policy object of type *parallel_policy* or *parallel_task_policy* are permitted to execute in an unordered fashion in unspecified threads, and indeterminately sequenced within each thread.

Note: Complexity: Exactly *distance(first, last)* invocations of *f* and assignments.

Template Parameters

- **ExPolicy** – The type of the execution policy to use (deduced). It describes the manner in which the execution of the algorithm may be parallelized and the manner in which it executes the assignments.
- **Rng** – The type of the source range used (deduced). The iterators extracted from this range type must meet the requirements of an forward iterator.
- **F** – The type of the function/function object to use (deduced). Unlike its sequential form, the parallel overload of *equal* requires *F* to meet the requirements of *CopyConstructible*.

Parameters

- **policy** – The execution policy to use for the scheduling of the iterations.
- **rng** – Refers to the sequence of elements the algorithm will be applied to.
- **f** – generator function that will be called. signature of function should be equivalent to the following:

```
Ret fun();
```

The type *Ret* must be such that an object of type *FwdIter* can be dereferenced and assigned a value of type *Ret*.

Returns The *replace_if* algorithm returns a *hpx::future<FwdIter>* if the execution policy is of type *sequenced_task_policy* or *parallel_task_policy* and returns *FwdIter* otherwise. It returns *last*.

```
template<typename ExPolicy, typename Iter, typename Sent, typename F>
hpx::parallel::util::detail::algorithm_result_t<ExPolicy, Iter> generate(ExPolicy &&policy, Iter first,
Sent last, F &&f)
```

Assign each element in range [first, last) a value generated by the given function object *f*

The assignments in the parallel *generate* algorithm invoked with an execution policy object of type *sequenced_policy* execute in sequential order in the calling thread.

The assignments in the parallel *generate* algorithm invoked with an execution policy object of type *parallel_policy* or *parallel_task_policy* are permitted to execute in an unordered fashion in unspecified threads, and indeterminately sequenced within each thread.

Note: Complexity: Exactly *distance(first, last)* invocations of *f* and assignments.

Template Parameters

- **ExPolicy** – The type of the execution policy to use (deduced). It describes the manner in which the execution of the algorithm may be parallelized and the manner in which it executes the assignments.
- **Iter** – The type of the source begin iterator used (deduced). This iterator type must meet the requirements of an forward iterator.
- **Sent** – The type of the source end iterator used (deduced). This iterator type must meet the requirements of an forward iterator.
- **F** – The type of the function/function object to use (deduced). Unlike its sequential form, the parallel overload of *equal* requires *F* to meet the requirements of *CopyConstructible*.

Parameters

- **policy** – The execution policy to use for the scheduling of the iterations.
- **first** – Refers to the beginning of the sequence of elements the algorithm will be applied to.
- **last** – Refers to the end of the sequence of elements the algorithm will be applied to.
- **f** – generator function that will be called. signature of function should be equivalent to the following:

```
Ret fun();
```

The type *Ret* must be such that an object of type *FwdIter* can be dereferenced and assigned a value of type *Ret*.

Returns The *replace_if* algorithm returns a *hpx::future<FwdIter>* if the execution policy is of type *sequenced_task_policy* or *parallel_task_policy* and returns *FwdIter* otherwise. It returns *last*.

```
template<typename Rng, typename F>
hpx::traits::range_iterator_t<Rng> generate(Rng &&rng, F &&f)
```

Assign each element in range [first, last) a value generated by the given function object *f*

Note: Complexity: Exactly *distance(first, last)* invocations of *f* and assignments.

Template Parameters

- **Rng** – The type of the source range used (deduced). The iterators extracted from this range type must meet the requirements of an forward iterator.
- **F** – The type of the function/function object to use (deduced). Unlike its sequential form, the parallel overload of *equal* requires *F* to meet the requirements of *CopyConstructible*.

Parameters

- **rng** – Refers to the sequence of elements the algorithm will be applied to.
- **f** – generator function that will be called. signature of function should be equivalent to the following:

```
Ret fun();
```

The type *Ret* must be such that an object of type *FwdIter* can be dereferenced and assigned a value of type *Ret*.

Returns The *replace_if* algorithm returns *last*.

```
template<typename Iter, typename Sent, typename F>
Iter generate(Iter first, Sent last, F &&f)
```

Assign each element in range [first, last) a value generated by the given function object *f*

Note: Complexity: Exactly *distance(first, last)* invocations of *f* and assignments.

Template Parameters

- **Iter** – The type of the source begin iterator used (deduced). This iterator type must meet the requirements of an forward iterator.
- **Sent** – The type of the source end iterator used (deduced). This iterator type must meet the requirements of an forward iterator.
- **F** – The type of the function/function object to use (deduced). Unlike its sequential form, the parallel overload of *equal* requires *F* to meet the requirements of *CopyConstructible*.

Parameters

- **first** – Refers to the beginning of the sequence of elements the algorithm will be applied to.
- **last** – Refers to the end of the sequence of elements the algorithm will be applied to.
- **f** – generator function that will be called. signature of function should be equivalent to the following:

```
Ret fun();
```

The type *Ret* must be such that an object of type *FwdIter* can be dereferenced and assigned a value of type *Ret*.

Returns The *replace_if* algorithm returns *last*.

```
template<typename ExPolicy, typename FwdIter, typename Size, typename F>
hpx::parallel::util::detail::algorithm_result_t<ExPolicy, FwdIter> generate_n(ExPolicy &&policy,
                                     FwdIter first, Size count,
                                     F &&f)
```

Assigns each element in range [first, first+count) a value generated by the given function object *g*.

The assignments in the parallel *generate_n* algorithm invoked with an execution policy object of type *sequenced_policy* execute in sequential order in the calling thread.

The assignments in the parallel *generate_n* algorithm invoked with an execution policy object of type *parallel_policy* or *parallel_task_policy* are permitted to execute in an unordered fashion in unspecified threads, and indeterminately sequenced within each thread.

Note: Complexity: Exactly *count* invocations of *f* and assignments, for count > 0.

Template Parameters

- **ExPolicy** – The type of the execution policy to use (deduced). It describes the manner in which the execution of the algorithm may be parallelized and the manner in which it executes the assignments.
- **FwdIter** – The type of the source iterators used (deduced). This iterator type must meet the requirements of an forward iterator.
- **Size** – The type of the argument specifying the number of elements to apply *f* to.
- **F** – The type of the function/function object to use (deduced). Unlike its sequential form, the parallel overload of *equal* requires *F* to meet the requirements of *CopyConstructible*.

Parameters

- **policy** – The execution policy to use for the scheduling of the iterations.

- **first** – Refers to the beginning of the sequence of elements the algorithm will be applied to.
- **count** – Refers to the number of elements in the sequence the algorithm will be applied to.
- **f** – Refers to the generator function object that will be called. The signature of the function should be equivalent to

```
Ret fun();
```

The type *Ret* must be such that an object of type *OutputIt* can be dereferenced and assigned a value of type *Ret*.

Returns The *replace_if* algorithm returns a *hpx::future<FwdIter>* if the execution policy is of type *sequenced_task_policy* or *parallel_task_policy* and returns *FwdIter* otherwise. It returns *last*.

```
template<typename FwdIter, typename Size, typename F>
FwdIter generate_n(FwdIter first, Size count, F &&f)
```

Assigns each element in range [first, first+count) a value generated by the given function object *g*.

Note: Complexity: Exactly *count* invocations of *f* and assignments, for count > 0.

Template Parameters

- **FwdIter** – The type of the source iterators used (deduced). This iterator type must meet the requirements of an forward iterator.
- **Size** – The type of the argument specifying the number of elements to apply *f* to.
- **F** – The type of the function/function object to use (deduced). Unlike its sequential form, the parallel overload of *equal* requires *F* to meet the requirements of *CopyConstructible*.

Parameters

- **first** – Refers to the beginning of the sequence of elements the algorithm will be applied to.
- **count** – Refers to the number of elements in the sequence the algorithm will be applied to.
- **f** – Refers to the generator function object that will be called. The signature of the function should be equivalent to

```
Ret fun();
```

The type *Ret* must be such that an object of type *OutputIt* can be dereferenced and assigned a value of type *Ret*.

Returns The *replace_if* algorithm returns *last*.

hpx::ranges::includes

Defined in header `hpx/algorithm.hpp`⁶⁵⁰.

See *Public API* for a list of names and headers that are part of the public *HPX* API.

```
namespace hpx
```

```
    namespace ranges
```

⁶⁵⁰ <http://github.com/STELLAR-GROUP/hpx/blob/8a3b7c1a4cb5693b2f7d9f587f759392ed0c51a0/libs/full/include/include/hpx/algorithm.hpp>

Functions

```
template<typename ExPolicy, typename Iter1, typename Sent1, typename Iter2, typename Sent2,
typename Pred = hpx::parallel::detail::less, typename Proj1 = hpx::identity, typename Proj2 =
hpx::identity>
hpx::parallel::util::detail::algorithm_result_t<ExPolicy, bool> includes(ExPolicy &&policy, Iter1
first1, Sent1 last1, Iter2 first2,
Sent2 last2, Pred &&op =
Pred(), Proj1 &&proj1 =
Proj1(), Proj2 &&proj2 =
Proj2())
```

Returns true if every element from the sorted range [first2, last2) is found within the sorted range [first1, last1). Also returns true if [first2, last2) is empty. The version expects both ranges to be sorted with the user supplied binary predicate *f*.

The comparison operations in the parallel *includes* algorithm invoked with an execution policy object of type *sequenced_policy* execute in sequential order in the calling thread.

The comparison operations in the parallel *includes* algorithm invoked with an execution policy object of type *parallel_policy* or *parallel_task_policy* are permitted to execute in an unordered fashion in unspecified threads, and indeterminately sequenced within each thread.

Note: At most $2*(N1+N2-1)$ comparisons, where $N1 = \text{std::distance}(\text{first1}, \text{last1})$ and $N2 = \text{std::distance}(\text{first2}, \text{last2})$.

Template Parameters

- **ExPolicy** – The type of the execution policy to use (deduced). It describes the manner in which the execution of the algorithm may be parallelized and the manner in which it executes the assignments.
- **Iter1** – The type of the source iterators used (deduced) representing the first sequence. This iterator type must meet the requirements of an forward iterator.
- **Sent1** – The type of the end source iterators used (deduced). This iterator type must meet the requirements of an sentinel for Iter1.
- **Iter2** – The type of the source iterators used (deduced) representing the second sequence. This iterator type must meet the requirements of an forward iterator.
- **Sent2** – The type of the end source iterators used (deduced) representing the second sequence. This iterator type must meet the requirements of an sentinel for Iter2.
- **Pred** – The type of an optional function/function object to use. Unlike its sequential form, the parallel overload of *includes* requires *Pred* to meet the requirements of *Copy-Constructible*. This defaults to `std::less<>`
- **Proj1** – The type of an optional projection function applied to the first sequence. This defaults to *hpx::identity*
- **Proj2** – The type of an optional projection function applied to the second sequence. This defaults to *hpx::identity*

Parameters

- **policy** – The execution policy to use for the scheduling of the iterations.
- **first1** – Refers to the beginning of the sequence of elements of the first range the algorithm will be applied to.
- **last1** – Refers to the end of the sequence of elements of the first range the algorithm will be applied to.
- **first2** – Refers to the beginning of the sequence of elements of the second range the algorithm will be applied to.

- **last2** – Refers to the end of the sequence of elements of the second range the algorithm will be applied to.
- **op** – The binary predicate which returns true if the elements should be treated as includes. The signature of the predicate function should be equivalent to the following:

```
bool pred(const Type1 &a, const Type2 &b);
```

The signature does not need to have `const &`, but the function must not modify the objects passed to it. The types *Type1* and *Type2* must be such that objects of types *FwdIter1* and *FwdIter2* can be dereferenced and then implicitly converted to *Type1* and *Type2* respectively

- **proj1** – Specifies the function (or function object) which will be invoked for each of the elements of the first sequence as a projection operation before the actual predicate *op* is invoked.
- **proj2** – Specifies the function (or function object) which will be invoked for each of the elements of the second sequence as a projection operation before the actual predicate *op* is invoked.

Returns The *includes* algorithm returns a *hpx::future<bool>* if the execution policy is of type *sequenced_task_policy* or *parallel_task_policy* and returns *bool* otherwise. The *includes* algorithm returns true every element from the sorted range [first2, last2) is found within the sorted range [first1, last1). Also returns true if [first2, last2) is empty.

```
template<typename Iter1, typename Sent1, typename Iter2, typename Sent2, typename Pred =
hpx::parallel::detail::less, typename Proj1 = hpx::identity, typename Proj2 = hpx::identity>
bool includes(Iter1 first1, Sent1 last1, Iter2 first2, Sent2 last2, Pred &&op = Pred(), Proj1 &&proj1 =
Proj1(), Proj2 &&proj2 = Proj2())
```

Returns true if every element from the sorted range [first2, last2) is found within the sorted range [first1, last1). Also returns true if [first2, last2) is empty. The version expects both ranges to be sorted with the user supplied binary predicate *f*.

Note: At most $2*(N1+N2-1)$ comparisons, where $N1 = \text{std::distance}(\text{first1}, \text{last1})$ and $N2 = \text{std::distance}(\text{first2}, \text{last2})$.

Template Parameters

- **Iter1** – The type of the source iterators used (deduced) representing the first sequence. This iterator type must meet the requirements of an forward iterator.
- **Sent1** – The type of the end source iterators used (deduced). This iterator type must meet the requirements of an sentinel for Iter1.
- **Iter2** – The type of the source iterators used (deduced) representing the second sequence. This iterator type must meet the requirements of an forward iterator.
- **Sent2** – The type of the end source iterators used (deduced) representing the second sequence. This iterator type must meet the requirements of an sentinel for Iter2.
- **Pred** – The type of an optional function/function object to use. Unlike its sequential form, the parallel overload of *includes* requires *Pred* to meet the requirements of *CopyConstructible*. This defaults to `std::less<>`
- **Proj1** – The type of an optional projection function applied to the first sequence. This defaults to *hpx::identity*
- **Proj2** – The type of an optional projection function applied to the second sequence. This defaults to *hpx::identity*

Parameters

- **first1** – Refers to the beginning of the sequence of elements of the first range the algorithm will be applied to.
- **last1** – Refers to the end of the sequence of elements of the first range the algorithm

will be applied to.

- **first2** – Refers to the beginning of the sequence of elements of the second range the algorithm will be applied to.
- **last2** – Refers to the end of the sequence of elements of the second range the algorithm will be applied to.
- **op** – The binary predicate which returns true if the elements should be treated as includes. The signature of the predicate function should be equivalent to the following:

```
bool pred(const Type1 &a, const Type2 &b);
```

The signature does not need to have `const &`, but the function must not modify the objects passed to it. The types *Type1* and *Type2* must be such that objects of types *FwdIter1* and *FwdIter2* can be dereferenced and then implicitly converted to *Type1* and *Type2* respectively

- **proj1** – Specifies the function (or function object) which will be invoked for each of the elements of the first sequence as a projection operation before the actual predicate *op* is invoked.
- **proj2** – Specifies the function (or function object) which will be invoked for each of the elements of the second sequence as a projection operation before the actual predicate *op* is invoked.

Returns The *includes* algorithm returns true every element from the sorted range [first2, last2) is found within the sorted range [first1, last1). Also returns true if [first2, last2) is empty.

```
template<typename ExPolicy, typename Rng1, typename Rng2, typename Pred =
hpx::parallel::detail::less, typename Proj1 = hpx::identity, typename Proj2 = hpx::identity>
hpx::parallel::util::detail::algorithm_result_t<ExPolicy, bool> includes(ExPolicy &&policy, Rng1
&&rng1, Rng2 &&rng2, Pred
&&op = Pred(), Proj1
&&proj1 = Proj1(), Proj2
&&proj2 = Proj2())
```

Returns true if every element from the sorted range [first2, last2) is found within the sorted range [first1, last1). Also returns true if [first2, last2) is empty. The version expects both ranges to be sorted with the user supplied binary predicate *f*.

The comparison operations in the parallel *includes* algorithm invoked with an execution policy object of type *sequenced_policy* execute in sequential order in the calling thread.

The comparison operations in the parallel *includes* algorithm invoked with an execution policy object of type *parallel_policy* or *parallel_task_policy* are permitted to execute in an unordered fashion in unspecified threads, and indeterminately sequenced within each thread.

Note: At most $2 \cdot (N1 + N2 - 1)$ comparisons, where $N1 = \text{std::distance}(\text{first1}, \text{last1})$ and $N2 = \text{std::distance}(\text{first2}, \text{last2})$.

Template Parameters

- **ExPolicy** – The type of the execution policy to use (deduced). It describes the manner in which the execution of the algorithm may be parallelized and the manner in which it executes the assignments.
- **Rng1** – The type of the source range used (deduced). The iterators extracted from this range type must meet the requirements of an input iterator.
- **Rng2** – The type of the source range used (deduced). The iterators extracted from this range type must meet the requirements of an input iterator.

- **Pred** – The type of an optional function/function object to use. Unlike its sequential form, the parallel overload of *includes* requires *Pred* to meet the requirements of *Copy-Constructible*. This defaults to `std::less<>`
- **Proj1** – The type of an optional projection function applied to the first sequence. This defaults to `hpx::identity`
- **Proj2** – The type of an optional projection function applied to the second sequence. This defaults to `hpx::identity`

Parameters

- **policy** – The execution policy to use for the scheduling of the iterations.
- **rng1** – Refers to the first sequence of elements the algorithm will be applied to.
- **rng2** – Refers to the second sequence of elements the algorithm will be applied to.
- **op** – The binary predicate which returns true if the elements should be treated as includes. The signature of the predicate function should be equivalent to the following:

```
bool pred(const Type1 &a, const Type2 &b);
```

The signature does not need to have `const &`, but the function must not modify the objects passed to it. The types *Type1* and *Type2* must be such that objects of types *FwdIter1* and *FwdIter2* can be dereferenced and then implicitly converted to *Type1* and *Type2* respectively

- **proj1** – Specifies the function (or function object) which will be invoked for each of the elements of the first sequence as a projection operation before the actual predicate *op* is invoked.
- **proj2** – Specifies the function (or function object) which will be invoked for each of the elements of the second sequence as a projection operation before the actual predicate *op* is invoked.

Returns The *includes* algorithm returns a `hpx::future<bool>` if the execution policy is of type *sequenced_task_policy* or *parallel_task_policy* and returns `bool` otherwise. The *includes* algorithm returns true every element from the sorted range [first2, last2) is found within the sorted range [first1, last1). Also returns true if [first2, last2) is empty.

```
template<typename Rng1, typename Rng2, typename Pred = hpx::parallel::detail::less, typename Proj1
= hpx::identity, typename Proj2 = hpx::identity>
bool includes(Rng1 &&rng1, Rng2 &&rng2, Pred &&op = Pred(), Proj1 &&proj1 = Proj1(), Proj2
&&proj2 = Proj2())
```

Returns true if every element from the sorted range [first2, last2) is found within the sorted range [first1, last1). Also returns true if [first2, last2) is empty. The version expects both ranges to be sorted with the user supplied binary predicate *f*.

Note: At most $2*(N1+N2-1)$ comparisons, where $N1 = \text{std::distance}(\text{first1}, \text{last1})$ and $N2 = \text{std::distance}(\text{first2}, \text{last2})$.

Template Parameters

- **Rng1** – The type of the source range used (deduced). The iterators extracted from this range type must meet the requirements of an input iterator.
- **Rng2** – The type of the source range used (deduced). The iterators extracted from this range type must meet the requirements of an input iterator.
- **Pred** – The type of an optional function/function object to use. Unlike its sequential form, the parallel overload of *includes* requires *Pred* to meet the requirements of *Copy-Constructible*. This defaults to `std::less<>`
- **Proj1** – The type of an optional projection function applied to the first sequence. This defaults to `hpx::identity`
- **Proj2** – The type of an optional projection function applied to the second sequence. This

defaults to `hpx::identity`

Parameters

- **rng1** – Refers to the first sequence of elements the algorithm will be applied to.
- **rng2** – Refers to the second sequence of elements the algorithm will be applied to.
- **op** – The binary predicate which returns true if the elements should be treated as includes. The signature of the predicate function should be equivalent to the following:

```
bool pred(const Type1 &a, const Type2 &b);
```

The signature does not need to have `const &`, but the function must not modify the objects passed to it. The types *Type1* and *Type2* must be such that objects of types *FwdIter1* and *FwdIter2* can be dereferenced and then implicitly converted to *Type1* and *Type2* respectively

- **proj1** – Specifies the function (or function object) which will be invoked for each of the elements of the first sequence as a projection operation before the actual predicate *op* is invoked.
- **proj2** – Specifies the function (or function object) which will be invoked for each of the elements of the second sequence as a projection operation before the actual predicate *op* is invoked.

Returns The *includes* algorithm returns true every element from the sorted range [first2, last2) is found within the sorted range [first1, last1). Also returns true if [first2, last2) is empty.

hpx::ranges::inclusive_scan

Defined in header `hpx/algorithm.hpp`⁶⁵¹.

See *Public API* for a list of names and headers that are part of the public *HPX* API.

namespace **hpx**

namespace **ranges**

Functions

```
template<typename InIter, typename Sent, typename OutIter, typename Op = std::plus<typename
std::iterator_traits<InIter>::value_type>>
```

```
inclusive_scan_result<InIter, OutIter> inclusive_scan(InIter first, Sent last, OutIter dest, Op &&op)
```

Assigns through each iterator *i* in [result, result + (last - first)) the value of GENERALIZED_NONCOMMUTATIVE_SUM(op, *first, ..., *(first + (i - result))).

The reduce operations in the parallel *inclusive_scan* algorithm invoked without an execution policy object will execute in sequential order in the calling thread.

The difference between *exclusive_scan* and *inclusive_scan* is that *inclusive_scan* includes the *i*th input element in the *i*th sum.

⁶⁵¹ <http://github.com/STELLAR-GROUP/hpx/blob/8a3b7c1a4cb5693b2f7d9f587f759392ed0c51a0/libs/full/include/include/hpx/algorithm.hpp>

Note: Complexity: $O(\text{last} - \text{first})$ applications of the predicate *op*.

Note: GENERALIZED_NONCOMMUTATIVE_SUM(+, a1, ..., aN) is defined as:

- a1 when N is 1
 - GENERALIZED_NONCOMMUTATIVE_SUM(+, a1, ..., aK)
 - GENERALIZED_NONCOMMUTATIVE_SUM(+, aM, ..., aN) where $1 < K+1 = M \leq N$.
-

Template Parameters

- **InIter** – The type of the source iterators used (deduced). This iterator type must meet the requirements of an input iterator.
- **Sent** – The type of the source sentinel (deduced). This sentinel type must be a sentinel for InIter.
- **OutIter** – The type of the iterator representing the destination range (deduced). This iterator type must meet the requirements of an output iterator.
- **Op** – The type of the binary function object used for the reduction operation.

Parameters

- **first** – Refers to the beginning of the sequence of elements the algorithm will be applied to.
- **last** – Refers to sentinel value denoting the end of the sequence of elements the algorithm will be applied.
- **dest** – Refers to the beginning of the destination range.
- **op** – Specifies the function (or function object) which will be invoked for each of the values of the input sequence. This is a binary predicate. The signature of this predicate should be equivalent to:

```
Ret fun(const Type1 &a, const Type1 &b);
```

The signature does not need to have const&, but the function must not modify the objects passed to it. The types *Type1* and *Ret* must be such that an object of a type as given by the input sequence can be implicitly converted to any of those types.

Returns The *inclusive_scan* algorithm returns *util::in_out_result<InIter, OutIter>*. The *inclusive_scan* algorithm returns an input iterator to the point denoted by the sentinel and an output iterator to the element in the destination range, one past the last element copied.

```
template<typename ExPolicy, typename FwdIter1, typename Sent, typename FwdIter2, typename Op = std::plus<typename std::iterator_traits<FwdIter1>::value_type>>
parallel::util::detail::algorithm_result<ExPolicy, inclusive_scan_result<FwdIter1, FwdIter2>>::type inclusive_scan(ExPolicy &&
&&
icity.
Fw
firs
Sen
last
Fw
des
Op
&&
```

Assigns through each iterator *i* in [result, result + (last - first)) the value of GENERALIZED_NONCOMMUTATIVE_SUM(op, *first, ..., *(first + (i - result))).

The reduce operations in the parallel *inclusive_scan* algorithm invoked with an execution policy object of type *sequenced_policy* execute in sequential order in the calling thread.

The reduce operations in the parallel *inclusive_scan* algorithm invoked with an execution policy object of type *parallel_policy* or *parallel_task_policy* are permitted to execute in an unordered fashion in unspecified threads, and indeterminately sequenced within each thread.

The difference between *exclusive_scan* and *inclusive_scan* is that *inclusive_scan* includes the *i*th input element in the *i*th sum.

Note: Complexity: $O(\text{last} - \text{first})$ applications of the predicate *op*.

Note: GENERALIZED_NONCOMMUTATIVE_SUM(+, a1, ..., aN) is defined as:

- a1 when N is 1
 - GENERALIZED_NONCOMMUTATIVE_SUM(op, a1, ..., aK)
 - GENERALIZED_NONCOMMUTATIVE_SUM(+, aM, ..., aN) where $1 < K+1 = M \leq N$.
-

Template Parameters

- **ExPolicy** – The type of the execution policy to use (deduced). It describes the manner in which the execution of the algorithm may be parallelized and the manner in which it executes the assignments.
- **FwdIter1** – The type of the source iterators used (deduced). This iterator type must meet the requirements of an forward iterator.
- **Sent** – The type of the source sentinel (deduced). This sentinel type must be a sentinel for *InIter*.
- **FwdIter2** – The type of the iterator representing the destination range (deduced). This iterator type must meet the requirements of an forward iterator.
- **Op** – The type of the binary function object used for the reduction operation.

Parameters

- **policy** – The execution policy to use for the scheduling of the iterations.
- **first** – Refers to the beginning of the sequence of elements the algorithm will be applied to.
- **last** – Refers to sentinel value denoting the end of the sequence of elements the algorithm will be applied.
- **dest** – Refers to the beginning of the destination range.
- **op** – Specifies the function (or function object) which will be invoked for each of the values of the input sequence. This is a binary predicate. The signature of this predicate should be equivalent to:

```
Ret fun(const Type1 &a, const Type1 &b);
```

The signature does not need to have `const&`, but the function must not modify the objects passed to it. The types *Type1* and *Ret* must be such that an object of a type as given by the input sequence can be implicitly converted to any of those types.

Returns The *inclusive_scan* algorithm returns a `hpx::future<util::in_out_result<FwdIter1, FwdIter2>>` if the execution policy is of type *sequenced_task_policy* or *parallel_task_policy* and returns `util::in_out_result<FwdIter1, FwdIter2>` otherwise. The *inclusive_scan* algorithm returns an input iterator to the point denoted by the sentinel and an output iterator to the element in the destination range, one past the last element copied.

```
template<typename Rng, typename O, typename Op = std::plus<typename
hpx::traits::range_traits<Rng>::value_type>>
```

```
inclusive_scan_result<hpx::traits::range_iterator_t<Rng>, O> inclusive_scan(Rng &&rng, O dest,
                                                                    Op &&op)
```

Assigns through each iterator i in $[\text{result}, \text{result} + (\text{last} - \text{first}))$ the value of GENERALIZED_NONCOMMUTATIVE_SUM($\text{op}, *first, \dots, *(first + (i - \text{result}))$).

The reduce operations in the parallel *inclusive_scan* algorithm invoked without an execution policy object will execute in sequential order in the calling thread.

The difference between *exclusive_scan* and *inclusive_scan* is that *inclusive_scan* includes the i th input element in the i th sum.

Note: Complexity: $O(\text{last} - \text{first})$ applications of the predicate op .

Note: GENERALIZED_NONCOMMUTATIVE_SUM(+, a_1, \dots, a_N) is defined as:

- a_1 when N is 1
 - GENERALIZED_NONCOMMUTATIVE_SUM(+, a_1, \dots, a_K)
– GENERALIZED_NONCOMMUTATIVE_SUM(+, a_M, \dots, a_N) where $1 < K+1 = M \leq N$.
-

Template Parameters

- **Rng** – The type of the source range used (deduced). The iterators extracted from this range type must meet the requirements of an input iterator.
- **O** – The type of the iterator representing the destination range (deduced). This iterator type must meet the requirements of an output iterator.
- **Op** – The type of the binary function object used for the reduction operation.

Parameters

- **rng** – Refers to the sequence of elements the algorithm will be applied to.
- **dest** – Refers to the beginning of the destination range.
- **op** – Specifies the function (or function object) which will be invoked for each of the values of the input sequence. This is a binary predicate. The signature of this predicate should be equivalent to:

```
Ret fun(const Type1 &a, const Type1 &b);
```

The signature does not need to have `const&`, but the function must not modify the objects passed to it. The types *Type1* and *Ret* must be such that an object of a type as given by the input sequence can be implicitly converted to any of those types.

Returns The *inclusive_scan* algorithm returns `util::in_out_result<traits::range_iterator_t<Rng>, O>`. The *inclusive_scan* algorithm returns an input iterator to the point denoted by the sentinel and an output iterator to the element in the destination range, one past the last element copied.

```
template<typename ExPolicy, typename Rng, typename O, typename Op = std::plus<typename
hpx::traits::range_traits<Rng>::value_type>>
```

`parallel::util::detail::algorithm_result<ExPolicy, inclusive_scan_result<hpx::traits::range_iterator_t<Rng>, O>> inclusive_scan`

Assigns through each iterator i in $[\text{result}, \text{result} + (\text{last} - \text{first}))$ the value of `GENERALIZED_NONCOMMUTATIVE_SUM(op, *first, ..., *(first + (i - result)))`.

The reduce operations in the parallel `inclusive_scan` algorithm invoked with an execution policy object of type `sequenced_policy` execute in sequential order in the calling thread.

The reduce operations in the parallel `inclusive_scan` algorithm invoked with an execution policy object of type `parallel_policy` or `parallel_task_policy` are permitted to execute in an unordered fashion in unspecified threads, and indeterminately sequenced within each thread.

The difference between `exclusive_scan` and `inclusive_scan` is that `inclusive_scan` includes the i th input element in the i th sum.

Note: Complexity: $O(\text{last} - \text{first})$ applications of the predicate `op`.

Note: `GENERALIZED_NONCOMMUTATIVE_SUM(+, a1, ..., aN)` is defined as:

- $a1$ when N is 1
 - `GENERALIZED_NONCOMMUTATIVE_SUM(op, a1, ..., aK)`
– `GENERALIZED_NONCOMMUTATIVE_SUM(+, aM, ..., aN)` where $1 < K+1 = M \leq N$.
-

Template Parameters

- **ExPolicy** – The type of the execution policy to use (deduced). It describes the manner in which the execution of the algorithm may be parallelized and the manner in which it executes the assignments.
- **Rng** – The type of the source range used (deduced). The iterators extracted from this range type must meet the requirements of an forward iterator.
- **O** – The type of the iterator representing the destination range (deduced). This iterator type must meet the requirements of an forward iterator.
- **Op** – The type of the binary function object used for the reduction operation.

Parameters

- **policy** – The execution policy to use for the scheduling of the iterations.
- **rng** – Refers to the sequence of elements the algorithm will be applied to.
- **dest** – Refers to the beginning of the destination range.
- **op** – Specifies the function (or function object) which will be invoked for each of the values of the input sequence. This is a binary predicate. The signature of this predicate should be equivalent to:

```
Ret fun(const Type1 &a, const Type1 &b);
```

The signature does not need to have `const&`, but the function must not modify the objects passed to it. The types `Type1` and `Ret` must be such that an object of a type as given by

the input sequence can be implicitly converted to any of those types.

Returns The *inclusive_scan* algorithm returns a `hpx::future<util::in_out_result<traits::range_iterator_t<Rng>, O>>` if the execution policy is of type *sequenced_task_policy* or *parallel_task_policy* and returns `util::in_out_result<traits::range_iterator_t<Rng>, O>` otherwise. The *inclusive_scan* algorithm returns an input iterator to the point denoted by the sentinel and an output iterator to the element in the destination range, one past the last element copied

```
template<typename InIter, typename Sent, typename OutIter, typename Op, typename T = typename
std::iterator_traits<InIter>::value_type>
inclusive_scan_result<InIter, OutIter> inclusive_scan(InIter first, Sent last, OutIter dest, Op &&op,
T init)
```

Assigns through each iterator *i* in [result, result + (last - first)) the value of GENERALIZED_NONCOMMUTATIVE_SUM(op, init, *first, ..., *(first + (i - result))).

The reduce operations in the parallel *inclusive_scan* algorithm invoked without an execution policy object will execute in sequential order in the calling thread.

The difference between *exclusive_scan* and *inclusive_scan* is that *inclusive_scan* includes the *i*th input element in the *i*th sum. If *op* is not mathematically associative, the behavior of *inclusive_scan* may be non-deterministic.

Note: Complexity: $O(\text{last} - \text{first})$ applications of the predicate *op*.

Note: GENERALIZED_NONCOMMUTATIVE_SUM(op, a1, ..., aN) is defined as:

- a1 when N is 1
 - op(GENERALIZED_NONCOMMUTATIVE_SUM(op, a1, ..., aK), GENERALIZED_NONCOMMUTATIVE_SUM(op, aM, ..., aN)) where $1 < K+1 = M \leq N$.
-

Template Parameters

- **InIter** – The type of the source iterators used (deduced). This iterator type must meet the requirements of an input iterator.
- **Sent** – The type of the source sentinel (deduced). This sentinel type must be a sentinel for InIter.
- **OutIter** – The type of the iterator representing the destination range (deduced). This iterator type must meet the requirements of an output iterator.
- **Op** – The type of the binary function object used for the reduction operation.
- **T** – The type of the value to be used as initial (and intermediate) values (deduced).

Parameters

- **first** – Refers to the beginning of the sequence of elements the algorithm will be applied to.
- **last** – Refers to sentinel value denoting the end of the sequence of elements the algorithm will be applied.
- **dest** – Refers to the beginning of the destination range.
- **op** – Specifies the function (or function object) which will be invoked for each of the values of the input sequence. This is a binary predicate. The signature of this predicate should be equivalent to:

```
Ret fun(const Type1 &a, const Type1 &b);
```

The signature does not need to have `const&`, but the function must not modify the objects passed to it. The types *Type1* and *Ret* must be such that an object of a type as given by the input sequence can be implicitly converted to any of those types.

- **init** – The initial value for the generalized sum.

Returns The *inclusive_scan* algorithm returns `util::in_out_result<InIter, OutIter>`. The *inclusive_scan* algorithm returns an input iterator to the point denoted by the sentinel and an output iterator to the element in the destination range, one past the last element copied.

```
template<typename ExPolicy, typename FwdIter1, typename Sent, typename FwdIter2, typename
Op, typename T = typename std::iterator_traits<FwdIter1>::value_type>
parallel::util::detail::algorithm_result<ExPolicy, inclusive_scan_result<FwdIter1, FwdIter2>>::type inclusive_scan(Ex
```

Assigns through each iterator *i* in $[\text{result}, \text{result} + (\text{last} - \text{first}))$ the value of `GENERALIZED_NONCOMMUTATIVE_SUM(op, init, *first, ..., *(first + (i - result)))`.

The reduce operations in the parallel *inclusive_scan* algorithm invoked with an execution policy object of type *sequenced_policy* execute in sequential order in the calling thread.

The reduce operations in the parallel *inclusive_scan* algorithm invoked with an execution policy object of type *parallel_policy* or *parallel_task_policy* are permitted to execute in an unordered fashion in unspecified threads, and indeterminately sequenced within each thread.

The difference between *exclusive_scan* and *inclusive_scan* is that *inclusive_scan* includes the *i*th input element in the *i*th sum. If *op* is not mathematically associative, the behavior of *inclusive_scan* may be non-deterministic.

Note: Complexity: $O(\text{last} - \text{first})$ applications of the predicate *op*.

Note: `GENERALIZED_NONCOMMUTATIVE_SUM(op, a1, ..., aN)` is defined as:

- a_1 when N is 1
 - $op(\text{GENERALIZED_NONCOMMUTATIVE_SUM}(op, a_1, \dots, a_K), \text{GENERALIZED_NONCOMMUTATIVE_SUM}(op, a_M, \dots, a_N))$ where $1 < K+1 = M \leq N$.
-

Template Parameters

- **ExPolicy** – The type of the execution policy to use (deduced). It describes the manner in which the execution of the algorithm may be parallelized and the manner in which it executes the assignments.

- **InIter** – The type of the source iterators used (deduced). This iterator type must meet the requirements of an input iterator.
- **Sent** – The type of the source sentinel (deduced). This sentinel type must be a sentinel for InIter.
- **OutIter** – The type of the iterator representing the destination range (deduced). This iterator type must meet the requirements of an output iterator.
- **Op** – The type of the binary function object used for the reduction operation.
- **T** – The type of the value to be used as initial (and intermediate) values (deduced).

Parameters

- **policy** – The execution policy to use for the scheduling of the iterations.
- **first** – Refers to the beginning of the sequence of elements the algorithm will be applied to.
- **last** – Refers to sentinel value denoting the end of the sequence of elements the algorithm will be applied.
- **dest** – Refers to the beginning of the destination range.
- **op** – Specifies the function (or function object) which will be invoked for each of the values of the input sequence. This is a binary predicate. The signature of this predicate should be equivalent to:

```
Ret fun(const Type1 &a, const Type1 &b);
```

The signature does not need to have const&, but the function must not modify the objects passed to it. The types *Type1* and *Ret* must be such that an object of a type as given by the input sequence can be implicitly converted to any of those types.

- **init** – The initial value for the generalized sum.

Returns The *inclusive_scan* algorithm returns a *hpx::future<util::in_out_result<InIter, OutIter>>* if the execution policy is of type *sequenced_task_policy* or *parallel_task_policy* and returns *util::in_out_result<InIter, OutIter>* otherwise. The *inclusive_scan* algorithm returns an input iterator to the point denoted by the sentinel and an output iterator to the element in the destination range, one past the last element copied.

```
template<typename Rng, typename O, typename Op, typename T = typename
std::iterator_traits<hpx::traits::range_iterator_t<Rng>>::value_type>
inclusive_scan_result<hpx::traits::range_iterator_t<Rng>, O> inclusive_scan(Rng &&rng, O dest,
Op &&op, T init)
```

Assigns through each iterator *i* in [result, result + (last - first)) the value of GENERALIZED_NONCOMMUTATIVE_SUM(op, init, *first, ..., *(first + (i - result))).

The reduce operations in the parallel *inclusive_scan* algorithm invoked without an execution policy object will execute in sequential order in the calling thread.

The difference between *exclusive_scan* and *inclusive_scan* is that *inclusive_scan* includes the *i*th input element in the *i*th sum. If *op* is not mathematically associative, the behavior of *inclusive_scan* may be non-deterministic.

Note: Complexity: $O(\text{last} - \text{first})$ applications of the predicate *op*.

Note: GENERALIZED_NONCOMMUTATIVE_SUM(op, a1, ..., aN) is defined as:

- a1 when N is 1

- `op(GENERALIZED_NONCOMMUTATIVE_SUM(op, a1, ..., aK), GENERALIZED_NONCOMMUTATIVE_SUM(op, aM, ..., aN))` where $1 < K+1 = M \leq N$.

Template Parameters

- **Rng** – The type of the source range used (deduced). The iterators extracted from this range type must meet the requirements of an input iterator.
- **O** – The type of the iterator representing the destination range (deduced). This iterator type must meet the requirements of an output iterator.
- **Op** – The type of the binary function object used for the reduction operation.
- **T** – The type of the value to be used as initial (and intermediate) values (deduced).

Parameters

- **rng** – Refers to the sequence of elements the algorithm will be applied to.
- **dest** – Refers to the beginning of the destination range.
- **op** – Specifies the function (or function object) which will be invoked for each of the values of the input sequence. This is a binary predicate. The signature of this predicate should be equivalent to:

```
Ret fun(const Type1 &a, const Type1 &b);
```

The signature does not need to have `const&`, but the function must not modify the objects passed to it. The types *Type1* and *Ret* must be such that an object of a type as given by the input sequence can be implicitly converted to any of those types.

- **init** – The initial value for the generalized sum.

Returns The *inclusive_scan* algorithm returns `util::in_out_result<traits::range_iterator_t<Rng>, O>`. The *inclusive_scan* algorithm returns an input iterator to the point denoted by the sentinel and an output iterator to the element in the destination range, one past the last element copied.

```
template<typename ExPolicy, typename Rng, typename O, typename Op, typename T = typename
std::iterator_traits<hpx::traits::range_iterator_t<Rng>>::value_type>
parallel::util::detail::algorithm_result<ExPolicy, inclusive_scan_result<hpx::traits::range_iterator_t<Rng>, O>> inclusiv
```

Assigns through each iterator *i* in `[result, result + (last - first))` the value of `GENERALIZED_NONCOMMUTATIVE_SUM(op, init, *first, ..., *(first + (i - result)))`.

The reduce operations in the parallel *inclusive_scan* algorithm invoked with an execution policy object of type *sequenced_policy* execute in sequential order in the calling thread.

The reduce operations in the parallel *inclusive_scan* algorithm invoked with an execution policy object of type *parallel_policy* or *parallel_task_policy* are permitted to execute in an unordered fashion in unspecified threads, and indeterminately sequenced within each thread.

The difference between *exclusive_scan* and *inclusive_scan* is that *inclusive_scan* includes the *i*th input

element in the i th sum. If op is not mathematically associative, the behavior of *inclusive_scan* may be non-deterministic.

Note: Complexity: $O(\text{last} - \text{first})$ applications of the predicate op .

Note: GENERALIZED_NONCOMMUTATIVE_SUM(op, a_1, \dots, a_N) is defined as:

- a_1 when N is 1
 - $op(\text{GENERALIZED_NONCOMMUTATIVE_SUM}(op, a_1, \dots, a_K), \text{GENERALIZED_NONCOMMUTATIVE_SUM}(op, a_{K+1}, \dots, a_N))$ where $1 < K+1 = M \leq N$.
-

Template Parameters

- **ExPolicy** – The type of the execution policy to use (deduced). It describes the manner in which the execution of the algorithm may be parallelized and the manner in which it executes the assignments.
- **Rng** – The type of the source range used (deduced). The iterators extracted from this range type must meet the requirements of a forward iterator.
- **O** – The type of the iterator representing the destination range (deduced). This iterator type must meet the requirements of a forward iterator.
- **Op** – The type of the binary function object used for the reduction operation.
- **T** – The type of the value to be used as initial (and intermediate) values (deduced).

Parameters

- **policy** – The execution policy to use for the scheduling of the iterations.
- **rng** – Refers to the sequence of elements the algorithm will be applied to.
- **dest** – Refers to the beginning of the destination range.
- **op** – Specifies the function (or function object) which will be invoked for each of the values of the input sequence. This is a binary predicate. The signature of this predicate should be equivalent to:

```
Ret fun(const Type1 &a, const Type1 &b);
```

The signature does not need to have `const&`, but the function must not modify the objects passed to it. The types *Type1* and *Ret* must be such that an object of a type as given by the input sequence can be implicitly converted to any of those types.

- **init** – The initial value for the generalized sum.

Returns The *inclusive_scan* algorithm returns a `hpx::future<util::in_out_result<traits::range_iterator_t<Rng>, O>>` if the execution policy is of type *sequenced_task_policy* or *parallel_task_policy* and returns `util::in_out_result<traits::range_iterator_t<Rng>, O>` otherwise. The *inclusive_scan* algorithm returns an input iterator to the point denoted by the sentinel and an output iterator to the element in the destination range, one past the last element copied

hpx::ranges::is_heap, hpx::ranges::is_heap_until

Defined in header `hpx/algorithm.hpp`⁶⁵².

See *Public API* for a list of names and headers that are part of the public HPX API.

namespace **hpx**

⁶⁵² <http://github.com/STELLAR-GROUP/hpx/blob/8a3b7c1a4cb5693b2f7d9f587f759392ed0c51a0/libs/full/include/include/hpx/algorithm.hpp>

namespace **ranges**

Functions

```
template<typename ExPolicy, typename Rng, typename Comp = hpx::parallel::detail::less, typename
Proj = hpx::identity>
hpx::parallel::util::detail::algorithm_result_t<ExPolicy, bool> is_heap(ExPolicy &&policy, Rng
&&rng, Comp &&comp =
Comp(), Proj &&proj = Proj())
```

Returns whether the range is max heap. That is, true if the range is max heap, false otherwise. The function uses the given comparison function object *comp* (defaults to using operator<()).

comp has to induce a strict weak ordering on the values.

The application of function objects in parallel algorithm invoked with an execution policy object of type *sequenced_policy* execute in sequential order in the calling thread.

The application of function objects in parallel algorithm invoked with an execution policy object of type *parallel_policy* or *parallel_task_policy* are permitted to execute in an unordered fashion in unspecified threads, and indeterminately sequenced within each thread.

Note: Complexity: Performs at most N applications of the comparison *comp*, at most 2 * N applications of the projection *proj*, where N = last - first.

Template Parameters

- **ExPolicy** – The type of the execution policy to use (deduced). It describes the manner in which the execution of the algorithm may be parallelized and the manner in which it executes the assignments.
- **Rng** – The type of the source range used (deduced). The iterators extracted from this range type must meet the requirements of a random access iterator.
- **Comp** – The type of the function/function object to use (deduced).
- **Proj** – The type of an optional projection function. This defaults to *hpx::identity*

Parameters

- **policy** – The execution policy to use for the scheduling of the iterations.
- **rng** – Refers to the sequence of elements the algorithm will be applied to.
- **comp** – *comp* is a callable object. The return value of the INVOKE operation applied to an object of type *Comp*, when contextually converted to bool, yields true if the first argument of the call is less than the second, and false otherwise. It is assumed that *comp* will not apply any non-constant function through the dereferenced iterator.
- **proj** – Specifies the function (or function object) which will be invoked for each of the elements as a projection operation before the actual predicate *is* is invoked.

Returns The *is_heap* algorithm returns a *hpx::future<bool>* if the execution policy is of type *sequenced_task_policy* or *parallel_task_policy* and returns *bool* otherwise. The *is_heap* algorithm returns whether the range is max heap. That is, true if the range is max heap, false otherwise.

```
template<typename ExPolicy, typename Iter, typename Sent, typename Comp =
hpx::parallel::detail::less, typename Proj = hpx::identity>
hpx::parallel::util::detail::algorithm_result_t<ExPolicy, bool> is_heap(ExPolicy &&policy, Iter first,
Sent last, Comp &&comp =
Comp(), Proj &&proj = Proj())
```

Returns whether the range is max heap. That is, true if the range is max heap, false otherwise. The function uses the given comparison function object *comp* (defaults to using operator<()).

comp has to induce a strict weak ordering on the values.

The application of function objects in parallel algorithm invoked with an execution policy object of type *sequenced_policy* execute in sequential order in the calling thread.

The application of function objects in parallel algorithm invoked with an execution policy object of type *parallel_policy* or *parallel_task_policy* are permitted to execute in an unordered fashion in unspecified threads, and indeterminately sequenced within each thread.

Note: Complexity: Performs at most N applications of the comparison *comp*, at most 2 * N applications of the projection *proj*, where N = last - first.

Template Parameters

- **ExPolicy** – The type of the execution policy to use (deduced). It describes the manner in which the execution of the algorithm may be parallelized and the manner in which it executes the assignments.
- **Iter** – The type of the begin source iterators used (deduced). This iterator type must meet the requirements of an forward iterator.
- **Sent** – The type of the end source iterators used (deduced). This iterator type must meet the requirements of an sentinel for Iter1.
- **Comp** – The type of the function/function object to use (deduced).
- **Proj** – The type of an optional projection function. This defaults to *hpx::identity*

Parameters

- **policy** – The execution policy to use for the scheduling of the iterations.
- **first** – Refers to the beginning of the sequence of elements the algorithm will be applied to.
- **last** – Refers to the end of the sequence of elements the algorithm will be applied to.
- **comp** – *comp* is a callable object. The return value of the INVOKE operation applied to an object of type *Comp*, when contextually converted to bool, yields true if the first argument of the call is less than the second, and false otherwise. It is assumed that *comp* will not apply any non-constant function through the dereferenced iterator.
- **proj** – Specifies the function (or function object) which will be invoked for each of the elements as a projection operation before the actual predicate *is* is invoked.

Returns The *is_heap* algorithm returns a *hpx::future<bool>* if the execution policy is of type *sequenced_task_policy* or *parallel_task_policy* and returns *bool* otherwise. The *is_heap* algorithm returns whether the range is max heap. That is, true if the range is max heap, false otherwise.

```
template<typename Rng, typename Comp = hpx::parallel::detail::less, typename Proj = hpx::identity>
bool is_heap(Rng &&rng, Comp &&comp = Comp(), Proj &&proj = Proj())
```

Returns whether the range is max heap. That is, true if the range is max heap, false otherwise. The function uses the given comparison function object *comp* (defaults to using operator<()).

comp has to induce a strict weak ordering on the values.

Note: Complexity: Performs at most N applications of the comparison *comp*, at most 2 * N applications of the projection *proj*, where N = last - first.

Template Parameters

- **Rng** – The type of the source range used (deduced). The iterators extracted from this range type must meet the requirements of an random access iterator.
- **Comp** – The type of the function/function object to use (deduced).
- **Proj** – The type of an optional projection function. This defaults to *hpx::identity*

Parameters

- **rng** – Refers to the sequence of elements the algorithm will be applied to.
- **comp** – *comp* is a callable object. The return value of the INVOKE operation applied to an object of type *Comp*, when contextually converted to *bool*, yields true if the first argument of the call is less than the second, and false otherwise. It is assumed that *comp* will not apply any non-constant function through the dereferenced iterator.
- **proj** – Specifies the function (or function object) which will be invoked for each of the elements as a projection operation before the actual predicate *is* invoked.

Returns The *is_heap* algorithm returns *bool*. The *is_heap* algorithm returns whether the range is max heap. That is, true if the range is max heap, false otherwise.

```
template<typename Iter, typename Sent, typename Comp = hpx::parallel::detail::less, typename Proj = hpx::identity>
```

```
bool is_heap(Iter first, Sent last, Comp &&comp = Comp(), Proj &&proj = Proj())
```

Returns whether the range is max heap. That is, true if the range is max heap, false otherwise. The function uses the given comparison function object *comp* (defaults to using operator<()).

comp has to induce a strict weak ordering on the values.

Note: Complexity: Performs at most N applications of the comparison *comp*, at most 2 * N applications of the projection *proj*, where N = last - first.

Template Parameters

- **Iter** – The type of the begin source iterators used (deduced). This iterator type must meet the requirements of an forward iterator.
- **Sent** – The type of the end source iterators used (deduced). This iterator type must meet the requirements of an sentinel for Iter1.
- **Comp** – The type of the function/function object to use (deduced).
- **Proj** – The type of an optional projection function. This defaults to *hpx::identity*

Parameters

- **first** – Refers to the beginning of the sequence of elements the algorithm will be applied to.
- **last** – Refers to the end of the sequence of elements the algorithm will be applied to.
- **comp** – *comp* is a callable object. The return value of the INVOKE operation applied to an object of type *Comp*, when contextually converted to *bool*, yields true if the first argument of the call is less than the second, and false otherwise. It is assumed that *comp* will not apply any non-constant function through the dereferenced iterator.
- **proj** – Specifies the function (or function object) which will be invoked for each of the elements as a projection operation before the actual predicate *is* invoked.

Returns The *is_heap* algorithm returns *bool*. The *is_heap* algorithm returns whether the range is max heap. That is, true if the range is max heap, false otherwise.

```
template<typename ExPolicy, typename Rng, typename Comp = hpx::parallel::detail::less, typename Proj = hpx::identity>
```

```

hpx::parallel::util::detail::algorithm_result<ExPolicy, hpx::traits::range_iterator_t<Rng>> is_heap_until(ExPolicy
&&pol-
icy,
Rng
&&rng,
Comp
&&comp
=
Comp(),
Proj
&&proj
=
Proj())

```

Returns the upper bound of the largest range beginning at *first* which is a max heap. That is, the last iterator *it* for which range [first, it) is a max heap. The function uses the given comparison function object *comp* (defaults to using operator<()).

comp has to induce a strict weak ordering on the values.

The application of function objects in parallel algorithm invoked with an execution policy object of type *sequenced_policy* execute in sequential order in the calling thread.

The application of function objects in parallel algorithm invoked with an execution policy object of type *parallel_policy* or *parallel_task_policy* are permitted to execute in an unordered fashion in unspecified threads, and indeterminately sequenced within each thread.

Note: Complexity: Performs at most N applications of the comparison *comp*, at most 2 * N applications of the projection *proj*, where N = last - first.

Template Parameters

- **ExPolicy** – The type of the execution policy to use (deduced). It describes the manner in which the execution of the algorithm may be parallelized and the manner in which it executes the assignments.
- **Rng** – The type of the source range used (deduced). The iterators extracted from this range type must meet the requirements of a random access iterator.
- **Comp** – The type of the function/function object to use (deduced).
- **Proj** – The type of an optional projection function. This defaults to *hpx::identity*

Parameters

- **policy** – The execution policy to use for the scheduling of the iterations.
- **rng** – Refers to the sequence of elements the algorithm will be applied to.
- **comp** – *comp* is a callable object. The return value of the INVOKE operation applied to an object of type *Comp*, when contextually converted to bool, yields true if the first argument of the call is less than the second, and false otherwise. It is assumed that *comp* will not apply any non-constant function through the dereferenced iterator.
- **proj** – Specifies the function (or function object) which will be invoked for each of the elements as a projection operation before the actual predicate *is* is invoked.

Returns The *is_heap_until* algorithm returns a *hpx::future*<*RandIter*> if the execution policy is of type *sequenced_task_policy* or *parallel_task_policy* and returns *RandIter* otherwise. The *is_heap_until* algorithm returns the upper bound of the largest range beginning at first which is a max heap. That is, the last iterator *it* for which range [first, it) is a max heap.

```

template<typename ExPolicy, typename Iter, typename Sent, typename Comp =
hpx::parallel::detail::less, typename Proj = hpx::identity>

```

```

hpx::parallel::util::detail::algorithm_result_t<ExPolicy, Iter> is_heap_until(ExPolicy &&policy, Iter
                                                                    first, Sent last, Comp
                                                                    &&comp = Comp(),
                                                                    Proj &&proj = Proj())

```

Returns the upper bound of the largest range beginning at *first* which is a max heap. That is, the last iterator *it* for which range [first, it) is a max heap. The function uses the given comparison function object *comp* (defaults to using operator<()).

comp has to induce a strict weak ordering on the values.

The application of function objects in parallel algorithm invoked with an execution policy object of type *sequenced_policy* execute in sequential order in the calling thread.

The application of function objects in parallel algorithm invoked with an execution policy object of type *parallel_policy* or *parallel_task_policy* are permitted to execute in an unordered fashion in unspecified threads, and indeterminately sequenced within each thread.

Note: Complexity: Performs at most N applications of the comparison *comp*, at most 2 * N applications of the projection *proj*, where N = last - first.

Template Parameters

- **ExPolicy** – The type of the execution policy to use (deduced). It describes the manner in which the execution of the algorithm may be parallelized and the manner in which it executes the assignments.
- **Iter** – The type of the begin source iterators used (deduced). This iterator type must meet the requirements of an forward iterator.
- **Sent** – The type of the end source iterators used (deduced). This iterator type must meet the requirements of an sentinel for Iter1.
- **Comp** – The type of the function/function object to use (deduced).
- **Proj** – The type of an optional projection function. This defaults to *hpx::identity*

Parameters

- **policy** – The execution policy to use for the scheduling of the iterations.
- **first** – Refers to the beginning of the sequence of elements the algorithm will be applied to.
- **last** – Refers to the end of the sequence of elements the algorithm will be applied to.
- **comp** – *comp* is a callable object. The return value of the INVOKE operation applied to an object of type *Comp*, when contextually converted to bool, yields true if the first argument of the call is less than the second, and false otherwise. It is assumed that *comp* will not apply any non-constant function through the dereferenced iterator.
- **proj** – Specifies the function (or function object) which will be invoked for each of the elements as a projection operation before the actual predicate *is* is invoked.

Returns The *is_heap_until* algorithm returns a *hpx::future<RandIter>* if the execution policy is of type *sequenced_task_policy* or *parallel_task_policy* and returns *RandIter* otherwise. The *is_heap_until* algorithm returns the upper bound of the largest range beginning at first which is a max heap. That is, the last iterator *it* for which range [first, it) is a max heap.

```

template<typename Rng, typename Comp = hpx::parallel::detail::less, typename Proj = hpx::identity>
hpx::traits::range_iterator_t<Rng> is_heap_until(Rng &&rng, Comp &&comp = Comp(), Proj
                                                                    &&proj = Proj())

```

Returns the upper bound of the largest range beginning at *first* which is a max heap. That is, the last iterator *it* for which range [first, it) is a max heap. The function uses the given comparison function object *comp* (defaults to using operator<()).

comp has to induce a strict weak ordering on the values.

Note: Complexity: Performs at most N applications of the comparison *comp*, at most $2 * N$ applications of the projection *proj*, where $N = \text{last} - \text{first}$.

Template Parameters

- **Rng** – The type of the source range used (deduced). The iterators extracted from this range type must meet the requirements of a random access iterator.
- **Comp** – The type of the function/function object to use (deduced).
- **Proj** – The type of an optional projection function. This defaults to *hpx::identity*

Parameters

- **rng** – Refers to the sequence of elements the algorithm will be applied to.
- **comp** – *comp* is a callable object. The return value of the INVOKE operation applied to an object of type *Comp*, when contextually converted to bool, yields true if the first argument of the call is less than the second, and false otherwise. It is assumed that *comp* will not apply any non-constant function through the dereferenced iterator.
- **proj** – Specifies the function (or function object) which will be invoked for each of the elements as a projection operation before the actual predicate *is* is invoked.

Returns The *is_heap_until* algorithm returns *RandIter*. The *is_heap_until* algorithm returns the upper bound of the largest range beginning at *first* which is a max heap. That is, the last iterator *it* for which range [*first*, *it*) is a max heap.

```
template<typename Iter, typename Sent, typename Comp = hpx::parallel::detail::less, typename Proj = hpx::identity>
```

```
Iter is_heap_until(Iter first, Sent last, Comp &&comp = Comp(), Proj &&proj = Proj())
```

Returns the upper bound of the largest range beginning at *first* which is a max heap. That is, the last iterator *it* for which range [*first*, *it*) is a max heap. The function uses the given comparison function object *comp* (defaults to using *operator<()*).

comp has to induce a strict weak ordering on the values.

Note: Complexity: Performs at most N applications of the comparison *comp*, at most $2 * N$ applications of the projection *proj*, where $N = \text{last} - \text{first}$.

Template Parameters

- **Iter** – The type of the begin source iterators used (deduced). This iterator type must meet the requirements of a forward iterator.
- **Sent** – The type of the end source iterators used (deduced). This iterator type must meet the requirements of a sentinel for *Iter1*.
- **Comp** – The type of the function/function object to use (deduced).
- **Proj** – The type of an optional projection function. This defaults to *hpx::identity*

Parameters

- **first** – Refers to the beginning of the sequence of elements the algorithm will be applied to.
- **last** – Refers to the end of the sequence of elements the algorithm will be applied to.
- **comp** – *comp* is a callable object. The return value of the INVOKE operation applied to an object of type *Comp*, when contextually converted to bool, yields true if the first argument of the call is less than the second, and false otherwise. It is assumed that *comp* will not apply any non-constant function through the dereferenced iterator.
- **proj** – Specifies the function (or function object) which will be invoked for each of the elements as a projection operation before the actual predicate *is* is invoked.

Returns The *is_heap_until* algorithm returns *RandIter*. The *is_heap_until* algorithm returns the upper bound of the largest range beginning at *first* which is a max heap. That is, the last iterator *it* for which range [*first*, *it*) is a max heap.

hpx::ranges::is_partitioned

Defined in header `hpx/algorithm.hpp`⁶⁵³.

See *Public API* for a list of names and headers that are part of the public HPX API.

```
namespace hpx
```

```
namespace ranges
```

Functions

```
template<typename FwdIter, typename Sent, typename Pred, typename Proj = hpx::identity>
bool is_partitioned(FwdIter first, Sent last, Pred &&pred, Proj &&proj = Proj())
```

Determines if the range [first, last) is partitioned.

Note: Complexity: at most (N) predicate evaluations where $N = \text{distance}(\text{first}, \text{last})$.

Template Parameters

- **FwdIter** – The type of the source iterators used for the This iterator type must meet the requirements of a forward iterator.
- **Sent** – The type of the source sentinel (deduced). This sentinel type must be a sentinel for FwdIter.
- **Pred** – The type of the function/function object to use (deduced).
- **Proj** – The type of an optional projection function. This defaults to `hpx::identity`.

Parameters

- **first** – Refers to the beginning of the sequence of elements of that the algorithm will be applied to.
- **last** – Refers to the end of the sequence of elements of that the algorithm will be applied to.
- **pred** – Refers to the unary predicate which returns true for elements expected to be found in the beginning of the range. The signature of the function should be equivalent to

```
bool pred(const Type &a);
```

The signature does not need to have `const &`, but the function must not modify the objects passed to it. The type *Type* must be such that objects of types *FwdIter* can be dereferenced and then implicitly converted to *Type*.

- **proj** – Specifies the function (or function object) which will be invoked for each of the elements as a projection operation before the actual predicate *is* invoked.

Returns The *is_partitioned* algorithm returns *bool*. The *is_partitioned* algorithm returns true if each element in the sequence for which *pred* returns true precedes those for which *pred* returns false. Otherwise *is_partitioned* returns false. If the range [first, last) contains less than two elements, the function is always true.

```
template<typename ExPolicy, typename FwdIter, typename Sent, typename Pred, typename Proj =
hpx::identity>
hpx::parallel::util::detail::algorithm_result_t<ExPolicy, bool> is_partitioned(ExPolicy &&policy,
FwdIter first, Sent last,
Pred &&pred, Proj
&&proj = Proj())
```

⁶⁵³ <http://github.com/STELLAR-GROUP/hpx/blob/8a3b7c1a4cb5693b2f7d9f587f759392ed0c51a0/libs/full/include/include/hpx/algorithm.hpp>

Determines if the range [first, last) is partitioned.

The predicate operations in the parallel *is_partitioned* algorithm invoked with an execution policy object of type *sequenced_policy* executes in sequential order in the calling thread.

The comparison operations in the parallel *is_partitioned* algorithm invoked with an execution policy object of type *parallel_policy* or *parallel_task_policy* are permitted to execute in an unordered fashion in unspecified threads, and indeterminately sequenced within each thread.

Note: Complexity: at most (N) predicate evaluations where $N = \text{distance}(\text{first}, \text{last})$.

Template Parameters

- **ExPolicy** – The type of the execution policy to use (deduced). It describes the manner in which the execution of the algorithm may be parallelized and the manner in which it executes the assignments.
- **FwdIter** – The type of the source iterators used for the This iterator type must meet the requirements of a forward iterator.
- **Sent** – The type of the source sentinel (deduced). This sentinel type must be a sentinel for FwdIter.
- **Pred** – The type of the function/function object to use (deduced). *Pred* must be *Copy-Constructible* when using a parallel policy.
- **Proj** – The type of an optional projection function. This defaults to *hpx::identity*.

Parameters

- **policy** – The execution policy to use for the scheduling of the iterations.
- **first** – Refers to the beginning of the sequence of elements of that the algorithm will be applied to.
- **last** – Refers to the end of the sequence of elements of that the algorithm will be applied to.
- **pred** – Refers to the unary predicate which returns true for elements expected to be found in the beginning of the range. The signature of the function should be equivalent to

```
bool pred(const Type &a);
```

The signature does not need to have `const &`, but the function must not modify the objects passed to it. The type *Type* must be such that objects of types *FwdIter* can be dereferenced and then implicitly converted to *Type*.

- **proj** – Specifies the function (or function object) which will be invoked for each of the elements as a projection operation before the actual predicate *is* invoked.

Returns The *is_partitioned* algorithm returns a *hpx::future<bool>* if the execution policy is of type *task_execution_policy* and returns *bool* otherwise. The *is_partitioned* algorithm returns true if each element in the sequence for which *pred* returns true precedes those for which *pred* returns false. Otherwise *is_partitioned* returns false. If the range [first, last) contains less than two elements, the function is always true.

```
template<typename Rng, typename Pred, typename Proj = hpx::identity>
bool is_partitioned(Rng &&rng, Pred &&pred, Proj &&proj = Proj())
```

Determines if the range *rng* is partitioned.

Note: Complexity: at most (N) predicate evaluations where $N = \text{std::size}(\text{rng})$.

Template Parameters

- **Rng** – The type of the source range used (deduced). The iterators extracted from this range type must meet the requirements of an forward iterator.
- **Pred** – The type of the function/function object to use (deduced).
- **Proj** – The type of an optional projection function. This defaults to `hpx::identity`.

Parameters

- **rng** – Refers to the sequence of elements the algorithm will be applied to.
- **pred** – Refers to the unary predicate which returns true for elements expected to be found in the beginning of the range. The signature of the function should be equivalent to

```
bool pred(const Type &a);
```

The signature does not need to have `const &`, but the function must not modify the objects passed to it. The type *Type* must be such that objects of types *FwdIter* can be dereferenced and then implicitly converted to *Type*.

- **proj** – Specifies the function (or function object) which will be invoked for each of the elements as a projection operation before the actual predicate *is* invoked.

Returns The *is_partitioned* algorithm returns *bool*. The *is_partitioned* algorithm returns true if each element in the sequence for which *pred* returns true precedes those for which *pred* returns false. Otherwise *is_partitioned* returns false. If the range *rng* contains less than two elements, the function is always true.

```
template<typename ExPolicy, typename Rng, typename Pred, typename Proj = hpx::identity>
hpx::parallel::util::detail::algorithm_result_t<ExPolicy, bool> is_partitioned(ExPolicy &&policy,
                                     Rng &&rng, Pred
                                     &&pred, Proj &&proj
                                     = Proj())
```

Determines if the range [first, last) is partitioned.

The predicate operations in the parallel *is_partitioned* algorithm invoked with an execution policy object of type *sequenced_policy* executes in sequential order in the calling thread.

The comparison operations in the parallel *is_partitioned* algorithm invoked with an execution policy object of type *parallel_policy* or *parallel_task_policy* are permitted to execute in an unordered fashion in unspecified threads, and indeterminately sequenced within each thread.

Note: Complexity: at most (N) predicate evaluations where $N = \text{std::size}(\text{rng})$.

Template Parameters

- **ExPolicy** – The type of the execution policy to use (deduced). It describes the manner in which the execution of the algorithm may be parallelized and the manner in which it executes the assignments.
- **Rng** – The type of the source range used (deduced). The iterators extracted from this range type must meet the requirements of an forward iterator.
- **Pred** – The type of the function/function object to use (deduced). *Pred* must be *Copy-Constructible* when using a parallel policy.
- **Proj** – The type of an optional projection function. This defaults to `hpx::identity`.

Parameters

- **policy** – The execution policy to use for the scheduling of the iterations.
- **rng** – Refers to the sequence of elements the algorithm will be applied to.
- **pred** – Refers to the unary predicate which returns true for elements expected to be found in the beginning of the range. The signature of the function should be equivalent to

```
bool pred(const Type &a);
```

The signature does not need to have `const &`, but the function must not modify the objects passed to it. The type *Type* must be such that objects of types *FwdIter* can be dereferenced and then implicitly converted to *Type*.

- **proj** – Specifies the function (or function object) which will be invoked for each of the elements as a projection operation before the actual predicate *is* is invoked.

Returns The *is_partitioned* algorithm returns a *hpx::future<bool>* if the execution policy is of type *task_execution_policy* and returns *bool* otherwise. The *is_partitioned* algorithm returns true if each element in the sequence for which *pred* returns true precedes those for which *pred* returns false. Otherwise *is_partitioned* returns false. If the range *rng* contains less than two elements, the function is always true.

hpx::ranges::is_sorted, hpx::ranges::is_sorted_until

Defined in header `hpx/algorithm.hpp`⁶⁵⁴.

See *Public API* for a list of names and headers that are part of the public *HPX* API.

```
namespace hpx
```

```
namespace ranges
```

Functions

```
template<typename FwdIter, typename Sent, typename Pred = hpx::parallel::detail::less, typename Proj = hpx::identity>
```

```
bool is_sorted(FwdIter first, Sent last, Pred &&pred = Pred(), Proj &&proj = Proj())
```

Determines if the range [first, last) is sorted. Uses *pred* to compare elements.

The comparison operations in the parallel *is_sorted* algorithm executes in sequential order in the calling thread.

Note: Complexity: at most $(N+S-1)$ comparisons where N = distance(first, last). S = number of partitions

Template Parameters

- **FwdIter** – The type of the source iterators used for the This iterator type must meet the requirements of a forward iterator.
- **Sent** – The type of the source sentinel (deduced). This sentinel type must be a sentinel for *FwdIter*.
- **Pred** – The type of an optional function/function object to use.
- **Proj** – The type of an optional projection function. This defaults to *hpx::identity*

Parameters

- **first** – Refers to the beginning of the sequence of elements of that the algorithm will be applied to.

⁶⁵⁴ <http://github.com/STELLAR-GROUP/hpx/blob/8a3b7c1a4cb5693b2f7d9f587f759392ed0c51a0/libs/full/include/include/hpx/algorithm.hpp>

- **last** – Refers to the end of the sequence of elements of that the algorithm will be applied to.
- **pred** – Refers to the binary predicate which returns true if the first argument should be treated as less than the second argument. The signature of the function should be equivalent to

```
bool pred(const Type &a, const Type &b);
```

The signature does not need to have `const &`, but the function must not modify the objects passed to it. The type *Type* must be such that objects of types *FwdIter* can be dereferenced and then implicitly converted to *Type*.

- **proj** – Specifies the function (or function object) which will be invoked for each of the elements as a projection operation before the actual predicate *is* invoked.

Returns The *is_sorted* algorithm returns a *bool*. The *is_sorted* algorithm returns true if each element in the sequence [first, last) satisfies the predicate passed. If the range [first, last) contains less than two elements, the function always returns true.

```
template<typename ExPolicy, typename FwdIter, typename Sent, typename Pred =
    hpx::parallel::detail::less, typename Proj = hpx::identity>
hpx::parallel::util::detail::algorithm_result_t<ExPolicy, bool> is_sorted(ExPolicy &&policy, FwdIter
    first, Sent last, Pred &&pred
    = Pred(), Proj &&proj =
    Proj())
```

Determines if the range [first, last) is sorted. Uses `pred` to compare elements.

The comparison operations in the parallel *is_sorted* algorithm invoked with an execution policy object of type *sequenced_policy* executes in sequential order in the calling thread.

The comparison operations in the parallel *is_sorted* algorithm invoked with an execution policy object of type *parallel_policy* or *parallel_task_policy* are permitted to execute in an unordered fashion in unspecified threads, and indeterminately sequenced within each thread.

Note: Complexity: at most $(N+S-1)$ comparisons where $N = \text{distance}(\text{first}, \text{last})$. $S = \text{number of partitions}$

Template Parameters

- **ExPolicy** – The type of the execution policy to use (deduced). It describes the manner in which the execution of the algorithm may be parallelized and the manner in which it executes the assignments.
- **FwdIter** – The type of the source iterators used for the This iterator type must meet the requirements of a forward iterator.
- **Sent** – The type of the source sentinel (deduced). This sentinel type must be a sentinel for *FwdIter*.
- **Pred** – The type of an optional function/function object to use. Unlike its sequential form, the parallel overload of *is_sorted* requires *Pred* to meet the requirements of *CopyConstructible*. This defaults to `std::less<>`
- **Proj** – The type of an optional projection function. This defaults to `hpx::identity`

Parameters

- **policy** – The execution policy to use for the scheduling of the iterations.
- **first** – Refers to the beginning of the sequence of elements of that the algorithm will be applied to.
- **last** – Refers to the end of the sequence of elements of that the algorithm will be applied to.

- **pred** – Refers to the binary predicate which returns true if the first argument should be treated as less than the second argument. The signature of the function should be equivalent to

```
bool pred(const Type &a, const Type &b);
```

The signature does not need to have `const &`, but the function must not modify the objects passed to it. The type *Type* must be such that objects of types *FwdIter* can be dereferenced and then implicitly converted to *Type*.

- **proj** – Specifies the function (or function object) which will be invoked for each of the elements as a projection operation before the actual predicate *is* invoked.

Returns The *is_sorted* algorithm returns a *hpx::future<bool>* if the execution policy is of type *task_execution_policy* and returns *bool* otherwise. The *is_sorted* algorithm returns a *bool* if each element in the sequence [first, last) satisfies the predicate passed. If the range [first, last) contains less than two elements, the function always returns true.

```
template<typename Rng, typename Pred = hpx::parallel::detail::less, typename Proj = hpx::identity>
bool is_sorted(Rng &&rng, Pred &&pred = Pred(), Proj &&proj = Proj())
```

Determines if the range *rng* is sorted. Uses *pred* to compare elements.

The comparison operations in the parallel *is_sorted* algorithm executes in sequential order in the calling thread.

Note: Complexity: at most $(N+S-1)$ comparisons where $N = \text{size}(\text{rng})$. $S = \text{number of partitions}$

Template Parameters

- **Rng** – The type of the source range used (deduced). The iterators extracted from this range type must meet the requirements of an forward iterator.
- **Pred** – The type of an optional function/function object to use.
- **Proj** – The type of an optional projection function. This defaults to *hpx::identity*

Parameters

- **rng** – Refers to the sequence of elements the algorithm will be applied to.
- **pred** – Refers to the binary predicate which returns true if the first argument should be treated as less than the second argument. The signature of the function should be equivalent to

```
bool pred(const Type &a, const Type &b);
```

The signature does not need to have `const &`, but the function must not modify the objects passed to it. The type *Type* must be such that objects of types *FwdIter* can be dereferenced and then implicitly converted to *Type*.

- **proj** – Specifies the function (or function object) which will be invoked for each of the elements as a projection operation before the actual predicate *is* invoked.

Returns The *is_sorted* algorithm returns a *bool*. The *is_sorted* algorithm returns true if each element in the *rng* satisfies the predicate passed. If the range *rng* contains less than two elements, the function always returns true.

```
template<typename ExPolicy, typename Rng, typename Pred = hpx::parallel::detail::less, typename
Proj = hpx::identity>
hpx::parallel::util::detail::algorithm_result_t<ExPolicy, bool> is_sorted(ExPolicy &&policy, Rng
&&rng, Pred &&pred =
Pred(), Proj &&proj =
Proj())
```

Determines if the range `rng` is sorted. Uses `pred` to compare elements.

The comparison operations in the parallel `is_sorted` algorithm invoked with an execution policy object of type `sequenced_policy` executes in sequential order in the calling thread.

The comparison operations in the parallel `is_sorted` algorithm invoked with an execution policy object of type `parallel_policy` or `parallel_task_policy` are permitted to execute in an unordered fashion in unspecified threads, and indeterminately sequenced within each thread.

Note: Complexity: at most $(N+S-1)$ comparisons where $N = \text{size}(\text{rng})$. $S = \text{number of partitions}$

Template Parameters

- **ExPolicy** – The type of the execution policy to use (deduced). It describes the manner in which the execution of the algorithm may be parallelized and the manner in which it executes the assignments.
- **Rng** – The type of the source range used (deduced). The iterators extracted from this range type must meet the requirements of a forward iterator.
- **Pred** – The type of an optional function/function object to use. Unlike its sequential form, the parallel overload of `is_sorted` requires `Pred` to meet the requirements of `CopyConstructible`. This defaults to `std::less<>`
- **Proj** – The type of an optional projection function. This defaults to `hpx::identity`

Parameters

- **policy** – The execution policy to use for the scheduling of the iterations.
- **rng** – Refers to the sequence of elements the algorithm will be applied to.
- **pred** – Refers to the binary predicate which returns true if the first argument should be treated as less than the second argument. The signature of the function should be equivalent to

```
bool pred(const Type &a, const Type &b);
```

The signature does not need to have `const &`, but the function must not modify the objects passed to it. The type `Type` must be such that objects of types `FwdIter` can be dereferenced and then implicitly converted to `Type`.

- **proj** – Specifies the function (or function object) which will be invoked for each of the elements as a projection operation before the actual predicate `is` is invoked.

Returns The `is_sorted` algorithm returns a `hpx::future<bool>` if the execution policy is of type `task_execution_policy` and returns `bool` otherwise. The `is_sorted` algorithm returns a `bool` if each element in the range `rng` satisfies the predicate passed. If the range `rng` contains less than two elements, the function always returns true.

```
template<typename FwdIter, typename Sent, typename Pred = hpx::parallel::detail::less, typename Proj = hpx::identity>
```

```
FwdIter is_sorted_until(FwdIter first, Sent last, Pred &&pred = Pred(), Proj &&proj = Proj())
```

Returns the first element in the range `[first, last)` that is not sorted. Uses a predicate to compare elements or the less than operator.

The comparison operations in the parallel `is_sorted_until` algorithm execute in sequential order in the calling thread.

Note: Complexity: at most $(N+S-1)$ comparisons where $N = \text{distance}(\text{first}, \text{last})$. $S = \text{number of}$

partitions

Template Parameters

- **FwdIter** – The type of the source iterators used for the This iterator type must meet the requirements of a forward iterator.
- **Sent** – The type of the source sentinel (deduced). This sentinel type must be a sentinel for FwdIter.
- **Pred** – The type of an optional function/function object to use.
- **Proj** – The type of an optional projection function. This defaults to `hpx::identity`

Parameters

- **first** – Refers to the beginning of the sequence of elements of that the algorithm will be applied to.
- **last** – Refers to the end of the sequence of elements of that the algorithm will be applied to.
- **pred** – Refers to the binary predicate which returns true if the first argument should be treated as less than the second argument. The signature of the function should be equivalent to

```
bool pred(const Type &a, const Type &b);
```

The signature does not need to have `const &`, but the function must not modify the objects passed to it. The type *Type* must be such that objects of types *FwdIter* can be dereferenced and then implicitly converted to *Type*.

- **proj** – Specifies the function (or function object) which will be invoked for each of the elements as a projection operation before the actual predicate *is* invoked.

Returns The *is_sorted_until* algorithm returns a *FwdIter*. The *is_sorted_until* algorithm returns the first unsorted element. If the sequence has less than two elements or the sequence is sorted, last is returned.

```
template<typename ExPolicy, typename FwdIter, typename Sent, typename Pred =
hpx::parallel::detail::less, typename Proj = hpx::identity>
hpx::parallel::util::detail::algorithm_result<ExPolicy, FwdIter>::type is_sorted_until(ExPolicy
&&policy,
FwdIter first,
Sent last,
Pred &&pred
= Pred(), Proj
&&proj =
Proj())
```

Returns the first element in the range [first, last) that is not sorted. Uses a predicate to compare elements or the less than operator.

The comparison operations in the parallel *is_sorted_until* algorithm invoked with an execution policy object of type *sequenced_policy* executes in sequential order in the calling thread.

The comparison operations in the parallel *is_sorted_until* algorithm invoked with an execution policy object of type *parallel_policy* or *parallel_task_policy* are permitted to execute in an unordered fashion in unspecified threads, and indeterminately sequenced within each thread.

Note: Complexity: at most $(N+S-1)$ comparisons where N = distance(first, last). S = number of partitions

Template Parameters

- **ExPolicy** – The type of the execution policy to use (deduced). It describes the manner in which the execution of the algorithm may be parallelized and the manner in which it executes the assignments.
- **FwdIter** – The type of the source iterators used for the This iterator type must meet the requirements of a forward iterator.
- **Sent** – The type of the source sentinel (deduced). This sentinel type must be a sentinel for FwdIter.
- **Pred** – The type of an optional function/function object to use. Unlike its sequential form, the parallel overload of *is_sorted_until* requires *Pred* to meet the requirements of *CopyConstructible*. This defaults to `std::less<>`
- **Proj** – The type of an optional projection function. This defaults to `hpx::identity`

Parameters

- **policy** – The execution policy to use for the scheduling of the iterations.
- **first** – Refers to the beginning of the sequence of elements of that the algorithm will be applied to.
- **last** – Refers to the end of the sequence of elements of that the algorithm will be applied to.
- **pred** – Refers to the binary predicate which returns true if the first argument should be treated as less than the second argument. The signature of the function should be equivalent to

```
bool pred(const Type &a, const Type &b);
```

The signature does not need to have `const &`, but the function must not modify the objects passed to it. The type *Type* must be such that objects of types *FwdIter* can be dereferenced and then implicitly converted to *Type*.

- **proj** – Specifies the function (or function object) which will be invoked for each of the elements as a projection operation before the actual predicate *is* invoked.

Returns The *is_sorted_until* algorithm returns a `hpx::future<FwdIter>` if the execution policy is of type *task_execution_policy* and returns *FwdIter* otherwise. The *is_sorted_until* algorithm returns the first unsorted element. If the sequence has less than two elements or the sequence is sorted, last is returned.

```
template<typename Rng, typename Pred = hpx::parallel::detail::less, typename Proj = hpx::identity>
hpx::traits::range_iterator_t<Rng> is_sorted_until(Rng &&rng, Pred &&pred = Pred(), Proj
&&proj = Proj())
```

Returns the first element in the range *rng* that is not sorted. Uses a predicate to compare elements or the less than operator.

Note: Complexity: at most $(N+S-1)$ comparisons where $N = \text{size}(\text{rng})$. $S = \text{number of partitions}$

Template Parameters

- **Rng** – The type of the source range used (deduced). The iterators extracted from this range type must meet the requirements of an forward iterator.
- **Pred** – The type of an optional function/function object to use. Unlike its sequential form, the parallel overload of *is_sorted_until* requires *Pred* to meet the requirements of *CopyConstructible*. This defaults to `std::less<>`
- **Proj** – The type of an optional projection function. This defaults to `hpx::identity`

Parameters

- **rng** – Refers to the sequence of elements the algorithm will be applied to.
- **pred** – Refers to the binary predicate which returns true if the first argument should be treated as less than the second argument. The signature of the function should be

equivalent to

```
bool pred(const Type &a, const Type &b);
```

The signature does not need to have `const &`, but the function must not modify the objects passed to it. The type *Type* must be such that objects of types *FwdIter* can be dereferenced and then implicitly converted to *Type*.

- **proj** – Specifies the function (or function object) which will be invoked for each of the elements as a projection operation before the actual predicate *is* is invoked.

Returns The *is_sorted_until* returns *FwdIter*. The *is_sorted_until* algorithm returns the first unsorted element. If the sequence has less than two elements or the sequence is sorted, last is returned.

```
template<typename ExPolicy, typename Rng, typename Pred = hpx::parallel::detail::less, typename Proj = hpx::identity>
```

```
hpx::parallel::util::detail::algorithm_result<ExPolicy, hpx::traits::range_iterator_t<Rng>> is_sorted_until(ExPolicy
&&policy,
Rng
&&rng,
Pred
&&pred
=
Pred(),
Proj
&&proj
=
Proj())
```

Returns the first element in the range *rng* that is not sorted. Uses a predicate to compare elements or the less than operator.

The comparison operations in the parallel *is_sorted_until* algorithm invoked with an execution policy object of type *sequenced_policy* executes in sequential order in the calling thread.

The comparison operations in the parallel *is_sorted_until* algorithm invoked with an execution policy object of type *parallel_policy* or *parallel_task_policy* are permitted to execute in an unordered fashion in unspecified threads, and indeterminately sequenced within each thread.

Note: Complexity: at most $(N+S-1)$ comparisons where $N = \text{size}(\text{rng})$. $S = \text{number of partitions}$

Template Parameters

- **ExPolicy** – The type of the execution policy to use (deduced). It describes the manner in which the execution of the algorithm may be parallelized and the manner in which it executes the assignments.
- **Rng** – The type of the source range used (deduced). The iterators extracted from this range type must meet the requirements of an forward iterator.
- **Pred** – The type of an optional function/function object to use. Unlike its sequential form, the parallel overload of *is_sorted_until* requires *Pred* to meet the requirements of *CopyConstructible*. This defaults to `std::less<>`
- **Proj** – The type of an optional projection function. This defaults to `hpx::identity`

Parameters

- **policy** – The execution policy to use for the scheduling of the iterations.
- **rng** – Refers to the sequence of elements the algorithm will be applied to.

- **pred** – Refers to the binary predicate which returns true if the first argument should be treated as less than the second argument. The signature of the function should be equivalent to

```
bool pred(const Type &a, const Type &b);
```

The signature does not need to have `const &`, but the function must not modify the objects passed to it. The type *Type* must be such that objects of types *FwdIter* can be dereferenced and then implicitly converted to *Type*.

- **proj** – Specifies the function (or function object) which will be invoked for each of the elements as a projection operation before the actual predicate *is* invoked.

Returns The *is_sorted_until* algorithm returns a *hpx::future<FwdIter>* if the execution policy is of type *task_execution_policy* and returns *FwdIter* otherwise. The *is_sorted_until* algorithm returns the first unsorted element. If the sequence has less than two elements or the sequence is sorted, last is returned.

hpx::ranges::lexicographical_compare

Defined in header `hpx/algorithm.hpp`⁶⁵⁵.

See *Public API* for a list of names and headers that are part of the public *HPX* API.

namespace **hpx**

namespace **ranges**

Functions

```
template<typename InIter1, typename Sent1, typename InIter2, typename Sent2, typename Proj1
= hpx::identity, typename Proj2 = hpx::identity, typename Pred = hpx::parallel::detail::less>
bool lexicographical_compare(InIter1 first1, Sent1 last1, InIter2 first2, Sent2 last2, Pred &&pred =
    Pred(), Proj1 &&proj1 = Proj1(), Proj2 &&proj2 = Proj2())
```

Checks if the first range [first1, last1) is lexicographically less than the second range [first2, last2). uses a provided predicate to compare elements.

The comparison operations in the parallel *lexicographical_compare* algorithm invoked without an execution policy object execute in sequential order in the calling thread.

Note: Complexity: At most $2 * \min(N1, N2)$ applications of the comparison operation, where $N1 = \text{std::distance}(\text{first1}, \text{last})$ and $N2 = \text{std::distance}(\text{first2}, \text{last2})$.

Note: Lexicographical comparison is an operation with the following properties

- Two ranges are compared element by element
- The first mismatching element defines which range is lexicographically *less* or *greater* than the other
- If one range is a prefix of another, the shorter range is lexicographically *less* than the other

⁶⁵⁵ <http://github.com/STELLAR-GROUP/hpx/blob/8a3b7c1a4cb5693b2f7d9f587f759392ed0c51a0/libs/full/include/include/hpx/algorithm.hpp>

- If two ranges have equivalent elements and are of the same length, then the ranges are lexicographically *equal*
- An empty range is lexicographically *less* than any non-empty range
- Two empty ranges are lexicographically *equal*

Template Parameters

- **InIter1** – The type of the source iterators used for the first range (deduced). This iterator type must meet the requirements of an input iterator.
- **Sent1** – The type of the source sentinel (deduced). This sentinel type must be a sentinel for InIter1.
- **InIter2** – The type of the source iterators used for the second range (deduced). This iterator type must meet the requirements of an input iterator.
- **Sent2** – The type of the source sentinel (deduced). This sentinel type must be a sentinel for InIter2.
- **Pred** – The type of an optional function/function object to use. Unlike its sequential form, the parallel overload of *lexicographical_compare* requires *Pred* to meet the requirements of *CopyConstructible*. This defaults to `std::less<>`
- **Proj1** – The type of an optional projection function for FwdIter1. This defaults to `hpx::identity`
- **Proj2** – The type of an optional projection function for FwdIter2. This defaults to `hpx::identity`

Parameters

- **first1** – Refers to the beginning of the sequence of elements of the first range the algorithm will be applied to.
- **last1** – Refers to the end of the sequence of elements of the first range the algorithm will be applied to.
- **first2** – Refers to the beginning of the sequence of elements of the second range the algorithm will be applied to.
- **last2** – Refers to the end of the sequence of elements of the second range the algorithm will be applied to.
- **pred** – Refers to the comparison function that the first and second ranges will be applied to
- **proj1** – Specifies the function (or function object) which will be invoked for each of the elements of the first range as a projection operation before the actual predicate *is* invoked.
- **proj2** – Specifies the function (or function object) which will be invoked for each of the elements of the second range as a projection operation before the actual predicate *is* invoked.

Returns The *lexicographically_compare* algorithm returns *bool*. The *lexicographically_compare* algorithm returns true if the first range is lexicographically less, otherwise it returns false. range [first2, last2), it returns false.

```
template<typename ExpPolicy, typename FwdIter1, typename Sent1, typename FwdIter2, typename Sent2,
typename Proj1 = hpx::identity, typename Proj2 = hpx::identity, typename Pred = hpx::parallel::detail::less>
```

```
hpx::parallel::util::detail::algorithm_result_t<ExPolicy, bool> lexicographical_compare(ExPolicy
&&policy,
FwdIter1
first1,
Sent1 last1,
FwdIter2
first2,
Sent2 last2,
Pred
&&pred =
Pred(),
Proj1
&&proj1 =
Proj1(),
Proj2
&&proj2 =
Proj2())
```

Checks if the first range [first1, last1) is lexicographically less than the second range [first2, last2). uses a provided predicate to compare elements.

The comparison operations in the parallel *lexicographical_compare* algorithm invoked with an execution policy object of type *sequenced_policy* execute in sequential order in the calling thread.

The comparison operations in the parallel *lexicographical_compare* algorithm invoked with an execution policy object of type *parallel_policy* or *parallel_task_policy* are permitted to execute in an unordered fashion in unspecified threads, and indeterminately sequenced within each thread.

Note: Complexity: At most $2 * \min(N1, N2)$ applications of the comparison operation, where $N1 = \text{std::distance}(\text{first1}, \text{last})$ and $N2 = \text{std::distance}(\text{first2}, \text{last2})$.

Note: Lexicographical comparison is an operation with the following properties

- Two ranges are compared element by element
 - The first mismatching element defines which range is lexicographically *less* or *greater* than the other
 - If one range is a prefix of another, the shorter range is lexicographically *less* than the other
 - If two ranges have equivalent elements and are of the same length, then the ranges are lexicographically *equal*
 - An empty range is lexicographically *less* than any non-empty range
 - Two empty ranges are lexicographically *equal*
-

Template Parameters

- **ExPolicy** – The type of the execution policy to use (deduced). It describes the manner in which the execution of the algorithm may be parallelized and the manner in which it executes the assignments.
- **FwdIter1** – The type of the source iterators used for the first range (deduced). This iterator type must meet the requirements of an forward iterator.
- **Sent1** – The type of the source sentinel (deduced). This sentinel type must be a sentinel for FwdIter1.
- **FwdIter2** – The type of the source iterators used for the second range (deduced). This iterator type must meet the requirements of an forward iterator.

- **Sent2** – The type of the source sentinel (deduced). This sentinel type must be a sentinel for `FwdIter2`.
- **Pred** – The type of an optional function/function object to use. Unlike its sequential form, the parallel overload of `lexicographical_compare` requires `Pred` to meet the requirements of `CopyConstructible`. This defaults to `std::less<>`
- **Proj1** – The type of an optional projection function for `FwdIter1`. This defaults to `hpx::identity`
- **Proj2** – The type of an optional projection function for `FwdIter2`. This defaults to `hpx::identity`

Parameters

- **policy** – The execution policy to use for the scheduling of the iterations.
- **first1** – Refers to the beginning of the sequence of elements of the first range the algorithm will be applied to.
- **last1** – Refers to the end of the sequence of elements of the first range the algorithm will be applied to.
- **first2** – Refers to the beginning of the sequence of elements of the second range the algorithm will be applied to.
- **last2** – Refers to the end of the sequence of elements of the second range the algorithm will be applied to.
- **pred** – Refers to the comparison function that the first and second ranges will be applied to
- **proj1** – Specifies the function (or function object) which will be invoked for each of the elements of the first range as a projection operation before the actual predicate *is* invoked.
- **proj2** – Specifies the function (or function object) which will be invoked for each of the elements of the second range as a projection operation before the actual predicate *is* invoked.

Returns The `lexicographically_compare` algorithm returns a `hpx::future<bool>` if the execution policy is of type `sequenced_task_policy` or `parallel_task_policy` and returns `bool` otherwise. The `lexicographically_compare` algorithm returns true if the first range is lexicographically less, otherwise it returns false. `range [first2, last2)`, it returns false.

```
template<typename Rng1, typename Rng2, typename Proj1 = hpx::identity, typename Proj2 =
hpx::identity, typename Pred = hpx::parallel::detail::less>
bool lexicographical_compare(Rng1 &&rng1, Rng2 &&rng2, Pred &&pred = Pred(), Proj1
&&proj1 = Proj1(), Proj2 &&proj2 = Proj2())
```

Checks if the first range `rng1` is lexicographically less than the second range `rng2`. uses a provided predicate to compare elements.

The comparison operations in the parallel `lexicographical_compare` algorithm invoked without an execution policy object execute in sequential order in the calling thread.

Note: Complexity: At most $2 * \min(N1, N2)$ applications of the comparison operation, where $N1 = \text{std::distance}(\text{std::begin}(\text{rng1}), \text{std::end}(\text{rng1}))$ and $N2 = \text{std::distance}(\text{std::begin}(\text{rng2}), \text{std::end}(\text{rng2}))$.

Note: Lexicographical comparison is an operation with the following properties

- Two ranges are compared element by element
- The first mismatching element defines which range is lexicographically *less* or *greater* than the other
- If one range is a prefix of another, the shorter range is lexicographically *less* than the other

- If two ranges have equivalent elements and are of the same length, then the ranges are lexicographically *equal*
- An empty range is lexicographically *less* than any non-empty range
- Two empty ranges are lexicographically *equal*

Template Parameters

- **Rng1** – The type of the source range used (deduced). The iterators extracted from this range type must meet the requirements of an input iterator.
- **Rng2** – The type of the source range used (deduced). The iterators extracted from this range type must meet the requirements of an input iterator.
- **Pred** – The type of an optional function/function object to use. Unlike its sequential form, the parallel overload of *lexicographical_compare* requires *Pred* to meet the requirements of *CopyConstructible*. This defaults to `std::less<>`
- **Proj1** – The type of an optional projection function for elements of the first range. This defaults to `hpx::identity`
- **Proj2** – The type of an optional projection function for elements of the second range. This defaults to `hpx::identity`

Parameters

- **rng1** – Refers to the sequence of elements the algorithm will be applied to.
- **rng2** – Refers to the sequence of elements the algorithm will be applied to.
- **pred** – Refers to the comparison function that the first and second ranges will be applied to
- **proj1** – Specifies the function (or function object) which will be invoked for each of the elements of the first range as a projection operation before the actual predicate *is* invoked.
- **proj2** – Specifies the function (or function object) which will be invoked for each of the elements of the second range as a projection operation before the actual predicate *is* invoked.

Returns The *lexicographically_compare* algorithm returns *bool*. The *lexicographically_compare* algorithm returns true if the first range is lexicographically less, otherwise it returns false. `range [first2, last2)`, it returns false.

```
template<typename ExPolicy, typename Rng1, typename Rng2, typename Proj1 = hpx::identity,
typename Proj2 = hpx::identity, typename Pred = hpx::parallel::detail::less>
hpx::parallel::util::detail::algorithm_result_t<ExPolicy, bool> lexicographical_compare(ExPolicy
&&policy,
Rng1
&&rng1,
Rng2
&&rng2,
Pred
&&pred =
Pred(),
Proj1
&&proj1 =
Proj1(),
Proj2
&&proj2 =
Proj2())
```

Checks if the first range `rng1` is lexicographically less than the second range `rng2`. uses a provided predicate to compare elements.

The comparison operations in the parallel *lexicographical_compare* algorithm invoked with an execution policy object of type *sequenced_policy* execute in sequential order in the calling thread.

The comparison operations in the parallel *lexicographical_compare* algorithm invoked with an execution policy object of type *parallel_policy* or *parallel_task_policy* are permitted to execute in an unordered fashion in unspecified threads, and indeterminately sequenced within each thread.

Note: Complexity: At most $2 * \min(N1, N2)$ applications of the comparison operation, where $N1 = \text{std::distance}(\text{std::begin}(\text{rng1}), \text{std::end}(\text{rng1}))$ and $N2 = \text{std::distance}(\text{std::begin}(\text{rng2}), \text{std::end}(\text{rng2}))$.

Note: Lexicographical comparison is an operation with the following properties

- Two ranges are compared element by element
 - The first mismatching element defines which range is lexicographically *less* or *greater* than the other
 - If one range is a prefix of another, the shorter range is lexicographically *less* than the other
 - If two ranges have equivalent elements and are of the same length, then the ranges are lexicographically *equal*
 - An empty range is lexicographically *less* than any non-empty range
 - Two empty ranges are lexicographically *equal*
-

Template Parameters

- **ExPolicy** – The type of the execution policy to use (deduced). It describes the manner in which the execution of the algorithm may be parallelized and the manner in which it executes the assignments.
- **Rng1** – The type of the source range used (deduced). The iterators extracted from this range type must meet the requirements of an input iterator.
- **Rng2** – The type of the source range used (deduced). The iterators extracted from this range type must meet the requirements of an input iterator.
- **Pred** – The type of an optional function/function object to use. Unlike its sequential form, the parallel overload of *lexicographical_compare* requires *Pred* to meet the requirements of *CopyConstructible*. This defaults to `std::less<>`
- **Proj1** – The type of an optional projection function for elements of the first range. This defaults to `hpx::identity`
- **Proj2** – The type of an optional projection function for elements of the second range. This defaults to `hpx::identity`

Parameters

- **policy** – The execution policy to use for the scheduling of the iterations.
- **rng1** – Refers to the sequence of elements the algorithm will be applied to.
- **rng2** – Refers to the sequence of elements the algorithm will be applied to.
- **pred** – Refers to the comparison function that the first and second ranges will be applied to
- **proj1** – Specifies the function (or function object) which will be invoked for each of the elements of the first range as a projection operation before the actual predicate *is* invoked.
- **proj2** – Specifies the function (or function object) which will be invoked for each of the elements of the second range as a projection operation before the actual predicate *is* invoked.

Returns The *lexicographically_compare* algorithm returns a `hpx::future<bool>` if the execution policy is of type *sequenced_task_policy* or *parallel_task_policy* and returns *bool* otherwise. The *lexicographically_compare* algorithm returns true if the first range is lexicographically less, otherwise it returns false. `range [first2, last2)`, it returns false.

hpx::ranges::make_heap

Defined in header `hpx/algorithm.hpp`⁶⁵⁶.

See *Public API* for a list of names and headers that are part of the public HPX API.

```
namespace hpx
```

```
namespace ranges
```

Functions

```
template<typename ExPolicy, typename Iter, typename Sent, typename Comp, typename Proj =
    hpx::identity>
    hpx::parallel::util::detail::algorithm_result_t<ExPolicy, Iter> make_heap(ExPolicy &&policy, Iter first,
        Sent last, Comp &&comp,
        Proj &&proj = Proj{})
```

Constructs a *max heap* in the range [first, last).

The predicate operations in the parallel *make_heap* algorithm invoked with an execution policy object of type *sequential_execution_policy* executes in sequential order in the calling thread.

The comparison operations in the parallel *make_heap* algorithm invoked with an execution policy object of type *parallel_execution_policy* or *parallel_task_execution_policy* are permitted to execute in an unordered fashion in unspecified threads, and indeterminately sequenced within each thread.

Note: Complexity: at most (3*N) comparisons where $N = \text{distance}(\text{first}, \text{last})$.

Template Parameters

- **ExPolicy** – The type of the execution policy to use (deduced). It describes the manner in which the execution of the algorithm may be parallelized and the manner in which it executes the assignments.
- **Iter** – The type of the begin source iterators used (deduced). This iterator type must meet the requirements of an forward iterator.
- **Sent** – The type of the end source iterators used (deduced). This iterator type must meet the requirements of an sentinel for Iter1.
- **Comp** – The type of the function/function object to use (deduced).
- **Proj** – The type of an optional projection function. This defaults to `hpx::identity`

Parameters

- **policy** – The execution policy to use for the scheduling of the iterations.
- **first** – Refers to the beginning of the sequence of elements the algorithm will be applied to.
- **last** – Refers to the end of the sequence of elements the algorithm will be applied to.
- **comp** – Refers to the binary predicate which returns true if the first argument should be treated as less than the second. The signature of the function should be equivalent to

```
bool comp(const Type &a, const Type &b);
```

⁶⁵⁶ <http://github.com/STELLAR-GROUP/hpx/blob/8a3b7c1a4cb5693b2f7d9f587f759392ed0c51a0/libs/full/include/include/hpx/algorithm.hpp>

The signature does not need to have `const &`, but the function must not modify the objects passed to it. The type *Type* must be such that objects of types *RndIter* can be dereferenced and then implicitly converted to *Type*.

- **proj** – Specifies the function (or function object) which will be invoked for each pair of elements as a projection operation before the actual predicate *comp* is invoked.

Returns The *make_heap* algorithm returns a *hpx::future<Iter>* if the execution policy is of type *sequenced_task_policy* or *parallel_task_policy* and returns *Iter* otherwise. It returns *last*.

```
template<typename ExPolicy, typename Rng, typename Comp, typename Proj = hpx::identity>
hpx::parallel::util::detail::algorithm_result<ExPolicy, hpx::traits::range_iterator_t<Rng>> make_heap(ExPolicy
&&pol-
icy,
Rng
&&rng,
Comp
&&comp,
Proj
&&proj
=
Proj{})
```

Constructs a *max heap* in the range [first, last).

The predicate operations in the parallel *make_heap* algorithm invoked with an execution policy object of type *sequential_execution_policy* executes in sequential order in the calling thread.

The comparison operations in the parallel *make_heap* algorithm invoked with an execution policy object of type *parallel_execution_policy* or *parallel_task_execution_policy* are permitted to execute in an unordered fashion in unspecified threads, and indeterminately sequenced within each thread.

Note: Complexity: at most (3*N) comparisons where *N* = distance(first, last).

Template Parameters

- **ExPolicy** – The type of the execution policy to use (deduced). It describes the manner in which the execution of the algorithm may be parallelized and the manner in which it executes the assignments.
- **Rng** – The type of the source range used (deduced). The iterators extracted from this range type must meet the requirements of an input iterator.
- **Comp** – The type of the function/function object to use (deduced).
- **Proj** – The type of an optional projection function. This defaults to *hpx::identity*

Parameters

- **policy** – The execution policy to use for the scheduling of the iterations.
- **rng** – Refers to the sequence of elements the algorithm will be applied to.
- **comp** – Refers to the binary predicate which returns true if the first argument should be treated as less than the second. The signature of the function should be equivalent to

```
bool comp(const Type &a, const Type &b);
```

The signature does not need to have `const &`, but the function must not modify the objects passed to it. The type *Type* must be such that objects of types *RndIter* can be dereferenced and then implicitly converted to *Type*.

- **proj** – Specifies the function (or function object) which will be invoked for each pair of elements as a projection operation before the actual predicate *comp* is invoked.

Returns The *make_heap* algorithm returns a *hpx::future<Iter>* if the execution policy is of type *sequenced_task_policy* or *parallel_task_policy* and returns *Iter* otherwise. It returns *last*.

```
template<typename ExPolicy, typename Iter, typename Sent, typename Proj = hpx::identity>
hpx::parallel::util::detail::algorithm_result_t<ExPolicy, Iter> make_heap(ExPolicy &&policy, Iter first,
                                                                    Sent last, Proj &&proj =
                                                                    Proj{})
```

Constructs a *max heap* in the range [first, last).

The predicate operations in the parallel *make_heap* algorithm invoked with an execution policy object of type *sequential_execution_policy* executes in sequential order in the calling thread.

The comparison operations in the parallel *make_heap* algorithm invoked with an execution policy object of type *parallel_execution_policy* or *parallel_task_execution_policy* are permitted to execute in an unordered fashion in unspecified threads, and indeterminately sequenced within each thread.

Note: Complexity: at most (3*N) comparisons where *N* = distance(first, last).

Template Parameters

- **ExPolicy** – The type of the execution policy to use (deduced). It describes the manner in which the execution of the algorithm may be parallelized and the manner in which it executes the assignments.
- **Iter** – The type of the begin source iterators used (deduced). This iterator type must meet the requirements of an forward iterator.
- **Sent** – The type of the end source iterators used (deduced). This iterator type must meet the requirements of an sentinel for *Iter1*.
- **Proj** – The type of an optional projection function. This defaults to *hpx::identity*

Parameters

- **policy** – The execution policy to use for the scheduling of the iterations.
- **first** – Refers to the beginning of the sequence of elements the algorithm will be applied to.
- **last** – Refers to the end of the sequence of elements the algorithm will be applied to.
- **proj** – Specifies the function (or function object) which will be invoked for each pair of elements as a projection operation before the actual predicate *comp* is invoked.

Returns The *make_heap* algorithm returns a *hpx::future<Iter>* if the execution policy is of type *sequenced_task_policy* or *parallel_task_policy* and returns *Iter* otherwise. It returns *last*.

```
template<typename ExPolicy, typename Rng, typename Proj = hpx::identity>
hpx::parallel::util::detail::algorithm_result_t<ExPolicy, hpx::traits::range_iterator_t<Rng>> make_heap(ExPolicy
                                                                                                     &&pol-
                                                                                                     istry,
                                                                                                     Rng
                                                                                                     &&rng,
                                                                                                     Proj
                                                                                                     &&proj
                                                                                                     =
                                                                                                     Proj{})
```

Constructs a *max heap* in the range [first, last).

The predicate operations in the parallel *make_heap* algorithm invoked with an execution policy object of type *sequential_execution_policy* executes in sequential order in the calling thread.

The comparison operations in the parallel *make_heap* algorithm invoked with an execution policy object of type *parallel_execution_policy* or *parallel_task_execution_policy* are permitted to execute in an unordered fashion in unspecified threads, and indeterminately sequenced within each thread.

Note: Complexity: at most (3*N) comparisons where $N = \text{distance}(\text{first}, \text{last})$.

Template Parameters

- **ExPolicy** – The type of the execution policy to use (deduced). It describes the manner in which the execution of the algorithm may be parallelized and the manner in which it executes the assignments.
- **Rng** – The type of the source range used (deduced). The iterators extracted from this range type must meet the requirements of an input iterator.
- **Proj** – The type of an optional projection function. This defaults to *hpx::identity*

Parameters

- **policy** – The execution policy to use for the scheduling of the iterations.
- **rng** – Refers to the sequence of elements the algorithm will be applied to.
- **proj** – Specifies the function (or function object) which will be invoked for each pair of elements as a projection operation before the actual predicate *comp* is invoked.

Returns The *make_heap* algorithm returns a *hpx::future<Iter>* if the execution policy is of type *sequenced_task_policy* or *parallel_task_policy* and returns *Iter* otherwise. It returns *last*.

```
template<typename Iter, typename Sent, typename Comp, typename Proj = hpx::identity>
Iter make_heap(Iter first, Sent last, Comp &&comp, Proj &&proj = Proj{ })
Constructs a max heap in the range [first, last).
```

Note: Complexity: at most (3*N) comparisons where $N = \text{distance}(\text{first}, \text{last})$.

Template Parameters

- **Iter** – The type of the begin source iterators used (deduced). This iterator type must meet the requirements of an forward iterator.
- **Sent** – The type of the end source iterators used (deduced). This iterator type must meet the requirements of an sentinel for *Iter1*.
- **Comp** – The type of the function/function object to use (deduced).
- **Proj** – The type of an optional projection function. This defaults to *hpx::identity*

Parameters

- **first** – Refers to the beginning of the sequence of elements the algorithm will be applied to.
- **last** – Refers to the end of the sequence of elements the algorithm will be applied to.
- **comp** – Refers to the binary predicate which returns true if the first argument should be treated as less than the second. The signature of the function should be equivalent to

```
bool comp(const Type &a, const Type &b);
```

The signature does not need to have `const &`, but the function must not modify the objects passed to it. The type *Type* must be such that objects of types *RndIter* can be dereferenced and then implicitly converted to *Type*.

- **proj** – Specifies the function (or function object) which will be invoked for each pair of elements as a projection operation before the actual predicate *comp* is invoked.

Returns The *make_heap* algorithm returns *Iter*. It returns *last*.

```
template<typename Rng, typename Comp, typename Proj = hpx::identity>
hpx::traits::range_iterator_t<Rng> make_heap(Rng &&rng, Comp &&comp, Proj &&proj = Proj{})
```

Constructs a *max heap* in the range [first, last).

Note: Complexity: at most (3*N) comparisons where $N = \text{distance}(\text{first}, \text{last})$.

Template Parameters

- **Rng** – The type of the source range used (deduced). The iterators extracted from this range type must meet the requirements of an input iterator.
- **Comp** – The type of the function/function object to use (deduced).
- **Proj** – The type of an optional projection function. This defaults to *hpx::identity*

Parameters

- **rng** – Refers to the sequence of elements the algorithm will be applied to.
- **comp** – Refers to the binary predicate which returns true if the first argument should be treated as less than the second. The signature of the function should be equivalent to

```
bool comp(const Type &a, const Type &b);
```

The signature does not need to have `const &`, but the function must not modify the objects passed to it. The type *Type* must be such that objects of types *RndIter* can be dereferenced and then implicitly converted to *Type*.

- **proj** – Specifies the function (or function object) which will be invoked for each pair of elements as a projection operation before the actual predicate *comp* is invoked.

Returns The *make_heap* algorithm returns *Iter*. It returns *last*.

```
template<typename Iter, typename Sent, typename Proj = hpx::identity>
Iter make_heap(Iter first, Sent last, Proj &&proj = Proj{})
```

Constructs a *max heap* in the range [first, last).

Note: Complexity: at most (3*N) comparisons where $N = \text{distance}(\text{first}, \text{last})$.

Template Parameters

- **Iter** – The type of the begin source iterators used (deduced). This iterator type must meet the requirements of an forward iterator.
- **Sent** – The type of the end source iterators used (deduced). This iterator type must meet the requirements of an sentinel for *Iter*1.
- **Proj** – The type of an optional projection function. This defaults to *hpx::identity*

Parameters

- **first** – Refers to the beginning of the sequence of elements the algorithm will be applied to.
- **last** – Refers to the end of the sequence of elements the algorithm will be applied to.
- **proj** – Specifies the function (or function object) which will be invoked for each pair of elements as a projection operation before the actual predicate *comp* is invoked.

Returns The *make_heap* algorithm returns *Iter*. It returns *last*.

```
template<typename Rng, typename Proj = hpx::identity>
hpx::traits::range_iterator_t<Rng> make_heap(Rng &&rng, Proj &&proj = Proj{})
```

Constructs a *max heap* in the range [first, last).

Note: Complexity: at most (3*N) comparisons where $N = \text{distance}(\text{first}, \text{last})$.

Template Parameters

- **Rng** – The type of the source range used (deduced). The iterators extracted from this range type must meet the requirements of an input iterator.
- **Proj** – The type of an optional projection function. This defaults to `hpx::identity`

Parameters

- **rng** – Refers to the sequence of elements the algorithm will be applied to.
- **proj** – Specifies the function (or function object) which will be invoked for each pair of elements as a projection operation before the actual predicate `comp` is invoked.

Returns The `make_heap` algorithm returns `Iter`. It returns `last`.

hpx::ranges::merge, hpx::ranges::inplace_merge

Defined in header `hpx/algorithm.hpp`⁶⁵⁷.

See *Public API* for a list of names and headers that are part of the public HPX API.

namespace **hpx**

namespace **ranges**

Functions

```
template<typename ExPolicy, typename Rng1, typename Rng2, typename Iter3, typename Comp =
    hpx::ranges::less, typename Proj1 = hpx::identity, typename Proj2 = hpx::identity>
    hpx::parallel::util::detail::algorithm_result<ExPolicy, hpx::ranges::merge_result<hpx::traits::range_iterator_t<Rng1>, hpx::
```

Merges two sorted ranges `[first1, last1)` and `[first2, last2)` into one sorted range beginning at `dest`. The order of equivalent elements in the each of original two ranges is preserved. For equivalent elements in the original two ranges, the elements from the first range precede the elements from the second range. The destination range cannot overlap with either of the input ranges.

⁶⁵⁷ <http://github.com/STELLAR-GROUP/hpx/blob/8a3b7c1a4cb5693b2f7d9f587f759392ed0c51a0/libs/full/include/include/hpx/algorithm.hpp>

The assignments in the parallel *merge* algorithm invoked with an execution policy object of type *sequenced_policy* execute in sequential order in the calling thread.

The assignments in the parallel *merge* algorithm invoked with an execution policy object of type *parallel_policy* or *parallel_task_policy* are permitted to execute in an unordered fashion in unspecified threads, and indeterminately sequenced within each thread.

Note: Complexity: Performs $O(\text{std::distance}(\text{first1}, \text{last1}) + \text{std::distance}(\text{first2}, \text{last2}))$ applications of the comparison *comp* and the each projection.

Template Parameters

- **ExPolicy** – The type of the execution policy to use (deduced). It describes the manner in which the execution of the algorithm may be parallelized and the manner in which it executes the assignments.
- **Rng1** – The type of the first source range used (deduced). The iterators extracted from this range type must meet the requirements of a random access iterator.
- **Rng2** – The type of the second source range used (deduced). The iterators extracted from this range type must meet the requirements of a random access iterator.
- **Iter3** – The type of the iterator representing the destination range (deduced). This iterator type must meet the requirements of a random access iterator.
- **Comp** – The type of the function/function object to use (deduced). Unlike its sequential form, the parallel overload of *merge* requires *Comp* to meet the requirements of *CopyConstructible*. This defaults to `std::less<>`
- **Proj1** – The type of an optional projection function to be used for elements of the first range. This defaults to `hpx::identity`
- **Proj2** – The type of an optional projection function to be used for elements of the second range. This defaults to `hpx::identity`

Parameters

- **policy** – The execution policy to use for the scheduling of the iterations.
- **rng1** – Refers to the first range of elements the algorithm will be applied to.
- **rng2** – Refers to the second range of elements the algorithm will be applied to.
- **dest** – Refers to the beginning of the destination range.
- **comp** – *comp* is a callable object which returns true if the first argument is less than the second, and false otherwise. The signature of this comparison should be equivalent to:

```
bool comp(const Type1 &a, const Type2 &b);
```

The signature does not need to have `const&`, but the function must not modify the objects passed to it. The types *Type1* and *Type2* must be such that objects of types *Iter1* and *Iter2* can be dereferenced and then implicitly converted to both *Type1* and *Type2*

- **proj1** – Specifies the function (or function object) which will be invoked for each of the elements of the first range as a projection operation before the actual comparison *comp* is invoked.
- **proj2** – Specifies the function (or function object) which will be invoked for each of the elements of the second range as a projection operation before the actual comparison *comp* is invoked.

Returns The *merge* algorithm returns a `hpx::future<merge_result<Iter1, Iter2, Iter3>>` if the execution policy is of type *sequenced_task_policy* or *parallel_task_policy* and returns `merge_result<Iter1, Iter2, Iter3>` otherwise. The *merge* algorithm returns the tuple of the source iterator *last1*, the source iterator *last2*, the destination iterator to the end of the *dest* range.

```
template<typename ExPolicy, typename Iter1, typename Sent1, typename Iter2, typename Sent2,
typename Iter3, typename Comp = hpx::ranges::less, typename Proj1 = hpx::identity, typename Proj2
= hpx::identity>
```

```
hpx::parallel::util::detail::algorithm_result<ExPolicy, hpx::ranges::merge_result<Iter1, Iter2, Iter3>>::type merge(ExPolicy
&&pol-
icy,
Iter1
first1,
Sent1
last1,
Iter2
first2,
Sent2
last2,
Iter3
dest,
Comp
&&com
=
Comp()
Proj1
&&proj
=
Proj1()
Proj2
&&proj
=
Proj2()
```

Merges two sorted ranges [first1, last1) and [first2, last2) into one sorted range beginning at *dest*. The order of equivalent elements in the each of original two ranges is preserved. For equivalent elements in the original two ranges, the elements from the first range precede the elements from the second range. The destination range cannot overlap with either of the input ranges.

The assignments in the parallel *merge* algorithm invoked with an execution policy object of type *sequenced_policy* execute in sequential order in the calling thread.

The assignments in the parallel *merge* algorithm invoked with an execution policy object of type *parallel_policy* or *parallel_task_policy* are permitted to execute in an unordered fashion in unspecified threads, and indeterminately sequenced within each thread.

Note: Complexity: Performs $O(\text{std::distance}(\text{first1}, \text{last1}) + \text{std::distance}(\text{first2}, \text{last2}))$ applications of the comparison *comp* and the each projection.

Template Parameters

- **ExPolicy** – The type of the execution policy to use (deduced). It describes the manner in which the execution of the algorithm may be parallelized and the manner in which it executes the assignments.
- **Iter1** – The type of the source iterators used (deduced) representing the first sequence. This iterator type must meet the requirements of a random access iterator.
- **Sent1** – The type of the end source iterators used (deduced). This iterator type must meet the requirements of a sentinel for *Iter1*.

- **Iter2** – The type of the source iterators used (deduced) representing the second sequence. This iterator type must meet the requirements of a random access iterator.
- **Sent2** – The type of the end source iterators used (deduced) representing the second sequence. This iterator type must meet the requirements of a sentinel for `Iter2`.
- **Iter3** – The type of the iterator representing the destination range (deduced). This iterator type must meet the requirements of a random access iterator.
- **Comp** – The type of the function/function object to use (deduced). Unlike its sequential form, the parallel overload of `merge` requires `Comp` to meet the requirements of `CopyConstructible`. This defaults to `std::less<>`
- **Proj1** – The type of an optional projection function to be used for elements of the first range. This defaults to `hpx::identity`
- **Proj2** – The type of an optional projection function to be used for elements of the second range. This defaults to `hpx::identity`

Parameters

- **policy** – The execution policy to use for the scheduling of the iterations.
- **first1** – Refers to the beginning of the sequence of elements of the first range the algorithm will be applied to.
- **last1** – Refers to the end of the sequence of elements of the first range the algorithm will be applied to.
- **first2** – Refers to the beginning of the sequence of elements of the second range the algorithm will be applied to.
- **last2** – Refers to the end of the sequence of elements of the second range the algorithm will be applied to.
- **dest** – Refers to the beginning of the destination range.
- **comp** – `comp` is a callable object which returns true if the first argument is less than the second, and false otherwise. The signature of this comparison should be equivalent to:

```
bool comp(const Type1 &a, const Type2 &b);
```

The signature does not need to have `const&`, but the function must not modify the objects passed to it. The types `Type1` and `Type2` must be such that objects of types `Iter1` and `Iter2` can be dereferenced and then implicitly converted to both `Type1` and `Type2`

- **proj1** – Specifies the function (or function object) which will be invoked for each of the elements of the first range as a projection operation before the actual comparison `comp` is invoked.
- **proj2** – Specifies the function (or function object) which will be invoked for each of the elements of the second range as a projection operation before the actual comparison `comp` is invoked.

Returns The `merge` algorithm returns a `hpx::future<merge_result<Iter1, Iter2, Iter3>>` if the execution policy is of type `sequenced_task_policy` or `parallel_task_policy` and returns `merge_result<Iter1, Iter2, Iter3>` otherwise. The `merge` algorithm returns the tuple of the source iterator `last1`, the source iterator `last2`, the destination iterator to the end of the `dest` range.

```
template<typename Rng1, typename Rng2, typename Iter3, typename Comp = hpx::ranges::less,
        typename Proj1 = hpx::identity, typename Proj2 = hpx::identity>
```

```

hpx::ranges::merge_result<hpx::traits::range_iterator_t<Rng1>, hpx::traits::range_iterator_t<Rng2>, Iter3> merge(Rng1
&&rng1
Rng2
&&rng2
Iter3
dest,
Comp
&&comp)
=
Comp()
Proj1
&&proj1
=
Proj1(),
Proj2
&&proj2
=
Proj2()

```

Merges two sorted ranges [first1, last1) and [first2, last2) into one sorted range beginning at *dest*. The order of equivalent elements in the each of original two ranges is preserved. For equivalent elements in the original two ranges, the elements from the first range precede the elements from the second range. The destination range cannot overlap with either of the input ranges.

Note: Complexity: Performs $O(\text{std::distance}(\text{first1}, \text{last1}) + \text{std::distance}(\text{first2}, \text{last2}))$ applications of the comparison *comp* and the each projection.

Template Parameters

- **Rng1** – The type of the first source range used (deduced). The iterators extracted from this range type must meet the requirements of a random access iterator.
- **Rng2** – The type of the second source range used (deduced). The iterators extracted from this range type must meet the requirements of a random access iterator.
- **Iter3** – The type of the iterator representing the destination range (deduced). This iterator type must meet the requirements of a random access iterator.
- **Comp** – The type of the function/function object to use (deduced). Unlike its sequential form, the parallel overload of *merge* requires *Comp* to meet the requirements of *CopyConstructible*. This defaults to `std::less<>`
- **Proj1** – The type of an optional projection function to be used for elements of the first range. This defaults to `hpx::identity`
- **Proj2** – The type of an optional projection function to be used for elements of the second range. This defaults to `hpx::identity`

Parameters

- **rng1** – Refers to the first range of elements the algorithm will be applied to.
- **rng2** – Refers to the second range of elements the algorithm will be applied to.
- **dest** – Refers to the beginning of the destination range.
- **comp** – *comp* is a callable object which returns true if the first argument is less than the second, and false otherwise. The signature of this comparison should be equivalent to:

```
bool comp(const Type1 &a, const Type2 &b);
```

The signature does not need to have `const&`, but the function must not modify the objects passed to it. The types *Type1* and *Type2* must be such that objects of types *Iter1* and *Iter2* can be dereferenced and then implicitly converted to both *Type1* and *Type2*

- **proj1** – Specifies the function (or function object) which will be invoked for each of the

elements of the first range as a projection operation before the actual comparison *comp* is invoked.

- **proj2** – Specifies the function (or function object) which will be invoked for each of the elements of the second range as a projection operation before the actual comparison *comp* is invoked.

Returns The *merge* algorithm returns *merge_result*<*Iter1*, *Iter2*, *Iter3*>. The *merge* algorithm returns the tuple of the source iterator *last1*, the source iterator *last2*, the destination iterator to the end of the *dest* range.

```
template<typename Iter1, typename Sent1, typename Iter2, typename Sent2, typename Iter3,
typename Comp = hpx::ranges::less, typename Proj1 = hpx::identity, typename Proj2 = hpx::identity>
hpx::ranges::merge_result<Iter1, Iter2, Iter3> merge(Iter1 first1, Sent1 last1, Iter2 first2, Sent2 last2,
Iter3 dest, Comp &&comp = Comp(), Proj1
&&proj1 = Proj1(), Proj2 &&proj2 = Proj2())
```

Merges two sorted ranges [first1, last1) and [first2, last2) into one sorted range beginning at *dest*. The order of equivalent elements in the each of original two ranges is preserved. For equivalent elements in the original two ranges, the elements from the first range precede the elements from the second range. The destination range cannot overlap with either of the input ranges.

Note: Complexity: Performs $O(\text{std::distance}(\text{first1}, \text{last1}) + \text{std::distance}(\text{first2}, \text{last2}))$ applications of the comparison *comp* and the each projection.

Template Parameters

- **Iter1** – The type of the source iterators used (deduced) representing the first sequence. This iterator type must meet the requirements of an random access iterator.
- **Sent1** – The type of the end source iterators used (deduced). This iterator type must meet the requirements of an sentinel for *Iter1*.
- **Iter2** – The type of the source iterators used (deduced) representing the second sequence. This iterator type must meet the requirements of an random access iterator.
- **Sent2** – The type of the end source iterators used (deduced) representing the second sequence. This iterator type must meet the requirements of an sentinel for *Iter2*.
- **Iter3** – The type of the iterator representing the destination range (deduced). This iterator type must meet the requirements of an random access iterator.
- **Comp** – The type of the function/function object to use (deduced). Unlike its sequential form, the parallel overload of *merge* requires *Comp* to meet the requirements of *CopyConstructible*. This defaults to *std::less*<>
- **Proj1** – The type of an optional projection function to be used for elements of the first range. This defaults to *hpx::identity*
- **Proj2** – The type of an optional projection function to be used for elements of the second range. This defaults to *hpx::identity*

Parameters

- **first1** – Refers to the beginning of the sequence of elements of the first range the algorithm will be applied to.
- **last1** – Refers to the end of the sequence of elements of the first range the algorithm will be applied to.
- **first2** – Refers to the beginning of the sequence of elements of the second range the algorithm will be applied to.
- **last2** – Refers to the end of the sequence of elements of the second range the algorithm will be applied to.
- **dest** – Refers to the beginning of the destination range.
- **comp** – *comp* is a callable object which returns true if the first argument is less than the second, and false otherwise. The signature of this comparison should be equivalent to:

```
bool comp(const Type1 &a, const Type2 &b);
```

The signature does not need to have `const&`, but the function must not modify the objects passed to it. The types *Type1* and *Type2* must be such that objects of types *Iter1* and *Iter2* can be dereferenced and then implicitly converted to both *Type1* and *Type2*

- **proj1** – Specifies the function (or function object) which will be invoked for each of the elements of the first range as a projection operation before the actual comparison *comp* is invoked.
- **proj2** – Specifies the function (or function object) which will be invoked for each of the elements of the second range as a projection operation before the actual comparison *comp* is invoked.

Returns The *merge* algorithm returns *merge_result*<*Iter1*, *Iter2*, *Iter3*>. The *merge* algorithm returns the tuple of the source iterator *last1*, the source iterator *last2*, the destination iterator to the end of the *dest* range.

```
template<typename ExPolicy, typename Rng, typename Iter, typename Comp = hpx::ranges::less,
typename Proj = hpx::identity>
hpx::parallel::util::detail::algorithm_result_t<ExPolicy, Iter> inplace_merge(ExPolicy &&policy, Rng
&&rng, Iter middle,
Comp &&comp =
Comp(), Proj &&proj =
Proj())
```

Merges two consecutive sorted ranges [first, middle) and [middle, last) into one sorted range [first, last). The order of equivalent elements in the each of original two ranges is preserved. For equivalent elements in the original two ranges, the elements from the first range precede the elements from the second range.

The assignments in the parallel *inplace_merge* algorithm invoked with an execution policy object of type *sequenced_policy* execute in sequential order in the calling thread.

The assignments in the parallel *inplace_merge* algorithm invoked with an execution policy object of type *parallel_policy* or *parallel_task_policy* are permitted to execute in an unordered fashion in unspecified threads, and indeterminately sequenced within each thread.

Note: Complexity: Performs $O(\text{std::distance}(\text{first}, \text{last}))$ applications of the comparison *comp* and the each projection.

Template Parameters

- **ExPolicy** – The type of the execution policy to use (deduced). It describes the manner in which the execution of the algorithm may be parallelized and the manner in which it executes the assignments.
- **Rng** – The type of the source range used (deduced). The iterators extracted from this range type must meet the requirements of a random access iterator.
- **Iter** – The type of the source iterators used (deduced). This iterator type must meet the requirements of a random access iterator.
- **Comp** – The type of the function/function object to use (deduced). Unlike its sequential form, the parallel overload of *inplace_merge* requires *Comp* to meet the requirements of *CopyConstructible*. This defaults to `std::less<>`
- **Proj** – The type of an optional projection function. This defaults to *hpx::identity*

Parameters

- **policy** – The execution policy to use for the scheduling of the iterations.
- **rng** – Refers to the range of elements the algorithm will be applied to.

- **middle** – Refers to the end of the first sorted range and the beginning of the second sorted range the algorithm will be applied to.
- **comp** – *comp* is a callable object which returns true if the first argument is less than the second, and false otherwise. The signature of this comparison should be equivalent to:

```
bool comp(const Type1 &a, const Type2 &b);
```

The signature does not need to have const&, but the function must not modify the objects passed to it. The types *Type1* and *Type2* must be such that objects of types *Iter* can be dereferenced and then implicitly converted to both *Type1* and *Type2*

- **proj** – Specifies the function (or function object) which will be invoked for each of the elements as a projection operation before the actual predicate *is* invoked.

Returns The *inplace_merge* algorithm returns a *hpx::future<Iter>* if the execution policy is of type *sequenced_task_policy* or *parallel_task_policy* and returns *Iter* otherwise. The *inplace_merge* algorithm returns the source iterator *last*

```
template<typename ExPolicy, typename Iter, typename Sent, typename Comp = hpx::ranges::less,
        typename Proj = hpx::identity>
hpx::parallel::util::detail::algorithm_result_t<ExPolicy, Iter> inplace_merge(ExPolicy &&policy, Iter
        first, Iter middle, Sent
        last, Comp &&comp =
        Comp(), Proj &&proj =
        Proj())
```

Merges two consecutive sorted ranges [first, middle) and [middle, last) into one sorted range [first, last). The order of equivalent elements in the each of original two ranges is preserved. For equivalent elements in the original two ranges, the elements from the first range precede the elements from the second range.

The assignments in the parallel *inplace_merge* algorithm invoked with an execution policy object of type *sequenced_policy* execute in sequential order in the calling thread.

The assignments in the parallel *inplace_merge* algorithm invoked with an execution policy object of type *parallel_policy* or *parallel_task_policy* are permitted to execute in an unordered fashion in unspecified threads, and indeterminately sequenced within each thread.

Note: Complexity: Performs $O(\text{std::distance}(\text{first}, \text{last}))$ applications of the comparison *comp* and the each projection.

Template Parameters

- **ExPolicy** – The type of the execution policy to use (deduced). It describes the manner in which the execution of the algorithm may be parallelized and the manner in which it executes the assignments.
- **Iter** – The type of the source iterators used (deduced). This iterator type must meet the requirements of an random access iterator.
- **Sent** – The type of the end source iterators used (deduced). This iterator type must meet the requirements of an sentinel for *Iter1*.
- **Comp** – The type of the function/function object to use (deduced). Unlike its sequential form, the parallel overload of *inplace_merge* requires *Comp* to meet the requirements of *CopyConstructible*. This defaults to `std::less<>`
- **Proj** – The type of an optional projection function. This defaults to *hpx::identity*

Parameters

- **policy** – The execution policy to use for the scheduling of the iterations.
- **first** – Refers to the beginning of the first sorted range the algorithm will be applied to.

- **middle** – Refers to the end of the first sorted range and the beginning of the second sorted range the algorithm will be applied to.
- **last** – Refers to the end of the second sorted range the algorithm will be applied to.
- **comp** – *comp* is a callable object which returns true if the first argument is less than the second, and false otherwise. The signature of this comparison should be equivalent to:

```
bool comp(const Type1 &a, const Type2 &b);
```

The signature does not need to have `const&`, but the function must not modify the objects passed to it. The types *Type1* and *Type2* must be such that objects of types *Iter* can be dereferenced and then implicitly converted to both *Type1* and *Type2*

- **proj** – Specifies the function (or function object) which will be invoked for each of the elements as a projection operation before the actual predicate *is* invoked.

Returns The *inplace_merge* algorithm returns a `hpx::future<Iter>` if the execution policy is of type *sequenced_task_policy* or *parallel_task_policy* and returns *Iter* otherwise. The *inplace_merge* algorithm returns the source iterator *last*

```
template<typename Rng, typename Iter, typename Comp = hpx::ranges::less, typename Proj = hpx::identity>
```

```
Iter inplace_merge(Rng &&rng, Iter middle, Comp &&comp = Comp(), Proj &&proj = Proj())
```

Merges two consecutive sorted ranges [first, middle) and [middle, last) into one sorted range [first, last). The order of equivalent elements in the each of original two ranges is preserved. For equivalent elements in the original two ranges, the elements from the first range precede the elements from the second range.

Note: Complexity: Performs $O(\text{std::distance}(\text{first}, \text{last}))$ applications of the comparison *comp* and the each projection.

Template Parameters

- **Rng** – The type of the source range used (deduced). The iterators extracted from this range type must meet the requirements of a random access iterator.
- **Iter** – The type of the source iterators used (deduced). This iterator type must meet the requirements of a random access iterator.
- **Comp** – The type of the function/function object to use (deduced). Unlike its sequential form, the parallel overload of *inplace_merge* requires *Comp* to meet the requirements of *CopyConstructible*. This defaults to `std::less<>`
- **Proj** – The type of an optional projection function. This defaults to `hpx::identity`

Parameters

- **rng** – Refers to the range of elements the algorithm will be applied to.
- **middle** – Refers to the end of the first sorted range and the beginning of the second sorted range the algorithm will be applied to.
- **comp** – *comp* is a callable object which returns true if the first argument is less than the second, and false otherwise. The signature of this comparison should be equivalent to:

```
bool comp(const Type1 &a, const Type2 &b);
```

The signature does not need to have `const&`, but the function must not modify the objects passed to it. The types *Type1* and *Type2* must be such that objects of types *Iter* can be dereferenced and then implicitly converted to both *Type1* and *Type2*

- **proj** – Specifies the function (or function object) which will be invoked for each of the elements as a projection operation before the actual predicate *is* invoked.

Returns The *inplace_merge* algorithm returns *Iter*. The *inplace_merge* algorithm returns the source iterator *last*

```
template<typename Iter, typename Sent, typename Comp = hpx::ranges::less, typename Proj =
hpx::identity>
```

```
Iter inplace_merge(Iter first, Iter middle, Sent last, Comp &&comp = Comp(), Proj &&proj = Proj())
```

Merges two consecutive sorted ranges [first, middle) and [middle, last) into one sorted range [first, last). The order of equivalent elements in the each of original two ranges is preserved. For equivalent elements in the original two ranges, the elements from the first range precede the elements from the second range.

Note: Complexity: Performs $O(\text{std::distance}(\text{first}, \text{last}))$ applications of the comparison *comp* and the each projection.

Template Parameters

- **Iter** – The type of the source iterators used (deduced). This iterator type must meet the requirements of a random access iterator.
- **Sent** – The type of the end source iterators used (deduced). This iterator type must meet the requirements of a sentinel for *Iter1*.
- **Comp** – The type of the function/function object to use (deduced). Unlike its sequential form, the parallel overload of *inplace_merge* requires *Comp* to meet the requirements of *CopyConstructible*. This defaults to `std::less<>`
- **Proj** – The type of an optional projection function. This defaults to *hpx::identity*

Parameters

- **first** – Refers to the beginning of the first sorted range the algorithm will be applied to.
- **middle** – Refers to the end of the first sorted range and the beginning of the second sorted range the algorithm will be applied to.
- **last** – Refers to the end of the second sorted range the algorithm will be applied to.
- **comp** – *comp* is a callable object which returns true if the first argument is less than the second, and false otherwise. The signature of this comparison should be equivalent to:

```
bool comp(const Type1 &a, const Type2 &b);
```

The signature does not need to have `const&`, but the function must not modify the objects passed to it. The types *Type1* and *Type2* must be such that objects of types *Iter* can be dereferenced and then implicitly converted to both *Type1* and *Type2*

- **proj** – Specifies the function (or function object) which will be invoked for each of the elements as a projection operation before the actual predicate *is* invoked.

Returns The *inplace_merge* algorithm *Iter*. The *inplace_merge* algorithm returns the source iterator *last*

hpx::ranges::min_element, hpx::ranges::max_element, hpx::ranges::minmax_element

Defined in header `hpx/algorithm.hpp`⁶⁵⁸.

See *Public API* for a list of names and headers that are part of the public HPX API.

```
namespace hpx
```

```
    namespace ranges
```

⁶⁵⁸ <http://github.com/STELLAR-GROUP/hpx/blob/8a3b7c1a4cb5693b2f7d9f587f759392ed0c51a0/libs/full/include/include/hpx/algorithm.hpp>

Functions

```
template<typename FwdIter, typename Sent, typename F = hpx::parallel::detail::less, typename Proj = hpx::identity>
```

```
FwdIter min_element(FwdIter first, Sent last, F &&f = F(), Proj &&proj = Proj())
```

Finds the smallest element in the range [first, last) using the given comparison function *f*.

The comparisons in the parallel *min_element* algorithm execute in sequential order in the calling thread.

Note: Complexity: Exactly $\max(N-1, 0)$ comparisons, where $N = \text{std::distance}(\text{first}, \text{last})$.

Template Parameters

- **FwdIter** – The type of the source iterator used (deduced). The iterator type must meet the requirements of an forward iterator.
- **Sent** – The type of the end iterators used (deduced). This sentinel type must be a sentinel for *FwdIter*.
- **F** – The type of the function/function object to use (deduced).
- **Proj** – The type of an optional projection function. This defaults to *hpx::identity*

Parameters

- **first** – Refers to the beginning of the sequence of elements the algorithm will be applied to.
- **last** – Refers to the end of the sequence of elements the algorithm will be applied to.
- **f** – The binary predicate which returns true if the the left argument is less than the right element. The signature of the predicate function should be equivalent to the following:

```
bool pred(const Type1 &a, const Type1 &b);
```

The signature does not need to have `const &`, but the function must not modify the objects passed to it. The type *Type1* must be such that objects of type *FwdIter* can be dereferenced and then implicitly converted to *Type1*.

- **proj** – Specifies the function (or function object) which will be invoked for each of the elements as a projection operation before the actual predicate *is* invoked.

Returns The *min_element* algorithm returns *FwdIter*. The *min_element* algorithm returns the iterator to the smallest element in the range [first, last). If several elements in the range are equivalent to the smallest element, returns the iterator to the first such element. Returns last if the range is empty.

```
template<typename Rng, typename F = hpx::parallel::detail::less, typename Proj = hpx::identity>
hpx::traits::range_iterator_t<Rng> min_element(Rng &&rng, F &&f = F(), Proj &&proj = Proj())
```

Finds the smallest element in the range [first, last) using the given comparison function *f*.

The comparisons in the parallel *min_element* algorithm execute in sequential order in the calling thread.

Note: Complexity: Exactly $\max(N-1, 0)$ comparisons, where $N = \text{std::distance}(\text{first}, \text{last})$.

Template Parameters

- **Rng** – The type of the source range used (deduced). The iterators extracted from this range type must meet the requirements of an forward iterator.

- **F** – The type of the function/function object to use (deduced).
- **Proj** – The type of an optional projection function. This defaults to `hpx::identity`

Parameters

- **rng** – Refers to the sequence of elements the algorithm will be applied to.
- **f** – The binary predicate which returns true if the the left argument is less than the right element. The signature of the predicate function should be equivalent to the following:

```
bool pred(const Type1 &a, const Type1 &b);
```

The signature does not need to have `const &`, but the function must not modify the objects passed to it. The type `Type1` must be such that objects of type `FwdIter` can be dereferenced and then implicitly converted to `Type1`.

- **proj** – Specifies the function (or function object) which will be invoked for each of the elements as a projection operation before the actual predicate *is* invoked.

Returns The `min_element` algorithm returns a `hpx::traits::range_iterator<Rng>::type` otherwise. The `min_element` algorithm returns the iterator to the smallest element in the range `[first, last)`. If several elements in the range are equivalent to the smallest element, returns the iterator to the first such element. Returns last if the range is empty.

```
template<typename ExPolicy, typename FwdIter, typename Sent, typename F =
hpx::parallel::detail::less, typename Proj = hpx::identity>
hpx::parallel::util::detail::algorithm_result_t<ExPolicy, FwdIter> min_element(ExPolicy &&policy,
FwdIter first, Sent last,
F &&f = F(), Proj
&&proj = Proj())
```

Finds the smallest element in the range `[first, last)` using the given comparison function *f*.

The comparisons in the parallel `min_element` algorithm invoked with an execution policy object of type `sequenced_policy` execute in sequential order in the calling thread.

The comparisons in the parallel `min_element` algorithm invoked with an execution policy object of type `parallel_policy` or `parallel_task_policy` are permitted to execute in an unordered fashion in unspecified threads, and indeterminately sequenced within each thread.

Note: Complexity: Exactly $\max(N-1, 0)$ comparisons, where $N = \text{std::distance}(\text{first}, \text{last})$.

Template Parameters

- **ExPolicy** – The type of the execution policy to use (deduced). It describes the manner in which the execution of the algorithm may be parallelized and the manner in which it executes the assignments.
- **FwdIter** – The type of the source iterator used (deduced). The iterator type must meet the requirements of an forward iterator.
- **Sent** – The type of the end iterators used (deduced). This sentinel type must be a sentinel for `FwdIter`.
- **F** – The type of the function/function object to use (deduced). Unlike its sequential form, the parallel overload of `min_element` requires *F* to meet the requirements of `CopyConstructible`.
- **Proj** – The type of an optional projection function. This defaults to `hpx::identity`

Parameters

- **policy** – The execution policy to use for the scheduling of the iterations.
- **first** – Refers to the beginning of the sequence of elements the algorithm will be applied to.
- **last** – Refers to the end of the sequence of elements the algorithm will be applied to.

- **f** – The binary predicate which returns true if the the left argument is less than the right element. The signature of the predicate function should be equivalent to the following:

```
bool pred(const Type1 &a, const Type1 &b);
```

The signature does not need to have `const &`, but the function must not modify the objects passed to it. The type *Type1* must be such that objects of type *FwdIter* can be dereferenced and then implicitly converted to *Type1*.

- **proj** – Specifies the function (or function object) which will be invoked for each of the elements as a projection operation before the actual predicate *is* invoked.

Returns The *min_element* algorithm returns a `hpx::future<FwdIter>` if the execution policy is of type *sequenced_task_policy* or *parallel_task_policy* and returns *FwdIter* otherwise. The *min_element* algorithm returns the iterator to the smallest element in the range [first, last). If several elements in the range are equivalent to the smallest element, returns the iterator to the first such element. Returns last if the range is empty.

```
template<typename ExPolicy, typename Rng, typename F = hpx::parallel::detail::less, typename Proj =  
hpx::identity>  
hpx::parallel::util::detail::algorithm_result_t<ExPolicy, hpx::traits::range_iterator_t<Rng>> min_element(ExPolicy  
&&pol-  
icy,  
Rng  
&&rng,  
F  
&&f  
=  
F(),  
Proj  
&&proj  
=  
Proj())
```

Finds the smallest element in the range [first, last) using the given comparison function *f*.

The comparisons in the parallel *min_element* algorithm invoked with an execution policy object of type *sequenced_policy* execute in sequential order in the calling thread.

The comparisons in the parallel *min_element* algorithm invoked with an execution policy object of type *parallel_policy* or *parallel_task_policy* are permitted to execute in an unordered fashion in unspecified threads, and indeterminately sequenced within each thread.

Note: Complexity: Exactly $\max(N-1, 0)$ comparisons, where $N = \text{std::distance}(\text{first}, \text{last})$.

Template Parameters

- **ExPolicy** – The type of the execution policy to use (deduced). It describes the manner in which the execution of the algorithm may be parallelized and the manner in which it executes the assignments.
- **Rng** – The type of the source range used (deduced). The iterators extracted from this range type must meet the requirements of an forward iterator.
- **F** – The type of the function/function object to use (deduced). Unlike its sequential form, the parallel overload of *min_element* requires *F* to meet the requirements of *CopyConstructible*.
- **Proj** – The type of an optional projection function. This defaults to `hpx::identity`

Parameters

- **policy** – The execution policy to use for the scheduling of the iterations.
- **rng** – Refers to the sequence of elements the algorithm will be applied to.
- **f** – The binary predicate which returns true if the the left argument is less than the right element. The signature of the predicate function should be equivalent to the following:

```
bool pred(const Type1 &a, const Type1 &b);
```

The signature does not need to have `const &`, but the function must not modify the objects passed to it. The type *Type1* must be such that objects of type *FwdIter* can be dereferenced and then implicitly converted to *Type1*.

- **proj** – Specifies the function (or function object) which will be invoked for each of the elements as a projection operation before the actual predicate *is* invoked.

Returns The *min_element* algorithm returns a `hpx::future<hpx::traits::range_iterator<Rng>::type>` if the execution policy is of type *sequenced_task_policy* or *parallel_task_policy* and returns *FwdIter* otherwise. The *min_element* algorithm returns the iterator to the smallest element in the range [first, last). If several elements in the range are equivalent to the smallest element, returns the iterator to the first such element. Returns last if the range is empty.

```
template<typename FwdIter, typename Sent, typename F = hpx::parallel::detail::less, typename Proj = hpx::identity>
```

```
FwdIter max_element(FwdIter first, Sent last, F &&f = F(), Proj &&proj = Proj())
```

Finds the greatest element in the range [first, last) using the given comparison function *f*.

The comparisons in the parallel *max_element* algorithm execute in sequential order in the calling thread.

Note: Complexity: Exactly $\max(N-1, 0)$ comparisons, where $N = \text{std::distance}(\text{first}, \text{last})$.

Template Parameters

- **FwdIter** – The type of the source iterator used (deduced). The iterator type must meet the requirements of an forward iterator.
- **Sent** – The type of the end iterators used (deduced). This sentinel type must be a sentinel for *FwdIter*.
- **F** – The type of the function/function object to use (deduced).
- **Proj** – The type of an optional projection function. This defaults to `hpx::identity`

Parameters

- **first** – Refers to the beginning of the sequence of elements the algorithm will be applied to.
- **last** – Refers to the end of the sequence of elements the algorithm will be applied to.
- **f** – The binary predicate which returns true if the This argument is optional and defaults to `std::less`. the left argument is less than the right element. The signature of the predicate function should be equivalent to the following:

```
bool pred(const Type1 &a, const Type1 &b);
```

The signature does not need to have `const &`, but the function must not modify the objects passed to it. The type *Type1* must be such that objects of type *FwdIter* can be dereferenced and then implicitly converted to *Type1*.

- **proj** – Specifies the function (or function object) which will be invoked for each of the elements as a projection operation before the actual predicate *is* invoked.

Returns The *max_element* algorithm returns a *FwdIter*. The *max_element* algorithm returns the iterator to the smallest element in the range [first, last). If several elements in the range

are equivalent to the smallest element, returns the iterator to the first such element. Returns last if the range is empty.

```
template<typename Rng, typename F = hpx::parallel::detail::less, typename Proj = hpx::identity>
hpx::traits::range_iterator_t<Rng> max_element(Rng &&rng, F &&f = F(), Proj &&proj = Proj())
```

Finds the greatest element in the range [first, last) using the given comparison function *f*.

The comparisons in the parallel *max_element* algorithm execute in sequential order in the calling thread.

Note: Complexity: Exactly $max(N-1, 0)$ comparisons, where $N = std::distance(first, last)$.

Template Parameters

- **Rng** – The type of the source range used (deduced). The iterators extracted from this range type must meet the requirements of an forward iterator.
- **F** – The type of the function/function object to use (deduced).
- **Proj** – The type of an optional projection function. This defaults to *hpx::identity*

Parameters

- **rng** – Refers to the sequence of elements the algorithm will be applied to.
- **f** – The binary predicate which returns true if the This argument is optional and defaults to *std::less*. the left argument is less than the right element. The signature of the predicate function should be equivalent to the following:

```
bool pred(const Type1 &a, const Type1 &b);
```

The signature does not need to have *const &*, but the function must not modify the objects passed to it. The type *Type1* must be such that objects of type *FwdIter* can be dereferenced and then implicitly converted to *Type1*.

- **proj** – Specifies the function (or function object) which will be invoked for each of the elements as a projection operation before the actual predicate *is* invoked.

Returns The *max_element* algorithm returns a *hpx::traits::range_iterator_t*<*Rng*>::*type* otherwise. The *max_element* algorithm returns the iterator to the smallest element in the range [first, last). If several elements in the range are equivalent to the smallest element, returns the iterator to the first such element. Returns last if the range is empty.

```
template<typename ExPolicy, typename FwdIter, typename Sent, typename F =
hpx::parallel::detail::less, typename Proj = hpx::identity>
hpx::parallel::util::detail::algorithm_result_t<ExPolicy, FwdIter> max_element(ExPolicy &&policy,
                                                                    FwdIter first, Sent last,
                                                                    F &&f = F(), Proj
                                                                    &&proj = Proj())
```

Finds the greatest element in the range [first, last) using the given comparison function *f*.

The comparisons in the parallel *max_element* algorithm invoked with an execution policy object of type *sequenced_policy* execute in sequential order in the calling thread.

The comparisons in the parallel *max_element* algorithm invoked with an execution policy object of type *parallel_policy* or *parallel_task_policy* are permitted to execute in an unordered fashion in unspecified threads, and indeterminately sequenced within each thread.

Note: Complexity: Exactly $max(N-1, 0)$ comparisons, where $N = std::distance(first, last)$.

Template Parameters

- **ExPolicy** – The type of the execution policy to use (deduced). It describes the manner in which the execution of the algorithm may be parallelized and the manner in which it executes the assignments.
- **FwdIter** – The type of the source iterator used (deduced). The iterator type must meet the requirements of an forward iterator.
- **Sent** – The type of the end iterators used (deduced). This sentinel type must be a sentinel for `FwdIter`.
- **F** – The type of the function/function object to use (deduced). Unlike its sequential form, the parallel overload of `max_element` requires `F` to meet the requirements of `CopyConstructible`.
- **Proj** – The type of an optional projection function. This defaults to `hpx::identity`

Parameters

- **policy** – The execution policy to use for the scheduling of the iterations.
- **first** – Refers to the beginning of the sequence of elements the algorithm will be applied to.
- **last** – Refers to the end of the sequence of elements the algorithm will be applied to.
- **f** – The binary predicate which returns true if the This argument is optional and defaults to `std::less`. the left argument is less than the right element. The signature of the predicate function should be equivalent to the following:

```
bool pred(const Type1 &a, const Type1 &b);
```

The signature does not need to have `const &`, but the function must not modify the objects passed to it. The type `Type1` must be such that objects of type `FwdIter` can be dereferenced and then implicitly converted to `Type1`.

- **proj** – Specifies the function (or function object) which will be invoked for each of the elements as a projection operation before the actual predicate `is` invoked.

Returns The `max_element` algorithm returns a `hpx::future<FwdIter>` if the execution policy is of type `sequenced_task_policy` or `parallel_task_policy` and returns `FwdIter` otherwise. The `max_element` algorithm returns the iterator to the smallest element in the range `[first, last)`. If several elements in the range are equivalent to the smallest element, returns the iterator to the first such element. Returns last if the range is empty.

```
template<typename ExPolicy, typename Rng, typename F = hpx::parallel::detail::less, typename Proj =
hpx::identity>
hpx::parallel::util::detail::algorithm_result_t<ExPolicy, hpx::traits::range_iterator_t<Rng>> max_element(ExPolicy
&&pol-
icy,
Rng
&&rng,
F
&&f
=
F(),
Proj
&&proj
=
Proj())
```

Finds the greatest element in the range `[first, last)` using the given comparison function `f`.

The comparisons in the parallel `max_element` algorithm invoked with an execution policy object of type `sequenced_policy` execute in sequential order in the calling thread.

The comparisons in the parallel *max_element* algorithm invoked with an execution policy object of type *parallel_policy* or *parallel_task_policy* are permitted to execute in an unordered fashion in unspecified threads, and indeterminately sequenced within each thread.

Note: Complexity: Exactly $\max(N-1, 0)$ comparisons, where $N = \text{std::distance}(\text{first}, \text{last})$.

Template Parameters

- **ExPolicy** – The type of the execution policy to use (deduced). It describes the manner in which the execution of the algorithm may be parallelized and the manner in which it executes the assignments.
- **Rng** – The type of the source range used (deduced). The iterators extracted from this range type must meet the requirements of an forward iterator.
- **F** – The type of the function/function object to use (deduced). Unlike its sequential form, the parallel overload of *max_element* requires *F* to meet the requirements of *CopyConstructible*.
- **Proj** – The type of an optional projection function. This defaults to *hpx::identity*

Parameters

- **policy** – The execution policy to use for the scheduling of the iterations.
- **rng** – Refers to the sequence of elements the algorithm will be applied to.
- **f** – The binary predicate which returns true if the This argument is optional and defaults to *std::less*. the left argument is less than the right element. The signature of the predicate function should be equivalent to the following:

```
bool pred(const Type1 &a, const Type1 &b);
```

The signature does not need to have *const &*, but the function must not modify the objects passed to it. The type *Type1* must be such that objects of type *FwdIter* can be dereferenced and then implicitly converted to *Type1*.

- **proj** – Specifies the function (or function object) which will be invoked for each of the elements as a projection operation before the actual predicate *is* invoked.

Returns The *max_element* algorithm returns a *hpx::future<hpx::traits::range_iterator<Rng>::type>* if the execution policy is of type *sequenced_task_policy* or *parallel_task_policy* and returns *FwdIter* otherwise. The *max_element* algorithm returns the iterator to the smallest element in the range [first, last). If several elements in the range are equivalent to the smallest element, returns the iterator to the first such element. Returns last if the range is empty.

```
template<typename FwdIter, typename Sent, typename F = hpx::parallel::detail::less, typename Proj = hpx::identity>
```

```
minmax_element_result<FwdIter> minmax_element(FwdIter first, Sent last, F &&f = F(), Proj &&proj = Proj())
```

Finds the greatest element in the range [first, last) using the given comparison function *f*.

The assignments in the parallel *minmax_element* algorithm execute in sequential order in the calling thread.

Note: Complexity: At most $\max(\text{floor}(3/2*(N-1)), 0)$ applications of the predicate, where $N = \text{std::distance}(\text{first}, \text{last})$.

Template Parameters

- **FwdIter** – The type of the source iterator used (deduced). The iterator type must meet the requirements of an forward iterator.

- **Sent** – The type of the end iterators used (deduced). This sentinel type must be a sentinel for `FwdIter`.
- **F** – The type of the function/function object to use (deduced).
- **Proj** – The type of an optional projection function. This defaults to `hpx::identity`

Parameters

- **first** – Refers to the beginning of the sequence of elements the algorithm will be applied to.
- **last** – Refers to the end of the sequence of elements the algorithm will be applied to.
- **f** – The binary predicate which returns true if the the left argument is less than the right element. This argument is optional and defaults to `std::less`. The signature of the predicate function should be equivalent to the following:

```
bool pred(const Type1 &a, const Type1 &b);
```

The signature does not need to have `const &`, but the function must not modify the objects passed to it. The type `Type1` must be such that objects of type `FwdIter` can be dereferenced and then implicitly converted to `Type1`.

- **proj** – Specifies the function (or function object) which will be invoked for each of the elements as a projection operation before the actual predicate *is* invoked.

Returns The `minmax_element` algorithm returns a `minmax_element_result<FwdIter, FwdIter>` The `minmax_element` algorithm returns a `min_max_result` consisting of an iterator to the smallest element as the min element and an iterator to the greatest element as the max element. Returns `minmax_element_result{first, first}` if the range is empty. If several elements are equivalent to the smallest element, the iterator to the first such element is returned. If several elements are equivalent to the largest element, the iterator to the last such element is returned.

```
template<typename Rng, typename F = hpx::parallel::detail::less, typename Proj = hpx::identity>
minmax_element_result<hpx::traits::range_iterator_t<Rng>> minmax_element(Rng &&rng, F &&f =
                                                                    F(), Proj &&proj =
                                                                    Proj())
```

Finds the greatest element in the range `[first, last)` using the given comparison function *f*.

The assignments in the parallel `minmax_element` algorithm execute in sequential order in the calling thread.

Note: Complexity: At most $\max(\text{floor}(3/2*(N-1)), 0)$ applications of the predicate, where $N = \text{std::distance}(\text{first}, \text{last})$.

Template Parameters

- **Rng** – The type of the source range used (deduced). The iterators extracted from this range type must meet the requirements of an forward iterator.
- **F** – The type of the function/function object to use (deduced).
- **Proj** – The type of an optional projection function. This defaults to `hpx::identity`

Parameters

- **rng** – Refers to the sequence of elements the algorithm will be applied to.
- **f** – The binary predicate which returns true if the the left argument is less than the right element. This argument is optional and defaults to `std::less`. The signature of the predicate function should be equivalent to the following:

```
bool pred(const Type1 &a, const Type1 &b);
```

The signature does not need to have `const &`, but the function must not modify the objects passed to it. The type *Type1* must be such that objects of type *FwdIter* can be dereferenced and then implicitly converted to *Type1*.

- **proj** – Specifies the function (or function object) which will be invoked for each of the elements as a projection operation before the actual predicate *is* invoked.

Returns The *minmax_element* algorithm returns a *min-max_element_result*`<hpx::traits::range_iterator<Rng>::type`, `hpx::traits::range_iterator<Rng>::type`. The *minmax_element* algorithm returns a *min_max_result* consisting of an range iterator to the smallest element as the min element and an range iterator to the greatest element as the max element. If several elements are equivalent to the smallest element, the iterator to the first such element is returned. If several elements are equivalent to the largest element, the iterator to the last such element is returned.

```
template<typename ExPolicy, typename FwdIter, typename Sent, typename F =
    hpx::parallel::detail::less, typename Proj = hpx::identity>
    hpx::parallel::util::detail::algorithm_result_t<ExPolicy, minmax_element_result<FwdIter>> minmax_element(ExPolicy
    &&pol-
    istry,
    FwdIter
    first,
    Sent
    last,
    F
    &&f
    =
    F(),
    Proj
    &&proj
    =
    Proj())
```

Finds the greatest element in the range [first, last) using the given comparison function *f*.

The comparisons in the parallel *minmax_element* algorithm invoked with an execution policy object of type *sequenced_policy* execute in sequential order in the calling thread.

The comparisons in the parallel *minmax_element* algorithm invoked with an execution policy object of type *parallel_policy* or *parallel_task_policy* are permitted to execute in an unordered fashion in unspecified threads, and indeterminately sequenced within each thread.

Note: Complexity: At most $\max(\text{floor}(3/2*(N-1)), 0)$ applications of the predicate, where $N = \text{std::distance}(\text{first}, \text{last})$.

Template Parameters

- **ExPolicy** – The type of the execution policy to use (deduced). It describes the manner in which the execution of the algorithm may be parallelized and the manner in which it executes the assignments.
- **FwdIter** – The type of the source iterator used (deduced). The iterator type must meet the requirements of an forward iterator.
- **Sent** – The type of the end iterators used (deduced). This sentinel type must be a sentinel for *FwdIter*.
- **F** – The type of the function/function object to use (deduced). Unlike its sequential form,

the parallel overload of *minmax_element* requires *F* to meet the requirements of *Copy-Constructible*.

- **Proj** – The type of an optional projection function. This defaults to *hpx::identity*

Parameters

- **policy** – The execution policy to use for the scheduling of the iterations.
- **first** – Refers to the beginning of the sequence of elements the algorithm will be applied to.
- **last** – Refers to the end of the sequence of elements the algorithm will be applied to.
- **f** – The binary predicate which returns true if the the left argument is less than the right element. This argument is optional and defaults to *std::less*. The signature of the predicate function should be equivalent to the following:

```
bool pred(const Type1 &a, const Type1 &b);
```

The signature does not need to have *const &*, but the function must not modify the objects passed to it. The type *Type1* must be such that objects of type *FwdIter* can be dereferenced and then implicitly converted to *Type1*.

- **proj** – Specifies the function (or function object) which will be invoked for each of the elements as a projection operation before the actual predicate *is* invoked.

Returns The *minmax_element* algorithm returns a *minmax_element_result*<*FwdIter*, *FwdIter*> The *minmax_element* algorithm returns a *min_max_result* consisting of an iterator to the smallest element as the min element and an iterator to the greatest element as the max element. Returns *minmax_element_result*{*first*, *first*} if the range is empty. If several elements are equivalent to the smallest element, the iterator to the first such element is returned. If several elements are equivalent to the largest element, the iterator to the last such element is returned.

```
template<typename ExPolicy, typename Rng, typename F = hpx::parallel::detail::less, typename Proj = hpx::identity>
hpx::parallel::util::detail::algorithm_result_t<ExPolicy, minmax_element_result<hpx::traits::range_iterator_t<Rng>>> min
```

Finds the greatest element in the range [*first*, *last*) using the given comparison function *f*.

The comparisons in the parallel *minmax_element* algorithm invoked with an execution policy object of type *sequenced_policy* execute in sequential order in the calling thread.

The comparisons in the parallel *minmax_element* algorithm invoked with an execution policy object of type *parallel_policy* or *parallel_task_policy* are permitted to execute in an unordered fashion in unspecified threads, and indeterminately sequenced within each thread.

Note: Complexity: At most $\max(\text{floor}(3/2*(N-1)), 0)$ applications of the predicate, where $N =$

std::distance(first, last).

Template Parameters

- **ExPolicy** – The type of the execution policy to use (deduced). It describes the manner in which the execution of the algorithm may be parallelized and the manner in which it executes the assignments.
- **Rng** – The type of the source range used (deduced). The iterators extracted from this range type must meet the requirements of a forward iterator.
- **F** – The type of the function/function object to use (deduced). Unlike its sequential form, the parallel overload of *minmax_element* requires *F* to meet the requirements of *CopyConstructible*.
- **Proj** – The type of an optional projection function. This defaults to *hpx::identity*

Parameters

- **policy** – The execution policy to use for the scheduling of the iterations.
- **rng** – Refers to the sequence of elements the algorithm will be applied to.
- **f** – The binary predicate which returns true if the left argument is less than the right element. This argument is optional and defaults to `std::less`. The signature of the predicate function should be equivalent to the following:

```
bool pred(const Type1 &a, const Type1 &b);
```

The signature does not need to have `const &`, but the function must not modify the objects passed to it. The type *Type1* must be such that objects of type *FwdIter* can be dereferenced and then implicitly converted to *Type1*.

- **proj** – Specifies the function (or function object) which will be invoked for each of the elements as a projection operation before the actual predicate *is* invoked.

Returns The *minmax_element* algorithm returns a *minmax_element_result*`<hpx::traits::range_iterator<Rng>::type, hpx::traits::range_iterator<Rng>::type>`. The *minmax_element* algorithm returns a *min_max_result* consisting of an range iterator to the smallest element as the min element and an range iterator to the greatest element as the max element. If several elements are equivalent to the smallest element, the iterator to the first such element is returned. If several elements are equivalent to the largest element, the iterator to the last such element is returned.

hpx::ranges::mismatch

Defined in header `hpx/algorithm.hpp`⁶⁵⁹.

See *Public API* for a list of names and headers that are part of the public *HPX* API.

namespace **hpx**

namespace **ranges**

⁶⁵⁹ <http://github.com/STELLAR-GROUP/hpx/blob/8a3b7c1a4cb5693b2f7d9f587f759392ed0c51a0/libs/full/include/include/hpx/algorithm.hpp>

Functions

```

template<typename ExPolicy, typename Iter1, typename Sent1, typename Iter2, typename Sent2,
typename Pred = equal_to, typename Proj1 = hpx::identity, typename Proj2 = hpx::identity>
hpx::parallel::util::detail::algorithm_result<ExPolicy, mismatch_result<Iter1, Iter2>>::type mismatch(ExPolicy
&&pol-
icy,
Iter1
first1,
Sent1
last1,
Iter2
first2,
Sent2
last2,
Pred
&&op
=
Pred(),
Proj1
&&proj1
=
Proj1(),
Proj2
&&proj2
=
Proj2())

```

Returns true if the range [first1, last1) is mismatch to the range [first2, last2), and false otherwise.

The comparison operations in the parallel *mismatch* algorithm invoked with an execution policy object of type *sequenced_policy* execute in sequential order in the calling thread.

The comparison operations in the parallel *mismatch* algorithm invoked with an execution policy object of type *parallel_policy* or *parallel_task_policy* are permitted to execute in an unordered fashion in unspecified threads, and indeterminately sequenced within each thread.

Note: Complexity: At most $\min(\text{last1} - \text{first1}, \text{last2} - \text{first2})$ applications of the predicate f . If *FwdIter1* and *FwdIter2* meet the requirements of *RandomAccessIterator* and $(\text{last1} - \text{first1}) \neq (\text{last2} - \text{first2})$ then no applications of the predicate f are made.

Note: The two ranges are considered mismatch if, for every iterator i in the range [first1, last1), $*i$ mismatches $*(\text{first2} + (i - \text{first1}))$. This overload of *mismatch* uses operator== to determine if two elements are mismatch.

Template Parameters

- **ExPolicy** – The type of the execution policy to use (deduced). It describes the manner in which the execution of the algorithm may be parallelized and the manner in which it executes the assignments.
- **Iter1** – The type of the source iterators used for the first range (deduced). This iterator type must meet the requirements of an forward iterator.

- **Sent1** – The type of the source iterators used for the end of the first range (deduced).
- **Iter2** – The type of the source iterators used for the second range (deduced). This iterator type must meet the requirements of an forward iterator.
- **Sent2** – The type of the source iterators used for the end of the second range (deduced).
- **Pred** – The type of an optional function/function object to use. Unlike its sequential form, the parallel overload of *mismatch* requires *Pred* to meet the requirements of *CopyConstructible*. This defaults to `std::equal_to<>`
- **Proj1** – The type of an optional projection function applied to the first range. This defaults to `hpx::identity`
- **Proj2** – The type of an optional projection function applied to the second range. This defaults to `hpx::identity`

Parameters

- **policy** – The execution policy to use for the scheduling of the iterations.
- **first1** – Refers to the beginning of the sequence of elements of the first range the algorithm will be applied to.
- **last1** – Refers to the end of the sequence of elements of the first range the algorithm will be applied to.
- **first2** – Refers to the beginning of the sequence of elements of the second range the algorithm will be applied to.
- **last2** – Refers to the end of the sequence of elements of the second range the algorithm will be applied to.
- **op** – The binary predicate which returns true if the elements should be treated as mismatch. The signature of the predicate function should be equivalent to the following:

```
bool pred(const Type1 &a, const Type2 &b);
```

The signature does not need to have `const &`, but the function must not modify the objects passed to it. The types *Type1* and *Type2* must be such that objects of types *FwdIter1* and *FwdIter2* can be dereferenced and then implicitly converted to *Type1* and *Type2* respectively

- **proj1** – Specifies the function (or function object) which will be invoked for each of the elements of the first range as a projection operation before the actual predicate *is* invoked.
- **proj2** – Specifies the function (or function object) which will be invoked for each of the elements of the second range as a projection operation before the actual predicate *is* invoked.

Returns The *mismatch* algorithm returns a `hpx::future<bool>` if the execution policy is of type *sequenced_task_policy* or *parallel_task_policy* and returns `bool` otherwise. The *mismatch* algorithm returns true if the elements in the two ranges are mismatch, otherwise it returns false. If the length of the range [first1, last1) does not mismatch the length of the range [first2, last2), it returns false.

```
template<typename ExPolicy, typename Rng1, typename Rng2, typename Pred = equal_to, typename Proj1 = hpx::identity, typename Proj2 = hpx::identity>
```

hpx::parallel::util::detail::algorithm_result<ExPolicy, mismatch_result<typename hpx::traits::range_traits<Rng1>::iterator_

Returns `std::pair` with iterators to the first two non-equivalent elements.

The comparison operations in the parallel *mismatch* algorithm invoked with an execution policy object of type *sequenced_policy* execute in sequential order in the calling thread.

The comparison operations in the parallel *mismatch* algorithm invoked with an execution policy object of type *parallel_policy* or *parallel_task_policy* are permitted to execute in an unordered fashion in unspecified threads, and indeterminately sequenced within each thread.

Note: Complexity: At most *last1 - first1* applications of the predicate *f*.

Template Parameters

- **ExPolicy** – The type of the execution policy to use (deduced). It describes the manner in which the execution of the algorithm may be parallelized and the manner in which it executes the assignments.
- **Rng1** – The type of the first source range used (deduced). The iterators extracted from this range type must meet the requirements of an forward iterator.
- **Rng2** – The type of the second source range used (deduced). The iterators extracted from this range type must meet the requirements of an forward iterator.
- **Pred** – The type of an optional function/function object to use. Unlike its sequential form, the parallel overload of *mismatch* requires *Pred* to meet the requirements of *Copy-Constructible*. This defaults to `std::equal_to<>`
- **Proj1** – The type of an optional projection function applied to the first range. This defaults to `hpx::identity`
- **Proj2** – The type of an optional projection function applied to the second range. This defaults to `hpx::identity`

Parameters

- **policy** – The execution policy to use for the scheduling of the iterations.
- **rng1** – Refers to the first sequence of elements the algorithm will be applied to.
- **rng2** – Refers to the second sequence of elements the algorithm will be applied to.
- **op** – The binary predicate which returns true if the elements should be treated as mismatch. The signature of the predicate function should be equivalent to the following:

```
bool pred(const Type1 &a, const Type2 &b);
```

The signature does not need to have `const &`, but the function must not modify the objects passed to it. The types *Type1* and *Type2* must be such that objects of types *FwdIter1* and *FwdIter2* can be dereferenced and then implicitly converted to *Type1* and *Type2* respectively

- **proj1** – Specifies the function (or function object) which will be invoked for each of the elements of the first range as a projection operation before the actual predicate *is* invoked.
- **proj2** – Specifies the function (or function object) which will be invoked for each of the elements of the second range as a projection operation before the actual predicate *is* invoked.

Returns The *mismatch* algorithm returns a `hpx::future<std::pair<FwdIter1, FwdIter2>>` if the execution policy is of type *sequenced_task_policy* or *parallel_task_policy* and returns `std::pair<FwdIter1, FwdIter2>` otherwise. The *mismatch* algorithm returns the first mismatching pair of elements from two ranges: one defined by `[first1, last1)` and another defined by `[first2, last2)`.

```
template<typename Iter1, typename Sent1, typename Iter2, typename Sent2, typename Pred =
equal_to, typename Proj1 = hpx::identity, typename Proj2 = hpx::identity>
mismatch_result<Iter1, Iter2> mismatch(Iter1 first1, Sent1 last1, Iter2 first2, Sent2 last2, Pred &&op =
Pred(), Proj1 &&proj1 = Proj1(), Proj2 &&proj2 = Proj2())
```

Returns true if the range `[first1, last1)` is mismatch to the range `[first2, last2)`, and false otherwise.

Note: Complexity: At most $\min(\text{last1} - \text{first1}, \text{last2} - \text{first2})$ applications of the predicate *f*. If *FwdIter1* and *FwdIter2* meet the requirements of *RandomAccessIterator* and $(\text{last1} - \text{first1}) \neq (\text{last2} - \text{first2})$ then no applications of the predicate *f* are made.

Note: The two ranges are considered mismatch if, for every iterator *i* in the range `[first1, last1)`, `*i` mismatches `*(first2 + (i - first1))`. This overload of *mismatch* uses operator`==` to determine if two elements are mismatch.

Template Parameters

- **Iter1** – The type of the source iterators used for the first range (deduced). This iterator type must meet the requirements of an forward iterator.
- **Sent1** – The type of the source iterators used for the end of the first range (deduced).
- **Iter2** – The type of the source iterators used for the second range (deduced). This iterator type must meet the requirements of an forward iterator.
- **Sent2** – The type of the source iterators used for the end of the second range (deduced).
- **Pred** – The type of an optional function/function object to use. Unlike its sequential form, the parallel overload of *mismatch* requires *Pred* to meet the requirements of *CopyConstructible*. This defaults to `std::equal_to<>`
- **Proj1** – The type of an optional projection function applied to the first range. This defaults to `hpx::identity`
- **Proj2** – The type of an optional projection function applied to the second range. This defaults to `hpx::identity`

Parameters

- **first1** – Refers to the beginning of the sequence of elements of the first range the algorithm will be applied to.
- **last1** – Refers to the end of the sequence of elements of the first range the algorithm will be applied to.

- **first2** – Refers to the beginning of the sequence of elements of the second range the algorithm will be applied to.
- **last2** – Refers to the end of the sequence of elements of the second range the algorithm will be applied to.
- **op** – The binary predicate which returns true if the elements should be treated as mismatch. The signature of the predicate function should be equivalent to the following:

```
bool pred(const Type1 &a, const Type2 &b);
```

The signature does not need to have `const &`, but the function must not modify the objects passed to it. The types *Type1* and *Type2* must be such that objects of types *FwdIter1* and *FwdIter2* can be dereferenced and then implicitly converted to *Type1* and *Type2* respectively

- **proj1** – Specifies the function (or function object) which will be invoked for each of the elements of the first range as a projection operation before the actual predicate *is* invoked.
- **proj2** – Specifies the function (or function object) which will be invoked for each of the elements of the second range as a projection operation before the actual predicate *is* invoked.

Returns The *mismatch* algorithm returns *bool*. The *mismatch* algorithm returns true if the elements in the two ranges are mismatch, otherwise it returns false. If the length of the range [first1, last1) does not mismatch the length of the range [first2, last2), it returns false.

```
template<typename Rng1, typename Rng2, typename Pred = equal_to, typename Proj1 = hpx::identity,  
typename Proj2 = hpx::identity>
```

```
mismatch_result<typename hpx::traits::range_traits<Rng1>::iterator_type, typename hpx::traits::range_traits<Rng2>::iterat
```

Returns `std::pair` with iterators to the first two non-equivalent elements.

Note: Complexity: At most *last1 - first1* applications of the predicate *f*.

Template Parameters

- **Rng1** – The type of the first source range used (deduced). The iterators extracted from this range type must meet the requirements of an forward iterator.
- **Rng2** – The type of the second source range used (deduced). The iterators extracted from this range type must meet the requirements of an forward iterator.
- **Pred** – The type of an optional function/function object to use. Unlike its sequential form, the parallel overload of *mismatch* requires *Pred* to meet the requirements of *Copy-Constructible*. This defaults to `std::equal_to<>`
- **Proj1** – The type of an optional projection function applied to the first range. This

defaults to `hpx::identity`

- **Proj2** – The type of an optional projection function applied to the second range. This defaults to `hpx::identity`

Parameters

- **rng1** – Refers to the first sequence of elements the algorithm will be applied to.
- **rng2** – Refers to the second sequence of elements the algorithm will be applied to.
- **op** – The binary predicate which returns true if the elements should be treated as mismatch. The signature of the predicate function should be equivalent to the following:

```
bool pred(const Type1 &a, const Type2 &b);
```

The signature does not need to have `const &`, but the function must not modify the objects passed to it. The types `Type1` and `Type2` must be such that objects of types `FwdIter1` and `FwdIter2` can be dereferenced and then implicitly converted to `Type1` and `Type2` respectively

- **proj1** – Specifies the function (or function object) which will be invoked for each of the elements of the first range as a projection operation before the actual predicate *is* invoked.
- **proj2** – Specifies the function (or function object) which will be invoked for each of the elements of the second range as a projection operation before the actual predicate *is* invoked.

Returns The *mismatch* algorithm returns `std::pair<FwdIter1, FwdIter2>`. The *mismatch* algorithm returns the first mismatching pair of elements from two ranges: one defined by [first1, last1) and another defined by [first2, last2).

hpx::ranges::move

Defined in header `hpx/algorithm.hpp`⁶⁶⁰.

See *Public API* for a list of names and headers that are part of the public *HPX* API.

namespace **hpx**

namespace **ranges**

Functions

```
template<typename ExPolicy, typename Iter1, typename Sent1, typename Iter2>
hpx::parallel::util::detail::algorithm_result<ExPolicy, move_result<Iter1, Iter2>>::type move(ExPolicy
&&policy,
Iter1 first,
Sent1 last,
Iter2 dest)
```

Moves the elements in the range *rng* to another range beginning at *dest*. After this operation the elements in the moved-from range will still contain valid values of the appropriate type, but not necessarily the same values as before the move.

The assignments in the parallel *copy* algorithm invoked with an execution policy object of type *sequenced_policy* execute in sequential order in the calling thread.

⁶⁶⁰ <http://github.com/STELLAR-GROUP/hpx/blob/8a3b7c1a4cb5693b2f7d9f587f759392ed0c51a0/libs/full/include/include/hpx/algorithm.hpp>

The assignments in the parallel *copy* algorithm invoked with an execution policy object of type *parallel_policy* or *parallel_task_policy* are permitted to execute in an unordered fashion in unspecified threads, and indeterminately sequenced within each thread.

Note: Complexity: Performs exactly `std::distance(begin(rng), end(rng))` assignments.

Template Parameters

- **ExPolicy** – The type of the execution policy to use (deduced). It describes the manner in which the execution of the algorithm may be parallelized and the manner in which it executes the assignments.
- **Iter1** – The type of the source iterators used for the first range (deduced). This iterator type must meet the requirements of a forward iterator.
- **Sent1** – The type of the source iterators used for the end of the first range (deduced).
- **Iter2** – The type of the source iterators used for the second range (deduced). This iterator type must meet the requirements of a forward iterator.

Parameters

- **policy** – The execution policy to use for the scheduling of the iterations.
- **first** – Refers to the beginning of the sequence of elements the algorithm will be applied to.
- **last** – Refers to the end of the sequence of elements the algorithm will be applied to.
- **dest** – Refers to the beginning of the destination range.

Returns The *move* algorithm returns a `hpx::future<ranges::move_result<iterator_t<Rng>, FwdIter2>>` if the execution policy is of type *sequenced_task_policy* or *parallel_task_policy* and returns `ranges::move_result<iterator_t<Rng>, FwdIter2>` otherwise. The *move* algorithm returns the pair of the input iterator *last* and the output iterator to the element in the destination range, one past the last element moved.

```
template<typename ExPolicy, typename Rng, typename Iter2>  
hpx::parallel::util::detail::algorithm_result<ExPolicy, move_result<hpx::traits::range_iterator_t<Rng>, Iter2>>::type move(
```

Moves the elements in the range *rng* to another range beginning at *dest*. After this operation the elements in the moved-from range will still contain valid values of the appropriate type, but not necessarily the same values as before the move.

The assignments in the parallel *copy* algorithm invoked with an execution policy object of type *sequenced_policy* execute in sequential order in the calling thread.

The assignments in the parallel *copy* algorithm invoked with an execution policy object of type *parallel_policy* or *parallel_task_policy* are permitted to execute in an unordered fashion in unspecified threads, and indeterminately sequenced within each thread.

Note: Complexity: Performs exactly `std::distance(begin(rng), end(rng))` assignments.

Template Parameters

- **ExPolicy** – The type of the execution policy to use (deduced). It describes the manner in which the execution of the algorithm may be parallelized and the manner in which it executes the assignments.

- **Rng** – The type of the source range used (deduced). The iterators extracted from this range type must meet the requirements of an input iterator.
- **Iter2** – The type of the source iterators used for the second range (deduced). This iterator type must meet the requirements of an forward iterator.

Parameters

- **policy** – The execution policy to use for the scheduling of the iterations.
- **rng** – Refers to the sequence of elements the algorithm will be applied to.
- **dest** – Refers to the beginning of the destination range.

Returns The *move* algorithm returns a `hpx::future<ranges::move_result<iterator_t<Rng>, FwdIter2>>` if the execution policy is of type *sequenced_task_policy* or *parallel_task_policy* and returns `ranges::move_result<iterator_t<Rng>, FwdIter2>` otherwise. The *move* algorithm returns the pair of the input iterator *last* and the output iterator to the element in the destination range, one past the last element moved.

```
template<typename Iter1, typename Sent1, typename Iter2>
move_result<Iter1, Iter2> move(Iter1 first, Sent1 last, Iter2 dest)
```

Moves the elements in the range *rng* to another range beginning at *dest*. After this operation the elements in the moved-from range will still contain valid values of the appropriate type, but not necessarily the same values as before the move.

Note: Complexity: Performs exactly `std::distance(begin(rng), end(rng))` assignments.

Template Parameters

- **Iter1** – The type of the source iterators used for the first range (deduced). This iterator type must meet the requirements of an forward iterator.
- **Sent1** – The type of the source iterators used for the end of the first range (deduced).
- **Iter2** – The type of the source iterators used for the second range (deduced). This iterator type must meet the requirements of an forward iterator.

Parameters

- **first** – Refers to the beginning of the sequence of elements the algorithm will be applied to.
- **last** – Refers to the end of the sequence of elements the algorithm will be applied to.
- **dest** – Refers to the beginning of the destination range.

Returns The *move* algorithm returns `ranges::move_result<iterator_t<Rng>, FwdIter2>`. The *move* algorithm returns the pair of the input iterator *last* and the output iterator to the element in the destination range, one past the last element moved.

```
template<typename Rng, typename Iter2>
move_result<hpx::traits::range_iterator_t<Rng>, Iter2> move(Rng &&rng, Iter2 dest)
```

Moves the elements in the range *rng* to another range beginning at *dest*. After this operation the elements in the moved-from range will still contain valid values of the appropriate type, but not necessarily the same values as before the move.

Note: Complexity: Performs exactly `std::distance(begin(rng), end(rng))` assignments.

Template Parameters

- **Rng** – The type of the source range used (deduced). The iterators extracted from this range type must meet the requirements of an input iterator.
- **Iter2** – The type of the source iterators used for the second range (deduced). This iterator type must meet the requirements of an forward iterator.

Parameters

- **rng** – Refers to the sequence of elements the algorithm will be applied to.

- **dest** – Refers to the beginning of the destination range.
- Returns** The *move* algorithm returns a `ranges::move_result<iterator_t<Rng>, FwdIter2>`. The *move* algorithm returns the pair of the input iterator *last* and the output iterator to the element in the destination range, one past the last element moved.

hpx::ranges::nth_element

Defined in header `hpx/algorithm.hpp`⁶⁶¹.

See *Public API* for a list of names and headers that are part of the public HPX API.

```
namespace hpx
```

```
    namespace ranges
```

Functions

```
template<typename RandomIt, typename Sent, typename Pred = hpx::parallel::detail::less, typename  
Proj = hpx::identity>  
RandomIt nth_element(RandomIt first, RandomIt nth, Sent last, Pred &&pred = Pred(), Proj &&proj  
                    = Proj())
```

`nth_element` is a partial sorting algorithm that rearranges elements in `[first, last)` such that the element pointed at by `nth` is changed to whatever element would occur in that position if `[first, last)` were sorted and all of the elements before this new `nth` element are less than or equal to the elements after the new `nth` element.

The comparison operations in the parallel *nth_element* algorithm invoked without an execution policy object execute in sequential order in the calling thread.

Note: Complexity: Linear in `std::distance(first, last)` on average. $O(N)$ applications of the predicate, and $O(N \log N)$ swaps, where $N = last - first$.

Template Parameters

- **RandomIt** – The type of the source begin, `nth`, and end iterators used (deduced). This iterator type must meet the requirements of a random access iterator.
- **Sent** – The type of the source sentinel (deduced). This sentinel type must be a sentinel for `RandomIt`.
- **Pred** – Comparison function object which returns true if the first argument is less than the second.
- **Proj** – The type of an optional projection function. This defaults to `hpx::identity`

Parameters

- **first** – Refers to the beginning of the sequence of elements the algorithm will be applied to.
- **nth** – Refers to the iterator defining the sort partition point
- **last** – Refers to sentinel value denoting the end of the sequence of elements the algorithm will be applied.

⁶⁶¹ <http://github.com/STELLAR-GROUP/hpx/blob/8a3b7c1a4cb5693b2f7d9f587f759392ed0c51a0/libs/full/include/include/hpx/algorithm.hpp>

- **pred** – Specifies the comparison function object which returns true if the first argument is less than (i.e. is ordered before) the second. The signature of this comparison function should be equivalent to:

```
bool cmp(const Type1 &a, const Type2 &b);
```

The signature does not need to have const&, but the function must not modify the objects passed to it. The type must be such that an object of type *RandomIt* can be dereferenced and then implicitly converted to *Type*. This defaults to `std::less<>`.

- **proj** – Specifies the function (or function object) which will be invoked for each of the elements as a projection operation before the actual predicate *is* invoked. This defaults to `hpx::identity`.

Returns The *nth_element* algorithm returns returns *RandomIt*. The *nth_element* algorithm returns an iterator equal to last.

```
template<typename ExPolicy, typename RandomIt, typename Sent, typename Pred =
    hpx::parallel::detail::less, typename Proj = hpx::identity>
parallel::util::detail::algorithm_result_t<ExPolicy, RandomIt> nth_element(ExPolicy &&policy,
    RandomIt first, RandomIt
    nth, Sent last, Pred
    &&pred = Pred(), Proj
    &&proj = Proj())
```

nth_element is a partial sorting algorithm that rearranges elements in `[first, last)` such that the element pointed at by *nth* is changed to whatever element would occur in that position if `[first, last)` were sorted and all of the elements before this new *nth* element are less than or equal to the elements after the new *nth* element.

The comparison operations in the parallel *nth_element* invoked with an execution policy object of type *sequenced_policy* execute in sequential order in the calling thread.

The assignments in the parallel *nth_element* algorithm invoked with an execution policy object of type *parallel_policy* or *parallel_task_policy* are permitted to execute in an unordered fashion in unspecified threads, and indeterminately sequenced within each thread.

Note: Complexity: Linear in `std::distance(first, last)` on average. $O(N)$ applications of the predicate, and $O(N \log N)$ swaps, where $N = last - first$.

Template Parameters

- **ExPolicy** – The type of the execution policy to use (deduced). It describes the manner in which the execution of the algorithm may be parallelized and the manner in which it executes the assignments.
- **RandomIt** – The type of the source begin, *nth*, and end iterators used (deduced). This iterator type must meet the requirements of a random access iterator.
- **Sent** – The type of the source sentinel (deduced). This sentinel type must be a sentinel for *RandomIt*.
- **Pred** – Comparison function object which returns true if the first argument is less than the second.
- **Proj** – The type of an optional projection function. This defaults to `hpx::identity`

Parameters

- **policy** – The execution policy to use for the scheduling of the iterations.
- **first** – Refers to the beginning of the sequence of elements the algorithm will be applied to.
- **nth** – Refers to the iterator defining the sort partition point

- **last** – Refers to sentinel value denoting the end of the sequence of elements the algorithm will be applied.
- **pred** – Specifies the comparison function object which returns true if the first argument is less than (i.e. is ordered before) the second. The signature of this comparison function should be equivalent to:

```
bool cmp(const Type1 &a, const Type2 &b);
```

The signature does not need to have `const&`, but the function must not modify the objects passed to it. The type must be such that an object of type `randomIt` can be dereferenced and then implicitly converted to `Type`. This defaults to `std::less<>`.

- **proj** – Specifies the function (or function object) which will be invoked for each of the elements as a projection operation before the actual predicate *is* invoked. This defaults to `hpx::identity`.

Returns The *partition* algorithm returns a `hpx::future<RandomIt>` if the execution policy is of type *parallel_task_policy* and returns `RandomIt` otherwise. The *nth_element* algorithm returns an iterator equal to `last`.

```
template<typename Rng, typename Pred = hpx::parallel::detail::less, typename Proj = hpx::identity>
hpx::traits::range_iterator_t<Rng> nth_element(Rng &&rng, hpx::traits::range_iterator_t<Rng> nth,
                                              Pred &&pred = Pred(), Proj &&proj = Proj())
```

`nth_element` is a partial sorting algorithm that rearranges elements in `[first, last)` such that the element pointed at by `nth` is changed to whatever element would occur in that position if `[first, last)` were sorted and all of the elements before this new `nth` element are less than or equal to the elements after the new `nth` element.

The comparison operations in the parallel *nth_element* algorithm invoked without an execution policy object execute in sequential order in the calling thread.

Note: Complexity: Linear in `std::distance(first, last)` on average. $O(N)$ applications of the predicate, and $O(N \log N)$ swaps, where $N = last - first$.

Template Parameters

- **Rng** – The type of the source range used (deduced). The iterators extracted from this range type must meet the requirements of a random access iterator.
- **Pred** – Comparison function object which returns true if the first argument is less than the second.
- **Proj** – The type of an optional projection function. This defaults to `hpx::identity`

Parameters

- **rng** – Refers to the sequence of elements the algorithm will be applied to.
- **nth** – Refers to the iterator defining the sort partition point
- **pred** – Specifies the comparison function object which returns true if the first argument is less than (i.e. is ordered before) the second. The signature of this comparison function should be equivalent to:

```
bool cmp(const Type1 &a, const Type2 &b);
```

The signature does not need to have `const&`, but the function must not modify the objects passed to it. The type must be such that an object of type `randomIt` can be dereferenced and then implicitly converted to `Type`. This defaults to `std::less<>`.

- **proj** – Specifies the function (or function object) which will be invoked for each of the elements as a projection operation before the actual predicate *is* invoked. This defaults to `hpx::identity`.

Returns The *nth_element* algorithm returns `hpx::traits::range_iterator_t<Rng>`.
The *nth_element* algorithm returns an iterator equal to last.

```
template<typename ExPolicy, typename Rng, typename Pred = hpx::parallel::detail::less, typename
Proj = hpx::identity>
```

```
parallel::util::detail::algorithm_result_t<ExPolicy, hpx::traits::range_iterator_t<Rng>> nth_element(ExPolicy
&&pol-
icy,
Rng
&&rng,
hpx::traits::range_ite
nth,
Pred
&&pred
=
Pred(),
Proj
&&proj
=
Proj())
```

nth_element is a partial sorting algorithm that rearranges elements in `[first, last)` such that the element pointed at by *nth* is changed to whatever element would occur in that position if `[first, last)` were sorted and all of the elements before this new *nth* element are less than or equal to the elements after the new *nth* element.

The comparison operations in the parallel *nth_element* invoked with an execution policy object of type *sequenced_policy* execute in sequential order in the calling thread.

The assignments in the parallel *nth_element* algorithm invoked with an execution policy object of type *parallel_policy* or *parallel_task_policy* are permitted to execute in an unordered fashion in unspecified threads, and indeterminately sequenced within each thread.

Note: Complexity: Linear in `std::distance(first, last)` on average. $O(N)$ applications of the predicate, and $O(N \log N)$ swaps, where $N = last - first$.

Template Parameters

- **ExPolicy** – The type of the execution policy to use (deduced). It describes the manner in which the execution of the algorithm may be parallelized and the manner in which it executes the assignments.
- **Rng** – The type of the source range used (deduced). The iterators extracted from this range type must meet the requirements of a random access iterator.
- **Pred** – Comparison function object which returns true if the first argument is less than the second.
- **Proj** – The type of an optional projection function. This defaults to *hpx::identity*

Parameters

- **policy** – The execution policy to use for the scheduling of the iterations.
- **rng** – Refers to the sequence of elements the algorithm will be applied to.
- **nth** – Refers to the iterator defining the sort partition point
- **pred** – Specifies the comparison function object which returns true if the first argument is less than (i.e. is ordered before) the second. The signature of this comparison function should be equivalent to:

```
bool cmp(const Type1 &a, const Type2 &b);
```

The signature does not need to have `const&`, but the function must not modify the objects passed to it. The type must be such that an object of type *randomIt* can be dereferenced and then implicitly converted to `Type`. This defaults to `std::less<>`.

- **proj** – Specifies the function (or function object) which will be invoked for each of the elements as a projection operation before the actual predicate *is* invoked. This defaults to `hpx::identity`.

Returns The *partition* algorithm returns a `hpx::future<hpx::traits::range_iterator_t<Rng>>` if the execution policy is of type *parallel_task_policy* and returns `hpx::traits::range_iterator_t<Rng>` otherwise. The *nth_element* algorithm returns an iterator equal to last.

hpx::ranges::partial_sort

Defined in header `hpx/algorithm.hpp`⁶⁶².

See *Public API* for a list of names and headers that are part of the public *HPX* API.

```
namespace hpx
```

```
namespace ranges
```

Functions

```
template<typename RandomIt, typename Sent, typename Comp = ranges::less, typename Proj =  
hpx::identity>  
RandomIt partial_sort(RandomIt first, RandomIt middle, Sent last, Comp &&comp = Comp(), Proj  
&&proj = Proj())
```

Places the first middle - first elements from the range [first, last) as sorted with respect to `comp` into the range [first, middle). The rest of the elements in the range [middle, last) are placed in an unspecified order.

The assignments in the parallel *partial_sort* algorithm invoked without an execution policy object execute in sequential order in the calling thread.

Note: Complexity: Approximately (last - first) * log(middle - first) comparisons.

Template Parameters

- **RandomIt** – The type of the source iterators used (deduced). This iterator type must meet the requirements of an random iterator.
- **Sent** – The type of the source sentinel (deduced). This sentinel type must be a sentinel for `RandomIt`.
- **Comp** – The type of the function/function object to use (deduced). `Comp` defaults to `detail::less`.
- **Proj** – The type of an optional projection function. This defaults to `hpx::identity`

Parameters

⁶⁶² <http://github.com/STELLAR-GROUP/hpx/blob/8a3b7c1a4cb5693b2f7d9f587f759392ed0c51a0/libs/full/include/include/hpx/algorithm.hpp>

- **first** – Refers to the beginning of the sequence of elements the algorithm will be applied to.
- **middle** – Refers to the middle of the sequence of elements the algorithm will be applied to.
- **last** – Refers to sentinel value denoting the end of the sequence of elements the algorithm will be applied.
- **comp** – `comp` is a callable object. The return value of the INVOKE operation applied to an object of type `Comp`, when contextually converted to `bool`, yields `true` if the first argument of the call is less than the second, and `false` otherwise. It is assumed that `comp` will not apply any non-constant function through the dereferenced iterator. `Comp` defaults to `detail::less`.
- **proj** – Specifies the function (or function object) which will be invoked for each pair of elements as a projection operation before the actual predicate `comp` is invoked.

Returns The `partial_sort` algorithm returns `RandomIt`. The algorithm returns an iterator pointing to the first element after the last element in the input sequence.

```
template<typename ExPolicy, typename RandomIt, typename Sent, typename Comp = ranges::less,
        typename Proj = hpx::identity>
parallel::util::detail::algorithm_result<ExPolicy, RandomIt>::type partial_sort(ExPolicy &&policy,
                                                                    RandomIt first,
                                                                    RandomIt middle,
                                                                    Sent last, Comp
                                                                    &&comp = Comp(),
                                                                    Proj &&proj =
                                                                    Proj())
```

Places the first middle - first elements from the range [first, last) as sorted with respect to `comp` into the range [first, middle). The rest of the elements in the range [middle, last) are placed in an unspecified order.

The application of function objects in parallel algorithm invoked with an execution policy object of type `sequenced_policy` execute in sequential order in the calling thread.

The application of function objects in parallel algorithm invoked with an execution policy object of type `parallel_policy` or `parallel_task_policy` are permitted to execute in an unordered fashion in unspecified threads, and indeterminately sequenced within each thread.

Note: Complexity: Approximately $(last - first) * \log(middle - first)$ comparisons.

Template Parameters

- **ExPolicy** – The type of the execution policy to use (deduced). It describes the manner in which the execution of the algorithm may be parallelized and the manner in which it executes the assignments.
- **RandomIt** – The type of the source iterators used (deduced). This iterator type must meet the requirements of a random iterator.
- **Sent** – The type of the source sentinel (deduced). This sentinel type must be a sentinel for `RandomIt`.
- **Comp** – The type of the function/function object to use (deduced). `Comp` defaults to `detail::less`.
- **Proj** – The type of an optional projection function. This defaults to `hpx::identity`

Parameters

- **policy** – The execution policy to use for the scheduling of the iterations.
- **first** – Refers to the beginning of the sequence of elements the algorithm will be applied to.

- **middle** – Refers to the middle of the sequence of elements the algorithm will be applied to.
- **last** – Refers to sentinel value denoting the end of the sequence of elements the algorithm will be applied.
- **comp** – `comp` is a callable object. The return value of the INVOKE operation applied to an object of type `Comp`, when contextually converted to `bool`, yields `true` if the first argument of the call is less than the second, and `false` otherwise. It is assumed that `comp` will not apply any non-constant function through the dereferenced iterator. `Comp` defaults to `detail::less`.
- **proj** – Specifies the function (or function object) which will be invoked for each pair of elements as a projection operation before the actual predicate `comp` is invoked.

Returns The `partial_sort` algorithm returns a `hpx::future<RandomIt>` if the execution policy is of type `sequenced_task_policy` or `parallel_task_policy` and returns `RandomIt` otherwise. The algorithm returns an iterator pointing to the first element after the last element in the input sequence.

```
template<typename Rng, typename Comp = ranges::less, typename Proj = hpx::identity>
hpx::traits::range_iterator_t<Rng> partial_sort(Rng &&rng, hpx::traits::range_iterator_t<Rng>
middle, Comp &&comp = Comp(), Proj &&proj =
Proj())
```

Places the first middle - first elements from the range [first, last) as sorted with respect to `comp` into the range [first, middle). The rest of the elements in the range [middle, last) are placed in an unspecified order.

The assignments in the parallel `partial_sort` algorithm invoked without an execution policy object execute in sequential order in the calling thread.

Note: Complexity: Approximately $(\text{last} - \text{first}) * \log(\text{middle} - \text{first})$ comparisons.

Template Parameters

- **Rng** – The type of the source range used (deduced). The iterators extracted from this range type must meet the requirements of an input iterator.
- **Comp** – The type of the function/function object to use (deduced). `Comp` defaults to `detail::less`.
- **Proj** – The type of an optional projection function. This defaults to `hpx::identity`

Parameters

- **rng** – Refers to the sequence of elements the algorithm will be applied to.
- **middle** – Refers to the middle of the sequence of elements the algorithm will be applied to.
- **comp** – `comp` is a callable object. The return value of the INVOKE operation applied to an object of type `Comp`, when contextually converted to `bool`, yields `true` if the first argument of the call is less than the second, and `false` otherwise. It is assumed that `comp` will not apply any non-constant function through the dereferenced iterator. `Comp` defaults to `detail::less`.
- **proj** – Specifies the function (or function object) which will be invoked for each pair of elements as a projection operation before the actual predicate `comp` is invoked.

Returns The `partial_sort` algorithm returns `hpx::traits::range_iterator_t<Rng>`. It returns `last`.

```
template<typename ExPolicy, typename Rng, typename Comp = ranges::less, typename Proj =
hpx::identity>
```

```

parallel::util::detail::algorithm_result_t<ExPolicy, hpx::traits::range_iterator_t<Rng>> partial_sort(ExPolicy
&&pol-
icy,
Rng
&&rng,
hpx::traits::range_i
mid-
dle,
Comp
&&comp
=
Comp(),
Proj
&&proj
=
Proj())

```

Sorts the elements in the range [first, last) in ascending order. The relative order of equal elements is preserved. The function uses the given comparison function object comp (defaults to using operator<()).

A sequence is sorted with respect to a comparator *comp* and a projection *proj* if for every iterator *i* pointing to the sequence and every non-negative integer *n* such that *i + n* is a valid iterator pointing to an element of the sequence, and INVOKE(comp, INVOKE(proj, *(i + n)), INVOKE(proj, *i)) == false.

The application of function objects in parallel algorithm invoked with an execution policy object of type *sequenced_policy* execute in sequential order in the calling thread.

The application of function objects in parallel algorithm invoked with an execution policy object of type *parallel_policy* or *parallel_task_policy* are permitted to execute in an unordered fashion in unspecified threads, and indeterminately sequenced within each thread.

Note: Complexity: $O(N \log(N))$, where $N = \text{std::distance}(\text{first}, \text{last})$ comparisons.

Template Parameters

- **ExPolicy** – The type of the execution policy to use (deduced). It describes the manner in which the execution of the algorithm may be parallelized and the manner in which it applies user-provided function objects.
- **Rng** – The type of the source range used (deduced). The iterators extracted from this range type must meet the requirements of an input iterator.
- **Comp** – The type of the function/function object to use (deduced). Comp defaults to detail::less;
- **Proj** – The type of an optional projection function. This defaults to *hpx::identity*

Parameters

- **policy** – The execution policy to use for the scheduling of the iterations.
- **rng** – Refers to the sequence of elements the algorithm will be applied to.
- **middle** – Refers to the middle of the sequence of elements the algorithm will be applied to.
- **comp** – comp is a callable object. The return value of the INVOKE operation applied to an object of type Comp, when contextually converted to bool, yields true if the first argument of the call is less than the second, and false otherwise. It is assumed that

comp will not apply any non-constant function through the dereferenced iterator. Comp defaults to detail::less.

- **proj** – Specifies the function (or function object) which will be invoked for each pair of elements as a projection operation before the actual predicate *comp* is invoked.

Returns The *partial_sort* algorithm returns a `hpx::future<hpx::traits::range_iterator_t<Rng>` if the execution policy is of type *sequenced_task_policy* or *parallel_task_policy* and returns `hpx::traits::range_iterator_t<Rng>` otherwise. It returns *last*.

hpx::ranges::partial_sort_copy

Defined in header `hpx/algorithm.hpp`⁶⁶³.

See *Public API* for a list of names and headers that are part of the public HPX API.

namespace **hpx**

namespace **ranges**

Functions

```
template<typename InIter, typename Sent1, typename RandIter, typename Sent2, typename Comp =
ranges::less, typename Proj1 = hpx::identity, typename Proj2 = hpx::identity>
partial_sort_copy_result<InIter, RandIter> partial_sort_copy(InIter first, Sent1 last, RandIter
r_first, Sent2 r_last, Comp &&comp =
Comp(), Proj1 &&proj1 = Proj1(),
Proj2 &&proj2 = Proj2())
```

Sorts some of the elements in the range [first, last) in ascending order, storing the result in the range [r_first, r_last). At most r_last - r_first of the elements are placed sorted to the range [r_first, r_first + n) where n is the number of elements to sort (n = min(last - first, r_last - r_first)).

The assignments in the parallel *partial_sort_copy* algorithm invoked without an execution policy object execute in sequential order in the calling thread.

Note: Complexity: $O(N \log(\min(D, N)))$, where $N = \text{std::distance}(\text{first}, \text{last})$ and $D = \text{std::distance}(\text{r_first}, \text{r_last})$ comparisons.

Template Parameters

- **InIter** – The type of the source iterators used (deduced). This iterator type must meet the requirements of an input iterator.
- **Sent1** – The type of the source sentinel (deduced). This sentinel type must be a sentinel for InIter.
- **RandIter** – The type of the destination iterators used (deduced) This iterator type must meet the requirements of an random iterator.
- **Sent2** – The type of the destination sentinel (deduced). This sentinel type must be a sentinel for RandIter.
- **Comp** – The type of the function/function object to use (deduced). Comp defaults to detail::less.

⁶⁶³ <http://github.com/STELLAR-GROUP/hpx/blob/8a3b7c1a4cb5693b2f7d9f587f759392ed0c51a0/libs/full/include/include/hpx/algorithm.hpp>

- **Proj1** – The type of an optional projection function for the input range. This defaults to `hpx::identity`.
- **Proj2** – The type of an optional projection function for the output range. This defaults to `hpx::identity`.

Parameters

- **first** – Refers to the beginning of the sequence of elements the algorithm will be applied to.
- **last** – Refers to the sentinel value denoting the end of the sequence of elements the algorithm will be applied to.
- **r_first** – Refers to the beginning of the destination range.
- **r_last** – Refers to the sentinel denoting the end of the destination range.
- **comp** – `comp` is a callable object. The return value of the INVOKE operation applied to an object of type `Comp`, when contextually converted to `bool`, yields true if the first argument of the call is less than the second, and false otherwise. It is assumed that `comp` will not apply any non-constant function through the dereferenced iterator. This defaults to `detail::less`.
- **proj1** – Specifies the function (or function object) which will be invoked for each pair of elements as a projection operation before the actual predicate `comp` is invoked.
- **proj2** – Specifies the function (or function object) which will be invoked for each pair of elements as a projection operation after the actual predicate `comp` is invoked.

Returns The `partial_sort_copy` algorithm returns a returns `partial_sort_copy_result<InIter, RandIter>`. The algorithm returns {last, result_first + N}.

```
template<typename ExPolicy, typename FwdIter, typename Sent1, typename RandIter, typename
Sent2, typename Comp = ranges::less, typename Proj1 = hpx::identity, typename Proj2 = hpx::identity>
parallel::util::detail::algorithm_result_t<ExPolicy, partial_sort_copy_result<FwdIter, RandIter>> partial_sort_copy(E
```

Sorts some of the elements in the range [first, last) in ascending order, storing the result in the range [r_first, r_last). At most r_last - r_first of the elements are placed sorted to the range [r_first, r_first + n) where n is the number of elements to sort (n = min(last - first, r_last - r_first)).

The application of function objects in parallel algorithm invoked with an execution policy object of type *sequenced_policy* execute in sequential order in the calling thread.

The application of function objects in parallel algorithm invoked with an execution policy object of type *parallel_policy* or *parallel_task_policy* are permitted to execute in an unordered fashion in unspecified threads, and indeterminately sequenced within each thread.

Note: Complexity: $O(N \log(\min(D,N)))$, where $N = \text{std::distance}(\text{first}, \text{last})$ and $D = \text{std::distance}(\text{r_first}, \text{r_last})$ comparisons.

Template Parameters

- **ExPolicy** – The type of the execution policy to use (deduced). It describes the manner in which the execution of the algorithm may be parallelized and the manner in which it executes the assignments.
- **FwdIter** – The type of the source iterators used (deduced). This iterator type must meet the requirements of an forward iterator.
- **Sent1** – The type of the source sentinel (deduced). This sentinel type must be a sentinel for FwdIter.
- **RandIter** – The type of the destination iterators used (deduced) This iterator type must meet the requirements of an random iterator.
- **Sent2** – The type of the destination sentinel (deduced). This sentinel type must be a sentinel for RandIter.
- **Comp** – The type of the function/function object to use (deduced). Comp defaults to `detail::less`.
- **Proj1** – The type of an optional projection function for the input range. This defaults to `hpx::identity`.
- **Proj2** – The type of an optional projection function for the output range. This defaults to `hpx::identity`.

Parameters

- **policy** – The execution policy to use for the scheduling of the iterations.
- **first** – Refers to the beginning of the sequence of elements the algorithm will be applied to.
- **last** – Refers to the sentinel value denoting the end of the sequence of elements the algorithm will be applied to.
- **r_first** – Refers to the beginning of the destination range.
- **r_last** – Refers to the sentinel denoting the end of the destination range.
- **comp** – `comp` is a callable object. The return value of the INVOKE operation applied to an object of type `Comp`, when contextually converted to `bool`, yields `true` if the first argument of the call is less than the second, and `false` otherwise. It is assumed that `comp` will not apply any non-constant function through the dereferenced iterator. This defaults to `detail::less`.
- **proj1** – Specifies the function (or function object) which will be invoked for each pair of elements as a projection operation before the actual predicate `comp` is invoked.
- **proj2** – Specifies the function (or function object) which will be invoked for each pair of elements as a projection operation after the actual predicate `comp` is invoked.

Returns The *partial_sort_copy* algorithm returns a `hpx::future<partial_sort_copy_result<FwdIter, RandIter>>` if the execution policy is of type *sequenced_task_policy* or *parallel_task_policy* and returns *partial_sort_copy_result<FwdIter, RandIter>* otherwise. The algorithm returns `{last, result_first + N}`.

```
template<typename Rng1, typename Rng2, typename Comp = ranges::less, typename Proj1 =
hpx::identity, typename Proj2 = hpx::identity>
```

```
partial_sort_copy_result<hpx::traits::range_iterator_t<Rng1>, hpx::traits::range_iterator_t<Rng2>> partial_sort_copy(
```

Sorts some of the elements in the range [first, last) in ascending order, storing the result in the range [r_first, r_last). At most r_last - r_first of the elements are placed sorted to the range [r_first, r_first + n) where n is the number of elements to sort (n = min(last - first, r_last - r_first)).

The assignments in the parallel *partial_sort_copy* algorithm invoked without an execution policy object execute in sequential order in the calling thread.

Note: Complexity: $O(N \log(\min(D, N)))$, where $N = \text{std::distance}(\text{first}, \text{last})$ and $D = \text{std::distance}(\text{r_first}, \text{r_last})$ comparisons.

Template Parameters

- **Rng1** – The type of the source range used (deduced). The iterators extracted from this range type must meet the requirements of a input iterator.
- **Rng2** – The type of the destination range used (deduced). The iterators extracted from this range type must meet the requirements of a random iterator.
- **Comp** – The type of the function/function object to use (deduced). Comp defaults to `detail::less`.
- **Proj1** – The type of an optional projection function for the input range. This defaults to `hpx::identity`.
- **Proj2** – The type of an optional projection function for the output range. This defaults to `hpx::identity`.

Parameters

- **rng1** – Refers to the source range.
- **rng2** – Refers to the destination range.
- **comp** – `comp` is a callable object. The return value of the INVOKE operation applied to an object of type `Comp`, when contextually converted to `bool`, yields true if the first argument of the call is less than the second, and false otherwise. It is assumed that `comp` will not apply any non-constant function through the dereferenced iterator. This defaults to `detail::less`.
- **proj1** – Specifies the function (or function object) which will be invoked for each pair of elements as a projection operation before the actual predicate `comp` is invoked.
- **proj2** – Specifies the function (or function object) which will be invoked for each pair of elements as a projection operation after the actual predicate `comp` is invoked.

Returns The *partial_sort_copy* algorithm returns *partial_sort_copy_result*<*range_iterator_t*<*Rng1*>, *range_iterator_t*<*Rng2*>>. The algorithm returns {last, result_first + N}.

```
template<typename ExPolicy, typename Rng1, typename Rng2, typename Comp = ranges::less,
typename Proj1 = hpx::identity, typename Proj2 = hpx::identity>
parallel::util::detail::algorithm_result_t<ExPolicy, partial_sort_copy_result<hpx::traits::range_iterator_t<Rng1>, hpx::traits::
```

Sorts some of the elements in the range [first, last) in ascending order, storing the result in the range [r_first, r_last). At most r_last - r_first of the elements are placed sorted to the range [r_first, r_first + n) where n is the number of elements to sort (n = min(last - first, r_last - r_first)).

The application of function objects in parallel algorithm invoked with an execution policy object of type *sequenced_policy* execute in sequential order in the calling thread.

The application of function objects in parallel algorithm invoked with an execution policy object of type *parallel_policy* or *parallel_task_policy* are permitted to execute in an unordered fashion in unspecified threads, and indeterminately sequenced within each thread.

Note: Complexity: $O(N \log(\min(D,N)))$, where $N = \text{std::distance}(\text{first}, \text{last})$ and $D = \text{std::distance}(\text{r_first}, \text{r_last})$ comparisons.

Template Parameters

- **ExPolicy** – The type of the execution policy to use (deduced). It describes the manner in which the execution of the algorithm may be parallelized and the manner in which it executes the assignments.
- **Rng1** – The type of the source range used (deduced). The iterators extracted from this range type must meet the requirements of a forward iterator.
- **Rng2** – The type of the destination range used (deduced). The iterators extracted from this range type must meet the requirements of a random iterator.
- **Comp** – The type of the function/function object to use (deduced). Comp defaults to *detail::less*.
- **Proj1** – The type of an optional projection function for the input range. This defaults to *hpx::identity*.
- **Proj2** – The type of an optional projection function for the output range. This defaults to *hpx::identity*.

Parameters

- **policy** – The execution policy to use for the scheduling of the iterations.
- **rng1** – Refers to the source range.

- **rng2** – Refers to the destination range.
- **comp** – `comp` is a callable object. The return value of the INVOKE operation applied to an object of type `Comp`, when contextually converted to `bool`, yields `true` if the first argument of the call is less than the second, and `false` otherwise. It is assumed that `comp` will not apply any non-constant function through the dereferenced iterator. This defaults to `detail::less`.
- **proj1** – Specifies the function (or function object) which will be invoked for each pair of elements as a projection operation before the actual predicate `comp` is invoked.
- **proj2** – Specifies the function (or function object) which will be invoked for each pair of elements as a projection operation after the actual predicate `comp` is invoked.

Returns The `partial_sort_copy` algorithm returns a `hpx::future<partial_sort_copy_result<range_iterator_t<Rng1>, range_iterator_t<Rng2>>>` if the execution policy is of type `sequenced_task_policy` or `parallel_task_policy` and returns `partial_sort_copy_result<range_iterator_t<Rng1>, range_iterator_t<Rng2>>` otherwise. The algorithm returns `{last, result_first + N}`.

hpx::ranges::partition, hpx::ranges::stable_partition, hpx::ranges::partition_copy

Defined in header `hpx/algorithm.hpp`⁶⁶⁴.

See *Public API* for a list of names and headers that are part of the public HPX API.

namespace **hpx**

namespace **ranges**

Functions

```
template<typename Rng, typename Pred, typename Proj = hpx::identity>
subrange_t<hpx::traits::range_iterator_t<Rng>> partition(Rng &&rng, Pred &&pred, Proj &&proj =
    Proj())
```

Reorders the elements in the range `rng` in such a way that all elements for which the predicate `pred` returns `true` precede the elements for which the predicate `pred` returns `false`. Relative order of the elements is not preserved.

The assignments in the parallel `partition` algorithm invoked without an execution policy object execute in sequential order in the calling thread.

Note: Complexity: Performs at most $2 * N$ swaps, exactly N applications of the predicate and projection, where $N = \text{std::distance}(\text{begin}(\text{rng}), \text{end}(\text{rng}))$.

Template Parameters

- **Rng** – The type of the source range used (deduced). The iterators extracted from this range type must meet the requirements of an forward iterator.
- **Pred** – The type of the function/function object to use (deduced). Unlike its sequential form, the parallel overload of `partition` requires `Pred` to meet the requirements of `CopyConstructible`.
- **Proj** – The type of an optional projection function. This defaults to `hpx::identity`

⁶⁶⁴ <http://github.com/STELLAR-GROUP/hpx/blob/8a3b7c1a4cb5693b2f7d9f587f759392ed0c51a0/libs/full/include/include/hpx/algorithm.hpp>

Parameters

- **rng** – Refers to the sequence of elements the algorithm will be applied to.
- **pred** – Specifies the function (or function object) which will be invoked for each of the elements in the sequence specified by the range *rng*. This is an unary predicate for partitioning the source iterators. The signature of this predicate should be equivalent to:

```
bool pred(const Type &a);
```

The signature does not need to have `const&`, but the function must not modify the objects passed to it. The type *Type* must be such that an object of type *FwdIter* can be dereferenced and then implicitly converted to *Type*.

- **proj** – Specifies the function (or function object) which will be invoked for each of the elements as a projection operation before the actual predicate *is* invoked.

Returns The *partition* algorithm returns *subrange_t<hpx::traits::range_iterator_t<Rng>>*. The *partition* algorithm returns a subrange starting with an iterator to the first element of the second group and finishing with an iterator equal to last.

```
template<typename ExPolicy, typename Rng, typename Pred, typename Proj = hpx::identity>
parallel::util::detail::algorithm_result<ExPolicy, subrange_t<hpx::traits::range_iterator_t<Rng>>> partition(ExPolicy
&&policy,
Rng
&&rng,
Pred
&&pred,
Proj
&&proj
=
Proj())
```

Reorders the elements in the range *rng* in such a way that all elements for which the predicate *pred* returns true precede the elements for which the predicate *pred* returns false. Relative order of the elements is not preserved.

The assignments in the parallel *partition* algorithm invoked with an execution policy object of type *sequenced_policy* execute in sequential order in the calling thread.

The assignments in the parallel *partition* algorithm invoked with an execution policy object of type *parallel_policy* or *parallel_task_policy* are permitted to execute in an unordered fashion in unspecified threads, and indeterminately sequenced within each thread.

Note: Complexity: Performs at most $2 * N$ swaps, exactly N applications of the predicate and projection, where $N = \text{std::distance}(\text{begin}(\text{rng}), \text{end}(\text{rng}))$.

Template Parameters

- **ExPolicy** – The type of the execution policy to use (deduced). It describes the manner in which the execution of the algorithm may be parallelized and the manner in which it executes the assignments.
- **Rng** – The type of the source range used (deduced). The iterators extracted from this range type must meet the requirements of an forward iterator.
- **Pred** – The type of the function/function object to use (deduced). Unlike its sequential form, the parallel overload of *partition* requires *Pred* to meet the requirements of *CopyConstructible*.
- **Proj** – The type of an optional projection function. This defaults to *hpx::identity*

Parameters

- **policy** – The execution policy to use for the scheduling of the iterations.
- **rng** – Refers to the sequence of elements the algorithm will be applied to.
- **pred** – Specifies the function (or function object) which will be invoked for each of the elements in the sequence specified by the range *rng*. This is an unary predicate for partitioning the source iterators. The signature of this predicate should be equivalent to:

```
bool pred(const Type &a);
```

The signature does not need to have `const&`, but the function must not modify the objects passed to it. The type *Type* must be such that an object of type *FwdIter* can be dereferenced and then implicitly converted to *Type*.

- **proj** – Specifies the function (or function object) which will be invoked for each of the elements as a projection operation before the actual predicate *is* invoked.

Returns The *partition* algorithm returns a `hpx::future<subrange_t<hpx::traits::range_iterator_t<Rng>>>` if the execution policy is of type *parallel_task_policy* and returns `subrange_t<hpx::traits::range_iterator_t<Rng>>` The *partition* algorithm returns a subrange starting with an iterator to the first element of the second group and finishing with an iterator equal to last.

```
template<typename FwdIter, typename Sent, typename Pred, typename Proj = hpx::identity>
subrange_t<FwdIter> partition(FwdIter first, Sent last, Pred &&pred, Proj &&proj = Proj())
```

Reorders the elements in the range [first, last) in such a way that all elements for which the predicate *pred* returns true precede the elements for which the predicate *pred* returns false. Relative order of the elements is not preserved.

The assignments in the parallel *partition* algorithm invoked without an execution policy object execute in sequential order in the calling thread.

Note: Complexity: At most $2 * (\text{last} - \text{first})$ swaps. Exactly *last - first* applications of the predicate and projection.

Template Parameters

- **FwdIter** – The type of the source iterators used (deduced). This iterator type must meet the requirements of an forward iterator.
- **Sent** – The type of the source sentinel (deduced). This sentinel type must be a sentinel for *FwdIter*.
- **Pred** – The type of the function/function object to use (deduced). Unlike its sequential form, the parallel overload of *partition* requires *Pred* to meet the requirements of *CopyConstructible*.
- **Proj** – The type of an optional projection function. This defaults to `hpx::identity`

Parameters

- **first** – Refers to the beginning of the sequence of elements the algorithm will be applied to.
- **last** – Refers to sentinel value denoting the end of the sequence of elements the algorithm will be applied.
- **pred** – Specifies the function (or function object) which will be invoked for each of the elements in the sequence specified by [first, last). This is an unary predicate for partitioning the source iterators. The signature of this predicate should be equivalent to:

```
bool pred(const Type &a);
```

The signature does not need to have `const&`, but the function must not modify the objects passed to it. The type *Type* must be such that an object of type *InIter* can be dereferenced and then implicitly converted to *Type*.

- **proj** – Specifies the function (or function object) which will be invoked for each of the elements as a projection operation before the actual predicate *is* invoked.

Returns The *partition* algorithm returns `subrange_t<FwdIter>`. The *partition* algorithm returns a subrange starting with an iterator to the first element of the second group and finishing with an iterator equal to last.

```
template<typename ExPolicy, typename FwdIter, typename Sent, typename Pred, typename Proj =
    hpx::identity>
parallel::util::detail::algorithm_result<ExPolicy, subrange_t<FwdIter>>::type partition(ExPolicy
    &&policy,
    FwdIter first,
    Sent last,
    Pred
    &&pred,
    Proj &&proj
    = Proj())
```

Reorders the elements in the range [first, last) in such a way that all elements for which the predicate *pred* returns true precede the elements for which the predicate *pred* returns false. Relative order of the elements is not preserved.

The assignments in the parallel *partition* algorithm invoked with an execution policy object of type *sequenced_policy* execute in sequential order in the calling thread.

The assignments in the parallel *partition* algorithm invoked with an execution policy object of type *parallel_policy* or *parallel_task_policy* are permitted to execute in an unordered fashion in unspecified threads, and indeterminately sequenced within each thread.

Note: Complexity: At most $2 * (\text{last} - \text{first})$ swaps. Exactly *last - first* applications of the predicate and projection.

Template Parameters

- **ExPolicy** – The type of the execution policy to use (deduced). It describes the manner in which the execution of the algorithm may be parallelized and the manner in which it executes the assignments.
- **FwdIter** – The type of the source iterators used (deduced). This iterator type must meet the requirements of an forward iterator.
- **Sent** – The type of the source sentinel (deduced). This sentinel type must be a sentinel for *FwdIter*.
- **Pred** – The type of the function/function object to use (deduced). Unlike its sequential form, the parallel overload of *partition* requires *Pred* to meet the requirements of *CopyConstructible*.
- **Proj** – The type of an optional projection function. This defaults to *hpx::identity*

Parameters

- **policy** – The execution policy to use for the scheduling of the iterations.
- **first** – Refers to the beginning of the sequence of elements the algorithm will be applied to.
- **last** – Refers to sentinel value denoting the end of the sequence of elements the algorithm will be applied.
- **pred** – Specifies the function (or function object) which will be invoked for each of the elements in the sequence specified by [first, last). This is a unary predicate for

partitioning the source iterators. The signature of this predicate should be equivalent to:

```
bool pred(const Type &a);
```

The signature does not need to have `const&`, but the function must not modify the objects passed to it. The type *Type* must be such that an object of type *Iter* can be dereferenced and then implicitly converted to *Type*.

- **proj** – Specifies the function (or function object) which will be invoked for each of the elements as a projection operation before the actual predicate *is* invoked.

Returns The *partition* algorithm returns a `hpx::future<subrange_t<FwdIter>>` if the execution policy is of type *parallel_task_policy* and returns `subrange_t<FwdIter>` otherwise. The *partition* algorithm returns a subrange starting with an iterator to the first element of the second group and finishing with an iterator equal to last.

```
template<typename Rng, typename Pred, typename Proj = hpx::identity>
subrange_t<hpx::traits::range_iterator_t<Rng>> stable_partition(Rng &&rng, Pred &&pred, Proj
&&proj = Proj())
```

Permutates the elements in the range `[first, last)` such that there exists an iterator *i* such that for every iterator *j* in the range `[first, i)` `INVOKE(f, INVOKE(proj, *j)) != false`, and for every iterator *k* in the range `[i, last)`, `INVOKE(f, INVOKE(proj, *k)) == false`

The invocations of *f* in the parallel *stable_partition* algorithm invoked without an execution policy object executes in sequential order in the calling thread.

Note: Complexity: At most $(last - first) * \log(last - first)$ swaps, but only linear number of swaps if there is enough extra memory Exactly *last - first* applications of the predicate and projection.

Template Parameters

- **Rng** – The type of the source range used (deduced). The iterators extracted from this range type must meet the requirements of an bidirectional iterator
- **Pred** – The type of the function/function object to use (deduced). Unlike its sequential form, the parallel overload of *partition* requires *Pred* to meet the requirements of *CopyConstructible*.
- **Proj** – The type of an optional projection function. This defaults to `hpx::identity`

Parameters

- **rng** – Refers to the sequence of elements the algorithm will be applied to.
- **pred** – Unary predicate which returns true if the element should be ordered before other elements. Specifies the function (or function object) which will be invoked for each of the elements in the sequence specified by `[first, last)`. The signature of this predicate should be equivalent to:

```
bool fun(const Type &a);
```

The signature does not need to have `const&`. The type *Type* must be such that an object of type *BidIter* can be dereferenced and then implicitly converted to *Type*.

- **proj** – Specifies the function (or function object) which will be invoked for each of the elements as a projection operation before the actual predicate *f* is invoked.

Returns The *stable_partition* algorithm returns an iterator *i* such that for every iterator *j* in the range `[first, i)`, `f(*j) != false` `INVOKE(f, INVOKE(proj, *j)) != false`, and for every iterator *k* in the range `[i, last)`, `f(*k) == false` `INVOKE(f, INVOKE(proj, *k)) == false`. The relative order of the elements in both groups is preserved.

```
template<typename ExPolicy, typename Rng, typename Pred, typename Proj = hpx::identity>
```


relative order of the elements in both groups is preserved. If the execution policy is of type *parallel_task_policy* the algorithm returns a future<> referring to this iterator.

```
template<typename BidirIter, typename Sent, typename Pred, typename Proj = hpx::identity>
subrange_t<BidirIter> stable_partition(BidirIter first, Sent last, Pred &&pred, Proj &&proj =
    Proj())
```

Permutates the elements in the range [first, last) such that there exists an iterator *i* such that for every iterator *j* in the range [first, *i*) INVOKE(*f*, INVOKE(*proj*, **j*)) != false, and for every iterator *k* in the range [*i*, last), INVOKE(*f*, INVOKE(*proj*, **k*)) == false

The invocations of *f* in the parallel *stable_partition* algorithm invoked without an execution policy object executes in sequential order in the calling thread.

Note: Complexity: At most (last - first) * log(last - first) swaps, but only linear number of swaps if there is enough extra memory Exactly *last - first* applications of the predicate and projection.

Template Parameters

- **BidirIter** – The type of the source iterators used (deduced). This iterator type must meet the requirements of an input iterator.
- **Sent** – The type of the source sentinel (deduced). This sentinel type must be a sentinel for BidirIter.
- **Pred** – The type of the function/function object to use (deduced). Unlike its sequential form, the parallel overload of *partition* requires *Pred* to meet the requirements of *CopyConstructible*.
- **Proj** – The type of an optional projection function. This defaults to *hpx::identity*

Parameters

- **first** – Refers to the beginning of the sequence of elements the algorithm will be applied to.
- **last** – Refers to sentinel value denoting the end of the sequence of elements the algorithm will be applied.
- **pred** – Unary predicate which returns true if the element should be ordered before other elements. Specifies the function (or function object) which will be invoked for each of the elements in the sequence specified by [first, last). The signature of this predicate should be equivalent to:

```
bool fun(const Type &a);
```

The signature does not need to have const&. The type *Type* must be such that an object of type *BidirIter* can be dereferenced and then implicitly converted to *Type*.

- **proj** – Specifies the function (or function object) which will be invoked for each of the elements as a projection operation before the actual predicate *f* is invoked.

Returns The *stable_partition* algorithm returns an iterator *i* such that for every iterator *j* in the range [first, *i*), *f*(**j*) != false INVOKE(*f*, INVOKE(*proj*, **j*)) != false, and for every iterator *k* in the range [*i*, last), *f*(**k*) == false INVOKE(*f*, INVOKE(*proj*, **k*)) == false. The relative order of the elements in both groups is preserved.

```
template<typename ExPolicy, typename BidirIter, typename Sent, typename Pred, typename Proj
    = hpx::identity>
```

```

parallel::util::detail::algorithm_result<ExPolicy, subrange_t<BidirIter>>::type stable_partition(ExPolicy
&&pol-
icy,
BidirIter
first,
Sent
last,
Pred
&&pred,
Proj
&&proj
=
Proj())

```

Permutes the elements in the range [first, last) such that there exists an iterator *i* such that for every iterator *j* in the range [first, *i*) INVOKE(*f*, INVOKE (proj, *j)) != false, and for every iterator *k* in the range [*i*, last), INVOKE(*f*, INVOKE (proj, *k)) == false

The invocations of *f* in the parallel *stable_partition* algorithm invoked with an execution policy object of type *sequenced_policy* executes in sequential order in the calling thread.

The invocations of *f* in the parallel *stable_partition* algorithm invoked with an execution policy object of type *parallel_policy* or *parallel_task_policy* are permitted to execute in an unordered fashion in unspecified threads, and indeterminately sequenced within each thread.

Note: Complexity: At most (last - first) * log(last - first) swaps, but only linear number of swaps if there is enough extra memory Exactly *last - first* applications of the predicate and projection.

Template Parameters

- **ExPolicy** – The type of the execution policy to use (deduced). It describes the manner in which the execution of the algorithm may be parallelized and the manner in which it executes the invocations of *f*.
- **BidirIter** – The type of the source iterators used (deduced). This iterator type must meet the requirements of an input iterator.
- **Sent** – The type of the source sentinel (deduced). This sentinel type must be a sentinel for BidirIter.
- **Pred** – The type of the function/function object to use (deduced). Unlike its sequential form, the parallel overload of *partition* requires *Pred* to meet the requirements of *CopyConstructible*.
- **Proj** – The type of an optional projection function. This defaults to *hpx::identity*

Parameters

- **policy** – The execution policy to use for the scheduling of the iterations.
- **first** – Refers to the beginning of the sequence of elements the algorithm will be applied to.
- **last** – Refers to sentinel value denoting the end of the sequence of elements the algorithm will be applied.
- **pred** – Unary predicate which returns true if the element should be ordered before other elements. Specifies the function (or function object) which will be invoked for each of the elements in the sequence specified by [first, last). The signature of this predicate should be equivalent to:

```
bool fun(const Type &a);
```

The signature does not need to have `const&`. The type *Type* must be such that an object of type *BidirIter* can be dereferenced and then implicitly converted to *Type*.

- **proj** – Specifies the function (or function object) which will be invoked for each of the elements as a projection operation before the actual predicate *f* is invoked.

Returns The *stable_partition* algorithm returns an iterator *i* such that for every iterator *j* in the range `[first, i)`, `f(*j) != false INVOKE(f, INVOKE(proj, *j)) != false`, and for every iterator *k* in the range `[i, last)`, `f(*k) == false INVOKE(f, INVOKE(proj, *k)) == false`. The relative order of the elements in both groups is preserved. If the execution policy is of type *parallel_task_policy* the algorithm returns a `future<>` referring to this iterator.

```
template<typename Rng, typename OutIter2, typename OutIter3, typename Pred, typename Proj =
hpx::identity>
partition_copy_result<hpx::traits::range_iterator_t<Rng>, OutIter2, OutIter3> partition_copy(Rng
&&rng,
OutIter2
dest_true,
OutIter3
dest_false,
Pred
&&pred,
Proj
&&proj
=
Proj())
```

Copies the elements in the range *rng*, to two different ranges depending on the value returned by the predicate *pred*. The elements, that satisfy the predicate *pred* are copied to the range beginning at *dest_true*. The rest of the elements are copied to the range beginning at *dest_false*. The order of the elements is preserved.

The assignments in the parallel *partition_copy* algorithm invoked without an execution policy object execute in sequential order in the calling thread.

Note: Complexity: Performs not more than *N* assignments, exactly *N* applications of the predicate *pred*, where $N = \text{std::distance}(\text{begin}(\text{rng}), \text{end}(\text{rng}))$.

Template Parameters

- **Rng** – The type of the source range used (deduced). The iterators extracted from this range type must meet the requirements of an forward iterator.
- **OutIter2** – The type of the iterator representing the destination range for the elements that satisfy the predicate *pred* (deduced). This iterator type must meet the requirements of an forward iterator.
- **OutIter3** – The type of the iterator representing the destination range for the elements that don't satisfy the predicate *pred* (deduced). This iterator type must meet the requirements of an forward iterator.
- **Pred** – The type of the function/function object to use (deduced). Unlike its sequential form, the parallel overload of *partition_copy* requires *Pred* to meet the requirements of *CopyConstructible*.
- **Proj** – The type of an optional projection function. This defaults to *hpx::identity*

Parameters

- **rng** – Refers to the sequence of elements the algorithm will be applied to.

- **dest_true** – Refers to the beginning of the destination range for the elements that satisfy the predicate *pred*
- **dest_false** – Refers to the beginning of the destination range for the elements that don't satisfy the predicate *pred*.
- **pred** – Specifies the function (or function object) which will be invoked for each of the elements in the sequence specified by [first, last). This is an unary predicate for partitioning the source iterators. The signature of this predicate should be equivalent to:

```
bool pred(const Type &a);
```

The signature does not need to have const&, but the function must not modify the objects passed to it. The type *Type* must be such that an object of type *FwdIter1* can be dereferenced and then implicitly converted to *Type*.

- **proj** – Specifies the function (or function object) which will be invoked for each of the elements as a projection operation before the actual predicate *is* invoked.

Returns The *partition_copy* algorithm returns a `partition_copy_result<hpx::traits::range_iterator_t<Rng>, FwdIter2, FwdIter3>>`. The *partition_copy* algorithm returns the tuple of the source iterator *last*, the destination iterator to the end of the *dest_true* range, and the destination iterator to the end of the *dest_false* range.

```
template<typename ExPolicy, typename Rng, typename FwdIter2, typename FwdIter3, typename Pred, typename Proj = hpx::identity>
```

```
parallel::util::detail::algorithm_result<ExPolicy, partition_copy_result<hpx::traits::range_iterator_t<Rng>, FwdIter2, FwdIter3>>
```

Copies the elements in the range *rng*, to two different ranges depending on the value returned by the predicate *pred*. The elements, that satisfy the predicate *pred* are copied to the range beginning at *dest_true*. The rest of the elements are copied to the range beginning at *dest_false*. The order of the elements is preserved.

The assignments in the parallel *partition_copy* algorithm invoked with an execution policy object of type *sequenced_policy* execute in sequential order in the calling thread.

The assignments in the parallel *partition_copy* algorithm invoked with an execution policy object of type *parallel_policy* or *parallel_task_policy* are permitted to execute in an unordered fashion in unspecified threads, and indeterminately sequenced within each thread.

Note: Complexity: Performs not more than N assignments, exactly N applications of the predicate *pred*, where $N = \text{std::distance}(\text{begin}(\text{rng}), \text{end}(\text{rng}))$.

Template Parameters

- **ExPolicy** – The type of the execution policy to use (deduced). It describes the manner in which the execution of the algorithm may be parallelized and the manner in which it executes the assignments.
- **Rng** – The type of the source range used (deduced). The iterators extracted from this range type must meet the requirements of an forward iterator.
- **FwdIter2** – The type of the iterator representing the destination range for the elements that satisfy the predicate *pred* (deduced). This iterator type must meet the requirements of an forward iterator.
- **FwdIter3** – The type of the iterator representing the destination range for the elements that don't satisfy the predicate *pred* (deduced). This iterator type must meet the requirements of an forward iterator.
- **Pred** – The type of the function/function object to use (deduced). Unlike its sequential form, the parallel overload of *partition_copy* requires *Pred* to meet the requirements of *CopyConstructible*.
- **Proj** – The type of an optional projection function. This defaults to *hpx::identity*

Parameters

- **policy** – The execution policy to use for the scheduling of the iterations.
- **rng** – Refers to the sequence of elements the algorithm will be applied to.
- **dest_true** – Refers to the beginning of the destination range for the elements that satisfy the predicate *pred*
- **dest_false** – Refers to the beginning of the destination range for the elements that don't satisfy the predicate *pred*.
- **pred** – Specifies the function (or function object) which will be invoked for each of the elements in the sequence specified by [first, last). This is an unary predicate for partitioning the source iterators. The signature of this predicate should be equivalent to:

```
bool pred(const Type &a);
```

The signature does not need to have const&, but the function must not modify the objects passed to it. The type *Type* must be such that an object of type *FwdIter1* can be dereferenced and then implicitly converted to *Type*.

- **proj** – Specifies the function (or function object) which will be invoked for each of the elements as a projection operation before the actual predicate *is* invoked.

Returns The *partition_copy* algorithm returns a *hpx::future<partition_copy_result<hpx::traits::range_iterator_t<Rng>, FwdIter2, FwdIter3>>* if the execution policy is of type *parallel_task_policy* and returns *partition_copy_result<hpx::traits::range_iterator_t<Rng>, FwdIter2, FwdIter3>* otherwise. The *partition_copy* algorithm returns the tuple of the source iterator *last*, the destination iterator to the end of the *dest_true* range, and the destination iterator to the end of the *dest_false* range.

```
template<typename InIter, typename Sent, typename OutIter2, typename OutIter3, typename
Pred, typename Proj = hpx::identity>
partition_copy_result<InIter, OutIter2, OutIter3> partition_copy(InIter first, Sent last, OutIter2
dest_true, OutIter3 dest_false, Pred
&&pred, Proj &&proj = Proj())
```

Copies the elements in the range, defined by [first, last), to two different ranges depending on the value returned by the predicate *pred*. The elements, that satisfy the predicate *pred* are copied to the range beginning at *dest_true*. The rest of the elements are copied to the range beginning at *dest_false*. The order of the elements is preserved.

The assignments in the parallel *partition_copy* algorithm invoked without an execution policy object

execute in sequential order in the calling thread.

Note: Complexity: Performs not more than *last - first* assignments, exactly *last - first* applications of the predicate *f*.

Template Parameters

- **InIter** – The type of the source iterators used (deduced). This iterator type must meet the requirements of an forward iterator.
- **Sent** – The type of the source sentinel (deduced). This sentinel type must be a sentinel for `FwdIter`.
- **OutIter2** – The type of the iterator representing the destination range for the elements that satisfy the predicate *pred* (deduced). This iterator type must meet the requirements of an forward iterator.
- **OutIter3** – The type of the iterator representing the destination range for the elements that don't satisfy the predicate *pred* (deduced). This iterator type must meet the requirements of an forward iterator.
- **Pred** – The type of the function/function object to use (deduced). Unlike its sequential form, the parallel overload of *partition_copy* requires *Pred* to meet the requirements of *CopyConstructible*.
- **Proj** – The type of an optional projection function. This defaults to `hpx::identity`

Parameters

- **first** – Refers to the beginning of the sequence of elements the algorithm will be applied to.
- **last** – Refers to sentinel value denoting the end of the sequence of elements the algorithm will be applied.
- **dest_true** – Refers to the beginning of the destination range for the elements that satisfy the predicate *pred*
- **dest_false** – Refers to the beginning of the destination range for the elements that don't satisfy the predicate *pred*.
- **pred** – Specifies the function (or function object) which will be invoked for each of the elements in the sequence specified by [first, last). This is an unary predicate for partitioning the source iterators. The signature of this predicate should be equivalent to:

```
bool pred(const Type &a);
```

The signature does not need to have `const&`, but the function must not modify the objects passed to it. The type *Type* must be such that an object of type *FwdIter1* can be dereferenced and then implicitly converted to *Type*.

- **proj** – Specifies the function (or function object) which will be invoked for each of the elements as a projection operation before the actual predicate *is* invoked.

Returns The *partition_copy* algorithm returns a *partition_copy_result*<*FwdIter*, *OutIter2*, *OutIter3*>. The *partition_copy* algorithm returns the tuple of the source iterator *last*, the destination iterator to the end of the *dest_true* range, and the destination iterator to the end of the *dest_false* range.

```
template<typename ExPolicy, typename FwdIter, typename Sent, typename OutIter2, typename OutIter3, typename Pred, typename Proj = hpx::identity>
```

`parallel::util::detail::algorithm_result<ExPolicy, partition_copy_result<FwdIter, OutIter2, OutIter3>>::type` **partition_c**

Copies the elements in the range, defined by [first, last), to two different ranges depending on the value returned by the predicate *pred*. The elements, that satisfy the predicate *pred* are copied to the range beginning at *dest_true*. The rest of the elements are copied to the range beginning at *dest_false*. The order of the elements is preserved.

The assignments in the parallel *partition_copy* algorithm invoked with an execution policy object of type *sequenced_policy* execute in sequential order in the calling thread.

The assignments in the parallel *partition_copy* algorithm invoked with an execution policy object of type *parallel_policy* or *parallel_task_policy* are permitted to execute in an unordered fashion in unspecified threads, and indeterminately sequenced within each thread.

Note: Complexity: Performs not more than *last - first* assignments, exactly *last - first* applications of the predicate *f*.

Template Parameters

- **ExPolicy** – The type of the execution policy to use (deduced). It describes the manner in which the execution of the algorithm may be parallelized and the manner in which it executes the assignments.
- **FwdIter** – The type of the source iterators used (deduced). This iterator type must meet the requirements of an forward iterator.
- **Sent** – The type of the source sentinel (deduced). This sentinel type must be a sentinel for FwdIter.
- **OutIter2** – The type of the iterator representing the destination range for the elements that satisfy the predicate *pred* (deduced). This iterator type must meet the requirements of an forward iterator.
- **OutIter3** – The type of the iterator representing the destination range for the elements that don't satisfy the predicate *pred* (deduced). This iterator type must meet the requirements of an forward iterator.
- **Pred** – The type of the function/function object to use (deduced). Unlike its sequential form, the parallel overload of *partition_copy* requires *Pred* to meet the requirements of *CopyConstructible*.
- **Proj** – The type of an optional projection function. This defaults to *hpx::identity*

Parameters

- **policy** – The execution policy to use for the scheduling of the iterations.
- **first** – Refers to the beginning of the sequence of elements the algorithm will be applied to.
- **last** – Refers to sentinel value denoting the end of the sequence of elements the algorithm will be applied.
- **dest_true** – Refers to the beginning of the destination range for the elements that satisfy the predicate *pred*
- **dest_false** – Refers to the beginning of the destination range for the elements that don't satisfy the predicate *pred*.
- **pred** – Specifies the function (or function object) which will be invoked for each of the elements in the sequence specified by [first, last). This is an unary predicate for partitioning the source iterators. The signature of this predicate should be equivalent to:

```
bool pred(const Type &a);
```

The signature does not need to have const&, but the function must not modify the objects passed to it. The type *Type* must be such that an object of type *FwdIter1* can be dereferenced and then implicitly converted to *Type*.

- **proj** – Specifies the function (or function object) which will be invoked for each of the elements as a projection operation before the actual predicate *is* invoked.

Returns The *partition_copy* algorithm returns a `hpx::future<partition_copy_result<FwdIter, OutIter2, OutIter3>>` if the execution policy is of type *parallel_task_policy* and returns `partition_copy_result<FwdIter, OutIter2, OutIter3>` otherwise. The *partition_copy* algorithm returns the tuple of the source iterator *last*, the destination iterator to the end of the *dest_true* range, and the destination iterator to the end of the *dest_false* range.

hpx::ranges::reduce

Defined in header `hpx/algorithm.hpp`⁶⁶⁵.

See *Public API* for a list of names and headers that are part of the public *HPX* API.

namespace **hpx**

namespace **ranges**

Functions

```
template<typename ExPolicy, typename FwdIter, typename Sent, typename F, typename T =
typename std::iterator_traits<FwdIter>::value_type>
hpx::parallel::util::detail::algorithm_result_t<ExPolicy, T> reduce(ExPolicy &&policy, FwdIter first,
Sent last, T init, F &&f)
```

Returns GENERALIZED_SUM(f, init, *first, ..., *(first + (last - first) - 1)).

The reduce operations in the parallel *reduce* algorithm invoked with an execution policy object of type *sequenced_policy* execute in sequential order in the calling thread.

⁶⁶⁵ <http://github.com/STELLAR-GROUP/hpx/blob/8a3b7c1a4cb5693b2f7d9f587f759392ed0c51a0/libs/full/include/include/hpx/algorithm.hpp>

The reduce operations in the parallel *copy_if* algorithm invoked with an execution policy object of type *parallel_policy* or *parallel_task_policy* are permitted to execute in an unordered fashion in unspecified threads, and indeterminately sequenced within each thread.

The difference between *reduce* and *accumulate* is that the behavior of reduce may be non-deterministic for non-associative or non-commutative binary predicate.

Note: Complexity: $O(\text{last} - \text{first})$ applications of the predicate f .

Note: GENERALIZED_SUM(op, a1, ..., aN) is defined as follows:

- a1 when N is 1
 - op(GENERALIZED_SUM(op, b1, ..., bK), GENERALIZED_SUM(op, bM, ..., bN)), where:
 - b1, ..., bN may be any permutation of a1, ..., aN and
 - $1 < K+1 = M \leq N$.
-

Template Parameters

- **ExPolicy** – The type of the execution policy to use (deduced). It describes the manner in which the execution of the algorithm may be parallelized and the manner in which it executes the assignments.
- **FwdIter** – The type of the source begin iterator used (deduced). This iterator type must meet the requirements of an forward iterator.
- **Sent** – The type of the source sentinel used (deduced). This iterator type must meet the requirements of an forward iterator.
- **F** – The type of the function/function object to use (deduced). Unlike its sequential form, the parallel overload of *copy_if* requires F to meet the requirements of *CopyConstructible*.
- **T** – The type of the value to be used as initial (and intermediate) values (deduced).

Parameters

- **policy** – The execution policy to use for the scheduling of the iterations.
- **first** – Refers to the beginning of the sequence of elements the algorithm will be applied to.
- **last** – Refers to the end of the sequence of elements the algorithm will be applied to.
- **f** – Specifies the function (or function object) which will be invoked for each of the elements in the sequence specified by [first, last). This is a binary predicate. The signature of this predicate should be equivalent to:

```
Ret fun(const Type1 &a, const Type1 &b);
```

The signature does not need to have const&. The types *Type1 Ret* must be such that an object of type *FwdIterB* can be dereferenced and then implicitly converted to any of those types.

- **init** – The initial value for the generalized sum.

Returns The *reduce* algorithm returns a *hpx::future<T>* if the execution policy is of type *sequenced_task_policy* or *parallel_task_policy* and returns T otherwise. The *reduce* algorithm returns the result of the generalized sum over the elements given by the input range [first, last).

```
template<typename ExPolicy, typename Rng, typename F, typename T = typename
std::iterator_traits<hpx::traits::range_iterator_t<Rng>>::value_type>
hpx::parallel::util::detail::algorithm_result_t<ExPolicy, T> reduce(ExPolicy &&policy, Rng &&rng, T
init, F &&f)
```

Returns `GENERALIZED_SUM(f, init, *first, ..., *(first + (last - first) - 1))`.

The reduce operations in the parallel *reduce* algorithm invoked with an execution policy object of type *sequenced_policy* execute in sequential order in the calling thread.

The reduce operations in the parallel *copy_if* algorithm invoked with an execution policy object of type *parallel_policy* or *parallel_task_policy* are permitted to execute in an unordered fashion in unspecified threads, and indeterminately sequenced within each thread.

The difference between *reduce* and *accumulate* is that the behavior of reduce may be non-deterministic for non-associative or non-commutative binary predicate.

Note: Complexity: $O(\text{last} - \text{first})$ applications of the predicate *f*.

Note: `GENERALIZED_SUM(op, a1, ..., aN)` is defined as follows:

- `a1` when `N` is 1
 - `op(GENERALIZED_SUM(op, b1, ..., bK), GENERALIZED_SUM(op, bM, ..., bN))`, where:
 - `b1, ..., bN` may be any permutation of `a1, ..., aN` and
 - $1 < K+1 = M \leq N$.
-

Template Parameters

- **ExPolicy** – The type of the execution policy to use (deduced). It describes the manner in which the execution of the algorithm may be parallelized and the manner in which it executes the assignments.
- **Rng** – The type of the source range used (deduced). The iterators extracted from this range type must meet the requirements of an input iterator.
- **F** – The type of the function/function object to use (deduced). Unlike its sequential form, the parallel overload of *copy_if* requires *F* to meet the requirements of *CopyConstructible*.
- **T** – The type of the value to be used as initial (and intermediate) values (deduced).

Parameters

- **policy** – The execution policy to use for the scheduling of the iterations.
- **rng** – Refers to the sequence of elements the algorithm will be applied to.
- **f** – Specifies the function (or function object) which will be invoked for each of the elements in the sequence specified by `[first, last)`. This is a binary predicate. The signature of this predicate should be equivalent to:

```
Ret fun(const Type1 &a, const Type1 &b);
```

The signature does not need to have `const&`. The types *Type1* *Ret* must be such that an object of type *FwdIterB* can be dereferenced and then implicitly converted to any of those types.

- **init** – The initial value for the generalized sum.

Returns The *reduce* algorithm returns a `hpx::future<T>` if the execution policy is of type *sequenced_task_policy* or *parallel_task_policy* and returns *T* otherwise. The *reduce* algorithm returns the result of the generalized sum over the elements given by the input range `[first, last)`.

```
template<typename ExPolicy, typename FwdIter, typename Sent, typename T = typename
std::iterator_traits<FwdIter>::value_type>
```

```

hpx::parallel::util::detail::algorithm_result_t<ExPolicy, T> reduce(ExPolicy &&policy, FwdIter first,
                                                                    Sent last, T init)

```

Returns GENERALIZED_SUM(+, init, *first, ..., *(first + (last - first) - 1)).

The reduce operations in the parallel *reduce* algorithm invoked with an execution policy object of type *sequenced_policy* execute in sequential order in the calling thread.

The reduce operations in the parallel *copy_if* algorithm invoked with an execution policy object of type *parallel_policy* or *parallel_task_policy* are permitted to execute in an unordered fashion in unspecified threads, and indeterminately sequenced within each thread.

The difference between *reduce* and *accumulate* is that the behavior of reduce may be non-deterministic for non-associative or non-commutative binary predicate.

Note: Complexity: $O(\text{last} - \text{first})$ applications of the operator+().

Note: GENERALIZED_SUM(+, a1, ..., aN) is defined as follows:

- a1 when N is 1
 - $\text{op}(\text{GENERALIZED_SUM}(+, b1, \dots, bK), \text{GENERALIZED_SUM}(+, bM, \dots, bN))$, where:
 - b1, ..., bN may be any permutation of a1, ..., aN and
 - $1 < K+1 = M \leq N$.
-

Template Parameters

- **ExPolicy** – The type of the execution policy to use (deduced). It describes the manner in which the execution of the algorithm may be parallelized and the manner in which it executes the assignments.
- **FwdIter** – The type of the source begin iterator used (deduced). This iterator type must meet the requirements of an forward iterator.
- **Sent** – The type of the source sentinel used (deduced). This iterator type must meet the requirements of an forward iterator.
- **T** – The type of the value to be used as initial (and intermediate) values (deduced).

Parameters

- **policy** – The execution policy to use for the scheduling of the iterations.
- **first** – Refers to the beginning of the sequence of elements the algorithm will be applied to.
- **last** – Refers to the end of the sequence of elements the algorithm will be applied to.
- **init** – The initial value for the generalized sum.

Returns The *reduce* algorithm returns a *hpx::future<T>* if the execution policy is of type *sequenced_task_policy* or *parallel_task_policy* and returns *T* otherwise. The *reduce* algorithm returns the result of the generalized sum (applying operator+()) over the elements given by the input range [first, last).

```

template<typename ExPolicy, typename Rng, typename T = typename
std::iterator_traits<hpx::traits::range_iterator_t<Rng>>::value_type>
hpx::parallel::util::detail::algorithm_result_t<ExPolicy, T> reduce(ExPolicy &&policy, Rng &&rng, T
                                                                    init)

```

Returns GENERALIZED_SUM(+, init, *first, ..., *(first + (last - first) - 1)).

The reduce operations in the parallel *reduce* algorithm invoked with an execution policy object of type *sequenced_policy* execute in sequential order in the calling thread.

The reduce operations in the parallel *copy_if* algorithm invoked with an execution policy object of type *parallel_policy* or *parallel_task_policy* are permitted to execute in an unordered fashion in unspecified threads, and indeterminately sequenced within each thread.

The difference between *reduce* and *accumulate* is that the behavior of reduce may be non-deterministic for non-associative or non-commutative binary predicate.

Note: Complexity: $O(\text{last} - \text{first})$ applications of the operator+().

Note: GENERALIZED_SUM(+, a1, ..., aN) is defined as follows:

- a1 when N is 1
 - op(GENERALIZED_SUM(+, b1, ..., bK), GENERALIZED_SUM(+, bM, ..., bN)), where:
 - b1, ..., bN may be any permutation of a1, ..., aN and
 - $1 < K+1 = M \leq N$.
-

Template Parameters

- **ExPolicy** – The type of the execution policy to use (deduced). It describes the manner in which the execution of the algorithm may be parallelized and the manner in which it executes the assignments.
- **Rng** – The type of the source range used (deduced). The iterators extracted from this range type must meet the requirements of an input iterator.
- **T** – The type of the value to be used as initial (and intermediate) values (deduced).

Parameters

- **policy** – The execution policy to use for the scheduling of the iterations.
- **rng** – Refers to the sequence of elements the algorithm will be applied to.
- **init** – The initial value for the generalized sum.

Returns The *reduce* algorithm returns a *hpx::future<T>* if the execution policy is of type *sequenced_task_policy* or *parallel_task_policy* and returns *T* otherwise. The *reduce* algorithm returns the result of the generalized sum (applying operator+()) over the elements given by the input range [first, last).

```
template<typename ExPolicy, typename FwdIter, typename Sent>
```

```
hpx::parallel::util::detail::algorithm_result<ExPolicy, typename std::iterator_traits<FwdIter>::value_type::type reduce(E
```

Returns GENERALIZED_SUM(+, T(), *first, ..., *(first + (last - first) - 1)).

The reduce operations in the parallel *reduce* algorithm invoked with an execution policy object of type *sequenced_policy* execute in sequential order in the calling thread.

The reduce operations in the parallel *copy_if* algorithm invoked with an execution policy object of type *parallel_policy* or *parallel_task_policy* are permitted to execute in an unordered fashion in unspecified threads, and indeterminately sequenced within each thread.

The difference between *reduce* and *accumulate* is that the behavior of *reduce* may be non-deterministic for non-associative or non-commutative binary predicate.

Note: Complexity: $O(\text{last} - \text{first})$ applications of the operator+().

Note: The type of the initial value (and the result type) T is determined from the `value_type` of the used `FwdIterB`.

Note: `GENERALIZED_SUM(+, a1, ..., aN)` is defined as follows:

- a_1 when N is 1
 - $\text{op}(\text{GENERALIZED_SUM}(+, b_1, \dots, b_K), \text{GENERALIZED_SUM}(+, b_M, \dots, b_N))$, where:
 - b_1, \dots, b_N may be any permutation of a_1, \dots, a_N and
 - $1 < K+1 = M \leq N$.
-

Template Parameters

- **ExPolicy** – The type of the execution policy to use (deduced). It describes the manner in which the execution of the algorithm may be parallelized and the manner in which it executes the assignments.
- **FwdIter** – The type of the source begin iterator used (deduced). This iterator type must meet the requirements of an forward iterator.
- **Sent** – The type of the source sentinel used (deduced). This iterator type must meet the requirements of an forward iterator.

Parameters

- **policy** – The execution policy to use for the scheduling of the iterations.
- **first** – Refers to the beginning of the sequence of elements the algorithm will be applied to.
- **last** – Refers to the end of the sequence of elements the algorithm will be applied to.

Returns The *reduce* algorithm returns a `hpx::future<T>` if the execution policy is of type `sequenced_task_policy` or `parallel_task_policy` and returns T otherwise (where T is the `value_type` of `FwdIterB`). The *reduce* algorithm returns the result of the generalized sum (applying operator+()) over the elements given by the input range `[first, last)`.

```
template<typename ExPolicy, typename Rng>
```

```
hpx::parallel::util::detail::algorithm_result<ExPolicy, typename std::iterator_traits<typename hpx::traits::range_traits<Rng>
```

Returns `GENERALIZED_SUM(+, T(), *first, ..., *(first + (last - first) - 1))`.

The *reduce* operations in the parallel *reduce* algorithm invoked with an execution policy object of type `sequenced_policy` execute in sequential order in the calling thread.

The *reduce* operations in the parallel *copy_if* algorithm invoked with an execution policy object of type `parallel_policy` or `parallel_task_policy` are permitted to execute in an unordered fashion in unspecified threads, and indeterminately sequenced within each thread.

The difference between *reduce* and *accumulate* is that the behavior of reduce may be non-deterministic for non-associative or non-commutative binary predicate.

Note: Complexity: $O(\text{last} - \text{first})$ applications of the operator+().

Note: The type of the initial value (and the result type) T is determined from the `value_type` of the used `FwdIterB`.

Note: GENERALIZED_SUM(+, a1, ..., aN) is defined as follows:

- a1 when N is 1
 - op(GENERALIZED_SUM(+, b1, ..., bK), GENERALIZED_SUM(+, bM, ..., bN)), where:
 - b1, ..., bN may be any permutation of a1, ..., aN and
 - $1 < K+1 = M \leq N$.
-

Template Parameters

- **ExPolicy** – The type of the execution policy to use (deduced). It describes the manner in which the execution of the algorithm may be parallelized and the manner in which it executes the assignments.
- **Rng** – The type of the source range used (deduced). The iterators extracted from this range type must meet the requirements of an input iterator.

Parameters

- **policy** – The execution policy to use for the scheduling of the iterations.
- **rng** – Refers to the sequence of elements the algorithm will be applied to.

Returns The *reduce* algorithm returns a `hpx::future<T>` if the execution policy is of type `sequenced_task_policy` or `parallel_task_policy` and returns T otherwise (where T is the `value_type` of `FwdIterB`). The *reduce* algorithm returns the result of the generalized sum (applying operator+()) over the elements given by the input range [first, last).

```
template<typename FwdIter, typename Sent, typename F, typename T = typename
std::iterator_traits<FwdIter>::value_type>
T reduce(FwdIter first, Sent last, T init, F &&f)
```

Returns GENERALIZED_SUM(f, init, *first, ..., *(first + (last - first) - 1)).

The difference between *reduce* and *accumulate* is that the behavior of reduce may be non-deterministic for non-associative or non-commutative binary predicate.

Note: Complexity: $O(\text{last} - \text{first})$ applications of the predicate f .

Note: GENERALIZED_SUM(op, a1, ..., aN) is defined as follows:

- a1 when N is 1
 - op(GENERALIZED_SUM(op, b1, ..., bK), GENERALIZED_SUM(op, bM, ..., bN)), where:
 - b1, ..., bN may be any permutation of a1, ..., aN and
 - $1 < K+1 = M \leq N$.
-

Template Parameters

- **FwdIter** – The type of the source begin iterator used (deduced). This iterator type must meet the requirements of an forward iterator.

- **Sent** – The type of the source sentinel used (deduced). This iterator type must meet the requirements of an forward iterator.
- **F** – The type of the function/function object to use (deduced). Unlike its sequential form, the parallel overload of *copy_if* requires *F* to meet the requirements of *CopyConstructible*.
- **T** – The type of the value to be used as initial (and intermediate) values (deduced).

Parameters

- **first** – Refers to the beginning of the sequence of elements the algorithm will be applied to.
- **last** – Refers to the end of the sequence of elements the algorithm will be applied to.
- **f** – Specifies the function (or function object) which will be invoked for each of the elements in the sequence specified by [first, last). This is a binary predicate. The signature of this predicate should be equivalent to:

```
Ret fun(const Type1 &a, const Type1 &b);
```

The signature does not need to have const&. The types *Type1 Ret* must be such that an object of type *FwdIterB* can be dereferenced and then implicitly converted to any of those types.

- **init** – The initial value for the generalized sum.

Returns The *reduce* algorithm returns *T*. The *reduce* algorithm returns the result of the generalized sum over the elements given by the input range [first, last).

```
template<typename Rng, typename F, typename T = typename
std::iterator_traits<hpx::traits::range_iterator_t<Rng>>::value_type>
T reduce(Rng &&rng, T init, F &&f)
```

Returns GENERALIZED_SUM(f, init, *first, ..., *(first + (last - first) - 1)).

The difference between *reduce* and *accumulate* is that the behavior of reduce may be non-deterministic for non-associative or non-commutative binary predicate.

Note: Complexity: $O(\text{last} - \text{first})$ applications of the predicate *f*.

Note: GENERALIZED_SUM(op, a1, ..., aN) is defined as follows:

- a1 when N is 1
 - op(GENERALIZED_SUM(op, b1, ..., bK), GENERALIZED_SUM(op, bM, ..., bN)), where:
 - b1, ..., bN may be any permutation of a1, ..., aN and
 - $1 < K+1 = M \leq N$.
-

Template Parameters

- **Rng** – The type of the source range used (deduced). The iterators extracted from this range type must meet the requirements of an input iterator.
- **F** – The type of the function/function object to use (deduced). Unlike its sequential form, the parallel overload of *copy_if* requires *F* to meet the requirements of *CopyConstructible*.
- **T** – The type of the value to be used as initial (and intermediate) values (deduced).

Parameters

- **rng** – Refers to the sequence of elements the algorithm will be applied to.
- **f** – Specifies the function (or function object) which will be invoked for each of the elements in the sequence specified by [first, last). This is a binary predicate. The signature of this predicate should be equivalent to:

```
Ret fun(const Type1 &a, const Type1 &b);
```

The signature does not need to have `const&`. The types *Type1* *Ret* must be such that an object of type *FwdIterB* can be dereferenced and then implicitly converted to any of those types.

- **init** – The initial value for the generalized sum.

Returns The *reduce* algorithm returns *T*. The *reduce* algorithm returns the result of the generalized sum over the elements given by the input range [first, last).

```
template<typename FwdIter, typename Sent, typename T = typename
std::iterator_traits<FwdIter>::value_type>
T reduce(FwdIter first, Sent last, T init)
```

Returns GENERALIZED_SUM(+, init, *first, ..., *(first + (last - first) - 1)).

The difference between *reduce* and *accumulate* is that the behavior of reduce may be non-deterministic for non-associative or non-commutative binary predicate.

Note: Complexity: $O(\text{last} - \text{first})$ applications of the operator+().

Note: GENERALIZED_SUM(+, a1, ..., aN) is defined as follows:

- a1 when N is 1
 - op(GENERALIZED_SUM(+, b1, ..., bK), GENERALIZED_SUM(+, bM, ..., bN)), where:
 - b1, ..., bN may be any permutation of a1, ..., aN and
 - $1 < K+1 = M \leq N$.
-

Template Parameters

- **FwdIter** – The type of the source begin iterator used (deduced). This iterator type must meet the requirements of an forward iterator.
- **Sent** – The type of the source sentinel used (deduced). This iterator type must meet the requirements of an forward iterator.
- **T** – The type of the value to be used as initial (and intermediate) values (deduced).

Parameters

- **first** – Refers to the beginning of the sequence of elements the algorithm will be applied to.
- **last** – Refers to the end of the sequence of elements the algorithm will be applied to.
- **init** – The initial value for the generalized sum.

Returns The *reduce* algorithm returns *T*. The *reduce* algorithm returns the result of the generalized sum (applying operator+()) over the elements given by the input range [first, last).

```
template<typename Rng, typename T = typename
std::iterator_traits<hpx::traits::range_iterator_t<Rng>>::value_type>
T reduce(Rng &&rng, T init)
```

Returns GENERALIZED_SUM(+, init, *first, ..., *(first + (last - first) - 1)).

The difference between *reduce* and *accumulate* is that the behavior of reduce may be non-deterministic for non-associative or non-commutative binary predicate.

Note: Complexity: $O(\text{last} - \text{first})$ applications of the operator+().

Note: GENERALIZED_SUM(+, a1, ..., aN) is defined as follows:

- a1 when N is 1
 - op(GENERALIZED_SUM(+, b1, ..., bK), GENERALIZED_SUM(+, bM, ..., bN)), where:
 - b1, ..., bN may be any permutation of a1, ..., aN and
 - 1 < K+1 = M <= N.
-

Template Parameters

- **Rng** – The type of the source range used (deduced). The iterators extracted from this range type must meet the requirements of an input iterator.
- **T** – The type of the value to be used as initial (and intermediate) values (deduced).

Parameters

- **rng** – Refers to the sequence of elements the algorithm will be applied to.
- **init** – The initial value for the generalized sum.

Returns The *reduce* algorithm returns *T*. The *reduce* algorithm returns the result of the generalized sum (applying operator+()) over the elements given by the input range [first, last).

```
template<typename FwdIter, typename Sent>
std::iterator_traits<FwdIter>::value_type reduce(FwdIter first, Sent last)
Returns GENERALIZED_SUM(+, T(), *first, ..., *(first + (last - first) - 1)).
```

The difference between *reduce* and *accumulate* is that the behavior of *reduce* may be non-deterministic for non-associative or non-commutative binary predicate.

Note: Complexity: $O(\text{last} - \text{first})$ applications of the operator+().

Note: The type of the initial value (and the result type) *T* is determined from the `value_type` of the used *FwdIterB*.

Note: GENERALIZED_SUM(+, a1, ..., aN) is defined as follows:

- a1 when N is 1
 - op(GENERALIZED_SUM(+, b1, ..., bK), GENERALIZED_SUM(+, bM, ..., bN)), where:
 - b1, ..., bN may be any permutation of a1, ..., aN and
 - 1 < K+1 = M <= N.
-

Template Parameters

- **FwdIter** – The type of the source begin iterator used (deduced). This iterator type must meet the requirements of an forward iterator.
- **Sent** – The type of the source sentinel used (deduced). This iterator type must meet the requirements of an forward iterator.

Parameters

- **first** – Refers to the beginning of the sequence of elements the algorithm will be applied to.
- **last** – Refers to the end of the sequence of elements the algorithm will be applied to.

Returns The *reduce* algorithm returns *T* (where *T* is the `value_type` of *FwdIterB*). The *reduce* algorithm returns the result of the generalized sum (applying operator+()) over the elements given by the input range [first, last).

```
template<typename Rng>
```

`std::iterator_traits<typename hpx::traits::range_traits<Rng>::iterator_type>::value_type` **reduce**(*Rng* &&rng)

Returns GENERALIZED_SUM(+, T(), *first, ..., *(first + (last - first) - 1)).

The difference between *reduce* and *accumulate* is that the behavior of reduce may be non-deterministic for non-associative or non-commutative binary predicate.

Note: Complexity: $O(\text{last} - \text{first})$ applications of the operator+().

Note: The type of the initial value (and the result type) *T* is determined from the `value_type` of the used *FwdIterB*.

Note: GENERALIZED_SUM(+, a1, ..., aN) is defined as follows:

- a1 when N is 1
 - op(GENERALIZED_SUM(+, b1, ..., bK), GENERALIZED_SUM(+, bM, ..., bN)), where:
 - b1, ..., bN may be any permutation of a1, ..., aN and
 - $1 < K+1 = M \leq N$.
-

Template Parameters *Rng* – The type of the source range used (deduced). The iterators extracted from this range type must meet the requirements of an input iterator.

Parameters *rng* – Refers to the sequence of elements the algorithm will be applied to.

Returns The *reduce* algorithm returns *T* (where T is the `value_type` of *FwdIterB*). The *reduce* algorithm returns the result of the generalized sum (applying operator+()) over the elements given by the input range [first, last).

hpx::ranges::remove, hpx::ranges::remove_if

Defined in header `hpx/algorithm.hpp`⁶⁶⁶.

See *Public API* for a list of names and headers that are part of the public HPX API.

```
namespace hpx
```

```
    namespace ranges
```

Functions

```
template<typename Iter, typename Sent, typename Pred, typename Proj = hpx::identity>
subrange_t<Iter, Sent> remove_if(Iter first, Sent sent, Pred &&pred, Proj &&proj = Proj())
```

Removes all elements for which predicate *pred* returns true from the range [first, last) and returns a subrange [ret, last), where ret is a past-the-end iterator for the new end of the range.

The assignments in the parallel *remove_if* algorithm execute in sequential order in the calling thread.

⁶⁶⁶ <http://github.com/STELLAR-GROUP/hpx/blob/8a3b7c1a4cb5693b2f7d9f587f759392ed0c51a0/libs/full/include/include/hpx/algorithm.hpp>

Note: Complexity: Performs not more than *last - first* assignments, exactly *last - first* applications of the predicate *pred* and the projection *proj*.

Template Parameters

- **Iter** – The type of the source iterators used for the This iterator type must meet the requirements of a forward iterator.
- **Sent** – The type of the end iterators used (deduced). This sentinel type must be a sentinel for `FwdIter`.
- **Pred** – The type of the function/function object to use (deduced). Unlike its sequential form, the parallel overload of `remove_if` requires *Pred* to meet the requirements of *CopyConstructible*.
- **Proj** – The type of an optional projection function. This defaults to `hpx::identity`

Parameters

- **first** – Refers to the beginning of the sequence of elements the algorithm will be applied to.
- **sent** – Refers to the end of the sequence of elements the algorithm will be applied to.
- **pred** – Specifies the function (or function object) which will be invoked for each of the elements in the sequence specified by [first, last). This is a unary predicate which returns *true* for the required elements. The signature of this predicate should be equivalent to:

```
bool pred(const Type &a);
```

The signature does not need to have `const&`, but the function must not modify the objects passed to it. The type *Type* must be such that an object of type *FwdIter* can be dereferenced and then implicitly converted to *Type*.

- **proj** – Specifies the function (or function object) which will be invoked for each of the elements as a projection operation before the actual predicate *is* invoked.

Returns The `remove_if` algorithm returns a `subrange_t<FwdIter, Sent>`. The `remove_if` algorithm returns an object {ret, last}, where ret is a past-the-end iterator for a new subrange of the values all in valid but unspecified state.

```
template<typename Rng, typename Pred, typename Proj = hpx::identity>
subrange_t<hpx::traits::range_iterator_t<Rng>> remove_if(Rng &&rng, Pred &&pred, Proj &&proj =
    Proj())
```

Removes all elements that are equal to *value* from the range *rng* and returns a subrange [ret, util::end(rng)), where ret is a past-the-end iterator for the new end of the range.

The assignments in the parallel `remove_if` algorithm execute in sequential order in the calling thread.

Note: Complexity: Performs not more than `util::end(rng)`

- `util::begin(rng)` assignments, exactly `util::end(rng) - util::begin(rng)` applications of the operator `==()` and the projection *proj*.
-

Template Parameters

- **Rng** – The type of the source range used (deduced). The iterators extracted from this range type must meet the requirements of an forward iterator.
- **Pred** – The type of the function/function object to use (deduced). Unlike its sequential form, the parallel overload of `remove_if` requires *Pred* to meet the requirements of *CopyConstructible*.
- **Proj** – The type of an optional projection function. This defaults to `hpx::identity`

Parameters

- **rng** – Refers to the sequence of elements the algorithm will be applied to.
- **pred** – Specifies the function (or function object) which will be invoked for each of the elements in the sequence specified by [first, last). This is an unary predicate which returns *true* for the required elements. The signature of this predicate should be equivalent to:

```
bool pred(const Type &a);
```

The signature does not need to have `const&`, but the function must not modify the objects passed to it. The type *Type* must be such that an object of type *FwdIter* can be dereferenced and then implicitly converted to *Type*.

- **proj** – Specifies the function (or function object) which will be invoked for each of the elements as a projection operation before the actual predicate *is* invoked.

Returns The *remove_if* algorithm returns a *subrange_t*<*hpx::traits::range_iterator_t*<*Rng*>>. The *remove_if* algorithm returns an object {ret, last}, where ret is a past-the-end iterator for a new subrange of the values all in valid but unspecified state.

```
template<typename ExPolicy, typename FwdIter, typename Sent, typename Pred, typename Proj =
hpx::identity>
parallel::util::detail::algorithm_result<ExPolicy, subrange_t<FwdIter, Sent>>::type remove_if(ExPolicy
&&pol-
icy,
FwdIter
first,
Sent
sent,
Pred
&&pred,
Proj
&&proj
=
Proj())
```

Removes all elements for which predicate *pred* returns true from the range [first, last) and returns a subrange [ret, last), where ret is a past-the-end iterator for the new end of the range.

The assignments in the parallel *remove_if* algorithm invoked with an execution policy object of type *sequenced_policy* execute in sequential order in the calling thread.

The assignments in the parallel *remove_if* algorithm invoked with an execution policy object of type *parallel_policy* or *parallel_task_policy* are permitted to execute in an unordered fashion in unspecified threads, and indeterminately sequenced within each thread.

Note: Complexity: Performs not more than *last - first* assignments, exactly *last - first* applications of the predicate *pred* and the projection *proj*.

Template Parameters

- **ExPolicy** – The type of the execution policy to use (deduced). It describes the manner in which the execution of the algorithm may be parallelized and the manner in which it executes the assignments.
- **FwdIter** – The type of the source iterators used for the This iterator type must meet the requirements of a forward iterator.
- **Sent** – The type of the end iterators used (deduced). This sentinel type must be a sentinel for *FwdIter*.

- **Pred** – The type of the function/function object to use (deduced). Unlike its sequential form, the parallel overload of *remove_if* requires *Pred* to meet the requirements of *CopyConstructible*.
- **Proj** – The type of an optional projection function. This defaults to *hpx::identity*

Parameters

- **policy** – The execution policy to use for the scheduling of the iterations.
- **first** – Refers to the beginning of the sequence of elements the algorithm will be applied to.
- **sent** – Refers to the end of the sequence of elements the algorithm will be applied to.
- **pred** – Specifies the function (or function object) which will be invoked for each of the elements in the sequence specified by [first, last). This is a unary predicate which returns *true* for the required elements. The signature of this predicate should be equivalent to:

```
bool pred(const Type &a);
```

The signature does not need to have `const&`, but the function must not modify the objects passed to it. The type *Type* must be such that an object of type *FwdIter* can be dereferenced and then implicitly converted to *Type*.

- **proj** – Specifies the function (or function object) which will be invoked for each of the elements as a projection operation before the actual predicate *is* invoked.

Returns The *remove_if* algorithm returns a *hpx::future<subrange_t<FwdIter, Sent>>*. The *remove_if* algorithm returns an object {ret, last}, where ret is a past-the-end iterator for a new subrange of the values all in valid but unspecified state.

```
template<typename ExPolicy, typename Rng, typename Pred, typename Proj = hpx::identity>
parallel::util::detail::algorithm_result<ExPolicy, subrange_t<hpx::traits::range_iterator_t<Rng>>> remove_if(ExPolicy
&&policy,
Rng
&&rng,
Pred
&&pred,
Proj
&&proj
=
Proj())
```

Removes all elements that are equal to *value* from the range *rng* and and returns a subrange [ret, util::end(rng)), where ret is a past-the-end iterator for the new end of the range.

The assignments in the parallel *remove_if* algorithm invoked with an execution policy object of type *sequenced_policy* execute in sequential order in the calling thread.

The assignments in the parallel *remove_if* algorithm invoked with an execution policy object of type *parallel_policy* or *parallel_task_policy* are permitted to execute in an unordered fashion in unspecified threads, and indeterminately sequenced within each thread.

Note: Complexity: Performs not more than *util::end(rng)*

- *util::begin(rng)* assignments, exactly *util::end(rng) - util::begin(rng)* applications of the operator `==()` and the projection *proj*.
-

Template Parameters

- **ExPolicy** – The type of the execution policy to use (deduced). It describes the manner in which the execution of the algorithm may be parallelized and the manner in which it

executes the assignments.

- **Rng** – The type of the source range used (deduced). The iterators extracted from this range type must meet the requirements of a forward iterator.
- **Pred** – The type of the function/function object to use (deduced). Unlike its sequential form, the parallel overload of *remove_if* requires *Pred* to meet the requirements of *CopyConstructible*.
- **Proj** – The type of an optional projection function. This defaults to *hpx::identity*

Parameters

- **policy** – The execution policy to use for the scheduling of the iterations.
- **rng** – Refers to the sequence of elements the algorithm will be applied to.
- **pred** – Specifies the function (or function object) which will be invoked for each of the elements in the sequence specified by [first, last). This is a unary predicate which returns *true* for the required elements. The signature of this predicate should be equivalent to:

```
bool pred(const Type &a);
```

The signature does not need to have `const&`, but the function must not modify the objects passed to it. The type *Type* must be such that an object of type *FwdIter* can be dereferenced and then implicitly converted to *Type*.

- **proj** – Specifies the function (or function object) which will be invoked for each of the elements as a projection operation before the actual predicate *is* invoked.

Returns The *remove_if* algorithm returns a *hpx::future<subrange_t<hpx::traits::range_iterator_t<Rng>>>* if the execution policy is of type *sequenced_task_policy* or *parallel_task_policy* and returns *FwdIter* otherwise. The *remove_if* algorithm returns an object {ret, last}, where ret is a past-the-end iterator for a new subrange of the values all in valid but unspecified state.

```
template<typename Iter, typename Sent, typename Proj = hpx::identity, typename T = typename
hpx::parallel::traits::projected<Iter, Proj>::value_type>
```

```
subrange_t<Iter, Sent> remove(Iter first, Sent last, T const &value, Proj &&proj = Proj())
```

Removes all elements that are equal to *value* from the range [first, last) and returns a subrange [ret, last), where ret is a past-the-end iterator for the new end of the range.

The assignments in the parallel *remove* algorithm execute in sequential order in the calling thread.

Note: Complexity: Performs not more than *last - first* assignments, exactly *last - first* applications of the operator `==()` and the projection *proj*.

Template Parameters

- **Iter** – The type of the source iterators used for the This iterator type must meet the requirements of a forward iterator.
- **Sent** – The type of the end iterators used (deduced). This sentinel type must be a sentinel for *FwdIter*.
- **T** – The type of the value to remove (deduced). This value type must meet the requirements of *CopyConstructible*.
- **Proj** – The type of an optional projection function. This defaults to *hpx::identity*

Parameters

- **first** – Refers to the beginning of the sequence of elements the algorithm will be applied to.
- **last** – Refers to the end of the sequence of elements the algorithm will be applied to.
- **value** – Specifies the value of elements to remove.

- **proj** – Specifies the function (or function object) which will be invoked for each of the elements as a projection operation before the actual predicate *is* invoked.

Returns The *remove* algorithm returns a *subrange_t<FwdIter, Sent>*. The *remove* algorithm returns an object {ret, last}, where ret is a past-the-end iterator for a new subrange of the values all in valid but unspecified state.

```
template<typename Rng, typename Proj = hpx::identity, typename T = typename
hpx::parallel::traits::projected<hpx::traits::range_iterator_t<Rng>, Proj>::value_type>
subrange_t<hpx::traits::range_iterator_t<Rng>> remove(Rng &&rng, T const &value, Proj &&proj =
Proj())
```

Removes all elements that are equal to *value* from the range *rng* and and returns a subrange [ret, util::end(rng)), where ret is a past-the-end iterator for the new end of the range.

The assignments in the parallel *remove* algorithm execute in sequential order in the calling thread.

Note: Complexity: Performs not more than *util::end(rng)*

- *util::begin(rng)* assignments, exactly *util::end(rng) - util::begin(rng)* applications of the operator==() and the projection *proj*.
-

Template Parameters

- **Rng** – The type of the source range used (deduced). The iterators extracted from this range type must meet the requirements of an forward iterator.
- **T** – The type of the value to remove (deduced). This value type must meet the requirements of *CopyConstructible*.
- **Proj** – The type of an optional projection function. This defaults to *hpx::identity*

Parameters

- **rng** – Refers to the sequence of elements the algorithm will be applied to.
- **value** – Specifies the value of elements to remove.
- **proj** – Specifies the function (or function object) which will be invoked for each of the elements as a projection operation before the actual predicate *is* invoked.

Returns The *remove* algorithm returns a *subrange_t<hpx::traits::range_iterator_t<Rng>>*. The *remove* algorithm returns an object {ret, last}, where ret is a past-the-end iterator for a new subrange of the values all in valid but unspecified state.

```
template<typename ExPolicy, typename FwdIter, typename Sent, typename Proj = hpx::identity,
typename T = typename hpx::parallel::traits::projected<FwdIter, Proj>::value_type>
parallel::util::detail::algorithm_result<ExPolicy, subrange_t<FwdIter, Sent>>::type remove(ExPolicy
&&policy,
FwdIter
first, Sent
last, T
const
&value,
Proj
&&proj =
Proj())
```

Removes all elements that are equal to *value* from the range [first, last) and and returns a subrange [ret, last), where ret is a past-the-end iterator for the new end of the range.

The assignments in the parallel *remove* algorithm invoked with an execution policy object of type *sequenced_policy* execute in sequential order in the calling thread.

The assignments in the parallel *remove* algorithm invoked with an execution policy object of type *parallel_policy* or *parallel_task_policy* are permitted to execute in an unordered fashion in unspecified threads, and indeterminately sequenced within each thread.

Note: Complexity: Performs not more than *last - first* assignments, exactly *last - first* applications of the operator `==()` and the projection *proj*.

Template Parameters

- **ExPolicy** – The type of the execution policy to use (deduced). It describes the manner in which the execution of the algorithm may be parallelized and the manner in which it executes the assignments.
- **FwdIter** – The type of the source iterators used for the This iterator type must meet the requirements of a forward iterator.
- **Sent** – The type of the end iterators used (deduced). This sentinel type must be a sentinel for FwdIter.
- **T** – The type of the value to remove (deduced). This value type must meet the requirements of *CopyConstructible*.
- **Proj** – The type of an optional projection function. This defaults to *hpx::identity*

Parameters

- **policy** – The execution policy to use for the scheduling of the iterations.
- **first** – Refers to the beginning of the sequence of elements the algorithm will be applied to.
- **last** – Refers to the end of the sequence of elements the algorithm will be applied to.
- **value** – Specifies the value of elements to remove.
- **proj** – Specifies the function (or function object) which will be invoked for each of the elements as a projection operation before the actual predicate *is* invoked.

Returns The *remove* algorithm returns a *hpx::future<subrange_t<FwdIter, Sent>>*. The *remove* algorithm returns an object {ret, last}, where ret is a past-the-end iterator for a new subrange of the values all in valid but unspecified state.

```
template<typename ExPolicy, typename Rng, typename Proj = hpx::identity, typename T = typename
hpx::parallel::traits::projected<hpx::traits::range_iterator_t<Rng>, Proj>::value_type>
parallel::util::detail::algorithm_result<ExPolicy, subrange_t<hpx::traits::range_iterator_t<Rng>>> remove(ExPolicy
&&pol-
icy,
Rng
&&rng,
T
const
&value,
Proj
&&proj
=
Proj())
```

Removes all elements that are equal to *value* from the range *rng* and and returns a subrange [ret, *util::end*(*rng*)), where ret is a past-the-end iterator for the new end of the range.

The assignments in the parallel *remove* algorithm invoked with an execution policy object of type *sequenced_policy* execute in sequential order in the calling thread.

The assignments in the parallel *remove* algorithm invoked with an execution policy object of type *parallel_policy* or *parallel_task_policy* are permitted to execute in an unordered fashion in unspecified threads, and indeterminately sequenced within each thread.

Note: Complexity: Performs not more than `util::end(rng)`

- `util::begin(rng)` assignments, exactly `util::end(rng) - util::begin(rng)` applications of the operator `==()` and the projection `proj`.
-

Template Parameters

- **ExPolicy** – The type of the execution policy to use (deduced). It describes the manner in which the execution of the algorithm may be parallelized and the manner in which it executes the assignments.
- **Rng** – The type of the source range used (deduced). The iterators extracted from this range type must meet the requirements of a forward iterator.
- **T** – The type of the value to remove (deduced). This value type must meet the requirements of `CopyConstructible`.
- **Proj** – The type of an optional projection function. This defaults to `hpx::identity`

Parameters

- **policy** – The execution policy to use for the scheduling of the iterations.
- **rng** – Refers to the sequence of elements the algorithm will be applied to.
- **value** – Specifies the value of elements to remove.
- **proj** – Specifies the function (or function object) which will be invoked for each of the elements as a projection operation before the actual predicate `is` is invoked.

Returns The `remove` algorithm returns a `hpx::future<sub-range_t<hpx::traits::range_iterator_t<Rng>>>` if the execution policy is of type `sequenced_task_policy` or `parallel_task_policy` and returns `FwdIter` otherwise. The `remove` algorithm returns the iterator to the new end of the range.

`hpx::ranges::remove_copy`, `hpx::ranges::remove_copy_if`

Defined in header `hpx/algorithm.hpp`⁶⁶⁷.

See *Public API* for a list of names and headers that are part of the public HPX API.

```
namespace hpx
```

```
    namespace ranges
```

```
        hpx::ranges::replace,           hpx::ranges::replace_if,           hpx::ranges::replace_copy,
        hpx::ranges::replace_copy_if
```

Defined in header `hpx/algorithm.hpp`⁶⁶⁸.

See *Public API* for a list of names and headers that are part of the public HPX API.

```
namespace hpx
```

```
    namespace ranges
```

⁶⁶⁷ <http://github.com/STELLAR-GROUP/hpx/blob/8a3b7c1a4cb5693b2f7d9f587f759392ed0c51a0/libs/full/include/include/hpx/algorithm.hpp>

⁶⁶⁸ <http://github.com/STELLAR-GROUP/hpx/blob/8a3b7c1a4cb5693b2f7d9f587f759392ed0c51a0/libs/full/include/include/hpx/algorithm.hpp>

Functions

```
template<typename Iter, typename Sent, typename Pred, typename Proj = hpx::identity, typename T
= typename hpx::parallel::traits::projected<Iter, Proj>::value_type>
```

```
Iter replace_if(Iter first, Sent sent, Pred &&pred, T const &new_value, Proj &&proj = Proj())
```

Replaces all elements satisfying specific criteria (for which predicate *f* returns true) with *new_value* in the range [first, sent).

Effects: Substitutes elements referred by the iterator *it* in the range [first, sent) with *new_value*, when the following corresponding conditions hold: `INVOKE(f, INVOKE(proj, *it)) != false`

The assignments in the parallel *replace_if* algorithm execute in sequential order in the calling thread.

Note: Complexity: Performs exactly *sent - first* applications of the predicate.

Template Parameters

- **Iter** – The type of the source iterator used (deduced). The iterator type must meet the requirements of a forward iterator.
- **Sent** – The type of the end iterators used (deduced). This sentinel type must be a sentinel for *Iter*.
- **Pred** – The type of the function/function object to use (deduced). Unlike its sequential form, the parallel overload of *equal* requires *F* to meet the requirements of *CopyConstructible*. (deduced).
- **T** – The type of the new values to replace (deduced).
- **Proj** – The type of an optional projection function. This defaults to *hpx::identity*

Parameters

- **first** – Refers to the beginning of the sequence of elements the algorithm will be applied to.
- **sent** – Refers to the end of the sequence of elements the algorithm will be applied to.
- **pred** – Specifies the function (or function object) which will be invoked for each of the elements in the sequence specified by [first, last). This is a unary predicate which returns *true* for the elements which need to be replaced. The signature of this predicate should be equivalent to:

```
bool pred(const Type &a);
```

The signature does not need to have `const&`, but the function must not modify the objects passed to it. The type *Type* must be such that an object of type *Iter* can be dereferenced and then implicitly converted to *Type*.

- **new_value** – Refers to the new value to use as the replacement.
- **proj** – Specifies the function (or function object) which will be invoked for each of the elements as a projection operation before the actual predicate *is* invoked.

Returns The *replace_if* algorithm returns *Iter*. It returns *last*.

```
template<typename Rng, typename Pred, typename Proj = hpx::identity, typename T = typename
hpx::parallel::traits::projected<hpx::traits::range_iterator_t<Rng>, Proj>::value_type>
hpx::traits::range_iterator_t<Rng> replace_if(Rng &&rng, Pred &&pred, T const &new_value, Proj
&&proj = Proj())
```

Replaces all elements satisfying specific criteria (for which predicate *pred* returns true) with *new_value* in the range *rng*.

Effects: Substitutes elements referred by the iterator *it* in the range *rng* with *new_value*, when the following corresponding conditions hold: `INVOKE(f, INVOKE(proj, *it)) != false`

Note: Complexity: Performs exactly `util::end(rng) - util::begin(rng)` applications of the predicate.

Template Parameters

- **Rng** – The type of the source range used (deduced). The iterators extracted from this range type must meet the requirements of a forward iterator.
- **Pred** – The type of the function/function object to use (deduced). Unlike its sequential form, the parallel overload of *equal* requires *F* to meet the requirements of *CopyConstructible*. (deduced).
- **T** – The type of the new values to replace (deduced).
- **Proj** – The type of an optional projection function. This defaults to `hpx::identity`

Parameters

- **rng** – Refers to the sequence of elements the algorithm will be applied to.
- **pred** – Specifies the function (or function object) which will be invoked for each of the elements in the sequence specified by *rng*. This is a unary predicate which returns *true* for the elements which need to be replaced. The signature of this predicate should be equivalent to:

```
bool pred(const Type &a);
```

The signature does not need to have `const&`, but the function must not modify the objects passed to it. The type *Type* must be such that an object of type *FwdIter* can be dereferenced and then implicitly converted to *Type*.

- **new_value** – Refers to the new value to use as the replacement.
- **proj** – Specifies the function (or function object) which will be invoked for each of the elements as a projection operation before the actual predicate *is* invoked.

Returns The *replace_if* algorithm returns an `hpx::traits::range_iterator<Rng>::type`. It returns *last*.

```
template<typename ExPolicy, typename Iter, typename Sent, typename Pred, typename Proj =
hpx::identity, typename T = typename hpx::parallel::traits::projected<Iter, Proj>::value_type>
hpx::parallel::util::detail::algorithm_result_t<ExPolicy, Iter> replace_if(ExPolicy &&policy, Iter
first, Sent sent, Pred
&&pred, T const
&new_value, Proj &&proj =
Proj())
```

Replaces all elements satisfying specific criteria (for which predicate *pred* returns true) with *new_value* in the range *rng*.

Effects: Substitutes elements referred by the iterator *it* in the range *rng* with *new_value*, when the following corresponding conditions hold: `INVOKE(f, INVOKE(proj, *it)) != false`

The assignments in the parallel *replace_if* algorithm invoked with an execution policy object of type *sequenced_policy* execute in sequential order in the calling thread.

The assignments in the parallel *replace_if* algorithm invoked with an execution policy object of type *parallel_policy* or *parallel_task_policy* are permitted to execute in an unordered fashion in unspecified threads, and indeterminately sequenced within each thread.

Note: Complexity: Performs exactly *util::end(rng) - util::begin(rng)* applications of the predicate.

Template Parameters

- **ExPolicy** – The type of the execution policy to use (deduced). It describes the manner in which the execution of the algorithm may be parallelized and the manner in which it executes the assignments.
- **Iter** – The type of the source iterator used (deduced). The iterator type must meet the requirements of a forward iterator.
- **Sent** – The type of the end iterators used (deduced). This sentinel type must be a sentinel for *Iter*.
- **Pred** – The type of the function/function object to use (deduced). Unlike its sequential form, the parallel overload of *equal* requires *Pred* to meet the requirements of *CopyConstructible*. (deduced).
- **T** – The type of the new values to replace (deduced).
- **Proj** – The type of an optional projection function. This defaults to *hpx::identity*

Parameters

- **policy** – The execution policy to use for the scheduling of the iterations.
- **first** – Refers to the beginning of the sequence of elements the algorithm will be applied to.
- **sent** – Refers to the end of the sequence of elements the algorithm will be applied to.
- **pred** – Specifies the function (or function object) which will be invoked for each of the elements in the sequence specified by [first, last). This is a unary predicate which returns *true* for the elements which need to be replaced. The signature of this predicate should be equivalent to:

```
bool pred(const Type &a);
```

The signature does not need to have `const&`, but the function must not modify the objects passed to it. The type *Type* must be such that an object of type *FwdIter* can be dereferenced and then implicitly converted to *Type*.

- **new_value** – Refers to the new value to use as the replacement.
- **proj** – Specifies the function (or function object) which will be invoked for each of the elements as a projection operation before the actual predicate *is* invoked.

Returns The *replace_if* algorithm returns a *hpx::future<Iter>* if the execution policy is of type *sequenced_task_policy* or *parallel_task_policy*. It returns *last*.

```
template<typename ExPolicy, typename Rng, typename Pred, typename Proj = hpx::identity, typename
T = typename hpx::parallel::traits::projected<hpx::traits::range_iterator_t<Rng>, Proj>::value_type>
parallel::util::detail::algorithm_result<ExPolicy, hpx::traits::range_iterator_t<Rng>> replace_if(ExPolicy
&&policy,
Rng
&&rng,
Pred
&&pred,
T
const
&new_value,
Proj
&&proj
=
Proj())
```

Replaces all elements satisfying specific criteria (for which predicate *pred* returns true) with *new_value*

in the range `rng`.

Effects: Substitutes elements referred by the iterator `it` in the range `rng` with `new_value`, when the following corresponding conditions hold: `INVOKE(f, INVOKE(proj, *it)) != false`

The assignments in the parallel *replace* algorithm invoked with an execution policy object of type *sequenced_policy* execute in sequential order in the calling thread.

The assignments in the parallel *replace* algorithm invoked with an execution policy object of type *parallel_policy* or *parallel_task_policy* are permitted to execute in an unordered fashion in unspecified threads, and indeterminately sequenced within each thread.

Note: Complexity: Performs exactly `util::end(rng) - util::begin(rng)` applications of the predicate.

Template Parameters

- **ExPolicy** – The type of the execution policy to use (deduced). It describes the manner in which the execution of the algorithm may be parallelized and the manner in which it executes the assignments.
- **Rng** – The type of the source range used (deduced). The iterators extracted from this range type must meet the requirements of a forward iterator.
- **Pred** – The type of the function/function object to use (deduced). Unlike its sequential form, the parallel overload of *equal* requires *F* to meet the requirements of *CopyConstructible*. (deduced).
- **T** – The type of the new values to replace (deduced).
- **Proj** – The type of an optional projection function. This defaults to `hpx::identity`

Parameters

- **policy** – The execution policy to use for the scheduling of the iterations.
- **rng** – Refers to the sequence of elements the algorithm will be applied to.
- **pred** – Specifies the function (or function object) which will be invoked for each of the elements in the sequence specified by `rng`. This is a unary predicate which returns *true* for the elements which need to be replaced. The signature of this predicate should be equivalent to:

```
bool pred(const Type &a);
```

The signature does not need to have `const&`, but the function must not modify the objects passed to it. The type *Type* must be such that an object of type *FwdIter* can be dereferenced and then implicitly converted to *Type*.

- **new_value** – Refers to the new value to use as the replacement.
- **proj** – Specifies the function (or function object) which will be invoked for each of the elements as a projection operation before the actual predicate *is* invoked.

Returns The *replace_if* algorithm returns a `hpx::future<hpx::traits::range_iterator_t<Rng>>` if the execution policy is of type *sequenced_task_policy* or *parallel_task_policy*. It returns *last*.

```
template<typename Iter, typename Sent, typename Proj = hpx::identity, typename T1 = typename
hpx::parallel::traits::projected<Iter, Proj>::value_type, typename T2 = T1>
Iter replace(Iter first, Sent sent, T1 const &old_value, T2 const &new_value, Proj &&proj = Proj())
    Replaces all elements satisfying specific criteria with new_value in the range [first, last).
```

Effects: Substitutes elements referred by the iterator *it* in the range `[first,last)` with `new_value`, when the following corresponding conditions hold: `INVOKE(proj, *i) == old_value`

The assignments in the parallel *replace* algorithm execute in sequential order in the calling thread.

Note: Complexity: Performs exactly *last - first* assignments.

Template Parameters

- **Iter** – The type of the source iterator used (deduced). The iterator type must meet the requirements of an input iterator.
- **Sent** – The type of the end iterators used (deduced). This sentinel type must be a sentinel for *Iter*.
- **T1** – The type of the old value to replace (deduced).
- **T2** – The type of the new values to replace (deduced).
- **Proj** – The type of an optional projection function. This defaults to `hpx::identity`

Parameters

- **first** – Refers to the beginning of the sequence of elements the algorithm will be applied to.
- **sent** – Refers to the end of the sequence of elements the algorithm will be applied to.
- **old_value** – Refers to the old value of the elements to replace.
- **new_value** – Refers to the new value to use as the replacement.
- **proj** – Specifies the function (or function object) which will be invoked for each of the elements as a projection operation before the actual predicate *is* invoked.

Returns The *replace* algorithm returns an *Iter*.

```
template<typename Rng, typename Proj = hpx::identity, typename T1 = typename
hpx::parallel::traits::projected<hpx::traits::range_iterator_t<Rng>, Proj>::value_type, typename T2 =
T1>
hpx::traits::range_iterator_t<Rng> replace(Rng &&rng, T1 const &old_value, T2 const &new_value,
Proj &&proj = Proj())
```

Replaces all elements satisfying specific criteria with *new_value* in the range *rng*.

Effects: Substitutes elements referred by the iterator *it* in the range *rng* with `new_value`, when the following corresponding conditions hold: `INVOKE(proj, *i) == old_value`

The assignments in the parallel *replace* algorithm execute in sequential order in the calling thread.

Note: Complexity: Performs exactly `util::end(rng) - util::begin(rng)` assignments.

Template Parameters

- **Rng** – The type of the source range used (deduced). The iterators extracted from this range type must meet the requirements of a forward iterator.
- **T1** – The type of the old value to replace (deduced).
- **T2** – The type of the new values to replace (deduced).
- **Proj** – The type of an optional projection function. This defaults to `hpx::identity`

Parameters

- **rng** – Refers to the sequence of elements the algorithm will be applied to.
- **old_value** – Refers to the old value of the elements to replace.
- **new_value** – Refers to the new value to use as the replacement.

- **proj** – Specifies the function (or function object) which will be invoked for each of the elements as a projection operation before the actual predicate *is* invoked.

Returns The *replace* algorithm returns an `hpx::traits::range_iterator<Rng>::type`.

```
template<typename ExPolicy, typename Iter, typename Sent, typename Proj = hpx::identity,
typename T1 = typename hpx::parallel::traits::projected<Iter, Proj>::value_type, typename T2 = T1>
hpx::parallel::util::detail::algorithm_result_t<ExPolicy, Iter> replace(ExPolicy &&policy, Iter first,
                               Sent sent, T1 const &old_value,
                               T2 const &new_value, Proj
                               &&proj = Proj())
```

Replaces all elements satisfying specific criteria with *new_value* in the range [first, last).

Effects: Substitutes elements referred by the iterator *it* in the range [first,last) with *new_value*, when the following corresponding conditions hold: `INVOKE(proj, *i) == old_value`

The assignments in the parallel *replace* algorithm invoked with an execution policy object of type *sequenced_policy* execute in sequential order in the calling thread.

The assignments in the parallel *replace* algorithm invoked with an execution policy object of type *parallel_policy* or *parallel_task_policy* are permitted to execute in an unordered fashion in unspecified threads, and indeterminately sequenced within each thread.

Note: Complexity: Performs exactly *last - first* assignments.

Template Parameters

- **ExPolicy** – The type of the execution policy to use (deduced). It describes the manner in which the execution of the algorithm may be parallelized and the manner in which it executes the assignments.
- **Iter** – The type of the source iterator used (deduced). The iterator type must meet the requirements of a forward iterator.
- **Sent** – The type of the end iterators used (deduced). This sentinel type must be a sentinel for *Iter*.
- **T1** – The type of the old value to replace (deduced).
- **T2** – The type of the new values to replace (deduced).
- **Proj** – The type of an optional projection function. This defaults to `hpx::identity`

Parameters

- **policy** – The execution policy to use for the scheduling of the iterations.
- **first** – Refers to the beginning of the sequence of elements the algorithm will be applied to.
- **sent** – Refers to the end of the sequence of elements the algorithm will be applied to.
- **old_value** – Refers to the old value of the elements to replace.
- **new_value** – Refers to the new value to use as the replacement.
- **proj** – Specifies the function (or function object) which will be invoked for each of the elements as a projection operation before the actual predicate *is* invoked.

Returns The *replace* algorithm returns a `hpx::future<Iter>` if the execution policy is of type *sequenced_task_policy* or *parallel_task_policy* and returns *Iter* otherwise.

```
template<typename ExPolicy, typename Rng, typename Proj = hpx::identity, typename T1 = typename
hpx::parallel::traits::projected<hpx::traits::range_iterator_t<Rng>, Proj>::value_type, typename T2 =
T1>
```

```

parallel::util::detail::algorithm_result<ExPolicy, hpx::traits::range_iterator_t<Rng>> replace(ExPolicy
                                                                                               &&pol-
                                                                                               icy, Rng
                                                                                               &&rng,
                                                                                               T1 const
                                                                                               &old_value,
                                                                                               T2 const
                                                                                               &new_value,
                                                                                               Proj
                                                                                               &&proj
                                                                                               = Proj())

```

Replaces all elements satisfying specific criteria with *new_value* in the range *rng*.

Effects: Substitutes elements referred by the iterator *it* in the range *rng* with *new_value*, when the following corresponding conditions hold: `INVOKE(proj, *i) == old_value`

The assignments in the parallel *replace* algorithm invoked with an execution policy object of type *parallel_policy* or *parallel_task_policy* are permitted to execute in an unordered fashion in unspecified threads, and indeterminately sequenced within each thread.

Note: Complexity: Performs exactly `util::end(rng) - util::begin(rng)` assignments.

Template Parameters

- **ExPolicy** – The type of the execution policy to use (deduced). It describes the manner in which the execution of the algorithm may be parallelized and the manner in which it executes the assignments.
- **Rng** – The type of the source range used (deduced). The iterators extracted from this range type must meet the requirements of a forward iterator.
- **T1** – The type of the old value to replace (deduced).
- **T2** – The type of the new values to replace (deduced).
- **Proj** – The type of an optional projection function. This defaults to `hpx::identity`

Parameters

- **policy** – The execution policy to use for the scheduling of the iterations.
- **rng** – Refers to the sequence of elements the algorithm will be applied to.
- **old_value** – Refers to the old value of the elements to replace.
- **new_value** – Refers to the new value to use as the replacement.
- **proj** – Specifies the function (or function object) which will be invoked for each of the elements as a projection operation before the actual predicate *is* invoked. The assignments in the parallel *replace* algorithm invoked with an execution policy object of type *sequenced_policy* execute in sequential order in the calling thread.

Returns The *replace* algorithm returns an `hpx::future<hpx::traits::range_iterator<Rng>::type>` if the execution policy is of type *sequenced_task_policy* or *parallel_task_policy* and returns `hpx::traits::range_iterator<Rng>::type` otherwise.

```

template<typename InIter, typename Sent, typename OutIter, typename Pred, typename T =
typename std::iterator_traits<OutIter>::value_type, typename Proj = hpx::identity>
replace_copy_if_result<InIter, OutIter> replace_copy_if(InIter first, Sent sent, OutIter dest, Pred
                                                       &&pred, T const &new_value, Proj
                                                       &&proj = Proj())

```

Copies the all elements from the range [first, sent) to another range beginning at *dest* replacing all elements satisfying a specific criteria with *new_value*.

Effects: Assigns to every iterator *it* in the range $[result, result + (sent - first))$ either *new_value* or $*(first + (it - result))$ depending on whether the following corresponding condition holds: `INVOKE(f, INVOKE(proj, *(first + (i - result)))) != false`

The assignments in the parallel *replace_copy_if* algorithm execute in sequential order in the calling thread.

Note: Complexity: Performs exactly *sent - first* applications of the predicate.

Template Parameters

- **InIter** – The type of the source iterator used (deduced). The iterator type must meet the requirements of an input iterator.
- **Sent** – The type of the end iterators used (deduced). This sentinel type must be a sentinel for *InIter*.
- **OutIter** – The type of the iterator representing the destination range (deduced). This iterator type must meet the requirements of an output iterator.
- **Pred** – The type of the function/function object to use (deduced). Unlike its sequential form, the parallel overload of *equal* requires *Pred* to meet the requirements of *CopyConstructible*. (deduced).
- **T** – The type of the new values to replace (deduced).
- **Proj** – The type of an optional projection function. This defaults to `hpx::identity`

Parameters

- **first** – Refers to the beginning of the sequence of elements the algorithm will be applied to.
- **sent** – Refers to the end of the sequence of elements the algorithm will be applied to.
- **dest** – Refers to the beginning of the destination range.
- **pred** – Specifies the function (or function object) which will be invoked for each of the elements in the sequence specified by $[first, last)$. This is a unary predicate which returns *true* for the elements which need to be replaced. The signature of this predicate should be equivalent to:

```
bool pred(const Type &a);
```

The signature does not need to have `const&`, but the function must not modify the objects passed to it. The type *Type* must be such that an object of type *FwdIter* can be dereferenced and then implicitly converted to *Type*.

- **new_value** – Refers to the new value to use as the replacement.
- **proj** – Specifies the function (or function object) which will be invoked for each of the elements as a projection operation before the actual predicate *is* invoked.

Returns The *replace_copy_if* algorithm returns a `in_out_result<InIter, OutIter>`. The *replace_copy_if* algorithm returns the input iterator *last* and the output iterator to the element in the destination range, one past the last element copied.

```
template<typename Rng, typename OutIter, typename Pred, typename T = typename
std::iterator_traits<OutIter>::value_type, typename Proj = hpx::identity>
replace_copy_if_result<hpx::traits::range_iterator_t<Rng>, OutIter> replace_copy_if(Rng &&rng,
OutIter dest,
Pred &&pred,
T const
&new_value,
Proj &&proj =
Proj())
```

Copies the all elements from the range `rng` to another range beginning at `dest` replacing all elements satisfying a specific criteria with `new_value`.

Effects: Assigns to every iterator `it` in the range `[result, result + (util::end(rng) - util::begin(rng))]` either `new_value` or `*(first + (it - result))` depending on whether the following corresponding condition holds: `INVOKE(f, INVOKE(proj, *(first + (i - result)))) != false`

The assignments in the parallel `replace_copy_if` algorithm execute in sequential order in the calling thread.

Note: Complexity: Performs exactly `util::end(rng) - util::begin(rng)` applications of the predicate.

Template Parameters

- **Rng** – The type of the source range used (deduced). The iterators extracted from this range type must meet the requirements of an input iterator.
- **OutIter** – The type of the iterator representing the destination range (deduced). This iterator type must meet the requirements of an output iterator.
- **Pred** – The type of the function/function object to use (deduced). Unlike its sequential form, the parallel overload of `equal` requires `Pred` to meet the requirements of `CopyConstructible`. (deduced).
- **T** – The type of the new values to replace (deduced).
- **Proj** – The type of an optional projection function. This defaults to `hpx::identity`

Parameters

- **rng** – Refers to the sequence of elements the algorithm will be applied to.
- **dest** – Refers to the beginning of the destination range.
- **pred** – Specifies the function (or function object) which will be invoked for each of the elements in the sequence specified by `[first, last)`. This is a unary predicate which returns `true` for the elements which need to be replaced. The signature of this predicate should be equivalent to:

```
bool pred(const Type &a);
```

The signature does not need to have `const&`, but the function must not modify the objects passed to it. The type `Type` must be such that an object of type `FwdIter` can be dereferenced and then implicitly converted to `Type`.

- **new_value** – Refers to the new value to use as the replacement.
- **proj** – Specifies the function (or function object) which will be invoked for each of the elements as a projection operation before the actual predicate `is` invoked.

Returns The `replace_copy_if` algorithm returns an `in_out_result<hpx::traits::range_iterator_t<Rng>, OutIter>`. The `replace_copy_if` algorithm returns the input iterator `last` and the output iterator to the element in the destination range, one past the last element copied.

```
template<typename ExPolicy, typename FwdIter1, typename Sent, typename FwdIter2, typename Pred,
typename T = typename std::iterator_traits<FwdIter2>::value_type, typename Proj = hpx::identity>
```

`parallel::util::detail::algorithm_result<ExPolicy, replace_copy_if_result<FwdIter1, FwdIter2>>::type` **replace_copy_if**(

Copies the all elements from the range [first, sent) to another range beginning at *dest* replacing all elements satisfying a specific criteria with *new_value*.

Effects: Assigns to every iterator it in the range [result, result + (sent - first)) either *new_value* or $*(first + (it - result))$ depending on whether the following corresponding condition holds: `INVOKE(f, INVOKE(proj, *(first + (i - result)))) != false`

The assignments in the parallel *replace_copy_if* algorithm invoked with an execution policy object of type *sequenced_policy* execute in sequential order in the calling thread.

The assignments in the parallel *replace_copy_if* algorithm invoked with an execution policy object of type *parallel_policy* or *parallel_task_policy* are permitted to execute in an unordered fashion in unspecified threads, and indeterminately sequenced within each thread.

Note: Complexity: Performs exactly *sent - first* applications of the predicate.

Template Parameters

- **ExPolicy** – The type of the execution policy to use (deduced). It describes the manner in which the execution of the algorithm may be parallelized and the manner in which it executes the assignments.
- **FwdIter1** – The type of the source iterator used (deduced). The iterator type must meet the requirements of a forward iterator.
- **Sent** – The type of the end iterators used (deduced). This sentinel type must be a sentinel for `InIter`.
- **FwdIter2** – The type of the iterator representing the destination range (deduced). This iterator type must meet the requirements of an forward iterator.
- **Pred** – The type of the function/function object to use (deduced). Unlike its sequential form, the parallel overload of *equal* requires *Pred* to meet the requirements of *CopyConstructible*. (deduced).
- **T** – The type of the new values to replace (deduced).
- **Proj** – The type of an optional projection function. This defaults to `hpx::identity`

Parameters

- **policy** – The execution policy to use for the scheduling of the iterations.
- **first** – Refers to the beginning of the sequence of elements the algorithm will be applied to.

- **sent** – Refers to the end of the sequence of elements the algorithm will be applied to.
- **dest** – Refers to the beginning of the destination range.
- **pred** – Specifies the function (or function object) which will be invoked for each of the elements in the sequence specified by [first, last). This is a unary predicate which returns *true* for the elements which need to be replaced. The signature of this predicate should be equivalent to:

```
bool pred(const Type &a);
```

The signature does not need to have `const&`, but the function must not modify the objects passed to it. The type *Type* must be such that an object of type *FwdIter* can be dereferenced and then implicitly converted to *Type*.

- **new_value** – Refers to the new value to use as the replacement.
- **proj** – Specifies the function (or function object) which will be invoked for each of the elements as a projection operation before the actual predicate *is* invoked.

Returns The *replace_copy_if* algorithm returns an `hpx::future<FwdIter1, FwdIter2>`. The *replace_copy_if* algorithm returns the input iterator *last* and the output iterator to the element in the destination range, one past the last element copied.

```
template<typename ExPolicy, typename Rng, typename FwdIter, typename Pred, typename T =
typename std::iterator_traits<FwdIter>::value_type, typename Proj = hpx::identity>
parallel::util::detail::algorithm_result<ExPolicy, replace_copy_if_result<hpx::traits::range_iterator_t<Rng>, FwdIter>>::ty
```

Copies all elements from the range *rng* to another range beginning at *dest* replacing all elements satisfying a specific criteria with *new_value*.

Effects: Assigns to every iterator *it* in the range [*result*, *result* + (*util::end(rng)* - *util::begin(rng)*)) either *new_value* or **(first + (it - result))* depending on whether the following corresponding condition holds: `INVOKE(f, INVOKE(proj, *(first + (i - result)))) != false`

The assignments in the parallel *replace_copy_if* algorithm invoked with an execution policy object of type *sequenced_policy* execute in sequential order in the calling thread.

The assignments in the parallel *replace_copy_if* algorithm invoked with an execution policy object of type *parallel_policy* or *parallel_task_policy* are permitted to execute in an unordered fashion in unspecified threads, and indeterminately sequenced within each thread.

Note: Complexity: Performs exactly `util::end(rng) - util::begin(rng)` applications of the predicate.

Template Parameters

- **ExPolicy** – The type of the execution policy to use (deduced). It describes the manner in which the execution of the algorithm may be parallelized and the manner in which it executes the assignments.
- **Rng** – The type of the source range used (deduced). The iterators extracted from this range type must meet the requirements of an input iterator.
- **FwdIter** – The type of the iterator representing the destination range (deduced). This iterator type must meet the requirements of an forward iterator.
- **Pred** – The type of the function/function object to use (deduced). Unlike its sequential form, the parallel overload of *equal* requires *Pred* to meet the requirements of *CopyConstructible*. (deduced).
- **T** – The type of the new values to replace (deduced).
- **Proj** – The type of an optional projection function. This defaults to *hpx::identity*

Parameters

- **policy** – The execution policy to use for the scheduling of the iterations.
- **rng** – Refers to the sequence of elements the algorithm will be applied to.
- **dest** – Refers to the beginning of the destination range.
- **pred** – Specifies the function (or function object) which will be invoked for each of the elements in the sequence specified by [first, last). This is a unary predicate which returns *true* for the elements which need to be replaced. The signature of this predicate should be equivalent to:

```
bool pred(const Type &a);
```

The signature does not need to have `const&`, but the function must not modify the objects passed to it. The type *Type* must be such that an object of type *FwdIter* can be dereferenced and then implicitly converted to *Type*.

- **new_value** – Refers to the new value to use as the replacement.
- **proj** – Specifies the function (or function object) which will be invoked for each of the elements as a projection operation before the actual predicate *is* invoked.

Returns The *replace_copy_if* algorithm returns an *hpx::future<in_out_result<hpx::traits::range_iterator_1<Rng> OutIter>>*. The *replace_copy_if* algorithm returns the input iterator *last* and the output iterator to the element in the destination range, one past the last element copied.

```
template<typename InIter, typename Sent, typename OutIter, typename Proj = hpx::identity,
typename T1 = typename hpx::parallel::traits::projected<InIter, Proj>::value_type, typename T2 = T1>
replace_copy_result<InIter, OutIter> replace_copy(InIter first, Sent sent, OutIter dest, T1 const
&old_value, T2 const &new_value, Proj &&proj
= Proj())
```

Copies the all elements from the range [first, sent) to another range beginning at *dest* replacing all elements satisfying a specific criteria with *new_value*.

Effects: Assigns to every iterator *it* in the range [result, result + (sent - first)) either *new_value* or **(first + (it - result))* depending on whether the following corresponding condition holds: `INVOKE(proj, *(first + (i - result))) == old_value`

The assignments in the parallel *replace_copy* algorithm execute in sequential order in the calling thread.

Note: Complexity: Performs exactly *sent - first* applications of the predicate.

Template Parameters

- **InIter** – The type of the source iterator used (deduced). The iterator type must meet the requirements of an input iterator.
- **Sent** – The type of the end iterators used (deduced). This sentinel type must be a sentinel for Iter.
- **OutIter** – The type of the iterator representing the destination range (deduced). This iterator type must meet the requirements of an output iterator.
- **T1** – The type of the old value to replace (deduced).
- **T2** – The type of the new values to replace (deduced).
- **Proj** – The type of an optional projection function. This defaults to `hpx::identity`

Parameters

- **first** – Refers to the beginning of the sequence of elements the algorithm will be applied to.
- **sent** – Refers to the end of the sequence of elements the algorithm will be applied to.
- **dest** – Refers to the beginning of the destination range.
- **old_value** – Refers to the old value of the elements to replace.
- **new_value** – Refers to the new value to use as the replacement.
- **proj** – Specifies the function (or function object) which will be invoked for each of the elements as a projection operation before the actual predicate *is* invoked.

Returns The `replace_copy` algorithm returns an `in_out_result<InIter, OutIter>`. The `copy` algorithm returns the pair of the input iterator `last` and the output iterator to the element in the destination range, one past the last element copied.

```
template<typename Rng, typename OutIter, typename Proj = hpx::identity, typename T1 = typename
hpx::parallel::traits::projected<hpx::traits::range_iterator_t<Rng>, Proj>::value_type, typename T2 =
T1>
```

```
replace_copy_result<hpx::traits::range_iterator_t<Rng>, OutIter> replace_copy(Rng &&rng, OutIter
dest, T1 const
&old_value, T2 const
&new_value, Proj
&&proj = Proj())
```

Copies the all elements from the range `rbg` to another range beginning at `dest` replacing all elements satisfying a specific criteria with `new_value`.

Effects: Assigns to every iterator `it` in the range `[result, result + (util::end(rng) - util::begin(rng))]` either `new_value` or `*(first + (it - result))` depending on whether the following corresponding condition holds: `INVOKE(proj, *(first + (i - result))) == old_value`

The assignments in the parallel `replace_copy` algorithm execute in sequential order in the calling thread.

Note: Complexity: Performs exactly `util::end(rng) - util::begin(rng)` applications of the predicate.

Template Parameters

- **Rng** – The type of the source range used (deduced). The iterators extracted from this range type must meet the requirements of an input iterator.
- **OutIter** – The type of the iterator representing the destination range (deduced). This iterator type must meet the requirements of an output iterator.
- **T1** – The type of the old value to replace (deduced).
- **T2** – The type of the new values to replace (deduced).
- **Proj** – The type of an optional projection function. This defaults to `hpx::identity`

Parameters

- **rng** – Refers to the sequence of elements the algorithm will be applied to.
- **dest** – Refers to the beginning of the destination range.

- **old_value** – Refers to the old value of the elements to replace.
- **new_value** – Refers to the new value to use as the replacement.
- **proj** – Specifies the function (or function object) which will be invoked for each of the elements as a projection operation before the actual predicate *is* invoked.

Returns The *replace_copy* algorithm returns an *in_out_result*<*hpx::traits::range_iterator_t*<*Rng*>, *OutIter*>. The *copy* algorithm returns the pair of the input iterator *last* and the output iterator to the element in the destination range, one past the last element copied.

```
template<typename ExPolicy, typename FwdIter1, typename Sent, typename FwdIter2, typename
Proj = hpx::identity, typename T1 = typename hpx::parallel::traits::projected<FwdIter1,
Proj>::value_type, typename T2 = T1>
```

```
parallel::util::detail::algorithm_result<ExPolicy, replace_copy_result<FwdIter1, FwdIter2>>::type replace_copy(ExPolicy
&&pol
icy,
FwdIte
first,
Sent
sent,
FwdIte
dest,
T1
const
&old_v
T2
const
&new_
Proj
&&pro
=
Proj())
```

Copies the all elements from the range [first, sent) to another range beginning at *dest* replacing all elements satisfying a specific criteria with *new_value*.

Effects: Assigns to every iterator it in the range [result, result + (sent - first)) either *new_value* or $*(first + (it - result))$ depending on whether the following corresponding condition holds: $INVOKE(proj, *(first + (i - result))) == old_value$

The assignments in the parallel *replace_copy* algorithm invoked with an execution policy object of type *sequenced_policy* execute in sequential order in the calling thread.

The assignments in the parallel *replace_copy* algorithm invoked with an execution policy object of type *parallel_policy* or *parallel_task_policy* are permitted to execute in an unordered fashion in unspecified threads, and indeterminately sequenced within each thread.

Note: Complexity: Performs exactly *sent - first* applications of the predicate.

Template Parameters

- **ExPolicy** – The type of the execution policy to use (deduced). It describes the manner in which the execution of the algorithm may be parallelized and the manner in which it executes the assignments.
- **FwdIter1** – The type of the source iterator used (deduced). The iterator type must meet the requirements of an forward iterator.

- **Sent** – The type of the end iterators used (deduced). This sentinel type must be a sentinel for `Iter`.
- **FwdIter2** – The type of the iterator representing the destination range (deduced). This iterator type must meet the requirements of an forward iterator.
- **T1** – The type of the old value to replace (deduced).
- **T2** – The type of the new values to replace (deduced).
- **Proj** – The type of an optional projection function. This defaults to `hpx::identity`

Parameters

- **policy** – The execution policy to use for the scheduling of the iterations.
- **first** – Refers to the beginning of the sequence of elements the algorithm will be applied to.
- **sent** – Refers to the end of the sequence of elements the algorithm will be applied to.
- **dest** – Refers to the beginning of the destination range.
- **old_value** – Refers to the old value of the elements to replace.
- **new_value** – Refers to the new value to use as the replacement.
- **proj** – Specifies the function (or function object) which will be invoked for each of the elements as a projection operation before the actual predicate *is* invoked.

Returns The `replace_copy` algorithm returns a `hpx::future<in_out_result<FwdIter1, FwdIter2>>` if the execution policy is of type `sequenced_task_policy` or `parallel_task_policy` and returns `in_out_result<FwdIter1, FwdIter2>` otherwise. The `copy` algorithm returns the pair of the forward iterator `last` and the output iterator to the element in the destination range, one past the last element copied.

```
template<typename ExPolicy, typename Rng, typename FwdIter, typename Proj = hpx::identity,
        typename T1 = typename hpx::parallel::traits::projected<hpx::traits::range_iterator_t<Rng>,
        Proj>::value_type, typename T2 = T1>
parallel::util::detail::algorithm_result<ExPolicy, replace_copy_result<hpx::traits::range_iterator_t<Rng>, FwdIter>>::type
```

Copies the all elements from the range `rbg` to another range beginning at `dest` replacing all elements satisfying a specific criteria with `new_value`.

Effects: Assigns to every iterator `it` in the range `[result, result + (util::end(rng) - util::begin(rng))]` either `new_value` or `*(first + (it - result))` depending on whether the following corresponding condition holds: `INVOKE(proj, *(first + (i - result))) == old_value`

The assignments in the parallel `replace_copy` algorithm invoked with an execution policy object of type `sequenced_policy` execute in sequential order in the calling thread.

The assignments in the parallel `replace_copy` algorithm invoked with an execution policy object of type

parallel_policy or *parallel_task_policy* are permitted to execute in an unordered fashion in unspecified threads, and indeterminately sequenced within each thread.

Note: Complexity: Performs exactly *util::end(rng) - util::begin(rng)* applications of the predicate.

Template Parameters

- **ExPolicy** – The type of the execution policy to use (deduced). It describes the manner in which the execution of the algorithm may be parallelized and the manner in which it executes the assignments.
- **Rng** – The type of the source range used (deduced). The iterators extracted from this range type must meet the requirements of an input iterator.
- **FwdIter** – The type of the iterator representing the destination range (deduced). This iterator type must meet the requirements of an forward iterator.
- **T1** – The type of the old value to replace (deduced).
- **T2** – The type of the new values to replace (deduced).
- **Proj** – The type of an optional projection function. This defaults to *hpx::identity*

Parameters

- **policy** – The execution policy to use for the scheduling of the iterations.
- **rng** – Refers to the sequence of elements the algorithm will be applied to.
- **dest** – Refers to the beginning of the destination range.
- **old_value** – Refers to the old value of the elements to replace.
- **new_value** – Refers to the new value to use as the replacement.
- **proj** – Specifies the function (or function object) which will be invoked for each of the elements as a projection operation before the actual predicate *is* invoked.

Returns The *replace_copy* algorithm returns a *hpx::future<in_out_result<hpx::traits::range_iterator_t<Rng>, FwdIter>>* if the execution policy is of type *sequenced_task_policy* or *parallel_task_policy* and returns *in_out_result<hpx::traits::range_iterator_t<Rng>, FwdIter>>* The *copy* algorithm returns the pair of the input iterator *last* and the forward iterator to the element in the destination range, one past the last element copied.

hpx::ranges::reverse, hpx::ranges::reverse_copy

Defined in header `hpx/algorithm.hpp`⁶⁶⁹.

See *Public API* for a list of names and headers that are part of the public *HPX* API.

```
namespace hpx
```

```
    namespace ranges
```

⁶⁶⁹ <http://github.com/STELLAR-GROUP/hpx/blob/8a3b7c1a4cb5693b2f7d9f587f759392ed0c51a0/libs/full/include/include/hpx/algorithm.hpp>

Functions

```
template<typename Iter, typename Sent>
Iter reverse(Iter first, Sent sent)
```

Reverses the order of the elements in the range [first, last). Behaves as if applying `std::iter_swap` to every pair of iterators `first+i`, `(last-i) - 1` for each non-negative `i < (last-first)/2`.

The assignments in the parallel *reverse* algorithm execute in sequential order in the calling thread.

Note: Complexity: Linear in the distance between *first* and *last*.

Template Parameters

- **Iter** – The type of the source iterator used (deduced). The iterator type must meet the requirements of an input iterator.
- **Sent** – The type of the end iterators used (deduced). This sentinel type must be a sentinel for *Iter*.

Parameters

- **first** – Refers to the beginning of the sequence of elements the algorithm will be applied to.
- **sent** – Refers to the end of the sequence of elements the algorithm will be applied to.

Returns The *reverse* algorithm returns a *Iter*. It returns *last*.

```
template<typename Rng>
hpx::traits::range_iterator_t<Rng> reverse(Rng &&rng)
```

Uses *rng* as the source range, as if using `util::begin(rng)` as *first* and `ranges::end(rng)` as *last*. Reverses the order of the elements in the range [first, last). Behaves as if applying `std::iter_swap` to every pair of iterators `first+i`, `(last-i) - 1` for each non-negative `i < (last-first)/2`.

The assignments in the parallel *reverse* algorithm execute in sequential order in the calling thread.

Note: Complexity: Linear in the distance between *first* and *last*.

Template Parameters **Rng** – The type of the source range used (deduced). The iterators extracted from this range type must meet the requirements of a bidirectional iterator.

Parameters **rng** – Refers to the sequence of elements the algorithm will be applied to.

Returns The *reverse* algorithm returns a `hpx::traits::range_iterator<Rng>::type`. It returns *last*.

```
template<typename ExPolicy, typename Iter, typename Sent>
hpx::parallel::util::detail::algorithm_result_t<ExPolicy, Iter> reverse(ExPolicy &&policy, Iter first,
                                                                    Sent sent)
```

Reverses the order of the elements in the range [first, last). Behaves as if applying `std::iter_swap` to every pair of iterators `first+i`, `(last-i) - 1` for each non-negative `i < (last-first)/2`.

The assignments in the parallel *reverse* algorithm invoked with an execution policy object of type *sequenced_policy* execute in sequential order in the calling thread.

The assignments in the parallel *reverse* algorithm invoked with an execution policy object of type *parallel_policy* or *parallel_task_policy* are permitted to execute in an unordered fashion in unspecified threads, and indeterminately sequenced within each thread.

Note: Complexity: Linear in the distance between *first* and *last*.

Template Parameters

- **ExPolicy** – The type of the execution policy to use (deduced). It describes the manner in which the execution of the algorithm may be parallelized and the manner in which it executes the assignments.
- **Iter** – The type of the source iterator used (deduced). The iterator type must meet the requirements of an input iterator.
- **Sent** – The type of the end iterators used (deduced). This sentinel type must be a sentinel for *Iter*.

Parameters

- **policy** – The execution policy to use for the scheduling of the iterations.
- **first** – Refers to the beginning of the sequence of elements the algorithm will be applied to.
- **sent** – Refers to the end of the sequence of elements the algorithm will be applied to.

Returns The *reverse* algorithm returns a *hpx::future<Iter>* if the execution policy is of type *sequenced_task_policy* or *parallel_task_policy* and returns *Iter* otherwise. It returns *last*.

```
template<typename ExPolicy, typename Rng>
parallel::util::detail::algorithm_result<ExPolicy, hpx::traits::range_iterator_t<Rng>> reverse(ExPolicy
&&pol-
icy, Rng
&&rng)
```

Uses *rng* as the source range, as if using *util::begin(rng)* as *first* and *ranges::end(rng)* as *last*. Reverses the order of the elements in the range [first, last). Behaves as if applying `std::iter_swap` to every pair of iterators `first+i, (last-i) - 1` for each non-negative `i < (last-first)/2`.

The assignments in the parallel *reverse* algorithm invoked with an execution policy object of type *sequenced_policy* execute in sequential order in the calling thread.

The assignments in the parallel *reverse* algorithm invoked with an execution policy object of type *parallel_policy* or *parallel_task_policy* are permitted to execute in an unordered fashion in unspecified threads, and indeterminately sequenced within each thread.

Note: Complexity: Linear in the distance between *first* and *last*.

Template Parameters

- **ExPolicy** – The type of the execution policy to use (deduced). It describes the manner in which the execution of the algorithm may be parallelized and the manner in which it executes the assignments.
- **Rng** – The type of the source range used (deduced). The iterators extracted from this range type must meet the requirements of a bidirectional iterator.

Parameters

- **policy** – The execution policy to use for the scheduling of the iterations.
- **rng** – Refers to the sequence of elements the algorithm will be applied to.

Returns The *reverse* algorithm returns a *hpx::future<hpx::traits::range_iterator_t<Rng>>* if the execution policy is of type *sequenced_task_policy* or *parallel_task_policy* and returns *hpx::future<hpx::traits::range_iterator_t<Rng>>* otherwise. It returns *last*.

```
template<typename Iter, typename Sent, typename OutIter>
```

`reverse_copy_result<Iter, OutIter> reverse_copy(Iter first, Sent last, OutIter result)`

Copies the elements from the range `[first, last)` to another range beginning at `result` in such a way that the elements in the new range are in reverse order. Behaves as if by executing the assignment $*(result + (last - first) - 1 - i) = *(first + i)$ once for each non-negative $i < (last - first)$. If the source and destination ranges (that is, `[first, last)` and `[result, result+(last-first))` respectively) overlap, the behavior is undefined.

The assignments in the parallel `reverse_copy` algorithm execute in sequential order in the calling thread.

Note: Complexity: Performs exactly *last - first* assignments.

Template Parameters

- **Iter** – The type of the source iterator used (deduced). The iterator type must meet the requirements of an input iterator.
- **Sent** – The type of the end iterators used (deduced). This sentinel type must be a sentinel for `Iter`.
- **OutIter** – The type of the iterator representing the destination range (deduced). This iterator type must meet the requirements of an output iterator.

Parameters

- **first** – Refers to the beginning of the sequence of elements the algorithm will be applied to.
- **last** – Refers to the end of the sequence of elements the algorithm will be applied to.
- **result** – Refers to the begin of the destination range.

Returns The `reverse_copy` algorithm returns a `reverse_copy_result<Iter, OutIter>`. The `reverse_copy` algorithm returns the pair of the input iterator forwarded to the first element after the last in the input sequence and the output iterator to the element in the destination range, one past the last element copied.

`template<typename Rng, typename OutIter>
reverse_copy_result<hpx::traits::range_iterator_t<Rng>, OutIter> reverse_copy(Rng &&rng, OutIter
result)`

Uses `rng` as the source range, as if using `util::begin(rng)` as `first` and `ranges::end(rng)` as `last`. Copies the elements from the range `[first, last)` to another range beginning at `result` in such a way that the elements in the new range are in reverse order. Behaves as if by executing the assignment $*(result + (last - first) - 1 - i) = *(first + i)$ once for each non-negative $i < (last - first)$. If the source and destination ranges (that is, `[first, last)` and `[result, result+(last-first))` respectively) overlap, the behavior is undefined.

The assignments in the parallel `reverse_copy` algorithm execute in sequential order in the calling thread.

Note: Complexity: Performs exactly *last - first* assignments.

Template Parameters

- **Rng** – The type of the source range used (deduced). The iterators extracted from this range type must meet the requirements of a bidirectional iterator.
- **OutIter** – The type of the iterator representing the destination range (deduced). This iterator type must meet the requirements of an output iterator.

Parameters

- **rng** – Refers to the sequence of elements the algorithm will be applied to.
- **result** – Refers to the begin of the destination range.

Returns The *reverse_copy* algorithm returns a *ranges::reverse_copy_result*<hpx::traits::range_iterator_t<Rng>, OutIter>. The *reverse_copy* algorithm returns an object equal to {last, result + N} where N = last - first

```
template<typename ExPolicy, typename Iter, typename Sent, typename FwdIter>
parallel::util::detail::algorithm_result<ExPolicy, reverse_copy_result<Iter, FwdIter>>::type reverse_copy(ExPolicy
&&pol-
icy,
Iter
first,
Sent
last,
FwdIter
re-
sult)
```

Copies the elements from the range [first, last) to another range beginning at result in such a way that the elements in the new range are in reverse order. Behaves as if by executing the assignment $*(result + (last - first) - 1 - i) = *(first + i)$ once for each non-negative $i < (last - first)$. If the source and destination ranges (that is, [first, last) and [result, result+(last-first)) respectively) overlap, the behavior is undefined.

The assignments in the parallel *reverse_copy* algorithm invoked with an execution policy object of type *sequenced_policy* execute in sequential order in the calling thread.

The assignments in the parallel *reverse_copy* algorithm invoked with an execution policy object of type *parallel_policy* or *parallel_task_policy* are permitted to execute in an unordered fashion in unspecified threads, and indeterminately sequenced within each thread.

Note: Complexity: Performs exactly *last - first* assignments.

Template Parameters

- **ExPolicy** – The type of the execution policy to use (deduced). It describes the manner in which the execution of the algorithm may be parallelized and the manner in which it executes the assignments.
- **Iter** – The type of the source iterator used (deduced). The iterator type must meet the requirements of an input iterator.
- **Sent** – The type of the end iterators used (deduced). This sentinel type must be a sentinel for Iter.
- **FwdIter** – The type of the iterator representing the destination range (deduced). This iterator type must meet the requirements of a forward iterator.

Parameters

- **policy** – The execution policy to use for the scheduling of the iterations.
- **first** – Refers to the beginning of the sequence of elements the algorithm will be applied to.
- **last** – Refers to the end of the sequence of elements the algorithm will be applied to.
- **result** – Refers to the begin of the destination range.

Returns The *reverse_copy* algorithm returns a *hpx::future*<*reverse_copy_result*<Iter, FwdIter>> if the execution policy is of type *sequenced_task_policy* or *parallel_task_policy* and returns *reverse_copy_result*<Iter, FwdIter> otherwise. The *reverse_copy* algorithm returns the pair of the input iterator forwarded to the first element after the last in the input sequence and the output iterator to the element in the destination range, one past the last element copied.

```
template<typename ExPolicy, typename Rng, typename OutIter>
parallel::util::detail::algorithm_result<ExPolicy, reverse_copy_result<hpx::traits::range_iterator_t<Rng>, OutIter>>>::type r
```

Uses *rng* as the source range, as if using *util::begin(rng)* as *first* and *ranges::end(rng)* as *last*. Copies the elements from the range [first, last) to another range beginning at *result* in such a way that the elements in the new range are in reverse order. Behaves as if by executing the assignment $*(result + (last - first) - 1 - i) = *(first + i)$ once for each non-negative $i < (last - first)$. If the source and destination ranges (that is, [first, last) and [result, result+(last-first)) respectively) overlap, the behavior is undefined.

The assignments in the parallel *reverse_copy* algorithm invoked with an execution policy object of type *sequenced_policy* execute in sequential order in the calling thread.

The assignments in the parallel *reverse_copy* algorithm invoked with an execution policy object of type *parallel_policy* or *parallel_task_policy* are permitted to execute in an unordered fashion in unspecified threads, and indeterminately sequenced within each thread.

Note: Complexity: Performs exactly *last - first* assignments.

Template Parameters

- **ExPolicy** – The type of the execution policy to use (deduced). It describes the manner in which the execution of the algorithm may be parallelized and the manner in which it executes the assignments.
- **Rng** – The type of the source range used (deduced). The iterators extracted from this range type must meet the requirements of a bidirectional iterator.
- **OutIter** – The type of the iterator representing the destination range (deduced). This iterator type must meet the requirements of an output iterator.

Parameters

- **policy** – The execution policy to use for the scheduling of the iterations.
- **rng** – Refers to the sequence of elements the algorithm will be applied to.
- **result** – Refers to the begin of the destination range.

Returns The *reverse_copy* algorithm returns a *hpx::future<ranges::reverse_copy_result<hpx::traits::range_iterator_t<Rng>, OutIter>>* if the execution policy is of type *sequenced_task_policy* or *parallel_task_policy* and returns *ranges::reverse_copy_result<hpx::traits::range_iterator_t<Rng>, OutIter>* otherwise. The *reverse_copy* algorithm returns an object equal to {last, result + N} where $N = last - first$

hpx::ranges::rotate, hpx::ranges::rotate_copy

Defined in header `hpx/algorithm.hpp`⁶⁷⁰.

See *Public API* for a list of names and headers that are part of the public HPX API.

```
namespace hpx
```

```
    namespace ranges
```

Functions

```
template<typename FwdIter, typename Sent>
subrange_t<FwdIter, Sent> rotate(FwdIter first, FwdIter middle, Sent last)
```

Performs a left rotation on a range of elements. Specifically, *rotate* swaps the elements in the range [first, last) in such a way that the element middle becomes the first element of the new range and middle - 1 becomes the last element.

The assignments in the parallel *rotate* algorithm execute in sequential order in the calling thread.

Note: Complexity: Linear in the distance between *first* and *last*.

Note: The type of dereferenced *FwdIter* must meet the requirements of *MoveAssignable* and *MoveConstructible*.

Template Parameters

- **FwdIter** – The type of the source iterators used (deduced). This iterator type must meet the requirements of an forward iterator.
- **Sent** – The type of the end iterators used (deduced). This sentinel type must be a sentinel for *FwdIter*.

Parameters

- **first** – Refers to the beginning of the sequence of elements the algorithm will be applied to.
- **middle** – Refers to the element that should appear at the beginning of the rotated range.
- **last** – Refers to the end of the sequence of elements the algorithm will be applied to.

Returns The *rotate* algorithm returns a *subrange_t<FwdIter, Sent>*. The *rotate* algorithm returns the iterator equal to pair(first + (last - middle), last).

```
template<typename ExPolicy, typename FwdIter, typename Sent>
parallel::util::detail::algorithm_result<ExPolicy, subrange_t<FwdIter, Sent>>::type rotate(ExPolicy
&&policy,
FwdIter
first,
FwdIter
middle,
Sent last)
```

Performs a left rotation on a range of elements. Specifically, *rotate* swaps the elements in the range

⁶⁷⁰ <http://github.com/STELLAR-GROUP/hpx/blob/8a3b7c1a4cb5693b2f7d9f587f759392ed0c51a0/libs/full/include/include/hpx/algorithm.hpp>

[first, last) in such a way that the element middle becomes the first element of the new range and middle - 1 becomes the last element.

The assignments in the parallel *rotate* algorithm invoked with an execution policy object of type *sequenced_policy* execute in sequential order in the calling thread.

The assignments in the parallel *rotate* algorithm invoked with an execution policy object of type *parallel_policy* or *parallel_task_policy* are permitted to execute in an unordered fashion in unspecified threads, and indeterminately sequenced within each thread.

Note: Complexity: Linear in the distance between *first* and *last*.

Note: The type of dereferenced *FwdIter* must meet the requirements of *MoveAssignable* and *MoveConstructible*.

Template Parameters

- **ExPolicy** – The type of the execution policy to use (deduced). It describes the manner in which the execution of the algorithm may be parallelized and the manner in which it executes the assignments.
- **FwdIter** – The type of the source iterators used (deduced). This iterator type must meet the requirements of an forward iterator.
- **Sent** – The type of the end iterators used (deduced). This sentinel type must be a sentinel for *FwdIter*.

Parameters

- **policy** – The execution policy to use for the scheduling of the iterations.
- **first** – Refers to the beginning of the sequence of elements the algorithm will be applied to.
- **middle** – Refers to the element that should appear at the beginning of the rotated range.
- **last** – Refers to the end of the sequence of elements the algorithm will be applied to.

Returns The *rotate* algorithm returns a *hpx::future<subrange_t<FwdIter, Sent>>* if the execution policy is of type *parallel_task_policy* and returns a *subrange_t<FwdIter, Sent>* otherwise. The *rotate* algorithm returns the iterator equal to `pair(first + (last - middle), last)`.

```
template<typename Rng>
subrange_t<hpx::traits::range_iterator_t<Rng>, hpx::traits::range_iterator_t<Rng>> rotate(Rng
                                                                                               &&rng,
                                                                                               hpx::traits::range_iterator_t<Rng>
                                                                                               middle)
```

Uses *rng* as the source range, as if using *util::begin(rng)* as *first* and *ranges::end(rng)* as *last*. Performs a left rotation on a range of elements. Specifically, *rotate* swaps the elements in the range [first, last) in such a way that the element middle becomes the first element of the new range and middle - 1 becomes the last element.

The assignments in the parallel *rotate* algorithm execute in sequential order in the calling thread.

Note: Complexity: Linear in the distance between *first* and *last*.

Note: The type of dereferenced *FwdIter* must meet the requirements of *MoveAssignable* and *MoveConstructible*.

Template Parameters **Rng** – The type of the source range used (deduced). The iterators extracted from this range type must meet the requirements of a forward iterator.

Parameters

- **rng** – Refers to the sequence of elements the algorithm will be applied to.
- **middle** – Refers to the element that should appear at the beginning of the rotated range.

Returns The *rotate* algorithm returns a *subrange_t*<*hpx::traits::range_iterator_t*<*Rng*>, *hpx::traits::range_iterator_t*<*Rng*>>. The *rotate* algorithm returns the iterator equal to *pair*(*first* + (*last* - *middle*), *last*).

```
template<typename ExPolicy, typename Rng>
parallel::util::detail::algorithm_result<ExPolicy, subrange_t<hpx::traits::range_iterator_t<Rng>, hpx::traits::range_iterator_t<Rng>>
```

Uses *rng* as the source range, as if using *util::begin(rng)* as *first* and *ranges::end(rng)* as *last*. Performs a left rotation on a range of elements. Specifically, *rotate* swaps the elements in the range [*first*, *last*) in such a way that the element *middle* becomes the first element of the new range and *middle* - 1 becomes the last element.

The assignments in the parallel *rotate* algorithm invoked with an execution policy object of type *sequenced_policy* execute in sequential order in the calling thread.

The assignments in the parallel *rotate* algorithm invoked with an execution policy object of type *parallel_policy* or *parallel_task_policy* are permitted to execute in an unordered fashion in unspecified threads, and indeterminately sequenced within each thread.

Note: Complexity: Linear in the distance between *first* and *last*.

Note: The type of dereferenced *FwdIter* must meet the requirements of *MoveAssignable* and *MoveConstructible*.

Template Parameters

- **ExPolicy** – The type of the execution policy to use (deduced). It describes the manner in which the execution of the algorithm may be parallelized and the manner in which it executes the assignments.
- **Rng** – The type of the source range used (deduced). The iterators extracted from this range type must meet the requirements of a forward iterator.

Parameters

- **policy** – The execution policy to use for the scheduling of the iterations.
- **rng** – Refers to the sequence of elements the algorithm will be applied to.
- **middle** – Refers to the element that should appear at the beginning of the rotated range.

Returns The *rotate* algorithm returns a *hpx::future* <*subrange_t*<*hpx::traits::range_iterator_t*<*Rng*>, *hpx::traits::range_iterator_t*<*Rng*>> if

the execution policy is of type *sequenced_task_policy* or *parallel_task_policy* and returns *subrange_t<hpx::traits::range_iterator_t<Rng>, hpx::traits::range_iterator_t<Rng>>*. otherwise. The *rotate* algorithm returns the iterator equal to `pair(first + (last - middle), last)`.

```
template<typename FwdIter, typename Sent, typename OutIter>
rotate_copy_result<FwdIter, OutIter> rotate_copy(FwdIter first, FwdIter middle, Sent last, OutIter
dest_first)
```

Copies the elements from the range `[first, last)`, to another range beginning at *dest_first* in such a way, that the element *middle* becomes the first element of the new range and *middle - 1* becomes the last element.

The assignments in the parallel *rotate_copy* algorithm execute in sequential order in the calling thread.

Note: Complexity: Performs exactly *last - first* assignments.

Template Parameters

- **FwdIter** – The type of the source iterators used (deduced). This iterator type must meet the requirements of an forward iterator.
- **Sent** – The type of the end iterators used (deduced). This sentinel type must be a sentinel for *FwdIter*.
- **OutIter** – The type of the iterator representing the destination range (deduced). This iterator type must meet the requirements of an output iterator.

Parameters

- **first** – Refers to the beginning of the sequence of elements the algorithm will be applied to.
- **middle** – Refers to the element that should appear at the beginning of the rotated range.
- **last** – Refers to the end of the sequence of elements the algorithm will be applied to.
- **dest_first** – Output iterator to the initial position of the range where the reversed range is stored. The pointed type shall support being assigned the value of an element in the range `[first,last)`.

Returns The *rotate_copy* algorithm returns a *rotate_copy_result<FwdIter, OutIter>*. The *rotate_copy* algorithm returns the output iterator to the element past the last element copied.

```
template<typename ExPolicy, typename FwdIter1, typename Sent, typename FwdIter2>
parallel::util::detail::algorithm_result<ExPolicy, rotate_copy_result<FwdIter1, FwdIter2>>::type rotate_copy(ExPolicy
&&pol-
icy,
FwdIter1
first,
FwdIter1
mid-
dle,
Sent
last,
FwdIter2
dest_first)
```

Copies the elements from the range `[first, last)`, to another range beginning at *dest_first* in such a way, that the element *middle* becomes the first element of the new range and *middle - 1* becomes the last element.

The assignments in the parallel *rotate_copy* algorithm invoked with an execution policy object of type *sequenced_policy* execute in sequential order in the calling thread.

The assignments in the parallel *rotate_copy* algorithm invoked with an execution policy object of type *parallel_policy* or *parallel_task_policy* are permitted to execute in an unordered fashion in unspecified threads, and indeterminately sequenced within each thread.

Note: Complexity: Performs exactly *last - first* assignments.

Template Parameters

- **ExPolicy** – The type of the execution policy to use (deduced). It describes the manner in which the execution of the algorithm may be parallelized and the manner in which it executes the assignments.
- **FwdIter1** – The type of the source iterators used (deduced). This iterator type must meet the requirements of an forward iterator.
- **Sent** – The type of the end iterators used (deduced). This sentinel type must be a sentinel for FwdIter.
- **FwdIter2** – The type of the iterator representing the destination range (deduced). This iterator type must meet the requirements of an forward iterator.

Parameters

- **policy** – The execution policy to use for the scheduling of the iterations.
- **first** – Refers to the beginning of the sequence of elements the algorithm will be applied to.
- **middle** – Refers to the element that should appear at the beginning of the rotated range.
- **last** – Refers to the end of the sequence of elements the algorithm will be applied to.
- **dest_first** – Output iterator to the initial position of the range where the reversed range is stored. The pointed type shall support being assigned the value of an element in the range [first,last).

Returns The *rotate_copy* algorithm returns `hpx::future<rotate_copy_result<FwdIter1, FwdIter2>>` if the execution policy is of type *sequenced_task_policy* or *parallel_task_policy* and returns *rotate_copy_result<FwdIter1, FwdIter2>* otherwise. The *rotate_copy* algorithm returns the output iterator to the element past the last element copied.

```
template<typename Rng, typename OutIter>
rotate_copy_result<hpx::traits::range_iterator_t<Rng>, OutIter> rotate_copy(Rng &&rng,
                                                                    hpx::traits::range_iterator_t<Rng>
                                                                    middle, OutIter
                                                                    dest_first)
```

Uses *rng* as the source range, as if using *util::begin(rng)* as *first* and *ranges::end(rng)* as *last*. Copies the elements from the range [first, last), to another range beginning at *dest_first* in such a way, that the element *middle* becomes the first element of the new range and *middle - 1* becomes the last element.

The assignments in the parallel *rotate_copy* algorithm execute in sequential order in the calling thread.

Note: Complexity: Performs exactly *last - first* assignments.

Template Parameters

- **Rng** – The type of the source range used (deduced). The iterators extracted from this range type must meet the requirements of a forward iterator.
- **OutIter** – The type of the iterator representing the destination range (deduced). This iterator type must meet the requirements of an forward iterator.

Parameters

- **rng** – Refers to the sequence of elements the algorithm will be applied to.
- **middle** – Refers to the element that should appear at the beginning of the rotated range.
- **dest_first** – Output iterator to the initial position of the range where the reversed range is stored. The pointed type shall support being assigned the value of an element in the range [first,last).

Returns The *rotate* algorithm returns a *rotate_copy_result*<*hpx::traits::range_iterator_t*<*Rng*>, *OutIter*>. The *rotate_copy* algorithm returns the output iterator to the element past the last element copied.

```
template<typename ExPolicy, typename Rng, typename OutIter>  
parallel::util::detail::algorithm_result<ExPolicy, rotate_copy_result<hpx::traits::range_iterator_t<Rng>, OutIter>> rotate
```

Uses *rng* as the source range, as if using *util::begin(rng)* as *first* and *ranges::end(rng)* as *last*. Copies the elements from the range [first, last), to another range beginning at *dest_first* in such a way, that the element *new_first* becomes the first element of the new range and *new_first* - 1 becomes the last element.

The assignments in the parallel *rotate_copy* algorithm invoked with an execution policy object of type *sequenced_policy* execute in sequential order in the calling thread.

The assignments in the parallel *rotate_copy* algorithm invoked with an execution policy object of type *parallel_policy* or *parallel_task_policy* are permitted to execute in an unordered fashion in unspecified threads, and indeterminately sequenced within each thread.

Note: Complexity: Performs exactly *last* - *first* assignments.

Template Parameters

- **ExPolicy** – The type of the execution policy to use (deduced). It describes the manner in which the execution of the algorithm may be parallelized and the manner in which it executes the assignments.
- **Rng** – The type of the source range used (deduced). The iterators extracted from this range type must meet the requirements of a forward iterator.
- **OutIter** – The type of the iterator representing the destination range (deduced). This iterator type must meet the requirements of an output iterator.

Parameters

- **policy** – The execution policy to use for the scheduling of the iterations.
- **rng** – Refers to the sequence of elements the algorithm will be applied to.
- **middle** – Refers to the element that should appear at the beginning of the rotated range.
- **dest_first** – Output iterator to the initial position of the range where the reversed range is stored. The pointed type shall support being assigned the value of an element in the range [first,last).

Returns The *rotate_copy* algorithm returns a *hpx::future*<*rotate_copy_result*<*hpx::traits::range_iterator_t*<*Rng*>, *OutIter*>> if the execution policy is of type *par-*

allel_task_policy and returns *rotate_copy_result*< *hpx::traits::range_iterator_t*<Rng>, *OutIter*> otherwise. The *rotate_copy* algorithm returns the output iterator to the element past the last element copied.

`hpx::ranges::search`, `hpx::ranges::search_n`

Defined in header `hpx/algorithm.hpp`⁶⁷¹.

See *Public API* for a list of names and headers that are part of the public *HPX* API.

namespace **hpx**

namespace **ranges**

Functions

```
template<typename FwdIter, typename Sent, typename FwdIter2, typename Sent2, typename Pred =
    hpx::ranges::equal_to, typename Proj1 = hpx::identity, typename Proj2 = hpx::identity>
FwdIter search(FwdIter first, Sent last, FwdIter2 s_first, Sent2 s_last, Pred &&op = Pred(), Proj1
    &&proj1 = Proj1(), Proj2 &&proj2 = Proj2())
```

Searches the range [first, last) for any elements in the range [s_first, s_last). Uses a provided predicate to compare elements.

The comparison operations in the parallel *search* algorithm execute in sequential order in the calling thread.

Note: Complexity: at most ($S \cdot N$) comparisons where S = distance(s_first, s_last) and N = distance(first, last).

Template Parameters

- **FwdIter** – The type of the source iterators used for the first range (deduced). This iterator type must meet the requirements of an forward iterator.
- **Sent** – The type of the source sentinel used for the first range (deduced). This iterator type must meet the requirements of an sentinel.
- **FwdIter2** – The type of the source iterators used for the second range (deduced). This iterator type must meet the requirements of an forward iterator.
- **Sent2** – The type of the source sentinel used for the second range (deduced). This iterator type must meet the requirements of an sentinel.
- **Pred** – The type of an optional function/function object to use. Unlike its sequential form, the parallel overload of *adjacent_find* requires *Pred* to meet the requirements of *CopyConstructible*. This defaults to `std::equal_to`<>
- **Proj1** – The type of an optional projection function. This defaults to *hpx::identity* and is applied to the elements of type dereferenced *FwdIter*.
- **Proj2** – The type of an optional projection function. This defaults to *hpx::identity* and is applied to the elements of type dereferenced *FwdIter2*.

Parameters

- **first** – Refers to the beginning of the sequence of elements of the first range the algorithm will be applied to.

⁶⁷¹ <http://github.com/STELLAR-GROUP/hpx/blob/8a3b7c1a4cb5693b2f7d9f587f759392ed0c51a0/libs/full/include/include/hpx/algorithm.hpp>

- **last** – Refers to the end of the sequence of elements of the first range the algorithm will be applied to.
- **s_first** – Refers to the beginning of the sequence of elements the algorithm will be searching for.
- **s_last** – Refers to the end of the sequence of elements of the algorithm will be searching for.
- **op** – Refers to the binary predicate which returns true if the elements should be treated as equal. the signature of the function should be equivalent to

```
bool pred(const Type1 &a, const Type2 &b);
```

The signature does not need to have `const &`, but the function must not modify the objects passed to it. The types *Type1* and *Type2* must be such that objects of types *FwdIter1* and *FwdIter2* can be dereferenced and then implicitly converted to *Type1* and *Type2* respectively

- **proj1** – Specifies the function (or function object) which will be invoked for each of the elements of type dereferenced *FwdIter1* as a projection operation before the actual predicate *is* invoked.
- **proj2** – Specifies the function (or function object) which will be invoked for each of the elements of type dereferenced *FwdIter2* as a projection operation before the actual predicate *is* invoked.

Returns The *search* algorithm returns a `hpx::future<FwdIter>` if the execution policy is of type *task_execution_policy* and returns *FwdIter* otherwise. The *search* algorithm returns an iterator to the beginning of the first subsequence [s_first, s_last) in range [first, last). If the length of the subsequence [s_first, s_last) is greater than the length of the range [first, last), *last* is returned. Additionally if the size of the subsequence is empty *first* is returned. If no subsequence is found, *last* is returned.

```
template<typename ExPolicy, typename FwdIter, typename Sent, typename FwdIter2, typename
Sent2, typename Pred = hpx::ranges::equal_to, typename Proj1 = hpx::identity, typename Proj2 =
hpx::identity>
parallel::util::detail::algorithm_result<ExPolicy, FwdIter>::type search(ExPolicy &&policy, FwdIter
first, Sent last, FwdIter2 s_first,
Sent2 s_last, Pred &&op =
Pred(), Proj1 &&proj1 =
Proj1(), Proj2 &&proj2 =
Proj2())
```

Searches the range [first, last) for any elements in the range [s_first, s_last). Uses a provided predicate to compare elements.

The comparison operations in the parallel *search* algorithm invoked with an execution policy object of type *sequenced_policy* execute in sequential order in the calling thread.

The comparison operations in the parallel *search* algorithm invoked with an execution policy object of type *parallel_policy* or *parallel_task_policy* are permitted to execute in an unordered fashion in unspecified threads, and indeterminately sequenced within each thread.

Note: Complexity: at most (S*N) comparisons where *S* = distance(s_first, s_last) and *N* = distance(first, last).

Template Parameters

- **ExPolicy** – The type of the execution policy to use (deduced). It describes the manner in which the execution of the algorithm may be parallelized and the manner in which it

executes the assignments.

- **FwdIter** – The type of the source iterators used for the first range (deduced). This iterator type must meet the requirements of an forward iterator.
- **Sent** – The type of the source sentinel used for the first range (deduced). This iterator type must meet the requirements of an sentinel.
- **FwdIter2** – The type of the source iterators used for the second range (deduced). This iterator type must meet the requirements of an forward iterator.
- **Sent2** – The type of the source sentinel used for the second range (deduced). This iterator type must meet the requirements of an sentinel.
- **Pred** – The type of an optional function/function object to use. Unlike its sequential form, the parallel overload of *adjacent_find* requires *Pred* to meet the requirements of *CopyConstructible*. This defaults to `std::equal_to<>`
- **Proj1** – The type of an optional projection function. This defaults to `hpx::identity` and is applied to the elements of type dereferenced *FwdIter*.
- **Proj2** – The type of an optional projection function. This defaults to `hpx::identity` and is applied to the elements of type dereferenced *FwdIter2*.

Parameters

- **policy** – The execution policy to use for the scheduling of the iterations.
- **first** – Refers to the beginning of the sequence of elements of the first range the algorithm will be applied to.
- **last** – Refers to the end of the sequence of elements of the first range the algorithm will be applied to.
- **s_first** – Refers to the beginning of the sequence of elements the algorithm will be searching for.
- **s_last** – Refers to the end of the sequence of elements of the algorithm will be searching for.
- **op** – Refers to the binary predicate which returns true if the elements should be treated as equal. the signature of the function should be equivalent to

```
bool pred(const Type1 &a, const Type2 &b);
```

The signature does not need to have `const &`, but the function must not modify the objects passed to it. The types *Type1* and *Type2* must be such that objects of types *FwdIter1* and *FwdIter2* can be dereferenced and then implicitly converted to *Type1* and *Type2* respectively

- **proj1** – Specifies the function (or function object) which will be invoked for each of the elements of type dereferenced *FwdIter1* as a projection operation before the actual predicate *is* invoked.
- **proj2** – Specifies the function (or function object) which will be invoked for each of the elements of type dereferenced *FwdIter2* as a projection operation before the actual predicate *is* invoked.

Returns The *search* algorithm returns a `hpx::future<FwdIter>` if the execution policy is of type *task_execution_policy* and returns *FwdIter* otherwise. The *search* algorithm returns an iterator to the beginning of the first subsequence [*s_first*, *s_last*) in range [*first*, *last*). If the length of the subsequence [*s_first*, *s_last*) is greater than the length of the range [*first*, *last*), *last* is returned. Additionally if the size of the subsequence is empty *first* is returned. If no subsequence is found, *last* is returned.

```
template<typename Rng1, typename Rng2, typename Pred = hpx::ranges::equal_to, typename Proj1 =
hpx::identity, typename Proj2 = hpx::identity>
hpx::traits::range_iterator_t<Rng1> search(Rng1 &&rng1, Rng2 &&rng2, Pred &&op = Pred(), Proj1
&&proj1 = Proj1(), Proj2 &&proj2 = Proj2())
```

Searches the range [*first*, *last*) for any elements in the range [*s_first*, *s_last*). Uses a provided predicate to compare elements.

The comparison operations in the parallel *search* algorithm execute in sequential order in the calling thread.

Note: Complexity: at most $(S*N)$ comparisons where $S = \text{distance}(s_first, s_last)$ and $N = \text{distance}(first, last)$.

Template Parameters

- **Rng1** – The type of the examine range used (deduced). The iterators extracted from this range type must meet the requirements of an input iterator.
- **Rng2** – The type of the search range used (deduced). The iterators extracted from this range type must meet the requirements of an input iterator.
- **Pred** – The type of an optional function/function object to use. Unlike its sequential form, the parallel overload of *adjacent_find* requires *Pred* to meet the requirements of *CopyConstructible*. This defaults to `std::equal_to<>`
- **Proj1** – The type of an optional projection function. This defaults to `hpx::identity` and is applied to the elements of *Rng1*.
- **Proj2** – The type of an optional projection function. This defaults to `hpx::identity` and is applied to the elements of *Rng2*.

Parameters

- **rng1** – Refers to the sequence of elements the algorithm will be examining.
- **rng2** – Refers to the sequence of elements the algorithm will be searching for.
- **op** – Refers to the binary predicate which returns true if the elements should be treated as equal. the signature of the function should be equivalent to

```
bool pred(const Type1 &a, const Type2 &b);
```

The signature does not need to have `const &`, but the function must not modify the objects passed to it. The types *Type1* and *Type2* must be such that objects of types *FwdIter1* and *FwdIter2* can be dereferenced and then implicitly converted to *Type1* and *Type2* respectively

- **proj1** – Specifies the function (or function object) which will be invoked for each of the elements of *rng1* as a projection operation before the actual predicate *is* invoked.
- **proj2** – Specifies the function (or function object) which will be invoked for each of the elements of *rng2* as a projection operation before the actual predicate *is* invoked.

Returns The *search* algorithm returns a `hpx::future<FwdIter>` if the execution policy is of type *task_execution_policy* and returns *FwdIter* otherwise. The *search* algorithm returns an iterator to the beginning of the first subsequence $[s_first, s_last)$ in range $[first, last)$. If the length of the subsequence $[s_first, s_last)$ is greater than the length of the range $[first, last)$, *last* is returned. Additionally if the size of the subsequence is empty *first* is returned. If no subsequence is found, *last* is returned.

```
template<typename ExPolicy, typename Rng1, typename Rng2, typename Pred =
hpx::ranges::equal_to, typename Proj1 = hpx::identity, typename Proj2 = hpx::identity>
```

```

hpx::parallel::util::detail::algorithm_result<ExPolicy, hpx::traits::range_iterator_t<Rng1>> search(ExPolicy
&&pol-
icy,
Rng1
&&rng1,
Rng2
&&rng2,
Pred
&&op
=
Pred(),
Proj1
&&proj1
=
Proj1(),
Proj2
&&proj2
=
Proj2())

```

Searches the range [first, last) for any elements in the range [s_first, s_last). Uses a provided predicate to compare elements.

The comparison operations in the parallel *search* algorithm invoked with an execution policy object of type *sequenced_policy* execute in sequential order in the calling thread.

The comparison operations in the parallel *search* algorithm invoked with an execution policy object of type *parallel_policy* or *parallel_task_policy* are permitted to execute in an unordered fashion in unspecified threads, and indeterminately sequenced within each thread.

Note: Complexity: at most ($S \cdot N$) comparisons where $S = \text{distance}(s_first, s_last)$ and $N = \text{distance}(first, last)$.

Template Parameters

- **ExPolicy** – The type of the execution policy to use (deduced). It describes the manner in which the execution of the algorithm may be parallelized and the manner in which it executes the assignments.
- **Rng1** – The type of the examine range used (deduced). The iterators extracted from this range type must meet the requirements of an input iterator.
- **Rng2** – The type of the search range used (deduced). The iterators extracted from this range type must meet the requirements of an input iterator.
- **Pred** – The type of an optional function/function object to use. Unlike its sequential form, the parallel overload of *adjacent_find* requires *Pred* to meet the requirements of *CopyConstructible*. This defaults to `std::equal_to<>`
- **Proj1** – The type of an optional projection function. This defaults to *hpx::identity* and is applied to the elements of *Rng1*.
- **Proj2** – The type of an optional projection function. This defaults to *hpx::identity* and is applied to the elements of *Rng2*.

Parameters

- **policy** – The execution policy to use for the scheduling of the iterations.
- **rng1** – Refers to the sequence of elements the algorithm will be examining.
- **rng2** – Refers to the sequence of elements the algorithm will be searching for.
- **op** – Refers to the binary predicate which returns true if the elements should be treated

as equal. the signature of the function should be equivalent to

```
bool pred(const Type1 &a, const Type2 &b);
```

The signature does not need to have `const &`, but the function must not modify the objects passed to it. The types *Type1* and *Type2* must be such that objects of types *FwdIter1* and *FwdIter2* can be dereferenced and then implicitly converted to *Type1* and *Type2* respectively

- **proj1** – Specifies the function (or function object) which will be invoked for each of the elements of *rng1* as a projection operation before the actual predicate *is* invoked.
- **proj2** – Specifies the function (or function object) which will be invoked for each of the elements of *rng2* as a projection operation before the actual predicate *is* invoked.

Returns The *search* algorithm returns a `hpx::future<FwdIter>` if the execution policy is of type `task_execution_policy` and returns *FwdIter* otherwise. The *search* algorithm returns an iterator to the beginning of the first subsequence [*s_first*, *s_last*) in range [*first*, *last*). If the length of the subsequence [*s_first*, *s_last*) is greater than the length of the range [*first*, *last*), *last* is returned. Additionally if the size of the subsequence is empty *first* is returned. If no subsequence is found, *last* is returned.

```
template<typename FwdIter, typename FwdIter2, typename Sent2, typename Pred =
hpx::ranges::equal_to, typename Proj1 = hpx::identity, typename Proj2 = hpx::identity>
FwdIter search_n(FwdIter first, std::size_t count, FwdIter2 s_first, Sent s_last, Pred &&op = Pred(),
Proj1 &&proj1 = Proj1(), Proj2 &&proj2 = Proj2())
```

Searches the range [*first*, *last*) for any elements in the range [*s_first*, *s_last*). Uses a provided predicate to compare elements.

The comparison operations in the parallel *search_n* algorithm execute in sequential order in the calling thread.

Note: Complexity: at most ($S \cdot N$) comparisons where $S = \text{distance}(s_first, s_last)$ and $N = \text{count}$.

Template Parameters

- **FwdIter** – The type of the source iterators used for the first range (deduced). This iterator type must meet the requirements of an forward iterator.
- **FwdIter2** – The type of the source iterators used for the second range (deduced). This iterator type must meet the requirements of an forward iterator.
- **Sent2** – The type of the source sentinel used for the second range (deduced). This iterator type must meet the requirements of an sentinel.
- **Pred** – The type of an optional function/function object to use. Unlike its sequential form, the parallel overload of *adjacent_find* requires *Pred* to meet the requirements of *CopyConstructible*. This defaults to `std::equal_to<>`
- **Proj1** – The type of an optional projection function. This defaults to `hpx::identity` and is applied to the elements of type dereferenced *FwdIter*.
- **Proj2** – The type of an optional projection function. This defaults to `hpx::identity` and is applied to the elements of type dereferenced *FwdIter2*.

Parameters

- **first** – Refers to the beginning of the sequence of elements of the first range the algorithm will be applied to.
- **count** – Refers to the range of elements of the first range the algorithm will be applied to.
- **s_first** – Refers to the beginning of the sequence of elements the algorithm will be searching for.

- **s_last** – Refers to the end of the sequence of elements of the algorithm will be searching for.
- **op** – Refers to the binary predicate which returns true if the elements should be treated as equal. the signature of the function should be equivalent to

```
bool pred(const Type1 &a, const Type2 &b);
```

The signature does not need to have `const &`, but the function must not modify the objects passed to it. The types *Type1* and *Type2* must be such that objects of types *FwdIter1* and *FwdIter2* can be dereferenced and then implicitly converted to *Type1* and *Type2* respectively

- **proj1** – Specifies the function (or function object) which will be invoked for each of the elements of type dereferenced *FwdIter1* as a projection operation before the actual predicate *is* invoked.
- **proj2** – Specifies the function (or function object) which will be invoked for each of the elements of type dereferenced *FwdIter2* as a projection operation before the actual predicate *is* invoked.

Returns The *search_n* algorithm returns *FwdIter*. The *search_n* algorithm returns an iterator to the beginning of the last subsequence [*s_first*, *s_last*) in range [*first*, *first*+*count*). If the length of the subsequence [*s_first*, *s_last*) is greater than the length of the range [*first*, *first*+*count*), *first* is returned. Additionally, if the size of the subsequence is empty or no subsequence is found, *first* is also returned.

```
template<typename ExPolicy, typename FwdIter, typename FwdIter2, typename Sent2, typename
Pred = hpx::ranges::equal_to, typename Proj1 = hpx::identity, typename Proj2 = hpx::identity>
hpx::parallel::util::detail::algorithm_result<ExPolicy, FwdIter>::type search_n(ExPolicy &&policy,
                                     FwdIter first,
                                     std::size_t count,
                                     FwdIter2 s_first, Sent2
                                     s_last, Pred &&op =
                                     Pred(), Proj1 &&proj1
                                     = Proj1(), Proj2
                                     &&proj2 = Proj2()
```

Searches the range [*first*, *last*) for any elements in the range [*s_first*, *s_last*). Uses a provided predicate to compare elements.

The comparison operations in the parallel *search_n* algorithm invoked with an execution policy object of type *sequenced_policy* execute in sequential order in the calling thread.

The comparison operations in the parallel *search_n* algorithm invoked with an execution policy object of type *parallel_policy* or *parallel_task_policy* are permitted to execute in an unordered fashion in unspecified threads, and indeterminately sequenced within each thread.

Note: Complexity: at most $(S*N)$ comparisons where $S = \text{distance}(s_first, s_last)$ and $N = \text{count}$.

Template Parameters

- **ExPolicy** – The type of the execution policy to use (deduced). It describes the manner in which the execution of the algorithm may be parallelized and the manner in which it executes the assignments.
- **FwdIter** – The type of the source iterators used for the first range (deduced). This iterator type must meet the requirements of an forward iterator.
- **FwdIter2** – The type of the source iterators used for the second range (deduced). This iterator type must meet the requirements of an forward iterator.

- **Sent2** – The type of the source sentinel used for the second range (deduced). This iterator type must meet the requirements of a sentinel.
- **Pred** – The type of an optional function/function object to use. Unlike its sequential form, the parallel overload of *adjacent_find* requires *Pred* to meet the requirements of *CopyConstructible*. This defaults to `std::equal_to<>`
- **Proj1** – The type of an optional projection function. This defaults to *hpx::identity* and is applied to the elements of type dereferenced *FwdIter*.
- **Proj2** – The type of an optional projection function. This defaults to *hpx::identity* and is applied to the elements of type dereferenced *FwdIter2*.

Parameters

- **policy** – The execution policy to use for the scheduling of the iterations.
- **first** – Refers to the beginning of the sequence of elements of the first range the algorithm will be applied to.
- **count** – Refers to the range of elements of the first range the algorithm will be applied to.
- **s_first** – Refers to the beginning of the sequence of elements the algorithm will be searching for.
- **s_last** – Refers to the end of the sequence of elements of the algorithm will be searching for.
- **op** – Refers to the binary predicate which returns true if the elements should be treated as equal. the signature of the function should be equivalent to

```
bool pred(const Type1 &a, const Type2 &b);
```

The signature does not need to have `const &`, but the function must not modify the objects passed to it. The types *Type1* and *Type2* must be such that objects of types *FwdIter1* and *FwdIter2* can be dereferenced and then implicitly converted to *Type1* and *Type2* respectively

- **proj1** – Specifies the function (or function object) which will be invoked for each of the elements of type dereferenced *FwdIter1* as a projection operation before the actual predicate *is* invoked.
- **proj2** – Specifies the function (or function object) which will be invoked for each of the elements of type dereferenced *FwdIter2* as a projection operation before the actual predicate *is* invoked.

Returns The *search_n* algorithm returns a *hpx::future<FwdIter>* if the execution policy is of type *task_execution_policy* and returns *FwdIter* otherwise. The *search_n* algorithm returns an iterator to the beginning of the last subsequence [*s_first*, *s_last*) in range [*first*, *first*+*count*). If the length of the subsequence [*s_first*, *s_last*) is greater than the length of the range [*first*, *first*+*count*), *first* is returned. Additionally if the size of the subsequence is empty or no subsequence is found, *first* is also returned.

```
template<typename Rng1, typename Rng2, typename Pred = hpx::ranges::equal_to, typename Proj1 =
hpx::identity, typename Proj2 = hpx::identity>
hpx::traits::range_iterator_t<Rng1> search_n(Rng1 &&rng1, std::size_t count, Rng2 &&rng2, Pred
&&op = Pred(), Proj1 &&proj1 = Proj1(), Proj2
&&proj2 = Proj2())
```

Searches the range [*first*, *last*) for any elements in the range [*s_first*, *s_last*). Uses a provided predicate to compare elements.

The comparison operations in the parallel *search* algorithm execute in sequential order in the calling thread.

Note: Complexity: at most (*S***N*) comparisons where *S* = distance(*s_first*, *s_last*) and *N* = dis-

tance(first, last).

Template Parameters

- **Rng1** – The type of the examine range used (deduced). The iterators extracted from this range type must meet the requirements of an input iterator.
- **Rng2** – The type of the search range used (deduced). The iterators extracted from this range type must meet the requirements of an input iterator.
- **Pred** – The type of an optional function/function object to use. Unlike its sequential form, the parallel overload of *adjacent_find* requires *Pred* to meet the requirements of *CopyConstructible*. This defaults to `std::equal_to<>`
- **Proj1** – The type of an optional projection function. This defaults to `hpx::identity` and is applied to the elements of *Rng1*.
- **Proj2** – The type of an optional projection function. This defaults to `hpx::identity` and is applied to the elements of *Rng2*.

Parameters

- **rng1** – Refers to the sequence of elements the algorithm will be examining.
- **count** – The number of elements to apply the algorithm on.
- **rng2** – Refers to the sequence of elements the algorithm will be searching for.
- **op** – Refers to the binary predicate which returns true if the elements should be treated as equal. the signature of the function should be equivalent to

```
bool pred(const Type1 &a, const Type2 &b);
```

The signature does not need to have `const &`, but the function must not modify the objects passed to it. The types *Type1* and *Type2* must be such that objects of types *FwdIter1* and *FwdIter2* can be dereferenced and then implicitly converted to *Type1* and *Type2* respectively

- **proj1** – Specifies the function (or function object) which will be invoked for each of the elements of *rng1* as a projection operation before the actual predicate *is* invoked.
- **proj2** – Specifies the function (or function object) which will be invoked for each of the elements of *rng2* as a projection operation before the actual predicate *is* invoked.

Returns The *search* algorithm returns a `hpx::future<FwdIter>` if the execution policy is of type *task_execution_policy* and returns *FwdIter* otherwise. The *search* algorithm returns an iterator to the beginning of the first subsequence [s_first, s_last) in range [first, last). If the length of the subsequence [s_first, s_last) is greater than the length of the range [first, last), *last* is returned. Additionally if the size of the subsequence is empty *first* is returned. If no subsequence is found, *last* is returned.

```
template<typename ExPolicy, typename Rng1, typename Rng2, typename Pred =
hpx::ranges::equal_to, typename Proj1 = hpx::identity, typename Proj2 = hpx::identity>
```

```

hpx::parallel::util::detail::algorithm_result<ExPolicy, hpx::traits::range_iterator_t<Rng1>> search_n(ExPolicy
&&pol-
icy,
Rng1
&&rng1,
std::size_t
count,
Rng2
&&rng2,
Pred
&&op
=
Pred(),
Proj1
&&proj1
=
Proj1(),
Proj2
&&proj2
=
Proj2())

```

Searches the range [first, last) for any elements in the range [s_first, s_last). Uses a provided predicate to compare elements.

The comparison operations in the parallel *search* algorithm invoked with an execution policy object of type *sequenced_policy* execute in sequential order in the calling thread.

The comparison operations in the parallel *search* algorithm invoked with an execution policy object of type *parallel_policy* or *parallel_task_policy* are permitted to execute in an unordered fashion in unspecified threads, and indeterminately sequenced within each thread.

Note: Complexity: at most ($S \cdot N$) comparisons where $S = \text{distance}(s_first, s_last)$ and $N = \text{distance}(first, last)$.

Template Parameters

- **ExPolicy** – The type of the execution policy to use (deduced). It describes the manner in which the execution of the algorithm may be parallelized and the manner in which it executes the assignments.
- **Rng1** – The type of the examine range used (deduced). The iterators extracted from this range type must meet the requirements of an input iterator.
- **Rng2** – The type of the search range used (deduced). The iterators extracted from this range type must meet the requirements of an input iterator.
- **Pred** – The type of an optional function/function object to use. Unlike its sequential form, the parallel overload of *adjacent_find* requires *Pred* to meet the requirements of *CopyConstructible*. This defaults to `std::equal_to<>`
- **Proj1** – The type of an optional projection function. This defaults to *hpx::identity* and is applied to the elements of *Rng1*.
- **Proj2** – The type of an optional projection function. This defaults to *hpx::identity* and is applied to the elements of *Rng2*.

Parameters

- **policy** – The execution policy to use for the scheduling of the iterations.
- **rng1** – Refers to the sequence of elements the algorithm will be examining.

- **count** – The number of elements to apply the algorithm on.
- **rng2** – Refers to the sequence of elements the algorithm will be searching for.
- **op** – Refers to the binary predicate which returns true if the elements should be treated as equal. the signature of the function should be equivalent to

```
bool pred(const Type1 &a, const Type2 &b);
```

The signature does not need to have `const &`, but the function must not modify the objects passed to it. The types *Type1* and *Type2* must be such that objects of types *FwdIter1* and *FwdIter2* can be dereferenced and then implicitly converted to *Type1* and *Type2* respectively

- **proj1** – Specifies the function (or function object) which will be invoked for each of the elements of *rng1* as a projection operation before the actual predicate *is* invoked.
- **proj2** – Specifies the function (or function object) which will be invoked for each of the elements of *rng2* as a projection operation before the actual predicate *is* invoked.

Returns The *search* algorithm returns a *hpx::future<FwdIter>* if the execution policy is of type *task_execution_policy* and returns *FwdIter* otherwise. The *search* algorithm returns an iterator to the beginning of the first subsequence [*s_first*, *s_last*) in range [*first*, *last*). If the length of the subsequence [*s_first*, *s_last*) is greater than the length of the range [*first*, *last*), *last* is returned. Additionally if the size of the subsequence is empty *first* is returned. If no subsequence is found, *last* is returned.

hpx::ranges::set_difference

Defined in header `hpx/algorithm.hpp`⁶⁷².

See *Public API* for a list of names and headers that are part of the public *HPX* API.

namespace **hpx**

namespace **ranges**

⁶⁷² <http://github.com/STELLAR-GROUP/hpx/blob/8a3b7c1a4cb5693b2f7d9f587f759392ed0c51a0/libs/full/include/include/hpx/algorithm.hpp>

Functions

```
template<typename ExPolicy, typename Iter1, typename Sent1, typename Iter2, typename Sent2,
typename Iter3, typename Pred = hpx::parallel::detail::less, typename Proj1 = hpx::identity, typename
Proj2 = hpx::identity>
```

```
hpx::parallel::util::detail::algorithm_result<ExPolicy, set_difference_result<Iter1, Iter3>>::type set_difference(ExPolicy
&&pol-
icy,
Iter1
first1,
Sent1
last1,
Iter2
first2,
Sent2
last2,
Iter3
dest,
Pred
&&op
=
Pred(),
Proj1
&&proj
=
Proj1()
Proj2
&&proj
=
Proj2()
```

Constructs a sorted range beginning at *dest* consisting of all elements present in the range $[first1, last1)$ and not present in the range $[first2, last2)$. This algorithm expects both input ranges to be sorted with the given binary predicate *f*.

Equivalent elements are treated individually, that is, if some element is found *m* times in $[first1, last1)$ and *n* times in $[first2, last2)$, it will be copied to *dest* exactly $\text{std::max}(m-n, 0)$ times. The resulting range cannot overlap with either of the input ranges.

The resulting range cannot overlap with either of the input ranges.

The application of function objects in parallel algorithm invoked with a sequential execution policy object execute in sequential order in the calling thread (*sequenced_policy*) or in a single new thread spawned from the current thread (for *sequenced_task_policy*).

The application of function objects in parallel algorithm invoked with an execution policy object of type *parallel_policy* or *parallel_task_policy* are permitted to execute in an unordered fashion in unspecified threads, and indeterminately sequenced within each thread.

Note: Complexity: At most $2 \cdot (N1 + N2 - 1)$ comparisons, where *N1* is the length of the first sequence and *N2* is the length of the second sequence.

Template Parameters

- **ExPolicy** – The type of the execution policy to use (deduced). It describes the manner in which the execution of the algorithm may be parallelized and the manner in which it applies user-provided function objects.
- **Iter1** – The type of the source iterators used (deduced) representing the first sequence. This iterator type must meet the requirements of an forward iterator.
- **Sent1** – The type of the end source iterators used (deduced). This iterator type must meet the requirements of an sentinel for Iter1.
- **Iter2** – The type of the source iterators used (deduced) representing the second sequence. This iterator type must meet the requirements of an forward iterator.
- **Sent2** – The type of the end source iterators used (deduced) representing the second sequence. This iterator type must meet the requirements of an sentinel for Iter2.
- **Iter3** – The type of the iterator representing the destination range (deduced). This iterator type must meet the requirements of an output iterator.
- **Pred** – The type of an optional function/function object to use. Unlike its sequential form, the parallel overload of *set_difference* requires *Pred* to meet the requirements of *CopyConstructible*. This defaults to `std::less<>`
- **Proj1** – The type of an optional projection function applied to the first sequence. This defaults to `hpx::identity`
- **Proj2** – The type of an optional projection function applied to the second sequence. This defaults to `hpx::identity`

Parameters

- **policy** – The execution policy to use for the scheduling of the iterations.
- **first1** – Refers to the beginning of the sequence of elements of the first range the algorithm will be applied to.
- **last1** – Refers to the end of the sequence of elements of the first range the algorithm will be applied to.
- **first2** – Refers to the beginning of the sequence of elements of the second range the algorithm will be applied to.
- **last2** – Refers to the end of the sequence of elements of the second range the algorithm will be applied to.
- **dest** – Refers to the beginning of the destination range.
- **op** – The binary predicate which returns true if the elements should be treated as equal. The signature of the predicate function should be equivalent to the following:

```
bool pred(const Type1 &a, const Type1 &b);
```

The signature does not need to have `const &`, but the function must not modify the objects passed to it. The type *Type1* must be such that objects of type *InIter* can be dereferenced and then implicitly converted to *Type1*

- **proj1** – Specifies the function (or function object) which will be invoked for each of the elements of the first sequence as a projection operation before the actual predicate *op* is invoked.
- **proj2** – Specifies the function (or function object) which will be invoked for each of the elements of the second sequence as a projection operation before the actual predicate *op* is invoked.

Returns The *set_difference* algorithm returns a `hpx::future<ranges::set_difference_result<Iter1, Iter3>>` if the execution policy is of type *sequenced_task_policy* or *parallel_task_policy* and returns `ranges::set_difference_result<Iter1, Iter3>` otherwise. The *set_difference* algorithm returns the output iterator to the element in the destination range, one past the last element copied.

```
template<typename ExPolicy, typename Rng1, typename Rng2, typename Iter3, typename Pred =
hpx::parallel::detail::less, typename Proj1 = hpx::identity, typename Proj2 = hpx::identity>
```

hpx::parallel::util::detail::algorithm_result<ExPolicy, set_difference_result<hpx::traits::range_iterator_t<Rng1>, Iter3>> se

Constructs a sorted range beginning at *dest* consisting of all elements present in the range [*first1*, *last1*) and not present in the range [*first2*, *last2*). This algorithm expects both input ranges to be sorted with the given binary predicate *f*.

Equivalent elements are treated individually, that is, if some element is found *m* times in [*first1*, *last1*) and *n* times in [*first2*, *last2*), it will be copied to *dest* exactly `std::max(m-n, 0)` times. The resulting range cannot overlap with either of the input ranges.

The resulting range cannot overlap with either of the input ranges.

The application of function objects in parallel algorithm invoked with a sequential execution policy object execute in sequential order in the calling thread (*sequenced_policy*) or in a single new thread spawned from the current thread (for *sequenced_task_policy*).

The application of function objects in parallel algorithm invoked with an execution policy object of type *parallel_policy* or *parallel_task_policy* are permitted to execute in an unordered fashion in unspecified threads, and indeterminately sequenced within each thread.

Note: Complexity: At most $2*(N1 + N2 - 1)$ comparisons, where *N1* is the length of the first sequence and *N2* is the length of the second sequence.

Template Parameters

- **ExPolicy** – The type of the execution policy to use (deduced). It describes the manner in which the execution of the algorithm may be parallelized and the manner in which it applies user-provided function objects.
- **Rng1** – The type of the source range used (deduced). The iterators extracted from this range type must meet the requirements of an input iterator.
- **Rng2** – The type of the source range used (deduced). The iterators extracted from this range type must meet the requirements of an input iterator.
- **Iter3** – The type of the iterator representing the destination range (deduced). This iterator type must meet the requirements of an output iterator.

- **Pred** – The type of an optional function/function object to use. Unlike its sequential form, the parallel overload of `set_difference` requires `Pred` to meet the requirements of `CopyConstructible`. This defaults to `std::less<>`
- **Proj1** – The type of an optional projection function applied to the first sequence. This defaults to `hpx::identity`
- **Proj2** – The type of an optional projection function applied to the second sequence. This defaults to `hpx::identity`

Parameters

- **policy** – The execution policy to use for the scheduling of the iterations.
- **rng1** – Refers to the first sequence of elements the algorithm will be applied to.
- **rng2** – Refers to the second sequence of elements the algorithm will be applied to.
- **dest** – Refers to the beginning of the destination range.
- **op** – The binary predicate which returns true if the elements should be treated as equal. The signature of the predicate function should be equivalent to the following:

```
bool pred(const Type1 &a, const Type1 &b);
```

The signature does not need to have `const &`, but the function must not modify the objects passed to it. The type `Type1` must be such that objects of type `Iter1` can be dereferenced and then implicitly converted to `Type1`

- **proj1** – Specifies the function (or function object) which will be invoked for each of the elements of the first sequence as a projection operation before the actual predicate `op` is invoked.
- **proj2** – Specifies the function (or function object) which will be invoked for each of the elements of the second sequence as a projection operation before the actual predicate `op` is invoked.

Returns The `set_difference` algorithm returns a `hpx::future<ranges::set_difference_result<Iter1, Iter3>>` if the execution policy is of type `sequenced_task_policy` or `parallel_task_policy` and returns `ranges::set_difference_result<Iter1, Iter3>` otherwise. where `Iter1` is `range_iterator_t<Rng1>` and `Iter2` is `range_iterator_t<Rng2>` The `set_difference` algorithm returns the output iterator to the element in the destination range, one past the last element copied.

```
template<typename Iter1, typename Sent1, typename Iter2, typename Sent2, typename Iter3,
typename Pred = hpx::parallel::detail::less, typename Proj1 = hpx::identity, typename Proj2 =
hpx::identity>
set_difference_result<Iter1, Iter3> set_difference(Iter1 first1, Sent1 last1, Iter2 first2, Sent2 last2,
Iter3 dest, Pred &&op = Pred(), Proj1 &&proj1 =
Proj1(), Proj2 &&proj2 = Proj2())
```

Constructs a sorted range beginning at `dest` consisting of all elements present in the range `[first1, last1)` and not present in the range `[first2, last2)`. This algorithm expects both input ranges to be sorted with the given binary predicate `f`.

Equivalent elements are treated individually, that is, if some element is found `m` times in `[first1, last1)` and `n` times in `[first2, last2)`, it will be copied to `dest` exactly `std::max(m-n, 0)` times. The resulting range cannot overlap with either of the input ranges.

The resulting range cannot overlap with either of the input ranges.

Note: Complexity: At most $2 \cdot (N1 + N2 - 1)$ comparisons, where $N1$ is the length of the first sequence and $N2$ is the length of the second sequence.

Template Parameters

- **Iter1** – The type of the source iterators used (deduced) representing the first sequence. This iterator type must meet the requirements of an forward iterator.
- **Sent1** – The type of the end source iterators used (deduced). This iterator type must meet the requirements of an sentinel for Iter1.
- **Iter2** – The type of the source iterators used (deduced) representing the second sequence. This iterator type must meet the requirements of an forward iterator.
- **Sent2** – The type of the end source iterators used (deduced) representing the second sequence. This iterator type must meet the requirements of an sentinel for Iter2.
- **Iter3** – The type of the iterator representing the destination range (deduced). This iterator type must meet the requirements of an output iterator.
- **Pred** – The type of an optional function/function object to use. Unlike its sequential form, the parallel overload of *set_difference* requires *Pred* to meet the requirements of *CopyConstructible*. This defaults to `std::less<>`
- **Proj1** – The type of an optional projection function applied to the first sequence. This defaults to `hpx::identity`
- **Proj2** – The type of an optional projection function applied to the second sequence. This defaults to `hpx::identity`

Parameters

- **first1** – Refers to the beginning of the sequence of elements of the first range the algorithm will be applied to.
- **last1** – Refers to the end of the sequence of elements of the first range the algorithm will be applied to.
- **first2** – Refers to the beginning of the sequence of elements of the second range the algorithm will be applied to.
- **last2** – Refers to the end of the sequence of elements of the second range the algorithm will be applied to.
- **dest** – Refers to the beginning of the destination range.
- **op** – The binary predicate which returns true if the elements should be treated as equal. The signature of the predicate function should be equivalent to the following:

```
bool pred(const Type1 &a, const Type1 &b);
```

The signature does not need to have `const &`, but the function must not modify the objects passed to it. The type *Type1* must be such that objects of type *InIter* can be dereferenced and then implicitly converted to *Type1*

- **proj1** – Specifies the function (or function object) which will be invoked for each of the elements of the first sequence as a projection operation before the actual predicate *op* is invoked.
- **proj2** – Specifies the function (or function object) which will be invoked for each of the elements of the second sequence as a projection operation before the actual predicate *op* is invoked.

Returns The *set_difference* algorithm returns `ranges::set_difference_result<Iter1, Iter3>`. The *set_difference* algorithm returns the output iterator to the element in the destination range, one past the last element copied.

```
template<typename Rng1, typename Rng2, typename Iter3, typename Pred = hpx::parallel::detail::less,
typename Proj1 = hpx::identity, typename Proj2 = hpx::identity>
set_difference_result<hpx::traits::range_iterator_t<Rng1>, Iter3> set_difference(Rng1 &&rng1,
                                                                              Rng2 &&rng2,
                                                                              Iter3 dest, Pred
                                                                              &&op = Pred(),
                                                                              Proj1 &&proj1 =
                                                                              Proj1(), Proj2
                                                                              &&proj2 =
                                                                              Proj2())
```

Constructs a sorted range beginning at *dest* consisting of all elements present in the range $[first1, last1)$ and not present in the range $[first2, last2)$. This algorithm expects both input ranges to be sorted with the given binary predicate *f*.

Equivalent elements are treated individually, that is, if some element is found *m* times in $[first1, last1)$ and *n* times in $[first2, last2)$, it will be copied to *dest* exactly $\text{std::max}(m-n, 0)$ times. The resulting range cannot overlap with either of the input ranges.

The resulting range cannot overlap with either of the input ranges.

Note: Complexity: At most $2*(N1 + N2 - 1)$ comparisons, where *N1* is the length of the first sequence and *N2* is the length of the second sequence.

Template Parameters

- **Rng1** – The type of the source range used (deduced). The iterators extracted from this range type must meet the requirements of an input iterator.
- **Rng2** – The type of the source range used (deduced). The iterators extracted from this range type must meet the requirements of an input iterator.
- **Iter3** – The type of the iterator representing the destination range (deduced). This iterator type must meet the requirements of an output iterator.
- **Pred** – The type of an optional function/function object to use. Unlike its sequential form, the parallel overload of *set_difference* requires *Pred* to meet the requirements of *CopyConstructible*. This defaults to `std::less<>`
- **Proj1** – The type of an optional projection function applied to the first sequence. This defaults to `hpx::identity`
- **Proj2** – The type of an optional projection function applied to the second sequence. This defaults to `hpx::identity`

Parameters

- **rng1** – Refers to the first sequence of elements the algorithm will be applied to.
- **rng2** – Refers to the second sequence of elements the algorithm will be applied to.
- **dest** – Refers to the beginning of the destination range.
- **op** – The binary predicate which returns true if the elements should be treated as equal. The signature of the predicate function should be equivalent to the following:

```
bool pred(const Type1 &a, const Type1 &b);
```

The signature does not need to have `const &`, but the function must not modify the objects passed to it. The type *Type1* must be such that objects of type *InIter* can be dereferenced and then implicitly converted to *Type1*

- **proj1** – Specifies the function (or function object) which will be invoked for each of the elements of the first sequence as a projection operation before the actual predicate *op* is invoked.
- **proj2** – Specifies the function (or function object) which will be invoked for each of the elements of the second sequence as a projection operation before the actual predicate *op* is invoked.

Returns The *set_difference* algorithm returns `ranges::set_difference_result<Iter1, Iter3>`, where *Iter1* is `range_iterator_t<Rng1>` and *Iter2* is `range_iterator_t<Rng2>`. The *set_difference* algorithm returns the output iterator to the element in the destination range, one past the last element copied.

hpx::ranges::set_intersection

Defined in header `hpx/algorithm.hpp`⁶⁷³.

See *Public API* for a list of names and headers that are part of the public HPX API.

```
namespace hpx
```

```
    namespace ranges
```

Functions

```
template<typename ExPolicy, typename Iter1, typename Sent1, typename Iter2, typename Sent2,  
        typename Iter3, typename Pred = hpx::parallel::detail::less, typename Proj1 = hpx::identity, typename  
Proj2 = hpx::identity>  
hpx::parallel::util::detail::algorithm_result<ExPolicy, set_intersection_result<Iter1, Iter2, Iter3>>::type set_intersection
```

Constructs a sorted range beginning at `dest` consisting of all elements present in both sorted ranges `[first1, last1)` and `[first2, last2)`. This algorithm expects both input ranges to be sorted with the given binary predicate *f*.

If some element is found *m* times in `[first1, last1)` and *n* times in `[first2, last2)`, the first `std::min(m, n)` elements will be copied from the first range to the destination range. The order of equivalent elements is preserved. The resulting range cannot overlap with either of the input ranges.

The resulting range cannot overlap with either of the input ranges.

⁶⁷³ <http://github.com/STELLAR-GROUP/hpx/blob/8a3b7c1a4cb5693b2f7d9f587f759392ed0c51a0/libs/full/include/include/hpx/algorithm.hpp>

The application of function objects in parallel algorithm invoked with a sequential execution policy object execute in sequential order in the calling thread (*sequenced_policy*) or in a single new thread spawned from the current thread (for *sequenced_task_policy*).

The application of function objects in parallel algorithm invoked with an execution policy object of type *parallel_policy* or *parallel_task_policy* are permitted to execute in an unordered fashion in unspecified threads, and indeterminately sequenced within each thread.

Note: Complexity: At most $2*(N1 + N2 - 1)$ comparisons, where $N1$ is the length of the first sequence and $N2$ is the length of the second sequence.

Template Parameters

- **ExPolicy** – The type of the execution policy to use (deduced). It describes the manner in which the execution of the algorithm may be parallelized and the manner in which it applies user-provided function objects.
- **Iter1** – The type of the source iterators used (deduced) representing the first sequence. This iterator type must meet the requirements of an forward iterator.
- **Sent1** – The type of the end source iterators used (deduced). This iterator type must meet the requirements of an sentinel for Iter1.
- **Iter2** – The type of the source iterators used (deduced) representing the second sequence. This iterator type must meet the requirements of an forward iterator.
- **Sent2** – The type of the end source iterators used (deduced) representing the second sequence. This iterator type must meet the requirements of an sentinel for Iter2.
- **Iter3** – The type of the iterator representing the destination range (deduced). This iterator type must meet the requirements of an output iterator.
- **Pred** – The type of an optional function/function object to use. Unlike its sequential form, the parallel overload of *set_intersection* requires *Pred* to meet the requirements of *CopyConstructible*. This defaults to `std::less<>`
- **Proj1** – The type of an optional projection function applied to the first sequence. This defaults to `hpx::identity`
- **Proj2** – The type of an optional projection function applied to the second sequence. This defaults to `hpx::identity`

Parameters

- **policy** – The execution policy to use for the scheduling of the iterations.
- **first1** – Refers to the beginning of the sequence of elements of the first range the algorithm will be applied to.
- **last1** – Refers to the end of the sequence of elements of the first range the algorithm will be applied to.
- **first2** – Refers to the beginning of the sequence of elements of the second range the algorithm will be applied to.
- **last2** – Refers to the end of the sequence of elements of the second range the algorithm will be applied to.
- **dest** – Refers to the beginning of the destination range.
- **op** – The binary predicate which returns true if the elements should be treated as equal. The signature of the predicate function should be equivalent to the following:

```
bool pred(const Type1 &a, const Type1 &b);
```

The signature does not need to have `const &`, but the function must not modify the objects passed to it. The type *Type1* must be such that objects of type *InIter* can be dereferenced and then implicitly converted to *Type1*

- **proj1** – Specifies the function (or function object) which will be invoked for each of the elements of the first sequence as a projection operation before the actual predicate *op* is invoked.

- **proj2** – Specifies the function (or function object) which will be invoked for each of the elements of the second sequence as a projection operation before the actual predicate *op* is invoked.

Returns The *set_intersection* algorithm returns a `hpx::future<ranges::set_intersection_result<Iter1, Iter2, Iter3>>` if the execution policy is of type *sequenced_task_policy* or *parallel_task_policy* and returns `ranges::set_intersection_result<Iter1, Iter2, Iter3>` otherwise. The *set_intersection* algorithm returns the output iterator to the element in the destination range, one past the last element copied.

```
template<typename ExPolicy, typename Rng1, typename Rng2, typename Iter3, typename Pred =  
hpx::parallel::detail::less, typename Proj1 = hpx::identity, typename Proj2 = hpx::identity>  
hpx::parallel::util::detail::algorithm_result<ExPolicy, set_intersection_result<hpx::traits::range_iterator_t<Rng1>, hpx::tra
```

Constructs a sorted range beginning at *dest* consisting of all elements present in both sorted ranges [*first1*, *last1*) and [*first2*, *last2*). This algorithm expects both input ranges to be sorted with the given binary predicate *f*.

If some element is found *m* times in [*first1*, *last1*) and *n* times in [*first2*, *last2*), the first `std::min(m, n)` elements will be copied from the first range to the destination range. The order of equivalent elements is preserved. The resulting range cannot overlap with either of the input ranges.

The resulting range cannot overlap with either of the input ranges.

The application of function objects in parallel algorithm invoked with a sequential execution policy object execute in sequential order in the calling thread (*sequenced_policy*) or in a single new thread spawned from the current thread (for *sequenced_task_policy*).

The application of function objects in parallel algorithm invoked with an execution policy object of type *parallel_policy* or *parallel_task_policy* are permitted to execute in an unordered fashion in unspecified threads, and indeterminately sequenced within each thread.

Note: Complexity: At most $2*(N1 + N2 - 1)$ comparisons, where *N1* is the length of the first sequence and *N2* is the length of the second sequence.

Template Parameters

- **ExPolicy** – The type of the execution policy to use (deduced). It describes the manner in which the execution of the algorithm may be parallelized and the manner in which it applies user-provided function objects.
- **Rng1** – The type of the source range used (deduced). The iterators extracted from this range type must meet the requirements of an input iterator.
- **Rng2** – The type of the source range used (deduced). The iterators extracted from this range type must meet the requirements of an input iterator.
- **Iter3** – The type of the iterator representing the destination range (deduced). This iterator type must meet the requirements of an output iterator.
- **Pred** – The type of an optional function/function object to use. Unlike its sequential form, the parallel overload of *set_intersection* requires *Pred* to meet the requirements of *CopyConstructible*. This defaults to `std::less<>`
- **Proj1** – The type of an optional projection function applied to the first sequence. This defaults to `hpx::identity`
- **Proj2** – The type of an optional projection function applied to the second sequence. This defaults to `hpx::identity`

Parameters

- **policy** – The execution policy to use for the scheduling of the iterations.
- **rng1** – Refers to the first sequence of elements the algorithm will be applied to.
- **rng2** – Refers to the second sequence of elements the algorithm will be applied to.
- **dest** – Refers to the beginning of the destination range.
- **op** – The binary predicate which returns true if the elements should be treated as equal. The signature of the predicate function should be equivalent to the following:

```
bool pred(const Type1 &a, const Type1 &b);
```

The signature does not need to have `const &`, but the function must not modify the objects passed to it. The type *Type1* must be such that objects of type *InIter* can be dereferenced and then implicitly converted to *Type1*

- **proj1** – Specifies the function (or function object) which will be invoked for each of the elements of the first sequence as a projection operation before the actual predicate *op* is invoked.
- **proj2** – Specifies the function (or function object) which will be invoked for each of the elements of the second sequence as a projection operation before the actual predicate *op* is invoked.

Returns The *set_intersection* algorithm returns a `hpx::future<ranges::set_intersection_result<Iter1, Iter2, Iter3>>` if the execution policy is of type *sequenced_task_policy* or *parallel_task_policy* and returns `ranges::set_intersection_result<Iter1, Iter2, Iter3>` otherwise. where *Iter1* is `range_iterator_t<Rng1>` and *Iter2* is `range_iterator_t<Rng2>` The *set_intersection* algorithm returns the output iterator to the element in the destination range, one past the last element copied.

```
template<typename Iter1, typename Sent1, typename Iter2, typename Sent2, typename Iter3,
typename Pred = hpx::parallel::detail::less, typename Proj1 = hpx::identity, typename Proj2 =
hpx::identity>
set_intersection_result<Iter1, Iter2, Iter3> set_intersection(Iter1 first1, Sent1 last1, Iter2 first2,
Sent2 last2, Iter3 dest, Pred &&op =
Pred(), Proj1 &&proj1 = Proj1(), Proj2
&&proj2 = Proj2())
```

Constructs a sorted range beginning at *dest* consisting of all elements present in both sorted ranges [*first1*, *last1*) and [*first2*, *last2*). This algorithm expects both input ranges to be sorted with the given binary predicate *f*.

If some element is found m times in $[first1, last1)$ and n times in $[first2, last2)$, the first $\text{std::min}(m, n)$ elements will be copied from the first range to the destination range. The order of equivalent elements is preserved. The resulting range cannot overlap with either of the input ranges.

The resulting range cannot overlap with either of the input ranges.

Note: Complexity: At most $2*(N1 + N2 - 1)$ comparisons, where $N1$ is the length of the first sequence and $N2$ is the length of the second sequence.

Template Parameters

- **Iter1** – The type of the source iterators used (deduced) representing the first sequence. This iterator type must meet the requirements of an forward iterator.
- **Sent1** – The type of the end source iterators used (deduced). This iterator type must meet the requirements of an sentinel for Iter1.
- **Iter2** – The type of the source iterators used (deduced) representing the second sequence. This iterator type must meet the requirements of an forward iterator.
- **Sent2** – The type of the end source iterators used (deduced) representing the second sequence. This iterator type must meet the requirements of an sentinel for Iter2.
- **Iter3** – The type of the iterator representing the destination range (deduced). This iterator type must meet the requirements of an output iterator.
- **Pred** – The type of an optional function/function object to use. Unlike its sequential form, the parallel overload of *set_intersection* requires *Pred* to meet the requirements of *CopyConstructible*. This defaults to `std::less<>`
- **Proj1** – The type of an optional projection function applied to the first sequence. This defaults to `hpx::identity`
- **Proj2** – The type of an optional projection function applied to the second sequence. This defaults to `hpx::identity`

Parameters

- **first1** – Refers to the beginning of the sequence of elements of the first range the algorithm will be applied to.
- **last1** – Refers to the end of the sequence of elements of the first range the algorithm will be applied to.
- **first2** – Refers to the beginning of the sequence of elements of the second range the algorithm will be applied to.
- **last2** – Refers to the end of the sequence of elements of the second range the algorithm will be applied to.
- **dest** – Refers to the beginning of the destination range.
- **op** – The binary predicate which returns true if the elements should be treated as equal. The signature of the predicate function should be equivalent to the following:

```
bool pred(const Type1 &a, const Type1 &b);
```

The signature does not need to have `const &`, but the function must not modify the objects passed to it. The type *Type1* must be such that objects of type *InIter* can be dereferenced and then implicitly converted to *Type1*

- **proj1** – Specifies the function (or function object) which will be invoked for each of the elements of the first sequence as a projection operation before the actual predicate *op* is invoked.
- **proj2** – Specifies the function (or function object) which will be invoked for each of the elements of the second sequence as a projection operation before the actual predicate *op* is invoked.

Returns The *set_intersection* algorithm returns `ranges::set_intersection_result<Iter1, Iter2, Iter3>`. The *set_intersection* algorithm returns the output iterator to the element in the destination range, one past the last element copied.

```
template<typename Rng1, typename Rng2, typename Iter3, typename Pred = hpx::parallel::detail::less,
typename Proj1 = hpx::identity, typename Proj2 = hpx::identity>
set_intersection_result<hpx::traits::range_iterator_t<Rng1>, hpx::traits::range_iterator_t<Rng2>, Iter3> set_intersection
```

Constructs a sorted range beginning at *dest* consisting of all elements present in both sorted ranges [*first1*, *last1*) and [*first2*, *last2*). This algorithm expects both input ranges to be sorted with the given binary predicate *f*.

If some element is found *m* times in [*first1*, *last1*) and *n* times in [*first2*, *last2*), the first $\text{std::min}(m, n)$ elements will be copied from the first range to the destination range. The order of equivalent elements is preserved. The resulting range cannot overlap with either of the input ranges.

The resulting range cannot overlap with either of the input ranges.

Note: Complexity: At most $2 \cdot (N1 + N2 - 1)$ comparisons, where *N1* is the length of the first sequence and *N2* is the length of the second sequence.

Template Parameters

- **Rng1** – The type of the source range used (deduced). The iterators extracted from this range type must meet the requirements of an input iterator.
- **Rng2** – The type of the source range used (deduced). The iterators extracted from this range type must meet the requirements of an input iterator.
- **Iter3** – The type of the iterator representing the destination range (deduced). This iterator type must meet the requirements of an output iterator.
- **Pred** – The type of an optional function/function object to use. Unlike its sequential form, the parallel overload of *set_intersection* requires *Pred* to meet the requirements of *CopyConstructible*. This defaults to `std::less<>`
- **Proj1** – The type of an optional projection function applied to the first sequence. This defaults to `hpx::identity`
- **Proj2** – The type of an optional projection function applied to the second sequence. This defaults to `hpx::identity`

Parameters

- **rng1** – Refers to the first sequence of elements the algorithm will be applied to.
- **rng2** – Refers to the second sequence of elements the algorithm will be applied to.
- **dest** – Refers to the beginning of the destination range.
- **op** – The binary predicate which returns true if the elements should be treated as equal.

The signature of the predicate function should be equivalent to the following:

```
bool pred(const Type1 &a, const Type1 &b);
```

The signature does not need to have `const &`, but the function must not modify the objects passed to it. The type *Type1* must be such that objects of type *Iter1* can be dereferenced and then implicitly converted to *Type1*

- **proj1** – Specifies the function (or function object) which will be invoked for each of the elements of the first sequence as a projection operation before the actual predicate *op* is invoked.
- **proj2** – Specifies the function (or function object) which will be invoked for each of the elements of the second sequence as a projection operation before the actual predicate *op* is invoked.

Returns The *set_intersection* algorithm returns *ranges::set_intersection_result<Iter1, Iter2, Iter3>*. where *Iter1* is *range_iterator_t<Rng1>* and *Iter2* is *range_iterator_t<Rng2>* The *set_intersection* algorithm returns the output iterator to the element in the destination range, one past the last element copied.

hpx::ranges::set_symmetric_difference

Defined in header `hpx/algorithm.hpp`⁶⁷⁴.

See *Public API* for a list of names and headers that are part of the public *HPX* API.

```
namespace hpx
```

```
    namespace ranges
```

Functions

```
template<typename ExPolicy, typename Iter1, typename Sent1, typename Iter2, typename Sent2,  
        typename Iter3, typename Pred = hpx::parallel::detail::less, typename Proj1 = hpx::identity, typename  
        Proj2 = hpx::identity>
```

⁶⁷⁴ <http://github.com/STELLAR-GROUP/hpx/blob/8a3b7c1a4cb5693b2f7d9f587f759392ed0c51a0/libs/full/include/include/hpx/algorithm.hpp>

hpx::parallel::util::detail::algorithm_result<ExPolicy, set_symmetric_difference_result<Iter1, Iter2, Iter3>>>::type set_symm

Constructs a sorted range beginning at *dest* consisting of all elements present in either of the sorted ranges *[first1, last1)* and *[first2, last2)*, but not in both of them are copied to the range beginning at *dest*. The resulting range is also sorted. This algorithm expects both input ranges to be sorted with the given binary predicate *f*.

If some element is found *m* times in *[first1, last1)* and *n* times in *[first2, last2)*, it will be copied to *dest* exactly $\text{std::abs}(m-n)$ times. If $m > n$, then the last $m-n$ of those elements are copied from *[first1, last1)*, otherwise the last $n-m$ elements are copied from *[first2, last2)*. The resulting range cannot overlap with either of the input ranges.

The resulting range cannot overlap with either of the input ranges.

The application of function objects in parallel algorithm invoked with a sequential execution policy object execute in sequential order in the calling thread (*sequenced_policy*) or in a single new thread spawned from the current thread (for *sequenced_task_policy*).

The application of function objects in parallel algorithm invoked with an execution policy object of type *parallel_policy* or *parallel_task_policy* are permitted to execute in an unordered fashion in unspecified threads, and indeterminately sequenced within each thread.

Note: Complexity: At most $2 \cdot (N1 + N2 - 1)$ comparisons, where *N1* is the length of the first sequence and *N2* is the length of the second sequence.

Template Parameters

- **ExPolicy** – The type of the execution policy to use (deduced). It describes the manner in which the execution of the algorithm may be parallelized and the manner in which it applies user-provided function objects.

- **Iter1** – The type of the source iterators used (deduced) representing the first sequence. This iterator type must meet the requirements of an forward iterator.
- **Sent1** – The type of the end source iterators used (deduced). This iterator type must meet the requirements of an sentinel for Iter1.
- **Iter2** – The type of the source iterators used (deduced) representing the second sequence. This iterator type must meet the requirements of an forward iterator.
- **Sent2** – The type of the end source iterators used (deduced) representing the second sequence. This iterator type must meet the requirements of an sentinel for Iter2.
- **Iter3** – The type of the iterator representing the destination range (deduced). This iterator type must meet the requirements of an output iterator.
- **Pred** – The type of an optional function/function object to use. Unlike its sequential form, the parallel overload of *set_symmetric_difference* requires *Pred* to meet the requirements of *CopyConstructible*. This defaults to `std::less<>`
- **Proj1** – The type of an optional projection function applied to the first sequence. This defaults to `hpx::identity`
- **Proj2** – The type of an optional projection function applied to the second sequence. This defaults to `hpx::identity`

Parameters

- **policy** – The execution policy to use for the scheduling of the iterations.
- **first1** – Refers to the beginning of the sequence of elements of the first range the algorithm will be applied to.
- **last1** – Refers to the end of the sequence of elements of the first range the algorithm will be applied to.
- **first2** – Refers to the beginning of the sequence of elements of the second range the algorithm will be applied to.
- **last2** – Refers to the end of the sequence of elements of the second range the algorithm will be applied to.
- **dest** – Refers to the beginning of the destination range.
- **op** – The binary predicate which returns true if the elements should be treated as equal. The signature of the predicate function should be equivalent to the following:

```
bool pred(const Type1 &a, const Type1 &b);
```

The signature does not need to have `const &`, but the function must not modify the objects passed to it. The type *Type1* must be such that objects of type *InIter* can be dereferenced and then implicitly converted to *Type1*

- **proj1** – Specifies the function (or function object) which will be invoked for each of the elements of the first sequence as a projection operation before the actual predicate *op* is invoked.
- **proj2** – Specifies the function (or function object) which will be invoked for each of the elements of the second sequence as a projection operation before the actual predicate *op* is invoked.

Returns The *set_symmetric_difference* algorithm returns a `hpx::future<ranges::set_symmetric_difference_result<Iter1, Iter2, Iter3>>` if the execution policy is of type *sequenced_task_policy* or *parallel_task_policy* and returns `ranges::set_symmetric_difference_result<Iter1, Iter2, Iter3>` otherwise. The *set_symmetric_difference* algorithm returns the output iterator to the element in the destination range, one past the last element copied.

```
template<typename ExPolicy, typename Rng1, typename Rng2, typename Iter3, typename Pred =
hpx::parallel::detail::less, typename Proj1 = hpx::identity, typename Proj2 = hpx::identity>
```

hpx::parallel::util::detail::algorithm_result<ExPolicy, set_symmetric_difference_result<hpx::traits::range_iterator_t<Rng1>

Constructs a sorted range beginning at *dest* consisting of all elements present in either of the sorted ranges *[first1, last1)* and *[first2, last2)*, but not in both of them are copied to the range beginning at *dest*. The resulting range is also sorted. This algorithm expects both input ranges to be sorted with the given binary predicate *f*.

If some element is found *m* times in *[first1, last1)* and *n* times in *[first2, last2)*, it will be copied to *dest* exactly $\text{std::abs}(m-n)$ times. If $m > n$, then the last $m-n$ of those elements are copied from *[first1, last1)*, otherwise the last $n-m$ elements are copied from *[first2, last2)*. The resulting range cannot overlap with either of the input ranges.

The resulting range cannot overlap with either of the input ranges.

The application of function objects in parallel algorithm invoked with a sequential execution policy object execute in sequential order in the calling thread (*sequenced_policy*) or in a single new thread spawned from the current thread (for *sequenced_task_policy*).

The application of function objects in parallel algorithm invoked with an execution policy object of type *parallel_policy* or *parallel_task_policy* are permitted to execute in an unordered fashion in unspecified threads, and indeterminately sequenced within each thread.

Note: Complexity: At most $2 \cdot (N1 + N2 - 1)$ comparisons, where *N1* is the length of the first sequence and *N2* is the length of the second sequence.

Template Parameters

- **ExPolicy** – The type of the execution policy to use (deduced). It describes the manner in which the execution of the algorithm may be parallelized and the manner in which it applies user-provided function objects.
- **Rng1** – The type of the source range used (deduced). The iterators extracted from this range type must meet the requirements of an input iterator.
- **Rng2** – The type of the source range used (deduced). The iterators extracted from this range type must meet the requirements of an input iterator.

- **Iter3** – The type of the iterator representing the destination range (deduced). This iterator type must meet the requirements of an output iterator.
- **Pred** – The type of an optional function/function object to use. Unlike its sequential form, the parallel overload of `set_symmetric_difference` requires `Pred` to meet the requirements of `CopyConstructible`. This defaults to `std::less<>`
- **Proj1** – The type of an optional projection function applied to the first sequence. This defaults to `hpx::identity`
- **Proj2** – The type of an optional projection function applied to the second sequence. This defaults to `hpx::identity`

Parameters

- **policy** – The execution policy to use for the scheduling of the iterations.
- **rng1** – Refers to the first sequence of elements the algorithm will be applied to.
- **rng2** – Refers to the second sequence of elements the algorithm will be applied to.
- **dest** – Refers to the beginning of the destination range.
- **op** – The binary predicate which returns true if the elements should be treated as equal. The signature of the predicate function should be equivalent to the following:

```
bool pred(const Type1 &a, const Type1 &b);
```

The signature does not need to have `const &`, but the function must not modify the objects passed to it. The type `Type1` must be such that objects of type `InIter` can be dereferenced and then implicitly converted to `Type1`

- **proj1** – Specifies the function (or function object) which will be invoked for each of the elements of the first sequence as a projection operation before the actual predicate `op` is invoked.
- **proj2** – Specifies the function (or function object) which will be invoked for each of the elements of the second sequence as a projection operation before the actual predicate `op` is invoked.

Returns The `set_symmetric_difference` algorithm returns a `hpx::future<ranges::set_symmetric_difference_result<Iter1, Iter2, Iter3>>` if the execution policy is of type `sequenced_task_policy` or `parallel_task_policy` and returns `ranges::set_symmetric_difference_result<Iter1, Iter2, Iter3>` otherwise. where `Iter1` is `range_iterator_t<Rng1>` and `Iter2` is `range_iterator_t<Rng2>` The `set_symmetric_difference` algorithm returns the output iterator to the element in the destination range, one past the last element copied.

```
template<typename Iter1, typename Sent1, typename Iter2, typename Sent2, typename Iter3,
typename Pred = hpx::parallel::detail::less, typename Proj1 = hpx::identity, typename Proj2 =
hpx::identity>
set_symmetric_difference_result<Iter1, Iter2, Iter3> set_symmetric_difference(Iter1 first1, Sent1
last1, Iter2 first2,
Sent2 last2, Iter3
dest, Pred &&op =
Pred(), Proj1
&&proj1 = Proj1(),
Proj2 &&proj2 =
Proj2())
```

Constructs a sorted range beginning at `dest` consisting of all elements present in either of the sorted ranges `[first1, last1)` and `[first2, last2)`, but not in both of them are copied to the range beginning at `dest`. The resulting range is also sorted. This algorithm expects both input ranges to be sorted with the given binary predicate `f`.

If some element is found m times in `[first1, last1)` and n times in `[first2, last2)`, it will be copied to `dest`

exactly `std::abs(m-n)` times. If $m > n$, then the last $m-n$ of those elements are copied from `[first1,last1)`, otherwise the last $n-m$ elements are copied from `[first2,last2)`. The resulting range cannot overlap with either of the input ranges.

The resulting range cannot overlap with either of the input ranges.

Note: Complexity: At most $2 \cdot (N1 + N2 - 1)$ comparisons, where $N1$ is the length of the first sequence and $N2$ is the length of the second sequence.

Template Parameters

- **Iter1** – The type of the source iterators used (deduced) representing the first sequence. This iterator type must meet the requirements of an forward iterator.
- **Sent1** – The type of the end source iterators used (deduced). This iterator type must meet the requirements of an sentinel for `Iter1`.
- **Iter2** – The type of the source iterators used (deduced) representing the second sequence. This iterator type must meet the requirements of an forward iterator.
- **Sent2** – The type of the end source iterators used (deduced) representing the second sequence. This iterator type must meet the requirements of an sentinel for `Iter2`.
- **Iter3** – The type of the iterator representing the destination range (deduced). This iterator type must meet the requirements of an output iterator.
- **Pred** – The type of an optional function/function object to use. Unlike its sequential form, the parallel overload of `set_symmetric_difference` requires `Pred` to meet the requirements of `CopyConstructible`. This defaults to `std::less<>`
- **Proj1** – The type of an optional projection function applied to the first sequence. This defaults to `hpx::identity`
- **Proj2** – The type of an optional projection function applied to the second sequence. This defaults to `hpx::identity`

Parameters

- **first1** – Refers to the beginning of the sequence of elements of the first range the algorithm will be applied to.
- **last1** – Refers to the end of the sequence of elements of the first range the algorithm will be applied to.
- **first2** – Refers to the beginning of the sequence of elements of the second range the algorithm will be applied to.
- **last2** – Refers to the end of the sequence of elements of the second range the algorithm will be applied to.
- **dest** – Refers to the beginning of the destination range.
- **op** – The binary predicate which returns true if the elements should be treated as equal. The signature of the predicate function should be equivalent to the following:

```
bool pred(const Type1 &a, const Type1 &b);
```

The signature does not need to have `const &`, but the function must not modify the objects passed to it. The type `Type1` must be such that objects of type `InIter` can be dereferenced and then implicitly converted to `Type1`

- **proj1** – Specifies the function (or function object) which will be invoked for each of the elements of the first sequence as a projection operation before the actual predicate `op` is invoked.
- **proj2** – Specifies the function (or function object) which will be invoked for each of the elements of the second sequence as a projection operation before the actual predicate `op` is invoked.

Returns The `set_symmetric_difference` algorithm returns `ranges::set_symmetric_difference_result<Iter1, Iter2, Iter3>`. The `set_symmetric_difference` algorithm returns the output iterator to the element in the

destination range, one past the last element copied.

```
template<typename Rng1, typename Rng2, typename Iter3, typename Pred = hpx::parallel::detail::less,
typename Proj1 = hpx::identity, typename Proj2 = hpx::identity>
set_symmetric_difference_result<hpx::traits::range_iterator_t<Rng1>, hpx::traits::range_iterator_t<Rng2>, Iter3> set_sym
```

Constructs a sorted range beginning at *dest* consisting of all elements present in either of the sorted ranges $[first1, last1)$ and $[first2, last2)$, but not in both of them are copied to the range beginning at *dest*. The resulting range is also sorted. This algorithm expects both input ranges to be sorted with the given binary predicate *f*.

If some element is found *m* times in $[first1, last1)$ and *n* times in $[first2, last2)$, it will be copied to *dest* exactly $\text{std::abs}(m-n)$ times. If $m > n$, then the last $m-n$ of those elements are copied from $[first1, last1)$, otherwise the last $n-m$ elements are copied from $[first2, last2)$. The resulting range cannot overlap with either of the input ranges.

The resulting range cannot overlap with either of the input ranges.

Note: Complexity: At most $2 \cdot (N1 + N2 - 1)$ comparisons, where *N1* is the length of the first sequence and *N2* is the length of the second sequence.

Template Parameters

- **Rng1** – The type of the source range used (deduced). The iterators extracted from this range type must meet the requirements of an input iterator.
- **Rng2** – The type of the source range used (deduced). The iterators extracted from this range type must meet the requirements of an input iterator.
- **Iter3** – The type of the iterator representing the destination range (deduced). This iterator type must meet the requirements of an output iterator.
- **Pred** – The type of an optional function/function object to use. Unlike its sequential form, the parallel overload of *set_symmetric_difference* requires *Pred* to meet the requirements of *CopyConstructible*. This defaults to `std::less<>`
- **Proj1** – The type of an optional projection function applied to the first sequence. This defaults to `hpx::identity`
- **Proj2** – The type of an optional projection function applied to the second sequence. This defaults to `hpx::identity`

Parameters

- **rng1** – Refers to the first sequence of elements the algorithm will be applied to.

- **rng2** – Refers to the second sequence of elements the algorithm will be applied to.
- **dest** – Refers to the beginning of the destination range.
- **op** – The binary predicate which returns true if the elements should be treated as equal. The signature of the predicate function should be equivalent to the following:

```
bool pred(const Type1 &a, const Type1 &b);
```

The signature does not need to have `const &`, but the function must not modify the objects passed to it. The type *Type1* must be such that objects of type *InIter* can be dereferenced and then implicitly converted to *Type1*

- **proj1** – Specifies the function (or function object) which will be invoked for each of the elements of the first sequence as a projection operation before the actual predicate *op* is invoked.
- **proj2** – Specifies the function (or function object) which will be invoked for each of the elements of the second sequence as a projection operation before the actual predicate *op* is invoked.

Returns The *set_symmetric_difference* algorithm returns *ranges::set_symmetric_difference_result<Iter1, Iter2, Iter3>*. where *Iter1* is *range_iterator_t<Rng1>* and *Iter2* is *range_iterator_t<Rng2>* The *set_symmetric_difference* algorithm returns the output iterator to the element in the destination range, one past the last element copied.

hpx::ranges::set_union

Defined in header `hpx/algorithm.hpp`⁶⁷⁵.

See *Public API* for a list of names and headers that are part of the public *HPX* API.

namespace **hpx**

namespace **ranges**

⁶⁷⁵ <http://github.com/STELLAR-GROUP/hpx/blob/8a3b7c1a4cb5693b2f7d9f587f759392ed0c51a0/libs/full/include/include/hpx/algorithm.hpp>

Functions

```

template<typename ExPolicy, typename Iter1, typename Sent1, typename Iter2, typename Sent2,
typename Iter3, typename Pred = hpx::parallel::detail::less, typename Proj1 = hpx::identity, typename
Proj2 = hpx::identity>
hpx::parallel::util::detail::algorithm_result<ExPolicy, set_union_result<Iter1, Iter2, Iter3>>::type set_union(ExPolicy
&&pol-
icy,
Iter1
first1,
Sent1
last1,
Iter2
first2,
Sent2
last2,
Iter3
dest,
Pred
&&op
=
Pred()
Proj1
&&proj1
=
Proj1()
Proj2
&&proj2
=
Proj2())

```

Constructs a sorted range beginning at `dest` consisting of all elements present in one or both sorted ranges `[first1, last1)` and `[first2, last2)`. This algorithm expects both input ranges to be sorted with the given binary predicate `f`.

If some element is found m times in `[first1, last1)` and n times in `[first2, last2)`, then all m elements will be copied from `[first1, last1)` to `dest`, preserving order, and then exactly $\text{std::max}(n-m, 0)$ elements will be copied from `[first2, last2)` to `dest`, also preserving order.

The resulting range cannot overlap with either of the input ranges.

The application of function objects in parallel algorithm invoked with a sequential execution policy object execute in sequential order in the calling thread (*sequenced_policy*) or in a single new thread spawned from the current thread (for *sequenced_task_policy*).

The application of function objects in parallel algorithm invoked with an execution policy object of type *parallel_policy* or *parallel_task_policy* are permitted to execute in an unordered fashion in unspecified threads, and indeterminately sequenced within each thread.

Note: Complexity: At most $2 \cdot (N1 + N2 - 1)$ comparisons, where $N1$ is the length of the first sequence and $N2$ is the length of the second sequence.

Template Parameters

- **ExPolicy** – The type of the execution policy to use (deduced). It describes the manner in which the execution of the algorithm may be parallelized and the manner in which it applies user-provided function objects.
- **Iter1** – The type of the source iterators used (deduced) representing the first sequence. This iterator type must meet the requirements of an forward iterator.
- **Sent1** – The type of the end source iterators used (deduced). This iterator type must meet the requirements of an sentinel for Iter1.
- **Iter2** – The type of the source iterators used (deduced) representing the second sequence. This iterator type must meet the requirements of an forward iterator.
- **Sent2** – The type of the end source iterators used (deduced) representing the second sequence. This iterator type must meet the requirements of an sentinel for Iter2.
- **Iter3** – The type of the iterator representing the destination range (deduced). This iterator type must meet the requirements of an output iterator.
- **Pred** – The type of an optional function/function object to use. Unlike its sequential form, the parallel overload of *set_union* requires *Pred* to meet the requirements of *CopyConstructible*. This defaults to `std::less<>`
- **Proj1** – The type of an optional projection function applied to the first sequence. This defaults to `hpx::identity`
- **Proj2** – The type of an optional projection function applied to the second sequence. This defaults to `hpx::identity`

Parameters

- **policy** – The execution policy to use for the scheduling of the iterations.
- **first1** – Refers to the beginning of the sequence of elements of the first range the algorithm will be applied to.
- **last1** – Refers to the end of the sequence of elements of the first range the algorithm will be applied to.
- **first2** – Refers to the beginning of the sequence of elements of the second range the algorithm will be applied to.
- **last2** – Refers to the end of the sequence of elements of the second range the algorithm will be applied to.
- **dest** – Refers to the beginning of the destination range.
- **op** – The binary predicate which returns true if the elements should be treated as equal. The signature of the predicate function should be equivalent to the following:

```
bool pred(const Type1 &a, const Type1 &b);
```

The signature does not need to have `const &`, but the function must not modify the objects passed to it. The type *Type1* must be such that objects of type *InIter* can be dereferenced and then implicitly converted to *Type1*

- **proj1** – Specifies the function (or function object) which will be invoked for each of the elements of the first sequence as a projection operation before the actual predicate *op* is invoked.
- **proj2** – Specifies the function (or function object) which will be invoked for each of the elements of the second sequence as a projection operation before the actual predicate *op* is invoked.

Returns The *set_union* algorithm returns a `hpx::future<ranges::set_union_result<Iter1, Iter2, Iter3>>` if the execution policy is of type *sequenced_task_policy* or *parallel_task_policy* and returns `ranges::set_union_result<Iter1, Iter2, Iter3>` otherwise. The *set_union* algorithm returns the output iterator to the element in the destination range, one past the last element copied.

```
template<typename ExPolicy, typename Rng1, typename Rng2, typename Iter3, typename Pred =
hpx::parallel::detail::less, typename Proj1 = hpx::identity, typename Proj2 = hpx::identity>
```

hpx::parallel::util::detail::algorithm_result<ExPolicy, set_union_result<hpx::traits::range_iterator_t<Rng1>, hpx::traits::ran

Constructs a sorted range beginning at *dest* consisting of all elements present in one or both sorted ranges *[first1, last1)* and *[first2, last2)*. This algorithm expects both input ranges to be sorted with the given binary predicate *f*.

If some element is found *m* times in *[first1, last1)* and *n* times in *[first2, last2)*, then all *m* elements will be copied from *[first1, last1)* to *dest*, preserving order, and then exactly `std::max(n-m, 0)` elements will be copied from *[first2, last2)* to *dest*, also preserving order.

The resulting range cannot overlap with either of the input ranges.

The application of function objects in parallel algorithm invoked with a sequential execution policy object execute in sequential order in the calling thread (*sequenced_policy*) or in a single new thread spawned from the current thread (for *sequenced_task_policy*).

The application of function objects in parallel algorithm invoked with an execution policy object of type *parallel_policy* or *parallel_task_policy* are permitted to execute in an unordered fashion in unspecified threads, and indeterminately sequenced within each thread.

Note: Complexity: At most $2*(N1 + N2 - 1)$ comparisons, where *N1* is the length of the first sequence and *N2* is the length of the second sequence.

Template Parameters

- **ExPolicy** – The type of the execution policy to use (deduced). It describes the manner in which the execution of the algorithm may be parallelized and the manner in which it applies user-provided function objects.
- **Rng1** – The type of the source range used (deduced). The iterators extracted from this range type must meet the requirements of an input iterator.
- **Rng2** – The type of the source range used (deduced). The iterators extracted from this range type must meet the requirements of an input iterator.
- **Iter3** – The type of the iterator representing the destination range (deduced). This iterator type must meet the requirements of an output iterator.

- **Pred** – The type of an optional function/function object to use. Unlike its sequential form, the parallel overload of `set_union` requires `Pred` to meet the requirements of `CopyConstructible`. This defaults to `std::less<>`
- **Proj1** – The type of an optional projection function applied to the first sequence. This defaults to `hpx::identity`
- **Proj2** – The type of an optional projection function applied to the second sequence. This defaults to `hpx::identity`

Parameters

- **policy** – The execution policy to use for the scheduling of the iterations.
- **rng1** – Refers to the first sequence of elements the algorithm will be applied to.
- **rng2** – Refers to the second sequence of elements the algorithm will be applied to.
- **dest** – Refers to the beginning of the destination range.
- **op** – The binary predicate which returns true if the elements should be treated as equal. The signature of the predicate function should be equivalent to the following:

```
bool pred(const Type1 &a, const Type1 &b);
```

The signature does not need to have `const &`, but the function must not modify the objects passed to it. The type `Type1` must be such that objects of type `Iter1` can be dereferenced and then implicitly converted to `Type1`

- **proj1** – Specifies the function (or function object) which will be invoked for each of the elements of the first sequence as a projection operation before the actual predicate `op` is invoked.
- **proj2** – Specifies the function (or function object) which will be invoked for each of the elements of the second sequence as a projection operation before the actual predicate `op` is invoked.

Returns The `set_union` algorithm returns a `hpx::future<ranges::set_union_result<Iter1, Iter2, Iter3>>` if the execution policy is of type `sequenced_task_policy` or `parallel_task_policy` and returns `ranges::set_union_result<Iter1, Iter2, Iter3>` otherwise. where `Iter1` is `range_iterator_t<Rng1>` and `Iter2` is `range_iterator_t<Rng2>` The `set_union` algorithm returns the output iterator to the element in the destination range, one past the last element copied.

```
template<typename Iter1, typename Sent1, typename Iter2, typename Sent2, typename Iter3,
typename Pred = hpx::parallel::detail::less, typename Proj1 = hpx::identity, typename Proj2 =
hpx::identity>
set_union_result<Iter1, Iter2, Iter3> tag_fallback_invoke(set_union_t, Iter1 first1, Sent1 last1, Iter2
first2, Sent2 last2, Iter3 dest, Pred &&op
= Pred(), Proj1 &&proj1 = Proj1(), Proj2
&&proj2 = Proj2())
```

Constructs a sorted range beginning at `dest` consisting of all elements present in one or both sorted ranges `[first1, last1)` and `[first2, last2)`. This algorithm expects both input ranges to be sorted with the given binary predicate `f`.

If some element is found m times in `[first1, last1)` and n times in `[first2, last2)`, then all m elements will be copied from `[first1, last1)` to `dest`, preserving order, and then exactly `std::max(n-m, 0)` elements will be copied from `[first2, last2)` to `dest`, also preserving order.

The resulting range cannot overlap with either of the input ranges.

Note: Complexity: At most $2*(N1 + N2 - 1)$ comparisons, where $N1$ is the length of the first sequence and $N2$ is the length of the second sequence.

Template Parameters

- **Iter1** – The type of the source iterators used (deduced) representing the first sequence. This iterator type must meet the requirements of an forward iterator.
- **Sent1** – The type of the end source iterators used (deduced). This iterator type must meet the requirements of an sentinel for Iter1.
- **Iter2** – The type of the source iterators used (deduced) representing the second sequence. This iterator type must meet the requirements of an forward iterator.
- **Sent2** – The type of the end source iterators used (deduced) representing the second sequence. This iterator type must meet the requirements of an sentinel for Iter2.
- **Iter3** – The type of the iterator representing the destination range (deduced). This iterator type must meet the requirements of an output iterator.
- **Pred** – The type of an optional function/function object to use. Unlike its sequential form, the parallel overload of *set_union* requires *Pred* to meet the requirements of *CopyConstructible*. This defaults to `std::less<>`
- **Proj1** – The type of an optional projection function applied to the first sequence. This defaults to `hpx::identity`
- **Proj2** – The type of an optional projection function applied to the second sequence. This defaults to `hpx::identity`

Parameters

- **first1** – Refers to the beginning of the sequence of elements of the first range the algorithm will be applied to.
- **last1** – Refers to the end of the sequence of elements of the first range the algorithm will be applied to.
- **first2** – Refers to the beginning of the sequence of elements of the second range the algorithm will be applied to.
- **last2** – Refers to the end of the sequence of elements of the second range the algorithm will be applied to.
- **dest** – Refers to the beginning of the destination range.
- **op** – The binary predicate which returns true if the elements should be treated as equal. The signature of the predicate function should be equivalent to the following:

```
bool pred(const Type1 &a, const Type1 &b);
```

The signature does not need to have `const &`, but the function must not modify the objects passed to it. The type *Type1* must be such that objects of type *InIter* can be dereferenced and then implicitly converted to *Type1*

- **proj1** – Specifies the function (or function object) which will be invoked for each of the elements of the first sequence as a projection operation before the actual predicate *op* is invoked.
- **proj2** – Specifies the function (or function object) which will be invoked for each of the elements of the second sequence as a projection operation before the actual predicate *op* is invoked.

Returns The *set_union* algorithm returns `ranges::set_union_result<Iter1, Iter2, Iter3>`. The *set_union* algorithm returns the output iterator to the element in the destination range, one past the last element copied.

```
template<typename Rng1, typename Rng2, typename Iter3, typename Pred = hpx::parallel::detail::less,
typename Proj1 = hpx::identity, typename Proj2 = hpx::identity>
```

```

set_union_result<hpx::traits::range_iterator_t<Rng1>, hpx::traits::range_iterator_t<Rng2>, Iter3> set_union(Rng1
&&rng1,
Rng2
&&rng2,
Iter3
dest,
Pred
&&op
=
Pred(),
Proj1
&&proj1
=
Proj1(),
Proj2
&&proj2
=
Proj2())

```

Constructs a sorted range beginning at *dest* consisting of all elements present in one or both sorted ranges [*first1*, *last1*) and [*first2*, *last2*). This algorithm expects both input ranges to be sorted with the given binary predicate *f*.

If some element is found *m* times in [*first1*, *last1*) and *n* times in [*first2*, *last2*), then all *m* elements will be copied from [*first1*, *last1*) to *dest*, preserving order, and then exactly `std::max(n-m, 0)` elements will be copied from [*first2*, *last2*) to *dest*, also preserving order.

The resulting range cannot overlap with either of the input ranges.

Note: Complexity: At most $2*(N1 + N2 - 1)$ comparisons, where *N1* is the length of the first sequence and *N2* is the length of the second sequence.

Template Parameters

- **Rng1** – The type of the source range used (deduced). The iterators extracted from this range type must meet the requirements of an input iterator.
- **Rng2** – The type of the source range used (deduced). The iterators extracted from this range type must meet the requirements of an input iterator.
- **Iter3** – The type of the iterator representing the destination range (deduced). This iterator type must meet the requirements of an output iterator.
- **Pred** – The type of an optional function/function object to use. Unlike its sequential form, the parallel overload of *set_union* requires *Pred* to meet the requirements of *CopyConstructible*. This defaults to `std::less<>`
- **Proj1** – The type of an optional projection function applied to the first sequence. This defaults to `hpx::identity`
- **Proj2** – The type of an optional projection function applied to the second sequence. This defaults to `hpx::identity`

Parameters

- **rng1** – Refers to the first sequence of elements the algorithm will be applied to.
- **rng2** – Refers to the second sequence of elements the algorithm will be applied to.
- **dest** – Refers to the beginning of the destination range.
- **op** – The binary predicate which returns true if the elements should be treated as equal. The signature of the predicate function should be equivalent to the following:

```
bool pred(const Type1 &a, const Type1 &b);
```

The signature does not need to have `const &`, but the function must not modify the objects passed to it. The type *Type1* must be such that objects of type *InIter* can be dereferenced and then implicitly converted to *Type1*

- **proj1** – Specifies the function (or function object) which will be invoked for each of the elements of the first sequence as a projection operation before the actual predicate *op* is invoked.
- **proj2** – Specifies the function (or function object) which will be invoked for each of the elements of the second sequence as a projection operation before the actual predicate *op* is invoked.

Returns The *set_union* algorithm returns *ranges::set_union_result<Iter1, Iter2, Iter3>*, where *Iter1* is *range_iterator_t<Rng1>* and *Iter2* is *range_iterator_t<Rng2>*. The *set_union* algorithm returns the output iterator to the element in the destination range, one past the last element copied.

hpx::ranges::shift_left

Defined in header `hpx/algorithm.hpp`⁶⁷⁶.

See *Public API* for a list of names and headers that are part of the public HPX API.

namespace **hpx**

namespace **ranges**

Functions

template<typename **FwdIter**, typename **Sent**, typename **Size**>

FwdIter **shift_left**(*FwdIter* first, *Sent* last, *Size* n)

Shifts the elements in the range [first, last) by *n* positions towards the beginning of the range. For every integer *i* in [0, last - first

- *n*), moves the element originally at position first + *n* + *i* to position first + *i*.

The assignment operations in the parallel *shift_left* algorithm invoked without an execution policy object will execute in sequential order in the calling thread.

Note: Complexity: At most (last - first) - *n* assignments.

Note: The type of dereferenced *FwdIter* must meet the requirements of *MoveAssignable*.

Template Parameters

- **FwdIter** – The type of the source iterators used (deduced). This iterator type must meet the requirements of an forward iterator.
- **Sent** – The type of the source sentinel (deduced). This sentinel type must be a sentinel for *FwdIter*.

⁶⁷⁶ <http://github.com/STELLAR-GROUP/hpx/blob/8a3b7c1a4cb5693b2f7d9f587f759392ed0c51a0/libs/full/include/include/hpx/algorithm.hpp>

- **Size** – The type of the argument specifying the number of positions to shift by.

Parameters

- **first** – Refers to the beginning of the sequence of elements the algorithm will be applied to.
- **last** – Refers to sentinel value denoting the end of the sequence of elements the algorithm will be applied.
- **n** – Refers to the number of positions to shift.

Returns The *shift_left* algorithm returns *FwdIter*. The *shift_left* algorithm returns an iterator to the end of the resulting range.

```
template<typename ExPolicy, typename FwdIter, typename Sent, typename Size>
hpx::parallel::util::detail::algorithm_result_t<ExPolicy, FwdIter> shift_left(ExPolicy &&policy,
                                                                    FwdIter first, Sent last,
                                                                    Size n)
```

Shifts the elements in the range [first, last) by n positions towards the beginning of the range. For every integer i in [0, last - first

- n), moves the element originally at position first + n + i to position first + i.

The assignment operations in the parallel *shift_left* algorithm invoked with an execution policy object of type *sequenced_policy* execute in sequential order in the calling thread.

The assignment operations in the parallel *shift_left* algorithm invoked with an execution policy object of type *parallel_policy* or *parallel_task_policy* are permitted to execute in an unordered fashion in unspecified threads, and indeterminately sequenced within each thread.

Note: Complexity: At most (last - first) - n assignments.

Note: The type of dereferenced *FwdIter* must meet the requirements of *MoveAssignable*.

Template Parameters

- **ExPolicy** – The type of the execution policy to use (deduced). It describes the manner in which the execution of the algorithm may be parallelized and the manner in which it executes the assignments.
- **FwdIter** – The type of the source iterators used (deduced). This iterator type must meet the requirements of an forward iterator.
- **Sent** – The type of the source sentinel (deduced). This sentinel type must be a sentinel for *FwdIter*.
- **Size** – The type of the argument specifying the number of positions to shift by.

Parameters

- **policy** – The execution policy to use for the scheduling of the iterations.
- **first** – Refers to the beginning of the sequence of elements the algorithm will be applied to.
- **last** – Refers to sentinel value denoting the end of the sequence of elements the algorithm will be applied.
- **n** – Refers to the number of positions to shift.

Returns The *shift_left* algorithm returns a *hpx::future<FwdIter>* if the execution policy is of type *sequenced_task_policy* or *parallel_task_policy* and returns *FwdIter* otherwise. The *shift_left* algorithm returns an iterator to the end of the resulting range.

```
template<typename Rng, typename Size>
hpx::traits::range_iterator_t<Rng> shift_left(Rng &&rng, Size n)
```

Shifts the elements in the range [first, last) by n positions towards the beginning of the range. For every

integer *i* in [0, last - first

- *n*), moves the element originally at position first + *n* + *i* to position first + *i*.

The assignment operations in the parallel *shift_left* algorithm invoked without an execution policy object will execute in sequential order in the calling thread.

Note: Complexity: At most (last - first) - *n* assignments.

Note: The type of dereferenced *hpx::traits::range_iterator_t<Rng>* must meet the requirements of *MoveAssignable*.

Template Parameters

- **Rng** – The type of the range used (deduced). The iterators extracted from this range type must meet the requirements of an forward iterator.
- **Size** – The type of the argument specifying the number of positions to shift by.

Parameters

- **rng** – Refers to the range in which the elements will be shifted.
- **n** – Refers to the number of positions to shift.

Returns The *shift_left* algorithm returns *hpx::traits::range_iterator_t<Rng>*. The *shift_left* algorithm returns an iterator to the end of the resulting range.

```
template<typename ExPolicy, typename Rng, typename Size>
parallel::util::detail::algorithm_result<ExPolicy, hpx::traits::range_iterator_t<Rng>> shift_left(ExPolicy
                                                                                               &&pol-
                                                                                               icy,
                                                                                               Rng
                                                                                               &&rng,
                                                                                               Size
                                                                                               n)
```

Shifts the elements in the range [first, last) by *n* positions towards the beginning of the range. For every integer *i* in [0, last - first

- *n*), moves the element originally at position first + *n* + *i* to position first + *i*.

The assignment operations in the parallel *shift_left* algorithm invoked with an execution policy object of type *sequenced_policy* execute in sequential order in the calling thread.

The assignment operations in the parallel *shift_left* algorithm invoked with an execution policy object of type *parallel_policy* or *parallel_task_policy* are permitted to execute in an unordered fashion in unspecified threads, and indeterminately sequenced within each thread.

Note: Complexity: At most (last - first) - *n* assignments.

Note: The type of dereferenced *hpx::traits::range_iterator_t<Rng>* must meet the requirements of *MoveAssignable*.

Template Parameters

- **ExPolicy** – The type of the execution policy to use (deduced). It describes the manner in which the execution of the algorithm may be parallelized and the manner in which it executes the assignments.

- **Rng** – The type of the range used (deduced). The iterators extracted from this range type must meet the requirements of an forward iterator.
- **Size** – The type of the argument specifying the number of positions to shift by.

Parameters

- **policy** – The execution policy to use for the scheduling of the iterations.
- **rng** – Refers to the range in which the elements will be shifted.
- **n** – Refers to the number of positions to shift.

Returns The *shift_left* algorithm returns a `hpx::future<hpx::traits::range_iterator_t<Rng>>` if the execution policy is of type *sequenced_task_policy* or *parallel_task_policy* and returns `hpx::traits::range_iterator_t<Rng>` otherwise. The *shift_left* algorithm returns an iterator to the end of the resulting range.

hpx::ranges::shift_right

Defined in header `hpx/algorithm.hpp`⁶⁷⁷.

See *Public API* for a list of names and headers that are part of the public HPX API.

namespace **hpx**

namespace **ranges**

Functions

template<typename **FwdIter**, typename **Sent**, typename **Size**>
FwdIter **shift_right**(*FwdIter* first, *Sent* last, *Size* n)

Shifts the elements in the range [first, last) by n positions towards the end of the range. For every integer i in [0, last - first - n), moves the element originally at position first + i to position first

- n + i.

The assignment operations in the parallel *shift_right* algorithm invoked without an execution policy object will execute in sequential order in the calling thread.

Note: Complexity: At most (last - first) - n assignments.

Note: The type of dereferenced *FwdIter* must meet the requirements of *MoveAssignable*.

Template Parameters

- **FwdIter** – The type of the source iterators used (deduced). This iterator type must meet the requirements of an forward iterator.
- **Sent** – The type of the source sentinel (deduced). This sentinel type must be a sentinel for *FwdIter*.
- **Size** – The type of the argument specifying the number of positions to shift by.

Parameters

- **first** – Refers to the beginning of the sequence of elements the algorithm will be applied to.

⁶⁷⁷ <http://github.com/STELLAR-GROUP/hpx/blob/8a3b7c1a4cb5693b2f7d9f587f759392ed0c51a0/libs/full/include/include/hpx/algorithm.hpp>

- **last** – Refers to sentinel value denoting the end of the sequence of elements the algorithm will be applied.
- **n** – Refers to the number of positions to shift.

Returns The *shift_right* algorithm returns *FwdIter*. The *shift_right* algorithm returns an iterator to the end of the resulting range.

```
template<typename ExPolicy, typename FwdIter, typename Sent, typename Size>  
hpx::parallel::util::detail::algorithm_result_t<ExPolicy, FwdIter> shift_right(ExPolicy &&policy,  
                                     FwdIter first, Sent last,  
                                     Size n)
```

Shifts the elements in the range [first, last) by n positions towards the end of the range. For every integer i in [0, last - first - n), moves the element originally at position first + i to position first

- n + i.

The assignment operations in the parallel *shift_right* algorithm invoked with an execution policy object of type *sequenced_policy* execute in sequential order in the calling thread.

The assignment operations in the parallel *shift_right* algorithm invoked with an execution policy object of type *parallel_policy* or *parallel_task_policy* are permitted to execute in an unordered fashion in unspecified threads, and indeterminately sequenced within each thread.

Note: Complexity: At most (last - first) - n assignments.

Note: The type of dereferenced *FwdIter* must meet the requirements of *MoveAssignable*.

Template Parameters

- **ExPolicy** – The type of the execution policy to use (deduced). It describes the manner in which the execution of the algorithm may be parallelized and the manner in which it executes the assignments.
- **FwdIter** – The type of the source iterators used (deduced). This iterator type must meet the requirements of an forward iterator.
- **Sent** – The type of the source sentinel (deduced). This sentinel type must be a sentinel for *FwdIter*.
- **Size** – The type of the argument specifying the number of positions to shift by.

Parameters

- **policy** – The execution policy to use for the scheduling of the iterations.
- **first** – Refers to the beginning of the sequence of elements the algorithm will be applied to.
- **last** – Refers to sentinel value denoting the end of the sequence of elements the algorithm will be applied.
- **n** – Refers to the number of positions to shift.

Returns The *shift_right* algorithm returns a *hpx::future<FwdIter>* if the execution policy is of type *sequenced_task_policy* or *parallel_task_policy* and returns *FwdIter* otherwise. The *shift_right* algorithm returns an iterator to the end of the resulting range.

```
template<typename Rng, typename Size>  
hpx::traits::range_iterator_t<Rng> shift_right(Rng &&rng, Size n)
```

Shifts the elements in the range [first, last) by n positions towards the end of the range. For every integer i in [0, last - first - n), moves the element originally at position first + i to position first

- n + i.

The assignment operations in the parallel *shift_right* algorithm invoked without an execution policy object will execute in sequential order in the calling thread.

Note: Complexity: At most (last - first) - n assignments.

Note: The type of dereferenced *hpx::traits::range_iterator_t<Rng>* must meet the requirements of *MoveAssignable*.

Template Parameters

- **Rng** – The type of the range used (deduced). The iterators extracted from this range type must meet the requirements of an forward iterator.
- **Size** – The type of the argument specifying the number of positions to shift by.

Parameters

- **rng** – Refers to the range in which the elements will be shifted.
- **n** – Refers to the number of positions to shift.

Returns The *shift_right* algorithm returns *hpx::traits::range_iterator_t<Rng>*. The *shift_right* algorithm returns an iterator to the end of the resulting range.

```
template<typename ExPolicy, typename Rng, typename Size>
parallel::util::detail::algorithm_result<ExPolicy, hpx::traits::range_iterator_t<Rng>> shift_right(ExPolicy
                                                                                               &&pol-
                                                                                               icy,
                                                                                               Rng
                                                                                               &&rng,
                                                                                               Size
                                                                                               n)
```

Shifts the elements in the range [first, last) by n positions towards the end of the range. For every integer i in [0, last - first - n), moves the element originally at position first + i to position first

- n + i.

The assignment operations in the parallel *shift_right* algorithm invoked with an execution policy object of type *sequenced_policy* execute in sequential order in the calling thread.

The assignment operations in the parallel *shift_right* algorithm invoked with an execution policy object of type *parallel_policy* or *parallel_task_policy* are permitted to execute in an unordered fashion in unspecified threads, and indeterminately sequenced within each thread.

Note: Complexity: At most (last - first) - n assignments.

Note: The type of dereferenced *hpx::traits::range_iterator_t<Rng>* must meet the requirements of *MoveAssignable*.

Template Parameters

- **ExPolicy** – The type of the execution policy to use (deduced). It describes the manner in which the execution of the algorithm may be parallelized and the manner in which it executes the assignments.
- **Rng** – The type of the range used (deduced). The iterators extracted from this range type must meet the requirements of an forward iterator.
- **Size** – The type of the argument specifying the number of positions to shift by.

Parameters

- **policy** – The execution policy to use for the scheduling of the iterations.
- **rng** – Refers to the range in which the elements will be shifted.
- **n** – Refers to the number of positions to shift.

Returns The *shift_right* algorithm returns a `hpx::future<hpx::traits::range_iterator_t<Rng>>` if the execution policy is of type *sequenced_task_policy* or *parallel_task_policy* and returns `hpx::traits::range_iterator_t<Rng>` otherwise. The *shift_right* algorithm returns an iterator to the end of the resulting range.

hpx::ranges::sort

Defined in header `hpx/algorithm.hpp`⁶⁷⁸.

See *Public API* for a list of names and headers that are part of the public HPX API.

namespace **hpx**

namespace **ranges**

Functions

```
template<typename RandomIt, typename Sent, typename Comp = ranges::less, typename Proj = hpx::identity>
```

```
RandomIt sort(RandomIt first, Sent last, Comp &&comp = Comp(), Proj &&proj = Proj())
```

Sorts the elements in the range [first, last) in ascending order. The order of equal elements is not guaranteed to be preserved. The function uses the given comparison function object comp (defaults to using operator<()).

A sequence is sorted with respect to a comparator *comp* and a projection *proj* if for every iterator *i* pointing to the sequence and every non-negative integer *n* such that *i + n* is a valid iterator pointing to an element of the sequence, and `INVOKE(comp, INVOKE(proj, *(i + n)), INVOKE(proj, *i)) == false`.

comp has to induce a strict weak ordering on the values.

The assignments in the parallel *sort* algorithm invoked without an execution policy object execute in sequential order in the calling thread.

Note: Complexity: $O(N \log(N))$, where $N = \text{detail::distance}(\text{first}, \text{last})$ comparisons.

Template Parameters

- **RandomIt** – The type of the source iterators used (deduced). This iterator type must meet the requirements of a random iterator.
- **Sent** – The type of the source sentinel (deduced). This sentinel type must be a sentinel for *RandomIt*.
- **Comp** – The type of the function/function object to use (deduced).
- **Proj** – The type of an optional projection function. This defaults to `hpx::identity`

Parameters

⁶⁷⁸ <http://github.com/STELLAR-GROUP/hpx/blob/8a3b7c1a4cb5693b2f7d9f587f759392ed0c51a0/libs/full/include/include/hpx/algorithm.hpp>

- **first** – Refers to the beginning of the sequence of elements the algorithm will be applied to.
- **last** – Refers to sentinel value denoting the end of the sequence of elements the algorithm will be applied.
- **comp** – `comp` is a callable object. The return value of the INVOKE operation applied to an object of type `Comp`, when contextually converted to `bool`, yields `true` if the first argument of the call is less than the second, and `false` otherwise. It is assumed that `comp` will not apply any non-constant function through the dereferenced iterator.
- **proj** – Specifies the function (or function object) which will be invoked for each pair of elements as a projection operation before the actual predicate `comp` is invoked.

Returns The `sort` algorithm returns `RandomIt`. The algorithm returns an iterator pointing to the first element after the last element in the input sequence.

```
template<typename ExPolicy, typename RandomIt, typename Sent, typename Comp = ranges::less,
        typename Proj = hpx::identity>
parallel::util::detail::algorithm_result<ExPolicy, RandomIt>::type sort(ExPolicy &&policy, RandomIt
                                                                    first, Sent last, Comp &&comp
                                                                    = Comp(), Proj &&proj =
                                                                    Proj())
```

Sorts the elements in the range `[first, last)` in ascending order. The order of equal elements is not guaranteed to be preserved. The function uses the given comparison function object `comp` (defaults to using `operator<()`).

A sequence is sorted with respect to a comparator `comp` and a projection `proj` if for every iterator `i` pointing to the sequence and every non-negative integer `n` such that `i + n` is a valid iterator pointing to an element of the sequence, and `INVOKE(comp, INVOKE(proj, *(i + n)), INVOKE(proj, *i)) == false`.

`comp` has to induce a strict weak ordering on the values.

The application of function objects in parallel algorithm invoked with an execution policy object of type `sequenced_policy` execute in sequential order in the calling thread.

The application of function objects in parallel algorithm invoked with an execution policy object of type `parallel_policy` or `parallel_task_policy` are permitted to execute in an unordered fashion in unspecified threads, and indeterminately sequenced within each thread.

Note: Complexity: $O(N \log(N))$, where $N = \text{detail::distance}(\text{first}, \text{last})$ comparisons.

Template Parameters

- **ExPolicy** – The type of the execution policy to use (deduced). It describes the manner in which the execution of the algorithm may be parallelized and the manner in which it executes the assignments.
- **RandomIt** – The type of the source iterators used (deduced). This iterator type must meet the requirements of a random iterator.
- **Sent** – The type of the source sentinel (deduced). This sentinel type must be a sentinel for `RandomIt`.
- **Comp** – The type of the function/function object to use (deduced).
- **Proj** – The type of an optional projection function. This defaults to `hpx::identity`

Parameters

- **policy** – The execution policy to use for the scheduling of the iterations.
- **first** – Refers to the beginning of the sequence of elements the algorithm will be applied to.

- **last** – Refers to sentinel value denoting the end of the sequence of elements the algorithm will be applied.
- **comp** – `comp` is a callable object. The return value of the INVOKE operation applied to an object of type `Comp`, when contextually converted to `bool`, yields `true` if the first argument of the call is less than the second, and `false` otherwise. It is assumed that `comp` will not apply any non-constant function through the dereferenced iterator.
- **proj** – Specifies the function (or function object) which will be invoked for each pair of elements as a projection operation before the actual predicate `comp` is invoked.

Returns The `sort` algorithm returns a `hpx::future<RandomIt>` if the execution policy is of type `sequenced_task_policy` or `parallel_task_policy` and returns `RandomIt` otherwise. The algorithm returns an iterator pointing to the first element after the last element in the input sequence.

```
template<typename Rng, typename Comp, typename Proj>
hpx::traits::range_iterator_t<Rng> sort(Rng &&rng, Comp &&comp = Comp(), Proj &&proj = Proj())
```

Sorts the elements in the range `rng` in ascending order. The order of equal elements is not guaranteed to be preserved. The function uses the given comparison function object `comp` (defaults to using `operator<()`).

A sequence is sorted with respect to a comparator `comp` and a projection `proj` if for every iterator `i` pointing to the sequence and every non-negative integer `n` such that `i + n` is a valid iterator pointing to an element of the sequence, and `INVOKE(comp, INVOKE(proj, *(i + n)), INVOKE(proj, *i)) == false`.

`comp` has to induce a strict weak ordering on the values.

The assignments in the parallel `sort` algorithm invoked without an execution policy object execute in sequential order in the calling thread.

Note: Complexity: $O(N \log(N))$, where $N = \text{std::distance}(\text{begin}(\text{rng}), \text{end}(\text{rng}))$ comparisons.

Template Parameters

- **Rng** – The type of the source range used (deduced). The iterators extracted from this range type must meet the requirements of an input iterator.
- **Comp** – The type of the function/function object to use (deduced).
- **Proj** – The type of an optional projection function. This defaults to `hpx::identity`

Parameters

- **rng** – Refers to the sequence of elements the algorithm will be applied to.
- **comp** – `comp` is a callable object. The return value of the INVOKE operation applied to an object of type `Comp`, when contextually converted to `bool`, yields `true` if the first argument of the call is less than the second, and `false` otherwise. It is assumed that `comp` will not apply any non-constant function through the dereferenced iterator.
- **proj** – Specifies the function (or function object) which will be invoked for each pair of elements as a projection operation before the actual predicate `comp` is invoked.

Returns The `sort` algorithm returns `hpx::traits::range_iterator_t<Rng>`. It returns `last`.

```
template<typename ExPolicy, typename Rng, typename Comp = ranges::less, typename Proj =
hpx::identity>
```

```

parallel::util::detail::algorithm_result<ExPolicy, hpx::traits::range_iterator_t<Rng>> sort(ExPolicy
                                                                    &&policy,
                                                                    Rng &&rng,
                                                                    Comp
                                                                    &&comp =
                                                                    Comp(), Proj
                                                                    &&proj =
                                                                    Proj())

```

Sorts the elements in the range *rng* in ascending order. The order of equal elements is not guaranteed to be preserved. The function uses the given comparison function object *comp* (defaults to using `operator<()`).

A sequence is sorted with respect to a comparator *comp* and a projection *proj* if for every iterator *i* pointing to the sequence and every non-negative integer *n* such that *i* + *n* is a valid iterator pointing to an element of the sequence, and `INVOKE(comp, INVOKE(proj, *(i + n)), INVOKE(proj, *i)) == false`.

comp has to induce a strict weak ordering on the values.

The application of function objects in parallel algorithm invoked with an execution policy object of type *sequenced_policy* execute in sequential order in the calling thread.

The application of function objects in parallel algorithm invoked with an execution policy object of type *parallel_policy* or *parallel_task_policy* are permitted to execute in an unordered fashion in unspecified threads, and indeterminately sequenced within each thread.

Note: Complexity: $O(N \log(N))$, where $N = \text{std::distance}(\text{begin}(\text{rng}), \text{end}(\text{rng}))$ comparisons.

Template Parameters

- **ExPolicy** – The type of the execution policy to use (deduced). It describes the manner in which the execution of the algorithm may be parallelized and the manner in which it applies user-provided function objects.
- **Rng** – The type of the source range used (deduced). The iterators extracted from this range type must meet the requirements of an input iterator.
- **Comp** – The type of the function/function object to use (deduced).
- **Proj** – The type of an optional projection function. This defaults to *hpx::identity*

Parameters

- **policy** – The execution policy to use for the scheduling of the iterations.
- **rng** – Refers to the sequence of elements the algorithm will be applied to.
- **comp** – *comp* is a callable object. The return value of the INVOKE operation applied to an object of type *Comp*, when contextually converted to `bool`, yields `true` if the first argument of the call is less than the second, and `false` otherwise. It is assumed that *comp* will not apply any non-constant function through the dereferenced iterator.
- **proj** – Specifies the function (or function object) which will be invoked for each pair of elements as a projection operation before the actual predicate *comp* is invoked.

Returns The *sort* algorithm returns a *hpx::future<hpx::traits::range_iterator_t<Rng>* if the execution policy is of type *sequenced_task_policy* or *parallel_task_policy* and returns *hpx::traits::range_iterator_t<Rng>* otherwise. It returns *last*.

hpx::ranges::stable_sort

Defined in header `hpx/algorithm.hpp`⁶⁷⁹.

See *Public API* for a list of names and headers that are part of the public HPX API.

namespace **hpx**

namespace **ranges**

Functions

```
template<typename RandomIt, typename Sent, typename Comp = ranges::less, typename Proj = hpx::identity>
```

```
RandomIt stable_sort(RandomIt first, Sent last, Comp &&comp = Comp(), Proj &&proj = Proj())
```

Sorts the elements in the range `[first, last)` in ascending order. The relative order of equal elements is preserved. The function uses the given comparison function object `comp` (defaults to using operator`<()`).

A sequence is sorted with respect to a comparator `comp` and a projection `proj` if for every iterator `i` pointing to the sequence and every non-negative integer `n` such that `i + n` is a valid iterator pointing to an element of the sequence, and `INVOKE(comp, INVOKE(proj, *(i + n)), INVOKE(proj, *i)) == false`.

`comp` has to induce a strict weak ordering on the values.

The assignments in the parallel `stable_sort` algorithm invoked without an execution policy object execute in sequential order in the calling thread.

Note: Complexity: $O(N \log(N))$, where $N = \text{std::distance}(\text{first}, \text{last})$ comparisons.

Template Parameters

- **RandomIt** – The type of the source iterators used (deduced). This iterator type must meet the requirements of an random iterator.
- **Sent** – The type of the source sentinel (deduced). This sentinel type must be a sentinel for `RandomIt`.
- **Comp** – The type of the function/function object to use (deduced).
- **Proj** – The type of an optional projection function. This defaults to `hpx::identity`

Parameters

- **first** – Refers to the beginning of the sequence of elements the algorithm will be applied to.
- **last** – Refers to sentinel value denoting the end of the sequence of elements the algorithm will be applied.
- **comp** – `comp` is a callable object. The return value of the `INVOKE` operation applied to an object of type `Comp`, when contextually converted to `bool`, yields `true` if the first argument of the call is less than the second, and `false` otherwise. It is assumed that `comp` will not apply any non-constant function through the dereferenced iterator.
- **proj** – Specifies the function (or function object) which will be invoked for each pair of elements as a projection operation before the actual predicate `comp` is invoked.

⁶⁷⁹ <http://github.com/STELLAR-GROUP/hpx/blob/8a3b7c1a4cb5693b2f7d9f587f759392ed0c51a0/libs/full/include/include/hpx/algorithm.hpp>

Returns The *stable_sort* algorithm returns *RandomIt*. The algorithm returns an iterator pointing to the first element after the last element in the input sequence.

```
template<typename ExPolicy, typename RandomIt, typename Sent, typename Comp = ranges::less,
        typename Proj = hpx::identity>
parallel::util::detail::algorithm_result<ExPolicy, RandomIt>::type stable_sort(ExPolicy &&policy,
                                                                    RandomIt first, Sent
                                                                    last, Comp &&comp =
                                                                    Comp(), Proj &&proj
                                                                    = Proj())
```

Sorts the elements in the range [first, last) in ascending order. The relative order of equal elements is preserved. The function uses the given comparison function object comp (defaults to using operator<()).

A sequence is sorted with respect to a comparator *comp* and a projection *proj* if for every iterator *i* pointing to the sequence and every non-negative integer *n* such that *i + n* is a valid iterator pointing to an element of the sequence, and INVOKE(comp, INVOKE(proj, *(i + n)), INVOKE(proj, *i)) == false.

comp has to induce a strict weak ordering on the values.

The application of function objects in parallel algorithm invoked with an execution policy object of type *sequenced_policy* execute in sequential order in the calling thread.

The application of function objects in parallel algorithm invoked with an execution policy object of type *parallel_policy* or *parallel_task_policy* are permitted to execute in an unordered fashion in unspecified threads, and indeterminately sequenced within each thread.

Note: Complexity: $O(N \log(N))$, where $N = \text{std::distance}(\text{first}, \text{last})$ comparisons.

Template Parameters

- **ExPolicy** – The type of the execution policy to use (deduced). It describes the manner in which the execution of the algorithm may be parallelized and the manner in which it executes the assignments.
- **RandomIt** – The type of the source iterators used (deduced). This iterator type must meet the requirements of an random iterator.
- **Sent** – The type of the source sentinel (deduced). This sentinel type must be a sentinel for *RandomIt*.
- **Comp** – The type of the function/function object to use (deduced).
- **Proj** – The type of an optional projection function. This defaults to *hpx::identity*

Parameters

- **policy** – The execution policy to use for the scheduling of the iterations.
- **first** – Refers to the beginning of the sequence of elements the algorithm will be applied to.
- **last** – Refers to sentinel value denoting the end of the sequence of elements the algorithm will be applied.
- **comp** – comp is a callable object. The return value of the INVOKE operation applied to an object of type *Comp*, when contextually converted to bool, yields true if the first argument of the call is less than the second, and false otherwise. It is assumed that comp will not apply any non-constant function through the dereferenced iterator.
- **proj** – Specifies the function (or function object) which will be invoked for each pair of elements as a projection operation before the actual predicate *comp* is invoked.

Returns The *stable_sort* algorithm returns a *hpx::future*<*RandomIt*> if the execution policy is of type *sequenced_task_policy* or *parallel_task_policy* and returns *RandomIt* otherwise.

The algorithm returns an iterator pointing to the first element after the last element in the input sequence.

```
template<typename Rng, typename Comp = ranges::less, typename Proj = hpx::identity>
hpx::traits::range_iterator_t<Rng> stable_sort(Rng &&rng, Comp &&comp = Comp(), Proj &&proj
    = Proj())
```

Sorts the elements in the range [first, last) in ascending order. The relative order of equal elements is preserved. The function uses the given comparison function object *comp* (defaults to using `operator<()`).

A sequence is sorted with respect to a comparator *comp* and a projection *proj* if for every iterator *i* pointing to the sequence and every non-negative integer *n* such that *i + n* is a valid iterator pointing to an element of the sequence, and `INVOKE(comp, INVOKE(proj, *(i + n)), INVOKE(proj, *i)) == false`.

comp has to induce a strict weak ordering on the values.

The assignments in the parallel *stable_sort* algorithm invoked without an execution policy object execute in sequential order in the calling thread.

Note: Complexity: $O(N \log(N))$, where $N = \text{std::distance}(\text{first}, \text{last})$ comparisons.

Template Parameters

- **Rng** – The type of the source range used (deduced). The iterators extracted from this range type must meet the requirements of an input iterator.
- **Comp** – The type of the function/function object to use (deduced).
- **Proj** – The type of an optional projection function. This defaults to *hpx::identity*

Parameters

- **rng** – Refers to the sequence of elements the algorithm will be applied to.
- **comp** – *comp* is a callable object. The return value of the INVOKE operation applied to an object of type *Comp*, when contextually converted to `bool`, yields `true` if the first argument of the call is less than the second, and `false` otherwise. It is assumed that *comp* will not apply any non-constant function through the dereferenced iterator.
- **proj** – Specifies the function (or function object) which will be invoked for each pair of elements as a projection operation before the actual predicate *comp* is invoked.

Returns The *stable_sort* algorithm returns *hpx::traits::range_iterator_t*<*Rng*>. It returns *last*.

```
template<typename ExPolicy, typename Rng, typename Comp = ranges::less, typename Proj =
hpx::identity>
parallel::util::detail::algorithm_result<ExPolicy, hpx::traits::range_iterator_t<Rng>> stable_sort(ExPolicy
    &&pol-
    icy,
    Rng
    &&rng,
    Comp
    &&comp
    =
    Comp(),
    Proj
    &&proj
    =
    Proj())
```

Sorts the elements in the range `[first, last)` in ascending order. The relative order of equal elements is preserved. The function uses the given comparison function object `comp` (defaults to using `operator<()`).

A sequence is sorted with respect to a comparator `comp` and a projection `proj` if for every iterator `i` pointing to the sequence and every non-negative integer `n` such that `i + n` is a valid iterator pointing to an element of the sequence, and `INVOKE(comp, INVOKE(proj, *(i + n)), INVOKE(proj, *i)) == false`.

`comp` has to induce a strict weak ordering on the values.

The application of function objects in parallel algorithm invoked with an execution policy object of type `sequenced_policy` execute in sequential order in the calling thread.

The application of function objects in parallel algorithm invoked with an execution policy object of type `parallel_policy` or `parallel_task_policy` are permitted to execute in an unordered fashion in unspecified threads, and indeterminately sequenced within each thread.

Note: Complexity: $O(N \log(N))$, where $N = \text{std::distance}(\text{first}, \text{last})$ comparisons.

Template Parameters

- **ExPolicy** – The type of the execution policy to use (deduced). It describes the manner in which the execution of the algorithm may be parallelized and the manner in which it applies user-provided function objects.
- **Rng** – The type of the source range used (deduced). The iterators extracted from this range type must meet the requirements of an input iterator.
- **Comp** – The type of the function/function object to use (deduced).
- **Proj** – The type of an optional projection function. This defaults to `hpx::identity`

Parameters

- **policy** – The execution policy to use for the scheduling of the iterations.
- **rng** – Refers to the sequence of elements the algorithm will be applied to.
- **comp** – `comp` is a callable object. The return value of the `INVOKE` operation applied to an object of type `Comp`, when contextually converted to `bool`, yields `true` if the first argument of the call is less than the second, and `false` otherwise. It is assumed that `comp` will not apply any non-constant function through the dereferenced iterator.
- **proj** – Specifies the function (or function object) which will be invoked for each pair of elements as a projection operation before the actual predicate `comp` is invoked.

Returns The `stable_sort` algorithm returns a `hpx::future<hpx::traits::range_iterator_t<Rng>` if the execution policy is of type `sequenced_task_policy` or `parallel_task_policy` and returns `hpx::traits::range_iterator_t<Rng>` otherwise. It returns `last`.

hpx::ranges::starts_with

Defined in header `hpx/algorithm.hpp`⁶⁸⁰.

See *Public API* for a list of names and headers that are part of the public *HPX* API.

```
namespace hpx
```

```
    namespace ranges
```

⁶⁸⁰ <http://github.com/STELLAR-GROUP/hpx/blob/8a3b7c1a4cb5693b2f7d9f587f759392ed0c51a0/libs/full/include/include/hpx/algorithm.hpp>

Functions

```
template<typename Iter1, typename Sent1, typename Iter2, typename Sent2, typename Pred =
ranges::equal_to, typename Proj1 = hpx::identity, typename Proj2 = hpx::identity>
bool starts_with(Iter1 first1, Sent1 last1, Iter2 first2, Sent2 last2, Pred &&pred = Pred(), Proj1
&&proj1 = Proj1(), Proj2 &&proj2 = Proj2())
```

Checks whether the second range defined by [first1, last1) matches the prefix of the first range defined by [first2, last2)

The assignments in the parallel *starts_with* algorithm invoked without an execution policy object execute in sequential order in the calling thread.

Note: Complexity: Linear: at most min(N1, N2) applications of the predicate and both projections.

Template Parameters

- **Iter1** – The type of the begin source iterators used (deduced). This iterator type must meet the requirements of an input iterator.
- **Sent1** – The type of the end source iterators used (deduced). This iterator type must meet the requirements of a sentinel for *Iter1*.
- **Iter2** – The type of the begin destination iterators used (deduced). This iterator type must meet the requirements of an input iterator.
- **Sent2** – The type of the end destination iterators used (deduced). This iterator type must meet the requirements of a sentinel for *Iter2*.
- **Pred** – The binary predicate that compares the projected elements.
- **Proj1** – The type of an optional projection function for the source range. This defaults to *hpx::identity*
- **Proj2** – The type of an optional projection function for the destination range. This defaults to *hpx::identity*

Parameters

- **first1** – Refers to the beginning of the source range.
- **last1** – Sentinel value referring to the end of the source range.
- **first2** – Refers to the beginning of the destination range.
- **last2** – Sentinel value referring to the end of the destination range.
- **pred** – Specifies the binary predicate function (or function object) which will be invoked for comparison of the elements in the in two ranges projected by *proj1* and *proj2* respectively.
- **proj1** – Specifies the function (or function object) which will be invoked for each of the elements in the source range as a projection operation before the actual predicate *is* invoked.
- **proj2** – Specifies the function (or function object) which will be invoked for each of the elements in the destination range as a projection operation before the actual predicate *is* invoked.

Returns The *starts_with* algorithm returns *bool*. The *starts_with* algorithm returns a boolean with the value true if the second range matches the prefix of the first range, false otherwise.

```
template<typename ExPolicy, typename FwdIter1, typename Sent1, typename FwdIter2, typename
Sent2, typename Pred = ranges::equal_to, typename Proj1 = hpx::identity, typename Proj2 =
hpx::identity>
```

```

hpx::parallel::util::detail::algorithm_result_t<ExPolicy, bool> starts_with(ExPolicy &&policy,
                                                                    FwdIter1 first1, Sent1
                                                                    last1, FwdIter2 first2,
                                                                    Sent2 last2, Pred &&pred
                                                                    = Pred(), Proj1 &&proj1 =
                                                                    Proj1(), Proj2 &&proj2 =
                                                                    Proj2())

```

Checks whether the second range defined by [first1, last1) matches the prefix of the first range defined by [first2, last2)

The assignments in the parallel *starts_with* algorithm invoked with an execution policy object of type *sequenced_policy* execute in sequential order in the calling thread.

The assignments in the parallel *starts_with* algorithm invoked with an execution policy object of type *parallel_policy* or *parallel_task_policy* are permitted to execute in an unordered fashion in unspecified threads, and indeterminately sequenced within each thread.

Note: Complexity: Linear: at most min(N1, N2) applications of the predicate and both projections.

Template Parameters

- **ExPolicy** – The type of the execution policy to use (deduced). It describes the manner in which the execution of the algorithm may be parallelized and the manner in which it executes the assignments.
- **FwdIter1** – The type of the begin source iterators used (deduced). This iterator type must meet the requirements of an forward iterator.
- **Sent1** – The type of the end source iterators used(deduced). This iterator type must meet the requirements of an sentinel for Iter1.
- **FwdIter2** – The type of the begin destination iterators used deduced). This iterator type must meet the requirements of a forward iterator.
- **Sent2** – The type of the end destination iterators used (deduced). This iterator type must meet the requirements of an sentinel for Iter2.
- **Pred** – The binary predicate that compares the projected elements.
- **Proj1** – The type of an optional projection function for the source range. This defaults to *hpx::identity*
- **Proj2** – The type of an optional projection function for the destination range. This defaults to *hpx::identity*

Parameters

- **policy** – The execution policy to use for the scheduling of the iterations.
- **first1** – Refers to the beginning of the source range.
- **last1** – Sentinel value referring to the end of the source range.
- **first2** – Refers to the beginning of the destination range.
- **last2** – Sentinel value referring to the end of the destination range.
- **pred** – Specifies the binary predicate function (or function object) which will be invoked for comparison of the elements in the in two ranges projected by proj1 and proj2 respectively.
- **proj1** – Specifies the function (or function object) which will be invoked for each of the elements in the source range as a projection operation before the actual predicate *is* invoked.
- **proj2** – Specifies the function (or function object) which will be invoked for each of the elements in the destination range as a projection operation before the actual predicate *is* invoked.

Returns The *starts_with* algorithm returns a *hpx::future<bool>* if the execution policy is

of type *sequenced_task_policy* or *parallel_task_policy* and returns *bool* otherwise. The *starts_with* algorithm returns a boolean with the value true if the second range matches the prefix of the first range, false otherwise.

```
template<typename Rng1, typename Rng2, typename Pred = ranges::equal_to, typename Proj1 =
hpx::identity, typename Proj2 = hpx::identity>
bool starts_with(Rng1 &&rng1, Rng2 &&rng2, Pred &&pred = Pred(), Proj1 &&proj1 = Proj1(),
Proj2 &&proj2 = Proj2())
```

Checks whether the second range *rng2* matches the prefix of the first range *rng1*.

The assignments in the parallel *starts_with* algorithm invoked without an execution policy object execute in sequential order in the calling thread.

Note: Complexity: Linear: at most min(N1, N2) applications of the predicate and both projections.

Template Parameters

- **Rng1** – The type of the source range used (deduced). The iterators extracted from this range type must meet the requirements of an forward iterator.
- **Rng2** – The type of the destination range used (deduced). The iterators extracted from this range type must meet the requirements of an forward iterator.
- **Pred** – The binary predicate that compares the projected elements.
- **Proj1** – The type of an optional projection function for the source range. This defaults to *hpx::identity*
- **Proj2** – The type of an optional projection function for the destination range. This defaults to *hpx::identity*

Parameters

- **rng1** – Refers to the source range.
- **rng2** – Refers to the destination range.
- **pred** – Specifies the binary predicate function (or function object) which will be invoked for comparison of the elements in the in two ranges projected by proj1 and proj2 respectively.
- **proj1** – Specifies the function (or function object) which will be invoked for each of the elements in the source range as a projection operation before the actual predicate *is* invoked.
- **proj2** – Specifies the function (or function object) which will be invoked for each of the elements in the destination range as a projection operation before the actual predicate *is* invoked.

Returns The *starts_with* algorithm returns *bool*. The *starts_with* algorithm returns a boolean with the value true if the second range matches the prefix of the first range, false otherwise.

```
template<typename ExPolicy, typename Rng1, typename Rng2, typename Pred = ranges::equal_to,
typename Proj1 = hpx::identity, typename Proj2 = hpx::identity>
hpx::parallel::util::detail::algorithm_result<ExPolicy, bool>::type starts_with(ExPolicy &&policy,
Rng1 &&rng1, Rng2
&&rng2, Pred
&&pred = Pred(),
Proj1 &&proj1 =
Proj1(), Proj2
&&proj2 = Proj2())
```

Checks whether the second range *rng2* matches the prefix of the first range *rng1*.

The assignments in the parallel *starts_with* algorithm invoked with an execution policy object of type *sequenced_policy* execute in sequential order in the calling thread.

The assignments in the parallel *starts_with* algorithm invoked with an execution policy object of type *parallel_policy* or *parallel_task_policy* are permitted to execute in an unordered fashion in unspecified threads, and indeterminately sequenced within each thread.

Note: Complexity: Linear: at most $\min(N1, N2)$ applications of the predicate and both projections.

Template Parameters

- **ExPolicy** – The type of the execution policy to use (deduced). It describes the manner in which the execution of the algorithm may be parallelized and the manner in which it executes the assignments.
- **Rng1** – The type of the source range used (deduced). The iterators extracted from this range type must meet the requirements of an forward iterator.
- **Rng2** – The type of the destination range used (deduced). The iterators extracted from this range type must meet the requirements of an forward iterator.
- **Pred** – The binary predicate that compares the projected elements.
- **Proj1** – The type of an optional projection function for the source range. This defaults to *hpx::identity*
- **Proj2** – The type of an optional projection function for the destination range. This defaults to *hpx::identity*

Parameters

- **policy** – The execution policy to use for the scheduling of the iterations.
- **rng1** – Refers to the source range.
- **rng2** – Refers to the destination range.
- **pred** – Specifies the binary predicate function (or function object) which will be invoked for comparison of the elements in the in two ranges projected by proj1 and proj2 respectively.
- **proj1** – Specifies the function (or function object) which will be invoked for each of the elements in the source range as a projection operation before the actual predicate is invoked.
- **proj2** – Specifies the function (or function object) which will be invoked for each of the elements in the destination range as a projection operation before the actual predicate is invoked.

Returns The *starts_with* algorithm returns a *hpx::future<bool>* if the execution policy is of type *sequenced_task_policy* or *parallel_task_policy* and returns *bool* otherwise. The *starts_with* algorithm returns a boolean with the value true if the second range matches the prefix of the first range, false otherwise.

hpx::ranges::swap_ranges

Defined in header `hpx/algorithm.hpp`⁶⁸¹.

See *Public API* for a list of names and headers that are part of the public *HPX* API.

```
namespace hpx
```

```
    namespace ranges
```

⁶⁸¹ <http://github.com/STELLAR-GROUP/hpx/blob/8a3b7c1a4cb5693b2f7d9f587f759392ed0c51a0/libs/full/include/include/hpx/algorithm.hpp>

Functions

```
template<typename InIter1, typename Sent1, typename InIter2, typename Sent2>
swap_ranges_result<InIter1, InIter2> swap_ranges(InIter1 first1, Sent1 last1, InIter2 first2, Sent2 last2)
```

Exchanges elements between range [first1, last1) and another range starting at *first2*.

The swap operations in the parallel *swap_ranges* algorithm invoked without an execution policy object execute in sequential order in the calling thread.

Note: Complexity: Linear in the distance between *first1* and *last1*

Template Parameters

- **InIter1** – The type of the first range of iterators to swap (deduced).
- **Sent1** – The type of the first sentinel (deduced). This sentinel type must be a sentinel for *InIter1*.
- **InIter2** – The type of the second range of iterators to swap (deduced).
- **Sent2** – The type of the second sentinel (deduced). This sentinel type must be a sentinel for *InIter2*.

Parameters

- **first1** – Refers to the beginning of the sequence of elements for the first range.
- **last1** – Refers to sentinel value denoting the end of the sequence of elements for the first range.
- **first2** – Refers to the beginning of the sequence of elements for the second range.
- **last2** – Refers to sentinel value denoting the end of the sequence of elements for the second range.

Returns The *swap_ranges* algorithm returns *swap_ranges_result*<*InIter1*, *InIter2*>. The *swap_ranges* algorithm returns *in_in_result* with the first element as the iterator to the element past the last element exchanged in range beginning with *first1* and the second element as the iterator to the element past the last element exchanged in the range beginning with *first2*.

```
template<typename ExPolicy, typename FwdIter1, typename Sent1, typename FwdIter2, typename Sent2>
```

```
parallel::util::detail::algorithm_result<ExPolicy, swap_ranges_result<FwdIter1, FwdIter2>>::type swap_ranges(ExPolicy
&&pol-
icy,
FwdIter1
first1,
Sent1
last1,
FwdIter2
first2,
Sent2
last2)
```

Exchanges elements between range [first1, last1) and another range starting at *first2*.

The swap operations in the parallel *swap_ranges* algorithm invoked with an execution policy object of type *sequenced_policy* execute in sequential order in the calling thread.

The swap operations in the parallel *swap_ranges* algorithm invoked with an execution policy object of type *parallel_policy* or *parallel_task_policy* are permitted to execute in an unordered fashion in

unspecified threads, and indeterminately sequenced within each thread.

Note: Complexity: Linear in the distance between *first1* and *last1*

Template Parameters

- **ExPolicy** – The type of the execution policy to use (deduced). It describes the manner in which the execution of the algorithm may be parallelized and the manner in which it executes the assignments.
- **FwdIter1** – The type of the first range of iterators to swap (deduced).
- **Sent1** – The type of the first sentinel (deduced). This sentinel type must be a sentinel for FwdIter1.
- **FwdIter2** – The type of the second range of iterators to swap (deduced).
- **Sent2** – The type of the second sentinel (deduced). This sentinel type must be a sentinel for FwdIter2.

Parameters

- **policy** – The execution policy to use for the scheduling of the iterations.
- **first1** – Refers to the beginning of the sequence of elements for the first range.
- **last1** – Refers to sentinel value denoting the end of the sequence of elements for the first range.
- **first2** – Refers to the beginning of the sequence of elements for the second range.
- **last2** – Refers to sentinel value denoting the end of the sequence of elements for the second range.

Returns The *swap_ranges* algorithm returns a *hpx::future<swap_ranges_result<FwdIter1, FwdIter2>>* if the execution policy is of type *parallel_task_policy* and returns *FwdIter2* otherwise. The *swap_ranges* algorithm returns *in_in_result* with the first element as the iterator to the element past the last element exchanged in range beginning with *first1* and the second element as the iterator to the element past the last element exchanged in the range beginning with *first2*.

```
template<typename Rng1, typename Rng2>
swap_ranges_result<hpx::traits::range_iterator_t<Rng1>, hpx::traits::range_iterator_t<Rng2>> swap_ranges(Rng1
&&rng1,
Rng2
&&rng2)
```

Exchanges elements between range [first1, last1) and another range starting at *first2*.

The swap operations in the parallel *swap_ranges* algorithm invoked without an execution policy object execute in sequential order in the calling thread.

Note: Complexity: Linear in the distance between *first1* and *last1*

Template Parameters

- **Rng1** – The type of the source range used (deduced). The iterators extracted from this range type must meet the requirements of an input iterator.
- **Rng2** – The type of the destination range used (deduced). The iterators extracted from this range type must meet the requirements of an input iterator.

Parameters

- **rng1** – Refers to the sequence of elements of the first range.
- **rng2** – Refers to the sequence of elements of the second range.

Returns The *swap_ranges* algorithm returns *swap_ranges_result<hpx::traits::range_iterator_t<Rng1>, hpx::traits::range_iterator_t<Rng1>>*. The

swap_ranges algorithm returns *in_in_result* with the first element as the iterator to the element past the last element exchanged in range beginning with *first1* and the second element as the iterator to the element past the last element exchanged in the range beginning with *first2*.

```
template<typename ExPolicy, typename Rng1, typename Rng2>  
parallel::util::detail::algorithm_result<ExPolicy, swap_ranges_result<hpx::traits::range_iterator_t<Rng1>, hpx::traits::rang
```

Exchanges elements between range [first1, last1) and another range starting at *first2*.

The swap operations in the parallel *swap_ranges* algorithm invoked with an execution policy object of type *sequenced_policy* execute in sequential order in the calling thread.

The swap operations in the parallel *swap_ranges* algorithm invoked with an execution policy object of type *parallel_policy* or *parallel_task_policy* are permitted to execute in an unordered fashion in unspecified threads, and indeterminately sequenced within each thread.

Note: Complexity: Linear in the distance between *first1* and *last1*

Template Parameters

- **ExPolicy** – The type of the execution policy to use (deduced). It describes the manner in which the execution of the algorithm may be parallelized and the manner in which it executes the assignments.
- **Rng1** – The type of the source range used (deduced). The iterators extracted from this range type must meet the requirements of an input iterator.
- **Rng2** – The type of the destination range used (deduced). The iterators extracted from this range type must meet the requirements of an input iterator.

Parameters

- **policy** – The execution policy to use for the scheduling of the iterations.
- **rng1** – Refers to the sequence of elements of the first range.
- **rng2** – Refers to the sequence of elements of the second range.

Returns The *swap_ranges* algorithm returns a *hpx::future*<*swap_ranges_result*<*hpx::traits::range_iterator_t*<*Rng1*>, *hpx::traits::range_iterator_t*<*Rng1*>>> if the execution policy is of type *parallel_task_policy* and returns *swap_ranges_result*<*hpx::traits::range_iterator_t*<*Rng1*>, *hpx::traits::range_iterator_t*<*Rng1*>>. otherwise. The *swap_ranges* algorithm returns *in_in_result* with the first element as the iterator to the element past the last element exchanged in range beginning with *first1* and the second element as the iterator to the element past the last element exchanged in the range beginning with *first2*.

hpx::ranges::transform

Defined in header `hpx/algorithm.hpp`⁶⁸².

See *Public API* for a list of names and headers that are part of the public HPX API.

```
namespace hpx
```

```
    namespace ranges
```

Functions

```
template<typename ExPolicy, typename FwdIter1, typename Sent1, typename FwdIter2, typename
F, typename Proj = hpx::identity>
parallel::util::detail::algorithm_result<ExPolicy, ranges::unary_transform_result<FwdIter1, FwdIter2>>::type transform(
```

Applies the given function f to the given range rng and stores the result in another range, beginning at $dest$.

The invocations of f in the parallel *transform* algorithm invoked with an execution policy object of type *sequenced_policy* execute in sequential order in the calling thread.

The invocations of f in the parallel *transform* algorithm invoked with an execution policy object of type *parallel_policy* or *parallel_task_policy* are permitted to execute in an unordered fashion in unspecified threads, and indeterminately sequenced within each thread.

Note: Complexity: Exactly $\text{size}(rng)$ applications of f

Template Parameters

- **ExPolicy** – The type of the execution policy to use (deduced). It describes the manner in which the execution of the algorithm may be parallelized and the manner in which it executes the invocations of f .
- **FwdIter1** – The type of the source iterators for the first range used (deduced). This iterator type must meet the requirements of a forward iterator.
- **Sent1** – The type of the end source iterators used (deduced). This iterator type must meet the requirements of a sentinel for `FwdIter1`.

⁶⁸² <http://github.com/STELLAR-GROUP/hpx/blob/8a3b7c1a4cb5693b2f7d9f587f759392ed0c51a0/libs/full/include/include/hpx/algorithm.hpp>

- **FwdIter2** – The type of the source iterators for the first range used (deduced). This iterator type must meet the requirements of a forward iterator.
- **F** – The type of the function/function object to use (deduced). Unlike its sequential form, the parallel overload of *transform* requires *F* to meet the requirements of *Copy-Constructible*.
- **Proj** – The type of an optional projection function. This defaults to *hpx::identity*

Parameters

- **policy** – The execution policy to use for the scheduling of the iterations.
- **first** – Refers to the beginning of the first sequence of elements the algorithm will be applied to.
- **last** – Refers to the end of the sequence of elements the algorithm will be applied to.
- **dest** – Refers to the beginning of the destination range.
- **f** – Specifies the function (or function object) which will be invoked for each of the elements in the sequence specified by [first, last). This is a unary predicate. The signature of this predicate should be equivalent to:

```
Ret fun(const Type &a);
```

The signature does not need to have `const&`. The type *Type* must be such that an object of type *FwdIter1* can be dereferenced and then implicitly converted to *Type*. The type *Ret* must be such that an object of type *FwdIter2* can be dereferenced and assigned a value of type *Ret*.

- **proj** – Specifies the function (or function object) which will be invoked for each of the elements as a projection operation before the actual predicate *f* is invoked.

Returns The *transform* algorithm returns a *hpx::future<ranges::unary_transform_result<FwdIter1, FwdIter2>>* if the execution policy is of type *parallel_task_policy* and returns *ranges::unary_transform_result<FwdIter1, FwdIter2>* otherwise. The *transform* algorithm returns a tuple holding an iterator referring to the first element after the input sequence and the output iterator to the element in the destination range, one past the last element copied.

```
template<typename ExPolicy, typename Rng, typename FwdIter, typename F, typename Proj =
hpx::identity>
parallel::util::detail::algorithm_result<ExPolicy, ranges::unary_transform_result<hpx::traits::range_iterator_t<Rng>, FwdIter
```

Applies the given function *f* to the given range *rng* and stores the result in another range, beginning at *dest*.

The invocations of *f* in the parallel *transform* algorithm invoked with an execution policy object of type *sequenced_policy* execute in sequential order in the calling thread.

The invocations of *f* in the parallel *transform* algorithm invoked with an execution policy object of type *parallel_policy* or *parallel_task_policy* are permitted to execute in an unordered fashion in unspecified

threads, and indeterminately sequenced within each thread.

Note: Complexity: Exactly $\text{size}(\text{rng})$ applications of f

Template Parameters

- **ExPolicy** – The type of the execution policy to use (deduced). It describes the manner in which the execution of the algorithm may be parallelized and the manner in which it executes the invocations of f .
- **Rng** – The type of the source range used (deduced). The iterators extracted from this range type must meet the requirements of an input iterator.
- **FwdIter** – The type of the iterator representing the destination range (deduced). This iterator type must meet the requirements of a forward iterator.
- **F** – The type of the function/function object to use (deduced). Unlike its sequential form, the parallel overload of *transform* requires F to meet the requirements of *CopyConstructible*.
- **Proj** – The type of an optional projection function. This defaults to `hpx::identity`

Parameters

- **policy** – The execution policy to use for the scheduling of the iterations.
- **rng** – Refers to the sequence of elements the algorithm will be applied to.
- **dest** – Refers to the beginning of the destination range.
- **f** – Specifies the function (or function object) which will be invoked for each of the elements in the sequence specified by [first, last). This is a unary predicate. The signature of this predicate should be equivalent to:

```
Ret fun(const Type &a);
```

The signature does not need to have `const&`. The type *Type* must be such that an object of type `range_iterator<Rng>::type` can be dereferenced and then implicitly converted to *Type*. The type *Ret* must be such that an object of type *OutIter* can be dereferenced and assigned a value of type *Ret*.

- **proj** – Specifies the function (or function object) which will be invoked for each of the elements as a projection operation before the actual predicate f is invoked.

Returns The *transform* algorithm returns a `hpx::future<ranges::unary_transform_result<range_iterator<Rng>::type, FwdIter>>` if the execution policy is of type `parallel_task_policy` and returns `ranges::unary_transform_result<range_iterator<Rng>::type, FwdIter>` otherwise. The *transform* algorithm returns a tuple holding an iterator referring to the first element after the input sequence and the output iterator to the element in the destination range, one past the last element copied.

```
template<typename ExPolicy, typename FwdIter1, typename Sent1, typename FwdIter2, typename Sent2, typename FwdIter3, typename F, typename Proj1 = hpx::identity, typename Proj2 = hpx::identity>
```

parallel::util::detail::algorithm_result<ExPolicy, ranges::binary_transform_result<FwdIter1, FwdIter2, FwdIter3>>::type t

Applies the given function f to pairs of elements from two ranges: one defined by rng and the other beginning at $first2$, and stores the result in another range, beginning at $dest$.

The invocations of f in the parallel *transform* algorithm invoked with an execution policy object of type *sequenced_policy* execute in sequential order in the calling thread.

The invocations of f in the parallel *transform* algorithm invoked with an execution policy object of type *parallel_policy* or *parallel_task_policy* are permitted to execute in an unordered fashion in unspecified threads, and indeterminately sequenced within each thread.

Note: Complexity: Exactly $\text{size}(rng)$ applications of f

Template Parameters

- **ExPolicy** – The type of the execution policy to use (deduced). It describes the manner in which the execution of the algorithm may be parallelized and the manner in which it executes the invocations of f .
- **FwdIter1** – The type of the source iterators for the first range used (deduced). This iterator type must meet the requirements of a forward iterator.
- **Sent1** – The type of the end source iterators used (deduced). This iterator type must meet the requirements of a sentinel for FwdIter1.
- **FwdIter2** – The type of the source iterators for the first range used (deduced). This iterator type must meet the requirements of a forward iterator.
- **Sent2** – The type of the end source iterators used (deduced). This iterator type must meet the requirements of a sentinel for FwdIter2.
- **FwdIter3** – The type of the source iterators for the first range used (deduced). This iterator type must meet the requirements of a forward iterator.
- **F** – The type of the function/function object to use (deduced). Unlike its sequential form, the parallel overload of *transform* requires F to meet the requirements of *Copy-Constructible*.

- **Proj1** – The type of an optional projection function to be used for elements of the first sequence. This defaults to `hpx::identity`
- **Proj2** – The type of an optional projection function to be used for elements of the second sequence. This defaults to `hpx::identity`

Parameters

- **policy** – The execution policy to use for the scheduling of the iterations.
- **first1** – Refers to the beginning of the first sequence of elements the algorithm will be applied to.
- **last1** – Refers to the end of the first sequence of elements the algorithm will be applied to.
- **first2** – Refers to the beginning of the second sequence of elements the algorithm will be applied to.
- **last2** – Refers to the end of the second sequence of elements the algorithm will be applied to.
- **dest** – Refers to the beginning of the destination range.
- **f** – Specifies the function (or function object) which will be invoked for each of the elements in the sequence specified by [first, last). This is a binary predicate. The signature of this predicate should be equivalent to:

```
Ret fun(const Type1 &a, const Type2 &b);
```

The signature does not need to have `const&`. The types *Type1* and *Type2* must be such that objects of types *FwdIter1* and *FwdIter2* can be dereferenced and then implicitly converted to *Type1* and *Type2* respectively. The type *Ret* must be such that an object of type *FwdIter3* can be dereferenced and assigned a value of type *Ret*.

- **proj1** – Specifies the function (or function object) which will be invoked for each of the elements of the first sequence as a projection operation before the actual predicate *f* is invoked.
- **proj2** – Specifies the function (or function object) which will be invoked for each of the elements of the second sequence as a projection operation before the actual predicate *f* is invoked.

Returns The *transform* algorithm returns `A hpx::future<ranges::binary_transform_result<FwdIter1, FwdIter2, FwdIter3>>` if the execution policy is of type *parallel_task_policy* and returns `ranges::binary_transform_result<FwdIter1, FwdIter2, FwdIter3>` otherwise. The *transform* algorithm returns a tuple holding an iterator referring to the first element after the first input sequence, an iterator referring to the first element after the second input sequence, and the output iterator referring to the element in the destination range, one past the last element copied.

```
template<typename ExPolicy, typename Rng1, typename Rng2, typename FwdIter, typename F,  
typename Proj1 = hpx::identity, typename Proj2 = hpx::identity>
```

parallel::util::detail::algorithm_result<ExPolicy, ranges::binary_transform_result<hpx::traits::range_iterator_t<Rng1>, hpx::

Applies the given function f to pairs of elements from two ranges: one defined by [first1, last1) and the other beginning at first2, and stores the result in another range, beginning at dest.

The invocations of f in the parallel *transform* algorithm invoked with an execution policy object of type *sequenced_policy* execute in sequential order in the calling thread.

The invocations of f in the parallel *transform* algorithm invoked with an execution policy object of type *parallel_policy* or *parallel_task_policy* are permitted to execute in an unordered fashion in unspecified threads, and indeterminately sequenced within each thread.

Note: Complexity: Exactly $\min(\text{last2}-\text{first2}, \text{last1}-\text{first1})$ applications of f

Note: The algorithm will invoke the binary predicate until it reaches the end of the shorter of the two given input sequences

Template Parameters

- **ExPolicy** – The type of the execution policy to use (deduced). It describes the manner in which the execution of the algorithm may be parallelized and the manner in which it executes the invocations of f .
- **Rng1** – The type of the first source range used (deduced). The iterators extracted from this range type must meet the requirements of an input iterator.
- **Rng2** – The type of the second source range used (deduced). The iterators extracted from this range type must meet the requirements of an input iterator.
- **FwdIter** – The type of the iterator representing the destination range (deduced). This iterator type must meet the requirements of an output iterator.
- **F** – The type of the function/function object to use (deduced). Unlike its sequential form, the parallel overload of *transform* requires F to meet the requirements of *Copy-Constructible*.
- **Proj1** – The type of an optional projection function to be used for elements of the first sequence. This defaults to *hpx::identity*
- **Proj2** – The type of an optional projection function to be used for elements of the second sequence. This defaults to *hpx::identity*

Parameters

- **policy** – The execution policy to use for the scheduling of the iterations.
- **rng1** – Refers to the first sequence of elements the algorithm will be applied to.
- **rng2** – Refers to the second sequence of elements the algorithm will be applied to.
- **dest** – Refers to the beginning of the destination range.
- **f** – Specifies the function (or function object) which will be invoked for each of the elements in the sequence specified by [first, last). This is a binary predicate. The signature of this predicate should be equivalent to:

```
Ret fun(const Type1 &a, const Type2 &b);
```

The signature does not need to have const&. The types *Type1* and *Type2* must be such that objects of types `range_iterator<Rng1>::type` and `range_iterator<Rng2>::type` can be dereferenced and then implicitly converted to *Type1* and *Type2* respectively. The type *Ret* must be such that an object of type *FwdIter* can be dereferenced and assigned a value of type *Ret*.

- **proj1** – Specifies the function (or function object) which will be invoked for each of the elements of the first sequence as a projection operation before the actual predicate *f* is invoked.
- **proj2** – Specifies the function (or function object) which will be invoked for each of the elements of the second sequence as a projection operation before the actual predicate *f* is invoked.

Returns The *transform* algorithm returns a `hpx::future<ranges::binary_transform_result<hpx::traits::range_iterator_t<Rng1>, hpx::traits::range_iterator_t<Rng2>, FwdIter>>` if the execution policy is of type *parallel_task_policy* and returns `ranges::binary_transform_result<hpx::traits::range_iterator_t<Rng1>, hpx::traits::range_iterator_t<Rng2>, FwdIter>` otherwise. The *transform* algorithm returns a tuple holding an iterator referring to the first element after the first input sequence, an iterator referring to the first element after the second input sequence, and the output iterator referring to the element in the destination range, one past the last element copied.

```
template<typename FwdIter1, typename Sent1, typename FwdIter2, typename F, typename Proj =
hpx::identity>
ranges::unary_transform_result<FwdIter1, FwdIter2> transform(FwdIter1 first, Sent1 last, FwdIter2
dest, F &&f, Proj &&proj = Proj())
```

Applies the given function *f* to the given range *rng* and stores the result in another range, beginning at *dest*.

Note: Complexity: Exactly `size(rng)` applications of *f*

Template Parameters

- **FwdIter1** – The type of the source iterators for the first range used (deduced). This iterator type must meet the requirements of a forward iterator.
- **Sent1** – The type of the end source iterators used (deduced). This iterator type must meet the requirements of a sentinel for *FwdIter1*.
- **FwdIter2** – The type of the source iterators for the first range used (deduced). This iterator type must meet the requirements of a forward iterator.
- **F** – The type of the function/function object to use (deduced). Unlike its sequential form, the parallel overload of *transform* requires *F* to meet the requirements of *CopyConstructible*.
- **Proj** – The type of an optional projection function. This defaults to `hpx::identity`

Parameters

- **first** – Refers to the beginning of the first sequence of elements the algorithm will be applied to.
- **last** – Refers to the end of the sequence of elements the algorithm will be applied to.
- **dest** – Refers to the beginning of the destination range.
- **f** – Specifies the function (or function object) which will be invoked for each of the elements in the sequence specified by [first, last). This is a unary predicate. The signature of this predicate should be equivalent to:

```
Ret fun(const Type &a);
```

The signature does not need to have `const&`. The type *Type* must be such that an object of type *FwdIter1* can be dereferenced and then implicitly converted to *Type*. The type *Ret* must be such that an object of type *FwdIter2* can be dereferenced and assigned a value of type *Ret*.

- **proj** – Specifies the function (or function object) which will be invoked for each of the elements as a projection operation before the actual predicate *f* is invoked.

Returns The *transform* algorithm returns `ranges::unary_transform_result<FwdIter1, FwdIter2>`. The *transform* algorithm returns a tuple holding an iterator referring to the first element after the input sequence and the output iterator to the element in the destination range, one past the last element copied.

```
template<typename Rng, typename FwdIter, typename F, typename Proj = hpx::identity>
ranges::unary_transform_result<hpx::traits::range_iterator_t<Rng>, FwdIter> transform(Rng &&rng,
                                                                                      FwdIter dest,
                                                                                      F &&f, Proj
                                                                                      &&proj =
                                                                                      Proj())
```

Applies the given function *f* to the given range *rng* and stores the result in another range, beginning at *dest*.

Note: Complexity: Exactly `size(rng)` applications of *f*

Template Parameters

- **Rng** – The type of the source range used (deduced). The iterators extracted from this range type must meet the requirements of an input iterator.
- **FwdIter** – The type of the iterator representing the destination range (deduced). This iterator type must meet the requirements of a forward iterator.
- **F** – The type of the function/function object to use (deduced). Unlike its sequential form, the parallel overload of *transform* requires *F* to meet the requirements of *CopyConstructible*.
- **Proj** – The type of an optional projection function. This defaults to `hpx::identity`

Parameters

- **rng** – Refers to the sequence of elements the algorithm will be applied to.
- **dest** – Refers to the beginning of the destination range.
- **f** – Specifies the function (or function object) which will be invoked for each of the elements in the sequence specified by [first, last). This is a unary predicate. The signature of this predicate should be equivalent to:

```
Ret fun(const Type &a);
```

The signature does not need to have `const&`. The type *Type* must be such that an object of type `range_iterator<Rng>::type` can be dereferenced and then implicitly converted to *Type*. The type *Ret* must be such that an object of type *OutIter* can be dereferenced and assigned a value of type *Ret*.

- **proj** – Specifies the function (or function object) which will be invoked for each of the elements as a projection operation before the actual predicate f is invoked.

Returns The *transform* algorithm returns `ranges::unary_transform_result<range_iterator<Rng>::type, FwdIter>`. The *transform* algorithm returns a tuple holding an iterator referring to the first element after the input sequence and the output iterator to the element in the destination range, one past the last element copied.

```
template<typename FwdIter1, typename Sent1, typename FwdIter2, typename Sent2, typename
FwdIter3, typename F, typename Proj1 = hpx::identity, typename Proj2 = hpx::identity>
ranges::binary_transform_result<FwdIter1, FwdIter2, FwdIter3> transform(FwdIter1 first1, Sent1
last1, FwdIter2 first2, Sent2 last2, FwdIter3 dest,
F &&f, Proj1 &&proj1 =
Proj1(), Proj2 &&proj2 =
Proj2())
```

Applies the given function f to pairs of elements from two ranges: one defined by *rng* and the other beginning at *first2*, and stores the result in another range, beginning at *dest*.

Note: Complexity: Exactly `size(rng)` applications of f

Template Parameters

- **FwdIter1** – The type of the source iterators for the first range used (deduced). This iterator type must meet the requirements of a forward iterator.
- **Sent1** – The type of the end source iterators used (deduced). This iterator type must meet the requirements of a sentinel for `FwdIter1`.
- **FwdIter2** – The type of the source iterators for the first range used (deduced). This iterator type must meet the requirements of a forward iterator.
- **Sent2** – The type of the end source iterators used (deduced). This iterator type must meet the requirements of a sentinel for `FwdIter2`.
- **FwdIter3** – The type of the source iterators for the first range used (deduced). This iterator type must meet the requirements of a forward iterator.
- **F** – The type of the function/function object to use (deduced). Unlike its sequential form, the parallel overload of *transform* requires F to meet the requirements of *CopyConstructible*.
- **Proj1** – The type of an optional projection function to be used for elements of the first sequence. This defaults to `hpx::identity`
- **Proj2** – The type of an optional projection function to be used for elements of the second sequence. This defaults to `hpx::identity`

Parameters

- **first1** – Refers to the beginning of the first sequence of elements the algorithm will be applied to.
- **last1** – Refers to the end of the first sequence of elements the algorithm will be applied to.
- **first2** – Refers to the beginning of the second sequence of elements the algorithm will be applied to.
- **last2** – Refers to the end of the second sequence of elements the algorithm will be applied to.
- **dest** – Refers to the beginning of the destination range.
- **f** – Specifies the function (or function object) which will be invoked for each of the elements in the sequence specified by `[first, last)`. This is a binary predicate. The signature of this predicate should be equivalent to:

```
Ret fun(const Type1 &a, const Type2 &b);
```

The signature does not need to have `const&`. The types *Type1* and *Type2* must be such that objects of types *FwdIter1* and *FwdIter2* can be dereferenced and then implicitly converted to *Type1* and *Type2* respectively. The type *Ret* must be such that an object of type *FwdIter3* can be dereferenced and assigned a value of type *Ret*.

- **proj1** – Specifies the function (or function object) which will be invoked for each of the elements of the first sequence as a projection operation before the actual predicate *f* is invoked.
- **proj2** – Specifies the function (or function object) which will be invoked for each of the elements of the second sequence as a projection operation before the actual predicate *f* is invoked.

Returns The *transform* algorithm returns `ranges::binary_transform_result<FwdIter1, FwdIter2, FwdIter3>`. The *transform* algorithm returns a tuple holding an iterator referring to the first element after the first input sequence, an iterator referring to the first element after the second input sequence, and the output iterator referring to the element in the destination range, one past the last element copied.

```
template<typename Rng1, typename Rng2, typename FwdIter, typename F, typename Proj1 =
hpx::identity, typename Proj2 = hpx::identity>
ranges::binary_transform_result<hpx::traits::range_iterator_t<Rng1>, hpx::traits::range_iterator_t<Rng2>, FwdIter> trans
```

Applies the given function *f* to pairs of elements from two ranges: one defined by [first1, last1) and the other beginning at first2, and stores the result in another range, beginning at dest.

Note: Complexity: Exactly $\min(\text{last2}-\text{first2}, \text{last1}-\text{first1})$ applications of *f*

Note: The algorithm will invoke the binary predicate until it reaches the end of the shorter of the two given input sequences

Template Parameters

- **Rng1** – The type of the first source range used (deduced). The iterators extracted from this range type must meet the requirements of an input iterator.
- **Rng2** – The type of the second source range used (deduced). The iterators extracted from this range type must meet the requirements of an input iterator.
- **FwdIter** – The type of the iterator representing the destination range (deduced). This iterator type must meet the requirements of an output iterator.

- **F** – The type of the function/function object to use (deduced). Unlike its sequential form, the parallel overload of *transform* requires *F* to meet the requirements of *Copy-Constructible*.
- **Proj1** – The type of an optional projection function to be used for elements of the first sequence. This defaults to *hpx::identity*
- **Proj2** – The type of an optional projection function to be used for elements of the second sequence. This defaults to *hpx::identity*

Parameters

- **rng1** – Refers to the first sequence of elements the algorithm will be applied to.
- **rng2** – Refers to the second sequence of elements the algorithm will be applied to.
- **dest** – Refers to the beginning of the destination range.
- **f** – Specifies the function (or function object) which will be invoked for each of the elements in the sequence specified by [first, last). This is a binary predicate. The signature of this predicate should be equivalent to:

```
Ret fun(const Type1 &a, const Type2 &b);
```

The signature does not need to have `const&`. The types *Type1* and *Type2* must be such that objects of types `range_iterator<Rng1>::type` and `range_iterator<Rng2>::type` can be dereferenced and then implicitly converted to *Type1* and *Type2* respectively. The type *Ret* must be such that an object of type *FwdIter* can be dereferenced and assigned a value of type *Ret*.

- **proj1** – Specifies the function (or function object) which will be invoked for each of the elements of the first sequence as a projection operation before the actual predicate *f* is invoked.
- **proj2** – Specifies the function (or function object) which will be invoked for each of the elements of the second sequence as a projection operation before the actual predicate *f* is invoked.

Returns The *transform* algorithm returns `ranges::binary_transform_result<hpx::traits::range_iterator_t<Rng1>, hpx::traits::range_iterator_t<Rng2>, FwdIter>`. The *transform* algorithm returns a tuple holding an iterator referring to the first element after the first input sequence, an iterator referring to the first element after the second input sequence, and the output iterator referring to the element in the destination range, one past the last element copied.

hpx::ranges::transform_exclusive_scan

Defined in header `hpx/algorithm.hpp`⁶⁸³.

See *Public API* for a list of names and headers that are part of the public *HPX* API.

namespace **hpx**

namespace **ranges**

⁶⁸³ <http://github.com/STELLAR-GROUP/hpx/blob/8a3b7c1a4cb5693b2f7d9f587f759392ed0c51a0/libs/full/include/include/hpx/algorithm.hpp>

Functions

```
template<typename InIter, typename Sent, typename OutIter, typename BinOp, typename UnOp,
typename T = typename std::iterator_traits<InIter>::value_type>
transform_exclusive_scan_result<InIter, OutIter> transform_exclusive_scan(InIter first, Sent last,
                                                                    OutIter dest, T init,
                                                                    BinOp &&binary_op,
                                                                    UnOp &&unary_op)
```

Assigns through each iterator *i* in [result, result + (last - first)) the value of GENERALIZED_NONCOMMUTATIVE_SUM(binary_op, init, conv(*first), ..., conv(*(first + (i - result) - 1))).

The reduce operations in the parallel *transform_exclusive_scan* algorithm invoked without an execution policy object execute in sequential order in the calling thread.

Neither *conv* nor *op* shall invalidate iterators or sub-ranges, or modify elements in the ranges [first,last) or [result,result + (last - first)).

The behavior of *transform_exclusive_scan* may be non-deterministic for a non-associative predicate.

Note: Complexity: $O(\textit{last} - \textit{first})$ applications of the predicates *op* and *conv*.

Note: GENERALIZED_NONCOMMUTATIVE_SUM(*op*, *a*₁, ..., *a*_N) is defined as:

- *a*₁ when *N* is 1
 - *op*(GENERALIZED_NONCOMMUTATIVE_SUM(*op*, *a*₁, ..., *a*_K), GENERALIZED_NONCOMMUTATIVE_SUM(*op*, *a*_M, ..., *a*_N)) where 1 < K+1 = M <= N.
-

Template Parameters

- **InIter** – The type of the source iterators used (deduced). This iterator type must meet the requirements of an input iterator.
- **Sent** – The type of the source sentinel (deduced). This sentinel type must be a sentinel for *InIter*.
- **OutIter** – The type of the iterator representing the destination range (deduced). This iterator type must meet the requirements of an output iterator.
- **T** – The type of the value to be used as initial (and intermediate) values (deduced).
- **BinOp** – The type of the binary function object used for the reduction operation.
- **UnOp** – The type of the unary function object used for the conversion operation.

Parameters

- **first** – Refers to the beginning of the sequence of elements the algorithm will be applied to.
- **last** – Refers to sentinel value denoting the end of the sequence of elements the algorithm will be applied.
- **dest** – Refers to the beginning of the destination range.
- **init** – The initial value for the generalized sum.
- **binary_op** – Specifies the function (or function object) which will be invoked for each of the values of the input sequence. This is a binary predicate. The signature of this predicate should be equivalent to:

```
Ret fun(const Type1 &a, const Type1 &b);
```

The signature does not need to have `const&`, but the function must not modify the objects passed to it. The types *Type1* and *Ret* must be such that an object of a type as given by the input sequence can be implicitly converted to any of those types.

- **unary_op** – Specifies the function (or function object) which will be invoked for each of the elements in the sequence specified by [first, last). This is a unary predicate. The signature of this predicate should be equivalent to:

```
R fun(const Type &a);
```

The signature does not need to have `const&`, but the function must not modify the objects passed to it. The type *Type* must be such that an object of type *FwdIter1* can be dereferenced and then implicitly converted to *Type*. The type *R* must be such that an object of this type can be implicitly converted to *T*.

Returns The *transform_exclusive_scan* algorithm returns *transform_exclusive_scan_result<InIter, OutIter>*. The *transform_exclusive_scan* algorithm returns an input iterator to the point denoted by the sentinel and an output iterator to the element in the destination range, one past the last element copied.

```
template<typename ExPolicy, typename FwdIter1, typename Sent, typename FwdIter2, typename BinOp,
typename UnOp, typename T = typename std::iterator_traits<FwdIter1>::value_type>
parallel::util::detail::algorithm_result<ExPolicy, transform_exclusive_result<FwdIter1, FwdIter2>>::type transform_exc
```

Assigns through each iterator *i* in [result, result + (last - first)) the value of GENERALIZED_NONCOMMUTATIVE_SUM(binary_op, init, conv(*first), ..., conv(*(first + (i - result) - 1))).

The reduce operations in the parallel *transform_exclusive_scan* algorithm invoked with an execution policy object of type *sequenced_policy* execute in sequential order in the calling thread.

The reduce operations in the parallel *transform_exclusive_scan* algorithm invoked with an execution policy object of type *parallel_policy* or *parallel_task_policy* are permitted to execute in an unordered fashion in unspecified threads, and indeterminately sequenced within each thread.

Neither *conv* nor *op* shall invalidate iterators or sub-ranges, or modify elements in the ranges [first,last) or [result,result + (last - first)).

The behavior of *transform_exclusive_scan* may be non-deterministic for a non-associative predicate.

Note: Complexity: $O(\textit{last} - \textit{first})$ applications of the predicates *op* and *conv*.

Note: GENERALIZED_NONCOMMUTATIVE_SUM(op, a1, ..., aN) is defined as:

- a1 when N is 1
 - op(GENERALIZED_NONCOMMUTATIVE_SUM(op, a1, ..., aK), GENERALIZED_NONCOMMUTATIVE_SUM(op, aM, ..., aN) where $1 < K+1 = M \leq N$).
-

Template Parameters

- **ExPolicy** – The type of the execution policy to use (deduced). It describes the manner in which the execution of the algorithm may be parallelized and the manner in which it executes the assignments.
- **FwdIter1** – The type of the source iterators used (deduced). This iterator type must meet the requirements of an forward iterator.
- **Sent** – The type of the source sentinel (deduced). This sentinel type must be a sentinel for FwdIter.
- **FwdIter2** – The type of the iterator representing the destination range (deduced). This iterator type must meet the requirements of an forward iterator.
- **T** – The type of the value to be used as initial (and intermediate) values (deduced).
- **BinOp** – The type of the binary function object used for the reduction operation.
- **UnOp** – The type of the unary function object used for the conversion operation.

Parameters

- **policy** – The execution policy to use for the scheduling of the iterations.
- **first** – Refers to the beginning of the sequence of elements the algorithm will be applied to.
- **last** – Refers to sentinel value denoting the end of the sequence of elements the algorithm will be applied.
- **dest** – Refers to the beginning of the destination range.
- **init** – The initial value for the generalized sum.
- **binary_op** – Specifies the function (or function object) which will be invoked for each of the values of the input sequence. This is a binary predicate. The signature of this predicate should be equivalent to:

```
Ret fun(const Type1 &a, const Type1 &b);
```

The signature does not need to have const&, but the function must not modify the objects passed to it. The types *Type1* and *Ret* must be such that an object of a type as given by the input sequence can be implicitly converted to any of those types.

- **unary_op** – Specifies the function (or function object) which will be invoked for each of the elements in the sequence specified by [first, last). This is a unary predicate. The signature of this predicate should be equivalent to:

```
R fun(const Type &a);
```

The signature does not need to have const&, but the function must not modify the objects passed to it. The type *Type* must be such that an object of type *FwdIter1* can be dereferenced and then implicitly converted to *Type*. The type *R* must be such that an object of this type can be implicitly converted to *T*.

Returns The `transform_exclusive_scan` algorithm returns a `hpx::future<transform_exclusive_result<FwdIter1, FwdIter2>>` if the execution policy is of type `sequenced_task_policy` or `parallel_task_policy` and returns `transform_exclusive_result<FwdIter1, FwdIter2>` otherwise. The `transform_exclusive_scan` algorithm returns an input iterator to the point denoted by the sentinel and an output iterator to the element in the destination range, one past the last element copied.

```
template<typename Rng, typename O, typename BinOp, typename UnOp, typename T = typename
std::iterator_traits<hpx::traits::range_iterator_t<Rng>>::value_type>
```

```
transform_exclusive_scan_result<hpx::traits::range_iterator_t<Rng>, O> transform_exclusive_scan(Rng
&&rng,
O
dest,
T
init,
BinOp
&&binary_op,
UnOp
&&unary_op)
```

Assigns through each iterator i in $[\text{result}, \text{result} + (\text{last} - \text{first}))$ the value of GENERALIZED_NONCOMMUTATIVE_SUM(binary_op, init, conv(*first), ..., conv(*(first + (i - result) - 1))).

The reduce operations in the parallel *transform_exclusive_scan* algorithm invoked without an execution policy object execute in sequential order in the calling thread.

Neither *conv* nor *op* shall invalidate iterators or sub-ranges, or modify elements in the ranges $[\text{first}, \text{last})$ or $[\text{result}, \text{result} + (\text{last} - \text{first}))$.

The behavior of *transform_exclusive_scan* may be non-deterministic for a non-associative predicate.

Note: Complexity: $O(\text{last} - \text{first})$ applications of the predicates *op* and *conv*.

Note: GENERALIZED_NONCOMMUTATIVE_SUM(*op*, *a*₁, ..., *a*_N) is defined as:

- *a*₁ when *N* is 1
 - *op*(GENERALIZED_NONCOMMUTATIVE_SUM(*op*, *a*₁, ..., *a*_K), GENERALIZED_NONCOMMUTATIVE_SUM(*op*, *a*_M, ..., *a*_N)) where $1 < K+1 = M \leq N$.
-

Template Parameters

- **Rng** – The type of the source range used (deduced). The iterators extracted from this range type must meet the requirements of an input iterator.
- **O** – The type of the iterator representing the destination range (deduced).
- **T** – The type of the value to be used as initial (and intermediate) values (deduced).
- **BinOp** – The type of the binary function object used for the reduction operation.
- **UnOp** – The type of the unary function object used for the conversion operation.

Parameters

- **rng** – Refers to the sequence of elements the algorithm will be applied to.
- **dest** – Refers to the beginning of the destination range.
- **init** – The initial value for the generalized sum.
- **binary_op** – Specifies the function (or function object) which will be invoked for each of the values of the input sequence. This is a binary predicate. The signature of this predicate should be equivalent to:

```
Ret fun(const Type1 &a, const Type1 &b);
```

The signature does not need to have `const&`, but the function must not modify the objects passed to it. The types *Type1* and *Ret* must be such that an object of a type as given by the input sequence can be implicitly converted to any of those types.

- **unary_op** – Specifies the function (or function object) which will be invoked for each of the elements in the sequence specified by [first, last). This is a unary predicate. The signature of this predicate should be equivalent to:

```
R fun(const Type &a);
```

The signature does not need to have const&, but the function must not modify the objects passed to it. The type *Type* must be such that an object of type *FwdIter1* can be dereferenced and then implicitly converted to *Type*. The type *R* must be such that an object of this type can be implicitly converted to *T*.

Returns The *transform_exclusive_scan* algorithm returns a *transform_exclusive_scan_result*< traits::range_iterator_t<Rng>, O>. The *transform_exclusive_scan* algorithm returns an input iterator to one past the end of the range and an output iterator to the element in the destination range, one past the last element copied.

```
template<typename ExPolicy, typename Rng, typename O, typename BinOp, typename UnOp, typename
T = typename std::iterator_traits<hpx::traits::range_iterator_t<Rng>>::value_type>
parallel::util::detail::algorithm_result<ExPolicy, transform_exclusive_scan_result<hpx::traits::range_iterator_t<Rng>, O>>
```

Assigns through each iterator *i* in [result, result + (last - first)) the value of GENERALIZED_NONCOMMUTATIVE_SUM(binary_op, init, conv(*first), ..., conv(*(first + (i - result) - 1))).

The reduce operations in the parallel *transform_exclusive_scan* algorithm invoked with an execution policy object of type *sequenced_policy* execute in sequential order in the calling thread.

The reduce operations in the parallel *transform_exclusive_scan* algorithm invoked with an execution policy object of type *parallel_policy* or *parallel_task_policy* are permitted to execute in an unordered fashion in unspecified threads, and indeterminately sequenced within each thread.

Neither *conv* nor *op* shall invalidate iterators or sub-ranges, or modify elements in the ranges [first,last) or [result,result + (last - first)).

The behavior of *transform_exclusive_scan* may be non-deterministic for a non-associative predicate.

Note: Complexity: $O(\text{last} - \text{first})$ applications of the predicates *op* and *conv*.

Note: GENERALIZED_NONCOMMUTATIVE_SUM(op, a1, ..., aN) is defined as:

- a1 when N is 1

- `op(GENERALIZED_NONCOMMUTATIVE_SUM(op, a1, ..., aK), GENERALIZED_NONCOMMUTATIVE_SUM(op, aM, ..., aN))` where $1 < K+1 = M \leq N$.

Template Parameters

- **ExPolicy** – The type of the execution policy to use (deduced). It describes the manner in which the execution of the algorithm may be parallelized and the manner in which it executes the assignments.
- **Rng** – The type of the source range used (deduced). The iterators extracted from this range type must meet the requirements of a forward iterator.
- **O** – The type of the iterator representing the destination range (deduced). This iterator type must meet the requirements of a forward iterator. This iterator type must meet the requirements of a forward iterator.
- **T** – The type of the value to be used as initial (and intermediate) values (deduced).
- **BinOp** – The type of the binary function object used for the reduction operation.
- **UnOp** – The type of the unary function object used for the conversion operation.

Parameters

- **policy** – The execution policy to use for the scheduling of the iterations.
- **rng** – Refers to the sequence of elements the algorithm will be applied to.
- **dest** – Refers to the beginning of the destination range.
- **init** – The initial value for the generalized sum.
- **binary_op** – Specifies the function (or function object) which will be invoked for each of the values of the input sequence. This is a binary predicate. The signature of this predicate should be equivalent to:

```
Ret fun(const Type1 &a, const Type1 &b);
```

The signature does not need to have `const&`, but the function must not modify the objects passed to it. The types *Type1* and *Ret* must be such that an object of a type as given by the input sequence can be implicitly converted to any of those types.

- **unary_op** – Specifies the function (or function object) which will be invoked for each of the elements in the sequence specified by [first, last). This is a unary predicate. The signature of this predicate should be equivalent to:

```
R fun(const Type &a);
```

The signature does not need to have `const&`, but the function must not modify the objects passed to it. The type *Type* must be such that an object of type *FwdIter1* can be dereferenced and then implicitly converted to *Type*. The type *R* must be such that an object of this type can be implicitly converted to *T*.

Returns The `transform_exclusive_scan` algorithm returns a `hpx::future<transform_exclusive_scan_result< traits::range_iterator_t<Rng>, O>>` if the execution policy is of type `sequenced_task_policy` or `parallel_task_policy` and returns `transform_exclusive_scan_result< traits::range_iterator_t<Rng>, O>` otherwise. The `transform_exclusive_scan` algorithm returns an input iterator to one past the end of the range and an output iterator to the element in the destination range, one past the last element copied.

hpx::ranges::transform_inclusive_scan

Defined in header `hpx/algorithm.hpp`⁶⁸⁴.

See *Public API* for a list of names and headers that are part of the public HPX API.

namespace **hpx**

namespace **ranges**

Functions

```
template<typename InIter, typename Sent, typename OutIter, typename BinOp, typename UnOp>
transform_inclusive_scan_result<InIter, OutIter> transform_inclusive_scan(InIter first, Sent last,
                                                                           OutIter dest, BinOp
                                                                           &&binary_op, UnOp
                                                                           &&unary_op)
```

Assigns through each iterator i in $[\text{result}, \text{result} + (\text{last} - \text{first}))$ the value of GENERALIZED_NONCOMMUTATIVE_SUM($\text{op}, \text{conv}(*\text{first}), \dots, \text{conv}(*(\text{first} + (i - \text{result})))$).

The reduce operations in the parallel *transform_inclusive_scan* algorithm invoked without an execution policy object execute in sequential order in the calling thread.

Neither *conv* nor *op* shall invalidate iterators or sub-ranges, or modify elements in the ranges $[\text{first}, \text{last})$ or $[\text{result}, \text{result} + (\text{last} - \text{first}))$.

The behavior of *transform_inclusive_scan* may be non-deterministic for a non-associative predicate.

Note: Complexity: $O(\text{last} - \text{first})$ applications of the predicates *op* and *conv*.

Note: GENERALIZED_NONCOMMUTATIVE_SUM($\text{op}, a_1, \dots, a_N$) is defined as:

- a_1 when N is 1
 - $\text{op}(\text{GENERALIZED_NONCOMMUTATIVE_SUM}(\text{op}, a_1, \dots, a_K), \text{GENERALIZED_NONCOMMUTATIVE_SUM}(\text{op}, a_{K+1}, \dots, a_N))$ where $1 < K+1 = M \leq N$.
-

Template Parameters

- **InIter** – The type of the source iterators used (deduced). This iterator type must meet the requirements of an input iterator.
- **Sent** – The type of the source sentinel (deduced). This sentinel type must be a sentinel for InIter.
- **OutIter** – The type of the iterator representing the destination range (deduced). This iterator type must meet the requirements of an output iterator.
- **BinOp** – The type of the binary function object used for the reduction operation.
- **UnOp** – The type of the unary function object used for the conversion operation.

Parameters

- **first** – Refers to the beginning of the sequence of elements the algorithm will be applied to.

⁶⁸⁴ <http://github.com/STELLAR-GROUP/hpx/blob/8a3b7c1a4cb5693b2f7d9f587f759392ed0c51a0/libs/full/include/include/hpx/algorithm.hpp>

- **last** – Refers to sentinel value denoting the end of the sequence of elements the algorithm will be applied.
- **dest** – Refers to the beginning of the destination range.
- **binary_op** – Specifies the function (or function object) which will be invoked for each of the values of the input sequence. This is a binary predicate. The signature of this predicate should be equivalent to:

```
Ret fun(const Type1 &a, const Type1 &b);
```

The signature does not need to have `const&`, but the function must not modify the objects passed to it. The types *Type1* and *Ret* must be such that an object of a type as given by the input sequence can be implicitly converted to any of those types.

- **unary_op** – Specifies the function (or function object) which will be invoked for each of the elements in the sequence specified by [first, last). This is a unary predicate. The signature of this predicate should be equivalent to:

```
R fun(const Type &a);
```

The signature does not need to have `const&`, but the function must not modify the objects passed to it. The type *Type* must be such that an object of type *FwdIter1* can be dereferenced and then implicitly converted to *Type*. The type *R* must be such that an object of this type can be implicitly converted to *T*.

Returns The *transform_inclusive_scan* algorithm returns *transform_inclusive_scan_result<InIter, OutIter>*. The *transform_inclusive_scan* algorithm returns an input iterator to the point denoted by the sentinel and an output iterator to the element in the destination range, one past the last element copied.

```
template<typename ExPolicy, typename FwdIter1, typename Sent, typename FwdIter2, typename BinOp, typename UnOp>
```

```
parallel::util::detail::algorithm_result<ExPolicy, transform_inclusive_result<FwdIter1, FwdIter2>>::type transform_inc
```

Assigns through each iterator *i* in [result, result + (last - first)) the value of GENERALIZED_NONCOMMUTATIVE_SUM(op, conv(*first), ..., conv(*(first + (i - result)))).

The reduce operations in the parallel *transform_inclusive_scan* algorithm invoked with an execution policy object of type *sequenced_policy* execute in sequential order in the calling thread.

The reduce operations in the parallel *transform_inclusive_scan* algorithm invoked with an execution policy object of type *parallel_policy* or *parallel_task_policy* are permitted to execute in an unordered fashion in unspecified threads, and indeterminately sequenced within each thread.

Neither *conv* nor *op* shall invalidate iterators or sub-ranges, or modify elements in the ranges [first,last) or [result,result + (last - first)).

The behavior of `transform_inclusive_scan` may be non-deterministic for a non-associative predicate.

Note: Complexity: $O(\text{last} - \text{first})$ applications of the predicates *op* and *conv*.

Note: `GENERALIZED_NONCOMMUTATIVE_SUM(op, a1, ..., aN)` is defined as:

- a_1 when N is 1
 - `op(GENERALIZED_NONCOMMUTATIVE_SUM(op, a1, ..., aK), GENERALIZED_NONCOMMUTATIVE_SUM(op, aM, ..., aN))` where $1 < K+1 = M \leq N$.
-

Template Parameters

- **ExPolicy** – The type of the execution policy to use (deduced). It describes the manner in which the execution of the algorithm may be parallelized and the manner in which it executes the assignments.
- **FwdIter1** – The type of the source iterators used (deduced). This iterator type must meet the requirements of an forward iterator.
- **Sent** – The type of the source sentinel (deduced). This sentinel type must be a sentinel for `FwdIter`.
- **FwdIter2** – The type of the iterator representing the destination range (deduced). This iterator type must meet the requirements of an forward iterator.
- **BinOp** – The type of the binary function object used for the reduction operation.
- **UnOp** – The type of the unary function object used for the conversion operation.

Parameters

- **policy** – The execution policy to use for the scheduling of the iterations.
- **first** – Refers to the beginning of the sequence of elements the algorithm will be applied to.
- **last** – Refers to sentinel value denoting the end of the sequence of elements the algorithm will be applied.
- **dest** – Refers to the beginning of the destination range.
- **binary_op** – Specifies the function (or function object) which will be invoked for each of the values of the input sequence. This is a binary predicate. The signature of this predicate should be equivalent to:

```
Ret fun(const Type1 &a, const Type1 &b);
```

The signature does not need to have `const&`, but the function must not modify the objects passed to it. The types *Type1* and *Ret* must be such that an object of a type as given by the input sequence can be implicitly converted to any of those types.

- **unary_op** – Specifies the function (or function object) which will be invoked for each of the elements in the sequence specified by [first, last). This is a unary predicate. The signature of this predicate should be equivalent to:

```
R fun(const Type &a);
```

The signature does not need to have `const&`, but the function must not modify the objects passed to it. The type *Type* must be such that an object of type *FwdIter1* can be dereferenced and then implicitly converted to *Type*. The type *R* must be such that an object of this type can be implicitly converted to *T*.

Returns The `transform_inclusive_scan` algorithm returns a `hpx::future<transform_inclusive_result<FwdIter1, FwdIter2>>` if the execution

policy is of type *sequenced_task_policy* or *parallel_task_policy* and returns *transform_inclusive_result*<*FwdIter1*, *FwdIter2*> otherwise. The *transform_inclusive_scan* algorithm returns an input iterator to the point denoted by the sentinel and an output iterator to the element in the destination range, one past the last element copied.

```
template<typename Rng, typename O, typename BinOp, typename UnOp>
transform_inclusive_scan_result<hpx::traits::range_iterator_t<Rng>, O> transform_inclusive_scan(Rng
&&rng,
O
dest,
BinOp
&&binary_op,
UnOp
&&unary_op)
```

Assigns through each iterator *i* in [result, result + (last - first)) the value of GENERALIZED_NONCOMMUTATIVE_SUM(op, conv(*first), ..., conv(*(first + (i - result)))).

The reduce operations in the parallel *transform_inclusive_scan* algorithm invoked without an execution policy object execute in sequential order in the calling thread.

Neither *conv* nor *op* shall invalidate iterators or sub-ranges, or modify elements in the ranges [first,last) or [result,result + (last - first)).

The behavior of *transform_inclusive_scan* may be non-deterministic for a non-associative predicate.

Note: Complexity: $O(\text{last} - \text{first})$ applications of the predicates *op* and *conv*.

Note: GENERALIZED_NONCOMMUTATIVE_SUM(op, a1, ..., aN) is defined as:

- a1 when N is 1
 - op(GENERALIZED_NONCOMMUTATIVE_SUM(op, a1, ..., aK), GENERALIZED_NONCOMMUTATIVE_SUM(op, aM, ..., aN) where $1 < K+1 = M \leq N$).
-

Template Parameters

- **Rng** – The type of the source range used (deduced). The iterators extracted from this range type must meet the requirements of an input iterator.
- **O** – The type of the iterator representing the destination range (deduced).
- **BinOp** – The type of the binary function object used for the reduction operation.
- **UnOp** – The type of the unary function object used for the conversion operation.

Parameters

- **rng** – Refers to the sequence of elements the algorithm will be applied to.
- **dest** – Refers to the beginning of the destination range.
- **binary_op** – Specifies the function (or function object) which will be invoked for each of the values of the input sequence. This is a binary predicate. The signature of this predicate should be equivalent to:

```
Ret fun(const Type1 &a, const Type1 &b);
```

The signature does not need to have const&, but the function must not modify the objects passed to it. The types *Type1* and *Ret* must be such that an object of a type as given by

the input sequence can be implicitly converted to any of those types.

- **unary_op** – Specifies the function (or function object) which will be invoked for each of the elements in the sequence specified by [first, last). This is a unary predicate. The signature of this predicate should be equivalent to:

```
R fun(const Type &a);
```

The signature does not need to have const&, but the function must not modify the objects passed to it. The type *Type* must be such that an object of type *FwdIter1* can be dereferenced and then implicitly converted to *Type*. The type *R* must be such that an object of this type can be implicitly converted to *T*.

Returns The *transform_inclusive_scan* algorithm returns a *transform_inclusive_scan_result*< traits::range_iterator_t<Rng>, O>. The *transform_inclusive_scan* algorithm returns an input iterator to one past the end of the range and an output iterator to the element in the destination range, one past the last element copied.

```
template<typename ExPolicy, typename Rng, typename O, typename BinOp, typename UnOp>
parallel::util::detail::algorithm_result<ExPolicy, transform_inclusive_scan_result<hpx::traits::range_iterator_t<Rng>, O>>
```

Assigns through each iterator *i* in [result, result + (last - first)) the value of GENERALIZED_NONCOMMUTATIVE_SUM(op, conv(*first), ..., conv(*(first + (i - result)))).

The reduce operations in the parallel *transform_inclusive_scan* algorithm invoked with an execution policy object of type *sequenced_policy* execute in sequential order in the calling thread.

The reduce operations in the parallel *transform_inclusive_scan* algorithm invoked with an execution policy object of type *parallel_policy* or *parallel_task_policy* are permitted to execute in an unordered fashion in unspecified threads, and indeterminately sequenced within each thread.

Neither *conv* nor *op* shall invalidate iterators or sub-ranges, or modify elements in the ranges [first,last) or [result,result + (last - first)).

The behavior of *transform_inclusive_scan* may be non-deterministic for a non-associative predicate.

Note: Complexity: $O(\text{last} - \text{first})$ applications of the predicates *op* and *conv*.

Note: GENERALIZED_NONCOMMUTATIVE_SUM(op, a1, ..., aN) is defined as:

- a1 when N is 1
- op(GENERALIZED_NONCOMMUTATIVE_SUM(op, a1, ..., aK), GENERALIZED_NONCOMMUTATIVE_SUM(op, aM, ..., aN) where $1 < K+1 = M \leq N$).

Template Parameters

- **ExPolicy** – The type of the execution policy to use (deduced). It describes the manner in which the execution of the algorithm may be parallelized and the manner in which it executes the assignments.
- **Rng** – The type of the source range used (deduced). The iterators extracted from this range type must meet the requirements of a forward iterator.
- **O** – The type of the iterator representing the destination range (deduced). This iterator type must meet the requirements of a forward iterator. This iterator type must meet the requirements of a forward iterator.
- **BinOp** – The type of the binary function object used for the reduction operation.
- **UnOp** – The type of the unary function object used for the conversion operation.

Parameters

- **policy** – The execution policy to use for the scheduling of the iterations.
- **rng** – Refers to the sequence of elements the algorithm will be applied to.
- **dest** – Refers to the beginning of the destination range.
- **binary_op** – Specifies the function (or function object) which will be invoked for each of the values of the input sequence. This is a binary predicate. The signature of this predicate should be equivalent to:

```
Ret fun(const Type1 &a, const Type1 &b);
```

The signature does not need to have `const&`, but the function must not modify the objects passed to it. The types *Type1* and *Ret* must be such that an object of a type as given by the input sequence can be implicitly converted to any of those types.

- **unary_op** – Specifies the function (or function object) which will be invoked for each of the elements in the sequence specified by [first, last). This is a unary predicate. The signature of this predicate should be equivalent to:

```
R fun(const Type &a);
```

The signature does not need to have `const&`, but the function must not modify the objects passed to it. The type *Type* must be such that an object of type *FwdIter1* can be dereferenced and then implicitly converted to *Type*. The type *R* must be such that an object of this type can be implicitly converted to *T*.

Returns The `transform_inclusive_scan` algorithm returns a `hpx::future<transform_inclusive_scan_result< traits::range_iterator_t<Rng>, O>>` if the execution policy is of type `sequenced_task_policy` or `parallel_task_policy` and returns `transform_inclusive_scan_result< traits::range_iterator_t<Rng>, O>` otherwise. The `transform_inclusive_scan` algorithm returns an input iterator to one past the end of the range and an output iterator to the element in the destination range, one past the last element copied.

```
template<typename InIter, typename Sent, typename OutIter, typename BinOp, typename UnOp,
typename T = typename std::iterator_traits<InIter>::value_type>
transform_inclusive_scan_result<InIter, OutIter> transform_inclusive_scan(InIter first, Sent last,
OutIter dest, BinOp
&&binary_op, UnOp
&&unary_op, T init)
```

Assigns through each iterator *i* in [result, result + (last - first)) the value of GENERALIZED_NONCOMMUTATIVE_SUM(binary_op, init, conv(*first), ..., conv(*(first + (i - result)))).

The reduce operations in the parallel `transform_inclusive_scan` algorithm invoked without an execution

policy object execute in sequential order in the calling thread.

Neither *conv* nor *op* shall invalidate iterators or sub-ranges, or modify elements in the ranges [first,last) or [result,result + (last - first)).

The behavior of `transform_inclusive_scan` may be non-deterministic for a non-associative predicate.

Note: Complexity: $O(\text{last} - \text{first})$ applications of the predicates *op* and *conv*.

Note: `GENERALIZED_NONCOMMUTATIVE_SUM(op, a1, ..., aN)` is defined as:

- a_1 when N is 1
 - `op(GENERALIZED_NONCOMMUTATIVE_SUM(op, a1, ..., aK), GENERALIZED_NONCOMMUTATIVE_SUM(op, aM, ..., aN))` where $1 < K+1 = M \leq N$.
-

Template Parameters

- **InIter** – The type of the source iterators used (deduced). This iterator type must meet the requirements of an input iterator.
- **Sent** – The type of the source sentinel (deduced). This sentinel type must be a sentinel for `InIter`.
- **OutIter** – The type of the iterator representing the destination range (deduced). This iterator type must meet the requirements of an output iterator.
- **BinOp** – The type of the binary function object used for the reduction operation.
- **UnOp** – The type of the unary function object used for the conversion operation.
- **T** – The type of the value to be used as initial (and intermediate) values (deduced).

Parameters

- **first** – Refers to the beginning of the sequence of elements the algorithm will be applied to.
- **last** – Refers to sentinel value denoting the end of the sequence of elements the algorithm will be applied.
- **dest** – Refers to the beginning of the destination range.
- **binary_op** – Specifies the function (or function object) which will be invoked for each of the values of the input sequence. This is a binary predicate. The signature of this predicate should be equivalent to:

```
Ret fun(const Type1 &a, const Type1 &b);
```

The signature does not need to have `const&`, but the function must not modify the objects passed to it. The types *Type1* and *Ret* must be such that an object of a type as given by the input sequence can be implicitly converted to any of those types.

- **unary_op** – Specifies the function (or function object) which will be invoked for each of the elements in the sequence specified by [first, last). This is a unary predicate. The signature of this predicate should be equivalent to:

```
R fun(const Type &a);
```

The signature does not need to have `const&`, but the function must not modify the objects passed to it. The type *Type* must be such that an object of type *FwdIter1* can be dereferenced and then implicitly converted to *Type*. The type *R* must be such that an object of this type can be implicitly converted to *T*.

- **init** – The initial value for the generalized sum.

Returns The `transform_inclusive_scan` algorithm returns `transform_inclusive_scan_result<InIter, OutIter>`. The `transform_inclusive_scan` algorithm returns an input iterator to the point denoted by the sentinel and an output iterator to the element in the destination range, one past the last element copied.

```
template<typename ExPolicy, typename FwdIter1, typename Sent, typename FwdIter2, typename
BinOp, typename UnOp, typename T = typename std::iterator_traits<FwdIter1>::value_type
parallel::util::detail::algorithm_result<ExPolicy, transform_inclusive_result<FwdIter1, FwdIter2>>::type transform_inc
```

Assigns through each iterator i in $[\text{result}, \text{result} + (\text{last} - \text{first}))$ the value of `GENERALIZED_NONCOMMUTATIVE_SUM(binary_op, init, conv(*first), ..., conv(*(first + (i - result))))`.

The reduce operations in the parallel `transform_inclusive_scan` algorithm invoked with an execution policy object of type `sequenced_policy` execute in sequential order in the calling thread.

The reduce operations in the parallel `transform_inclusive_scan` algorithm invoked with an execution policy object of type `parallel_policy` or `parallel_task_policy` are permitted to execute in an unordered fashion in unspecified threads, and indeterminately sequenced within each thread.

Neither `conv` nor `op` shall invalidate iterators or sub-ranges, or modify elements in the ranges $[\text{first}, \text{last})$ or $[\text{result}, \text{result} + (\text{last} - \text{first}))$.

The behavior of `transform_inclusive_scan` may be non-deterministic for a non-associative predicate.

Note: Complexity: $O(\text{last} - \text{first})$ applications of the predicates `op` and `conv`.

Note: `GENERALIZED_NONCOMMUTATIVE_SUM(op, a1, ..., aN)` is defined as:

- $a1$ when N is 1
 - `op(GENERALIZED_NONCOMMUTATIVE_SUM(op, a1, ..., aK), GENERALIZED_NONCOMMUTATIVE_SUM(op, aM, ..., aN))` where $1 < K+1 = M \leq N$.
-

Template Parameters

- **ExPolicy** – The type of the execution policy to use (deduced). It describes the manner in which the execution of the algorithm may be parallelized and the manner in which it executes the assignments.
- **FwdIter1** – The type of the source iterators used (deduced). This iterator type must meet the requirements of an forward iterator.

- **Sent** – The type of the source sentinel (deduced). This sentinel type must be a sentinel for `FwdIter`.
- **FwdIter2** – The type of the iterator representing the destination range (deduced). This iterator type must meet the requirements of an forward iterator.
- **BinOp** – The type of the binary function object used for the reduction operation.
- **UnOp** – The type of the unary function object used for the conversion operation.
- **T** – The type of the value to be used as initial (and intermediate) values (deduced).

Parameters

- **policy** – The execution policy to use for the scheduling of the iterations.
- **first** – Refers to the beginning of the sequence of elements the algorithm will be applied to.
- **last** – Refers to sentinel value denoting the end of the sequence of elements the algorithm will be applied.
- **dest** – Refers to the beginning of the destination range.
- **binary_op** – Specifies the function (or function object) which will be invoked for each of the values of the input sequence. This is a binary predicate. The signature of this predicate should be equivalent to:

```
Ret fun(const Type1 &a, const Type1 &b);
```

The signature does not need to have `const&`, but the function must not modify the objects passed to it. The types `Type1` and `Ret` must be such that an object of a type as given by the input sequence can be implicitly converted to any of those types.

- **unary_op** – Specifies the function (or function object) which will be invoked for each of the elements in the sequence specified by `[first, last)`. This is a unary predicate. The signature of this predicate should be equivalent to:

```
R fun(const Type &a);
```

The signature does not need to have `const&`, but the function must not modify the objects passed to it. The type `Type` must be such that an object of type `FwdIter1` can be dereferenced and then implicitly converted to `Type`. The type `R` must be such that an object of this type can be implicitly converted to `T`.

- **init** – The initial value for the generalized sum.

Returns The `transform_inclusive_scan` algorithm returns a `hpx::future<transform_inclusive_result<FwdIter1, FwdIter2>>` if the execution policy is of type `sequenced_task_policy` or `parallel_task_policy` and returns `transform_inclusive_result<FwdIter1, FwdIter2>` otherwise. The `transform_inclusive_scan` algorithm returns an input iterator to the point denoted by the sentinel and an output iterator to the element in the destination range, one past the last element copied.

```
template<typename Rng, typename O, typename BinOp, typename UnOp, typename T = typename
std::iterator_traits<hpx::traits::range_iterator_t<Rng>>::value_type>
transform_inclusive_scan_result<hpx::traits::range_iterator_t<Rng>, O> transform_inclusive_scan(Rng
&&rng,
O
dest,
BinOp
&&binary_op,
UnOp
&&unary_op,
T
init)
```

Assigns through each iterator i in $[\text{result}, \text{result} + (\text{last} - \text{first}))$ the value of `GENERALIZED_NONCOMMUTATIVE_SUM(binary_op, init, conv(*first), ..., conv(*(first + (i - result))))`.

The reduce operations in the parallel `transform_inclusive_scan` algorithm invoked without an execution policy object execute in sequential order in the calling thread.

Neither `conv` nor `op` shall invalidate iterators or sub-ranges, or modify elements in the ranges $[\text{first}, \text{last})$ or $[\text{result}, \text{result} + (\text{last} - \text{first}))$.

The behavior of `transform_inclusive_scan` may be non-deterministic for a non-associative predicate.

Note: Complexity: $O(\text{last} - \text{first})$ applications of the predicates `op` and `conv`.

Note: `GENERALIZED_NONCOMMUTATIVE_SUM(op, a1, ..., aN)` is defined as:

- a_1 when N is 1
 - `op(GENERALIZED_NONCOMMUTATIVE_SUM(op, a1, ..., aK), GENERALIZED_NONCOMMUTATIVE_SUM(op, aM, ..., aN))` where $1 < K+1 = M \leq N$.
-

Template Parameters

- **Rng** – The type of the source range used (deduced). The iterators extracted from this range type must meet the requirements of an input iterator.
- **O** – The type of the iterator representing the destination range (deduced).
- **BinOp** – The type of the binary function object used for the reduction operation.
- **UnOp** – The type of the unary function object used for the conversion operation.
- **T** – The type of the value to be used as initial (and intermediate) values (deduced).

Parameters

- **rng** – Refers to the sequence of elements the algorithm will be applied to.
- **dest** – Refers to the beginning of the destination range.
- **binary_op** – Specifies the function (or function object) which will be invoked for each of the values of the input sequence. This is a binary predicate. The signature of this predicate should be equivalent to:

```
Ret fun(const Type1 &a, const Type1 &b);
```

The signature does not need to have `const&`, but the function must not modify the objects passed to it. The types `Type1` and `Ret` must be such that an object of a type as given by the input sequence can be implicitly converted to any of those types.

- **unary_op** – Specifies the function (or function object) which will be invoked for each of the elements in the sequence specified by $[\text{first}, \text{last})$. This is a unary predicate. The signature of this predicate should be equivalent to:

```
R fun(const Type &a);
```

The signature does not need to have `const&`, but the function must not modify the objects passed to it. The type `Type` must be such that an object of type `FwdIter1` can be dereferenced and then implicitly converted to `Type`. The type `R` must be such that an object of this type can be implicitly converted to `T`.

- **init** – The initial value for the generalized sum.

Returns The `transform_inclusive_scan` algorithm returns a `transform_inclusive_scan_result` `< traits::range_iterator_t<Rng>, O>`. The `trans-`

form_inclusive_scan algorithm returns an input iterator to one past the end of the range and an output iterator to the element in the destination range, one past the last element copied.

```
template<typename ExPolicy, typename Rng, typename O, typename BinOp, typename UnOp, typename  
T = typename std::iterator_traits<hpx::traits::range_iterator_t<Rng>>::value_type>  
parallel::util::detail::algorithm_result<ExPolicy, transform_inclusive_scan_result<hpx::traits::range_iterator_t<Rng>, O>>
```

Assigns through each iterator *i* in [result, result + (last - first)) the value of GENERALIZED_NONCOMMUTATIVE_SUM(binary_op, init, conv(*first), ..., conv(*(first + (i - result)))).

The reduce operations in the parallel *transform_inclusive_scan* algorithm invoked with an execution policy object of type *sequenced_policy* execute in sequential order in the calling thread.

The reduce operations in the parallel *transform_inclusive_scan* algorithm invoked with an execution policy object of type *parallel_policy* or *parallel_task_policy* are permitted to execute in an unordered fashion in unspecified threads, and indeterminately sequenced within each thread.

Neither *conv* nor *op* shall invalidate iterators or sub-ranges, or modify elements in the ranges [first,last) or [result,result + (last - first)).

The behavior of *transform_inclusive_scan* may be non-deterministic for a non-associative predicate.

Note: Complexity: $O(\text{last} - \text{first})$ applications of the predicates *op* and *conv*.

Note: GENERALIZED_NONCOMMUTATIVE_SUM(op, a1, ..., aN) is defined as:

- a1 when N is 1
 - op(GENERALIZED_NONCOMMUTATIVE_SUM(op, a1, ..., aK), GENERALIZED_NONCOMMUTATIVE_SUM(op, aM, ..., aN) where $1 < K+1 = M \leq N$).
-

Template Parameters

- **ExPolicy** – The type of the execution policy to use (deduced). It describes the manner in which the execution of the algorithm may be parallelized and the manner in which it executes the assignments.
- **Rng** – The type of the source range used (deduced). The iterators extracted from this range type must meet the requirements of an forward iterator.
- **O** – The type of the iterator representing the destination range (deduced). This iterator type must meet the requirements of an forward iterator. This iterator type must meet the requirements of an forward iterator.

- **BinOp** – The type of the binary function object used for the reduction operation.
- **UnOp** – The type of the unary function object used for the conversion operation.
- **T** – The type of the value to be used as initial (and intermediate) values (deduced).

Parameters

- **policy** – The execution policy to use for the scheduling of the iterations.
- **rng** – Refers to the sequence of elements the algorithm will be applied to.
- **dest** – Refers to the beginning of the destination range.
- **binary_op** – Specifies the function (or function object) which will be invoked for each of the values of the input sequence. This is a binary predicate. The signature of this predicate should be equivalent to:

```
Ret fun(const Type1 &a, const Type1 &b);
```

The signature does not need to have `const&`, but the function must not modify the objects passed to it. The types *Type1* and *Ret* must be such that an object of a type as given by the input sequence can be implicitly converted to any of those types.

- **unary_op** – Specifies the function (or function object) which will be invoked for each of the elements in the sequence specified by [first, last). This is a unary predicate. The signature of this predicate should be equivalent to:

```
R fun(const Type &a);
```

The signature does not need to have `const&`, but the function must not modify the objects passed to it. The type *Type* must be such that an object of type *FwdIter1* can be dereferenced and then implicitly converted to *Type*. The type *R* must be such that an object of this type can be implicitly converted to *T*.

- **init** – The initial value for the generalized sum.

Returns The `transform_inclusive_scan` algorithm returns a `hpx::future<transform_inclusive_scan_result< traits::range_iterator_t<Rng>, O>>` if the execution policy is of type `sequenced_task_policy` or `parallel_task_policy` and returns `transform_inclusive_scan_result< traits::range_iterator_t<Rng>, O>` otherwise. The `transform_inclusive_scan` algorithm returns an input iterator to one past the end of the range and an output iterator to the element in the destination range, one past the last element copied.

hpx::ranges::transform_reduce

Defined in header `hpx/algorithm.hpp`⁶⁸⁵.

See *Public API* for a list of names and headers that are part of the public *HPX* API.

namespace **hpx**

⁶⁸⁵ <http://github.com/STELLAR-GROUP/hpx/blob/8a3b7c1a4cb5693b2f7d9f587f759392ed0c51a0/libs/full/include/include/hpx/algorithm.hpp>

Functions

```
template<typename ExPolicy, typename Iter, typename Sent, typename T, typename Reduce, typename Convert>
```

```
hpx::parallel::util::detail::algorithm_result_t<ExPolicy, T> transform_reduce(ExPolicy &&policy, Iter
                                                                    first, Sent last, T init, Reduce
                                                                    &&red_op, Convert
                                                                    &&conv_op)
```

Returns GENERALIZED_SUM(red_op, init, conv_op(*first), ..., conv_op(*(first + (last - first) - 1))).

The reduce operations in the parallel *transform_reduce* algorithm invoked with an execution policy object of type *sequenced_policy* execute in sequential order in the calling thread.

The reduce operations in the parallel *transform_reduce* algorithm invoked with an execution policy object of type *parallel_policy* or *parallel_task_policy* are permitted to execute in an unordered fashion in unspecified threads, and indeterminately sequenced within each thread.

The difference between *transform_reduce* and *accumulate* is that the behavior of *transform_reduce* may be non-deterministic for non-associative or non-commutative binary predicate.

Note: Complexity: $O(\text{last} - \text{first})$ applications of the predicates *red_op* and *conv_op*.

Note: GENERALIZED_SUM(op, a1, ..., aN) is defined as follows:

- a1 when N is 1
 - op(GENERALIZED_SUM(op, b1, ..., bK), GENERALIZED_SUM(op, bM, ..., bN)), where:
 - b1, ..., bN may be any permutation of a1, ..., aN and
 - $1 < K+1 = M \leq N$.
-

Template Parameters

- **ExPolicy** – The type of the execution policy to use (deduced). It describes the manner in which the execution of the algorithm may be parallelized and the manner in which it executes the assignments.
- **Iter** – The type of the source iterators used (deduced). This iterator type must meet the requirements of an random access iterator.
- **Sent** – The type of the end source iterators used (deduced). This iterator type must meet the requirements of an sentinel for Iter.
- **T** – The type of the value to be used as initial (and intermediate) values (deduced).
- **Reduce** – The type of the binary function object used for the reduction operation.
- **Convert** – The type of the unary function object used to transform the elements of the input sequence before invoking the reduce function.

Parameters

- **policy** – The execution policy to use for the scheduling of the iterations.

- **first** – Refers to the beginning of the first sorted range the algorithm will be applied to.
- **last** – Refers to the end of the second sorted range the algorithm will be applied to.
- **init** – The initial value for the generalized sum.
- **red_op** – Specifies the function (or function object) which will be invoked for each of the values returned from the invocation of *conv_op*. This is a binary predicate. The signature of this predicate should be equivalent to:

```
Ret fun(const Type1 &a, const Type2 &b);
```

The signature does not need to have `const&`, but the function must not modify the objects passed to it. The types *Type1*, *Type2*, and *Ret* must be such that an object of a type as returned from *conv_op* can be implicitly converted to any of those types.

- **conv_op** – Specifies the function (or function object) which will be invoked for each of the elements in the sequence specified by [first, last). This is a unary predicate. The signature of this predicate should be equivalent to:

```
R fun(const Type &a);
```

The signature does not need to have `const&`, but the function must not modify the objects passed to it. The type *Type* must be such that an object of type *Iter* can be dereferenced and then implicitly converted to *Type*. The type *R* must be such that an object of this type can be implicitly converted to *T*.

Returns The *transform_reduce* algorithm returns a *hpx::future<T>* if the execution policy is of type *parallel_task_policy* and returns *T* otherwise. The *transform_reduce* algorithm returns the result of the generalized sum over the values returned from *conv_op* when applied to the elements given by the input range [first, last).

```
template<typename Iter, typename Sent, typename T, typename Reduce, typename Convert>
T transform_reduce(Iter first, Sent last, T init, Reduce &&red_op, Convert &&conv_op)
```

Returns GENERALIZED_SUM(red_op, init, conv_op(*first), ..., conv_op(*(first + (last - first) - 1))).

The difference between *transform_reduce* and *accumulate* is that the behavior of *transform_reduce* may be non-deterministic for non-associative or non-commutative binary predicate.

Note: Complexity: $O(\text{last} - \text{first})$ applications of the predicates *red_op* and *conv_op*.

Note: GENERALIZED_SUM(op, a1, ..., aN) is defined as follows:

- a1 when N is 1
 - op(GENERALIZED_SUM(op, b1, ..., bK), GENERALIZED_SUM(op, bM, ..., bN)), where:
 - b1, ..., bN may be any permutation of a1, ..., aN and
 - $1 < K+1 = M \leq N$.
-

Template Parameters

- **Iter** – The type of the source iterators used (deduced). This iterator type must meet the requirements of a random access iterator.

- **Sent** – The type of the end source iterators used (deduced). This iterator type must meet the requirements of an sentinel for `Iter`.
- **T** – The type of the value to be used as initial (and intermediate) values (deduced).
- **Reduce** – The type of the binary function object used for the reduction operation.
- **Convert** – The type of the unary function object used to transform the elements of the input sequence before invoking the reduce function.

Parameters

- **first** – Refers to the beginning of the first sorted range the algorithm will be applied to.
- **last** – Refers to the end of the second sorted range the algorithm will be applied to.
- **init** – The initial value for the generalized sum.
- **red_op** – Specifies the function (or function object) which will be invoked for each of the values returned from the invocation of `conv_op`. This is a binary predicate. The signature of this predicate should be equivalent to:

```
Ret fun(const Type1 &a, const Type2 &b);
```

The signature does not need to have `const&`, but the function must not modify the objects passed to it. The types `Type1`, `Type2`, and `Ret` must be such that an object of a type as returned from `conv_op` can be implicitly converted to any of those types.

- **conv_op** – Specifies the function (or function object) which will be invoked for each of the elements in the sequence specified by `[first, last)`. This is a unary predicate. The signature of this predicate should be equivalent to:

```
R fun(const Type &a);
```

The signature does not need to have `const&`, but the function must not modify the objects passed to it. The type `Type` must be such that an object of type `Iter` can be dereferenced and then implicitly converted to `Type`. The type `R` must be such that an object of this type can be implicitly converted to `T`.

Returns The `transform_reduce` algorithm returns `T`. The `transform_reduce` algorithm returns the result of the generalized sum over the values returned from `conv_op` when applied to the elements given by the input range `[first, last)`.

```
template<typename ExPolicy, typename Iter, typename Sent, typename Iter2, typename T>
hpx::parallel::util::detail::algorithm_result_t<ExPolicy, T> transform_reduce(ExPolicy &&policy, Iter
                                                                    first, Sent last, Iter2 first2, T
                                                                    init)
```

Returns GENERALIZED_SUM(`red_op`, `init`, `conv_op`(*`first`), ..., `conv_op`*(`first` + (`last` - `first`) - 1))).

The reduce operations in the parallel `transform_reduce` algorithm invoked with an execution policy object of type `sequenced_policy` execute in sequential order in the calling thread.

The reduce operations in the parallel `transform_reduce` algorithm invoked with an execution policy object of type `parallel_policy` or `parallel_task_policy` are permitted to execute in an unordered fashion in unspecified threads, and indeterminately sequenced within each thread.

The difference between `transform_reduce` and `accumulate` is that the behavior of `transform_reduce` may be non-deterministic for non-associative or non-commutative binary predicate.

Note: Complexity: $O(\text{last} - \text{first})$ applications of the predicates *red_op* and *conv_op*.

Note: GENERALIZED_SUM(op, a1, ..., aN) is defined as follows:

- a1 when N is 1
 - op(GENERALIZED_SUM(op, b1, ..., bK), GENERALIZED_SUM(op, bM, ..., bN)), where:
 - b1, ..., bN may be any permutation of a1, ..., aN and
 - $1 < K+1 = M \leq N$.
-

Template Parameters

- **ExPolicy** – The type of the execution policy to use (deduced). It describes the manner in which the execution of the algorithm may be parallelized and the manner in which it executes the assignments.
- **Iter** – The type of the source iterators used (deduced). This iterator type must meet the requirements of a random access iterator.
- **Sent** – The type of the end source iterators used (deduced). This iterator type must meet the requirements of a sentinel for Iter.
- **Iter2** – The type of the source iterators used (deduced) representing the second sequence. This iterator type must meet the requirements of a random access iterator.
- **T** – The type of the value to be used as initial (and intermediate) values (deduced).

Parameters

- **policy** – The execution policy to use for the scheduling of the iterations.
- **first** – Refers to the beginning of the first sorted range the algorithm will be applied to.
- **last** – Refers to the end of the second sorted range the algorithm will be applied to.
- **first2** – Refers to the beginning of the sequence of elements of the second range the algorithm will be applied to.
- **init** – The initial value for the generalized sum.

Returns The *transform_reduce* algorithm returns a *hpx::future<T>* if the execution policy is of type *parallel_task_policy* and returns *T* otherwise. The *transform_reduce* algorithm returns the result of the generalized sum over the values returned from *conv_op* when applied to the elements given by the input range [first, last).

```
template<typename Iter, typename Sent, typename Iter2, typename T>
```

```
T transform_reduce(Iter first, Sent last, Iter2 first2, T init)
```

```
Returns GENERALIZED_SUM(red_op, init, conv_op(*first), ..., conv_op(*(first + (last - first) - 1))).
```

The difference between *transform_reduce* and *accumulate* is that the behavior of *transform_reduce* may be non-deterministic for non-associative or non-commutative binary predicate.

Note: Complexity: $O(\text{last} - \text{first})$ applications of the predicates *red_op* and *conv_op*.

Note: GENERALIZED_SUM(*op*, *a*₁, ..., *a*_N) is defined as follows:

- *a*₁ when *N* is 1
 - *op*(GENERALIZED_SUM(*op*, *b*₁, ..., *b*_K), GENERALIZED_SUM(*op*, *b*_M, ..., *b*_N)), where:
 - *b*₁, ..., *b*_N may be any permutation of *a*₁, ..., *a*_N and
 - 1 < *K*+1 = *M* <= *N*.
-

Template Parameters

- **Iter** – The type of the source iterators used (deduced). This iterator type must meet the requirements of a random access iterator.
- **Sent** – The type of the end source iterators used (deduced). This iterator type must meet the requirements of a sentinel for **Iter**.
- **Iter2** – The type of the source iterators used (deduced) representing the second sequence. This iterator type must meet the requirements of a random access iterator.
- **T** – The type of the value to be used as initial (and intermediate) values (deduced).

Parameters

- **first** – Refers to the beginning of the first sorted range the algorithm will be applied to.
- **last** – Refers to the end of the second sorted range the algorithm will be applied to.
- **first2** – Refers to the beginning of the sequence of elements of the second range the algorithm will be applied to.
- **init** – The initial value for the generalized sum.

Returns The *transform_reduce* algorithm returns *T*. The *transform_reduce* algorithm returns the result of the generalized sum over the values returned from *conv_op* when applied to the elements given by the input range [*first*, *last*).

```
template<typename ExPolicy, typename Iter, typename Sent, typename Iter2, typename T, typename
Reduce, typename Convert>
hpx::parallel::util::detail::algorithm_result_t<ExPolicy, T> transform_reduce(ExPolicy &&policy, Iter
                                                                    first, Sent last, Iter2 first2, T
                                                                    init, Reduce &&red_op,
                                                                    Convert &&conv_op)
```

Returns GENERALIZED_SUM(*red_op*, *init*, *conv_op*(**first*), ..., *conv_op*((**first* + (*last* - *first*) - 1))).

The reduce operations in the parallel *transform_reduce* algorithm invoked with an execution policy object of type *sequenced_policy* execute in sequential order in the calling thread.

The reduce operations in the parallel *transform_reduce* algorithm invoked with an execution policy object of type *parallel_policy* or *parallel_task_policy* are permitted to execute in an unordered fashion in unspecified threads, and indeterminately sequenced within each thread.

The difference between *transform_reduce* and *accumulate* is that the behavior of *transform_reduce* may be non-deterministic for non-associative or non-commutative binary predicate.

Note: Complexity: $O(\text{last} - \text{first})$ applications of the predicates *red_op* and *conv_op*.

Note: GENERALIZED_SUM(op, a1, ..., aN) is defined as follows:

- a1 when N is 1
 - op(GENERALIZED_SUM(op, b1, ..., bK), GENERALIZED_SUM(op, bM, ..., bN)), where:
 - b1, ..., bN may be any permutation of a1, ..., aN and
 - $1 < K+1 = M \leq N$.
-

Template Parameters

- **ExPolicy** – The type of the execution policy to use (deduced). It describes the manner in which the execution of the algorithm may be parallelized and the manner in which it executes the assignments.
- **Iter** – The type of the source iterators used (deduced). This iterator type must meet the requirements of a random access iterator.
- **Sent** – The type of the end source iterators used (deduced). This iterator type must meet the requirements of a sentinel for Iter.
- **Iter2** – The type of the source iterators used (deduced) representing the second sequence. This iterator type must meet the requirements of a random access iterator.
- **T** – The type of the value to be used as initial (and intermediate) values (deduced).
- **Reduce** – The type of the binary function object used for the reduction operation.
- **Convert** – The type of the unary function object used to transform the elements of the input sequence before invoking the reduce function.

Parameters

- **policy** – The execution policy to use for the scheduling of the iterations.
- **first** – Refers to the beginning of the first sorted range the algorithm will be applied to.
- **last** – Refers to the end of the second sorted range the algorithm will be applied to.
- **first2** – Refers to the beginning of the sequence of elements of the second range the algorithm will be applied to.
- **init** – The initial value for the generalized sum.
- **red_op** – Specifies the function (or function object) which will be invoked for each of the values returned from the invocation of *conv_op*. This is a binary predicate. The signature of this predicate should be equivalent to:

```
Ret fun(const Type1 &a, const Type2 &b);
```

The signature does not need to have const&, but the function must not modify the objects passed to it. The types *Type1*, *Type2*, and *Ret* must be such that an object of a type as returned from *conv_op* can be implicitly converted to any of those types.

- **conv_op** – Specifies the function (or function object) which will be invoked for each of the elements in the sequence specified by [first, last). This is a unary predicate. The signature of this predicate should be equivalent to:

```
R fun(const Type &a);
```

The signature does not need to have `const&`, but the function must not modify the objects passed to it. The type *Type* must be such that an object of type *Iter* can be dereferenced and then implicitly converted to *Type*. The type *R* must be such that an object of this type can be implicitly converted to *T*.

Returns The *transform_reduce* algorithm returns a `hpx::future<T>` if the execution policy is of type *parallel_task_policy* and returns *T* otherwise. The *transform_reduce* algorithm returns the result of the generalized sum over the values returned from *conv_op* when applied to the elements given by the input range [first, last).

```
template<typename Iter, typename Sent, typename Iter2, typename T, typename Reduce, typename Convert>
```

```
T transform_reduce(Iter first, Sent last, Iter2 first2, T init, Reduce &&red_op, Convert &&conv_op)
```

Returns GENERALIZED_SUM(red_op, init, conv_op(*first), ..., conv_op(*(first + (last - first) - 1))).

The difference between *transform_reduce* and *accumulate* is that the behavior of *transform_reduce* may be non-deterministic for non-associative or non-commutative binary predicate.

Note: Complexity: $O(\text{last} - \text{first})$ applications of the predicates *red_op* and *conv_op*.

Note: GENERALIZED_SUM(op, a1, ..., aN) is defined as follows:

- a1 when N is 1
 - op(GENERALIZED_SUM(op, b1, ..., bK), GENERALIZED_SUM(op, bM, ..., bN)), where:
 - b1, ..., bN may be any permutation of a1, ..., aN and
 - $1 < K+1 = M \leq N$.
-

Template Parameters

- **Iter** – The type of the source iterators used (deduced). This iterator type must meet the requirements of a random access iterator.
- **Sent** – The type of the end source iterators used (deduced). This iterator type must meet the requirements of a sentinel for *Iter*.
- **Iter2** – The type of the source iterators used (deduced) representing the second sequence. This iterator type must meet the requirements of a random access iterator.
- **T** – The type of the value to be used as initial (and intermediate) values (deduced).
- **Reduce** – The type of the binary function object used for the reduction operation.
- **Convert** – The type of the unary function object used to transform the elements of the input sequence before invoking the reduce function.

Parameters

- **first** – Refers to the beginning of the first sorted range the algorithm will be applied to.
- **last** – Refers to the end of the second sorted range the algorithm will be applied to.

- **first2** – Refers to the beginning of the sequence of elements of the second range the algorithm will be applied to.
- **init** – The initial value for the generalized sum.
- **red_op** – Specifies the function (or function object) which will be invoked for each of the values returned from the invocation of *conv_op*. This is a binary predicate. The signature of this predicate should be equivalent to:

```
Ret fun(const Type1 &a, const Type2 &b);
```

The signature does not need to have `const&`, but the function must not modify the objects passed to it. The types *Type1*, *Type2*, and *Ret* must be such that an object of a type as returned from *conv_op* can be implicitly converted to any of those types.

- **conv_op** – Specifies the function (or function object) which will be invoked for each of the elements in the sequence specified by [first, last). This is a unary predicate. The signature of this predicate should be equivalent to:

```
R fun(const Type &a);
```

The signature does not need to have `const&`, but the function must not modify the objects passed to it. The type *Type* must be such that an object of type *Iter* can be dereferenced and then implicitly converted to *Type*. The type *R* must be such that an object of this type can be implicitly converted to *T*.

Returns The *transform_reduce* algorithm returns *T*. The *transform_reduce* algorithm returns the result of the generalized sum over the values returned from *conv_op* when applied to the elements given by the input range [first, last).

```
template<typename ExPolicy, typename Rng, typename T, typename Reduce, typename Convert>
hpx::parallel::util::detail::algorithm_result_t<ExPolicy, T> transform_reduce(ExPolicy &&policy, Rng
&&rng, T init, Reduce
&&red_op, Convert
&&conv_op)
```

Returns GENERALIZED_SUM(red_op, init, conv_op(*first), ..., conv_op(*(first + (last - first) - 1))).

The reduce operations in the parallel *transform_reduce* algorithm invoked with an execution policy object of type *sequenced_policy* execute in sequential order in the calling thread.

The reduce operations in the parallel *transform_reduce* algorithm invoked with an execution policy object of type *parallel_policy* or *parallel_task_policy* are permitted to execute in an unordered fashion in unspecified threads, and indeterminately sequenced within each thread.

The difference between *transform_reduce* and *accumulate* is that the behavior of *transform_reduce* may be non-deterministic for non-associative or non-commutative binary predicate.

Note: Complexity: $O(\text{last} - \text{first})$ applications of the predicates *red_op* and *conv_op*.

Note: GENERALIZED_SUM(op, a1, ..., aN) is defined as follows:

- a1 when N is 1
- op(GENERALIZED_SUM(op, b1, ..., bK), GENERALIZED_SUM(op, bM, ..., bN)), where:

- b_1, \dots, b_N may be any permutation of a_1, \dots, a_N and
 - $1 < K+1 = M \leq N$.
-

Template Parameters

- **ExPolicy** – The type of the execution policy to use (deduced). It describes the manner in which the execution of the algorithm may be parallelized and the manner in which it executes the assignments.
- **Rng** – The type of the source range used (deduced). The iterators extracted from this range type must meet the requirements of an input iterator.
- **T** – The type of the value to be used as initial (and intermediate) values (deduced).
- **Reduce** – The type of the binary function object used for the reduction operation.
- **Convert** – The type of the unary function object used to transform the elements of the input sequence before invoking the reduce function.

Parameters

- **policy** – The execution policy to use for the scheduling of the iterations.
- **rng** – Refers to the sequence of elements the algorithm will be applied to.
- **init** – The initial value for the generalized sum.
- **red_op** – Specifies the function (or function object) which will be invoked for each of the values returned from the invocation of *conv_op*. This is a binary predicate. The signature of this predicate should be equivalent to:

```
Ret fun(const Type1 &a, const Type2 &b);
```

The signature does not need to have `const&`, but the function must not modify the objects passed to it. The types *Type1*, *Type2*, and *Ret* must be such that an object of a type as returned from *conv_op* can be implicitly converted to any of those types.

- **conv_op** – Specifies the function (or function object) which will be invoked for each of the elements in the sequence specified by [first, last). This is a unary predicate. The signature of this predicate should be equivalent to:

```
R fun(const Type &a);
```

The signature does not need to have `const&`, but the function must not modify the objects passed to it. The type *Type* must be such that an object of type *Iter* can be dereferenced and then implicitly converted to *Type*. The type *R* must be such that an object of this type can be implicitly converted to *T*.

Returns The *transform_reduce* algorithm returns a *hpx::future<T>* if the execution policy is of type *parallel_task_policy* and returns *T* otherwise. The *transform_reduce* algorithm returns the result of the generalized sum over the values returned from *conv_op* when applied to the elements given by the input range [first, last).

```
template<typename Rng, typename T, typename Reduce, typename Convert>  
T transform_reduce(Rng &&rng, T init, Reduce &&red_op, Convert &&conv_op)
```

Returns GENERALIZED_SUM(red_op, init, conv_op(*first), ..., conv_op(*(first + (last - first) - 1))).

The difference between *transform_reduce* and *accumulate* is that the behavior of *transform_reduce* may be non-deterministic for non-associative or non-commutative binary predicate.

Note: Complexity: $O(\text{last} - \text{first})$ applications of the predicates *red_op* and *conv_op*.

Note: GENERALIZED_SUM(op, a1, ..., aN) is defined as follows:

- a1 when N is 1
 - op(GENERALIZED_SUM(op, b1, ..., bK), GENERALIZED_SUM(op, bM, ..., bN)), where:
 - b1, ..., bN may be any permutation of a1, ..., aN and
 - $1 < K+1 = M \leq N$.
-

Template Parameters

- **Rng** – The type of the source range used (deduced). The iterators extracted from this range type must meet the requirements of an input iterator.
- **T** – The type of the value to be used as initial (and intermediate) values (deduced).
- **Reduce** – The type of the binary function object used for the reduction operation.
- **Convert** – The type of the unary function object used to transform the elements of the input sequence before invoking the reduce function.

Parameters

- **rng** – Refers to the sequence of elements the algorithm will be applied to.
- **init** – The initial value for the generalized sum.
- **red_op** – Specifies the function (or function object) which will be invoked for each of the values returned from the invocation of *conv_op*. This is a binary predicate. The signature of this predicate should be equivalent to:

```
Ret fun(const Type1 &a, const Type2 &b);
```

The signature does not need to have const&, but the function must not modify the objects passed to it. The types *Type1*, *Type2*, and *Ret* must be such that an object of a type as returned from *conv_op* can be implicitly converted to any of those types.

- **conv_op** – Specifies the function (or function object) which will be invoked for each of the elements in the sequence specified by [first, last). This is a unary predicate. The signature of this predicate should be equivalent to:

```
R fun(const Type &a);
```

The signature does not need to have const&, but the function must not modify the objects passed to it. The type *Type* must be such that an object of type *Iter* can be dereferenced and then implicitly converted to *Type*. The type *R* must be such that an object of this type can be implicitly converted to *T*.

Returns The *transform_reduce* algorithm returns *T*. The *transform_reduce* algorithm returns the result of the generalized sum over the values returned from *conv_op* when applied to the elements given by the input range [first, last).

```
template<typename ExPolicy, typename Rng, typename Iter2, typename T>
hpx::parallel::util::detail::algorithm_result_t<ExPolicy, T> transform_reduce(ExPolicy &&policy, Rng
&&rng, Iter2 first2, T init)
```

Returns the result of accumulating `init` with the inner products of the pairs formed by the elements of two ranges starting at `first1` and `first2`.

The operations in the parallel `transform_reduce` algorithm invoked with an execution policy object of type `sequenced_policy` execute in sequential order in the calling thread.

The operations in the parallel `transform_reduce` algorithm invoked with an execution policy object of type `parallel_policy` or `parallel_task_policy` are permitted to execute in an unordered fashion in unspecified threads, and indeterminately sequenced within each thread.

Note: Complexity: $O(\text{last} - \text{first})$ applications of the predicate `op2`.

Template Parameters

- **ExPolicy** – The type of the execution policy to use (deduced). It describes the manner in which the execution of the algorithm may be parallelized and the manner in which it executes the assignments.
- **Rng** – The type of the source range used (deduced). The iterators extracted from this range type must meet the requirements of an input iterator.
- **Iter2** – The type of the second source iterators used (deduced). This iterator type must meet the requirements of an forward iterator.
- **T** – The type of the value to be used as return) values (deduced).

Parameters

- **policy** – The execution policy to use for the scheduling of the iterations.
- **rng** – Refers to the sequence of elements the algorithm will be applied to.
- **first2** – Refers to the beginning of the second sequence of elements the result will be calculated with.
- **init** – The initial value for the sum.

Returns The `transform_reduce` algorithm returns a `hpx::future<T>` if the execution policy is of type `sequenced_task_policy` or `parallel_task_policy` and returns `T` otherwise.

```
template<typename Rng, typename Iter2, typename T>
T transform_reduce(Rng &&rng, Iter2 first2, T init)
```

Returns the result of accumulating `init` with the inner products of the pairs formed by the elements of two ranges starting at `first1` and `first2`.

Note: Complexity: $O(\text{last} - \text{first})$ applications of the predicate `op2`.

Template Parameters

- **Rng** – The type of the source range used (deduced). The iterators extracted from this range type must meet the requirements of an input iterator.

- **Iter2** – The type of the second source iterators used (deduced). This iterator type must meet the requirements of an forward iterator.
- **T** – The type of the value to be used as return) values (deduced).

Parameters

- **rng** – Refers to the sequence of elements the algorithm will be applied to.
- **first2** – Refers to the beginning of the second sequence of elements the result will be calculated with.
- **init** – The initial value for the sum.

Returns The *transform_reduce* algorithm returns *T*.

```
template<typename ExPolicy, typename Rng, typename Iter2, typename T, typename Reduce, typename
Convert>
hpx::parallel::util::detail::algorithm_result_t<ExPolicy, T> transform_reduce(ExPolicy &&policy, Rng
&&rng, Iter2 first2, T init,
Reduce &&red_op, Convert
&&conv_op)
```

Returns the result of accumulating *init* with the inner products of the pairs formed by the elements of two ranges starting at *first1* and *first2*.

The operations in the parallel *transform_reduce* algorithm invoked with an execution policy object of type *sequenced_policy* execute in sequential order in the calling thread.

The operations in the parallel *transform_reduce* algorithm invoked with an execution policy object of type *parallel_policy* or *parallel_task_policy* are permitted to execute in an unordered fashion in unspecified threads, and indeterminately sequenced within each thread.

Note: Complexity: $O(\textit{last} - \textit{first})$ applications of the predicate *op2*.

Template Parameters

- **ExPolicy** – The type of the execution policy to use (deduced). It describes the manner in which the execution of the algorithm may be parallelized and the manner in which it executes the assignments.
- **Rng** – The type of the source range used (deduced). The iterators extracted from this range type must meet the requirements of an input iterator.
- **Iter2** – The type of the second source iterators used (deduced). This iterator type must meet the requirements of an forward iterator.
- **T** – The type of the value to be used as return) values (deduced).
- **Reduce** – The type of the binary function object used for the multiplication operation.
- **Convert** – The type of the unary function object used to transform the elements of the input sequence before invoking the reduce function.

Parameters

- **policy** – The execution policy to use for the scheduling of the iterations.
- **rng** – Refers to the sequence of elements the algorithm will be applied to.

- **first2** – Refers to the beginning of the second sequence of elements the result will be calculated with.
- **init** – The initial value for the sum.
- **red_op** – Specifies the function (or function object) which will be invoked for the initial value and each of the return values of *op2*. This is a binary predicate. The signature of this predicate should be equivalent to should be equivalent to:

```
Ret fun(const Type1 &a, const Type1 &b);
```

The signature does not need to have `const&`, but the function must not modify the objects passed to it. The type *Ret* must be such that it can be implicitly converted to a type of *T*.

- **conv_op** – Specifies the function (or function object) which will be invoked for each of the input values of the sequence. This is a binary predicate. The signature of this predicate should be equivalent to

```
Ret fun(const Type1 &a, const Type2 &b);
```

The signature does not need to have `const&`, but the function must not modify the objects passed to it. The type *Ret* must be such that it can be implicitly converted to an object for the second argument type of *op1*.

Returns The *transform_reduce* algorithm returns a *hpx::future<T>* if the execution policy is of type *sequenced_task_policy* or *parallel_task_policy* and returns *T* otherwise.

```
template<typename Rng, typename Iter2, typename T, typename Reduce, typename Convert>  
T transform_reduce(Rng &&rng, Iter2 first2, T init, Reduce &&red_op, Convert &&conv_op)
```

Returns the result of accumulating *init* with the inner products of the pairs formed by the elements of two ranges starting at *first1* and *first2*.

Note: Complexity: $O(\text{last} - \text{first})$ applications of the predicate *op2*.

Template Parameters

- **Rng** – The type of the source range used (deduced). The iterators extracted from this range type must meet the requirements of an input iterator.
- **Iter2** – The type of the second source iterators used (deduced). This iterator type must meet the requirements of an forward iterator.
- **T** – The type of the value to be used as return) values (deduced).
- **Reduce** – The type of the binary function object used for the multiplication operation.
- **Convert** – The type of the unary function object used to transform the elements of the input sequence before invoking the reduce function.

Parameters

- **rng** – Refers to the sequence of elements the algorithm will be applied to.
- **first2** – Refers to the beginning of the second sequence of elements the result will be calculated with.
- **init** – The initial value for the sum.

- **red_op** – Specifies the function (or function object) which will be invoked for the initial value and each of the return values of *op2*. This is a binary predicate. The signature of this predicate should be equivalent to should be equivalent to:

```
Ret fun(const Type1 &a, const Type1 &b);
```

The signature does not need to have `const&`, but the function must not modify the objects passed to it. The type *Ret* must be such that it can be implicitly converted to a type of *T*.

- **conv_op** – Specifies the function (or function object) which will be invoked for each of the input values of the sequence. This is a binary predicate. The signature of this predicate should be equivalent to

```
Ret fun(const Type1 &a, const Type2 &b);
```

The signature does not need to have `const&`, but the function must not modify the objects passed to it. The type *Ret* must be such that it can be implicitly converted to an object for the second argument type of *op1*.

Returns The *transform_reduce* algorithm returns *T*.

hpx::ranges::uninitialized_copy, hpx::ranges::uninitialized_copy_n

Defined in header `hpx/algorithm.hpp`⁶⁸⁶.

See *Public API* for a list of names and headers that are part of the public *HPX* API.

namespace **hpx**

namespace **ranges**

Functions

```
template<typename InIter, typename Sent1, typename FwdIter, typename Sent2>
hpx::parallel::util::in_out_result<InIter, FwdIter> uninitialized_copy(InIter first1, Sent1 last1,
                                                                    FwdIter first2, Sent2 last2)
```

Copies the elements in the range, defined by [first, last), to an uninitialized memory area beginning at *dest*. If an exception is thrown during the copy operation, the function has no effects.

The assignments in the parallel *uninitialized_copy* algorithm invoked without an execution policy object will execute in sequential order in the calling thread.

Note: Complexity: Performs exactly *last - first* assignments.

Template Parameters

- **InIter** – The type of the source iterators used (deduced). This iterator type must meet the requirements of an input iterator.
- **Sent1** – The type of the source sentinel (deduced). This sentinel type must be a sentinel for *InIter*.

⁶⁸⁶ <http://github.com/STELLAR-GROUP/hpx/blob/8a3b7c1a4cb5693b2f7d9f587f759392ed0c51a0/libs/full/include/include/hpx/algorithm.hpp>

- **FwdIter** – The type of the iterator representing the destination range (deduced). This iterator type must meet the requirements of a forward iterator.
- **Sent2** – The type of the source sentinel (deduced). This sentinel type must be a sentinel for InIter2.

Parameters

- **first1** – Refers to the beginning of the sequence of elements that will be copied from
- **last1** – Refers to sentinel value denoting the end of the sequence of elements the algorithm will be applied
- **first2** – Refers to the beginning of the destination range.
- **last2** – Refers to sentinel value denoting the end of the second range the algorithm will be applied to.

Returns The *uninitialized_copy* algorithm returns an *in_out_result<InIter, FwdIter>*. The *uninitialized_copy* algorithm returns an input iterator to one past the last element copied from and the output iterator to the element in the destination range, one past the last element copied.

```
template<typename ExPolicy, typename FwdIter1, typename Sent1, typename FwdIter2, typename Sent2>
parallel::util::detail::algorithm_result<ExPolicy, parallel::util::in_out_result<FwdIter1, FwdIter2>>::type uninitialized
```

Copies the elements in the range, defined by [first, last), to an uninitialized memory area beginning at *dest*. If an exception is thrown during the copy operation, the function has no effects.

The assignments in the parallel *uninitialized_copy* algorithm invoked with an execution policy object of type *sequenced_policy* execute in sequential order in the calling thread.

The assignments in the parallel *uninitialized_copy* algorithm invoked with an execution policy object of type *parallel_policy* or *parallel_task_policy* are permitted to execute in an unordered fashion in unspecified threads, and indeterminately sequenced within each thread.

Note: Complexity: Performs exactly *last - first* assignments.

Template Parameters

- **ExPolicy** – The type of the execution policy to use (deduced). It describes the manner in which the execution of the algorithm may be parallelized and the manner in which it executes the assignments.
- **FwdIter1** – The type of the source iterators used (deduced). This iterator type must meet the requirements of an input iterator.
- **Sent1** – The type of the source sentinel (deduced). This sentinel type must be a sentinel for InIter.
- **FwdIter2** – The type of the iterator representing the destination range (deduced). This iterator type must meet the requirements of a forward iterator.
- **Sent2** – The type of the source sentinel (deduced). This sentinel type must be a sentinel for InIter2.

Parameters

- **policy** – The execution policy to use for the scheduling of the iterations.
- **first1** – Refers to the beginning of the sequence of elements that will be copied from
- **last1** – Refers to sentinel value denoting the end of the sequence of elements the algorithm will be applied.
- **first2** – Refers to the beginning of the destination range.
- **last2** – Refers to sentinel value denoting the end of the second range the algorithm will be applied to.

Returns The *uninitialized_copy* algorithm returns a `hpx::future<in_out_result<InIter, FwdIter>>`, if the execution policy is of type *sequenced_task_policy* or *parallel_task_policy* and returns `in_out_result<InIter, FwdIter>` otherwise. The *uninitialized_copy* algorithm returns an input iterator to one past the last element copied from and the output iterator to the element in the destination range, one past the last element copied.

```
template<typename Rng1, typename Rng2>
hpx::parallel::util::in_out_result<typename hpx::traits::range_traits<Rng1>::iterator_type, typename hpx::traits::range_traits
```

Copies the elements in the range, defined by [first, last), to an uninitialized memory area beginning at *dest*. If an exception is thrown during the copy operation, the function has no effects.

The assignments in the parallel *uninitialized_copy* algorithm invoked without an execution policy object will execute in sequential order in the calling thread.

Note: Complexity: Performs exactly *last - first* assignments.

Template Parameters

- **Rng1** – The type of the source range used (deduced). The iterators extracted from this range type must meet the requirements of an input iterator.
- **Rng2** – The type of the destination range used (deduced). The iterators extracted from this range type must meet the requirements of an forward iterator.

Parameters

- **rng1** – Refers to the range from which the elements will be copied from
- **rng2** – Refers to the range to which the elements will be copied to

Returns The *uninitialized_copy* algorithm returns an `in_out_result<typename hpx::traits::range_traits<Rng1>::iterator_type, typename hpx::traits::range_traits<Rng2>::iterator_type>`. The *uninitialized_copy* algorithm returns an input iterator to one past the last element copied from and the output iterator to the element in the destination range, one past the last element copied.

```
template<typename ExPolicy, typename Rng1, typename Rng2>
parallel::util::detail::algorithm_result<ExPolicy, hpx::parallel::util::in_out_result<typename hpx::traits::range_traits<Rng1>
```

Copies the elements in the range, defined by [first, last), to an uninitialized memory area beginning at *dest*. If an exception is thrown during the copy operation, the function has no effects.

The assignments in the parallel *uninitialized_copy* algorithm invoked with an execution policy object of type *sequenced_policy* execute in sequential order in the calling thread.

The assignments in the parallel *uninitialized_copy* algorithm invoked with an execution policy object of type *parallel_policy* or *parallel_task_policy* are permitted to execute in an unordered fashion in unspecified threads, and indeterminately sequenced within each thread.

Note: Complexity: Performs exactly *last - first* assignments.

Template Parameters

- **ExPolicy** – The type of the execution policy to use (deduced). It describes the manner in which the execution of the algorithm may be parallelized and the manner in which it executes the assignments.
- **Rng1** – The type of the source range used (deduced). The iterators extracted from this range type must meet the requirements of an input iterator.
- **Rng2** – The type of the destination range used (deduced). The iterators extracted from this range type must meet the requirements of a forward iterator.

Parameters

- **policy** – The execution policy to use for the scheduling of the iterations.
- **rng1** – Refers to the range from which the elements will be copied from
- **rng2** – Refers to the range to which the elements will be copied to

Returns The *uninitialized_copy* algorithm returns a `hpx::future<in_out_result<InIter, FwdIter>>`, if the execution policy is of type *sequenced_task_policy* or *parallel_task_policy* and returns `in_out_result<typename hpx::traits::range_traits<Rng1>::iterator_type, typename hpx::traits::range_traits<Rng2>::iterator_type>` otherwise. The *uninitialized_copy* algorithm returns the input iterator to one past the last element copied from and the output iterator to the element in the destination range, one past the last element copied.

```
template<typename InIter, typename Size, typename FwdIter, typename Sent2>
hpx::parallel::util::in_out_result<InIter, FwdIter> uninitialized_copy_n(InIter first1, Size count,
                                                                    FwdIter first2, Sent2 last2)
```

Copies the elements in the range [first, first + count), starting from first and proceeding to first + count - 1., to another range beginning at dest. If an exception is thrown during the copy operation, the function has no effects.

The assignments in the parallel *uninitialized_copy_n* algorithm invoked with an execution policy object of type *sequenced_policy* execute in sequential order in the calling thread.

Note: Complexity: Performs exactly *last - first* assignments.

Template Parameters

- **InIter** – The type of the source iterators used (deduced). This iterator type must meet the requirements of an input iterator.
- **Size** – The type of the argument specifying the number of elements to apply *f* to.
- **FwdIter** – The type of the iterator representing the destination range (deduced). This iterator type must meet the requirements of a forward iterator.
- **Sent2** – The type of the source sentinel (deduced). This sentinel type must be a sentinel for FwdIter.

Parameters

- **first1** – Refers to the beginning of the sequence of elements that will be copied from

- **count** – Refers to the number of elements starting at *first* the algorithm will be applied to.
- **first2** – Refers to the beginning of the destination range.
- **last2** – Refers to sentinel value denoting the end of the second range the algorithm will be applied to.

Returns The *uninitialized_copy_n* algorithm returns *in_out_result<InIter, FwdIter>*. The *uninitialized_copy_n* algorithm returns the output iterator to the element in the destination range, one past the last element copied.

```
template<typename ExPolicy, typename FwdIter1, typename Size, typename FwdIter2, typename Sent2>
```

```
parallel::util::detail::algorithm_result<ExPolicy, parallel::util::in_out_result<FwdIter1, FwdIter2>>::type uninitialized
```

Copies the elements in the range [first, first + count), starting from first and proceeding to first + count - 1., to another range beginning at dest. If an exception is thrown during the copy operation, the function has no effects.

The assignments in the parallel *uninitialized_copy_n* algorithm invoked with an execution policy object of type *sequenced_policy* execute in sequential order in the calling thread.

The assignments in the parallel *uninitialized_copy_n* algorithm invoked with an execution policy object of type *parallel_policy* or *parallel_task_policy* are permitted to execute in an unordered fashion in unspecified threads, and indeterminately sequenced within each thread.

Note: Complexity: Performs exactly *last - first* assignments.

Template Parameters

- **ExPolicy** – The type of the execution policy to use (deduced). It describes the manner in which the execution of the algorithm may be parallelized and the manner in which it executes the assignments.
- **FwdIter1** – The type of the source iterators used (deduced). This iterator type must meet the requirements of an input iterator.
- **Size** – The type of the argument specifying the number of elements to apply *f* to.
- **FwdIter2** – The type of the iterator representing the destination range (deduced). This iterator type must meet the requirements of a forward iterator.
- **Sent2** – The type of the source sentinel (deduced). This sentinel type must be a sentinel for InIter2.

Parameters

- **policy** – The execution policy to use for the scheduling of the iterations.
- **first1** – Refers to the beginning of the sequence of elements that will be copied from
- **count** – Refers to the number of elements starting at *first* the algorithm will be applied to.
- **first2** – Refers to the beginning of the destination range.

- **last2** – Refers to sentinel value denoting the end of the second range the algorithm will be applied to.

Returns The *uninitialized_copy_n* algorithm returns a `hpx::future<in_out_result<FwdIter1, FwdIter2>>` if the execution policy is of type *sequenced_task_policy* or *parallel_task_policy* and returns `FwdIter2` otherwise. The *uninitialized_copy_n* algorithm returns the output iterator to the element in the destination range, one past the last element copied.

hpx::ranges::uninitialized_default_construct, hpx::ranges::uninitialized_default_construct_n

Defined in header `hpx/algorithm.hpp`⁶⁸⁷.

See *Public API* for a list of names and headers that are part of the public HPX API.

namespace **hpx**

namespace **ranges**

Functions

template<typename **FwdIter**, typename **Sent**>
FwdIter **uninitialized_default_construct**(*FwdIter* first, *Sent* last)

Constructs objects of type `typename iterator_traits<ForwardIt>::value_type` in the uninitialized storage designated by the range by default-initialization. If an exception is thrown during the initialization, the function has no effects.

The assignments in the parallel *uninitialized_default_construct* algorithm invoked without an execution policy object will execute in sequential order in the calling thread.

Note: Complexity: Performs exactly *last - first* assignments.

Template Parameters

- **FwdIter** – The type of the source iterators used (deduced). This iterator type must meet the requirements of a forward iterator.
- **Sent** – The type of the source sentinel (deduced). This sentinel type must be a sentinel for `FwdIter`.

Parameters

- **first** – Refers to the beginning of the sequence of elements the algorithm will be applied to.
- **last** – Refers to sentinel value denoting the end of the sequence of elements the algorithm will be applied.

Returns The *uninitialized_default_construct* algorithm returns a `FwdIter`. The *uninitialized_default_construct* algorithm returns the output iterator to the element in the range, one past the last element constructed.

template<typename **ExPolicy**, typename **FwdIter**, typename **Sent**>

⁶⁸⁷ <http://github.com/STELLAR-GROUP/hpx/blob/8a3b7c1a4cb5693b2f7d9f587f759392ed0c51a0/libs/full/include/include/hpx/algorithm.hpp>

hpx::parallel::util::detail::algorithm_result_t<ExPolicy, FwdIter> **uninitialized_default_construct**(*ExPolicy* &&policy, *FwdIter* first, *Sent* last)

Constructs objects of type `typename iterator_traits<ForwardIt>::value_type` in the uninitialized storage designated by the range by default-initialization. If an exception is thrown during the initialization, the function has no effects.

The assignments in the parallel *uninitialized_default_construct* algorithm invoked with an execution policy object of type *sequenced_policy* execute in sequential order in the calling thread.

The assignments in the parallel *uninitialized_default_construct* algorithm invoked with an execution policy object of type *parallel_policy* or *parallel_task_policy* are permitted to execute in an unordered fashion in unspecified threads, and indeterminately sequenced within each thread.

Note: Complexity: Performs exactly *last - first* assignments.

Template Parameters

- **ExPolicy** – The type of the execution policy to use (deduced). It describes the manner in which the execution of the algorithm may be parallelized and the manner in which it executes the assignments.
- **FwdIter** – The type of the source iterators used (deduced). This iterator type must meet the requirements of a forward iterator.
- **Sent** – The type of the source sentinel (deduced). This sentinel type must be a sentinel for *FwdIter*.

Parameters

- **policy** – The execution policy to use for the scheduling of the iterations.
- **first** – Refers to the beginning of the sequence of elements the algorithm will be applied to.
- **last** – Refers to sentinel value denoting the end of the sequence of elements the algorithm will be applied.

Returns The *uninitialized_default_construct* algorithm returns a *hpx::future<FwdIter>* if the execution policy is of type *sequenced_task_policy* or *parallel_task_policy* and returns *FwdIter* otherwise. The *uninitialized_default_construct* algorithm returns the iterator to the element in the source range, one past the last element constructed.

```
template<typename Rng>
hpx::traits::range_traits<Rng>::iterator_type uninitialized_default_construct(Rng &&rng)
```

Constructs objects of type `typename iterator_traits<ForwardIt>::value_type` in the uninitialized storage designated by the range by default-initialization. If an exception is thrown during the initialization, the function has no effects.

The assignments in the parallel *uninitialized_default_construct* algorithm invoked without an execution policy object will execute in sequential order in the calling thread.

Note: Complexity: Performs exactly *last - first* assignments.

Template Parameters Rng – The type of the source range used (deduced). The iterators extracted from this range type must meet the requirements of an input iterator.

Parameters rng – Refers to the range to which will be default constructed.

Returns The `uninitialized_default_construct` algorithm returns a `hpx::traits::range_traits<Rng>::iterator_type`. The `uninitialized_default_construct` algorithm returns the output iterator to the element in the range, one past the last element constructed.

```
template<typename ExPolicy, typename Rng>
parallel::util::detail::algorithm_result<ExPolicy, typename hpx::traits::range_traits<Rng>::iterator_type>::type uninitial
```

Constructs objects of type `typename iterator_traits<ForwardIt>::value_type` in the uninitialized storage designated by the range by default-initialization. If an exception is thrown during the initialization, the function has no effects.

The assignments in the parallel `uninitialized_default_construct` algorithm invoked with an execution policy object of type `sequenced_policy` execute in sequential order in the calling thread.

The assignments in the parallel `uninitialized_default_construct` algorithm invoked with an execution policy object of type `parallel_policy` or `parallel_task_policy` are permitted to execute in an unordered fashion in unspecified threads, and indeterminately sequenced within each thread.

Note: Complexity: Performs exactly *last - first* assignments.

Template Parameters

- **ExPolicy** – The type of the execution policy to use (deduced). It describes the manner in which the execution of the algorithm may be parallelized and the manner in which it executes the assignments.
- **Rng** – The type of the source range used (deduced). The iterators extracted from this range type must meet the requirements of an input iterator.

Parameters

- **policy** – The execution policy to use for the scheduling of the iterations.
- **rng** – Refers to the range to which the value will be default constructed

Returns The `uninitialized_default_construct` algorithm returns a `hpx::future<typename hpx::traits::range_traits<Rng>::iterator_type>`, if the execution policy is of type `sequenced_task_policy` or `parallel_task_policy` and returns `typename hpx::traits::range_traits<Rng>::iterator_type` otherwise. The `uninitialized_default_construct` algorithm returns the output iterator to the element in the range, one past the last element constructed.

```
template<typename FwdIter, typename Size>
FwdIter uninitialized_default_construct_n(FwdIter first, Size count)
```

Constructs objects of type `typename iterator_traits<ForwardIt>::value_type` in the uninitialized storage designated by the range `[first, first + count)` by default-initialization. If an exception is thrown during the initialization, the function has no effects.

The assignments in the parallel `uninitialized_default_construct_n` algorithm invoked without an execution policy object execute in sequential order in the calling thread.

Note: Complexity: Performs exactly *count* assignments, if *count* > 0, no assignments otherwise.

Template Parameters

- **FwdIter** – The type of the source iterators used (deduced). This iterator type must meet the requirements of a forward iterator.
- **Size** – The type of the argument specifying the number of elements to apply *f* to.

Parameters

- **first** – Refers to the beginning of the sequence of elements the algorithm will be applied to.
- **count** – Refers to the number of elements starting at *first* the algorithm will be applied to.

Returns The *uninitialized_default_construct_n* algorithm returns a returns *FwdIter*. The *uninitialized_default_construct_n* algorithm returns the iterator to the element in the source range, one past the last element constructed.

```
template<typename ExPolicy, typename FwdIter, typename Size>
parallel::util::detail::algorithm_result<ExPolicy, FwdIter>::type uninitialized_default_construct_n(ExPolicy
&&pol-
icy,
FwdIter
first,
Size
count)
```

Constructs objects of type `typename iterator_traits<ForwardIt>::value_type` in the uninitialized storage designated by the range `[first, first + count)` by default-initialization. If an exception is thrown during the initialization, the function has no effects.

The assignments in the parallel *uninitialized_default_construct_n* algorithm invoked with an execution policy object of type *sequenced_policy* execute in sequential order in the calling thread.

The assignments in the parallel *uninitialized_default_construct_n* algorithm invoked with an execution policy object of type *parallel_policy* or *parallel_task_policy* are permitted to execute in an unordered fashion in unspecified threads, and indeterminately sequenced within each thread.

Note: Complexity: Performs exactly *count* assignments, if *count* > 0, no assignments otherwise.

Template Parameters

- **ExPolicy** – The type of the execution policy to use (deduced). It describes the manner in which the execution of the algorithm may be parallelized and the manner in which it executes the assignments.
- **FwdIter** – The type of the source iterators used (deduced). This iterator type must meet the requirements of a forward iterator.
- **Size** – The type of the argument specifying the number of elements to apply *f* to.

Parameters

- **policy** – The execution policy to use for the scheduling of the iterations.
- **first** – Refers to the beginning of the sequence of elements the algorithm will be applied to.
- **count** – Refers to the number of elements starting at *first* the algorithm will be applied to.

Returns The *uninitialized_default_construct_n* algorithm returns a *hpx::future<FwdIter>* if the execution policy is of type *sequenced_task_policy* or *parallel_task_policy* and returns

FwdIter otherwise. The *uninitialized_default_construct_n* algorithm returns the iterator to the element in the source range, one past the last element constructed.

hpx::ranges::uninitialized_fill, hpx::ranges::uninitialized_fill_n

Defined in header `hpx/algorithm.hpp`⁶⁸⁸.

See *Public API* for a list of names and headers that are part of the public HPX API.

namespace **hpx**

namespace **ranges**

Functions

```
template<typename FwdIter, typename Sent, typename T>
FwdIter uninitialized_fill(FwdIter first, Sent last, T const &value)
```

Copies the given *value* to an uninitialized memory area, defined by the range [first, last). If an exception is thrown during the initialization, the function has no effects.

The assignments in the ranges *uninitialized_fill* algorithm invoked without an execution policy object will execute in sequential order in the calling thread.

Note: Complexity: Linear in the distance between *first* and *last*

Template Parameters

- **FwdIter** – The type of the source iterators used (deduced). This iterator type must meet the requirements of a forward iterator.
- **Sent** – The type of the source sentinel (deduced). This sentinel type must be a sentinel for *FwdIter*.
- **T** – The type of the value to be assigned (deduced).

Parameters

- **first** – Refers to the beginning of the sequence of elements the algorithm will be applied to.
- **last** – Refers to sentinel value denoting the end of the sequence of elements the algorithm will be applied.
- **value** – The value to be assigned.

Returns The *uninitialized_fill* algorithm returns a returns *FwdIter*. The *uninitialized_fill* algorithm returns the output iterator to the element in the range, one past the last element copied.

```
template<typename ExPolicy, typename FwdIter, typename Sent, typename T>
hpx::parallel::util::detail::algorithm_result_t<ExPolicy, FwdIter> uninitialized_fill(ExPolicy
                                                                                               &&policy,
                                                                                               FwdIter first,
                                                                                               Sent last, T
                                                                                               const
                                                                                               &value)
```

⁶⁸⁸ <http://github.com/STELLAR-GROUP/hpx/blob/8a3b7c1a4cb5693b2f7d9f587f759392ed0c51a0/libs/full/include/include/hpx/algorithm.hpp>

Copies the given *value* to an uninitialized memory area, defined by the range [first, last). If an exception is thrown during the initialization, the function has no effects.

The assignments in the parallel *uninitialized_fill* algorithm invoked with an execution policy object of type *sequenced_policy* execute in sequential order in the calling thread.

The assignments in the parallel *uninitialized_fill* algorithm invoked with an execution policy object of type *parallel_policy* or *parallel_task_policy* are permitted to execute in an unordered fashion in unspecified threads, and indeterminately sequenced within each thread.

Note: Complexity: Linear in the distance between *first* and *last*

Template Parameters

- **ExPolicy** – The type of the execution policy to use (deduced). It describes the manner in which the execution of the algorithm may be parallelized and the manner in which it executes the assignments.
- **FwdIter** – The type of the source iterators used (deduced). This iterator type must meet the requirements of a forward iterator.
- **Sent** – The type of the source sentinel (deduced). This sentinel type must be a sentinel for FwdIter.
- **T** – The type of the value to be assigned (deduced).

Parameters

- **policy** – The execution policy to use for the scheduling of the iterations.
- **first** – Refers to the beginning of the sequence of elements the algorithm will be applied to.
- **last** – Refers to sentinel value denoting the end of the sequence of elements the algorithm will be applied.
- **value** – The value to be assigned.

Returns The *uninitialized_fill* algorithm returns a returns *FwdIter*. The *uninitialized_fill* algorithm returns the output iterator to the element in the range, one past the last element copied.

```
template<typename Rng, typename T>
hpx::traits::range_traits<Rng>::iterator_type uninitialized_fill(Rng &&rng, T const &value)
```

Copies the given *value* to an uninitialized memory area, defined by the range [first, last). If an exception is thrown during the initialization, the function has no effects.

The assignments in the parallel *uninitialized_fill* algorithm invoked without an execution policy object will execute in sequential order in the calling thread.

Note: Complexity: Linear in the distance between *first* and *last*

Template Parameters

- **Rng** – The type of the source range used (deduced). The iterators extracted from this range type must meet the requirements of an input iterator.
- **T** – The type of the value to be assigned (deduced).

Parameters

- **rng** – Refers to the range to which the value will be filled
- **value** – The value to be assigned.

Returns The `uninitialized_fill` algorithm returns a `hpx::traits::range_traits<Rng>::iterator_type`. The `uninitialized_fill` algorithm returns the output iterator to the element in the range, one past the last element copied.

```
template<typename ExPolicy, typename Rng, typename T>
parallel::util::detail::algorithm_result<ExPolicy, typename hpx::traits::range_traits<Rng1>::iterator_type>::type uninitia
```

Copies the given *value* to an uninitialized memory area, defined by the range [first, last). If an exception is thrown during the initialization, the function has no effects.

The assignments in the parallel `uninitialized_fill` algorithm invoked with an execution policy object of type `sequenced_policy` execute in sequential order in the calling thread.

The assignments in the parallel `uninitialized_fill` algorithm invoked with an execution policy object of type `parallel_policy` or `parallel_task_policy` are permitted to execute in an unordered fashion in unspecified threads, and indeterminately sequenced within each thread.

Note: Complexity: Linear in the distance between *first* and *last*

Template Parameters

- **ExPolicy** – The type of the execution policy to use (deduced). It describes the manner in which the execution of the algorithm may be parallelized and the manner in which it executes the assignments.
- **Rng** – The type of the source range used (deduced). The iterators extracted from this range type must meet the requirements of an input iterator.
- **T** – The type of the value to be assigned (deduced).

Parameters

- **policy** – The execution policy to use for the scheduling of the iterations.
- **rng** – Refers to the range to which the value will be filled
- **value** – The value to be assigned.

Returns The `uninitialized_fill` algorithm returns a `hpx::future<typename hpx::traits::range_traits<Rng>::iterator_type>`, if the execution policy is of type `sequenced_task_policy` or `parallel_task_policy` and returns `typename hpx::traits::range_traits<Rng>::iterator_type` otherwise. The `uninitialized_fill` algorithm returns the iterator to one past the last element filled in the range.

```
template<typename FwdIter, typename Size, typename T>
FwdIter uninitialized_fill_n(FwdIter first, Size count, T const &value)
```

Copies the given *value* value to the first count elements in an uninitialized memory area beginning at first. If an exception is thrown during the initialization, the function has no effects.

The assignments in the parallel `uninitialized_fill_n` algorithm invoked with an execution policy object of type `sequenced_policy` execute in sequential order in the calling thread.

Note: Complexity: Performs exactly *count* assignments, if *count* > 0, no assignments otherwise.

Template Parameters

- **FwdIter** – The type of the source iterators used (deduced). This iterator type must meet the requirements of a forward iterator.
- **Size** – The type of the argument specifying the number of elements to apply *f* to.
- **T** – The type of the value to be assigned (deduced).

Parameters

- **first** – Refers to the beginning of the sequence of elements the algorithm will be applied to.
- **count** – Refers to the number of elements starting at *first* the algorithm will be applied to.
- **value** – The value to be assigned.

Returns The *uninitialized_fill_n* algorithm returns a returns *FwdIter*. The *uninitialized_fill_n* algorithm returns the output iterator to the element in the range, one past the last element copied.

```
template<typename ExPolicy, typename FwdIter, typename Size, typename T>
hpx::parallel::util::detail::algorithm_result_t<ExPolicy, FwdIter> uninitialized_fill_n(ExPolicy
                                                                                       &&policy,
                                                                                       FwdIter
                                                                                       first, Size
                                                                                       count, T
                                                                                       const
                                                                                       &value)
```

Copies the given *value* value to the first *count* elements in an uninitialized memory area beginning at *first*. If an exception is thrown during the initialization, the function has no effects.

The assignments in the parallel *uninitialized_fill_n* algorithm invoked with an execution policy object of type *sequenced_policy* execute in sequential order in the calling thread.

The assignments in the parallel *uninitialized_fill_n* algorithm invoked with an execution policy object of type *parallel_policy* or *parallel_task_policy* are permitted to execute in an unordered fashion in unspecified threads, and indeterminately sequenced within each thread.

Note: Complexity: Performs exactly *count* assignments, if *count* > 0, no assignments otherwise.

Template Parameters

- **ExPolicy** – The type of the execution policy to use (deduced). It describes the manner in which the execution of the algorithm may be parallelized and the manner in which it executes the assignments.
- **FwdIter** – The type of the source iterators used (deduced). This iterator type must meet the requirements of a forward iterator.
- **Size** – The type of the argument specifying the number of elements to apply *f* to.
- **T** – The type of the value to be assigned (deduced).

Parameters

- **policy** – The execution policy to use for the scheduling of the iterations.
- **first** – Refers to the beginning of the sequence of elements the algorithm will be applied to.
- **count** – Refers to the number of elements starting at *first* the algorithm will be applied to.

- **value** – The value to be assigned.

Returns The *uninitialized_fill_n* algorithm returns a *hpx::future<FwdIter>*, if the execution policy is of type *sequenced_task_policy* or *parallel_task_policy* and returns *FwdIter* otherwise. The *uninitialized_fill_n* algorithm returns the output iterator to the element in the range, one past the last element copied.

hpx::ranges::uninitialized_move, hpx::ranges::uninitialized_move_n

Defined in header *hpx/algorithm.hpp*⁶⁸⁹.

See *Public API* for a list of names and headers that are part of the public *HPX* API.

namespace **hpx**

namespace **ranges**

Functions

```
template<typename InIter, typename Sent1, typename FwdIter, typename Sent2>  
hpx::parallel::util::in_out_result<InIter, FwdIter> uninitialized_move(InIter first1, Sent1 last1,  
                                                                    FwdIter first2, Sent2 last2)
```

Moves the elements in the range, defined by [first, last), to an uninitialized memory area beginning at *dest*. If an exception is thrown during the initialization, some objects in [first, last) are left in a valid but unspecified state.

The assignments in the parallel *uninitialized_move* algorithm invoked without an execution policy object will execute in sequential order in the calling thread.

Note: Complexity: Performs exactly *last - first* assignments.

Template Parameters

- **InIter** – The type of the source iterators used (deduced). This iterator type must meet the requirements of an input iterator.
- **Sent1** – The type of the source sentinel (deduced). This sentinel type must be a sentinel for *InIter*.
- **FwdIter** – The type of the iterator representing the destination range (deduced). This iterator type must meet the requirements of a forward iterator.
- **Sent2** – The type of the source sentinel (deduced). This sentinel type must be a sentinel for *InIter2*.

Parameters

- **first1** – Refers to the beginning of the sequence of elements that will be moved from
- **last1** – Refers to sentinel value denoting the end of the sequence of elements the algorithm will be applied
- **first2** – Refers to the beginning of the destination range.
- **last2** – Refers to sentinel value denoting the end of the second range the algorithm will be applied to.

⁶⁸⁹ <http://github.com/STELLAR-GROUP/hpx/blob/8a3b7c1a4cb5693b2f7d9f587f759392ed0c51a0/libs/full/include/include/hpx/algorithm.hpp>

Returns The *uninitialized_move* algorithm returns an *in_out_result*<*InIter*, *FwdIter*>. The *uninitialized_move* algorithm returns an input iterator to one past the last element moved from and the output iterator to the element in the destination range, one past the last element moved.

```
template<typename ExPolicy, typename FwdIter1, typename Sent1, typename FwdIter2, typename Sent2>
parallel::util::detail::algorithm_result<ExPolicy, parallel::util::in_out_result<FwdIter1, FwdIter2>>::type uninitialized
```

Moves the elements in the range, defined by [first, last), to an uninitialized memory area beginning at *dest*. If an exception is thrown during the initialization, some objects in [first, last) are left in a valid but unspecified state.

The assignments in the parallel *uninitialized_move* algorithm invoked with an execution policy object of type *sequenced_policy* execute in sequential order in the calling thread.

The assignments in the parallel *uninitialized_move* algorithm invoked with an execution policy object of type *parallel_policy* or *parallel_task_policy* are permitted to execute in an unordered fashion in unspecified threads, and indeterminately sequenced within each thread.

Note: Complexity: Performs exactly *last - first* assignments.

Template Parameters

- **ExPolicy** – The type of the execution policy to use (deduced). It describes the manner in which the execution of the algorithm may be parallelized and the manner in which it executes the assignments.
- **FwdIter1** – The type of the source iterators used (deduced). This iterator type must meet the requirements of an input iterator.
- **Sent1** – The type of the source sentinel (deduced). This sentinel type must be a sentinel for *InIter*.
- **FwdIter2** – The type of the iterator representing the destination range (deduced). This iterator type must meet the requirements of a forward iterator.
- **Sent2** – The type of the source sentinel (deduced). This sentinel type must be a sentinel for *InIter2*.

Parameters

- **policy** – The execution policy to use for the scheduling of the iterations.
- **first1** – Refers to the beginning of the sequence of elements that will be moved from
- **last1** – Refers to sentinel value denoting the end of the sequence of elements the algorithm will be applied.
- **first2** – Refers to the beginning of the destination range.
- **last2** – Refers to sentinel value denoting the end of the second range the algorithm will be applied to.

Returns The *uninitialized_move* algorithm returns a *hpx::future*<*in_out_result*<*InIter*, *FwdIter*>>, if the execution policy is of type *sequenced_task_policy* or *paral-*

lel_task_policy and returns *in_out_result<InIter, FwdIter>* otherwise. The *uninitialized_move* algorithm returns an input iterator to one past the last element moved from and the output iterator to the element in the destination range, one past the last element moved.

```
template<typename Rng1, typename Rng2>
hpx::parallel::util::in_out_result<typename hpx::traits::range_traits<Rng1>::iterator_type, typename hpx::traits::range_traits
```

Moves the elements in the range, defined by [first, last), to an uninitialized memory area beginning at *dest*. If an exception is thrown during the initialization, some objects in [first, last) are left in a valid but unspecified state.

The assignments in the parallel *uninitialized_move* algorithm invoked without an execution policy object will execute in sequential order in the calling thread.

Note: Complexity: Performs exactly *last - first* assignments.

Template Parameters

- **Rng1** – The type of the source range used (deduced). The iterators extracted from this range type must meet the requirements of an input iterator.
- **Rng2** – The type of the destination range used (deduced). The iterators extracted from this range type must meet the requirements of an forward iterator.

Parameters

- **rng1** – Refers to the range from which the elements will be moved from
- **rng2** – Refers to the range to which the elements will be moved to

Returns The *uninitialized_move* algorithm returns an *in_out_result<typename hpx::traits::range_traits<Rng1>::iterator_type, typename hpx::traits::range_traits<Rng2>::iterator_type>*. The *uninitialized_move* algorithm returns an input iterator to one past the last element moved from and the output iterator to the element in the destination range, one past the last element moved.

```
template<typename ExPolicy, typename Rng1, typename Rng2>
parallel::util::detail::algorithm_result<ExPolicy, hpx::parallel::util::in_out_result<typename hpx::traits::range_traits<Rng1>
```

Moves the elements in the range, defined by [first, last), to an uninitialized memory area beginning at *dest*. If an exception is thrown during the initialization, some objects in [first, last) are left in a valid but unspecified state.

The assignments in the parallel *uninitialized_move* algorithm invoked with an execution policy object of type *sequenced_policy* execute in sequential order in the calling thread.

The assignments in the parallel *uninitialized_move* algorithm invoked with an execution policy object of type *parallel_policy* or *parallel_task_policy* are permitted to execute in an unordered fashion in unspecified threads, and indeterminately sequenced within each thread.

Note: Complexity: Performs exactly *last - first* assignments.

Template Parameters

- **ExPolicy** – The type of the execution policy to use (deduced). It describes the manner in which the execution of the algorithm may be parallelized and the manner in which it executes the assignments.
- **Rng1** – The type of the source range used (deduced). The iterators extracted from this range type must meet the requirements of an input iterator.
- **Rng2** – The type of the destination range used (deduced). The iterators extracted from this range type must meet the requirements of an forward iterator.

Parameters

- **policy** – The execution policy to use for the scheduling of the iterations.
- **rng1** – Refers to the range from which the elements will be moved from
- **rng2** – Refers to the range to which the elements will be moved to

Returns The *uninitialized_move* algorithm returns a `hpx::future<in_out_result<InIter, FwdIter>>`, if the execution policy is of type *sequenced_task_policy* or *parallel_task_policy* and returns `in_out_result<typename hpx::traits::range_traits<Rng1>::iterator_type, typename hpx::traits::range_traits<Rng2>::iterator_type>` otherwise. The *uninitialized_move* algorithm returns the input iterator to one past the last element moved from and the output iterator to the element in the destination range, one past the last element moved.

```
template<typename InIter, typename Size, typename FwdIter, typename Sent2>
hpx::parallel::util::in_out_result<InIter, FwdIter> uninitialized_move_n(InIter first1, Size count,
                                                                    FwdIter first2, Sent2 last2)
```

Moves the elements in the range [first, first + count), starting from first and proceeding to first + count - 1., to another range beginning at dest. If an exception is thrown during the initialization, some objects in [first, first + count) are left in a valid but unspecified state.

The assignments in the parallel *uninitialized_move_n* algorithm invoked with an execution policy object of type *sequenced_policy* execute in sequential order in the calling thread.

Note: Complexity: Performs exactly *count* movements, if count > 0, no move operations otherwise.

Template Parameters

- **InIter** – The type of the source iterators used (deduced). This iterator type must meet the requirements of an input iterator.
- **Size** – The type of the argument specifying the number of elements to apply *f* to.
- **FwdIter** – The type of the iterator representing the destination range (deduced). This iterator type must meet the requirements of a forward iterator.
- **Sent2** – The type of the source sentinel (deduced). This sentinel type must be a sentinel for FwdIter.

Parameters

- **first1** – Refers to the beginning of the sequence of elements that will be moved from
- **count** – Refers to the number of elements starting at *first* the algorithm will be applied to.
- **first2** – Refers to the beginning of the destination range.
- **last2** – Refers to sentinel value denoting the end of the second range the algorithm will be applied to.

Returns The *uninitialized_move_n* algorithm returns `in_out_result<InIter, FwdIter>`. The *uninitialized_move_n* algorithm returns the output iterator to the element in the destination

range, one past the last element moved.

```
template<typename ExPolicy, typename FwdIter1, typename Size, typename FwdIter2, typename Sent2>
parallel::util::detail::algorithm_result<ExPolicy, parallel::util::in_out_result<FwdIter1, FwdIter2>>::type uninitialized
```

Moves the elements in the range [first, first + count), starting from first and proceeding to first + count - 1., to another range beginning at dest. If an exception is thrown during the initialization, some objects in [first, first + count) are left in a valid but unspecified state.

The assignments in the parallel *uninitialized_move_n* algorithm invoked with an execution policy object of type *sequenced_policy* execute in sequential order in the calling thread.

The assignments in the parallel *uninitialized_move_n* algorithm invoked with an execution policy object of type *parallel_policy* or *parallel_task_policy* are permitted to execute in an unordered fashion in unspecified threads, and indeterminately sequenced within each thread.

Note: Complexity: Performs exactly *count* movements, if count > 0, no move operations otherwise.

Template Parameters

- **ExPolicy** – The type of the execution policy to use (deduced). It describes the manner in which the execution of the algorithm may be parallelized and the manner in which it executes the assignments.
- **FwdIter1** – The type of the source iterators used (deduced). This iterator type must meet the requirements of an input iterator.
- **Size** – The type of the argument specifying the number of elements to apply *f* to.
- **FwdIter2** – The type of the iterator representing the destination range (deduced). This iterator type must meet the requirements of a forward iterator.
- **Sent2** – The type of the source sentinel (deduced). This sentinel type must be a sentinel for *InIter2*.

Parameters

- **policy** – The execution policy to use for the scheduling of the iterations.
- **first1** – Refers to the beginning of the sequence of elements that will be moved from
- **count** – Refers to the number of elements starting at *first* the algorithm will be applied to.
- **first2** – Refers to the beginning of the destination range.
- **last2** – Refers to sentinel value denoting the end of the second range the algorithm will be applied to.

Returns The *uninitialized_move_n* algorithm returns a *hpx::future<in_out_result<FwdIter1, FwdIter2>>* if the execution policy is of type *sequenced_task_policy* or *parallel_task_policy* and returns *FwdIter2* otherwise. The *uninitialized_move_n* algorithm returns the output iterator to the element in the destination range, one past the last element moved.

hpx::ranges::uninitialized_value_construct, hpx::ranges::uninitialized_value_construct_n

Defined in header `hpx/algorithm.hpp`⁶⁹⁰.

See *Public API* for a list of names and headers that are part of the public *HPX* API.

namespace **hpx**

namespace **ranges**

Functions

```
template<typename FwdIter, typename Sent>
FwdIter uninitialized_value_construct(FwdIter first, Sent last)
```

Constructs objects of type `typename iterator_traits<ForwardIt>::value_type` in the uninitialized storage designated by the range by value-initialization. If an exception is thrown during the initialization, the function has no effects.

The assignments in the parallel *uninitialized_value_construct* algorithm invoked without an execution policy object will execute in sequential order in the calling thread.

Note: Complexity: Performs exactly *last - first* assignments.

Template Parameters

- **FwdIter** – The type of the source iterators used (deduced). This iterator type must meet the requirements of a forward iterator.
- **Sent** – The type of the source sentinel (deduced). This sentinel type must be a sentinel for `FwdIter`.

Parameters

- **first** – Refers to the beginning of the sequence of elements the algorithm will be applied to.
- **last** – Refers to sentinel value denoting the end of the sequence of elements the algorithm will be applied.

Returns The *uninitialized_value_construct* algorithm returns a returns *FwdIter*. The *uninitialized_value_construct* algorithm returns the output iterator to the element in the range, one past the last element constructed.

```
template<typename ExPolicy, typename FwdIter, typename Sent>
hpx::parallel::util::detail::algorithm_result_t<ExPolicy, FwdIter> uninitialized_value_construct(ExPolicy
&&pol-
icy,
FwdIter
first,
Sent
last)
```

Constructs objects of type `typename iterator_traits<ForwardIt>::value_type` in the uninitialized storage designated by the range by value-initialization. If an exception is thrown during the initialization, the function has no effects.

⁶⁹⁰ <http://github.com/STELLAR-GROUP/hpx/blob/8a3b7c1a4cb5693b2f7d9f587f759392ed0c51a0/libs/full/include/include/hpx/algorithm.hpp>

The assignments in the parallel *uninitialized_value_construct* algorithm invoked with an execution policy object of type *sequenced_policy* execute in sequential order in the calling thread.

The assignments in the parallel *uninitialized_value_construct* algorithm invoked with an execution policy object of type *parallel_policy* or *parallel_task_policy* are permitted to execute in an unordered fashion in unspecified threads, and indeterminately sequenced within each thread.

Note: Complexity: Performs exactly *last - first* assignments.

Template Parameters

- **ExPolicy** – The type of the execution policy to use (deduced). It describes the manner in which the execution of the algorithm may be parallelized and the manner in which it executes the assignments.
- **FwdIter** – The type of the source iterators used (deduced). This iterator type must meet the requirements of a forward iterator.
- **Sent** – The type of the source sentinel (deduced). This sentinel type must be a sentinel for *FwdIter*.

Parameters

- **policy** – The execution policy to use for the scheduling of the iterations.
- **first** – Refers to the beginning of the sequence of elements the algorithm will be applied to.
- **last** – Refers to sentinel value denoting the end of the sequence of elements the algorithm will be applied.

Returns The *uninitialized_value_construct* algorithm returns a *hpx::future<FwdIter>* if the execution policy is of type *sequenced_task_policy* or *parallel_task_policy* and returns *FwdIter* otherwise. The *uninitialized_value_construct* algorithm returns the iterator to the element in the source range, one past the last element constructed.

```
template<typename Rng>  
hpx::traits::range_traits<Rng>::iterator_type uninitialized_value_construct(Rng &&rng)
```

Constructs objects of type *typename iterator_traits<ForwardIt>::value_type* in the uninitialized storage designated by the range by value-initialization. If an exception is thrown during the initialization, the function has no effects.

The assignments in the parallel *uninitialized_value_construct* algorithm invoked without an execution policy object will execute in sequential order in the calling thread.

Note: Complexity: Performs exactly *last - first* assignments.

Template Parameters **Rng** – The type of the source range used (deduced). The iterators extracted from this range type must meet the requirements of an input iterator.

Parameters **rng** – Refers to the range to which will be value constructed.

Returns The *uninitialized_value_construct* algorithm returns a returns *hpx::traits::range_traits<Rng>::iterator_type*. The *uninitialized_value_construct* algorithm returns the output iterator to the element in the range, one past the last element constructed.

```
template<typename ExPolicy, typename Rng>
```

`parallel::util::detail::algorithm_result<ExPolicy, typename hpx::traits::range_traits<Rng>::iterator_type>::type` **uninitial**

Constructs objects of type `typename iterator_traits<ForwardIt>::value_type` in the uninitialized storage designated by the range by value-initialization. If an exception is thrown during the initialization, the function has no effects.

The assignments in the parallel `uninitialized_value_construct` algorithm invoked with an execution policy object of type `sequenced_policy` execute in sequential order in the calling thread.

The assignments in the parallel `uninitialized_value_construct` algorithm invoked with an execution policy object of type `parallel_policy` or `parallel_task_policy` are permitted to execute in an unordered fashion in unspecified threads, and indeterminately sequenced within each thread.

Note: Complexity: Performs exactly *last - first* assignments.

Template Parameters

- **ExPolicy** – The type of the execution policy to use (deduced). It describes the manner in which the execution of the algorithm may be parallelized and the manner in which it executes the assignments.
- **Rng** – The type of the source range used (deduced). The iterators extracted from this range type must meet the requirements of an input iterator.

Parameters

- **policy** – The execution policy to use for the scheduling of the iterations.
- **rng** – Refers to the range to which the value will be value constructed

Returns The `uninitialized_value_construct` algorithm returns a `hpx::future<typename hpx::traits::range_traits<Rng>::iterator_type>`, if the execution policy is of type `sequenced_task_policy` or `parallel_task_policy` and returns `typename hpx::traits::range_traits<Rng>::iterator_type` otherwise. The `uninitialized_value_construct` algorithm returns the output iterator to the element in the range, one past the last element constructed.

```
template<typename FwdIter, typename Size>
FwdIter uninitialized_value_construct_n(FwdIter first, Size count)
```

Constructs objects of type `typename iterator_traits<ForwardIt>::value_type` in the uninitialized storage designated by the range `[first, first + count)` by value-initialization. If an exception is thrown during the initialization, the function has no effects.

The assignments in the parallel `uninitialized_value_construct_n` algorithm invoked without an execution policy object execute in sequential order in the calling thread.

Note: Complexity: Performs exactly *count* assignments, if *count* > 0, no assignments otherwise.

Template Parameters

- **FwdIter** – The type of the source iterators used (deduced). This iterator type must meet the requirements of a forward iterator.
- **Size** – The type of the argument specifying the number of elements to apply *f* to.

Parameters

- **first** – Refers to the beginning of the sequence of elements the algorithm will be applied to.
- **count** – Refers to the number of elements starting at *first* the algorithm will be applied to.

Returns The *uninitialized_value_construct_n* algorithm returns a *FwdIter*. The *uninitialized_value_construct_n* algorithm returns the iterator to the element in the source range, one past the last element constructed.

```
template<typename ExPolicy, typename FwdIter, typename Size>
hpx::parallel::util::detail::algorithm_result_t<ExPolicy, FwdIter> uninitialized_value_construct_n(ExPolicy
&&pol-
icy,
FwdIter
first,
Size
count)
```

Constructs objects of type `typename iterator_traits<ForwardIt>::value_type` in the uninitialized storage designated by the range `[first, first + count)` by value-initialization. If an exception is thrown during the initialization, the function has no effects.

The assignments in the parallel *uninitialized_value_construct_n* algorithm invoked with an execution policy object of type *sequenced_policy* execute in sequential order in the calling thread.

The assignments in the parallel *uninitialized_value_construct_n* algorithm invoked with an execution policy object of type *parallel_policy* or *parallel_task_policy* are permitted to execute in an unordered fashion in unspecified threads, and indeterminately sequenced within each thread.

Note: Complexity: Performs exactly *count* assignments, if *count* > 0, no assignments otherwise.

Template Parameters

- **ExPolicy** – The type of the execution policy to use (deduced). It describes the manner in which the execution of the algorithm may be parallelized and the manner in which it executes the assignments.
- **FwdIter** – The type of the source iterators used (deduced). This iterator type must meet the requirements of a forward iterator.
- **Size** – The type of the argument specifying the number of elements to apply *f* to.

Parameters

- **policy** – The execution policy to use for the scheduling of the iterations.
- **first** – Refers to the beginning of the sequence of elements the algorithm will be applied to.
- **count** – Refers to the number of elements starting at *first* the algorithm will be applied to.

Returns The *uninitialized_value_construct_n* algorithm returns a *hpx::future<FwdIter>* if the execution policy is of type *sequenced_task_policy* or *parallel_task_policy* and returns *FwdIter* otherwise. The *uninitialized_value_construct_n* algorithm returns the iterator to the element in the source range, one past the last element constructed.

hpx::ranges::unique, hpx::ranges::unique_copy

Defined in header `hpx/algorithm.hpp`⁶⁹¹.

See *Public API* for a list of names and headers that are part of the public HPX API.

namespace **hpx**

namespace **ranges**

Functions

```
template<typename FwdIter, typename Sent, typename Pred = ranges::equal_to, typename Proj =
hpx::identity>
subrange_t<FwdIter, Sent> unique(FwdIter first, Sent last, Pred &&pred = Pred(), Proj &&proj =
Proj())
```

Eliminates all but the first element from every consecutive group of equivalent elements from the range [first, last) and returns a past-the-end iterator for the new logical end of the range.

The assignments in the parallel *unique* algorithm invoked without an execution policy object execute in sequential order in the calling thread.

Note: Complexity: Performs not more than *last - first* assignments, exactly *last - first - 1* applications of the predicate *pred* and no more than twice as many applications of the projection *proj*.

Template Parameters

- **FwdIter** – The type of the source iterators used (deduced). This iterator type must meet the requirements of a forward iterator.
- **Sent** – The type of the source sentinel (deduced). This sentinel type must be a sentinel for FwdIter.
- **Pred** – The type of the function/function object to use (deduced). Unlike its sequential form, the parallel overload of *unique* requires *Pred* to meet the requirements of *Copy-Constructible*. This defaults to `std::equal_to<>`
- **Proj** – The type of an optional projection function. This defaults to `hpx::identity`

Parameters

- **first** – Refers to the beginning of the sequence of elements the algorithm will be applied to.
- **last** – Refers to sentinel value denoting the end of the sequence of elements the algorithm will be applied.
- **pred** – Specifies the function (or function object) which will be invoked for each of the elements in the sequence specified by [first, last). This is a binary predicate which returns *true* for the required elements. The signature of this predicate should be equivalent to:

```
bool pred(const Type1 &a, const Type2 &b);
```

The signature does not need to have `const&`, but the function must not modify the objects passed to it. The types *Type1* and *Type2* must be such that objects of types *FwdIter* can be dereferenced and then implicitly converted to both *Type1* and *Type2*

⁶⁹¹ <http://github.com/STELLAR-GROUP/hpx/blob/8a3b7c1a4cb5693b2f7d9f587f759392ed0c51a0/libs/full/include/include/hpx/algorithm.hpp>

- **proj** – Specifies the function (or function object) which will be invoked for each of the elements as a projection operation before the actual predicate *is* invoked.

Returns The *unique* algorithm returns *subrange_t<FwdIter, Sent>*. The *unique* algorithm returns an object {ret, last}, where ret is a past-the-end iterator for a new subrange.

```
template<typename ExPolicy, typename FwdIter, typename Sent, typename Pred = ranges::equal_to,
        typename Proj = hpx::identity>
parallel::util::detail::algorithm_result<ExPolicy, subrange_t<FwdIter, Sent>>::type unique(ExPolicy
                                                                                               &&policy,
                                                                                               FwdIter
                                                                                               first, Sent
                                                                                               last, Pred
                                                                                               &&pred =
                                                                                               Pred(),
                                                                                               Proj
                                                                                               &&proj =
                                                                                               Proj())
```

Eliminates all but the first element from every consecutive group of equivalent elements from the range [first, last) and returns a past-the-end iterator for the new logical end of the range.

The assignments in the parallel *unique* algorithm invoked with an execution policy object of type *sequenced_policy* execute in sequential order in the calling thread.

The assignments in the parallel *unique* algorithm invoked with an execution policy object of type *parallel_policy* or *parallel_task_policy* are permitted to execute in an unordered fashion in unspecified threads, and indeterminately sequenced within each thread.

Note: Complexity: Performs not more than *last - first* assignments, exactly *last - first - 1* applications of the predicate *pred* and no more than twice as many applications of the projection *proj*.

Template Parameters

- **ExPolicy** – The type of the execution policy to use (deduced). It describes the manner in which the execution of the algorithm may be parallelized and the manner in which it executes the assignments.
- **FwdIter** – The type of the source iterators used (deduced). This iterator type must meet the requirements of a forward iterator.
- **Sent** – The type of the source sentinel (deduced). This sentinel type must be a sentinel for *FwdIter*.
- **Pred** – The type of the function/function object to use (deduced). Unlike its sequential form, the parallel overload of *unique* requires *Pred* to meet the requirements of *CopyConstructible*. This defaults to *std::equal_to<>*
- **Proj** – The type of an optional projection function. This defaults to *hpx::identity*

Parameters

- **policy** – The execution policy to use for the scheduling of the iterations.
- **first** – Refers to the beginning of the sequence of elements the algorithm will be applied to.
- **last** – Refers to sentinel value denoting the end of the sequence of elements the algorithm will be applied.
- **pred** – Specifies the function (or function object) which will be invoked for each of the elements in the sequence specified by [first, last). This is a binary predicate which returns *true* for the required elements. The signature of this predicate should be equivalent to:

```
bool pred(const Type1 &a, const Type2 &b);
```

The signature does not need to have `const&`, but the function must not modify the objects passed to it. The types *Type1* and *Type2* must be such that objects of types *FwdIter* can be dereferenced and then implicitly converted to both *Type1* and *Type2*

- **proj** – Specifies the function (or function object) which will be invoked for each of the elements as a projection operation before the actual predicate *is* invoked.

Returns The *unique* algorithm returns *subrange_t*<*FwdIter*, *Sent*>. The *unique* algorithm returns an object {ret, last}, where ret is a past-the-end iterator for a new subrange.

```
template<typename Rng, typename Pred = ranges::equal_to, typename Proj = hpx::identity>
subrange_t<hpx::traits::range_iterator_t<Rng>, hpx::traits::range_iterator_t<Rng>> unique(Rng
                                                                                               &&rng,
                                                                                               Pred
                                                                                               &&pred =
                                                                                               Pred(),
                                                                                               Proj
                                                                                               &&proj =
                                                                                               Proj())
```

Eliminates all but the first element from every consecutive group of equivalent elements from the range *rng* and returns a past-the-end iterator for the new logical end of the range.

The assignments in the parallel *unique* algorithm invoked without an execution policy object execute in sequential order in the calling thread.

Note: Complexity: Performs not more than N assignments, exactly N - 1 applications of the predicate *pred* and no more than twice as many applications of the projection *proj*, where N = `std::distance(begin(rng), end(rng))`.

Template Parameters

- **Rng** – The type of the source range used (deduced). The iterators extracted from this range type must meet the requirements of an forward iterator.
- **Pred** – The type of the function/function object to use (deduced). Unlike its sequential form, the parallel overload of *unique* requires *Pred* to meet the requirements of *Copy-Constructible*. This defaults to `std::equal_to`
- **Proj** – The type of an optional projection function. This defaults to `hpx::identity`

Parameters

- **rng** – Refers to the sequence of elements the algorithm will be applied to.
- **pred** – Specifies the function (or function object) which will be invoked for each of the elements in the sequence specified by [first, last). This is a binary predicate which returns *true* for the required elements. The signature of this predicate should be equivalent to:

```
bool pred(const Type &a, const Type &b);
```

The signature does not need to have `const&`, but the function must not modify the objects passed to it. The type *Type* must be such that an object of type *FwdIter1* can be dereferenced and then implicitly converted to *Type*.

- **proj** – Specifies the function (or function object) which will be invoked for each of the elements as a projection operation before the actual predicate *is* invoked.

Returns The *unique* algorithm returns *subrange_t*<*hpx::traits::range_iterator_t*<*Rng*>, *hpx::traits::range_iterator_t*<*Rng*>>. The *unique* algorithm returns an object {ret, last},

where `ret` is a past-the-end iterator for a new subrange.

```
template<typename ExPolicy, typename Rng, typename Pred = ranges::equal_to, typename Proj =  
hpx::identity>  
parallel::util::detail::algorithm_result<ExPolicy, subrange_t<hpx::traits::range_iterator_t<Rng>, hpx::traits::range_iterator
```

Eliminates all but the first element from every consecutive group of equivalent elements from the range `rng` and returns a past-the-end iterator for the new logical end of the range.

The assignments in the parallel *unique* algorithm invoked with an execution policy object of type *sequenced_policy* execute in sequential order in the calling thread.

The assignments in the parallel *unique* algorithm invoked with an execution policy object of type *parallel_policy* or *parallel_task_policy* are permitted to execute in an unordered fashion in unspecified threads, and indeterminately sequenced within each thread.

Note: Complexity: Performs not more than N assignments, exactly $N - 1$ applications of the predicate `pred` and no more than twice as many applications of the projection `proj`, where $N = \text{std::distance}(\text{begin}(\text{rng}), \text{end}(\text{rng}))$.

Template Parameters

- **ExPolicy** – The type of the execution policy to use (deduced). It describes the manner in which the execution of the algorithm may be parallelized and the manner in which it executes the assignments.
- **Rng** – The type of the source range used (deduced). The iterators extracted from this range type must meet the requirements of an forward iterator.
- **Pred** – The type of the function/function object to use (deduced). Unlike its sequential form, the parallel overload of *unique* requires *Pred* to meet the requirements of *Copy-Constructible*. This defaults to `std::equal_to<>`
- **Proj** – The type of an optional projection function. This defaults to `hpx::identity`

Parameters

- **policy** – The execution policy to use for the scheduling of the iterations.
- **rng** – Refers to the sequence of elements the algorithm will be applied to.
- **pred** – Specifies the function (or function object) which will be invoked for each of the elements in the sequence specified by `[first, last)`. This is a binary predicate which returns *true* for the required elements. The signature of this predicate should be equivalent to:

```
bool pred(const Type &a, const Type &b);
```

The signature does not need to have `const&`, but the function must not modify the objects passed to it. The type *Type* must be such that an object of type *FwdIter1* can be

dereferenced and then implicitly converted to *Type*.

- **proj** – Specifies the function (or function object) which will be invoked for each of the elements as a projection operation before the actual predicate *is* invoked.

Returns The *unique* algorithm returns a `hpx::future` `<sub-range_t<hpx::traits::range_iterator_t<Rng>, hpx::traits::range_iterator_t<Rng>>>` if the execution policy is of type *sequenced_task_policy* or *parallel_task_policy* and returns `subrange_t<hpx::traits::range_iterator_t<Rng>, hpx::traits::range_iterator_t<Rng>>` otherwise. The *unique* algorithm returns an object {ret, last}, where ret is a past-the-end iterator for a new subrange.

```
template<typename InIter, typename Sent, typename O, typename Pred = ranges::equal_to, typename Proj = hpx::identity>
```

```
unique_copy_result<InIter, O> unique_copy(InIter first, Sent last, O dest, Pred &&pred = Pred(), Proj &&proj = Proj())
```

Copies the elements from the range [first, last), to another range beginning at *dest* in such a way that there are no consecutive equal elements. Only the first element of each group of equal elements is copied.

The assignments in the parallel *unique_copy* algorithm invoked without an execution policy object will execute in sequential order in the calling thread.

Note: Complexity: Performs not more than *last - first* assignments, exactly *last - first - 1* applications of the predicate *pred* and no more than twice as many applications of the projection *proj*

Template Parameters

- **InIter** – The type of the source iterators used (deduced). This iterator type must meet the requirements of an input iterator.
- **Sent** – The type of the source sentinel (deduced). This sentinel type must be a sentinel for InIter.
- **O** – The type of the iterator representing the destination range (deduced).
- **Pred** – The type of the function/function object to use (deduced). Unlike its sequential form, the parallel overload of *unique_copy* requires *Pred* to meet the requirements of *CopyConstructible*. This defaults to `std::equal_to<>`
- **Proj** – The type of an optional projection function. This defaults to `hpx::identity`

Parameters

- **first** – Refers to the beginning of the sequence of elements the algorithm will be applied to.
- **last** – Refers to sentinel value denoting the end of the sequence of elements the algorithm will be applied.
- **dest** – Refers to the beginning of the destination range.
- **pred** – Specifies the function (or function object) which will be invoked for each of the elements in the sequence specified by [first, last). This is a binary predicate which returns *true* for the required elements. The signature of this predicate should be equivalent to:

```
bool pred(const Type &a, const Type &b);
```

The signature does not need to have `const&`, but the function must not modify the objects passed to it. The type *Type* must be such that an object of type *InIter1* can be dereferenced and then implicitly converted to *Type*.

- **proj** – Specifies the function (or function object) which will be invoked for each of the elements as a projection operation before the actual predicate *is* invoked.

Returns The *unique_copy* algorithm returns a `unique_copy_result<InIter, O>`. The *unique_copy* algorithm returns an `in_out_result` with the source iterator to one past the last element and out containing the destination iterator to the end of the *dest* range.

```
template<typename ExPolicy, typename FwdIter, typename Sent, typename O, typename Pred =
    ranges::equal_to, typename Proj = hpx::identity>
parallel::util::detail::algorithm_result<ExPolicy, unique_copy_result<FwdIter, O>>::type unique_copy(ExPolicy
    &&pol-
    icy,
    FwdIter
    first,
    Sent
    last,
    O
    dest,
    Pred
    &&pred
    =
    Pred(),
    Proj
    &&proj
    =
    Proj())
```

Copies the elements from the range [first, last), to another range beginning at *dest* in such a way that there are no consecutive equal elements. Only the first element of each group of equal elements is copied.

The assignments in the parallel *unique_copy* algorithm invoked with an execution policy object of type *sequenced_policy* execute in sequential order in the calling thread.

The assignments in the parallel *unique_copy* algorithm invoked with an execution policy object of type *parallel_policy* or *parallel_task_policy* are permitted to execute in an unordered fashion in unspecified threads, and indeterminately sequenced within each thread.

Note: Complexity: Performs not more than *last - first* assignments, exactly *last - first - 1* applications of the predicate *pred* and no more than twice as many applications of the projection *proj*

Template Parameters

- **ExPolicy** – The type of the execution policy to use (deduced). It describes the manner in which the execution of the algorithm may be parallelized and the manner in which it executes the assignments.
- **FwdIter** – The type of the source iterators used (deduced). This iterator type must meet the requirements of a forward iterator.
- **Sent** – The type of the source sentinel (deduced). This sentinel type must be a sentinel for `FwdIter1`.
- **O** – The type of the iterator representing the destination range (deduced).
- **Pred** – The type of the function/function object to use (deduced). Unlike its sequential form, the parallel overload of *unique_copy* requires *Pred* to meet the requirements of *CopyConstructible*. This defaults to `std::equal_to<>`
- **Proj** – The type of an optional projection function. This defaults to `hpx::identity`

Parameters

- **policy** – The execution policy to use for the scheduling of the iterations.

- **first** – Refers to the beginning of the sequence of elements the algorithm will be applied to.
- **last** – Refers to sentinel value denoting the end of the sequence of elements the algorithm will be applied.
- **dest** – Refers to the beginning of the destination range.
- **pred** – Specifies the function (or function object) which will be invoked for each of the elements in the sequence specified by [first, last). This is a binary predicate which returns *true* for the required elements. The signature of this predicate should be equivalent to:

```
bool pred(const Type &a, const Type &b);
```

The signature does not need to have `const&`, but the function must not modify the objects passed to it. The type *Type* must be such that an object of type *FwdIter* can be dereferenced and then implicitly converted to *Type*.

- **proj** – Specifies the function (or function object) which will be invoked for each of the elements as a projection operation before the actual predicate *is* invoked.

Returns The *unique_copy* algorithm returns a `hpx::future<unique_copy_result<FwdIter, O>>` if the execution policy is of type *sequenced_task_policy* or *parallel_task_policy* and returns `unique_copy_result<FwdIter, O>` otherwise. The *unique_copy* algorithm returns an `in_out_result` with the source iterator to one past the last element and out containing the destination iterator to the end of the *dest* range.

```
template<typename Rng, typename O, typename Pred = ranges::equal_to, typename Proj =
hpx::identity>
unique_copy_result<hpx::traits::range_iterator_t<Rng>, O> unique_copy(Rng &&rng, O dest, Pred
&&pred = Pred(), Proj
&&proj = Proj())
```

Copies the elements from the range *rng*, to another range beginning at *dest* in such a way that there are no consecutive equal elements. Only the first element of each group of equal elements is copied.

The assignments in the parallel *unique_copy* algorithm invoked without an execution policy object will execute in sequential order in the calling thread.

Note: Complexity: Performs not more than N assignments, exactly N - 1 applications of the predicate *pred*, where N = `std::distance(begin(rng), end(rng))`.

Template Parameters

- **Rng** – The type of the source range used (deduced). The iterators extracted from this range type must meet the requirements of a forward iterator.
- **O** – The type of the iterator representing the destination range (deduced). This iterator type must meet the requirements of a forward iterator.
- **Pred** – The type of the function/function object to use (deduced). Unlike its sequential form, the parallel overload of *unique_copy* requires *Pred* to meet the requirements of *CopyConstructible*. This defaults to `std::equal_to<>`
- **Proj** – The type of an optional projection function. This defaults to `hpx::identity`

Parameters

- **rng** – Refers to the sequence of elements the algorithm will be applied to.
- **dest** – Refers to the beginning of the destination range.
- **pred** – Specifies the function (or function object) which will be invoked for each of the elements in the sequence specified by the range *rng*. This is a binary predicate which returns *true* for the required elements. The signature of this predicate should be

equivalent to:

```
bool pred(const Type &a, const Type &b);
```

The signature does not need to have `const&`, but the function must not modify the objects passed to it. The type *Type* must be such that an object of type *FwdIter1* can be dereferenced and then implicitly converted to *Type*.

- **proj** – Specifies the function (or function object) which will be invoked for each of the elements as a projection operation before the actual predicate *is* invoked.

Returns The *unique_copy* algorithm returns *unique_copy_result*<hpx::traits::range_iterator_t<Rng>, O>. The *unique_copy* algorithm returns the pair of the source iterator to *last*, and the destination iterator to the end of the *dest* range.

```
template<typename ExPolicy, typename Rng, typename O, typename Pred = ranges::equal_to,
typename Proj = hpx::identity>
```

```
parallel::util::detail::algorithm_result<ExPolicy, unique_copy_result<hpx::traits::range_iterator_t<Rng>, O>> unique_cop
```

Copies the elements from the range *rng*, to another range beginning at *dest* in such a way that there are no consecutive equal elements. Only the first element of each group of equal elements is copied.

The assignments in the parallel *unique_copy* algorithm invoked with an execution policy object of type *sequenced_policy* execute in sequential order in the calling thread.

The assignments in the parallel *unique_copy* algorithm invoked with an execution policy object of type *parallel_policy* or *parallel_task_policy* are permitted to execute in an unordered fashion in unspecified threads, and indeterminately sequenced within each thread.

Note: Complexity: Performs not more than N assignments, exactly N - 1 applications of the predicate *pred*, where N = `std::distance(begin(rng), end(rng))`.

Template Parameters

- **ExPolicy** – The type of the execution policy to use (deduced). It describes the manner in which the execution of the algorithm may be parallelized and the manner in which it executes the assignments.
- **Rng** – The type of the source range used (deduced). The iterators extracted from this range type must meet the requirements of an forward iterator.
- **O** – The type of the iterator representing the destination range (deduced). This iterator type must meet the requirements of a forward iterator.
- **Pred** – The type of the function/function object to use (deduced). Unlike its sequential form, the parallel overload of *unique_copy* requires *Pred* to meet the requirements of

CopyConstructible. This defaults to `std::equal_to<>`

- **Proj** – The type of an optional projection function. This defaults to `hpx::identity`

Parameters

- **policy** – The execution policy to use for the scheduling of the iterations.
- **rng** – Refers to the sequence of elements the algorithm will be applied to.
- **dest** – Refers to the beginning of the destination range.
- **pred** – Specifies the function (or function object) which will be invoked for each of the elements in the sequence specified by the range *rng*. This is a binary predicate which returns *true* for the required elements. The signature of this predicate should be equivalent to:

```
bool pred(const Type &a, const Type &b);
```

The signature does not need to have `const&`, but the function must not modify the objects passed to it. The type *Type* must be such that an object of type *FwdIter1* can be dereferenced and then implicitly converted to *Type*.

- **proj** – Specifies the function (or function object) which will be invoked for each of the elements as a projection operation before the actual predicate *is* invoked.

Returns The *unique_copy* algorithm returns a `hpx::future<unique_copy_result<hpx::traits::range_iterator_t<Rng>, O>>` if the execution policy is of type *sequenced_task_policy* or *parallel_task_policy* and returns `unique_copy_result<hpx::traits::range_iterator_t<Rng>, O>` otherwise. The *unique_copy* algorithm returns the pair of the source iterator to *last*, and the destination iterator to the end of the *dest* range.

hpx/parallel/util/range.hpp

Defined in header `hpx/parallel/util/range.hpp`.

See *Public API* for a list of names and headers that are part of the public *HPX* API.

namespace **hpx**

namespace **parallel**

namespace **util**

Typedefs

```
template<typename Iterator, typename Sentinel = Iterator>
```

```
using range = hpx::util::iterator_range<Iterator, Sentinel>
```

Functions

```
template<typename Iter, typename Sent>
range<Iter, Sent> concat(range<Iter, Sent> const &it1, range<Iter, Sent> const &it2)
```

```
template<typename Iter1, typename Sent1, typename Iter2, typename Sent2>
range<Iter2, Iter2> init_move(range<Iter2, Sent2> const &dest, range<Iter1, Sent1> const &src)
```

Move objects from the range src to dest.

Parameters

- **dest** – **[in]** : range where move the objects
- **src** – **[in]** : range from where move the objects

Returns range with the objects moved and the size adjusted

```
template<typename Iter1, typename Sent1, typename Iter2, typename Sent2>
range<Iter2, Sent2> uninit_move(range<Iter2, Sent2> const &dest, range<Iter1, Sent1> const
&src)
```

Move objects from the range src creating them in dest.

Parameters

- **dest** – **[in]** : range where move and create the objects
- **src** – **[in]** : range from where move the objects

Returns range with the objects moved and the size adjusted

```
template<typename Iter, typename Sent>
void destroy_range(range<Iter, Sent> r)
```

destroy a range of objects

Parameters **r** – **[in]** : range to destroy

```
template<typename Iter, typename Sent>
range<Iter, Sent> init(range<Iter, Sent> const &r, typename std::iterator_traits<Iter>::value_type
&val)
```

initialize a range of objects with the object val moving across them

Parameters

- **r** – **[in]** : range of elements not initialized
- **val** – **[in]** : object used for the initialization

Returns range initialized

```
template<typename Iter1, typename Sent1, typename Iter2, typename Sent2, typename
Compare>
bool is_mergeable(range<Iter1, Sent1> const &src1, range<Iter2, Sent2> const &src2, Compare
comp)
```

: indicate if two ranges have a possible merge

Remark

Parameters

- **src1** – **[in]** : first range
- **src2** – **[in]** : second range
- **comp** – **[in]** : object for to compare elements

Returns true : they can be merged false : they can't be merged

```
template<typename Iter1, typename Sent1, typename Iter2, typename Sent2, typename Iter3,
typename Sent3, typename Compare>
```

```
range<Iter3, Sent3> full_merge(range<Iter3, Sent3> const &dest, range<Iter1, Sent1> const
&src1, range<Iter2, Sent2> const &src2, Compare comp)
```

Merge two contiguous ranges src1 and src2 , and put the result in the range dest, returning the range merged.

Parameters

- **dest** – [in] : range where locate the elements merged. the size of dest must be greater or equal than the sum of the sizes of src1 and src2
- **src1** – [in] : first range to merge
- **src2** – [in] : second range to merge
- **comp** – [in] : comparison object

Returns range with the elements merged and the size adjusted

```
template<typename Iter1, typename Sent1, typename Iter2, typename Sent2, typename Value,
typename Compare>
```

```
range<Value*> uninit_full_merge(range<Value*> const &dest, range<Iter1, Sent1> const
&src1, range<Iter2, Sent2> const &src2, Compare comp)
```

Merge two contiguous ranges src1 and src2 , and create and move the result in the uninitialized range dest, returning the range merged.

Parameters

- **dest** – [in] : range where locate the elements merged. the size of dest must be greater or equal than the sum of the sizes of src1 and src2. Initially is un-initialize memory
- **src1** – [in] : first range to merge
- **src2** – [in] : second range to merge
- **comp** – [in] : comparison object

Returns range with the elements merged and the size adjusted

```
template<typename Iter1, typename Sent1, typename Iter2, typename Sent2, typename
Compare>
```

```
range<Iter2, Sent2> half_merge(range<Iter2, Sent2> const &dest, range<Iter1, Sent1> const
&src1, range<Iter2, Sent2> const &src2, Compare comp)
```

: Merge two buffers. The first buffer is in a separate memory

Parameters

- **dest** – [in] : range where finish the two buffers merged
- **src1** – [in] : first range to merge in a separate memory
- **src2** – [in] : second range to merge, in the final part of the range where deposit the final results
- **comp** – [in] : object for compare two elements of the type pointed by the Iter1 and Iter2

Returns : range with the two buffers merged

```
template<typename Iter1, typename Sent1, typename Iter2, typename Sent2, typename Iter3,
typename Sent3, typename Compare>
```

```
bool in_place_merge_uncontiguous(range<Iter1, Sent1> const &src1, range<Iter2, Sent2>
const &src2, range<Iter3, Sent3> &aux, Compare comp)
```

: merge two non contiguous buffers src1 , src2, using the range aux as auxiliary memory

Remark

Parameters

- **src1** – [in] : first range to merge
- **src2** – [in] : second range to merge

- **aux** – [in] : auxiliary range used in the merge
- **comp** – [in] : object for to compare elements

Returns true : not changes done false : changes in the buffers

```
template<typename Iter1, typename Sent1, typename Iter2, typename Sent2, typename  
Compare>  
range<Iter1, Sent1> in_place_merge(range<Iter1, Sent1> const &src1, range<Iter1, Sent1> const  
    &src2, range<Iter2, Sent2> &buf, Compare comp)  
  
: merge two contiguous buffers ( src1, src2) using buf as auxiliary memory
```

Remark

Parameters

- **src1** – [in] : first range to merge
- **src2** – [in] : second range to merge
- **buf** – [in] : auxiliary memory used in the merge
- **comp** – [in] : object for to compare elements

Returns true : not changes done false : changes in the buffers

```
template<typename Iter1, typename Sent1, typename Iter2, typename Sent2, typename  
Compare>  
void merge_flow(range<Iter1, Sent1> rng1, range<Iter2, Sent2> rbuf, range<Iter1, Sent1> rng2,  
    Compare cmp)
```

asio

See *Public API* for a list of names and headers that are part of the public *HPX* API.

hpx/asio/asio_util.hpp

Defined in header hpx/asio/asio_util.hpp.

See *Public API* for a list of names and headers that are part of the public *HPX* API.

namespace **hpx**

namespace **util**

Typedefs

```
using endpoint_iterator_type = asio::ip::tcp::resolver::iterator
```

Functions

```
bool get_endpoint(std::string const &addr, std::uint16_t port, asio::ip::tcp::endpoint &ep, bool
    force_ipv4 = false)
```

```
std::string get_endpoint_name(asio::ip::tcp::endpoint const &ep)
```

```
asio::ip::tcp::endpoint resolve_hostname(std::string const &hostname, std::uint16_t port,
    asio::io_context &io_service, bool force_ipv4 = false)
```

```
std::string resolve_public_ip_address()
```

```
std::string cleanup_ip_address(std::string const &addr)
```

```
endpoint_iterator_type connect_begin(std::string const &address, std::uint16_t port, asio::io_context
    &io_service)
```

```
template<typename Locality>
```

```
endpoint_iterator_type connect_begin(Locality const &loc, asio::io_context &io_service)
```

Returns an iterator which when dereferenced will give an endpoint suitable for a call to connect() related to this locality.

```
inline endpoint_iterator_type connect_end()
```

```
endpoint_iterator_type accept_begin(std::string const &address, std::uint16_t port, asio::io_context
    &io_service)
```

```
template<typename Locality>
```

```
endpoint_iterator_type accept_begin(Locality const &loc, asio::io_context &io_service)
```

Returns an iterator which when dereferenced will give an endpoint suitable for a call to accept() related to this locality.

```
inline endpoint_iterator_type accept_end()
```

```
bool split_ip_address(std::string const &v, std::string &host, std::uint16_t &port)
```

assertion

See *Public API* for a list of names and headers that are part of the public HPX API.

hpx/assertion/evaluate_assert.hpp

Defined in header hpx/assertion/evaluate_assert.hpp.

See *Public API* for a list of names and headers that are part of the public HPX API.

```
namespace hpx
```

```
    namespace assertion
```

HPX_CURRENT_SOURCE_LOCATION, hpx::source_location

Defined in header `hpx/source_location.hpp`⁶⁹².

See *Public API* for a list of names and headers that are part of the public *HPX* API.

Defines

`HPX_CURRENT_SOURCE_LOCATION()`

namespace **hpx**

Functions

`std::ostream &operator<<(std::ostream &os, source_location const &loc)`

struct **source_location**

`#include <source_location.hpp>` This contains the location information where `HPX_ASSERT` has been called. The `source_location` class represents certain information about the source code, such as file names, line numbers, and function names. Previously, functions that desire to obtain this information about the call site (for logging, testing, or debugging purposes) must use macros so that predefined macros like `HPX_ASSERT` and `HPX_ASSERT_ALWAYS` are expanded in the context of the caller. The `source_location` class provides a better alternative. `source_location` meets the *DefaultConstructible*, *CopyConstructible*, *CopyAssignable* and *Destructible* requirements. Lvalue of `source_location` meets the *Swappable* requirement. Additionally, the following conditions are true:

-

```
std::is_nothrow_move_constructible_v<std::source_location>
```

-

```
std::is_nothrow_move_assignable_v<std::source_location>
```

-

```
std::is_nothrow_swappable_v<std::source_location>
```

It is intended that `source_location` has a small size and can be copied efficiently. It is unspecified whether the copy/move constructors and the copy/move assignment operators of `source_location` are trivial and/or constexpr.

⁶⁹² http://github.com/STELLAR-GROUP/hpx/blob/8a3b7c1a4cb5693b2f7d9f587f759392ed0c51a0/libs/core/include_local/include/hpx/source_location.hpp

Public Functions

inline constexpr `std::uint_least32_t` **line**() const noexcept
 return the line number represented by this object

inline constexpr char const ***file_name**() const noexcept
 return the file name represented by this object

inline constexpr char const ***function_name**() const noexcept
 return the name of the function represented by this object, if any

Public Members

char const ***filename**

`std::uint_least32_t` **line_number**

char const ***functionname**

Public Static Functions

static inline constexpr `std::uint_least32_t` **column**() noexcept
 return the column number represented by this object

HPX_ASSERT, HPX_ASSERT_MSG

Defined in header `hpx/assert.hpp`.

See *Public API* for a list of names and headers that are part of the public *HPX* API.

Defines

HPX_ASSERT(*expr*)

This macro asserts that *expr* evaluates to true.

If *expr* evaluates to false, The source location and *msg* is being printed along with the expression and additional. Afterwards the program is being aborted. The assertion handler can be customized by calling `hpx::assertion::set_assertion_handler()`.

Asserts are enabled if *HPX_DEBUG* is set. This is the default for *CMAKE_BUILD_TYPE=Debug*

Parameters

- **expr** – The expression to assert on. This can either be an expression that's convertible to bool or a callable which returns bool
- **msg** – The optional message that is used to give further information if the assert fails. This should be convertible to a `std::string`

HPX_ASSERT_MSG(*expr*, *msg*)

See also:

HPX_ASSERT

namespace **hpx**

namespace **assertion**

Typedefs

```
using assertion_handler = void (*)(hpx::source_location const &loc, const char *expr, std::string const &msg)
```

The signature for an assertion handler.

Functions

```
void set_assertion_handler(assertion_handler handler)
```

Set the assertion handler to be used within a program. If the handler has been set already once, the call to this function will be ignored.

Note: This function is not thread safe

async_base

See *Public API* for a list of names and headers that are part of the public *HPX* API.

hpx::async

Defined in header `hpx/future.hpp`⁶⁹³.

See *Public API* for a list of names and headers that are part of the public *HPX* API.

namespace **hpx**

Functions

```
template<typename F, typename ...Ts>  
decltype(auto) async(F &&f, Ts&&... ts)
```

The function template *async* runs the function *f* asynchronously (potentially in a separate thread which might be a part of a thread pool) and returns an *hpx::future* that will eventually hold the result of that function call. If no policy is defined, *async* behaves as if it is called with policy being `hpx::launch::async` | `hpx::launch::deferred`. Otherwise, it calls a function *f* with arguments *ts* according to a specific launch policy.

⁶⁹³ <http://github.com/STELLAR-GROUP/hpx/blob/8a3b7c1a4cb5693b2f7d9f587f759392ed0c51a0/libs/full/include/include/hpx/future.hpp>

- If the `async` flag is set (i.e. `(policy & hpx::launch::async) != 0`), then `async` executes the callable object `f` on a new thread of execution (with all thread-locals initialized) as if spawned by `hpx::thread(std::forward<F>(f), std::forward<Ts>(ts)...)` , except that if the function `f` returns a value or throws an exception, it is stored in the shared state accessible through the `hpx::future` that `async` returns to the caller.
- If the `deferred` flag is set (i.e. `(policy & hpx::launch::deferred) != 0`), then `async` converts `f` and `ts...` the same way as by `hpx::thread` constructor, but does not spawn a new thread of execution. Instead, lazy evaluation is performed: the first call to a non-timed wait function on the `hpx::future` that `async` returned to the caller will cause the copy of `f` to be invoked (as an rvalue) with the copies of `ts...` (also passed as rvalues) in the current thread (which does not have to be the thread that originally called `hpx::async`). The result or exception is placed in the shared state associated with the future and only then it is made ready. All further accesses to the same `hpx::future` will return the result immediately.
- If neither `hpx::launch::async` nor `hpx::launch::deferred`, nor any implementation-defined policy flag is set in policy, the behavior is undefined.

If more than one flag is set, it is implementation-defined which policy is selected. For the default (both the `hpx::launch::async` and `hpx::launch::deferred` flags are set in policy), standard recommends (but doesn't require) utilizing available concurrency, and deferring any additional tasks.

In any case, the call to `hpx::async` synchronizes-with (as defined in `std::memory_order`) the call to `f`, and the completion of `f` is sequenced-before making the shared state ready. If the `async` policy is chosen, the associated thread completion synchronizes-with the successful return from the first function that is waiting on the shared state, or with the return of the last function that releases the shared state, whichever comes first. If `std::decay<Function>::type` or each type in `std::decay<Ts>::type` is not constructible from its corresponding argument, the program is ill-formed.

Parameters

- `f` – Callable object to call
- `ts` – parameters to pass to `f`

Returns `hpx::future` referring to the shared state created by this call to `hpx::async`.

hpx::dataflow

Defined in header `hpx/future.hpp`⁶⁹⁴.

See *Public API* for a list of names and headers that are part of the public *HPX* API.

namespace **hpx**

Functions

```
template<typename F, typename ...Ts>
decltype(auto) dataflow(F &&f, Ts&&... ts)
```

The function template `dataflow` runs the function `f` asynchronously (potentially in a separate thread which might be a part of a thread pool) and returns a `hpx::future` that will eventually hold the result of that function call. Its behavior is similar to `hpx::async` with the exception that if one of the arguments is a *future*, then `hpx::dataflow` will wait for the *future* to be ready to launch the thread. Hence, the operation is delayed until all the arguments are ready.

⁶⁹⁴ <http://github.com/STELLAR-GROUP/hpx/blob/8a3b7c1a4cb5693b2f7d9f587f759392ed0c51a0/libs/full/include/include/hpx/future.hpp>

hpx::launch

Defined in header `hpx/future.hpp`⁶⁹⁵.

See *Public API* for a list of names and headers that are part of the public HPX API.

namespace **hpx**

```
struct launch : public detail::policy_holder<>
    #include <launch_policy.hpp> Launch policies for hpx::async etc.
```

Public Functions

```
inline constexpr launch() noexcept
```

Default constructor. This creates a launch policy representing all possible launch modes

```
inline constexpr launch(detail::async_policy p) noexcept
```

Create a launch policy representing asynchronous execution.

```
inline constexpr launch(detail::fork_policy p) noexcept
```

Create a launch policy representing asynchronous execution. The new thread is executed in a preferred way

```
inline constexpr launch(detail::sync_policy p) noexcept
```

Create a launch policy representing synchronous execution.

```
inline constexpr launch(detail::deferred_policy p) noexcept
```

Create a launch policy representing deferred execution.

```
inline constexpr launch(detail::apply_policy p) noexcept
```

Create a launch policy representing fire and forget execution.

```
template<typename F>
```

```
inline constexpr launch(detail::select_policy<F> const &p) noexcept
```

Create a launch policy representing fire and forget execution.

```
template<typename Launch, typename Enable =
```

```
std::enable_if_t<hpx::traits::is_launch_policy_v<Launch>>>
```

```
inline constexpr launch(Launch l, threads::thread_priority priority, threads::thread_stacksize stacksize,
    threads::thread_schedule_hint hint) noexcept
```

Public Static Attributes

```
static const detail::async_policy async
```

Predefined launch policy representing asynchronous execution.

```
static const detail::fork_policy fork
```

Predefined launch policy representing asynchronous execution. The new thread is executed in a preferred way

⁶⁹⁵ <http://github.com/STELLAR-GROUP/hpx/blob/8a3b7c1a4cb5693b2f7d9f587f759392ed0c51a0/libs/full/include/include/hpx/future.hpp>

static const detail::sync_policy **sync**

Predefined launch policy representing synchronous execution.

static const detail::deferred_policy **deferred**

Predefined launch policy representing deferred execution.

static const detail::apply_policy **apply**

Predefined launch policy representing fire and forget execution.

static const detail::select_policy_generator **select**

Predefined launch policy representing delayed policy selection.

Friends

inline friend *launch* **tag_invoke**(*hpx::execution::experimental::with_priority_t*, *launch* const &policy, *threads::thread_priority* priority) noexcept

inline friend constexpr friend hpx::threads::thread_priority tag_invoke (**hpx::execution::experimental::with_priority_t**, **launch** const &policy) noexcept

inline friend *launch* **tag_invoke**(*hpx::execution::experimental::with_stacksize_t*, *launch* const &policy, *threads::thread_stacksize* stacksize) noexcept

inline friend constexpr friend hpx::threads::thread_stacksize tag_invoke (**hpx::execution::experimental::with_stacksize_t**, **launch** const &policy) noexcept

inline friend *launch* **tag_invoke**(*hpx::execution::experimental::with_hint_t*, *launch* const &policy, *threads::thread_schedule_hint* hint) noexcept

inline friend constexpr friend hpx::threads::thread_schedule_hint tag_invoke (**hpx::execution::experimental::with_hint_t**, **launch** const &policy) noexcept

hpx::post

Defined in header `hpx/future.hpp`⁶⁹⁶.

See *Public API* for a list of names and headers that are part of the public *HPX* API.

namespace **hpx**

⁶⁹⁶ <http://github.com/STELLAR-GROUP/hpx/blob/8a3b7c1a4cb5693b2f7d9f587f759392ed0c51a0/libs/full/include/include/hpx/future.hpp>

Functions

```
template<typename F, typename ...Ts>  
bool post(F &&f, Ts&&... ts)
```

Runs the function *f* asynchronously (potentially in a separate thread which might be a part of a thread pool). This is done in a fire-and-forget manner, meaning there is no return value or way to synchronize with the function execution (it does not return an `hpx::future` that would hold the result of that function call).

`hpx::post` is particularly useful when synchronization mechanisms as heavyweight as futures are not desired, and instead, more lightweight mechanisms like latches or atomic variables are preferred. Essentially, the `post` function enables the launch of a new thread without the overhead of creating a future.

Note: `hpx::post` is similar to `hpx::async` but does not return a future. This is why there is no way of finding out the result/failure of the execution of this function.

`hpx::sync`

Defined in header `hpx/future.hpp`⁶⁹⁷.

See *Public API* for a list of names and headers that are part of the public *HPX* API.

```
namespace hpx
```

Functions

```
template<typename F, typename ...Ts>  
decltype(auto) sync(F &&f, Ts&&... ts)
```

The function template `sync` runs the function *f* synchronously and returns an `hpx::future` that will eventually hold the result of that function call.

`async_combinators`

See *Public API* for a list of names and headers that are part of the public *HPX* API.

`hpx/async_combinators/split_future.hpp`

Defined in header `hpx/async_combinators/split_future.hpp`.

See *Public API* for a list of names and headers that are part of the public *HPX* API.

```
namespace hpx
```

Top level HPX namespace.

⁶⁹⁷ <http://github.com/STELLAR-GROUP/hpx/blob/8a3b7c1a4cb5693b2f7d9f587f759392ed0c51a0/libs/full/include/include/hpx/future.hpp>

Functions

```
template<typename ...Ts>
inline tuple<future<Ts>...> split_future(future<tuple<Ts...>> &&f)
```

The function `split_future` is an operator allowing to split a given future of a sequence of values (any tuple, `std::pair`, or `std::array`) into an equivalent container of futures where each future represents one of the values from the original future. In some sense this function provides the inverse operation of `when_all`.

Note: The following cases are special:

```
tuple<future<void> > split_future(future<tuple<> > && f);
array<future<void>, 1> split_future(future<array<T, 0> > && f);
```

here the returned futures are directly representing the futures which were passed to the function.

Parameters **f** – [in] A future holding an arbitrary sequence of values stored in a tuple-like container. This facility supports `hpx::tuple<>`, `std::pair<T1, T2>`, and `std::array<T, N>`

Returns Returns an equivalent container (same container type as passed as the argument) of futures, where each future refers to the corresponding value in the input parameter. All of the returned futures become ready once the input future has become ready. If the input future is exceptional, all output futures will be exceptional as well.

```
template<typename T>
inline std::vector<future<T>> split_future(future<std::vector<T>> &&f, std::size_t size)
```

The function `split_future` is an operator allowing to split a given future of a sequence of values (any `std::vector`) into a `std::vector` of futures where each future represents one of the values from the original `std::vector`. In some sense this function provides the inverse operation of `when_all`.

Parameters

- **f** – [in] A future holding an arbitrary sequence of values stored in a `std::vector`.
- **size** – [in] The number of elements the vector will hold once the input future has become ready

Returns Returns a `std::vector` of futures, where each future refers to the corresponding value in the input parameter. All of the returned futures become ready once the input future has become ready. If the input future is exceptional, all output futures will be exceptional as well.

hpx::wait_all

Defined in header `hpx/future.hpp`⁶⁹⁸.

See *Public API* for a list of names and headers that are part of the public HPX API.

namespace **hpx**

Top level HPX namespace.

⁶⁹⁸ <http://github.com/STELLAR-GROUP/hpx/blob/8a3b7c1a4cb5693b2f7d9f587f759392ed0c51a0/libs/full/include/include/hpx/future.hpp>

Functions

```
template<typename InputIter>  
void wait_all(InputIter first, InputIter last)
```

The function *wait_all* is an operator allowing to join on the result of all given futures. It AND-composes all future objects given and returns after they finished executing.

Note: The function *wait_all* returns after all futures have become ready. All input futures are still valid after *wait_all* returns.

Note: The function *wait_all* will rethrow any exceptions captured by the futures while becoming ready. If this behavior is undesirable, use *wait_all_nothrow* instead.

Parameters

- **first** – The iterator pointing to the first element of a sequence of *future* or *shared_future* objects for which *wait_all* should wait.
- **last** – The iterator pointing to the last element of a sequence of *future* or *shared_future* objects for which *wait_all* should wait.

```
template<typename R>  
void wait_all(std::vector<future<R>> &&futures)
```

The function *wait_all* is an operator allowing to join on the result of all given futures. It AND-composes all future objects given and returns after they finished executing.

Note: The function *wait_all* returns after all futures have become ready. All input futures are still valid after *wait_all* returns.

Note: The function *wait_all* will rethrow any exceptions captured by the futures while becoming ready. If this behavior is undesirable, use *wait_all_nothrow* instead.

Parameters futures – A vector or array holding an arbitrary amount of *future* or *shared_future* objects for which *wait_all* should wait.

```
template<typename R, std::size_t N>  
void wait_all(std::array<future<R>, N> &&futures)
```

The function *wait_all* is an operator allowing to join on the result of all given futures. It AND-composes all future objects given and returns after they finished executing.

Note: The function *wait_all* returns after all futures have become ready. All input futures are still valid after *wait_all* returns.

Note: The function *wait_all* will rethrow any exceptions captured by the futures while becoming ready. If this behavior is undesirable, use *wait_all_nothrow* instead.

Parameters futures – A vector or array holding an arbitrary amount of *future* or *shared_future* objects for which *wait_all* should wait.

```
template<typename T>
void wait_all(hpx::future<T> const &f)
```

The function *wait_all* is an operator allowing to join on the result of all given futures. It AND-composes all future objects given and returns after they finished executing.

Note: The function *wait_all* returns after the future has become ready. The input future is still valid after *wait_all* returns.

Note: The function *wait_all* will rethrow any exceptions captured by the future while becoming ready. If this behavior is undesirable, use *wait_all_nothrow* instead.

Parameters f – A *future* or *shared_future* for which *wait_all* should wait.

```
template<typename ...T>
void wait_all(T&&... futures)
```

The function *wait_all* is an operator allowing to join on the result of all given futures. It AND-composes all future objects given and returns after they finished executing.

Note: The function *wait_all* returns after all futures have become ready. All input futures are still valid after *wait_all* returns.

Note: The function *wait_all* will rethrow any exceptions captured by the futures while becoming ready. If this behavior is undesirable, use *wait_all_nothrow* instead.

Parameters futures – An arbitrary number of *future* or *shared_future* objects, possibly holding different types for which *wait_all* should wait.

```
template<typename InputIter>
void wait_all_n(InputIter begin, std::size_t count)
```

The function *wait_all_n* is an operator allowing to join on the result of all given futures. It AND-composes all future objects given and returns after they finished executing.

Note: The function *wait_all_n* returns after all futures have become ready. All input futures are still valid after *wait_all_n* returns.

Note: The function *wait_all_n* will rethrow any exceptions captured by the futures while becoming ready. If this behavior is undesirable, use *wait_all_n_nothrow* instead.

Parameters

- **begin** – The iterator pointing to the first element of a sequence of *future* or *shared_future* objects for which *wait_all_n* should wait.

- **count** – The number of elements in the sequence starting at *first*.

Returns The function `wait_all_n` will return an iterator referring to the first element in the input sequence after the last processed element.

hpx::wait_any

Defined in header `hpx/future.hpp`⁶⁹⁹.

See *Public API* for a list of names and headers that are part of the public HPX API.

namespace **hpx**

Top level HPX namespace.

Functions

```
template<typename InputIter>
void wait_any(InputIter first, InputIter last)
```

The function `wait_any` is a non-deterministic choice operator. It OR-composes all future objects given and returns after one future of that list finishes execution.

Note: The function `wait_any` returns after at least one future has become ready. All input futures are still valid after `wait_any` returns.

Note: The function `wait_any` will rethrow any exceptions captured by the futures while becoming ready. If this behavior is undesirable, use `wait_any_nothrow` instead.

Parameters

- **first** – [in] The iterator pointing to the first element of a sequence of *future* or *shared_future* objects for which `wait_any` should wait.
- **last** – [in] The iterator pointing to the last element of a sequence of *future* or *shared_future* objects for which `wait_any` should wait.

```
template<typename R>
void wait_any(std::vector<future<R>> &futures)
```

The function `wait_any` is a non-deterministic choice operator. It OR-composes all future objects given and returns after one future of that list finishes execution.

Note: The function `wait_any` returns after at least one future has become ready. All input futures are still valid after `wait_any` returns.

Note: The function `wait_any` will rethrow any exceptions captured by the futures while becoming ready. If this behavior is undesirable, use `wait_any_nothrow` instead.

⁶⁹⁹ <http://github.com/STELLAR-GROUP/hpx/blob/8a3b7c1a4cb5693b2f7d9f587f759392ed0c51a0/libs/full/include/include/hpx/future.hpp>

Parameters futures – [in] A vector holding an arbitrary amount of *future* or *shared_future* objects for which *wait_any* should wait.

```
template<typename R, std::size_t N>
void wait_any(std::array<future<R>, N> &futures)
```

The function *wait_any* is a non-deterministic choice operator. It OR-composes all future objects given and returns after one future of that list finishes execution.

Note: The function *wait_any* returns after at least one future has become ready. All input futures are still valid after *wait_any* returns.

Note: The function *wait_any* will rethrow any exceptions captured by the futures while becoming ready. If this behavior is undesirable, use *wait_any_nothrow* instead.

Parameters futures – [in] An array holding an arbitrary amount of *future* or *shared_future* objects for which *wait_any* should wait.

```
template<typename ...T>
void wait_any(T&&... futures)
```

The function *wait_any* is a non-deterministic choice operator. It OR-composes all future objects given and returns after one future of that list finishes execution.

Note: The function *wait_any* returns after at least one future has become ready. All input futures are still valid after *wait_any* returns.

Note: The function *wait_any* will rethrow any exceptions captured by the futures while becoming ready. If this behavior is undesirable, use *wait_any_nothrow* instead.

Parameters futures – [in] An arbitrary number of *future* or *shared_future* objects, possibly holding different types for which *wait_any* should wait.

```
template<typename InputIter>
void wait_any_n(InputIter first, std::size_t count)
```

The function *wait_any_n* is a non-deterministic choice operator. It OR-composes all future objects given and returns after one future of that list finishes execution.

Note: The function *wait_any_n* returns after at least one future has become ready. All input futures are still valid after *wait_any_n* returns.

Note: The function *wait_any_n* will rethrow any exceptions captured by the futures while becoming ready. If this behavior is undesirable, use *wait_any_n_nothrow* instead.

Parameters

- **first** – [in] The iterator pointing to the first element of a sequence of *future* or *shared_future* objects for which *wait_any_n* should wait.
- **count** – [in] The number of elements in the sequence starting at *first*.

hpx::wait_each

Defined in header `hpx/future.hpp`⁷⁰⁰.

See *Public API* for a list of names and headers that are part of the public HPX API.

namespace **hpx**

Top level HPX namespace.

Functions

```
template<typename F, typename Future>  
void wait_each(F &&f, std::vector<Future> &&futures)
```

The function *wait_each* is an operator allowing to join on the results of all given futures. It AND-composes all future objects given and returns after they finished executing. Additionally, the supplied function is called for each of the passed futures as soon as the future has become ready. *wait_each* returns after all futures have been become ready.

Note: This function consumes the futures as they are passed on to the supplied function. The callback should take one or two parameters, namely either a *future* to be processed or a type that *std::size_t* is implicitly convertible to as the first parameter and the *future* as the second parameter. The first parameter will correspond to the index of the current *future* in the collection.

Parameters

- **f** – The function which will be called for each of the input futures once the future has become ready.
- **futures** – A vector holding an arbitrary amount of *future* or *shared_future* objects for which *wait_each* should wait.

```
template<typename F, typename Iterator>  
void wait_each(F &&f, Iterator begin, Iterator end)
```

The function *wait_each* is an operator allowing to join on the results of all given futures. It AND-composes all future objects given and returns after they finished executing. Additionally, the supplied function is called for each of the passed futures as soon as the future has become ready. *wait_each* returns after all futures have been become ready.

Note: This function consumes the futures as they are passed on to the supplied function. The callback should take one or two parameters, namely either a *future* to be processed or a type that *std::size_t* is implicitly convertible to as the first parameter and the *future* as the second parameter. The first parameter will correspond to the index of the current *future* in the collection.

Parameters

⁷⁰⁰ <http://github.com/STELLAR-GROUP/hpx/blob/8a3b7c1a4cb5693b2f7d9f587f759392ed0c51a0/libs/full/include/include/hpx/future.hpp>

- **f** – The function which will be called for each of the input futures once the future has become ready.
- **begin** – The iterator pointing to the first element of a sequence of *future* or *shared_future* objects for which *wait_each* should wait.
- **end** – The iterator pointing to the last element of a sequence of *future* or *shared_future* objects for which *wait_each* should wait.

```
template<typename F, typename ...T>
void wait_each(F &&f, T&&... futures)
```

The function *wait_each* is an operator allowing to join on the results of all given futures. It AND-composes all future objects given and returns after they finished executing. Additionally, the supplied function is called for each of the passed futures as soon as the future has become ready. *wait_each* returns after all futures have been become ready.

Note: This function consumes the futures as they are passed on to the supplied function. The callback should take one or two parameters, namely either a *future* to be processed or a type that *std::size_t* is implicitly convertible to as the first parameter and the *future* as the second parameter. The first parameter will correspond to the index of the current *future* in the collection.

Parameters

- **f** – The function which will be called for each of the input futures once the future has become ready.
- **futures** – An arbitrary number of *future* or *shared_future* objects, possibly holding different types for which *wait_each* should wait.

```
template<typename F, typename Iterator>
void wait_each_n(F &&f, Iterator begin, std::size_t count)
```

The function *wait_each* is an operator allowing to join on the result of all given futures. It AND-composes all future objects given and returns after they finished executing. Additionally, the supplied function is called for each of the passed futures as soon as the future has become ready.

Note: This function consumes the futures as they are passed on to the supplied function. The callback should take one or two parameters, namely either a *future* to be processed or a type that *std::size_t* is implicitly convertible to as the first parameter and the *future* as the second parameter. The first parameter will correspond to the index of the current *future* in the collection.

Parameters

- **f** – The function which will be called for each of the input futures once the future has become ready.
- **begin** – The iterator pointing to the first element of a sequence of *future* or *shared_future* objects for which *wait_each_n* should wait.
- **count** – The number of elements in the sequence starting at *first*.

hpx::wait_some

Defined in header `hpx/future.hpp`⁷⁰¹.

See *Public API* for a list of names and headers that are part of the public HPX API.

namespace **hpx**

Top level HPX namespace.

Functions

```
template<typename InputIter>  
void wait_some(std::size_t n, InputIter first, InputIter last)
```

The function *wait_some* is an operator allowing to join on the result of all given futures. It AND-composes all future objects given and returns a new future object representing the same list of futures after *n* of them finished executing.

Note: The function *wait_some* returns after *n* futures have become ready. All input futures are still valid after *wait_some* returns.

Note: The function *wait_some* will rethrow any exceptions captured by the futures while becoming ready. If this behavior is undesirable, use *wait_some_nothrow* instead.

Parameters

- **n** – [in] The number of futures out of the arguments which have to become ready in order for the function to return.
- **first** – [in] The iterator pointing to the first element of a sequence of *future* or *shared_future* objects for which *when_all* should wait.
- **last** – [in] The iterator pointing to the last element of a sequence of *future* or *shared_future* objects for which *when_all* should wait.

```
template<typename R>  
void wait_some(std::size_t n, std::vector<future<R>> &&futures)
```

The function *wait_some* is an operator allowing to join on the result of all given futures. It AND-composes all future objects given and returns a new future object representing the same list of futures after *n* of them finished executing.

Note: The function *wait_some* returns after *n* futures have become ready. All input futures are still valid after *wait_some* returns.

Note: The function *wait_some* will rethrow any exceptions captured by the futures while becoming ready. If this behavior is undesirable, use *wait_some_nothrow* instead.

⁷⁰¹ <http://github.com/STELLAR-GROUP/hpx/blob/8a3b7c1a4cb5693b2f7d9f587f759392ed0c51a0/libs/full/include/include/hpx/future.hpp>

Parameters

- **n** – [in] The number of futures out of the arguments which have to become ready in order for the returned future to get ready.
- **futures** – [in] A vector holding an arbitrary amount of *future* or *shared_future* objects for which *wait_some* should wait.

```
template<typename R, std::size_t N>
void wait_some(std::size_t n, std::array<future<R>, N> &&futures)
```

The function *wait_some* is an operator allowing to join on the result of all given futures. It AND-composes all future objects given and returns a new future object representing the same list of futures after *n* of them finished executing.

Note: The function *wait_some* returns after *n* futures have become ready. All input futures are still valid after *wait_some* returns.

Note: The function *wait_some* will rethrow any exceptions captured by the futures while becoming ready. If this behavior is undesirable, use *wait_some_nothrow* instead.

Parameters

- **n** – [in] The number of futures out of the arguments which have to become ready in order for the returned future to get ready.
- **futures** – [in] An array holding an arbitrary amount of *future* or *shared_future* objects for which *wait_some* should wait.

```
template<typename ...T>
void wait_some(std::size_t n, T&&... futures)
```

The function *wait_some* is an operator allowing to join on the result of all given futures. It AND-composes all future objects given and returns a new future object representing the same list of futures after *n* of them finished executing.

Note: The function *wait_all* returns after *n* futures have become ready. All input futures are still valid after *wait_some* returns.

Note: The function *wait_some* will rethrow any exceptions captured by the futures while becoming ready. If this behavior is undesirable, use *wait_some_nothrow* instead.

Parameters

- **n** – [in] The number of futures out of the arguments which have to become ready in order for the returned future to get ready.
- **futures** – [in] An arbitrary number of *future* or *shared_future* objects, possibly holding different types for which *wait_some* should wait.
- **ec** – [in,out] this represents the error status on exit, if this is pre-initialized to *hpx::throws* the function will throw on error instead.

```
template<typename InputIter>
void wait_some_n(std::size_t n, InputIter first, std::size_t count)
```

The function *wait_some_n* is an operator allowing to join on the result of all given futures. It AND-composes all future objects given and returns a new future object representing the same list of futures after *n* of them finished executing.

Note: The function *wait_some_n* returns after *n* futures have become ready. All input futures are still valid after *wait_some_n* returns.

Note: The function *wait_some_n* will rethrow any exceptions captured by the futures while becoming ready. If this behavior is undesirable, use *wait_some_n_nothrow* instead.

Parameters

- **n** – [in] The number of futures out of the arguments which have to become ready in order for the returned future to get ready.
- **first** – [in] The iterator pointing to the first element of a sequence of *future* or *shared_future* objects for which *when_all* should wait.
- **count** – [in] The number of elements in the sequence starting at *first*.

hpx::when_all

Defined in header `hpx/future.hpp`⁷⁰².

See *Public API* for a list of names and headers that are part of the public *HPX* API.

namespace **hpx**

Top level HPX namespace.

Functions

```
template<typename InputIter, typename Container = vector<future<typename
std::iterator_traits<InputIter>::value_type>>>
hpx::future<Container> when_all(InputIter first, InputIter last)
```

function *when_all* creates a future object that becomes ready when all elements in a set of *future* and *shared_future* objects become ready. It is an operator allowing to join on the result of all given futures. It AND-composes all given future objects and returns a new future object representing the same list of futures after they finished executing.

Note: Calling this version of *when_all* where *first* == *last*, returns a future with an empty container that is immediately ready. Each future and *shared_future* is waited upon and then copied into the collection of the output (returned) future, maintaining the order of the futures in the input collection. The future returned by *when_all* will not throw an exception, but the futures held in the output collection may.

Parameters

⁷⁰² <http://github.com/STELLAR-GROUP/hpx/blob/8a3b7c1a4cb5693b2f7d9f587f759392ed0c51a0/libs/full/include/include/hpx/future.hpp>

- **first** – [in] The iterator pointing to the first element of a sequence of *future* or *shared_future* objects for which *when_all* should wait.
- **last** – [in] The iterator pointing to the last element of a sequence of *future* or *shared_future* objects for which *when_all* should wait.

Returns Returns a future holding the same list of futures as has been passed to *when_all*.

- `future<Container<future<R>>>`: If the input cardinality is unknown at compile time and the futures are all of the same type. The order of the futures in the output container will be the same as given by the input iterator.

```
template<typename Range>
hpx::future<Range> when_all(Range &&values)
```

function *when_all* creates a future object that becomes ready when all elements in a set of *future* and *shared_future* objects become ready. It is an operator allowing to join on the result of all given futures. It AND-composes all given future objects and returns a new future object representing the same list of futures after they finished executing.

Note: Calling this version of *when_all* where the input container is empty, returns a future with an empty container that is immediately ready. Each future and *shared_future* is waited upon and then copied into the collection of the output (returned) future, maintaining the order of the futures in the input collection. The future returned by *when_all* will not throw an exception, but the futures held in the output collection may.

Parameters values – [in] A range holding an arbitrary amount of *future* or *shared_future* objects for which *when_all* should wait.

Returns Returns a future holding the same list of futures as has been passed to *when_all*.

- `future<Container<future<R>>>`: If the input cardinality is unknown at compile time and the futures are all of the same type.

```
template<typename ...T>
hpx::future<hpx::tuple<hpx::future<T>...>> when_all(T&&... futures)
```

function *when_all* creates a future object that becomes ready when all elements in a set of *future* and *shared_future* objects become ready. It is an operator allowing to join on the result of all given futures. It AND-composes all given future objects and returns a new future object representing the same list of futures after they finished executing.

Note: Each future and *shared_future* is waited upon and then copied into the collection of the output (returned) future, maintaining the order of the futures in the input collection. The future returned by *when_all* will not throw an exception, but the futures held in the output collection may.

Parameters futures – [in] An arbitrary number of *future* or *shared_future* objects, possibly holding different types for which *when_all* should wait.

Returns Returns a future holding the same list of futures as has been passed to *when_all*.

- `future<tuple<future<T0>, future<T1>, future<T2>...>>`: If inputs are fixed in number and are of heterogeneous types. The inputs can be any arbitrary number of future objects.
- `future<tuple<>>` if *when_all* is called with zero arguments. The returned future will be initially ready.

```
template<typename InputIter, typename Container = vector<future<typename  
std::iterator_traits<InputIter>::value_type>>>  
hpx::future<Container> when_all_n(InputIter begin, std::size_t count)
```

function *when_all* creates a future object that becomes ready when all elements in a set of *future* and *shared_future* objects become ready. It is an operator allowing to join on the result of all given futures. It AND-composes all given future objects and returns a new future object representing the same list of futures after they finished executing.

Note: As long as *ec* is not pre-initialized to *hpx::throws* this function doesn't throw but returns the result code using the parameter *ec*. Otherwise it throws an instance of *hpx::exception*.

Note: None of the futures in the input sequence are invalidated.

Parameters

- **begin** – [in] The iterator pointing to the first element of a sequence of *future* or *shared_future* objects for which *wait_all_n* should wait.
- **count** – [in] The number of elements in the sequence starting at *first*.

Throws This – function will throw errors which are encountered while setting up the requested operation only. Errors encountered while executing the operations delivering the results to be stored in the futures are reported through the futures themselves.

Returns Returns a future holding the same list of futures as has been passed to *when_all_n*.

- `future<Container<future<R>>>`: If the input cardinality is unknown at compile time and the futures are all of the same type. The order of the futures in the output vector will be the same as given by the input iterator.

hpx::when_any

Defined in header `hpx/future.hpp`⁷⁰³.

See *Public API* for a list of names and headers that are part of the public *HPX* API.

namespace **hpx**

Top level HPX namespace.

Functions

```
template<typename InputIter, typename Container = vector<future<typename  
std::iterator_traits<InputIter>::value_type>>>  
future<when_any_result<Container>> when_any(InputIter first, InputIter last)
```

function *when_any* creates a future object that becomes when at least one element in a set of *future* and *shared_future* objects becomes ready. It is a non-deterministic choice operator. It OR-composes all given future objects and returns a new future object representing the same list of futures after one future of that list finishes execution.

Parameters

⁷⁰³ <http://github.com/STELLAR-GROUP/hpx/blob/8a3b7c1a4cb5693b2f7d9f587f759392ed0c51a0/libs/full/include/include/hpx/future.hpp>

- **first** – [in] The iterator pointing to the first element of a sequence of *future* or *shared_future* objects for which *when_any* should wait.
- **last** – [in] The iterator pointing to the last element of a sequence of *future* or *shared_future* objects for which *when_any* should wait.

Returns Returns a *when_any_result* holding the same list of futures as has been passed to *when_any* and an index pointing to a ready future.

- *future*<*when_any_result*<Container<future<R>>>>: If the input cardinality is unknown at compile time and the futures are all of the same type. The order of the futures in the output container will be the same as given by the input iterator.

```
template<typename Range>
future<when_any_result<Range>> when_any(Range &values)
```

function *when_any* creates a future object that becomes when at least one element in a set of *future* and *shared_future* objects becomes ready. It is a non-deterministic choice operator. It OR-composes all given future objects and returns a new future object representing the same list of futures after one future of that list finishes execution.

Parameters values – [in] A range holding an arbitrary amount of *futures* or *shared_future* objects for which *when_any* should wait.

Returns Returns a *when_any_result* holding the same list of futures as has been passed to *when_any* and an index pointing to a ready future.

- *future*<*when_any_result*<Container<future<R>>>>: If the input cardinality is unknown at compile time and the futures are all of the same type. The order of the futures in the output container will be the same as given by the input iterator.

```
template<typename ...T>
future<when_any_result<tuple<future<T>...>>> when_any(T&&... futures)
```

function *when_any* creates a future object that becomes when at least one element in a set of *future* and *shared_future* objects becomes ready. It is a non-deterministic choice operator. It OR-composes all given future objects and returns a new future object representing the same list of futures after one future of that list finishes execution.

Parameters futures – [in] An arbitrary number of *future* or *shared_future* objects, possibly holding different types for which *when_any* should wait.

Returns Returns a *when_any_result* holding the same list of futures as has been passed to *when_any* and an index pointing to a ready future..

- *future*<*when_any_result*<tuple<future<T0>, future<T1>...>>>: If inputs are fixed in number and are of heterogeneous types. The inputs can be any arbitrary number of future objects.
- *future*<*when_any_result*<tuple<>>> if *when_any* is called with zero arguments. The returned future will be initially ready.

```
template<typename InputIter, typename Container = vector<future<typename
std::iterator_traits<InputIter>::value_type>>>
future<when_any_result<Container>> when_any_n(InputIter first, std::size_t count)
```

function *when_any_n* creates a future object that becomes when at least one element in a set of *future* and *shared_future* objects becomes ready. It is a non-deterministic choice operator. It OR-composes all given future objects and returns a new future object representing the same list of futures after one future of that list finishes execution.

Note: None of the futures in the input sequence are invalidated.

Parameters

- **first** – [in] The iterator pointing to the first element of a sequence of *future* or *shared_future* objects for which *when_any_n* should wait.
- **count** – [in] The number of elements in the sequence starting at *first*.

Returns Returns a *when_any_result* holding the same list of futures as has been passed to *when_any* and an index pointing to a ready future.

- `future<when_any_result<Container<future<R>>>>`: If the input cardinality is unknown at compile time and the futures are all of the same type. The order of the futures in the output container will be the same as given by the input iterator.

```
template<typename Sequence>
```

```
struct when_any_result
```

```
#include <when_any.hpp> Result type for when_any, contains a sequence of futures and an index pointing to a ready future.
```

Public Members

```
std::size_t index
```

The index of a future which has become ready.

```
Sequence futures
```

The sequence of futures as passed to `hpx::when_any`

hpx::when_each

Defined in header `hpx/future.hpp`⁷⁰⁴.

See *Public API* for a list of names and headers that are part of the public *HPX* API.

```
namespace hpx
```

```
    Top level HPX namespace.
```

Functions

```
template<typename F, typename Future>
```

```
future<void> when_each(F &&f, std::vector<Future> &&futures)
```

The function *when_each* is an operator allowing to join on the results of all given futures. It AND-composes all future objects given and returns a new future object representing the event of all those futures having finished executing. It also calls the supplied callback for each of the futures which becomes ready.

⁷⁰⁴ <http://github.com/STELLAR-GROUP/hpx/blob/8a3b7c1a4cb5693b2f7d9f587f759392ed0c51a0/libs/full/include/include/hpx/future.hpp>

Note: This function consumes the futures as they are passed on to the supplied function. The callback should take one or two parameters, namely either a *future* to be processed or a type that *std::size_t* is implicitly convertible to as the first parameter and the *future* as the second parameter. The first parameter will correspond to the index of the current *future* in the collection.

Parameters

- **f** – The function which will be called for each of the input futures once the future has become ready.
- **futures** – A vector holding an arbitrary amount of *future* or *shared_future* objects for which *wait_each* should wait.

Returns Returns a future representing the event of all input futures being ready.

```
template<typename F, typename Iterator>
future<Iterator> when_each(F &&f, Iterator begin, Iterator end)
```

The function *when_each* is an operator allowing to join on the results of all given futures. It AND-composes all future objects given and returns a new future object representing the event of all those futures having finished executing. It also calls the supplied callback for each of the futures which becomes ready.

Note: This function consumes the futures as they are passed on to the supplied function. The callback should take one or two parameters, namely either a *future* to be processed or a type that *std::size_t* is implicitly convertible to as the first parameter and the *future* as the second parameter. The first parameter will correspond to the index of the current *future* in the collection.

Parameters

- **f** – The function which will be called for each of the input futures once the future has become ready.
- **begin** – The iterator pointing to the first element of a sequence of *future* or *shared_future* objects for which *wait_each* should wait.
- **end** – The iterator pointing to the last element of a sequence of *future* or *shared_future* objects for which *wait_each* should wait.

Returns Returns a future representing the event of all input futures being ready.

```
template<typename F, typename ...Ts>
future<void> when_each(F &&f, Ts&&... futures)
```

The function *when_each* is an operator allowing to join on the results of all given futures. It AND-composes all future objects given and returns a new future object representing the event of all those futures having finished executing. It also calls the supplied callback for each of the futures which becomes ready.

Note: This function consumes the futures as they are passed on to the supplied function. The callback should take one or two parameters, namely either a *future* to be processed or a type that *std::size_t* is implicitly convertible to as the first parameter and the *future* as the second parameter. The first parameter will correspond to the index of the current *future* in the collection.

Parameters

- **f** – The function which will be called for each of the input futures once the future has become ready.
- **futures** – An arbitrary number of *future* or *shared_future* objects, possibly holding different types for which *wait_each* should wait.

Returns Returns a future representing the event of all input futures being ready.

```
template<typename F, typename Iterator>  
future<Iterator> when_each_n(F &&f, Iterator begin, std::size_t count)
```

The function *when_each* is an operator allowing to join on the results of all given futures. It AND-composes all future objects given and returns a new future object representing the event of all those futures having finished executing. It also calls the supplied callback for each of the futures which becomes ready.

Note: This function consumes the futures as they are passed on to the supplied function. The callback should take one or two parameters, namely either a *future* to be processed or a type that *std::size_t* is implicitly convertible to as the first parameter and the *future* as the second parameter. The first parameter will correspond to the index of the current *future* in the collection.

Parameters

- **f** – The function which will be called for each of the input futures once the future has become ready.
- **begin** – The iterator pointing to the first element of a sequence of *future* or *shared_future* objects for which *wait_each_n* should wait.
- **count** – The number of elements in the sequence starting at *first*.

Returns Returns a future holding the iterator pointing to the first element after the last one.

hpx::when_some

Defined in header `hpx/future.hpp`⁷⁰⁵.

See *Public API* for a list of names and headers that are part of the public *HPX* API.

namespace **hpx**

Top level HPX namespace.

Functions

```
template<typename InputIter, typename Container = vector<future<typename  
std::iterator_traits<InputIter>::value_type>>>  
future<when_some_result<Container>> when_some(std::size_t n, Iterator first, Iterator last)
```

The function *when_some* is an operator allowing to join on the result of all given futures. It AND-composes all future objects given and returns a new future object representing the same list of futures after *n* of them finished executing.

Note: The future returned by the function *when_some* becomes ready when at least *n* argument futures have become ready.

⁷⁰⁵ <http://github.com/STELLAR-GROUP/hpx/blob/8a3b7c1a4cb5693b2f7d9f587f759392ed0c51a0/libs/full/include/include/hpx/future.hpp>

Note: Calling this version of *when_some* where `first == last`, returns a future with an empty container that is immediately ready. Each future and `shared_future` is waited upon and then copied into the collection of the output (returned) future, maintaining the order of the futures in the input collection. The future returned by *when_some* will not throw an exception, but the futures held in the output collection may.

Parameters

- **n** – [in] The number of futures out of the arguments which have to become ready in order for the returned future to get ready.
- **first** – [in] The iterator pointing to the first element of a sequence of *future* or *shared_future* objects for which *when_all* should wait.
- **last** – [in] The iterator pointing to the last element of a sequence of *future* or *shared_future* objects for which *when_all* should wait.

Returns Returns a *when_some_result* holding the same list of futures as has been passed to *when_some* and indices pointing to ready futures.

- `future<when_some_result<Container<future<R>>>>`: If the input cardinality is unknown at compile time and the futures are all of the same type. The order of the futures in the output container will be the same as given by the input iterator.

```
template<typename Range>
future<when_some_result<Range>> when_some(std::size_t n, Range &&futures)
```

The function *when_some* is an operator allowing to join on the result of all given futures. It AND-composes all future objects given and returns a new future object representing the same list of futures after *n* of them finished executing.

Note: The future returned by the function *when_some* becomes ready when at least *n* argument futures have become ready.

Note: Each future and `shared_future` is waited upon and then copied into the collection of the output (returned) future, maintaining the order of the futures in the input collection. The future returned by *when_some* will not throw an exception, but the futures held in the output collection may.

Parameters

- **n** – [in] The number of futures out of the arguments which have to become ready in order for the returned future to get ready.
- **futures** – [in] A container holding an arbitrary amount of *future* or *shared_future* objects for which *when_some* should wait.

Returns Returns a *when_some_result* holding the same list of futures as has been passed to *when_some* and indices pointing to ready futures.

- `future<when_some_result<Container<future<R>>>>`: If the input cardinality is unknown at compile time and the futures are all of the same type. The order of the futures in the output container will be the same as given by the input iterator.

```
template<typename ...Ts>
```

future<*when_some_result*<*tuple*<*future*<*T*>...>>> **when_some**(*std::size_t* n, *Ts*&&... futures)

The function *when_some* is an operator allowing to join on the result of all given futures. It AND-composes all future objects and returns a new future object representing the same list of futures after *n* of them finished executing.

Note: The future returned by the function *when_some* becomes ready when at least *n* argument futures have become ready.

Note: Each future and *shared_future* is waited upon and then copied into the collection of the output (returned) future, maintaining the order of the futures in the input collection. The future returned by *when_some* will not throw an exception, but the futures held in the output collection may.

Parameters

- **n** – [in] The number of futures out of the arguments which have to become ready in order for the returned future to get ready.
- **futures** – [in] An arbitrary number of *future* or *shared_future* objects, possibly holding different types for which *when_some* should wait.

Returns Returns a *when_some_result* holding the same list of futures as has been passed to *when_some* and an index pointing to a ready future..

- *future*<*when_some_result*<*tuple*<*future*<*T0*>, *future*<*T1*>...>>>: If inputs are fixed in number and are of heterogeneous types. The inputs can be any arbitrary number of future objects.
- *future*<*when_some_result*<*tuple*<>>> if *when_some* is called with zero arguments. The returned future will be initially ready.

template<typename **InputIter**, typename **Container** = vector<*future*<typename *std::iterator_traits*<*InputIter*>::value_type>>>
future<*when_some_result*<*Container*>> **when_some_n**(*std::size_t* n, *Iterator* first, *std::size_t* count)

The function *when_some_n* is an operator allowing to join on the result of all given futures. It AND-composes all future objects given and returns a new future object representing the same list of futures after *n* of them finished executing.

Note: The future returned by the function *when_some_n* becomes ready when at least *n* argument futures have become ready.

Note: Calling this version of *when_some_n* where *count* == 0, returns a future with the same elements as the arguments that is immediately ready. Possibly none of the futures in that container are ready. Each future and *shared_future* is waited upon and then copied into the collection of the output (returned) future, maintaining the order of the futures in the input collection. The future returned by *when_some_n* will not throw an exception, but the futures held in the output collection may.

Parameters

- **n** – [in] The number of futures out of the arguments which have to become ready in order for the returned future to get ready.

- **first** – [in] The iterator pointing to the first element of a sequence of *future* or *shared_future* objects for which *when_all* should wait.
- **count** – [in] The number of elements in the sequence starting at *first*.

Returns Returns a *when_some_result* holding the same list of futures as has been passed to *when_some* and indices pointing to ready futures.

- `future<when_some_result<Container<future<R>>>>`: If the input cardinality is unknown at compile time and the futures are all of the same type. The order of the futures in the output container will be the same as given by the input iterator.

```
template<typename Sequence>
```

```
struct when_some_result
```

```
#include <when_some.hpp> Result type for when_some, contains a sequence of futures and indices pointing to ready futures.
```

Public Members

```
std::vector<std::size_t> indices
```

List of indices of futures that have become ready.

```
Sequence futures
```

The sequence of futures as passed to `hpx::when_some`.

async_cuda

See *Public API* for a list of names and headers that are part of the public *HPX* API.

hpx/async_cuda/cublas_executor.hpp

Defined in header `hpx/async_cuda/cublas_executor.hpp`.

See *Public API* for a list of names and headers that are part of the public *HPX* API.

hpx/async_cuda/cuda_executor.hpp

Defined in header `hpx/async_cuda/cuda_executor.hpp`.

See *Public API* for a list of names and headers that are part of the public *HPX* API.

```
namespace hpx
```

```
    namespace cuda
```

```
        namespace experimental
```

```
            struct cuda_executor : public hpx::cuda::experimental::cuda_executor_base
```

Public Functions

```
inline explicit cuda_executor(std::size_t device, bool event_mode = true)
```

```
inline ~cuda_executor()
```

```
template<typename F, typename ...Ts>
```

```
inline decltype(auto) friend tag_invoke(hpx::parallel::execution::post_t, cuda_executor const  
&exec, F &&f, Ts&&... ts)
```

```
template<typename F, typename ...Ts>
```

```
inline decltype(auto) friend tag_invoke(hpx::parallel::execution::async_execute_t,  
cuda_executor const &exec, F &&f, Ts&&... ts)
```

Protected Functions

```
template<typename R, typename ...Params, typename ...Args>
```

```
inline void post(R (*cuda_function)(Params...), Args&&... args) const
```

```
template<typename R, typename ...Params, typename ...Args>
```

```
inline hpx::future<void> async(R (*cuda_kernel)(Params...), Args&&... args) const
```

```
struct cuda_executor_base
```

```
Subclassed by hpx::cuda::experimental::cuda_executor
```

Public Types

```
using future_type = hpx::future<void>
```

Public Functions

```
inline cuda_executor_base(std::size_t device, bool event_mode)
```

```
inline future_type get_future() const
```

Protected Attributes

```
int device_
```

```
bool event_mode_
```

```
cudaStream_t stream_
```

```
std::shared_ptr<hpx::cuda::experimental::target> target_
```

```
namespace execution
```

```
namespace experimental
```

async_mpi

See *Public API* for a list of names and headers that are part of the public *HPX* API.

hpx/async_mpi/mpi_executor.hpp

Defined in header `hpx/async_mpi/mpi_executor.hpp`.

See *Public API* for a list of names and headers that are part of the public *HPX* API.

```
namespace hpx
```

```
namespace mpi
```

```
namespace experimental
```

```
struct executor
```

Public Types

```
using execution_category = hpx::execution::parallel_execution_tag
```

```
using executor_parameters_type = hpx::execution::experimental::default_parameters
```

Public Functions

```
inline explicit constexpr executor(MPI_Comm communicator = MPI_COMM_WORLD)
```

```
template<typename F, typename ...Ts>
```

```
inline decltype(auto) friend tag_invoke(hpx::parallel::execution::async_execute_t, executor  
const &exec, F &&f, Ts&&... ts)
```

```
inline std::size_t in_flight_estimate() const
```

Private Members

```
MPI_Comm communicator_
```

hpx/async_mpi/transform_mpi.hpp

Defined in header hpx/async_mpi/transform_mpi.hpp.

See *Public API* for a list of names and headers that are part of the public *HPX* API.

```
namespace hpx
```

```
    namespace mpi
```

```
        namespace experimental
```

Variables

```
hpx::mpi::experimental::transform_mpi_t transform_mpi
```

```
struct transform_mpi_t : public hpx::functional::detail::tag_fallback<transform_mpi_t>
```

Friends

```
    template<typename Sender,  
            typename F> inline friend constexpr friend auto tag_fallback_invoke (transform_mpi_t,  
            Sender &&s, F &&f)
```

```
    template<typename F> inline friend constexpr friend auto tag_fallback_invoke (transform  
    F &&f)
```

cache

See *Public API* for a list of names and headers that are part of the public *HPX* API.

hpx/cache/local_cache.hpp

Defined in header hpx/cache/local_cache.hpp.

See *Public API* for a list of names and headers that are part of the public *HPX* API.

```
namespace hpx
```

```
    namespace util
```

```
        namespace cache
```

```
            template<typename Key, typename Entry, typename UpdatePolicy = std::less<Entry>, typename  
            InsertPolicy = policies::always<Entry>, typename CacheStorage = std::map<Key, Entry>,  
            typename Statistics = statistics::no_statistics>
```

class **local_cache**

`#include <hpx/cache/local_cache.hpp>` The `local_cache` implements the basic functionality needed for a local (non-distributed) cache.

Template Parameters

- **Key** – The type of the keys to use to identify the entries stored in the cache
- **Entry** – The type of the items to be held in the cache, must model the `CacheEntry` concept
- **UpdatePolicy** – A (optional) type specifying a (binary) function object used to sort the cache entries based on their ‘age’. The ‘oldest’ entries (according to this sorting criteria) will be discarded first if the maximum capacity of the cache is reached. The default is `std::less<Entry>`. The function object will be invoked using 2 entry instances of the type `Entry`. This type must model the `UpdatePolicy` model.
- **InsertPolicy** – A (optional) type specifying a (unary) function object used to allow global decisions whether a particular entry should be added to the cache or not. The default is `policies::always`, imposing no global insert related criteria on the cache. The function object will be invoked using the entry instance to be inserted into the cache. This type must model the `InsertPolicy` model.
- **CacheStorage** – A (optional) container type used to store the cache items. The container must be an associative and STL compatible container. The default is a `std::map<Key, Entry>`.
- **Statistics** – A (optional) type allowing to collect some basic statistics about the operation of the cache instance. The type must conform to the `CacheStatistics` concept. The default value is the type `statistics::no_statistics` which does not collect any numbers, but provides empty stubs allowing the code to compile.

Public Types

using **key_type** = *Key*

using **entry_type** = *Entry*

using **update_policy_type** = *UpdatePolicy*

using **insert_policy_type** = *InsertPolicy*

using **storage_type** = *CacheStorage*

using **statistics_type** = *Statistics*

using **value_type** = typename *entry_type*::value_type

using **size_type** = typename *storage_type*::size_type

using **storage_value_type** = typename *storage_type*::value_type

Public Functions

inline explicit **local_cache**(*size_type* max_size = 0, *update_policy_type* const &up = *update_policy_type*(), *insert_policy_type* const &ip = *insert_policy_type*())

Construct an instance of a *local_cache*.

Parameters

- **max_size** – [in] The maximal size this cache is allowed to reach any time. The default is zero (no size limitation). The unit of this value is usually determined by the unit of the values returned by the entry's *get_size* function.
- **up** – [in] An instance of the *UpdatePolicy* to use for this cache. The default is to use a default constructed instance of the type as defined by the *UpdatePolicy* template parameter.
- **ip** – [in] An instance of the *InsertPolicy* to use for this cache. The default is to use a default constructed instance of the type as defined by the *InsertPolicy* template parameter.

local_cache(*local_cache* const &other) = default

local_cache(*local_cache* &&other) = default

local_cache &**operator**=(*local_cache* const &other) = default

local_cache &**operator**=(*local_cache* &&other) = default

~local_cache() = default

inline constexpr *size_type* **size**() const noexcept

Return current size of the cache.

Returns The current size of this cache instance.

inline constexpr *size_type* **capacity**() const noexcept

Access the maximum size the cache is allowed to grow to.

Note: The unit of this value is usually determined by the unit of the return values of the entry's function *entry::get_size*.

Returns The maximum size this cache instance is currently allowed to reach. If this number is zero the cache has no limitation with regard to a maximum size.

inline bool **reserve**(*size_type* max_size)

Change the maximum size this cache can grow to.

Parameters **max_size** – [in] The new maximum size this cache will be allowed to grow to.

Returns This function returns *true* if successful. It returns *false* if the new *max_size* is smaller than the current limit and the cache could not be shrunk to the new maximum size.

inline bool **holds_key**(*key_type* const &k) const

Check whether the cache currently holds an entry identified by the given key.

Note: This function does not call the entry's function *entry::touch*. It just checks if the cache contains an entry corresponding to the given key.

Parameters **k** – [in] The key for the entry which should be looked up in the cache.

Returns This function returns *true* if the cache holds the referenced entry, otherwise it returns *false*.

```
inline bool get_entry(key_type const &k, key_type &realkey, entry_type &val)
```

Get a specific entry identified by the given key.

Note: The function will call the entry's *entry::touch* function if the value corresponding to the provided key is found in the cache.

Parameters

- **k** – [in] The key for the entry which should be retrieved from the cache.
- **realkey[out]** – Return the full real key found in the cache
- **val** – [out] If the entry indexed by the key is found in the cache this value on successful return will be a copy of the corresponding entry.

Returns This function returns *true* if the cache holds the referenced entry, otherwise it returns *false*.

```
inline bool get_entry(key_type const &k, entry_type &val)
```

Get a specific entry identified by the given key.

Note: The function will call the entry's *entry::touch* function if the value corresponding to the provided key is found in the cache.

Parameters

- **k** – [in] The key for the entry which should be retrieved from the cache.
- **val** – [out] If the entry indexed by the key is found in the cache this value on successful return will be a copy of the corresponding entry.

Returns This function returns *true* if the cache holds the referenced entry, otherwise it returns *false*.

```
inline bool get_entry(key_type const &k, value_type &val)
```

Get a specific entry identified by the given key.

Note: The function will call the entry's *entry::touch* function if the value corresponding to the provided is found in the cache.

Parameters

- **k** – [in] The key for the entry which should be retrieved from the cache
- **val** – [out] If the entry indexed by the key is found in the cache this value on successful return will be a copy of the corresponding value.

Returns This function returns *true* if the cache holds the referenced entry, otherwise it returns *false*.

```
inline bool insert(key_type const &k, value_type const &val)
```

Insert a new element into this cache.

Note: This function invokes both, the insert policy as provided to the constructor and the function *entry::insert* of the newly constructed entry instance. If either of these functions returns *false* the key/value pair doesn't get inserted into the cache and the *insert* function will return *false*. Other reasons for this function to fail (return *false*) are a) the key/value pair is already

held in the cache or b) inserting the new value into the cache maxed out its capacity and it was not possible to free any of the existing entries.

Parameters

- **k** – [in] The key for the entry which should be added to the cache.
- **val** – [in] The value which should be added to the cache.

Returns This function returns *true* if the entry has been successfully added to the cache, otherwise it returns *false*.

```
inline bool insert(key_type const &k, value_type &&val)
```

```
template<typename Entry_, std::enable_if_t<std::is_convertible_v<std::decay_t<Entry_>, entry_type>, int> = 0>
```

```
inline bool insert(key_type const &k, Entry_ &&e)
```

Insert a new entry into this cache.

Note: This function invokes both, the insert policy as provided to the constructor and the function *entry::insert* of the provided entry instance. If either of these functions returns false the key/value pair doesn't get inserted into the cache and the *insert* function will return *false*. Other reasons for this function to fail (return *false*) are a) the key/value pair is already held in the cache or b) inserting the new value into the cache maxed out its capacity and it was not possible to free any of the existing entries.

Parameters

- **k** – [in] The key for the entry which should be added to the cache.
- **e** – [in] The entry which should be added to the cache.

Returns This function returns *true* if the entry has been successfully added to the cache, otherwise it returns *false*.

```
template<typename Value, std::enable_if_t<std::is_convertible_v<std::decay_t<Value>, value_type>, int> = 0>
```

```
inline bool update(key_type const &k, Value &&val)
```

Update an existing element in this cache.

Note: The function will call the entry's *entry::touch* function if the indexed value is found in the cache.

Note: The difference to the other overload of the *insert* function is that this overload replaces the cached value only, while the other overload replaces the whole cache entry, updating the cache entry properties.

Parameters

- **k** – [in] The key for the value which should be updated in the cache.
- **val** – [in] The value which should be used as a replacement for the existing value in the cache. Any existing cache entry is not changed except for its value.

Returns This function returns *true* if the entry has been successfully updated, otherwise it returns *false*. If the entry currently is not held by the cache it is added and the return value reflects the outcome of the corresponding insert operation.

```
template<typename F, typename Value, typename = std::enable_if_t<std::is_convertible_v<std::decay_t<Value>, value_type>>>
```

```
inline bool update_if(key_type const &k, Value &&val, F &&f)
```

Update an existing element in this cache.

Note: The function will call the entry's `entry::touch` function if the indexed value is found in the cache.

Note: The difference to the other overload of the `insert` function is that this overload replaces the cached value only, while the other overload replaces the whole cache entry, updating the cache entry properties.

Parameters

- **k** – [in] The key for the value which should be updated in the cache.
- **val** – [in] The value which should be used as a replacement for the existing value in the cache. Any existing cache entry is not changed except for its value.
- **f** – [in] A callable taking two arguments, *k* and the key found in the cache (in that order). If *f* returns true, then the update will continue. If *f* returns false, then the update will not succeed.

Returns This function returns *true* if the entry has been successfully updated, otherwise it returns *false*. If the entry currently is not held by the cache it is added and the return value reflects the outcome of the corresponding insert operation.

```
template<typename Entry_, std::enable_if_t<std::is_convertible_v<std::decay_t<Entry_>,  
entry_type>, int> = 0>
```

```
inline bool update(key_type const &k, Entry_ &&e)
```

Update an existing entry in this cache.

Note: The function will call the entry's `entry::touch` function if the indexed value is found in the cache.

Note: The difference to the other overload of the `insert` function is that this overload replaces the whole cache entry, while the other overload replaces the cached value only, leaving the cache entry properties untouched.

Parameters

- **k** – [in] The key for the entry which should be updated in the cache.
- **e** – [in] The entry which should be used as a replacement for the existing entry in the cache. Any existing entry is first removed and then this entry is added.

Returns This function returns *true* if the entry has been successfully updated, otherwise it returns *false*. If the entry currently is not held by the cache it is added and the return value reflects the outcome of the corresponding insert operation.

```
template<typename Func = policies::always<storage_value_type>>
```

```
inline size_type erase(Func &&ep = Func())
```

Remove stored entries from the cache for which the supplied function object returns true.

Parameters **ep** – [in] This parameter has to be a (unary) function object. It is invoked for each of the entries currently held in the cache. An entry is considered for removal from the cache whenever the value returned from this invocation is *true*. Even then the entry might not be removed from the cache as its `entry::remove` function might return false.

Returns This function returns the overall size of the removed entries (which is the sum of the values returned by the `entry::get_size` functions of the removed entries).

inline *size_type* **erase**()

Remove all stored entries from the cache.

Note: All entries are considered for removal, but in the end an entry might not be removed from the cache as its `entry::remove` function might return false. This function is very useful for instance in conjunction with an entry's `entry::remove` function enforcing additional criteria like entry expiration, etc.

Returns This function returns the overall size of the removed entries (which is the sum of the values returned by the `entry::get_size` functions of the removed entries).

inline void **clear**()

Clear the cache.

Unconditionally removes all stored entries from the cache.

inline constexpr *statistics_type* const &**get_statistics**() const noexcept

Allow to access the embedded statistics instance.

Returns This function returns a reference to the statistics instance embedded inside this cache

inline *statistics_type* &**get_statistics**() noexcept

Protected Functions

inline bool **free_space**(long num_free)

Private Types

using **iterator** = typename *storage_type*::iterator

using **const_iterator** = typename *storage_type*::const_iterator

using **heap_type** = *std*::deque<iterator>

using **heap_iterator** = typename *heap_type*::iterator

using **adapted_update_policy_type** = *adapt*<*UpdatePolicy*, iterator>

using **update_on_exit** = typename *statistics_type*::update_on_exit

Private Members*size_type* **max_size_***size_type* **current_size_***storage_type* **store_***heap_type* **entry_heap_***adapted_update_policy_type* **update_policy_***insert_policy_type* **insert_policy_***statistics_type* **statistics_**template<typename **Func**, typename **Iterator**>struct **adapt****Public Functions**inline explicit **adapt**(*Func* const &f)inline explicit **adapt**(*Func* &&f) noexceptinline bool **operator**()(*Iterator* const &lhs, *Iterator* const &rhs) const**Public Members***Func* **f_****hpx/cache/lru_cache.hpp**

Defined in header hpx/cache/lru_cache.hpp.

See *Public API* for a list of names and headers that are part of the public *HPX* API.namespace **hpx**namespace **util**namespace **cache**template<typename **Key**, typename **Entry**, typename **Statistics** = *statistics::no_statistics*>

class **lru_cache**

#include <hpx/cache/lru_cache.hpp> The **lru_cache** implements the basic functionality needed for a local (non-distributed) LRU cache.

Template Parameters

- **Key** – The type of the keys to use to identify the entries stored in the cache
- **Entry** – The type of the items to be held in the cache.
- **Statistics** – A (optional) type allowing to collect some basic statistics about the operation of the cache instance. The type must conform to the `CacheStatistics` concept. The default value is the type `statistics::no_statistics` which does not collect any numbers, but provides empty stubs allowing the code to compile.

Public Types

using **key_type** = *Key*

using **entry_type** = *Entry*

using **statistics_type** = *Statistics*

using **entry_pair** = *std::pair<key_type, entry_type>*

using **storage_type** = *std::list<entry_pair>*

using **map_type** = *std::map<Key, typename storage_type::iterator>*

using **size_type** = *std::size_t*

Public Functions

inline explicit **lru_cache**(*size_type* max_size = 0)

Construct an instance of a *lru_cache*.

Parameters **max_size** – [in] The maximal size this cache is allowed to reach any time. The default is zero (no size limitation). The unit of this value is usually determined by the unit of the values returned by the entry's *get_size* function.

lru_cache(*lru_cache* const &other) = default

lru_cache(*lru_cache* &&other) = default

lru_cache &operator=(*lru_cache* const &other) = default

lru_cache &operator=(*lru_cache* &&other) = default

~**lru_cache**() = default

inline constexpr *size_type* **size**() const noexcept

Return current size of the cache.

Returns The current size of this cache instance.

```
inline constexpr size_type capacity() const noexcept
```

Access the maximum size the cache is allowed to grow to.

Note: The unit of this value is usually determined by the unit of the return values of the entry's function `entry::get_size`.

Returns The maximum size this cache instance is currently allowed to reach. If this number is zero the cache has no limitation with regard to a maximum size.

```
inline void reserve(size_type max_size)
```

Change the maximum size this cache can grow to.

Parameters `max_size` – [in] The new maximum size this cache will be allowed to grow to.

```
inline bool holds_key(key_type const &key) const
```

Check whether the cache currently holds an entry identified by the given key.

Note: This function does not call the entry's function `entry::touch`. It just checks if the cache contains an entry corresponding to the given key.

Parameters `key` – [in] The key for the entry which should be looked up in the cache.

Returns This function returns `true` if the cache holds the referenced entry, otherwise it returns `false`.

```
inline bool get_entry(key_type const &key, key_type &realkey, entry_type &entry)
```

Get a specific entry identified by the given key.

Note: The function will “touch” the entry and mark it as recently used if the key was found in the cache.

Parameters

- `key` – [in] The key for the entry which should be retrieved from the cache.
- `realkey[out]` – Return the full real key found in the cache
- `entry` – [out] If the entry indexed by the key is found in the cache this value on successful return will be a copy of the corresponding entry.

Returns This function returns `true` if the cache holds the referenced entry, otherwise it returns `false`.

```
inline bool get_entry(key_type const &key, entry_type const &entry)
```

Get a specific entry identified by the given key.

Note: The function will “touch” the entry and mark it as recently used if the key was found in the cache.

Parameters

- `key` – [in] The key for the entry which should be retrieved from the cache.
- `entry` – [out] If the entry indexed by the key is found in the cache this value on successful return will be a copy of the corresponding entry.

Returns This function returns `true` if the cache holds the referenced entry, otherwise it returns `false`.

```
template<typename Entry_, typename =  
std::enable_if_t<std::is_convertible_v<std::decay_t<Entry_>, entry_type>>>  
inline bool insert(key_type const &key, Entry_ &&entry)
```

Insert a new entry into this cache.

Note: This function assumes that the entry is not in the cache already. Inserting an already existing entry is considered undefined behavior

Parameters

- **key** – [in] The key for the entry which should be added to the cache.
- **entry** – [in] The entry which should be added to the cache.

```
template<typename Entry_, typename =  
std::enable_if_t<std::is_convertible_v<std::decay_t<Entry_>, entry_type>>>  
inline void update(key_type const &key, Entry_ &&entry)
```

Update an existing element in this cache.

Note: The function will “touch” the entry and mark it as recently used if the key was found in the cache.

Note: The difference to the other overload of the *insert* function is that this overload replaces the cached value only, while the other overload replaces the whole cache entry, updating the cache entry properties.

Parameters

- **key** – [in] The key for the value which should be updated in the cache.
- **entry** – [in] The entry which should be used as a replacement for the existing value in the cache. Any existing cache entry is not changed except for its value.

```
template<typename F, typename Entry_,  
std::enable_if_t<std::is_convertible_v<std::decay_t<Entry_>, entry_type>, int> = 0>  
inline bool update_if(key_type const &key, Entry_ &&entry, F &&f)
```

Update an existing element in this cache.

Note: The function will “touch” the entry and mark it as recently used if the key was found in the cache.

Note: The difference to the other overload of the *insert* function is that this overload replaces the cached value only, while the other overload replaces the whole cache entry, updating the cache entry properties.

Parameters

- **key** – [in] The key for the value which should be updated in the cache.
- **entry** – [in] The value which should be used as a replacement for the existing value in the cache. Any existing cache entry is not changed except for its value.
- **f** – [in] A callable taking two arguments, *k* and the key found in the cache (in that order). If *f* returns true, then the update will continue. If *f* returns false, then the update will not succeed.

Returns This function returns *true* if the entry has been successfully updated, otherwise it returns *false*. If the entry currently is not held by the cache it is added and the return value reflects the outcome of the corresponding insert operation.

```
template<typename Func>
inline size_type erase(Func const &ep)
```

Remove stored entries from the cache for which the supplied function object returns true.

Parameters **ep** – [in] This parameter has to be a (unary) function object. It is invoked for each of the entries currently held in the cache. An entry is considered for removal from the cache whenever the value returned from this invocation is *true*.

Returns This function returns the overall size of the removed entries (which is the sum of the values returned by the *entry::get_size* functions of the removed entries).

```
inline size_type erase()
```

Remove all stored entries from the cache.

Returns This function returns the overall size of the removed entries (which is the sum of the values returned by the *entry::get_size* functions of the removed entries).

```
inline size_type clear()
```

Clear the cache.

Unconditionally removes all stored entries from the cache.

```
inline constexpr statistics_type const &get_statistics() const noexcept
```

Allow to access the embedded statistics instance.

Returns This function returns a reference to the statistics instance embedded inside this cache

```
inline statistics_type &get_statistics() noexcept
```

Private Types

```
using update_on_exit = typename statistics_type::update_on_exit
```

Private Functions

```
template<typename Entry_, typename =
std::enable_if_t<std::is_convertible_v<std::decay_t<Entry_>, entry_type>>>
```

```
inline void insert_nonexist(key_type const &key, Entry_ &&entry)
```

```
inline void touch(typename storage_type::iterator it)
```

```
inline void evict()
```

Private Members

size_type **max_size_**

size_type **current_size_** = 0

storage_type **storage_**

map_type **map_**

statistics_type **statistics_**

hpx/cache/entries/entry.hpp

Defined in header hpx/cache/entries/entry.hpp.

See *Public API* for a list of names and headers that are part of the public *HPX* API.

namespace **hpx**

namespace **util**

namespace **cache**

namespace **entries**

class **entry**

#include <hpx/cache/entries/entry.hpp>

Template Parameters

- **Value** – The data type to be stored in a cache. It has to be default constructible, copy constructible and less_than_comparable.
- **Derived** – The (optional) type for which this type is used as a base class.

Public Types

using **value_type** = Value

Public Functions

entry() = default

Any cache entry has to be default constructible.

```
inline explicit entry(value_type const &val)
    noexcept(std::is_nothrow_copy_constructible_v<value_type>)
```

Construct a new instance of a cache entry holding the given value.

```
inline explicit entry(value_type &&val) noexcept
```

Construct a new instance of a cache entry holding the given value.

```
inline value_type &get() noexcept
```

Get a reference to the stored data value.

Note: This function is part of the CacheEntry concept

```
inline constexpr value_type const &get() const noexcept
```

Public Static Functions

```
static inline constexpr bool touch() noexcept
```

The function *touch* is called by a cache holding this instance whenever it has been requested (touched).

Note: It is possible to change the entry in a way influencing the sort criteria mandated by the UpdatePolicy. In this case the function should return *true* to indicate this to the cache, forcing to reorder the cache entries.

Note: This function is part of the CacheEntry concept

Returns This function should return *true* if the cache needs to update it's internal heap. Usually this is needed if the entry has been changed by *touch()* in a way influencing the sort order as mandated by the cache's UpdatePolicy

```
static inline constexpr bool insert() noexcept
```

The function *insert* is called by a cache whenever it is about to be inserted into the cache.

Note: This function is part of the CacheEntry concept

Returns This function should return *true* if the entry should be added to the cache, otherwise it should return *false*.

```
static inline constexpr bool remove() noexcept
```

The function *remove* is called by a cache holding this instance whenever it is about to be removed from the cache.

Note: This function is part of the CacheEntry concept

Returns The return value can be used to avoid removing this instance from the cache. If the value is *true* it is ok to remove the entry, other wise it will stay in the cache.

static inline constexpr *std::size_t* **get_size**() noexcept

Return the 'size' of this entry. By default the size of each entry is just one (1), which is sensible if the cache has a limit (capacity) measured in number of entries.

Private Members

value_type **value_**

Friends

```
inline friend bool operator<(entry const &lhs, entry const &rhs)
    noexcept(noexcept(std::declval<value_type const&>() <
        std::declval<value_type const&>()))
```

Forwarding operator< allowing to compare entries instead of the values.

hpx/cache/entries/fifo_entry.hpp

Defined in header `hpx/cache/entries/fifo_entry.hpp`.

See *Public API* for a list of names and headers that are part of the public *HPX* API.

```
namespace hpx
```

```
    namespace util
```

```
        namespace cache
```

```
            namespace entries
```

```
                template<typename Value>
```

```
                class fifo_entry : public hpx::util::cache::entries::entry<Value, fifo_entry<Value>>
```

```
                #include <hpx/cache/entries/fifo_entry.hpp> The fifo_entry type can be used to store arbitrary values in a cache. Using this type as the cache's entry type makes sure that the least recently inserted entries are discarded from the cache first.
```

Note: The *fifo_entry* conforms to the CacheEntry concept.

Note: This type can be used to model a 'last in first out' cache policy if it is used with a *std::greater* as the caches' UpdatePolicy (instead of the default *std::less*).

Template Parameters **Value** – The data type to be stored in a cache. It has to be default constructible, copy constructible and *less_than_comparable*.

Public Functions

fifo_entry() = default

Any cache entry has to be default constructible.

```
inline explicit fifo_entry(Value const &val)
    noexcept(std::is_nothrow_constructible_v<base_type, Value
            const&>)
```

Construct a new instance of a cache entry holding the given value.

```
inline explicit fifo_entry(Value &&val) noexcept
```

Construct a new instance of a cache entry holding the given value.

```
inline constexpr bool insert()
```

The function *insert* is called by a cache whenever it is about to be inserted into the cache.

Note: This function is part of the CacheEntry concept

Returns This function should return *true* if the entry should be added to the cache, otherwise it should return *false*.

```
inline constexpr time_point const &get_creation_time() const noexcept
```

Private Types

```
using base_type = entry<Value, fifo_entry<Value>>
```

```
using time_point = std::chrono::steady_clock::time_point
```

Private Members

```
time_point insertion_time_
```

Friends

```
inline friend bool operator<(fifo_entry const &lhs, fifo_entry const &rhs)
    noexcept(noexcept(std::declval<time_point const&>() <
                    std::declval<time_point const&>()))
```

Compare the ‘age’ of two entries. An entry is ‘older’ than another entry if it has been created earlier (FIFO).

hpx/cache/entries/lfu_entry.hpp

Defined in header hpx/cache/entries/lfu_entry.hpp.

See *Public API* for a list of names and headers that are part of the public HPX API.

```
namespace hpx
```

```
    namespace util
```

```
        namespace cache
```

```
            namespace entries
```

```
                template<typename Value>
```

```
                class lfu_entry : public hpx::util::cache::entries::entry<Value, lfu_entry<Value>>
```

```
                {  
                    #include <hpx/cache/entries/lfu_entry.hpp> The lfu_entry type can be used to store arbitrary  
                    values in a cache. Using this type as the cache's entry type makes sure that the least frequently  
                    used entries are discarded from the cache first.  
                }  
            }  
        }  
    }
```

Note: The `lfu_entry` conforms to the CacheEntry concept.

Note: This type can be used to model a 'most frequently used' cache policy if it is used with a `std::greater` as the caches' UpdatePolicy (instead of the default `std::less`).

Template Parameters **Value** – The data type to be stored in a cache. It has to be default constructible, copy constructible and `less_than_comparable`.

Public Functions

```
lfu_entry() = default
```

Any cache entry has to be default constructible.

```
inline explicit lfu_entry(Value const &val)  
    noexcept(std::is_nothrow_constructible_v<base_type, Value  
    const&>)
```

Construct a new instance of a cache entry holding the given value.

```
inline explicit lfu_entry(Value &&val) noexcept
```

Construct a new instance of a cache entry holding the given value.

```
inline bool touch() noexcept
```

The function `touch` is called by a cache holding this instance whenever it has been requested (touched).

In the case of the LFU entry we store the reference count tracking the number of times this entry has been requested. This which will be used to compare the age of an entry during the invocation of the `operator<()`.

Returns This function should return true if the cache needs to update it's internal heap. Usually this is needed if the entry has been changed by *touch()* in a way influencing the sort order as mandated by the cache's UpdatePolicy

```
inline constexpr unsigned long const &get_access_count() const noexcept
```

Private Types

```
using base_type = entry<Value, lfu_entry<Value>>
```

Private Members

```
unsigned long ref_count_ = 0
```

Friends

```
inline friend bool operator<(lfu_entry const &lhs, lfu_entry const &rhs) noexcept
```

Compare the 'age' of two entries. An entry is 'older' than another entry if it has been accessed less frequently (LFU).

hpx/cache/entries/lru_entry.hpp

Defined in header `hpx/cache/entries/lru_entry.hpp`.

See *Public API* for a list of names and headers that are part of the public *HPX* API.

```
namespace hpx
```

```
    namespace util
```

```
        namespace cache
```

```
            namespace entries
```

```
                template<typename Value>
```

```
                class lru_entry : public hpx::util::cache::entries::entry<Value, lru_entry<Value>>
```

#include <hpx/cache/entries/lru_entry.hpp> The `lru_entry` type can be used to store arbitrary values in a cache. Using this type as the cache's entry type makes sure that the least recently used entries are discarded from the cache first.

Note: The `lru_entry` conforms to the CacheEntry concept.

Note: This type can be used to model a 'most recently used' cache policy if it is used with a `std::greater` as the caches' UpdatePolicy (instead of the default `std::less`).

Template Parameters Value – The data type to be stored in a cache. It has to be default constructible, copy constructible and less_than_comparable.

Public Functions

inline **lru_entry**()

Any cache entry has to be default constructible.

inline explicit **lru_entry**(*Value* const &val)
noexcept(*std::is_nothrow_constructible_v*<*base_type*, *Value*
const&>)

Construct a new instance of a cache entry holding the given value.

inline explicit **lru_entry**(*Value* &&val) noexcept

Construct a new instance of a cache entry holding the given value.

inline bool **touch**()

The function *touch* is called by a cache holding this instance whenever it has been requested (touched).

In the case of the LRU entry we store the time of the last access which will be used to compare the age of an entry during the invocation of the *operator*<().

Returns This function should return true if the cache needs to update its internal heap.

Usually this is needed if the entry has been changed by *touch*() in a way influencing the sort order as mandated by the cache's UpdatePolicy

inline constexpr *time_point* const &**get_access_time**() const noexcept

Returns the last access time of the entry.

Private Types

using **base_type** = *entry*<*Value*, *lru_entry*<*Value*>>

using **time_point** = *std::chrono::steady_clock::time_point*

Private Members

time_point **access_time_**

Friends

inline friend bool **operator**<(*lru_entry* const &lhs, *lru_entry* const &rhs)
noexcept(noexcept(*std::declval*<*time_point* const&>() <
std::declval<*time_point* const&>()))

Compare the 'age' of two entries. An entry is 'older' than another entry if it has been accessed less recently (LRU).

hpx/cache/entries/size_entry.hpp

Defined in header hpx/cache/entries/size_entry.hpp.

See *Public API* for a list of names and headers that are part of the public HPX API.

```
namespace hpx
```

```
    namespace util
```

```
        namespace cache
```

```
            namespace entries
```

```
                class size_entry
```

```
                    #include <hpx/cache/entries/size_entry.hpp> The size_entry type can be used to store values in a cache which have a size associated (such as files, etc.). Using this type as the cache's entry type makes sure that the entries with the biggest size are discarded from the cache first.
```

Note: The `size_entry` conforms to the CacheEntry concept.

Note: This type can be used to model a 'discard smallest first' cache policy if it is used with a `std::greater` as the caches' UpdatePolicy (instead of the default `std::less`).

Template Parameters

- **Value** – The data type to be stored in a cache. It has to be default constructible, copy constructible and `less_than_comparable`.
- **Derived** – The (optional) type for which this type is used as a base class.

Public Functions

```
size_entry() = default
```

Any cache entry has to be default constructible.

```
inline explicit size_entry(Value const &val, std::size_t size = 0)
    noexcept(std::is_nothrow_constructible_v<base_type, Value const&>)
```

Construct a new instance of a cache entry holding the given value.

```
inline explicit size_entry(Value &&val, std::size_t size = 0) noexcept
```

Construct a new instance of a cache entry holding the given value.

```
inline constexpr std::size_t get_size() const noexcept
```

Return the 'size' of this entry.

Private Types

```
using derived_type = typename detail::size_derived<Value, Derived>::type

using base_type = entry<Value, derived_type>
```

Private Members

```
std::size_t size_ = 0
```

Friends

```
inline friend constexpr friend bool operator< (size_entry const &lhs,  
size_entry const &rhs) noexcept
```

Compare the ‘age’ of two entries. An entry is ‘older’ than another entry if it has a bigger size.

hpx/cache/statistics/local_statistics.hpp

Defined in header `hpx/cache/statistics/local_statistics.hpp`.

See *Public API* for a list of names and headers that are part of the public *HPX* API.

```
namespace hpx
```

```
    namespace util
```

```
        namespace cache
```

```
            namespace statistics
```

```
                class local_statistics : public hpx::util::cache::statistics::no_statistics
```

Public Functions

```
local_statistics() = default
```

```
inline constexpr std::size_t hits() const noexcept
```

```
inline constexpr std::size_t misses() const noexcept
```

```
inline constexpr std::size_t insertions() const noexcept
```

```
inline constexpr std::size_t evictions() const noexcept
```

```
inline std::size_t hits(bool reset) noexcept
```

```
inline std::size_t misses(bool reset) noexcept
```

```
inline std::size_t insertions(bool reset) noexcept
```

```
inline std::size_t evictions(bool reset) noexcept
```

```
inline void got_hit() noexcept
```

The function *got_hit* will be called by a cache instance whenever a entry got touched.

```
inline void got_miss() noexcept
```

The function *got_miss* will be called by a cache instance whenever a requested entry has not been found in the cache.

```
inline void got_insertion() noexcept
```

The function *got_insertion* will be called by a cache instance whenever a new entry has been inserted.

```
inline void got_eviction() noexcept
```

The function *got_eviction* will be called by a cache instance whenever an entry has been removed from the cache because a new inserted entry let the cache grow beyond its capacity.

```
inline void clear() noexcept
```

Reset all statistics.

Private Members

```
std::size_t hits_ = 0
```

```
std::size_t misses_ = 0
```

```
std::size_t insertions_ = 0
```

```
std::size_t evictions_ = 0
```

Private Static Functions

```
static inline std::size_t get_and_reset(std::size_t &value, bool reset) noexcept
```

hpx/cache/statistics/no_statistics.hpp

Defined in header `hpx/cache/statistics/no_statistics.hpp`.

See *Public API* for a list of names and headers that are part of the public *HPX* API.

```
namespace hpx
```

```
    namespace util
```

```
        namespace cache
```

namespace **statistics**

Enums

enum class **method**

Values:

enumerator **get_entry**

enumerator **insert_entry**

enumerator **update_entry**

enumerator **erase_entry**

class **no_statistics**

Subclassed by *hpx::util::cache::statistics::local_statistics*

Public Static Functions

static inline constexpr void **got_hit**() noexcept

The function *got_hit* will be called by a cache instance whenever a entry got touched.

static inline constexpr void **got_miss**() noexcept

The function *got_miss* will be called by a cache instance whenever a requested entry has not been found in the cache.

static inline constexpr void **got_insertion**() noexcept

The function *got_insertion* will be called by a cache instance whenever a new entry has been inserted.

static inline constexpr void **got_eviction**() noexcept

The function *got_eviction* will be called by a cache instance whenever an entry has been removed from the cache because a new inserted entry let the cache grow beyond its capacity.

static inline constexpr void **clear**() noexcept

Reset all statistics.

static inline constexpr *std::int64_t* **get_get_entry_count**(bool) noexcept

The function *get_get_entry_count* returns the number of invocations of the *get_entry*() API function of the cache.

static inline constexpr *std::int64_t* **get_insert_entry_count**(bool) noexcept

The function *get_insert_entry_count* returns the number of invocations of the *insert_entry*() API function of the cache.

static inline constexpr *std::int64_t* **get_update_entry_count**(bool) noexcept

The function *get_update_entry_count* returns the number of invocations of the *update_entry*() API function of the cache.

static inline constexpr *std::int64_t* **get_erase_entry_count**(bool) noexcept
 The function *get_erase_entry_count* returns the number of invocations of the *erase()* API function of the cache.

static inline constexpr *std::int64_t* **get_get_entry_time**(bool) noexcept
 The function *get_get_entry_time* returns the overall time spent executing of the *get_entry()* API function of the cache.

static inline constexpr *std::int64_t* **get_insert_entry_time**(bool) noexcept
 The function *get_insert_entry_time* returns the overall time spent executing of the *insert_entry()* API function of the cache.

static inline constexpr *std::int64_t* **get_update_entry_time**(bool) noexcept
 The function *get_update_entry_time* returns the overall time spent executing of the *update_entry()* API function of the cache.

static inline constexpr *std::int64_t* **get_erase_entry_time**(bool) noexcept
 The function *get_erase_entry_time* returns the overall time spent executing of the *erase()* API function of the cache.

struct **update_on_exit**
#include <no_statistics.hpp> Helper class to update timings and counts on function exit.

Public Functions

inline constexpr **update_on_exit**(*no_statistics* const&, *method*) noexcept

compute_local

See *Public API* for a list of names and headers that are part of the public *HPX* API.

hpx/compute_local/vector.hpp

Defined in header *hpx/compute_local/vector.hpp*.

See *Public API* for a list of names and headers that are part of the public *HPX* API.

namespace **hpx**

namespace **compute**

Functions

template<typename **T**, typename **Allocator**>
 void **swap**(*vector*<*T*, *Allocator*> &x, *vector*<*T*, *Allocator*> &y) noexcept
 Effects: x.swap(y);

template<typename **T**, typename **Allocator** = *std::allocator*<*T*>>

class **vector**

Public Types

using **value_type** = *T*

Member types (FIXME: add reference to std.)

using **allocator_type** = *Allocator*

using **access_target** = typename *alloc_traits::access_target*

using **size_type** = *std::size_t*

using **difference_type** = *std::ptrdiff_t*

using **reference** = typename *alloc_traits::reference*

using **const_reference** = typename *alloc_traits::const_reference*

using **pointer** = typename *alloc_traits::pointer*

using **const_pointer** = typename *alloc_traits::const_pointer*

using **iterator** = detail::iterator<*T*, *Allocator*>

using **const_iterator** = detail::iterator<*T* const, *Allocator*>

using **reverse_iterator** = detail::reverse_iterator<*T*, *Allocator*>

using **const_reverse_iterator** = detail::const_reverse_iterator<*T*, *Allocator*>

Public Functions

inline explicit **vector**(*Allocator* const &alloc = *Allocator*())

inline **vector**(*size_type* count, *T* const &value, *Allocator* const &alloc = *Allocator*())

inline explicit **vector**(*size_type* count, *Allocator* const &alloc = *Allocator*())

template<typename **InIter**, typename **Enable** = typename
std::enable_if<*hpx::traits::is_input_iterator*<*InIter*>::value>::type>
inline **vector**(*InIter* first, *InIter* last, *Allocator* const &alloc)

inline **vector**(*vector* const &other)

inline **vector**(*vector* const &other, *Allocator* const &alloc)

inline **vector**(*vector* &&other) noexcept

```

inline vector(vector &&other, Allocator const &alloc)

inline vector(std::initializer_list<T> init, Allocator const &alloc)

inline ~vector()

inline vector &operator=(vector const &other)

inline vector &operator=(vector &&other) noexcept

inline allocator_type get_allocator() const noexcept
    Returns the allocator associated with the container.

inline reference operator[]( size_type pos)

inline const_reference operator[]( size_type pos) const

inline pointer data() noexcept
    Returns pointer to the underlying array serving as element storage. The pointer is such that range
    [data(); data() + size()] is always a valid range, even if the container is empty (data() is not
    dereference-able in that case).

inline const_pointer data() const noexcept
    Returns pointer to the underlying array serving as element storage. The pointer is such that range
    [data(); data() + size()] is always a valid range, even if the container is empty (data() is not
    dereference-able in that case).

inline T *device_data() const noexcept
    Returns a raw pointer corresponding to the address of the data allocated on the device.

inline std::size_t size() const noexcept

inline std::size_t capacity() const noexcept

inline bool empty() const noexcept
    Returns: size() == 0.

inline void resize(size_type, T const&)
    Effects: If size <= size(), equivalent to calling pop_back() size() - size times. If size() < size,
    appends size - size() copies of val to the sequence.
    Requires: T shall be CopyInsertable into *this.
    Remarks: If an exception is thrown there are no effects.

inline iterator begin() noexcept

inline iterator end() noexcept

inline const_iterator cbegin() const noexcept

inline const_iterator cend() const noexcept

inline const_iterator begin() const noexcept

inline const_iterator end() const noexcept

inline void swap(vector &other) noexcept
    Effects: Exchanges the contents and capacity() of *this with that of x.
    Complexity: Constant time.

```

inline void **clear**() noexcept

Effects: Erases all elements in the range [begin(),end()). Destroys all elements in 'a'. Invalidates all references, pointers, and iterators referring to the elements of a and may invalidate the past-the-end iterator.

Post: a.empty() returns true.

Complexity: Linear.

Public Static Functions

static inline void **resize**(*size_type*)

Effects: If size <= size(), equivalent to calling pop_back() size()

- size times. If size() < size, appends size - size() default-inserted elements to the sequence.

Requires: T shall be MoveInsertable and DefaultInsertable into *this.

Remarks: If an exception is thrown other than by the move constructor of a non-CopyInsertable T there are no effects.

Private Types

using **alloc_traits** = *traits::allocator_traits*<*Allocator*>

Private Members

size_type **size_**

size_type **capacity_**

allocator_type **alloc_**

pointer **data_**

hpx/compute_local/host/block_executor.hpp

Defined in header hpx/compute_local/host/block_executor.hpp.

See *Public API* for a list of names and headers that are part of the public *HPX* API.

```
template<typename Executor>
```

```
struct
```

```
hpx::execution::experimental::executor_execution_category<compute::host::block_executor<Executor>>
```

Public Types

```

using type = hpx::execution::parallel_execution_tag

template<typename Executor>
struct is_one_way_executor<compute::host::block_executor<Executor>> : public true_type

template<typename Executor>
struct is_two_way_executor<compute::host::block_executor<Executor>> : public true_type

template<typename Executor>
struct is_bulk_one_way_executor<compute::host::block_executor<Executor>> : public true_type

template<typename Executor>
struct is_bulk_two_way_executor<compute::host::block_executor<Executor>> : public true_type

namespace hpx

    namespace compute

        namespace host

            template<typename Executor = hpx::execution::experimental::restricted_thread_pool_executor>
            struct block_executor

                #include <block_executor.hpp> The block executor can be used to build NUMA aware programs.
                It will distribute work evenly across the passed targets
                Template Parameters Executor – The underlying executor to use

```

Public Types

```

using executor_parameters_type = hpx::execution::experimental::default_parameters

```

Public Functions

```

inline explicit block_executor(std::vector<host::target> const &targets,
                               threads::thread_priority priority =
                               threads::thread_priority::high, threads::thread_stacksize
                               stacksize = threads::thread_stacksize::default_,
                               threads::thread_schedule_hint schedulehint = { })

inline explicit block_executor(std::vector<host::target> &&targets)

inline block_executor(block_executor const &other)

inline block_executor(block_executor &&other) noexcept

```

```
inline block_executor &operator=(block_executor const &other)

inline block_executor &operator=(block_executor &&other) noexcept

inline std::vector<host::target> const &targets() const noexcept
```

Private Functions

```
inline auto get_next_executor() const

template<typename F, typename ...Ts>
inline decltype(auto) friend tag_invoke(hpx::parallel::execution::post_t, block_executor const
&exec, F &&f, Ts&&... ts)

template<typename F, typename ...Ts>
inline decltype(auto) friend tag_invoke(hpx::parallel::execution::async_execute_t,
block_executor const &exec, F &&f, Ts&&... ts)

template<typename F, typename ...Ts>
inline decltype(auto) friend tag_invoke(hpx::parallel::execution::sync_execute_t,
block_executor const &exec, F &&f, Ts&&... ts)

template<typename F, typename Shape, typename ...Ts>
inline decltype(auto) bulk_async_execute_impl(F &&f, Shape const &shape, Ts&&... ts)
const

template<typename F, typename Shape, typename ...Ts>
inline decltype(auto) friend tag_invoke(hpx::parallel::execution::bulk_async_execute_t,
block_executor const &exec, F &&f, Shape const
&shape, Ts&&... ts)

template<typename F, typename Shape, typename ...Ts>
inline decltype(auto) bulk_sync_execute_impl(F &&f, Shape const &shape, Ts&&... ts)
const

template<typename F, typename Shape, typename ...Ts>
inline decltype(auto) friend tag_invoke(hpx::parallel::execution::bulk_sync_execute_t,
block_executor const &exec, F &&f, Shape const
&shape, Ts&&... ts)

inline void init_executors()
```

Private Members

```
std::vector<host::target> targets_

mutable std::atomic<std::size_t> current_

std::vector<Executor> executors_

threads::thread_priority priority_ = threads::thread_priority::high
```

```
threads::thread_stacksize stacksize_ = threads::thread_stacksize::default_
```

```
threads::thread_schedule_hint schedulehint_ = {}
```

```
namespace execution
```

```
namespace experimental
```

```
template<typename Executor> block_executor< Executor > >
```

Public Types

```
using type = hpx::execution::parallel_execution_tag
```

```
template<typename Executor> block_executor< Executor > > : public true_type
```

```
template<typename Executor> block_executor< Executor > > : public true_type
```

```
template<typename Executor> block_executor< Executor > > : public true_type
```

```
template<typename Executor> block_executor< Executor > > : public true_type
```

hpx/compute_local/host/block_fork_join_executor.hpp

Defined in header `hpx/compute_local/host/block_fork_join_executor.hpp`.

See *Public API* for a list of names and headers that are part of the public *HPX* API.

```
namespace hpx
```

```
namespace execution
```

```
namespace experimental
```

```
class block_fork_join_executor
```

```
#include <block_fork_join_executor.hpp> An executor with fork-join (blocking) semantics.
```

The *block_fork_join_executor* creates on construction a set of worker threads that are kept alive for the duration of the executor. Copying the executor has reference semantics, i.e. copies of a *block_fork_join_executor* hold a reference to the worker threads of the original instance. Scheduling work through the executor concurrently from different threads is undefined behaviour.

The executor keeps a set of worker threads alive for the lifetime of the executor, meaning other work will not be executed while the executor is busy or waiting for work. The executor has a customizable delay after which it will yield to other work. Since starting and resuming the worker

threads is a slow operation the executor should be reused whenever possible for multiple adjacent parallel algorithms or invocations of `bulk_(a)sync_execute`.

This behaviour is similar to the plain `fork_join_executor` except that the `block_fork_join_executor` creates a hierarchy of `fork_join_executors`, one for each target used to initialize it.

Public Functions

```
inline explicit block_fork_join_executor(threads::thread_priority priority =
                                         threads::thread_priority::bound,
                                         threads::thread_stacksize stacksize =
                                         threads::thread_stacksize::small,
                                         fork_join_executor::loop_schedule const
                                         schedule =
                                         fork_join_executor::loop_schedule::static,
                                         std::chrono::nanoseconds yield_delay =
                                         std::chrono::milliseconds(1))
```

Construct a `block_fork_join_executor`.

Note: This constructor will create one `fork_join_executor` for each numa domain

Parameters

- **priority** – The priority of the worker threads.
- **stacksize** – The stacksize of the worker threads. Must not be `nostack`.
- **schedule** – The loop schedule of the parallel regions.
- **yield_delay** – The time after which the executor yields to other work if it has not received any new work for execution.

```
inline explicit block_fork_join_executor(std::vector<compute::host::target> const
                                         &targets, threads::thread_priority priority =
                                         threads::thread_priority::bound,
                                         threads::thread_stacksize stacksize =
                                         threads::thread_stacksize::small,
                                         fork_join_executor::loop_schedule const
                                         schedule =
                                         fork_join_executor::loop_schedule::static,
                                         std::chrono::nanoseconds yield_delay =
                                         std::chrono::milliseconds(1))
```

Construct a `block_fork_join_executor`.

Note: This constructor will create one `fork_join_executor` for each given target

Parameters

- **targets** – The list of targets to use for thread placement
- **priority** – The priority of the worker threads.
- **stacksize** – The stacksize of the worker threads. Must not be `nostack`.
- **schedule** – The loop schedule of the parallel regions.
- **yield_delay** – The time after which the executor yields to other work if it has not received any new work for execution.

```
template<typename F, typename S, typename ...Ts>
```

```

inline void bulk_sync_execute_helper(F &&f, S const &shape, Ts&&... ts)

template<typename F, typename S, typename ...Ts>
inline decltype(auto) friend tag_invoke(hpx::parallel::execution::bulk_async_execute_t,
                                         block_fork_join_executor &exec, F &&f, S const
                                         &shape, Ts&&... ts)

template<typename ...Fs>
inline void sync_invoke_helper(Fs&&... fs) const

template<typename F, typename ...Fs>
inline decltype(auto) friend tag_invoke(hpx::parallel::execution::sync_invoke_t,
                                         block_fork_join_executor const &exec, F &&f,
                                         Fs&&... fs)

template<typename F, typename ...Fs>
inline decltype(auto) friend tag_invoke(hpx::parallel::execution::async_invoke_t,
                                         block_fork_join_executor const &exec, F &&f,
                                         Fs&&... fs)

template<typename Tag>
inline decltype(auto) friend tag_invoke(Tag tag, block_fork_join_executor const &exec)
noexcept

```

Private Members

```

fork_join_executor exec_

std::vector<fork_join_executor> block_execs_

```

Private Static Functions

```

static inline hpx::threads::mask_type cores_for_targets(std::vector<compute::host::target>
                                                         const &targets)

```

Friends

```

template<typename F, typename S, typename ...Ts>
inline friend void tag_invoke(hpx::parallel::execution::bulk_sync_execute_t,
                               block_fork_join_executor &exec, F &&f, S const &shape,
                               Ts&&... ts)

template<typename Tag, typename Property>
inline friend block_fork_join_executor tag_invoke(Tag tag, block_fork_join_executor const
                                                  &exec, Property &&prop) noexcept

```

config

See *Public API* for a list of names and headers that are part of the public *HPX* API.

hpx/config/endian.hpp

Defined in header `hpx/config/endian.hpp`.

See *Public API* for a list of names and headers that are part of the public *HPX* API.

coroutines

See *Public API* for a list of names and headers that are part of the public *HPX* API.

hpx/coroutines/thread_enums.hpp

Defined in header `hpx/coroutines/thread_enums.hpp`.

See *Public API* for a list of names and headers that are part of the public *HPX* API.

namespace **hpx**

namespace **threads**

Enums

enum class **thread_schedule_state** : *std::int8_t*

The *thread_schedule_state* enumerator encodes the current state of a *thread* instance

Values:

enumerator **unknown**

enumerator **active**

thread is currently active (running, has resources)

enumerator **pending**

thread is pending (ready to run, but no hardware resource available)

enumerator **suspended**

thread has been suspended (waiting for synchronization event, but still known and under control of the thread-manager)

enumerator **depleted**

thread has been depleted (deeply suspended, it is not known to the thread-manager)

enumerator **terminated**

thread has been stopped and may be garbage collected

enumerator **staged**

this is not a real thread state, but allows to reference staged task descriptions, which eventually will be converted into thread objects

enumerator **pending_do_not_schedule**

this is not a real thread state, but allows to create a thread in pending state without scheduling it (internal, do not use)

enumerator **pending_boost**

this is not a real thread state, but allows to suspend a thread in pending state without high priority rescheduling

enumerator **deleted**

thread has been stopped and was deleted

enum class **thread_priority** : *std::int8_t*

This enumeration lists all possible thread-priorities for HPX threads.

Values:

enumerator **unknown**

enumerator **default_**

Will assign the priority of the task to the default (normal) priority.

enumerator **low**

Task goes onto a special low priority queue and will not be executed until all high/normal priority tasks are done, even if they are added after the low priority task.

enumerator **normal**

Task will be executed when it is taken from the normal priority queue, this is usually a first in-first-out ordering of tasks (depending on scheduler choice). This is the default priority.

enumerator **high_recursive**

The task is a high priority task and any child tasks spawned by this task will be made high priority as well - unless they are specifically flagged as non default priority.

enumerator **boost**

Same as *thread_priority_high* except that the thread will fall back to *thread_priority_normal* if resumed after being suspended.

enumerator **high**

Task goes onto a special high priority queue and will be executed before normal/low priority tasks are taken (some schedulers modify the behavior slightly and the documentation for those should be consulted).

enumerator **bound**

Task goes onto a special high priority queue and will never be stolen by another thread after initial assignment. This should be used for thread placement tasks such as OpenMP type for loops.

enum class **thread_restart_state** : *std::int8_t*

The *thread_restart_state* enumerator encodes the reason why a thread is being restarted

Values:

enumerator **unknown**

enumerator **signaled**

The thread has been signaled.

enumerator **timeout**

The thread has been reactivated after a timeout.

enumerator **terminate**

The thread needs to be terminated.

enumerator **abort**

The thread needs to be aborted.

enum class **thread_stacksize** : *std::int8_t*

A *thread_stacksize* references any of the possible stack-sizes for HPX threads.

Values:

enumerator **unknown**

enumerator **small_**

use small stack size (the underscore is to work around 'small' being defined to char on Windows)

enumerator **medium**

use medium sized stack size

enumerator **large**

use large stack size

enumerator **huge**

use very large stack size

enumerator **nostack**

this thread does not suspend (does not need a stack)

enumerator **current**

use size of current thread's stack

enumerator **default_**
 use default stack size

enumerator **minimal**
 use minimally stack size

enumerator **maximal**
 use maximally stack size

enum class **thread_schedule_hint_mode** : *std::int8_t*

The type of hint given when creating new tasks.

Values:

enumerator **none**
 A hint that leaves the choice of scheduling entirely up to the scheduler.

enumerator **thread**
 A hint that tells the scheduler to prefer scheduling a task on the local thread number associated with this hint. Local thread numbers are indexed from zero. It is up to the scheduler to decide how to interpret thread numbers that are larger than the number of threads available to the scheduler. Typically thread numbers will wrap around when too large.

enumerator **numa**
 A hint that tells the scheduler to prefer scheduling a task on the NUMA domain associated with this hint. NUMA domains are indexed from zero. It is up to the scheduler to decide how to interpret NUMA domain indices that are larger than the number of available NUMA domains to the scheduler. Typically indices will wrap around when too large.

enum class **thread_placement_hint** : *std::int8_t*

The type of hint given to the scheduler related to thread placement

The type of hint given to the scheduler related running a thread as a child directly in the context of the parent thread

Values:

enumerator **none**
 No hint is specified. The implementation is free to chose what placement methods to use.

enumerator **depth_first**
 A hint that tells the scheduler to prefer spreading thread placement on a depth-first basis (i.e. consecutively scheduled threads are placed on the same core).

enumerator **breadth_first**
 A hint that tells the scheduler to prefer spreading thread placement on a breadth-first basis (i.e. consecutively scheduled threads are placed on the neighboring cores).

enumerator **depth_first_reverse**

A hint that tells the scheduler to prefer spreading thread placement on a depth-first basis (i.e. consecutively scheduled threads are placed on the same core). Threads are being scheduled in reverse order.

enumerator **breadth_first_reverse**

A hint that tells the scheduler to prefer spreading thread placement on a breadth-first basis (i.e. consecutively scheduled threads are placed on the neighboring cores). Threads are being scheduled in reverse order.

enum class **thread_sharing_hint** : *std::int8_t*

The type of hint given to the scheduler related to whether it is ok to share the invoked function object between threads

Values:

enumerator **none**

No hint is specified. The implementation is free to chose what sharing methods to use.

enumerator **do_not_share_function**

A hint that tells the scheduler to avoid sharing the given function (object) between threads.

enumerator **do_not_combine_tasks**

A hint that tells the scheduler to avoid combining tasks on the same thread. This is important for tasks that may synchronize between each other, which could lead to deadlocks if those tasks are combined running by the same thread.

enum class **thread_execution_hint** : *std::int8_t*

Values:

enumerator **none**

No hint is specified. Always run the thread in its own execution environment.

enumerator **run_as_child**

Attempt to run the thread in the execution context of the parent thread.

Functions

std::ostream &**operator**<<(*std::ostream* &os, *thread_schedule_state* t)

char const ***get_thread_state_name**(*thread_schedule_state* state) noexcept

Returns the name of the given state.

Get the readable string representing the name of the given *thread_state* constant.

Parameters *state* – this represents the thread state.

std::ostream &**operator**<<(*std::ostream* &os, *thread_priority* t)

char const ***get_thread_priority_name**(*thread_priority* priority) noexcept

Return the thread priority name.

Get the readable string representing the name of the given *thread_priority* constant.

Parameters *priority* – this represents the thread priority.

std::ostream &**operator**<<(*std::ostream* &os, *thread_restart_state* t)

char const ***get_thread_state_ex_name**(*thread_restart_state* state) noexcept

Get the readable string representing the name of the given *thread_restart_state* constant.

char const ***get_thread_state_name**(*thread_state* state) noexcept

Get the readable string representing the name of the given *thread_state* constant.

std::ostream &**operator**<<(*std::ostream* &os, *thread_stacksize* t)

char const ***get_stack_size_enum_name**(*thread_stacksize* size) noexcept

Returns the stack size name.

Get the readable string representing the given stack size constant.

Parameters *size* – this represents the stack size

constexpr bool **do_not_share_function**(*thread_sharing_hint* hint) noexcept

constexpr bool **do_not_combine_tasks**(*thread_sharing_hint* hint) noexcept

constexpr *thread_sharing_hint* **operator**| (*thread_sharing_hint* lhs, *thread_sharing_hint* rhs) noexcept

constexpr bool **run_as_child**(*thread_execution_hint* hint) noexcept

Variables

constexpr *thread_execution_hint* **default_runs_as_child_hint** = *thread_execution_hint::none*

Default value to use for runs-as-child mode (if *true*, then futures will attempt to execute associated threads directly if they have not started running).

struct **thread_schedule_hint**

#include <thread_enums.hpp> A hint given to a scheduler to guide where a task should be scheduled.

A scheduler is free to ignore the hint, or modify the hint to suit the resources available to the scheduler.

Public Functions

inline constexpr **thread_schedule_hint**() noexcept

Construct a default hint with mode *thread_schedule_hint_mode::none*.

inline explicit constexpr **thread_schedule_hint**(*std::int16_t* thread_hint, *thread_placement_hint* placement = *thread_placement_hint::none*, *thread_execution_hint* runs_as_child = *default_runs_as_child_hint*, *thread_sharing_hint* sharing = *thread_sharing_hint::none*) noexcept

Construct a hint with mode *thread_schedule_hint_mode::thread* and the given hint as the local thread number.

```
inline constexpr thread_schedule_hint(thread_schedule_hint_mode mode, std::int16_t hint,  
                                         thread_placement_hint placement =  
                                         thread_placement_hint::none, thread_execution_hint  
                                         runs_as_child = default_runs_as_child_hint,  
                                         thread_sharing_hint sharing =  
                                         thread_sharing_hint::none) noexcept
```

Construct a hint with the given mode and hint. The numerical hint is unused when the mode is `thread_schedule_hint_mode::none`.

```
inline constexpr thread_placement_hint placement_mode() const noexcept
```

```
inline void placement_mode(thread_placement_hint bits) noexcept
```

```
inline constexpr thread_sharing_hint sharing_mode() const noexcept
```

```
inline void sharing_mode(thread_sharing_hint bits) noexcept
```

```
inline constexpr thread_execution_hint runs_as_child_mode() const noexcept
```

```
inline void runs_as_child_mode(thread_execution_hint bits) noexcept
```

Public Members

```
std::int16_t hint = -1
```

The hint associated with the mode. The interpretation of this hint depends on the given mode.

```
thread_schedule_hint_mode mode = thread_schedule_hint_mode::none
```

The mode of the scheduling hint.

```
std::uint8_t placement_mode_bits
```

The mode of the desired thread placement.

```
std::uint8_t sharing_mode_bits
```

The mode of the desired sharing hint.

```
std::uint8_t runs_as_child_mode_bits
```

The thread will run as a child directly in the context of the current thread

hpx/coroutines/thread_id_type.hpp

Defined in header `hpx/coroutines/thread_id_type.hpp`.

See *Public API* for a list of names and headers that are part of the public *HPX* API.

```
template<>
```

```
struct std::hash<::hpx::threads::thread_id>
```

Public Functions

```

inline std::size_t operator() (::hpx::threads::thread_id const &v) const noexcept
template<>
struct std::hash<::hpx::threads::thread_id_ref>

```

Public Functions

```

inline std::size_t operator() (::hpx::threads::thread_id_ref const &v) const noexcept

namespace hpx

    namespace threads

```

Enums

```

enum class thread_id_addrf
    Values:

    enumerator yes

    enumerator no

```

Variables

```

constexpr const thread_id invalid_thread_id

```

```

struct thread_id

```

Public Functions

```

constexpr thread_id() noexcept = default
thread_id(thread_id const&) = default
thread_id &operator=(thread_id const&) = default
~thread_id() = default
inline constexpr thread_id(thread_id &&rhs) noexcept
inline constexpr thread_id &operator=(thread_id &&rhs) noexcept
inline explicit constexpr thread_id(thread_id_repr thrd) noexcept

```

```
inline constexpr thread_id &operator=(thread_id_repr rhs) noexcept  
inline explicit constexpr operator bool() const noexcept  
inline constexpr thread_id_repr get() const noexcept  
inline constexpr void reset() noexcept
```

Private Types

```
using thread_id_repr = void*
```

Private Members

```
thread_id_repr thrd_ = nullptr
```

Friends

```
inline friend constexpr friend bool operator== (std::nullptr_t,  
thread_id const &rhs) noexcept
```

```
inline friend constexpr friend bool operator!= (std::nullptr_t,  
thread_id const &rhs) noexcept
```

```
inline friend constexpr friend bool operator== (thread_id const &lhs,  
std::nullptr_t) noexcept
```

```
inline friend constexpr friend bool operator!= (thread_id const &lhs,  
std::nullptr_t) noexcept
```

```
inline friend constexpr friend bool operator== (thread_id const &lhs,  
thread_id const &rhs) noexcept
```

```
inline friend constexpr friend bool operator!= (thread_id const &lhs,  
thread_id const &rhs) noexcept
```

```
inline friend constexpr friend bool operator< (thread_id const &lhs,  
thread_id const &rhs) noexcept
```

```
inline friend constexpr friend bool operator> (thread_id const &lhs,  
thread_id const &rhs) noexcept
```

```
inline friend constexpr friend bool operator<= (thread_id const &lhs,  
thread_id const &rhs) noexcept
```

```
inline friend constexpr friend bool operator>= (thread_id const &lhs,
thread_id const &rhs) noexcept
```

```
friend std::ostream &operator<<(std::ostream &os, thread_id const &id)
```

```
friend void format_value(std::ostream &os, std::string_view spec, thread_id const &id)
```

```
struct thread_id_ref
```

Public Types

```
using thread_repr = detail::thread_data_reference_counting
```

Public Functions

```
thread_id_ref() noexcept = default
```

```
thread_id_ref(thread_id_ref const&) = default
```

```
thread_id_ref &operator=(thread_id_ref const&) = default
```

```
thread_id_ref(thread_id_ref &&rhs) noexcept = default
```

```
thread_id_ref &operator=(thread_id_ref &&rhs) noexcept = default
```

```
~thread_id_ref() = default
```

```
inline explicit thread_id_ref(thread_id_repr const &thrd) noexcept
```

```
inline explicit thread_id_ref(thread_id_repr &&thrd) noexcept
```

```
inline thread_id_ref &operator=(thread_id_repr const &rhs) noexcept
```

```
inline thread_id_ref &operator=(thread_id_repr &&rhs) noexcept
```

```
inline explicit thread_id_ref(thread_repr *thrd, thread_id_addrf addrf =
thread_id_addrf::yes) noexcept
```

```
inline thread_id_ref &operator=(thread_repr *rhs) noexcept
```

```
inline thread_id_ref(thread_id const &noref)
```

```
inline thread_id_ref(thread_id &&noref) noexcept
```

```
inline thread_id_ref &operator=(thread_id const &noref)
```

```
inline thread_id_ref &operator=(thread_id &&noref) noexcept
```

```
inline explicit constexpr operator bool() const noexcept
```

```
inline constexpr thread_id noref() const noexcept
```

```
inline constexpr thread_id_repr &get() & noexcept
```

```
inline thread_id_repr &&get() && noexcept
```

```
inline constexpr thread_id_repr const &get() const & noexcept  
inline void reset() noexcept  
inline void reset(thread_repr *thrd, bool add_ref = true) noexcept  
inline constexpr thread_repr *detach() noexcept
```

Private Types

```
using thread_id_repr = hpx::intrusive_ptr<detail::thread_data_reference_counting>
```

Private Members

```
thread_id_repr thrd_
```

Friends

```
inline friend constexpr friend bool operator== (std::nullptr_t,  
thread_id_ref const &rhs) noexcept  
  
inline friend constexpr friend bool operator!= (std::nullptr_t,  
thread_id_ref const &rhs) noexcept  
  
inline friend constexpr friend bool operator== (thread_id_ref const &lhs,  
std::nullptr_t) noexcept  
  
inline friend constexpr friend bool operator!= (thread_id_ref const &lhs,  
std::nullptr_t) noexcept  
  
inline friend constexpr friend bool operator== (thread_id_ref const &lhs,  
thread_id_ref const &rhs) noexcept  
  
inline friend constexpr friend bool operator!= (thread_id_ref const &lhs,  
thread_id_ref const &rhs) noexcept  
  
inline friend constexpr friend bool operator< (thread_id_ref const &lhs,  
thread_id_ref const &rhs) noexcept  
  
inline friend constexpr friend bool operator> (thread_id_ref const &lhs,  
thread_id_ref const &rhs) noexcept  
  
inline friend constexpr friend bool operator<= (thread_id_ref const &lhs,  
thread_id_ref const &rhs) noexcept
```

```
inline friend constexpr friend bool operator>= (thread_id_ref const &lhs,
thread_id_ref const &rhs) noexcept
```

```
friend std::ostream &operator<<(std::ostream &os, thread_id_ref const &id)
```

```
friend void format_value(std::ostream &os, std::string_view spec, thread_id_ref const &id)
```

namespace **std**

```
template<> thread_id >
```

Public Functions

```
inline std::size_t operator() (::hpx::threads::thread_id const &v) const noexcept
```

```
template<> thread_id_ref >
```

Public Functions

```
inline std::size_t operator() (::hpx::threads::thread_id_ref const &v) const noexcept
```

datastructures

See *Public API* for a list of names and headers that are part of the public *HPX* API.

hpx::any_nonser, **hpx::bad_any_cast**, **hpx::unique_any_nonser**, **hpx::any_cast**,
hpx::make_any_nonser, **hpx::make_unique_any_nonser**

Defined in header `hpx/any.hpp`⁷⁰⁶.

See *Public API* for a list of names and headers that are part of the public *HPX* API.

```
template<>
```

```
class hpx::util::basic_any<void, void, void, std::true_type>
```

Public Functions

```
inline constexpr basic_any() noexcept
```

```
inline basic_any(basic_any const &x)
```

```
inline basic_any(basic_any &&x) noexcept
```

```
template<typename T, typename Enable = std::enable_if_t<!std::is_same_v<basic_any, std::decay_t<T>>>>
```

⁷⁰⁶ http://github.com/STELLAR-GROUP/hpx/blob/8a3b7c1a4cb5693b2f7d9f587f759392ed0c51a0/libs/core/include_local/include/hpx/any.hpp

```
inline explicit basic_any(T && x, std::enable_if_t<std::is_copy_constructible_v<std::decay_t<T>>>* =  
    nullptr)
```

```
template<typename T, typename ...Ts, typename Enable =  
std::enable_if_t<std::is_constructible_v<std::decay_t<T>, Ts...> &&  
std::is_copy_constructible_v<std::decay_t<T>>>>  
inline explicit basic_any(std::in_place_type_t<T>, Ts&&... ts)
```

```
template<typename T, typename U, typename ...Ts, typename Enable =  
std::enable_if_t<std::is_constructible_v<std::decay_t<T>, Ts...> &&  
std::is_copy_constructible_v<std::decay_t<T>>>>  
inline explicit basic_any(std::in_place_type_t<T>, std::initializer_list<U> il, Ts&&... ts)
```

```
inline ~basic_any()
```

```
inline basic_any &operator=(basic_any const &x)
```

```
inline basic_any &operator=(basic_any &&rhs) noexcept
```

```
template<typename T, typename Enable = std::enable_if_t<!std::is_same_v<basic_any, std::decay_t<T>>  
&& std::is_copy_constructible_v<std::decay_t<T>>>>  
inline basic_any &operator=(T &&rhs)
```

```
inline basic_any &swap(basic_any &x) noexcept
```

```
inline std::type_info const &type() const
```

```
template<typename T>  
inline T const &cast() const
```

```
inline bool has_value() const noexcept
```

```
inline void reset()
```

Private Functions

```
inline basic_any &assign(basic_any const &x)
```

Private Members

```
detail::any::fxn_ptr_table<void, void, void, std::true_type> *table
```

```
void *object
```

Private Static Functions

```
template<typename T, typename ...Ts>
static inline void new_object(void *&object, std::true_type, Ts&&... ts)
```

```
template<typename T, typename ...Ts>
static inline void new_object(void *&object, std::false_type, Ts&&... ts)
```

```
template<typename Char>
```

```
class hpx::util::basic_any<void, void, Char, std::true_type>
```

Public Functions

```
inline constexpr basic_any() noexcept
```

```
inline basic_any(basic_any const &x)
```

```
inline basic_any(basic_any &&x) noexcept
```

```
template<typename T, typename Enable = std::enable_if_t<!std::is_same_v<basic_any, std::decay_t<T>>>>
inline explicit basic_any(T &&x, std::enable_if_t<std::is_copy_constructible_v<std::decay_t<T>>>* =
    nullptr)
```

```
template<typename T, typename ...Ts, typename Enable =
std::enable_if_t<std::is_constructible_v<std::decay_t<T>, Ts...> &&
std::is_copy_constructible_v<std::decay_t<T>>>>
inline explicit basic_any(std::in_place_type_t<T>, Ts&&... ts)
```

```
template<typename T, typename U, typename ...Ts, typename Enable =
std::enable_if_t<std::is_constructible_v<std::decay_t<T>, Ts...> &&
std::is_copy_constructible_v<std::decay_t<T>>>>
inline explicit basic_any(std::in_place_type_t<T>, std::initializer_list<U> il, Ts&&... ts)
```

```
inline ~basic_any()
```

```
inline basic_any &operator=(basic_any const &x)
```

```
inline basic_any &operator=(basic_any &&rhs) noexcept
```

```
template<typename T, typename Enable = std::enable_if_t<!std::is_same_v<basic_any, std::decay_t<T>>>>
&& std::is_copy_constructible_v<std::decay_t<T>>>>
inline basic_any &operator=(T &&rhs) noexcept
```

```
inline basic_any &swap(basic_any &x) noexcept
```

```
inline std::type_info const &type() const
```

```
template<typename T>
inline T const &cast() const
```

```
inline bool has_value() const noexcept
```

```
inline void reset()
```

Private Functions

```
inline basic_any &assign(basic_any const &x)
```

Private Members

```
detail::any::fxn_ptr_table<void, void, Char, std::true_type> *table
```

```
void *object
```

Private Static Functions

```
template<typename T, typename ...Ts>  
static inline void new_object(void *&object, std::true_type, Ts&&... ts)
```

```
template<typename T, typename ...Ts>  
static inline void new_object(void *&object, std::false_type, Ts&&... ts)
```

```
template<>
```

```
class hpx::util::basic_any<void, void, void, std::false_type>
```

Public Functions

```
inline constexpr basic_any() noexcept
```

```
inline basic_any(basic_any &&x) noexcept
```

```
template<typename T, typename Enable = std::enable_if_t<!std::is_same_v<basic_any, std::decay_t<T>>>>  
inline explicit basic_any(T &&x, std::enable_if_t<std::is_move_constructible_v<std::decay_t<T>>>* =  
    nullptr)
```

```
template<typename T, typename ...Ts, typename Enable =  
    std::enable_if_t<std::is_constructible_v<std::decay_t<T>, Ts...> &&  
    std::is_copy_constructible_v<std::decay_t<T>>>>  
inline explicit basic_any(std::in_place_type_t<T>, Ts&&... ts)
```

```
template<typename T, typename U, typename ...Ts, typename Enable =  
    std::enable_if_t<std::is_constructible_v<std::decay_t<T>, Ts...> &&  
    std::is_copy_constructible_v<std::decay_t<T>>>>  
inline explicit basic_any(std::in_place_type_t<T>, std::initializer_list<U> il, Ts&&... ts)
```

```
basic_any(basic_any const &x) = delete
```

```
basic_any &operator=(basic_any const &x) = delete
```

```
inline ~basic_any()
```

```
inline basic_any &operator=(basic_any &&rhs) noexcept
```

```
template<typename T, typename Enable = std::enable_if_t<!std::is_same_v<basic_any, std::decay_t<T>>>>  
&& std::is_move_constructible_v<std::decay_t<T>>>>
```

```

inline basic_any &operator=(T &&rhs)

inline basic_any &swap(basic_any &x) noexcept

inline std::type_info const &type() const

template<typename T>
inline T const &cast() const

inline bool has_value() const noexcept

inline void reset()

```

Private Members

```

detail::any::fxn_ptr_table<void, void, void, std::false_type> *table

void *object

```

Private Static Functions

```

template<typename T, typename ...Ts>
static inline void new_object(void *&object, std::true_type, Ts&&... ts)

template<typename T, typename ...Ts>
static inline void new_object(void *&object, std::false_type, Ts&&... ts)

template<typename Char>
class hpx::util::basic_any<void, void, Char, std::false_type>

```

Public Functions

```

inline constexpr basic_any() noexcept

inline basic_any(basic_any &&x) noexcept

template<typename T, typename Enable = std::enable_if_t<!std::is_same_v<basic_any, std::decay_t<T>>>>
inline explicit basic_any(T &&x, std::enable_if_t<std::is_move_constructible_v<std::decay_t<T>>>* =
    nullptr)

template<typename T, typename ...Ts, typename Enable =
std::enable_if_t<std::is_constructible_v<std::decay_t<T>, Ts...> &&
std::is_copy_constructible_v<std::decay_t<T>>>>
inline explicit basic_any(std::in_place_type_t<T>, Ts&&... ts)

template<typename T, typename U, typename ...Ts, typename Enable =
std::enable_if_t<std::is_constructible_v<std::decay_t<T>, Ts...> &&
std::is_copy_constructible_v<std::decay_t<T>>>>
inline explicit basic_any(std::in_place_type_t<T>, std::initializer_list<U> il, Ts&&... ts)

basic_any(basic_any const &x) = delete

```

```
basic_any &operator=(basic_any const &x) = delete

inline ~basic_any()

inline basic_any &operator=(basic_any &&rhs) noexcept

template<typename T, typename Enable = std::enable_if_t<!std::is_same_v<basic_any, std::decay_t<T>>>
&& std::is_move_constructible_v<std::decay_t<T>>>>
inline basic_any &operator=(T &&rhs) noexcept

inline basic_any &swap(basic_any &x) noexcept

inline std::type_info const &type() const

template<typename T>
inline T const &cast() const

inline bool has_value() const noexcept

inline void reset()
```

Private Members

```
detail::any::fxn_ptr_table<void, void, Char, std::false_type> *table
```

```
void *object
```

Private Static Functions

```
template<typename T, typename ...Ts>
static inline void new_object(void *&object, std::true_type, Ts&&... ts)
```

```
template<typename T, typename ...Ts>
static inline void new_object(void *&object, std::false_type, Ts&&... ts)
```

```
namespace hpx
```

```
    Top level HPX namespace.
```

Typedefs

```
using any_nonser = util::basic_any<void, void, void, std::true_type>
```

```
using unique_any_nonser = util::basic_any<void, void, void, std::false_type>
```

Functions

```
template<typename T, typename ...Ts>
util::basic_any<void, void, void, std::true_type> make_any_nonser(Ts&&... ts)
```

```
template<typename T, typename U, typename ...Ts>
util::basic_any<void, void, void, std::true_type> make_any_nonser(std::initializer_list<U> il, Ts&&... ts)
```

```
template<typename T, typename ...Ts>
util::basic_any<void, void, void, std::false_type> make_unique_any_nonser(Ts&&... ts)
```

```
template<typename T, typename U, typename ...Ts>
util::basic_any<void, void, void, std::false_type> make_unique_any_nonser(std::initializer_list<U> il,
Ts&&... ts)
```

```
template<typename T>
util::basic_any<void, void, void, std::true_type> make_any_nonser(T &&t)
```

```
template<typename T>
util::basic_any<void, void, void, std::false_type> make_unique_any_nonser(T &&t)
```

```
template<typename T, typename IArch, typename OArch, typename Char, typename Copyable>
T *any_cast(util::basic_any<IArch, OArch, Char, Copyable> *operand) noexcept
```

Performs type-safe access to the contained object.

Parameters *operand* – target any object

Returns If *operand* is not a null pointer, and the *typeid* of the requested *T* matches that of the contents of *operand*, a pointer to the value contained by *operand*, otherwise a null pointer.

```
template<typename T, typename IArch, typename OArch, typename Char, typename Copyable>
T const *any_cast(util::basic_any<IArch, OArch, Char, Copyable> const *operand) noexcept
```

Performs type-safe access to the contained object.

Parameters *operand* – target any object

Returns If *operand* is not a null pointer, and the *typeid* of the requested *T* matches that of the contents of *operand*, a pointer to the value contained by *operand*, otherwise a null pointer.

```
template<typename T, typename IArch, typename OArch, typename Char, typename Copyable>
T any_cast(util::basic_any<IArch, OArch, Char, Copyable> &operand)
```

Performs type-safe access to the contained object. Let *U* be `std::remove_cv_t<std::remove_reference_t<T>>`. The program is ill-formed if `std::is_constructible_v<T, U&>` is false.

Parameters *operand* – target any object

Returns `static_cast<T>(*std::any_cast<U>(&operand))`

```
template<typename T, typename IArch, typename OArch, typename Char, typename Copyable>
T const &any_cast(util::basic_any<IArch, OArch, Char, Copyable> const &operand)
```

Performs type-safe access to the contained object. Let *U* be `std::remove_cv_t<std::remove_reference_t<T>>`. The program is ill-formed if `std::is_constructible_v<T, const U&>` is false.

Parameters *operand* – target any object

Returns `static_cast<T>(*std::any_cast<U>(&operand))`

struct **bad_any_cast** : public bad_cast

#include <any.hpp> Defines a type of object to be thrown by the value-returning forms of *hpx::any_cast* on failure.

Public Functions

inline **bad_any_cast**(*std::type_info* const &src, *std::type_info* const &dest)

Constructs a new *bad_any_cast* object with an implementation-defined null-terminated byte string which is accessible through *what()*.

inline char const ***what**() const noexcept override

Returns the explanatory string.

Note: Implementations are allowed but not required to override *what()*.

Returns Pointer to a null-terminated string with explanatory information. The string is suitable for conversion and display as a *std::wstring*. The pointer is guaranteed to be valid at least until the exception object from which it is obtained is destroyed, or until a non-const member function (e.g. copy assignment operator) on the exception object is called.

Public Members

char const ***from**

char const ***to**

namespace **util**

Typedefs

using **streamable_any_nonser** = *basic_any*<void, void, char, *std::true_type*>

using **streamable_wany_nonser** = *basic_any*<void, void, *wchar_t*, *std::true_type*>

using **streamable_unique_any_nonser** = *basic_any*<void, void, char, *std::false_type*>

using **streamable_unique_wany_nonser** = *basic_any*<void, void, *wchar_t*, *std::false_type*>

Functions

```
template<typename IArch, typename OArch, typename Char, typename Copyable, typename Enable =
std::enable_if_t<!std::is_void_v<Char>>>
std::basic_istream<Char> &operator>>(std::basic_istream<Char> &i, basic_any<IArch, OArch,
Char, Copyable> &obj)
```

```
template<typename IArch, typename OArch, typename Char, typename Copyable, typename Enable =
std::enable_if_t<!std::is_void_v<Char>>>
std::basic_ostream<Char> &operator<<(std::basic_ostream<Char> &o, basic_any<IArch, OArch,
Char, Copyable> const &obj)
```

```
template<typename IArch, typename OArch, typename Char, typename Copyable>
void swap(basic_any<IArch, OArch, Char, Copyable> &lhs, basic_any<IArch, OArch, Char, Copyable>
&rhs) noexcept
```

```
template<typename T, typename Char, typename ...Ts>
basic_any<void, void, Char, std::true_type> make_streamable_any_nonser(Ts&&... ts)
```

```
template<typename T, typename Char, typename U, typename ...Ts>
basic_any<void, void, Char, std::true_type> make_streamable_any_nonser(std::initializer_list<U>
il, Ts&&... ts)
```

```
template<typename T, typename Char, typename ...Ts>
basic_any<void, void, Char, std::false_type> make_streamable_unique_any_nonser(Ts&&... ts)
```

```
template<typename T, typename Char, typename U, typename ...Ts>
basic_any<void, void, Char, std::false_type> make_streamable_unique_any_nonser(std::initializer_list<U>
il, Ts&&... ts)
```

```
template<typename T, typename Char>
basic_any<void, void, Char, std::true_type> make_streamable_any_nonser(T &&t)
```

```
template<typename T, typename Char>
basic_any<void, void, Char, std::false_type> make_streamable_unique_any_nonser(T &&t)
```

```
template<typename IArch, typename OArch, typename Char = char, typename Copyable =
std::true_type>
class basic_any
```

```
template<typename Char> false_type >
```

Public Functions

```
inline constexpr basic_any() noexcept
```

```
inline basic_any(basic_any &&x) noexcept
```

```
template<typename T, typename Enable = std::enable_if_t<!std::is_same_v<basic_any,
std::decay_t<T>>>>
```

```
inline explicit basic_any(T &&x,
std::enable_if_t<std::is_move_constructible_v<std::decay_t<T>>>*> =
nullptr)
```

```
template<typename T, typename ...Ts, typename Enable =
std::enable_if_t<std::is_constructible_v<std::decay_t<T>, Ts...> &&
std::is_copy_constructible_v<std::decay_t<T>>>>
inline explicit basic_any(std::in_place_type_t<T>, Ts&&... ts)

template<typename T, typename U, typename ...Ts, typename Enable =
std::enable_if_t<std::is_constructible_v<std::decay_t<T>, Ts...> &&
std::is_copy_constructible_v<std::decay_t<T>>>>
inline explicit basic_any(std::in_place_type_t<T>, std::initializer_list<U> il, Ts&&... ts)

basic_any(basic_any const &x) = delete

basic_any &operator=(basic_any const &x) = delete

inline ~basic_any()

inline basic_any &operator=(basic_any &&rhs) noexcept

template<typename T, typename Enable = std::enable_if_t<!std::is_same_v<basic_any,
std::decay_t<T>> && std::is_move_constructible_v<std::decay_t<T>>>>
inline basic_any &operator=(T &&rhs) noexcept

inline basic_any &swap(basic_any &x) noexcept

inline std::type_info const &type() const

template<typename T>
inline T const &cast() const

inline bool has_value() const noexcept

inline void reset()
```

Private Members

```
detail::any::fxn_ptr_table<void, void, Char, std::false_type> *table
```

```
void *object
```

Private Static Functions

```
template<typename T, typename ...Ts>
static inline void new_object(void *&object, std::true_type, Ts&&... ts)
```

```
template<typename T, typename ...Ts>
static inline void new_object(void *&object, std::false_type, Ts&&... ts)
```

```
template<typename Char> true_type >
```

Public Functions

```

inline constexpr basic_any() noexcept

inline basic_any(basic_any const &x)

inline basic_any(basic_any &&x) noexcept

template<typename T, typename Enable = std::enable_if_t<!std::is_same_v<basic_any,
std::decay_t<T>>>>
inline explicit basic_any(T &&x,
                          std::enable_if_t<std::is_copy_constructible_v<std::decay_t<T>>>* =
                          nullptr)

template<typename T, typename ...Ts, typename Enable =
std::enable_if_t<std::is_constructible_v<std::decay_t<T>, Ts...> &&
std::is_copy_constructible_v<std::decay_t<T>>>>
inline explicit basic_any(std::in_place_type_t<T>, Ts&&... ts)

template<typename T, typename U, typename ...Ts, typename Enable =
std::enable_if_t<std::is_constructible_v<std::decay_t<T>, Ts...> &&
std::is_copy_constructible_v<std::decay_t<T>>>>
inline explicit basic_any(std::in_place_type_t<T>, std::initializer_list<U> il, Ts&&... ts)

inline ~basic_any()

inline basic_any &operator=(basic_any const &x)

inline basic_any &operator=(basic_any &&rhs) noexcept

template<typename T, typename Enable = std::enable_if_t<!std::is_same_v<basic_any,
std::decay_t<T>> && std::is_copy_constructible_v<std::decay_t<T>>>>
inline basic_any &operator=(T &&rhs) noexcept

inline basic_any &swap(basic_any &x) noexcept

inline std::type_info const &type() const

template<typename T>
inline T const &cast() const

inline bool has_value() const noexcept

inline void reset()

```

Private Functions

```

inline basic_any &assign(basic_any const &x)

```

Private Members

```
detail::any::fxn_ptr_table<void, void, Char, std::true_type> *table
```

```
void *object
```

Private Static Functions

```
template<typename T, typename ...Ts>  
static inline void new_object(void *&object, std::true_type, Ts&&... ts)
```

```
template<typename T, typename ...Ts>  
static inline void new_object(void *&object, std::false_type, Ts&&... ts)
```

```
template<> false_type >
```

Public Functions

```
inline constexpr basic_any() noexcept
```

```
inline basic_any(basic_any &&x) noexcept
```

```
template<typename T, typename Enable = std::enable_if_t<!std::is_same_v<basic_any,  
std::decay_t<T>>>>
```

```
inline explicit basic_any(T &&x,  
                        std::enable_if_t<std::is_move_constructible_v<std::decay_t<T>>>* =  
                        nullptr)
```

```
template<typename T, typename ...Ts, typename Enable =  
std::enable_if_t<std::is_constructible_v<std::decay_t<T>, Ts...> &&  
std::is_copy_constructible_v<std::decay_t<T>>>>
```

```
inline explicit basic_any(std::in_place_type_t<T>, Ts&&... ts)
```

```
template<typename T, typename U, typename ...Ts, typename Enable =  
std::enable_if_t<std::is_constructible_v<std::decay_t<T>, Ts...> &&  
std::is_copy_constructible_v<std::decay_t<T>>>>
```

```
inline explicit basic_any(std::in_place_type_t<T>, std::initializer_list<U> il, Ts&&... ts)
```

```
basic_any(basic_any const &x) = delete
```

```
basic_any &operator=(basic_any const &x) = delete
```

```
inline ~basic_any()
```

```
inline basic_any &operator=(basic_any &&rhs) noexcept
```

```
template<typename T, typename Enable = std::enable_if_t<!std::is_same_v<basic_any,  
std::decay_t<T>> && std::is_move_constructible_v<std::decay_t<T>>>>
```

```
inline basic_any &operator=(T &&rhs)
```

```
inline basic_any &swap(basic_any &x) noexcept
```

```

inline std::type_info const &type() const

template<typename T>
inline T const &cast() const

inline bool has_value() const noexcept

inline void reset()

```

Private Members

```

detail::any::fxn_ptr_table<void, void, void, std::false_type> *table

```

```

void *object

```

Private Static Functions

```

template<typename T, typename ...Ts>
static inline void new_object(void *&object, std::true_type, Ts&&... ts)

template<typename T, typename ...Ts>
static inline void new_object(void *&object, std::false_type, Ts&&... ts)

```

```

template<> true_type >

```

Public Functions

```

inline constexpr basic_any() noexcept

inline basic_any(basic_any const &x)

inline basic_any(basic_any &&x) noexcept

template<typename T, typename Enable = std::enable_if_t<!std::is_same_v<basic_any,
std::decay_t<T>>>>
inline explicit basic_any(T &&x,
                        std::enable_if_t<std::is_copy_constructible_v<std::decay_t<T>>>* =
                        nullptr)

template<typename T, typename ...Ts, typename Enable =
std::enable_if_t<std::is_constructible_v<std::decay_t<T>, Ts...> &&
std::is_copy_constructible_v<std::decay_t<T>>>>
inline explicit basic_any(std::in_place_type_t<T>, Ts&&... ts)

template<typename T, typename U, typename ...Ts, typename Enable =
std::enable_if_t<std::is_constructible_v<std::decay_t<T>, Ts...> &&
std::is_copy_constructible_v<std::decay_t<T>>>>
inline explicit basic_any(std::in_place_type_t<T>, std::initializer_list<U> il, Ts&&... ts)

inline ~basic_any()

```

```
inline basic_any &operator=(basic_any const &x)

inline basic_any &operator=(basic_any &&rhs) noexcept

template<typename T, typename Enable = std::enable_if_t<!std::is_same_v<basic_any,
std::decay_t<T>> && std::is_copy_constructible_v<std::decay_t<T>>>>
inline basic_any &operator=(T &&rhs)

inline basic_any &swap(basic_any &x) noexcept

inline std::type_info const &type() const

template<typename T>
inline T const &cast() const

inline bool has_value() const noexcept

inline void reset()
```

Private Functions

```
inline basic_any &assign(basic_any const &x)
```

Private Members

```
detail::any::fxn_ptr_table<void, void, void, std::true_type> *table

void *object
```

Private Static Functions

```
template<typename T, typename ...Ts>
static inline void new_object(void *&object, std::true_type, Ts&&... ts)

template<typename T, typename ...Ts>
static inline void new_object(void *&object, std::false_type, Ts&&... ts)
```

hpx::ignore, **hpx::tuple**, **hpx::tuple_size**, **hpx::tuple_element**, **hpx::make_tuple**, **hpx::tie**,
hpx::forward_as_tuple, **hpx::tuple_cat**, **hpx::get**

Defined in header `hpx/tuple.hpp`⁷⁰⁷.

See *Public API* for a list of names and headers that are part of the public HPX API.

namespace **hpx**

Top level HPX namespace.

⁷⁰⁷ http://github.com/STELLAR-GROUP/hpx/blob/8a3b7c1a4cb5693b2f7d9f587f759392ed0c51a0/libs/core/include_local/include/hpx/tuple.hpp

Functions

```
template<typename ...Ts>
constexpr tuple<util::decay_unwrap_t<Ts>...> make_tuple(Ts&&... ts)
```

Provides compile-time indexed access to the types of the elements of the tuple.

```
template<typename ...Ts>
constexpr tuple<Ts&&...> forward_as_tuple(Ts&&... ts)
```

Constructs a tuple of references to the arguments in *args* suitable for forwarding as an argument to a function. The tuple has rvalue reference data members when rvalues are used as arguments, and otherwise has lvalue reference data members.

Parameters *ts* – zero or more arguments to construct the tuple from

Returns *hpx::tuple* object created as if by

```
hpx::tuple<Ts&&...>(HPX_FORWARD(Ts, ts)...)

```

```
template<typename ...Ts>
constexpr tuple<Ts&...> tie(Ts&... ts)
```

Creates a tuple of lvalue references to its arguments or instances of *hpx::ignore*.

Parameters *ts* – zero or more lvalue arguments to construct the tuple from.

Returns *hpx::tuple* object containing lvalue references.

```
template<typename ...Tuples>
constexpr auto tuple_cat(Tuples&&... tuples)
```

Constructs a tuple that is a concatenation of all tuples in *tuples*. The behavior is undefined if any type in *std::decay_t<Tuples>...* is not a specialization of *hpx::tuple*. However, an implementation may choose to support types (such as *std::array* and *std::pair*) that follow the tuple-like protocol.

Parameters *tuples* – zero or more tuples to concatenate

Returns *hpx::tuple* object composed of all elements of all argument tuples constructed from *hpx::get<Is>(HPX_FORWARD(UTuple,t))* for each individual element.

```
template<std::size_t I>
util::at_index<I, Ts...>::type &get() noexcept
```

Extracts the *I*th element from the tuple. *I* must be an integer value in $[0, \text{sizeof}...(Ts))$.

```
template<std::size_t I>
util::at_index<I, Ts...>::type const &get() const noexcept
```

Extracts the *I*th element from the tuple. *I* must be an integer value in $[0, \text{sizeof}...(Ts))$.

Variables

```
constexpr hpx::detail::ignore_type ignore = {}
```

An object of unspecified type such that any value can be assigned to it with no effect. Intended for use with *hpx::tie* when unpacking a *hpx::tuple*, as a placeholder for the arguments that are not used. While the behavior of *hpx::ignore* outside of *hpx::tie* is not formally specified, some code guides recommend using *hpx::ignore* to avoid warnings from unused return values of `[[nodiscard]]` functions.

```
template<typename ...Ts>
```

class tuple

#include <tuple.hpp> Class template *hpx::tuple* is a fixed-size collection of heterogeneous values. It is a generalization of *hpx::pair*. If *std::is_trivially_destructible<Ti>::value* is true for every *Ti* in *Ts*, the destructor of tuple is trivial.

Param Ts... the types of the elements that the tuple stores.

```
template<std::size_t I, typename T, typename Enable = void>
```

struct tuple_element

#include <tuple.hpp> Provides compile-time indexed access to the types of the elements of a tuple-like type.

The primary template is not defined. An explicit (full) or partial specialization is required to make a type tuple-like.

```
template<typename T>
```

struct tuple_size

#include <tuple.hpp> Provides access to the number of elements in a tuple-like type as a compile-time constant expression.

The primary template is not defined. An explicit (full) or partial specialization is required to make a type tuple-like.

hpx::any, hpx::make_any

Defined in header *hpx/any.hpp*⁷⁰⁸.

See *Public API* for a list of names and headers that are part of the public *HPX* API.

```
template<typename IArch, typename OArch, typename Char>
```

```
class hpx::util::basic_any<IArch, OArch, Char, std::true_type>
```

Public Functions

```
inline constexpr basic_any() noexcept
```

```
inline basic_any(basic_any const &x)
```

```
inline basic_any(basic_any &&x) noexcept
```

```
template<typename T, typename Enable = std::enable_if_t<!std::is_same_v<basic_any, std::decay_t<T>>>>
inline basic_any(T &&x, std::enable_if_t<std::is_copy_constructible_v<std::decay_t<T>>>* = nullptr)
```

```
template<typename T, typename ...Ts, typename Enable =
std::enable_if_t<std::is_constructible_v<std::decay_t<T>, Ts...> &&
std::is_copy_constructible_v<std::decay_t<T>>>>
inline explicit basic_any(std::in_place_type_t<T>, Ts&&... ts)
```

```
template<typename T, typename U, typename ...Ts, typename Enable =
std::enable_if_t<std::is_constructible_v<std::decay_t<T>, Ts...> &&
std::is_copy_constructible_v<std::decay_t<T>>>>
```

⁷⁰⁸ http://github.com/STELLAR-GROUP/hpx/blob/8a3b7c1a4cb5693b2f7d9f587f759392ed0c51a0/libs/core/include_local/include/hpx/any.hpp

```

inline explicit basic_any(std::in_place_type_t<T>, std::initializer_list<U> il, Ts&&... ts)

inline ~basic_any()

inline basic_any &operator=(basic_any const &x)

inline basic_any &operator=(basic_any &&rhs) noexcept

template<typename T, typename Enable = std::enable_if<!std::is_same_v<basic_any, std::decay_t<T>> &&
std::is_copy_constructible_v<std::decay_t<T>>>>
inline basic_any &operator=(T &&rhs)

inline basic_any &swap(basic_any &x) noexcept

inline std::type_info const &type() const

template<typename T>
inline T const &cast() const

inline bool has_value() const noexcept

inline void reset()

inline bool equal_to(basic_any const &rhs) const noexcept

```

Private Functions

```

inline basic_any &assign(basic_any const &x)

inline void load(IArch &ar, unsigned const version)

inline void save(OArch &ar, unsigned const version) const

```

Private Members

```

detail::any::fxn_ptr_table<IArch, OArch, Char, std::true_type> *table

void *object

```

Private Static Functions

```

template<typename T, typename ...Ts>
static inline void new_object(void *&object, std::true_type, Ts&&... ts)

template<typename T, typename ...Ts>
static inline void new_object(void *&object, std::false_type, Ts&&... ts)

```

Friends

friend class `hpx::serialization::access`

namespace **hpx**

Top level HPX namespace.

Typedefs

using **any** = `util::basic_any<serialization::input_archive, serialization::output_archive, char, std::true_type>`

Functions

template<typename **T**, typename **Char**>

`util::basic_any<serialization::input_archive, serialization::output_archive, Char>` **make_any**(*T* &&t)

Constructs an any object containing an object of type *T*, passing the provided arguments to *T*'s constructor.
Equivalent to:

```
return std::any(std::in_place_type<T>, std::forward<Args>(args)...);
```

namespace **util**

Typedefs

using **wany** = `basic_any<serialization::input_archive, serialization::output_archive, wchar_t, std::true_type>`

Functions

template<typename **T**, typename **Char**, typename ...**Ts**>

`basic_any<serialization::input_archive, serialization::output_archive, Char>` **make_any**(*Ts*&&... ts)

template<typename **T**, typename **Char**, typename **U**, typename ...**Ts**>

`basic_any<serialization::input_archive, serialization::output_archive, Char>` **make_any**(`std::initializer_list<U>` il, *Ts*&&... ts)

template<typename **IArch**, typename **OArch**, typename **Char**> **true_type** >

Public Functions

```

inline constexpr basic_any() noexcept

inline basic_any(basic_any const &x)

inline basic_any(basic_any &&x) noexcept

template<typename T, typename Enable = std::enable_if_t<!std::is_same_v<basic_any,
std::decay_t<T>>>>
inline basic_any(T &&x, std::enable_if_t<std::is_copy_constructible_v<std::decay_t<T>>>* =
    nullptr)

template<typename T, typename ...Ts, typename Enable =
std::enable_if_t<std::is_constructible_v<std::decay_t<T>, Ts...> &&
std::is_copy_constructible_v<std::decay_t<T>>>>
inline explicit basic_any(std::in_place_type_t<T>, Ts&&... ts)

template<typename T, typename U, typename ...Ts, typename Enable =
std::enable_if_t<std::is_constructible_v<std::decay_t<T>, Ts...> &&
std::is_copy_constructible_v<std::decay_t<T>>>>
inline explicit basic_any(std::in_place_type_t<T>, std::initializer_list<U> il, Ts&&... ts)

inline ~basic_any()

inline basic_any &operator=(basic_any const &x)

inline basic_any &operator=(basic_any &&rhs) noexcept

template<typename T, typename Enable = std::enable_if_t<!std::is_same_v<basic_any,
std::decay_t<T>> && std::is_copy_constructible_v<std::decay_t<T>>>>
inline basic_any &operator=(T &&rhs)

inline basic_any &swap(basic_any &x) noexcept

inline std::type_info const &type() const

template<typename T>
inline T const &cast() const

inline bool has_value() const noexcept

inline void reset()

inline bool equal_to(basic_any const &rhs) const noexcept

```

Private Functions

```

inline basic_any &assign(basic_any const &x)

inline void load(IArch &ar, unsigned const version)

inline void save(OArch &ar, unsigned const version) const

```

Private Members

detail::any::fxn_ptr_table<IArch, OArch, Char, *std::true_type*> ***table**

void ***object**

Private Static Functions

```
template<typename T, typename ...Ts>  
static inline void new_object(void *&object, std::true_type, Ts&&... ts)
```

```
template<typename T, typename ...Ts>  
static inline void new_object(void *&object, std::false_type, Ts&&... ts)
```

Friends

friend class hpx::serialization::access

struct **hash_any**

Public Functions

```
template<typename Char>  
std::size_t operator()(basic_any<serialization::input_archive, serialization::output_archive,  
Char, std::true_type> const &elem) const
```

debugging

See *Public API* for a list of names and headers that are part of the public *HPX* API.

hpx/debugging/print.hpp

Defined in header hpx/debugging/print.hpp.

See *Public API* for a list of names and headers that are part of the public *HPX* API.

Defines

HPX_DP_LAZY(Expr, printer)

errors

See *Public API* for a list of names and headers that are part of the public *HPX* API.

hpx/errors/error.hpp

Defined in header `hpx/errors/error.hpp`.

See *Public API* for a list of names and headers that are part of the public *HPX* API.

Defines

HPX_ERROR_UNSCOPED_ENUM_DEPRECATION_MSG

namespace **hpx**

Enums

enum class **error** : *std::int16_t*

Possible error conditions.

This enumeration lists all possible error conditions which can be reported from any of the API functions.

Values:

enumerator **success**

The operation was successful.

enumerator **no_success**

The operation did failed, but not in an unexpected manner.

enumerator **not_implemented**

The operation is not implemented.

enumerator **out_of_memory**

The operation caused an out of memory condition.

enumerator **bad_action_code**

enumerator **bad_component_type**

The specified component type is not known or otherwise invalid.

enumerator **network_error**

A generic network error occurred.

enumerator **version_too_new**

The version of the network representation for this object is too new.

enumerator **version_too_old**

The version of the network representation for this object is too old.

enumerator **version_unknown**

The version of the network representation for this object is unknown.

enumerator **unknown_component_address**

enumerator **duplicate_component_address**

The given global id has already been registered.

enumerator **invalid_status**

The operation was executed in an invalid status.

enumerator **bad_parameter**

One of the supplied parameters is invalid.

enumerator **internal_server_error**

enumerator **service_unavailable**

enumerator **bad_request**

enumerator **repeated_request**

enumerator **lock_error**

enumerator **duplicate_console**

There is more than one console locality.

enumerator **no_registered_console**

There is no registered console locality available.

enumerator **startup_timed_out**

enumerator **uninitialized_value**

enumerator **bad_response_type**

enumerator **deadlock**

enumerator **assertion_failure**

enumerator **null_thread_id**

Attempt to invoke an API function from a non-HPX thread.

enumerator **invalid_data**

enumerator **yield_aborted**

The yield operation was aborted.

enumerator **dynamic_link_failure**

enumerator **commandline_option_error**

One of the options given on the command line is erroneous.

enumerator **serialization_error**

There was an error during serialization of this object.

enumerator **unhandled_exception**

An unhandled exception has been caught.

enumerator **kernel_error**

The OS kernel reported an error.

enumerator **broken_task**

The task associated with this future object is not available anymore.

enumerator **task_moved**

The task associated with this future object has been moved.

enumerator **task_already_started**

The task associated with this future object has already been started.

enumerator **future_already_retrieved**

The future object has already been retrieved.

enumerator **promise_already_satisfied**

The value for this future object has already been set.

enumerator **future_does_not_support_cancellation**

The future object does not support cancellation.

enumerator **future_can_not_be_cancelled**

The future can't be canceled at this time.

enumerator **no_state**

The future object has no valid shared state.

enumerator **broken_promise**

The promise has been deleted.

enumerator **thread_resource_error**

enumerator **future_cancelled**

enumerator **thread_cancelled**

enumerator **thread_not_interruptable**

enumerator **duplicate_component_id**

The component type has already been registered.

enumerator **unknown_error**

An unknown error occurred.

enumerator **bad_plugin_type**

The specified plugin type is not known or otherwise invalid.

enumerator **filesystem_error**

The specified file does not exist or other filesystem related error.

enumerator **bad_function_call**

equivalent of `std::bad_function_call`

enumerator **task_canceled_exception**

`parallel::task_canceled_exception`

enumerator **task_block_not_active**

`task_region` is not active

enumerator **out_of_range**

Equivalent to `std::out_of_range`.

enumerator **length_error**

Equivalent to `std::length_error`.

enumerator **migration_needs_retry**

migration failed because of global race, retry

Functions

```

inline constexpr bool operator==(int lhs, error rhs) noexcept
inline constexpr bool operator==(error lhs, int rhs) noexcept
inline constexpr bool operator!=(int lhs, error rhs) noexcept
inline constexpr bool operator!=(error lhs, int rhs) noexcept
inline constexpr bool operator<(int lhs, error rhs) noexcept
inline constexpr bool operator>=(int lhs, error rhs) noexcept
inline constexpr int operator&(error lhs, error rhs) noexcept
inline constexpr int operator&(int lhs, error rhs) noexcept
inline constexpr int operator|=(int &lhs, error rhs) noexcept
char const *get_error_name(error e) noexcept

```

Variables

```

constexpr error success = error::success

constexpr error no_success = error::no_success

constexpr error not_implemented = error::not_implemented

constexpr error out_of_memory = error::out_of_memory

constexpr error bad_action_code = error::bad_action_code

constexpr error bad_component_type = error::bad_component_type

constexpr error network_error = error::network_error

constexpr error version_too_new = error::version_too_new

constexpr error version_too_old = error::version_too_old

constexpr error version_unknown = error::version_unknown

constexpr error unknown_component_address = error::unknown_component_address

constexpr error duplicate_component_address = error::duplicate_component_address

```

```
constexpr error invalid_status = error::invalid_status

constexpr error bad_parameter = error::bad_parameter

constexpr error internal_server_error = error::internal_server_error

constexpr error service_unavailable = error::service_unavailable

constexpr error bad_request = error::bad_request

constexpr error repeated_request = error::repeated_request

constexpr error lock_error = error::lock_error

constexpr error duplicate_console = error::duplicate_console

constexpr error no_registered_console = error::no_registered_console

constexpr error startup_timed_out = error::startup_timed_out

constexpr error uninitialized_value = error::uninitialized_value

constexpr error bad_response_type = error::bad_response_type

constexpr error deadlock = error::deadlock

constexpr error assertion_failure = error::assertion_failure

constexpr error null_thread_id = error::null_thread_id

constexpr error invalid_data = error::invalid_data

constexpr error yield_aborted = error::yield_aborted

constexpr error dynamic_link_failure = error::dynamic_link_failure

constexpr error commandline_option_error = error::commandline_option_error

constexpr error serialization_error = error::serialization_error

constexpr error unhandled_exception = error::unhandled_exception
```

```
constexpr error kernel_error = error::kernel_error

constexpr error broken_task = error::broken_task

constexpr error task_moved = error::task_moved

constexpr error task_already_started = error::task_already_started

constexpr error future_already_retrieved = error::future_already_retrieved

constexpr error promise_already_satisfied = error::promise_already_satisfied

constexpr error future_does_not_support_cancellation =
error::future_does_not_support_cancellation

constexpr error future_can_not_be_cancelled = error::future_can_not_be_cancelled

constexpr error no_state = error::no_state

constexpr error broken_promise = error::broken_promise

constexpr error thread_resource_error = error::thread_resource_error

constexpr error future_cancelled = error::future_cancelled

constexpr error thread_cancelled = error::thread_cancelled

constexpr error thread_not_interruptable = error::thread_not_interruptable

constexpr error duplicate_component_id = error::duplicate_component_id

constexpr error unknown_error = error::unknown_error

constexpr error bad_plugin_type = error::bad_plugin_type

constexpr error filesystem_error = error::filesystem_error

constexpr error bad_function_call = error::bad_function_call

constexpr error task_canceled_exception = error::task_canceled_exception

constexpr error task_block_not_active = error::task_block_not_active
```

```
constexpr error out_of_range = error::out_of_range
```

```
constexpr error length_error = error::length_error
```

```
constexpr error migration_needs_retry = error::migration_needs_retry
```

hpx::error_code

Defined in header `hpx/system_error.hpp`⁷⁰⁹.

See *Public API* for a list of names and headers that are part of the public HPX API.

```
namespace hpx
```

Unnamed Group

```
inline error_code make_error_code(error e, throwmode mode = throwmode::plain)
```

Returns a new *error_code* constructed from the given parameters.

```
inline error_code make_error_code(error e, char const *func, char const *file, long line, throwmode mode = throwmode::plain)
```

```
inline error_code make_error_code(error e, char const *msg, throwmode mode = throwmode::plain)
```

Returns *error_code*(e, msg, mode).

```
inline error_code make_error_code(error e, char const *msg, char const *func, char const *file, long line, throwmode mode = throwmode::plain)
```

```
inline error_code make_error_code(error e, std::string const &msg, throwmode mode = throwmode::plain)
```

Returns *error_code*(e, msg, mode).

```
inline error_code make_error_code(error e, std::string const &msg, char const *func, char const *file, long line, throwmode mode = throwmode::plain)
```

```
inline error_code make_error_code(std::exception_ptr const &e)
```

Functions

```
std::error_category const &get_hpx_category() noexcept
```

Returns generic HPX error category used for new errors.

```
std::error_category const &get_hpx_rethrow_category() noexcept
```

Returns generic HPX error category used for errors re-thrown after the exception has been de-serialized.

```
inline error_code make_success_code(throwmode mode = throwmode::plain)
```

Returns *error_code*(hpx::error::success, "success", mode).

⁷⁰⁹ http://github.com/STELLAR-GROUP/hpx/blob/8a3b7c1a4cb5693b2f7d9f587f759392ed0c51a0/libs/core/include_local/include/hpx/system_error.hpp

class **error_code** : public *error_code*

#include <error_code.hpp> A *hpx::error_code* represents an arbitrary error condition.

The class *hpx::error_code* describes an object used to hold error code values, such as those originating from the operating system or other low-level application program interfaces.

Note: Class *hpx::error_code* is an adjunct to error reporting by exception

Public Functions

inline explicit **error_code**(*throwmode* mode = *throwmode::plain*)

Construct an object of type *error_code*.

Parameters **mode** – The parameter *mode* specifies whether the constructed *hpx::error_code* belongs to the error category *hpx_category* (if *mode* is *plain*, this is the default) or to the category *hpx_category_rethrow* (if *mode* is *rethrow*).

Throws nothing –

explicit **error_code**(*error* e, *throwmode* mode = *throwmode::plain*)

Construct an object of type *error_code*.

Parameters

- **e** – The parameter *e* holds the *hpx::error* code the new exception should encapsulate.
- **mode** – The parameter *mode* specifies whether the constructed *hpx::error_code* belongs to the error category *hpx_category* (if *mode* is *plain*, this is the default) or to the category *hpx_category_rethrow* (if *mode* is *rethrow*).

Throws nothing –

error_code(*error* e, char const **func*, char const **file*, long *line*, *throwmode* mode = *throwmode::plain*)

Construct an object of type *error_code*.

Parameters

- **e** – The parameter *e* holds the *hpx::error* code the new exception should encapsulate.
- **func** – The name of the function where the error was raised.
- **file** – The file name of the code where the error was raised.
- **line** – The line number of the code line where the error was raised.
- **mode** – The parameter *mode* specifies whether the constructed *hpx::error_code* belongs to the error category *hpx_category* (if *mode* is *plain*, this is the default) or to the category *hpx_category_rethrow* (if *mode* is *rethrow*).

Throws nothing –

error_code(*error* e, char const **msg*, *throwmode* mode = *throwmode::plain*)

Construct an object of type *error_code*.

Parameters

- **e** – The parameter *e* holds the *hpx::error* code the new exception should encapsulate.
- **msg** – The parameter *msg* holds the error message the new exception should encapsulate.
- **mode** – The parameter *mode* specifies whether the constructed *hpx::error_code* belongs to the error category *hpx_category* (if *mode* is *plain*, this is the default) or to the category *hpx_category_rethrow* (if *mode* is *rethrow*).

Throws *std::bad_alloc* – (if allocation of a copy of the passed string fails).

error_code(*error* e, char const **msg*, char const **func*, char const **file*, long *line*, *throwmode* mode = *throwmode::plain*)

Construct an object of type *error_code*.

Parameters

- **e** – The parameter `e` holds the `hpx::error` code the new exception should encapsulate.
- **msg** – The parameter `msg` holds the error message the new exception should encapsulate.
- **func** – The name of the function where the error was raised.
- **file** – The file name of the code where the error was raised.
- **line** – The line number of the code line where the error was raised.
- **mode** – The parameter `mode` specifies whether the constructed `hpx::error_code` belongs to the error category `hpx_category` (if `mode` is `plain`, this is the default) or to the category `hpx_category_rethrow` (if `mode` is `rethrow`).

Throws `std::bad_alloc` – (if allocation of a copy of the passed string fails).

error_code(*error* e, *std::string* const &msg, *throwmode* mode = *throwmode::plain*)

Construct an object of type `error_code`.

Parameters

- **e** – The parameter `e` holds the `hpx::error` code the new exception should encapsulate.
- **msg** – The parameter `msg` holds the error message the new exception should encapsulate.
- **mode** – The parameter `mode` specifies whether the constructed `hpx::error_code` belongs to the error category `hpx_category` (if `mode` is `plain`, this is the default) or to the category `hpx_category_rethrow` (if `mode` is `rethrow`).

Throws `std::bad_alloc` – (if allocation of a copy of the passed string fails).

error_code(*error* e, *std::string* const &msg, *char* const *func, *char* const *file, *long* line, *throwmode* mode = *throwmode::plain*)

Construct an object of type `error_code`.

Parameters

- **e** – The parameter `e` holds the `hpx::error` code the new exception should encapsulate.
- **msg** – The parameter `msg` holds the error message the new exception should encapsulate.
- **func** – The name of the function where the error was raised.
- **file** – The file name of the code where the error was raised.
- **line** – The line number of the code line where the error was raised.
- **mode** – The parameter `mode` specifies whether the constructed `hpx::error_code` belongs to the error category `hpx_category` (if `mode` is `plain`, this is the default) or to the category `hpx_category_rethrow` (if `mode` is `rethrow`).

Throws `std::bad_alloc` – (if allocation of a copy of the passed string fails).

std::string **get_message**() const

Return a reference to the error message stored in the `hpx::error_code`.

Throws nothing –

inline void **clear**()

Clear this `error_code` object. The postconditions of invoking this method are.

- `value() == hpx::error::success` and `category() == hpx::get_hpx_category()`

error_code(*error_code* const &rhs)

Copy constructor for `error_code`

Note: This function maintains the error category of the left hand side if the right hand side is a success code.

error_code &**operator**=(*error_code* const &rhs)

Assignment operator for `error_code`

Note: This function maintains the error category of the left hand side if the right hand side is a success

code.

Private Functions

error_code(int err, *hpx::exception* const &e)

explicit **error_code**(*std::exception_ptr* const &e)

Private Members

std::exception_ptr **exception_**

Friends

friend class exception

friend *error_code* **make_error_code**(*std::exception_ptr* const&)

hpx::exception

Defined in header `hpx/exception.hpp`⁷¹⁰.

See *Public API* for a list of names and headers that are part of the public *HPX* API.

namespace **hpx**

Typedefs

using **custom_exception_info_handler_type** = *std::function*<*hpx::exception_info*(*std::string* const&, *std::string* const&, long, *std::string* const&)>

using **pre_exception_handler_type** = *std::function*<void()>

Functions

void **set_custom_exception_info_handler**(*custom_exception_info_handler_type* f)

void **set_pre_exception_handler**(*pre_exception_handler_type* f)

⁷¹⁰ http://github.com/STELLAR-GROUP/hpx/blob/8a3b7c1a4cb5693b2f7d9f587f759392ed0c51a0/libs/core/include_local/include/hpx/exception.hpp

`std::string get_error_what(exception_info const &xi)`

Return the error message of the thrown exception.

The function `hpx::get_error_what` can be used to extract the diagnostic information element representing the error message as stored in the given exception instance.

See also:

`hpx::diagnostic_information()`, `hpx::get_error_host_name()`, `hpx::get_error_process_id()`,
`hpx::get_error_function_name()`, `hpx::get_error_file_name()`, `hpx::get_error_line_number()`,
`hpx::get_error_os_thread()`, `hpx::get_error_thread_id()`, `hpx::get_error_thread_description()`,
`hpx::get_error()` `hpx::get_error_backtrace()`, `hpx::get_error_env()`, `hpx::get_error_config()`,
`hpx::get_error_state()`

Parameters `xi` – The parameter `e` will be inspected for the requested diagnostic information elements which have been stored at the point where the exception was thrown. This parameter can be one of the following types: `hpx::exception_info`, `hpx::error_code`, `std::exception`, or `std::exception_ptr`.

Throws `std::bad_alloc` – (if one of the required allocations fails)

Returns The error message stored in the exception. If the exception instance does not hold this information, the function will return an empty string.

`error get_error(hpx::exception const &e)`

Return the error code value of the exception thrown.

The function `hpx::get_error` can be used to extract the diagnostic information element representing the error value code as stored in the given exception instance.

See also:

`hpx::diagnostic_information()`, `hpx::get_error_host_name()`, `hpx::get_error_process_id()`,
`hpx::get_error_function_name()`, `hpx::get_error_file_name()`, `hpx::get_error_line_number()`,
`hpx::get_error_os_thread()`, `hpx::get_error_thread_id()`, `hpx::get_error_thread_description()`,
`hpx::get_error_backtrace()`, `hpx::get_error_env()`, `hpx::get_error_what()`, `hpx::get_error_config()`,
`hpx::get_error_state()`

Parameters `e` – The parameter `e` will be inspected for the requested diagnostic information elements which have been stored at the point where the exception was thrown. This parameter can be one of the following types: `hpx::exception`, `hpx::error_code`, or `std::exception_ptr`.

Throws nothing –

Returns The error value code of the locality where the exception was thrown. If the exception instance does not hold this information, the function will return `hpx::naming::invalid_locality_id`.

`error get_error(hpx::error_code const &e)`

`std::string get_error_function_name(hpx::exception_info const &xi)`

Return the function name from which the exception was thrown.

The function `hpx::get_error_function_name` can be used to extract the diagnostic information element representing the name of the function as stored in the given exception instance.

See also:

[`hpx::diagnostic_information\(\)`](#), [`hpx::get_error_host_name\(\)`](#), [`hpx::get_error_process_id\(\)`](#)
[`hpx::get_error_file_name\(\)`](#), [`hpx::get_error_line_number\(\)`](#), [`hpx::get_error_os_thread\(\)`](#),
[`hpx::get_error_thread_id\(\)`](#), [`hpx::get_error_thread_description\(\)`](#), [`hpx::get_error\(\)`](#),
[`hpx::get_error_backtrace\(\)`](#), [`hpx::get_error_env\(\)`](#), [`hpx::get_error_what\(\)`](#), [`hpx::get_error_config\(\)`](#),
[`hpx::get_error_state\(\)`](#)

Parameters `xi` – The parameter `e` will be inspected for the requested diagnostic information elements which have been stored at the point where the exception was thrown. This parameter can be one of the following types: `hpx::exception_info`, `hpx::error_code`, `std::exception`, or `std::exception_ptr`.

Throws `std::bad_alloc` – (if one of the required allocations fails)

Returns The name of the function from which the exception was thrown. If the exception instance does not hold this information, the function will return an empty string.

`std::string` **get_error_file_name**(`hpx::exception_info` const &`xi`)

Return the (source code) file name of the function from which the exception was thrown.

The function `hpx::get_error_file_name` can be used to extract the diagnostic information element representing the name of the source file as stored in the given exception instance.

See also:

[`hpx::diagnostic_information\(\)`](#), [`hpx::get_error_host_name\(\)`](#), [`hpx::get_error_process_id\(\)`](#),
[`hpx::get_error_function_name\(\)`](#), [`hpx::get_error_line_number\(\)`](#), [`hpx::get_error_os_thread\(\)`](#),
[`hpx::get_error_thread_id\(\)`](#), [`hpx::get_error_thread_description\(\)`](#), [`hpx::get_error\(\)`](#),
[`hpx::get_error_backtrace\(\)`](#), [`hpx::get_error_env\(\)`](#), [`hpx::get_error_what\(\)`](#), [`hpx::get_error_config\(\)`](#),
[`hpx::get_error_state\(\)`](#)

Parameters `xi` – The parameter `e` will be inspected for the requested diagnostic information elements which have been stored at the point where the exception was thrown. This parameter can be one of the following types: `hpx::exception_info`, `hpx::error_code`, `std::exception`, or `std::exception_ptr`.

Throws `std::bad_alloc` – (if one of the required allocations fails)

Returns The name of the source file of the function from which the exception was thrown. If the exception instance does not hold this information, the function will return an empty string.

`long` **get_error_line_number**(`hpx::exception_info` const &`xi`)

Return the line number in the (source code) file of the function from which the exception was thrown.

The function `hpx::get_error_line_number` can be used to extract the diagnostic information element representing the line number as stored in the given exception instance.

See also:

[`hpx::diagnostic_information\(\)`](#), [`hpx::get_error_host_name\(\)`](#), [`hpx::get_error_process_id\(\)`](#),
[`hpx::get_error_function_name\(\)`](#), [`hpx::get_error_file_name\(\)`](#) [`hpx::get_error_os_thread\(\)`](#),
[`hpx::get_error_thread_id\(\)`](#), [`hpx::get_error_thread_description\(\)`](#), [`hpx::get_error\(\)`](#),
[`hpx::get_error_backtrace\(\)`](#), [`hpx::get_error_env\(\)`](#), [`hpx::get_error_what\(\)`](#), [`hpx::get_error_config\(\)`](#),
[`hpx::get_error_state\(\)`](#)

Parameters *xi* – The parameter *e* will be inspected for the requested diagnostic information elements which have been stored at the point where the exception was thrown. This parameter can be one of the following types: *hpx::exception_info*, *hpx::error_code*, *std::exception*, or *std::exception_ptr*.

Throws nothing –

Returns The line number of the place where the exception was thrown. If the exception instance does not hold this information, the function will return -1.

```
class bad_alloc_exception : public hpx::exception, public bad_alloc
```

Public Functions

```
bad_alloc_exception()
```

Construct a *hpx::bad_alloc_exception*.

```
error_code get_error_code(throwmode mode = throwmode::plain) const noexcept
```

The function `get_error_code()` returns a *hpx::error_code* which represents the same error condition as this *hpx::exception* instance.

Parameters *mode* – The parameter *mode* specifies whether the returned *hpx::error_code* belongs to the error category *hpx_category* (if *mode* is *throwmode::plain*, this is the default) or to the category *hpx_category_rethrow* (if *mode* is *rethrow*).

Public Static Functions

```
static inline constexpr error get_error() noexcept
```

The function `get_error()` returns *hpx::error::out_of_memory*

Throws nothing –

```
class exception : public system_error
```

#include <exception.hpp> A *hpx::exception* is the main exception type used by HPX to report errors.

The *hpx::exception* type is the main exception type used by HPX to report errors. Any exceptions thrown by functions in the HPX library are either of this type or of a type derived from it. This implies that it is always safe to use this type only in catch statements guarding HPX library calls.

Subclassed by *hpx::bad_alloc_exception*, *hpx::exception_list*

Public Functions

```
explicit exception(error e = hpx::error::success)
```

Construct a *hpx::exception* from a *hpx::error*.

Parameters *e* – The parameter *e* holds the *hpx::error* code the new exception should encapsulate.

```
explicit exception(std::system_error const &e)
```

Construct a *hpx::exception* from a *boost::system_error*.

```
explicit exception(std::error_code const &e)
```

Construct a *hpx::exception* from a *boost::system::error_code* (this is new for Boost V1.69). This constructor is required to compensate for the changes introduced as a resolution to LWG3162 (<https://cplusplus.github.io/LWG/issue3162>).

exception(*error* e, char const *msg, *throwmode* mode = *throwmode::plain*)

Construct a *hpx::exception* from a *hpx::error* and an error message.

Parameters

- **e** – The parameter *e* holds the *hpx::error* code the new exception should encapsulate.
- **msg** – The parameter *msg* holds the error message the new exception should encapsulate.
- **mode** – The parameter *mode* specifies whether the returned *hpx::error_code* belongs to the error category *hpx_category* (if *mode* is *plain*, this is the default) or to the category *hpx_category_rethrow* (if *mode* is *rethrow*).

exception(*error* e, std::string const &msg, *throwmode* mode = *throwmode::plain*)

Construct a *hpx::exception* from a *hpx::error* and an error message.

Parameters

- **e** – The parameter *e* holds the *hpx::error* code the new exception should encapsulate.
- **msg** – The parameter *msg* holds the error message the new exception should encapsulate.
- **mode** – The parameter *mode* specifies whether the returned *hpx::error_code* belongs to the error category *hpx_category* (if *mode* is *plain*, this is the default) or to the category *hpx_category_rethrow* (if *mode* is *rethrow*).

~exception() override

Destruct a *hpx::exception*

Throws nothing –

error **get_error**() const noexcept

The function *get_error*() returns the *hpx::error* code stored in the referenced instance of a *hpx::exception*. It returns the *hpx::error* code this exception instance was constructed from.

Throws nothing –

error_code **get_error_code**(*throwmode* mode = *throwmode::plain*) const noexcept

The function *get_error_code*() returns a *hpx::error_code* which represents the same error condition as this *hpx::exception* instance.

Parameters mode – The parameter *mode* specifies whether the returned *hpx::error_code* belongs to the error category *hpx_category* (if *mode* is *throwmode::plain*, this is the default) or to the category *hpx_category_rethrow* (if *mode* is *rethrow*).

struct **thread_interrupted** : public *exception*

#include <exception.hpp> A *hpx::thread_interrupted* is the exception type used by HPX to interrupt a running HPX thread.

The *hpx::thread_interrupted* type is the exception type used by HPX to interrupt a running thread.

A running thread can be interrupted by invoking the *interrupt*() member function of the corresponding *hpx::thread* object. When the interrupted thread next executes one of the specified interruption points (or if it is currently blocked whilst executing one) with interruption enabled, then a *hpx::thread_interrupted* exception will be thrown in the interrupted thread. If not caught, this will cause the execution of the interrupted thread to terminate. As with any other exception, the stack will be unwound, and destructors for objects of automatic storage duration will be executed.

If a thread wishes to avoid being interrupted, it can create an instance of *hpx::this_thread::disable_interruption*. Objects of this class disable interruption for the thread that created them on construction, and restore the interruption state to whatever it was before on destruction.

```
void f()
{
    // interruption enabled here
```

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```

{
    hpx::this_thread::disable_interruption di;
    // interruption disabled
    {
        hpx::this_thread::disable_interruption di2;
        // interruption still disabled
    } // di2 destroyed, interruption state restored
    // interruption still disabled
} // di destroyed, interruption state restored
// interruption now enabled
}

```

The effects of an instance of `hpx::this_thread::disable_interruption` can be temporarily reversed by constructing an instance of `hpx::this_thread::restore_interruption`, passing in the `hpx::this_thread::disable_interruption` object in question. This will restore the interruption state to what it was when the `hpx::this_thread::disable_interruption` object was constructed, and then disable interruption again when the `hpx::this_thread::restore_interruption` object is destroyed.

```

void g()
{
    // interruption enabled here
    {
        hpx::this_thread::disable_interruption di;
        // interruption disabled
        {
            hpx::this_thread::restore_interruption ri(di);
            // interruption now enabled
        } // ri destroyed, interruption disable again
    } // di destroyed, interruption state restored
    // interruption now enabled
}

```

At any point, the interruption state for the current thread can be queried by calling `hpx::this_thread::interruption_enabled()`.

hpx/errors/exception_fwd.hpp

Defined in header `hpx/errors/exception_fwd.hpp`.

See *Public API* for a list of names and headers that are part of the public *HPX* API.

namespace **hpx**

Enums

enum class **throwmode** : *std::uint8_t*
 Encode error category for new *error_code*.

Values:

enumerator **plain**

enumerator **rethrow**

enumerator **lightweight**

Functions

constexpr bool **operator&**(*throwmode* lhs, *throwmode* rhs) noexcept

Variables

error_code **throws**

Predefined *error_code* object used as “throw on error” tag.

The predefined *hpx::error_code* object *hpx::throws* is supplied for use as a “throw on error” tag.

Functions that specify an argument in the form ‘*error_code*& ec=throws’ (with appropriate namespace qualifiers), have the following error handling semantics:

If &ec != &throws and an error occurred: ec.value() returns the implementation specific error number for the particular error that occurred and ec.category() returns the error_category for ec.value().

If &ec != &throws and an error did not occur, ec.clear().

If an error occurs and &ec == &throws, the function throws an exception of type *hpx::exception* or of a type derived from it. The exception’s *get_errorcode()* member function returns a reference to an *hpx::error_code* object with the behavior as specified above.

hpx/errors/exception_list.hpp

Defined in header *hpx/errors/exception_list.hpp*.

See *Public API* for a list of names and headers that are part of the public *HPX* API.

namespace **hpx**

class **exception_list** : public *hpx::exception*

#include <exception_list.hpp> The class *exception_list* is a container of *exception_ptr* objects parallel algorithms may use to communicate uncaught exceptions encountered during parallel execution to the caller of the algorithm

The type *exception_list::const_iterator* fulfills the requirements of a forward iterator.

Public Types

using **iterator** = exception_list_type::const_iterator
bidirectional iterator

Public Functions

inline *std::size_t* **size**() const noexcept
The number of exception_ptr objects contained within the *exception_list*.

Note: Complexity: Constant time.

inline exception_list_type::const_iterator **begin**() const noexcept
An iterator referring to the first exception_ptr object contained within the *exception_list*.

inline exception_list_type::const_iterator **end**() const noexcept
An iterator which is the past-the-end value for the *exception_list*.

HPX_THROW_EXCEPTION, HPX_THROW_BAD_ALLOC, HPX_THROWS_IF

Defined in header `hpx/exception.hpp`⁷¹¹.

See *Public API* for a list of names and headers that are part of the public HPX API.

Defines

HPX_THROW_EXCEPTION(errcode, f, ...)

Throw a *hpx::exception* initialized from the given parameters.

The macro *HPX_THROW_EXCEPTION* can be used to throw a *hpx::exception*. The purpose of this macro is to prepend the source file name and line number of the position where the exception is thrown to the error message. Moreover, this associates additional diagnostic information with the exception, such as file name and line number, locality id and thread id, and stack backtrace from the point where the exception was thrown.

The parameter *errcode* holds the *hpx::error* code the new exception should encapsulate. The parameter *f* is expected to hold the name of the function exception is thrown from and the parameter *msg* holds the error message the new exception should encapsulate.

```
void raise_exception()
{
    // Throw a hpx::exception initialized from the given parameters.
    // Additionally associate with this exception some detailed
    // diagnostic information about the throw-site.
    HPX_THROW_EXCEPTION(hpx::error::no_success, "raise_exception",
        "simulated error");
}
```

⁷¹¹ http://github.com/STELLAR-GROUP/hpx/blob/8a3b7c1a4cb5693b2f7d9f587f759392ed0c51a0/libs/core/include_local/include/hpx/exception.hpp

Example:**HPX_THROW_BAD_ALLOC(f)**

Throw a `hpx::bad_alloc_exception` initialized from the given parameters.

The macro `HPX_THROW_BAD_ALLOC` can be used to throw a `hpx::exception`. The purpose of this macro is to prepend the source file name and line number of the position where the exception is thrown to the error message. Moreover, this associates additional diagnostic information with the exception, such as file name and line number, locality id and thread id, and stack backtrace from the point where the exception was thrown.

The parameter `errcode` holds the `hpx::error` code the new exception should encapsulate. The parameter `f` is expected to hold the name of the function exception is thrown from and the parameter `msg` holds the error message the new exception should encapsulate.

```
void raise_exception()
{
    // Throw a hpx::exception initialized from the given parameters.
    // Additionally associate with this exception some detailed
    // diagnostic information about the throw-site.
    HPX_THROW_BAD_ALLOC("raise_exception", "simulated error");
}
```

Example:**HPX_THROWS_IF(ec, errcode, f, ...)**

Either throw a `hpx::exception` or initialize `hpx::error_code` from the given parameters.

The macro `HPX_THROWS_IF` can be used to either throw a `hpx::exception` or to initialize a `hpx::error_code` from the given parameters. If `&ec == &hpx::throws`, the semantics of this macro are equivalent to `HPX_THROW_EXCEPTION`. If `&ec != &hpx::throws`, the `hpx::error_code` instance `ec` is initialized instead.

The parameter `errcode` holds the `hpx::error` code from which the new exception should be initialized. The parameter `f` is expected to hold the name of the function exception is thrown from and the parameter `msg` holds the error message the new exception should encapsulate.

HPX_THROWS_BAD_ALLOC_IF(ec, f)

Either throw a `hpx::bad_alloc_exception` or `hpx::error_code` to `out_of_memory`.

The macro `HPX_THROWS_BAD_ALLOC_IF` can be used to either throw a `hpx::bad_alloc_exception` or to initialize a `hpx::error_code` to `hpx::error::out_of_memory`. If `&ec == &hpx::throws`, the semantics of this macro are equivalent to `HPX_THROW_BAD_ALLOC`. If `&ec != &hpx::throws`, the `hpx::error_code` instance `ec` is initialized instead.

namespace **hpx**

execution

See *Public API* for a list of names and headers that are part of the public *HPX* API.

hpx/execution/executors/adaptive_static_chunk_size.hpp

Defined in header `hpx/execution/executors/adaptive_static_chunk_size.hpp`.

See *Public API* for a list of names and headers that are part of the public *HPX* API.

namespace **hpx**

namespace **execution**

Typedefs

typedef `hpx::execution::experimental::adaptive_static_chunk_size` **instead**

namespace **experimental**

struct **adaptive_static_chunk_size**

#include <adaptive_static_chunk_size.hpp> Loop iterations are divided into pieces of size *chunk_size* and then assigned to threads. If *chunk_size* is not specified, the iterations are evenly (if possible) divided contiguously among the threads.

Note: This executor parameters type is equivalent to OpenMP's `STATIC` scheduling directive.

Public Functions

adaptive_static_chunk_size() = default

Construct a `adaptive_static_chunk_size` executor parameters object

Note: By default the number of loop iterations is determined from the number of available cores and the overall number of loop iterations to schedule.

inline explicit constexpr **adaptive_static_chunk_size**(*std::size_t* chunk_size) noexcept

Construct a `adaptive_static_chunk_size` executor parameters object

Parameters **chunk_size** – [in] The optional chunk size to use as the number of loop iterations to run on a single thread.

hpx::execution::experimental::auto_chunk_size

Defined in header `hpx/execution.hpp`⁷¹².

See *Public API* for a list of names and headers that are part of the public *HPX* API.

```
namespace hpx
```

```
    namespace execution
```

```
        namespace experimental
```

```
            struct auto_chunk_size
```

```
                #include <auto_chunk_size.hpp> Loop iterations are divided into pieces and then assigned to threads. The number of loop iterations combined is determined based on measurements of how long the execution of 1% of the overall number of iterations takes. This executor parameters type makes sure that as many loop iterations are combined as necessary to run for the amount of time specified.
```

Public Functions

```
inline explicit constexpr auto_chunk_size(std::uint64_t num_iters_for_timing = 0) noexcept
    Construct an auto_chunk_size executor parameters object
```

Note: Default constructed `auto_chunk_size` executor parameter types will use 80 microseconds as the minimal time for which any of the scheduled chunks should run.

```
inline explicit auto_chunk_size(hpx::chrono::steady_duration const &rel_time, std::uint64_t
                                num_iters_for_timing = 0) noexcept
```

```
    Construct an auto_chunk_size executor parameters object
```

Parameters

- **rel_time** – [in] The time duration to use as the minimum to decide how many loop iterations should be combined.
- **num_iters_for_timing** – [in] The number of iterations to use for the timing operation

hpx/execution/executors/default_parameters.hpp

Defined in header `hpx/execution/executors/default_parameters.hpp`.

See *Public API* for a list of names and headers that are part of the public *HPX* API.

```
namespace hpx
```

```
    namespace execution
```

⁷¹² http://github.com/STELLAR-GROUP/hpx/blob/8a3b7c1a4cb5693b2f7d9f587f759392ed0c51a0/libs/core/include_local/include/hpx/execution.hpp

namespace **experimental**

struct **default_parameters**

#include <default_parameters.hpp> Loop iterations are divided into pieces of size *chunk_size* and then assigned to threads. If *chunk_size* is not specified, the iterations are evenly (if possible) divided contiguously among the threads.

Note: This executor parameters type is equivalent to OpenMP's STATIC scheduling directive.

Public Functions

default_parameters() = default

Construct a `default_parameters` executor parameters object

Note: By default the number of loop iterations is determined from the number of available cores and the overall number of loop iterations to schedule.

hpx::execution::experimental::dynamic_chunk_size

Defined in header `hpx/execution.hpp`⁷¹³.

See *Public API* for a list of names and headers that are part of the public HPX API.

namespace **hpx**

namespace **execution**

namespace **experimental**

struct **dynamic_chunk_size**

#include <dynamic_chunk_size.hpp> Loop iterations are divided into pieces of size *chunk_size* and then dynamically scheduled among the threads; when a thread finishes one chunk, it is dynamically assigned another. If *chunk_size* is not specified, the default chunk size is 1.

Note: This executor parameters type is equivalent to OpenMP's DYNAMIC scheduling directive.

⁷¹³ http://github.com/STELLAR-GROUP/hpx/blob/8a3b7c1a4cb5693b2f7d9f587f759392ed0c51a0/libs/core/include_local/include/hpx/execution.hpp

Public Functions

dynamic_chunk_size() = default

Construct an `dynamic_chunk_size` executor parameters object

Note: Default constructed `dynamic_chunk_size` executor parameter types will use a chunk size of '1'.

inline explicit constexpr **dynamic_chunk_size**(*std::size_t* chunk_size) noexcept

Construct a `dynamic_chunk_size` executor parameters object

Parameters `chunk_size` – [in] The optional chunk size to use as the number of loop iterations to schedule together. The default chunk size is 1.

hpx/execution/executors/execution.hpp

Defined in header `hpx/execution/executors/execution.hpp`.

See *Public API* for a list of names and headers that are part of the public *HPX* API.

namespace **hpx**

namespace **parallel**

namespace **execution**

hpx/execution/executors/execution_information.hpp

Defined in header `hpx/execution/executors/execution_information.hpp`.

See *Public API* for a list of names and headers that are part of the public *HPX* API.

namespace **hpx**

namespace **execution**

namespace **experimental**

Variables

hpx::execution::experimental::has_pending_closures_t **has_pending_closures**

hpx::execution::experimental::get_pu_mask_t **get_pu_mask**

hpx::execution::experimental::set_scheduler_mode_t **set_scheduler_mode**

```
struct get_pu_mask_t : public hpx::functional::detail::tag_fallback<get_pu_mask_t>
    #include <execution_information.hpp> Retrieve the bitmask describing the processing units the
    given thread is allowed to run on

    All threads::executors invoke sched.get_pu_mask().
```

Note: If the executor does not support this operation, this call will always invoke `hpx::threads::get_pu_mask()`

Param exec [in] The executor object to use for querying the number of pending tasks.
Param topo [in] The topology object to use to extract the requested information.
Param thream_num [in] The sequence number of the thread to retrieve information for.

Private Functions

```
template<typename Executor>
inline decltype(auto) friend tag_fallback_invoke(get_pu_mask_t, Executor&&,
                                                threads::topology &topo, std::size_t
                                                thread_num)

template<typename Executor>
inline decltype(auto) friend tag_invoke(get_pu_mask_t, Executor &&exec, threads::topology
                                         &topo, std::size_t thread_num)
```

```
struct has_pending_closures_t : public
hpx::functional::detail::tag_fallback<has_pending_closures_t>
    #include <execution_information.hpp> Retrieve whether this executor has operations pending or
    not.
```

Note: If the executor does not expose this information, this call will always return *false*

Param exec [in] The executor object to use to extract the requested information for.

Private Functions

```
template<typename Executor>
inline decltype(auto) friend tag_fallback_invoke(has_pending_closures_t, Executor&&)

template<typename Executor>
inline decltype(auto) friend tag_invoke(has_pending_closures_t, Executor &&exec)
```

```
struct set_scheduler_mode_t : public
hpx::functional::detail::tag_fallback<set_scheduler_mode_t>
    #include <execution_information.hpp> Set various modes of operation on the scheduler under-
    neath the given executor.
```

Note: This calls `exec.set_scheduler_mode(mode)` if it exists; otherwise it does nothing.

Param exec [in] The executor object to use.

Param mode [in] The new mode for the scheduler to pick up

Friends

```
template<typename Executor, typename Mode>
inline friend void tag_fallback_invoke(set_scheduler_mode_t, Executor&&, Mode const&)
```

```
template<typename Executor, typename Mode>
inline friend void tag_invoke(set_scheduler_mode_t, Executor &&exec, Mode const &mode)
```

hpx/execution/executors/execution_parameters.hpp

Defined in header hpx/execution/executors/execution_parameters.hpp.

See *Public API* for a list of names and headers that are part of the public *HPX* API.

```
namespace hpx
```

```
    namespace execution
```

```
        namespace experimental
```

Functions

```
template<typename ...Params>
constexpr executor_parameters_join<Params...>::type join_executor_parameters(Params&&...
                                                                    params)
```

```
template<typename Param>
constexpr Param &&join_executor_parameters(Param &&param) noexcept
```

```
template<typename ...Params>
struct executor_parameters_join
```

Public Types

```
using type = detail::executor_parameters<std::decay_t<Params>...>
```

```
template<typename Param>
struct executor_parameters_join<Param>
```

Public Types

```
using type = Param
```

hpx/execution/executors/execution_parameters_fwd.hpp

Defined in header `hpx/execution/executors/execution_parameters_fwd.hpp`.

See *Public API* for a list of names and headers that are part of the public *HPX* API.

```
namespace hpx
```

```
    namespace execution
```

```
        namespace experimental
```

Variables

```
constexpr struct hpx::execution::experimental::null_parameters_t null_parameters
```

```
hpx::execution::experimental::get_chunk_size_t get_chunk_size
```

```
hpx::execution::experimental::measure_iteration_t measure_iteration
```

```
hpx::execution::experimental::maximal_number_of_chunks_t maximal_number_of_chunks
```

```
hpx::execution::experimental::reset_thread_distribution_t reset_thread_distribution
```

```
hpx::execution::experimental::processing_units_count_t processing_units_count
```

```
hpx::execution::experimental::with_processing_units_count_t with_processing_units_count
```

```
hpx::execution::experimental::mark_begin_execution_t mark_begin_execution
```

```
hpx::execution::experimental::mark_end_of_scheduling_t mark_end_of_scheduling
```

```
hpx::execution::experimental::mark_end_execution_t mark_end_execution
```

```
struct get_chunk_size_t : public hpx::functional::detail::tag_priority<get_chunk_size_t>
```

```
    #include <execution_parameters_fwd.hpp> Return the number of invocations of the given function f which should be combined into a single task
```

```
    Param params [in] The executor parameters object to use for determining the chunk size for the given number of tasks num_tasks.
```

```
    Param exec [in] The executor object which will be used for scheduling of the loop iterations.
```

Param iteration_duration [in] The time one of the tasks require to be executed.
Param cores [in] The number of cores the number of chunks should be determined for.
Param num_tasks [in] The number of tasks the chunk size should be determined for
Return The size of the chunks (number of iterations per chunk) that should be used for parallel execution.

Private Functions

```
template<typename Parameters, typename Executor>
inline decltype(auto) friend tag_fallback_invoke(get_chunk_size_t, Parameters &&params,
                                                Executor &&exec,
                                                hpx::chrono::steady_duration const
                                                &iteration_duration, std::size_t cores,
                                                std::size_t num_tasks)
```

```
template<typename Parameters, typename Executor>
inline decltype(auto) friend tag_fallback_invoke(get_chunk_size_t tag, Parameters
                                                &&params, Executor &&exec, std::size_t
                                                cores, std::size_t num_tasks)
```

```
template<>
```

```
struct is_scheduling_property<with_processing_units_count_t> : public true_type
```

```
struct mark_begin_execution_t : public
hpx::functional::detail::tag_priority<mark_begin_execution_t>
    #include <execution_parameters_fwd.hpp> Mark the begin of a parallel algorithm execution
```

Note: This calls `params.mark_begin_execution(exec)` if it exists; otherwise it does nothing.

Param params [in] The executor parameters object to use as a fallback if the executor does not expose

Private Functions

```
template<typename Parameters, typename Executor>
inline decltype(auto) friend tag_fallback_invoke(mark_begin_execution_t, Parameters
                                                &&params, Executor &&exec)
```

```
struct mark_end_execution_t : public
hpx::functional::detail::tag_priority<mark_end_execution_t>
    #include <execution_parameters_fwd.hpp> Mark the end of a parallel algorithm execution
```

Note: This calls `params.mark_end_execution(exec)` if it exists; otherwise it does nothing.

Param params [in] The executor parameters object to use as a fallback if the executor does not expose

Private Functions

```
template<typename Parameters, typename Executor>
inline decltype(auto) friend tag_fallback_invoke(mark_end_execution_t, Parameters
&&params, Executor &&exec)
```

```
struct mark_end_of_scheduling_t : public
hpx::functional::detail::tag_priority<mark_end_of_scheduling_t>
    #include <execution_parameters_fwd.hpp> Mark the end of scheduling tasks during parallel al-
    gorithm execution
```

Note: This calls `params.mark_begin_execution(exec)` if it exists; otherwise it does nothing.

Param params [in] The executor parameters object to use as a fallback if the executor does not expose

Private Functions

```
template<typename Parameters, typename Executor>
inline decltype(auto) friend tag_fallback_invoke(mark_end_of_scheduling_t, Parameters
&&params, Executor &&exec)
```

```
struct maximal_number_of_chunks_t : public
hpx::functional::detail::tag_priority<maximal_number_of_chunks_t>
    #include <execution_parameters_fwd.hpp> Return the largest reasonable number of chunks to
    create for a single algorithm invocation.
```

Param params [in] The executor parameters object to use for determining the number of chunks for the given number of *cores*.

Param exec [in] The executor object which will be used for scheduling of the loop iterations.

Param cores [in] The number of cores the number of chunks should be determined for.

Param num_tasks [in] The number of tasks the chunk size should be determined for

Private Functions

```
template<typename Parameters, typename Executor>
inline decltype(auto) friend tag_fallback_invoke(maximal_number_of_chunks_t,
Parameters &&params, Executor
&&exec, std::size_t cores, std::size_t
num_tasks)
```

```
struct measure_iteration_t : public hpx::functional::detail::tag_priority<measure_iteration_t>
    #include <execution_parameters_fwd.hpp> Return the measured execution time for one iteration
    based on running the given function.
```

Note: The parameter *f* is expected to be a nullary function returning a `std::size_t` representing the number of iteration the function has already executed (i.e. which don't have to be scheduled anymore).

Param params [in] The executor parameters object to use for determining the chunk size for the given number of tasks *num_tasks*.
Param exec [in] The executor object which will be used for scheduling of the loop iterations.
Param f [in] The function which will be optionally scheduled using the given executor.
Param num_tasks [in] The number of tasks the chunk size should be determined for
Return The execution time for one of the tasks.

Private Functions

```
template<typename Parameters, typename Executor, typename F>
inline decltype(auto) friend tag_fallback_invoke(measure_iteration_t, Parameters
&&params, Executor &&exec, F &&f,
std::size_t num_tasks)
```

```
struct null_parameters_t
```

```
struct processing_units_count_t : public
hpx::functional::detail::tag_priority<processing_units_count_t>
#include <execution_parameters_fwd.hpp> Retrieve the number of (kernel-)threads used by the
associated executor.
```

Note: This calls `params.processing_units_count(Executor&&)` if it exists; otherwise it forwards the request to the executor parameters object.

Param params [in] The executor parameters object to use as a fallback if the executor does not expose
Param iteration_duration [in] The time one of the tasks require to be executed.
Param num_tasks [in] The number of tasks the number of cores should be determined for
Return The number of cores to use

Private Functions

```
template<typename Parameters, typename Executor>
inline decltype(auto) friend tag_fallback_invoke(processing_units_count_t, Parameters
&&params, Executor &&exec,
hpx::chrono::steady_duration const
&iteration_duration, std::size_t
num_tasks)
```

```
template<typename Parameters, typename Executor>
inline decltype(auto) friend tag_fallback_invoke(processing_units_count_t tag, Parameters
&&params, Executor &&exec, std::size_t
num_tasks = 0)
```

```
template<typename Executor>
inline decltype(auto) friend tag_fallback_invoke(processing_units_count_t, Executor
&&exec, hpx::chrono::steady_duration
const &iteration_duration, std::size_t
num_tasks)
```

```
template<typename Executor>
```

```
inline decltype(auto) friend tag_fallback_invoke(processing_units_count_t tag, Executor
&&exec, std::size_t num_tasks = 0)
```

```
struct reset_thread_distribution_t : public
hpx::functional::detail::tag_priority<reset_thread_distribution_t>
    #include <execution_parameters_fwd.hpp> Reset the internal round robin thread distribution
    scheme for the given executor.
```

Note: This calls `params.reset_thread_distribution(exec)` if it exists; otherwise it does nothing.

Param params [in] The executor parameters object to use for resetting the thread distribution scheme.

Param exec [in] The executor object to use.

Private Functions

```
template<typename Parameters, typename Executor>
inline decltype(auto) friend tag_fallback_invoke(reset_thread_distribution_t, Parameters
&&params, Executor &&exec)
```

```
struct with_processing_units_count_t : public
hpx::functional::detail::tag_priority<with_processing_units_count_t>
    #include <execution_parameters_fwd.hpp> Generate a policy that supports setting the number of
    cores for execution.
```

hpx::execution::experimental::guided_chunk_size

Defined in header `hpx/execution.hpp`⁷¹⁴.

See *Public API* for a list of names and headers that are part of the public HPX API.

```
namespace hpx
```

```
    namespace execution
```

```
        namespace experimental
```

```
            struct guided_chunk_size
```

```
                #include <guided_chunk_size.hpp> Iterations are dynamically assigned to threads in blocks as
                threads request those until no blocks remain to be assigned. Similar to dynamic_chunk_size except
                that the block size decreases each time a number of loop iterations is given to a thread. The size of
                the initial block is proportional to number_of_iterations / number_of_cores. Subsequent blocks
                are proportional to number_of_iterations_remaining / number_of_cores. The optional chunk size
                parameter defines the minimum block size. The default chunk size is 1.
```

⁷¹⁴ http://github.com/STELLAR-GROUP/hpx/blob/8a3b7c1a4cb5693b2f7d9f587f759392ed0c51a0/libs/core/include_local/include/hpx/execution.hpp

Note: This executor parameters type is equivalent to OpenMP's GUIDED scheduling directive.

Public Functions

guided_chunk_size() = default

Construct an `dynamic_chunk_size` executor parameters object

Note: Default constructed `dynamic_chunk_size` executor parameter types will use a chunk size of '1'.

inline explicit constexpr **guided_chunk_size**(`std::size_t` min_chunk_size) noexcept

Construct a `guided_chunk_size` executor parameters object

Parameters `min_chunk_size` – [in] The optional minimal chunk size to use as the minimal number of loop iterations to schedule together. The default minimal chunk size is 1.

hpx::execution::experimental::num_cores

Defined in header `hpx/execution.hpp`⁷¹⁵.

See *Public API* for a list of names and headers that are part of the public HPX API.

namespace **hpx**

namespace **execution**

namespace **experimental**

struct **num_cores**

#include <`num_cores.hpp`> Control number of cores in executors which need a functionality for setting the number of cores to be used by an algorithm directly

Public Functions

inline explicit constexpr **num_cores**(`std::size_t` cores = 1) noexcept

Construct a `num_cores` executor parameters object

Note: make sure the minimal number of cores is and the maximum number of cores is what's available to HPX

⁷¹⁵ http://github.com/STELLAR-GROUP/hpx/blob/8a3b7c1a4cb5693b2f7d9f587f759392ed0c51a0/libs/core/include_local/include/hpx/execution.hpp

hpx::execution::experimental::persistent_auto_chunk_size

Defined in header `hpx/execution.hpp`⁷¹⁶.

See *Public API* for a list of names and headers that are part of the public HPX API.

```
namespace hpx
```

```
    namespace execution
```

```
        namespace experimental
```

```
            struct persistent_auto_chunk_size
```

#include <persistent_auto_chunk_size.hpp> Loop iterations are divided into pieces and then assigned to threads. The number of loop iterations combined is determined based on measurements of how long the execution of 1% of the overall number of iterations takes. This executor parameters type makes sure that as many loop iterations are combined as necessary to run for the amount of time specified.

Public Functions

```
inline explicit constexpr persistent_auto_chunk_size(std::uint64_t num_iters_for_timing
                                                    = 0) noexcept
```

Construct an `persistent_auto_chunk_size` executor parameters object

Note: Default constructed `persistent_auto_chunk_size` executor parameter types will use 0 microseconds as the execution time for each chunk and 80 microseconds as the minimal time for which any of the scheduled chunks should run.

```
inline explicit persistent_auto_chunk_size(hpx::chrono::steady_duration const &time_cs,
                                           std::uint64_t num_iters_for_timing = 0)
    noexcept
```

Construct an `persistent_auto_chunk_size` executor parameters object

Parameters

- **time_cs** – The execution time for each chunk.
- **num_iters_for_timing** – [in] The number of iterations to use for measuring the execution time of one iteration

```
inline persistent_auto_chunk_size(hpx::chrono::steady_duration const &time_cs,
                                  hpx::chrono::steady_duration const &rel_time,
                                  std::uint64_t num_iters_for_timing = 0) noexcept
```

Construct an `persistent_auto_chunk_size` executor parameters object

Parameters

- **rel_time** – [in] The time duration to use as the minimum to decide how many loop iterations should be combined.
- **time_cs** – The execution time for each chunk.
- **num_iters_for_timing** – [in] The number of iterations to use for measuring the execution time of one iteration

⁷¹⁶ http://github.com/STELLAR-GROUP/hpx/blob/8a3b7c1a4cb5693b2f7d9f587f759392ed0c51a0/libs/core/include_local/include/hpx/execution.hpp

hpx/execution/executors/polymorphic_executor.hpp

Defined in header `hpx/execution/executors/polymorphic_executor.hpp`.

See *Public API* for a list of names and headers that are part of the public *HPX* API.

```
namespace hpx

    namespace execution

        namespace experimental

            namespace parallel

                namespace execution

                    template<typename Sig>

                    class polymorphic_executor

                    template<typename R, typename ...Ts>

                    class polymorphic_executor<R(Ts...)> : private
                    hpx::parallel::execution::detail::polymorphic_executor_base
```

Public Types

```
template<typename>

using future_type = hpx::future<R>
```

Public Functions

```
inline constexpr polymorphic_executor() noexcept

inline polymorphic_executor(polymorphic_executor const &other)

inline polymorphic_executor(polymorphic_executor &&other) noexcept

inline polymorphic_executor &operator=(polymorphic_executor const &other)

inline polymorphic_executor &operator=(polymorphic_executor &&other) noexcept

template<typename Exec, typename PE = std::decay_t<Exec>, typename Enable =
std::enable_if_t<!std::is_same_v<PE, polymorphic_executor>>>
inline polymorphic_executor(Exec &&exec)

template<typename Exec, typename PE = std::decay_t<Exec>, typename Enable =
std::enable_if_t<!std::is_same_v<PE, polymorphic_executor>>>
inline polymorphic_executor &operator=(Exec &&exec)

inline void reset() noexcept
```

Private Types

```
using base_type = detail::polymorphic_executor_base
```

```
using vtable = detail::polymorphic_executor_vtable<R(Ts...)>
```

Private Functions

```
inline void assign(std::nullptr_t) noexcept
```

```
template<typename Exec>  
inline void assign(Exec &&exec)
```

Private Static Functions

```
static inline constexpr vtable const *get_empty_vtable() noexcept
```

```
template<typename T>  
static inline constexpr vtable const *get_vtable() noexcept
```

Friends

```
template<typename F>  
inline friend void tag_invoke(hpx::parallel::execution::post_t, polymorphic_executor const  
    &exec, F &&f, Ts... ts)
```

```
template<typename F>  
inline friend R tag_invoke(hpx::parallel::execution::sync_execute_t, polymorphic_executor  
    const &exec, F &&f, Ts... ts)
```

```
template<typename F>  
inline friend hpx::future<R> tag_invoke(hpx::parallel::execution::async_execute_t,  
    polymorphic_executor const &exec, F &&f, Ts... ts)
```

```
template<typename F, typename Future>  
inline friend hpx::future<R> tag_invoke(hpx::parallel::execution::then_execute_t,  
    polymorphic_executor const &exec, F &&f, Future  
    &&predecessor, Ts&&... ts)
```

```
template<typename F, typename Shape>  
inline friend std::vector<R> tag_invoke(hpx::parallel::execution::bulk_sync_execute_t,  
    polymorphic_executor const &exec, F &&f, Shape  
    const &s, Ts&&... ts)
```

```
template<typename F, typename Shape>  
inline friend std::vector<hpx::future<R>> tag_invoke(hpx::parallel::execution::bulk_async_execute_t,  
    polymorphic_executor const &exec, F  
    &&f, Shape const &s, Ts&&... ts)
```

```
template<typename F, typename Shape>
```

```
inline friend hpx::future<std::vector<R>> tag_invoke(hpx::parallel::execution::bulk_then_execute_t,
polymorphic_executor const &exec, F
&&f, Shape const &s,
hpx::shared_future<void> const
&predecessor, Ts&&... ts)
```

hpx/execution/executors/rebind_executor.hpp

Defined in header `hpx/execution/executors/rebind_executor.hpp`.

See *Public API* for a list of names and headers that are part of the public *HPX* API.

```
namespace hpx
```

```
namespace execution
```

```
namespace experimental
```

Typedefs

```
template<typename ExPolicy, typename Executor, typename Parameters>
using rebind_executor_t = typename rebind_executor<ExPolicy, Executor, Parameters>::type
```

Variables

```
constexpr struct hpx::execution::experimental::create_rebound_policy_t create_rebound_policy
```

```
struct create_rebound_policy_t
```

Public Functions

```
template<typename ExPolicy, typename Executor, typename Parameters>
inline constexpr decltype(auto) operator() (ExPolicy&&, Executor &&exec, Parameters
&&parameters) const
```

```
template<typename ExPolicy, typename Executor, typename Parameters>
```

```
struct rebind_executor
```

```
#include <rebind_executor.hpp> Rebind the type of executor used by an execution policy. The
execution category of Executor shall not be weaker than that of ExecutionPolicy.
```

Public Types

using **type** = typename policy_type::template rebound<executor_type, parameters_type>::type

The type of the rebound execution policy.

hpx::execution::experimental::static_chunk_size

Defined in header `hpx/execution.hpp`⁷¹⁷.

See *Public API* for a list of names and headers that are part of the public *HPX* API.

```
namespace hpx
```

```
    namespace execution
```

```
        namespace experimental
```

```
            struct static_chunk_size
```

```
                #include <static_chunk_size.hpp> Loop iterations are divided into pieces of size chunk_size and then assigned to threads. If chunk_size is not specified, the iterations are evenly (if possible) divided contiguously among the threads.
```

Note: This executor parameters type is equivalent to OpenMP's `STATIC` scheduling directive.

Public Functions

```
static_chunk_size() = default
```

```
Construct a static_chunk_size executor parameters object
```

Note: By default the number of loop iterations is determined from the number of available cores and the overall number of loop iterations to schedule.

```
inline explicit constexpr static_chunk_size(std::size_t chunk_size) noexcept
```

```
Construct a static_chunk_size executor parameters object
```

```
Parameters chunk_size – [in] The optional chunk size to use as the number of loop iterations to run on a single thread.
```

⁷¹⁷ http://github.com/STELLAR-GROUP/hpx/blob/8a3b7c1a4cb5693b2f7d9f587f759392ed0c51a0/libs/core/include_local/include/hpx/execution.hpp

hpx/execution/traits/is_execution_policy.hpp

Defined in header `hpx/execution/traits/is_execution_policy.hpp`.

See *Public API* for a list of names and headers that are part of the public *HPX* API.

namespace **hpx**

Variables

```
template<typename T>
```

```
constexpr bool is_execution_policy_v = is_execution_policy<T>::value
```

```
template<typename T>
```

```
constexpr bool is_parallel_execution_policy_v = is_parallel_execution_policy<T>::value
```

```
template<typename T>
```

```
constexpr bool is_sequenced_execution_policy_v = is_sequenced_execution_policy<T>::value
```

```
template<typename T>
```

```
constexpr bool is_async_execution_policy_v = is_async_execution_policy<T>::value
```

```
template<typename T>
```

```
struct is_async_execution_policy : public hpx::detail::is_async_execution_policy<std::decay_t<T>>
```

```
    #include <is_execution_policy.hpp> Extension: Detect whether given execution policy makes algorithms asynchronous
```

- i. The type *is_async_execution_policy* can be used to detect asynchronous execution policies for the purpose of excluding function signatures from otherwise ambiguous overload resolution participation.
- ii. If T is the type of a standard or implementation-defined execution policy, *is_async_execution_policy*<T> shall be publicly derived from *integral_constant*<bool, true>, otherwise from *integral_constant*<bool, false>.
- iii. The behavior of a program that adds specializations for *is_async_execution_policy* is undefined.

```
template<typename T>
```

```
struct is_execution_policy : public hpx::detail::is_execution_policy<std::decay_t<T>>
```

```
    #include <is_execution_policy.hpp>
```

- i. The type *is_execution_policy* can be used to detect execution policies for the purpose of excluding function signatures from otherwise ambiguous overload resolution participation.
- ii. If T is the type of a standard or implementation-defined execution policy, *is_execution_policy*<T> shall be publicly derived from *integral_constant*<bool, true>, otherwise from *integral_constant*<bool, false>.
- iii. The behavior of a program that adds specializations for *is_execution_policy* is undefined.

```
template<typename T>
```

```
struct is_parallel_execution_policy : public
    hpx::detail::is_parallel_execution_policy<std::decay_t<T>>
    #include <is_execution_policy.hpp> Extension: Detect whether given execution policy enables parallelization
```

- i. The type *is_parallel_execution_policy* can be used to detect parallel execution policies for the purpose of excluding function signatures from otherwise ambiguous overload resolution participation.
- ii. If *T* is the type of a standard or implementation-defined execution policy, *is_parallel_execution_policy*<*T*> shall be publicly derived from *integral_constant*<bool, true>, otherwise from *integral_constant*<bool, false>.
- iii. The behavior of a program that adds specializations for *is_parallel_execution_policy* is undefined.

```
template<typename T>
```

```
struct is_sequenced_execution_policy : public
    hpx::detail::is_sequenced_execution_policy<std::decay_t<T>>
    #include <is_execution_policy.hpp> Extension: Detect whether given execution policy does not enable parallelization
```

- i. The type *is_sequenced_execution_policy* can be used to detect non-parallel execution policies for the purpose of excluding function signatures from otherwise ambiguous overload resolution participation.
- ii. If *T* is the type of a standard or implementation-defined execution policy, *is_sequenced_execution_policy*<*T*> shall be publicly derived from *integral_constant*<bool, true>, otherwise from *integral_constant*<bool, false>.
- iii. The behavior of a program that adds specializations for *is_sequenced_execution_policy* is undefined.

execution_base

See *Public API* for a list of names and headers that are part of the public *HPX* API.

hpx/execution_base/execution.hpp

Defined in header *hpx/execution_base/execution.hpp*.

See *Public API* for a list of names and headers that are part of the public *HPX* API.

```
namespace hpx
```

```
    namespace execution
```

```
        struct parallel_execution_tag
            #include <execution.hpp> Function invocations executed by a group of parallel execution agents execute in unordered fashion. Any such invocations executing in the same thread are indeterminately sequenced with respect to each other.
```

Note: *parallel_execution_tag* is weaker than *sequenced_execution_tag*.

struct **sequenced_execution_tag**

#include <execution.hpp> Function invocations executed by a group of sequential execution agents execute in sequential order.

struct **unsequenced_execution_tag**

#include <execution.hpp> Function invocations executed by a group of vector execution agents are permitted to execute in unordered fashion when executed in different threads, and un-sequenced with respect to one another when executed in the same thread.

Note: `unsequenced_execution_tag` is weaker than `parallel_execution_tag`.

namespace **parallel**

namespace **execution**

Variables

hpx::parallel::execution::sync_execute_t **sync_execute**

hpx::parallel::execution::async_execute_t **async_execute**

hpx::parallel::execution::then_execute_t **then_execute**

hpx::parallel::execution::post_t **post**

hpx::parallel::execution::bulk_sync_execute_t **bulk_sync_execute**

hpx::parallel::execution::bulk_async_execute_t **bulk_async_execute**

hpx::parallel::execution::bulk_then_execute_t **bulk_then_execute**

hpx::parallel::execution::async_invoke_t **async_invoke**

hpx::parallel::execution::sync_invoke_t **sync_invoke**

struct **async_execute_t** : public *hpx::functional::detail::tag_fallback<async_execute_t>*

#include <execution.hpp> Customization point for asynchronous execution agent creation.

This asynchronously creates a single function invocation `f()` using the associated executor.

Note: Executors have to implement only `async_execute()`. All other functions will be emulated by this or other customization points in terms of this single basic primitive. However, some executors will naturally specialize all operations for maximum efficiency.

Note: This is valid for one way executors (calls `make_ready_future(exec.sync_execute(f, ts...))` if it exists) and for two way executors (calls `exec.async_execute(f, ts...)` if it exists).

Param exec [in] The executor object to use for scheduling of the function *f*.
Param f [in] The function which will be scheduled using the given executor.
Param ts [in] Additional arguments to use to invoke *f*.
Return `f(ts...)`'s result through a future

Private Functions

```
template<typename Executor, typename F, typename ...Ts>  
inline decltype(auto) friend tag_fallback_invoke(async_execute_t, Executor &&exec, F  
                                                &&f, Ts&&... ts)
```

```
struct async_invoke_t : public hpx::functional::detail::tag_fallback<async_invoke_t>  
    #include <execution.hpp> Asynchronously invoke the given set of nullary functions, each on its  
    own execution agent
```

This creates a group of function invocations whose ordering is given by the `execution_category` associated with the executor.

All exceptions thrown by invocations of the functions are reported in a manner consistent with parallel algorithm execution through the returned future.

Note: This calls `exec.async_invoke(fs...)` if it exists; otherwise it executes `async_execute(fs)` for each *fs*.

Param exec [in] The executor object to use for scheduling of the functions *fs*.
Param fs [in] The functions which will be scheduled using the given executor.
Return The return type of `executor_type::async_invoke` if defined by `executor_type`. Otherwise a `future<void>` representing finishing the execution of all functions *fs*.

Private Functions

```
template<typename Executor, typename F, typename ...Fs>  
inline decltype(auto) friend tag_fallback_invoke(async_invoke_t, Executor &&exec, F  
                                                &&f, Fs&&... fs)
```

```
struct bulk_async_execute_t : public  
hpx::functional::detail::tag_fallback<bulk_async_execute_t>  
    #include <execution.hpp> Bulk form of asynchronous execution agent creation.
```

This asynchronously creates a group of function invocations `f(i)` whose ordering is given by the `execution_category` associated with the executor.

Here *i* takes on all values in the index space implied by `shape`. All exceptions thrown by invocations of `f(i)` are reported in a manner consistent with parallel algorithm execution through the returned future.

Note: This is deliberately different from the `bulk_async_execute` customization points specified in P0443. The `bulk_async_execute` customization point defined here is more generic and is used as the workhorse for implementing the specified APIs.

Note: This calls `exec.bulk_async_execute(f, shape, ts...)` if it exists; otherwise it executes `async_execute(f, shape, ts...)` as often as needed.

Param exec [in] The executor object to use for scheduling of the function *f*.

Param f [in] The function which will be scheduled using the given executor.

Param shape [in] The shape objects which defines the iteration boundaries for the arguments to be passed to *f*.

Param ts [in] Additional arguments to use to invoke *f*.

Return The return type of `executor_type::bulk_async_execute` if defined by `executor_type`. Otherwise a vector of futures holding the returned values of each invocation of *f*.

Private Functions

```
template<typename Executor, typename F, typename Shape, typename ...Ts>
inline decltype(auto) friend tag_fallback_invoke(bulk_async_execute_t, Executor &&exec,
                                                F &&f, Shape const &shape, Ts&&... ts)
```

```
template<typename Executor, typename F, typename Shape, typename ...Ts>
inline decltype(auto) friend tag_fallback_invoke(bulk_async_execute_t tag, Executor
                                                &&exec, F &&f, Shape const &shape,
                                                Ts&&... ts)
```

```
struct bulk_sync_execute_t : public hpx::functional::detail::tag_fallback<bulk_sync_execute_t>
#include <execution.hpp> Bulk form of synchronous execution agent creation.
```

This synchronously creates a group of function invocations `f(i)` whose ordering is given by the `execution_category` associated with the executor. The function synchronizes the execution of all scheduled functions with the caller.

Here *i* takes on all values in the index space implied by `shape`. All exceptions thrown by invocations of `f(i)` are reported in a manner consistent with parallel algorithm execution through the returned future.

Note: This is deliberately different from the `bulk_sync_execute` customization points specified in P0443. The `bulk_sync_execute` customization point defined here is more generic and is used as the workhorse for implementing the specified APIs.

Note: This calls `exec.bulk_sync_execute(f, shape, ts...)` if it exists; otherwise it executes `sync_execute(f, shape, ts...)` as often as needed.

Param exec [in] The executor object to use for scheduling of the function *f*.

Param f [in] The function which will be scheduled using the given executor.

Param shape [in] The shape objects which defines the iteration boundaries for the arguments to be passed to *f*.

Param ts [in] Additional arguments to use to invoke *f*.

Return The return type of *executor_type::bulk_sync_execute* if defined by *executor_type*. Otherwise a vector holding the returned values of each invocation of *f* except when *f* returns void, which case void is returned.

Private Functions

```
template<typename Executor, typename F, typename Shape, typename ...Ts>
inline decltype(auto) friend tag_fallback_invoke(bulk_sync_execute_t, Executor &&exec,
                                                F &&f, Shape const &shape, Ts&&... ts)
```

```
template<typename Executor, typename F, typename Shape, typename ...Ts>
inline decltype(auto) friend tag_fallback_invoke(bulk_sync_execute_t tag, Executor
                                                &&exec, F &&f, Shape const &shape,
                                                Ts&&... ts)
```

```
struct bulk_then_execute_t : public hpx::functional::detail::tag_fallback<bulk_then_execute_t>
    #include <execution.hpp> Bulk form of execution agent creation depending on a given future.
```

This creates a group of function invocations *f*(*i*) whose ordering is given by the *execution_category* associated with the executor.

Here *i* takes on all values in the index space implied by *shape*. All exceptions thrown by invocations of *f*(*i*) are reported in a manner consistent with parallel algorithm execution through the returned future.

Note: This is deliberately different from the *then_sync_execute* customization points specified in P0443. The *bulk_then_execute* customization point defined here is more generic and is used as the workhorse for implementing the specified APIs.

Note: This calls *exec.bulk_then_execute*(*f*, *shape*, *pred*, *ts*...) if it exists; otherwise it executes *sync_execute*(*f*, *shape*, *pred.share*(), *ts*...) (if this executor is also an *OneWayExecutor*), or *async_execute*(*f*, *shape*, *pred.share*(), *ts*...) (if this executor is also a *TwoWayExecutor*) - as often as needed.

Param exec [in] The executor object to use for scheduling of the function *f*.

Param f [in] The function which will be scheduled using the given executor.

Param shape [in] The shape objects which defines the iteration boundaries for the arguments to be passed to *f*.

Param predecessor [in] The future object the execution of the given function depends on.

Param ts [in] Additional arguments to use to invoke *f*.

Return The return type of *executor_type::bulk_then_execute* if defined by *executor_type*. Otherwise a vector holding the returned values of each invocation of *f*.

Private Functions

```
template<typename Executor, typename F, typename Shape, typename Future, typename
...Ts>
```

```
inline decltype(auto) friend tag_fallback_invoke(bulk_then_execute_t, Executor &&exec,
F &&f, Shape const &shape, Future
&&predecessor, Ts&&... ts)
```

```
template<typename Executor, typename F, typename Shape, typename Future, typename
...Ts>
```

```
inline decltype(auto) friend tag_fallback_invoke(bulk_then_execute_t tag, Executor
&&exec, F &&f, Shape const &shape,
Future &&predecessor, Ts&&... ts)
```

```
struct post_t : public hpx::functional::detail::tag_fallback<post_t>
```

#include <*execution.hpp*> Customization point for asynchronous fire & forget execution agent creation.

This asynchronously (fire & forget) creates a single function invocation *f*() using the associated executor.

Note: This is valid for two way executors (calls `exec.post(f, ts...)`, if available, otherwise it calls `exec.async_execute(f, ts...)` while discarding the returned future), and for non-blocking two way executors (calls `exec.post(f, ts...)` if it exists).

Param *exec* [in] The executor object to use for scheduling of the function *f*.

Param *f* [in] The function which will be scheduled using the given executor.

Param *ts* [in] Additional arguments to use to invoke *f*.

Private Functions

```
template<typename Executor, typename F, typename ...Ts>
```

```
inline decltype(auto) friend tag_fallback_invoke(post_t, Executor &&exec, F &&f,
Ts&&... ts)
```

```
struct sync_execute_t : public hpx::functional::detail::tag_fallback<sync_execute_t>
```

#include <*execution.hpp*> Customization point for synchronous execution agent creation.

This synchronously creates a single function invocation *f*() using the associated executor. The execution of the supplied function synchronizes with the caller

Note: It will call `tag_invoke(sync_execute_t, exec, f, ts...)` if it exists. For two-way executors it will invoke `async_execute_t` and wait for the task's completion before returning.

Param *exec* [in] The executor object to use for scheduling of the function *f*.

Param *f* [in] The function which will be scheduled using the given executor.

Param *ts* [in] Additional arguments to use to invoke *f*.

Return *f*(*ts...*)'s result

Private Functions

```
template<typename Executor, typename F, typename ...Ts>
inline decltype(auto) friend tag_fallback_invoke(sync_execute_t, Executor &&exec, F
&&f, Ts&&... ts)
```

```
struct sync_invoke_t : public hpx::functional::detail::tag_fallback<sync_invoke_t>
```

#include <execution.hpp> Synchronously invoke the given set of nullary functions, each on its own execution agent

This creates a group of function invocations whose ordering is given by the `execution_category` associated with the executor.

All exceptions thrown by invocations of the functions are reported in a manner consistent with parallel algorithm execution through the returned future.

Note: This calls `exec.sync_invoke(fs...)` if it exists; otherwise it executes `sync_execute(fs)` for each `fs`.

Param exec [in] The executor object to use for scheduling of the functions *fs*.

Param fs [in] The functions which will be scheduled using the given executor.

Return The return type of `executor_type::async_invoke` if defined by `executor_type`.

Private Functions

```
template<typename Executor, typename F, typename ...Fs>
inline decltype(auto) friend tag_fallback_invoke(sync_invoke_t, Executor &&exec, F &&f,
Fs&&... fs)
```

```
struct then_execute_t : public hpx::functional::detail::tag_fallback<then_execute_t>
```

#include <execution.hpp> Customization point for execution agent creation depending on a given future.

This creates a single function invocation `f()` using the associated executor after the given future object has become ready.

Note: This is valid for two way executors (calls `exec.then_execute(f, predecessor, ts...)` if it exists) and for one way executors (calls `predecessor.then(bind(f, ts...))`).

Param exec [in] The executor object to use for scheduling of the function *f*.

Param f [in] The function which will be scheduled using the given executor.

Param predecessor [in] The future object the execution of the given function depends on.

Param ts [in] Additional arguments to use to invoke *f*.

Return `f(ts...)`'s result through a future

Private Functions

```
template<typename Executor, typename F, typename Future, typename ...Ts>
inline decltype(auto) friend tag_fallback_invoke(then_execute_t, Executor &&exec, F
&&f, Future &&predecessor, Ts&&... ts)
```

hpx/execution_base/receiver.hpp

Defined in header hpx/execution_base/receiver.hpp.

See *Public API* for a list of names and headers that are part of the public *HPX* API.

```
namespace hpx
```

```
namespace execution
```

```
namespace experimental
```

Functions

```
template<typename R, typename ...As>
void set_value(R &&r, As&&... as)
```

`set_value` is a customization point object. The expression `hpx::execution::set_value(r, as...)` is equivalent to:

- `r.set_value(as...)`, if that expression is valid. If the function selected does not send the value(s) `as...` to the Receiver `r`'s value channel, the program is ill-formed (no diagnostic required).
- Otherwise, `set_value(r, as...)`, if that expression is valid, with overload resolution performed in a context that include the declaration `void set_value()`;
- Otherwise, the expression is ill-formed.

The customization is implemented in terms of `hpx::functional::tag_invoke`.

```
template<typename R>
void set_stopped(R &&r)
```

`set_stopped` is a customization point object. The expression `hpx::execution::set_stopped(r)` is equivalent to:

- `r.set_stopped()`, if that expression is valid. If the function selected does not signal the Receiver `r`'s done channel, the program is ill-formed (no diagnostic required).
- Otherwise, `set_stopped(r)`, if that expression is valid, with overload resolution performed in a context that include the declaration `void set_stopped()`;
- Otherwise, the expression is ill-formed.

The customization is implemented in terms of `hpx::functional::tag_invoke`.

```
template<typename R, typename E>
void set_error(R &&r, E &&e)
```

`set_error` is a customization point object. The expression `hpx::execution::set_error(r, e)` is equivalent to:

- `r.set_error(e)`, if that expression is valid. If the function selected does not send the error `e` the Receiver `r`'s error channel, the program is ill-formed (no diagnostic required).
- Otherwise, `set_error(r, e)`, if that expression is valid, with overload resolution performed in a context that include the declaration `void set_error()`;

- Otherwise, the expression is ill-formed.
The customization is implemented in terms of `hpx::functional::tag_invoke`.

Variables

hpx::execution::experimental::set_value_t **set_value**

hpx::execution::experimental::set_error_t **set_error**

hpx::execution::experimental::set_stopped_t **set_stopped**

template<typename **T**, typename **E** = *std::exception_ptr*>

constexpr bool **is_receiver_v** = *is_receiver<T, E>::value*

template<typename **T**, typename **CS**>

constexpr bool **is_receiver_of_v** = *is_receiver_of<T, CS>::value*

template<typename **T**, typename **CS**>

constexpr bool **is_nothrow_receiver_of_v** = *is_nothrow_receiver_of<T, CS>::value*

template<typename **T**, typename **CS**>

struct **is_nothrow_receiver_of** : public

*hpx::execution::experimental::detail::is_nothrow_receiver_of_impl<is_receiver_v<T> &&
is_receiver_of_v<T, CS>, T, CS>*

template<typename **T**, typename **E**>

struct **is_receiver**

#include <receiver.hpp> Receiving values from asynchronous computations is handled by the `Receiver` concept. A `Receiver` needs to be able to receive an error or be marked as being canceled. As such, the `Receiver` concept is defined by having the following two customization points defined, which form the completion-signal operations:

- `hpx::execution::experimental::set_stopped * hpx::execution::experimental::set_error`

Those two functions denote the completion-signal operations. The `Receiver` contract is as follows:

- None of a `Receiver`'s completion-signal operation shall be invoked before `hpx::execution::experimental::start` has been called on the operation state object that was returned by connecting a `Receiver` to a sender `hpx::execution::experimental::connect`.
- Once `hpx::execution::start` has been called on the operation state object, exactly one of the `Receiver`'s completion-signal operation shall complete without an exception before the `Receiver` is destroyed

Once one of the `Receiver`'s completion-signal operation has been completed without throwing an exception, the `Receiver` contract has been satisfied. In other words: The asynchronous operation has been completed.

See also:

hpx::execution::experimental::is_receiver_of

template<typename **T**, typename **CS**>

```
struct is_receiver_of
```

#include <receiver.hpp> The `receiver_of` concept is a refinement of the `Receiver` concept by requiring one additional completion-signal operation:

- `hpx::execution::set_value`

The `receiver_of` concept takes a receiver and an instance of the `completion_signatures<>` class template. The `receiver_of` concept, rather than accepting a receiver and some value types, is changed to take a receiver and an instance of the `completion_signatures<>` class template. A sender uses `completion_signatures<>` to describe the signals with which it completes. The `receiver_of` concept ensures that a particular receiver is capable of receiving those signals.

This completion-signal operation adds the following to the `Receiver`'s contract:

- If `hpx::execution::set_value` exits with an exception, it is still valid to call `hpx::execution::set_error` or `hpx::execution::set_stopped`

See also:

`hpx::execution::traits::is_receiver`

```
struct set_error_t : public hpx::functional::tag_noexcept<set_error_t>
```

```
struct set_stopped_t : public hpx::functional::tag_noexcept<set_stopped_t>
```

```
struct set_value_t : public hpx::functional::tag<set_value_t>
```

hpx/execution_base/traits/is_executor_parameters.hpp

Defined in header `hpx/execution_base/traits/is_executor_parameters.hpp`.

See *Public API* for a list of names and headers that are part of the public *HPX* API.

```
template<typename Executor>
```

```
struct hpx::execution::experimental::extract_executor_parameters<Executor, std::void_t<typename Executor::executor_parameters_type>>
```

Public Types

```
using type = typename Executor::executor_parameters_type
```

```
template<typename Parameters>
```

```
struct extract_has_variable_chunk_size<Parameters, std::void_t<typename Parameters::has_variable_chunk_size>> : public true_type
```

```
template<typename Parameters>
```

```
struct extract_has_variable_chunk_size<::std::reference_wrapper<Parameters>> : public hpx::execution::experimental::extract_has_variable_chunk_size<Parameters>
```

```
template<typename Parameters>
```

```
struct extract_invokes_testing_function<::std::reference_wrapper<Parameters>> : public  
hpx::execution::experimental::extract_invokes_testing_function<Parameters>
```

```
namespace hpx
```

```
    namespace execution
```

```
        namespace experimental
```

Typedefs

```
template<typename Executor>  
using extract_executor_parameters_t = typename  
extract_executor_parameters<Executor>::type
```

Variables

```
template<typename Parameters>  
constexpr bool extract_has_variable_chunk_size_v =  
extract_has_variable_chunk_size<Parameters>::value  
  
template<typename Parameters>  
constexpr bool extract_invokes_testing_function_v =  
extract_invokes_testing_function<Parameters>::value  
  
template<typename T>  
constexpr bool is_executor_parameters_v = is_executor_parameters<T>::value  
  
template<typename Executor, typename Enable = void>  
struct extract_executor_parameters
```

Public Types

```
using type = sequential_executor_parameters  
  
template<typename Executor> executor_parameters_type > >
```

Public Types

```

using type = typename Executor::executor_parameters_type

template<typename Parameters, typename Enable = void>
struct extract_has_variable_chunk_size : public false_type

template<typename Parameters> has_variable_chunk_size > > : public true_type

template<typename Parameters> reference_wrapper< Parameters > > : public hpx::execution::ex

template<typename Parameters, typename Enable = void>
struct extract_invokes_testing_function : public false_type

template<typename Parameters> reference_wrapper< Parameters > > : public hpx::execution::ex

template<typename T>
struct is_executor_parameters : public detail::is_executor_parameters<std::decay_t<T>>

struct sequential_executor_parameters

namespace traits

```

Variables

```

template<typename T>
constexpr bool is_executor_parameters_v = is_executor_parameters<T>::value

template<typename Parameters, typename Enable>
struct is_executor_parameters

```

executors

See *Public API* for a list of names and headers that are part of the public *HPX* API.

hpx/executors/annotating_executor.hpp

Defined in header `hpx/executors/annotating_executor.hpp`.

See *Public API* for a list of names and headers that are part of the public *HPX* API.

```
namespace hpx
```

```
    namespace execution
```

```
namespace experimental
```

Functions

```
template<typename Tag, typename BaseExecutor, typename Property>  
auto tag_invoke(Tag tag, annotating_executor<BaseExecutor> const &exec, Property &&prop)  
-> de-  
cltype(annotating_executor<BaseExecutor>(std::declval<Tag>()(std::declval<BaseExecutor>(),  
std::declval<Property>()))))
```

```
template<typename Tag, typename BaseExecutor>  
auto tag_invoke(Tag tag, annotating_executor<BaseExecutor> const &exec) ->  
decltype(std::declval<Tag>()(std::declval<BaseExecutor>()))
```

```
template<typename Executor>  
constexpr auto tag_fallback_invoke(with_annotation_t, Executor &&exec, char const  
*annotation)
```

```
template<typename Executor>  
auto tag_fallback_invoke(with_annotation_t, Executor &&exec, std::string annotation)
```

```
template<typename BaseExecutor>
```

```
struct annotating_executor
```

```
#include <annotating_executor.hpp> An annotating_executor wraps any other executor and adds  
the capability to add annotations to the launched threads.
```

Public Functions

```
template<typename Executor, typename Enable =  
std::enable_if_t<hpx::traits::is_executor_any_v<Executor> &&  
!std::is_same_v<std::decay_t<Executor>, annotating_executor>>>  
inline explicit constexpr annotating_executor(Executor &&exec, char const *annotation =  
nullptr)
```

```
template<typename Executor, typename Enable =  
std::enable_if_t<hpx::traits::is_executor_any_v<Executor>>>  
inline explicit annotating_executor(Executor &&exec, std::string annotation)
```

hpx/executors/current_executor.hpp

Defined in header `hpx/executors/current_executor.hpp`.

See *Public API* for a list of names and headers that are part of the public *HPX* API.

```
namespace hpx
```

```
namespace parallel
```

```
namespace execution
```

Typedefs

```
typedef hpx::execution::parallel_executor instead
```

```
namespace this_thread
```

Functions

```
hpx::execution::parallel_executor get_executor(error_code &ec = throws)
```

Returns a reference to the executor that was used to create the current thread.

Throws If – &ec != &throws, never throws, but will set *ec* to an appropriate value when an error occurs. Otherwise, this function will throw an *hpx::exception* with an error code of *hpx::error::yield_aborted* if it is signaled with *wait_aborted*. If called outside of a HPX-thread, this function will throw an *hpx::exception* with an error code of *hpx::error::null_thread_id*. If this function is called while the thread-manager is not running, it will throw an *hpx::exception* with an error code of *hpx::error::invalid_status*.

```
namespace threads
```

Functions

```
hpx::execution::parallel_executor get_executor(thread_id_type const &id, error_code &ec = throws)
```

Returns a reference to the executor that was used to create the given thread.

Throws If – &ec != &throws, never throws, but will set *ec* to an appropriate value when an error occurs. Otherwise, this function will throw an *hpx::exception* with an error code of *hpx::error::yield_aborted* if it is signaled with *wait_aborted*. If called outside of a HPX-thread, this function will throw an *hpx::exception* with an error code of *hpx::error::null_thread_id*. If this function is called while the thread-manager is not running, it will throw an *hpx::exception* with an error code of *hpx::error::invalid_status*.

hpx/executors/exception_list.hpp

Defined in header `hpx/executors/exception_list.hpp`.

See *Public API* for a list of names and headers that are part of the public *HPX* API.

```
namespace hpx
```

```
    namespace parallel
```

hpx::execution::seq, **hpx::execution::par,** **hpx::execution::par_unseq,**
hpx::execution::task, **hpx::execution::sequenced_policy,** **hpx::execution::parallel_policy,**
hpx::execution::parallel_unsequenced_policy, **hpx::execution::sequenced_task_policy,**
hpx::execution::parallel_task_policy

Defined in header `hpx/execution.hpp`⁷¹⁸.

See *Public API* for a list of names and headers that are part of the public *HPX* API.

namespace **hpx**

namespace **execution**

Typedefs

using **sequenced_task_policy** = detail::sequenced_task_policy_shim<*sequenced_executor*,
hpx::traits::executor_parameters_type_t<sequenced_executor>>>

Extension: The class `sequenced_task_policy` is an execution policy type used as a unique type to disambiguate parallel algorithm overloading and indicate that a parallel algorithm's execution may not be parallelized (has to run sequentially).

The algorithm returns a future representing the result of the corresponding algorithm when invoked with the `sequenced_policy`.

using **sequenced_policy** = detail::sequenced_policy_shim<*sequenced_executor*,
hpx::traits::executor_parameters_type_t<sequenced_executor>>>

The class `sequenced_policy` is an execution policy type used as a unique type to disambiguate parallel algorithm overloading and require that a parallel algorithm's execution may not be parallelized.

using **parallel_task_policy** = detail::parallel_task_policy_shim<*parallel_executor*,
hpx::traits::executor_parameters_type_t<parallel_executor>>>

Extension: The class `parallel_task_policy` is an execution policy type used as a unique type to disambiguate parallel algorithm overloading and indicate that a parallel algorithm's execution may be parallelized.

The algorithm returns a future representing the result of the corresponding algorithm when invoked with the `parallel_policy`.

using **parallel_policy** = detail::parallel_policy_shim<*parallel_executor*,
hpx::traits::executor_parameters_type_t<parallel_executor>>>

The class `parallel_policy` is an execution policy type used as a unique type to disambiguate parallel algorithm overloading and indicate that a parallel algorithm's execution may be parallelized.

using **parallel_unsequenced_task_policy** =
detail::parallel_unsequenced_task_policy_shim<*parallel_executor*,
hpx::traits::executor_parameters_type_t<parallel_executor>>>

The class `parallel_unsequenced_task_policy` is an execution policy type used as a unique type to disambiguate parallel algorithm overloading and indicate that a parallel algorithm's execution may be parallelized and vectorized.

⁷¹⁸ http://github.com/STELLAR-GROUP/hpx/blob/8a3b7c1a4cb5693b2f7d9f587f759392ed0c51a0/libs/core/include_local/include/hpx/execution.hpp

```
using parallel_unsequenced_policy =
detail::parallel_unsequenced_policy_shim<parallel_executor,
hpx::traits::executor_parameters_type_t<parallel_executor>>
```

The class `parallel_unsequenced_policy` is an execution policy type used as a unique type to disambiguate parallel algorithm overloading and indicate that a parallel algorithm's execution may be parallelized and vectorized.

```
using unsequenced_task_policy = detail::unsequenced_task_policy_shim<sequenced_executor,
hpx::traits::executor_parameters_type_t<sequenced_executor>>
```

The class `unsequenced_task_policy` is an execution policy type used as a unique type to disambiguate parallel algorithm overloading and indicate that a parallel algorithm's execution may be vectorized.

```
using unsequenced_policy = detail::unsequenced_policy_shim<sequenced_executor,
hpx::traits::executor_parameters_type_t<sequenced_executor>>
```

The class `unsequenced_policy` is an execution policy type used as a unique type to disambiguate parallel algorithm overloading and indicate that a parallel algorithm's execution may be vectorized.

Variables

```
constexpr task_policy_tag task = {}
```

```
constexpr non_task_policy_tag non_task = {}
```

```
constexpr sequenced_policy seq = {}
```

Default sequential execution policy object.

```
constexpr parallel_policy par = {}
```

Default parallel execution policy object.

```
constexpr parallel_unsequenced_policy par_unseq = {}
```

Default vector execution policy object.

```
constexpr unsequenced_policy unseq = {}
```

Default vector execution policy object.

```
struct non_task_policy_tag : public hpx::execution::experimental::to_non_task_t
```

```
struct task_policy_tag : public hpx::execution::experimental::to_task_t
```

```
namespace experimental
```

```
template<>
```

```
struct is_execution_policy_mapping<non_task_policy_tag> : public true_type
```

```
template<>
```

```
struct is_execution_policy_mapping<task_policy_tag> : public true_type
```

hpx/executors/execution_policy_annotation.hpp

Defined in header `hpx/executors/execution_policy_annotation.hpp`.

See *Public API* for a list of names and headers that are part of the public *HPX* API.

```
namespace hpx
```

```
    namespace execution
```

```
        namespace experimental
```

Functions

```
template<typename ExPolicy>  
constexpr decltype(auto) tag_invoke(hpx::execution::experimental::with_annotation_t, ExPolicy  
                                     &&policy, char const *annotation)
```

```
template<typename ExPolicy>  
decltype(auto) tag_invoke(hpx::execution::experimental::with_annotation_t, ExPolicy &&policy,  
                           std::string annotation)
```

```
template<typename ExPolicy>  
constexpr decltype(auto) tag_invoke(hpx::execution::experimental::get_annotation_t, ExPolicy  
                                     &&policy)
```

hpx/executors/execution_policy_mappings.hpp

Defined in header `hpx/executors/execution_policy_mappings.hpp`.

See *Public API* for a list of names and headers that are part of the public *HPX* API.

```
namespace hpx
```

```
    namespace execution
```

```
        namespace experimental
```

Variables

```
template<typename Tag>  
constexpr bool is_execution_policy_mapping_v = is_execution_policy_mapping<Tag>::value
```

```
hpx::execution::experimental::to_non_par_t to_non_par
```

```
hpx::execution::experimental::to_par_t to_par
```

hpx::execution::experimental::to_non_task_t to_non_task

hpx::execution::experimental::to_task_t to_task

hpx::execution::experimental::to_non_unseq_t to_non_unseq

hpx::execution::experimental::to_unseq_t to_unseq

```
template<typename Tag>
struct is_execution_policy_mapping : public false_type

template<>
struct is_execution_policy_mapping<to_non_par_t> : public true_type

template<>
struct is_execution_policy_mapping<to_non_task_t> : public true_type

template<>
struct is_execution_policy_mapping<to_non_unseq_t> : public true_type

template<>
struct is_execution_policy_mapping<to_par_t> : public true_type

template<>
struct is_execution_policy_mapping<to_task_t> : public true_type

template<>
struct is_execution_policy_mapping<to_unseq_t> : public true_type

struct to_non_par_t : public hpx::functional::detail::tag_fallback<to_non_par_t>
```

Private Functions

```
template<typename ExPolicy>
inline constexpr decltype(auto) friend tag_fallback_invoke(to_non_par_t, ExPolicy
&&policy) noexcept

struct to_non_task_t : public hpx::functional::detail::tag_fallback<to_non_task_t>
    Subclassed by hpx::execution::non_task_policy_tag
```

Private Functions

```
template<typename ExPolicy>
inline constexpr decltype(auto) friend tag_fallback_invoke(to_non_task_t, ExPolicy
&&policy) noexcept
```

```
struct to_non_unseq_t : public hpx::functional::detail::tag_fallback<to_non_unseq_t>
```

Private Functions

```
template<typename ExPolicy>
inline constexpr decltype(auto) friend tag_fallback_invoke(to_non_unseq_t, ExPolicy
&&policy) noexcept
```

```
struct to_par_t : public hpx::functional::detail::tag_fallback<to_par_t>
```

Private Functions

```
template<typename ExPolicy>
inline constexpr decltype(auto) friend tag_fallback_invoke(to_par_t, ExPolicy &&policy)
noexcept
```

```
struct to_task_t : public hpx::functional::detail::tag_fallback<to_task_t>
```

Subclassed by *hpx::execution::task_policy_tag*

Private Functions

```
template<typename ExPolicy>
inline constexpr decltype(auto) friend tag_fallback_invoke(to_task_t, ExPolicy &&policy)
noexcept
```

```
struct to_unseq_t : public hpx::functional::detail::tag_fallback<to_unseq_t>
```

Private Functions

```
template<typename ExPolicy>
inline constexpr decltype(auto) friend tag_fallback_invoke(to_unseq_t, ExPolicy
&&policy) noexcept
```

hpx/executors/execution_policy_parameters.hpp

Defined in header hpx/executors/execution_policy_parameters.hpp.

See *Public API* for a list of names and headers that are part of the public *HPX* API.

```
namespace hpx
```

```
    namespace execution
```

```
        namespace experimental
```

Functions

```
template<typename ExPolicy>
constexpr decltype(auto) tag_invoke(with_processing_units_count_t, ExPolicy &&policy,
                                     std::size_t num_cores)
```

```
template<typename ExPolicy, typename Params>
constexpr decltype(auto) tag_invoke(with_processing_units_count_t, ExPolicy &&policy, Params
                                     &&params)
```

```
template<typename ParametersProperty, typename ExPolicy, typename Params>
constexpr decltype(auto) tag_fallback_invoke(ParametersProperty, ExPolicy &&policy,
                                             Params &&params)
```

```
template<typename ParametersProperty, typename ExPolicy, typename ...Ts>
constexpr auto tag_fallback_invoke(ParametersProperty prop, ExPolicy &&policy, Ts&&... ts)
    -> de-
    cltype(std::declval<ParametersProperty>())(std::declval<typename
    std::decay_t<ExPolicy>::executor_type>(),
    std::declval<Ts>()...))
```

hpx/executors/execution_policy_scheduling_property.hpp

Defined in header hpx/executors/execution_policy_scheduling_property.hpp.

See *Public API* for a list of names and headers that are part of the public *HPX* API.

```
namespace hpx
```

```
    namespace execution
```

```
        namespace experimental
```

Functions

```
template<typename Tag, typename ExPolicy, typename Property>  
constexpr decltype(auto) tag_invoke(Tag tag, ExPolicy &&policy, Property prop)
```

```
template<typename Tag, typename ExPolicy>  
constexpr decltype(auto) tag_invoke(Tag tag, ExPolicy &&policy)
```

hpx/executors/explicit_scheduler_executor.hpp

Defined in header `hpx/executors/explicit_scheduler_executor.hpp`.

See *Public API* for a list of names and headers that are part of the public *HPX* API.

```
namespace hpx
```

```
    namespace execution
```

```
        namespace experimental
```

Functions

```
template<typename BaseScheduler>  
explicit explicit_scheduler_executor(BaseScheduler &&sched) -> explicit_scheduler_executor<std::decay_t<BaseScheduler>>
```

```
template<typename Tag, typename BaseScheduler, typename Property>  
auto tag_invoke(Tag tag, explicit_scheduler_executor<BaseScheduler> const &exec, Property &&prop) -> decltype(explicit_scheduler_executor<BaseScheduler>(std::declval<Tag>()(std::declval<BaseScheduler>(), std::declval<Property>())))
```

```
template<typename Tag, typename BaseScheduler>  
auto tag_invoke(Tag tag, explicit_scheduler_executor<BaseScheduler> const &exec) -> decltype(std::declval<Tag>()(std::declval<BaseScheduler>()))
```

```
template<typename BaseScheduler>  
struct explicit_scheduler_executor
```

hpx/executors/fork_join_executor.hpp

Defined in header `hpx/executors/fork_join_executor.hpp`.

See *Public API* for a list of names and headers that are part of the public *HPX* API.

hpx/executors/parallel_executor.hpp

Defined in header `hpx/executors/parallel_executor.hpp`.

See *Public API* for a list of names and headers that are part of the public *HPX* API.

```
namespace hpx
```

```
    namespace execution
```

Typedefs

```
using parallel_executor = parallel_policy_executor<hpx::launch>
```

Functions

```
template<typename Tag, typename Policy, typename Property>
auto tag_invoke(Tag tag, parallel_policy_executor<Policy> const &exec, Property &&prop) -> de-
    cltype(std::declval<parallel_policy_executor<Policy>>().policy(std::declval<Tag>()(std::declval<Policy>
    std::declval<Property>()), parallel_policy_executor<Policy>()))
```

```
template<typename Tag, typename Policy>
auto tag_invoke(Tag tag, parallel_policy_executor<Policy> const &exec) ->
    decltype(std::declval<Tag>()(std::declval<Policy>()))
```

```
template<typename Policy>
```

```
struct parallel_policy_executor
```

#include <*parallel_executor.hpp*> A *parallel_executor* creates groups of parallel execution agents which execute in threads implicitly created by the executor. This executor prefers continuing with the creating thread first before executing newly created threads.

This executor conforms to the concepts of a *TwoWayExecutor*, and a *BulkTwoWayExecutor*

Public Types

```
using execution_category = std::conditional_t<std::is_same_v<Policy, launch::sync_policy>,
sequenced_execution_tag, parallel_execution_tag>
```

Associate the *parallel_execution_tag* executor tag type as a default with this executor, except if the given launch policy is *synch*.

```
using executor_parameters_type = experimental::default_parameters
```

Associate the *default_parameters* executor parameters type as a default with this executor.

Public Functions

```
inline explicit constexpr parallel_policy_executor(threads::thread_priority priority,
threads::thread_stacksize stacksize =
threads::thread_stacksize::default_,
threads::thread_schedule_hint
schedulehint = {}, Policy l = parallel::execution::detail::get_default_policy<Policy>::call(),
std::size_t hierarchical_threshold =
hierarchical_threshold_default_)
```

Create a new parallel executor.

```
inline explicit constexpr parallel_policy_executor(threads::thread_stacksize stacksize,
threads::thread_schedule_hint
schedulehint = {}, Policy l = parallel::execution::detail::get_default_policy<Policy>::call())
```

```
inline explicit constexpr parallel_policy_executor(threads::thread_schedule_hint
schedulehint, Policy l = parallel::execution::detail::get_default_policy<Policy>::call())
```

```
inline explicit constexpr parallel_policy_executor(Policy l)
```

```
inline constexpr parallel_policy_executor()
```

```
inline explicit constexpr parallel_policy_executor(threads::thread_pool_base *pool, Policy l,
std::size_t hierarchical_threshold =
hierarchical_threshold_default_)
```

```
inline explicit constexpr parallel_policy_executor(threads::thread_pool_base *pool,
threads::thread_priority priority =
threads::thread_priority::default_,
threads::thread_stacksize stacksize =
threads::thread_stacksize::default_,
threads::thread_schedule_hint
schedulehint = {}, Policy l = parallel::execution::detail::get_default_policy<Policy>::call(),
std::size_t hierarchical_threshold =
hierarchical_threshold_default_)
```

```
inline constexpr void set_hierarchical_threshold(std::size_t threshold) noexcept
```

```
template<typename Parameters>
```

```
inline std::size_t processing_units_count(Parameters&&, hpx::chrono::steady_duration const&
= hpx::chrono::null_duration, std::size_t = 0) const
```

Friends

```
template<typename Executor_> inline friend constexpr friend auto tag_invoke (hpx::execution::
Executor_ const &exec, std::size_t num_cores) noexcept
```

```
template<typename Parameters> inline friend constexpr friend std::size_t tag_invoke (hpx::e
Parameters &&, parallel_policy_executor const &exec,
hpx::chrono::steady_duration const &=hpx::chrono::null_duration,
std::size_t=0)
```

```
template<typename Executor_> inline friend constexpr friend auto tag_invoke (hpx::execution
Executor_ const &exec, std::size_t first_core) noexcept
```

```
inline friend constexpr friend std::size_t tag_invoke (hpx::execution::experimental::get_fi
parallel_policy_executor const &exec) noexcept
```

```
inline friend auto tag_invoke(hpx::execution::experimental::get_processing_units_mask_t,
parallel_policy_executor const &exec)
```

```
inline friend auto tag_invoke(hpx::execution::experimental::get_cores_mask_t,
parallel_policy_executor const &exec)
```

```
namespace experimental
```

```
namespace parallel
```

```
namespace execution
```

hpx/executors/parallel_executor_aggregated.hpp

Defined in header `hpx/executors/parallel_executor_aggregated.hpp`.

See *Public API* for a list of names and headers that are part of the public *HPX* API.

```
namespace hpx
```

```
namespace parallel
```

```
namespace execution
```

hpx/executors/restricted_thread_pool_executor.hpp

Defined in header `hpx/executors/restricted_thread_pool_executor.hpp`.

See *Public API* for a list of names and headers that are part of the public *HPX* API.

```
namespace hpx
```

```
    namespace execution
```

```
        namespace experimental
```

Typedefs

```
using restricted_thread_pool_executor = restricted_policy_executor<hpx::launch>
```

```
template<typename Policy>
```

```
class restricted_policy_executor
```

Public Types

```
using execution_category = typename embedded_executor::execution_category
```

Associate the `parallel_execution_tag` executor tag type as a default with this executor.

```
using executor_parameters_type = typename  
embedded_executor::executor_parameters_type
```

Public Functions

```
inline explicit restricted_policy_executor(std::size_t first_thread = 0, std::size_t  
    num_threads = 1, threads::thread_priority  
    priority = threads::thread_priority::default_,  
    threads::thread_stacksize stacksize =  
    threads::thread_stacksize::default_,  
    threads::thread_schedule_hint schedulehint =  
    {}, std::size_t hierarchical_threshold =  
    hierarchical_threshold_default_)
```

Create a new parallel executor.

```
inline restricted_policy_executor(restricted_policy_executor const &other)
```

```
inline restricted_policy_executor &operator=(restricted_policy_executor const &rhs)
```

Private Types

```
using embedded_executor = hpx::execution::parallel_policy_executor<Policy>
```

Private Members

```
std::uint16_t first_thread_
```

```
mutable std::atomic<std::size_t> os_thread_
```

```
embedded_executor exec_
```

Private Static Attributes

```
static constexpr std::size_t hierarchical_threshold_default_ = 6
```

hpx/executors/scheduler_executor.hpp

Defined in header `hpx/executors/scheduler_executor.hpp`.

See *Public API* for a list of names and headers that are part of the public *HPX* API.

```
namespace hpx
```

```
    namespace execution
```

```
        namespace experimental
```

Functions

```
template<typename BaseScheduler>
explicit scheduler_executor(BaseScheduler &&sched) ->
    scheduler_executor<std::decay_t<BaseScheduler>>
```

```
template<typename Tag, typename BaseScheduler, typename Property>
auto tag_invoke(Tag tag, scheduler_executor<BaseScheduler> const &exec, Property &&prop)
-> de-
    cltype(scheduler_executor<BaseScheduler>(std::declval<Tag>()(std::declval<BaseScheduler>()),
    std::declval<Property>()))
```

```
template<typename Tag, typename BaseScheduler>
auto tag_invoke(Tag tag, scheduler_executor<BaseScheduler> const &exec) ->
    decltype(std::declval<Tag>()(std::declval<BaseScheduler>()))
```

```
template<typename BaseScheduler>
```

```
struct scheduler_executor
```

hpx/executors/sequenced_executor.hpp

Defined in header hpx/executors/sequenced_executor.hpp.

See *Public API* for a list of names and headers that are part of the public *HPX* API.

```
namespace hpx
```

```
    namespace execution
```

```
        struct sequenced_executor
```

```
            #include <sequenced_executor.hpp> A sequential_executor creates groups of sequential execution agents which execute in the calling thread. The sequential order is given by the lexicographical order of indices in the index space.
```

```
        namespace experimental
```

hpx/executors/service_executors.hpp

Defined in header hpx/executors/service_executors.hpp.

See *Public API* for a list of names and headers that are part of the public *HPX* API.

```
namespace hpx
```

```
    namespace parallel
```

```
        namespace execution
```

hpx/executors/std_execution_policy.hpp

Defined in header hpx/executors/std_execution_policy.hpp.

See *Public API* for a list of names and headers that are part of the public *HPX* API.

hpx/executors/thread_pool_scheduler.hpp

Defined in header hpx/executors/thread_pool_scheduler.hpp.

See *Public API* for a list of names and headers that are part of the public *HPX* API.

```
namespace hpx
```

```
    namespace execution
```

```
        namespace experimental
```

Typedefs

```
using thread_pool_scheduler = thread_pool_policy_scheduler<hpx::launch>
```

Functions

```
template<typename Tag, typename Policy, typename Property>
auto tag_invoke(Tag tag, thread_pool_policy_scheduler<Policy> const &scheduler, Property
    &&prop) -> de-
    cltype(std::declval<thread_pool_policy_scheduler<Policy>>().policy(std::declval<Tag>()(std::decl
std::declval<Property>()), thread_pool_policy_scheduler<Policy>())
```

```
template<typename Tag, typename Policy>
auto tag_invoke(Tag tag, thread_pool_policy_scheduler<Policy> const &scheduler) ->
    decltype(std::declval<Tag>()(std::declval<Policy>()))
```

```
template<typename Policy>
```

```
struct thread_pool_policy_scheduler
```

Public Types

```
using execution_category = std::conditional_t<std::is_same_v<Policy,
    launch::sync_policy>, sequenced_execution_tag, parallel_execution_tag>
```

Public Functions

```
inline explicit constexpr thread_pool_policy_scheduler(Policy l = experimen-
    tal::detail::get_default_scheduler_policy<Policy>::c
```

```
inline explicit thread_pool_policy_scheduler(hpx::threads::thread_pool_base *pool,
    Policy l = experimen-
    tal::detail::get_default_scheduler_policy<Policy>::call())
    noexcept
```

hpx/executors/datapar/execution_policy.hpp

Defined in header `hpx/executors/datapar/execution_policy.hpp`.

See *Public API* for a list of names and headers that are part of the public *HPX* API.

hpx/executors/datapar/execution_policy_mappings.hpp

Defined in header hpx/executors/datapar/execution_policy_mappings.hpp.

See *Public API* for a list of names and headers that are part of the public *HPX* API.

filesystem

See *Public API* for a list of names and headers that are part of the public *HPX* API.

hpx/modules/filesystem.hpp

Defined in header hpx/modules/filesystem.hpp.

See *Public API* for a list of names and headers that are part of the public *HPX* API.

This file provides a compatibility layer using Boost.Filesystem for the C++17 filesystem library. It is *not* intended to be a complete compatibility layer. It only contains functions required by the HPX codebase. It also provides some functions only available in Boost.Filesystem when using C++17 filesystem.

namespace **hpx**

namespace **filesystem**

Functions

inline path **initial_path**()

inline *std::string* **basename**(path const &p)

inline path **canonical**(path const &p, path const &base)

inline path **canonical**(path const &p, path const &base, *std::error_code* &ec)

namespace **filesystem**

functional

See *Public API* for a list of names and headers that are part of the public *HPX* API.

hpx::bind, hpx::placeholders::_1, hpx::placeholders::_2, ..., hpx::placeholders::_9

Defined in header [hpx/functional.hpp](#)⁷¹⁹.

See *Public API* for a list of names and headers that are part of the public *HPX* API.

namespace **hpx**

Top level namespace.

⁷¹⁹ http://github.com/STELLAR-GROUP/hpx/blob/8a3b7c1a4cb5693b2f7d9f587f759392ed0c51a0/libs/core/include_local/include/hpx/functional.hpp

Functions

```
template<typename F, typename ...Ts, typename Enable =
std::enable_if_t<!traits::is_action_v<std::decay_t<F>>>>
constexpr detail::bound<std::decay_t<F>, util::make_index_pack_t<sizeof...(Ts)>, util::decay_unwrap_t<Ts>...> bind(F
&&f,
Ts&&...
vs)
```

The function template *bind* generates a forwarding call wrapper for *f*. Calling this wrapper is equivalent to invoking *f* with some of its arguments bound to *vs*.

Parameters

- **f** – Callable object (function object, pointer to function, reference to function, pointer to member function, or pointer to data member) that will be bound to some arguments
- **vs** – list of arguments to bind, with the unbound arguments replaced by the placeholders `_1, _2, _3...` of namespace `hpx::placeholders`

Returns A function object of unspecified type *T*, for which

```
hpx::is_bind_expression<T>::value == true.
```

namespace `placeholders`

The `hpx::placeholders` namespace contains the placeholder objects `[_1, ..., _N]` where *N* is an implementation defined maximum number.

When used as an argument in a `hpx::bind` expression, the placeholder objects are stored in the generated function object, and when that function object is invoked with unbound arguments, each placeholder `_N` is replaced by the corresponding *N*th unbound argument.

The types of the placeholder objects are `DefaultConstructible` and `CopyConstructible`, their default copy/move constructors do not throw exceptions, and for any placeholder `_N`, the type `hpx::is_placeholder<decltype(_N)>` is defined, where `hpx::is_placeholder<decltype(_N)>` is derived from `std::integral_constant<int, N>`.

Variables

```
constexpr detail::placeholder<1> _1 = {}
```

```
constexpr detail::placeholder<2> _2 = {}
```

```
constexpr detail::placeholder<3> _3 = {}
```

```
constexpr detail::placeholder<4> _4 = {}
```

```
constexpr detail::placeholder<5> _5 = {}
```

```
constexpr detail::placeholder<6> _6 = {}
```

```
constexpr detail::placeholder<7> _7 = {}
```

```
constexpr detail::placeholder<8> _8 = {}
```

```
constexpr detail::placeholder<9> _9 = {}
```

namespace **serialization**

Functions

```
template<typename Archive, typename F, typename ...Ts>  
void serialize(Archive &ar, ::hpx::detail::bound<F, Ts...> &bound, unsigned int const version = 0)
```

```
template<typename Archive, std::size_t I>  
constexpr void serialize(Archive&, ::hpx::detail::placeholder<I>&, unsigned int const = 0) noexcept
```

hpx::bind_back

Defined in header `hpx/functional.hpp`⁷²⁰.

See *Public API* for a list of names and headers that are part of the public HPX API.

namespace **hpx**

Top level namespace.

Functions

```
template<typename F, typename ...Ts>  
constexpr hpx::detail::bound_back<std::decay_t<F>, util::make_index_pack_t<sizeof...(Ts)>, util::decay_unwrap_t<Ts...>> bind
```

Function templates `bind_back` generate a forwarding call wrapper for `f`. Calling this wrapper is equivalent to invoking `f` with its last `sizeof...(Ts)` parameters bound to `vs`.

Parameters

- **f** – Callable object (function object, pointer to function, reference to function, pointer to member function, or pointer to data member) that will be bound to some arguments
- **vs** – list of the arguments to bind to the last `sizeof...(Ts)` parameters of `f`

Returns A function object of type `T` that is unspecified, except that the types of objects returned by two calls to `hpx::bind_back` with the same arguments are the same.

```
template<typename F>  
constexpr std::decay_t<F> bind_back(F &&f)
```

namespace **serialization**

⁷²⁰ http://github.com/STELLAR-GROUP/hpx/blob/8a3b7c1a4cb5693b2f7d9f587f759392ed0c51a0/libs/core/include_local/include/hpx/functional.hpp

Functions

```
template<typename Archive, typename F, typename ...Ts>
void serialize(Archive &ar, ::hpx::detail::bound_back<F, Ts...> &bound, unsigned int const version =
    0)
```

hpx::bind_front

Defined in header `hpx/functional.hpp`⁷²¹.

See *Public API* for a list of names and headers that are part of the public *HPX* API.

namespace **hpx**

Top level namespace.

Functions

```
template<typename F, typename ...Ts>
constexpr detail::bound_front<std::decay_t<F>, util::make_index_pack_t<sizeof...(Ts)>, util::decay_unwrap_t<Ts>...> bind_front(F &&f, Ts...)
```

Function template `bind_front` generates a forwarding call wrapper for `f`. Calling this wrapper is equivalent to invoking `f` with its first `sizeof...(Ts)` parameters bound to `vs`.

Parameters

- **f** – Callable object (function object, pointer to function, reference to function, pointer to member function, or pointer to data member) that will be bound to some arguments
- **vs** – list of the arguments to bind to the first or `sizeof...(Ts)` parameters of `f`

Returns A function object of type `T` that is unspecified, except that the types of objects returned by two calls to `hpx::bind_front` with the same arguments are the same.

```
template<typename F>
constexpr std::decay_t<F> bind_front(F &&f)
```

namespace **serialization**

Functions

```
template<typename Archive, typename F, typename ...Ts>
void serialize(Archive &ar, ::hpx::detail::bound_front<F, Ts...> &bound, unsigned int const version =
    0)
```

⁷²¹ http://github.com/STELLAR-GROUP/hpx/blob/8a3b7c1a4cb5693b2f7d9f587f759392ed0c51a0/libs/core/include_local/include/hpx/functional.hpp

hpx::function

Defined in header `hpx/functional.hpp`⁷²².

See *Public API* for a list of names and headers that are part of the public HPX API.

Defines

HPX_UTIL_REGISTER_FUNCTION_DECLARATION(Sig, F, Name)

HPX_UTIL_REGISTER_FUNCTION(Sig, F, Name)

namespace **hpx**

Top level namespace.

template<typename **Sig**, bool **Serializable** = false>

class **function**

#include <function.hpp> Class template *hpx::function* is a general-purpose polymorphic function wrapper. Instances of *hpx::function* can store, copy, and invoke any CopyConstructible Callable target `—` functions, lambda expressions, bind expressions, or other function objects, as well as pointers to member functions and pointers to data members. The stored callable object is called the target of *hpx::function*. If an *hpx::function* contains no target, it is called empty. Invoking the target of an empty *hpx::function* results in *hpx::error::bad_function_call* exception being thrown. *hpx::function* satisfies the requirements of CopyConstructible and CopyAssignable.

template<typename **R**, typename ...**Ts**, bool **Serializable**>

class **function**<*R*(*Ts...*), *Serializable*> : public *util::detail::basic_function*<*R*(*Ts...*), true, *Serializable*>

Public Types

using **result_type** = *R*

Public Functions

inline constexpr **function**(*std::nullptr_t* = nullptr) noexcept

function(*function* const&) = default

function(*function*&&) noexcept = default

function &**operator**=(*function* const&) = default

function &**operator**=(*function*&&) noexcept = default

~function() = default

template<typename **F**, typename **FD** = *std::decay_t*<*F*>, typename **Enable1** = *std::enable_if_t*<!*std::is_same_v*<*FD*, *function*>>, typename **Enable2** = *std::enable_if_t*<*is_invocable_r_v*<*R*, *FD*&, *Ts...*>>>

⁷²² http://github.com/STELLAR-GROUP/hpx/blob/8a3b7c1a4cb5693b2f7d9f587f759392ed0c51a0/libs/core/include_local/include/hpx/functional.hpp

```

inline function(F &&f)

template<typename F, typename FD = std::decay_t<F>, typename Enable1 =
std::enable_if_t<!std::is_same_v<FD, function>>, typename Enable2 =
std::enable_if_t<is_invocable_r_v<R, FD&, Ts...>>>
inline function &operator=(F &&f)

```

Private Types

```
using base_type = util::detail::basic_function<R(Ts...), true, Serializable>
```

```
namespace distributed
```

Typedefs

```

template<typename Sig>

using function = hpx::function<Sig, true>

```

hpx::function_ref

Defined in header `hpx/functionality.hpp`⁷²³.

See *Public API* for a list of names and headers that are part of the public HPX API.

```
namespace hpx
```

Top level namespace.

```
template<typename Sig>
```

```
class function_ref
```

#include <function_ref.hpp> *function_ref* class is a vocabulary type with reference semantics for passing entities to call.

An example use case that benefits from higher-order functions is `retry(n, f)` which attempts to call `f` up to `n` times synchronously until success. This example might model the real-world scenario of repeatedly querying a flaky web service.

```

using payload = std::optional< /* ... */ >;
// Repeatedly invokes `action` up to `times` repetitions.
// Immediately returns if `action` returns a valid `payload`.
// Returns `std::nullopt` otherwise.
payload retry(size_t times, /* ????? */ action);

```

The passed-in action should be a callable entity that takes no arguments and returns a payload. This can be done with function pointers, `hpx::function` or a template but it is much simpler with `function_ref` as seen below:

⁷²³ http://github.com/STELLAR-GROUP/hpx/blob/8a3b7c1a4cb5693b2f7d9f587f759392ed0c51a0/libs/core/include_local/include/hpx/functionality.hpp

```
payload retry(size_t times, function_ref<payload()> action);
```

```
template<typename R, typename ...Ts>
```

```
class function_ref<R(Ts...)>
```

Public Functions

```
template<typename F, typename FD = std::decay_t<F>, typename Enable =  
std::enable_if_t<!std::is_same_v<FD, function_ref> && is_invocable_r_v<R, F&, Ts...>>>  
inline function_ref(F &&f)
```

```
inline function_ref(function_ref const &other) noexcept
```

```
template<typename F, typename FD = std::decay_t<F>, typename Enable =  
std::enable_if_t<!std::is_same_v<FD, function_ref> && is_invocable_r_v<R, F&, Ts...>>>  
inline function_ref &operator=(F &&f)
```

```
inline function_ref &operator=(function_ref const &other) noexcept
```

```
template<typename F, typename T = std::remove_reference_t<F>, typename Enable =  
std::enable_if_t<!std::is_pointer_v<T>>>  
inline void assign(F &&f)
```

```
template<typename T>  
inline void assign(std::reference_wrapper<T> f_ref) noexcept
```

```
template<typename T>  
inline void assign(T *f_ptr) noexcept
```

```
inline void swap(function_ref &f) noexcept
```

```
inline R operator() (Ts... vs) const
```

```
inline std::size_t get_function_address() const
```

```
inline char const *get_function_annotation() const
```

```
inline util::itt::string_handle get_function_annotation_itt() const
```

Protected Attributes

```
R (*vptr)(void*, Ts&&...)
```

```
void *object
```

Private Types

```
using VTable = util::detail::function_ref_vtable<R(Ts...)>
```

Private Static Functions

```
template<typename T>
static inline constexpr VTable const *get_vtable() noexcept
```

```
namespace util
```

hpx::invoke

Defined in header `hpx/functional.hpp`⁷²⁴.

See *Public API* for a list of names and headers that are part of the public HPX API.

Defines

```
HPX_INVOKE_R(R, F, ...)
```

```
namespace hpx
```

Top level namespace.

Functions

```
template<typename F, typename ...Ts>
constexpr util::invoke_result_t<F, Ts&&...> invoke(F &&f, Ts&&... vs)
    noexcept(noexcept(HPX_INVOKE(HPX_FORWARD(F,
    f), HPX_FORWARD(Ts, vs)...)))
```

Invokes the given callable object `f` with the content of the argument pack `vs`

Note: This function is similar to `std::invoke` (C++17)

Parameters

- **f** – Requires to be a callable object. If `f` is a member function pointer, the first argument in the pack will be treated as the callee (this object).
- **vs** – An arbitrary pack of arguments

Throws `std::exception` – like objects thrown by call to object `f` with the argument types `vs`.

Returns The result of the callable object when it's called with the given argument types.

```
template<typename R, typename F, typename ...Ts>
```

⁷²⁴ http://github.com/STELLAR-GROUP/hpx/blob/8a3b7c1a4cb5693b2f7d9f587f759392ed0c51a0/libs/core/include_local/include/hpx/functional.hpp

```
constexpr R invoke_r(F &&f, Ts&&... vs) noexcept(noexcept(HPX_INVOKE(HPX_FORWARD(F, f),  
HPX_FORWARD(Ts, vs)...)))
```

Invokes the given callable object *f* with the content of the argument pack *vs*

Note: This function is similar to `std::invoke` (C++17)

Parameters

- **f** – Requires to be a callable object. If *f* is a member function pointer, the first argument in the pack will be treated as the callee (this object).
- **vs** – An arbitrary pack of arguments

Throws `std::exception` – like objects thrown by call to object *f* with the argument types *vs*.

Template Parameters R – The result type of the function when it's called with the content of the given argument types *vs*.

Returns The result of the callable object when it's called with the given argument types.

namespace **functional**

struct **invoke**

Public Functions

```
template<typename F, typename ...Ts>  
inline constexpr util::invoke_result_t<F, Ts&&...> operator() (F &&f, Ts&&... vs) const noexcept(noexcept(HPX_INVOKE(HPX_FORWARD(F,  
f), HPX_FORWARD(Ts, vs)...)))
```

```
template<typename R>
```

```
struct invoke_r
```

Public Functions

```
template<typename F, typename ...Ts>  
inline constexpr R operator() (F &&f, Ts&&... vs) const  
noexcept(noexcept(HPX_INVOKE(HPX_FORWARD(F, f),  
HPX_FORWARD(Ts, vs)...)))
```

hpx::invoke_fused, hpx::invoke_fused_r

Defined in header `hpx/functional.hpp`⁷²⁵.

See *Public API* for a list of names and headers that are part of the public HPX API.

namespace **hpx**

Top level namespace.

Functions

```
template<typename F, typename Tuple>
constexpr detail::invoke_fused_result_t<F, Tuple> invoke_fused(F &&f, Tuple &&t) noexcept(
    noexcept(detail::invoke_fused_impl(detail::fused_index_pack_t<Tuple> {},
    HPX_FORWARD(F, f),
    HPX_FORWARD(Tuple, t))))
```

Invokes the given callable object `f` with the content of the sequenced type `t` (tuples, pairs).

Note: This function is similar to `std::apply` (C++17). The difference between `hpx::invoke` and `hpx::invoke_fused` is that the later unpacks the tuples while the former cannot. Turning a tuple into a parameter pack is not a trivial operation which makes `hpx::invoke_fused` rather useful.

Parameters

- **f** – Must be a callable object. If `f` is a member function pointer, the first argument in the sequenced type will be treated as the callee (this object).
- **t** – A type whose contents are accessible through a call to `hpx::get`.

Throws `std::exception` – like objects thrown by call to object `f` with the arguments contained in the sequenceable type `t`.

Returns The result of the callable object when it's called with the content of the given sequenced type.

```
template<typename R, typename F, typename Tuple>
constexpr R invoke_fused_r(F &&f, Tuple &&t) noexcept(
    noexcept(detail::invoke_fused_impl(detail::fused_index_pack_t<Tuple> {},
    HPX_FORWARD(F, f), HPX_FORWARD(Tuple, t))))
```

Invokes the given callable object `f` with the content of the sequenced type `t` (tuples, pairs).

Note: This function is similar to `std::apply` (C++17). The difference between `hpx::invoke` and `hpx::invoke_fused` is that the later unpacks the tuples while the former cannot. Turning a tuple into a parameter pack is not a trivial operation which makes `hpx::invoke_fused` rather useful.

Note: The difference between `hpx::invoke_fused` and `hpx::invoke_fused_r` is that the later allows to specify the return type as well.

⁷²⁵ http://github.com/STELLAR-GROUP/hpx/blob/8a3b7c1a4cb5693b2f7d9f587f759392ed0c51a0/libs/core/include_local/include/hpx/functional.hpp

Parameters

- **f** – Must be a callable object. If **f** is a member function pointer, the first argument in the sequenced type will be treated as the callee (this object).
- **t** – A type whose contents are accessible through a call to `hpx::get`.

Throws `std::exception` – like objects thrown by call to object **f** with the arguments contained in the sequenceable type **t**.

Template Parameters **R** – The result type of the function when it's called with the content of the given sequenced type.

Returns The result of the callable object when it's called with the content of the given sequenced type.

hpx::mem_fn

Defined in header `hpx/functional.hpp`⁷²⁶.

See *Public API* for a list of names and headers that are part of the public *HPX* API.

namespace **hpx**

Top level namespace.

Functions

```
template<typename M, typename C>
constexpr detail::mem_fn<M C::*> mem_fn(M C::* pm) noexcept
```

Function template `hpx::mem_fn` generates wrapper objects for pointers to members, which can store, copy, and invoke a pointer to member. Both references and pointers (including smart pointers) to an object can be used when invoking a `hpx::mem_fn`.

Parameters **pm** – pointer to member that will be wrapped

Returns a call wrapper of unspecified type with the following member:

```
template <typename... Ts>
constexpr typename util::invoke_result<MemberPointer, Ts...>::type
operator()(Ts&&... vs) noexcept;
```

Let **fn** be the call wrapper returned by a call to `hpx::mem_fn` with a pointer to member **pm**. Then the expression `fn(t,a2,...,aN)` is equivalent to `HPX_INVOKE(pm,t,a2,...,aN)`. Thus, the return type of `operator()` is `std::result_of<decltype(pm)(Ts&&...)>::type` or equivalently `std::invoke_result_t<decltype(pm),Ts&&...>`, and the value in `noexcept` specifier is equal to `std::is_nothrow_invocable_v<decltype(pm),Ts&&...>`. Each argument in **vs** is perfectly forwarded, as if by `std::forward<Ts>(vs)...`

```
template<typename R, typename C, typename ...Ps>
constexpr detail::mem_fn<R (C::*)(Ps...)> mem_fn(R (C::* pm)(Ps...)) noexcept
```

Function template `hpx::mem_fn` generates wrapper objects for pointers to members, which can store, copy, and invoke a pointer to member. Both references and pointers (including smart pointers) to an object can be used when invoking a `hpx::mem_fn`.

⁷²⁶ http://github.com/STELLAR-GROUP/hpx/blob/8a3b7c1a4cb5693b2f7d9f587f759392ed0c51a0/libs/core/include_local/include/hpx/functional.hpp

Parameters `pm` – pointer to member that will be wrapped

Returns a call wrapper of unspecified type with the following member:

```
template <typename... Ts>
constexpr typename util::invoke_result<MemberPointer, Ts...>::type
operator()(Ts&&... vs) noexcept;
```

Let `fn` be the call wrapper returned by a call to `hpx::mem_fn` with a pointer to member `pm`. Then the expression `fn(t,a2,...,aN)` is equivalent to `HPX_INVOKE(pm,t,a2,...,aN)`. Thus, the return type of `operator()` is `std::result_of<decltype(pm)(Ts&&...)>::type` or equivalently `std::invoke_result_t<decltype(pm),Ts&&...>`, and the value in `noexcept` specifier is equal to `std::is_nothrow_invocable_v<decltype(pm),Ts&&...>`. Each argument in `vs` is perfectly forwarded, as if by `std::forward<Ts>(vs)...`.

```
template<typename R, typename C, typename ...Ps>
constexpr detail::mem_fn<R(C::*)(Ps...) const> mem_fn(R(C::* pm)(Ps...) const) noexcept
```

Function template `hpx::mem_fn` generates wrapper objects for pointers to members, which can store, copy, and invoke a pointer to member. Both references and pointers (including smart pointers) to an object can be used when invoking a `hpx::mem_fn`.

Parameters `pm` – pointer to member that will be wrapped

Returns a call wrapper of unspecified type with the following member:

```
template <typename... Ts>
constexpr typename util::invoke_result<MemberPointer, Ts...>::type
operator()(Ts&&... vs) noexcept;
```

Let `fn` be the call wrapper returned by a call to `hpx::mem_fn` with a pointer to member `pm`. Then the expression `fn(t,a2,...,aN)` is equivalent to `HPX_INVOKE(pm,t,a2,...,aN)`. Thus, the return type of `operator()` is `std::result_of<decltype(pm)(Ts&&...)>::type` or equivalently `std::invoke_result_t<decltype(pm),Ts&&...>`, and the value in `noexcept` specifier is equal to `std::is_nothrow_invocable_v<decltype(pm),Ts&&...>`. Each argument in `vs` is perfectly forwarded, as if by `std::forward<Ts>(vs)...`.

hpx::move_only_function

Defined in header `hpx/functional.hpp`⁷²⁷.

See *Public API* for a list of names and headers that are part of the public *HPX* API.

⁷²⁷ http://github.com/STELLAR-GROUP/hpx/blob/8a3b7c1a4cb5693b2f7d9f587f759392ed0c51a0/libs/core/include_local/include/hpx/functional.hpp

Defines

HPX_UTIL_REGISTER_UNIQUE_FUNCTION_DECLARATION(Sig, F, Name)

HPX_UTIL_REGISTER_UNIQUE_FUNCTION(Sig, F, Name)

namespace **hpx**

Top level namespace.

template<typename **Sig**, bool **Serializable** = false>

class **move_only_function**

#include <move_only_function.hpp> Class template *hpx::move_only_function* is a general-purpose polymorphic function wrapper. *hpx::move_only_function* objects can store and invoke any constructible (not required to be move constructible) Callable target $\&\#8212$; functions, lambda expressions, bind expressions, or other function objects, as well as pointers to member functions and pointers to member objects.

The stored callable object is called the target of *hpx::move_only_function*. If an *hpx::move_only_function* contains no target, it is called empty. Unlike *hpx::function*, invoking an empty *hpx::move_only_function* results in undefined behavior.

hpx::move_only_function supports every possible combination of cv-qualifiers, ref-qualifiers, and noexcept-specifiers not including volatile provided in its template parameter. These qualifiers and specifier (if any) are added to its operator(). *hpx::move_only_function* satisfies the requirements of MoveConstructible and MoveAssignable, but does not satisfy CopyConstructible or CopyAssignable.

template<typename **R**, typename ...**Ts**, bool **Serializable**>

class **move_only_function**<*R*(*Ts...*), *Serializable*> : public *util::detail::basic_function*<*R*(*Ts...*), false, *Serializable*>

Public Types

using **result_type** = *R*

Public Functions

inline constexpr **move_only_function**(*std::nullptr_t* = nullptr) noexcept

move_only_function(*move_only_function* const&) = delete

move_only_function(*move_only_function*&&) noexcept = default

move_only_function &operator=(*move_only_function* const&) = delete

move_only_function &operator=(*move_only_function*&&) noexcept = default

~**move_only_function**() = default

template<typename **F**, typename **FD** = *std::decay_t*<*F*>, typename **Enable1** = *std::enable_if_t*<!*std::is_same_v*<*FD*, *move_only_function*>>, typename **Enable2** = *std::enable_if_t*<*is_invocable_r_v*<*R*, *FD*&, *Ts...*>>>

```

inline move_only_function(F &&f)

template<typename F, typename FD = std::decay_t<F>, typename Enable1 =
std::enable_if_t<!std::is_same_v<FD, move_only_function>>, typename Enable2 =
std::enable_if_t<is_invocable_r_v<R, FD&, Ts...>>>
inline move_only_function &operator=(F &&f)

```

Private Types

```

using base_type = util::detail::basic_function<R(Ts...), false, Serializable>

```

```

namespace distributed

```

Typedefs

```

template<typename Sig>

using move_only_function = hpx::move_only_function<Sig, true>

```

hpx::reference_wrapper, **hpx::ref**, **hpx::cref**

Defined in header `hpx/functional.hpp`⁷²⁸.

See *Public API* for a list of names and headers that are part of the public HPX API.

```

template<typename T>

struct hpx::reference_wrapper<T, std::enable_if_t<traits::needs_reference_semantics_v<T>>>

```

Public Types

```

using type = T

```

Public Functions

```

reference_wrapper() = default

```

```

template<typename U, typename Enable = std::enable_if_t<!std::is_same_v<std::decay_t<U>,
reference_wrapper>>>>
inline reference_wrapper(U &&val)

```

```

inline reference_wrapper(reference_wrapper const &rhs)

```

```

reference_wrapper(reference_wrapper &&rhs) = default

```

```

inline reference_wrapper &operator=(reference_wrapper const &rhs)

```

⁷²⁸ http://github.com/STELLAR-GROUP/hpx/blob/8a3b7c1a4cb5693b2f7d9f587f759392ed0c51a0/libs/core/include_local/include/hpx/functional.hpp

```
reference_wrapper &operator=(reference_wrapper &&rhs) = default
```

```
inline operator type() const
```

```
inline type get() const
```

Private Members

```
T ptr = {}
```

```
template<typename T>
```

```
struct hpx::util::unwrap_reference<::hpx::reference_wrapper<T>>
```

Public Types

```
using type = T
```

```
template<typename T>
```

```
struct hpx::util::unwrap_reference<::hpx::reference_wrapper<T> const>
```

Public Types

```
using type = T
```

```
namespace hpx
```

Top level namespace.

Functions

```
template<typename T>  
reference_wrapper(T&) -> reference_wrapper<T>
```

```
template<typename T>  
constexpr reference_wrapper<T> ref(T &val) noexcept
```

```
template<typename T>  
void ref(T const&&) = delete
```

```
template<typename T>  
constexpr reference_wrapper<T> ref(reference_wrapper<T> val) noexcept
```

```
template<typename T>  
constexpr reference_wrapper<T const> cref(T const &val) noexcept
```

```
template<typename T>  
void cref(T const&&) = delete
```

```
template<typename T>
```

```
constexpr reference_wrapper<T const> cref(reference_wrapper<T> val) noexcept

template<typename T, typename Enable = std::enable_if_t<traits::needs_reference_semantics_v<T>>>
reference_wrapper<T> ref(T &&val) noexcept

template<typename T, typename Enable = void>

struct reference_wrapper : public std::reference_wrapper<T>
```

Public Functions

```
reference_wrapper() = delete
```

```
template<typename T> needs_reference_semantics_v< T > > >
```

Public Types

```
using type = T
```

Public Functions

```
reference_wrapper() = default
```

```
template<typename U, typename Enable = std::enable_if_t<!std::is_same_v<std::decay_t<U>,
reference_wrapper>>>
```

```
inline reference_wrapper(U &&val)
```

```
inline reference_wrapper(reference_wrapper const &rhs)
```

```
reference_wrapper(reference_wrapper &&rhs) = default
```

```
inline reference_wrapper &operator=(reference_wrapper const &rhs)
```

```
reference_wrapper &operator=(reference_wrapper &&rhs) = default
```

```
inline operator type() const
```

```
inline type get() const
```

Private Members

```
T ptr = {}
```

```
namespace traits
```

Variables

```
template<typename T>
constexpr bool needs_reference_semantics_v = needs_reference_semantics<T>::value

template<typename T>
struct needs_reference_semantics : public false_type
    Subclassed by hpx::traits::needs_reference_semantics< T const >
template<typename T>
struct needs_reference_semantics<T const> : public hpx::traits::needs_reference_semantics<T>
```

namespace **util**

```
template<typename T> reference_wrapper< T > >
```

Public Types

```
using type = T
```

```
template<typename T> reference_wrapper< T > const >
```

Public Types

```
using type = T
```

hpx::experimental::scope_exit

Defined in header `hpx/experimental/scope.hpp`.

See *Public API* for a list of names and headers that are part of the public *HPX* API.

namespace **hpx**

Top level namespace.

namespace **experimental**

Functions

```
template<typename F>
auto scope_exit(F &&f)
```

The class template `scope_exit` is a general-purpose scope guard intended to call its exit function when a scope is exited.

Template Parameters **F** – type of stored exit function

Parameters **f** – stored exit function

`hpx::experimental::scope_fail`

Defined in header `hpx/experimental/scope.hpp`.

See *Public API* for a list of names and headers that are part of the public *HPX* API.

```
namespace hpx
```

Top level namespace.

```
namespace experimental
```

Functions

```
template<typename F>
auto scope_fail(F &&f)
```

The class template `scope_fail` is a general-purpose scope guard intended to call its exit function when a scope is exited via an exception.

Template Parameters **F** – type of stored exit function

Parameters **f** – stored exit function

`hpx::experimental::scope_success`

Defined in header `hpx/experimental/scope.hpp`.

See *Public API* for a list of names and headers that are part of the public *HPX* API.

```
namespace hpx
```

Top level namespace.

```
namespace experimental
```

Functions

```
template<typename F>  
auto scope_success(F &&f)
```

The class template `scope_success` is a general-purpose scope guard intended to call its exit function when a scope is normally exited.

Template Parameters **F** – type of stored exit function

Parameters **f** – stored exit function

`hpx::is_bind_expression`

Defined in header `hpx/functional.hpp`⁷²⁹.

See *Public API* for a list of names and headers that are part of the public *HPX* API.

namespace **hpx**

Top level namespace.

Variables

```
template<typename T>  
constexpr bool is_bind_expression_v = is_bind_expression<T>::value
```

```
template<typename T>
```

```
struct is_bind_expression : public std::is_bind_expression<T>
```

#include <is_bind_expression.hpp> If `T` is the type produced by a call to `hpx::bind`, this template is derived from `std::true_type`. For any other type, this template is derived from `std::false_type`.

This template may be specialized for a user-defined type `T` to implement *UnaryTypeTrait* with base characteristic of `std::true_type` to indicate that `T` should be treated by `hpx::bind` as if it were the type of a bind subexpression: when a bind-generated function object is invoked, a bound argument of this type will be invoked as a function object and will be given all the unbound arguments passed to the bind-generated object.

Subclassed by `hpx::is_bind_expression< T const >`

```
template<typename T>
```

```
struct is_bind_expression<T const> : public hpx::is_bind_expression<T>
```

⁷²⁹ http://github.com/STELLAR-GROUP/hpx/blob/8a3b7c1a4cb5693b2f7d9f587f759392ed0c51a0/libs/core/include_local/include/hpx/functional.hpp

hpx::is_placeholder

Defined in header `hpx/functional.hpp`⁷³⁰.

See *Public API* for a list of names and headers that are part of the public *HPX* API.

namespace **hpx**

Top level namespace.

template<typename T>

struct **is_placeholder**

#include <is_placeholder.hpp> If T is a standard, Boost, or HPX placeholder (`_1`, `_2`, `_3`, ...) then this template is derived from `std::integral_constant<int,1>`, `std::integral_constant<int,2>`, `std::integral_constant<int,3>`, respectively. Otherwise, it is derived from `std::integral_constant<int,0>`.

The template may be specialized for any user-defined T type: the specialization must satisfy *UnaryTypeTrait* with base characteristic of `std::integral_constant<int,N>` with `N>0` to indicate that T should be treated as N'th placeholder type. `hpx::bind` uses `hpx::is_placeholder` to detect placeholders for unbound arguments.

futures

See *Public API* for a list of names and headers that are part of the public *HPX* API.

hpx::future, **hpx::shared_future**, **hpx::make_future**, **hpx::make_shared_future**,
hpx::make_ready_future, **hpx::make_ready_future_alloc**, **hpx::make_ready_future_at**,
hpx::make_ready_future_after, **hpx::make_exceptional_future**

Defined in header `hpx/future.hpp`⁷³¹.

See *Public API* for a list of names and headers that are part of the public *HPX* API.

Defines

HPX_MAKE_EXCEPTIONAL_FUTURE(T, errorcode, f, msg)

namespace **hpx**

Top level HPX namespace.

⁷³⁰ http://github.com/STELLAR-GROUP/hpx/blob/8a3b7c1a4cb5693b2f7d9f587f759392ed0c51a0/libs/core/include_local/include/hpx/functional.hpp

⁷³¹ <http://github.com/STELLAR-GROUP/hpx/blob/8a3b7c1a4cb5693b2f7d9f587f759392ed0c51a0/libs/full/include/include/hpx/future.hpp>

Functions

```
template<typename R, typename U>
```

```
hpx::future<R> make_future(hpx::future<U> &&f)
```

Converts any future of type U to any other future of type R based on an existing conversion path from U to R.

```
template<typename R, typename U, typename Conv>
```

```
hpx::future<R> make_future(hpx::future<U> &&f, Conv &&conv)
```

Converts any future of type U to any other future of type R based on a given conversion function: R conv(U).

```
template<typename R, typename U>
```

```
hpx::future<R> make_future(hpx::shared_future<U> f)
```

Converts any *shared_future* of type U to any other future of type R based on an existing conversion path from U to R.

```
template<typename R, typename U, typename Conv>
```

```
hpx::future<R> make_future(hpx::shared_future<U> f, Conv &&conv)
```

Converts any future of type U to any other future of type R based on an existing conversion path from U to R.

```
template<typename R>
```

```
hpx::shared_future<R> make_shared_future(hpx::future<R> &&f) noexcept
```

Converts any future or *shared_future* of type T to a corresponding *shared_future* of type T.

```
template<typename R>
```

```
hpx::shared_future<R> &make_shared_future(hpx::shared_future<R> &f) noexcept
```

Converts any future or *shared_future* of type T to a corresponding *shared_future* of type T.

```
template<typename R>
```

```
hpx::shared_future<R> &&make_shared_future(hpx::shared_future<R> &&f) noexcept
```

Converts any future or *shared_future* of type T to a corresponding *shared_future* of type T.

```
template<typename R>
```

```
hpx::shared_future<R> const &make_shared_future(hpx::shared_future<R> const &f) noexcept
```

Converts any future or *shared_future* of type T to a corresponding *shared_future* of type T.

```
template<typename T, typename Allocator, typename ...Ts>
```

```
std::enable_if_t<std::is_constructible_v<T, Ts&&...> || std::is_void_v<T>, future<T>> make_ready_future_alloc(Allocator
```

```
const  
&a,  
Ts&&...  
ts)
```

Creates a pre-initialized future object with allocator (extension)

```
template<typename T, typename ...Ts>
```

```
std::enable_if_t<std::is_constructible_v<T, Ts&&...> || std::is_void_v<T>, future<T>> make_ready_future(Ts&&...  
ts)
```

The function creates a shared state that is immediately ready and returns a future associated with that shared state. For the returned future, valid() == true and is_ready() == true.

```
template<int DeductionGuard = 0, typename Allocator, typename T>
```

```
future<hpx::util::decay_unwrap_t<T>> make_ready_future_alloc(Allocator const &a, T &&init)
```

```
template<int DeductionGuard = 0, typename T>
```

```
future<hpx::util::decay_unwrap_t<T>> make_ready_future(T &&init)
```

The function creates a shared state that is immediately ready and returns a future associated with that shared state. For the returned future, `valid() == true` and `is_ready() == true`.

```
template<typename T>
```

```
future<T> make_exceptional_future(std::exception_ptr const &e)
```

Creates a pre-initialized future object which holds the given error (extension)

```
template<typename T, typename E>
```

```
future<T> make_exceptional_future(E e)
```

Creates a pre-initialized future object which holds the given error (extension)

```
template<int DeductionGuard = 0, typename T>
```

```
future<hpx::util::decay_unwrap_t<T>> make_ready_future_at(hpx::chrono::steady_time_point const  
&abs_time, T &&init)
```

Creates a pre-initialized future object which gets ready at a given point in time (extension)

```
template<int DeductionGuard = 0, typename T>
```

```
future<hpx::util::decay_unwrap_t<T>> make_ready_future_after(hpx::chrono::steady_duration const  
&rel_time, T &&init)
```

Creates a pre-initialized future object which gets ready after a given point in time (extension)

```
template<typename Allocator>
```

```
inline future<void> make_ready_future_alloc(Allocator const &a)
```

```
future<void> make_ready_future()
```

The function creates a shared state that is immediately ready and returns a future associated with that shared state. For the returned future, `valid() == true` and `is_ready() == true`.

```
inline future<void> make_ready_future_at(hpx::chrono::steady_time_point const &abs_time)
```

Creates a pre-initialized future object which gets ready at a given point in time (extension)

```
inline future<void> make_ready_future_after(hpx::chrono::steady_duration const &rel_time)
```

Creates a pre-initialized future object which gets ready after a given point in time (extension)

```
template<typename R>
```

```
class future : public hpx::lcos::detail::future_base<future<R>, R>
```

`#include <future_fwd.hpp>` The class template `hpx::future` provides a mechanism to access the result of asynchronous operations:

- An asynchronous operation (created via `hpx::async`, `hpx::packaged_task`, or `hpx::promise`) can provide a `hpx::future` object to the creator of that asynchronous operation.
- The creator of the asynchronous operation can then use a variety of methods to query, wait for, or extract a value from the `hpx::future`. These methods may block if the asynchronous operation has not yet provided a value.
- When the asynchronous operation is ready to send a result to the creator, it can do so by modifying shared state (e.g. `hpx::promise::set_value`) that is linked to the creator's `hpx::future`. Note that `hpx::future` references shared state that is not shared with any other asynchronous return objects (as opposed to `hpx::shared_future`).

Public Types

```
using result_type = R
```

```
using shared_state_type = typename base_type::shared_state_type
```

Public Functions

```
constexpr future() noexcept = default
```

```
future(future &&other) noexcept = default
```

```
future(future const &other) noexcept = delete
```

```
inline future(future<future> &&other) noexcept
```

```
inline future(future<shared_future<R>> &&other) noexcept
```

```
template<typename T>
```

```
inline future(future<T> &&other, std::enable_if_t<std::is_void_v<R> && !traits::is_future_v<T>,
             T>* = nullptr) noexcept
```

```
~future() = default
```

```
future &operator=(future &&other) noexcept = default
```

```
future &operator=(future const &other) noexcept = delete
```

```
inline shared_future<R> share() noexcept
```

```
inline hpx::traits::future_traits<future>::result_type get()
```

```
inline hpx::traits::future_traits<future>::result_type get(error_code &ec)
```

```
template<typename F>
```

```
inline decltype(auto) then(F &&f, error_code &ec = throws)
```

Attaches a continuation to **this*. The behavior is undefined if **this* has no associated shared state (i.e., *valid()* == *false*).

In cases where *decltype(func(*this))* is *future*<*R*>, the resulting type is *future*<*R*> instead of *future*<*future*<*R*>>. Effects:

- The continuation is called when the object's shared state is ready (has a value or exception stored).
- The continuation launches according to the specified launch policy or executor.
- When the executor or launch policy is not provided the continuation inherits the parent's launch policy or executor.
- If the parent was created with *std::promise* or with a *packaged_task* (has no associated launch policy), the continuation behaves the same as the third overload with a policy argument of *launch::async* | *launch::deferred* and the same argument for *func*.
- If the parent has a policy of *launch::deferred* and the continuation does not have a specified launch policy or scheduler, then the parent is filled by immediately calling *.wait()*, and the policy of the antecedent is *launch::deferred*.

Note: Postcondition:

- The future object is moved to the parameter of the continuation function.
- *valid()* == *false* on original future object immediately after it returns.

Template Parameters

- **F** – The type of the function/function object to use (deduced). F must meet requirements of *MoveConstructible*.
- **error_code** – The type of error code.

Parameters

- **f** – A continuation to be attached.
- **ec** – Used to hold error code value originated during the operation. Defaults to *throws* — A special ‘throw on error’ *error_code*.

Returns An object of type *future<decltype(func(*this))>* that refers to the shared state created by the continuation.

```
template<typename T0, typename F>
inline decltype(auto) then(T0 &&t0, F &&f, error_code &ec = throws)
```

Attaches a continuation to **this*. The behavior is undefined if **this* has no associated shared state (i.e., *valid() == false*). \copydetail *hpx::future::then(F&& f, error_code& ec = throws)*

Note: Postcondition:

- The future object is moved to the parameter of the continuation function.
 - *valid() == false* on original future object immediately after it returns.
-

Template Parameters

- **T0** – The type of executor or launch policy.
- **F** – The type of the function/function object to use (deduced). F must meet requirements of *MoveConstructible*.
- **error_code** – The type of error code.

Parameters

- **t0** – The executor or launch policy to be used.
- **f** – A continuation to be attached.
- **ec** – Used to hold error code value originated during the operation. Defaults to *throws* — A special ‘throw on error’ *error_code*.

Returns An object of type *future<decltype(func(*this))>* that refers to the shared state created by the continuation.

```
template<typename Allocator, typename F>
inline auto then_alloc(Allocator const &alloc, F &&f, error_code &ec = throws) ->
    decltype(base_type::then_alloc(alloc, HPX_MOVE(*this),
    HPX_FORWARD(F, f), ec))
```

Private Types

```
using base_type = lcos::detail::future_base<future<R>, R>
```

Private Functions

```
inline explicit future(hpx::intrusive_ptr<shared_state_type> const &state)
```

```
inline explicit future(hpx::intrusive_ptr<shared_state_type> &&state)
```

```
template<typename SharedState>
```

```
inline explicit future(hpx::intrusive_ptr<SharedState> const &state)
```

Friends

```
friend struct hpx::traits::future_access
```

```
template<typename R>
```

```
class shared_future : public hpx::lcos::detail::future_base<shared_future<R>, R>
```

#include <*future_fwd.hpp*> The class template *hpx::shared_future* provides a mechanism to access the result of asynchronous operations, similar to *hpx::future*, except that multiple threads are allowed to wait for the same shared state. Unlike *hpx::future*, which is only moveable (so only one instance can refer to any particular asynchronous result), *hpx::shared_future* is copyable and multiple shared future objects may refer to the same shared state. Access to the same shared state from multiple threads is safe if each thread does it through its own copy of a *shared_future* object.

Public Types

```
using result_type = R
```

```
using shared_state_type = typename base_type::shared_state_type
```

Public Functions

```
constexpr shared_future() noexcept = default
```

```
shared_future(shared_future const &other) = default
```

```
shared_future(shared_future &&other) noexcept = default
```

```
inline shared_future(future<R> &&other) noexcept
```

```
inline shared_future(future<shared_future> &&other) noexcept
```

```
template<typename T>
```

```
inline shared_future(shared_future<T> const &other, std::enable_if_t<std::is_void_v<R> &&  
!traits::is_future_v<T>, T>* = nullptr)
```

```
~shared_future() = default
```

shared_future &operator=(*shared_future* const &other) = default

shared_future &operator=(*shared_future* &&other) noexcept = default

inline *hpx::traits::future_traits*<*shared_future*>::result_type get() const

inline *hpx::traits::future_traits*<*shared_future*>::result_type get(*error_code* &ec) const

template<typename **F**>

inline decltype(auto) then(*F* &&*f*, *error_code* &ec = *throws*) const

Attaches a continuation to **this*. The behavior is undefined if **this* has no associated shared state (i.e., *valid() == false*).

In cases where *decltype(func(*this))* is *future*<*R*>, the resulting type is *future*<*R*> instead of *future*<*future*<*R*>>. Effects:

- The continuation is called when the object's shared state is ready (has a value or exception stored).
- The continuation launches according to the specified launch policy or executor.
- When the executor or launch policy is not provided the continuation inherits the parent's launch policy or executor.
- If the parent was created with *std::promise* or with a *packaged_task* (has no associated launch policy), the continuation behaves the same as the third overload with a policy argument of *launch::async* | *launch::deferred* and the same argument for *func*.
- If the parent has a policy of *launch::deferred* and the continuation does not have a specified launch policy or scheduler, then the parent is filled by immediately calling *.wait()*, and the policy of the antecedent is *launch::deferred*

Note: Postcondition:

- The future object is moved to the parameter of the continuation function.
 - *valid() == false* on original future object immediately after it returns.
-

Template Parameters

- **F** – The type of the function/function object to use (deduced). **F** must meet requirements of *MoveConstructible*.
- **error_code** – The type of error code.

Parameters

- **f** – A continuation to be attached.
- **ec** – Used to hold error code value originated during the operation. Defaults to *throws* — A special 'throw on error' *error_code*.

Returns An object of type *future*<*decltype(func(*this))*> that refers to the shared state created by the continuation.

template<typename **T0**, typename **F**>

inline decltype(auto) then(*T0* &&*t0*, *F* &&*f*, *error_code* &ec = *throws*) const

Attaches a continuation to **this*. The behavior is undefined if **this* has no associated shared state (i.e., *valid() == false*). \copydetail *hpx::future::then*(*F*&& *f*, *error_code*& *ec* = *throws*)

Note: Postcondition:

- The future object is moved to the parameter of the continuation function.
 - *valid() == false* on original future object immediately after it returns.
-

Template Parameters

- **T0** – The type of executor or launch policy.
- **F** – The type of the function/function object to use (deduced). **F** must meet requirements of *MoveConstructible*.

- **error_code** – The type of error code.

Parameters

- **t0** – The executor or launch policy to be used.
- **f** – A continuation to be attached.
- **ec** – Used to hold error code value originated during the operation. Defaults to *throws* — A special ‘throw on error’ *error_code*.

Returns An object of type *future<decltype(func(*this))>* that refers to the shared state created by the continuation.

```
template<typename Allocator, typename F>
inline auto then_alloc(Allocator const &alloc, F &&f, error_code &ec = throws) ->
    decltype(base_type::then_alloc(alloc, HPX_MOVE(*this),
    HPX_FORWARD(F, f), ec))
```

Private Types

```
using base_type = lcos::detail::future_base<shared_future<R>, R>
```

Private Functions

```
inline explicit shared_future(hpx::intrusive_ptr<shared_state_type> const &state)
```

```
inline explicit shared_future(hpx::intrusive_ptr<shared_state_type> &&state)
```

```
template<typename SharedState>
```

```
inline explicit shared_future(hpx::intrusive_ptr<SharedState> const &state)
```

Friends

```
friend struct hpx::traits::future_access
```

```
namespace lcos
```

```
namespace serialization
```

Functions

```
template<typename Archive, typename T>
```

```
void serialize(Archive &ar, ::hpx::future<T> &f, unsigned version)
```

```
template<typename Archive, typename T>
```

```
void serialize(Archive &ar, ::hpx::shared_future<T> &f, unsigned version)
```

hpx/futures/future_fwd.hpp

Defined in header `hpx/futures/future_fwd.hpp`.

See *Public API* for a list of names and headers that are part of the public *HPX* API.

namespace **hpx**

Top level HPX namespace.

template<typename **R**>

class **future** : public `hpx::lcos::detail::future_base<future<R>, R>`

`#include <future_fwd.hpp>`

template<typename **R**>

class **shared_future** : public `hpx::lcos::detail::future_base<shared_future<R>, R>`

`#include <future_fwd.hpp>`

namespace **lcos**

namespace **lcos**

hpx::packaged_task

Defined in header `hpx/future.hpp`⁷³².

See *Public API* for a list of names and headers that are part of the public *HPX* API.

template<typename **Sig**, typename **Allocator**>

struct **uses_allocator**<`hpx::packaged_task<Sig>`, *Allocator*> : public `true_type`

namespace **hpx**

Top level HPX namespace.

template<typename **Sig**>

class **packaged_task**

`#include <packaged_task.hpp>` The class template `hpx::packaged_task` wraps any Callable` target (function, lambda expression, bind expression, or another function object) so that it can be invoked asynchronously. Its return value or exception thrown is stored in a shared state which can be accessed through `hpx::future` objects. Just like `hpx::function`, `hpx::packaged_task` is a polymorphic, allocator-aware container: the stored callable target may be allocated on heap or with a provided allocator.

template<typename **R**, typename ...**Ts**>

class **packaged_task**<*R*(*Ts*...)>

⁷³² <http://github.com/STELLAR-GROUP/hpx/blob/8a3b7c1a4cb5693b2f7d9f587f759392ed0c51a0/libs/full/include/include/hpx/future.hpp>

Public Functions

packaged_task() = default

```
template<typename F, typename FD = std::decay_t<F>, typename Enable =
std::enable_if_t<!std::is_same_v<FD, packaged_task> && is_invocable_r_v<R, FD&, Ts...>>>
inline explicit packaged_task(F &&f)
```

```
template<typename Allocator, typename F, typename FD = std::decay_t<F>, typename Enable =
std::enable_if_t<!std::is_same_v<FD, packaged_task> && is_invocable_r_v<R, FD&, Ts...>>>
inline explicit packaged_task(std::allocator_arg_t, Allocator const &a, F &&f)
```

packaged_task(*packaged_task* const &rhs) noexcept = delete

packaged_task(*packaged_task* &&rhs) noexcept = default

packaged_task &**operator**=(*packaged_task* const &rhs) noexcept = delete

packaged_task &**operator**=(*packaged_task* &&rhs) noexcept = default

inline void **swap**(*packaged_task* &rhs) noexcept

inline void **operator**() (Ts... ts)

inline *hpx::future*<R> **get_future**(*error_code* &ec = *throws*)

inline bool **valid**() const noexcept

inline void **reset**(*error_code* &ec = *throws*)

inline void **set_exception**(std::exception_ptr const &e)

Private Types

using **function_type** = *hpx::move_only_function*<R(Ts...)>

Private Members

function_type **function_**

hpx::promise<R> **promise_**

namespace **std**

Functions

```
template<typename Sig>
void swap(hpx::packaged_task<Sig> &lhs, hpx::packaged_task<Sig> &rhs) noexcept
```

```
template<typename Sig, typename Allocator> packaged_task< Sig >,
Allocator > : public true_type
```

hpx::promise

Defined in header `hpx/future.hpp`⁷³³.

See *Public API* for a list of names and headers that are part of the public HPX API.

```
template<typename R, typename Allocator>
struct uses_allocator<hpx::promise<R>, Allocator> : public true_type
```

namespace hpx

Top level HPX namespace.

```
template<typename R>
```

```
class promise : public hpx::detail::promise_base<R>
```

#include <promise.hpp> The class template `hpx::promise` provides a facility to store a value or an exception that is later acquired asynchronously via a `hpx::future` object created by the `hpx::promise` object. Note that the `hpx::promise` object is meant to be used only once. Each promise is associated with a shared state, which contains some state information and a result which may be not yet evaluated, evaluated to a value (possibly void) or evaluated to an exception. A promise may do three things with the shared state:

- **make ready:** the promise stores the result or the exception in the shared state. Marks the state ready and unblocks any thread waiting on a future associated with the shared state.
- **release:** the promise gives up its reference to the shared state. If this was the last such reference, the shared state is destroyed. Unless this was a shared state created by `hpx::async` which is not yet ready, this operation does not block.
- **abandon:** the promise stores the exception of type `hpx::future_error` with error code `hpx::error::broken_promise`, makes the shared state ready, and then releases it. The promise is the “push” end of the promise-future communication channel: the operation that stores a value in the shared state synchronizes-with (as defined in `hpx::memory_order`) the successful return from any function that is waiting on the shared state (such as `hpx::future::get`). Concurrent access to the same shared state may conflict otherwise: for example multiple callers of `hpx::shared_future::get` must either all be read-only or provide external synchronization.

⁷³³ <http://github.com/STELLAR-GROUP/hpx/blob/8a3b7c1a4cb5693b2f7d9f587f759392ed0c51a0/libs/full/include/include/hpx/future.hpp>

Public Functions

```
promise() = default

template<typename Allocator>
inline promise(std::allocator_arg_t, Allocator const &a)

promise(promise &&other) noexcept = default

promise(promise const &other) = delete

~promise() = default

promise &operator=(promise &&other) noexcept = default

promise &operator=(promise const &other) = delete

inline void swap(promise &other) noexcept

inline void set_value(R const &r)

inline void set_value(R &&r)

template<typename ...Ts>
inline void set_value(Ts&&... ts)
```

Private Types

```
using base_type = detail::promise_base<R>

template<typename R>

class promise<R&> : public hpx::detail::promise_base<R&>
```

Public Functions

```
promise() = default

template<typename Allocator>
inline promise(std::allocator_arg_t, Allocator const &a)

promise(promise &&other) noexcept = default

promise(promise const &other) = delete

~promise() = default

promise &operator=(promise &&other) noexcept = default

promise &operator=(promise const &other) = delete

inline void swap(promise &other) noexcept

inline void set_value(R &r)
```

Private Types

```
using base_type = detail::promise_base<R&>

template<>

class promise<void> : public hpx::detail::promise_base<void>
```

Public Functions

```
promise() = default

template<typename Allocator>
inline promise(std::allocator_arg_t, Allocator const &a)

promise(promise &&other) noexcept = default

promise(promise const &other) noexcept = delete

~promise() = default

promise &operator=(promise &&other) noexcept = default

promise &operator=(promise const &other) noexcept = delete

inline void swap(promise &other) noexcept

inline void set_value()
```

Private Types

```
using base_type = detail::promise_base<void>
```

```
namespace std
```

Functions

```
template<typename R>
void swap(hpx::promise<R> &x, hpx::promise<R> &y) noexcept

template<typename R, typename Allocator> promise< R >,
Allocator > : public true_type
```

io_service

See *Public API* for a list of names and headers that are part of the public *HPX* API.

hpx/io_service/io_service_pool.hpp

Defined in header `hpx/io_service/io_service_pool.hpp`.

See *Public API* for a list of names and headers that are part of the public *HPX* API.

namespace **hpx**

namespace **util**

class **io_service_pool**

#include <io_service_pool.hpp> A pool of `io_service` objects.

Public Functions

explicit **io_service_pool**(*std::size_t* pool_size = 2, *threads::policies::callback_notifier* const ¬ifier = *threads::policies::callback_notifier*(), char const *pool_name = "", char const *name_postfix = "")

Construct the `io_service` pool.

Parameters

- **pool_size** – [in] The number of threads to run to serve incoming requests
- **notifier** – [in]
- **pool_name** – [in]
- **name_postfix** – [in]

explicit **io_service_pool**(*threads::policies::callback_notifier* const ¬ifier, char const *pool_name = "", char const *name_postfix = "")

Construct the `io_service` pool.

Parameters

- **notifier** – [in]
- **pool_name** – [in]
- **name_postfix** – [in]

io_service_pool(*io_service_pool* const&) = delete

io_service_pool(*io_service_pool*&&) = delete

io_service_pool &**operator**=(*io_service_pool* const&) = delete

io_service_pool &**operator**=(*io_service_pool*&&) = delete

~io_service_pool()

bool **run**(bool join_threads = true, *barrier* *startup = nullptr)

Run all `io_service` objects in the pool. If `join_threads` is true this will also wait for all threads to complete

```

bool run(std::size_t num_threads, bool join_threads = true, barrier *startup = nullptr)
    Run all io_service objects in the pool. If join_threads is true this will also wait for all threads to
    complete

void stop()
    Stop all io_service objects in the pool.

void join()
    Join all io_service threads in the pool.

void clear()
    Clear all internal data structures.

void wait()
    Wait for all work to be done.

bool stopped()

asio::io_context &get_io_service(int index = -1)
    Get an io_service to use.

std::thread &get_os_thread_handle(std::size_t thread_num)
    access underlying thread handle

inline constexpr std::size_t size() const noexcept
    Get number of threads associated with this I/O service.

void thread_run(std::size_t index, barrier *startup = nullptr) const
    Activate the thread index for this thread pool.

inline constexpr char const *get_name() const noexcept
    Return name of this pool.

void init(std::size_t pool_size)

```

Protected Functions

```

bool run_locked(std::size_t num_threads, bool join_threads, barrier *startup)

void stop_locked()

void join_locked()

void clear_locked()

void wait_locked()

```

Private Types

```

using io_service_ptr = std::unique_ptr<asio::io_context>

using raw_work_type = asio::executor_work_guard<asio::io_context::executor_type>

using work_type = std::unique_ptr<raw_work_type>

```

Private Members

std::mutex **mtx_**

std::vector<io_service_ptr> **io_services_**

The pool of io_services.

std::vector<std::thread> **threads_**

std::vector<work_type> **work_**

The work that keeps the io_services running.

std::size_t **next_io_service_**

The next io_service to use for a connection.

bool **stopped_**

set to true if stopped

std::size_t **pool_size_**

initial number of OS threads to execute in this pool

threads::policies::callback_notifier const &**notifier_**

call this for each thread start/stop

char const ***pool_name_**

char const ***pool_name_postfix_**

bool **waiting_**

Set to true if waiting for work to finish.

std::unique_ptr<barrier> **wait_barrier_**

std::unique_ptr<barrier> **continue_barrier_**

Private Static Functions

static *work_type* **initialize_work**(asio::io_context &io_service)

lcos_local

See *Public API* for a list of names and headers that are part of the public *HPX* API.

hpx/lcos_local/trigger.hpp

Defined in header `hpx/lcos_local/trigger.hpp`.

See *Public API* for a list of names and headers that are part of the public *HPX* API.

```
namespace hpx
```

```
    namespace lcos
```

```
        namespace local
```

```
            template<typename Mutex = hpx::spinlock>
```

```
            struct base_trigger
```

Public Functions

```
            inline base_trigger() noexcept
```

```
            inline base_trigger(base_trigger &&rhs) noexcept
```

```
            inline base_trigger &operator=(base_trigger &&rhs) noexcept
```

```
            inline hpx::future<void> get_future(std::size_t *generation_value = nullptr, error_code &ec  
                = hpx::throws)
```

get a future allowing to wait for the trigger to fire

```
            inline bool set(error_code &ec = throws)
```

Trigger this object.

```
            inline void synchronize(std::size_t generation_value, char const *function_name =  
                "trigger::synchronize", error_code &ec = throws)
```

Wait for the generational counter to reach the requested stage.

```
            inline std::size_t next_generation()
```

```
            inline std::size_t generation() const
```

Protected Types

```
            using mutex_type = Mutex
```

Protected Functions

```
inline bool trigger_conditions(error_code &ec = throws)
```

```
template<typename Lock>
```

```
inline void synchronize(std::size_t generation_value, Lock &l, char const *function_name =  
    "trigger::synchronize", error_code &ec = throws)
```

Private Types

```
using condition_list_type = hpx::detail::intrusive_list<condition_list_entry>
```

Private Functions

```
inline bool test_condition(std::size_t const generation_value) const noexcept
```

Private Members

```
mutable mutex_type mtx_
```

```
hpx::promise<void> promise_
```

```
std::size_t generation_
```

```
condition_list_type conditions_
```

```
struct condition_list_entry : public conditional_trigger
```

Public Functions

```
condition_list_entry() = default
```

Public Members

```
condition_list_entry *prev = nullptr
```

```
condition_list_entry *next = nullptr
```

```
struct manage_condition
```

Public Functions

```

inline manage_condition(base_trigger &gate, condition_list_entry &cond) noexcept

inline ~manage_condition()

template<typename Condition>
inline hpx::future<void> get_future(Condition &&func, error_code &ec = hpx::throws)

```

Public Members

```
base_trigger &this_
```

```
condition_list_entry &e_
```

```
struct trigger : public hpx::local::local::base_trigger<hpx::no_mutex>
```

Public Functions

```
trigger() = default
```

```
inline trigger(trigger &&rhs) noexcept
```

```
inline trigger &operator=(trigger &&rhs) noexcept
```

```
template<typename Lock>
```

```
inline void synchronize(std::size_t generation_value, Lock &l, char const *function_name =
    "trigger::synchronize", error_code &ec = throws)
```

Private Types

```
using base_type = base_trigger<hpx::no_mutex>
```

pack_traversal

See *Public API* for a list of names and headers that are part of the public *HPX* API.

hpx/pack_traversal/pack_traversal.hpp

Defined in header `hpx/pack_traversal/pack_traversal.hpp`.

See *Public API* for a list of names and headers that are part of the public *HPX* API.

```
namespace hpx
```

```
    namespace util
```

Functions

```
template<typename Mapper, typename...  
T> < unspecified > map_pack (Mapper &&mapper, T &&... pack)
```

Maps the pack with the given mapper.

This function tries to visit all plain elements which may be wrapped in:

- homogeneous containers (`std::vector`, `std::list`)
- heterogeneous containers (`hpx::tuple`, `std::pair`, `std::array`) and re-assembles the pack with the result of the mapper. Mapping from one type to a different one is supported.

Elements that aren't accepted by the mapper are routed through and preserved through the hierarchy.

```
// Maps all integers to floats  
map_pack([](int value) {  
    return float(value);  
},  
1, hpx::make_tuple(2, std::vector<int>{3, 4}), 5);
```

Throws `std::exception` – like objects which are thrown by an invocation to the mapper.

Parameters

- **mapper** – A callable object, which accept an arbitrary type and maps it to another type or the same one.
- **pack** – An arbitrary variadic pack which may contain any type.

Returns The mapped element or in case the pack contains multiple elements, the pack is wrapped into a `hpx::tuple`.

hpx/pack_traversal/pack_traversal_async.hpp

Defined in header `hpx/pack_traversal/pack_traversal_async.hpp`.

See *Public API* for a list of names and headers that are part of the public *HPX* API.

namespace **hpx**

namespace **util**

Functions

```
template<typename Visitor, typename ...T>  
auto traverse_pack_async(Visitor &&visitor, T&&... pack) ->  
    decltype(detail::apply_pack_transform_async(HPX_FORWARD(Visitor,  
        visitor), HPX_FORWARD(T, pack)...))
```

Traverses the pack with the given visitor in an asynchronous way.

This function works in the same way as `traverse_pack`, however, we are able to suspend and continue the traversal at later time. Thus we require a visitor callable object which provides three `operator()` overloads as depicted by the code sample below:

```

// The synchronous overload is called for each object, // it may
return false to suspend the current control. // In that case the
overload below is called. template <typename T> bool
operator()(async_traverse_visit_tag, T&& element) {
    return true;
}

// The asynchronous overload this is called when the //
synchronous overload returned false. // In addition to the
current visited element the overload is // called with a
continuation callable object which resumes the // traversal when
it's called later. // The continuation next may be stored and
called later or // dropped completely to abort the traversal
early. template <typename T, typename N> void
operator()(async_traverse_detach_tag, T&& element, N&& next) { }

// The overload is called when the traversal was finished. // As
argument the whole pack is passed over which we // traversed
asynchronously. template <typename T> void
operator()(async_traverse_complete_tag, T&& pack) { }
};

```

See `traverse_pack` for a detailed description about the traversal behavior and capabilities.

Parameters

- **visitor** – A visitor object which provides the three `operator()` overloads that were described above. Additionally the visitor must be compatible for referencing it from a `hpx::intrusive_ptr`. The visitor should must have a virtual destructor!
- **pack** – The arbitrary parameter pack which is traversed asynchronously. Nested objects inside containers and tuple like types are traversed recursively.

Returns A `hpx::intrusive_ptr` that references an instance of the given visitor object.

`hpx::functional::unwrap`, `hpx::functional::unwrap_n`, `hpx::functional::unwrap_all`, `hpx::unwrap`, `hpx::unwrap_n`, `hpx::unwrap_all`, `hpx::unwrapping`, `hpx::unwrapping_n`, `hpx::unwrapping_all`

Defined in header `hpx/unwrap.hpp`⁷³⁴.

See *Public API* for a list of names and headers that are part of the public *HPX* API.

namespace **hpx**

⁷³⁴ http://github.com/STELLAR-GROUP/hpx/blob/8a3b7c1a4cb5693b2f7d9f587f759392ed0c51a0/libs/core/include_local/include/hpx/unwrap.hpp

Functions

```
template<typename ...Args>
auto unwrap(Args&&... args) -> decltype(util::detail::unwrap_depth_impl<1U>(HPX_FORWARD(Args,
    args)...))
```

A helper function for retrieving the actual result of any `hpx::future` like type which is wrapped in an arbitrary way.

Unwraps the given pack of arguments, so that any `hpx::future` object is replaced by its future result type in the argument pack:

- `hpx::future<int> -> int`
- `hpx::future<std::vector<float>> -> std::vector<float>`
- `std::vector<future<float>> -> std::vector<float>`

The function is capable of unwrapping `hpx::future` like objects that are wrapped inside any container or tuple like type, see `hpx::util::map_pack()` for a detailed description about which surrounding types are supported. Non `hpx::future` like types are permitted as arguments and passed through.

```
hpx::unwrap(hpx::make_ready_future(0));

// Multiple arguments hpx::tuple<int, int> i2 =
    hpx::unwrap(hpx::make_ready_future(1),
                hpx::make_ready_future(2));
```

Note: This function unwraps the given arguments until the first traversed nested `hpx::future` which corresponds to an unwrapping depth of one. See `hpx::unwrap_n()` for a function which unwraps the given arguments to a particular depth or `hpx::unwrap_all()` that unwraps all future like objects recursively which are contained in the arguments.

Parameters `args` – the arguments that are unwrapped which may contain any arbitrary future or non future type.

Throws `std::exception` – like objects in case any of the given wrapped `hpx::future` objects were resolved through an exception. See `hpx::future::get()` for details.

Returns Depending on the count of arguments this function returns a `hpx::tuple` containing the unwrapped arguments if multiple arguments are given. In case the function is called with a single argument, the argument is unwrapped and returned.

```
template<std::size_t Depth, typename ...Args>
auto unwrap_n(Args&&... args) ->
    decltype(util::detail::unwrap_depth_impl<Depth>(HPX_FORWARD(Args, args)...))
```

An alternative version of `hpx::unwrap()`, which unwraps the given arguments to a certain depth of `hpx::future` like objects.

See `unwrap` for a detailed description.

Template Parameters `Depth` – The count of `hpx::future` like objects which are unwrapped maximally.

```
template<typename ...Args>
auto unwrap_all(Args&&... args) ->
    decltype(util::detail::unwrap_depth_impl<0U>(HPX_FORWARD(Args, args)...))
```

An alternative version of `hpx::unwrap()`, which unwraps the given arguments recursively so that all contained `hpx::future` like objects are replaced by their actual value.

See `hpx::unwrap()` for a detailed description.

```
template<typename T>
auto unwrapping(T &&callable) ->
    decltype(util::detail::functional_unwrap_depth_impl<1U>(HPX_FORWARD(T, callable)))
```

Returns a callable object which unwraps its arguments upon invocation using the `hpx::unwrap()` function and then passes the result to the given callable object.

```
    return left + right;
};

int i1 = callable(hpx::make_ready_future(1),
                  hpx::make_ready_future(2));
```

See `hpx::unwrap()` for a detailed description.

Parameters `callable` – the callable object which which is called with the result of the corresponding `unwrap` function.

```
template<std::size_t Depth, typename T>
auto unwrapping_n(T &&callable) ->
    decltype(util::detail::functional_unwrap_depth_impl<Depth>(HPX_FORWARD(T,
    callable)))
```

Returns a callable object which unwraps its arguments upon invocation using the `hpx::unwrap_n()` function and then passes the result to the given callable object.

See `hpx::unwrapping()` for a detailed description.

```
template<typename T>
auto unwrapping_all(T &&callable) ->
    decltype(util::detail::functional_unwrap_depth_impl<0U>(HPX_FORWARD(T,
    callable)))
```

Returns a callable object which unwraps its arguments upon invocation using the `hpx::unwrap_all()` function and then passes the result to the given callable object.

See `hpx::unwrapping()` for a detailed description.

namespace **functional**

struct **unwrap**

#include <unwrap.hpp> A helper function object for functionally invoking `hpx::unwrap`. For more information please refer to its documentation.

struct **unwrap_all**

#include <unwrap.hpp> A helper function object for functionally invoking `hpx::unwrap_all`. For more information please refer to its documentation.

template<std::size_t Depth>

struct **unwrap_n**

#include <unwrap.hpp> A helper function object for functionally invoking `hpx::unwrap_n`. For more information please refer to its documentation.

preprocessor

See *Public API* for a list of names and headers that are part of the public *HPX* API.

hpx/preprocessor/cat.hpp

Defined in header `hpx/preprocessor/cat.hpp`.

See *Public API* for a list of names and headers that are part of the public *HPX* API.

Defines

HPX_PP_CAT(A, B)

Concatenates the tokens A and B into a single token. Evaluates to AB

Parameters

- **A** – First token
- **B** – Second token

hpx/preprocessor/expand.hpp

Defined in header `hpx/preprocessor/expand.hpp`.

See *Public API* for a list of names and headers that are part of the public *HPX* API.

Defines

HPX_PP_EXPAND(X)

The `HPX_PP_EXPAND` macro performs a double macro-expansion on its argument.

This macro can be used to produce a delayed preprocessor expansion.

Example:

```
#define MACRO(a, b, c) (a)(b)(c)
#define ARGS() (1, 2, 3)

HPX_PP_EXPAND(MACRO ARGS()) // expands to (1)(2)(3)
```

Parameters

- **X** – Token to be expanded twice

hpx/preprocessor/nargs.hpp

Defined in header hpx/preprocessor/nargs.hpp.

See *Public API* for a list of names and headers that are part of the public *HPX* API.

Defines

HPX_PP_NARGS(...)

Expands to the number of arguments passed in

Example Usage:

```

HPX_PP_NARGS(hpx, pp, nargs)
HPX_PP_NARGS(hpx, pp)
HPX_PP_NARGS(hpx)

```

Expands to:

```

3
2
1

```

Parameters

- ... – The variadic number of arguments

hpx/preprocessor/stringize.hpp

Defined in header hpx/preprocessor/stringize.hpp.

See *Public API* for a list of names and headers that are part of the public *HPX* API.

Defines

HPX_PP_STRINGIZE(X)

The *HPX_PP_STRINGIZE* macro stringizes its argument after it has been expanded.

The passed argument *X* will expand to "*X*". Note that the stringizing operator (*#*) prevents arguments from expanding. This macro circumvents this shortcoming.

Parameters

- *X* – The text to be converted to a string literal

hpx/preprocessor/strip_parens.hpp

Defined in header `hpx/preprocessor/strip_parens.hpp`.

See *Public API* for a list of names and headers that are part of the public *HPX* API.

Defines

HPX_PP_STRIP_PARENS(X)

For any symbol *X*, this macro returns the same symbol from which potential outer parens have been removed. If no outer parens are found, this macros evaluates to *X* itself without error.

The original implementation of this macro is from Steven Watanbe as shown in <http://boost.2283326.n4.nabble.com/preprocessor-removing-parentheses-td2591973.html#a2591976>

```
HPX_PP_STRIP_PARENS(no_parens)
HPX_PP_STRIP_PARENS((with_parens))
```

Example Usage:

This produces the following output

```
no_parens
with_parens
```

Parameters

- *X* – Symbol to strip parens from

resiliency

See *Public API* for a list of names and headers that are part of the public *HPX* API.

hpx/resiliency/replay_executor.hpp

Defined in header `hpx/resiliency/replay_executor.hpp`.

See *Public API* for a list of names and headers that are part of the public *HPX* API.

```
template<typename BaseExecutor, typename Validator>
struct is_two_way_executor<hpx::resiliency::experimental::replay_executor<BaseExecutor, Validator>> : public
true_type

template<typename BaseExecutor, typename Validator>
struct is_bulk_two_way_executor<hpx::resiliency::experimental::replay_executor<BaseExecutor, Validator>> :
public true_type

namespace hpx
```

```
namespace execution
```

```
    namespace experimental
```

```
        template<typename BaseExecutor,
                typename Validator> replay_executor< BaseExecutor,
                Validator > > : public true_type
```

```
        template<typename BaseExecutor,
                typename Validator> replay_executor< BaseExecutor,
                Validator > > : public true_type
```

```
namespace resiliency
```

```
    namespace experimental
```

Functions

```
template<typename Tag, typename BaseExecutor, typename Validate, typename Property>
auto tag_invoke(Tag tag, replay_executor<BaseExecutor, Validate> const &exec, Property
                &&prop) -> decltype(replay_executor<BaseExecutor,
                Validate>(std::declval<Tag>()(std::declval<BaseExecutor>()),
                std::declval<Property>()), std::declval<std::size_t>(), std::declval<Validate>()))
```

```
template<typename Tag, typename BaseExecutor, typename Validate>
auto tag_invoke(Tag tag, replay_executor<BaseExecutor, Validate> const &exec) ->
    decltype(std::declval<Tag>()(std::declval<BaseExecutor>()))
```

```
template<typename BaseExecutor, typename Validate>
replay_executor<BaseExecutor, std::decay_t<Validate>> make_replay_executor(BaseExecutor
                                                                    &exec,
                                                                    std::size_t n,
                                                                    Validate
                                                                    &&validate)
```

```
template<typename BaseExecutor>
replay_executor<BaseExecutor, detail::replay_validator> make_replay_executor(BaseExecutor
                                                                    &exec,
                                                                    std::size_t n)
```

```
template<typename BaseExecutor, typename Validate>
```

```
class replay_executor
```

Public Types

```
using execution_category = hpx::traits::executor_execution_category_t<BaseExecutor>

using executor_parameters_type = hpx::traits::executor_parameters_type_t<BaseExecutor>

template<typename Result>

using future_type = hpx::traits::executor_future_t<BaseExecutor, Result>
```

Public Functions

```
template<typename BaseExecutor_, typename F>
inline explicit replay_executor(BaseExecutor_ &&exec, std::size_t n, F &&f)

inline bool operator==(replay_executor const &rhs) const noexcept

inline bool operator!=(replay_executor const &rhs) const noexcept

inline constexpr replay_executor const &context() const noexcept

inline BaseExecutor const &get_executor() const

inline std::size_t get_replay_count() const

inline Validate const &get_validator() const
```

Public Static Attributes

```
static constexpr int num_spread = 4

static constexpr int num_tasks = 128
```

Private Functions

```
template<typename F, typename ...Ts>
inline decltype(auto) friend tag_invoke(hpx::parallel::execution::async_execute_t,
replay_executor const &exec, F &&f, Ts&&... ts)

template<typename F, typename S, typename ...Ts>
inline decltype(auto) friend tag_invoke(hpx::parallel::execution::bulk_async_execute_t,
replay_executor const &exec, F &&f, S const
&shape, Ts&&... ts)
```

Private Members*BaseExecutor* **exec_***std::size_t* **replay_count_***Validate* **validator_****hpx/resiliency/replicate_executor.hpp**

Defined in header hpx/resiliency/replicate_executor.hpp.

See *Public API* for a list of names and headers that are part of the public HPX API.

```
template<typename BaseExecutor, typename Voter, typename Validator>
struct is_two_way_executor<hpx::resiliency::experimental::replicate_executor<BaseExecutor, Voter,
Validator>> : public true_type

template<typename BaseExecutor, typename Voter, typename Validator>
struct is_bulk_two_way_executor<hpx::resiliency::experimental::replicate_executor<BaseExecutor, Voter,
Validator>> : public true_type
```

namespace **hpx**namespace **execution**namespace **experimental**

```
template<typename BaseExecutor, typename Voter,
typename Validator> replicate_executor< BaseExecutor, Voter,
Validator > > : public true_type
```

```
template<typename BaseExecutor, typename Voter,
typename Validator> replicate_executor< BaseExecutor, Voter,
Validator > > : public true_type
```

namespace **resiliency**namespace **experimental**

Functions

```
template<typename Tag, typename BaseExecutor, typename Vote, typename Validate,
typename Property>
auto tag_invoke(Tag tag, replicate_executor<BaseExecutor, Vote, Validate> const &exec,
                Property &&prop) -> decltype(replicate_executor<BaseExecutor, Vote,
                Validate>(std::declval<Tag>()(std::declval<BaseExecutor>()),
                std::declval<Property>()), std::declval<std::size_t>(), std::declval<Vote>(),
                std::declval<Validate>()))
```

```
template<typename Tag, typename BaseExecutor, typename Vote, typename Validate>
auto tag_invoke(Tag tag, replicate_executor<BaseExecutor, Vote, Validate> const &exec) ->
decltype(std::declval<Tag>()(std::declval<BaseExecutor>()))
```

```
template<typename BaseExecutor, typename Voter, typename Validate>
replicate_executor<BaseExecutor, std::decay_t<Voter>, std::decay_t<Validate>> make_replicate_executor(BaseExecutor
&exec,
std::size_t n,
Voter &&voter,
Validate &&validator) -> replicate_executor<BaseExecutor, std::decay_t<Voter>, std::decay_t<Validate>>
```

```
template<typename BaseExecutor, typename Validate>
replicate_executor<BaseExecutor, detail::replicate_voter, std::decay_t<Validate>> make_replicate_executor(BaseExecutor
&exec,
std::size_t n,
Validate &&validator) -> replicate_executor<BaseExecutor, detail::replicate_voter, std::decay_t<Validate>>
```

```
template<typename BaseExecutor>
replicate_executor<BaseExecutor, detail::replicate_voter, detail::replicate_validator> make_replicate_executor(BaseExecutor
&exec,
std::size_t n,
```

```
template<typename BaseExecutor, typename Vote, typename Validate>
class replicate_executor
```

Public Types

```
using execution_category = hpx::traits::executor_execution_category_t<BaseExecutor>

using executor_parameters_type = hpx::traits::executor_parameters_type_t<BaseExecutor>

template<typename Result>

using future_type = hpx::traits::executor_future_t<BaseExecutor, Result>
```

Public Functions

```
template<typename BaseExecutor_, typename V, typename F>
inline explicit replicate_executor(BaseExecutor_ &&exec, std::size_t n, V &&v, F &&f)

inline bool operator==(replicate_executor const &rhs) const noexcept

inline bool operator!=(replicate_executor const &rhs) const noexcept

inline constexpr replicate_executor const &context() const noexcept

inline BaseExecutor const &get_executor() const

inline std::size_t get_replicate_count() const

inline Vote const &get_voter() const

inline Validate const &get_validator() const
```

Public Static Attributes

```
static constexpr int num_spread = 4

static constexpr int num_tasks = 128
```

Private Functions

```
template<typename F, typename ...Ts>
inline decltype(auto) friend tag_invoke(hpx::parallel::execution::async_execute_t,
                                         replicate_executor const &exec, F &&f, Ts&&... ts)

template<typename F, typename S, typename ...Ts>
inline decltype(auto) friend tag_invoke(hpx::parallel::execution::bulk_async_execute_t,
                                         replicate_executor const &exec, F &&f, S const
                                         &shape, Ts&&... ts)
```

Private Members

BaseExecutor **exec_**

std::size_t **replicate_count_**

Vote **voter_**

Validate **validator_**

runtime_configuration

See *Public API* for a list of names and headers that are part of the public *HPX* API.

hpx::components::component_commandline_base

Defined in header `hpx/components.hpp`.

See *Public API* for a list of names and headers that are part of the public *HPX* API.

Defines

HPX_REGISTER_COMMANDLINE_REGISTRY(RegistryType, componentname)

The macro *HPX_REGISTER_COMMANDLINE_REGISTRY* is used to register the given component factory with `Hpx.Plugin`. This macro has to be used for each of the components.

HPX_REGISTER_COMMANDLINE_REGISTRY_DYNAMIC(RegistryType, componentname)

HPX_REGISTER_COMMANDLINE_OPTIONS()

The macro *HPX_REGISTER_COMMANDLINE_OPTIONS* is used to define the required `Hpx.Plugin` entry point for the command line option registry. This macro has to be used in not more than one compilation unit of a component module.

HPX_REGISTER_COMMANDLINE_OPTIONS_DYNAMIC()

namespace **hpx**

namespace **components**

struct **component_commandline_base**

#include <component_commandline_base.hpp> The `component_commandline_base` has to be used as a base class for all component command-line line handling registries.

Public Functions

virtual `~component_commandline_base()` = default

virtual `hpx::program_options::options_description add_commandline_options()` = 0

Return any additional command line options valid for this component.

Note: This function will be executed by the runtime system during system startup.

Returns The module is expected to fill a `options_description` object with any additional command line options this component will handle.

HPX_REGISTER_COMPONENT_MODULE

Defined in header `hpx/components.hpp`.

See *Public API* for a list of names and headers that are part of the public *HPX* API.

Defines

HPX_REGISTER_COMPONENT_FACTORY(componentname)

This macro is used to register the given component factory with `Hpx.Plugin`. This macro has to be used for each of the component factories.

HPX_REGISTER_COMPONENT_MODULE()

This macro is used to define the required `Hpx.Plugin` entry points. This macro has to be used in exactly one compilation unit of a component module.

HPX_REGISTER_COMPONENT_MODULE_DYNAMIC()

namespace **hpx**

namespace **components**

hpx/runtime_configuration/component_registry_base.hpp

Defined in header `hpx/runtime_configuration/component_registry_base.hpp`.

See *Public API* for a list of names and headers that are part of the public *HPX* API.

Defines

HPX_REGISTER_COMPONENT_REGISTRY(RegistryType, componentname)

This macro is used to register the given component factory with `Hpx.Plugin`. This macro has to be used for each of the components.

HPX_REGISTER_COMPONENT_REGISTRY_DYNAMIC(RegistryType, componentname)

HPX_REGISTER_REGISTRY_MODULE()

This macro is used to define the required Hpx.Plugin entry points. This macro has to be used in exactly one compilation unit of a component module.

HPX_REGISTER_REGISTRY_MODULE_DYNAMIC()

namespace **hpx**

namespace **components**

struct **component_registry_base**

#include <component_registry_base.hpp> The `component_registry_base` has to be used as a base class for all component registries.

Public Functions

virtual `~component_registry_base()` = default

virtual bool **get_component_info**(*std::vector<std::string>* &fillini, *std::string* const &filepath, bool is_static = false) = 0

Return the ini-information for all contained components.

Parameters

- **fillini** – [in, out] The module is expected to fill this vector with the ini-information (one line per vector element) for all components implemented in this module.
- **filepath** – [in]
- **is_static** – [in]

Returns Returns *true* if the parameter *fillini* has been successfully initialized with the registry data of all implemented in this module.

virtual void **register_component_type**() = 0

Register the component type represented by this component.

hpx/runtime_configuration/plugin_registry_base.hpp

Defined in header `hpx/runtime_configuration/plugin_registry_base.hpp`.

See *Public API* for a list of names and headers that are part of the public *HPX* API.

Defines**HPX_REGISTER_PLUGIN_BASE_REGISTRY(PluginType, name)**

This macro is used to register the given component factory with Hpx.Plugin. This macro has to be used for each of the components.

HPX_REGISTER_PLUGIN_REGISTRY_MODULE()

This macro is used to define the required Hpx.Plugin entry points. This macro has to be used in exactly one compilation unit of a component module.

HPX_REGISTER_PLUGIN_REGISTRY_MODULE_DYNAMIC()

namespace **hpx**

namespace **plugins**

struct **plugin_registry_base**

#include <plugin_registry_base.hpp> The `plugin_registry_base` has to be used as a base class for all plugin registries.

Public Functions

virtual `~plugin_registry_base()` = default

virtual bool **get_plugin_info**(*std::vector<std::string>* &fillini) = 0

Return the configuration information for any plugin implemented by this module

Parameters *fillini* – [in, out] The module is expected to fill this vector with the information (one line per vector element) for all plugins implemented in this module.

Returns Returns *true* if the parameter *fillini* has been successfully initialized with the registry data of all implemented in this module.

inline virtual void **init**(int*, char***, *util::runtime_configuration*&)

hpx::runtime_mode

Defined in header `hpx/init.hpp`⁷³⁵.

See *Public API* for a list of names and headers that are part of the public HPX API.

namespace **hpx**

Enums

enum class **runtime_mode** : *std::int8_t*

A HPX runtime can be executed in two different modes: console mode and worker mode.

Values:

enumerator **invalid**

enumerator **console**

The runtime is the console locality.

enumerator **worker**

The runtime is a worker locality.

⁷³⁵ http://github.com/STELLAR-GROUP/hpx/blob/8a3b7c1a4cb5693b2f7d9f587f759392ed0c51a0/libs/full/init_runtime/include/hpx/init.hpp

enumerator **connect**

The runtime is a worker locality connecting late

enumerator **local**

The runtime is fully local.

enumerator **default_**

The runtime mode will be determined based on the command line arguments

enumerator **last**

Functions

char const ***get_runtime_mode_name**(*runtime_mode* state) noexcept

Get the readable string representing the name of the given *runtime_mode* constant.

runtime_mode **get_runtime_mode_from_name**(*std::string* const &mode)

Returns the internal representation (*runtime_mode* constant) from the readable string representing the name.

This represents the internal representation from the readable string representing the name.

Parameters *mode* – this represents the runtime mode

runtime_local

See *Public API* for a list of names and headers that are part of the public *HPX* API.

hpx/runtime_local/component_startup_shutdown_base.hpp

Defined in header `hpx/runtime_local/component_startup_shutdown_base.hpp`.

See *Public API* for a list of names and headers that are part of the public *HPX* API.

Defines

HPX_REGISTER_STARTUP_SHUTDOWN_REGISTRY(RegistryType, componentname)

This macro is used to register the given component factory with `Hpx.Plugin`. This macro has to be used for each of the components.

HPX_REGISTER_STARTUP_SHUTDOWN_REGISTRY_DYNAMIC(RegistryType, componentname)

HPX_REGISTER_STARTUP_SHUTDOWN_FUNCTIONS()

This macro is used to define the required `Hpx.Plugin` entry point for the startup/shutdown registry. This macro has to be used in not more than one compilation unit of a component module.

HPX_REGISTER_STARTUP_SHUTDOWN_FUNCTIONS_DYNAMIC()

namespace **hpx**

namespace **components**

struct **component_startup_shutdown_base**

#include <component_startup_shutdown_base.hpp> The `component_startup_shutdown_base` has to be used as a base class for all component startup/shutdown registries.

Public Functions

virtual `~component_startup_shutdown_base()` = default

virtual bool **get_startup_function**(*startup_function_type* &startup, bool &pre_startup) = 0

Return any startup function for this component.

Parameters

- **startup** – [in, out] The module is expected to fill this function object with a reference to a startup function. This function will be executed by the runtime system during system startup.
- **pre_startup** – [in, out] Will be set to true if the returned startup function is executed during the first round of calls.

Returns Returns *true* if the parameter *startup* has been successfully initialized with the startup function.

virtual bool **get_shutdown_function**(*shutdown_function_type* &shutdown, bool &pre_shutdown) = 0

Return any startup function for this component.

Parameters

- **shutdown** – [in, out] The module is expected to fill this function object with a reference to a startup function. This function will be executed by the runtime system during system startup.
- **pre_shutdown** – [in, out] Will be set to true if the returned shutdown function is executed during the first round of calls.

Returns Returns *true* if the parameter *shutdown* has been successfully initialized with the shutdown function.

hpx/runtime_local/custom_exception_info.hpp

Defined in header `hpx/runtime_local/custom_exception_info.hpp`.

See *Public API* for a list of names and headers that are part of the public *HPX* API.

namespace **hpx**

Functions

`std::string diagnostic_information(exception_info const &xi)`

Extract the diagnostic information embedded in the given exception and return a string holding a formatted message.

The function `hpx::diagnostic_information` can be used to extract all diagnostic information stored in the given exception instance as a formatted string. This simplifies debug output as it composes the diagnostics into one, easy to use function call. This includes the name of the source file and line number, the sequence number of the OS-thread and the HPX-thread id, the locality id and the stack backtrace of the point where the original exception was thrown.

See also:

`hpx::get_error_locality_id()`, `hpx::get_error_host_name()`, `hpx::get_error_process_id()`,
`hpx::get_error_function_name()`, `hpx::get_error_file_name()`, `hpx::get_error_line_number()`,
`hpx::get_error_os_thread()`, `hpx::get_error_thread_id()`, `hpx::get_error_thread_description()`,
`hpx::get_error()`, `hpx::get_error_backtrace()`, `hpx::get_error_env()`, `hpx::get_error_what()`,
`hpx::get_error_config()`, `hpx::get_error_state()`

Parameters `xi` – The parameter `e` will be inspected for all diagnostic information elements which have been stored at the point where the exception was thrown. This parameter can be one of the following types: `hpx::exception_info`, `hpx::error_code`, `std::exception`, or `std::exception_ptr`.

Throws `std::bad_alloc` – (if any of the required allocation operations fail)

Returns The formatted string holding all the available diagnostic information stored in the given exception instance.

`std::string default_diagnostic_information(std::exception_ptr const &e)`

`std::uint32_t get_error_locality_id(hpx::exception_info const &xi) noexcept`

Return the locality id where the exception was thrown.

The function `hpx::get_error_locality_id` can be used to extract the diagnostic information element representing the locality id as stored in the given exception instance.

See also:

`hpx::diagnostic_information()`, `hpx::get_error_host_name()`, `hpx::get_error_process_id()`,
`hpx::get_error_function_name()`, `hpx::get_error_file_name()`, `hpx::get_error_line_number()`,
`hpx::get_error_os_thread()`, `hpx::get_error_thread_id()`, `hpx::get_error_thread_description()`,
`hpx::get_error()`, `hpx::get_error_backtrace()`, `hpx::get_error_env()`, `hpx::get_error_what()`,
`hpx::get_error_config()`, `hpx::get_error_state()`

Parameters `xi` – The parameter `e` will be inspected for the requested diagnostic information elements which have been stored at the point where the exception was thrown. This parameter can be one of the following types: `hpx::exception_info`, `hpx::error_code`, `std::exception`, or `std::exception_ptr`.

Throws nothing –

Returns The locality id of the locality where the exception was thrown. If the exception instance does not hold this information, the function will return `hpx::naming::invalid_locality_id`.

`std::string get_error_host_name(hpx::exception_info const &xi)`

Return the hostname of the locality where the exception was thrown.

The function `hpx::get_error_host_name` can be used to extract the diagnostic information element representing the host name as stored in the given exception instance.

See also:

`hpx::diagnostic_information()`, `hpx::get_error_process_id()`, `hpx::get_error_function_name()`,
`hpx::get_error_file_name()`, `hpx::get_error_line_number()`, `hpx::get_error_os_thread()`,
`hpx::get_error_thread_id()`, `hpx::get_error_thread_description()`, `hpx::get_error()`,
`hpx::get_error_backtrace()`, `hpx::get_error_env()`, `hpx::get_error_what()`, `hpx::get_error_config()`,
`hpx::get_error_state()`

Parameters xi – The parameter `e` will be inspected for the requested diagnostic information elements which have been stored at the point where the exception was thrown. This parameter can be one of the following types: `hpx::exception_info`, `hpx::error_code`, `std::exception`, or `std::exception_ptr`.

Throws `std::bad_alloc` – (if one of the required allocations fails)

Returns The hostname of the locality where the exception was thrown. If the exception instance does not hold this information, the function will return an empty string.

`std::int64_t get_error_process_id(hpx::exception_info const &xi) noexcept`

Return the (operating system) process id of the locality where the exception was thrown.

The function `hpx::get_error_process_id` can be used to extract the diagnostic information element representing the process id as stored in the given exception instance.

See also:

`hpx::diagnostic_information()`, `hpx::get_error_host_name()`, `hpx::get_error_function_name()`,
`hpx::get_error_file_name()`, `hpx::get_error_line_number()`, `hpx::get_error_os_thread()`,
`hpx::get_error_thread_id()`, `hpx::get_error_thread_description()`, `hpx::get_error()`,
`hpx::get_error_backtrace()`, `hpx::get_error_env()`, `hpx::get_error_what()`, `hpx::get_error_config()`,
`hpx::get_error_state()`

Parameters xi – The parameter `e` will be inspected for the requested diagnostic information elements which have been stored at the point where the exception was thrown. This parameter can be one of the following types: `hpx::exception_info`, `hpx::error_code`, `std::exception`, or `std::exception_ptr`.

Throws nothing –

Returns The process id of the OS-process which threw the exception. If the exception instance does not hold this information, the function will return 0.

`std::string get_error_env(hpx::exception_info const &xi)`

Return the environment of the OS-process at the point the exception was thrown.

The function `hpx::get_error_env` can be used to extract the diagnostic information element representing the environment of the OS-process collected at the point the exception was thrown.

See also:

hpx::diagnostic_information(), *hpx::get_error_host_name()*, *hpx::get_error_process_id()*,
hpx::get_error_function_name(), *hpx::get_error_file_name()*, *hpx::get_error_line_number()*,
hpx::get_error_os_thread(), *hpx::get_error_thread_id()*, *hpx::get_error_thread_description()*,
hpx::get_error(), *hpx::get_error_backtrace()*, *hpx::get_error_what()*, *hpx::get_error_config()*,
hpx::get_error_state()

Parameters *xi* – The parameter *e* will be inspected for the requested diagnostic information elements which have been stored at the point where the exception was thrown. This parameter can be one of the following types: *hpx::exception_info*, *hpx::error_code*, *std::exception*, or *std::exception_ptr*.

Throws *std::bad_alloc* – (if one of the required allocations fails)

Returns The environment from the point the exception was thrown. If the exception instance does not hold this information, the function will return an empty string.

std::string **get_error_backtrace**(*hpx::exception_info* const &*xi*)

Return the stack backtrace from the point the exception was thrown.

The function *hpx::get_error_backtrace* can be used to extract the diagnostic information element representing the stack backtrace collected at the point the exception was thrown.

See also:

hpx::diagnostic_information(), *hpx::get_error_host_name()*, *hpx::get_error_process_id()*,
hpx::get_error_function_name(), *hpx::get_error_file_name()*, *hpx::get_error_line_number()*,
hpx::get_error_os_thread(), *hpx::get_error_thread_id()*, *hpx::get_error_thread_description()*,
hpx::get_error(), *hpx::get_error_env()*, *hpx::get_error_what()*, *hpx::get_error_config()*,
hpx::get_error_state()

Parameters *xi* – The parameter *e* will be inspected for the requested diagnostic information elements which have been stored at the point where the exception was thrown. This parameter can be one of the following types: *hpx::exception_info*, *hpx::error_code*, *std::exception*, or *std::exception_ptr*.

Throws *std::bad_alloc* – (if one of the required allocations fails)

Returns The stack back trace from the point the exception was thrown. If the exception instance does not hold this information, the function will return an empty string.

std::size_t **get_error_os_thread**(*hpx::exception_info* const &*xi*) noexcept

Return the sequence number of the OS-thread used to execute HPX-threads from which the exception was thrown.

The function *hpx::get_error_os_thread* can be used to extract the diagnostic information element representing the sequence number of the OS-thread as stored in the given exception instance.

See also:

hpx::diagnostic_information(), *hpx::get_error_host_name()*, *hpx::get_error_process_id()*,
hpx::get_error_function_name(), *hpx::get_error_file_name()*, *hpx::get_error_line_number()*,
hpx::get_error_thread_id(), *hpx::get_error_thread_description()*, *hpx::get_error()*,
hpx::get_error_backtrace(), *hpx::get_error_env()*, *hpx::get_error_what()*, *hpx::get_error_config()*,
hpx::get_error_state()

Parameters *xi* – The parameter *e* will be inspected for the requested diagnostic information elements which have been stored at the point where the exception was thrown. This parameter can be one of the following types: *hpx::exception_info*, *hpx::error_code*, *std::exception*, or *std::exception_ptr*.

Throws nothing –

Returns The sequence number of the OS-thread used to execute the HPX-thread from which the exception was thrown. If the exception instance does not hold this information, the function will return *std::size(-1)*.

std::size_t **get_error_thread_id**(*hpx::exception_info* const &*xi*) noexcept

Return the unique thread id of the HPX-thread from which the exception was thrown.

The function *hpx::get_error_thread_id* can be used to extract the diagnostic information element representing the HPX-thread id as stored in the given exception instance.

See also:

hpx::diagnostic_information(), *hpx::get_error_host_name()*, *hpx::get_error_process_id()*,
hpx::get_error_function_name(), *hpx::get_error_file_name()*, *hpx::get_error_line_number()*,
hpx::get_error_os_thread(), *hpx::get_error_thread_description()*, *hpx::get_error()*,
hpx::get_error_backtrace(), *hpx::get_error_env()*, *hpx::get_error_what()*, *hpx::get_error_config()*,
hpx::get_error_state()

Parameters *xi* – The parameter *e* will be inspected for the requested diagnostic information elements which have been stored at the point where the exception was thrown. This parameter can be one of the following types: *hpx::exception_info*, *hpx::error_code*, *std::exception*, or *std::exception_ptr*.

Throws nothing –

Returns The unique thread id of the HPX-thread from which the exception was thrown. If the exception instance does not hold this information, the function will return *std::size_t(0)*.

std::string **get_error_thread_description**(*hpx::exception_info* const &*xi*)

Return any additionally available thread description of the HPX-thread from which the exception was thrown.

The function *hpx::get_error_thread_description* can be used to extract the diagnostic information element representing the additional thread description as stored in the given exception instance.

See also:

hpx::diagnostic_information(), *hpx::get_error_host_name()*, *hpx::get_error_process_id()*,
hpx::get_error_function_name(), *hpx::get_error_file_name()*, *hpx::get_error_line_number()*,
hpx::get_error_os_thread(), *hpx::get_error_thread_id()*, *hpx::get_error_backtrace()*,
hpx::get_error_env(), *hpx::get_error()*, *hpx::get_error_state()*, *hpx::get_error_what()*,
hpx::get_error_config()

Parameters *xi* – The parameter *e* will be inspected for the requested diagnostic information elements which have been stored at the point where the exception was thrown. This parameter can be one of the following types: *hpx::exception_info*, *hpx::error_code*, *std::exception*, or *std::exception_ptr*.

Throws *std::bad_alloc* – (if one of the required allocations fails)

Returns Any additionally available thread description of the HPX-thread from which the exception was thrown. If the exception instance does not hold this information, the function will return an empty string.

`std::string get_error_config(hpx::exception_info const &xi)`

Return the HPX configuration information point from which the exception was thrown.

The function `hpx::get_error_config` can be used to extract the HPX configuration information element representing the full HPX configuration information as stored in the given exception instance.

See also:

`hpx::diagnostic_information()`, `hpx::get_error_host_name()`, `hpx::get_error_process_id()`,
`hpx::get_error_function_name()`, `hpx::get_error_file_name()`, `hpx::get_error_line_number()`,
`hpx::get_error_os_thread()`, `hpx::get_error_thread_id()`, `hpx::get_error_backtrace()`,
`hpx::get_error_env()`, `hpx::get_error()`, `hpx::get_error_state()` `hpx::get_error_what()`,
`hpx::get_error_thread_description()`

Parameters xi – The parameter `e` will be inspected for the requested diagnostic information elements which have been stored at the point where the exception was thrown. This parameter can be one of the following types: `hpx::exception_info`, `hpx::error_code`, `std::exception`, or `std::exception_ptr`.

Throws `std::bad_alloc` – (if one of the required allocations fails)

Returns Any additionally available HPX configuration information the point from which the exception was thrown. If the exception instance does not hold this information, the function will return an empty string.

`std::string get_error_state(hpx::exception_info const &xi)`

Return the HPX runtime state information at which the exception was thrown.

The function `hpx::get_error_state` can be used to extract the HPX runtime state information element representing the state the runtime system is currently in as stored in the given exception instance.

See also:

`hpx::diagnostic_information()`, `hpx::get_error_host_name()`, `hpx::get_error_process_id()`,
`hpx::get_error_function_name()`, `hpx::get_error_file_name()`, `hpx::get_error_line_number()`,
`hpx::get_error_os_thread()`, `hpx::get_error_thread_id()`, `hpx::get_error_backtrace()`,
`hpx::get_error_env()`, `hpx::get_error()`, `hpx::get_error_what()`, `hpx::get_error_thread_description()`

Parameters xi – The parameter `e` will be inspected for the requested diagnostic information elements which have been stored at the point where the exception was thrown. This parameter can be one of the following types: `hpx::exception_info`, `hpx::error_code`, `std::exception`, or `std::exception_ptr`.

Throws `std::bad_alloc` – (if one of the required allocations fails)

Returns The point runtime state at the point at which the exception was thrown. If the exception instance does not hold this information, the function will return an empty string.

hpx::get_locality_id

Defined in header `hpx/runtime.hpp`⁷³⁶.

See *Public API* for a list of names and headers that are part of the public *HPX* API.

namespace **hpx**

Functions

`std::uint32_t get_locality_id(error_code &ec = throws)`

Return the number of the locality this function is being called from.

This function returns the id of the current locality.

Note: The returned value is zero based and its maximum value is smaller than the overall number of localities the current application is running on (as returned by `get_num_localities()`).

Note: As long as *ec* is not pre-initialized to `hpx::throws` this function doesn't throw but returns the result code using the parameter *ec*. Otherwise, it throws an instance of `hpx::exception`.

Note: This function needs to be executed on a HPX-thread. It will fail otherwise (it will return -1).

Parameters *ec* – [in,out] this represents the error status on exit, if this is pre-initialized to `hpx::throws` the function will throw on error instead.

hpx::get_locality_name

Defined in header `hpx/runtime.hpp`⁷³⁷.

See *Public API* for a list of names and headers that are part of the public *HPX* API.

namespace **hpx**

Functions

`std::string get_locality_name()`

Return the name of the locality this function is called on.

This function returns the name for the locality on which this function is called.

See also:

`future<std::string> get_locality_name(hpx::id_type const& id)`

⁷³⁶ <http://github.com/STELLAR-GROUP/hpx/blob/8a3b7c1a4cb5693b2f7d9f587f759392ed0c51a0/libs/full/include/include/hpx/runtime.hpp>

⁷³⁷ <http://github.com/STELLAR-GROUP/hpx/blob/8a3b7c1a4cb5693b2f7d9f587f759392ed0c51a0/libs/full/include/include/hpx/runtime.hpp>

Returns This function returns the name for the locality on which the function is called. The name is retrieved from the underlying networking layer and may be different for different parcelports.

hpx::get_initial_num_localities, hpx::get_num_localities

Defined in header `hpx/runtime.hpp`⁷³⁸.

See *Public API* for a list of names and headers that are part of the public HPX API.

namespace **hpx**

Functions

`std::uint32_t get_initial_num_localities()`

Return the number of localities which were registered at startup for the running application.

The function `get_initial_num_localities` returns the number of localities which were connected to the console at application startup.

See also:

`hpx::find_all_localities`, `hpx::get_num_localities`

Note: As long as `ec` is not pre-initialized to `hpx::throws` this function doesn't throw but returns the result code using the parameter `ec`. Otherwise, it throws an instance of `hpx::exception`.

`hpx::future<std::uint32_t> get_num_localities()`

Asynchronously return the number of localities which are currently registered for the running application.

The function `get_num_localities` asynchronously returns the number of localities currently connected to the console. The returned future represents the actual result.

See also:

`hpx::find_all_localities`, `hpx::get_num_localities`

Note: This function will return meaningful results only if called from an HPX-thread. It will return 0 otherwise.

`std::uint32_t get_num_localities(launch::sync_policy, error_code &ec = throws)`

Return the number of localities which are currently registered for the running application.

The function `get_num_localities` returns the number of localities currently connected to the console.

See also:

`hpx::find_all_localities`, `hpx::get_num_localities`

⁷³⁸ <http://github.com/STELLAR-GROUP/hpx/blob/8a3b7c1a4cb5693b2f7d9f587f759392ed0c51a0/libs/full/include/include/hpx/runtime.hpp>

Note: This function will return meaningful results only if called from an HPX-thread. It will return 0 otherwise.

Note: As long as *ec* is not pre-initialized to *hpx::throws* this function doesn't throw but returns the result code using the parameter *ec*. Otherwise, it throws an instance of *hpx::exception*.

Parameters *ec* – [in,out] this represents the error status on exit, if this is pre-initialized to *hpx::throws* the function will throw on error instead.

hpx/runtime_local/get_os_thread_count.hpp

Defined in header `hpx/runtime_local/get_os_thread_count.hpp`.

See *Public API* for a list of names and headers that are part of the public *HPX* API.

namespace **hpx**

Functions

std::size_t **get_os_thread_count**()

Return the number of OS-threads running in the runtime instance the current HPX-thread is associated with.

std::size_t **get_os_thread_count**(*threads::executor* const &exec)

Return the number of worker OS- threads used by the given executor to execute HPX threads.

This function returns the number of cores used to execute HPX threads for the given executor. If the function is called while no HPX runtime system is active, it will return zero. If the executor is not valid, this function will fall back to retrieving the number of OS threads used by HPX.

Parameters *exec* – [in] The executor to be used.

namespace **threads**

hpx::get_thread_name

Defined in header `hpx/runtime.hpp`⁷³⁹.

See *Public API* for a list of names and headers that are part of the public *HPX* API.

namespace **hpx**

⁷³⁹ <http://github.com/STELLAR-GROUP/hpx/blob/8a3b7c1a4cb5693b2f7d9f587f759392ed0c51a0/libs/full/include/include/hpx/runtime.hpp>

Functions

`std::string get_thread_name()`

Return the name of the calling thread.

This function returns the name of the calling thread. This name uniquely identifies the thread in the context of HPX. If the function is called while no HPX runtime system is active, the result will be “<unknown>”.

hpx/runtime_local/get_worker_thread_num.hpp

Defined in header `hpx/runtime_local/get_worker_thread_num.hpp`.

See *Public API* for a list of names and headers that are part of the public *HPX* API.

hpx/runtime_local/report_error.hpp

Defined in header `hpx/runtime_local/report_error.hpp`.

See *Public API* for a list of names and headers that are part of the public *HPX* API.

namespace **hpx**

Functions

void **report_error**(`std::size_t num_thread`, `std::exception_ptr const &e`)

The function `report_error` reports the given exception to the console.

void **report_error**(`std::exception_ptr const &e`)

The function `report_error` reports the given exception to the console.

hpx/runtime_local/runtime_local.hpp

Defined in header `hpx/runtime_local/runtime_local.hpp`.

See *Public API* for a list of names and headers that are part of the public *HPX* API.

namespace **hpx**

Functions

void **set_error_handlers**(`hpx::util::runtime_configuration const &cfg`)

class **runtime**

Public Types

using **notification_policy_type** = *threads::policies::callback_notifier*

Generate a new notification policy instance for the given thread name prefix

using **hpx_main_function_type** = int()

The *hpx_main_function_type* is the default function type usable as the main HPX thread function.

using **hpx_errorsink_function_type** = void(*std::uint32_t*, *std::string* const&)

Public Functions

virtual *notification_policy_type* **get_notification_policy**(char const *prefix,
runtime_local::os_thread_type type)

state **get_state**() const

void **set_state**(state s)

explicit **runtime**(*hpx::util::runtime_configuration* rtcfg, bool initialize)

Construct a new HPX runtime instance.

virtual **~runtime**()

The destructor makes sure all HPX runtime services are properly shut down before exiting.

void **on_exit**(*hpx::function*<void()> const &f)

Manage list of functions to call on exit.

void **starting**()

Manage runtime 'stopped' state.

void **stopping**()

Call all registered on_exit functions.

bool **stopped**() const

This accessor returns whether the runtime instance has been stopped.

hpx::util::runtime_configuration &**get_config**()

access configuration information

hpx::util::runtime_configuration const &**get_config**() const

std::size_t **get_instance_number**() const

util::thread_mapper &**get_thread_mapper**() const

Return a reference to the internal PAPI thread manager.

threads::topology const &**get_topology**() const

virtual int **run**(*hpx::function*<*hpx_main_function_type*> const &func)

Run the HPX runtime system, use the given function for the main *thread* and block waiting for all threads to finish.

Note: The parameter *func* is optional. If no function is supplied, the runtime system will simply wait for the shutdown action without explicitly executing any main thread.

Parameters **func** – [in] This is the main function of an HPX application. It will be scheduled for execution by the thread manager as soon as the runtime has been initialized. This function is expected to expose an interface as defined by the typedef *hpx_main_function_type*. This parameter is optional and defaults to none main thread function, in which case all threads have to be scheduled explicitly.

Returns This function will return the value as returned as the result of the invocation of the function object given by the parameter **func**.

virtual int **run**()

Run the HPX runtime system, initially use the given number of (OS) threads in the thread-manager and block waiting for all threads to finish.

Returns This function will always return 0 (zero).

virtual void **rethrow_exception**()

Rethrow any stored exception (to be called after *stop()*)

virtual int **start**(*hpx::function*<*hpx_main_function_type*> const &func, bool blocking = false)

Start the runtime system.

Parameters

- **func** – [in] This is the main function of an HPX application. It will be scheduled for execution by the thread manager as soon as the runtime has been initialized. This function is expected to expose an interface as defined by the typedef *hpx_main_function_type*.
- **blocking** – [in] This allows to control whether this call blocks until the runtime system has been stopped. If this parameter is *true* the function *runtime::start* will call *runtime::wait* internally.

Returns If a blocking is a true, this function will return the value as returned as the result of the invocation of the function object given by the parameter **func**. Otherwise, it will return zero.

virtual int **start**(bool blocking = false)

Start the runtime system.

Parameters **blocking** – [in] This allows to control whether this call blocks until the runtime system has been stopped. If this parameter is *true* the function *runtime::start* will call *runtime::wait* internally .

Returns If a blocking is a true, this function will return the value as returned as the result of the invocation of the function object given by the parameter **func**. Otherwise, it will return zero.

virtual int **wait**()

Wait for the shutdown action to be executed.

Returns This function will return the value as returned as the result of the invocation of the function object given by the parameter **func**.

virtual void **stop**(bool blocking = true)

Initiate termination of the runtime system.

Parameters **blocking** – [in] This allows to control whether this call blocks until the runtime system has been fully stopped. If this parameter is *false* then this call will initiate the stop action but will return immediately. Use a second call to stop with this parameter set to *true* to wait for all internal work to be completed.

virtual int **suspend**()

Suspend the runtime system.

virtual int **resume**()

Resume the runtime system.

virtual int **finalize**(double)

virtual bool **is_networking_enabled**()

Return true if networking is enabled.

virtual *hpx::threads::threadmanager* &**get_thread_manager**()

Allow access to the thread manager instance used by the HPX runtime.

virtual *std::string* **here**() const

Returns a string of the locality endpoints (usable in debug output)

virtual bool **report_error**(*std::size_t* num_thread, *std::exception_ptr* const &e, bool terminate_all = true)

Report a non-recoverable error to the runtime system.

Parameters

- **num_thread** – [in] The number of the operating system thread the error has been detected in.
- **e** – [in] This is an instance encapsulating an exception which lead to this function call.
- **terminate_all** – [in] signal whether all localities should be terminated

virtual bool **report_error**(*std::exception_ptr* const &e, bool terminate_all = true)

Report a non-recoverable error to the runtime system.

Note: This function will retrieve the number of the current shepherd thread and forward to the `report_error` function above.

Parameters

- **e** – [in] This is an instance encapsulating an exception which lead to this function call.
- **terminate_all** – [in] signal whether all localities should be terminated

virtual void **add_pre_startup_function**(*startup_function_type* f)

Add a function to be executed inside a HPX thread before `hpx_main` but guaranteed to be executed before any startup function registered with `add_startup_function`.

Note: The difference to a startup function is that all pre-startup functions will be (system-wide) executed before any startup function.

Parameters f – The function ‘f’ will be called from inside a HPX thread before `hpx_main` is executed. This is very useful to set up the runtime environment of the application (install performance counters, etc.)

virtual void **add_startup_function**(*startup_function_type* f)

Add a function to be executed inside a HPX thread before `hpx_main`

Parameters f – The function ‘f’ will be called from inside a HPX thread before `hpx_main` is executed. This is very useful to set up the runtime environment of the application (install performance counters, etc.)

virtual void **add_pre_shutdown_function**(*shutdown_function_type* f)

Add a function to be executed inside a HPX thread during `hpx::finalize`, but guaranteed before any of the shutdown functions is executed.

Note: The difference to a shutdown function is that all pre-shutdown functions will be (system-wide) executed before any shutdown function.

Parameters f – The function ‘f’ will be called from inside a HPX thread while `hpx::finalize` is executed. This is very useful to tear down the runtime environment of the application (uninstall performance counters, etc.)

virtual void **add_shutdown_function**(*shutdown_function_type* f)

Add a function to be executed inside a HPX thread during `hpx::finalize`

Parameters f – The function ‘f’ will be called from inside a HPX thread while `hpx::finalize` is executed. This is very useful to tear down the runtime environment of the application (uninstall performance counters, etc.)

virtual *hpx::util::io_service_pool* ***get_thread_pool**(char const *name)

Access one of the internal thread pools (`io_service` instances) HPX is using to perform specific tasks. The three possible values for the argument `name` are “main_pool”, “io_pool”, “parcel_pool”, and “timer_pool”. For any other argument value the function will return zero.

virtual bool **register_thread**(char const *name, *std::size_t* num = 0, bool service_thread = true, *error_code* &ec = *throws*)

Register an external OS-thread with HPX.

This function should be called from any OS-thread which is external to HPX (not created by HPX), but which needs to access HPX functionality, such as setting a value on a promise or similar.

‘main’, ‘io’, ‘timer’, ‘parcel’, ‘worker’

Note: The function will compose a thread name of the form ‘<name>-thread#<num>’ which is used to register the thread. It is the user’s responsibility to ensure that each (composed) thread name is unique. HPX internally uses the following names for the threads it creates, do not reuse those:

Note: This function should be called for each thread exactly once. It will fail if it is called more than once.

Parameters

- **name** – [in] The name to use for thread registration.
- **num** – [in] The sequence number to use for thread registration. The default for this parameter is zero.
- **service_thread** – [in] The thread should be registered as a service thread. The default for this parameter is ‘true’. Any service threads will be pinned to cores not currently used by any of the HPX worker threads.
- **ec** – [in,out] this represents the error status on exit, if this is pre-initialized to *hpx::throws* the function will throw on error instead.

Returns This function will return whether the requested operation succeeded or not.

virtual bool **unregister_thread**()

Unregister an external OS-thread with HPX.

This function will unregister any external OS-thread from HPX.

Note: This function should be called for each thread exactly once. It will fail if it is called more than once. It will fail as well if the thread has not been registered before (see *register_thread*).

Returns This function will return whether the requested operation succeeded or not.

virtual runtime_local::os_thread_data **get_os_thread_data**(std::string const &label) const

Access data for a given OS thread that was previously registered by *register_thread*.

virtual bool **enumerate_os_threads**(hpx::function<bool(runtime_local::os_thread_data const&)> const &f) const

Enumerate all OS threads that have registered with the runtime.

notification_policy_type::on_startstop_type **on_start_func**() const

notification_policy_type::on_startstop_type **on_stop_func**() const

notification_policy_type::on_error_type **on_error_func**() const

notification_policy_type::on_startstop_type **on_start_func**(*notification_policy_type::on_startstop_type*&&)

notification_policy_type::on_startstop_type **on_stop_func**(*notification_policy_type::on_startstop_type*&&)

notification_policy_type::on_error_type **on_error_func**(*notification_policy_type::on_error_type*&&)

virtual std::uint32_t **get_locality_id**(*error_code* &ec) const

virtual std::size_t **get_num_worker_threads**() const

virtual std::uint32_t **get_num_localities**(hpx::launch::sync_policy, *error_code* &ec) const

virtual std::uint32_t **get_initial_num_localities**() const

virtual hpx::future<std::uint32_t> **get_num_localities**() const

virtual std::string **get_locality_name**() const

virtual std::uint32_t **assign_cores**(std::string const&, std::uint32_t)

virtual std::uint32_t **assign_cores**()

inline hpx::program_options::options_description const &**get_app_options**() const

inline void **set_app_options**(hpx::program_options::options_description const &app_options)

Public Static Functions

static std::uint64_t **get_system_uptime**()

Return the system uptime measure on the thread executing this call.

Protected Types

using **on_exit_type** = *std::vector*<*hpx::function*<void()>>

Protected Functions

explicit **runtime**(*hpx::util::runtime_configuration* rtcfg)

void **set_notification_policies**(*notification_policy_type* &¬ifier,
threads::detail::network_background_callback_type const
&network_background_callback)

void **init**()

Common initialization for different constructors.

void **init_global_data**()

threads::thread_result_type **run_helper**(*hpx::function*<*runtime::hpx_main_function_type*> const
&func, int &result, bool call_startup_functions, void
(*handle_print_bind)(*std::size_t*) = nullptr)

void **wait_helper**(*std::mutex* &mtx, *std::condition_variable* &cond, bool &running)

Protected Attributes

on_exit_type **on_exit_functions_**

mutable *std::mutex* **mtx_**

hpx::util::runtime_configuration **rtcfg_**

long **instance_number_**

std::unique_ptr<*util::thread_mapper*> **thread_support_**

threads::topology &**topology_**

std::atomic<state> **state_**

notification_policy_type::on_startstop_type **on_start_func_**

notification_policy_type::on_startstop_type **on_stop_func_**

notification_policy_type::on_error_type **on_error_func_**

int **result_**

std::exception_ptr **exception_**

notification_policy_type **main_pool_notifier_**

std::unique_ptr<util::io_service_pool> **main_pool_**

notification_policy_type **notifier_**

std::unique_ptr<hpx::threads::threadmanager> **thread_manager_**

Protected Static Functions

static void **deinit_global_data**()

Protected Static Attributes

static *std::atomic<int>* **instance_number_counter_**

Private Functions

void **stop_helper**(bool blocking, *std::condition_variable* &cond, *std::mutex* &mtx) const

Helper function to stop the runtime.

Parameters

- **blocking** – [in] This allows to control whether this call blocks until the runtime system has been fully stopped. If this parameter is *false* then this call will initiate the stop action but will return immediately. Use a second call to stop with this parameter set to *true* to wait for all internal work to be completed.
- **cond** –
- **mtx** –

void **deinit_tss_helper**(char const *context, *std::size_t* num) const

void **init_tss_ex**(char const *context, *runtime_local::os_thread_type* type, *std::size_t* local_thread_num, *std::size_t* global_thread_num, char const *pool_name, char const *postfix, bool service_thread, *error_code* &ec) const

void **init_tss_helper**(char const *context, *runtime_local::os_thread_type* type, *std::size_t* local_thread_num, *std::size_t* global_thread_num, char const *pool_name, char const *postfix, bool service_thread) const

void **notify_finalize**()

void **wait_finalize**()

void **call_startup_functions**(bool pre_startup)

Private Members

std::list<startup_function_type> **pre_startup_functions_**

std::list<startup_function_type> **startup_functions_**

std::list<shutdown_function_type> **pre_shutdown_functions_**

std::list<shutdown_function_type> **shutdown_functions_**

bool **stop_called_**

bool **stop_done_**

std::condition_variable **wait_condition_**

hpx::program_options::options_description **app_options_**

namespace **threads**

Functions

char const ***get_stack_size_name**(*std::ptrdiff_t* size)

Returns the stack size name.

Get the readable string representing the given stack size constant.

Parameters **size** – this represents the stack size

std::ptrdiff_t **get_default_stack_size**()

Returns the default stack size.

Get the default stack size in bytes.

std::ptrdiff_t **get_stack_size**(*thread_stacksize*)

Returns the stack size corresponding to the given stack size enumeration.

Get the stack size corresponding to the given stack size enumeration.

Parameters **size** – this represents the stack size

namespace **util**

Functions

bool **retrieve_commandline_arguments**(*hpx::program_options::options_description* const &app_options, *hpx::program_options::variables_map* &vm)

bool **retrieve_commandline_arguments**(*std::string* const &appname, *hpx::program_options::variables_map* &vm)

hpx::register_thread, **hpx::unregister_thread**, **hpx::get_os_thread_data**,
hpx::enumerate_os_threads, **hpx::get_runtime_instance_number**, **hpx::register_on_exit**,
hpx::is_starting, **hpx::tolerate_node_faults**, **hpx::is_running**, **hpx::is_stopped**,
hpx::is_stopped_or_shutting_down, **hpx::get_num_worker_threads**, **hpx::get_system_uptime**

Defined in header [hpx/runtime.hpp](#)⁷⁴⁰.

See *Public API* for a list of names and headers that are part of the public *HPX* API.

namespace **hpx**

Functions

bool **register_thread**(*runtime* *rt, char const *name, *error_code* &ec = *throws*)

Register the current kernel thread with HPX, this should be done once for each external OS-thread intended to invoke HPX functionality. Calling this function more than once will return false.

void **unregister_thread**(*runtime* *rt)

Unregister the thread from HPX, this should be done once in the end before the external thread exists.

runtime_local::os_thread_data **get_os_thread_data**(*std::string* const &label)

Access data for a given OS thread that was previously registered by *register_thread*. This function must be called from a thread that was previously registered with the runtime.

bool **enumerate_os_threads**(*hpx::function*<bool(*os_thread_data* const&)> const &f)

Enumerate all OS threads that have registered with the runtime.

std::size_t **get_runtime_instance_number**()

Return the runtime instance number associated with the runtime instance the current thread is running in.

bool **register_on_exit**(*hpx::function*<void()> const&)

Register a function to be called during system shutdown.

bool **is_starting**()

Test whether the runtime system is currently being started.

This function returns whether the runtime system is currently being started or not, e.g. whether the current state of the runtime system is *hpx::state::startup*

Note: This function needs to be executed on a HPX-thread. It will return false otherwise.

⁷⁴⁰ <http://github.com/STELLAR-GROUP/hpx/blob/8a3b7c1a4cb5693b2f7d9f587f759392ed0c51a0/libs/full/include/include/hpx/runtime.hpp>

bool **tolerate_node_faults()**

Test if HPX runs in fault-tolerant mode.

This function returns whether the runtime system is running in fault-tolerant mode

bool **is_running()**

Test whether the runtime system is currently running.

This function returns whether the runtime system is currently running or not, e.g. whether the current state of the runtime system is *hpx::state::running*

Note: This function needs to be executed on a HPX-thread. It will return false otherwise.

bool **is_stopped()**

Test whether the runtime system is currently stopped.

This function returns whether the runtime system is currently stopped or not, e.g. whether the current state of the runtime system is *hpx::state::stopped*

Note: This function needs to be executed on a HPX-thread. It will return false otherwise.

bool **is_stopped_or_shutting_down()**

Test whether the runtime system is currently being shut down.

This function returns whether the runtime system is currently being shut down or not, e.g. whether the current state of the runtime system is *hpx::state::stopped* or *hpx::state::shutdown*

Note: This function needs to be executed on a HPX-thread. It will return false otherwise.

std::size_t **get_num_worker_threads()**

Return the number of worker OS- threads used to execute HPX threads.

This function returns the number of OS-threads used to execute HPX threads. If the function is called while no HPX runtime system is active, it will return zero.

std::uint64_t **get_system_uptime()**

Return the system uptime measure on the thread executing this call.

This function returns the system uptime measured in nanoseconds for the thread executing this call. If the function is called while no HPX runtime system is active, it will return zero.

namespace **threads**

hpx/runtime_local/service_executors.hpp

Defined in header `hpx/runtime_local/service_executors.hpp`.

See *Public API* for a list of names and headers that are part of the public *HPX* API.

namespace **hpx**

namespace **execution**

namespace **experimental**

Enums

enum class **service_executor_type** : *std::uint8_t*

Values:

enumerator **io_thread_pool**

Selects creating a service executor using the I/O pool of threads

enumerator **parcel_thread_pool**

Selects creating a service executor using the parcel pool of threads

enumerator **timer_thread_pool**

Selects creating a service executor using the timer pool of threads

enumerator **main_thread**

Selects creating a service executor using the main thread

struct **io_pool_executor** : public *hpx::execution::experimental::service_executor*

Public Functions

io_pool_executor()

struct **main_pool_executor** : public *hpx::execution::experimental::service_executor*

Public Functions

main_pool_executor()

```
struct parcel_pool_executor : public hpx::execution::experimental::service_executor
```

Public Functions

explicit **parcel_pool_executor**(char const *name_suffix = "-tcp")

```
struct service_executor : public service_executor
```

Subclassed by *hpx::execution::experimental::io_pool_executor*,
hpx::execution::experimental::main_pool_executor, *hpx::execution::experimental::parcel_pool_executor*,
hpx::execution::experimental::timer_pool_executor

Public Functions

explicit **service_executor**(*service_executor_type* t, char const *name_suffix = "")

```
struct timer_pool_executor : public hpx::execution::experimental::service_executor
```

Public Functions

timer_pool_executor()

hpx::shutdown_function_type, hpx::register_pre_shutdown_function, hpx::register_shutdown_function

Defined in header *hpx/runtime.hpp*⁷⁴¹.

See *Public API* for a list of names and headers that are part of the public *HPX* API.

namespace **hpx**

Typedefs

using **shutdown_function_type** = *hpx::move_only_function*<void()>

The type of the function which is registered to be executed as a shutdown or pre-shutdown function.

⁷⁴¹ <http://github.com/STELLAR-GROUP/hpx/blob/8a3b7c1a4cb5693b2f7d9f587f759392ed0c51a0/libs/full/include/include/hpx/runtime.hpp>

Functions

void **register_pre_shutdown_function**(*shutdown_function_type* f)

Add a function to be executed by a HPX thread during *hpx::finalize()* but guaranteed before any shutdown function is executed (system-wide)

Any of the functions registered with *register_pre_shutdown_function* are guaranteed to be executed by an HPX thread during the execution of *hpx::finalize()* before any of the registered shutdown functions are executed (see: *hpx::register_shutdown_function()*).

See also:

hpx::register_shutdown_function()

Note: If this function is called while the pre-shutdown functions are being executed, or after that point, it will raise an *invalid_status* exception.

Parameters **f** – [in] The function to be registered to run by an HPX thread as a pre-shutdown function.

void **register_shutdown_function**(*shutdown_function_type* f)

Add a function to be executed by a HPX thread during *hpx::finalize()* but guaranteed after any pre-shutdown function is executed (system-wide)

Any of the functions registered with *register_shutdown_function* are guaranteed to be executed by an HPX thread during the execution of *hpx::finalize()* after any of the registered pre-shutdown functions are executed (see: *hpx::register_pre_shutdown_function()*).

See also:

hpx::register_pre_shutdown_function()

Note: If this function is called while the shutdown functions are being executed, or after that point, it will raise an *invalid_status* exception.

Parameters **f** – [in] The function to be registered to run by an HPX thread as a shutdown function.

hpx::startup_function_type, hpx::register_pre_startup_function, hpx::register_startup_function

Defined in header *hpx/runtime.hpp*⁷⁴².

See *Public API* for a list of names and headers that are part of the public *HPX* API.

namespace **hpx**

⁷⁴² <http://github.com/STELLAR-GROUP/hpx/blob/8a3b7c1a4cb5693b2f7d9f587f759392ed0c51a0/libs/full/include/include/hpx/runtime.hpp>

Typedefs

using **startup_function_type** = *hpx::move_only_function*<void()>

The type of the function which is registered to be executed as a startup or pre-startup function.

Functions

void **register_pre_startup_function**(*startup_function_type* f)

Add a function to be executed by a HPX thread before `hpx_main` but guaranteed before any startup function is executed (system-wide).

Any of the functions registered with *register_pre_startup_function* are guaranteed to be executed by an HPX thread before any of the registered startup functions are executed (see [hpx::register_startup_function\(\)](#)).

This function is one of the few API functions which can be called before the runtime system has been fully initialized. It will automatically stage the provided startup function to the runtime system during its initialization (if necessary).

See also:

[hpx::register_startup_function\(\)](#)

Note: If this function is called while the pre-startup functions are being executed or after that point, it will raise an `invalid_status` exception.

Parameters **f** – [in] The function to be registered to run by an HPX thread as a pre-startup function.

void **register_startup_function**(*startup_function_type* f)

Add a function to be executed by a HPX thread before `hpx_main` but guaranteed after any pre-startup function is executed (system-wide).

Any of the functions registered with *register_startup_function* are guaranteed to be executed by an HPX thread after any of the registered pre-startup functions are executed (see: [hpx::register_pre_startup_function\(\)](#)), but before `hpx_main` is being called.

This function is one of the few API functions which can be called before the runtime system has been fully initialized. It will automatically stage the provided startup function to the runtime system during its initialization (if necessary).

See also:

[hpx::register_pre_startup_function\(\)](#)

Note: If this function is called while the startup functions are being executed or after that point, it will raise an `invalid_status` exception.

Parameters **f** – [in] The function to be registered to run by an HPX thread as a startup function.

hpx/runtime_local/thread_hooks.hpp

Defined in header `hpx/runtime_local/thread_hooks.hpp`.

See *Public API* for a list of names and headers that are part of the public *HPX* API.

namespace **hpx**

Functions

threads::policies::callback_notifier::on_startstop_type **get_thread_on_start_func()**

Retrieve the currently installed start handler function. This is a function that will be called by HPX for each newly created thread that is made known to the runtime. HPX stores exactly one such function reference, thus the caller needs to make sure any newly registered start function chains into the previous one (see *register_thread_on_start_func*).

Note: This function can be called before the HPX runtime is initialized.

Returns The currently installed error handler function.

threads::policies::callback_notifier::on_startstop_type **get_thread_on_stop_func()**

Retrieve the currently installed stop handler function. This is a function that will be called by HPX for each newly created thread that is made known to the runtime. HPX stores exactly one such function reference, thus the caller needs to make sure any newly registered stop function chains into the previous one (see *register_thread_on_stop_func*).

Note: This function can be called before the HPX runtime is initialized.

Returns The currently installed error handler function.

threads::policies::callback_notifier::on_error_type **get_thread_on_error_func()**

Retrieve the currently installed error handler function. This is a function that will be called by HPX for each newly created thread that is made known to the runtime. HPX stores exactly one such function reference, thus the caller needs to make sure any newly registered error function chains into the previous one (see *register_thread_on_error_func*).

Note: This function can be called before the HPX runtime is initialized.

Returns The currently installed error handler function.

threads::policies::callback_notifier::on_startstop_type **register_thread_on_start_func**(*threads::policies::callback_notifier::*
&&f)

Set the currently installed start handler function. This is a function that will be called by HPX for each newly created thread that is made known to the runtime. HPX stores exactly one such function reference,

thus the caller needs to make sure any newly registered start function chains into the previous one (see *get_thread_on_start_func*).

Note: This function can be called before the HPX runtime is initialized.

Parameters **f** – The function to install as the new start handler.

Returns The previously registered function of this category. It is the user’s responsibility to call that function if the callback is invoked by HPX.

threads::policies::callback_notifier::on_startstop_type **register_thread_on_stop_func**(*threads::policies::callback_notifier::on_startstop_type* &&f)

Set the currently installed stop handler function. This is a function that will be called by HPX for each newly created thread that is made known to the runtime. HPX stores exactly one such function reference, thus the caller needs to make sure any newly registered stop function chains into the previous one (see *get_thread_on_stop_func*).

Note: This function can be called before the HPX runtime is initialized.

Parameters **f** – The function to install as the new stop handler.

Returns The previously registered function of this category. It is the user’s responsibility to call that function if the callback is invoked by HPX.

threads::policies::callback_notifier::on_error_type **register_thread_on_error_func**(*threads::policies::callback_notifier::on_error_type* &&f)

Set the currently installed error handler function. This is a function that will be called by HPX for each newly created thread that is made known to the runtime. HPX stores exactly one such function reference, thus the caller needs to make sure any newly registered error function chains into the previous one (see *get_thread_on_error_func*).

Note: This function can be called before the HPX runtime is initialized.

Parameters **f** – The function to install as the new error handler.

Returns The previously registered function of this category. It is the user’s responsibility to call that function if the callback is invoked by HPX.

hpx/runtime_local/thread_pool_helpers.hpp

Defined in header `hpx/runtime_local/thread_pool_helpers.hpp`.

See *Public API* for a list of names and headers that are part of the public HPX API.

```
namespace hpx
```

```
    namespace resource
```

Functions

`std::size_t get_num_thread_pools()`

Return the number of thread pools currently managed by the *resource_partitioner*

`std::size_t get_num_threads()`

Return the number of threads in all thread pools currently managed by the *resource_partitioner*

`std::size_t get_num_threads(std::string const &pool_name)`

Return the number of threads in the given thread pool currently managed by the *resource_partitioner*

`std::size_t get_num_threads(std::size_t pool_index)`

Return the number of threads in the given thread pool currently managed by the *resource_partitioner*

`std::size_t get_pool_index(std::string const &pool_name)`

Return the internal index of the pool given its name.

`std::string const &get_pool_name(std::size_t pool_index)`

Return the name of the pool given its internal index.

`threads::thread_pool_base &get_thread_pool(std::string const &pool_name)`

Return the name of the pool given its name.

`threads::thread_pool_base &get_thread_pool(std::size_t pool_index)`

Return the thread pool given its internal index.

`bool pool_exists(std::string const &pool_name)`

Return true if the pool with the given name exists.

`bool pool_exists(std::size_t pool_index)`

Return true if the pool with the given index exists.

namespace **threads**

Functions

`std::int64_t get_thread_count(thread_schedule_state state = thread_schedule_state::unknown)`

The function *get_thread_count* returns the number of currently known threads.

Note: If `state == unknown` this function will not only return the number of currently existing threads, but will add the number of registered task descriptions (which have not been converted into threads yet).

Parameters `state` – [in] This specifies the thread-state for which the number of threads should be retrieved.

`std::int64_t get_thread_count(thread_priority priority, thread_schedule_state state = thread_schedule_state::unknown)`

The function *get_thread_count* returns the number of currently known threads.

Note: If `state == unknown` this function will not only return the number of currently existing threads, but will add the number of registered task descriptions (which have not been converted into threads yet).

Parameters

- **priority** – [in] This specifies the thread-priority for which the number of threads should be retrieved.
- **state** – [in] This specifies the thread-state for which the number of threads should be retrieved.

`std::int64_t get_idle_core_count()`

The function `get_idle_core_count` returns the number of currently idling threads (cores).

`mask_type get_idle_core_mask()`

The function `get_idle_core_mask` returns a bit-mask representing the currently idling threads (cores).

`bool enumerate_threads(hpx::function<bool(thread_id_type)> const &f, thread_schedule_state state = thread_schedule_state::unknown)`

The function `enumerate_threads` will invoke the given function `f` for each thread with a matching thread state.

Parameters

- **f** – [in] The function which should be called for each matching thread. Returning ‘false’ from this function will stop the enumeration process.
- **state** – [in] This specifies the thread-state for which the threads should be enumerated.

serialization

See *Public API* for a list of names and headers that are part of the public HPX API.

hpx/serialization/base_object.hpp

Defined in header `hpx/serialization/base_object.hpp`.

See *Public API* for a list of names and headers that are part of the public HPX API.

`template<typename Derived, typename Base>`

```
struct hpx::serialization::base_object_type<Derived, Base,
std::enable_if_t<hpx::traits::is_intrusive_polymorphic_v<Derived>>>
```

Public Functions

```
inline explicit constexpr base_object_type(Derived &d) noexcept
```

```
template<typename Archive>
inline void save(Archive &ar, unsigned) const
```

```
template<typename Archive>
inline void load(Archive &ar, unsigned)
```

```
HPX_SERIALIZATION_SPLIT_MEMBER()
```

Public Members

Derived &d_

namespace **hpx**

namespace **serialization**

Functions

```
template<typename Base, typename Derived>
constexpr base_object_type<Derived, Base> base_object(Derived &d) noexcept
```

```
template<typename D, typename B>
output_archive &operator<<(output_archive &ar, base_object_type<D, B> t)
```

```
template<typename D, typename B>
input_archive &operator>>(input_archive &ar, base_object_type<D, B> t)
```

```
template<typename D, typename B>
output_archive &operator&(output_archive &ar, base_object_type<D, B> t)
```

```
template<typename D, typename B>
input_archive &operator&(input_archive &ar, base_object_type<D, B> t)
```

```
template<typename Derived, typename Base, typename Enable = void>
```

```
struct base_object_type
```

Public Functions

```
inline explicit constexpr base_object_type(Derived &d) noexcept
```

```
template<typename Archive>
inline void serialize(Archive &ar, unsigned)
```

Public Members

Derived &d_

```
template<typename Derived,
typename Base> is_intrusive_polymorphic_v< Derived > > >
```

Public Functions

inline explicit constexpr **base_object_type**(Derived &d) noexcept

template<typename **Archive**>
inline void **save**(*Archive* &ar, unsigned) const

template<typename **Archive**>
inline void **load**(*Archive* &ar, unsigned)

HPX_SERIALIZATION_SPLIT_MEMBER()

Public Members

Derived &d_

synchronization

See *Public API* for a list of names and headers that are part of the public *HPX* API.

hpx::barrier

Defined in header `hpx/barrier.hpp`⁷⁴³.

See *Public API* for a list of names and headers that are part of the public *HPX* API.

namespace **hpx**

```
template<typename OnCompletion = detail::empty_oncompletion>
```

```
class barrier
```

#include <barrier.hpp> A barrier is a thread coordination mechanism whose lifetime consists of a sequence of barrier phases, where each phase allows at most an expected number of threads to block until the expected number of threads arrive at the barrier. [Note: A barrier is useful for managing repeated tasks that are handled by multiple threads. - end note] Each barrier phase consists of the following steps:

- The expected count is decremented by each call to `arrive` or `arrive_and_drop`.
- When the expected count reaches zero, the phase completion step is run. For the specialization with the default value of the `CompletionFunction` template parameter, the completion step is run as part of the call to `arrive` or `arrive_and_drop` that caused the expected count to reach zero. For other specializations, the completion step is run on one of the threads that arrived at the barrier during the phase.
- When the completion step finishes, the expected count is reset to what was specified by the expected argument to the constructor, possibly adjusted by calls to `arrive_and_drop`, and the next phase starts.

Each phase defines a phase synchronization point. Threads that arrive at the barrier during the phase can block on the phase synchronization point by calling `wait`, and will remain blocked until the phase completion step is run. The phase completion step that is executed at the end of each phase has the following effects:

⁷⁴³ <http://github.com/STELLAR-GROUP/hpx/blob/8a3b7c1a4cb5693b2f7d9f587f759392ed0c51a0/libs/full/include/include/hpx/barrier.hpp>

- Invokes the completion function, equivalent to `completion()`.
- Unblocks all threads that are blocked on the phase synchronization point.

The end of the completion step strongly happens before the returns from all calls that were unblocked by the completion step. For specializations that do not have the default value of the `CompletionFunction` template parameter, the behavior is undefined if any of the barrier object's member functions other than `wait` are called while the completion step is in progress.

Concurrent invocations of the member functions of `barrier`, other than its destructor, do not introduce data races. The member functions `arrive` and `arrive_and_drop` execute atomically.

`CompletionFunction` shall meet the `Cpp17MoveConstructible` (Table 28) and `Cpp17Destructible` (Table 32) requirements. `std::is_nothrow_invocable_v<CompletionFunction&>` shall be true.

The default value of the `CompletionFunction` template parameter is an unspecified type, such that, in addition to satisfying the requirements of `CompletionFunction`, it meets the `Cpp17DefaultConstructible` requirements (Table 27) and `completion()` has no effects.

`barrier::arrival_token` is an unspecified type, such that it meets the `Cpp17MoveConstructible` (Table 28), `Cpp17MoveAssignable` (Table 30), and `Cpp17Destructible` (Table 32) requirements.

Public Types

using `arrival_token` = bool

Public Functions

inline explicit constexpr **barrier**(*std::ptrdiff_t* expected, *OnCompletion* completion = *OnCompletion*())

Preconditions: `expected >= 0` is true and `expected <= max()` is true.

Effects: Sets both the initial expected count for each barrier phase and the current expected count for the first phase to `expected`. Initializes completion with `std::move(f)`. Starts the first phase. [Note: If `expected` is 0 this object can only be destroyed.- end note]

Throws: Any exception thrown by `CompletionFunction`'s move constructor.

`~barrier()` = default

inline *arrival_token* **arrive**(*std::ptrdiff_t* update = 1)

Preconditions: `update > 0` is true, and `update` is less than or equal to the expected count for the current barrier phase.

Effects: Constructs an object of type `arrival_token` that is associated with the phase synchronization point for the current phase. Then, decrements the expected count by `update`.

Synchronization: The call to `arrive` strongly happens before the start of the phase completion step for the current phase.

Error conditions: Any of the error conditions allowed for `mutex` types ([`thread.mutex.requirements.mutex`]). [Note: This call can cause the completion step for the current phase to start.- end note]

Throws `system_error` – when an exception is required ([`thread.req.exception`]).

Returns : The constructed `arrival_token` object.

```
inline void wait(arrival_token &&old_phase) const
```

Preconditions: arrival is associated with the phase synchronization point for the current phase or the immediately preceding phase of the same barrier object.

Effects: Blocks at the synchronization point associated with HPX_MOVE(arrival) until the phase completion step of the synchronization point's phase is run. [Note: If arrival is associated with the synchronization point for a previous phase, the call returns immediately. - end note]

Throws `system_error` – when an exception is required ([thread.req.exception]).

Error conditions: Any of the error conditions allowed for mutex types ([thread.mutex.requirements.mutex]).

```
inline void arrive_and_wait()
```

Effects: Equivalent to: wait(arrive()).

```
inline void arrive_and_drop()
```

Preconditions: The expected count for the current barrier phase is greater than zero.

Effects: Decrements the initial expected count for all subsequent phases by one. Then decrements the expected count for the current phase by one.

Synchronization: The call to arrive_and_drop strongly happens before the start of the phase completion step for the current phase.

Throws `system_error` – when an exception is required ([thread.req.exception]).

Error conditions: Any of the error conditions allowed for mutex types ([thread.mutex.requirements.mutex]). [Note: This call can cause the completion step for the current phase to start.- end note]

Public Static Functions

```
static inline constexpr std::ptrdiff_t() max() noexcept
```

Private Types

```
using mutex_type = hpx::spinlock
```

Private Members

```
hpx::intrusive_ptr<detail::barrier_data> mtx_
```

```
mutable hpx::local::local::detail::condition_variable cond_
```

```
std::ptrdiff_t expected_
```

```
std::ptrdiff_t arrived_
```

```
OnCompletion completion_
```

```
bool phase_
```

hpx::binary_semaphore

Defined in header `hpx/semaphore.hpp`⁷⁴⁴.

See *Public API* for a list of names and headers that are part of the public *HPX* API.

namespace **hpx**

class **binary_semaphore**

#include <binary_semaphore.hpp> A binary semaphore is a semaphore object that has only two states. `binary_semaphore` is an alias for specialization of `hpx::counting_semaphore` with *LeastMaxValue* being 1. HPX's implementation of `binary_semaphore` is more efficient than the default implementation of a counting semaphore with a unit resource count (`hpx::counting_semaphore`).

Public Functions

`binary_semaphore(binary_semaphore const&) = delete`

`binary_semaphore &operator=(binary_semaphore const&) = delete`

`binary_semaphore(binary_semaphore&&) = delete`

`binary_semaphore &operator=(binary_semaphore&&) = delete`

explicit `binary_semaphore(std::ptrdiff_t value = 1)`

Constructs an object of type `hpx::binary_semaphore` with the internal counter initialized to *value*.

Parameters *value* – The initial value of the internal semaphore lock count. Normally this value should be zero (which is the default), values greater than zero are equivalent to the same number of signals pre-set, and negative values are equivalent to the same number of waits pre-set.

`~binary_semaphore()` = default

void `release(std::ptrdiff_t update = 1)`

Atomically increments the internal counter by the value of *update*. Any thread(s) waiting for the counter to be greater than 0, such as due to being blocked in acquire, will subsequently be unblocked.

Note: Synchronization: Strongly happens before invocations of *try_acquire* that observe the result of the effects.

Throws `std::system_error` –

Parameters *update* – the amount to increment the internal counter by

Pre Both *update* ≥ 0 and *update* $\leq \text{max}()$ – *counter* are *true*, where *counter* is the value of the internal counter.

bool `try_acquire()` noexcept

Tries to atomically decrement the internal counter by 1 if it is greater than 0; no blocking occurs regardless.

Returns *true* if it decremented the internal counter, otherwise *false*

⁷⁴⁴ http://github.com/STELLAR-GROUP/hpx/blob/8a3b7c1a4cb5693b2f7d9f587f759392ed0c51a0/libs/core/include_local/include/hpx/semaphore.hpp

void **acquire**()

Repeatedly performs the following steps, in order:

- Evaluates `try_acquire`. If the result is true, returns.

Blocks on `*this` until counter is greater than zero.

Throws `std::system_error` –

Returns `void`.

bool **try_acquire_until**(`hpx::chrono::steady_time_point` const &`abs_time`)

Tries to atomically decrement the internal counter by 1 if it is greater than 0; otherwise blocks until it is greater than 0 and can successfully decrement the internal counter, or the `abs_time` time point has been passed.

Parameters `abs_time` – the earliest time the function must wait until in order to fail

Throws `std::system_error` –

Returns `true` if it decremented the internal counter, otherwise `false`.

bool **try_acquire_for**(`hpx::chrono::steady_duration` const &`rel_time`)

Tries to atomically decrement the internal counter by 1 if it is greater than 0; otherwise blocks until it is greater than 0 and can successfully decrement the internal counter, or the `rel_time` duration has been exceeded.

Throws `std::system_error` –

Parameters `rel_time` – the minimum duration the function must wait for to fail

Returns `true` if it decremented the internal counter, otherwise `false`

Public Static Functions

static constexpr `std::ptrdiff_t` **max**() noexcept

Returns The maximum value of counter. This value is greater than or equal to `LeastMaxValue`.

Returns The internal counter's maximum possible value, as a `std::ptrdiff_t`.

`hpx::condition_variable`, `hpx::condition_variable_any`, `hpx::cv_status`

Defined in header `hpx/condition_variable.hpp`⁷⁴⁵.

See *Public API* for a list of names and headers that are part of the public *HPX* API.

namespace **hpx**

Enums

enum class **cv_status**

The scoped enumeration `hpx::cv_status` describes whether a timed wait returned because of timeout or not. `hpx::cv_status` is used by the `wait_for` and `wait_until` member functions of `hpx::condition_variable` and `hpx::condition_variable_any`.

Values:

⁷⁴⁵ http://github.com/STELLAR-GROUP/hpx/blob/8a3b7c1a4cb5693b2f7d9f587f759392ed0c51a0/libs/core/include_local/include/hpx/condition_variable.hpp

enumerator **no_timeout**

The condition variable was awakened with *notify_all*, *notify_one*, or spuriously

enumerator **timeout**

the condition variable was awakened by timeout expiration

enumerator **error**

there was an error

class **condition_variable**

#include <condition_variable.hpp> The `condition_variable` class is a synchronization primitive that can be used to block a thread, or multiple threads at the same time, until another thread both modifies a shared variable (the condition), and notifies the `condition_variable`.

The thread that intends to modify the shared variable has to

- i. acquire a `hpx::mutex` (typically via `std::lock_guard`)
- ii. perform the modification while the lock is held
- iii. execute *notify_one* or *notify_all* on the `condition_variable` (the lock does not need to be held for notification)

Even if the shared variable is atomic, it must be modified under the mutex in order to correctly publish the modification to the waiting thread. Any thread that intends to wait on `condition_variable` has to

- i. acquire a `std::unique_lock<hpx::mutex>`, on the same mutex as used to protect the shared variable
- ii. either
 - A. check the condition, in case it was already updated and notified
 - B. execute *wait*, *await_for*, or *wait_until*. The wait operations atomically release the mutex and suspend the execution of the thread.
 - C. When the condition variable is notified, a timeout expires, or a spurious wakeup occurs, the thread is awakened, and the mutex is atomically reacquired. The thread should then check the condition and resume waiting if the wake up was spurious. or
- A. use the predicated overload of *wait*, *wait_for*, and *wait_until*, which takes care of the three steps above.

`hpx::condition_variable` works only with `std::unique_lock<hpx::mutex>`. This restriction allows for maximal efficiency on some platforms. `hpx::condition_variable_any` provides a condition variable that works with any `BasicLockable`⁷⁴⁶ object, such as `std::shared_lock`.

Condition variables permit concurrent invocation of the *wait*, *wait_for*, *wait_until*, *notify_one* and *notify_all* member functions.

The class `hpx::condition_variable` is a `StandardLayoutType`⁷⁴⁷. It is not `CopyConstructible`⁷⁴⁸, `MoveConstructible`⁷⁴⁹, `CopyAssignable`⁷⁵⁰, or `MoveAssignable`⁷⁵¹.

Public Functions

inline **condition_variable**()

Construct an object of type `hpx::condition_variable`.

~condition_variable() = default

Destroys the object of type `hpx::condition_variable`.

IOW, `~condition_variable()` can execute before a signaled thread returns from a wait. If this happens with `condition_variable`, that waiting thread will attempt to lock the destructed mutex. To fix this, there must be shared ownership of the data members between the `condition_variable` object and the member functions `wait` (`wait_for`, etc.).

Note: Preconditions: There is no thread blocked on `*this`. [Note: That is, all threads have been notified; they could subsequently block on the lock specified in the wait. This relaxes the usual rules, which would have required all wait calls to happen before destruction. Only the notification to unblock the wait needs to happen before destruction. The user should take care to ensure that no threads wait on `*this` once the destructor has been started, especially when the waiting threads are calling the `wait` functions in a loop or using the overloads of `wait`, `wait_for`, or `wait_until` that take a predicate. end note]

condition_variable(*condition_variable* const&) = delete

condition_variable(*condition_variable*&&) = delete

condition_variable &**operator=**(*condition_variable* const&) = delete

condition_variable &**operator=**(*condition_variable*&&) = delete

inline void **notify_one**(*error_code* &ec = *throws*) const

If any threads are waiting on `*this`, calling `notify_one` unblocks one of the waiting threads.

Parameters *ec* – Used to hold error code value originated during the operation. Defaults to `throws —`; A special ‘throw on error’ `error_code`.

Returns `notify_one` returns `void`.

inline void **notify_all**(*error_code* &ec = *throws*) const

Unblocks all threads currently waiting for `*this`.

Parameters *ec* – Used to hold error code value originated during the operation. Defaults to `throws —`; A special ‘throw on error’ `error_code`.

Returns `notify_all` returns `void`.

template<typename **Mutex**>

inline void **wait**(*std::unique_lock*<*Mutex*> &lock, *error_code* &ec = *throws*)

`wait` causes the current thread to block until the condition variable is notified or a spurious wakeup occurs, optionally looping until some predicate is satisfied (`bool(pred())==true`).

Atomically unlocks `lock`, blocks the current executing thread, and adds it to the list of threads waiting on `*this`. The thread will be unblocked when `notify_all()` or `notify_one()` is executed. It may also be unblocked spuriously. When unblocked, regardless of the reason, `lock` is reacquired and `wait` exits.

Note: 1. Calling this function if `lock.mutex()` is not locked by the current thread is undefined behavior.
A. Calling this function if `lock.mutex()` is not the same mutex as the one used by all other threads that are currently waiting on the same condition variable is undefined behavior.

Template Parameters **Mutex** – Type of mutex to wait on.

Parameters

- **lock** – *unique_lock* that must be locked by the current thread
- **ec** – Used to hold error code value originated during the operation. Defaults to *throws* — A special ‘throw on error’ *error_code*.

Returns *wait* returns *void*.

```
template<typename Mutex, typename Predicate>
inline void wait(std::unique_lock<Mutex> &lock, Predicate pred, error_code& = throws)
```

wait causes the current thread to block until the condition variable is notified or a spurious wakeup occurs, optionally looping until some predicate is satisfied (`bool(pred())==true`).

Equivalent to

```
while (!pred()) {
    wait(lock);
}
```

This overload may be used to ignore spurious awakenings while waiting for a specific condition to become true. Note that lock must be acquired before entering this method, and it is reacquired after *wait(lock)* exits, which means that lock can be used to guard access to *pred()*.

Note: 1. Calling this function if *lock.mutex()* is not locked by the current thread is undefined behavior.
A. Calling this function if *lock.mutex()* is not the same mutex as the one used by all other threads that are currently waiting on the same condition variable is undefined behavior.

Template Parameters

- **Mutex** – Type of mutex to wait on.
- **Predicate** – Type of predicate *pred* function.

Parameters

- **lock** – *unique_lock* that must be locked by the current thread
- **pred** – Predicate which returns *false* if the waiting should be continued (`bool(pred())==false`). The signature of the predicate function should be equivalent to the following: `bool pred()`;

Returns *wait* returns *void*.

```
template<typename Mutex>
inline cv_status wait_until(std::unique_lock<Mutex> &lock, hpx::chrono::steady_time_point const
    &abs_time, error_code &ec = throws)
```

wait_until causes the current thread to block until the condition variable is notified, a specific time is reached, or a spurious wakeup occurs, optionally looping until some predicate is satisfied (`bool(pred())==true`).

Atomically releases lock, blocks the current executing thread, and adds it to the list of threads waiting on **this*. The thread will be unblocked when `notify_all()` or `notify_one()` is executed, or when the absolute time point *abs_time* is reached. It may also be unblocked spuriously. When unblocked, regardless of the reason, lock is reacquired and *wait_until* exits.

Note: 1. Calling this function if *lock.mutex()* is not locked by the current thread is undefined behavior.
A. Calling this function if *lock.mutex()* is not the same mutex as the one used by all other threads that are currently waiting on the same condition variable is undefined behavior.

Template Parameters **Mutex** – Type of mutex to wait on.

Parameters

- **lock** – *unique_lock* that must be locked by the current thread
- **abs_time** – Represents the time when waiting should be stopped
- **ec** – Used to hold error code value originated during the operation. Defaults to *throws* — A special ‘throw on error’ *error_code*.

Returns *cv_status wait_until* returns *hpx::cv_status::timeout* if the absolute timeout specified by *abs_time* was reached and *hpx::cv_status::no_timeout* otherwise.

```
template<typename Mutex, typename Predicate>
inline bool wait_until(std::unique_lock<Mutex> &lock, hpx::chrono::steady_time_point const
    &abs_time, Predicate pred, error_code &ec = throws)
```

wait_until causes the current thread to block until the condition variable is notified, a specific time is reached, or a spurious wakeup occurs, optionally looping until some predicate is satisfied (`bool(pred())==true`).

Equivalent to

```
while (!pred()) {
    if (wait_until(lock, abs_time) == hpx::cv_status::timeout) {
        return pred();
    }
}
return true;
```

This overload may be used to ignore spurious wakeups.

Note: 1. Calling this function if *lock.mutex()* is not locked by the current thread is undefined behavior.
A. Calling this function if *lock.mutex()* is not the same mutex as the one used by all other threads that are currently waiting on the same condition variable is undefined behavior.

Template Parameters

- **Mutex** – Type of mutex to wait on.
- **Predicate** – Type of predicate *pred* function.

Parameters

- **lock** – *unique_lock* that must be locked by the current thread
- **abs_time** – Represents the time when waiting should be stopped
- **pred** – Predicate which returns *false* if the waiting should be continued (`bool(pred())==false`). The signature of the predicate function should be equivalent to the following: `bool pred();`
- **ec** – Used to hold error code value originated during the operation. Defaults to *throws* — A special ‘throw on error’ *error_code*.

Returns `bool wait_until` returns *false* if the predicate *pred* still evaluates to false after the *abs_time* timeout has expired, otherwise *true*. If the timeout had already expired, evaluates and returns the result of *pred*.

```
template<typename Mutex>
inline cv_status wait_for(std::unique_lock<Mutex> &lock, hpx::chrono::steady_duration const
    &rel_time, error_code &ec = throws)
```

Atomically releases lock, blocks the current executing thread, and adds it to the list of threads waiting on **this*. The thread will be unblocked when `notify_all()` or `notify_one()` is executed, or when the relative timeout *rel_time* expires. It may also be unblocked spuriously. When unblocked, regardless of the reason, lock is reacquired and `wait_for()` exits.

The standard recommends that a steady clock be used to measure the duration. This function may block for longer than *rel_time* due to scheduling or resource contention delays.

-
- Note:** 1. Calling this function if *lock.mutex()* is not locked by the current thread is undefined behavior.
- A. Calling this function if *lock.mutex()* is not the same mutex as the one used by all other threads that are currently waiting on the same condition variable is undefined behavior.
 - B. Even if notified under lock, this overload makes no guarantees about the state of the associated predicate when returning due to timeout.
-

Template Parameters **Mutex** – Type of mutex to wait on.

Parameters

- **lock** – *unique_lock* that must be locked by the current thread
- **rel_time** – represents the maximum time to spend waiting. Note that *rel_time* must be small enough not to overflow when added to *hpx::chrono::steady_clock::now()*.
- **ec** – Used to hold error code value originated during the operation. Defaults to *throws* — A special ‘throw on error’ *error_code*.

Returns *cv_status* *hpx::cv_status::timeout* if the relative timeout specified by *rel_time* expired, *hpx::cv_status::no_timeout* otherwise.

```
template<typename Mutex, typename Predicate>
inline bool wait_for(std::unique_lock<Mutex> &lock, hpx::chrono::steady_duration const &rel_time,
                    Predicate pred, error_code &ec = throws)
```

Equivalent to.

```
return wait_until(lock,
                  hpx::chrono::steady_clock::now() + rel_time,
                  hpx::move(pred));
```

This overload may be used to ignore spurious awakenings by looping until some predicate is satisfied (`bool(pred())==true`).

The standard recommends that a steady clock be used to measure the duration. This function may block for longer than *rel_time* due to scheduling or resource contention delays.

-
- Note:** 1. Calling this function if *lock.mutex()* is not locked by the current thread is undefined behavior.
- A. Calling this function if *lock.mutex()* is not the same mutex as the one used by all other threads that are currently waiting on the same condition variable is undefined behavior.
-

Template Parameters

- **Mutex** – Type of mutex to wait on.
- **Predicate** – Type of predicate *pred* function.

Parameters

- **lock** – *unique_lock* that must be locked by the current thread
- **rel_time** – represents the maximum time to spend waiting. Note that *rel_time* must be small enough not to overflow when added to *hpx::chrono::steady_clock::now()*.
- **pred** – Predicate which returns *false* if the waiting should be continued (`bool(pred())==false`). The signature of the predicate function should be equivalent to the following: `bool pred()`;
- **ec** – Used to hold error code value originated during the operation. Defaults to *throws* — A special ‘throw on error’ *error_code*.

Returns bool *wait_for* returns *false* if the predicate *pred* still evaluates to *false* after the *rel_time* timeout expired, otherwise *true*.

Private Types

```
using mutex_type = lcos::local::detail::condition_variable_data::mutex_type
```

```
using data_type = hpx::intrusive_ptr<lcos::local::detail::condition_variable_data>
```

Private Members

```
hpx::util::cache_aligned_data_derived<data_type> data_
```

```
class condition_variable_any
```

`#include <condition_variable.hpp>` The `condition_variable_any` class is a generalization of `hpx::condition_variable`. Whereas `hpx::condition_variable` works only on `std::unique_lock<std::mutex>`, a `condition_variable_any` can operate on any lock that meets the `BasicLockable`⁷⁵² requirements.

See `hpx::condition_variable` for the description of the semantics of condition variables. It is not `CopyConstructible`⁷⁵³, `MoveConstructible`⁷⁵⁴, `CopyAssignable`⁷⁵⁵, or `MoveAssignable`⁷⁵⁶.

Public Functions

```
inline condition_variable_any()
```

Constructs an object of type `hpx::condition_variable_any`.

```
~condition_variable_any() = default
```

Destroys the object of type `hpx::condition_variable_any`.

It is only safe to invoke the destructor if all threads have been notified. It is not required that they have exited their respective wait functions: some threads may still be waiting to reacquire the associated lock, or may be waiting to be scheduled to run after reacquiring it.

The programmer must ensure that no threads attempt to wait on **this* once the destructor has been started, especially when the waiting threads are calling the wait functions in a loop or are using the overloads of the wait functions that take a predicate.

Preconditions: There is no thread blocked on **this*. [Note: That is, all threads have been notified; they could subsequently block on the lock specified in the wait. This relaxes the usual rules, which would have required all wait calls to happen before destruction. Only the notification to unblock the wait needs to happen before destruction. The user should take care to ensure that no threads wait on **this* once the destructor has been started, especially when the waiting threads are calling the *wait* functions in a loop or using the overloads of *wait*, *wait_for*, or *wait_until* that take a predicate. end note]

IOW, `~condition_variable_any()` can execute before a signaled thread returns from a wait. If this happens with `condition_variable_any`, that waiting thread will attempt to lock the destructed mutex. To fix this, there must be shared ownership of the data members between the `condition_variable_any` object and the member functions *wait* (*wait_for*, etc.).

```
condition_variable_any(condition_variable_any const&) = delete
```

```
condition_variable_any(condition_variable_any&&) = delete
```

```
condition_variable_any &operator=(condition_variable_any const&) = delete
```

```
condition_variable_any &operator=(condition_variable_any&&) = delete
```

```
inline void notify_one(error_code &ec = throws) const
```

If any threads are waiting on **this*, calling *notify_one* unblocks one of the waiting threads.

The notifying thread does not need to hold the lock on the same mutex as the one held by the waiting thread(s); in fact doing so is a pessimization, since the notified thread would immediately block again, waiting for the notifying thread to release the lock. However, some implementations (in particular many implementations of pthreads) recognize this situation and avoid this “hurry up and wait” scenario by transferring the waiting thread from the condition variable’s queue directly to the queue of the mutex within the notify call, without waking it up.

Notifying while under the lock may nevertheless be necessary when precise scheduling of events is required, e.g. if the waiting thread would exit the program if the condition is satisfied, causing destruction of the notifying thread’s condition variable. A spurious wakeup after mutex unlock but before notify would result in notify called on a destroyed object.

Note: The effects of *notify_one()/notify_all()* and each of the three atomic parts of *wait()/wait_for()/wait_until()* (unlock+wait wakeup, and lock) take place in a single total order that can be viewed as modification order of an atomic variable: the order is specific to this individual condition variable. This makes it impossible for *notify_one()* to, for example, be delayed and unblock a thread that started waiting just after the call to *notify_one()* was made.

Parameters *ec* – Used to hold error code value originated during the operation. Defaults to *throws* — A special ‘throw on error’ *error_code*.

Returns *notify_one* returns *void*.

```
inline void notify_all(error_code &ec = throws) const
```

Unblocks all threads currently waiting for **this*.

The notifying thread does not need to hold the lock on the same mutex as the one held by the waiting thread(s); in fact doing so is a pessimization, since the notified thread would immediately block again, waiting for the notifying thread to release the lock.

Note: The effects of *notify_one()/notify_all()* and each of the three atomic parts of *wait()/wait_for()/wait_until()* (unlock+wait, wakeup, and lock) take place in a single total order that can be viewed as modification order of an atomic variable: the order is specific to this individual condition variable. This makes it impossible for *notify_one()* to, for example, be delayed and unblock a thread that started waiting just after the call to *notify_one()* was made.

Parameters *ec* – Used to hold error code value originated during the operation. Defaults to *throws* — A special ‘throw on error’ *error_code*.

Returns *notify_all* returns *void*.

```
template<typename Lock>
```

```
inline void wait(Lock &lock, error_code &ec = throws)
```

wait causes the current thread to block until the condition variable is notified or a spurious wakeup occurs, optionally looping until some predicate is satisfied (`bool(pred())==true`).

Atomically unlocks lock, blocks the current executing thread, and adds it to the list of threads waiting on **this*. The thread will be unblocked when `notify_all()` or `notify_one()` is executed. It may also be unblocked spuriously. When unblocked, regardless of the reason, lock is reacquired and wait exits.

The effects of `notify_one()/notify_all()` and each of the three atomic parts of `wait()/wait_for()/wait_until()` (unlock+wait, wakeup, and lock) take place in a single total order that can be viewed as modification order of an atomic variable: the order is specific to this individual condition variable. This makes it impossible for `notify_one()` to, for example, be delayed and unblock a thread that started waiting just after the call to `notify_one()` was made.

Note: If these functions fail to meet the postconditions (lock is locked by the calling thread), `std::terminate` is called. For example, this could happen if re-locking the mutex throws an exception.

Template Parameters **Lock** – Type of *lock*.

Parameters

- **lock** – An object of type `Lock` that meets the `BasicLockable`⁷⁵⁷ requirements, which must be locked by the current thread
- **ec** – Used to hold error code value originated during the operation. Defaults to `throws` `—` A special 'throw on error' `error_code`.

Returns `wait` returns `void`.

```
template<typename Lock, typename Predicate>
inline void wait(Lock &lock, Predicate pred, error_code& = throws)
```

`wait` causes the current thread to block until the condition variable is notified or a spurious wakeup occurs, optionally looping until some predicate is satisfied (`bool(pred())==true`).

Equivalent to

```
while (!pred()) {
    wait(lock);
}
```

This overload may be used to ignore spurious awakenings while waiting for a specific condition to become true. Note that lock must be acquired before entering this method, and it is reacquired after `wait(lock)` exits, which means that lock can be used to guard access to `pred()`.

The effects of `notify_one()/notify_all()` and each of the three atomic parts of `wait()/wait_for()/wait_until()` (unlock+wait, wakeup, and lock) take place in a single total order that can be viewed as modification order of an atomic variable: the order is specific to this individual condition variable. This makes it impossible for `notify_one()` to, for example, be delayed and unblock a thread that started waiting just after the call to `notify_one()` was made.

Note: If these functions fail to meet the postconditions (lock is locked by the calling thread), `std::terminate` is called. For example, this could happen if re-locking the mutex throws an exception.

Template Parameters

- **Lock** – Type of *lock*.
- **Predicate** – Type of *pred*.

Parameters

- **lock** – an object of type `Lock` that meets the `BasicLockable`⁷⁵⁸ requirements, which must be locked by the current thread

- **pred** – predicate which returns `false` if the waiting should be continued (`bool(pred()) == false`). The signature of the predicate function should be equivalent to the following: `bool pred()`.

Returns `wait` returns `void`.

```
template<typename Lock>
inline cv_status wait_until(Lock &lock, hpx::chrono::steady_time_point const &abs_time, error_code
    &ec = throws)
```

`wait_until` causes the current thread to block until the condition variable is notified, a specific time is reached, or a spurious wakeup occurs, optionally looping until some predicate is satisfied (`bool(pred()) == true`).

Atomically releases lock, blocks the current executing thread, and adds it to the list of threads waiting on `*this`. The thread will be unblocked when `notify_all()` or `notify_one()` is executed, or when the absolute time point `abs_time` is reached. It may also be unblocked spuriously. When unblocked, regardless of the reason, lock is reacquired and `wait_until` exits.

Note: The effects of `notify_one()/notify_all()` and each of the three atomic parts of `wait()/wait_for()/wait_until()` (unlock+wait, wakeup, and lock) take place in a single total order that can be viewed as modification order of an atomic variable: the order is specific to this individual condition variable. This makes it impossible for `notify_one()` to, for example, be delayed and unblock a thread that started waiting just after the call to `notify_one()` was made.

Template Parameters `Lock` – Type of `lock`.

Parameters

- **lock** – an object of type `Lock` that meets the requirements of `BasicLockable`⁷⁵⁹, which must be locked by the current thread
- **abs_time** – represents the time when waiting should be stopped.
- **ec** – used to hold error code value originated during the operation. Defaults to `throws` — A special ‘throw on error’ `error_code`.

Returns `cv_status` `hpx::cv_status::timeout` if the absolute timeout specified by `abs_time` was reached, `hpx::cv_status::no_timeout` otherwise.

```
template<typename Lock, typename Predicate>
inline bool wait_until(Lock &lock, hpx::chrono::steady_time_point const &abs_time, Predicate pred,
    error_code &ec = throws)
```

`wait_until` causes the current thread to block until the condition variable is notified, a specific time is reached, or a spurious wakeup occurs, optionally looping until some predicate is satisfied (`bool(pred()) == true`).

Equivalent to

```
while (!pred()) {
    if (wait_until(lock, timeout_time) == hpx::cv_status::timeout) {
        return pred();
    }
}
return true;
```

This overload may be used to ignore spurious wakeups.

Note: The effects of `notify_one()/notify_all()` and each of the three atomic parts of `wait()/wait_for()/wait_until()` (unlock+wait, wakeup, and lock) take place in a single total order that

can be viewed as modification order of an atomic variable: the order is specific to this individual condition variable. This makes it impossible for `notify_one()` to, for example, be delayed and unblock a thread that started waiting just after the call to `notify_one()` was made.

Template Parameters

- **Lock** – Type of *lock*.
- **Predicate** – Type of *pred*.

Parameters

- **lock** – an object of type *Lock* that meets the requirements of `BasicLockable`⁷⁶⁰, which must be locked by the current thread
- **abs_time** – represents the time when waiting should be stopped.
- **pred** – predicate which returns *false* if the waiting should be continued (`bool(pred()) == false`). The signature of the predicate function should be equivalent to the following: `bool pred()`;
- **ec** – Used to hold error code value originated during the operation. Defaults to *throws* — A special ‘throw on error’ *error_code*.

Returns `bool false` if the predicate *pred* still evaluates to *false* after the *abs_time* timeout expired, otherwise true. If the timeout had already expired, evaluates and returns the result of *pred*.

```
template<typename Lock>
inline cv_status wait_for(Lock &lock, hpx::chrono::steady_duration const &rel_time, error_code &ec
                        = throws)
```

Atomically releases lock, blocks the current executing thread, and adds it to the list of threads waiting on **this*. The thread will be unblocked when `notify_all()` or `notify_one()` is executed, or when the relative timeout *rel_time* expires. It may also be unblocked spuriously. When unblocked, regardless of the reason, *lock* is reacquired and `wait_for()` exits.

The effects of `notify_one()/notify_all()` and each of the three atomic parts of `wait()/wait_for()/wait_until()` (unlock+wait, wakeup, and lock) take place in a single total order that can be viewed as modification order of an atomic variable: the order is specific to this individual condition variable. This makes it impossible for `notify_one()` to, for example, be delayed and unblock a thread that started waiting just after the call to `notify_one()` was made.

Note: Even if notified under lock, this overload makes no guarantees about the state of the associated predicate when returning due to timeout.

Template Parameters **Lock** – Type of *lock*.**Parameters**

- **lock** – an object of type *Lock* that meets the `BasicLockable`⁷⁶¹ requirements, which must be locked by the current thread.
- **rel_time** – an object of type `hpx::chrono::duration` representing the maximum time to spend waiting. Note that *rel_time* must be small enough not to overflow when added to `hpx::chrono::steady_clock::now()`.
- **ec** – Used to hold error code value originated during the operation. Defaults to *throws* — A special ‘throw on error’ *error_code*.

Returns `cv_status hpx::cv_status::timeout` if the relative timeout specified by *rel_time* expired, `hpx::cv_status::no_timeout` otherwise.

```
template<typename Lock, typename Predicate>
inline bool wait_for(Lock &lock, hpx::chrono::steady_duration const &rel_time, Predicate pred,
                  error_code &ec = throws)
```

Equivalent to.

```
return wait_until(lock,
    hpx::chrono::steady_clock::now() + rel_time,
    std::move(pred));
```

This overload may be used to ignore spurious awakenings by looping until some predicate is satisfied (`bool(pred()) == true`).

Note: The effects of `notify_one()/notify_all()` and each of the three atomic parts of `wait()/wait_for()/wait_until()` (unlock+wait, wakeup, and lock) take place in a single total order that can be viewed as modification order of an atomic variable: the order is specific to this individual condition variable. This makes it impossible for `notify_one()` to, for example, be delayed and unblock a thread that started waiting just after the call to `notify_one()` was made.

Template Parameters

- **Lock** – Type of *lock*.
- **Predicate** – Type of *pred*.

Parameters

- **lock** – an object of type *Lock* that meets the [BasicLockable](#)⁷⁶² requirements, which must be locked by the current thread.
- **rel_time** – an object of type `hpx::chrono::duration` representing the maximum time to spend waiting. Note that *rel_time* must be small enough not to overflow when added to `hpx::chrono::steady_clock::now()`.
- **pred** – predicate which returns *false* if the waiting should be continued (`bool(pred()) == false`). The signature of the predicate function should be equivalent to the following: `bool pred();`
- **ec** – Used to hold error code value originated during the operation. Defaults to *throws* — A special ‘throw on error’ *error_code*.

Returns *bool false* if the predicate *pred* still evaluates to *false* after the *rel_time* timeout expired, otherwise *true*.

```
template<typename Lock, typename Predicate>
```

```
inline bool wait(Lock &lock, stop_token token, Predicate pred, error_code &ec = throws)
```

wait causes the current thread to block until the condition variable is notified or a spurious wakeup occurs, optionally looping until some predicate is satisfied (`bool(pred())==true`).

An interruptible wait: registers the `condition_variable_any` for the duration of `wait()`, to be notified if a stop request is made on the given `token`'s associated stop-state; it is then equivalent to

```
while (!token.stop_requested()) {
    if (pred()) return true;
    wait(lock);
}
return pred();
```

Note that the returned value indicates whether *pred* evaluated to *true*, regardless of whether there was a stop requested or not.

Note: The effects of `notify_one()/notify_all()` and each of the three atomic parts of `wait()/wait_for()/wait_until()` (unlock+wait, wakeup, and lock) take place in a single total or-

der that can be viewed as modification order of an atomic variable: the order is specific to this individual condition variable. This makes it impossible for `notify_one()` to, for example, be delayed and unblock a thread that started waiting just after the call to `notify_one()` was made.

Template Parameters

- **Lock** – Type of *lock*.
- **Predicate** – Type of *pred*.

Parameters

- **lock** – an object of type *Lock* that meets the `BasicLockable`⁷⁶³ requirements, which must be locked by the current thread
- **stoken** – a `hpx::stop_token` to register interruption for
- **pred** – predicate which returns `false` if the waiting should be continued (`bool(pred()) == false`). The signature of the predicate function should be equivalent to the following: `bool pred()`.
- **ec** – Used to hold error code value originated during the operation. Defaults to `throws` — A special ‘throw on error’ `error_code`.

Returns `bool` result of `pred()`.

```
template<typename Lock, typename Predicate>
inline bool wait_until(Lock &lock, stop_token stoken, hpx::chrono::steady_time_point const
    &abs_time, Predicate pred, error_code &ec = throws)
```

`wait_until` causes the current thread to block until the condition variable is notified, a specific time is reached, or a spurious wakeup occurs, optionally looping until some predicate is satisfied (`bool(pred()) == true`).

An interruptible wait: registers the `condition_variable_any` for the duration of `wait_until()`, to be notified if a stop request is made on the given `stoken`’s associated stop-state; it is then equivalent to

```
while (!stoken.stop_requested()) {
    if (pred())
        return true;
    if (wait_until(lock, timeout_time) == hpx::cv_status::timeout)
        return pred();
}
return pred();
```

Note: The effects of `notify_one()/notify_all()` and each of the three atomic parts of `wait()/wait_for()/wait_until()` (unlock+wait, wakeup, and lock) take place in a single total order that can be viewed as modification order of an atomic variable: the order is specific to this individual condition variable. This makes it impossible for `notify_one()` to, for example, be delayed and unblock a thread that started waiting just after the call to `notify_one()` was made.

Template Parameters

- **Lock** – Type of *lock*.
- **Predicate** – Type of *pred*.

Parameters

- **lock** – an object of type *Lock* that meets the requirements of `BasicLockable`⁷⁶⁴, which must be locked by the current thread.
- **stoken** – a `hpx::stop_token` to register interruption for.
- **abs_time** – represents the time when waiting should be stopped.
- **pred** – predicate which returns `false` if the waiting should be continued (`bool(pred()) == false`). The signature of the predicate function should be equivalent to the following: `bool pred();`.

- **ec** – Used to hold error code value originated during the operation. Defaults to *throws* — A special ‘throw on error’ *error_code*.

Returns `bool pred()`, regardless of whether the timeout was met or stop was requested.

```
template<typename Lock, typename Predicate>
inline bool wait_for(Lock &lock, stop_token stoken, hpx::chrono::steady_duration const &rel_time,
                    Predicate pred, error_code &ec = throws)
```

Equivalent to.

```
return wait_until(lock, std::move(stoken),
                  hpx::chrono::steady_clock::now() + rel_time,
                  std::move(pred));
```

Note: The effects of `notify_one()/notify_all()` and each of the three atomic parts of `wait()/wait_for()/wait_until()` (unlock+wait, wakeup, and lock) take place in a single total order that can be viewed as modification order of an atomic variable: the order is specific to this individual condition variable. This makes it impossible for `notify_one()` to, for example, be delayed and unblock a thread that started waiting just after the call to `notify_one()` was made.

Template Parameters

- **Lock** – Type of *lock*.
- **Predicate** – Type of *pred*.

Parameters

- **lock** – an object of type *Lock* that meets the `BasicLockable`⁷⁶⁵ requirements, which must be locked by the current thread.
- **stoken** – a `hpx::stop_token` to register interruption for.
- **rel_time** – an object of type `hpx::chrono::duration` representing the maximum time to spend waiting. Note that *rel_time* must be small enough not to overflow when added to `hpx::chrono::steady_clock::now()`.
- **pred** – predicate which returns *false* if the waiting should be continued (`bool(pred()) == false`). The signature of the predicate function should be equivalent to the following: `bool pred()`;
- **ec** – Used to hold error code value originated during the operation. Defaults to *throws* — A special ‘throw on error’ *error_code*.

Returns `bool pred()`, regardless of whether the timeout was met or stop was requested.

Private Types

```
using mutex_type = lcos::local::detail::condition_variable_data::mutex_type
```

```
using data_type = hpx::intrusive_ptr<lcos::local::detail::condition_variable_data>
```

Private Members

hpx::util::cache_aligned_data_derived<data_type> data_

hpx::counting_semaphore

Defined in header `hpx/semaphore.hpp`⁷⁶⁶.

See *Public API* for a list of names and headers that are part of the public *HPX* API.

namespace **hpx**

```
template<std::ptrdiff_t LeastMaxValue = PTRDIFF_MAX>
```

```
class counting_semaphore
```

#include <counting_semaphore.hpp> A semaphore is a protected variable (an entity storing a value) or abstract data type (an entity grouping several variables that may or may not be numerical) which constitutes the classic method for restricting access to shared resources, such as shared memory, in a multiprogramming environment. Semaphores exist in many variants, though usually the term refers to a counting semaphore, since a binary semaphore is better known as a mutex. A counting semaphore is a counter for a set of available resources, rather than a locked/unlocked flag of a single resource. It was invented by Edsger Dijkstra. Semaphores are the classic solution to preventing race conditions in the dining philosophers problem, although they do not prevent resource deadlocks.

Counting semaphores can be used for synchronizing multiple threads as well: one thread waiting for several other threads to touch (signal) the semaphore, or several threads waiting for one other thread to touch this semaphore. Unlike `hpx::mutex` a `counting_semaphore` is not tied to threads of execution — acquiring a semaphore can occur on a different thread than releasing the semaphore, for example. All operations on `counting_semaphore` can be performed concurrently and without any relation to specific threads of execution, with the exception of the destructor which cannot be performed concurrently but can be performed on a different thread.

Semaphores are lightweight synchronization primitives used to constrain concurrent access to a shared resource. They are widely used to implement other synchronization primitives and, whenever both are applicable, can be more efficient than condition variables.

⁷⁴⁶ https://en.cppreference.com/w/cpp/named_req/BasicLockable
⁷⁴⁷ https://en.cppreference.com/w/cpp/named_req/StandardLayoutType
⁷⁴⁸ https://en.cppreference.com/w/cpp/named_req/CopyConstructible
⁷⁴⁹ https://en.cppreference.com/w/cpp/named_req/MoveConstructible
⁷⁵⁰ https://en.cppreference.com/w/cpp/named_req/CopyAssignable
⁷⁵¹ https://en.cppreference.com/w/cpp/named_req/MoveAssignable
⁷⁵² https://en.cppreference.com/w/cpp/named_req/BasicLockable
⁷⁵³ https://en.cppreference.com/w/cpp/named_req/CopyConstructible
⁷⁵⁴ https://en.cppreference.com/w/cpp/named_req/MoveConstructible
⁷⁵⁵ https://en.cppreference.com/w/cpp/named_req/CopyAssignable
⁷⁵⁶ https://en.cppreference.com/w/cpp/named_req/MoveAssignable
⁷⁵⁷ https://en.cppreference.com/w/cpp/named_req/BasicLockable
⁷⁵⁸ https://en.cppreference.com/w/cpp/named_req/BasicLockable
⁷⁵⁹ https://en.cppreference.com/w/cpp/named_req/BasicLockable
⁷⁶⁰ https://en.cppreference.com/w/cpp/named_req/BasicLockable
⁷⁶¹ https://en.cppreference.com/w/cpp/named_req/BasicLockable
⁷⁶² https://en.cppreference.com/w/cpp/named_req/BasicLockable
⁷⁶³ https://en.cppreference.com/w/cpp/named_req/BasicLockable
⁷⁶⁴ https://en.cppreference.com/w/cpp/named_req/BasicLockable
⁷⁶⁵ https://en.cppreference.com/w/cpp/named_req/BasicLockable
⁷⁶⁶ http://github.com/STELLAR-GROUP/hpx/blob/8a3b7c1a4cb5693b2f7d9f587f759392ed0c51a0/libs/core/include_local/include/hpx/semaphore.hpp

A counting semaphore is a semaphore object that models a non-negative resource count.

Class template `counting_semaphore` maintains an internal counter that is initialized when the semaphore is created. The counter is decremented when a thread acquires the semaphore, and is incremented when a thread releases the semaphore. If a thread tries to acquire the semaphore when the counter is zero, the thread will block until another thread increments the counter by releasing the semaphore.

Specializations of `hpx::counting_semaphore` are not `DefaultConstructible`⁷⁶⁷, `CopyConstructible`⁷⁶⁸, `MoveConstructible`⁷⁶⁹, `CopyAssignable`⁷⁷⁰, or `MoveAssignable`⁷⁷¹.

Note: `counting_semaphore`'s `try_acquire()` can spuriously fail.

Template Parameters `LeastMaxValue` – `counting_semaphore` allows more than one concurrent access to the same resource, for at least `LeastMaxValue` concurrent accessors. As its name indicates, the `LeastMaxValue` is the minimum max value, not the actual max value. Thus `max()` can yield a number larger than `LeastMaxValue`.

Public Functions

`counting_semaphore(counting_semaphore const&) = delete`

`counting_semaphore &operator=(counting_semaphore const&) = delete`

`counting_semaphore(counting_semaphore&&) = delete`

`counting_semaphore &operator=(counting_semaphore&&) = delete`

explicit `counting_semaphore(std::ptrdiff_t value)`

Constructs an object of type `hpx::counting_semaphore` with the internal counter initialized to `value`.

Parameters `value` – The initial value of the internal semaphore lock count. Normally this value should be zero (which is the default), values greater than zero are equivalent to the same number of signals pre-set, and negative values are equivalent to the same number of waits pre-set.

`~counting_semaphore()` = default

void `release(std::ptrdiff_t update = 1)`

Atomically increments the internal counter by the value of `update`. Any thread(s) waiting for the counter to be greater than 0, such as due to being blocked in `acquire`, will subsequently be unblocked.

Note: Synchronization: Strongly happens before invocations of `try_acquire` that observe the result of the effects.

Throws `std::system_error` –

Parameters `update` – the amount to increment the internal counter by

Pre Both `update >= 0` and `update <= max()` – `counter` are `true`, where `counter` is the value of the internal counter.

bool `try_acquire()` noexcept

Tries to atomically decrement the internal counter by 1 if it is greater than 0; no blocking occurs regardless.

Returns `true` if it decremented the internal counter, otherwise `false`

void **acquire**()

Repeatedly performs the following steps, in order:

- Evaluates `try_acquire`. If the result is true, returns.
- Blocks on `*this` until counter is greater than zero.

Throws `std::system_error` –

Returns `void`.

bool **try_acquire_until**(`hpx::chrono::steady_time_point` const &`abs_time`)

Tries to atomically decrement the internal counter by 1 if it is greater than 0; otherwise blocks until it is greater than 0 and can successfully decrement the internal counter, or the `abs_time` time point has been passed.

Parameters `abs_time` – the earliest time the function must wait until in order to fail

Throws `std::system_error` –

Returns `true` if it decremented the internal counter, otherwise `false`.

bool **try_acquire_for**(`hpx::chrono::steady_duration` const &`rel_time`)

Tries to atomically decrement the internal counter by 1 if it is greater than 0; otherwise blocks until it is greater than 0 and can successfully decrement the internal counter, or the `rel_time` duration has been exceeded.

Throws `std::system_error` –

Parameters `rel_time` – the minimum duration the function must wait for to fail

Returns `true` if it decremented the internal counter, otherwise `false`

Public Static Functions

static constexpr `std::ptrdiff_t` **max**() noexcept

Returns The maximum value of counter. This value is greater than or equal to `LeastMaxValue`.

Returns The internal counter's maximum possible value, as a `std::ptrdiff_t`.

template<typename **Mutex** = `hpx::spinlock`, int **N** = 0>

class **counting_semaphore_var**

`#include <counting_semaphore.hpp>` A semaphore is a protected variable (an entity storing a value) or abstract data type (an entity grouping several variables that may or may not be numerical) which constitutes the classic method for restricting access to shared resources, such as shared memory, in a multiprogramming environment. Semaphores exist in many variants, though usually the term refers to a counting semaphore, since a binary semaphore is better known as a mutex. A counting semaphore is a counter for a set of available resources, rather than a locked/unlocked flag of a single resource. It was invented by Edsger Dijkstra. Semaphores are the classic solution to preventing race conditions in the dining philosophers problem, although they do not prevent resource deadlocks.

Counting semaphores can be used for synchronizing multiple threads as well: one thread waiting for several other threads to touch (signal) the semaphore, or several threads waiting for one other thread to touch this semaphore. Unlike `hpx::mutex` a `counting_semaphore_var` is not tied to threads of execution — acquiring a semaphore can occur on a different thread than releasing the semaphore, for example. All operations on `counting_semaphore_var` can be performed concurrently and without any relation to specific threads of execution, with the exception of the destructor which cannot be performed concurrently but can be performed on a different thread.

Semaphores are lightweight synchronization primitives used to constrain concurrent access to a shared resource. They are widely used to implement other synchronization primitives and, whenever both are applicable, can be more efficient than condition variables.

A counting semaphore is a semaphore object that models a non-negative resource count.

Class template `counting_semaphore_var` maintains an internal counter that is initialized when the semaphore is created. The counter is decremented when a thread acquires the semaphore, and is incremented when a thread releases the semaphore. If a thread tries to acquire the semaphore when the counter is zero, the thread will block until another thread increments the counter by releasing the semaphore.

Specializations of `hpx::counting_semaphore_var` are not `DefaultConstructible`⁷⁷², `CopyConstructible`⁷⁷³, `MoveConstructible`⁷⁷⁴, `CopyAssignable`⁷⁷⁵, or `MoveAssignable`⁷⁷⁶.

Note: `counting_semaphore_var`'s `try_acquire()` can spuriously fail.

Template Parameters

- **Mutex** – Type of mutex
- **N** – The initial value of the internal semaphore lock count.

Public Functions

explicit `counting_semaphore_var`(*std::ptrdiff_t* value = *N*)

Constructs an object of type `hpx::counting_semaphore_value` with the internal counter initialized to *N*.

Parameters **value** – The initial value of the internal semaphore lock count. Normally this value should be zero, values greater than zero are equivalent to the same number of signals pre-set, and negative values are equivalent to the same number of waits pre-set. Defaults to *N* (which in turn defaults to zero).

`counting_semaphore_var`(*counting_semaphore_var* const&) = delete

counting_semaphore_var &**operator=**(*counting_semaphore_var* const&) = delete

void **wait**(*std::ptrdiff_t* count = 1)

Wait for the semaphore to be signaled.

Parameters **count** – The value by which the internal lock count will be decremented. At the same time this is the minimum value of the lock count at which the thread is not yielded.

bool **try_wait**(*std::ptrdiff_t* count = 1)

Try to wait for the semaphore to be signaled.

Parameters **count** – The value by which the internal lock count will be decremented. At the same time this is the minimum value of the lock count at which the thread is not yielded.

Returns *try_wait* returns true if the calling thread was able to acquire the requested amount of credits. *try_wait* returns false if not sufficient credits are available at this point in time.

void **signal**(*std::ptrdiff_t* count = 1)

Signal the semaphore.

Parameters **count** – The value by which the internal lock count will be incremented.

std::ptrdiff_t **signal_all**()

Unblock all acquirers.

Returns *std::ptrdiff_t* internal lock count after the operation.

void **release**(*std::ptrdiff_t* update = 1)

Atomically increments the internal counter by the value of *update*. Any thread(s) waiting for the counter to be greater than 0, such as due to being blocked in `acquire`, will subsequently be unblocked.

Note: Synchronization: Strongly happens before invocations of *try_acquire* that observe the result of the effects.

Throws *std::system_error* –

Parameters *update* – the amount to increment the internal counter by

Pre Both *update* ≥ 0 and *update* \leq *max()* – *counter* are *true*, where *counter* is the value of the internal counter.

bool **try_acquire()** noexcept

Tries to atomically decrement the internal counter by 1 if it is greater than 0; no blocking occurs regardless.

Returns *true* if it decremented the internal counter, otherwise *false*

void **acquire()**

Repeatedly performs the following steps, in order:

- Evaluates *try_acquire*. If the result is true, returns. Blocks on **this* until counter is greater than zero.

Throws *std::system_error* –

Returns *void*.

bool **try_acquire_until**(*hpx::chrono::steady_time_point* const &*abs_time*)

Tries to atomically decrement the internal counter by 1 if it is greater than 0; otherwise blocks until it is greater than 0 and can successfully decrement the internal counter, or the *abs_time* time point has been passed.

Parameters *abs_time* – the earliest time the function must wait until in order to fail

Throws *std::system_error* –

Returns *true* if it decremented the internal counter, otherwise *false*.

bool **try_acquire_for**(*hpx::chrono::steady_duration* const &*rel_time*)

Tries to atomically decrement the internal counter by 1 if it is greater than 0; otherwise blocks until it is greater than 0 and can successfully decrement the internal counter, or the *rel_time* duration has been exceeded.

Throws *std::system_error* –

Parameters *rel_time* – the minimum duration the function must wait for to fail

Returns *true* if it decremented the internal counter, otherwise *false*

Public Static Functions

static constexpr *std::ptrdiff_t* **max**() noexcept

Returns The maximum value of counter. This value is greater than or equal to *LeastMaxValue*.

Returns The internal counter's maximum possible value, as a *std::ptrdiff_t*.

Private Types

using **mutex_type** = *Mutex*

hpx/synchronization/event.hpp

Defined in header `hpx/synchronization/event.hpp`.

See *Public API* for a list of names and headers that are part of the public *HPX* API.

namespace **hpx**

namespace **lcos**

namespace **local**

class **event**

#include <event.hpp> Event semaphores can be used for synchronizing multiple threads that need to wait for an event to occur. When the event occurs, all threads waiting for the event are woken up.

Public Functions

inline **event**() noexcept

Construct a new event semaphore.

inline bool **occurred**() const noexcept

Check if the event has occurred.

inline void **wait**()

Wait for the event to occur.

inline void **set**()

Release all threads waiting on this semaphore.

⁷⁶⁷ https://en.cppreference.com/w/cpp/named_req/DefaultConstructible

⁷⁶⁸ https://en.cppreference.com/w/cpp/named_req/CopyConstructible

⁷⁶⁹ https://en.cppreference.com/w/cpp/named_req/MoveConstructible

⁷⁷⁰ https://en.cppreference.com/w/cpp/named_req/CopyAssignable

⁷⁷¹ https://en.cppreference.com/w/cpp/named_req/MoveAssignable

⁷⁷² https://en.cppreference.com/w/cpp/named_req/DefaultConstructible

⁷⁷³ https://en.cppreference.com/w/cpp/named_req/CopyConstructible

⁷⁷⁴ https://en.cppreference.com/w/cpp/named_req/MoveConstructible

⁷⁷⁵ https://en.cppreference.com/w/cpp/named_req/CopyAssignable

⁷⁷⁶ https://en.cppreference.com/w/cpp/named_req/MoveAssignable

```
inline void reset() noexcept  
    Reset the event.
```

Private Types

```
using mutex_type = hpx::spinlock
```

Private Functions

```
inline void wait_locked(std::unique_lock<mutex_type> &l)
```

```
inline void set_locked(std::unique_lock<mutex_type> l)
```

Private Members

```
mutex_type mtx_
```

This mutex protects the queue.

```
local::detail::condition_variable cond_
```

```
std::atomic<bool> event_
```

hpx::latch

Defined in header `hpx/latch.hpp`⁷⁷⁷.

See *Public API* for a list of names and headers that are part of the public *HPX* API.

```
namespace hpx
```

```
    class latch
```

```
        #include <latch.hpp> Latches are a thread coordination mechanism that allow one or more threads to block until an operation is completed. An individual latch is a single-use object; once the operation has been completed, the latch cannot be reused.
```

```
        Subclassed by hpx::lcos::local::latch
```

⁷⁷⁷ <http://github.com/STELLAR-GROUP/hpx/blob/8a3b7c1a4cb5693b2f7d9f587f759392ed0c51a0/libs/full/include/include/hpx/latch.hpp>

Public Functions

latch(*latch* const&) = delete

latch(*latch*&&) = delete

latch &**operator**=(*latch* const&) = delete

latch &**operator**=(*latch*&&) = delete

inline explicit **latch**(*std::ptrdiff_t* count)

Initialize the latch

Requires: count >= 0. Synchronization: None Postconditions: counter_ == count.

~latch() = default

Requires: No threads are blocked at the synchronization point.

Note: May be called even if some threads have not yet returned from *wait()* or *count_down_and_wait()*, provided that counter_ is 0.

Note: The destructor might not return until all threads have exited *wait()* or *count_down_and_wait()*.

Note: It is the caller's responsibility to ensure that no other thread enters *wait()* after one thread has called the destructor. This may require additional coordination.

inline void **count_down**(*std::ptrdiff_t* update)

Decrements counter_ by n. Does not block.

Requires: counter_ >= n and n >= 0.

Synchronization: Synchronizes with all calls that block on this latch and with all *try_wait* calls on this latch that return true .

Throws Nothing. –

inline bool **try_wait**() const noexcept

Returns: With very low probability false. Otherwise counter == 0.

inline void **wait**() const

If counter_ is 0, returns immediately. Otherwise, blocks the calling thread at the synchronization point until counter_ reaches 0.

Throws Nothing. –

inline void **arrive_and_wait**(*std::ptrdiff_t* update = 1)

Effects: Equivalent to: *count_down*(update); *wait*();

Public Static Functions

```
static inline constexpr std::ptrdiff_t() max () noexcept
```

Returns: The maximum value of counter that the implementation supports.

Protected Types

```
using mutex_type = hpx::spinlock
```

Protected Attributes

```
mutable util::cache_line_data<mutex_type> mtx_
```

```
mutable util::cache_line_data<hpx::lcos::local::detail::condition_variable> cond_
```

```
std::atomic<std::ptrdiff_t> counter_
```

```
bool notified_
```

```
namespace lcos
```

```
namespace local
```

```
class latch : public hpx::latch
```

#include <latch.hpp> A latch maintains an internal counter_ that is initialized when the latch is created. Threads may block at a synchronization point waiting for counter_ to be decremented to 0. When counter_ reaches 0, all such blocked threads are released.

Calls to countdown_and_wait(), count_down(), wait(), is_ready(), count_up(), and reset() behave as atomic operations.

Note: A hpx::latch is not an LCO in the sense that it has no global id and it can't be triggered using the action (parcel) mechanism. Use hpx::distributed::latch instead if this is required. It is just a low level synchronization primitive allowing to synchronize a given number of threads.

Public Functions

```
HPX_NON_COPYABLE(latch)
```

```
inline explicit latch(std::ptrdiff_t count)
```

Initialize the latch

Requires: count >= 0. Synchronization: None Postconditions: counter_ == count.

`~latch()` = default

Requires: No threads are blocked at the synchronization point.

Note: May be called even if some threads have not yet returned from `wait()` or `count_down_and_wait()`, provided that `counter_` is 0.

Note: The destructor might not return until all threads have exited `wait()` or `count_down_and_wait()`.

Note: It is the caller's responsibility to ensure that no other thread enters `wait()` after one thread has called the destructor. This may require additional coordination.

inline void **count_down_and_wait**()

Decrements `counter_` by 1. Blocks at the synchronization point until `counter_` reaches 0.

Requires: `counter_ > 0`.

Synchronization: Synchronizes with all calls that block on this latch and with all `is_ready` calls on this latch that return true.

Throws Nothing. –

inline bool **is_ready**() const noexcept

Returns: `counter_ == 0`. Does not block.

Throws Nothing. –

inline void **abort_all**() const

inline void **count_up**(*std::ptrdiff_t* n)

Increments `counter_` by n. Does not block.

Requires: `n >= 0`.

Throws Nothing. –

inline void **reset**(*std::ptrdiff_t* n)

Reset `counter_` to n. Does not block.

Requires: `n >= 0`.

Throws Nothing. –

inline bool **reset_if_needed_and_count_up**(*std::ptrdiff_t* n, *std::ptrdiff_t* count)

Effects: Equivalent to: if (`is_ready()`) `reset(count)`; `count_up(n)`; Returns: true if the latch was reset

hpx::mutex, hpx::timed_mutex

Defined in header `hpx/mutex.hpp`⁷⁷⁸.

See *Public API* for a list of names and headers that are part of the public HPX API.

namespace **hpx**

class **mutex**

#include <mutex.hpp> *mutex* class is a synchronization primitive that can be used to protect shared data from being simultaneously accessed by multiple threads. *mutex* offers exclusive, non-recursive ownership semantics:

- A calling thread owns a *mutex* from the time that it successfully calls either *lock* or *try_lock* until it calls *unlock*.
- When a thread owns a *mutex*, all other threads will block (for calls to *lock*) or receive a *false* return value (for *try_lock*) if they attempt to claim ownership of the *mutex*.
- A calling thread must not own the *mutex* prior to calling *lock* or *try_lock*.

The behavior of a program is undefined if a *mutex* is destroyed while still owned by any threads, or a thread terminates while owning a *mutex*. The *mutex* class satisfies all requirements of `Mutex`⁷⁷⁹ and `StandardLayoutType`⁷⁸⁰.

`hpx::mutex` is neither copyable nor movable.

Subclassed by `hpx::timed_mutex`

Public Functions

HPX_NON_COPYABLE(*mutex*)

`hpx::mutex` is neither copyable nor movable

inline `HPX_HOST_DEVICE_CONSTEXPR mutex`(char const*const = "") noexcept

Constructs the *mutex*. The *mutex* is in unlocked state after the constructor completes.

Note: Because the default constructor is *constexpr*, static mutexes are initialized as part of static non-local initialization, before any dynamic non-local initialization begins. This makes it safe to lock a *mutex* in a constructor of any static object.

Parameters description – description of the *mutex*.

~mutex()

Destroys the *mutex*. The behavior is undefined if the *mutex* is owned by any thread or if any thread terminates while holding any ownership of the *mutex*.

void **lock**(char const *description, *error_code* &ec = *throws*)

Locks the *mutex*. If another thread has already locked the *mutex*, a call to *lock* will block execution until the lock is acquired. If *lock* is called by a thread that already owns the *mutex*, the behavior is undefined: for example, the program may deadlock. `hpx::mutex` can detect the invalid usage and

⁷⁷⁸ http://github.com/STELLAR-GROUP/hpx/blob/8a3b7c1a4cb5693b2f7d9f587f759392ed0c51a0/libs/core/include_local/include/hpx/mutex.hpp

throws a `std::system_error` with error condition `resource_deadlock_would_occur` instead of deadlocking. Prior `unlock()` operations on the same mutex synchronize-with (as defined in `std::memory_order`) this operation.

Note: `lock()` is usually not called directly: `std::unique_lock`, `std::scoped_lock`, and `std::lock_guard` are used to manage exclusive locking.

Parameters

- **description** – Description of the *mutex*
- **ec** – Used to hold error code value originated during the operation. Defaults to `throws` — A special ‘throw on error’ *error_code*.

Returns `void lock` returns *void*.

inline void **lock**(*error_code* &ec = *throws*)

Locks the mutex. If another thread has already locked the mutex, a call to `lock` will block execution until the lock is acquired. If `lock` is called by a thread that already owns the mutex, the behavior is undefined: for example, the program may deadlock. `hpx::mutex` can detect the invalid usage and throws a `std::system_error` with error condition `resource_deadlock_would_occur` instead of deadlocking. Prior `unlock()` operations on the same mutex synchronize-with (as defined in `std::memory_order`) this operation.

Note: `lock()` is usually not called directly: `std::unique_lock`, `std::scoped_lock`, and `std::lock_guard` are used to manage exclusive locking. This overload essentially calls `void lock(char const* description, error_code& ec =throws);` with *description* as `mutex::lock`.

Parameters **ec** – Used to hold error code value originated during the operation. Defaults to `throws` — A special ‘throw on error’ *error_code*.

Returns `void lock` returns *void*.

bool **try_lock**(char const *description, *error_code* &ec = *throws*)

Tries to lock the *mutex*. Returns immediately. On successful lock acquisition returns *true*, otherwise returns *false*. This function is allowed to fail spuriously and return *false* even if the *mutex* is not currently locked by any other thread. If `try_lock` is called by a thread that already owns the *mutex*, the behavior is undefined. Prior `unlock()` operation on the same mutex synchronizes-with (as defined in `std::memory_order`) this operation if it returns *true*. Note that prior `lock()` does not synchronize with this operation if it returns *false*.

Parameters

- **description** – Description of the *mutex*
- **ec** – Used to hold error code value originated during the operation. Defaults to `throws` — A special ‘throw on error’ *error_code*.

Returns `bool try_lock` returns *true* on successful lock acquisition, otherwise returns *false*.

inline bool **try_lock**(*error_code* &ec = *throws*)

Tries to lock the *mutex*. Returns immediately. On successful lock acquisition returns *true*, otherwise returns *false*. This function is allowed to fail spuriously and return *false* even if the *mutex* is not currently locked by any other thread. If `try_lock` is called by a thread that already owns the *mutex*, the behavior is undefined. Prior `unlock()` operation on the same mutex synchronizes-with (as defined in `std::memory_order`) this operation if it returns *true*. Note that prior `lock()` does not synchronize with this operation if it returns *false*.

Note: This overload essentially calls

```
void try_lock(char const* description,
             error_code& ec = throws);
```

with *description* as `mutex::try_lock`.

Parameters `ec` – Used to hold error code value originated during the operation. Defaults to `throws`; A special ‘throw on error’ `error_code`.

Returns `bool try_lock` returns `true` on successful lock acquisition, otherwise returns `false`.

void `unlock(error_code &ec = throws)`

Unlocks the `mutex`. The `mutex` must be locked by the current thread of execution, otherwise, the behavior is undefined. This operation *synchronizes-with* (as defined in `std::memory_order`) any subsequent lock operation that obtains ownership of the same `mutex`.

Parameters `ec` – Used to hold error code value originated during the operation. Defaults to `throws`; A special ‘throw on error’ `error_code`.

Returns `unlock` returns `void`.

class `timed_mutex` : private `hpx::mutex`

`#include <mutex.hpp>` The `timed_mutex` class is a synchronization primitive that can be used to protect shared data from being simultaneously accessed by multiple threads. In a manner similar to `mutex`, `timed_mutex` offers exclusive, non-recursive ownership semantics. In addition, `timed_mutex` provides the ability to attempt to claim ownership of a `timed_mutex` with a timeout via the member functions `try_lock_for()` and `try_lock_until()`. The `timed_mutex` class satisfies all requirements of `TimedMutex`⁷⁸¹ and `StandardLayoutType`⁷⁸².

`hpx::timed_mutex` is neither copyable nor movable.

Public Functions

`HPX_NON_COPYABLE(timed_mutex)`

`hpx::timed_mutex` is neither copyable nor movable

`timed_mutex(char const *description = "")`

Constructs a `timed_mutex`. The mutex is in unlocked state after the call.

Parameters `description` – Description of the `timed_mutex`.

`~timed_mutex()`

Destroys the `timed_mutex`. The behavior is undefined if the mutex is owned by any thread or if any thread terminates while holding any ownership of the mutex.

`bool try_lock_until(hpx::chrono::steady_time_point const &abs_time, char const *description, error_code &ec = throws)`

Tries to lock the mutex. Blocks until specified `abs_time` has been reached or the lock is acquired, whichever comes first. On successful lock acquisition returns `true`, otherwise returns `false`. If `abs_time` has already passed, this function behaves like `try_lock()`. As with `try_lock()`, this function is allowed to fail spuriously and return `false` even if the mutex was not locked by any other thread at some point before `abs_time`. Prior `unlock()` operation on the same mutex *synchronizes-with* (as defined in `std::memory_order`) this operation if it returns `true`. If `try_lock_until` is called by a thread that already owns the mutex, the behavior is undefined.

Parameters

- `abs_time` – time point to block until
- `description` – Description of the `timed_mutex`

- **ec** – Used to hold error code value originated during the operation. Defaults to *throws* — A special ‘throw on error’ *error_code*.

Returns bool *try_lock_until* returns *true* if the lock was acquired successfully, otherwise *false*.

```
inline bool try_lock_until(hpx::chrono::steady_time_point const &abs_time, error_code &ec = throws)
```

Tries to lock the mutex. Blocks until specified *abs_time* has been reached or the lock is acquired, whichever comes first. On successful lock acquisition returns *true*, otherwise returns *false*. If *abs_time* has already passed, this function behaves like *try_lock()*. As with *try_lock()*, this function is allowed to fail spuriously and return *false* even if the mutex was not locked by any other thread at some point before *abs_time*. Prior *unlock()* operation on the same mutex *synchronizes-with* (as defined in *std::memory_order*) this operation if it returns *true*. If *try_lock_until* is called by a thread that already owns the mutex, the behavior is undefined.

Note: This overload essentially calls

```
bool try_lock_until(
    hpx::chrono::steady_time_point const& abs_time,
    char const* description, error_code& ec = throws);
```

with *description* as *mutex::try_lock_until*.

Parameters

- **abs_time** – time point to block until
- **ec** – Used to hold error code value originated during the operation. Defaults to *throws* — A special ‘throw on error’ *error_code*.

Returns bool *try_lock_until* returns *true* if the lock was acquired successfully, otherwise *false*.

```
inline bool try_lock_for(hpx::chrono::steady_duration const &rel_time, char const *description,
    error_code &ec = throws)
```

Tries to lock the mutex. Blocks until specified *rel_time* has elapsed or the lock is acquired, whichever comes first. On successful lock acquisition returns *true*, otherwise returns *false*. If *rel_time* is less or equal *rel_time.zero()*, the function behaves like *try_lock()*. This function may block for longer than *rel_time* due to scheduling or resource contention delays. As with *try_lock()*, this function is allowed to fail spuriously and return *false* even if the mutex was not locked by any other thread at some point during *rel_time*. Prior *unlock()* operation on the same mutex *synchronizes-with* (as defined in *std::memory_order*) this operation if it returns *true*. If *try_lock_for* is called by a thread that already owns the mutex, the behavior is undefined.

Parameters

- **rel_time** – minimum duration to block for
- **description** – Description of the *timed_mutex*
- **ec** – Used to hold error code value originated during the operation. Defaults to *throws* — A special ‘throw on error’ *error_code*.

Returns bool *try_lock_for* returns *true* if the lock was acquired successfully, otherwise *false*.

```
inline bool try_lock_for(hpx::chrono::steady_duration const &rel_time, error_code &ec = throws)
```

Tries to lock the mutex. Blocks until specified *rel_time* has elapsed or the lock is acquired, whichever comes first. On successful lock acquisition returns *true*, otherwise returns *false*. If *rel_time* is less or equal *rel_time.zero()*, the function behaves like *try_lock()*. This function may block for longer than *rel_time* due to scheduling or resource contention delays. As with *try_lock()*, this function is allowed to fail spuriously and return *false* even if the mutex was not locked by any other thread at some point during *rel_time*. Prior *unlock()* operation on the same mutex *synchronizes-with* (as defined in

std::memory_order) this operation if it returns *true*. If *try_lock_for* is called by a thread that already owns the mutex, the behavior is undefined.

Note: This overload essentially calls

```
bool try_lock_for(  
    hpx::chrono::steady_duration const& rel_time,  
    char const* description, error_code& ec = throws)
```

with *description* as `mutex::try_lock_for`.

Parameters

- **rel_time** – minimum duration to block for
- **ec** – Used to hold error code value originated during the operation. Defaults to *throws* — A special ‘throw on error’ *error_code*.

Returns `bool try_lock_for` returns *true* if the lock was acquired successfully, otherwise *false*.

void **lock**(char const *description, *error_code* &ec = *throws*)

Locks the mutex. If another thread has already locked the mutex, a call to `lock` will block execution until the lock is acquired. If `lock` is called by a thread that already owns the mutex, the behavior is undefined: for example, the program may deadlock. `hpx::mutex` can detect the invalid usage and throws a *std::system_error* with error condition *resource_deadlock_would_occur* instead of deadlocking. Prior `unlock()` operations on the same mutex synchronize- with (as defined in *std::memory_order*) this operation.

Note: `lock()` is usually not called directly: *std::unique_lock*, *std::scoped_lock*, and *std::lock_guard* are used to manage exclusive locking.

Parameters

- **description** – Description of the *mutex*
- **ec** – Used to hold error code value originated during the operation. Defaults to *throws* — A special ‘throw on error’ *error_code*.

Returns `void lock` returns *void*.

inline void **lock**(*error_code* &ec = *throws*)

Locks the mutex. If another thread has already locked the mutex, a call to `lock` will block execution until the lock is acquired. If `lock` is called by a thread that already owns the mutex, the behavior is undefined: for example, the program may deadlock. `hpx::mutex` can detect the invalid usage and throws a *std::system_error* with error condition *resource_deadlock_would_occur* instead of deadlocking. Prior `unlock()` operations on the same mutex synchronize - with(as defined in *std::memory_order*) this operation.

Note: `lock()` is usually not called directly: *std::unique_lock*, *std::scoped_lock*, and *std::lock_guard* are used to manage exclusive locking. This overload essentially calls `void lock(char const* description, error_code& ec =throws);` with *description* as `mutex::lock`.

Parameters **ec** – Used to hold error code value originated during the operation. Defaults to *throws* — A special ‘throw on error’ *error_code*.

Returns `void lock` returns *void*.

bool **try_lock**(char const *description, *error_code* &ec = *throws*)

Tries to lock the *mutex*. Returns immediately. On successful lock acquisition returns *true*, otherwise

returns *false*. This function is allowed to fail spuriously and return *false* even if the *mutex* is not currently locked by any other thread. If *try_lock* is called by a thread that already owns the *mutex*, the behavior is undefined. Prior `unlock()` operation on the same mutex synchronizes-with (as defined in *std::memory_order*) this operation if it returns *true*. Note that prior `lock()` does not synchronize with this operation if it returns *false*.

Parameters

- **description** – Description of the *mutex*
- **ec** – Used to hold error code value originated during the operation. Defaults to *throws* — A special ‘throw on error’ *error_code*.

Returns `bool try_lock` returns *true* on successful lock acquisition, otherwise returns *false*.

inline `bool try_lock(error_code &ec = throws)`

Tries to lock the *mutex*. Returns immediately. On successful lock acquisition returns *true*, otherwise returns *false*. This function is allowed to fail spuriously and return *false* even if the *mutex* is not currently locked by any other thread. If *try_lock* is called by a thread that already owns the *mutex*, the behavior is undefined. Prior `unlock()` operation on the same mutex synchronizes-with (as defined in *std::memory_order*) this operation if it returns *true*. Note that prior `lock()` does not synchronize with this operation if it returns *false*.

Note: This overload essentially calls

```
void try_lock(char const* description,
              error_code& ec = throws);
```

with *description* as `mutex::try_lock`.

Parameters **ec** – Used to hold error code value originated during the operation. Defaults to *throws* — A special ‘throw on error’ *error_code*.

Returns `bool try_lock` returns *true* on successful lock acquisition, otherwise returns *false*.

`void unlock(error_code &ec = throws)`

Unlocks the *mutex*. The *mutex* must be locked by the current thread of execution, otherwise, the behavior is undefined. This operation *synchronizes-with* (as defined in *std::memory_order*) any subsequent *lock* operation that obtains ownership of the same *mutex*.

Parameters **ec** – Used to hold error code value originated during the operation. Defaults to *throws* — A special ‘throw on error’ *error_code*.

Returns `unlock` returns *void*.

namespace **threads**

Typedefs

using **thread_id_ref_type** = *thread_id_ref*

using **thread_self** = *coroutines::detail::coroutine_self*

Functions

thread_id **get_self_id**() noexcept

The function *get_self_id* returns the HPX thread id of the current thread (or zero if the current thread is not a HPX thread).

thread_self ***get_self_ptr**() noexcept

The function *get_self_ptr* returns a pointer to the (OS thread specific) self reference to the current HPX thread.

hpx::no_mutex

Defined in header `hpx/mutex.hpp`⁷⁸³.

See *Public API* for a list of names and headers that are part of the public HPX API.

namespace **hpx**

struct **no_mutex**

#include <no_mutex.hpp> *no_mutex* class can be used in cases where the shared data between multiple threads can be accessed simultaneously without causing inconsistencies.

Public Static Functions

static inline constexpr void **lock**() noexcept

static inline constexpr bool **try_lock**() noexcept

static inline constexpr void **unlock**() noexcept

hpx::once_flag, hpx::call_once

Defined in header `hpx/mutex.hpp`⁷⁸⁴.

See *Public API* for a list of names and headers that are part of the public HPX API.

⁷⁷⁹ https://en.cppreference.com/w/cpp/named_req/Mutex

⁷⁸⁰ https://en.cppreference.com/w/cpp/named_req/StandardLayoutType

⁷⁸¹ https://en.cppreference.com/w/cpp/named_req/TimedMutex

⁷⁸² https://en.cppreference.com/w/cpp/named_req/StandardLayoutType

⁷⁸³ http://github.com/STELLAR-GROUP/hpx/blob/8a3b7c1a4cb5693b2f7d9f587f759392ed0c51a0/libs/core/include_local/include/hpx/mutex.hpp

hpp

⁷⁸⁴ http://github.com/STELLAR-GROUP/hpx/blob/8a3b7c1a4cb5693b2f7d9f587f759392ed0c51a0/libs/core/include_local/include/hpx/mutex.hpp

hpp

Defines

HPX_ONCE_INIT

namespace **hpx**

Functions

```
template<typename F, typename ...Args>
void call_once(once_flag &flag, F &&f, Args&&... args)
```

Executes the Callable object *f* exactly once, even if called concurrently, from several threads.

In detail:

- If, by the time *call_once* is called, *flag* indicates that *f* was already called, *call_once* returns right away (such a call to *call_once* is known as passive).
- Otherwise, *call_once* invokes `std::forward<Callable>(f)` with the arguments `std::forward<Args>(args)...` (as if by `hpx::invoke`). Unlike the `hpx::thread` constructor or `hpx::async`, the arguments are not moved or copied because they don't need to be transferred to another thread of execution. (such a call to *call_once* is known as active).
 - If that invocation throws an exception, it is propagated to the caller of *call_once*, and the flag is not flipped so that another call will be attempted (such a call to *call_once* is known as exceptional).
 - If that invocation returns normally (such a call to *call_once* is known as returning), the flag is flipped, and all other calls to *call_once* with the same flag are guaranteed to be passive. All active calls on the same flag form a single total order consisting of zero or more exceptional calls, followed by one returning call. The end of each active call synchronizes-with the next active call in that order. The return from the returning call synchronizes-with the returns from all passive calls on the same flag: this means that all concurrent calls to *call_once* are guaranteed to observe any side-effects made by the active call, with no additional synchronization.

Note: If concurrent calls to *call_once* pass different functions *f*, it is unspecified which *f* will be called. The selected function runs in the same thread as the *call_once* invocation it was passed to. Initialization of function-local statics is guaranteed to occur only once even when called from multiple threads, and may be more efficient than the equivalent code using `hpx::call_once`. The POSIX equivalent of this function is *pthread_once*.

Parameters

- **flag** – an object, for which exactly one function gets executed
- **f** – Callable object to invoke
- **args** – arguments to pass to the function

Throws `std::system_error` – if any condition prevents calls to *call_once* from executing as specified or any exception thrown by *f*

struct **once_flag**

#include <once.hpp> The class `hpx::once_flag` is a helper structure for `hpx::call_once`. An object of type `hpx::once_flag` that is passed to multiple calls to `hpx::call_once` allows those calls to coordinate

with each other such that only one of the calls will actually run to completion. `hpx::once_flag` is neither copyable nor movable.

Public Functions

`HPX_NON_COPYABLE(once_flag)`

inline `once_flag()` noexcept

Constructs an `once_flag` object. The internal state is set to indicate that no function has been called yet.

Private Members

`std::atomic<long> status_`

`lcos::local::event event_`

Friends

template<typename **F**, typename ...**Args**>

friend void `call_once(once_flag &flag, F &&f, Args&&... args)`

Executes the Callable object *f* exactly once, even if called concurrently, from several threads.

In detail:

- If, by the time `call_once` is called, *flag* indicates that *f* was already called, `call_once` returns right away (such a call to `call_once` is known as passive).
- Otherwise, `call_once` invokes `std::forward<Callable>(f)` with the arguments `std::forward<Args>(args)...` (as if by `hpx::invoke`). Unlike the `hpx::thread` constructor or `hpx::async`, the arguments are not moved or copied because they don't need to be transferred to another thread of execution. (such a call to `call_once` is known as active).
 - If that invocation throws an exception, it is propagated to the caller of `call_once`, and the flag is not flipped so that another call will be attempted (such a call to `call_once` is known as exceptional).
 - If that invocation returns normally (such a call to `call_once` is known as returning), the flag is flipped, and all other calls to `call_once` with the same flag are guaranteed to be passive. All active calls on the same flag form a single total order consisting of zero or more exceptional calls, followed by one returning call. The end of each active call synchronizes-with the next active call in that order. The return from the returning call synchronizes-with the returns from all passive calls on the same flag: this means that all concurrent calls to `call_once` are guaranteed to observe any side-effects made by the active call, with no additional synchronization.

Note: If concurrent calls to `call_once` pass different functions *f*, it is unspecified which *f* will be called. The selected function runs in the same thread as the `call_once` invocation it was passed to. Initialization of function-local statics is guaranteed to occur only once even when called from multiple threads, and may be more efficient than the equivalent code using `hpx::call_once`. The POSIX equivalent of this function is `pthread_once`.

Parameters

- **flag** – an object, for which exactly one function gets executed
- **f** – Callable object to invoke

- **args** – arguments to pass to the function
- Throws** `std::system_error` – if any condition prevents calls to `call_once` from executing as specified or any exception thrown by `f`

hpx::recursive_mutex

Defined in header `hpx/mutex.hpp`⁷⁸⁵.

See *Public API* for a list of names and headers that are part of the public *HPX* API.

namespace **hpx**

Typedefs

```
using recursive_mutex = detail::recursive_mutex_impl<>
```

hpx::shared_mutex

Defined in header `hpx/shared_mutex.hpp`⁷⁸⁶.

See *Public API* for a list of names and headers that are part of the public *HPX* API.

namespace **hpx**

Typedefs

```
using shared_mutex = detail::shared_mutex<>
```

The `shared_mutex` class is a synchronization primitive that can be used to protect shared data from being simultaneously accessed by multiple threads. In contrast to other mutex types which facilitate exclusive access, a `shared_mutex` has two levels of access:

- *shared* - several threads can share ownership of the same mutex.
- *exclusive* - only one thread can own the mutex.

If one thread has acquired the exclusive lock (through `lock`, `try_lock`), no other threads can acquire the lock (including the shared). If one thread has acquired the shared lock (through `lock_shared`, `try_lock_shared`), no other thread can acquire the exclusive lock, but can acquire the shared lock. Only when the exclusive lock has not been acquired by any thread, the shared lock can be acquired by multiple threads. Within one thread, only one lock (shared or exclusive) can be acquired at the same time. Shared mutexes are especially useful when shared data can be safely read by any number of threads simultaneously, but a thread may only write the same data when no other thread is reading or writing at the same time. The `shared_mutex` class satisfies all requirements of `SharedMutex` and `StandardLayoutType`.

⁷⁸⁵ http://github.com/STELLAR-GROUP/hpx/blob/8a3b7c1a4cb5693b2f7d9f587f759392ed0c51a0/libs/core/include_local/include/hpx/mutex.hpp

⁷⁸⁶ http://github.com/STELLAR-GROUP/hpx/blob/8a3b7c1a4cb5693b2f7d9f587f759392ed0c51a0/libs/core/include_local/include/hpx/shared_mutex.hpp

hpx/synchronization/sliding_semaphore.hpp

Defined in header `hpx/synchronization/sliding_semaphore.hpp`.

See *Public API* for a list of names and headers that are part of the public *HPX* API.

namespace **hpx**

Typedefs

```
using sliding_semaphore = sliding_semaphore_var<>
```

```
template<typename Mutex = hpx::spinlock>
```

```
class sliding_semaphore_var
```

#include <sliding_semaphore.hpp> A semaphore is a protected variable (an entity storing a value) or abstract data type (an entity grouping several variables that may or may not be numerical) which constitutes the classic method for restricting access to shared resources, such as shared memory, in a multiprogramming environment. Semaphores exist in many variants, though usually the term refers to a counting semaphore, since a binary semaphore is better known as a mutex. A counting semaphore is a counter for a set of available resources, rather than a locked/unlocked flag of a single resource. It was invented by Edsger Dijkstra. Semaphores are the classic solution to preventing race conditions in the dining philosophers problem, although they do not prevent resource deadlocks.

Sliding semaphores can be used for synchronizing multiple threads as well: one thread waiting for several other threads to touch (signal) the semaphore, or several threads waiting for one other thread to touch this semaphore. The difference to a counting semaphore is that a sliding semaphore will not limit the number of threads which are allowed to proceed, but will make sure that the difference between the (arbitrary) number passed to set and wait does not exceed a given threshold.

Public Functions

```
sliding_semaphore_var(sliding_semaphore_var const&) = delete
```

```
sliding_semaphore_var &operator=(sliding_semaphore_var const&) = delete
```

```
sliding_semaphore_var(sliding_semaphore_var&&) = delete
```

```
sliding_semaphore_var &operator=(sliding_semaphore_var&&) = delete
```

```
inline explicit sliding_semaphore_var(std::int64_t max_difference, std::int64_t lower_limit = 0)  
noexcept
```

Construct a new sliding semaphore.

Parameters

- **max_difference** – [in] The max difference between the upper limit (as set by *wait()*) and the lower limit (as set by *signal()*) which is allowed without suspending any thread calling *wait()*.
- **lower_limit** – [in] The initial lower limit.

```
inline void set_max_difference(std::int64_t max_difference, std::int64_t lower_limit = 0) noexcept
```

Set/Change the difference that will cause the semaphore to trigger

Parameters

- **max_difference** – [in] The max difference between the upper limit (as set by *wait()*) and the lower limit (as set by *signal()*) which is allowed without suspending any thread calling *wait()*.
- **lower_limit** – [in] The initial lower limit.

inline void **wait**(*std::int64_t* upper_limit)

Wait for the semaphore to be signaled.

Parameters **upper_limit** – [in] The new upper limit. The calling thread will be suspended if the difference between this value and the largest lower_limit which was set by *signal()* is larger than the max_difference.

inline bool **try_wait**(*std::int64_t* upper_limit = 1)

Try to wait for the semaphore to be signaled.

Parameters **upper_limit** – [in] The new upper limit. The calling thread will be suspended if the difference between this value and the largest lower_limit which was set by *signal()* is larger than the max_difference.

Returns The function returns true if the calling thread would not block if it was calling *wait()*.

inline void **signal**(*std::int64_t* lower_limit)

Signal the semaphore.

Parameters **lower_limit** – [in] The new lower limit. This will update the current lower limit of this semaphore. It will also re-schedule all suspended threads for which their associated upper limit is not larger than the lower limit plus the max_difference.

inline *std::int64_t* **signal_all**()

Private Types

using **mutex_type** = *Mutex*

using **data_type** = *lcos::local::detail::sliding_semaphore_data<mutex_type>*

Private Members

hpx::intrusive_ptr<data_type> **data_**

hpx::spinlock

Defined in header *hpx/mutex.hpp*⁷⁸⁷.

See *Public API* for a list of names and headers that are part of the public *HPX* API.

namespace **hpx**

⁷⁸⁷ http://github.com/STELLAR-GROUP/hpx/blob/8a3b7c1a4cb5693b2f7d9f587f759392ed0c51a0/libs/core/include_local/include/hpx/mutex.hpp

Typedefs

```
using spinlock = detail::spinlock<true>
```

`spinlock` is a type of lock that causes a thread attempting to obtain it to check for its availability while waiting in a loop continuously.

```
using spinlock_no_backoff = detail::spinlock<false>
```

`hpx::nostopstate`, `hpx::stop_callback`, `hpx::stop_source`, `hpx::stop_token`, `hpx::nostopstate_t`

Defined in header `hpx/stop_token.hpp`⁷⁸⁸.

See *Public API* for a list of names and headers that are part of the public *HPX* API.

```
namespace hpx
```

Functions

```
template<typename Callback>
```

```
stop_callback(stop_token, Callback) -> stop_callback<Callback>
```

The `stop_callback` class template provides an RAII object type that registers a callback function for an associated `hpx::stop_token` object, such that the callback function will be invoked when the `hpx::stop_token`'s associated `hpx::stop_source` is requested to stop. Callback functions registered via `stop_callback`'s constructor are invoked either in the same thread that successfully invokes `request_stop()` for a `hpx::stop_source` of the `stop_callback`'s associated `hpx::stop_token`; or if stop has already been requested prior to the constructor's registration, then the callback is invoked in the thread constructing the `stop_callback`. More than one `stop_callback` can be created for the same `hpx::stop_token`, from the same or different threads concurrently. No guarantee is provided for the order in which they will be executed, but they will be invoked synchronously; except for `stop_callback(s)` constructed after stop has already been requested for the `hpx::stop_token`, as described previously. If an invocation of a callback exits via an exception then `hpx::terminate` is called. `hpx::stop_callback` is not *CopyConstructible*, *CopyAssignable*, *MoveConstructible*, nor *MoveAssignable*. The template param `Callback` type must be both *invocable* and *destructible*. Any return value is ignored.

```
inline void swap(stop_token &lhs, stop_token &rhs) noexcept
```

```
inline void swap(stop_source &lhs, stop_source &rhs) noexcept
```

Variables

```
constexpr nostopstate_t nostopstate = { }
```

This is a constant object instance of `hpx::nostopstate_t` for use in constructing an empty `hpx::stop_source`, as a placeholder value in the non-default constructor.

```
struct nostopstate_t
```

```
#include <stop_token.hpp> Unit type intended for use as a placeholder in hpx::stop_source non-default constructor, that makes the constructed hpx::stop_source empty with no associated stop-state.
```

⁷⁸⁸ http://github.com/STELLAR-GROUP/hpx/blob/8a3b7c1a4cb5693b2f7d9f587f759392ed0c51a0/libs/core/include_local/include/hpx/stop_token.hpp

Public Functions

explicit **nostopstate_t**() = default

template<typename **Callback**>

class **stop_callback**

class **stop_source**

#include <stop_token.hpp> The **stop_source** class provides the means to issue a stop request, such as for *hpx::jthread* cancellation. A stop request made for one **stop_source** object is visible to all *stop_sources* and *hpx::stop_tokens* of the same associated stop-state; any *hpx::stop_callback*(s) registered for associated *hpx::stop_token*(s) will be invoked, and any *hpx::condition_variable_any* objects waiting on associated *hpx::stop_token*(s) will be awoken. Once a stop is requested, it cannot be withdrawn. Additional stop requests have no effect.

Note: For the purposes of *hpx::jthread* cancellation the **stop_source** object should be retrieved from the *hpx::jthread* object using *get_stop_source()*; or stop should be requested directly from the *hpx::jthread* object using *request_stop()*. This will then use the same associated stop-state as that passed into the *hpx::jthread*'s invoked function argument (i.e., the function being executed on its thread). For other uses, however, a **stop_source** can be constructed separately using the default constructor, which creates new stop-state.

Public Functions

inline **stop_source**()

inline explicit **stop_source**(*nostopstate_t*) noexcept

inline **stop_source**(*stop_source* const &rhs) noexcept

stop_source(*stop_source*&&) noexcept = default

inline *stop_source* &**operator**=(*stop_source* const &rhs) noexcept

stop_source &**operator**=(*stop_source*&&) noexcept = default

inline ~**stop_source**()

inline void **swap**(*stop_source* &s) noexcept

swaps two *stop_source* objects

inline *stop_token* **get_token**() const noexcept

returns a *stop_token* for the associated stop-state

inline bool **stop_possible**() const noexcept

checks whether associated stop-state can be requested to stop

inline bool **stop_requested**() const noexcept

checks whether the associated stop-state has been requested to stop

inline bool **request_stop**() const noexcept

makes a stop request for the associated stop-state, if any

Private Members

hpx::intrusive_ptr<detail::stop_state> **state_**

Friends

inline friend bool **operator==(***stop_source* const &lhs, *stop_source* const &rhs) noexcept

inline friend bool **operator!=(***stop_source* const &lhs, *stop_source* const &rhs) noexcept

class **stop_token**

#include <stop_token.hpp> The *stop_token* class provides the means to check if a stop request has been made or can be made, for its associated *hpx::stop_source* object. It is essentially a thread-safe “view” of the associated stop-state. The *stop_token* can also be passed to the constructor of *hpx::stop_callback*, such that the callback will be invoked if the *stop_token*’s associated *hpx::stop_source* is requested to stop. And *stop_token* can be passed to the interruptible waiting functions of *hpx::condition_variable_any*, to interrupt the condition variable’s wait if stop is requested.

Note: A *stop_token* object is not generally constructed independently, but rather retrieved from a *hpx::jthread* or *hpx::stop_source*. This makes it share the same associated stop-state as the *hpx::jthread* or *hpx::stop_source*.

Public Types

template<typename **Callback**>

using **callback_type** = *stop_callback*<*Callback*>

Public Functions

constexpr **stop_token**() noexcept = default

stop_token(*stop_token* const &rhs) = default

stop_token(*stop_token*&&) noexcept = default

stop_token &**operator=(***stop_token* const &rhs) = default

stop_token &**operator=(***stop_token*&&) noexcept = default

~stop_token() = default

inline void **swap**(*stop_token* &s) noexcept

swaps two *stop_token* objects

inline bool **stop_requested**() const noexcept

checks whether the associated stop-state has been requested to stop

inline bool **stop_possible**() const noexcept

checks whether associated stop-state can be requested to stop

Private Functions

```
inline explicit stop_token(hpx::intrusive_ptr<detail::stop_state> state) noexcept
```

Private Members

```
hpx::intrusive_ptr<detail::stop_state> state_
```

Friends

```
friend class stop_callback
```

```
friend class stop_source
```

```
inline friend constexpr friend bool operator== (stop_token const &lhs,  
stop_token const &rhs) noexcept
```

```
inline friend constexpr friend bool operator!= (stop_token const &lhs,  
stop_token const &rhs) noexcept
```

```
namespace experimental
```

```
namespace p2300_stop_token
```

Functions

```
template<typename Callback>  
in_place_stop_callback(in_place_stop_token, Callback) -> in_place_stop_callback<Callback>
```

```
template<typename Callback>
```

```
class in_place_stop_callback
```

```
class in_place_stop_source
```

Public Functions

```
inline in_place_stop_source() noexcept
```

```
inline ~in_place_stop_source()
```

```
in_place_stop_source(in_place_stop_source const&) = delete
```

```
in_place_stop_source(in_place_stop_source&&) noexcept = delete
```

```
in_place_stop_source &operator=(in_place_stop_source const&) = delete
```

```
in_place_stop_source &operator=(in_place_stop_source&&) noexcept = delete
```

```
inline in_place_stop_token get_token() const noexcept
```

```
inline bool request_stop() noexcept
```

```
inline bool stop_requested() const noexcept
```

```
inline bool stop_possible() const noexcept
```

Private Functions

```
inline bool register_callback(hpx::detail::stop_callback_base *cb) noexcept
```

```
inline void remove_callback(hpx::detail::stop_callback_base *cb) noexcept
```

Private Members

```
hpx::detail::stop_state state_
```

Friends

```
friend class in_place_stop_token
```

```
friend class in_place_stop_callback
```

```
class in_place_stop_token
```

Public Types

```
template<typename Callback>
```

```
using callback_type = in_place_stop_callback<Callback>
```

Public Functions

```
inline constexpr in_place_stop_token() noexcept
```

```
~in_place_stop_token() = default
```

```
in_place_stop_token(in_place_stop_token const &rhs) noexcept = default
```

```
inline in_place_stop_token(in_place_stop_token &&rhs) noexcept
```

```
in_place_stop_token &operator=(in_place_stop_token const &rhs) noexcept = default
```

```
inline in_place_stop_token &operator=(in_place_stop_token &&rhs) noexcept
```

```
inline bool stop_requested() const noexcept
```

```
inline bool stop_possible() const noexcept
```

```
inline void swap(in_place_stop_token &rhs) noexcept
```

Private Functions

```
inline explicit in_place_stop_token(in_place_stop_source const *source) noexcept
```

Private Members

```
in_place_stop_source const *source_
```

Friends

```
friend class in_place_stop_source
```

```
friend class in_place_stop_callback
```

```
inline friend constexpr friend bool operator== (in_place_stop_token const &lhs,  
in_place_stop_token const &rhs) noexcept
```

```
inline friend constexpr friend bool operator!  
= (in_place_stop_token const &lhs, in_place_stop_token const &rhs) noexcept
```

```
inline friend void swap(in_place_stop_token &x, in_place_stop_token &y) noexcept
```

```
struct never_stop_token
```

Public Types

```
template<typename>
```

```
using callback_type = callback_impl
```

Public Static Functions

```
static inline constexpr bool stop_requested() noexcept
```

```
static inline constexpr bool stop_possible() noexcept
```

Friends

```
inline friend constexpr friend bool operator== (never_stop_token,  
never_stop_token) noexcept
```

```
inline friend constexpr friend bool operator!= (never_stop_token,  
never_stop_token) noexcept
```

```
struct callback_impl
```

Public Functions

```
template<typename Callback>
inline explicit constexpr callback_impl(never_stop_token, Callback&&) noexcept
```

tag_invoke

See *Public API* for a list of names and headers that are part of the public HPX API.

hpx::is_invocable, hpx::is_invocable_r

Defined in header `hpx/type_traits.hpp`⁷⁸⁹.

See *Public API* for a list of names and headers that are part of the public HPX API.

namespace **hpx**

Variables

```
template<typename F, typename ...Ts>
```

```
constexpr bool is_invocable_v = is_invocable<F, Ts...>::value
```

```
template<typename R, typename F, typename ...Ts>
```

```
constexpr bool is_invocable_r_v = is_invocable_r<R, F, Ts...>::value
```

```
template<typename F, typename ...Ts>
```

```
constexpr bool is_nothrow_invocable_v = is_nothrow_invocable<F, Ts...>::value
```

```
template<typename F, typename ...Ts>
```

```
struct is_invocable : public hpx::detail::is_invocable_impl<F&&(Ts&&...)>
```

#include <*is_invocable.hpp*> Determines whether *F* can be invoked with the arguments *Ts...*. Formally, determines whether

```
INVOKE(std::declval<F>(), std::declval<Ts>()...)
```

is well formed when treated as an unevaluated operand, where *INVOKE* is the operation defined in *Callable*.

F, *R* and all types in the parameter pack *Ts* shall each be a complete type, (possibly cv-qualified) void, or an array of unknown bound. Otherwise, the behavior is undefined. If an instantiation of a template above depends, directly or indirectly, on an incomplete type, and that instantiation could yield a different result if that type were hypothetically completed, the behavior is undefined.

```
template<typename R, typename F, typename ...Ts>
```

```
struct is_invocable_r : public hpx::detail::is_invocable_r_impl<F&&(Ts&&...), R>
```

#include <*is_invocable.hpp*> Determines whether *F* can be invoked with the arguments *Ts...* to yield a result that is convertible to *R* and the implicit conversion does not bind a reference to a temporary object (since C++23). If *R* is cv void, the result can be any type. Formally, determines whether

⁷⁸⁹ http://github.com/STELLAR-GROUP/hpx/blob/8a3b7c1a4cb5693b2f7d9f587f759392ed0c51a0/libs/core/include_local/include/hpx/type_traits.hpp

```
INVOKE<R>(std::declval<F>(), std::declval<Ts>()...)
```

is well formed when treated as an unevaluated operand, where *INVOKE* is the operation defined in *Callable*. Determines whether *F* can be invoked with the arguments *Ts...* Formally, determines whether

```
INVOKE(std::declval<F>(), std::declval<Ts>()...)
```

is well formed when treated as an unevaluated operand, where *INVOKE* is the operation defined in *Callable*.

F, *R* and all types in the parameter pack *Ts* shall each be a complete type, (possibly cv-qualified) void, or an array of unknown bound. Otherwise, the behavior is undefined. If an instantiation of a template above depends, directly or indirectly, on an incomplete type, and that instantiation could yield a different result if that type were hypothetically completed, the behavior is undefined.

```
template<typename F, typename ...Ts>
```

```
struct is_nothrow_invocable : public hpx::detail::is_nothrow_invocable_impl<F(Ts...), is_invocable_v<F,  
Ts...>>
```

thread_pool_util

See *Public API* for a list of names and headers that are part of the public *HPX* API.

hpx/thread_pool_util/thread_pool_suspension_helpers.hpp

Defined in header `hpx/thread_pool_util/thread_pool_suspension_helpers.hpp`.

See *Public API* for a list of names and headers that are part of the public *HPX* API.

```
namespace hpx
```

```
namespace threads
```

Functions

```
hpx::future<void> resume_processing_unit(thread_pool_base &pool, std::size_t virt_core)
```

Resumes the given processing unit. When the processing unit has been resumed the returned future will be ready.

Note: Can only be called from an HPX thread. Use `resume_processing_unit_cb` or to resume the processing unit from outside HPX. Requires that the pool has `threads::policies::enable_elasticity` set.

Parameters

- **pool** – [in] The thread pool to resume a processing unit on.
- **virt_core** – [in] The processing unit on the pool to be resumed. The processing units are indexed starting from 0.

Returns A `future<void>` which is ready when the given processing unit has been resumed.

void **resume_processing_unit_cb**(*thread_pool_base* &pool, *hpx::function*<void()> callback, *std::size_t* virt_core, *error_code* &ec = *throws*)

Resumes the given processing unit. Takes a callback as a parameter which will be called when the processing unit has been resumed.

Note: Requires that the pool has `threads::policies::enable_elasticity` set.

Parameters

- **pool** – [in] The thread pool to resume a processing unit on.
- **callback** – [in] Callback which is called when the processing unit has been suspended.
- **virt_core** – [in] The processing unit to resume.
- **ec** – [in,out] this represents the error status on exit, if this is pre-initialized to *hpx::throws* the function will throw on error instead.

hpx::future<void> **suspend_processing_unit**(*thread_pool_base* &pool, *std::size_t* virt_core)

Suspends the given processing unit. When the processing unit has been suspended the returned future will be ready.

Note: Can only be called from an HPX thread. Use `suspend_processing_unit_cb` or to suspend the processing unit from outside HPX. Requires that the pool has `threads::policies::enable_elasticity` set.

Parameters

- **pool** – [in] The thread pool to suspend a processing unit from.
- **virt_core** – [in] The processing unit on the pool to be suspended. The processing units are indexed starting from 0.

Throws *hpx::exception* – if called from outside the HPX runtime.

Returns A `future<void>` which is ready when the given processing unit has been suspended.

void **suspend_processing_unit_cb**(*hpx::function*<void()> callback, *thread_pool_base* &pool, *std::size_t* virt_core, *error_code* &ec = *throws*)

Suspends the given processing unit. Takes a callback as a parameter which will be called when the processing unit has been suspended.

Note: Requires that the pool has `threads::policies::enable_elasticity` set.

Parameters

- **pool** – [in] The thread pool to suspend a processing unit from.
- **callback** – [in] Callback which is called when the processing unit has been suspended.
- **virt_core** – [in] The processing unit to suspend.
- **ec** – [in,out] this represents the error status on exit, if this is pre-initialized to *hpx::throws* the function will throw on error instead.

hpx::future<void> **resume_pool**(*thread_pool_base* &pool)

Resumes the thread pool. When the all OS threads on the thread pool have been resumed the returned future will be ready.

Note: Can only be called from an HPX thread. Use `resume_cb` or `resume_direct` to suspend the pool from outside HPX.

Parameters `pool` – [in] The thread pool to resume.

Throws `hpx::exception` – if called from outside the HPX runtime.

Returns A `future<void>` which is ready when the thread pool has been resumed.

```
void resume_pool_cb(thread_pool_base &pool, hpx::function<void()> callback, error_code &ec =
    throws)
```

Resumes the thread pool. Takes a callback as a parameter which will be called when all OS threads on the thread pool have been resumed.

Parameters

- `pool` – [in] The thread pool to resume.
- `callback` – [in] called when the thread pool has been resumed.
- `ec` – [in,out] this represents the error status on exit, if this is pre-initialized to `hpx::throws` the function will throw on error instead.

```
hpx::future<void> suspend_pool(thread_pool_base &pool)
```

Suspends the thread pool. When the all OS threads on the thread pool have been suspended the returned future will be ready.

Note: Can only be called from an HPX thread. Use `suspend_cb` or `suspend_direct` to suspend the pool from outside HPX. A thread pool cannot be suspended from an HPX thread running on the pool itself.

Parameters `pool` – [in] The thread pool to suspend.

Throws `hpx::exception` – if called from outside the HPX runtime.

Returns A `future<void>` which is ready when the thread pool has been suspended.

```
void suspend_pool_cb(thread_pool_base &pool, hpx::function<void()> callback, error_code &ec =
    throws)
```

Suspends the thread pool. Takes a callback as a parameter which will be called when all OS threads on the thread pool have been suspended.

Note: A thread pool cannot be suspended from an HPX thread running on the pool itself.

Parameters

- `pool` – [in] The thread pool to suspend.
- `callback` – [in] called when the thread pool has been suspended.
- `ec` – [in,out] this represents the error status on exit, if this is pre-initialized to `hpx::throws` the function will throw on error instead.

Throws `hpx::exception` – if called from an HPX thread which is running on the pool itself.

thread_support

See [Public API](#) for a list of names and headers that are part of the public HPX API.

hpx::unlock_guard

Defined in header `hpx/mutex.hpp`⁷⁹⁰.

See *Public API* for a list of names and headers that are part of the public *HPX* API.

namespace **hpx**

```
template<typename Mutex>
```

```
class unlock_guard
```

#include <unlock_guard.hpp> The class *unlock_guard* is a mutex wrapper that provides a convenient mechanism for releasing a mutex for the duration of a scoped block.

unlock_guard performs the opposite functionality of *lock_guard*. When a *lock_guard* object is created, it attempts to take ownership of the mutex it is given. When control leaves the scope in which the *lock_guard* object was created, the *lock_guard* is destructed and the mutex is released. Accordingly, when an *unlock_guard* object is created, it attempts to release the ownership of the mutex it is given. So, when control leaves the scope in which the *unlock_guard* object was created, the *unlock_guard* is destructed and the mutex is owned again. In this way, the mutex is unlocked in the constructor and locked in the destructor, so that one can have an unlocked section within a locked one.

Public Types

```
using mutex_type = Mutex
```

Public Functions

```
inline explicit constexpr unlock_guard(Mutex &m) noexcept
```

```
HPX_NON_COPYABLE(unlock_guard)
```

```
inline ~unlock_guard()
```

Private Members

```
Mutex &m_
```

```
namespace util
```

⁷⁹⁰ http://github.com/STELLAR-GROUP/hpx/blob/8a3b7c1a4cb5693b2f7d9f587f759392ed0c51a0/libs/core/include_local/include/hpx/mutex.hpp

Typedefs

```
using instead = hpx::unlock_guard<Mutex>
```

threading

See *Public API* for a list of names and headers that are part of the public *HPX* API.

`hpx::jthread`

Defined in header `hpx/thread.hpp`⁷⁹¹.

See *Public API* for a list of names and headers that are part of the public *HPX* API.

namespace **hpx**

Functions

```
inline void swap(jthread &lhs, jthread &rhs) noexcept
```

class `jthread`

#include <*jthread.hpp*> The class *jthread* represents a single thread of execution. It has the same general behavior as `hpx::thread`, except that *jthread* automatically rejoins on destruction, and can be cancelled/stopped in certain situations. Threads begin execution immediately upon construction of the associated thread object (pending any OS scheduling delays), starting at the top-level function provided as a constructor argument. The return value of the top-level function is ignored and if it terminates by throwing an exception, *hpx::terminate* is called. The top-level function may communicate its return value or an exception to the caller via *hpx::promise* or by modifying shared variables (which may require synchronization, see *hpx::mutex* and *hpx::atomic*) Unlike `hpx::thread`, the *jthread* logically holds an internal private member of type *hpx::stop_source*, which maintains a shared stop-state. The *jthread* constructor accepts a function that takes a *hpx::stop_token* as its first argument, which will be passed in by the *jthread* from its internal *stop_source*. This allows the function to check if stop has been requested during its execution, and return if it has. `hpx::jthread` objects may also be in the state that does not represent any thread (after default construction, move from, detach, or join), and a thread of execution may be not associated with any *jthread* objects (after detach). No two `hpx::jthread` objects may represent the same thread of execution; `hpx::jthread` is not *CopyConstructible* or *CopyAssignable*, although it is *MoveConstructible* and *MoveAssignable*.

Public Types

```
using id = thread::id
```

```
using native_handle_type = thread::native_handle_type
```

⁷⁹¹ http://github.com/STELLAR-GROUP/hpx/blob/8a3b7c1a4cb5693b2f7d9f587f759392ed0c51a0/libs/core/include_local/include/hpx/thread.hpp

Public Functions

inline **jthread**() noexcept

template<typename **F**, typename ...**Ts**, typename **Enable** =
std::enable_if_t<!std::is_same_v<std::decay_t<F>, jthread>>>
inline explicit **jthread**(*F* &&*f*, *Ts*&&... *ts*)

inline ~**jthread**()

jthread(*jthread* const&) = delete

jthread(*jthread* &&*x*) noexcept = default

jthread &**operator**=(*jthread* const&) = delete

jthread &**operator**=(*jthread*&&) noexcept = default
moves the jthread object

inline void **swap**(*jthread* &*t*) noexcept
swaps two jthread objects

inline bool **joinable**() const noexcept
checks whether the thread is joinable, i.e. potentially running in parallel context

inline void **join**()
waits for the thread to finish its execution

inline void **detach**()
permits the thread to execute independently from the thread handle

inline *id* **get_id**() const noexcept
returns the id of the thread

inline *native_handle_type* **native_handle**()
returns the underlying implementation-defined thread handle

inline *stop_source* **get_stop_source**() noexcept
returns a stop_source object associated with the shared stop state of the thread

inline *stop_token* **get_stop_token**() const noexcept
returns a stop_token associated with the shared stop state of the thread

inline bool **request_stop**() noexcept
requests execution stop via the shared stop state of the thread

Public Static Functions

static inline unsigned int **hardware_concurrency**()
returns the number of concurrent threads supported by the implementation

Private Members

stop_source **ssource_**

hpx::thread **thread_** = { }

Private Static Functions

```
template<typename F, typename ...Ts>
static inline void invoke(std::false_type, F &&f, stop_token&&, Ts&&... ts)
```

```
template<typename F, typename ...Ts>
static inline void invoke(std::true_type, F &&f, stop_token &&st, Ts&&... ts)
```

hpx::thread, **hpx::this_thread::yield**, **hpx::this_thread::get_id**, **hpx::this_thread::sleep_for**,
hpx::this_thread::sleep_until

Defined in header `hpx/thread.hpp`⁷⁹².

See *Public API* for a list of names and headers that are part of the public *HPX* API.

```
template<>
```

```
struct std::hash<:hpx::thread::id>
```

Public Functions

```
inline std::size_t operator() (::hpx::thread::id const &id) const
```

```
namespace hpx
```

Typedefs

```
using thread_termination_handler_type = hpx::function<void(std::exception_ptr const &e)>
```

Functions

```
void set_thread_termination_handler(thread_termination_handler_type f)
```

```
inline void swap(thread &x, thread &y) noexcept
```

```
inline bool operator==( thread::id const &x, thread::id const &y) noexcept
```

```
inline bool operator!=( thread::id const &x, thread::id const &y) noexcept
```

```
inline bool operator<( thread::id const &x, thread::id const &y) noexcept
```

⁷⁹² http://github.com/STELLAR-GROUP/hpx/blob/8a3b7c1a4cb5693b2f7d9f587f759392ed0c51a0/libs/core/include_local/include/hpx/thread.hpp

```
inline bool operator>(thread::id const &x, thread::id const &y) noexcept
inline bool operator<=(thread::id const &x, thread::id const &y) noexcept
inline bool operator>=(thread::id const &x, thread::id const &y) noexcept
template<typename Char, typename Traits>
std::basic_ostream<Char, Traits> &operator<<(std::basic_ostream<Char, Traits> &out, thread::id const
&id)
```

class **thread**

#include <thread.hpp> The class `thread` represents a single thread of execution. Threads allow multiple functions to execute concurrently. Threads begin execution immediately upon construction of the associated thread object (pending any OS scheduling delays), starting at the top-level function provided as a constructor argument. The return value of the top-level function is ignored and if it terminates by throwing an exception, `hpx::terminate` is called. The top-level function may communicate its return value or an exception to the caller via `hpx::promise` or by modifying shared variables (which may require synchronization, see `hpx::mutex` and `hpx::atomic`) `hpx::thread` objects may also be in the state that does not represent any thread (after default construction, move from, detach, or join), and a thread of execution may not be associated with any thread objects (after detach). No two `hpx::thread` objects may represent the same thread of execution; `hpx::thread` is not *CopyConstructible* or *CopyAssignable*, although it is *MoveConstructible* and *MoveAssignable*.

Public Types

using **native_handle_type** = `threads::thread_id_type`

Public Functions

thread() noexcept

template<typename **F**, typename **Enable** = `std::enable_if_t<!std::is_same_v<std::decay_t<F>, thread>>>`

inline explicit **thread**(**F** &&f)

template<typename **F**, typename ...**Ts**>

inline explicit **thread**(**F** &&f, **Ts**&&... vs)

template<typename **F**>

inline **thread**(`threads::thread_pool_base` *pool, **F** &&f)

template<typename **F**, typename ...**Ts**>

inline **thread**(`threads::thread_pool_base` *pool, **F** &&f, **Ts**&&... vs)

~**thread**()

thread(`thread`&&) noexcept

`thread` &**operator**=(`thread`&&) noexcept

void **swap**(`thread`&) noexcept

swaps two thread objects

inline bool **joinable**() const noexcept

Checks whether the thread is joinable, i.e. potentially running in parallel context

void **join**()

waits for the thread to finish its execution

inline void **detach**()

permits the thread to execute independently from the thread handle

id **get_id**() const noexcept

returns the id of the thread

inline *native_handle_type* **native_handle**() const

returns the underlying implementation-defined thread handle

void **interrupt**(bool flag = true)

bool **interruption_requested**() const

hpx::future<void> **get_future**(*error_code* &ec = *throws*)

std::size_t **get_thread_data**() const

std::size_t **set_thread_data**(*std::size_t*)

Public Static Functions

static unsigned int **hardware_concurrency**() noexcept

returns the number of concurrent threads supported by the implementation

static void **interrupt**(*id*, bool flag = true)

Private Types

using **mutex_type** = *hpx::spinlock*

Private Functions

void **terminate**(char const *function, char const *reason) const

inline bool **joinable_locked**() const noexcept

inline void **detach_locked**()

void **start_thread**(*threads::thread_pool_base* *pool, *hpx::move_only_function*<void()> &&func)

Private Members

mutable *mutex_type* **mtx_**

threads::thread_id_ref_type **id_**

Private Static Functions

static *threads::thread_result_type* **thread_function_nullary**(*hpx::move_only_function*<void()> const &func)

class **id**

Public Functions

id() noexcept = default

inline explicit **id**(*threads::thread_id_type* const &i) noexcept

inline explicit **id**(*threads::thread_id_type* &&i) noexcept

inline explicit **id**(*threads::thread_id_ref_type* const &i) noexcept

inline explicit **id**(*threads::thread_id_ref_type* &&i) noexcept

inline *threads::thread_id_type* const &**native_handle**() const noexcept

Private Members

threads::thread_id_type **id_**

Friends

friend class thread

friend bool operator==(*thread::id* const &x, *thread::id* const &y) noexcept

friend bool operator!=(*thread::id* const &x, *thread::id* const &y) noexcept

friend bool operator<(*thread::id* const &x, *thread::id* const &y) noexcept

friend bool operator>(*thread::id* const &x, *thread::id* const &y) noexcept

friend bool operator<=(*thread::id* const &x, *thread::id* const &y) noexcept

friend bool operator>=(*thread::id* const &x, *thread::id* const &y) noexcept

template<typename **Char**, typename **Traits**>

friend std::basic_ostream<*Char*, *Traits*> &**operator<<**(*std::basic_ostream*<*Char*, *Traits*>&, *thread::id* const&)

namespace **this_thread**

Functions

thread::id **get_id**() noexcept

Returns the id of the current thread.

void **yield**() noexcept

Provides a hint to the implementation to reschedule the execution of threads, allowing other threads to run.

Note: The exact behavior of this function depends on the implementation, in particular on the mechanics of the OS scheduler in use and the state of the system. For example, a first-in-first-out realtime scheduler (SCHED_FIFO in Linux) would suspend the current thread and put it on the back of the queue of the same-priority threads that are ready to run (and if there are no other threads at the same priority, yield has no effect).

void **yield_to**(*thread::id*) noexcept

threads::thread_priority **get_priority**() noexcept

std::ptrdiff_t **get_stack_size**() noexcept

void **interruption_point**()

bool **interruption_enabled**()

bool **interruption_requested**()

void **interrupt**()

void **sleep_until**(*hpx::chrono::steady_time_point* const &*abs_time*)

Blocks the execution of the current thread until specified *abs_time* has been reached.

It is recommended to use the clock tied to *abs_time*, in which case adjustments of the clock may be taken into account. Thus, the duration of the block might be more or less than *abs_time* - *Clock::now*() at the time of the call, depending on the direction of the adjustment and whether it is honored by the implementation. The function also may block until after *abs_time* has been reached due to process scheduling or resource contention delays.

Parameters *abs_time* – absolute time to block until

inline void **sleep_for**(*hpx::chrono::steady_duration* const &*rel_time*)

Blocks the execution of the current thread for at least the specified *rel_time*. This function may block for longer than *rel_time* due to scheduling or resource contention delays.

It is recommended to use a steady clock to measure the duration. If an implementation uses a system clock instead, the wait time may also be sensitive to clock adjustments.

Parameters *rel_time* – time duration to sleep

std::size_t **get_thread_data**()

std::size_t **set_thread_data**(*std::size_t*)

class **disable_interruption**

Public Functions

```
disable_interruption()  
~disable_interruption()
```

Private Functions

```
disable_interruption(disable_interruption const&)  
disable_interruption &operator=(disable_interruption const&)
```

Private Members

```
bool interruption_was_enabled_
```

Friends

```
friend class restore_interruption
```

```
class restore_interruption
```

Public Functions

```
explicit restore_interruption(disable_interruption &d)  
~restore_interruption()
```

Private Functions

```
restore_interruption(restore_interruption const&)  
restore_interruption &operator=(restore_interruption const&)
```

Private Members

```
bool interruption_was_enabled_
```

```
namespace std
```

```
template<> id >
```

Public Functions

```
inline std::size_t operator() (::hpx::thread::id const &id) const
```

threading_base

See *Public API* for a list of names and headers that are part of the public *HPX* API.

hpx::annotated_function

Defined in header `hpx/functional.hpp`⁷⁹³.

See *Public API* for a list of names and headers that are part of the public *HPX* API.

namespace **hpx**

Functions

```
template<typename F>
constexpr F &&annotated_function(F &&f, char const* = nullptr) noexcept
    Returns a function annotated with the given annotation.
```

Annotating includes setting the thread description per thread id.

Parameters function –

```
template<typename F>
constexpr F &&annotated_function(F &&f, std::string const&) noexcept
```

hpx/threading_base/print.hpp

Defined in header `hpx/threading_base/print.hpp`.

See *Public API* for a list of names and headers that are part of the public *HPX* API.

hpx/threading_base/register_thread.hpp

Defined in header `hpx/threading_base/register_thread.hpp`.

See *Public API* for a list of names and headers that are part of the public *HPX* API.

namespace **hpx**

namespace **threads**

⁷⁹³ http://github.com/STELLAR-GROUP/hpx/blob/8a3b7c1a4cb5693b2f7d9f587f759392ed0c51a0/libs/core/include_local/include/hpx/functional.hpp

Functions

```
template<typename F>  
thread_function_type make_thread_function(F &&f)
```

```
template<typename F>  
thread_function_type make_thread_function_nullary(F &&f)
```

```
void register_thread(threads::thread_init_data &data, threads::thread_pool_base *pool,  
                    threads::thread_id_ref_type &id, error_code &ec = hpx::throws)
```

Create a new *thread* using the given data.

Note: As long as *ec* is not pre-initialized to *hpx::throws* this function doesn't throw but returns the result code using the parameter *ec*. Otherwise it throws an instance of *hpx::exception*.

Parameters

- **data** – [in] The data to use for creating the thread.
- **pool** – [in] The thread pool to use for launching the work.
- **id** – [out] The id of the newly created thread (if applicable)
- **ec** – [in,out] This represents the error status on exit, if this is pre-initialized to *hpx::throws* the function will throw on error instead.

Throws *invalid_status* – if the runtime system has not been started yet.

Returns This function will return the internal id of the newly created HPX-thread.

```
threads::thread_id_ref_type register_thread(threads::thread_init_data &data,  
                                           threads::thread_pool_base *pool, error_code &ec =  
                                           hpx::throws)
```

```
void register_thread(threads::thread_init_data &data, threads::thread_id_ref_type &id, error_code  
                    &ec = throws)
```

Create a new *thread* using the given data on the same thread pool as the calling thread, or on the default thread pool if not on an HPX thread.

Note: As long as *ec* is not pre-initialized to *hpx::throws* this function doesn't throw but returns the result code using the parameter *ec*. Otherwise it throws an instance of *hpx::exception*.

Parameters

- **data** – [in] The data to use for creating the thread.
- **id** – [out] The id of the newly created thread (if applicable)
- **ec** – [in,out] This represents the error status on exit, if this is pre-initialized to *hpx::throws* the function will throw on error instead.

Throws *invalid_status* – if the runtime system has not been started yet.

Returns This function will return the internal id of the newly created HPX-thread.

```
threads::thread_id_ref_type register_thread(threads::thread_init_data &data, error_code &ec =  
                                           throws)
```

```
thread_id_ref_type register_work(threads::thread_init_data &data, threads::thread_pool_base *pool,  
                                error_code &ec = hpx::throws)
```

Create a new work item using the given data.

Note: As long as *ec* is not pre-initialized to *hpx::throws* this function doesn't throw but returns the result code using the parameter *ec*. Otherwise it throws an instance of *hpx::exception*.

Parameters

- **data** – [in] The data to use for creating the thread.
- **pool** – [in] The thread pool to use for launching the work.
- **ec** – [in,out] This represents the error status on exit, if this is pre-initialized to *hpx::throws* the function will throw on error instead.

Throws *invalid_status* – if the runtime system has not been started yet.

thread_id_ref_type **register_work**(*threads::thread_init_data* &data, *error_code* &ec = *throws*)

Create a new work item using the given data on the same thread pool as the calling thread, or on the default thread pool if not on an HPX thread.

Note: As long as *ec* is not pre-initialized to *hpx::throws* this function doesn't throw but returns the result code using the parameter *ec*. Otherwise it throws an instance of *hpx::exception*.

Parameters

- **data** – [in] The data to use for creating the thread.
- **ec** – [in,out] This represents the error status on exit, if this is pre-initialized to *hpx::throws* the function will throw on error instead.

Throws *invalid_status* – if the runtime system has not been started yet.

hpx::scoped_annotation

Defined in header `hpx/functional.hpp`⁷⁹⁴.

See *Public API* for a list of names and headers that are part of the public *HPX* API.

namespace **hpx**

struct **scoped_annotation**

#include <*scoped_annotation.hpp*> *scoped_annotation* associates a **name** with a section of code (scope). It can be used to visualize code execution in profiling tools like *Intel VTune*, *Apex Profiler*, etc. That allows analyzing performance to figure out which part(s) of code is (are) responsible for performance degradation, etc.

Public Functions

HPX_NON_COPYABLE(*scoped_annotation*)

inline explicit constexpr **scoped_annotation**(char const*) noexcept

template<typename **F**>

inline explicit constexpr **scoped_annotation**(*F*&&) noexcept

inline ~**scoped_annotation**()

⁷⁹⁴ http://github.com/STELLAR-GROUP/hpx/blob/8a3b7c1a4cb5693b2f7d9f587f759392ed0c51a0/libs/core/include_local/include/hpx/functional.hpp

hpx/threading_base/thread_data.hpp

Defined in header `hpx/threading_base/thread_data.hpp`.

See *Public API* for a list of names and headers that are part of the public *HPX* API.

```
namespace hpx
```

```
    namespace threads
```

Functions

```
constexpr thread_data *get_thread_id_data(thread_id_ref_type const &tid) noexcept
```

```
constexpr thread_data *get_thread_id_data(thread_id_type const &tid) noexcept
```

```
class thread_data : public thread_data_reference_counting
```

#include <thread_data.hpp> A *thread* is the representation of a HPX thread. It's a first class object in HPX. In our implementation this is a user level thread running on top of one of the OS threads spawned by the *thread-manager*.

A *thread* encapsulates:

- A thread status word (see the functions *thread::get_state* and *thread::set_state*)
- A function to execute (the thread function)
- A frame (in this implementation this is a block of memory used as the threads stack)
- A block of registers (not implemented yet)

Generally, *threads* are not created or executed directly. All functionality related to the management of *threads* is implemented by the *thread-manager*.

Public Types

```
using spinlock_pool = util::spinlock_pool<thread_data>
```

Public Functions

```
thread_data(thread_data const&) = delete
```

```
thread_data(thread_data&&) = delete
```

```
thread_data &operator=(thread_data const&) = delete
```

```
thread_data &operator=(thread_data&&) = delete
```

```
inline thread_state get_state(std::memory_order const order = std::memory_order_acquire) const  
    noexcept
```

The `get_state` function queries the state of this thread instance.

Note: This function will be seldom used directly. Most of the time the state of a thread will be retrieved by using the function *threadmanager::get_state*.

Returns This function returns the current state of this thread. It will return one of the values as defined by the *thread_state* enumeration.

```
inline thread_state set_state(thread_schedule_state const state, thread_restart_state state_ex =
    thread_restart_state::unknown, std::memory_order const load_order
    = std::memory_order_acquire, std::memory_order const
    exchange_order = std::memory_order_acq_rel) const noexcept
```

The `set_state` function changes the state of this thread instance.

Note: This function will be seldom used directly. Most of the time the state of a thread will have to be changed using the thread-manager. Moreover, changing the thread state using this function does not change its scheduling status. It only sets the thread's status word. To change the thread's scheduling status *threadmanager::set_state* should be used.

Parameters

- **state** – [in] The new state to be set for the thread.
- **state_ex** – [in]
- **load_order** – [in]
- **exchange_order** – [in]

```
inline bool set_state_tagged(thread_schedule_state const newstate, thread_state const
    &prev_state, thread_state &new_tagged_state, std::memory_order
    exchange_order = std::memory_order_acq_rel) const noexcept
```

```
inline bool restore_state(thread_state const new_state, thread_state const old_state,
    std::memory_order const load_order = std::memory_order_relaxed,
    std::memory_order const load_exchange =
    std::memory_order_acq_rel) const noexcept
```

The `restore_state` function changes the state of this thread instance depending on its current state. It will change the state atomically only if the current state is still the same as passed as the second parameter. Otherwise it won't touch the thread state of this instance.

Note: This function will be seldom used directly. Most of the time the state of a thread will have to be changed using the threadmanager. Moreover, changing the thread state using this function does not change its scheduling status. It only sets the thread's status word. To change the thread's scheduling status *threadmanager::set_state* should be used.

Parameters

- **new_state** – [in] The new state to be set for the thread.
- **old_state** – [in] The old state of the thread which still has to be the current state.
- **load_order** – [in]
- **load_exchange** – [in]

Returns This function returns *true* if the state has been changed successfully

```
inline bool restore_state(thread_schedule_state new_state, thread_restart_state const state_ex,
    thread_state old_state, std::memory_order const load_exchange =
    std::memory_order_acq_rel) const noexcept
```

```
inline constexpr thread_priority get_priority() const noexcept
```

```
inline void set_priority(thread_priority priority) noexcept
```

```
inline bool interruption_requested() const noexcept
```

```
inline bool interruption_enabled() const noexcept
inline bool set_interruption_enabled(bool enable) noexcept
inline void interrupt(bool flag = true)
bool interruption_point(bool throw_on_interrupt = true)
bool add_thread_exit_callback(function<void()> const &f)
void run_thread_exit_callbacks()
void free_thread_exit_callbacks()
inline bool runs_as_child(std::memory_order mo = std::memory_order_acquire) const noexcept
inline constexpr bool is_stackless() const noexcept
void destroy_thread() override
inline constexpr policies::scheduler_base *get_scheduler_base() const noexcept
inline constexpr std::uint16_t get_last_worker_thread_num() const noexcept
inline void set_last_worker_thread_num(std::uint16_t last_worker_thread_num) noexcept
inline constexpr std::ptrdiff_t get_stack_size() const noexcept
inline thread_stacksize get_stack_size_enum() const noexcept
template<typename ThreadQueue>
inline constexpr ThreadQueue &get_queue() noexcept
inline coroutinetype::result_type operator() (hpx::execution_base::this_thread::detail::agent_storage
                                             *agent_storage)
    Execute the thread function.
    Returns This function returns the thread state the thread should be scheduled from this point
    on. The thread manager will use the returned value to set the thread's scheduling status.
inline coroutinetype::result_type invoke_directly()
    Directly execute the thread function (inline)
    Returns This function returns the thread state the thread should be scheduled from this point
    on. The thread manager will use the returned value to set the thread's scheduling status.
inline virtual thread_id_type get_thread_id() const
inline virtual std::size_t get_thread_phase() const noexcept
virtual std::size_t get_thread_data() const = 0
virtual std::size_t set_thread_data(std::size_t data) = 0
virtual void init() = 0
virtual void rebind(thread_init_data &init_data) = 0
thread_data(thread_init_data &init_data, void *queue, std::ptrdiff_t stacksize, bool is_stackless =
             false, thread_id_addrf addrf = thread_id_addrf::yes)
virtual ~thread_data() override
virtual void destroy() noexcept = 0
```

Public Static Functions

static inline constexpr *std::uint64_t* **get_component_id**() noexcept

Return the id of the component this thread is running in.

static inline constexpr *threads::thread_description* **get_description**() noexcept

static inline constexpr *threads::thread_description* **set_description**(*threads::thread_description*)
noexcept

static inline constexpr *threads::thread_description* **get_lco_description**() noexcept

static inline constexpr *threads::thread_description* **set_lco_description**(*threads::thread_description*)
noexcept

static inline constexpr *std::uint32_t* **get_parent_locality_id**() noexcept

Return the locality of the parent thread.

static inline constexpr *thread_id_type* **get_parent_thread_id**() noexcept

Return the thread id of the parent thread.

static inline constexpr *std::size_t* **get_parent_thread_phase**() noexcept

Return the phase of the parent thread.

static inline constexpr *util::backtrace* const* **get_backtrace**() noexcept

static inline constexpr *util::backtrace* const* **set_backtrace**(*util::backtrace* const*) noexcept

Protected Functions

inline *thread_restart_state* **set_state_ex**(*thread_restart_state* const new_state,
std::memory_order const load_order =
std::memory_order_acquire, *std::memory_order* const
load_exchange = *std::memory_order_acq_rel*) const
noexcept

The `set_state` function changes the extended state of this thread instance.

Note: This function will be seldom used directly. Most of the time the state of a thread will have to be changed using the threadmanager.

Parameters

- **new_state** – [in] The new extended state to be set for the thread.
- **load_order** – [in]
- **load_exchange** – [in]

void **rebind_base**(*thread_init_data* &init_data)

Private Members

thread_priority **priority_**

bool **requested_interrupt_**

bool **enabled_interrupt_**

bool **ran_exit_funcs_**

const bool **is_stackless_**

std::atomic<bool> **runs_as_child_**

std::uint16_t **last_worker_thread_num_**

thread_stacksize **stacksize_enum_**

std::int32_t **stacksize_**

mutable *std::atomic<thread_state>* **current_state_**

std::forward_list<hpx::function<void()>> **exit_funcs_**

policies::scheduler_base ***scheduler_base_**

void ***queue_**

hpx/threading_base/thread_description.hpp

Defined in header `hpx/threading_base/thread_description.hpp`.

See *Public API* for a list of names and headers that are part of the public *HPX* API.

```
namespace hpx
```

```
    namespace threads
```

Functions

```
std::ostream &operator<<(std::ostream&, thread_description const&)
```

```
std::string as_string(thread_description const &desc)
```

```
threads::thread_description get_thread_description(thread_id_type const &id, error_code &ec =
                                                    throws)
```

The function `get_thread_description` is part of the thread related API allows to query the description of one of the threads known to the thread-manager.

Note: As long as *ec* is not pre-initialized to `hpx::throws` this function doesn't throw but returns the result code using the parameter *ec*. Otherwise it throws an instance of `hpx::exception`.

Parameters

- **id** – [in] The thread id of the thread being queried.
- **ec** – [in,out] this represents the error status on exit, if this is pre-initialized to `hpx::throws` the function will throw on error instead.

Returns This function returns the description of the thread referenced by the *id* parameter. If the thread is not known to the thread-manager the return value will be the string “<unknown>”.

```
threads::thread_description set_thread_description(thread_id_type const &id,
                                                    threads::thread_description const &desc =
                                                    threads::thread_description(), error_code &ec
                                                    = throws)
```

```
threads::thread_description get_thread_lco_description(thread_id_type const &id, error_code
                                                         &ec = throws)
```

```
threads::thread_description set_thread_lco_description(thread_id_type const &id,
                                                         threads::thread_description const &desc
                                                         = threads::thread_description(),
                                                         error_code &ec = throws)
```

```
struct thread_description
```

Public Types

```
enum class data_type : std::uint8_t
```

Values:

```
enumerator description
```

```
enumerator address
```

Public Functions

```
thread_description() noexcept = default  
  
inline constexpr thread_description(char const*) noexcept  
  
inline explicit constexpr thread_description(std::string const&) noexcept  
  
template<typename F, typename = std::enable_if_t<!std::is_same_v<F, thread_description> &&  
!traits::is_action_v<F>>>  
inline explicit constexpr thread_description(F const&, char const* = nullptr) noexcept  
  
template<typename Action, typename = std::enable_if_t<traits::is_action_v<Action>>>  
inline explicit constexpr thread_description(Action, char const* = nullptr) noexcept  
  
inline explicit constexpr operator bool() const noexcept
```

Public Static Functions

```
static inline constexpr data_type kind() noexcept  
  
static inline constexpr char const* get_description() noexcept  
  
static inline constexpr std::size_t get_address() noexcept  
  
static inline constexpr bool valid() noexcept
```

Private Functions

```
void init_from_alternative_name(char const *altname)
```

```
namespace util
```

Typedefs

```
using instead = hpx::threads::thread_description
```

hpx/threading_base/thread_helpers.hpp

Defined in header `hpx/threading_base/thread_helpers.hpp`.

See *Public API* for a list of names and headers that are part of the public *HPX* API.

```
namespace hpx
```

```
    namespace this_thread
```

Functions

```
threads::thread_restart_state suspend(threads::thread_schedule_state state, threads::thread_id_type
nextid, threads::thread_description const &description =
threads::thread_description("this_thread::suspend"), error_code
&ec = throws)
```

The function *suspend* will return control to the thread manager (suspends the current thread). It sets the new state of this thread to the thread state passed as the parameter.

Note: Must be called from within a HPX-thread.

Throws If – &ec != &throws, never throws, but will set *ec* to an appropriate value when an error occurs. Otherwise, this function will throw an *hpx::exception* with an error code of *hpx::error::yield_aborted* if it is signaled with *wait_aborted*. If called outside of a HPX-thread, this function will throw an *hpx::exception* with an error code of *hpx::error::null_thread_id*. If this function is called while the thread-manager is not running, it will throw an *hpx::exception* with an error code of *hpx::error::invalid_status*.

```
inline threads::thread_restart_state suspend(threads::thread_schedule_state state =
threads::thread_schedule_state::pending,
threads::thread_description const &description =
threads::thread_description("this_thread::suspend"),
error_code &ec = throws)
```

The function *suspend* will return control to the thread manager (suspends the current thread). It sets the new state of this thread to the thread state passed as the parameter.

Note: Must be called from within a HPX-thread.

Throws If – &ec != &throws, never throws, but will set *ec* to an appropriate value when an error occurs. Otherwise, this function will throw an *hpx::exception* with an error code of *hpx::error::yield_aborted* if it is signaled with *wait_aborted*. If called outside of a HPX-thread, this function will throw an *hpx::exception* with an error code of *hpx::error::null_thread_id*. If this function is called while the thread-manager is not running, it will throw an *hpx::exception* with an error code of *hpx::error::invalid_status*.

```
threads::thread_restart_state suspend(hpx::chrono::steady_time_point const &abs_time,
threads::thread_id_type id, threads::thread_description const
&description =
threads::thread_description("this_thread::suspend"), error_code
&ec = throws)
```

The function *suspend* will return control to the thread manager (suspends the current thread). It sets the new state of this thread to *suspended* and schedules a wakeup for this threads at the given time.

Note: Must be called from within a HPX-thread.

Throws If – &ec != &throws, never throws, but will set *ec* to an appropriate value when an error occurs. Otherwise, this function will throw an *hpx::exception* with an error code of *hpx::error::yield_aborted* if it is signaled with *wait_aborted*. If called outside of a HPX-thread, this function will throw an *hpx::exception* with an error code of *hpx::error::null_thread_id*. If this function is called while the thread-manager is not running, it will throw an *hpx::exception* with an error code of *hpx::error::invalid_status*.

```
inline threads::thread_restart_state suspend(hpx::chrono::steady_time_point const &abs_time,
                                             threads::thread_description const &description =
                                             threads::thread_description("this_thread::suspend"),
                                             error_code &ec = throws)
```

The function *suspend* will return control to the thread manager (suspends the current thread). It sets the new state of this thread to *suspended* and schedules a wakeup for this threads at the given time.

Note: Must be called from within a HPX-thread.

Throws If – `&ec != &throws`, never throws, but will set *ec* to an appropriate value when an error occurs. Otherwise, this function will throw an *hpx::exception* with an error code of *hpx::error::yield_aborted* if it is signaled with *wait_aborted*. If called outside of a HPX-thread, this function will throw an *hpx::exception* with an error code of *hpx::error::null_thread_id*. If this function is called while the thread-manager is not running, it will throw an *hpx::exception* with an error code of *hpx::error::invalid_status*.

```
inline threads::thread_restart_state suspend(hpx::chrono::steady_duration const &rel_time,
                                             threads::thread_description const &description =
                                             threads::thread_description("this_thread::suspend"),
                                             error_code &ec = throws)
```

The function *suspend* will return control to the thread manager (suspends the current thread). It sets the new state of this thread to *suspended* and schedules a wakeup for this threads after the given duration.

Note: Must be called from within a HPX-thread.

Throws If – `&ec != &throws`, never throws, but will set *ec* to an appropriate value when an error occurs. Otherwise, this function will throw an *hpx::exception* with an error code of *hpx::error::yield_aborted* if it is signaled with *wait_aborted*. If called outside of a HPX-thread, this function will throw an *hpx::exception* with an error code of *hpx::error::null_thread_id*. If this function is called while the thread-manager is not running, it will throw an *hpx::exception* with an error code of *hpx::error::invalid_status*.

```
inline threads::thread_restart_state suspend(hpx::chrono::steady_duration const &rel_time,
                                             threads::thread_id_type const &id,
                                             threads::thread_description const &description =
                                             threads::thread_description("this_thread::suspend"),
                                             error_code &ec = throws)
```

The function *suspend* will return control to the thread manager (suspends the current thread). It sets the new state of this thread to *suspended* and schedules a wakeup for this threads after the given duration.

Note: Must be called from within a HPX-thread.

Throws If – `&ec != &throws`, never throws, but will set *ec* to an appropriate value when an error occurs. Otherwise, this function will throw an *hpx::exception* with an error code of *hpx::error::yield_aborted* if it is signaled with *wait_aborted*. If called outside of a HPX-thread, this function will throw an *hpx::exception* with an error code of *hpx::error::null_thread_id*. If this function is called while the thread-manager is not running, it will throw an *hpx::exception* with an error code of *hpx::error::invalid_status*.

```
inline threads::thread_restart_state suspend(std::uint64_t ms, threads::thread_description const
&description =
threads::thread_description("this_thread::suspend"),
error_code &ec = throws)
```

The function *suspend* will return control to the thread manager (suspends the current thread). It sets the new state of this thread to *suspended* and schedules a wakeup for this threads after the given time (specified in milliseconds).

Note: Must be called from within a HPX-thread.

Throws If – `&ec != &throws`, never throws, but will set *ec* to an appropriate value when an error occurs. Otherwise, this function will throw an *hpx::exception* with an error code of *hpx::error::yield_aborted* if it is signaled with *wait_aborted*. If called outside of a HPX-thread, this function will throw an *hpx::exception* with an error code of *hpx::error::null_thread_id*. If this function is called while the thread-manager is not running, it will throw an *hpx::exception* with an error code of *hpx::error::invalid_status*.

```
threads::thread_pool_base *get_pool(error_code &ec = throws)
```

Returns a pointer to the pool that was used to run the current thread

Throws If – `&ec != &throws`, never throws, but will set *ec* to an appropriate value when an error occurs. Otherwise, this function will throw an *hpx::exception* with an error code of *hpx::error::yield_aborted* if it is signaled with *wait_aborted*. If called outside of a HPX-thread, this function will throw an *hpx::exception* with an error code of *hpx::error::null_thread_id*. If this function is called while the thread-manager is not running, it will throw an *hpx::exception* with an error code of *hpx::error::invalid_status*.

namespace **threads**

Functions

```
thread_state set_thread_state(thread_id_type const &id, thread_schedule_state state =
thread_schedule_state::pending, thread_restart_state stateex =
thread_restart_state::signaled, thread_priority priority =
thread_priority::normal, bool retry_on_active = true, hpx::error_code
&ec = throws)
```

Set the thread state of the *thread* referenced by the *thread_id id*.

Note: If the thread referenced by the parameter *id* is in *thread_state::active* state this function schedules a new thread which will set the state of the thread as soon as its not active anymore. The function returns *thread_state::active* in this case.

Note: As long as *ec* is not pre-initialized to *hpx::throws* this function doesn't throw but returns the result code using the parameter *ec*. Otherwise it throws an instance of *hpx::exception*.

Parameters

- **id** – [in] The thread id of the thread the state should be modified for.
- **state** – [in] The new state to be set for the thread referenced by the *id* parameter.
- **stateex** – [in] The new extended state to be set for the thread referenced by the *id* parameter.

- **priority** – [in]
- **retry_on_active** – [in]
- **ec** – [in,out] this represents the error status on exit, if this is pre-initialized to *hpx::throws* the function will throw on error instead.

Returns This function returns the previous state of the thread referenced by the *id* parameter. It will return one of the values as defined by the *thread_state* enumeration. If the thread is not known to the thread-manager the return value will be *thread_state::unknown*.

```
thread_id_ref_type set_thread_state(thread_id_type const &id, hpx::chrono::steady_time_point
    const &abs_time, std::atomic<bool> *started,
    thread_schedule_state state = thread_schedule_state::pending,
    thread_restart_state stateex = thread_restart_state::timeout,
    thread_priority priority = thread_priority::normal, bool
    retry_on_active = true, error_code &ec = throws)
```

Set the thread state of the *thread* referenced by the thread_id *id*.

Set a timer to set the state of the given *thread* to the given new value after it expired (at the given time)

Note: As long as *ec* is not pre-initialized to *hpx::throws* this function doesn't throw but returns the result code using the parameter *ec*. Otherwise it throws an instance of *hpx::exception*.

Parameters

- **id** – [in] The thread id of the thread the state should be modified for.
- **abs_time** – [in] Absolute point in time for the new thread to be run
- **started** – [in,out] A helper variable allowing to track the state of the timer helper thread
- **state** – [in] The new state to be set for the thread referenced by the *id* parameter.
- **stateex** – [in] The new extended state to be set for the thread referenced by the *id* parameter.
- **priority** – [in]
- **retry_on_active** – [in]
- **ec** – [in,out] this represents the error status on exit, if this is pre-initialized to *hpx::throws* the function will throw on error instead.

Returns

```
inline thread_id_ref_type set_thread_state(thread_id_type const &id,
    hpx::chrono::steady_time_point const &abs_time,
    thread_schedule_state state =
    thread_schedule_state::pending, thread_restart_state
    stateex = thread_restart_state::timeout, thread_priority
    priority = thread_priority::normal, bool retry_on_active
    = true, error_code& = throws)
```

```
inline thread_id_ref_type set_thread_state(thread_id_type const &id, hpx::chrono::steady_duration
    const &rel_time, thread_schedule_state state =
    thread_schedule_state::pending, thread_restart_state
    stateex = thread_restart_state::timeout, thread_priority
    priority = thread_priority::normal, bool retry_on_active
    = true, error_code &ec = throws)
```

Set the thread state of the *thread* referenced by the thread_id *id*.

Set a timer to set the state of the given *thread* to the given new value after it expired (after the given duration)

Note: As long as *ec* is not pre-initialized to *hpx::throws* this function doesn't throw but returns the

result code using the parameter *ec*. Otherwise it throws an instance of `hpx::exception`.

Parameters

- **id** – [in] The thread id of the thread the state should be modified for.
- **rel_time** – [in] Time duration after which the new thread should be run
- **state** – [in] The new state to be set for the thread referenced by the *id* parameter.
- **stateex** – [in] The new extended state to be set for the thread referenced by the *id* parameter.
- **priority** – [in]
- **retry_on_active** – [in]
- **ec** – [in,out] this represents the error status on exit, if this is pre-initialized to `hpx::throws` the function will throw on error instead.

Returns

thread_state **get_thread_state**(thread_id_type const &id, *error_code* &ec = *throws*) noexcept

The function `get_thread_backtrace` is part of the thread related API allows to query the currently stored thread back trace (which is captured during thread suspension).

Note: As long as *ec* is not pre-initialized to `hpx::throws` this function doesn't throw but returns the result code using the parameter *ec*. Otherwise it throws an instance of `hpx::exception`. The function `get_thread_state` is part of the thread related API. It queries the state of one of the threads known to the thread-manager.

Note: As long as *ec* is not pre-initialized to `hpx::throws` this function doesn't throw but returns the result code using the parameter *ec*. Otherwise it throws an instance of `hpx::exception`.

Parameters

- **id** – [in] The thread id of the thread being queried.
- **ec** – [in,out] this represents the error status on exit, if this is pre-initialized to `hpx::throws` the function will throw on error instead.
- **id** – [in] The thread id of the thread the state should be modified for.
- **ec** – [in,out] this represents the error status on exit, if this is pre-initialized to `hpx::throws` the function will throw on error instead.

Returns This function returns the currently captured stack back trace of the thread referenced by the *id* parameter. If the thread is not known to the thread-manager the return value will be the zero.

Returns This function returns the thread state of the thread referenced by the *id* parameter. If the thread is not known to the thread-manager the return value will be *terminated*.

`std::size_t` **get_thread_phase**(thread_id_type const &id, *error_code* &ec = *throws*) noexcept

The function `get_thread_phase` is part of the thread related API. It queries the phase of one of the threads known to the thread-manager.

Note: As long as *ec* is not pre-initialized to `hpx::throws` this function doesn't throw but returns the result code using the parameter *ec*. Otherwise it throws an instance of `hpx::exception`.

Parameters

- **id** – [in] The thread id of the thread the phase should be modified for.
- **ec** – [in,out] this represents the error status on exit, if this is pre-initialized to `hpx::throws` the function will throw on error instead.

Returns This function returns the thread phase of the thread referenced by the *id* parameter. If the thread is not known to the thread-manager the return value will be `-0`.

bool **get_thread_interruption_enabled**(thread_id_type const &id, *error_code* &ec = *throws*)

Returns whether the given thread can be interrupted at this point.

Note: As long as *ec* is not pre-initialized to *hpx::throws* this function doesn't throw but returns the result code using the parameter *ec*. Otherwise it throws an instance of *hpx::exception*.

Parameters

- **id** – [in] The thread id of the thread which should be queried.
- **ec** – [in,out] this represents the error status on exit, if this is pre-initialized to *hpx::throws* the function will throw on error instead.

Returns This function returns *true* if the given thread can be interrupted at this point in time. It will return *false* otherwise.

bool **set_thread_interruption_enabled**(thread_id_type const &id, bool enable, *error_code* &ec = *throws*)

Set whether the given thread can be interrupted at this point.

Note: As long as *ec* is not pre-initialized to *hpx::throws* this function doesn't throw but returns the result code using the parameter *ec*. Otherwise it throws an instance of *hpx::exception*.

Parameters

- **id** – [in] The thread id of the thread which should receive the new value.
- **enable** – [in] This value will determine the new interruption enabled status for the given thread.
- **ec** – [in,out] this represents the error status on exit, if this is pre-initialized to *hpx::throws* the function will throw on error instead.

Returns This function returns the previous value of whether the given thread could have been interrupted.

bool **get_thread_interruption_requested**(thread_id_type const &id, *error_code* &ec = *throws*)

Returns whether the given thread has been flagged for interruption.

Note: As long as *ec* is not pre-initialized to *hpx::throws* this function doesn't throw but returns the result code using the parameter *ec*. Otherwise it throws an instance of *hpx::exception*.

Parameters

- **id** – [in] The thread id of the thread which should be queried.
- **ec** – [in,out] this represents the error status on exit, if this is pre-initialized to *hpx::throws* the function will throw on error instead.

Returns This function returns *true* if the given thread was flagged for interruption. It will return *false* otherwise.

void **interrupt_thread**(thread_id_type const &id, bool flag, *error_code* &ec = *throws*)

Flag the given thread for interruption.

Note: As long as *ec* is not pre-initialized to *hpx::throws* this function doesn't throw but returns the result code using the parameter *ec*. Otherwise it throws an instance of *hpx::exception*.

Parameters

- **id** – [in] The thread id of the thread which should be interrupted.
- **flag** – [in] The flag encodes whether the thread should be interrupted (if it is *true*), or ‘uninterrupted’ (if it is *false*).
- **ec** – [in,out] this represents the error status on exit, if this is pre-initialized to *hpx::throws* the function will throw on error instead.

inline void **interrupt_thread**(thread_id_type const &id, *error_code* &ec = *throws*)

void **interruption_point**(thread_id_type const &id, *error_code* &ec = *throws*)

Interrupt the current thread at this point if it was canceled. This will throw a *thread_interrupted* exception, which will cancel the thread.

Note: As long as *ec* is not pre-initialized to *hpx::throws* this function doesn’t throw but returns the result code using the parameter *ec*. Otherwise it throws an instance of *hpx::exception*.

Parameters

- **id** – [in] The thread id of the thread which should be interrupted.
- **ec** – [in,out] this represents the error status on exit, if this is pre-initialized to *hpx::throws* the function will throw on error instead.

threads::thread_priority **get_thread_priority**(thread_id_type const &id, *error_code* &ec = *throws*)
noexcept

Return priority of the given thread

Note: As long as *ec* is not pre-initialized to *hpx::throws* this function doesn’t throw but returns the result code using the parameter *ec*. Otherwise it throws an instance of *hpx::exception*.

Parameters

- **id** – [in] The thread id of the thread whose priority is queried.
- **ec** – [in,out] this represents the error status on exit, if this is pre-initialized to *hpx::throws* the function will throw on error instead.

std::ptrdiff_t **get_stack_size**(thread_id_type const &id, *error_code* &ec = *throws*) noexcept

Return stack size of the given thread

Note: As long as *ec* is not pre-initialized to *hpx::throws* this function doesn’t throw but returns the result code using the parameter *ec*. Otherwise it throws an instance of *hpx::exception*.

Parameters

- **id** – [in] The thread id of the thread whose priority is queried.
- **ec** – [in,out] this represents the error status on exit, if this is pre-initialized to *hpx::throws* the function will throw on error instead.

threads::thread_pool_base ***get_pool**(thread_id_type const &id, *error_code* &ec = *throws*)

Returns a pointer to the pool that was used to run the current thread

Throws If – &ec != &throws, never throws, but will set *ec* to an appropriate value when an error occurs. Otherwise, this function will throw an *hpx::exception* with an error code of *hpx::error::yield_aborted* if it is signaled with *wait_aborted*. If called outside of a HPX-thread, this function will throw an *hpx::exception* with an error code of *hpx::error::null_thread_id*. If this function is called while the thread-manager is not running, it will throw an *hpx::exception* with an error code of *hpx::error::invalid_status*.

`hpx::get_worker_thread_num`, `hpx::get_local_worker_thread_num`, `hpx::get_local_worker_thread_num`,
`hpx::get_thread_pool_num`, `hpx::get_thread_pool_num`

Defined in header `hpx/runtime.hpp`⁷⁹⁵.

See *Public API* for a list of names and headers that are part of the public *HPX* API.

namespace **hpx**

Functions

`std::size_t get_worker_thread_num()` noexcept

Return the number of the current OS-thread running in the runtime instance the current HPX-thread is executed with.

This function returns the zero based index of the OS-thread which executes the current HPX-thread.

Note: The returned value is zero based and its maximum value is smaller than the overall number of OS-threads executed (as returned by `get_os_thread_count()`).

Note: This function needs to be executed on a HPX-thread. It will fail otherwise (it will return -1).

`std::size_t get_worker_thread_num(error_code&)` noexcept

Return the number of the current OS-thread running in the runtime instance the current HPX-thread is executed with.

This function returns the zero based index of the OS-thread which executes the current HPX-thread.

Note: The returned value is zero based and its maximum value is smaller than the overall number of OS-threads executed (as returned by `get_os_thread_count()`). It will return -1 if the current thread is not a known thread or if the runtime is not in running state.

Note: This function needs to be executed on a HPX-thread. It will fail otherwise (it will return -1).

Parameters `ec` – [in,out] this represents the error status on exit (obsolete, ignored).

`std::size_t get_local_worker_thread_num()` noexcept

Return the number of the current OS-thread running in the current thread pool the current HPX-thread is executed with.

This function returns the zero based index of the OS-thread on the current thread pool which executes the current HPX-thread.

Note: The returned value is zero based and its maximum value is smaller than the number of OS-threads executed on the current thread pool. It will return -1 if the current thread is not a known thread or if the runtime is not in running state.

⁷⁹⁵ <http://github.com/STELLAR-GROUP/hpx/blob/8a3b7c1a4cb5693b2f7d9f587f759392ed0c51a0/libs/full/include/include/hpx/runtime.hpp>

Note: This function needs to be executed on a HPX-thread. It will fail otherwise (it will return -1).

`std::size_t get_local_worker_thread_num(error_code&) noexcept`

Return the number of the current OS-thread running in the current thread pool the current HPX-thread is executed with.

This function returns the zero based index of the OS-thread on the current thread pool which executes the current HPX-thread.

Note: The returned value is zero based and its maximum value is smaller than the number of OS-threads executed on the current thread pool. It will return -1 if the current thread is not a known thread or if the runtime is not in running state.

Note: This function needs to be executed on a HPX-thread. It will fail otherwise (it will return -1).

Parameters `ec` – [in,out] this represents the error status on exit (obsolete, ignored).

`std::size_t get_thread_pool_num()` noexcept

Return the number of the current thread pool the current HPX-thread is executed with.

This function returns the zero based index of the thread pool which executes the current HPX-thread.

Note: The returned value is zero based and its maximum value is smaller than the number of thread pools started by the runtime. It will return -1 if the current thread pool is not a known thread pool or if the runtime is not in running state.

Note: This function needs to be executed on a HPX-thread. It will fail otherwise (it will return -1).

`std::size_t get_thread_pool_num(error_code&) noexcept`

Return the number of the current thread pool the current HPX-thread is executed with.

This function returns the zero based index of the thread pool which executes the current HPX-thread.

Note: The returned value is zero based and its maximum value is smaller than the number of thread pools started by the runtime. It will return -1 if the current thread pool is not a known thread pool or if the runtime is not in running state.

Note: This function needs to be executed on a HPX-thread. It will fail otherwise (it will return -1).

Parameters `ec` – [in,out] this represents the error status on exit (obsolete, ignored).

namespace **threads**

hpx/threading_base/thread_pool_base.hpp

Defined in header `hpx/threading_base/thread_pool_base.hpp`.

See *Public API* for a list of names and headers that are part of the public *HPX* API.

namespace **hpx**

namespace **threads**

Functions

`std::ostream &operator<<(std::ostream &os, thread_pool_base const &thread_pool)`

class **thread_pool_base**

#include <thread_pool_base.hpp> The base class used to manage a pool of OS threads.

Public Functions

virtual void **suspend_processing_unit_direct**(`std::size_t virt_core, error_code &ec = throws`)
= 0

Suspends the given processing unit. Blocks until the processing unit has been suspended.

Parameters

- **virt_core** – [in] The processing unit on the the pool to be suspended. The processing units are indexed starting from 0.
- **ec** – [in,out] this represents the error status on exit, if this is pre-initialized to `hpx::throws` the function will throw on error instead.

virtual void **resume_processing_unit_direct**(`std::size_t virt_core, error_code &ec = throws`)
= 0

Resumes the given processing unit. Blocks until the processing unit has been resumed.

Parameters

- **virt_core** – [in] The processing unit on the the pool to be resumed. The processing units are indexed starting from 0.
- **ec** – [in,out] this represents the error status on exit, if this is pre-initialized to `hpx::throws` the function will throw on error instead.

virtual void **resume_direct**(`error_code &ec = throws`) = 0

Resumes the thread pool. Blocks until all OS threads on the thread pool have been resumed.

Parameters **ec** – [in,out] this represents the error status on exit, if this is pre-initialized to `hpx::throws` the function will throw on error instead.

virtual void **suspend_direct**(`error_code &ec = throws`) = 0

Suspends the thread pool. Blocks until all OS threads on the thread pool have been suspended.

Note: A thread pool cannot be suspended from an HPX thread running on the pool itself.

Parameters **ec** – [in,out] this represents the error status on exit, if this is pre-initialized to `hpx::throws` the function will throw on error instead.

Throws `hpx::exception` – if called from an HPX thread which is running on the pool itself.

struct `thread_pool_init_parameters`

Public Functions

```
inline thread_pool_init_parameters(std::string const &name, std::size_t index,
                                   policies::scheduler_mode mode, std::size_t num_threads,
                                   std::size_t thread_offset,
                                   hpx::threads::policies::callback_notifier &notifier,
                                   hpx::threads::policies::detail::affinity_data const
                                   &affinity_data,
                                   hpx::threads::detail::network_background_callback_type
                                   const &network_background_callback =
                                   hpx::threads::detail::network_background_callback_type(),
                                   std::size_t max_background_threads =
                                   static_cast<std::size_t>(-1), std::size_t
                                   max_idle_loop_count =
                                   HPX_IDLE_LOOP_COUNT_MAX, std::size_t
                                   max_busy_loop_count =
                                   HPX_BUSY_LOOP_COUNT_MAX, std::size_t
                                   shutdown_check_count = 10)
```

Public Members

std::string const &name_

std::size_t index_

policies::scheduler_mode mode_

std::size_t num_threads_

std::size_t thread_offset_

hpx::threads::policies::callback_notifier ¬ifier_

hpx::threads::policies::detail::affinity_data const &affinity_data_

hpx::threads::detail::network_background_callback_type const
&network_background_callback_

std::size_t max_background_threads_

std::size_t max_idle_loop_count_

`std::size_t max_busy_loop_count_`

`std::size_t shutdown_check_count_`

hpx/threading_base/threading_base_fwd.hpp

Defined in header `hpx/threading_base/threading_base_fwd.hpp`.

See *Public API* for a list of names and headers that are part of the public *HPX* API.

namespace **hpx**

namespace **threads**

Functions

`thread_data *get_self_id_data()` noexcept

The function `get_self_id_data` returns the data of the HPX thread id associated with the current thread (or nullptr if the current thread is not a HPX thread).

`thread_self &get_self()`

The function `get_self` returns a reference to the (OS thread specific) self reference to the current HPX thread.

`thread_self *get_self_ptr()` noexcept

The function `get_self_ptr` returns a pointer to the (OS thread specific) self reference to the current HPX thread.

`thread_self_impl_type *get_ctx_ptr()`

The function `get_ctx_ptr` returns a pointer to the internal data associated with each coroutine.

`thread_self *get_self_ptr_checked(error_code &ec = throws)`

The function `get_self_ptr_checked` returns a pointer to the (OS thread specific) self reference to the current HPX thread.

`thread_id_type get_self_id()` noexcept

The function `get_self_id` returns the HPX thread id of the current thread (or zero if the current thread is not a HPX thread).

`thread_id_type get_outer_self_id()` noexcept

The function `get_outer_self_id` returns the HPX thread id of the current outer thread (or zero if the current thread is not a HPX thread). This usually returns the same as `get_self_id`, except for directly executed threads, in which case this returns the thread id of the outermost HPX thread.

`thread_id_type get_parent_id()` noexcept

The function `get_parent_id` returns the HPX thread id of the current thread's parent (or zero if the current thread is not a HPX thread).

Note: This function will return a meaningful value only if the code was compiled with `HPX_HAVE_THREAD_PARENT_REFERENCE` being defined.

`std::size_t get_parent_phase()` noexcept

The function `get_parent_phase` returns the HPX phase of the current thread's parent (or zero if the current thread is not a HPX thread).

Note: This function will return a meaningful value only if the code was compiled with `HPX_HAVE_THREAD_PARENT_REFERENCE` being defined.

`std::ptrdiff_t get_self_stacksize()` noexcept

The function `get_self_stacksize` returns the stack size of the current thread (or zero if the current thread is not a HPX thread).

`thread_stacksize get_self_stacksize_enum()` noexcept

The function `get_self_stacksize_enum` returns the stack size of the `/`.

`std::uint32_t get_parent_locality_id()` noexcept

The function `get_parent_locality_id` returns the id of the locality of the current thread's parent (or zero if the current thread is not a HPX thread).

Note: This function will return a meaningful value only if the code was compiled with `HPX_HAVE_THREAD_PARENT_REFERENCE` being defined.

`std::uint64_t get_self_component_id()` noexcept

The function `get_self_component_id` returns the lva of the component the current thread is acting on

Note: This function will return a meaningful value only if the code was compiled with `HPX_HAVE_THREAD_TARGET_ADDRESS` being defined.

namespace **policies**

threadmanager

See *Public API* for a list of names and headers that are part of the public *HPX* API.

hpx/modules/threadmanager.hpp

Defined in header `hpx/modules/threadmanager.hpp`.

See *Public API* for a list of names and headers that are part of the public *HPX* API.

namespace **hpx**

namespace **threads**

class **threadmanager**

`#include <threadmanager.hpp>` The *thread-manager* class is the central instance of management for all (non-depleted) threads

Public Types

```
using notification_policy_type = threads::policies::callback_notifier
```

```
using pool_type = std::unique_ptr<thread_pool_base>
```

```
using pool_vector = std::vector<pool_type>
```

Public Functions

```
threadmanager(hpx::util::runtime_configuration &rtcfg_, notification_policy_type &notifier,  
               detail::network_background_callback_type network_background_callback =  
               detail::network_background_callback_type())
```

```
threadmanager(threadmanager const&) = delete
```

```
threadmanager(threadmanager&&) = delete
```

```
threadmanager &operator=(threadmanager const&) = delete
```

```
threadmanager &operator=(threadmanager&&) = delete
```

```
~threadmanager()
```

```
void init() const
```

```
void create_pools()
```

```
void print_pools(std::ostream&) const
```

FIXME move to private and add `—hpx:printpools` cmd line option.

```
thread_pool_base &default_pool() const
```

```
thread_pool_base &get_pool(std::string const &pool_name) const
```

```
thread_pool_base &get_pool(pool_id_type const &pool_id) const
```

```
thread_pool_base &get_pool(std::size_t thread_index) const
```

```
bool pool_exists(std::string const &pool_name) const
```

```
bool pool_exists(std::size_t pool_index) const
```

```
thread_id_ref_type register_work(thread_init_data &data, error_code &ec = throws) const
```

The function `register_work` adds a new work item to the thread manager. It doesn't immediately create a new *thread*, it just adds the task parameters (function, initial state and description) to the internal management data structures. The thread itself will be created when the number of existing threads drops below the number of threads specified by the constructor's `max_count` parameter.

Parameters

- **data** – [in] The value of this parameter allows to specify a description of the thread to create. This information is used for logging purposes mainly, but might be useful for debugging as well. This parameter is optional and defaults to an empty string.
- **ec** –

void **register_thread**(thread_init_data &data, *thread_id_ref_type* &id, *error_code* &ec = *throws*) const

The function *register_thread* adds a new work item to the thread manager. It creates a new *thread*, adds it to the internal management data structures, and schedules the new thread, if appropriate.

Parameters

- **data** – [in] The value of this parameter allows to specify a description of the thread to create. This information is used for logging purposes mainly, but might be useful for debugging as well. This parameter is optional and defaults to an empty string.
- **id** – [out] This parameter will hold the id of the created thread. This id is guaranteed to be validly initialized before the thread function is executed.
- **ec** –

bool **run**() const

Run the thread manager’s work queue. This function instantiates the specified number of OS threads in each pool. All OS threads are started to execute the function *tfunc*.

Returns The function returns *true* if the thread manager has been started successfully, otherwise it returns *false*.

void **stop**(bool blocking = true) const

Forcefully stop the thread-manager.

Parameters **blocking** –

bool **is_busy**() const

bool **is_idle**() const

void **wait**() const

bool **wait_for**(*hpx::chrono::steady_duration* const &rel_time) const

void **suspend**() const

void **resume**() const

hpx::state **status**() const

Return whether the thread manager is still running This returns the “minimal state”, i.e. the state of the least advanced thread pool

std::int64_t **get_thread_count**(*thread_schedule_state* state = *thread_schedule_state::unknown*, *thread_priority* priority = *thread_priority::default_*, *std::size_t* num_thread = static_cast<*std::size_t*>(-1), bool reset = false) const

return the number of HPX-threads with the given state

Note: This function locks the internal OS lock in the thread manager

std::int64_t **get_idle_core_count**() const

mask_type **get_idle_core_mask**() const

std::int64_t **get_background_thread_count**() const

bool **enumerate_threads**(*hpx::function*<bool(thread_id_type)> const &f, *thread_schedule_state* state = *thread_schedule_state::unknown*) const

void **abort_all_suspended_threads**() const

bool **cleanup_terminated**(bool delete_all) const

std::size_t **get_os_thread_count**() const

Return the number of OS threads running in this thread-manager.

This function will return correct results only if the thread-manager is running.

std::thread &**get_os_thread_handle**(*std::size_t* num_thread) const

void **report_error**(*std::size_t* num_thread, *std::exception_ptr* const &e) const

API functions forwarding to notification policy.

This notifies the thread manager that the passed exception has been raised. The exception will be routed through the notifier and the scheduler (which will result in it being passed to the runtime object, which in turn will report it to the console, etc.).

mask_type **get_used_processing_units**() const

Returns the mask identifying all processing units used by this thread manager.

hwloc_bitmap_ptr **get_pool_numa_bitmap**(*std::string* const &pool_name) const

void **set_scheduler_mode**(*threads::policies::scheduler_mode* mode) const noexcept

void **add_scheduler_mode**(*threads::policies::scheduler_mode* mode) const noexcept

void **add_remove_scheduler_mode**(*threads::policies::scheduler_mode* to_add_mode,
threads::policies::scheduler_mode to_remove_mode) const
noexcept

void **remove_scheduler_mode**(*threads::policies::scheduler_mode* mode) const noexcept

void **reset_thread_distribution**() const noexcept

std::int64_t **get_queue_length**(bool reset) const

std::int64_t **get_cumulative_duration**(bool reset) const

std::int64_t **get_thread_count_unknown**(bool reset) const

std::int64_t **get_thread_count_active**(bool reset) const

std::int64_t **get_thread_count_pending**(bool reset) const

std::int64_t **get_thread_count_suspended**(bool reset) const

std::int64_t **get_thread_count_terminated**(bool reset) const

std::int64_t **get_thread_count_staged**(bool reset) const

Public Static Functions

```
static void init_tss(std::size_t global_thread_num)
```

```
static void deinit_tss()
```

Private Types

```
using mutex_type = std::mutex
```

Private Functions

```
policies::thread_queue_init_parameters get_init_parameters() const
```

```
void create_scheduler_user_defined(hpx::resource::scheduler_function const&,
                                   thread_pool_init_parameters const&,
                                   policies::thread_queue_init_parameters const&)
```

```
void create_scheduler_local(thread_pool_init_parameters const&,
                             policies::thread_queue_init_parameters const&, std::size_t)
```

```
void create_scheduler_local_priority_fifo(thread_pool_init_parameters const&,
                                           policies::thread_queue_init_parameters
                                           const&, std::size_t)
```

```
void create_scheduler_local_priority_lifo(thread_pool_init_parameters const&,
                                           policies::thread_queue_init_parameters
                                           const&, std::size_t)
```

```
void create_scheduler_static(thread_pool_init_parameters const&,
                              policies::thread_queue_init_parameters const&, std::size_t)
```

```
void create_scheduler_static_priority(thread_pool_init_parameters const&,
                                       policies::thread_queue_init_parameters const&,
                                       std::size_t)
```

```
void create_scheduler_abp_priority_fifo(thread_pool_init_parameters const&,
                                          policies::thread_queue_init_parameters const&,
                                          std::size_t)
```

```
void create_scheduler_abp_priority_lifo(thread_pool_init_parameters const&,
                                          policies::thread_queue_init_parameters const&,
                                          std::size_t)
```

```
void create_scheduler_shared_priority(thread_pool_init_parameters const&,
                                       policies::thread_queue_init_parameters const&,
                                       std::size_t)
```

```
void create_scheduler_local_workrequesting_fifo(thread_pool_init_parameters const&,
                                                  policies::thread_queue_init_parameters
                                                  const&, std::size_t)
```

```
void create_scheduler_local_workrequesting_lifo(thread_pool_init_parameters const&,
                                               policies::thread_queue_init_parameters
                                               const&, std::size_t)
```

```
void create_scheduler_local_workrequesting_mc(thread_pool_init_parameters const&,
                                              policies::thread_queue_init_parameters
                                              const&, std::size_t)
```

Private Members

```
mutable mutex_type mtx_
```

```
hpx::util::runtime_configuration &rtcfg_
```

```
std::vector<pool_id_type> threads_lookup_
```

```
pool_vector pools_
```

```
notification_policy_type &notifier_
```

```
detail::network_background_callback_type network_background_callback_
```

timed_execution

See *Public API* for a list of names and headers that are part of the public *HPX* API.

hpx/timed_execution/timed_execution.hpp

Defined in header `hpx/timed_execution/timed_execution.hpp`.

See *Public API* for a list of names and headers that are part of the public *HPX* API.

```
namespace hpx
```

```
    namespace parallel
```

```
        namespace execution
```

hpx/timed_execution/timed_execution_fwd.hpp

Defined in header `hpx/timed_execution/timed_execution_fwd.hpp`.

See *Public API* for a list of names and headers that are part of the public *HPX* API.

namespace **hpx**

namespace **parallel**

namespace **execution**

Variables

hpx::parallel::execution::post_at_t **post_at**

hpx::parallel::execution::post_after_t **post_after**

hpx::parallel::execution::async_execute_at_t **async_execute_at**

hpx::parallel::execution::async_execute_after_t **async_execute_after**

hpx::parallel::execution::sync_execute_at_t **sync_execute_at**

hpx::parallel::execution::sync_execute_after_t **sync_execute_after**

struct **async_execute_after_t** : public

hpx::functional::detail::tag_fallback<async_execute_after_t>

#include <timed_execution_fwd.hpp> Customization point of asynchronous execution agent creation supporting timed execution.

This asynchronously creates a single function invocation `f()` using the associated executor at the given point in time.

Note: This calls `exec.async_execute_after(rel_time, f, ts...)`, if available, otherwise it emulates timed scheduling by delaying calling `execution::async_execute()` on the underlying non-time-scheduled execution agent.

Param `exec` [in] The executor object to use for scheduling of the function `f`.

Param `rel_time` [in] The duration of time after which the given function should be scheduled to run.

Param `f` [in] The function which will be scheduled using the given executor.

Param `ts...` [in] Additional arguments to use to invoke `f`.

Return `f(ts...)`'s result through a future

Private Functions

```
template<typename Executor, typename F, typename ...Ts>
inline decltype(auto) friend tag_fallback_invoke(async_execute_after_t, Executor &&exec,
                                                hpx::chrono::steady_duration const
                                                &rel_time, F &&f, Ts&&... ts)
```

```
struct async_execute_at_t : public hpx::functional::detail::tag_fallback<async_execute_at_t>
    #include <timed_execution_fwd.hpp> Customization point of asynchronous execution agent creation supporting timed execution.
```

This asynchronously creates a single function invocation $f()$ using the associated executor at the given point in time.

Note: This calls `exec.async_execute_at(abs_time, f, ts...)`, if available, otherwise it emulates timed scheduling by delaying calling `execution::async_execute()` on the underlying non-time-scheduled execution agent.

Param exec [in] The executor object to use for scheduling of the function f .

Param abs_time [in] The point in time the given function should be scheduled at to run.

Param f [in] The function which will be scheduled using the given executor.

Param ts... [in] Additional arguments to use to invoke f .

Return $f(ts...)$'s result through a future

Private Functions

```
template<typename Executor, typename F, typename ...Ts>
inline decltype(auto) friend tag_fallback_invoke(async_execute_at_t, Executor &&exec,
                                                hpx::chrono::steady_time_point const
                                                &abs_time, F &&f, Ts&&... ts)
```

```
struct post_after_t : public hpx::functional::detail::tag_fallback<post_after_t>
    #include <timed_execution_fwd.hpp> Customization point of asynchronous fire & forget execution agent creation supporting timed execution.
```

This asynchronously (fire & forget) creates a single function invocation $f()$ using the associated executor at the given point in time.

Note: This calls `exec.post_after(rel_time, f, ts...)`, if available, otherwise it emulates timed scheduling by delaying calling `execution::post()` on the underlying non-time-scheduled execution agent.

Param exec [in] The executor object to use for scheduling of the function f .

Param rel_time [in] The duration of time after which the given function should be scheduled to run.

Param f [in] The function which will be scheduled using the given executor.

Param ts... [in] Additional arguments to use to invoke f .

Private Functions

```
template<typename Executor, typename F, typename ...Ts>
inline decltype(auto) friend tag_fallback_invoke(post_after_t, Executor &&exec,
                                                hpx::chrono::steady_duration const
                                                &rel_time, F &&f, Ts&&... ts)
```

```
struct post_at_t : public hpx::functional::detail::tag_fallback<post_at_t>
```

#include <timed_execution_fwd.hpp> Customization point of asynchronous fire & forget execution agent creation supporting timed execution.

This asynchronously (fire & forget) creates a single function invocation $f()$ using the associated executor at the given point in time.

Note: This calls `exec.post_at(abs_time, f, ts...)`, if available, otherwise it emulates timed scheduling by delaying calling `execution::post()` on the underlying non-time-scheduled execution agent.

Param exec [in] The executor object to use for scheduling of the function f .

Param abs_time [in] The point in time the given function should be scheduled at to run.

Param f [in] The function which will be scheduled using the given executor.

Param ts... [in] Additional arguments to use to invoke f .

Private Functions

```
template<typename Executor, typename F, typename ...Ts>
inline decltype(auto) friend tag_fallback_invoke(post_at_t, Executor &&exec,
                                                hpx::chrono::steady_time_point const
                                                &abs_time, F &&f, Ts&&... ts)
```

```
struct sync_execute_after_t : public
hpx::functional::detail::tag_fallback<sync_execute_after_t>
```

#include <timed_execution_fwd.hpp> Customization point of synchronous execution agent creation supporting timed execution.

This synchronously creates a single function invocation $f()$ using the associated executor at the given point in time.

Note: This calls `exec.sync_execute_after(rel_time, f, ts...)`, if available, otherwise it emulates timed scheduling by delaying calling `execution::sync_execute()` on the underlying non-time-scheduled execution agent.

Param exec [in] The executor object to use for scheduling of the function f .

Param rel_time [in] The duration of time after which the given function should be scheduled to run.

Param f [in] The function which will be scheduled using the given executor.

Param ts... [in] Additional arguments to use to invoke f .

Return $f(ts...)$'s result

Private Functions

```
template<typename Executor, typename F, typename ...Ts>
inline decltype(auto) friend tag_fallback_invoke(sync_execute_after_t, Executor &&exec,
                                                hpx::chrono::steady_duration const
                                                &rel_time, F &&f, Ts&&... ts)
```

```
struct sync_execute_at_t : public hpx::functional::detail::tag_fallback<sync_execute_at_t>
    #include <timed_execution_fwd.hpp> Customization point of synchronous execution agent creation supporting timed execution.
```

This synchronously creates a single function invocation `f()` using the associated executor at the given point in time.

Note: This calls `exec.sync_execute_at(abs_time, f, ts...)`, if available, otherwise it emulates timed scheduling by delaying calling `execution::sync_execute()` on the underlying non-time-scheduled execution agent.

Param `exec` [in] The executor object to use for scheduling of the function `f`.
Param `abs_time` [in] The point in time the given function should be scheduled at to run.
Param `f` [in] The function which will be scheduled using the given executor.
Param `ts...` [in] Additional arguments to use to invoke `f`.
Return `f(ts...)`'s result

Private Functions

```
template<typename Executor, typename F, typename ...Ts>
inline decltype(auto) friend tag_fallback_invoke(sync_execute_at_t, Executor &&exec,
                                                hpx::chrono::steady_time_point const
                                                &abs_time, F &&f, Ts&&... ts)
```

```
template<typename BaseExecutor>
struct timed_executor
```

`hpx/timed_execution/timed_executors.hpp`

Defined in header `hpx/timed_execution/timed_executors.hpp`.

See *Public API* for a list of names and headers that are part of the public *HPX* API.

```
namespace hpx
```

```
    namespace execution
```

```
        namespace experimental
```

```
            namespace parallel
```

```
                namespace execution
```

Typedefs

```
using sequenced_timed_executor = timed_executor<hpx::execution::sequenced_executor>

using parallel_timed_executor = timed_executor<hpx::execution::parallel_executor>

template<typename BaseExecutor>

struct timed_executor
```

hpx/timed_execution/traits/is_timed_executor.hpp

Defined in header `hpx/timed_execution/traits/is_timed_executor.hpp`.

See *Public API* for a list of names and headers that are part of the public *HPX* API.

```
namespace hpx
```

```
    namespace parallel
```

```
        namespace execution
```

Typedefs

```
template<typename T>

using is_timed_executor_t = typename is_timed_executor<T>::type
```

Variables

```
template<typename T>

constexpr bool is_timed_executor_v = is_timed_executor<T>::value

template<typename T>

struct is_timed_executor : public detail::is_timed_executor<std::decay_t<T>>
```

```
namespace traits
```

```
    template<typename Executor, typename Enable = void>

    struct is_timed_executor : public hpx::parallel::execution::is_timed_executor<Executor>
```

timing

See *Public API* for a list of names and headers that are part of the public *HPX* API.

hpx::chrono::high_resolution_clock

Defined in header `hpx/chrono.hpp`⁷⁹⁶.

See *Public API* for a list of names and headers that are part of the public *HPX* API.

namespace **hpx**

namespace **chrono**

struct **high_resolution_clock**

#include <high_resolution_clock.hpp> Class `hpx::chrono::high_resolution_clock` represents the clock with the smallest tick period provided by the implementation. It may be an alias of `std::chrono::system_clock` or `std::chrono::steady_clock`, or a third, independent clock. `hpx::chrono::high_resolution_clock` meets the requirements of *TrivialClock*.

Public Static Functions

static inline `std::uint64_t now()` noexcept
returns a `std::chrono::time_point` representing the current value of the clock

static inline constexpr `std::uint64_t min()` noexcept

static inline constexpr `std::uint64_t max()` noexcept

hpx::chrono::high_resolution_timer

Defined in header `hpx/chrono.hpp`⁷⁹⁷.

See *Public API* for a list of names and headers that are part of the public *HPX* API.

namespace **hpx**

namespace **chrono**

class **high_resolution_timer**

#include <high_resolution_timer.hpp> `high_resolution_timer` is a timer object which measures the elapsed time

⁷⁹⁶ http://github.com/STELLAR-GROUP/hpx/blob/8a3b7c1a4cb5693b2f7d9f587f759392ed0c51a0/libs/core/include_local/include/hpx/chrono.

hpp

⁷⁹⁷ http://github.com/STELLAR-GROUP/hpx/blob/8a3b7c1a4cb5693b2f7d9f587f759392ed0c51a0/libs/core/include_local/include/hpx/chrono.

hpp

Public Types

enum class **init**

Values:

enumerator **no_init**

Public Functions

inline **high_resolution_timer**() noexcept

inline explicit constexpr **high_resolution_timer**(*init*) noexcept

inline explicit constexpr **high_resolution_timer**(double t) noexcept

inline void **restart**() noexcept

restarts the timer

inline double **elapsed**() const noexcept

returns the elapsed time in seconds

inline *std::int64_t* **elapsed_microseconds**() const noexcept

returns the elapsed time in microseconds

inline *std::int64_t* **elapsed_nanoseconds**() const noexcept

returns the elapsed time in nanoseconds

Public Static Functions

static inline double **now**() noexcept

returns the current time

static inline constexpr double **elapsed_max**() noexcept

returns the estimated maximum value for *elapsed*()

static inline constexpr double **elapsed_min**() noexcept

returns the estimated minimum value for *elapsed*()

Protected Static Functions

static inline *std::uint64_t* **take_time_stamp**() noexcept

Private Members

std::uint64_t **start_time_**

topology

See *Public API* for a list of names and headers that are part of the public *HPX* API.

hpx/topology/cpu_mask.hpp

Defined in header `hpx/topology/cpu_mask.hpp`.

See *Public API* for a list of names and headers that are part of the public *HPX* API.

namespace **hpx**

namespace **threads**

hpx/topology/topology.hpp

Defined in header `hpx/topology/topology.hpp`.

See *Public API* for a list of names and headers that are part of the public *HPX* API.

namespace **hpx**

namespace **threads**

Typedefs

using **hwloc_bitmap_ptr** = *std::shared_ptr*<*hpx_hwloc_bitmap_wrapper*>

Enums

enum **hpx_hwloc_membind_policy**

Please see `hwloc` documentation for the corresponding enums `HWLOC_MEMBIND_XXX`.

Values:

enumerator **membind_default**

enumerator **membind_firsttouch**

enumerator **membind_bind**

enumerator **membind_interleave**

enumerator **membind_replicate**

enumerator **membind_nexttouch**

enumerator **membind_mixed**

enumerator **membind_user**

Functions

topology &**create_topology**()

inline *std::size_t* **get_memory_page_size**()

struct **hpx_hwloc_bitmap_wrapper**

Public Functions

HPX_NON_COPYABLE(*hpx_hwloc_bitmap_wrapper*)

inline **hpx_hwloc_bitmap_wrapper**() noexcept

inline explicit **hpx_hwloc_bitmap_wrapper**(void *bmp) noexcept

inline **~hpx_hwloc_bitmap_wrapper**()

inline void **reset**(hwloc_bitmap_t bmp) noexcept

inline explicit constexpr **operator bool**() const noexcept

inline hwloc_bitmap_t **get_bitmap**() const noexcept

Private Members

hwloc_bitmap_t **bmp_**

Friends

friend *std::ostream* &**operator**<<(*std::ostream* &os, *hpx_hwloc_bitmap_wrapper* const *bmp)

struct **topology**

Public Functions**topology**()**topology**(*topology* const&) = delete**topology**(*topology*&&) = delete*topology* &**operator**=(*topology* const&) = delete*topology* &**operator**=(*topology*&&) = delete**~topology**()

```
inline std::size_t get_socket_number(std::size_t num_thread, [[maybe_unused]] error_code &ec
                                     = throws) const noexcept
```

Return the Socket number of the processing unit the given thread is running on.

Parameters

- **num_thread** – [in]
- **ec** – [in,out] this represents the error status on exit, if this is pre-initialized to *hpx::throws* the function will throw on error instead.

```
inline std::size_t get_numa_node_number(std::size_t num_thread, [[maybe_unused]] error_code
                                         &ec = throws) const noexcept
```

Return the NUMA node number of the processing unit the given thread is running on.

Parameters

- **num_thread** – [in]
- **ec** – [in,out] this represents the error status on exit, if this is pre-initialized to *hpx::throws* the function will throw on error instead.

```
mask_cref_type get_machine_affinity_mask(error_code &ec = throws) const noexcept
```

Return a bit mask where each set bit corresponds to a processing unit available to the application.

Parameters **ec** – [in,out] this represents the error status on exit, if this is pre-initialized to *hpx::throws* the function will throw on error instead.

```
mask_type get_service_affinity_mask(mask_cref_type used_processing_units, error_code
                                     &ec = throws) const
```

Return a bit mask where each set bit corresponds to a processing unit available to the service threads in the application.

Parameters

- **used_processing_units** – [in] This is the mask of processing units which are not available for service threads.
- **ec** – [in,out] this represents the error status on exit, if this is pre-initialized to *hpx::throws* the function will throw on error instead.

```
mask_cref_type get_socket_affinity_mask(std::size_t num_thread, error_code &ec = throws)
                                         const
```

Return a bit mask where each set bit corresponds to a processing unit available to the given thread inside the socket it is running on.

Parameters

- **num_thread** – [in]
- **ec** – [in,out] this represents the error status on exit, if this is pre-initialized to *hpx::throws* the function will throw on error instead.

```
mask_cref_type get_numa_node_affinity_mask(std::size_t num_thread, error_code &ec =
                                             throws) const
```

Return a bit mask where each set bit corresponds to a processing unit available to the given thread inside the NUMA domain it is running on.

Parameters

- **num_thread** – [in]
- **ec** – [in,out] this represents the error status on exit, if this is pre-initialized to *hpx::throws* the function will throw on error instead.

mask_cref_type **get_core_affinity_mask**(*std::size_t* num_thread, *error_code* &ec = *throws*)
const

Return a bit mask where each set bit corresponds to a processing unit available to the given thread inside the core it is running on.

Parameters

- **num_thread** – [in]
- **ec** – [in,out] this represents the error status on exit, if this is pre-initialized to *hpx::throws* the function will throw on error instead.

mask_cref_type **get_thread_affinity_mask**(*std::size_t* num_thread, *error_code* &ec = *throws*)
const

Return a bit mask where each set bit corresponds to a processing unit available to the given thread.

Parameters

- **num_thread** – [in]
- **ec** – [in,out] this represents the error status on exit, if this is pre-initialized to *hpx::throws* the function will throw on error instead.

void **set_thread_affinity_mask**(mask_cref_type mask, *error_code* &ec = *throws*) const

Use the given bit mask to set the affinity of the given thread. Each set bit corresponds to a processing unit the thread will be allowed to run on.

Note: Use this function on systems where the affinity must be set from inside the thread itself.

Parameters

- **mask** – [in]
- **ec** – [in,out] this represents the error status on exit, if this is pre-initialized to *hpx::throws* the function will throw on error instead.

mask_type **get_thread_affinity_mask_from_lva**(void const *lva, *error_code* &ec = *throws*)
const

Return a bit mask where each set bit corresponds to a processing unit co-located with the memory the given address is currently allocated on.

Parameters

- **lva** – [in]
- **ec** – [in,out] this represents the error status on exit, if this is pre-initialized to *hpx::throws* the function will throw on error instead.

void **print_affinity_mask**(*std::ostream* &os, *std::size_t* num_thread, mask_cref_type m,
std::string const &pool_name) const

Prints the given mask *m* to *os* in a human readable form.

bool **reduce_thread_priority**(*error_code* &ec = *throws*) const

Reduce thread priority of the current thread.

- Parameters** **ec** – [in,out] this represents the error status on exit, if this is pre-initialized to *hpx::throws* the function will throw on error instead.

std::size_t **get_number_of_sockets**() const
Return the number of available NUMA domains.

std::size_t **get_number_of_numa_nodes**() const
Return the number of available NUMA domains.

std::size_t **get_number_of_cores**() const
Return the number of available cores.

std::size_t **get_number_of_pus**() const noexcept
Return the number of available hardware processing units.

std::size_t **get_number_of_numa_node_cores**(*std::size_t* numa) const
Return number of cores in given numa domain.

std::size_t **get_number_of_numa_node_pus**(*std::size_t* numa) const
Return number of processing units in a given numa domain.

std::size_t **get_number_of_socket_pus**(*std::size_t* socket) const
Return number of processing units in a given socket.

std::size_t **get_number_of_core_pus**(*std::size_t* core) const
Return number of processing units in given core.

std::size_t **get_number_of_socket_cores**(*std::size_t* socket) const
Return number of cores units in given socket.

inline *std::size_t* **get_core_number**(*std::size_t* num_thread, *error_code*& = *throws*) const

std::size_t **get_pu_number**(*std::size_t* num_core, *std::size_t* num_pu, *error_code* &ec = *throws*) const

std::size_t **get_cache_size**(mask_cref_type mask, int level) const
Return the size of the cache associated with the given mask.

mask_type **get_cpupbind_mask**(*error_code* &ec = *throws*) const

mask_type **get_cpupbind_mask**(*std::thread* &handle, *error_code* &ec = *throws*) const

hwloc_bitmap_ptr **cpuset_to_nodese**t(mask_cref_type mask) const
convert a cpu mask into a numa node mask in hwloc bitmap form

void **write_to_log**() const

void ***allocate**(*std::size_t* len) const
This is equivalent to malloc(), except that it tries to allocate page-aligned memory from the OS.

void ***allocate_membind**(*std::size_t* len, const *hwloc_bitmap_ptr* &bitmap, *hpx_hwloc_membind_policy* policy, int flags) const
allocate memory with binding to a numa node set as specified by the policy and flags (see hwloc docs)

threads::mask_type **get_area_membind_nodese**t(void const *addr, *std::size_t* len) const

bool **set_area_membind_nodese**t(void const *addr, *std::size_t* len, void *nodese

int **get_numa_domain**(void const *addr) const

```

void deallocate(void *addr, std::size_t len) const noexcept
    Free memory that was previously allocated by allocate.

void print_hwloc(std::ostream&) const

mask_type init_socket_affinity_mask_from_socket(std::size_t num_socket) const

mask_type init_numa_node_affinity_mask_from_numa_node(std::size_t num_numa_node)
    const

mask_type init_core_affinity_mask_from_core(std::size_t num_core, mask_cref_type
    default_mask = empty_mask) const

mask_type init_thread_affinity_mask(std::size_t num_thread) const

mask_type init_thread_affinity_mask(std::size_t num_core, std::size_t num_pu) const

hwloc_bitmap_t mask_to_bitmap(mask_cref_type mask, hwloc_obj_type_t htype) const

mask_type bitmap_to_mask(hwloc_bitmap_t bitmap, hwloc_obj_type_t htype) const

```

Public Static Functions

```

static void print_vector(std::ostream &os, std::vector<std::size_t> const &v)

static void print_mask_vector(std::ostream &os, std::vector<mask_type> const &v)

```

Private Types

```

using mutex_type = hpx::util::spinlock

```

Private Functions

```

std::size_t init_node_number(std::size_t num_thread, hwloc_obj_type_t type) const

inline std::size_t init_socket_number(std::size_t num_thread) const

std::size_t init_numa_node_number(std::size_t num_thread) const

inline std::size_t init_core_number(std::size_t num_thread) const

void extract_node_mask(hwloc_obj_t parent, mask_type &mask) const

std::size_t get_number_of_core_pus_locked(std::size_t core) const

std::size_t extract_node_count(hwloc_obj_t parent, hwloc_obj_type_t type, std::size_t count)
    const

std::size_t extract_node_count_locked(hwloc_obj_t parent, hwloc_obj_type_t type, std::size_t
    count) const

mask_type init_machine_affinity_mask() const

inline mask_type init_socket_affinity_mask(std::size_t num_thread) const

```

```
inline mask_type init_numa_node_affinity_mask(std::size_t num_thread) const  
inline mask_type init_core_affinity_mask(std::size_t num_thread) const  
void init_num_of_pus()  
hwloc_obj_t get_pu_obj(std::size_t num_pu) const
```

Private Members

```
hwloc_topology_t topo = nullptr  
  
std::size_t num_of_pus_ = 0  
  
bool use_pus_as_cores_ = false  
  
mutable mutex_type topo_mtx  
  
std::vector<std::size_t> socket_numbers_  
  
std::vector<std::size_t> numa_node_numbers_  
  
std::vector<std::size_t> core_numbers_  
  
mask_type machine_affinity_mask_ = mask_type()  
  
std::vector<mask_type> socket_affinity_masks_  
  
std::vector<mask_type> numa_node_affinity_masks_  
  
std::vector<mask_type> core_affinity_masks_  
  
std::vector<mask_type> thread_affinity_masks_
```

Private Static Attributes

```
static mask_type empty_mask  
  
static std::size_t memory_page_size_  
  
static constexpr std::size_t pu_offset = 0  
  
static constexpr std::size_t core_offset = 0
```

Friends

friend `std::size_t get_memory_page_size()`

util

See *Public API* for a list of names and headers that are part of the public *HPX* API.

hpx/util/insert_checked.hpp

Defined in header `hpx/util/insert_checked.hpp`.

See *Public API* for a list of names and headers that are part of the public *HPX* API.

namespace **hpx**

namespace **util**

Functions

```
template<typename Iterator>
constexpr bool insert_checked(std::pair<Iterator, bool> const &r) noexcept
```

Helper function for writing predicates that test whether an `std::map` insertion succeeded. This inline template function negates the need to explicitly write the sometimes lengthy `std::pair<Iterator, bool>` type.

Parameters **r** – [in] The return value of a `std::map` insert operation.

Returns This function returns **r.second**.

```
template<typename Iterator>
bool insert_checked(std::pair<Iterator, bool> const &r, Iterator &it)
```

Helper function for writing predicates that test whether an `std::map` insertion succeeded. This inline template function negates the need to explicitly write the sometimes lengthy `std::pair<Iterator, bool>` type.

Parameters

- **r** – [in] The return value of a `std::map` insert operation.
- **r** – [out] A reference to an `Iterator`, which is set to **r.first**.
- **it** – [out] on exit, will hold the iterator referring to the inserted element

Returns This function returns **r.second**.

hpx/util/sed_transform.hpp

Defined in header `hpx/util/sed_transform.hpp`.

See *Public API* for a list of names and headers that are part of the public *HPX* API.

namespace **hpx**

namespace **util**

Functions

bool **parse_sed_expression**(*std::string* const &input, *std::string* &search, *std::string* &replace)

Parse a sed command.

Note: Currently, only supports search and replace syntax (s/search/replace/)

Parameters

- **input** – [in] The content to parse.
- **search** – [out] If the parsing is successful, this string is set to the search expression.
- **replace** – [out] If the parsing is successful, this string is set to the replace expression.

Returns *true* if the parsing was successful, false otherwise.

struct **sed_transform**

#include <sed_transform.hpp> An unary function object which applies a sed command to its subject and returns the resulting string.

Note: Currently, only supports search and replace syntax (s/search/replace/)

Public Functions

sed_transform(*std::string* const &search, *std::string* replace)

explicit **sed_transform**(*std::string* const &expression)

std::string **operator**()(*std::string* const &input) const

inline explicit **operator** **bool**() const noexcept

inline **bool** **operator!**() const noexcept

Private Members

std::shared_ptr<command> **command_**

actions

See *Public API* for a list of names and headers that are part of the public *HPX* API.

hpx/actions/action_support.hpp

Defined in header `hpx/actions/action_support.hpp`.

See *Public API* for a list of names and headers that are part of the public *HPX* API.

hpx/actions/actions_fwd.hpp

Defined in header `hpx/actions/actions_fwd.hpp`.

See *Public API* for a list of names and headers that are part of the public *HPX* API.

hpx/actions/base_action.hpp

Defined in header `hpx/actions/base_action.hpp`.

See *Public API* for a list of names and headers that are part of the public *HPX* API.

hpx/actions/transfer_action.hpp

Defined in header `hpx/actions/transfer_action.hpp`.

See *Public API* for a list of names and headers that are part of the public *HPX* API.

hpx/actions/transfer_base_action.hpp

Defined in header `hpx/actions/transfer_base_action.hpp`.

See *Public API* for a list of names and headers that are part of the public *HPX* API.

actions_base

See *Public API* for a list of names and headers that are part of the public *HPX* API.

hpx/actions_base/actions_base_fwd.hpp

Defined in header `hpx/actions_base/actions_base_fwd.hpp`.

See *Public API* for a list of names and headers that are part of the public *HPX* API.

namespace **hpx**

namespace **actions**

hpx/actions_base/actions_base_support.hpp

Defined in header `hpx/actions_base/actions_base_support.hpp`.

See *Public API* for a list of names and headers that are part of the public *HPX* API.

```
namespace hpx
```

```
    namespace actions
```

HPX_REGISTER_ACTION_DECLARATION, HPX_REGISTER_ACTION

Defined in header `hpx/components.hpp`.

See *Public API* for a list of names and headers that are part of the public *HPX* API.

Defines

HPX_REGISTER_ACTION_DECLARATION(...)

Declare the necessary component action boilerplate code.

The macro `HPX_REGISTER_ACTION_DECLARATION` can be used to declare all the boilerplate code which is required for proper functioning of component actions in the context of *HPX*.

The parameter *action* is the type of the action to declare the boilerplate for.

This macro can be invoked with an optional second parameter. This parameter specifies a unique name of the action to be used for serialization purposes. The second parameter has to be specified if the first parameter is not usable as a plain (non-qualified) C++ identifier, i.e. the first parameter contains special characters which cannot be part of a C++ identifier, such as '<', '>', or ':'.

```
namespace app
{
    // Define a simple component exposing one action 'print_greeting'
    class HPX_COMPONENT_EXPORT server
    : public hpx::components::component_base<server>
    {
        void print_greeting ()
        {
            hpx::cout << "Hey, how are you?\n" << std::flush;
        }

        // Component actions need to be declared, this also defines the
        // type 'print_greeting_action' representing the action.
        HPX_DEFINE_COMPONENT_ACTION(server,
            print_greeting, print_greeting_action);
    };
}

// Declare boilerplate code required for each of the component actions.
HPX_REGISTER_ACTION_DECLARATION(app::server::print_greeting_action)
```

Example:

Note: This macro has to be used once for each of the component actions defined using one of the *HPX_DEFINE_COMPONENT_ACTION* macros. It has to be visible in all translation units using the action, thus it is recommended to place it into the header file defining the component.

HPX_REGISTER_ACTION_DECLARATION(...)**HPX_REGISTER_ACTION_DECLARATION_1(action)****HPX_REGISTER_ACTION(...)**

Define the necessary component action boilerplate code.

The macro *HPX_REGISTER_ACTION* can be used to define all the boilerplate code which is required for proper functioning of component actions in the context of HPX.

The parameter *action* is the type of the action to define the boilerplate for.

This macro can be invoked with an optional second parameter. This parameter specifies a unique name of the action to be used for serialization purposes. The second parameter has to be specified if the first parameter is not usable as a plain (non-qualified) C++ identifier, i.e. the first parameter contains special characters which cannot be part of a C++ identifier, such as '<', '>', or ':'.

Note: This macro has to be used once for each of the component actions defined using one of the *HPX_DEFINE_COMPONENT_ACTION* or *HPX_DEFINE_PLAIN_ACTION* macros. It has to occur exactly once for each of the actions, thus it is recommended to place it into the source file defining the component.

Note: Only one of the forms of this macro *HPX_REGISTER_ACTION* or *HPX_REGISTER_ACTION_ID* should be used for a particular action, never both.

HPX_REGISTER_ACTION_ID(action, actionname, actionid)

Define the necessary component action boilerplate code and assign a predefined unique id to the action.

The macro *HPX_REGISTER_ACTION* can be used to define all the boilerplate code which is required for proper functioning of component actions in the context of HPX.

The parameter *action* is the type of the action to define the boilerplate for.

The parameter *actionname* specifies a unique name of the action to be used for serialization purposes. The second parameter has to be usable as a plain (non-qualified) C++ identifier, it should not contain special characters which cannot be part of a C++ identifier, such as '<', '>', or ':'.

The parameter *actionid* specifies a unique integer value which will be used to represent the action during serialization.

Note: This macro has to be used once for each of the component actions defined using one of the *HPX_DEFINE_COMPONENT_ACTION* or global actions *HPX_DEFINE_PLAIN_ACTION* macros. It has to occur exactly once for each of the actions, thus it is recommended to place it into the source file defining the component.

Note: Only one of the forms of this macro `HPX_REGISTER_ACTION` or `HPX_REGISTER_ACTION_ID` should be used for a particular action, never both.

```
namespace hpx
```

```
    namespace actions
```

hpx/actions_base/basic_action_fwd.hpp

Defined in header `hpx/actions_base/basic_action_fwd.hpp`.

See *Public API* for a list of names and headers that are part of the public *HPX* API.

```
namespace hpx
```

```
    namespace actions
```

```
        template<typename Component, typename Signature, typename Derived>
```

```
        struct basic_action
```

```
            #include <basic_action_fwd.hpp>
```

Template Parameters

- **Component** – component type
- **Signature** – return type and arguments
- **Derived** – derived action class

HPX_DEFINE_COMPONENT_ACTION

Defined in header `hpx/components.hpp`.

See *Public API* for a list of names and headers that are part of the public *HPX* API.

Defines

HPX_DEFINE_COMPONENT_ACTION(...)

Registers a member function of a component as an action type with HPX.

The macro `HPX_DEFINE_COMPONENT_ACTION` can be used to register a member function of a component as an action type named `action_type`.

The parameter `component` is the type of the component exposing the member function `func` which should be associated with the newly defined action type. The parameter `action_type` is the name of the action type to register with HPX.

```
namespace app
{
    // Define a simple component exposing one action 'print_greeting'
```

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```
class HPX_COMPONENT_EXPORT server
: public hpx::components::component_base<server>
{
    void print_greeting() const
    {
        hpx::cout << "Hey, how are you?\n" << std::flush;
    }

    // Component actions need to be declared, this also defines the
    // type 'print_greeting_action' representing the action.
    HPX_DEFINE_COMPONENT_ACTION(server, print_greeting,
        print_greeting_action);
};
```

Example:

The first argument must provide the type name of the component the action is defined for.

The second argument must provide the member function name the action should wrap.

The default value for the third argument (the typename of the defined action) is derived from the name of the function (as passed as the second argument) by appending ‘_action’. The third argument can be omitted only if the second argument with an appended suffix ‘_action’ resolves to a valid, unqualified C++ type name.

Note: The macro *HPX_DEFINE_COMPONENT_ACTION* can be used with 2 or 3 arguments. The third argument is optional.

namespace **hpx**

namespace **actions**

hpx/actions_base/lambda_to_action.hpp

Defined in header `hpx/actions_base/lambda_to_action.hpp`.

See *Public API* for a list of names and headers that are part of the public *HPX* API.

hpx/actions_base/plain_action.hpp

Defined in header `hpx/actions_base/plain_action.hpp`.

See *Public API* for a list of names and headers that are part of the public *HPX* API.

Defines

HPX_DEFINE_PLAIN_ACTION(...)

Defines a plain action type.

```
namespace app
{
    void some_global_function(double d)
    {
        cout << d;
    }

    // This will define the action type 'app::some_global_action' which
    // represents the function 'app::some_global_function'.
    HPX_DEFINE_PLAIN_ACTION(some_global_function, some_global_action);
}
```

Example:

Note: Usually this macro will not be used in user code unless the intent is to avoid defining the `action_type` in global namespace. Normally, the use of the macro `HPX_PLAIN_ACTION` is recommended.

Note: The macro `HPX_DEFINE_PLAIN_ACTION` can be used with 1 or 2 arguments. The second argument is optional. The default value for the second argument (the typename of the defined action) is derived from the name of the function (as passed as the first argument) by appending ‘_action’. The second argument can be omitted only if the first argument with an appended suffix ‘_action’ resolves to a valid, unqualified C++ type name.

HPX_DECLARE_PLAIN_ACTION(...)

Declares a plain action type.

HPX_PLAIN_ACTION(...)

Defines a plain action type based on the given function *func* and registers it with HPX.

The macro `HPX_PLAIN_ACTION` can be used to define a plain action (e.g. an action encapsulating a global or free function) based on the given function *func*. It defines the action type *name* representing the given function. This macro additionally registers the newly define action type with HPX.

The parameter `func` is a global or free (non-member) function which should be encapsulated into a plain action. The parameter `name` is the name of the action type defined by this macro.

```
namespace app {
    void some_global_function(double d) {
        cout << d;
    }
}

// This will define the action type 'some_global_action' which
```

(continues on next page)

(continued from previous page)

```
// represents the function 'app::some_global_function'.
HPX_PLAIN_ACTION(app::some_global_function, some_global_action)
```

Example:

Note: The macro `HPX_PLAIN_ACTION` has to be used at global namespace even if the wrapped function is located in some other namespace. The newly defined action type is placed into the global namespace as well.

Note: The macro `HPX_PLAIN_ACTION_ID` can be used with 1, 2, or 3 arguments. The second and third arguments are optional. The default value for the second argument (the typename of the defined action) is derived from the name of the function (as passed as the first argument) by appending ‘_action’. The second argument can be omitted only if the first argument with an appended suffix ‘_action’ resolves to a valid, unqualified C++ type name. The default value for the third argument is `hpx::components::factory_state::check`.

Note: Only one of the forms of this macro `HPX_PLAIN_ACTION` or `HPX_PLAIN_ACTION_ID` should be used for a particular action, never both.

HPX_PLAIN_ACTION_ID(func, name, id)

Defines a plain action type based on the given function *func* and registers it with HPX.

The macro `HPX_PLAIN_ACTION_ID` can be used to define a plain action (e.g. an action encapsulating a global or free function) based on the given function *func*. It defines the action type *actionname* representing the given function.

The parameter *actionid* specifies a unique integer value which will be used to represent the action during serialization.

The parameter *func* is a global or free (non-member) function which should be encapsulated into a plain action. The parameter *name* is the name of the action type defined by this macro.

The second parameter has to be usable as a plain (non-qualified) C++ identifier, it should not contain special characters which cannot be part of a C++ identifier, such as ‘<’, ‘>’, or ‘.’.

```
namespace app {
    void some_global_function(double d) {
        cout << d;
    }
}

// This will define the action type 'some_global_action' which
// represents the function 'app::some_global_function'.
HPX_PLAIN_ACTION_ID(app::some_global_function, some_global_action,
    some_unique_id);
```

Example:

Note: The macro `HPX_PLAIN_ACTION_ID` has to be used at global namespace even if the wrapped function is located in some other namespace. The newly defined action type is placed into the global namespace as well.

Note: Only one of the forms of this macro `HPX_PLAIN_ACTION` or `HPX_PLAIN_ACTION_ID` should be used for a particular action, never both.

```
namespace hpx
```

```
    namespace actions
```

```
        namespace traits
```

hpx/actions_base/preassigned_action_id.hpp

Defined in header `hpx/actions_base/preassigned_action_id.hpp`.

See [Public API](#) for a list of names and headers that are part of the public *HPX* API.

```
namespace hpx
```

```
    namespace actions
```

hpx/actions_base/traits/action_remote_result.hpp

Defined in header `hpx/actions_base/traits/action_remote_result.hpp`.

See [Public API](#) for a list of names and headers that are part of the public *HPX* API.

```
namespace hpx
```

```
    namespace traits
```

Typedefs

```
template<typename Result>
```

```
using action_remote_result_t = typename action_remote_result<Result>::type
```

```
template<typename Result>
```

```
struct action_remote_result : public detail::action_remote_result_customization_point<Result>
```

agas

See *Public API* for a list of names and headers that are part of the public *HPX* API.

hpx/agas/addressing_service.hpp

Defined in header `hpx/agas/addressing_service.hpp`.

See *Public API* for a list of names and headers that are part of the public *HPX* API.

```
namespace hpx
```

```
    namespace agas
```

```
        struct addressing_service
```

Public Types

```
using component_id_type = components::component_type
```

```
using iterate_names_return_type = std::map<std::string, hpx::id_type>
```

```
using iterate_types_function_type = hpx::function<void(std::string const&, components::component_type), true>
```

```
using mutex_type = hpx::spinlock
```

```
using gva_cache_type = hpx::util::cache::lru_cache<gva_cache_key, gva, hpx::util::cache::statistics::local_full_statistics>
```

```
using migrated_objects_table_type = std::set<naming::gid_type>
```

```
using refcnt_requests_type = std::map<naming::gid_type, std::int64_t>
```

```
using resolved_localities_type = std::map<naming::gid_type, parcelset::endpoints_type>
```

Public Functions

```
HPX_NON_COPYABLE(addressing_service)
```

```
explicit addressing_service(util::runtime_configuration const &ini_)
```

```
~addressing_service() = default
```

```
void bootstrap(parcelset::endpoints_type const &endpoints, util::runtime_configuration &rtcfg)
```

```
void initialize(std::uint64_t rts_lva)

void adjust_local_cache_size(std::size_t) const
    Adjust the size of the local AGAS Address resolution cache.

inline state get_status() const

inline void set_status(state new_state)

inline namings::gid_type const &get_local_locality(error_code& = throws) const

void set_local_locality(namings::gid_type const &g)

void register_console(parcelset::endpoints_type const &eps)

inline bool is_bootstrap() const

inline bool is_console() const
    Returns whether this addressing_service represents the console locality.

inline bool is_connecting() const
    Returns whether this addressing_service is connecting to a running application.

bool resolve_locally_known_addresses(namings::gid_type const &id, namings::address &addr)
    const

void register_server_instances()

void garbage_collect_non_blocking(error_code &ec = throws)

void garbage_collect(error_code &ec = throws)

inline server::primary_namespace &get_local_primary_namespace_service()

inline namings::address::address_type get_primary_ns_lva() const

inline namings::address::address_type get_symbol_ns_lva() const

inline server::component_namespace *get_local_component_namespace_service() const

inline server::locality_namespace *get_local_locality_namespace_service() const

inline server::symbol_namespace &get_local_symbol_namespace_service() const

inline namings::address::address_type get_runtime_support_lva() const

std::uint64_t get_cache_entries(bool) const

std::uint64_t get_cache_hits(bool) const

std::uint64_t get_cache_misses(bool) const

std::uint64_t get_cache_evictions(bool) const

std::uint64_t get_cache_insertions(bool) const

std::uint64_t get_cache_get_entry_count(bool reset) const

std::uint64_t get_cache_insertion_entry_count(bool reset) const
```

`std::uint64_t get_cache_update_entry_count`(bool reset) const

`std::uint64_t get_cache_erase_entry_count`(bool reset) const

`std::uint64_t get_cache_get_entry_time`(bool reset) const

`std::uint64_t get_cache_insertion_entry_time`(bool reset) const

`std::uint64_t get_cache_update_entry_time`(bool reset) const

`std::uint64_t get_cache_erase_entry_time`(bool reset) const

bool **register_locality**(*parcelset::endpoints_type* const &endpoints, *naming::gid_type* &prefix, *std::uint32_t* num_threads, *error_code* &ec = *throws*)

Add a locality to the runtime.

parcelset::endpoints_type const &**resolve_locality**(*naming::gid_type* const &gid, *error_code* &ec = *throws*)

Resolve a locality to its prefix.

Returns Returns an empty vector if the locality is not registered.

bool **has_resolved_locality**(*naming::gid_type* const &gid)

bool **unregister_locality**(*naming::gid_type* const &gid, *error_code* &ec = *throws*)

Remove a locality from the runtime.

void **remove_resolved_locality**(*naming::gid_type* const &gid)

remove given locality from locality cache

bool **get_console_locality**(*naming::gid_type* &locality, *error_code* &ec = *throws*)

Get locality `locality_id` of the console locality.

Note: As long as *ec* is not pre-initialized to *hpx::throws* this function doesn't throw but returns the result code using the parameter *ec*. Otherwise it throws an instance of *hpx::exception*.

Parameters

- **locality** – [out] The `locality_id` value uniquely identifying the console locality. This is valid only, if the return value of this function is true.
- **try_cache** – [in] If this is set to true the console is first tried to be found in the local cache. Otherwise this function will always query AGAS, even if the console `locality_id` is already known locally.
- **ec** – [in,out] this represents the error status on exit, if this is pre-initialized to *hpx::throws* the function will throw on error instead.

Returns This function returns *true* if a console `locality_id` exists and returns *false* otherwise.

bool **get_localities**(*std::vector<naming::gid_type>* &locality_ids, *components::component_type* type, *error_code* &ec = *throws*) const

Query for the `locality_ids` of all known localities.

This function returns the `locality_ids` of all localities known to the AGAS server or all localities having a registered factory for a given component type.

Note: As long as *ec* is not pre-initialized to *hpx::throws* this function doesn't throw but returns the result code using the parameter *ec*. Otherwise, it throws an instance of *hpx::exception*.

Parameters

- **locality_ids** – [out] The vector will contain the prefixes of all localities registered with the AGAS server. The returned vector holds the prefixes representing the runtime_support components of these localities.
- **type** – [in] The component type will be used to determine the set of prefixes having a registered factory for this component. The default value for this parameter is `components::component_enum_type::invalid`, which will return prefixes of all localities.
- **ec** – [in,out] this represents the error status on exit, if this is pre-initialized to `hpx::throws` the function will throw on error instead.

```
inline bool get_localities(std::vector<naming::gid_type> &locality_ids, error_code &ec =
    throws) const
```

```
hpx::future<std::uint32_t> get_num_localities_async(components::component_type type =
    to_int(hpx::components::component_enum_type::invalid))
    const
```

Query for the number of all known localities.

This function returns the number of localities known to the AGAS server or the number of localities having a registered factory for a given component type.

Note: As long as *ec* is not pre-initialized to `hpx::throws` this function doesn't throw but returns the result code using the parameter *ec*. Otherwise, it throws an instance of `hpx::exception`.

Parameters

- **type** – [in] The component type will be used to determine the set of prefixes having a registered factory for this component. The default value for this parameter is `components::component_type::invalid`, which will return prefixes of all localities.
- **ec** – [in,out] this represents the error status on exit, if this is pre-initialized to `hpx::throws` the function will throw on error instead.

```
std::uint32_t get_num_localities(components::component_type type, error_code &ec = throws)
    const
```

```
inline std::uint32_t get_num_localities(error_code &ec = throws) const
```

```
hpx::future<std::uint32_t> get_num_overall_threads_async() const
```

```
std::uint32_t get_num_overall_threads(error_code &ec = throws) const
```

```
hpx::future<std::vector<std::uint32_t>> get_num_threads_async() const
```

```
std::vector<std::uint32_t> get_num_threads(error_code &ec = throws) const
```

```
components::component_type get_component_id(std::string const &name, error_code &ec =
    throws) const
```

Return a unique id usable as a component type.

This function returns the component type id associated with the given component name. If this is the first request for this component name a new unique id will be created.

Note: As long as *ec* is not pre-initialized to `hpx::throws` this function doesn't throw but returns the result code using the parameter *ec*. Otherwise it throws an instance of `hpx::exception`.

Parameters

- **name** – [in] The component name (string) to get the component type for.
- **ec** – [in,out] this represents the error status on exit, if this is pre-initialized to `hpx::throws` the function will throw on error instead.

Returns The function returns the currently associated component type. Any error results in an exception thrown from this function.

```
void iterate_types(iterate_types_function_type const &f, error_code &ec = throws) const
std::string get_component_type_name(components::component_type id, error_code &ec =
                                     throws) const
```

```
inline components::component_type register_factory(naming::gid_type const &locality_id,
                                                  std::string const &name, error_code &ec
                                                  = throws) const
```

Register a factory for a specific component type.

This function allows to register a component factory for a given locality and component type.

Note: As long as *ec* is not pre-initialized to `hpx::throws` this function doesn't throw but returns the result code using the parameter *ec*. Otherwise it throws an instance of `hpx::exception`.

Parameters

- **locality_id** – [in] The locality value uniquely identifying the given locality the factory needs to be registered for.
- **name** – [in] The component name (string) to register a factory for the given component type for.
- **ec** – [in,out] this represents the error status on exit, if this is pre-initialized to `hpx::throws` the function will throw on error instead.

Returns The function returns the currently associated component type. Any error results in an exception thrown from this function. The returned component type is the same as if the function `get_component_id` was called using the same component name.

```
components::component_type register_factory(std::uint32_t locality_id, std::string const
                                             &name, error_code &ec = throws) const
```

```
bool get_id_range(std::uint64_t count, naming::gid_type &lower_bound, naming::gid_type
                  &upper_bound, error_code &ec = throws)
```

Get unique range of freely assignable global ids.

Every locality needs to be able to assign global ids to different components without having to consult the AGAS server for every id to generate. This function can be called to preallocate a range of ids usable for this purpose.

Note: This function assigns a range of global ids usable by the given locality for newly created components. Any of the returned global ids still has to be bound to a local address, either by calling `bind` or `bind_range`.

Note: As long as *ec* is not pre-initialized to `hpx::throws` this function doesn't throw but returns the result code using the parameter *ec*. Otherwise it throws an instance of `hpx::exception`.

Parameters

- **l** – [in] The locality the locality id needs to be generated for. Repeating calls using the same locality results in identical `locality_id` values.

- **count** – [in] The number of global ids to be generated.
- **lower_bound** – [out] The lower bound of the assigned id range. The returned value can be used as the first id to assign. This is valid only, if the return value of this function is true.
- **upper_bound** – [out] The upper bound of the assigned id range. The returned value can be used as the last id to assign. This is valid only, if the return value of this function is true.
- **ec** – [in,out] this represents the error status on exit, if this is pre-initialized to *hpx::throws* the function will throw on error instead.

Returns This function returns *true* if a new range has been generated (it has been called for the first time for the given locality) and returns *false* if this locality already got a range assigned in an earlier call. Any error results in an exception thrown from this function.

```
inline bool bind_local(naming::gid_type const &id, naming::address const &addr, error_code  
                        &ec = throws)
```

Bind a global address to a local address.

Every element in the HPX namespace has a unique global address (global id). This global address has to be associated with a concrete local address to be able to address an instance of a component using its global address.

Note: As long as *ec* is not pre-initialized to *hpx::throws* this function doesn't throw but returns the result code using the parameter *ec*. Otherwise it throws an instance of *hpx::exception*.

Note: Binding a gid to a local address sets its global reference count to one.

Parameters

- **id** – [in] The global address which has to be bound to the local address.
- **addr** – [in] The local address to be bound to the global address.
- **ec** – [in,out] this represents the error status on exit, if this is pre-initialized to *hpx::throws* the function will throw on error instead.

Returns This function returns *true*, if this global id got associated with an local address. It returns *false* otherwise.

```
inline hpx::future<bool> bind_async(naming::gid_type const &id, naming::address const &addr,  
                                   std::uint32_t locality_id)
```

```
inline hpx::future<bool> bind_async(naming::gid_type const &id, naming::address const &addr,  
                                   naming::gid_type const &locality)
```

```
bool bind_range_local(naming::gid_type const &lower_id, std::uint64_t count, naming::address  
                     const &baseaddr, std::uint64_t offset, error_code &ec = throws)
```

Bind unique range of global ids to given base address.

Every locality needs to be able to bind global ids to different components without having to consult the AGAS server for every id to bind. This function can be called to bind a range of consecutive global ids to a range of consecutive local addresses (separated by a given *offset*).

Note: As long as *ec* is not pre-initialized to *hpx::throws* this function doesn't throw but returns the result code using the parameter *ec*. Otherwise it throws an instance of *hpx::exception*.

Note: Binding a gid to a local address sets its global reference count to one.

Parameters

- **lower_id** – [in] The lower bound of the assigned id range. The value can be used as the first id to assign.
- **count** – [in] The number of consecutive global ids to bind starting at *lower_id*.
- **baseaddr** – [in] The local address to bind to the global id given by *lower_id*. This is the base address for all additional local addresses to bind to the remaining global ids.
- **offset** – [in] The offset to use to calculate the local addresses to be bound to the range of global ids.
- **ec** – [in,out] this represents the error status on exit, if this is pre-initialized to *hpx::throws* the function will throw on error instead.

Returns This function returns *true*, if the given range was successfully bound. It returns *false* otherwise.

```
hpx::future<bool> bind_range_async(naming::gid_type const &lower_id, std::uint64_t count,
                                naming::address const &baseaddr, std::uint64_t offset,
                                naming::gid_type const &locality)
```

```
inline hpx::future<bool> bind_range_async(naming::gid_type const &lower_id, std::uint64_t
                                         count, naming::address const &baseaddr,
                                         std::uint64_t offset, std::uint32_t locality_id)
```

```
inline bool unbind_local(naming::gid_type const &id, error_code &ec = throws)
```

Unbind a global address.

Remove the association of the given global address with any local address, which was bound to this global address. Additionally it returns the local address which was bound at the time of this call.

Note: You can unbind only global ids bound using the function *bind*. Do not use this function to unbind any of the global ids bound using *bind_range*.

Note: As long as *ec* is not pre-initialized to *hpx::throws* this function doesn't throw but returns the result code using the parameter *ec*. Otherwise it throws an instance of *hpx::exception*.

Note: This function will raise an error if the global reference count of the given gid is not zero!

Parameters

- **id** – [in] The global address (id) for which the association has to be removed.
- **ec** – [in,out] this represents the error status on exit, if this is pre-initialized to *hpx::throws* the function will throw on error instead.

Returns The function returns *true* if the association has been removed, and it returns *false* if no association existed. Any error results in an exception thrown from this function.

```
inline bool unbind_local(naming::gid_type const &id, naming::address &addr, error_code &ec =
                        throws)
```

Unbind a global address.

Remove the association of the given global address with any local address, which was bound to this global address. Additionally it returns the local address which was bound at the time of this call.

Note: You can unbind only global ids bound using the function *bind*. Do not use this function to unbind any of the global ids bound using *bind_range*.

Note: As long as *ec* is not pre-initialized to *hpx::throws* this function doesn't throw but returns the result code using the parameter *ec*. Otherwise it throws an instance of *hpx::exception*.

Note: This function will raise an error if the global reference count of the given gid is not zero!

Parameters

- **id** – [in] The global address (id) for which the association has to be removed.
- **addr** – [out] The local address which was associated with the given global address (id). This is valid only if the return value of this function is true.
- **ec** – [in,out] this represents the error status on exit, if this is pre-initialized to *hpx::throws* the function will throw on error instead.

Returns The function returns *true* if the association has been removed, and it returns *false* if no association existed. Any error results in an exception thrown from this function.

```
inline bool unbind_range_local(naming::gid_type const &lower_id, std::uint64_t count,  
                                error_code &ec = throws)
```

Unbind the given range of global ids.

Note: You can unbind only global ids bound using the function *bind_range*. Do not use this function to unbind any of the global ids bound using *bind*.

Note: As long as *ec* is not pre-initialized to *hpx::throws* this function doesn't throw but returns the result code using the parameter *ec*. Otherwise it throws an instance of *hpx::exception*.

Note: This function will raise an error if the global reference count of the given gid is not zero!

Parameters

- **lower_id** – [in] The lower bound of the assigned id range. The value must be the first id of the range as specified to the corresponding call to *bind_range*.
- **count** – [in] The number of consecutive global ids to unbind starting at *lower_id*. This number must be identical to the number of global ids bound by the corresponding call to *bind_range*.
- **ec** – [in,out] this represents the error status on exit, if this is pre-initialized to *hpx::throws* the function will throw on error instead.

Returns This function returns *true* if a new range has been generated (it has been called for the first time for the given locality) and returns *false* if this locality already got a range assigned in an earlier call. Any error results in an exception thrown from this function.

```
bool unbind_range_local(naming::gid_type const &lower_id, std::uint64_t count,  
                        naming::address &addr, error_code &ec = throws)
```

Unbind the given range of global ids.

Note: You can unbind only global ids bound using the function *bind_range*. Do not use this function to unbind any of the global ids bound using *bind*.

Note: As long as *ec* is not pre-initialized to *hpx::throws* this function doesn't throw but returns the result code using the parameter *ec*. Otherwise it throws an instance of *hpx::exception*.

Note: This function will raise an error if the global reference count of the given gid is not zero!

Parameters

- **lower_id** – [in] The lower bound of the assigned id range. The value must be the first id of the range as specified to the corresponding call to *bind_range*.
- **count** – [in] The number of consecutive global ids to unbind starting at *lower_id*. This number must be identical to the number of global ids bound by the corresponding call to *bind_range*.
- **addr** – [out] The local address which was associated with the given global address (id). This is valid only if the return value of this function is true.
- **ec** – [in,out] this represents the error status on exit, if this is pre-initialized to *hpx::throws* the function will throw on error instead.

Returns This function returns *true* if a new range has been generated (it has been called for the first time for the given locality) and returns *false* if this locality already got a range assigned in an earlier call.

```
hpx::future<naming::address> unbind_range_async(naming::gid_type const &lower_id,
                                             std::uint64_t count = 1)
```

```
inline bool is_local_address_cached(naming::gid_type const &id, error_code &ec = throws)
```

Test whether the given address refers to a local object.

This function will test whether the given address refers to an object living on the locality of the caller.

Note: As long as *ec* is not pre-initialized to *hpx::throws* this function doesn't throw but returns the result code using the parameter *ec*. Otherwise it throws an instance of *hpx::exception*.

Parameters

- **id** – [in] The address to test.
- **ec** – [in,out] this represents the error status on exit, if this is pre-initialized to *hpx::throws* the function will throw on error instead.

Returns This function returns *true* if the passed address refers to an object which lives on the locality of the caller.

```
bool is_local_address_cached(naming::gid_type const &id, naming::address &addr,
                             error_code &ec = throws)
```

```
bool is_local_address_cached(naming::gid_type const &id, naming::address &addr,
                             std::pair<bool, components::pinned_ptr> &r,
                             hpx::move_only_function<std::pair<bool,
                             components::pinned_ptr>( naming::address const&)> &&f,
                             error_code &ec = throws)
```

```
bool is_local_lva_encoded_address(std::uint64_t msb) const
```

```
inline bool resolve_local(naming::gid_type const &id, naming::address &addr, error_code &ec
                           = throws)
```

Resolve a given global address (*id*) to its associated local address.

This function returns the local address which is currently associated with the given global address (*id*).

Note: As long as *ec* is not pre-initialized to *hpx::throws* this function doesn't throw but returns the result code using the parameter *ec*. Otherwise it throws an instance of *hpx::exception*.

Parameters

- **id** – [in] The global address (*id*) for which the associated local address should be returned.
- **addr** – [out] The local address which currently is associated with the given global address (*id*), this is valid only if the return value of this function is true.
- **ec** – [in,out] this represents the error status on exit, if this is pre-initialized to *hpx::throws* the function will throw on error instead.

Returns This function returns *true* if the global address has been resolved successfully (there exists an association to a local address) and the associated local address has been returned. The function returns *false* if no association exists for the given global address. Any error results in an exception thrown from this function.

```
inline bool resolve_local(hpx::id_type const &id, naming::address &addr, error_code &ec =
                           throws)
```

```
inline naming::address resolve_local(naming::gid_type const &id, error_code &ec = throws)
```

```
inline naming::address resolve_local(hpx::id_type const &id, error_code &ec = throws)
```

```
hpx::future_or_value<naming::address> resolve_async(naming::gid_type const &id)
```

```
inline hpx::future_or_value<naming::address> resolve_async(hpx::id_type const &id)
```

```
hpx::future_or_value<id_type> get_colocation_id_async(hpx::id_type const &id)
```

```
bool resolve_full_local(naming::gid_type const &id, naming::address &addr, error_code &ec
                        = throws)
```

```
inline bool resolve_full_local(hpx::id_type const &id, naming::address &addr, error_code &ec
                                = throws)
```

```
inline naming::address resolve_full_local(naming::gid_type const &id, error_code &ec =
                                           throws)
```

```
inline naming::address resolve_full_local(hpx::id_type const &id, error_code &ec = throws)
```

```
hpx::future_or_value<naming::address> resolve_full_async(naming::gid_type const &id)
```

```

inline hpx::future_or_value<namings::address> resolve_full_async(hpx::id_type const &id)

bool resolve_cached(namings::gid_type const &id, namings::address &addr, error_code &ec =
    throws)

inline bool resolve_cached(hpx::id_type const &id, namings::address &addr, error_code &ec =
    throws)

inline bool resolve_local(namings::gid_type const *gids, namings::address *addrs, std::size_t size,
    hpx::detail::dynamic_bitset<> &locals, error_code &ec = throws)

bool resolve_full_local(namings::gid_type const *gids, namings::address *addrs, std::size_t size,
    hpx::detail::dynamic_bitset<> &locals, error_code &ec = throws)

bool resolve_cached(namings::gid_type const *gids, namings::address *addrs, std::size_t size,
    hpx::detail::dynamic_bitset<> &locals, error_code &ec = throws)

hpx::future_or_value<std::int64_t> incref_async(namings::gid_type const &gid, std::int64_t
    credits = 1, hpx::id_type const &keep_alive =
    hpx::invalid_id)

```

Increment the global reference count for the given id.

Note: As long as *ec* is not pre-initialized to *hpx::throws* this function doesn't throw but returns the result code using the parameter *ec*. Otherwise it throws an instance of *hpx::exception*.

Parameters

- **gid** – [in] The global address (id) for which the global reference count has to be incremented.
- **credits** – [in] The number of reference counts to add for the given id.
- **keep_alive** – [in] Id to keep alive (if valid)
- **ec** – [in,out] this represents the error status on exit, if this is pre-initialized to *hpx::throws* the function will throw on error instead.

Returns Whether the operation was successful.

```

inline std::int64_t incref(namings::gid_type const &gid, std::int64_t credits = 1, error_code &ec =
    throws)

```

```

void decref(namings::gid_type const &id, std::int64_t credits = 1, error_code &ec = throws)

```

Decrement the global reference count for the given id.

Note: As long as *ec* is not pre-initialized to *hpx::throws* this function doesn't throw but returns the result code using the parameter *ec*. Otherwise it throws an instance of *hpx::exception*.

Parameters

- **id** – [in] The global address (id) for which the global reference count has to be decremented.
- **t** – [out] If this was the last outstanding global reference for the given gid (the return value of this function is zero), t will be set to the component type of the corresponding element. Otherwise t will not be modified.
- **credits** – [in] The number of reference counts to add for the given id.
- **ec** – [in,out] this represents the error status on exit, if this is pre-initialized to *hpx::throws* the function will throw on error instead.

Returns The global reference count after the decrement.

hpx::future<*iterate_names_return_type*> **iterate_ids**(*std::string* const &pattern) const

Invoke the supplied *hpx::function* for every registered global name.

This function iterates over all registered global ids and returns every found entry matching the given name pattern. Any error results in an exception thrown (or reported) from this function.

Parameters **pattern** – [in] pattern (possibly using wildcards) to match all existing entries against

bool **register_name**(*std::string* const &name, *namings::gid_type* const &id, *error_code* &ec = *throws*) const

Register a global name with a global address (id)

This function registers an association between a global name (string) and a global address (id) usable with one of the functions above (bind, unbind, and resolve).

Note: As long as *ec* is not pre-initialized to *hpx::throws* this function doesn't throw but returns the result code using the parameter *ec*. Otherwise it throws an instance of *hpx::exception*.

Parameters

- **name** – [in] The global name (string) to be associated with the global address.
- **id** – [in] The global address (id) to be associated with the global address.
- **ec** – [in,out] this represents the error status on exit, if this is pre-initialized to *hpx::throws* the function will throw on error instead.

Returns The function returns *true* if the global name was registered. It returns false if the global name is not registered.

hpx::future<bool> **register_name_async**(*std::string* const &name, *hpx::id_type* const &id) const

bool **register_name**(*std::string* const &name, *hpx::id_type* const &id, *error_code* &ec = *throws*) const

hpx::future<*hpx::id_type*> **unregister_name_async**(*std::string* const &name) const

Unregister a global name (release any existing association)

This function releases any existing association of the given global name with a global address (id).

Note: As long as *ec* is not pre-initialized to *hpx::throws* this function doesn't throw but returns the result code using the parameter *ec*. Otherwise it throws an instance of *hpx::exception*.

Parameters

- **name** – [in] The global name (string) for which any association with a global address (id) has to be released.
- **ec** – [in,out] this represents the error status on exit, if this is pre-initialized to *hpx::throws* the function will throw on error instead.

Returns The function returns *true* if an association of this global name has been released, and it returns *false*, if no association existed. Any error results in an exception thrown from this function.

hpx::id_type **unregister_name**(*std::string* const &name, *error_code* &ec = *throws*) const

hpx::future<*hpx::id_type*> **resolve_name_async**(*std::string* const &name) const

Query for the global address associated with a given global name.

This function returns the global address associated with the given global name.

This function returns true if it returned global address (id), which is currently associated with the given global name, and it returns false, if currently there is no association for this global name. Any error results in an exception thrown from this function.

Note: As long as *ec* is not pre-initialized to *hpx::throws* this function doesn't throw but returns the result code using the parameter *ec*. Otherwise it throws an instance of *hpx::exception*.

Parameters

- **name** – [in] The global name (string) for which the currently associated global address has to be retrieved.
- **ec** – [in,out] this represents the error status on exit, if this is pre-initialized to *hpx::throws* the function will throw on error instead.

Returns [out] The id currently associated with the given global name (valid only if the return value is true).

```
hpx::id_type resolve_name(std::string const &name, error_code &ec = throws) const
```

```
future<hpx::id_type> on_symbol_namespace_event(std::string const &name, bool
                                             call_for_past_events = false) const
```

Install a listener for a given symbol namespace event.

This function installs a listener for a given symbol namespace event. It returns a future which becomes ready as a result of the listener being triggered.

Note: The only event type which is currently supported is *symbol_ns_bind*, i.e. the listener is triggered whenever a global id is registered with the given name.

Parameters

- **name** – [in] The global name (string) for which the given event should be triggered.
- **evt** – [in] The event for which a listener should be installed.
- **call_for_past_events** – [in, optional] Trigger the listener even if the given event has already happened in the past. The default for this parameter is *false*.

Returns A future instance encapsulating the global id which is causing the registered listener to be triggered.

```
void update_cache_entry(naming::gid_type const &gid, gva const &gva, error_code &ec =
                       throws)
```

Warning: This function is for internal use only. It is dangerous and may break your code if you use it.

```
inline void update_cache_entry(naming::gid_type const &gid, naming::address const &addr,
                              std::uint64_t count = 0, std::uint64_t offset = 0, error_code &ec
                              = throws)
```

Warning: This function is for internal use only. It is dangerous and may break your code if you use it.

```
bool get_cache_entry(naming::gid_type const &gid, gva &gva, naming::gid_type &idbase,
                    error_code &ec = throws) const
```

Warning: This function is for internal use only. It is dangerous and may break your code if you use it.

void **remove_cache_entry**(*naming::gid_type* const &id, *error_code* &ec = *throws*) const

Warning: This function is for internal use only. It is dangerous and may break your code if you use it.

void **clear_cache**(*error_code* &ec = *throws*) const

Warning: This function is for internal use only. It is dangerous and may break your code if you use it.

void **start_shutdown**(*error_code* &ec = *throws*)

hpx::future<*std::pair*<*hpx::id_type*, *naming::address*>> **begin_migration**(*hpx::id_type* const &id)
start/stop migration of an object

Returns Current locality and address of the object to migrate

bool **end_migration**(*hpx::id_type* const &id)

std::pair<bool, *components::pinned_ptr*> **was_object_migrated**(*naming::gid_type* const &gid,
hpx::move_only_function<*components::pinned_ptr*
&&f)

Maintain list of migrated objects.

hpx::future<void> **mark_as_migrated**(*naming::gid_type* const &gid,
hpx::move_only_function<*std::pair*<bool,
hpx::future<void>>()> &&f, bool
expect_to_be_marked_as_migrating)

Mark the given object as being migrated (if the object is unpinned). Delay migration until the object is unpinned otherwise.

void **unmark_as_migrated**(*naming::gid_type* const &gid, *hpx::move_only_function*<void()>
&&f)

Remove the given object from the table of migrated objects.

void **pre_cache_endpoints**(*std::vector*<*parcelset::endpoints_type*> const&)

Public Members

`mutable hpx::shared_mutex gva_cache_mtx_`

`std::shared_ptr<gva_cache_type> gva_cache_`

`mutable mutex_type migrated_objects_mtx_`

`migrated_objects_table_type migrated_objects_table_`

`mutable mutex_type console_cache_mtx_`

`std::uint32_t console_cache_`

`const std::size_t max_refcnt_requests_`

`mutex_type refcnt_requests_mtx_`

`std::size_t refcnt_requests_count_`

`bool enable_refcnt_caching_`

`std::shared_ptr<refcnt_requests_type> refcnt_requests_`

`const service_mode service_type`

`const runtime_mode runtime_type`

`const bool caching_`

`const bool range_caching_`

`const threads::thread_priority action_priority_`

`std::uint64_t rts_lva_`

`std::unique_ptr<component_namespace> component_ns_`

`std::unique_ptr<locality_namespace> locality_ns_`

`symbol_namespace symbol_ns_`

primary_namespace **primary_ns_**

std::atomic<hpx::state> **state_**

naming::gid_type **locality_**

mutable *hpx::shared_mutex* **resolved_localities_mtx_**

resolved_localities_type **resolved_localities_**

Public Static Functions

static *std::int64_t* **synchronize_with_async_incref**(*std::int64_t* old_credit, *hpx::id_type* const &id, *std::int64_t* compensated_credit)

Protected Functions

void **launch_bootstrap**(*parcelsset::endpoints_type* const &endpoints, *util::runtime_configuration* &rtcfg)

naming::address **resolve_full_postproc**(*naming::gid_type* const &id, *primary_namespace::resolved_type* const&)

bool **bind_postproc**(*naming::gid_type* const &id, *gva* const &g, *future*<bool> f)

bool **was_object_migrated_locked**(*naming::gid_type* const &id)

Maintain list of migrated objects.

Private Functions

void **send_refcnt_requests**(*std::unique_lock*<*mutex_type*> &l, *error_code* &ec = *throws*)

Assumes that *refcnt_requests_mtx_* is locked.

void **send_refcnt_requests_non_blocking**(*std::unique_lock*<*mutex_type*> &l, *error_code* &ec)

Assumes that *refcnt_requests_mtx_* is locked.

std::vector<*hpx::future*<*std::vector*<*std::int64_t*>>> **send_refcnt_requests_async**(*std::unique_lock*<*mutex_type*> &l)

Assumes that *refcnt_requests_mtx_* is locked.

void **send_refcnt_requests_sync**(*std::unique_lock*<*mutex_type*> &l, *error_code* &ec)

Assumes that *refcnt_requests_mtx_* is locked.

agas_base

See *Public API* for a list of names and headers that are part of the public *HPX* API.

hpx/agas_base/server/primary_namespace.hpp

Defined in header `hpx/agas_base/server/primary_namespace.hpp`.

See *Public API* for a list of names and headers that are part of the public *HPX* API.

Variables

`HPX_ACTION_USES_MEDIUM_STACK(hpx::agas::server::primary_namespace::allocate_action)` `HPX_REGISTER_ACTION(hpx::naming::address > std_pair_address_id_type)`

namespace **hpx**

namespace **agas**

Functions

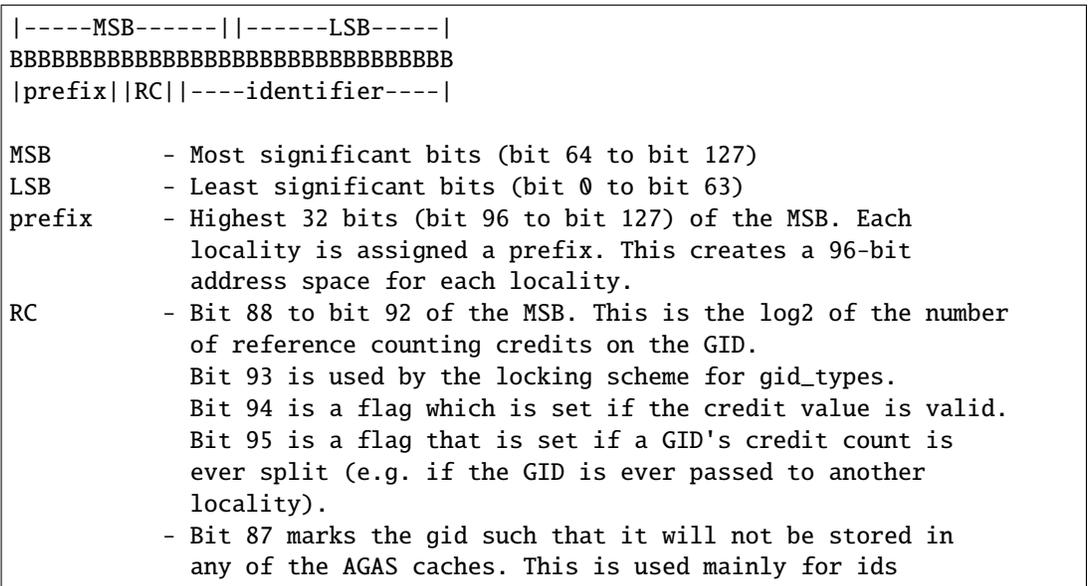
`naming::gid_type bootstrap_primary_namespace_gid()`

`hpx::id_type bootstrap_primary_namespace_id()`

namespace **server**

AGAS's primary namespace maps 128-bit global identifiers (GIDs) to resolved addresses.

The following is the canonical description of the partitioning of AGAS's primary namespace.



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which represent 'one-shot' objects (like promises).
 identifier - Bit 64 to bit 86 of the MSB, and the entire LSB. The content of these bits depends on the component type of the underlying object. For all user-defined components, these bits contain a unique 88-bit number which is assigned sequentially for each locality. For
 \a hpx#components#component_enum_type#runtime_support the high 24 bits are zeroed and the low 64 bits hold the LVA of the component.

The following address ranges are reserved. Some are either explicitly or implicitly protected by AGAS. The letter x represents a single-byte wild card.

```
00000000xxxxxxxxxxxxxxxxxxxxxxxxxxxx
  Historically unused address space reserved for future use.
xxxxxxxxxxxx0000xxxxxxxxxxxxxxxxxxxx
  Address space for LVA-encoded GIDs.
00000001xxxxxxxxxxxxxxxxxxxxxxxxxxxx
  Prefix of the bootstrap AGAS locality.
00000001000000001000000000000001
  Address of the primary_namespace component on the bootstrap AGAS
  locality.
00000001000000001000000000000002
  Address of the component_namespace component on the bootstrap AGAS
  locality.
00000001000000001000000000000003
  Address of the symbol_namespace component on the bootstrap AGAS
  locality.
00000001000000001000000000000004
  Address of the locality_namespace component on the bootstrap AGAS
  locality.
```

Note: The layout of the address space is implementation defined, and subject to change. Never write application code that relies on the internal layout of GIDs. AGAS only guarantees that all assigned GIDs will be unique.

Variables

```
static constexpr char const *const primary_namespace_service_name = "primary/"
```

```
struct primary_namespace : public components::fixed_component_base<primary_namespace>
```

Public Types

```
using mutex_type = hpx::spinlock

using base_type = components::fixed_component_base<primary_namespace>

using component_type = std::int32_t

using gva_table_data_type = std::pair<gva, naming::gid_type>

using gva_table_type = std::map<naming::gid_type, gva_table_data_type>

using refcnt_table_type = std::map<naming::gid_type, std::int64_t>

using resolved_type = hpx::tuple<naming::gid_type, gva, naming::gid_type>
```

Public Functions

```
inline mutex_type &mutex()

void wait_for_migration_locked(std::unique_lock<mutex_type> &l, naming::gid_type
                                const &id, error_code &ec)

inline primary_namespace()

void finalize() const

inline void set_local_locality(naming::gid_type const &g)

void register_server_instance(char const *servicename, std::uint32_t locality_id =
                                naming::invalid_locality_id, error_code &ec = throws)

void unregister_server_instance(error_code &ec = throws) const

bool bind_gid(gva const &g, naming::gid_type id, naming::gid_type const &locality)

std::pair<hpx::id_type, naming::address> begin_migration(naming::gid_type id)

bool end_migration(naming::gid_type const &id)

resolved_type resolve_gid(naming::gid_type const &id)

hpx::id_type colocate(naming::gid_type const &id)

naming::address unbind_gid(std::uint64_t count, naming::gid_type id)

std::int64_t increment_credit(std::int64_t credits, naming::gid_type lower,
                                naming::gid_type upper)

std::vector<std::int64_t> decrement_credit(std::vector<hpx::tuple<std::int64_t,
                                            naming::gid_type, naming::gid_type>> const
                                            &requests)
```

```
std::pair<naming::gid_type, naming::gid_type> allocate(std::uint64_t count)

resolved_type resolve_gid_locked(std::unique_lock<mutex_type> &l, naming::gid_type
    const &gid, error_code &ec)
```

Public Members

```
counter_data counter_data_
```

Private Types

```
using migration_table_type = std::map<naming::gid_type, hpx::tuple<bool, std::size_t,
lcos::local::detail::condition_variable>>
```

```
using free_entry_allocator_type = util::internal_allocator<free_entry>
```

```
using free_entry_list_type = std::list<free_entry, free_entry_allocator_type>
```

Private Functions

```
resolved_type resolve_gid_locked_non_local(std::unique_lock<mutex_type> &l,
    naming::gid_type const &gid, error_code
    &ec)
```

```
void increment(naming::gid_type const &lower, naming::gid_type const &upper, std::int64_t
    const &credits, error_code &ec)
```

```
void resolve_free_list(std::unique_lock<mutex_type> &l,
    std::list<refcnt_table_type::iterator> const &free_list,
    free_entry_list_type &free_entry_list, naming::gid_type const
    &lower, naming::gid_type const &upper, error_code &ec)
```

```
void decrement_sweep(free_entry_list_type &free_list, naming::gid_type const &lower,
    naming::gid_type const &upper, std::int64_t credits, error_code &ec)
```

```
void free_components_sync(free_entry_list_type const &free_list, naming::gid_type const
    &lower, naming::gid_type const &upper, error_code &ec)
    const
```

Private Members

```
mutex_type mutex_
```

```
gva_table_type gvas_
```

```
refcnt_table_type refcnts_
```

```

std::string instance_name_

naming::gid_type next_id_

naming::gid_type locality_

migration_table_type migrating_objects_

struct counter_data

```

Public Functions

```

HPX_NON_COPYABLE(counter_data)

counter_data() = default

std::int64_t get_bind_gid_count(bool)

std::int64_t get_resolve_gid_count(bool)

std::int64_t get_unbind_gid_count(bool)

std::int64_t get_increment_credit_count(bool)

std::int64_t get_decrement_credit_count(bool)

std::int64_t get_allocate_count(bool)

std::int64_t get_begin_migration_count(bool)

std::int64_t get_end_migration_count(bool)

std::int64_t get_overall_count(bool)

std::int64_t get_bind_gid_time(bool)

std::int64_t get_resolve_gid_time(bool)

std::int64_t get_unbind_gid_time(bool)

std::int64_t get_increment_credit_time(bool)

std::int64_t get_decrement_credit_time(bool)

std::int64_t get_allocate_time(bool)

std::int64_t get_begin_migration_time(bool)

std::int64_t get_end_migration_time(bool)

std::int64_t get_overall_time(bool)

void increment_bind_gid_count()

void increment_resolve_gid_count()

```

```
void increment_unbind_gid_count()  
void increment_increment_credit_count()  
void increment_decrement_credit_count()  
void increment_allocate_count()  
void increment_begin_migration_count()  
void increment_end_migration_count()  
void enable_all()
```

Public Members

```
api_counter_data bind_gid_  
  
api_counter_data resolve_gid_  
  
api_counter_data unbind_gid_  
  
api_counter_data increment_credit_  
  
api_counter_data decrement_credit_  
  
api_counter_data allocate_  
  
api_counter_data begin_migration_  
  
api_counter_data end_migration_  
  
struct api_counter_data
```

Public Functions

```
inline api_counter_data()
```

Public Members

```
std::atomic<std::int64_t> count_  
  
std::atomic<std::int64_t> time_  
  
bool enabled_  
  
struct free_entry
```

Public Functions

```
inline free_entry(agas::gva const &gva, naming::gid_type const &gid, naming::gid_type
                  const &loc)
```

Public Members

```
agas::gva gva_
```

```
naming::gid_type gid_
```

```
naming::gid_type locality_
```

async_colocated

See *Public API* for a list of names and headers that are part of the public *HPX* API.

hpx::get_colocation_id

Defined in header `hpx/runtime.hpp`⁷⁹⁸.

See *Public API* for a list of names and headers that are part of the public *HPX* API.

namespace **hpx**

Functions

```
hpx::id_type get_colocation_id(launch::sync_policy, hpx::id_type const &id, error_code &ec = throws)
```

Return the id of the locality where the object referenced by the given id is currently located on.

The function `hpx::get_colocation_id()` returns the id of the locality where the given object is currently located.

See also:

`hpx::get_colocation_id()`

Note: As long as *ec* is not pre-initialized to `hpx::throws` this function doesn't throw but returns the result code using the parameter *ec*. Otherwise it throws an instance of `hpx::exception`.

Parameters

- **id** – [in] The id of the object to locate.
- **ec** – [in,out] this represents the error status on exit, if this is pre-initialized to `hpx::throws` the function will throw on error instead.

⁷⁹⁸ <http://github.com/STELLAR-GROUP/hpx/blob/8a3b7c1a4cb5693b2f7d9f587f759392ed0c51a0/libs/full/include/include/hpx/runtime.hpp>

hpx::future<*hpx::id_type*> **get_colocation_id**(*hpx::id_type* const &id)

Asynchronously return the id of the locality where the object referenced by the given id is currently located on.

See also:

hpx::get_colocation_id(*launch::sync_policy*)

Parameters **id** – [in] The id of the object to locate.

async_distributed

See *Public API* for a list of names and headers that are part of the public *HPX* API.

hpx::async (distributed)

Defined in header *hpx/async.hpp*.

See *Public API* for a list of names and headers that are part of the public *HPX* API.

namespace **hpx**

Functions

template<typename **Action**, typename **Target**, typename ...**Ts**>
auto **async**(*Action* &&action, *Target* &&target, *Ts*&&... ts)

The distributed implementation of `hpx::async` can be used by giving an action instance as argument instead of a function, and also by providing another argument with the locality ID or the target ID. The action executes asynchronously.

Template Parameters

- **Action** – The type of action instance
- **Target** – The type of target where the action should be executed
- **Ts** – The type of any additional arguments

Parameters

- **action** – The action instance to be executed
- **target** – The target where the action should be executed
- **ts** – Additional arguments

Returns `hpx::future` referring to the shared state created by this call to `hpx::async`

hpx/async_distributed/base_lco.hpp

Defined in header `hpx/async_distributed/base_lco.hpp`.

See *Public API* for a list of names and headers that are part of the public *HPX* API.

```
template<>
struct hpx::get_lva<hpx::lcos::base_lco>
```

Public Static Functions

```
static inline constexpr hpx::lcos::base_lco *call(hpx::naming::address_type lva) noexcept
```

```
template<>
struct hpx::get_lva<hpx::lcos::base_lco const>
```

Public Static Functions

```
static inline constexpr hpx::lcos::base_lco const *call(hpx::naming::address_type lva) noexcept
```

```
namespace hpx
```

```
template<> base_lco >
```

Public Static Functions

```
static inline constexpr hpx::lcos::base_lco *call(hpx::naming::address_type lva) noexcept
```

```
template<> base_lco const >
```

Public Static Functions

```
static inline constexpr hpx::lcos::base_lco const *call(hpx::naming::address_type lva) noexcept
```

```
namespace lcos
```

```
class base_lco
```

#include <*base_lco.hpp*> The `base_lco` class is the common base class for all LCO's implementing a simple `set_event` action

Subclassed by `hpx::lcos::base_lco_with_value< Result, RemoteResult, ComponentTag >`, `hpx::lcos::base_lco_with_value< void, void, ComponentTag >`

Public Types

```
typedef components::managed_component<base_lco> wrapping_type
```

```
typedef base_lco base_type_holder
```

Public Functions

```
virtual void set_event() = 0
```

```
virtual void set_exception(std::exception_ptr const &e)
```

```
virtual void connect(hpx::id_type const&)
```

```
virtual void disconnect(hpx::id_type const&)
```

```
virtual ~base_lco()
```

Destructor, needs to be virtual to allow for clean destruction of derived objects

```
void set_event_nonvirt()
```

The *function* `set_event_nonvirt` is called whenever a *set_event_action* is applied on a instance of a LCO. This function just forwards to the virtual function `set_event`, which is overloaded by the derived concrete LCO.

```
void set_exception_nonvirt(std::exception_ptr const &e)
```

The *function* `set_exception` is called whenever a *set_exception_action* is applied on a instance of a LCO. This function just forwards to the virtual function `set_exception`, which is overloaded by the derived concrete LCO.

Parameters `e` – [in] The exception encapsulating the error to report to this LCO instance.

```
void connect_nonvirt(hpx::id_type const &id)
```

The *function* `connect_nonvirt` is called whenever a *connect_action* is applied on a instance of a LCO. This function just forwards to the virtual function `connect`, which is overloaded by the derived concrete LCO.

Parameters `id` – [in] target id

```
void disconnect_nonvirt(hpx::id_type const &id)
```

The *function* `disconnect_nonvirt` is called whenever a *disconnect_action* is applied on a instance of a LCO. This function just forwards to the virtual function `disconnect`, which is overloaded by the derived concrete LCO.

Parameters `id` – [in] target id

```
HPX_DEFINE_COMPONENT_DIRECT_ACTION (base_lco, set_event_nonvirt,  
set_event_action) HPX_DEFINE_COMPONENT_DIRECT_ACTION(base_lco
```

Each of the exposed functions needs to be encapsulated into an action type, allowing to generate all required boilerplate code for threads, serialization, etc.

The *set_event_action* may be used to unconditionally trigger any LCO instances, it carries no additional parameters. The *set_exception_action* may be used to transfer arbitrary error information from the remote site to the LCO instance specified as a continuation. This action carries 2 parameters:

Parameters `std::exception_ptr` – [in] The exception encapsulating the error to report to this LCO instance.

`set_exception_action` `HPX_DEFINE_COMPONENT_DIRECT_ACTION` (`base_lco`,
`connect_nonvirt`, `connect_action`) `HPX_DEFINE_COMPONENT_DIRECT_ACTION`(`base_lco`

The `connect_action` may be used to.

The `set_exception_action` may be used to

Public Members

`set_exception_nonvirt`

`set_exception_action` `disconnect_nonvirt`

Public Static Functions

static `components::component_type` `get_component_type`() noexcept

static void `set_component_type`(`components::component_type` type)

hpx/async_distributed/base_lco_with_value.hpp

Defined in header `hpx/async_distributed/base_lco_with_value.hpp`.

See *Public API* for a list of names and headers that are part of the public *HPX* API.

Defines

`HPX_REGISTER_BASE_LCO_WITH_VALUE_DECLARATION(...)`

`HPX_REGISTER_BASE_LCO_WITH_VALUE_DECLARATION_(...)`

`HPX_REGISTER_BASE_LCO_WITH_VALUE_DECLARATION2`(Value, RemoteValue, Name)

`HPX_REGISTER_BASE_LCO_WITH_VALUE_DECLARATION_1`(Value)

`HPX_REGISTER_BASE_LCO_WITH_VALUE_DECLARATION_2`(Value, Name)

`HPX_REGISTER_BASE_LCO_WITH_VALUE_DECLARATION_3`(Value, RemoteValue, Name)

`HPX_REGISTER_BASE_LCO_WITH_VALUE_DECLARATION_4`(Value, RemoteValue, Name, Tag)

`HPX_REGISTER_BASE_LCO_WITH_VALUE(...)`

`HPX_REGISTER_BASE_LCO_WITH_VALUE_(...)`

`HPX_REGISTER_BASE_LCO_WITH_VALUE_1`(Value)

`HPX_REGISTER_BASE_LCO_WITH_VALUE_2`(Value, Name)

`HPX_REGISTER_BASE_LCO_WITH_VALUE_3`(Value, RemoteValue, Name)

`HPX_REGISTER_BASE_LCO_WITH_VALUE_4`(Value, RemoteValue, Name, Tag)

`HPX_REGISTER_BASE_LCO_WITH_VALUE_ID(...)`

`HPX_REGISTER_BASE_LCO_WITH_VALUE_ID(...)`

`HPX_REGISTER_BASE_LCO_WITH_VALUE_ID2(Value, RemoteValue, Name, ActionIdGet, ActionIdSet)`

`HPX_REGISTER_BASE_LCO_WITH_VALUE_ID_4(Value, Name, ActionIdGet, ActionIdSet)`

`HPX_REGISTER_BASE_LCO_WITH_VALUE_ID_5(Value, RemoteValue, Name, ActionIdGet, ActionIdSet)`

`HPX_REGISTER_BASE_LCO_WITH_VALUE_ID_6(Value, RemoteValue, Name, ActionIdGet, ActionIdSet, Tag)`

namespace **hpx**

namespace **components**

namespace **lcos**

template<typename **Result**, typename **RemoteResult**, typename **ComponentTag**>

class **base_lco_with_value** : public *hpx::lcos::base_lco*, public *ComponentTag*

#include <base_lco_with_value.hpp> The *base_lco_with_value* class is the common base class for all LCO's synchronizing on a value. The *RemoteResult* template argument should be set to the type of the argument expected for the *set_value* action.

Template Parameters

- **RemoteResult** – The type of the result value to be carried back to the LCO instance.
- **ComponentTag** – The tag type representing the type of the component (either *component_tag* or *managed_component_tag*).

Public Types

using **wrapping_type** = typename detail::base_lco_wrapping_type<*ComponentTag*, *base_lco_with_value*>::type

using **base_type_holder** = *base_lco_with_value*

Public Functions

inline void **set_value_nonvirt**(*RemoteResult* &&result)

The *function* *set_value_nonvirt* is called whenever a *set_value_action* is applied on this LCO instance. This function just forwards to the virtual function *set_value*, which is overloaded by the derived concrete LCO.

Parameters **result** – [in] The result value to be transferred from the remote operation back to this LCO instance.

inline *Result* **get_value_nonvirt**()

The *function* *get_result_nonvirt* is called whenever a *get_result_action* is applied on this LCO instance. This function just forwards to the virtual function *get_result*, which is overloaded by the derived concrete LCO.

HPX_DEFINE_COMPONENT_DIRECT_ACTION (*base_lco_with_value*, *set_value_nonvirt*, *set_value_action*) **HPX_DEFINE_COMPONENT_DIRECT_ACTION**(*base_lco_with_value*

The *set_value_action* may be used to trigger any LCO instances while carrying an additional parameter of any type.

RemoteResult is taken by rvalue ref. This allows for perfect forwarding. When the action thread function is created, the values are moved into the called function. If we took it by const lvalue reference, we would disable the possibility to further move the result to the designated destination.

Parameters RemoteResult – [in] The type of the result to be transferred back to this LCO instance. The *get_value_action* may be used to query the value this LCO instance exposes as its 'result' value.

Public Members

get_value_nonvirt

Public Static Functions

static inline *components::component_type* **get_component_type**() noexcept

static inline void **set_component_type**(*components::component_type* type)

Protected Types

using **result_type** = *std::conditional_t<std::is_void_v<Result>, util::unused_type, Result>*

Protected Functions

~base_lco_with_value() override = default

Destructor, needs to be virtual to allow for clean destruction of derived objects

inline virtual void **set_event**() override

virtual void **set_value**(*RemoteResult* &&result) = 0

virtual *result_type* **get_value**() = 0

inline virtual *result_type* **get_value**(*error_code*&)

template<typename **ComponentTag**>

class **base_lco_with_value**<void, void, *ComponentTag*> : public *hpx::lcos::base_lco*, public *ComponentTag*

#include <base_lco_with_value.hpp> The *base_lco<void>* specialization is used whenever the *set_event* action for a particular LCO doesn't carry any argument.

Template Parameters void – This specialization expects no result value and is almost completely equivalent to the plain *base_lco*.

Public Types

```
using wrapping_type = typename detail::base_lco_wrapping_type<ComponentTag,  
base_lco_with_value>::type
```

```
using base_type_holder = base_lco_with_value
```

```
using set_value_action = typename base_lco::set_event_action
```

Public Functions

```
inline void get_value()
```

Protected Functions

```
~base_lco_with_value() override = default
```

Destructor, needs to be virtual to allow for clean destruction of derived objects

```
namespace traits
```

hpx::dataflow (distributed)

Defined in header `hpx/async.hpp`.

See *Public API* for a list of names and headers that are part of the public *HPX* API.

```
namespace hpx
```

Functions

```
template<typename Action, typename Target, typename ...Ts>  
decltype(auto) dataflow(Action &&action, Target &&target, Ts&&... ts)
```

The distributed implementation of `hpx::dataflow` can be used by giving an action instance as argument instead of a function, and also by providing another argument with the locality ID or the target ID. The action executes asynchronously.

Note: Its behavior is similar to `hpx::async` with the exception that if one of the arguments is a future, then `hpx::dataflow` will wait for the future to be ready to launch the thread.

Template Parameters

- **Action** – The type of action instance
- **Target** – The type of target where the action should be executed
- **Ts** – The type of any additional arguments

Parameters

- **action** – The action instance to be executed
- **target** – The target where the action should be executed
- **ts** – Additional arguments

Returns `hpx::future` referring to the shared state created by this call to `hpx::dataflow`

`hpx::distributed::promise`

Defined in header `hpx/future.hpp`⁷⁹⁹.

See *Public API* for a list of names and headers that are part of the public *HPX* API.

namespace **hpx**

namespace **distributed**

template<typename **Result**, typename **RemoteResult**>

class **promise**

#include <promise.hpp> A promise can be used by a single *thread* to invoke a (remote) action and wait for the result. The result is expected to be sent back to the promise using the LCO's `set_event` action

A promise is one of the simplest synchronization primitives provided by HPX. It allows to synchronize on a eager evaluated remote operation returning a result of the type *Result*. The *promise* allows to synchronize exactly one *thread* (the one passed during construction time).

```
// Create the promise (the expected result is a id_type)
hpx::distributed::promise<hpx::id_type> p;

// Get the associated future
future<hpx::id_type> f = p.get_future();

// initiate the action supplying the promise as a
// continuation
apply<some_action>(new continuation(p.get_id()), ...);

// Wait for the result to be returned, yielding control
// in the meantime.
hpx::id_type result = f.get();
// ...
```

Note: The action executed by the promise must return a value of a type convertible to the type as specified by the template parameter *RemoteResult*

Template Parameters

- **Result** – The template parameter *Result* defines the type this promise is expected to return from *promise::get*.

⁷⁹⁹ <http://github.com/STELLAR-GROUP/hpx/blob/8a3b7c1a4cb5693b2f7d9f587f759392ed0c51a0/libs/full/include/include/hpx/future.hpp>

- **RemoteResult** – The template parameter *RemoteResult* defines the type this promise is expected to receive from the remote action.

namespace **lcos**

```
template<typename Result, typename RemoteResult, typename ComponentTag>
```

```
class base_lco_with_value : public hpx::lcos::base_lco, public ComponentTag
    #include <base_lco_with_value.hpp>
```

```
template<typename Action, typename Result = typename traits::promise_local_result<typename
Action::remote_result_type>::type, bool DirectExecute = Action::direct_execution::value>
```

```
class packaged_action
```

#include <packaged_action.hpp> A *packaged_action* can be used by a single *thread* to invoke a (remote) action and wait for the result. The result is expected to be sent back to the *packaged_action* using the LCO's *set_event* action

A *packaged_action* is one of the simplest synchronization primitives provided by HPX. It allows to synchronize on a eager evaluated remote operation returning a result of the type *Result*.

Note: The action executed using the *packaged_action* as a continuation must return a value of a type convertible to the type as specified by the template parameter *Result*.

Template Parameters

- **Action** – The template parameter *Action* defines the action to be executed by this *packaged_action* instance. The arguments *arg0*,... *argN* are used as parameters for this action.
- **Result** – The template parameter *Result* defines the type this *packaged_action* is expected to return from its associated future *packaged_action::get_future*.
- **DirectExecute** – The template parameter *DirectExecute* is an optimization aid allowing to execute the action directly if the target is local (without spawning a new thread for this). This template does not have to be supplied explicitly as it is derived from the template parameter *Action*.

namespace **lcos**

hpx/async_distributed/packaged_action.hpp

Defined in header *hpx/async_distributed/packaged_action.hpp*.

See *Public API* for a list of names and headers that are part of the public *HPX* API.

namespace **hpx**

namespace **lcos**

```
template<typename Action, typename Result = typename traits::promise_local_result<typename
Action::remote_result_type>::type, bool DirectExecute = Action::direct_execution::value>
```

```
class packaged_action
```

```
    #include <packaged_action.hpp>
```

```
template<typename Action, typename Result>
```

```
class packaged_action<Action, Result, false> : public hpx::distributed::promise<Result,  
hpx::traits::extract_action<Action>::remote_result_type>
```

Subclassed by *hpx::lcos::packaged_action*< *Action*, *Result*, true >

Public Functions

```
inline packaged_action()
```

```
template<typename Allocator>  
inline packaged_action(std::allocator_arg_t, Allocator const &alloc)
```

```
template<typename ...Ts>  
inline void post(hpx::id_type const &id, Ts&&... vs)
```

```
template<typename ...Ts>  
inline void post(naming::address &&addr, hpx::id_type const &id, Ts&&... vs)
```

```
template<typename Callback, typename ...Ts>  
inline void post_cb(hpx::id_type const &id, Callback &&cb, Ts&&... vs)
```

```
template<typename Callback, typename ...Ts>  
inline void post_cb(naming::address &&addr, hpx::id_type const &id, Callback &&cb, Ts&&...  
vs)
```

```
template<typename ...Ts>  
inline void post_p(hpx::id_type const &id, hpx::launch policy, Ts&&... vs)
```

```
template<typename ...Ts>  
inline void post_p(naming::address &&addr, hpx::id_type const &id, hpx::launch policy, Ts&&...  
vs)
```

```
template<typename Callback, typename ...Ts>  
inline void post_p_cb(hpx::id_type const &id, hpx::launch policy, Callback &&cb, Ts&&... vs)
```

```
template<typename Callback, typename ...Ts>  
inline void post_p_cb(naming::address &&addr, hpx::id_type const &id, hpx::launch policy,  
Callback &&cb, Ts&&... vs)
```

```
template<typename ...Ts>  
inline void post_deferred(naming::address &&addr, hpx::id_type const &id, hpx::launch policy,  
Ts&&... vs)
```

```
template<typename Callback, typename ...Ts>  
inline void post_deferred_cb(naming::address &&addr, hpx::id_type const &id, hpx::launch  
policy, Callback &&cb, Ts&&... vs)
```

Protected Types

```
using action_type = typename hpx::traits::extract_action<Action>::type

using remote_result_type = typename action_type::remote_result_type

using base_type = hpx::distributed::promise<Result, remote_result_type>
```

Protected Functions

```
template<typename ...Ts>
inline void do_post(naming::address &&addr, hpx::id_type const &id, hpx::launch policy, Ts&&...
                    vs)

template<typename ...Ts>
inline void do_post(hpx::id_type const &id, hpx::launch policy, Ts&&... vs)

template<typename Callback, typename ...Ts>
inline void do_post_cb(naming::address &&addr, hpx::id_type const &id, hpx::launch policy,
                       Callback &&cb, Ts&&... vs)

template<typename Callback, typename ...Ts>
inline void do_post_cb(hpx::id_type const &id, hpx::launch policy, Callback &&cb, Ts&&... vs)

template<typename Action, typename Result>

class packaged_action<Action, Result, true> : public hpx::lcos::packaged_action<Action, Result,
false>
```

Public Functions

```
inline packaged_action()
    Construct a (non-functional) instance of an packaged_action. To use this instance its member
    function post needs to be directly called.

template<typename Allocator>
inline packaged_action(std::allocator_arg_t, Allocator const &alloc)

template<typename ...Ts>
inline void post(hpx::id_type const &id, Ts&&... vs)

template<typename ...Ts>
inline void post(naming::address &&addr, hpx::id_type const &id, Ts&&... vs)

template<typename Callback, typename ...Ts>
inline void post_cb(hpx::id_type const &id, Callback &&cb, Ts&&... vs)

template<typename Callback, typename ...Ts>
inline void post_cb(naming::address &&addr, hpx::id_type const &id, Callback &&cb, Ts&&...
                    vs)
```

Private Types

using **action_type** = typename *packaged_action*<*Action*, *Result*, false>::action_type

hpx::post (distributed)

Defined in header `hpx/async.hpp`.

See *Public API* for a list of names and headers that are part of the public *HPX* API.

namespace **hpx**

Functions

```
template<typename Action, typename Target, typename ...Ts>
bool post(Action &&action, Target &&target, Ts&&... ts)
```

The distributed implementation of `hpx::post` can be used by giving an action instance as argument instead of a function, and also by providing another argument with the locality ID or the target ID.

Template Parameters

- **Action** – The type of action instance
- **Target** – The type of target where the action should be executed
- **Ts** – The type of any additional arguments

Parameters

- **action** – The action instance to be executed
- **target** – The target where the action should be executed
- **ts** – Additional arguments

Returns `true` if the action was successfully posted, `false` otherwise.

hpx/async_distributed/promise.hpp

Defined in header `hpx/async_distributed/promise.hpp`.

See *Public API* for a list of names and headers that are part of the public *HPX* API.

```
template<>
```

```
class hpx::distributed::promise<void, hpx::util::unused_type> : public lcos::detail::promise_base<void,
hpx::util::unused_type, lcos::detail::promise_data<void>>
```

Public Functions

promise() = default

constructs a promise object and a shared state.

template<typename **Allocator**>

inline **promise**(*std::allocator_arg_t*, *Allocator* const &a)

constructs a promise object and a shared state. The constructor uses the allocator a to allocate the memory for the shared state.

promise(*promise* &&other) noexcept = default

constructs a new promise object and transfers ownership of the shared state of other (if any) to the newly-constructed object.

Post other has no shared state.

~promise() = default

Abandons any shared state.

promise &**operator**=(*promise* &&other) noexcept = default

Abandons any shared state (30.6.4) and then as if `promise(HPX_MOVE(other)).swap(*this)`.

Returns *this.

inline void **swap**(*promise* &other) noexcept

Exchanges the shared state of *this and other.

Post *this has the shared state (if any) that other had prior to the call to swap. other has the shared state (if any) that *this had prior to the call to swap.

inline void **set_value**()

atomically stores the value r in the shared state and makes that state ready (30.6.4).

Throws `future_error` – if its shared state already has a stored value. if shared state has no stored value exception is raised. `promise_already_satisfied` if its shared state already has a stored value or exception. `no_state` if *this has no shared state.

Private Types

using **base_type** = *lcos::detail::promise_base*<void, *hpx::util::unused_type*, *lcos::detail::promise_data*<void>>

template<typename **R**, typename **Allocator**>

struct **uses_allocator**<*hpx::distributed::promise*<*R*>, *Allocator*> : public `true_type`

#include <*promise.hpp*> Requires: Allocator shall be an allocator (17.6.3.5)

namespace **hpx**

namespace **distributed**

Functions

```
template<typename Result, typename RemoteResult>
void swap(promise<Result, RemoteResult> &x, promise<Result, RemoteResult> &y) noexcept

template<typename Result, typename RemoteResult>
class promise
    #include <promise.hpp>

template<> unused_type > : public lcos::detail::promise_base< void,
hpx::util::unused_type, lcos::detail::promise_data< void > >
```

Public Functions

promise() = default

constructs a promise object and a shared state.

```
template<typename Allocator>
inline promise(std::allocator_arg_t, Allocator const &a)
```

constructs a promise object and a shared state. The constructor uses the allocator *a* to allocate the memory for the shared state.

promise(*promise* &&other) noexcept = default

constructs a new promise object and transfers ownership of the shared state of *other* (if any) to the newly-constructed object.

Post *other* has no shared state.

~promise() = default

Abandons any shared state.

promise &**operator**=(*promise* &&other) noexcept = default

Abandons any shared state (30.6.4) and then as if `promise(HPX_MOVE(other)).swap(*this)`.

Returns **this*.

inline void **swap**(*promise* &other) noexcept

Exchanges the shared state of **this* and *other*.

Post **this* has the shared state (if any) that *other* had prior to the call to `swap`. *other* has the shared state (if any) that **this* had prior to the call to `swap`.

inline void **set_value**()

atomically stores the value *r* in the shared state and makes that state ready (30.6.4).

Throws `future_error` – if its shared state already has a stored value. if shared state has no stored value exception is raised. `promise_already_satisfied` if its shared state already has a stored value or exception. `no_state` if **this* has no shared state.

Private Types

```
using base_type = lcos::detail::promise_base<void, hpx::util::unused_type,  
lcos::detail::promise_data<void>>
```

namespace **std**

```
template<typename R, typename Allocator> promise< R >,  
Allocator > : public true_type  
#include <promise.hpp> Requires: Allocator shall be an allocator (17.6.3.5)
```

hpx::sync (distributed)

Defined in header `hpx/async.hpp`.

See *Public API* for a list of names and headers that are part of the public *HPX* API.

namespace **hpx**

Functions

```
template<typename Action, typename Target, typename ...Ts>  
decltype(auto) sync(Action &&action, Target &&target, Ts&&... ts)
```

The distributed implementation of `hpx::sync` can be used by giving an action instance as argument instead of a function, and also by providing another argument with the locality ID or the target ID. The action executes synchronously.

Template Parameters

- **Action** – The type of action instance
- **Target** – The type of target where the action should be executed
- **Ts** – The type of any additional arguments

Parameters

- **action** – The action instance to be executed
- **target** – The target where the action should be executed
- **ts** – Additional arguments

Returns `hpx::future` referring to the shared state created by this call to `hpx::sync`

hpx/async_distributed/transfer_continuation_action.hpp

Defined in header hpx/async_distributed/transfer_continuation_action.hpp.

See *Public API* for a list of names and headers that are part of the public *HPX* API.

hpx/async_distributed/trigger_lco.hpp

Defined in header hpx/async_distributed/trigger_lco.hpp.

See *Public API* for a list of names and headers that are part of the public *HPX* API.

namespace **hpx**

hpx/async_distributed/trigger_lco_fwd.hpp

Defined in header hpx/async_distributed/trigger_lco_fwd.hpp.

See *Public API* for a list of names and headers that are part of the public *HPX* API.

namespace **hpx**

Functions

void **trigger_lco_event**(*hpx::id_type* id, *naming::address* &&addr, bool move_credits = true)

Trigger the LCO referenced by the given id.

Parameters

- **id** – [in] This represents the id of the LCO which should be triggered.
- **addr** – [in] This represents the addr of the LCO which should be triggered.
- **move_credits** – [in] If this is set to *true* then it is ok to send all credits in *id* along with the generated message. The default value is *true*.

inline void **trigger_lco_event**(*hpx::id_type* const &id, bool move_credits = true)

Trigger the LCO referenced by the given id.

Parameters

- **id** – [in] This represents the id of the LCO which should be triggered.
- **move_credits** – [in] If this is set to *true* then it is ok to send all credits in *id* along with the generated message. The default value is *true*.

void **trigger_lco_event**(*hpx::id_type* id, *naming::address* &&addr, *hpx::id_type* const &cont, bool move_credits = true)

Trigger the LCO referenced by the given id.

Parameters

- **id** – [in] This represents the id of the LCO which should be triggered.
- **addr** – [in] This represents the addr of the LCO which should be triggered.
- **cont** – [in] This represents the LCO to trigger after completion.

- **move_credits** – [in] If this is set to *true* then it is ok to send all credits in *id* along with the generated message. The default value is *true*.

```
inline void trigger_lco_event(hpx::id_type const &id, hpx::id_type const &cont, bool move_credits = true)
```

Trigger the LCO referenced by the given id.

Parameters

- **id** – [in] This represents the id of the LCO which should be triggered.
- **cont** – [in] This represents the LCO to trigger after completion.
- **move_credits** – [in] If this is set to *true* then it is ok to send all credits in *id* along with the generated message. The default value is *true*.

```
template<typename Result>
void set_lco_value(hpx::id_type id, naming::address &&addr, Result &&t, bool move_credits = true)
```

Set the result value for the LCO referenced by the given id.

Parameters

- **id** – [in] This represents the id of the LCO which should receive the given value.
- **addr** – [in] This represents the addr of the LCO which should be triggered.
- **t** – [in] This is the value which should be sent to the LCO.
- **move_credits** – [in] If this is set to *true* then it is ok to send all credits in *id* along with the generated message. The default value is *true*.

```
template<typename Result>
std::enable_if_t<!std::is_same_v<std::decay_t<Result>, naming::address>> set_lco_value(hpx::id_type
const &id,
Result &&t,
bool
move_credits =
true)
```

Set the result value for the (managed) LCO referenced by the given id.

Parameters

- **id** – [in] This represents the id of the LCO which should receive the given value.
- **t** – [in] This is the value which should be sent to the LCO.
- **move_credits** – [in] If this is set to *true* then it is ok to send all credits in *id* along with the generated message. The default value is *true*.

```
template<typename Result>
std::enable_if_t<!std::is_same_v<std::decay_t<Result>, naming::address>> set_lco_value_unmanaged(hpx::id_type
const
&id,
Re-
sult
&&t,
bool
move_credits
=
true)
```

Set the result value for the (unmanaged) LCO referenced by the given id.

Parameters

- **id** – [in] This represents the id of the LCO which should receive the given value.
- **t** – [in] This is the value which should be sent to the LCO.
- **move_credits** – [in] If this is set to *true* then it is ok to send all credits in *id* along with the generated message. The default value is *true*.

```
template<typename Result>
void set_lco_value(hpx::id_type id, naming::address &&addr, Result &&t, hpx::id_type const &cont, bool
    move_credits = true)
```

Set the result value for the LCO referenced by the given id.

Parameters

- **id** – [in] This represents the id of the LCO which should receive the given value.
- **addr** – [in] This represents the addr of the LCO which should be triggered.
- **t** – [in] This is the value which should be sent to the LCO.
- **cont** – [in] This represents the LCO to trigger after completion.
- **move_credits** – [in] If this is set to *true* then it is ok to send all credits in *id* along with the generated message. The default value is *true*.

```
template<typename Result>
std::enable_if_t<!std::is_same_v<std::decay_t<Result>, naming::address>> set_lco_value(hpx::id_type
    const &id,
    Result &&t,
    hpx::id_type
    const &cont,
    bool
    move_credits =
    true)
```

Set the result value for the (managed) LCO referenced by the given id.

Parameters

- **id** – [in] This represents the id of the LCO which should receive the given value.
- **t** – [in] This is the value which should be sent to the LCO.
- **cont** – [in] This represents the LCO to trigger after completion.
- **move_credits** – [in] If this is set to *true* then it is ok to send all credits in *id* along with the generated message. The default value is *true*.

```
template<typename Result>
std::enable_if_t<!std::is_same_v<std::decay_t<Result>, naming::address>> set_lco_value_unmanaged(hpx::id_type
    const
    &id,
    Re-
sult
    &&t,
    hpx::id_type
    const
    &cont,
    bool
    move_credits
    =
    true)
```

Set the result value for the (unmanaged) LCO referenced by the given id.

Parameters

- **id** – [in] This represents the id of the LCO which should receive the given value.
- **t** – [in] This is the value which should be sent to the LCO.
- **cont** – [in] This represents the LCO to trigger after completion.
- **move_credits** – [in] If this is set to *true* then it is ok to send all credits in *id* along with the generated message. The default value is *true*.

```
void set_lco_error(hpx::id_type id, naming::address &&addr, std::exception_ptr const &e, bool move_credits = true)
```

Set the error state for the LCO referenced by the given id.

Parameters

- **id** – [in] This represents the id of the LCO which should receive the error value.
- **addr** – [in] This represents the addr of the LCO which should be triggered.
- **e** – [in] This is the error value which should be sent to the LCO.
- **move_credits** – [in] If this is set to *true* then it is ok to send all credits in *id* along with the generated message. The default value is *true*.

```
void set_lco_error(hpx::id_type id, naming::address &&addr, std::exception_ptr &&e, bool move_credits = true)
```

Set the error state for the LCO referenced by the given id.

Parameters

- **id** – [in] This represents the id of the LCO which should receive the error value.
- **addr** – [in] This represents the addr of the LCO which should be triggered.
- **e** – [in] This is the error value which should be sent to the LCO.
- **move_credits** – [in] If this is set to *true* then it is ok to send all credits in *id* along with the generated message. The default value is *true*.

```
inline void set_lco_error(hpx::id_type const &id, std::exception_ptr const &e, bool move_credits = true)
```

Set the error state for the LCO referenced by the given id.

Parameters

- **id** – [in] This represents the id of the LCO which should receive the error value.
- **e** – [in] This is the error value which should be sent to the LCO.
- **move_credits** – [in] If this is set to *true* then it is ok to send all credits in *id* along with the generated message. The default value is *true*.

```
inline void set_lco_error(hpx::id_type const &id, std::exception_ptr &&e, bool move_credits = true)
```

Set the error state for the LCO referenced by the given id.

Parameters

- **id** – [in] This represents the id of the LCO which should receive the error value.
- **e** – [in] This is the error value which should be sent to the LCO.

- **move_credits** – [in] If this is set to *true* then it is ok to send all credits in *id* along with the generated message. The default value is *true*.

```
void set_lco_error(hpx::id_type id, naming::address &&addr, std::exception_ptr const &e, hpx::id_type
    const &cont, bool move_credits = true)
```

Set the error state for the LCO referenced by the given id.

Parameters

- **id** – [in] This represents the id of the LCO which should receive the error value.
- **addr** – [in] This represents the addr of the LCO which should be triggered.
- **e** – [in] This is the error value which should be sent to the LCO.
- **cont** – [in] This represents the LCO to trigger after completion.
- **move_credits** – [in] If this is set to *true* then it is ok to send all credits in *id* along with the generated message. The default value is *true*.

```
void set_lco_error(hpx::id_type id, naming::address &&addr, std::exception_ptr &&e, hpx::id_type const
    &cont, bool move_credits = true)
```

Set the error state for the LCO referenced by the given id.

Parameters

- **id** – [in] This represents the id of the LCO which should receive the error value.
- **addr** – [in] This represents the addr of the LCO which should be triggered.
- **e** – [in] This is the error value which should be sent to the LCO.
- **cont** – [in] This represents the LCO to trigger after completion.
- **move_credits** – [in] If this is set to *true* then it is ok to send all credits in *id* along with the generated message. The default value is *true*.

```
inline void set_lco_error(hpx::id_type const &id, std::exception_ptr const &e, hpx::id_type const &cont,
    bool move_credits = true)
```

Set the error state for the LCO referenced by the given id.

Parameters

- **id** – [in] This represents the id of the LCO which should receive the error value.
- **e** – [in] This is the error value which should be sent to the LCO.
- **cont** – [in] This represents the LCO to trigger after completion.
- **move_credits** – [in] If this is set to *true* then it is ok to send all credits in *id* along with the generated message. The default value is *true*.

```
inline void set_lco_error(hpx::id_type const &id, std::exception_ptr &&e, hpx::id_type const &cont, bool
    move_credits = true)
```

Set the error state for the LCO referenced by the given id.

Parameters

- **id** – [in] This represents the id of the LCO which should receive the error value.
- **e** – [in] This is the error value which should be sent to the LCO.
- **cont** – [in] This represents the LCO to trigger after completion.
- **move_credits** – [in] If this is set to *true* then it is ok to send all credits in *id* along with the generated message. The default value is *true*.

checkpoint

See *Public API* for a list of names and headers that are part of the public *HPX* API.

hpx/checkpoint/checkpoint.hpp

Defined in header `hpx/checkpoint/checkpoint.hpp`.

See *Public API* for a list of names and headers that are part of the public *HPX* API.

This header defines the `save_checkpoint` and `restore_checkpoint` functions. These functions are designed to help HPX application developer's checkpoint their applications. `save_checkpoint` serializes one or more objects and saves them as a byte stream. `restore_checkpoint` converts the byte stream back into instances of the objects.

namespace **hpx**

namespace **util**

Functions

```
inline std::ostream &operator<<( std::ostream &ost, checkpoint const &ckp)
```

Operator<< Overload

This overload is the main way to write data from a checkpoint to an object such as a file. Inside the function, the size of the checkpoint will be written to the stream before the checkpoint's data. The `operator>>` overload uses this to read the correct number of bytes. Be mindful of this additional write and read when you use different facilities to write out or read in data to a checkpoint!

Parameters

- **ost** – Output stream to write to.
- **ckp** – Checkpoint to copy from.

Returns Operator<< returns the ostream object.

```
inline std::istream &operator>>( std::istream &ist, checkpoint &ckp)
```

Operator>> Overload

This overload is the main way to read in data from an object such as a file to a checkpoint. It is important to note that inside the function, the first variable to be read is the size of the checkpoint. This size variable is written to the stream before the checkpoint's data in the `operator<<` overload. Be mindful of this additional read and write when you use different facilities to read in or write out data from a checkpoint!

Parameters

- **ist** – Input stream to write from.
- **ckp** – Checkpoint to write to.

Returns Operator>> returns the ostream object.

```
template<typename T, typename ...Ts, typename U = typename  
std::enable_if<! hpx::traits::is_launch_policy<T>::value && !std::is_same<typename  
std::decay<T>::type, checkpoint>::value>::type>
```

```
hpx::future<checkpoint> save_checkpoint(T &&t, Ts&&... ts)
```

Save_checkpoint

Save_checkpoint takes any number of objects which a user may wish to store and returns a future to a checkpoint object. This function can also store a component either by passing a shared_ptr to the component or by passing a component's client instance to save_checkpoint. Additionally the function can take a policy as a first object which changes its behavior depending on the policy passed to it. Most notably, if a sync policy is used save_checkpoint will simply return a checkpoint object.

Template Parameters

- **T** – Containers passed to save_checkpoint to be serialized and placed into a checkpoint object.
- **Ts** – More containers passed to save_checkpoint to be serialized and placed into a checkpoint object.
- **U** – This parameter is used to make sure that T is not a launch policy or a checkpoint. This forces the compiler to choose the correct overload.

Parameters

- **t** – A container to restore.
- **ts** – Other containers to restore Containers must be in the same order that they were inserted into the checkpoint.

Returns Save_checkpoint returns a future to a checkpoint with one exception: if you pass hpx::launch::sync as the first argument. In this case save_checkpoint will simply return a checkpoint.

```
template<typename T, typename ...Ts>
```

```
hpx::future<checkpoint> save_checkpoint(checkpoint &&c, T &&t, Ts&&... ts)
```

Save_checkpoint - Take a pre-initialized checkpoint

Save_checkpoint takes any number of objects which a user may wish to store and returns a future to a checkpoint object. This function can also store a component either by passing a shared_ptr to the component or by passing a component's client instance to save_checkpoint. Additionally the function can take a policy as a first object which changes its behavior depending on the policy passed to it. Most notably, if a sync policy is used save_checkpoint will simply return a checkpoint object.

Template Parameters

- **T** – Containers passed to save_checkpoint to be serialized and placed into a checkpoint object.
- **Ts** – More containers passed to save_checkpoint to be serialized and placed into a checkpoint object.

Parameters

- **c** – Takes a pre-initialized checkpoint to copy data into.
- **t** – A container to restore.
- **ts** – Other containers to restore Containers must be in the same order that they were inserted into the checkpoint.

Returns Save_checkpoint returns a future to a checkpoint with one exception: if you pass hpx::launch::sync as the first argument. In this case save_checkpoint will simply return a checkpoint.

```
template<typename T, typename ...Ts, typename U = typename std::enable_if<!std::is_same<typename std::decay<T>::type, checkpoint>::value>::type>
```

```
hpx::future<checkpoint> save_checkpoint(hpx::launch p, T &&t, Ts&&... ts)
```

Save_checkpoint - Policy overload

Save_checkpoint takes any number of objects which a user may wish to store and returns a future to a checkpoint object. This function can also store a component either by passing a shared_ptr to the component or by passing a component's client instance to save_checkpoint. Additionally the function can take a policy as a first object which changes its behavior depending on the policy passed to it. Most notably, if a sync policy is used save_checkpoint will simply return a checkpoint object.

Template Parameters

- **T** – Containers passed to save_checkpoint to be serialized and placed into a checkpoint object.
- **Ts** – More containers passed to save_checkpoint to be serialized and placed into a checkpoint object.

Parameters

- **p** – Takes an HPX launch policy. Allows the user to change the way the function is launched i.e. async, sync, etc.
- **t** – A container to restore.
- **ts** – Other containers to restore Containers must be in the same order that they were inserted into the checkpoint.

Returns Save_checkpoint returns a future to a checkpoint with one exception: if you pass hpx::launch::sync as the first argument. In this case save_checkpoint will simply return a checkpoint.

```
template<typename T, typename ...Ts>
hpx::future<checkpoint> save_checkpoint(hpx::launch p, checkpoint &&c, T &&t, Ts&&... ts)
Save_checkpoint - Policy overload & pre-initialized checkpoint
```

Save_checkpoint takes any number of objects which a user may wish to store and returns a future to a checkpoint object. This function can also store a component either by passing a shared_ptr to the component or by passing a component's client instance to save_checkpoint. Additionally the function can take a policy as a first object which changes its behavior depending on the policy passed to it. Most notably, if a sync policy is used save_checkpoint will simply return a checkpoint object.

Template Parameters

- **T** – Containers passed to save_checkpoint to be serialized and placed into a checkpoint object.
- **Ts** – More containers passed to save_checkpoint to be serialized and placed into a checkpoint object.

Parameters

- **p** – Takes an HPX launch policy. Allows the user to change the way the function is launched i.e. async, sync, etc.
- **c** – Takes a pre-initialized checkpoint to copy data into.
- **t** – A container to restore.
- **ts** – Other containers to restore Containers must be in the same order that they were inserted into the checkpoint.

Returns Save_checkpoint returns a future to a checkpoint with one exception: if you pass hpx::launch::sync as the first argument. In this case save_checkpoint will simply return a checkpoint.

```
template<typename T, typename ...Ts, typename U = typename std::enable_if<!std::is_same<typename
std::decay<T>::type, checkpoint>::value>::type>
checkpoint save_checkpoint(hpx::launch::sync_policy sync_p, T &&t, Ts&&... ts)
Save_checkpoint - Sync_policy overload
```

Save_checkpoint takes any number of objects which a user may wish to store and returns a future to a checkpoint object. This function can also store a component either by passing a shared_ptr to the

component or by passing a component's client instance to `save_checkpoint`. Additionally the function can take a policy as a first object which changes its behavior depending on the policy passed to it. Most notably, if a sync policy is used `save_checkpoint` will simply return a checkpoint object.

Template Parameters

- **T** – Containers passed to `save_checkpoint` to be serialized and placed into a checkpoint object.
- **Ts** – More containers passed to `save_checkpoint` to be serialized and placed into a checkpoint object.
- **U** – This parameter is used to make sure that **T** is not a checkpoint. This forces the compiler to choose the correct overload.

Parameters

- **sync_p** – `hpx::launch::sync_policy`
- **t** – A container to restore.
- **ts** – Other containers to restore Containers must be in the same order that they were inserted into the checkpoint.

Returns `Save_checkpoint` which is passed `hpx::launch::sync_policy` will return a checkpoint which contains the serialized values checkpoint.

```
template<typename T, typename ...Ts>
checkpoint save_checkpoint(hpx::launch::sync_policy sync_p, checkpoint &&c, T &&t, Ts&&... ts)
Save_checkpoint - Sync_policy overload & pre-init. checkpoint
```

`Save_checkpoint` takes any number of objects which a user may wish to store and returns a future to a checkpoint object. This function can also store a component either by passing a `shared_ptr` to the component or by passing a component's client instance to `save_checkpoint`. Additionally the function can take a policy as a first object which changes its behavior depending on the policy passed to it. Most notably, if a sync policy is used `save_checkpoint` will simply return a checkpoint object.

Template Parameters

- **T** – Containers passed to `save_checkpoint` to be serialized and placed into a checkpoint object.
- **Ts** – More containers passed to `save_checkpoint` to be serialized and placed into a checkpoint object.

Parameters

- **sync_p** – `hpx::launch::sync_policy`
- **c** – Takes a pre-initialized checkpoint to copy data into.
- **t** – A container to restore.
- **ts** – Other containers to restore Containers must be in the same order that they were inserted into the checkpoint.

Returns `Save_checkpoint` which is passed `hpx::launch::sync_policy` will return a checkpoint which contains the serialized values checkpoint.

```
template<typename T, typename ...Ts, typename U = typename
std::enable_if<!hpx::traits::is_launch_policy<T>::value && !std::is_same<typename
std::decay<T>::type, checkpoint>::value>::type>
hpx::future<checkpoint> prepare_checkpoint(T const &t, Ts const&... ts)
prepare_checkpoint
```

`prepare_checkpoint` takes the containers which have to be filled from the byte stream by a subsequent `restore_checkpoint` invocation. `prepare_checkpoint` will calculate the necessary buffer size and will return an appropriately sized checkpoint object.

Template Parameters

- **T** – A container to restore.
- **Ts** – Other containers to restore. Containers must be in the same order that they were inserted into the checkpoint.

Parameters

- **t** – A container to restore.
- **ts** – Other containers to restore Containers must be in the same order that they were inserted into the checkpoint.

Returns `prepare_checkpoint` returns a properly resized checkpoint object that can be used for a subsequent `restore_checkpoint` operation.

```
template<typename T, typename ...Ts>
hpx::future<checkpoint> prepare_checkpoint (checkpoint &&c, T const &t, Ts const&... ts)
prepare_checkpoint
```

`prepare_checkpoint` takes the containers which have to be filled from the byte stream by a subsequent `restore_checkpoint` invocation. `prepare_checkpoint` will calculate the necessary buffer size and will return an appropriately sized checkpoint object.

Template Parameters

- **T** – A container to restore.
- **Ts** – Other containers to restore. Containers must be in the same order that they were inserted into the checkpoint.

Parameters

- **c** – Takes a pre-initialized checkpoint to prepare
- **t** – A container to restore.
- **ts** – Other containers to restore Containers must be in the same order that they were inserted into the checkpoint.

Returns `prepare_checkpoint` returns a properly resized checkpoint object that can be used for a subsequent `restore_checkpoint` operation.

```
template<typename T, typename ...Ts, typename U = typename std::enable_if<!std::is_same<T,
checkpoint>::value>::type>
hpx::future<checkpoint> prepare_checkpoint (hpx::launch p, T const &t, Ts const&... ts)
prepare_checkpoint
```

`prepare_checkpoint` takes the containers which have to be filled from the byte stream by a subsequent `restore_checkpoint` invocation. `prepare_checkpoint` will calculate the necessary buffer size and will return an appropriately sized checkpoint object.

Template Parameters

- **T** – A container to restore.
- **Ts** – Other containers to restore. Containers must be in the same order that they were inserted into the checkpoint.

Parameters

- **p** – Takes an HPX launch policy. Allows the user to change the way the function is launched i.e. `async`, `sync`, etc.
- **t** – A container to restore.
- **ts** – Other containers to restore Containers must be in the same order that they were inserted into the checkpoint.

Returns `prepare_checkpoint` returns a properly resized checkpoint object that can be used for a subsequent `restore_checkpoint` operation.

```
template<typename T, typename ...Ts>
hpx::future<checkpoint> prepare_checkpoint (hpx::launch p, checkpoint &&c, T const &t, Ts
const&... ts)
prepare_checkpoint
```

`prepare_checkpoint` takes the containers which have to be filled from the byte stream by a subsequent `restore_checkpoint` invocation. `prepare_checkpoint` will calculate the necessary buffer size and will return an appropriately sized checkpoint object.

Template Parameters

- **T** – A container to restore.
- **Ts** – Other containers to restore. Containers must be in the same order that they were inserted into the checkpoint.

Parameters

- **p** – Takes an HPX launch policy. Allows the user to change the way the function is launched i.e. async, sync, etc.
- **c** – Takes a pre-initialized checkpoint to prepare
- **t** – A container to restore.
- **ts** – Other containers to restore Containers must be in the same order that they were inserted into the checkpoint.

Returns prepare_checkpoint returns a properly resized checkpoint object that can be used for a subsequent restore_checkpoint operation.

```
template<typename T, typename ...Ts>
void restore_checkpoint(checkpoint const &c, T &t, Ts&... ts)
```

Restore_checkpoint

Restore_checkpoint takes a checkpoint object as a first argument and the containers which will be filled from the byte stream (in the same order as they were placed in save_checkpoint). Restore_checkpoint can resurrect a stored component in two ways: by passing in a instance of a component's shared_ptr or by passing in an instance of the component's client.

Template Parameters

- **T** – A container to restore.
- **Ts** – Other containers to restore. Containers must be in the same order that they were inserted into the checkpoint.

Parameters

- **c** – The checkpoint to restore.
- **t** – A container to restore.
- **ts** – Other containers to restore Containers must be in the same order that they were inserted into the checkpoint.

Returns Restore_checkpoint returns void.

class **checkpoint**

```
#include <checkpoint.hpp> Checkpoint Object
```

Checkpoint is the container object which is produced by save_checkpoint and is consumed by a restore_checkpoint. A checkpoint may be moved into the save_checkpoint object to write the byte stream to the pre-created checkpoint object.

Checkpoints are able to store all containers which are able to be serialized including components.

Public Types

using **const_iterator** = *std::vector<char>::const_iterator*

Public Functions

checkpoint() = default

~checkpoint() = default

checkpoint(*checkpoint* const &c) = default

checkpoint(*checkpoint* &&c) noexcept = default

inline **checkpoint**(*std::vector<char>* const &vec)

inline **checkpoint**(*std::vector<char>* &&vec) noexcept

checkpoint &**operator**=(*checkpoint* const &c) = default

checkpoint &**operator**=(*checkpoint* &&c) noexcept = default

inline *const_iterator* **begin**() const noexcept

inline *const_iterator* **end**() const noexcept

inline *std::size_t* **size**() const noexcept

inline char ***data**() noexcept

inline char const ***data**() const noexcept

Private Functions

template<typename **Archive**>

inline void **serialize**(*Archive* &arch, const unsigned int)

Private Members

std::vector<char> **data_**

Friends

friend class hpx::serialization::access

friend *std::ostream* &**operator**<<(*std::ostream* &ost, *checkpoint* const &ckp)

Operator<< Overload

This overload is the main way to write data from a checkpoint to an object such as a file. Inside the function, the size of the checkpoint will be written to the stream before the checkpoint's data. The operator>> overload uses this to read the correct number of bytes. Be mindful of this additional write and read when you use different facilities to write out or read in data to a checkpoint!

Parameters

- **ost** – Output stream to write to.
- **ckp** – Checkpoint to copy from.

Returns Operator<< returns the ostream object.

```
friend std::istream &operator>>(std::istream &ist, checkpoint &ckp)
```

Operator>> Overload

This overload is the main way to read in data from an object such as a file to a checkpoint. It is important to note that inside the function, the first variable to be read is the size of the checkpoint. This size variable is written to the stream before the checkpoint's data in the operator<< overload. Be mindful of this additional read and write when you use different facilities to read in or write out data from a checkpoint!

Parameters

- **ist** – Input stream to write from.
- **ckp** – Checkpoint to write to.

Returns Operator>> returns the ostream object.

```
template<typename T, typename ...Ts>
```

```
friend void restore_checkpoint(checkpoint const &c, T &t, Ts&... ts)
```

Restore_checkpoint

Restore_checkpoint takes a checkpoint object as a first argument and the containers which will be filled from the byte stream (in the same order as they were placed in save_checkpoint). Restore_checkpoint can resurrect a stored component in two ways: by passing in a instance of a component's shared_ptr or by passing in an instance of the component's client.

Template Parameters

- **T** – A container to restore.
- **Ts** – Other containers to restore. Containers must be in the same order that they were inserted into the checkpoint.

Parameters

- **c** – The checkpoint to restore.
- **t** – A container to restore.
- **ts** – Other containers to restore Containers must be in the same order that they were inserted into the checkpoint.

Returns Restore_checkpoint returns void.

```
inline friend bool operator==(checkpoint const &lhs, checkpoint const &rhs)
```

```
inline friend bool operator!=(checkpoint const &lhs, checkpoint const &rhs)
```

checkpoint_base

See *Public API* for a list of names and headers that are part of the public *HPX* API.

hpx/checkpoint_base/checkpoint_data.hpp

Defined in header `hpx/checkpoint_base/checkpoint_data.hpp`.

See *Public API* for a list of names and headers that are part of the public *HPX* API.

namespace **hpx**

namespace **util**

Functions

```
template<typename Container, typename ...Ts>
void save_checkpoint_data(Container &data, Ts&&... ts)
    save_checkpoint_data
```

`save_checkpoint_data` takes any number of objects which a user may wish to store in the given container.

Template Parameters

- **Container** – Container used to store the check-pointed data.
- **Ts** – Types of variables to checkpoint

Parameters

- **data** – Container instance used to store the checkpoint data
- **ts** – Variable instances to be inserted into the checkpoint.

```
template<typename ...Ts>
std::size_t prepare_checkpoint_data(Ts const&... ts)
    prepare_checkpoint_data
```

`prepare_checkpoint_data` takes any number of objects which a user may wish to store in a subsequent `save_checkpoint_data` operation. The function will return the number of bytes necessary to store the data that will be produced.

Template Parameters **Ts** – Types of variables to checkpoint

Parameters **ts** – Variable instances to be inserted into the checkpoint.

```
template<typename Container, typename ...Ts>
void restore_checkpoint_data(Container const &cont, Ts&&... ts)
    restore_checkpoint_data
```

`restore_checkpoint_data` takes any number of objects which a user may wish to restore from the given container. The sequence of objects has to correspond to the sequence of objects for the corresponding call to `save_checkpoint_data` that had used the given container instance.

Template Parameters

- **Container** – Container used to restore the check-pointed data.
- **Ts** – Types of variables to restore

Parameters

- **cont** – Container instance used to restore the checkpoint data
- **ts** – Variable instances to be restored from the container

```
struct checkpointing_tag

template<>

struct extra_data_helper<checkpointing_tag>
```

Public Static Functions

```
static extra_data_id_type id() noexcept

static inline constexpr void reset(checkpointing_tag*) noexcept
```

collectives

See *Public API* for a list of names and headers that are part of the public *HPX* API.

hpx/collectives/all_gather.hpp

Defined in header `hpx/collectives/all_gather.hpp`.

See *Public API* for a list of names and headers that are part of the public *HPX* API.

namespace **hpx**

Top level HPX namespace.

namespace **collectives**

Top level HPX namespace.

Functions

```
template<typename T>
hpx::future<std::vector<std::decay_t<T>>> all_gather(char const *basename, T &&result,
                                                    num_sites_arg num_sites = num_sites_arg(),
                                                    this_site_arg this_site = this_site_arg(),
                                                    generation_arg generation = generation_arg(),
                                                    root_site_arg root_site = root_site_arg())
```

AllGather a set of values from different call sites

This function receives a set of values from all call sites operating on the given base name.

Parameters

- **basename** – The base name identifying the `all_gather` operation
- **result** – The value to transmit to all participating sites from this call site.
- **num_sites** – The number of participating sites (default: all localities).
- **this_site** – The sequence number of this invocation (usually the locality id). This value is optional and defaults to whatever `hpx::get_locality_id()` returns.

- **generation** – The generational counter identifying the sequence number of the all_gather operation performed on the given base name. This is optional and needs to be supplied only if the all_gather operation on the given base name has to be performed more than once. The generation number (if given) must be a positive number greater than zero.
- **root_site** – The site that is responsible for creating the all_gather support object. This value is optional and defaults to '0' (zero).

Returns This function returns a future holding a vector with all values send by all participating sites. It will become ready once the all_gather operation has been completed.

```
template<typename T>
hpx::future<std::vector<std::decay_t<T>>> all_gather(communicator comm, T &&result,
                                                this_site_arg this_site = this_site_arg(),
                                                generation_arg generation =
                                                generation_arg())
```

AllGather a set of values from different call sites

This function receives a set of values from all call sites operating on the given base name.

AllGather a set of values from different call sites

This function receives a set of values from all call sites operating on the given base name.

Parameters

- **comm** – A communicator object returned from *create_communicator*
- **result** – The value to transmit to all participating sites from this call site.
- **this_site** – The sequence number of this invocation (usually the locality id). This value is optional and defaults to whatever `hpx::get_locality_id()` returns.
- **generation** – The generational counter identifying the sequence number of the all_reduce operation performed on the given base name. This is optional and needs to be supplied only if the all_reduce operation on the given base name has to be performed more than once. The generation number (if given) must be a positive number greater than zero.
- **comm** – A communicator object returned from *create_communicator*
- **result** – The value to transmit to all participating sites from this call site.
- **generation** – The generational counter identifying the sequence number of the all_reduce operation performed on the given base name. This is optional and needs to be supplied only if the all_reduce operation on the given base name has to be performed more than once. The generation number (if given) must be a positive number greater than zero.
- **this_site** – The sequence number of this invocation (usually the locality id). This value is optional and defaults to whatever `hpx::get_locality_id()` returns.

Returns This function returns a future holding a vector with all values send by all participating sites. It will become ready once the all_gather operation has been completed.

Returns This function returns a future holding a vector with all values send by all participating sites. It will become ready once the all_gather operation has been completed.

```
template<typename T>
std::vector<std::decay_t<T>> all_gather(hpx::launch::sync_policy, char const *basename, T
&&result, num_sites_arg num_sites = num_sites_arg(),
this_site_arg this_site = this_site_arg(), generation_arg
generation = generation_arg(), root_site_arg root_site =
root_site_arg())
```

AllGather a set of values from different call sites

This function receives a set of values from all call sites operating on the given base name.

Parameters

- **policy** – The execution policy specifying synchronous execution.
- **basename** – The base name identifying the `all_gather` operation
- **result** – The value to transmit to all participating sites from this call site.
- **num_sites** – The number of participating sites (default: all localities).
- **this_site** – The sequence number of this invocation (usually the locality id). This value is optional and defaults to whatever `hpx::get_locality_id()` returns.
- **generation** – The generational counter identifying the sequence number of the `all_gather` operation performed on the given base name. This is optional and needs to be supplied only if the `all_gather` operation on the given base name has to be performed more than once. The generation number (if given) must be a positive number greater than zero.
- **root_site** – The site that is responsible for creating the `all_gather` support object. This value is optional and defaults to '0' (zero).

Returns This function returns a vector with all values send by all participating sites. This function executes synchronously and directly returns the result.

```
template<typename T>
std::vector<std::decay_t<T>> all_gather(hpx::launch::sync_policy, communicator comm, T
&&result, this_site_arg this_site = this_site_arg(),
generation_arg generation = generation_arg())
```

AllGather a set of values from different call sites

This function receives a set of values from all call sites operating on the given base name.

AllGather a set of values from different call sites

This function receives a set of values from all call sites operating on the given base name.

Parameters

- **policy** – The execution policy specifying synchronous execution.
- **comm** – A communicator object returned from `create_communicator`
- **result** – The value to transmit to all participating sites from this call site.
- **this_site** – The sequence number of this invocation (usually the locality id). This value is optional and defaults to whatever `hpx::get_locality_id()` returns.
- **generation** – The generational counter identifying the sequence number of the `all_reduce` operation performed on the given base name. This is optional and needs to be supplied only if the `all_reduce` operation on the given base name has to be performed more than once. The generation number (if given) must be a positive number greater than zero.
- **policy** – The execution policy specifying synchronous execution.
- **comm** – A communicator object returned from `create_communicator`
- **result** – The value to transmit to all participating sites from this call site.
- **generation** – The generational counter identifying the sequence number of the `all_reduce` operation performed on the given base name. This is optional and needs to be supplied only if the `all_reduce` operation on the given base name has to be performed more than once. The generation number (if given) must be a positive number greater than zero.
- **this_site** – The sequence number of this invocation (usually the locality id). This value is optional and defaults to whatever `hpx::get_locality_id()` returns.

Returns This function returns a vector with all values send by all participating sites. This function executes synchronously and directly returns the result.

Returns This function returns a vector with all values send by all participating sites. This function executes synchronously and directly returns the result.

hpx/collectives/all_reduce.hpp

Defined in header hpx/collectives/all_reduce.hpp.

See *Public API* for a list of names and headers that are part of the public *HPX* API.

namespace **hpx**

Top level HPX namespace.

namespace **collectives**

Top level HPX namespace.

Functions

```
template<typename T, typename F>
hpx::future<std::decay_t<T>> all_reduce(char const *basename, T &&result, F &&op,
                                     num_sites_arg num_sites = num_sites_arg(), this_site_arg
                                     this_site = this_site_arg(), generation_arg generation =
                                     generation_arg(), root_site_arg root_site = root_site_arg())
```

AllReduce a set of values from different call sites

This function receives a set of values from all call sites operating on the given base name.

Parameters

- **basename** – The base name identifying the all_reduce operation
- **result** – The value to transmit to all participating sites from this call site.
- **op** – Reduction operation to apply to all values supplied from all participating sites
- **num_sites** – The number of participating sites (default: all localities).
- **generation** – The generational counter identifying the sequence number of the all_reduce operation performed on the given base name. This is optional and needs to be supplied only if the all_reduce operation on the given base name has to be performed more than once. The generation number (if given) must be a positive number greater than zero.
- **this_site** – The sequence number of this invocation (usually the locality id). This value is optional and defaults to whatever hpx::get_locality_id() returns.
- **root_site** – The site that is responsible for creating the all_reduce support object. This value is optional and defaults to '0' (zero).

Returns This function returns a future holding a vector with all values send by all participating sites. It will become ready once the all_reduce operation has been completed.

```
template<typename T, typename F>
hpx::future<std::decay_t<T>> all_reduce(communicator comm, T &&result, F &&op, this_site_arg
                                     this_site = this_site_arg(), generation_arg generation =
                                     generation_arg())
```

AllReduce a set of values from different call sites

This function receives a set of values from all call sites operating on the given base name.

AllReduce a set of values from different call sites

This function receives a set of values from all call sites operating on the given base name.

Parameters

- **comm** – A communicator object returned from *create_communicator*
- **result** – The value to transmit to all participating sites from this call site.

- **op** – Reduction operation to apply to all values supplied from all participating sites
- **this_site** – The sequence number of this invocation (usually the locality id). This value is optional and defaults to whatever `hpx::get_locality_id()` returns.
- **generation** – The generational counter identifying the sequence number of the `all_reduce` operation performed on the given base name. This is optional and needs to be supplied only if the `all_reduce` operation on the given base name has to be performed more than once. The generation number (if given) must be a positive number greater than zero.
- **comm** – A communicator object returned from `create_communicator`
- **result** – The value to transmit to all participating sites from this call site.
- **op** – Reduction operation to apply to all values supplied from all participating sites
- **generation** – The generational counter identifying the sequence number of the `all_reduce` operation performed on the given base name. This is optional and needs to be supplied only if the `all_reduce` operation on the given base name has to be performed more than once. The generation number (if given) must be a positive number greater than zero.
- **this_site** – The sequence number of this invocation (usually the locality id). This value is optional and defaults to whatever `hpx::get_locality_id()` returns.

Returns This function returns a future holding a vector with all values send by all participating sites. It will become ready once the `all_reduce` operation has been completed.

Returns This function returns a future holding a vector with all values send by all participating sites. It will become ready once the `all_reduce` operation has been completed.

```
template<typename T, typename F>
decltype(auto) all_reduce(hpx::launch::sync_policy, char const *basename, T &&result, F &&op,
                           num_sites_arg num_sites = num_sites_arg(), this_site_arg this_site =
                           this_site_arg(), generation_arg generation = generation_arg(),
                           root_site_arg root_site = root_site_arg())
```

AllReduce a set of values from different call sites

This function receives a set of values from all call sites operating on the given base name.

Parameters

- **policy** – The execution policy specifying synchronous execution.
- **basename** – The base name identifying the `all_reduce` operation
- **result** – The value to transmit to all participating sites from this call site.
- **op** – Reduction operation to apply to all values supplied from all participating sites
- **num_sites** – The number of participating sites (default: all localities).
- **this_site** – The sequence number of this invocation (usually the locality id). This value is optional and defaults to whatever `hpx::get_locality_id()` returns.
- **generation** – The generational counter identifying the sequence number of the `all_reduce` operation performed on the given base name. This is optional and needs to be supplied only if the `all_reduce` operation on the given base name has to be performed more than once. The generation number (if given) must be a positive number greater than zero.
- **root_site** – The site that is responsible for creating the `all_reduce` support object. This value is optional and defaults to '0' (zero).

Returns This function returns a vector with all values send by all participating sites. This function executes synchronously and directly returns the result.

```
template<typename T, typename F>
decltype(auto) all_reduce(hpx::launch::sync_policy, communicator comm, T &&result, F &&op,
                           this_site_arg this_site = this_site_arg(), generation_arg generation =
                           generation_arg())
```

AllReduce a set of values from different call sites

This function receives a set of values from all call sites operating on the given base name.

AllReduce a set of values from different call sites

This function receives a set of values from all call sites operating on the given base name.

Parameters

- **policy** – The execution policy specifying synchronous execution.
- **comm** – A communicator object returned from *create_communicator*
- **result** – The value to transmit to all participating sites from this call site.
- **op** – Reduction operation to apply to all values supplied from all participating sites
- **this_site** – The sequence number of this invocation (usually the locality id). This value is optional and defaults to whatever `hpx::get_locality_id()` returns.
- **generation** – The generational counter identifying the sequence number of the `all_reduce` operation performed on the given base name. This is optional and needs to be supplied only if the `all_reduce` operation on the given base name has to be performed more than once. The generation number (if given) must be a positive number greater than zero.
- **policy** – The execution policy specifying synchronous execution.
- **comm** – A communicator object returned from *create_communicator*
- **result** – The value to transmit to all participating sites from this call site.
- **op** – Reduction operation to apply to all values supplied from all participating sites
- **generation** – The generational counter identifying the sequence number of the `all_reduce` operation performed on the given base name. This is optional and needs to be supplied only if the `all_reduce` operation on the given base name has to be performed more than once. The generation number (if given) must be a positive number greater than zero.
- **this_site** – The sequence number of this invocation (usually the locality id). This value is optional and defaults to whatever `hpx::get_locality_id()` returns.

Returns This function returns a vector with all values send by all participating sites. This function executes synchronously and directly returns the result.

Returns This function returns a vector with all values send by all participating sites. This function executes synchronously and directly returns the result.

hpx/collectives/all_to_all.hpp

Defined in header `hpx/collectives/all_to_all.hpp`.

See *Public API* for a list of names and headers that are part of the public *HPX* API.

namespace **hpx**

Top level HPX namespace.

namespace **collectives**

Top level HPX namespace.

Functions

```
template<typename T>
hpx::future<std::vector<T>> all_to_all(char const *basename, std::vector<T> &&local_result,
                                     num_sites_arg num_sites = num_sites_arg(), this_site_arg
                                     this_site = this_site_arg(), generation_arg generation =
                                     generation_arg(), root_site_arg root_site = root_site_arg())
```

AllToAll a set of values from different call sites

This function receives a set of values from all call sites operating on the given base name.

Parameters

- **basename** – The base name identifying the all_to_all operation
- **local_result** – A vector of values to transmit to all participating sites from this call site.
- **num_sites** – The number of participating sites (default: all localities).
- **this_site** – The sequence number of this invocation (usually the locality id). This value is optional and defaults to whatever `hpx::get_locality_id()` returns.
- **generation** – The generational counter identifying the sequence number of the all_to_all operation performed on the given base name. This is optional and needs to be supplied only if the all_to_all operation on the given base name has to be performed more than once. The generation number (if given) must be a positive number greater than zero.
- **root_site** – The site that is responsible for creating the all_to_all support object. This value is optional and defaults to '0' (zero).

Returns This function returns a future holding a vector with all values send by all participating sites. It will become ready once the all_to_all operation has been completed.

```
template<typename T>
hpx::future<std::vector<T>> all_to_all(communicator fid, std::vector<T> &&local_result,
                                     this_site_arg this_site = this_site_arg(), generation_arg
                                     generation = generation_arg())
```

AllToAll a set of values from different call sites

This function receives a set of values from all call sites operating on the given base name.

AllToAll a set of values from different call sites

This function receives a set of values from all call sites operating on the given base name.

Parameters

- **fid** – A communicator object returned from `create_communicator`
- **local_result** – A vector of values to transmit to all participating sites from this call site.
- **this_site** – The sequence number of this invocation (usually the locality id). This value is optional and defaults to whatever `hpx::get_locality_id()` returns.
- **generation** – The generational counter identifying the sequence number of the all_to_all operation performed on the given base name. This is optional and needs to be supplied only if the all_to_all operation on the given base name has to be performed more than once. The generation number (if given) must be a positive number greater than zero.
- **fid** – A communicator object returned from `create_communicator`
- **local_result** – A vector of values to transmit to all participating sites from this call site.
- **generation** – The generational counter identifying the sequence number of the all_to_all operation performed on the given base name. This is optional and needs to

be supplied only if the `all_to_all` operation on the given base name has to be performed more than once. The generation number (if given) must be a positive number greater than zero.

- **this_site** – The sequence number of this invocation (usually the locality id). This value is optional and defaults to whatever `hpx::get_locality_id()` returns.

Returns This function returns a future holding a vector with all values send by all participating sites. It will become ready once the `all_to_all` operation has been completed.

Returns This function returns a future holding a vector with all values send by all participating sites. It will become ready once the `all_to_all` operation has been completed.

```
template<typename T>
std::vector<T> all_to_all(hpx::launch::sync_policy, char const *basename, std::vector<T>
    &&local_result, num_sites_arg num_sites = num_sites_arg(), this_site_arg
    this_site = this_site_arg(), generation_arg generation = generation_arg(),
    root_site_arg root_site = root_site_arg())
```

AllToAll a set of values from different call sites

This function receives a set of values from all call sites operating on the given base name.

Parameters

- **policy** – The execution policy specifying synchronous execution.
- **basename** – The base name identifying the `all_to_all` operation
- **local_result** – A vector of values to transmit to all participating sites from this call site.
- **num_sites** – The number of participating sites (default: all localities).
- **this_site** – The sequence number of this invocation (usually the locality id). This value is optional and defaults to whatever `hpx::get_locality_id()` returns.
- **generation** – The generational counter identifying the sequence number of the `all_to_all` operation performed on the given base name. This is optional and needs to be supplied only if the `all_to_all` operation on the given base name has to be performed more than once. The generation number (if given) must be a positive number greater than zero.
- **root_site** – The site that is responsible for creating the `all_to_all` support object. This value is optional and defaults to '0' (zero).

Returns This function returns a vector with all values send by all participating sites. This function executes synchronously and directly returns the result.

```
template<typename T>
std::vector<T> all_to_all(hpx::launch::sync_policy, communicator fid, std::vector<T>
    &&local_result, this_site_arg this_site = this_site_arg(), generation_arg
    generation = generation_arg())
```

AllToAll a set of values from different call sites

This function receives a set of values from all call sites operating on the given base name.

AllToAll a set of values from different call sites

This function receives a set of values from all call sites operating on the given base name.

Parameters

- **policy** – The execution policy specifying synchronous execution.
- **fid** – A communicator object returned from `create_communicator`
- **local_result** – A vector of values to transmit to all participating sites from this call site.
- **this_site** – The sequence number of this invocation (usually the locality id). This value is optional and defaults to whatever `hpx::get_locality_id()` returns.

- **generation** – The generational counter identifying the sequence number of the all_to_all operation performed on the given base name. This is optional and needs to be supplied only if the all_to_all operation on the given base name has to be performed more than once. The generation number (if given) must be a positive number greater than zero.
 - **policy** – The execution policy specifying synchronous execution.
 - **fid** – A communicator object returned from *create_communicator*
 - **local_result** – A vector of values to transmit to all participating sites from this call site.
 - **generation** – The generational counter identifying the sequence number of the all_to_all operation performed on the given base name. This is optional and needs to be supplied only if the all_to_all operation on the given base name has to be performed more than once. The generation number (if given) must be a positive number greater than zero.
 - **this_site** – The sequence number of this invocation (usually the locality id). This value is optional and defaults to whatever `hpx::get_locality_id()` returns.
- Returns** This function returns a vector with all values send by all participating sites. This function executes synchronously and directly returns the result.
- Returns** This function returns a vector with all values send by all participating sites. This function executes synchronously and directly returns the result.

hpx/collectives/argument_types.hpp

Defined in header `hpx/collectives/argument_types.hpp`.

See *Public API* for a list of names and headers that are part of the public *HPX* API.

namespace **hpx**

Top level HPX namespace.

namespace **collectives**

Top level HPX namespace.

Typedefs

using **num_sites_arg** = detail::argument_type<detail::num_sites_tag>

The number of participating sites (default: all localities)

using **this_site_arg** = detail::argument_type<detail::this_site_tag>

The local end of the communication channel.

using **that_site_arg** = detail::argument_type<detail::that_site_tag>

The opposite end of the communication channel.

using **generation_arg** = detail::argument_type<detail::generation_tag>

The generational counter identifying the sequence number of the operation performed on the given base name. It needs to be supplied only if the operation on the given base name has to be performed more than once. It must be a positive number greater than zero.

using **root_site_arg** = detail::argument_type<detail::root_site_tag, 0>

The site that is responsible for creating the support object of the operation. It defaults to '0' (zero).

using **tag_arg** = detail::argument_type<detail::tag_tag, 0>

The tag identifying the concrete operation.

using **arity_arg** = detail::argument_type<detail::arity_tag>

The number of children each of the communication nodes is connected to (default: picked based on num_sites).

hpx::distributed::barrier

Defined in header `hpx/barrier.hpp`⁸⁰⁰.

See *Public API* for a list of names and headers that are part of the public HPX API.

namespace **hpx**

Top level HPX namespace.

namespace **distributed**

Functions

explicit **barrier**(*std::string* const &base_name)

Creates a barrier, rank is locality id, size is number of localities

A barrier *base_name* is created. It expects that `hpx::get_num_localities()` participate and the local rank is `hpx::get_locality_id()`.

Parameters **base_name** – The name of the barrier

barrier(*std::string* const &base_name, *std::size_t* num)

Creates a barrier with a given size, rank is locality id

A barrier *base_name* is created. It expects that *num* participate and the local rank is `hpx::get_locality_id()`.

Parameters

- **base_name** – The name of the barrier
- **num** – The number of participating threads

barrier(*std::string* const &base_name, *std::size_t* num, *std::size_t* rank)

Creates a barrier with a given size and rank

A barrier *base_name* is created. It expects that *num* participate and the local rank is *rank*.

Parameters

- **base_name** – The name of the barrier

⁸⁰⁰ <http://github.com/STELLAR-GROUP/hpx/blob/8a3b7c1a4cb5693b2f7d9f587f759392ed0c51a0/libs/full/include/include/hpx/barrier.hpp>

- **num** – The number of participating threads
- **rank** – The rank of the calling site for this invocation

barrier(*std::string* const &base_name, *std::vector<std::size_t>* const &ranks, *std::size_t* rank)

Creates a barrier with a vector of ranks

A barrier *base_name* is created. It expects that *ranks.size()* and the local rank is *rank* (must be contained in *ranks*).

Parameters

- **base_name** – The name of the barrier
- **ranks** – Gives a list of participating ranks (this could be derived from a list of locality ids)
- **rank** – The rank of the calling site for this invocation

void **wait**() const

Wait until each participant entered the barrier. Must be called by all participants

Returns This function returns once all participants have entered the barrier (have called *wait*).

hpx::future<void> **wait**(*hpx::launch::async_policy*) const

Wait until each participant entered the barrier. Must be called by all participants

Returns a future that becomes ready once all participants have entered the barrier (have called *wait*).

static void **synchronize**()

Perform a global synchronization using the default global barrier The barrier is created once at startup and can be reused throughout the lifetime of an HPX application.

Note: This function currently does not support dynamic connection and disconnection of localities.

hpx/collectives/broadcast.hpp

Defined in header `hpx/collectives/broadcast.hpp`.

See *Public API* for a list of names and headers that are part of the public *HPX* API.

namespace **hpx**

Top level HPX namespace.

namespace **collectives**

Top level HPX namespace.

Functions

```
template<typename T>
hpx::future<T> broadcast_to(char const *basename, T &&local_result, num_sites_arg num_sites =
    num_sites_arg(), this_site_arg this_site = this_site_arg(),
    generation_arg generation = generation_arg())
```

Broadcast a value to different call sites

This function sends a set of values to all call sites operating on the given base name.

Parameters

- **basename** – The base name identifying the broadcast operation
- **local_result** – A value to transmit to all participating sites from this call site.
- **num_sites** – The number of participating sites (default: all localities).
- **generation** – The generational counter identifying the sequence number of the broadcast operation performed on the given base name. This is optional and needs to be supplied only if the broadcast operation on the given base name has to be performed more than once. The generation number (if given) must be a positive number greater than zero.
- **this_site** – The sequence number of this invocation (usually the locality id). This value is optional and defaults to whatever `hpx::get_locality_id()` returns.

Returns This function returns a future holding the value that was sent to all participating sites. It will become ready once the broadcast operation has been completed.

```
template<typename T>
hpx::future<T> broadcast_to(communicator comm, T &&local_result, this_site_arg this_site =
    this_site_arg(), generation_arg generation = generation_arg())
```

Broadcast a value to different call sites

This function sends a set of values to all call sites operating on the given base name.

Note: The generation values from corresponding *broadcast_to* and *broadcast_from* have to match.

Parameters

- **comm** – A communicator object returned from *create_communicator*
- **local_result** – A value to transmit to all participating sites from this call site.
- **this_site** – The sequence number of this invocation (usually the locality id). This value is optional and defaults to whatever `hpx::get_locality_id()` returns.
- **generation** – The generational counter identifying the sequence number of the broadcast operation performed on the given base name. This is optional and needs to be supplied only if the broadcast operation on the given base name has to be performed more than once. The generation number (if given) must be a positive number greater than zero.

Returns This function returns a future holding the value that was sent to all participating sites. It will become ready once the broadcast operation has been completed.

```
template<typename T>
hpx::future<T> broadcast_to(communicator comm, generation_arg generation, T &&local_result,
    this_site_arg this_site = this_site_arg())
```

Broadcast a value to different call sites

This function sends a set of values to all call sites operating on the given base name.

Note: The generation values from corresponding *broadcast_to* and *broadcast_from* have to match.

Parameters

- **comm** – A communicator object returned from *create_communicator*
- **local_result** – A value to transmit to all participating sites from this call site.
- **generation** – The generational counter identifying the sequence number of the broadcast operation performed on the given base name. This is optional and needs to be supplied only if the broadcast operation on the given base name has to be performed more than once. The generation number (if given) must be a positive number greater than zero.
- **this_site** – The sequence number of this invocation (usually the locality id). This value is optional and defaults to whatever `hpx::get_locality_id()` returns.

Returns This function returns a future holding the value that was sent to all participating sites. It will become ready once the broadcast operation has been completed.

```
template<typename T>
hpx::future<T> broadcast_from(char const *basename, this_site_arg this_site = this_site_arg(),
                             generation_arg generation = generation_arg(), root_site_arg
                             root_site = root_site_arg())
```

Receive a value that was broadcast to different call sites

This function sends a set of values to all call sites operating on the given base name.

Parameters

- **basename** – The base name identifying the broadcast operation
- **generation** – The generational counter identifying the sequence number of the broadcast operation performed on the given base name. This is optional and needs to be supplied only if the broadcast operation on the given base name has to be performed more than once. The generation number (if given) must be a positive number greater than zero.
- **this_site** – The sequence number of this invocation (usually the locality id). This value is optional and defaults to whatever `hpx::get_locality_id()` returns.
- **root_site** – The site responsible for broadcasting the value. This is optional and defaults to site 0 (zero).

Returns This function returns a future holding the value that was sent to all participating sites. It will become ready once the broadcast operation has been completed.

```
template<typename T>
hpx::future<T> broadcast_from(communicator comm, this_site_arg this_site = this_site_arg(),
                             generation_arg generation = generation_arg())
```

Receive a value that was broadcast to different call sites

This function sends a set of values to all call sites operating on the given base name.

Receive a value that was broadcast to different call sites

This function sends a set of values to all call sites operating on the given base name.

Note: The generation values from corresponding *broadcast_to* and *broadcast_from* have to match.

Note: The generation values from corresponding *broadcast_to* and *broadcast_from* have to match.

Parameters

- **comm** – A communicator object returned from *create_communicator*
- **this_site** – The sequence number of this invocation (usually the locality id). This value is optional and defaults to whatever `hpx::get_locality_id()` returns.
- **generation** – The generational counter identifying the sequence number of the broadcast operation performed on the given base name. This is optional and needs to be supplied only if the broadcast operation on the given base name has to be performed more than once. The generation number (if given) must be a positive number greater than zero.

plied only if the broadcast operation on the given base name has to be performed more than once. The generation number (if given) must be a positive number greater than zero.

- **comm** – A communicator object returned from *create_communicator*
- **generation** – The generational counter identifying the sequence number of the broadcast operation performed on the given base name. This is optional and needs to be supplied only if the broadcast operation on the given base name has to be performed more than once. The generation number (if given) must be a positive number greater than zero.
- **this_site** – The sequence number of this invocation (usually the locality id). This value is optional and defaults to whatever *hpx::get_locality_id()* returns.

Returns This function returns a future holding the value that was sent to all participating sites. It will become ready once the broadcast operation has been completed.

Returns This function returns a future holding the value that was sent to all participating sites. It will become ready once the broadcast operation has been completed.

```
template<typename T>
decltype(auto) broadcast_to(hpx::launch::sync_policy, char const *basename, T &&local_result,
                           num_sites_arg num_sites = num_sites_arg(), this_site_arg this_site =
                           this_site_arg(), generation_arg generation = generation_arg())
```

Broadcast a value to different call sites

This function sends a set of values to all call sites operating on the given base name.

Parameters

- **policy** – The execution policy specifying synchronous execution.
- **basename** – The base name identifying the broadcast operation
- **local_result** – A value to transmit to all participating sites from this call site.
- **num_sites** – The number of participating sites (default: all localities).
- **generation** – The generational counter identifying the sequence number of the broadcast operation performed on the given base name. This is optional and needs to be supplied only if the broadcast operation on the given base name has to be performed more than once. The generation number (if given) must be a positive number greater than zero.
- **this_site** – The sequence number of this invocation (usually the locality id). This value is optional and defaults to whatever *hpx::get_locality_id()* returns.

Returns This function returns a vector with all values send by all participating sites. This function executes synchronously and directly returns the result.

```
template<typename T>
decltype(auto) broadcast_to(hpx::launch::sync_policy, communicator comm, T &&local_result,
                           this_site_arg this_site = this_site_arg(), generation_arg generation =
                           generation_arg())
```

Broadcast a value to different call sites

This function sends a set of values to all call sites operating on the given base name.

Broadcast a value to different call sites

This function sends a set of values to all call sites operating on the given base name.

Note: The generation values from corresponding *broadcast_to* and *broadcast_from* have to match.

Note: The generation values from corresponding *broadcast_to* and *broadcast_from* have to match.

Parameters

- **policy** – The execution policy specifying synchronous execution.
- **comm** – A communicator object returned from `create_communicator`
- **local_result** – A value to transmit to all participating sites from this call site.
- **this_site** – The sequence number of this invocation (usually the locality id). This value is optional and defaults to whatever `hpx::get_locality_id()` returns.
- **generation** – The generational counter identifying the sequence number of the broadcast operation performed on the given base name. This is optional and needs to be supplied only if the broadcast operation on the given base name has to be performed more than once. The generation number (if given) must be a positive number greater than zero.
- **policy** – The execution policy specifying synchronous execution.
- **comm** – A communicator object returned from `create_communicator`
- **local_result** – A value to transmit to all participating sites from this call site.
- **generation** – The generational counter identifying the sequence number of the broadcast operation performed on the given base name. This is optional and needs to be supplied only if the broadcast operation on the given base name has to be performed more than once. The generation number (if given) must be a positive number greater than zero.
- **this_site** – The sequence number of this invocation (usually the locality id). This value is optional and defaults to whatever `hpx::get_locality_id()` returns.

Returns This function returns a vector with all values send by all participating sites. This function executes synchronously and directly returns the result.

Returns This function returns a vector with all values send by all participating sites. This function executes synchronously and directly returns the result.

```
template<typename T>
T broadcast_from(hpx::launch::sync_policy, char const *basename, this_site_arg this_site =
               this_site_arg(), generation_arg generation = generation_arg(), root_site_arg
               root_site = root_site_arg())
```

Receive a value that was broadcast to different call sites

This function sends a set of values to all call sites operating on the given base name.

Parameters

- **policy** – The execution policy specifying synchronous execution.
- **basename** – The base name identifying the broadcast operation
- **this_site** – The sequence number of this invocation (usually the locality id). This value is optional and defaults to whatever `hpx::get_locality_id()` returns.
- **generation** – The generational counter identifying the sequence number of the broadcast operation performed on the given base name. This is optional and needs to be supplied only if the broadcast operation on the given base name has to be performed more than once. The generation number (if given) must be a positive number greater than zero.
- **root_site** – The site responsible for broadcasting the value. This is optional and defaults to site 0 (zero).

Returns This function returns a vector with all values send by all participating sites. This function executes synchronously and directly returns the result.

```
template<typename T>
T broadcast_from(hpx::launch::sync_policy, communicator comm, this_site_arg this_site =
               this_site_arg(), generation_arg generation = generation_arg())
```

Receive a value that was broadcast to different call sites

This function sends a set of values to all call sites operating on the given base name.

Receive a value that was broadcast to different call sites

This function sends a set of values to all call sites operating on the given base name.

Note: The generation values from corresponding *broadcast_to* and *broadcast_from* have to match.

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Parameters

- **policy** – The execution policy specifying synchronous execution.
- **comm** – A communicator object returned from *create_communicator*
- **this_site** – The sequence number of this invocation (usually the locality id). This value is optional and defaults to whatever `hpx::get_locality_id()` returns.
- **generation** – The generational counter identifying the sequence number of the broadcast operation performed on the given base name. This is optional and needs to be supplied only if the broadcast operation on the given base name has to be performed more than once. The generation number (if given) must be a positive number greater than zero.
- **policy** – The execution policy specifying synchronous execution.
- **comm** – A communicator object returned from *create_communicator*
- **generation** – The generational counter identifying the sequence number of the broadcast operation performed on the given base name. This is optional and needs to be supplied only if the broadcast operation on the given base name has to be performed more than once. The generation number (if given) must be a positive number greater than zero.
- **this_site** – The sequence number of this invocation (usually the locality id). This value is optional and defaults to whatever `hpx::get_locality_id()` returns.

Returns This function returns a vector with all values send by all participating sites. This function executes synchronously and directly returns the result.

Returns This function returns a vector with all values send by all participating sites. This function executes synchronously and directly returns the result.

hpx/collectives/broadcast_direct.hpp

Defined in header `hpx/collectives/broadcast_direct.hpp`.

See *Public API* for a list of names and headers that are part of the public *HPX* API.

namespace **hpx**

Top level HPX namespace.

namespace **lcos**

Functions

```
template<typename Action, typename ArgN, ...  
> hpx::future< std::vector< decltype(Action(hpx::id_type, ArgN,...  
)>> broadcast (std::vector< hpx::id_type > const &ids, ArgN argN,...)
```

Perform a distributed broadcast operation.

The function `hpx::lcos::broadcast` performs a distributed broadcast operation resulting in action invocations on a given set of global identifiers. The action can be either a plain action (in which case the global identifiers have to refer to localities) or a component action (in which case the global identifiers have to refer to instances of a component type which exposes the action).

The given action is invoked asynchronously on all given identifiers, and the arguments ArgN are passed along to those invocations.

Note: If `decltype(Action(...))` is `void`, then the result of this function is `future<void>`.

Parameters

- **ids** – [in] A list of global identifiers identifying the target objects for which the given action will be invoked.
- **argN** – [in] Any number of arbitrary arguments (passed by const reference) which will be forwarded to the action invocation.

Returns This function returns a future representing the result of the overall reduction operation.

```
template<typename Action, typename ArgN, ...
> void broadcast_post (std::vector< hpx::id_type > const &ids, ArgN argN,...)
```

Perform an asynchronous (fire&forget) distributed broadcast operation.

The function `hpx::lcos::broadcast_post` performs an asynchronous (fire&forget) distributed broadcast operation resulting in action invocations on a given set of global identifiers. The action can be either a plain action (in which case the global identifiers have to refer to localities) or a component action (in which case the global identifiers have to refer to instances of a component type which exposes the action).

The given action is invoked asynchronously on all given identifiers, and the arguments ArgN are passed along to those invocations.

Parameters

- **ids** – [in] A list of global identifiers identifying the target objects for which the given action will be invoked.
- **argN** – [in] Any number of arbitrary arguments (passed by const reference) which will be forwarded to the action invocation.

```
template<typename Action, typename ArgN, ...
> hpx::future< std::vector< decltype(Action(hpx::id_type, ArgN,...,
std::size_t))> > broadcast_with_index (std::vector< hpx::id_type > const &ids,
ArgN argN,...)
```

Perform a distributed broadcast operation.

The function `hpx::lcos::broadcast_with_index` performs a distributed broadcast operation resulting in action invocations on a given set of global identifiers. The action can be either a plain action (in which case the global identifiers have to refer to localities) or a component action (in which case the global identifiers have to refer to instances of a component type which exposes the action).

The given action is invoked asynchronously on all given identifiers, and the arguments ArgN are passed along to those invocations.

The function passes the index of the global identifier in the given list of identifiers as the last argument to the action.

Note: If `decltype(Action(...))` is `void`, then the result of this function is `future<void>`.

Parameters

- **ids** – [in] A list of global identifiers identifying the target objects for which the given action will be invoked.

- **argN** – [in] Any number of arbitrary arguments (passed by const reference) which will be forwarded to the action invocation.

Returns This function returns a future representing the result of the overall reduction operation.

```
template<typename Action, typename ArgN, ...  
> void broadcast_post_with_index (std::vector< hpx::id_type > const &ids,  
ArgN argN,...)
```

Perform an asynchronous (fire&forget) distributed broadcast operation.

The function `hpx::lcos::broadcast_post_with_index` performs an asynchronous (fire&forget) distributed broadcast operation resulting in action invocations on a given set of global identifiers. The action can be either a plain action (in which case the global identifiers have to refer to localities) or a component action (in which case the global identifiers have to refer to instances of a component type which exposes the action).

The given action is invoked asynchronously on all given identifiers, and the arguments `ArgN` are passed along to those invocations.

The function passes the index of the global identifier in the given list of identifiers as the last argument to the action.

Parameters

- **ids** – [in] A list of global identifiers identifying the target objects for which the given action will be invoked.
- **argN** – [in] Any number of arbitrary arguments (passed by const reference) which will be forwarded to the action invocation.

hpx/collectives/channel_communicator.hpp

Defined in header `hpx/collectives/channel_communicator.hpp`.

See *Public API* for a list of names and headers that are part of the public *HPX* API.

namespace **hpx**

Top level HPX namespace.

namespace **collectives**

Top level HPX namespace.

Functions

```
hpx::future<channel_communicator> create_channel_communicator(char const *basename,  
                                                             num_sites_arg num_sites =  
                                                             num_sites_arg(), this_site_arg  
                                                             this_site = this_site_arg())
```

Create a new communicator object usable with peer-to-peer channel-based operations

This functions creates a new communicator object that can be called in order to pre-allocate a communicator object usable with multiple invocations of channel-based peer-to-peer operations.

Parameters

- **basename** – The base name identifying the collective operation
- **num_sites** – The number of participating sites (default: all localities).

- **this_site** – The sequence number of this invocation (usually the locality id). This value is optional and defaults to whatever `hpx::get_locality_id()` returns.

Returns This function returns a future to a new communicator object usable with the collective operation.

```
channel_communicator create_channel_communicator(hpx::launch::sync_policy, char const
                                                *basename, num_sites_arg num_sites =
                                                num_sites_arg(), this_site_arg this_site =
                                                this_site_arg())
```

Create a new communicator object usable with peer-to-peer channel-based operations

This functions creates a new communicator object that can be called in order to pre-allocate a communicator object usable with multiple invocations of channel-based peer-to-peer operations.

Parameters

- **basename** – The base name identifying the collective operation
- **num_sites** – The number of participating sites (default: all localities).
- **this_site** – The sequence number of this invocation (usually the locality id). This value is optional and defaults to whatever `hpx::get_locality_id()` returns.

Returns This function returns a new communicator object usable with the collective operation.

```
template<typename T>
hpx::future<void> set(channel_communicator comm, that_site_arg site, T &&value, tag_arg tag =
                    tag_arg())
```

Send a value to the given site

This function sends a value to the given site based on the given communicator.

Parameters

- **comm** – The channel communicator object to use for the data transfer
- **site** – The destination site
- **value** – The value to send
- **tag** – The (optional) tag identifying the concrete operation

Returns This function returns a `future<void>` that becomes ready once the data transfer operation has finished.

```
template<typename T>
hpx::future<T> get(channel_communicator comm, that_site_arg site, tag_arg tag = tag_arg())
```

Send a value to the given site

This function receives a value from the given site based on the given communicator.

Parameters

- **comm** – The channel communicator object to use for the data transfer
- **site** – The source site

Returns This function returns a `future<T>` that becomes ready once the data transfer operation has finished. The future will hold the received value.

class **channel_communicator**

#include <channel_communicator.hpp> A handle identifying the communication channel to use for get/set operations

hpx/collectives/communication_set.hpp

Defined in header `hpx/collectives/communication_set.hpp`.

See *Public API* for a list of names and headers that are part of the public *HPX* API.

namespace **hpx**

Top level HPX namespace.

namespace **collectives**

Top level HPX namespace.

Functions

```
communicator create_communication_set(char const *basename, num_sites_arg num_sites =  
    num_sites_arg(), this_site_arg this_site = this_site_arg(),  
    generation_arg generation = generation_arg(), arity_arg  
    arity = arity_arg())
```

The function `create_communication_set` sets up a (distributed) tree-like communication structure that can be used with any of the collective APIs (such like `all_to_all` and similar).

Parameters

- **basename** – The base name identifying the `all_to_all` operation
- **num_sites** – The number of participating sites (default: all localities).
- **this_site** – The sequence number of this invocation (usually the locality id). This value is optional and defaults to whatever `hpx::get_locality_id()` returns.
- **generation** – The generational counter identifying the sequence number of the collective operation performed on the given base name. This is optional and needs to be supplied only if the collective operation on the given base name has to be performed more than once.
- **arity** – The number of children each of the communication nodes is connected to (default: picked based on `num_sites`).

Returns This function returns a new communicator object usable with the collective operation.

hpx/collectives/create_communicator.hpp

Defined in header `hpx/collectives/create_communicator.hpp`.

See *Public API* for a list of names and headers that are part of the public *HPX* API.

namespace **hpx**

Top level HPX namespace.

namespace **collectives**

Top level HPX namespace.

Functions

```
communicator create_communicator(char const *basename, num_sites_arg num_sites =
    num_sites_arg(), this_site_arg this_site = this_site_arg(),
    generation_arg generation = generation_arg(), root_site_arg
    root_site = root_site_arg())
```

Create a new communicator object usable with any collective operation

This functions creates a new communicator object that can be called in order to pre-allocate a communicator object usable with multiple invocations of the collective operations (such as *all_gather*, *all_reduce*, *all_to_all*, *broadcast*, etc.).

Parameters

- **basename** – The base name identifying the collective operation
- **num_sites** – The number of participating sites (default: all localities).
- **this_site** – The sequence number of this invocation (usually the locality id). This value is optional and defaults to whatever `hpx::get_locality_id()` returns.
- **generation** – The generational counter identifying the sequence number of the collective operation performed on the given base name. This is optional and needs to be supplied only if the collective operation on the given base name has to be performed more than once.
- **root_site** – The site that is responsible for creating the collective support object. This value is optional and defaults to '0' (zero).

Returns This function returns a new communicator object usable with the collective operation.

```
communicator create_local_communicator(char const *basename, num_sites_arg num_sites,
    this_site_arg this_site, generation_arg generation =
    generation_arg(), root_site_arg root_site =
    root_site_arg())
```

Create a new communicator object usable with any local collective operation

This functions creates a new communicator object that can be called in order to pre-allocate a communicator object usable with multiple invocations of the collective operations (such as *all_gather*, *all_reduce*, *all_to_all*, *broadcast*, etc.).

Parameters

- **basename** – The base name identifying the collective operation
- **num_sites** – The number of participating sites
- **this_site** – The sequence number of this invocation (usually the sequence number of the object participating in the collective operation). This value must be in the range [0, `num_sites`).
- **generation** – The generational counter identifying the sequence number of the collective operation performed on the given base name. This is optional and needs to be supplied only if the collective operation on the given base name has to be performed more than once.
- **root_site** – The site that is responsible for creating the collective support object. This value is optional and defaults to '0' (zero).

Returns This function returns a new communicator object usable for all local collective operations.

```
struct communicator
```

`#include <create_communicator.hpp>` A communicator instance represents the list of sites that participate in a particular collective operation.

Public Functions

void **set_info**(*num_sites_arg* num_sites, *this_site_arg* this_site) noexcept

Store the number of used sites and the index of the current site for this communicator instance.

Parameters

- **num_sites** – The number of participating sites (default: all localities).
- **this_site** – The sequence number of this site (usually the locality id).

std::pair<*num_sites_arg*, *this_site_arg*> **get_info**() const noexcept

Retrieve the number of used sites and the index of the current site for this communicator instance.

bool **is_root**() const

Return whether this communicator instance represents the root site of the communication operation.

hpx/collectives/exclusive_scan.hpp

Defined in header `hpx/collectives/exclusive_scan.hpp`.

See *Public API* for a list of names and headers that are part of the public *HPX* API.

namespace **hpx**

Top level HPX namespace.

namespace **collectives**

Top level HPX namespace.

Functions

```
template<typename T, typename F>
hpx::future<std::decay_t<T>> exclusive_scan(char const *basename, T &&result, F &&op,
                                           num_sites_arg num_sites = num_sites_arg(),
                                           this_site_arg this_site = this_site_arg(),
                                           generation_arg generation = generation_arg(),
                                           root_site_arg root_site = root_site_arg())
```

Exclusive scan a set of values from different call sites

This function performs an exclusive scan operation on a set of values received from all call sites operating on the given base name.

Note: The result returned on the `root_site` is always the same as the result returned on `this_site == 1` and is the same as the value provided by the `root_site`.

Parameters

- **basename** – The base name identifying the `exclusive_scan` operation
- **result** – The value to transmit to all participating sites from this call site.
- **op** – Reduction operation to apply to all values supplied from all participating sites
- **num_sites** – The number of participating sites (default: all localities).
- **this_site** – The sequence number of this invocation (usually the locality id). This value is optional and defaults to whatever `hpx::get_locality_id()` returns.

- **generation** – The generational counter identifying the sequence number of the exclusive_scan operation performed on the given base name. This is optional and needs to be supplied only if the exclusive_scan operation on the given base name has to be performed more than once. The generation number (if given) must be a positive number greater than zero.
- **root_site** – The site that is responsible for creating the exclusive_scan support object. This value is optional and defaults to '0' (zero).

Returns For the participating site *i* this function returns a future the reduction (calculated according to the function *op*) of the values passed in by the participating sites 0, ..., *i*-1. The value returned on participating site 0 is undefined. The value returned on participating site on process 1 is always the value passed in by participating site 1. The returned future will become ready once the exclusive_scan operation has been completed.

```
template<typename T, typename F>
hpx::future<std::decay_t<T>> exclusive_scan(communicator comm, T &&result, F &&op,
                                         this_site_arg this_site = this_site_arg(),
                                         generation_arg generation = generation_arg())
```

Exclusive scan a set of values from different call sites

This function performs an exclusive scan operation on a set of values received from all call sites operating on the given base name.

Exclusive scan a set of values from different call sites

This function performs an exclusive scan operation on a set of values received from all call sites operating on the given base name.

Note: The result returned on the root_site is always the same as the result returned on thus_site == 1 and is the same as the value provided by the root_site.

Note: The result returned on the root_site is always the same as the result returned on thus_site == 1 and is the same as the value provided by the root_site.

Parameters

- **comm** – A communicator object returned from *create_communicator*
- **result** – The value to transmit to all participating sites from this call site.
- **op** – Reduction operation to apply to all values supplied from all participating sites
- **this_site** – The sequence number of this invocation (usually the locality id). This value is optional and defaults to whatever *hpx::get_locality_id()* returns.
- **generation** – The generational counter identifying the sequence number of the exclusive_scan operation performed on the given base name. This is optional and needs to be supplied only if the exclusive_scan operation on the given base name has to be performed more than once. The generation number (if given) must be a positive number greater than zero.
- **comm** – A communicator object returned from *create_communicator*
- **result** – The value to transmit to all participating sites from this call site.
- **op** – Reduction operation to apply to all values supplied from all participating sites
- **generation** – The generational counter identifying the sequence number of the exclusive_scan operation performed on the given base name. This is optional and needs to be supplied only if the exclusive_scan operation on the given base name has to be performed more than once. The generation number (if given) must be a positive number greater than zero.

- **this_site** – The sequence number of this invocation (usually the locality id). This value is optional and defaults to whatever `hpx::get_locality_id()` returns.

Returns For the participating site *i* this function returns a future the reduction (calculated according to the function *op*) of the values passed in by the participating sites 0, ..., *i*-1. The value returned on participating site 0 is undefined. The value returned on participating site on process 1 is always the value passed in by participating site 1. The returned future will become ready once the `exclusive_scan` operation has been completed.

Returns For the participating site *i* this function returns a future the reduction (calculated according to the function *op*) of the values passed in by the participating sites 0, ..., *i*-1. The value returned on participating site 0 is undefined. The value returned on participating site on process 1 is always the value passed in by participating site 1. The returned future will become ready once the `exclusive_scan` operation has been completed.

```
template<typename T, typename F>
decltype(auto) exclusive_scan(hpx::launch::sync_policy, char const *basename, T &&result, F
    &&op, num_sites_arg num_sites = num_sites_arg(), this_site_arg
    this_site = this_site_arg(), generation_arg generation =
    generation_arg(), root_site_arg root_site = root_site_arg())
```

Exclusive scan a set of values from different call sites

This function performs an exclusive scan operation on a set of values received from all call sites operating on the given base name.

Note: The result returned on the `root_site` is always the same as the result returned on `this_site == 1` and is the same as the value provided by the `root_site`.

Parameters

- **policy** – The execution policy specifying synchronous execution.
- **basename** – The base name identifying the `exclusive_scan` operation
- **result** – The value to transmit to all participating sites from this call site.
- **op** – Reduction operation to apply to all values supplied from all participating sites
- **num_sites** – The number of participating sites (default: all localities).
- **this_site** – The sequence number of this invocation (usually the locality id). This value is optional and defaults to whatever `hpx::get_locality_id()` returns.
- **generation** – The generational counter identifying the sequence number of the `exclusive_scan` operation performed on the given base name. This is optional and needs to be supplied only if the `exclusive_scan` operation on the given base name has to be performed more than once. The generation number (if given) must be a positive number greater than zero.
- **root_site** – The site that is responsible for creating the `exclusive_scan` support object. This value is optional and defaults to '0' (zero).

Returns For the participating site *i* this function returns a future the reduction (calculated according to the function *op*) of the values passed in by the participating sites 0, ..., *i*-1. The value returned on participating site 0 is undefined. The value returned on participating site on process 1 is always the value passed in by participating site 1. The returned future will become ready once the `exclusive_scan` operation has been completed.

```
template<typename T, typename F>
decltype(auto) exclusive_scan(hpx::launch::sync_policy, communicator comm, T &&result, F
    &&op, this_site_arg this_site = this_site_arg(), generation_arg
    generation = generation_arg())
```

Exclusive scan a set of values from different call sites

This function performs an exclusive scan operation on a set of values received from all call sites oper-

ating on the given base name.

Exclusive scan a set of values from different call sites

This function performs an exclusive scan operation on a set of values received from all call sites operating on the given base name.

Note: The result returned on the `root_site` is always the same as the result returned on `thus_site == 1` and is the same as the value provided by the `root_site`.

Note: The result returned on the `root_site` is always the same as the result returned on `thus_site == 1` and is the same as the value provided by the `root_site`.

Parameters

- **policy** – The execution policy specifying synchronous execution.
- **comm** – A communicator object returned from `create_communicator`
- **result** – The value to transmit to all participating sites from this call site.
- **op** – Reduction operation to apply to all values supplied from all participating sites
- **this_site** – The sequence number of this invocation (usually the locality id). This value is optional and defaults to whatever `hpx::get_locality_id()` returns.
- **generation** – The generational counter identifying the sequence number of the `exclusive_scan` operation performed on the given base name. This is optional and needs to be supplied only if the `exclusive_scan` operation on the given base name has to be performed more than once. The generation number (if given) must be a positive number greater than zero.
- **policy** – The execution policy specifying synchronous execution.
- **comm** – A communicator object returned from `create_communicator`
- **result** – The value to transmit to all participating sites from this call site.
- **op** – Reduction operation to apply to all values supplied from all participating sites
- **generation** – The generational counter identifying the sequence number of the `exclusive_scan` operation performed on the given base name. This is optional and needs to be supplied only if the `exclusive_scan` operation on the given base name has to be performed more than once. The generation number (if given) must be a positive number greater than zero.
- **this_site** – The sequence number of this invocation (usually the locality id). This value is optional and defaults to whatever `hpx::get_locality_id()` returns.

Returns For the participating site `i` this function returns a future the reduction (calculated according to the function `op`) of the values passed in by the participating sites `0, ..., i-1`. The value returned on participating site `0` is undefined. The value returned on participating site on process `1` is always the value passed in by participating site `1`. The returned future will become ready once the `exclusive_scan` operation has been completed.

Returns For the participating site `i` this function returns the reduction (calculated according to the function `op`) of the values passed in by the participating sites `0, ..., i-1`. The value returned on participating site `0` is undefined. The value returned on participating site on process `1` is always the value passed in by participating site `1`. The returned future will become ready once the `exclusive_scan` operation has been completed.

hpx/collectives/fold.hpp

Defined in header hpx/collectives/fold.hpp.

See *Public API* for a list of names and headers that are part of the public *HPX* API.

namespace **hpx**

Top level HPX namespace.

namespace **lcos**

Functions

```
template<typename Action, typename FoldOp, typename Init, typename ArgN, ...
> hpx::future< decltype(Action(hpx::id_type, ArgN,...
))> fold (std::vector< hpx::id_type > const &ids, FoldOp &&fold_op, Init &&init,
ArgN argN,...)
```

Perform a distributed fold operation.

The function `hpx::lcos::fold` performs a distributed folding operation over results returned from action invocations on a given set of global identifiers. The action can be either a plain action (in which case the global identifiers have to refer to localities) or a component action (in which case the global identifiers have to refer to instances of a component type which exposes the action).

Note: The type of the initial value must be convertible to the result type returned from the invoked action.

Parameters

- **ids** – [in] A list of global identifiers identifying the target objects for which the given action will be invoked.
- **fold_op** – [in] A binary function expecting two results as returned from the action invocations. The function (or function object) is expected to return the result of the folding operation performed on its arguments.
- **init** – [in] The initial value to be used for the folding operation
- **argN** – [in] Any number of arbitrary arguments (passed by value, by const reference or by rvalue reference) which will be forwarded to the action invocation.

Returns This function returns a future representing the result of the overall folding operation.

```
template<typename Action, typename FoldOp, typename Init, typename ArgN, ...
> hpx::future< decltype(Action(hpx::id_type, ArgN,...,
std::size_t))> fold_with_index (std::vector< hpx::id_type > const &ids,
FoldOp &&fold_op, Init &&init, ArgN argN,...)
```

Perform a distributed folding operation.

The function `hpx::lcos::fold_with_index` performs a distributed folding operation over results returned from action invocations on a given set of global identifiers. The action can be either plain action (in which case the global identifiers have to refer to localities) or a component action (in which case the global identifiers have to refer to instances of a component type which exposes the action).

The function passes the index of the global identifier in the given list of identifiers as the last argument to the action.

Note: The type of the initial value must be convertible to the result type returned from the invoked action.

Parameters

- **ids** – [in] A list of global identifiers identifying the target objects for which the given action will be invoked.
- **fold_op** – [in] A binary function expecting two results as returned from the action invocations. The function (or function object) is expected to return the result of the folding operation performed on its arguments.
- **init** – [in] The initial value to be used for the folding operation
- **argN** – [in] Any number of arbitrary arguments (passed by value, by const reference or by rvalue reference) which will be forwarded to the action invocation.

Returns This function returns a future representing the result of the overall folding operation.

```
template<typename Action, typename FoldOp, typename Init, typename ArgN, ...
> hpx::future< decltype(Action(hpx::id_type, ArgN,...
))> inverse_fold (std::vector< hpx::id_type > const &ids, FoldOp &&fold_op,
Init &&init, ArgN argN,...)
```

Perform a distributed inverse folding operation.

The function `hpx::lcos::inverse_fold` performs an inverse distributed folding operation over results returned from action invocations on a given set of global identifiers. The action can be either a plain action (in which case the global identifiers have to refer to localities) or a component action (in which case the global identifiers have to refer to instances of a component type which exposes the action).

Note: The type of the initial value must be convertible to the result type returned from the invoked action.

Parameters

- **ids** – [in] A list of global identifiers identifying the target objects for which the given action will be invoked.
- **fold_op** – [in] A binary function expecting two results as returned from the action invocations. The function (or function object) is expected to return the result of the folding operation performed on its arguments.
- **init** – [in] The initial value to be used for the folding operation
- **argN** – [in] Any number of arbitrary arguments (passed by value, by const reference or by rvalue reference) which will be forwarded to the action invocation.

Returns This function returns a future representing the result of the overall folding operation.

```
template<typename Action, typename FoldOp, typename Init, typename ArgN, ...
> hpx::future< decltype(Action(hpx::id_type, ArgN,...,
std::size_t))> inverse_fold_with_index (std::vector< hpx::id_type > const &ids,
FoldOp &&fold_op, Init &&init, ArgN argN,...)
```

Perform a distributed inverse folding operation.

The function `hpx::lcos::inverse_fold_with_index` performs an inverse distributed folding operation over results returned from action invocations on a given set of global identifiers. The action can be either plain action (in which case the global identifiers have to refer to localities) or a component action (in which case the global identifiers have to refer to instances of a component type which exposes the action).

The function passes the index of the global identifier in the given list of identifiers as the last argument

to the action.

Note: The type of the initial value must be convertible to the result type returned from the invoked action.

Parameters

- **ids** – [in] A list of global identifiers identifying the target objects for which the given action will be invoked.
- **fold_op** – [in] A binary function expecting two results as returned from the action invocations. The function (or function object) is expected to return the result of the folding operation performed on its arguments.
- **init** – [in] The initial value to be used for the folding operation
- **argN** – [in] Any number of arbitrary arguments (passed by value, by const reference or by rvalue reference) which will be forwarded to the action invocation.

Returns This function returns a future representing the result of the overall folding operation.

hpx/collectives/gather.hpp

Defined in header `hpx/collectives/gather.hpp`.

See *Public API* for a list of names and headers that are part of the public *HPX* API.

namespace **hpx**

Top level HPX namespace.

namespace **collectives**

Top level HPX namespace.

Functions

```
template<typename T>
hpx::future<std::vector<decay_t<T>>> gather_here(char const *basename, T &&result,
                                             num_sites_arg num_sites = num_sites_arg(),
                                             this_site_arg this_site = this_site_arg(),
                                             generation_arg generation = generation_arg())
```

Gather a set of values from different call sites

This function receives a set of values from all call sites operating on the given base name.

Parameters

- **basename** – The base name identifying the gather operation
- **result** – The value to transmit to the central gather point from this call site.
- **num_sites** – The number of participating sites (default: all localities).
- **this_site** – The sequence number of this invocation (usually the locality id). This value is optional and defaults to whatever `hpx::get_locality_id()` returns.
- **generation** – The generational counter identifying the sequence number of the gather operation performed on the given base name. This is optional and needs to be supplied only if the gather operation on the given base name has to be performed more than once. The generation number (if given) must be a positive number greater than zero.

Returns This function returns a future holding a vector with all gathered values. It will become ready once the gather operation has been completed.

```
template<typename T>
hpx::future<std::vector<decay_t<T>>> gather_here(communicator comm, T &&result, this_site_arg
                                             this_site = this_site_arg(), generation_arg
                                             generation = generation_arg())
```

Gather a set of values from different call sites

This function receives a set of values from all call sites operating on the given base name.

Gather a set of values from different call sites

This function receives a set of values from all call sites operating on the given base name.

Note: The generation values from corresponding *gather_here* and *gather_there* have to match.

Note: The generation values from corresponding *gather_here* and *gather_there* have to match.

Parameters

- **comm** – A communicator object returned from *create_communicator*
- **result** – The value to transmit to the central gather point from this call site.
- **this_site** – The sequence number of this invocation (usually the locality id). This value is optional and defaults to whatever `hpx::get_locality_id()` returns.
- **generation** – The generational counter identifying the sequence number of the gather operation performed on the given base name. This is optional and needs to be supplied only if the gather operation on the given base name has to be performed more than once. The generation number (if given) must be a positive number greater than zero.
- **comm** – A communicator object returned from *create_communicator*
- **result** – The value to transmit to the central gather point from this call site.
- **generation** – The generational counter identifying the sequence number of the gather operation performed on the given base name. This is optional and needs to be supplied only if the gather operation on the given base name has to be performed more than once. The generation number (if given) must be a positive number greater than zero.
- **this_site** – The sequence number of this invocation (usually the locality id). This value is optional and defaults to whatever `hpx::get_locality_id()` returns.

Returns This function returns a future holding a vector with all gathered values. It will become ready once the gather operation has been completed.

Returns This function returns a future holding a vector with all gathered values. It will become ready once the gather operation has been completed.

```
template<typename T>
hpx::future<void> gather_there(char const *basename, T &&result, this_site_arg this_site =
                             this_site_arg(), generation_arg generation = generation_arg(),
                             root_site_arg root_site = root_site_arg())
```

Gather a given value at the given call site

This function transmits the value given by *result* to a central gather site (where the corresponding *gather_here* is executed)

Parameters

- **basename** – The base name identifying the gather operation
- **result** – The value to transmit to the central gather point from this call site.
- **this_site** – The sequence number of this invocation (usually the locality id). This value is optional and defaults to whatever `hpx::get_locality_id()` returns.

- **generation** – The generational counter identifying the sequence number of the gather operation performed on the given base name. This is optional and needs to be supplied only if the gather operation on the given base name has to be performed more than once. The generation number (if given) must be a positive number greater than zero.
- **root_site** – The sequence number of the central gather point (usually the locality id). This value is optional and defaults to 0.

Returns This function returns a future holding a vector with all gathered values. It will become ready once the gather operation has been completed.

```
template<typename T>
hpx::future<void> gather_there(communicator comm, T &&result, this_site_arg this_site =
                             this_site_arg(), generation_arg generation = generation_arg())
```

Gather a given value at the given call site

This function transmits the value given by *result* to a central gather site (where the corresponding *gather_here* is executed)

Gather a given value at the given call site

This function transmits the value given by *result* to a central gather site (where the corresponding *gather_here* is executed)

Note: The generation values from corresponding *gather_here* and *gather_there* have to match.

Note: The generation values from corresponding *gather_here* and *gather_there* have to match.

Parameters

- **comm** – A communicator object returned from *create_communicator*
- **result** – The value to transmit to the central gather point from this call site.
- **this_site** – The sequence number of this invocation (usually the locality id). This value is optional and defaults to whatever *hpx::get_locality_id()* returns.
- **generation** – The generational counter identifying the sequence number of the gather operation performed on the given base name. This is optional and needs to be supplied only if the gather operation on the given base name has to be performed more than once. The generation number (if given) must be a positive number greater than zero.
- **comm** – A communicator object returned from *create_communicator*
- **result** – The value to transmit to the central gather point from this call site.
- **generation** – The generational counter identifying the sequence number of the gather operation performed on the given base name. This is optional and needs to be supplied only if the gather operation on the given base name has to be performed more than once. The generation number (if given) must be a positive number greater than zero.
- **this_site** – The sequence number of this invocation (usually the locality id). This value is optional and defaults to whatever *hpx::get_locality_id()* returns.

Returns This function returns a future holding a vector with all gathered values. It will become ready once the gather operation has been completed.

Returns This function returns a future holding a vector with all gathered values. It will become ready once the gather operation has been completed.

```
template<typename T>
decltype(auto) gather_here(hpx::launch::sync_policy, char const *basename, T &&result,
                           num_sites_arg num_sites = num_sites_arg(), this_site_arg this_site =
                           this_site_arg(), generation_arg generation = generation_arg())
```

Gather a set of values from different call sites

This function receives a set of values from all call sites operating on the given base name.

Parameters

- **policy** – The execution policy specifying synchronous execution.
- **basename** – The base name identifying the gather operation
- **result** – The value to transmit to the central gather point from this call site.
- **num_sites** – The number of participating sites (default: all localities).
- **this_site** – The sequence number of this invocation (usually the locality id). This value is optional and defaults to whatever `hpx::get_locality_id()` returns.
- **generation** – The generational counter identifying the sequence number of the gather operation performed on the given base name. This is optional and needs to be supplied only if the gather operation on the given base name has to be performed more than once. The generation number (if given) must be a positive number greater than zero.

Returns This function returns a vector with all values send by all participating sites. This function executes synchronously and directly returns the result.

```
template<typename T>
decltype(auto) gather_here(hpx::launch::sync_policy, communicator comm, T &&result, this_site_arg
                           this_site = this_site_arg(), generation_arg generation = generation_arg())
```

Gather a set of values from different call sites

This function receives a set of values from all call sites operating on the given base name.

Gather a set of values from different call sites

This function receives a set of values from all call sites operating on the given base name.

Note: The generation values from corresponding *gather_here* and *gather_there* have to match.

Note: The generation values from corresponding *gather_here* and *gather_there* have to match.

Parameters

- **policy** – The execution policy specifying synchronous execution.
- **comm** – A communicator object returned from *create_communicator*
- **result** – The value to transmit to the central gather point from this call site.
- **this_site** – The sequence number of this invocation (usually the locality id). This value is optional and defaults to whatever `hpx::get_locality_id()` returns.
- **generation** – The generational counter identifying the sequence number of the gather operation performed on the given base name. This is optional and needs to be supplied only if the gather operation on the given base name has to be performed more than once. The generation number (if given) must be a positive number greater than zero.
- **policy** – The execution policy specifying synchronous execution.
- **comm** – A communicator object returned from *create_communicator*
- **result** – The value to transmit to the central gather point from this call site.
- **generation** – The generational counter identifying the sequence number of the gather operation performed on the given base name. This is optional and needs to be supplied only if the gather operation on the given base name has to be performed more than once. The generation number (if given) must be a positive number greater than zero.
- **this_site** – The sequence number of this invocation (usually the locality id). This value is optional and defaults to whatever `hpx::get_locality_id()` returns.

Returns This function returns a vector with all values send by all participating sites. This function executes synchronously and directly returns the result.

Returns This function returns a vector with all values send by all participating sites. This function executes synchronously and directly returns the result.

```
template<typename T>
void gather_here(hpx::launch::sync_policy, char const *basename, T &&result, this_site_arg
                this_site = this_site_arg(), generation_arg generation = generation_arg(),
                root_site_arg root_site = root_site_arg())
```

Gather a given value at the given call site

This function transmits the value given by *result* to a central gather site (where the corresponding *gather_here* is executed)

Parameters

- **policy** – The execution policy specifying synchronous execution.
- **basename** – The base name identifying the gather operation
- **result** – The value to transmit to the central gather point from this call site.
- **this_site** – The sequence number of this invocation (usually the locality id). This value is optional and defaults to whatever `hpx::get_locality_id()` returns.
- **generation** – The generational counter identifying the sequence number of the gather operation performed on the given base name. This is optional and needs to be supplied only if the gather operation on the given base name has to be performed more than once. The generation number (if given) must be a positive number greater than zero.
- **root_site** – The sequence number of the central gather point (usually the locality id). This value is optional and defaults to 0.

Returns This function returns a vector with all values send by all participating sites. This function executes synchronously and directly returns the result.

```
template<typename T>
void gather_here(hpx::launch::sync_policy, communicator comm, T &&result, this_site_arg
                this_site = this_site_arg(), generation_arg generation = generation_arg())
```

Gather a given value at the given call site

This function transmits the value given by *result* to a central gather site (where the corresponding *gather_here* is executed)

Gather a given value at the given call site

This function transmits the value given by *result* to a central gather site (where the corresponding *gather_here* is executed)

Note: The generation values from corresponding *gather_here* and *gather_there* have to match.

Note: The generation values from corresponding *gather_here* and *gather_there* have to match.

Parameters

- **policy** – The execution policy specifying synchronous execution.
- **comm** – A communicator object returned from *create_communicator*
- **result** – The value to transmit to the central gather point from this call site.
- **this_site** – The sequence number of this invocation (usually the locality id). This value is optional and defaults to whatever `hpx::get_locality_id()` returns.

- **generation** – The generational counter identifying the sequence number of the gather operation performed on the given base name. This is optional and needs to be supplied only if the gather operation on the given base name has to be performed more than once. The generation number (if given) must be a positive number greater than zero.
- **policy** – The execution policy specifying synchronous execution.
- **comm** – A communicator object returned from `create_communicator`
- **result** – The value to transmit to the central gather point from this call site.
- **generation** – The generational counter identifying the sequence number of the gather operation performed on the given base name. This is optional and needs to be supplied only if the gather operation on the given base name has to be performed more than once. The generation number (if given) must be a positive number greater than zero.
- **this_site** – The sequence number of this invocation (usually the locality id). This value is optional and defaults to whatever `hpx::get_locality_id()` returns.

Returns This function returns a vector with all values send by all participating sites. This function executes synchronously and directly returns the result.

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hpx/collectives/inclusive_scan.hpp

Defined in header `hpx/collectives/inclusive_scan.hpp`.

See *Public API* for a list of names and headers that are part of the public *HPX* API.

namespace **hpx**

Top level HPX namespace.

namespace **collectives**

Top level HPX namespace.

Functions

```
template<typename T, typename F>
hpx::future<std::decay_t<T>> inclusive_scan(char const *basename, T &&result, F &&op,
                                         num_sites_arg num_sites = num_sites_arg(),
                                         this_site_arg this_site = this_site_arg(),
                                         generation_arg generation = generation_arg(),
                                         root_site_arg root_site = root_site_arg())
```

Inclusive `inclusive_scan` a set of values from different call sites

This function performs an inclusive scan operation on a set of values received from all call sites operating on the given base name.

Parameters

- **basename** – The base name identifying the `inclusive_scan` operation
- **result** – The value to transmit to all participating sites from this call site.
- **op** – Reduction operation to apply to all values supplied from all participating sites
- **num_sites** – The number of participating sites (default: all localities).
- **this_site** – The sequence number of this invocation (usually the locality id). This value is optional and defaults to whatever `hpx::get_locality_id()` returns.
- **generation** – The generational counter identifying the sequence number of the `inclusive_scan` operation performed on the given base name. This is optional and needs to be supplied only if the `inclusive_scan` operation on the given base name has to be performed

more than once. The generation number (if given) must be a positive number greater than zero.

- **root_site** – The site that is responsible for creating the `inclusive_scan` support object. This value is optional and defaults to '0' (zero).

Returns This function returns a future holding a vector with all values send by all participating sites. It will become ready once the `inclusive_scan` operation has been completed.

```
template<typename T, typename F>
hpx::future<std::decay_t<T>> inclusive_scan(communicator comm, T &&result, F &&op,
                                         this_site_arg this_site = this_site_arg(),
                                         generation_arg generation = generation_arg())
```

Inclusive `inclusive_scan` a set of values from different call sites

This function performs an inclusive scan operation on a set of values received from all call sites operating on the given base name.

Inclusive `inclusive_scan` a set of values from different call sites

This function performs an inclusive scan operation on a set of values received from all call sites operating on the given base name.

Parameters

- **comm** – A communicator object returned from `create_communicator`
- **result** – The value to transmit to all participating sites from this call site.
- **op** – Reduction operation to apply to all values supplied from all participating sites
- **this_site** – The sequence number of this invocation (usually the locality id). This value is optional and defaults to whatever `hpx::get_locality_id()` returns.
- **generation** – The generational counter identifying the sequence number of the `inclusive_scan` operation performed on the given base name. This is optional and needs to be supplied only if the `inclusive_scan` operation on the given base name has to be performed more than once. The generation number (if given) must be a positive number greater than zero.
- **comm** – A communicator object returned from `create_communicator`
- **result** – The value to transmit to all participating sites from this call site.
- **op** – Reduction operation to apply to all values supplied from all participating sites
- **generation** – The generational counter identifying the sequence number of the `inclusive_scan` operation performed on the given base name. This is optional and needs to be supplied only if the `inclusive_scan` operation on the given base name has to be performed more than once. The generation number (if given) must be a positive number greater than zero.
- **this_site** – The sequence number of this invocation (usually the locality id). This value is optional and defaults to whatever `hpx::get_locality_id()` returns.

Returns This function returns a future holding a vector with all values send by all participating sites. It will become ready once the `inclusive_scan` operation has been completed.

Returns This function returns a future holding a vector with all values send by all participating sites. It will become ready once the `inclusive_scan` operation has been completed.

```
template<typename T, typename F>
decltype(auto) inclusive_scan(hpx::launch::sync_policy, char const *basename, T &&result, F
                              &&op, num_sites_arg num_sites = num_sites_arg(), this_site_arg
                              this_site = this_site_arg(), generation_arg generation =
                              generation_arg(), root_site_arg root_site = root_site_arg())
```

Inclusive `inclusive_scan` a set of values from different call sites

This function performs an inclusive scan operation on a set of values received from all call sites operating on the given base name.

Parameters

- **policy** – The execution policy specifying synchronous execution.
- **basename** – The base name identifying the `inclusive_scan` operation
- **result** – The value to transmit to all participating sites from this call site.
- **op** – Reduction operation to apply to all values supplied from all participating sites
- **num_sites** – The number of participating sites (default: all localities).
- **this_site** – The sequence number of this invocation (usually the locality id). This value is optional and defaults to whatever `hpx::get_locality_id()` returns.
- **generation** – The generational counter identifying the sequence number of the `inclusive_scan` operation performed on the given base name. This is optional and needs to be supplied only if the `inclusive_scan` operation on the given base name has to be performed more than once. The generation number (if given) must be a positive number greater than zero.
- **root_site** – The site that is responsible for creating the `inclusive_scan` support object. This value is optional and defaults to '0' (zero).

Returns This function returns a vector with all values send by all participating sites. This function executes synchronously and directly returns the result.

```
template<typename T, typename F>
decltype(auto) inclusive_scan(hpx::launch::sync_policy, communicator comm, T &&result, F
    &&op, this_site_arg this_site = this_site_arg(), generation_arg
    generation = generation_arg())
```

Inclusive `inclusive_scan` a set of values from different call sites

This function performs an inclusive scan operation on a set of values received from all call sites operating on the given base name.

Inclusive `inclusive_scan` a set of values from different call sites

This function performs an inclusive scan operation on a set of values received from all call sites operating on the given base name.

Parameters

- **policy** – The execution policy specifying synchronous execution.
- **comm** – A communicator object returned from `create_communicator`
- **result** – The value to transmit to all participating sites from this call site.
- **op** – Reduction operation to apply to all values supplied from all participating sites
- **this_site** – The sequence number of this invocation (usually the locality id). This value is optional and defaults to whatever `hpx::get_locality_id()` returns.
- **generation** – The generational counter identifying the sequence number of the `inclusive_scan` operation performed on the given base name. This is optional and needs to be supplied only if the `inclusive_scan` operation on the given base name has to be performed more than once. The generation number (if given) must be a positive number greater than zero.
- **policy** – The execution policy specifying synchronous execution.
- **comm** – A communicator object returned from `create_communicator`
- **result** – The value to transmit to all participating sites from this call site.
- **op** – Reduction operation to apply to all values supplied from all participating sites
- **generation** – The generational counter identifying the sequence number of the `inclusive_scan` operation performed on the given base name. This is optional and needs to be supplied only if the `inclusive_scan` operation on the given base name has to be performed more than once. The generation number (if given) must be a positive number greater than zero.
- **this_site** – The sequence number of this invocation (usually the locality id). This value is optional and defaults to whatever `hpx::get_locality_id()` returns.

Returns This function returns a vector with all values send by all participating sites. This function executes synchronously and directly returns the result.

Returns This function returns a vector with all values send by all participating sites. This function executes synchronously and directly returns the result.

hpx::distributed::latch

Defined in header `hpx/latch.hpp`⁸⁰¹.

See *Public API* for a list of names and headers that are part of the public HPX API.

namespace **hpx**

Top level HPX namespace.

namespace **distributed**

class **latch** : public *components::client_base*<*latch*, *hpx::lcos::server::latch*>

#include <*latch.hpp*> Latch is an implementation of a synchronization primitive that allows multiple threads to wait for a shared event to occur before proceeding. This latch can be invoked in a distributed application.

For a local only latch

See also:

`hpx::latch`.

Public Functions

latch() = default

explicit **latch**(*std::ptrdiff_t* count)

Initialize the latch

Requires: count >= 0. Synchronization: None Postconditions: counter_ == count.

inline **latch**(*hpx::id_type* const &id)

Extension: Create a client side representation for the existing *server::latch* instance with the given global id *id*.

inline **latch**(*hpx::future*<*hpx::id_type*> &&f)

Extension: Create a client side representation for the existing *server::latch* instance with the given global id *id*.

inline **latch**(*hpx::shared_future*<*hpx::id_type*> const &id)

Extension: Create a client side representation for the existing *server::latch* instance with the given global id *id*.

inline **latch**(*hpx::shared_future*<*hpx::id_type*> &&id)

⁸⁰¹ <http://github.com/STELLAR-GROUP/hpx/blob/8a3b7c1a4cb5693b2f7d9f587f759392ed0c51a0/libs/full/include/include/hpx/latch.hpp>

```
inline void count_down_and_wait()
```

Decrements `counter_` by 1 . Blocks at the synchronization point until `counter_` reaches 0.

Requires: `counter_ > 0`.

Synchronization: Synchronizes with all calls that block on this latch and with all `is_ready` calls on this latch that return true.

Throws Nothing. –

```
inline void arrive_and_wait()
```

Decrements `counter_` by `update` . Blocks at the synchronization point until `counter_` reaches 0.

Requires: `counter_ > 0`.

Synchronization: Synchronizes with all calls that block on this latch and with all `is_ready` calls on this latch that return true.

Throws Nothing. –

```
inline void count_down(std::ptrdiff_t n)
```

Decrements `counter_` by `n`. Does not block.

Requires: `counter_ >= n` and `n >= 0`.

Synchronization: Synchronizes with all calls that block on this latch and with all `is_ready` calls on this latch that return true .

Throws Nothing. –

```
inline bool is_ready() const noexcept
```

Returns: `counter_ == 0`. Does not block.

Throws Nothing. –

```
inline bool try_wait() const noexcept
```

Returns: `counter_ == 0`. Does not block.

Throws Nothing. –

```
inline void wait() const
```

If `counter_` is 0, returns immediately. Otherwise, blocks the calling thread at the synchronization point until `counter_` reaches 0.

Throws Nothing. –

Private Types

```
typedef components::client_base<latch, hpx::lcos::server::latch> base_type
```

hpx/collectives/reduce.hpp

Defined in header `hpx/collectives/reduce.hpp`.

See *Public API* for a list of names and headers that are part of the public *HPX* API.

namespace **hpx**

Top level HPX namespace.

namespace **collectives**

Top level HPX namespace.

Functions

```
template<typename T, typename F>
hpx::future<std::decay_t<T>> reduce_here(char const *basename, T &&result, F &&op,
                                     num_sites_arg num_sites = num_sites_arg(), this_site_arg
                                     this_site = this_site_arg(), generation_arg generation =
                                     generation_arg())
```

Reduce a set of values from different call sites

This function receives a set of values from all call sites operating on the given base name.

Parameters

- **basename** – The base name identifying the all_reduce operation
- **result** – A value to reduce on the central reduction point from this call site.
- **op** – Reduction operation to apply to all values supplied from all participating sites
- **num_sites** – The number of participating sites (default: all localities).
- **this_site** – The sequence number of this invocation (usually the locality id). This value is optional and defaults to whatever `hpx::get_locality_id()` returns.
- **generation** – The generational counter identifying the sequence number of the all_reduce operation performed on the given base name. This is optional and needs to be supplied only if the all_reduce operation on the given base name has to be performed more than once. The generation number (if given) must be a positive number greater than zero.

Returns This function returns a future holding a vector with all values send by all participating sites. It will become ready once the reduce operation has been completed.

```
template<typename T, typename F>
hpx::future<decay_t<T>> reduce_here(communicator comm, T &&result, F &&op, this_site_arg
                                     this_site = this_site_arg(), generation_arg generation =
                                     generation_arg())
```

Reduce a set of values from different call sites

This function receives a set of values that are the result of applying a given operator on values supplied from all call sites operating on the given base name.

Reduce a set of values from different call sites

This function receives a set of values that are the result of applying a given operator on values supplied from all call sites operating on the given base name.

Note: The generation values from corresponding *reduce_here* and *reduce_there* have to match.

Note: The generation values from corresponding *reduce_here* and *reduce_there* have to match.

Parameters

- **comm** – A communicator object returned from *create_communicator*
- **result** – A value to reduce on the root_site from this call site.
- **op** – Reduction operation to apply to all values supplied from all participating sites
- **this_site** – The sequence number of this invocation (usually the locality id). This value is optional and defaults to whatever `hpx::get_locality_id()` returns.
- **generation** – The generational counter identifying the sequence number of the all_reduce operation performed on the given base name. This is optional and needs to be supplied only if the all_reduce operation on the given base name has to be performed

more than once. The generation number (if given) must be a positive number greater than zero.

- **comm** – A communicator object returned from *create_communicator*
- **result** – A value to reduce on the *root_site* from this call site.
- **op** – Reduction operation to apply to all values supplied from all participating sites
- **generation** – The generational counter identifying the sequence number of the *all_reduce* operation performed on the given base name. This is optional and needs to be supplied only if the *all_reduce* operation on the given base name has to be performed more than once. The generation number (if given) must be a positive number greater than zero.
- **this_site** – The sequence number of this invocation (usually the locality id). This value is optional and defaults to whatever *hpx::get_locality_id()* returns.

Returns This function returns a future holding a value calculated based on the values send by all participating sites. It will become ready once the reduce operation has been completed.

Returns This function returns a future holding a value calculated based on the values send by all participating sites. It will become ready once the reduce operation has been completed.

```
template<typename T, typename F>
hpx::future<void> reduce_here(char const *basename, T &&result, this_site_arg this_site =
    this_site_arg(), generation_arg generation = generation_arg(),
    root_site_arg root_site = root_site_arg())
```

Reduce a given value at the given call site

This function transmits the value given by *result* to a central reduce site (where the corresponding *reduce_here* is executed)

Parameters

- **basename** – The base name identifying the reduction operation
- **result** – A future referring to the value to transmit to the central reduction point from this call site.
- **this_site** – The sequence number of this invocation (usually the locality id). This value is optional and defaults to whatever *hpx::get_locality_id()* returns.
- **generation** – The generational counter identifying the sequence number of the *all_reduce* operation performed on the given base name. This is optional and needs to be supplied only if the *all_reduce* operation on the given base name has to be performed more than once. The generation number (if given) must be a positive number greater than zero.
- **root_site** – The sequence number of the central reduction point (usually the locality id). This value is optional and defaults to 0.

Returns This function returns a *future<void>*. It will become ready once the reduction operation has been completed.

```
template<typename T>
hpx::future<void> reduce_here(communicator comm, T &&result, this_site_arg this_site =
    this_site_arg(), generation_arg generation = generation_arg())
```

Reduce a given value at the given call site

This function transmits the value given by *result* to a central reduce site (where the corresponding *reduce_here* is executed)

Reduce a given value at the given call site

This function transmits the value given by *result* to a central reduce site (where the corresponding *reduce_here* is executed)

Note: The generation values from corresponding *reduce_here* and *reduce_there* have to match.

Note: The generation values from corresponding *reduce_here* and *reduce_there* have to match.

Parameters

- **comm** – A communicator object returned from *create_communicator*
- **result** – A value to reduce on the central reduction point from this call site.
- **this_site** – The sequence number of this invocation (usually the locality id). This value is optional and defaults to whatever `hpx::get_locality_id()` returns.
- **generation** – The generational counter identifying the sequence number of the `all_reduce` operation performed on the given base name. This is optional and needs to be supplied only if the `all_reduce` operation on the given base name has to be performed more than once. The generation number (if given) must be a positive number greater than zero.
- **comm** – A communicator object returned from *create_communicator*
- **result** – A value to reduce on the central reduction point from this call site.
- **generation** – The generational counter identifying the sequence number of the `all_reduce` operation performed on the given base name. This is optional and needs to be supplied only if the `all_reduce` operation on the given base name has to be performed more than once. The generation number (if given) must be a positive number greater than zero.
- **this_site** – The sequence number of this invocation (usually the locality id). This value is optional and defaults to whatever `hpx::get_locality_id()` returns.

Returns This function returns a future holding a value calculated based on the values send by all participating sites. It will become ready once the reduce operation has been completed.

Returns This function returns a future holding a value calculated based on the values send by all participating sites. It will become ready once the reduce operation has been completed.

```
template<typename T, typename F>
decltype(auto) reduce_here(hpx::launch::sync_policy, char const *basename, T &&result, F &&op,
                           num_sites_arg num_sites = num_sites_arg(), this_site_arg this_site =
                           this_site_arg(), generation_arg generation = generation_arg())
```

Reduce a set of values from different call sites

This function receives a set of values from all call sites operating on the given base name.

Parameters

- **policy** – The execution policy specifying synchronous execution.
- **basename** – The base name identifying the `all_reduce` operation
- **result** – A value to reduce on the central reduction point from this call site.
- **op** – Reduction operation to apply to all values supplied from all participating sites
- **num_sites** – The number of participating sites (default: all localities).
- **this_site** – The sequence number of this invocation (usually the locality id). This value is optional and defaults to whatever `hpx::get_locality_id()` returns.
- **generation** – The generational counter identifying the sequence number of the `all_reduce` operation performed on the given base name. This is optional and needs to be supplied only if the `all_reduce` operation on the given base name has to be performed more than once. The generation number (if given) must be a positive number greater than zero.

Returns The final reduced value after applying `op` to all contributions.

```
template<typename T, typename F>
```

```
decltype(auto) reduce_here(hpx::launch::sync_policy, communicator comm, T &&result, F &&op,
    this_site_arg this_site = this_site_arg(), generation_arg generation =
    generation_arg())
```

Reduce a set of values from different call sites

This function receives a set of values that are the result of applying a given operator on values supplied from all call sites operating on the given base name.

Reduce a set of values from different call sites

This function receives a set of values that are the result of applying a given operator on values supplied from all call sites operating on the given base name.

Note: The generation values from corresponding *reduce_here* and *reduce_there* have to match.

Note: The generation values from corresponding *reduce_here* and *reduce_there* have to match.

Parameters

- **policy** – The execution policy specifying synchronous execution.
- **comm** – A communicator object returned from *create_communicator*
- **result** – A value to reduce on the root_site from this call site.
- **op** – Reduction operation to apply to all values supplied from all participating sites
- **this_site** – The sequence number of this invocation (usually the locality id). This value is optional and defaults to whatever `hpx::get_locality_id()` returns.
- **generation** – The generational counter identifying the sequence number of the all_reduce operation performed on the given base name. This is optional and needs to be supplied only if the all_reduce operation on the given base name has to be performed more than once. The generation number (if given) must be a positive number greater than zero.
- **policy** – The execution policy specifying synchronous execution.
- **comm** – A communicator object returned from *create_communicator*
- **result** – A value to reduce on the root_site from this call site.
- **op** – Reduction operation to apply to all values supplied from all participating sites
- **generation** – The generational counter identifying the sequence number of the all_reduce operation performed on the given base name. This is optional and needs to be supplied only if the all_reduce operation on the given base name has to be performed more than once. The generation number (if given) must be a positive number greater than zero.
- **this_site** – The sequence number of this invocation (usually the locality id). This value is optional and defaults to whatever `hpx::get_locality_id()` returns.

Returns The final reduced value after applying **op** to all contributions.

Returns The final reduced value after applying **op** to all contributions.

```
template<typename T>
void reduce_there(hpx::launch::sync_policy, char const *basename, T &&result, this_site_arg
    this_site = this_site_arg(), generation_arg generation = generation_arg(),
    root_site_arg root_site = root_site_arg())
```

Reduce a given value at the given call site

This function transmits the value given by *result* to a central reduce site (where the corresponding *reduce_here* is executed)

Parameters

- **policy** – The execution policy specifying synchronous execution.
- **basename** – The base name identifying the reduction operation
- **result** – A future referring to the value to transmit to the central reduction point from this call site.
- **this_site** – The sequence number of this invocation (usually the locality id). This value is optional and defaults to whatever `hpx::get_locality_id()` returns.
- **generation** – The generational counter identifying the sequence number of the `all_reduce` operation performed on the given base name. This is optional and needs to be supplied only if the `all_reduce` operation on the given base name has to be performed more than once. The generation number (if given) must be a positive number greater than zero.
- **root_site** – The sequence number of the central reduction point (usually the locality id). This value is optional and defaults to 0.

```
template<typename T>  
void reduce_there(hpx::launch::sync_policy, communicator comm, T &&result, this_site_arg  
                 this_site = this_site_arg(), generation_arg generation = generation_arg())
```

Reduce a given value at the given call site

This function transmits the value given by *result* to a central reduce site (where the corresponding *reduce_here* is executed)

Reduce a given value at the given call site

This function transmits the value given by *result* to a central reduce site (where the corresponding *reduce_here* is executed)

Note: The generation values from corresponding *reduce_here* and *reduce_there* have to match.

Note: The generation values from corresponding *reduce_here* and *reduce_there* have to match.

Parameters

- **policy** – The execution policy specifying synchronous execution.
- **comm** – A communicator object returned from *create_communicator*
- **result** – A value to reduce on the central reduction point from this call site.
- **this_site** – The sequence number of this invocation (usually the locality id). This value is optional and defaults to whatever `hpx::get_locality_id()` returns.
- **generation** – The generational counter identifying the sequence number of the `all_reduce` operation performed on the given base name. This is optional and needs to be supplied only if the `all_reduce` operation on the given base name has to be performed more than once. The generation number (if given) must be a positive number greater than zero.
- **policy** – The execution policy specifying synchronous execution.
- **comm** – A communicator object returned from *create_communicator*
- **result** – A value to reduce on the central reduction point from this call site.
- **generation** – The generational counter identifying the sequence number of the `all_reduce` operation performed on the given base name. This is optional and needs to be supplied only if the `all_reduce` operation on the given base name has to be performed more than once. The generation number (if given) must be a positive number greater than zero.
- **this_site** – The sequence number of this invocation (usually the locality id). This value is optional and defaults to whatever `hpx::get_locality_id()` returns.

hpx/collectives/reduce_direct.hpp

Defined in header `hpx/collectives/reduce_direct.hpp`.

See *Public API* for a list of names and headers that are part of the public HPX API.

namespace **hpx**

Top level HPX namespace.

namespace **lcos**

Functions

```
template<typename Action, typename ReduceOp, typename ArgN, ...
> hpx::future< decltype(Action(hpx::id_type, ArgN,...
))> reduce (std::vector< hpx::id_type > const &ids, ReduceOp &&reduce_op,
ArgN argN,...)
```

Perform a distributed reduction operation.

The function `hpx::lcos::reduce` performs a distributed reduction operation over results returned from action invocations on a given set of global identifiers. The action can be either a plain action (in which case the global identifiers have to refer to localities) or a component action (in which case the global identifiers have to refer to instances of a component type which exposes the action).

Parameters

- **ids** – [in] A list of global identifiers identifying the target objects for which the given action will be invoked.
- **reduce_op** – [in] A binary function expecting two results as returned from the action invocations. The function (or function object) is expected to return the result of the reduction operation performed on its arguments.
- **argN** – [in] Any number of arbitrary arguments (passed by const reference) which will be forwarded to the action invocation.

Returns This function returns a future representing the result of the overall reduction operation.

```
template<typename Action, typename ReduceOp, typename ArgN, ...
> hpx::future< decltype(Action(hpx::id_type, ArgN,...,
std::size_t))> reduce_with_index (std::vector< hpx::id_type > const &ids,
ReduceOp &&reduce_op, ArgN argN,...)
```

Perform a distributed reduction operation.

The function `hpx::lcos::reduce_with_index` performs a distributed reduction operation over results returned from action invocations on a given set of global identifiers. The action can be either plain action (in which case the global identifiers have to refer to localities) or a component action (in which case the global identifiers have to refer to instances of a component type which exposes the action).

The function passes the index of the global identifier in the given list of identifiers as the last argument to the action.

Parameters

- **ids** – [in] A list of global identifiers identifying the target objects for which the given action will be invoked.
- **reduce_op** – [in] A binary function expecting two results as returned from the action invocations. The function (or function object) is expected to return the result of the reduction operation performed on its arguments.

- **argN** – [in] Any number of arbitrary arguments (passed by const reference) which will be forwarded to the action invocation.

Returns This function returns a future representing the result of the overall reduction operation.

hpx/collectives/scatter.hpp

Defined in header `hpx/collectives/scatter.hpp`.

See *Public API* for a list of names and headers that are part of the public *HPX* API.

namespace **hpx**

Top level HPX namespace.

namespace **collectives**

Top level HPX namespace.

Functions

```
template<typename T>
hpx::future<T> scatter_from(char const *basename, this_site_arg this_site = this_site_arg(),
                           generation_arg generation = generation_arg(), root_site_arg root_site =
                           root_site_arg())
```

Scatter (receive) a set of values to different call sites

This function receives an element of a set of values operating on the given base name.

Parameters

- **basename** – The base name identifying the scatter operation
- **this_site** – The sequence number of this invocation (usually the locality id). This value is optional and defaults to whatever `hpx::get_locality_id()` returns.
- **generation** – The generational counter identifying the sequence number of the `all_gather` operation performed on the given base name. This is optional and needs to be supplied only if the `all_gather` operation on the given base name has to be performed more than once. The generation number (if given) must be a positive number greater than zero.
- **root_site** – The sequence number of the central scatter point (usually the locality id). This value is optional and defaults to 0.

Returns This function returns a future holding the scattered value. It will become ready once the scatter operation has been completed.

```
template<typename T>
hpx::future<T> scatter_from(communicator comm, this_site_arg this_site = this_site_arg(),
                           generation_arg generation = generation_arg())
```

Scatter (receive) a set of values to different call sites

This function receives an element of a set of values operating on the given base name.

Scatter (receive) a set of values to different call sites

This function receives an element of a set of values operating on the given base name.

Note: The generation values from corresponding *scatter_to* and *scatter_from* have to match.

Note: The generation values from corresponding *scatter_to* and *scatter_from* have to match.

Parameters

- **comm** – A communicator object returned from *create_communicator*
- **this_site** – The sequence number of this invocation (usually the locality id). This value is optional and defaults to whatever `hpx::get_locality_id()` returns.
- **generation** – The generational counter identifying the sequence number of the `all_gather` operation performed on the given base name. This is optional and needs to be supplied only if the `all_gather` operation on the given base name has to be performed more than once. The generation number (if given) must be a positive number greater than zero.
- **comm** – A communicator object returned from *create_communicator*
- **generation** – The generational counter identifying the sequence number of the `all_gather` operation performed on the given base name. This is optional and needs to be supplied only if the `all_gather` operation on the given base name has to be performed more than once. The generation number (if given) must be a positive number greater than zero.
- **this_site** – The sequence number of this invocation (usually the locality id). This value is optional and defaults to whatever `hpx::get_locality_id()` returns.

Returns This function returns a future holding the scattered value. It will become ready once the scatter operation has been completed.

Returns This function returns a future holding the scattered value. It will become ready once the scatter operation has been completed.

```
template<typename T>
hpx::future<T> scatter_to(char const *basename, std::vector<T> &&result, num_sites_arg num_sites
                        = num_sites_arg(), this_site_arg this_site = this_site_arg(), generation_arg
                        generation = generation_arg())
```

Scatter (send) a part of the value set at the given call site

This function transmits the value given by *result* to a central scatter site (where the corresponding *scatter_from* is executed)

Parameters

- **basename** – The base name identifying the scatter operation
- **result** – The value to transmit to the central scatter point from this call site.
- **num_sites** – The number of participating sites (default: all localities).
- **this_site** – The sequence number of this invocation (usually the locality id). This value is optional and defaults to whatever `hpx::get_locality_id()` returns.
- **generation** – The generational counter identifying the sequence number of the `all_gather` operation performed on the given base name. This is optional and needs to be supplied only if the `all_gather` operation on the given base name has to be performed more than once. The generation number (if given) must be a positive number greater than zero.

Returns This function returns a future holding the scattered value. It will become ready once the scatter operation has been completed.

```
template<typename T>
hpx::future<T> scatter_to(communicator comm, std::vector<T> &&result, this_site_arg this_site =
                        this_site_arg(), generation_arg generation = generation_arg())
```

Scatter (send) a part of the value set at the given call site

This function transmits the value given by *result* to a central scatter site (where the corresponding *scatter_from* is executed)

Scatter (send) a part of the value set at the given call site

This function transmits the value given by *result* to a central scatter site (where the corresponding *scatter_from* is executed)

Note: The generation values from corresponding *scatter_to* and *scatter_from* have to match.

Note: The generation values from corresponding *scatter_to* and *scatter_from* have to match.

Parameters

- **comm** – A communicator object returned from *create_communicator*
- **result** – The value to transmit to the central scatter point from this call site.
- **this_site** – The sequence number of this invocation (usually the locality id). This value is optional and defaults to whatever `hpx::get_locality_id()` returns.
- **generation** – The generational counter identifying the sequence number of the `all_gather` operation performed on the given base name. This is optional and needs to be supplied only if the `all_gather` operation on the given base name has to be performed more than once. The generation number (if given) must be a positive number greater than zero.
- **comm** – A communicator object returned from *create_communicator*
- **result** – The value to transmit to the central scatter point from this call site.
- **generation** – The generational counter identifying the sequence number of the `all_gather` operation performed on the given base name. This is optional and needs to be supplied only if the `all_gather` operation on the given base name has to be performed more than once. The generation number (if given) must be a positive number greater than zero.
- **this_site** – The sequence number of this invocation (usually the locality id). This value is optional and defaults to whatever `hpx::get_locality_id()` returns.

Returns This function returns a future holding the scattered value. It will become ready once the scatter operation has been completed.

Returns This function returns a future holding the scattered value. It will become ready once the scatter operation has been completed.

```
template<typename T>
T scatter_from(hpx::launch::sync_policy, char const *basename, this_site_arg this_site =
              this_site_arg(), generation_arg generation = generation_arg(), root_site_arg root_site
              = root_site_arg())
```

Scatter (receive) a set of values to different call sites

This function receives an element of a set of values operating on the given base name.

Parameters

- **policy** – The execution policy specifying synchronous execution.
- **basename** – The base name identifying the scatter operation
- **this_site** – The sequence number of this invocation (usually the locality id). This value is optional and defaults to whatever `hpx::get_locality_id()` returns.
- **generation** – The generational counter identifying the sequence number of the `all_gather` operation performed on the given base name. This is optional and needs to be supplied only if the `all_gather` operation on the given base name has to be performed

more than once. The generation number (if given) must be a positive number greater than zero.

- **root_site** – The sequence number of the central scatter point (usually the locality id). This value is optional and defaults to 0.

Returns This function returns the scattered value. It executes synchronously and directly returns the result.

```
template<typename T>
```

```
T scatter_from(hpx::launch::sync_policy, communicator comm, this_site_arg this_site =
               this_site_arg(), generation_arg generation = generation_arg())
```

Scatter (receive) a set of values to different call sites

This function receives an element of a set of values operating on the given base name.

Scatter (receive) a set of values to different call sites

This function receives an element of a set of values operating on the given base name.

Note: The generation values from corresponding *scatter_to* and *scatter_from* have to match.

Note: The generation values from corresponding *scatter_to* and *scatter_from* have to match.

Parameters

- **policy** – The execution policy specifying synchronous execution.
- **comm** – A communicator object returned from *create_communicator*
- **this_site** – The sequence number of this invocation (usually the locality id). This value is optional and defaults to whatever *hpx::get_locality_id()* returns.
- **generation** – The generational counter identifying the sequence number of the all_gather operation performed on the given base name. This is optional and needs to be supplied only if the all_gather operation on the given base name has to be performed more than once. The generation number (if given) must be a positive number greater than zero.
- **policy** – The execution policy specifying synchronous execution.
- **comm** – A communicator object returned from *create_communicator*
- **generation** – The generational counter identifying the sequence number of the all_gather operation performed on the given base name. This is optional and needs to be supplied only if the all_gather operation on the given base name has to be performed more than once. The generation number (if given) must be a positive number greater than zero.
- **this_site** – The sequence number of this invocation (usually the locality id). This value is optional and defaults to whatever *hpx::get_locality_id()* returns.

Returns This function returns the scattered value. It executes synchronously and directly returns the result.

Returns This function returns the scattered value. It executes synchronously and directly returns the result.

```
template<typename T>
```

```
T scatter_to(hpx::launch::sync_policy, char const *basename, std::vector<T> &&result,
             num_sites_arg num_sites = num_sites_arg(), this_site_arg this_site = this_site_arg(),
             generation_arg generation = generation_arg())
```

Scatter (send) a part of the value set at the given call site

This function transmits the value given by *result* to a central scatter site (where the corresponding *scatter_from* is executed)

Parameters

- **policy** – The execution policy specifying synchronous execution.
- **basename** – The base name identifying the scatter operation
- **result** – The value to transmit to the central scatter point from this call site.
- **num_sites** – The number of participating sites (default: all localities).
- **this_site** – The sequence number of this invocation (usually the locality id). This value is optional and defaults to whatever `hpx::get_locality_id()` returns.
- **generation** – The generational counter identifying the sequence number of the `all_gather` operation performed on the given base name. This is optional and needs to be supplied only if the `all_gather` operation on the given base name has to be performed more than once. The generation number (if given) must be a positive number greater than zero.

Returns This function returns the scattered value. It executes synchronously and directly returns the result.

```
template<typename T>  
T scatter_to(hpx::launch::sync_policy, communicator comm, std::vector<T> &&result, this_site_arg  
            this_site = this_site_arg(), generation_arg generation = generation_arg())
```

Scatter (send) a part of the value set at the given call site

This function transmits the value given by *result* to a central scatter site (where the corresponding *scatter_from* is executed)

Scatter (send) a part of the value set at the given call site

This function transmits the value given by *result* to a central scatter site (where the corresponding *scatter_from* is executed)

Note: The generation values from corresponding *scatter_to* and *scatter_from* have to match.

Note: The generation values from corresponding *scatter_to* and *scatter_from* have to match.

Parameters

- **policy** – The execution policy specifying synchronous execution.
- **comm** – A communicator object returned from `create_communicator`
- **result** – The value to transmit to the central scatter point from this call site.
- **this_site** – The sequence number of this invocation (usually the locality id). This value is optional and defaults to whatever `hpx::get_locality_id()` returns.
- **generation** – The generational counter identifying the sequence number of the `all_gather` operation performed on the given base name. This is optional and needs to be supplied only if the `all_gather` operation on the given base name has to be performed more than once. The generation number (if given) must be a positive number greater than zero.
- **policy** – The execution policy specifying synchronous execution.
- **comm** – A communicator object returned from `create_communicator`
- **result** – The value to transmit to the central scatter point from this call site.
- **generation** – The generational counter identifying the sequence number of the `all_gather` operation performed on the given base name. This is optional and needs to be supplied only if the `all_gather` operation on the given base name has to be performed

more than once. The generation number (if given) must be a positive number greater than zero.

- **this_site** – The sequence number of this invocation (usually the locality id). This value is optional and defaults to whatever `hpx::get_locality_id()` returns.

Returns This function returns the scattered value. It executes synchronously and directly returns the result.

Returns This function returns the scattered value. It executes synchronously and directly returns the result.

components

See *Public API* for a list of names and headers that are part of the public *HPX* API.

hpx/components/basename_registration.hpp

Defined in header `hpx/components/basename_registration.hpp`.

See *Public API* for a list of names and headers that are part of the public *HPX* API.

namespace **hpx**

Functions

```
template<typename Client>
std::vector<Client> find_all_from_basename(std::string base_name, std::size_t num_ids)
```

Return all registered clients from all localities from the given base name.

This function locates all ids which were registered with the given base name. It returns a list of futures representing those ids.

Return all registered ids from all localities from the given base name.

This function locates all ids which were registered with the given base name. It returns a list of futures representing those ids.

Note: The futures embedded in the returned client objects will become ready even if the event (for instance, binding the name to an id) has already happened in the past. This is important in order to reliably retrieve ids from a name, even if the name was already registered.

Note: The futures will become ready even if the event (for instance, binding the name to an id) has already happened in the past. This is important in order to reliably retrieve ids from a name, even if the name was already registered.

Template Parameters **Client** – The client type to return

Parameters

- **base_name** – [in] The base name for which to retrieve the registered ids.
- **num_ids** – [in] The number of registered ids to expect.

- **base_name** – [in] The base name for which to retrieve the registered ids.
- **num_ids** – [in] The number of registered ids to expect.

Returns A list of futures representing the ids which were registered using the given base name.

Returns A list of futures representing the ids which were registered using the given base name.

```
template<typename Client>
std::vector<Client> find_all_from_basename(hpx::launch::sync_policy policy, std::string base_name,
                                         std::size_t num_ids)
```

```
template<typename Client>
std::vector<Client> find_from_basename(std::string base_name, std::vector<std::size_t> const &ids)
```

Return registered clients from the given base name and sequence numbers.

This function locates the ids which were registered with the given base name and the given sequence numbers. It returns a list of futures representing those ids.

Return registered ids from the given base name and sequence numbers.

This function locates the ids which were registered with the given base name and the given sequence numbers. It returns a list of futures representing those ids.

Note: The futures embedded in the returned client objects will become ready even if the event (for instance, binding the name to an id) has already happened in the past. This is important in order to reliably retrieve ids from a name, even if the name was already registered.

Note: The futures will become ready even if the event (for instance, binding the name to an id) has already happened in the past. This is important in order to reliably retrieve ids from a name, even if the name was already registered.

Template Parameters **Client** – The client type to return

Parameters

- **base_name** – [in] The base name for which to retrieve the registered ids.
- **ids** – [in] The sequence numbers of the registered ids.
- **base_name** – [in] The base name for which to retrieve the registered ids.
- **ids** – [in] The sequence numbers of the registered ids.

Returns A list of futures representing the ids which were registered using the given base name and sequence numbers.

Returns A list of futures representing the ids which were registered using the given base name and sequence numbers.

```
template<typename Client>
std::vector<Client> find_from_basename(hpx::launch::sync_policy policy, std::string base_name,
                                       std::vector<std::size_t> const &ids)
```

```
template<typename Client>
```

Client **find_from_basename**(*std::string* base_name, *std::size_t* sequence_nr)

Return registered id from the given base name and sequence number.

This function locates the id which was registered with the given base name and the given sequence number. It returns a future representing those id.

This function locates the id which was registered with the given base name and the given sequence number. It returns a future representing those id.

Note: The future embedded in the returned client object will become ready even if the event (for instance, binding the name to an id) has already happened in the past. This is important in order to reliably retrieve ids from a name, even if the name was already registered.

Note: The future will become ready even if the event (for instance, binding the name to an id) has already happened in the past. This is important in order to reliably retrieve ids from a name, even if the name was already registered.

Template Parameters **Client** – The client type to return

Parameters

- **base_name** – [in] The base name for which to retrieve the registered ids.
- **sequence_nr** – [in] The sequence number of the registered id.
- **base_name** – [in] The base name for which to retrieve the registered ids.
- **sequence_nr** – [in] The sequence number of the registered id.

Returns A representing the id which was registered using the given base name and sequence numbers.

Returns A representing the id which was registered using the given base name and sequence numbers.

```
template<typename Client>
```

```
Client find_from_basename(hpx::launch::sync_policy policy, std::string base_name, std::size_t
sequence_nr)
```

```
template<typename Client, typename Stub, typename Data>
```

```
hpx::future<bool> register_with_basename(std::string base_name, components::client_base<Client, Stub,
Data> &client, std::size_t sequence_nr)
```

Register the id wrapped in the given client using the given base name.

The function registers the object the given client refers to using the provided base name.

Note: The operation will fail if the given sequence number is not unique.

Template Parameters **Client** – The client type to register

Parameters

- **base_name** – [in] The base name for which to retrieve the registered ids.

- **client** – [in] The client which should be registered using the given base name.
- **sequence_nr** – [in, optional] The sequential number to use for the registration of the id. This number has to be unique system-wide for each registration using the same base name. The default is the current locality identifier. Also, the sequence numbers have to be consecutive starting from zero.

Returns A future representing the result of the registration operation itself.

```
template<typename Client>  
Client unregister_with_basename(std::string base_name, std::size_t sequence_nr =  
                               ~static_cast<std::size_t>(0))
```

Unregister the given id using the given base name.

Unregister the given base name.

The function unregisters the given ids using the provided base name.

The function unregisters the given ids using the provided base name.

Template Parameters **Client** – The client type to return

Parameters

- **base_name** – [in] The base name for which to retrieve the registered ids.
- **sequence_nr** – [in, optional] The sequential number to use for the un-registration. This number has to be the same as has been used with *register_with_basename* before.
- **base_name** – [in] The base name for which to retrieve the registered ids.
- **sequence_nr** – [in, optional] The sequential number to use for the un-registration. This number has to be the same as has been used with *register_with_basename* before.

Returns A future representing the result of the un-registration operation itself.

Returns A future representing the result of the un-registration operation itself.

hpx/components/basename_registration_fwd.hpp

Defined in header hpx/components/basename_registration_fwd.hpp.

See *Public API* for a list of names and headers that are part of the public *HPX* API.

```
namespace hpx
```

Functions

```
hpx::future<bool> register_with_basename(std::string base_name, hpx::id_type const &id, std::size_t  
                                       sequence_nr = ~static_cast<std::size_t>(0))
```

Register the given id using the given base name.

The function registers the given ids using the provided base name.

Note: The operation will fail if the given sequence number is not unique.

Parameters

- **base_name** – [in] The base name for which to retrieve the registered ids.
- **id** – [in] The id to register using the given base name.
- **sequence_nr** – [in, optional] The sequential number to use for the registration of the id. This number has to be unique system-wide for each registration using the same base name. The default is the current locality identifier. Also, the sequence numbers have to be consecutive starting from zero.

Returns A future representing the result of the registration operation itself.

```
bool register_with_basename(hpx::launch::sync_policy, std::string base_name, hpx::id_type const &id,
                           std::size_t sequence_nr = ~static_cast<std::size_t>(0), error_code &ec =
                           throws)
```

```
hpx::future<bool> register_with_basename(std::string base_name, hpx::future<hpx::id_type> f,
                                       std::size_t sequence_nr = ~static_cast<std::size_t>(0))
```

Register the id wrapped in the given future using the given base name.

The function registers the object the given future refers to using the provided base name.

Note: The operation will fail if the given sequence number is not unique.

Parameters

- **base_name** – [in] The base name for which to retrieve the registered ids.
- **f** – [in] The future which should be registered using the given base name.
- **sequence_nr** – [in, optional] The sequential number to use for the registration of the id. This number has to be unique system-wide for each registration using the same base name. The default is the current locality identifier. Also, the sequence numbers have to be consecutive starting from zero.

Returns A future representing the result of the registration operation itself.

hpx::components::client

Defined in header `hpx/components.hpp`.

See *Public API* for a list of names and headers that are part of the public HPX API.

namespace **hpx**

namespace **components**

```
template<typename Component, typename Data = void>
```

```
class client : public hpx::components::client_base<client<Component, void>, Component, void>
```

#include <client.hpp> The client class is a wrapper that manages a distributed component. It extends *client_base* with specific *Component* and *Data* types.

Template Parameters

- **Component** – The type of the component.
- **Data** – The type of the data associated with the client (default is void).

Public Functions

```
client() = default  
  
inline explicit client(hpx::id_type const &id)  
inline explicit client(hpx::id_type &&id)  
inline explicit client(future_type const &f) noexcept  
inline explicit client(future_type &&f) noexcept  
inline client(future<hpx::id_type> &&f) noexcept  
inline client(future<client> &&c)  
  
client(client const &rhs) noexcept = default  
client(client &&rhs) noexcept = default  
  
~client() = default  
  
inline client &operator=(hpx::id_type const &id)  
inline client &operator=(hpx::id_type &&id)  
inline client &operator=(future_type const &f) noexcept  
inline client &operator=(future_type &&f) noexcept  
inline client &operator=(future<hpx::id_type> &&f) noexcept  
client &operator=(client const &rhs) noexcept = default  
client &operator=(client &&rhs) noexcept = default
```

Private Types

```
using base_type = client_base<client, Component, Data>  
  
using future_type = typename base_type::future_type
```

hpx::components::client_base

Defined in header `hpx/components.hpp`.

See *Public API* for a list of names and headers that are part of the public *HPX* API.

```
template<typename Derived>  
struct is_client<Derived, std::void_t<typename Derived::is_client_tag>> : public true_type  
  
namespace hpx  
  
    namespace components
```

Functions

```
template<typename Derived, typename Stub, typename Data>
bool operator==(client_base<Derived, Stub, Data> const &lhs, client_base<Derived, Stub, Data>
               const &rhs)
```

```
template<typename Derived, typename Stub, typename Data>
bool operator<(client_base<Derived, Stub, Data> const &lhs, client_base<Derived, Stub, Data> const
              &rhs)
```

```
template<typename Derived, typename Stub, typename Data>
```

```
class client_base : public detail::make_stub::type<Stub>
```

#include <*client_base.hpp*> This class template serves as a base class for client components, providing common functionality such as managing shared state, ID retrieval, and asynchronous operations.

Template Parameters

- **Derived** – The derived client component type.
- **Stub** – The stub type used for communication.
- **Data** – The extra data type used for additional information.

Public Types

```
using stub_argument_type = Stub
```

```
using server_component_type = typename detail::make_stub<Stub>::server_component_type
```

```
using is_client_tag = void
```

Public Functions

```
client_base() = default
```

```
inline explicit client_base(id_type const &id)
```

```
inline explicit client_base(id_type &&id)
```

```
inline client_base(id_type const &id, bool make_unmanaged)
```

```
inline client_base(id_type &&id, bool make_unmanaged)
```

```
inline explicit client_base(hpx::shared_future<hpx::id_type> const &f) noexcept
```

```
inline explicit client_base(hpx::shared_future<hpx::id_type> &&f) noexcept
```

```
inline explicit client_base(hpx::future<hpx::id_type> &&f) noexcept
```

```
client_base(client_base const &rhs) = default
```

```
client_base(client_base &&rhs) noexcept = default
```

```
inline client_base(hpx::future<Derived> &&d)
```

```
~client_base() = default
```

```
inline client_base &operator=(hpx::id_type const &id)
inline client_base &operator=(hpx::id_type &&id)
inline client_base &operator=(hpx::shared_future<hpx::id_type> const &f) noexcept
inline client_base &operator=(hpx::shared_future<hpx::id_type> &&f) noexcept
inline client_base &operator=(hpx::future<hpx::id_type> &&f) noexcept
client_base &operator=(client_base const &rhs) = default
client_base &operator=(client_base &&rhs) noexcept = default
inline bool valid() const noexcept
inline explicit operator bool() const noexcept
inline void free()
inline hpx::id_type const &get_id(error_code &ec = hpx::throws) const
inline naming::gid_type const &get_raw_gid() const
inline hpx::shared_future<hpx::id_type> detach()
inline hpx::shared_future<hpx::id_type> share() const
inline void reset(hpx::id_type const &id)
inline void reset(hpx::id_type &&id)
inline void reset(shared_future<hpx::id_type> &&rhs)
inline id_type const &get(error_code &ec = hpx::throws) const
inline bool is_ready() const noexcept
inline bool has_value() const noexcept
inline bool has_exception() const noexcept
inline void wait() const
inline std::exception_ptr get_exception_ptr() const
template<typename F>
inline hpx::traits::future_then_result_t<Derived, F> then(launch l, F &&f) const
template<typename F>
inline hpx::traits::future_then_result_t<Derived, F> then(launch::sync_policy l, F &&f) const
template<typename F>
inline hpx::traits::future_then_result_t<Derived, F> then(F &&f) const
inline hpx::future<bool> register_as(std::string symbolic_name, bool manage_lifetime = true)
inline bool register_as(launch::sync_policy, std::string symbolic_name, bool manage_lifetime =
    true)
```

```

inline void connect_to(std::string const &symbolic_name)

inline std::string const &registered_name() const

template<typename T>
inline T &get_extra_data()

template<typename T>
inline T *try_get_extra_data() const noexcept

```

Protected Types

```

using stub_type = typename detail::make_stub<Stub>::type

using base_shared_state_type = lcos::detail::future_data_base<hpx::id_type>

using shared_state_type = lcos::detail::future_data<hpx::id_type>

using future_type = shared_future<hpx::id_type>

using extra_data_type = Data

```

Protected Functions

```

inline client_base(hpx::intrusive_ptr<base_shared_state_type> const &state)

inline client_base(hpx::intrusive_ptr<base_shared_state_type> &&state)

```

Protected Attributes

```

hpx::intrusive_ptr<base_shared_state_type> shared_state_

```

Private Static Functions

```

template<typename F>
static inline hpx::traits::future_then_result<Derived, F>::cont_result on_ready(hpx::shared_future<id_type>
&&fut, F f)

static inline bool register_as_helper(client_base const &f, std::string symbolic_name, bool
manage_lifetime)

```

```
namespace lcos
```

```
namespace serialization
```

Functions

```
template<typename Archive, typename Derived, typename Stub, typename Data>
void serialize(Archive &ar, ::hpx::components::client_base<Derived, Stub, Data> &f, unsigned
    version)
```

```
namespace traits
```

```
    template<typename Derived> is_client_tag > > : public true_type
```

hpx/components/get_ptr.hpp

Defined in header `hpx/components/get_ptr.hpp`.

See *Public API* for a list of names and headers that are part of the public *HPX* API.

```
namespace hpx
```

Functions

```
template<typename Component>
hpx::future<std::shared_ptr<Component>> get_ptr(hpx::id_type const &id)
```

Returns a future referring to the pointer to the underlying memory of a component.

The function `hpx::get_ptr` can be used to extract a future referring to the pointer to the underlying memory of a given component.

Note: This function will successfully return the requested result only if the given component is currently located on the calling locality. Otherwise, the function will raise an error.

Note: The component instance the returned pointer refers to can not be migrated as long as there is at least one copy of the returned `shared_ptr` alive.

Parameters `id` – [in] The global id of the component for which the pointer to the underlying memory should be retrieved.

Template Parameters `Component` – The type of the server side component.

Returns This function returns a future representing the pointer to the underlying memory for the component instance with the given `id`.

```
template<typename Derived, typename Stub, typename Data>
hpx::future<std::shared_ptr<typename components::client_base<Derived, Stub, Data>::server_component_type>> get_ptr(con
    Stub
    Data
    con
    &c
```

Returns a future referring to the pointer to the underlying memory of a component.

The function `hpx::get_ptr` can be used to extract a future referring to the pointer to the underlying memory of a given component.

Note: This function will successfully return the requested result only if the given component is currently located on the calling locality. Otherwise, the function will raise an error.

Note: The component instance the returned pointer refers to can not be migrated as long as there is at least one copy of the returned `shared_ptr` alive.

Parameters `c` – [in] A client side representation of the component for which the pointer to the underlying memory should be retrieved.

Returns This function returns a future representing the pointer to the underlying memory for the component instance with the given `id`.

```
template<typename Component>
std::shared_ptr<Component> get_ptr(launch::sync_policy p, hpx::id_type const &id, error_code &ec =
    throws)
```

Returns the pointer to the underlying memory of a component.

The function `hpx::get_ptr_sync` can be used to extract the pointer to the underlying memory of a given component.

Note: This function will successfully return the requested result only if the given component is currently located on the requesting locality. Otherwise, the function will raise an error.

Note: The component instance the returned pointer refers to can not be migrated as long as there is at least one copy of the returned `shared_ptr` alive.

Note: As long as `ec` is not pre-initialized to `hpx::throws` this function doesn't throw but returns the result code using the parameter `ec`. Otherwise, it throws an instance of `hpx::exception`.

Parameters

- `p` – [in] The parameter `p` represents a placeholder type to turn make the call synchronous.
- `id` – [in] The global id of the component for which the pointer to the underlying memory should be retrieved.
- `ec` – [in,out] this represents the error status on exit, if this is pre-initialized to `hpx::throws` the function will throw on error instead.

Template Parameters `Component` – The only template parameter has to be the type of the server side component.

Returns This function returns the pointer to the underlying memory for the component instance with the given `id`.

```
template<typename Derived, typename Stub, typename Data>
std::shared_ptr<typename components::client_base<Derived, Stub, Data>::server_component_type> get_ptr(launch::sync_policy
    p,
    com-
    po-
    ponents::client_base
    Stub,
    Data>
    const
    &c,
    er-
    ror_code
    &ec
    =
    throws)
```

Returns the pointer to the underlying memory of a component.

The function `hpx::get_ptr_sync` can be used to extract the pointer to the underlying memory of a given component.

Note: This function will successfully return the requested result only if the given component is currently located on the requesting locality. Otherwise, the function will raise an error.

Note: The component instance the returned pointer refers to can not be migrated as long as there is at least one copy of the returned `shared_ptr` alive.

Note: As long as `ec` is not pre-initialized to `hpx::throws` this function doesn't throw but returns the result code using the parameter `ec`. Otherwise, it throws an instance of `hpx::exception`.

Parameters

- **p** – [in] The parameter `p` represents a placeholder type to turn make the call synchronous.
- **c** – [in] A client side representation of the component for which the pointer to the underlying memory should be retrieved.
- **ec** – [in,out] this represents the error status on exit, if this is pre-initialized to `hpx::throws` the function will throw on error instead.

Returns This function returns the pointer to the underlying memory for the component instance with the given `id`.

components_base

See *Public API* for a list of names and headers that are part of the public *HPX* API.

hpx/components_base/agas_interface.hpp

Defined in header `hpx/components_base/agas_interface.hpp`.

See *Public API* for a list of names and headers that are part of the public *HPX* API.

namespace **hpx**

namespace **agas**

Functions

bool **is_console**()

bool **register_name**(*launch::sync_policy*, *std::string* const &name, *naming::gid_type* const &gid, *error_code* &ec = *throws*)

bool **register_name**(*launch::sync_policy*, *std::string* const &name, *hpx::id_type* const &id, *error_code* &ec = *throws*)

hpx::future<bool> **register_name**(*std::string* const &name, *hpx::id_type* const &id)

hpx::id_type **unregister_name**(*launch::sync_policy*, *std::string* const &name, *error_code* &ec = *throws*)

hpx::future<*hpx::id_type*> **unregister_name**(*std::string* const &name)

hpx::id_type **resolve_name**(*launch::sync_policy*, *std::string* const &name, *error_code* &ec = *throws*)

hpx::future<*hpx::id_type*> **resolve_name**(*std::string* const &name)

hpx::future<*std::uint32_t*> **get_num_localities**(*naming::component_type* type = *naming::component_invalid*)

std::uint32_t **get_num_localities**(*launch::sync_policy*, *naming::component_type* type, *error_code* &ec = *throws*)

inline *std::uint32_t* **get_num_localities**(*launch::sync_policy*, *error_code* &ec = *throws*)

std::string **get_component_type_name**(*naming::component_type* type, *error_code* &ec = *throws*)

hpx::future<*std::vector*<*std::uint32_t*>> **get_num_threads**()

std::vector<*std::uint32_t*> **get_num_threads**(*launch::sync_policy*, *error_code* &ec = *throws*)

hpx::future<*std::uint32_t*> **get_num_overall_threads**()

std::uint32_t **get_num_overall_threads**(*launch::sync_policy*, *error_code* &ec = *throws*)

std::uint32_t **get_locality_id**(*error_code* &ec = *throws*)

```
inline hpx::naming::gid_type get_locality()

std::vector<std::uint32_t> get_all_locality_ids(naming::component_type type, error_code &ec =
    throws)

inline std::vector<std::uint32_t> get_all_locality_ids(error_code &ec = throws)

bool is_local_address_cached(naming::gid_type const &gid, error_code &ec = throws)

bool is_local_address_cached(naming::gid_type const &gid, naming::address &addr, error_code
    &ec = throws)

bool is_local_address_cached(naming::gid_type const &gid, naming::address &addr,
    std::pair<bool, components::pinned_ptr> &r,
    hpx::move_only_function<std::pair<bool,
    components::pinned_ptr>(naming::address const&> &&f,
    error_code &ec = throws)

inline bool is_local_address_cached(hpx::id_type const &id, error_code &ec = throws)

inline bool is_local_address_cached(hpx::id_type const &id, naming::address &addr, error_code
    &ec = throws)

inline bool is_local_address_cached(hpx::id_type const &id, naming::address &addr,
    std::pair<bool, components::pinned_ptr> &r,
    hpx::move_only_function<std::pair<bool,
    components::pinned_ptr>(naming::address const&> &&f,
    error_code &ec = throws)

void update_cache_entry(naming::gid_type const &gid, naming::address const &addr, std::uint64_t
    count = 0, std::uint64_t offset = 0, error_code &ec = throws)

bool is_local_lva_encoded_address(naming::gid_type const &gid)

inline bool is_local_lva_encoded_address(hpx::id_type const &id)

hpx::future_or_value<naming::address> resolve_async(hpx::id_type const &id)

hpx::future<naming::address> resolve(hpx::id_type const &id)

naming::address resolve(launch::sync_policy, hpx::id_type const &id, error_code &ec = throws)

bool resolve_local(naming::gid_type const &gid, naming::address &addr, error_code &ec = throws)

bool resolve_cached(naming::gid_type const &gid, naming::address &addr)

hpx::future<bool> bind(naming::gid_type const &gid, naming::address const &addr, std::uint32_t
    locality_id)

bool bind(launch::sync_policy, naming::gid_type const &gid, naming::address const &addr,
    std::uint32_t locality_id, error_code &ec = throws)

hpx::future<bool> bind(naming::gid_type const &gid, naming::address const &addr, naming::gid_type
    const &locality_)

bool bind(launch::sync_policy, naming::gid_type const &gid, naming::address const &addr,
    naming::gid_type const &locality_, error_code &ec = throws)
```

```

hpx::future<naming::address> unbind(naming::gid_type const &gid, std::uint64_t count = 1)

naming::address unbind(launch::sync_policy, naming::gid_type const &gid, std::uint64_t count = 1,
    error_code &ec = throws)

bool bind_gid_local(naming::gid_type const &gid, naming::address const &addr, error_code &ec =
    throws)

void unbind_gid_local(naming::gid_type const &gid, error_code &ec = throws)

bool bind_range_local(naming::gid_type const &gid, std::size_t count, naming::address const &addr,
    std::size_t offset, error_code &ec = throws)

void unbind_range_local(naming::gid_type const &gid, std::size_t count, error_code &ec = throws)

void garbage_collect_non_blocking(error_code &ec = throws)

void garbage_collect(error_code &ec = throws)

void garbage_collect_non_blocking(hpx::id_type const &id, error_code &ec = throws)
    Invoke an asynchronous garbage collection step on the given target locality.

void garbage_collect(hpx::id_type const &id, error_code &ec = throws)
    Invoke a synchronous garbage collection step on the given target locality.

hpx::id_type get_console_locality(error_code &ec = throws)
    Return an id_type referring to the console locality.

naming::gid_type get_next_id(std::size_t count, error_code &ec = throws)

void decref(naming::gid_type const &id, std::int64_t credits, error_code &ec = throws)

hpx::future_or_value<std::int64_t> incref(naming::gid_type const &gid, std::int64_t credits,
    hpx::id_type const &keep_alive = hpx::invalid_id)

std::int64_t incref(launch::sync_policy, naming::gid_type const &gid, std::int64_t credits = 1,
    hpx::id_type const &keep_alive = hpx::invalid_id, error_code &ec = throws)

std::int64_t replenish_credits(naming::gid_type &gid)

hpx::future_or_value<id_type> get_colocation_id(hpx::id_type const &id)

hpx::id_type get_colocation_id(launch::sync_policy, hpx::id_type const &id, error_code &ec =
    throws)

hpx::future<hpx::id_type> on_symbol_namespace_event(std::string const &name, bool
    call_for_past_events)

hpx::future<std::pair<hpx::id_type, naming::address>> begin_migration(hpx::id_type const &id)

bool end_migration(hpx::id_type const &id)

hpx::future<void> mark_as_migrated(naming::gid_type const &gid,
    hpx::move_only_function<std::pair<bool,
    hpx::future<void>>()> &&f, bool
    expect_to_be_marked_as_migrating)

```

```
std::pair<bool, components::pinned_ptr> was_object_migrated(naming::gid_type const &gid,
                                                         hpx::move_only_function<components::pinned_ptr()>
                                                         &&f)

void unmark_as_migrated(naming::gid_type const &gid, hpx::move_only_function<void()> &&f)

hpx::future<std::map<std::string, hpx::id_type>> find_symbols(std::string const &pattern = "")

std::map<std::string, hpx::id_type> find_symbols(hpx::launch::sync_policy, std::string const &pattern
                                               = "")

naming::component_type register_factory(std::uint32_t prefix, std::string const &name, error_code
                                          &ec = throws)

naming::component_type get_component_id(std::string const &name, error_code &ec = throws)

void destroy_component(naming::gid_type const &gid, naming::address const &addr)

naming::address_type get_primary_ns_lva()

naming::address_type get_symbol_ns_lva()

naming::address_type get_runtime_support_lva()

struct agas_interface_functions &agas_init()
```

HPX_REGISTER_COMMANDLINE_MODULE

Defined in header `hpx/components.hpp`.

See *Public API* for a list of names and headers that are part of the public HPX API.

Defines

HPX_DEFINE_COMPONENT_COMMANDLINE_OPTIONS(*add_options_function*)

HPX_REGISTER_COMMANDLINE_MODULE(*add_options_function*)

Macro to register a command-line module with the HPX runtime.

This macro facilitates the registration of a command-line module with the HPX runtime system. A command-line module typically provides additional command-line options that can be used to configure the HPX application.

Parameters

- **add_options_function** – The function that adds custom command-line options.

HPX_REGISTER_COMMANDLINE_MODULE_DYNAMIC(*add_options_function*)

namespace **hpx**

namespace **components**

```
struct component_commandline : public component_commandline_base
```

#include <*component_commandline.hpp*> The `component_startup_shutdown` provides a minimal implementation of a component's startup/shutdown function provider.

Public Functions

inline `hpx::program_options::options_description` **add_commandline_options**() override
 Return any additional command line options valid for this component.

Note: This function will be executed by the runtime system during system startup.

Returns The module is expected to fill a `options_description` object with any additional command line options this component will handle.

namespace **commandline_options_provider**

Functions

`hpx::program_options::options_description` **add_commandline_options**()

HPX_REGISTER_STARTUP_MODULE

Defined in header `hpx/components.hpp`.

See *Public API* for a list of names and headers that are part of the public *HPX* API.

Defines

HPX_DEFINE_COMPONENT_STARTUP_SHUTDOWN(startup_, shutdown_)

HPX_REGISTER_STARTUP_SHUTDOWN_MODULE_(startup, shutdown)

HPX_REGISTER_STARTUP_SHUTDOWN_MODULE(startup, shutdown)

HPX_REGISTER_STARTUP_SHUTDOWN_MODULE_DYNAMIC(startup, shutdown)

HPX_REGISTER_STARTUP_MODULE(startup)

Macro to register a startup module with the HPX runtime.

This macro facilitates the registration of a startup module with the HPX runtime system. A startup module typically contains initialization code that should be executed when the HPX runtime starts.

Parameters

- **startup** – The name of the startup function to be registered.

HPX_REGISTER_STARTUP_MODULE_DYNAMIC(startup)

HPX_REGISTER_SHUTDOWN_MODULE(shutdown)

HPX_REGISTER_SHUTDOWN_MODULE_DYNAMIC(shutdown)

namespace **hpx**

namespace **components**

```
template<bool (*Startup)(startup_function_type&, bool&), bool  
(*Shutdown)(shutdown_function_type&, bool&)>
```

```
struct component_startup_shutdown : public component_startup_shutdown_base
```

#include <component_startup_shutdown.hpp> The `component_startup_shutdown` class provides a minimal implementation of a component's startup/shutdown function provider.

Public Functions

```
inline bool get_startup_function(startup_function_type &startup, bool &pre_startup) override
```

Return any startup function for this component.

Parameters

- **startup** – [in, out] The module is expected to fill this function object with a reference to a startup function. This function will be executed by the runtime system during system startup.
- **pre_startup** –

Returns Returns *true* if the parameter *startup* has been successfully initialized with the startup function.

```
inline bool get_shutdown_function(shutdown_function_type &shutdown, bool &pre_shutdown)  
override
```

Return any startup function for this component.

Parameters

- **shutdown** – [in, out] The module is expected to fill this function object with a reference to a startup function. This function will be executed by the runtime system during system startup.
- **pre_shutdown** –

Returns Returns *true* if the parameter *shutdown* has been successfully initialized with the shutdown function.

hpx/components_base/component_type.hpp

Defined in header `hpx/components_base/component_type.hpp`.

See *Public API* for a list of names and headers that are part of the public *HPX* API.

Defines

`HPX_COMPONENT_ENUM_TYPE_ENUM_DEPRECATION_MSG`

`HPX_FACTORY_STATE_ENUM_DEPRECATION_MSG`

`HPX_DEFINE_GET_COMPONENT_TYPE(component)`

`HPX_DEFINE_GET_COMPONENT_TYPE_TEMPLATE(template_, component)`

`HPX_DEFINE_GET_COMPONENT_TYPE_STATIC(component, type)`

`HPX_DEFINE_COMPONENT_NAME(...)`

HPX_DEFINE_COMPONENT_NAME_1(...)

HPX_DEFINE_COMPONENT_NAME_2(Component, name)

HPX_DEFINE_COMPONENT_NAME_3(Component, name, base_name)

namespace **hpx**

namespace **components**

Typedefs

using **component_deleter_type** = void (*)(*hpx::naming::gid_type* const&, *hpx::naming::address* const&)

Enums

enum class **component_enum_type** : *naming::component_type*

Values:

enumerator **invalid**

enumerator **runtime_support**

enumerator **plain_function**

enumerator **base_lco**

enumerator **base_lco_with_value_unmanaged**

enumerator **base_lco_with_value**

enumerator **latch**

enumerator **barrier**

enumerator **promise**

enumerator **agas_locality_namespace**

enumerator **agas_primary_namespace**

enumerator **agas_component_namespace**

enumerator **agas_symbol_namespace**

enumerator **last**

enumerator **first_dynamic**

enum class **factory_state** : *std::uint8_t*

Values:

enumerator **enabled**

enumerator **disabled**

enumerator **check**

Functions

constexpr *namings::component_type* **to_int**(*component_enum_type* t) noexcept

constexpr int **to_int**(*factory_state* t) noexcept

bool &**enabled**(*component_type* type)

util::atomic_count &**instance_count**(*component_type* type)

component_deleter_type &**deleter**(*component_type* type)

bool **enumerate_instance_counts**(*hpx::move_only_function*<bool(*component_type*)> const &f)

std::string **get_component_type_name**(*component_type* type)

Return the string representation for a given component type id.

constexpr *component_type* **get_base_type**(*component_type* t) noexcept

The lower short word of the component type is the type of the component exposing the actions.

constexpr *component_type* **get_derived_type**(*component_type* t) noexcept

The upper short word of the component is the actual component type.

constexpr *component_type* **derived_component_type**(*component_type* derived, *component_type* base) noexcept

A component derived from a base component exposing the actions needs to have a specially formatted component type.

constexpr bool **types_are_compatible**(*component_type* lhs, *component_type* rhs) noexcept

Verify the two given component types are matching (compatible)

template<typename **Component**, typename **Enable** = void>

char const ***get_component_name**() noexcept

template<typename **Component**, typename **Enable** = void>

char const ***get_component_base_name**() noexcept

template<typename **Component**>

```
component_type get_component_type() noexcept
```

```
template<typename Component>
```

```
void set_component_type(component_type type)
```

Variables

```
constexpr component_enum_type component_invalid = component_enum_type::invalid
```

```
constexpr component_enum_type component_runtime_support =  
component_enum_type::runtime_support
```

```
constexpr component_enum_type component_plain_function =  
component_enum_type::plain_function
```

```
constexpr component_enum_type component_base_lco = component_enum_type::base_lco
```

```
constexpr component_enum_type component_base_lco_with_value_unmanaged =  
component_enum_type::base_lco_with_value_unmanaged
```

```
constexpr component_enum_type component_base_lco_with_value =  
component_enum_type::base_lco_with_value
```

```
constexpr component_enum_type component_latch = component_enum_type::latch
```

```
constexpr component_enum_type component_barrier = component_enum_type::barrier
```

```
constexpr component_enum_type component_promise = component_enum_type::promise
```

```
constexpr component_enum_type component_agas_locality_namespace =  
component_enum_type::agas_locality_namespace
```

```
constexpr component_enum_type component_agas_primary_namespace =  
component_enum_type::agas_primary_namespace
```

```
constexpr component_enum_type component_agas_component_namespace =  
component_enum_type::agas_component_namespace
```

```
constexpr component_enum_type component_agas_symbol_namespace =  
component_enum_type::agas_symbol_namespace
```

```
constexpr component_enum_type component_last = component_enum_type::last
```

```
constexpr component_enum_type component_first_dynamic = component_enum_type::first_dynamic
```

```
constexpr factory_state factory_enabled = factory_state::enabled
```

```
constexpr factory_state factory_disabled = factory_state::disabled
```

```
constexpr factory_state factory_check = factory_state::check
```

hpx::components::component, hpx::components::component_base

Defined in header `hpx/components.hpp`.

See *Public API* for a list of names and headers that are part of the public *HPX* API.

```
namespace hpx
```

```
    namespace components
```

```
        template<typename Component = void>
```

```
        class abstract_component_base
```

```
        template<typename Component, typename Derived = void>
```

```
        class abstract_managed_component_base
```

```
        template<typename Component>
```

```
        class component
```

#include <components_base_fwd.hpp> The *component* class wraps around a given component type, adding additional type aliases and constructors. It inherits from the specified component type.

```
        template<typename Component = void>
```

```
        class component_base
```

#include <components_base_fwd.hpp> *component_base* serves as a base class for components. It provides common functionality needed by components, such as address and ID retrieval. The template parameter *Component* specifies the derived component type.

```
        template<typename Component>
```

```
        class fixed_component
```

```
        template<typename Component>
```

```
        class fixed_component_base
```

```
        template<typename Component, typename Derived>
```

```
        class managed_component
```

#include <managed_component_base.hpp> The *managed_component* template is used as an indirection layer for components allowing to gracefully handle the access to non-existing components.

Additionally, it provides memory management capabilities for the wrapping instances, and it integrates the memory management with the AGAS service. Every instance of a *managed_component* gets assigned a global id. The provided memory management allocates the *managed_component* instances

from a special heap, ensuring fast allocation and avoids a full network round trip to the AGAS service for each of the allocated instances.

Template Parameters

- **Component** – Component type
- **Derived** – Most derived component type

```
template<typename Component, typename Wrapper, typename CtorPolicy, typename DtorPolicy>
class managed_component_base
```

hpx/components_base/get_lva.hpp

Defined in header `hpx/components_base/get_lva.hpp`.

See *Public API* for a list of names and headers that are part of the public *HPX* API.

```
namespace hpx
```

```
    template<typename Component, typename Enable = void>
```

```
    struct get_lva
```

#include <get_lva.hpp> The `get_lva` template is a helper structure allowing to convert a local virtual address as stored in a local address (returned from the function `resolver_client::resolve`) to the address of the component implementing the action.

The default implementation uses the template argument *Component* to deduce the type wrapping the component implementing the action. This is used to get the needed address.

Template Parameters **Component** – This is the type of the component implementing the action to execute.

Public Static Functions

```
    static inline constexpr Component *call(naming::address_type lva) noexcept
```

hpx/components_base/server/fixed_component_base.hpp

Defined in header `hpx/components_base/server/fixed_component_base.hpp`.

See *Public API* for a list of names and headers that are part of the public *HPX* API.

```
namespace hpx
```

```
    namespace components
```

```
        template<typename Component>
```

```
        class fixed_component
```

```
        template<typename Component>
```

```
        class fixed_component_base
```

hpx/components_base/server/managed_component_base.hpp

Defined in header hpx/components_base/server/managed_component_base.hpp.

See *Public API* for a list of names and headers that are part of the public *HPX* API.

```
template<>
```

```
struct hpx::components::detail_adl_barrier::init<traits::construct_with_back_ptr>
```

Public Static Functions

```
template<typename Component, typename Managed>  
static inline constexpr void call(Component*, Managed*) noexcept
```

```
template<typename Component, typename Managed, typename ...Ts>  
static inline void call_new(Component *&component, Managed *this_, Ts&&... vs)
```

```
template<>
```

```
struct hpx::components::detail_adl_barrier::init<traits::construct_without_back_ptr>
```

Public Static Functions

```
template<typename Component, typename Managed>  
static inline void call(Component *component, Managed *this_)
```

```
template<typename Component, typename Managed, typename ...Ts>  
static inline void call_new(Component *&component, Managed *this_, Ts&&... vs)
```

```
template<>
```

```
struct
```

```
hpx::components::detail_adl_barrier::destroy_backptr<traits::managed_object_is_lifetime_controlled>
```

Public Static Functions

```
template<typename BackPtr>  
static inline void call(BackPtr *back_ptr)
```

```
template<>
```

```
struct
```

```
hpx::components::detail_adl_barrier::destroy_backptr<traits::managed_object_controls_lifetime>
```

Public Static Functions

```
template<typename BackPtr>
static inline constexpr void call(BackPtr*) noexcept
```

```
template<>
```

```
struct
```

```
hpx::components::detail_adl_barrier::manage_lifetime<traits::managed_object_is_lifetime_controlled>
```

Public Static Functions

```
template<typename Component>
static inline constexpr void call(Component*) noexcept
```

```
template<typename Component>
static inline void addref(Component *component) noexcept
```

```
template<typename Component>
static inline void release(Component *component) noexcept
```

```
template<>
```

```
struct
```

```
hpx::components::detail_adl_barrier::manage_lifetime<traits::managed_object_controls_lifetime>
```

Public Static Functions

```
template<typename Component>
static inline void call(Component *component) noexcept(noexcept(component->finalize()))
```

```
template<typename Component>
static inline constexpr void addref(Component*) noexcept
```

```
template<typename Component>
static inline constexpr void release(Component*) noexcept
```

```
namespace hpx
```

```
namespace components
```

Functions

```
template<typename Component, typename Derived>
void intrusive_ptr_add_ref(managed_component<Component, Derived> *p) noexcept
```

```
template<typename Component, typename Derived>
void intrusive_ptr_release(managed_component<Component, Derived> *p) noexcept
```

```
template<typename Component, typename Derived>
```

```
class managed_component
    #include <managed_component_base.hpp>
template<typename Component, typename Wrapper, typename CtorPolicy, typename DtorPolicy>
class managed_component_base

namespace detail_adl_barrier

    template<typename DtorTag>
    struct destroy_backptr

template<> managed_object_controls_lifetime >
```

Public Static Functions

```
template<typename BackPtr>
static inline constexpr void call(BackPtr*) noexcept
```

```
template<> managed_object_is_lifetime_controlled >
```

Public Static Functions

```
template<typename BackPtr>
static inline void call(BackPtr *back_ptr)
```

```
template<typename BackPtrTag>
```

```
struct init
```

```
template<> construct_with_back_ptr >
```

Public Static Functions

```
template<typename Component, typename Managed>
static inline constexpr void call(Component*, Managed*) noexcept
```

```
template<typename Component, typename Managed, typename ...Ts>
static inline void call_new(Component *&component, Managed *this_, Ts&&... vs)
```

```
template<> construct_without_back_ptr >
```

Public Static Functions

```
template<typename Component, typename Managed>
static inline void call(Component *component, Managed *this_)

template<typename Component, typename Managed, typename ...Ts>
static inline void call_new(Component *&component, Managed *this_, Ts&&... vs)
```

```
template<typename DtorTag>
```

```
struct manage_lifetime
```

```
template<> managed_object_controls_lifetime >
```

Public Static Functions

```
template<typename Component>
static inline void call(Component *component) noexcept(noexcept(component->finalize()))
```

```
template<typename Component>
static inline constexpr void addref(Component*) noexcept
```

```
template<typename Component>
static inline constexpr void release(Component*) noexcept
```

```
template<> managed_object_is_lifetime_controlled >
```

Public Static Functions

```
template<typename Component>
static inline constexpr void call(Component*) noexcept
```

```
template<typename Component>
static inline void addref(Component *component) noexcept
```

```
template<typename Component>
static inline void release(Component *component) noexcept
```

hpx/components_base/server/migration_support.hpp

Defined in header `hpx/components_base/server/migration_support.hpp`.

See *Public API* for a list of names and headers that are part of the public *HPX* API.

namespace **hpx**

namespace **components**

```
template<typename BaseComponent, typename Mutex = hpx::spinlock>
```

```
struct migration_support : public BaseComponent
```

```
    #include <migration_support.hpp> This hook has to be inserted into the derivation chain of any component for it to support migration.
```

Public Types

using **decorates_action** = void

Public Functions

inline **migration_support**()

template<typename T, typename ...Ts, typename =
std::enable_if_t<!std::is_same_v<std::decay_t<T>, migration_support>>>
inline explicit **migration_support**(T &&t, Ts&&... ts)

migration_support(*migration_support* const&) = default

migration_support(*migration_support*&&) = default

migration_support &**operator**=(*migration_support* const&) = default

migration_support &**operator**=(*migration_support*&&) = default

~migration_support() = default

inline *naming::gid_type* **get_base_gid**(*naming::gid_type* const &assign_gid =
naming::invalid_gid) const

inline void **pin**() noexcept

inline bool **unpin**()

inline *std::uint32_t* **pin_count**() const noexcept

inline void **mark_as_migrated**()

inline *hpx::future*<void> **mark_as_migrated**(*hpx::id_type* const &to_migrate)

inline void **unmark_as_migrated**(*hpx::id_type* const &to_migrate)

Public Static Functions

static inline constexpr bool **supports_migration**() noexcept

static inline constexpr void **on_migrated**() noexcept

template<typename F>

static inline *threads::thread_function_type* **decorate_action**(*naming::address_type* lva, F &&f)

static inline *std::pair*<bool, *components::pinned_ptr*> **was_object_migrated**(*hpx::naming::gid_type*
const &id, *naming::address_type*
lva)

Protected Functions

```
inline threads::thread_result_type thread_function(threads::thread_function_type &&f,
                                                components::pinned_ptr,
                                                threads::thread_restart_state state)
```

Private Types

```
using base_type = BaseComponent
```

```
using this_component_type = typename base_type::this_component_type
```

Private Members

```
hpx::intrusive_ptr<detail::migration_support_data<Mutex>> data_
```

```
hpx::promise<void> trigger_migration_
```

```
bool started_migration_ = false
```

```
bool was_marked_for_migration_ = false
```

compute

See *Public API* for a list of names and headers that are part of the public *HPX* API.

hpx/compute/host/target_distribution_policy.hpp

Defined in header `hpx/compute/host/target_distribution_policy.hpp`.

See *Public API* for a list of names and headers that are part of the public *HPX* API.

distribution_policies

See *Public API* for a list of names and headers that are part of the public *HPX* API.

hpx/distribution_policies/binpacking_distribution_policy.hpp

Defined in header `hpx/distribution_policies/binpacking_distribution_policy.hpp`.

See *Public API* for a list of names and headers that are part of the public *HPX* API.

```
namespace hpx
```

```
    namespace components
```

Variables

```
constexpr char const *const default_binpacking_counter_name =  
"/runtime{locality/total}/count/component@"
```

```
static const binpacking_distribution_policy binpacked = {}
```

A predefined instance of the binpacking *distribution_policy*. It will represent the local locality and will place all items to create here.

```
struct binpacking_distribution_policy
```

#include <binpacking_distribution_policy.hpp> This class specifies the parameters for a binpacking distribution policy to use for creating a given number of items on a given set of localities. The binpacking policy will distribute the new objects in a way such that each of the localities will equalize the number of overall objects of this type based on a given criteria (by default this criteria is the overall number of objects of this type).

Public Functions

```
inline binpacking_distribution_policy()
```

Default-construct a new instance of a *binpacking_distribution_policy*. This policy will represent one locality (the local locality).

```
inline binpacking_distribution_policy operator() (std::vector<id_type> const &locs, char const  
*perf_counter_name =  
default_binpacking_counter_name) const
```

Create a new *default_distribution* policy representing the given set of localities.

Parameters

- **locs** – [in] The list of localities the new instance should represent
- **perf_counter_name** – [in] The name of the performance counter which should be used as the distribution criteria (by default the overall number of existing instances of the given component type will be used).

```
inline binpacking_distribution_policy operator() (std::vector<id_type> &&locs, char const  
*perf_counter_name =  
default_binpacking_counter_name) const
```

Create a new *default_distribution* policy representing the given set of localities.

Parameters

- **locs** – [in] The list of localities the new instance should represent
- **perf_counter_name** – [in] The name of the performance counter which should be used as the distribution criteria (by default the overall number of existing instances of the given component type will be used).

```
inline binpacking_distribution_policy operator() (id_type const &loc, char const  
*perf_counter_name =  
default_binpacking_counter_name) const
```

Create a new *default_distribution* policy representing the given locality

Parameters

- **loc** – [in] The locality the new instance should represent
- **perf_counter_name** – [in] The name of the performance counter that should be used as the distribution criteria (by default the overall number of existing instances of the given component type will be used).

```
template<typename Component, typename ...Ts>
inline hpx::future<hpx::id_type> create(Ts&&... vs) const
```

Create one object on one of the localities associated by this policy instance

Parameters *vs* – [in] The arguments which will be forwarded to the constructor of the new object.

Returns A future holding the global address which represents the newly created object

```
template<bool WithCount, typename Component, typename ...Ts>
inline hpx::future<std::vector<bulk_locality_result>> bulk_create(std::size_t count, Ts&&... vs)
const
```

Create multiple objects on the localities associated by this policy instance

Parameters

- **count** – [in] The number of objects to create
- **vs** – [in] The arguments which will be forwarded to the constructors of the new objects.

Returns A future holding the list of global addresses which represent the newly created objects

```
inline std::string const &get_counter_name() const
```

Returns the name of the performance counter associated with this policy instance.

```
inline std::size_t get_num_localities() const
```

Returns the number of associated localities for this distribution policy

Note: This function is part of the creation policy implemented by this class

hpx/distribution_policies/colocating_distribution_policy.hpp

Defined in header `hpx/distribution_policies/colocating_distribution_policy.hpp`.

See *Public API* for a list of names and headers that are part of the public *HPX* API.

```
namespace hpx
```

```
namespace components
```

Variables

```
static const colocating_distribution_policy colocated = {}
```

A predefined instance of the co-locating *distribution_policy*. It will represent the local locality and will place all items to create here.

```
struct colocating_distribution_policy
```

#include <*colocating_distribution_policy.hpp*> This class specifies the parameters for a distribution policy to use for creating a given number of items on the locality where a given object is currently placed.

Public Functions

```
constexpr colocating_distribution_policy() = default
```

Default-construct a new instance of a `colocating_distribution_policy`. This policy will represent the local locality.

```
inline colocating_distribution_policy operator()(id_type const &id) const
```

Create a new `colocating_distribution_policy` representing the locality where the given object is current located

Parameters `id` – [in] The global address of the object with which the new instances should be colocated on

```
template<typename Client, typename Stub, typename Data>
```

```
inline colocating_distribution_policy operator()(client_base<Client, Stub, Data> const &client) const
```

Create a new `colocating_distribution_policy` representing the locality where the given object is current located

Parameters `client` – [in] The client side representation of the object with which the new instances should be colocated on

```
template<typename Component, typename ...Ts>
```

```
inline hpx::future<hpx::id_type> create(Ts&&... vs) const
```

Create one object on the locality of the object this distribution policy instance is associated with

Note: This function is part of the placement policy implemented by this class

Parameters `vs` – [in] The arguments which will be forwarded to the constructor of the new object.

Returns A future holding the global address which represents the newly created object

```
template<bool WithCount, typename Component, typename ...Ts>
```

```
inline hpx::future<std::vector<bulk_locality_result>> bulk_create(std::size_t count, Ts&&... vs) const
```

Create multiple objects colocated with the object represented by this policy instance

Note: This function is part of the placement policy implemented by this class

Parameters

- `count` – [in] The number of objects to create
- `vs` – [in] The arguments which will be forwarded to the constructors of the new objects.

Returns A future holding the list of global addresses which represent the newly created objects

```
template<typename Action, typename ...Ts>
```

```
inline async_result<Action>::type async(launch policy, Ts&&... vs) const
```

```
template<typename Action, typename Callback, typename ...Ts>
```

```
inline async_result<Action>::type async_cb(launch policy, Callback &&cb, Ts&&... vs) const
```

Note: This function is part of the invocation policy implemented by this class

```
template<typename Action, typename Continuation, typename ...Ts>
```

```
inline bool apply(Continuation &&c, launch policy, Ts&&... vs) const
```

Note: This function is part of the invocation policy implemented by this class

```
template<typename Action, typename ...Ts>
inline bool apply(launch policy, Ts&&... vs) const
```

```
template<typename Action, typename Continuation, typename Callback, typename ...Ts>
inline bool apply_cb(Continuation &&c, launch policy, Callback &&cb, Ts&&... vs) const
```

Note: This function is part of the invocation policy implemented by this class

```
template<typename Action, typename Callback, typename ...Ts>
inline bool apply_cb(launch policy, Callback &&cb, Ts&&... vs) const
```

```
inline hpx::id_type get_next_target() const
```

Returns the locality which is anticipated to be used for the next async operation

Public Static Functions

```
static inline std::size_t get_num_localities()
```

Returns the number of associated localities for this distribution policy

Note: This function is part of the creation policy implemented by this class

```
template<typename Action>
```

```
struct async_result
```

```
    #include <colocating_distribution_policy.hpp>
```

Note: This function is part of the invocation policy implemented by this class

Public Types

```
using type = hpx::future<typename traits::promise_local_result<typename
hpx::traits::extract_action<Action>::remote_result_type>::type>
```

hpx/distribution_policies/default_distribution_policy.hpp

Defined in header hpx/distribution_policies/default_distribution_policy.hpp.

See *Public API* for a list of names and headers that are part of the public *HPX* API.

namespace **hpx**

namespace **components**

Variables

static const *default_distribution_policy* **default_layout** = { }

A predefined instance of the default *distribution_policy*. It will represent the local locality and will place all items to create here.

struct **default_distribution_policy**

#include <default_distribution_policy.hpp> This class specifies the parameters for a simple distribution policy to use for creating (and evenly distributing) a given number of items on a given set of localities.

Public Functions

constexpr **default_distribution_policy**() = default

Default-construct a new instance of a *default_distribution_policy*. This policy will represent one locality (the local locality).

inline *default_distribution_policy* **operator**() (std::vector<id_type> locs) const

Create a new *default_distribution* policy representing the given set of localities.

Parameters **locs** – [in] The list of localities the new instance should represent

inline *default_distribution_policy* **operator**() (id_type loc) const

Create a new *default_distribution* policy representing the given locality

Parameters **loc** – [in] The locality the new instance should represent

template<typename **Component**, typename ...**Ts**>

inline *hpx::future*<*hpx::id_type*> **create**(*Ts*&&... vs) const

Create one object on one of the localities associated by this policy instance

Note: This function is part of the placement policy implemented by this class

Parameters **vs** – [in] The arguments which will be forwarded to the constructor of the new object.

Returns A future holding the global address which represents the newly created object

template<bool **WithCount**, typename **Component**, typename ...**Ts**>

inline *hpx::future*<std::vector<bulk_locality_result>> **bulk_create**(std::size_t count, *Ts*&&... vs) const

Create multiple objects on the localities associated by this policy instance

Note: This function is part of the placement policy implemented by this class

Parameters

- **count** – [in] The number of objects to create
- **vs** – [in] The arguments which will be forwarded to the constructors of the new objects.

Returns A future holding the list of global addresses that represent the newly created objects

```
template<typename Action, typename ...Ts>
inline async_result<Action>::type async(launch policy, Ts&&... vs) const
```

```
template<typename Action, typename Callback, typename ...Ts>
inline async_result<Action>::type async_cb(launch policy, Callback &&cb, Ts&&... vs) const
```

Note: This function is part of the invocation policy implemented by this class

```
template<typename Action, typename Continuation, typename ...Ts>
inline bool apply(Continuation &&c, launch policy, Ts&&... vs) const
```

Note: This function is part of the invocation policy implemented by this class

```
template<typename Action, typename ...Ts>
inline bool apply(threads::thread_priority priority, Ts&&... vs) const
```

```
template<typename Action, typename Continuation, typename Callback, typename ...Ts>
inline bool apply_cb(Continuation &&c, launch policy, Callback &&cb, Ts&&... vs) const
```

Note: This function is part of the invocation policy implemented by this class

```
template<typename Action, typename Callback, typename ...Ts>
inline bool apply_cb(launch policy, Callback &&cb, Ts&&... vs) const
```

```
inline std::size_t get_num_localities() const
```

Returns the number of associated localities for this distribution policy

Note: This function is part of the creation policy implemented by this class

```
inline hpx::id_type get_next_target() const
```

Returns the locality which is anticipated to be used for the next async operation

```
template<typename Action>
```

```
struct async_result
```

```
    #include <default_distribution_policy.hpp>
```

Note: This function is part of the invocation policy implemented by this class

Public Types

```
using type = hpx::future<typename traits::promise_local_result<typename  
hpx::traits::extract_action<Action>::remote_result_type>::type>
```

hpx/distribution_policies/target_distribution_policy.hpp

Defined in header `hpx/distribution_policies/target_distribution_policy.hpp`.

See *Public API* for a list of names and headers that are part of the public *HPX* API.

```
namespace hpx
```

```
    namespace components
```

Variables

```
static const target_distribution_policy target = { }
```

A predefined instance of the `target_distribution_policy`. It will represent the local locality and will place all items to create here.

```
struct target_distribution_policy
```

#include <target_distribution_policy.hpp> This class specifies the parameters for a simple distribution policy to use for creating (and evenly distributing) a given number of items on a given set of localities.

Public Functions

```
target_distribution_policy() = default
```

Default-construct a new instance of a `target_distribution_policy`. This policy will represent one locality (the local locality).

```
inline target_distribution_policy operator() (id_type const &id) const
```

Create a new `target_distribution_policy` representing the given locality

Parameters `loc` – [in] The locality the new instance should represent

```
template<typename Component, typename ...Ts>
```

```
inline hpx::future<hpx::id_type> create(Ts&&... vs) const
```

Create one object on one of the localities associated by this policy instance

Note: This function is part of the placement policy implemented by this class

Parameters `vs` – [in] The arguments which will be forwarded to the constructor of the new object.

Returns A future holding the global address which represents the newly created object

```
template<bool WithCount, typename Component, typename ...Ts>
```

```
inline hpx::future<std::vector<bulk_locality_result>> bulk_create(std::size_t count, Ts&&... vs)
                                                    const
```

Create multiple objects on the localities associated by this policy instance

Note: This function is part of the placement policy implemented by this class

Parameters

- **count** – [in] The number of objects to create
- **vs** – [in] The arguments which will be forwarded to the constructors of the new objects.

Returns A future holding the list of global addresses which represent the newly created objects

```
template<typename Action, typename ...Ts>
inline async_result<Action>::type async(launch policy, Ts&&... vs) const
```

```
template<typename Action, typename Callback, typename ...Ts>
inline async_result<Action>::type async_cb(launch policy, Callback &&cb, Ts&&... vs) const
```

Note: This function is part of the invocation policy implemented by this class

```
template<typename Action, typename Continuation, typename ...Ts>
inline bool apply(Continuation &&c, launch policy, Ts&&... vs) const
```

Note: This function is part of the invocation policy implemented by this class

```
template<typename Action, typename ...Ts>
inline bool apply(launch policy, Ts&&... vs) const
```

```
template<typename Action, typename Continuation, typename Callback, typename ...Ts>
inline bool apply_cb(Continuation &&c, launch policy, Callback &&cb, Ts&&... vs) const
```

Note: This function is part of the invocation policy implemented by this class

```
template<typename Action, typename Callback, typename ...Ts>
inline bool apply_cb(launch policy, Callback &&cb, Ts&&... vs) const
```

```
inline std::size_t get_num_localities() const
```

Returns the number of associated localities for this distribution policy

Note: This function is part of the creation policy implemented by this class

```
inline hpx::id_type get_next_target() const
```

Returns the locality which is anticipated to be used for the next async operation

```
template<typename Action>
```

```
struct async_result
```

```
    #include <target_distribution_policy.hpp>
```

Note: This function is part of the invocation policy implemented by this class

Public Types

```
using type = hpx::future<typename traits::promise_local_result<typename  
hpx::traits::extract_action<Action>::remote_result_type>::type>
```

`hpx/distribution_policies/unwrapping_result_policy.hpp`

Defined in header `hpx/distribution_policies/unwrapping_result_policy.hpp`.

See *Public API* for a list of names and headers that are part of the public *HPX* API.

namespace **hpx**

namespace **components**

struct **unwrapping_result_policy**

#include <unwrapping_result_policy.hpp> This class is a distribution policy that can be using with actions that return futures. For those actions it is possible to apply certain optimizations if the action is invoked synchronously.

Public Functions

```
inline explicit unwrapping_result_policy(id_type const &id)
```

```
template<typename Client, typename Stub, typename Data>  
inline explicit unwrapping_result_policy(client_base<Client, Stub, Data> const &client)
```

```
template<typename Action, typename ...Ts>  
inline async_result<Action>::type async(launch policy, Ts&&... vs) const
```

```
template<typename Action, typename ...Ts>  
inline async_result<Action>::type async(launch::sync_policy, Ts&&... vs) const
```

```
template<typename Action, typename Callback, typename ...Ts>  
inline async_result<Action>::type async_cb(launch policy, Callback &&cb, Ts&&... vs) const
```

```
template<typename Action, typename Continuation, typename ...Ts>  
inline bool apply(Continuation &&c, launch policy, Ts&&... vs) const
```

Note: This function is part of the invocation policy implemented by this class

```
template<typename Action, typename ...Ts>  
inline bool apply(launch policy, Ts&&... vs) const
```

```
template<typename Action, typename Continuation, typename Callback, typename ...Ts>
```

```
inline bool apply_cb(Continuation &&c, launch policy, Callback &&cb, Ts&&... vs) const
```

Note: This function is part of the invocation policy implemented by this class

```
template<typename Action, typename Callback, typename ...Ts>
inline bool apply_cb(launch policy, Callback &&cb, Ts&&... vs) const
```

```
inline hpx::id_type const &get_next_target() const
```

```
template<typename Action>
```

```
struct async_result
```

Public Types

```
using type = typename traits::promise_local_result<typename
hpx::traits::extract_action<Action>::remote_result_type>::type
```

executors_distributed

See *Public API* for a list of names and headers that are part of the public *HPX* API.

hpx/executors_distributed/distribution_policy_executor.hpp

Defined in header `hpx/executors_distributed/distribution_policy_executor.hpp`.

See *Public API* for a list of names and headers that are part of the public *HPX* API.

```
namespace hpx
```

```
namespace execution
```

```
namespace experimental
```

Functions

```
template<typename DistPolicy>
distribution_policy_executor(DistPolicy&&) ->
    distribution_policy_executor<std::decay_t<DistPolicy>>
```

```
template<typename DistPolicy> HPX_DEPRECATED_V (1, 9,
"hpx::parallel::execution::make_distribution_policy_executor is " "deprecated,
use " "hpx::parallel::execution::distribution_policy_executor instead") distribution_policy_executor
```

Create a new *distribution_policy_executor* from the given *distribution_policy*.

Parameters *policy* – The *distribution_policy* to create an executor from

```
template<typename DistPolicy>
```

class **distribution_policy_executor**

#include <distribution_policy_executor.hpp> A `distribution_policy_executor` creates groups of parallel execution agents that execute in threads implicitly created by the executor and placed on any of the associated localities.

Template Parameters `DistPolicy` – The distribution policy type for which an executor should be created. The expression `hpx::traits::is_distribution_policy_v<DistPolicy>` must evaluate to true.

init_runtime

See *Public API* for a list of names and headers that are part of the public *HPX* API.

hpx::finalize, hpx::disconnect

Defined in header `hpx/init.hpp`⁸⁰².

See *Public API* for a list of names and headers that are part of the public *HPX* API.

namespace **hpx**

Functions

int **finalize**(double shutdown_timeout, double localwait = -1.0, *error_code* &ec = *throws*)

Main function to gracefully terminate the HPX runtime system.

The function `hpx::finalize` is the main way to (gracefully) exit any HPX application. It must be called at least once, but can be called multiple times as well. However, only the first invocation will have effect. It will notify all connected localities to finish execution. Only after all other localities have exited this function will return, allowing to exit the console locality as well.

During the execution of this function the runtime system will invoke all registered shutdown functions (see `hpx::init`) on all localities.

The default value (-1.0) will try to find a globally set timeout value (can be set as the configuration parameter `hpx.shutdown_timeout`), and if that is not set or -1.0 as well, it will disable any timeout, each connected locality will wait for all existing HPX-threads to terminate.

The default value (-1.0) will try to find a globally set wait time value (can be set as the configuration parameter “`hpx.finalize_wait_time`”), and if this is not set or -1.0 as well, it will disable any addition local wait time before proceeding.

This function will block and wait for all connected localities to exit before returning to the caller. It should be the last HPX-function called by any application.

Using this function is an alternative to `hpx::disconnect`, these functions do not need to be called both.

⁸⁰² http://github.com/STELLAR-GROUP/hpx/blob/8a3b7c1a4cb5693b2f7d9f587f759392ed0c51a0/libs/full/init_runtime/include/hpx/init.hpp

Note: As long as *ec* is not pre-initialized to *hpx::throws* this function doesn't throw but returns the result code using the parameter *ec*. Otherwise it throws an instance of *hpx::exception*.

Parameters

- **shutdown_timeout** – This parameter allows to specify a timeout (in microseconds), specifying how long any of the connected localities should wait for pending tasks to be executed. After this timeout, all suspended HPX-threads will be aborted. Note, that this function will not abort any running HPX-threads. In any case the shutdown will not proceed as long as there is at least one pending/running HPX-thread.
- **localwait** – This parameter allows to specify a local wait time (in microseconds) before the connected localities will be notified and the overall shutdown process starts.
- **ec** – [in,out] this represents the error status on exit, if this is pre-initialized to *hpx::throws* the function will throw on error instead.

Returns This function will always return zero.

```
inline int finalize(error_code &ec = throws)
```

Main function to gracefully terminate the HPX runtime system.

The function *hpx::finalize* is the main way to (gracefully) exit any HPX application. It must be called at least once, but can be called multiple times as well. However, only the first invocation will have effect. It will notify all connected localities to finish execution. Only after all other localities have exited this function will return, allowing to exit the console locality as well.

During the execution of this function the runtime system will invoke all registered shutdown functions (see *hpx::init*) on all localities.

This function will block and wait for all connected localities to exit before returning to the caller. It should be the last HPX-function called by any application.

Using this function is an alternative to *hpx::disconnect*, these functions do not need to be called both.

Note: As long as *ec* is not pre-initialized to *hpx::throws* this function doesn't throw but returns the result code using the parameter *ec*. Otherwise it throws an instance of *hpx::exception*.

Parameters **ec** – [in,out] this represents the error status on exit, if this is pre-initialized to *hpx::throws* the function will throw on error instead.

Returns This function will always return zero.

```
void terminate()
```

Terminate any application non-gracefully.

The function *hpx::terminate* is the non-graceful way to exit any application immediately. It can be called from any locality and will terminate all localities currently used by the application.

Note: This function will cause HPX to call *std::terminate()* on all localities associated with this application. If the function is called not from an HPX thread it will fail and return an error using the argument *ec*.

int **disconnect**(double shutdown_timeout, double localwait = -1.0, *error_code* &ec = *throws*)

Disconnect this locality from the application.

The function *hpx::disconnect* can be used to disconnect a locality from a running HPX application.

During the execution of this function the runtime system will invoke all registered shutdown functions (see *hpx::init*) on this locality.

The default value (-1.0) will try to find a globally set timeout value (can be set as the configuration parameter “hpx.shutdown_timeout”), and if that is not set or -1.0 as well, it will disable any timeout, each connected locality will wait for all existing HPX-threads to terminate.

The default value (-1.0) will try to find a globally set wait time value (can be set as the configuration parameter *hpx.finalize_wait_time*), and if this is not set or -1.0 as well, it will disable any addition local wait time before proceeding.

This function will block and wait for this locality to finish executing before returning to the caller. It should be the last HPX-function called by any locality being disconnected.

Note: As long as *ec* is not pre-initialized to *hpx::throws* this function doesn't throw but returns the result code using the parameter *ec*. Otherwise it throws an instance of *hpx::exception*.

Parameters

- **shutdown_timeout** – This parameter allows to specify a timeout (in microseconds), specifying how long this locality should wait for pending tasks to be executed. After this timeout, all suspended HPX-threads will be aborted. Note, that this function will not abort any running HPX-threads. In any case the shutdown will not proceed as long as there is at least one pending/running HPX-thread.
- **localwait** – This parameter allows to specify a local wait time (in microseconds) before the connected localities will be notified and the overall shutdown process starts.
- **ec** – [in,out] this represents the error status on exit, if this is pre-initialized to *hpx::throws* the function will throw on error instead.

Returns This function will always return zero.

inline int **disconnect**(*error_code* &ec = *throws*)

Disconnect this locality from the application.

The function *hpx::disconnect* can be used to disconnect a locality from a running HPX application.

During the execution of this function the runtime system will invoke all registered shutdown functions (see *hpx::init*) on this locality.

This function will block and wait for this locality to finish executing before returning to the caller. It should be the last HPX-function called by any locality being disconnected.

Note: As long as *ec* is not pre-initialized to *hpx::throws* this function doesn't throw but returns the result code using the parameter *ec*. Otherwise it throws an instance of *hpx::exception*.

Parameters **ec** – [in,out] this represents the error status on exit, if this is pre-initialized to *hpx::throws* the function will throw on error instead.

Returns This function will always return zero.

```
int stop(error_code &ec = throws)
```

Stop the runtime system.

This function will block and wait for this locality to finish executing before returning to the caller. It should be the last HPX-function called on every locality. This function should be used only if the runtime system was started using `hpx::start`.

Returns The function returns the value, which has been returned from the user supplied main HPX function (usually `hpx_main`).

hpx/hpx_init.hpp

Defined in header `hpx/hpx_init.hpp`.

See *Public API* for a list of names and headers that are part of the public *HPX* API.

```
namespace hpx
```

hpx::init

Defined in header `hpx/init.hpp`⁸⁰³.

See *Public API* for a list of names and headers that are part of the public *HPX* API.

```
namespace hpx_startup
```

Variables

```
std::function<int(hpx::program_options::variables_map&)> const &get_main_func()
```

```
namespace hpx
```

Functions

```
inline int init(std::function<int(hpx::program_options::variables_map&)> f, int argc, char **argv,
               init_params const &params = init_params())
```

Main entry point for launching the HPX runtime system.

This is the main entry point for any HPX application. This function (or one of its overloads) should be called from the users `main()` function. It will set up the HPX runtime environment and schedule the function given by `f` as a HPX thread. This overload will not call `hpx_main`.

⁸⁰³ http://github.com/STELLAR-GROUP/hpx/blob/8a3b7c1a4cb5693b2f7d9f587f759392ed0c51a0/libs/full/init_runtime/include/hpx/init.hpp

This is the main entry point for any HPX application. This function (or one of its overloads below) should be called from the users `main()` function. It will set up the HPX runtime environment and schedule the function given by `f` as a HPX thread.

Note: If the parameter `mode` is not given (defaulted), the created runtime system instance will be executed in console or worker mode depending on the command line arguments passed in `argc/argv`. Otherwise, it will be executed as specified by the parameter `mode`.

Parameters

- **f** – [in] The function to be scheduled as an HPX thread. Usually this function represents the main entry point of any HPX application. If `f` is `nullptr` the HPX runtime environment will be started without invoking `f`.
- **argc** – [in] The number of command line arguments passed in `argv`. This is usually the unchanged value as passed by the operating system (to `main()`).
- **argv** – [in] The command line arguments for this application, usually that is the value as passed by the operating system (to `main()`).
- **params** – [in] The parameters to the `hpx::init` function (See documentation of [hpx::init_params](#))

Returns The function returns the value, which has been returned from the user supplied `f`.

```
inline int init(std::function<int(int, char**)> f, int argc, char **argv, init_params const &params =  
    init_params())
```

Main entry point for launching the HPX runtime system.

This is the main entry point for any HPX application. This function (or one of its overloads) should be called from the users `main()` function. It will set up the HPX runtime environment and schedule the function given by `f` as a HPX thread. This overload will not call `hpx_main`.

This is the main entry point for any HPX application. This function (or one of its overloads below) should be called from the users `main()` function. It will set up the HPX runtime environment and schedule the function given by `f` as a HPX thread.

Note: If the parameter `mode` is not given (defaulted), the created runtime system instance will be executed in console or worker mode depending on the command line arguments passed in `argc/argv`. Otherwise, it will be executed as specified by the parameter `mode`.

Parameters

- **f** – [in] The function to be scheduled as an HPX thread. Usually this function represents the main entry point of any HPX application. If `f` is `nullptr` the HPX runtime environment will be started without invoking `f`.
- **argc** – [in] The number of command line arguments passed in `argv`. This is usually the unchanged value as passed by the operating system (to `main()`).
- **argv** – [in] The command line arguments for this application, usually that is the value as passed by the operating system (to `main()`).
- **params** – [in] The parameters to the `hpx::init` function (See documentation of [hpx::init_params](#))

Returns The function returns the value, which has been returned from the user supplied `f`.

```
inline int init(int argc, char **argv, init_params const &params = init_params())
```

Main entry point for launching the HPX runtime system.

This is the main entry point for any HPX application. This function (or one of its overloads) should be called from the users `main()` function. This overload expects a user-defined function named `hpx_main` at global scope, which will be used as the entry point for the HPX application.

This is the main entry point for any HPX application. This function (or one of its overloads below) should be called from the users `main()` function. It will set up the HPX runtime environment and schedule the function given by `f` as a HPX thread.

Note: If the parameter `mode` is not given (defaulted), the created runtime system instance will be executed in console or worker mode depending on the command line arguments passed in `argc/argv`. Otherwise, it will be executed as specified by the parameter `mode`.

Parameters

- **argc** – [in] The number of command line arguments passed in `argv`. This is usually the unchanged value as passed by the operating system (to `main()`).
- **argv** – [in] The command line arguments for this application, usually that is the value as passed by the operating system (to `main()`).
- **params** – [in] The parameters to the `hpx::init` function (See documentation of `hpx::init_params`)

Returns The function returns the value, which has been returned from `hpx_main` (or 0 when executed in worker mode).

```
inline int init(std::nullptr_t f, int argc, char **argv, init_params const &params = init_params())
```

Main entry point for launching the HPX runtime system.

This is the main entry point for any HPX application. This function (or one of its overloads below) should be called from the users `main()` function. It will set up the HPX runtime environment and schedule the function given by `f` as a HPX thread. This overload will not call `hpx_main`.

This is the main entry point for any HPX application. This function (or one of its overloads below) should be called from the users `main()` function. It will set up the HPX runtime environment and schedule the function given by `f` as a HPX thread.

Note: If the parameter `mode` is not given (defaulted), the created runtime system instance will be executed in console or worker mode depending on the command line arguments passed in `argc/argv`. Otherwise, it will be executed as specified by the parameter `mode`.

Parameters

- **f** – [in] The function to be scheduled as an HPX thread. Usually this function represents the main entry point of any HPX application. If `f` is `nullptr` the HPX runtime environment will be started without invoking `f`.

- **argc** – [in] The number of command line arguments passed in `argv`. This is usually the unchanged value as passed by the operating system (to `main()`).
- **argv** – [in] The command line arguments for this application, usually that is the value as passed by the operating system (to `main()`).
- **params** – [in] The parameters to the `hpx::init` function (See documentation of [hpx::init_params](#))

Returns The function returns the value, which has been returned from the user supplied `f`.

```
inline int init(init_params const &params = init_params())
```

Main entry point for launching the HPX runtime system.

This is a simplified main entry point, which can be used to set up the runtime for an HPX application (the runtime system will be set up in console mode or worker mode depending on the command line settings). This overload expects a user-defined function named `hpx_main` at global scope, which will be used as the entry point for the HPX application.

This is a simplified main entry point, which can be used to set up the runtime for an HPX application (the runtime system will be set up in console mode or worker mode depending on the command line settings).

Note: The created runtime system instance will be executed in console or worker mode depending on the command line arguments passed in `argc/argv`. If not command line arguments are passed, console mode is assumed.

Note: If no command line arguments are passed the HPX runtime system will not support any of the default command line options as described in the section ‘HPX Command Line Options’.

Parameters **params** – [in] The parameters to the `hpx::init` function (See documentation of [hpx::init_params](#))

Returns The function returns the value, which has been returned from `hpx_main` (or 0 when executed in worker mode).

`hpx::init_params`

Defined in header `hpx/init.hpp`⁸⁰⁴.

See *Public API* for a list of names and headers that are part of the public *HPX* API.

namespace **hpx**

```
struct init_params
```

```
    #include <hpx_init_params.hpp> Parameters used to initialize the HPX runtime through hpx::init and hpx::start.
```

⁸⁰⁴ http://github.com/STELLAR-GROUP/hpx/blob/8a3b7c1a4cb5693b2f7d9f587f759392ed0c51a0/libs/full/init_runtime/include/hpx/init.hpp

Public Functions

inline **init_params()**

Public Members

std::reference_wrapper<*hpx::program_options::options_description* const> **desc_cmdline** =
hpx::local::detail::default_desc(HPX_APPLICATION_STRING)

std::vector<*std::string*> **cfg**

std::function<void()> **startup**

std::function<void()> **shutdown**

hpx::runtime_mode **mode** = *::hpx::runtime_mode::default_*

hpx::resource::partitioner_mode **rp_mode** = *::hpx::resource::partitioner_mode::default_*

hpx::resource::rp_callback_type **rp_callback**

hpx/hpx_start.hpp

Defined in header `hpx/hpx_start.hpp`.

See *Public API* for a list of names and headers that are part of the public *HPX* API.

namespace **hpx**

hpx::start

Defined in header `hpx/init.hpp`⁸⁰⁵.

See *Public API* for a list of names and headers that are part of the public *HPX* API.

namespace **hpx_startup**

namespace **hpx**

⁸⁰⁵ http://github.com/STELLAR-GROUP/hpx/blob/8a3b7c1a4cb5693b2f7d9f587f759392ed0c51a0/libs/full/init_runtime/include/hpx/init.hpp

Functions

```
inline bool start(std::function<int(hpx::program_options::variables_map&)> f, int argc, char **argv,  
                 init_params const &params = init_params())
```

Main non-blocking entry point for launching the HPX runtime system.

This is the main, non-blocking entry point for any HPX application. This function (or one of its overloads below) should be called from the users `main()` function. It will set up the HPX runtime environment and schedule the function given by `f` as a HPX thread. It will return immediately after that. Use `hpx::wait` and `hpx::stop` to synchronize with the runtime system's execution. This overload will not call `hpx_main`.

This is the main, non-blocking entry point for any HPX application. This function (or one of its overloads below) should be called from the users `main()` function. It will set up the HPX runtime environment and schedule the function given by `f` as an HPX thread. It will return immediately after that. Use `hpx::wait` and `hpx::stop` to synchronize with the runtime system's execution.

Note: If the parameter `mode` is not given (defaulted), the created runtime system instance will be executed in console or worker mode depending on the command line arguments passed in `argc/argv`. Otherwise, it will be executed as specified by the parameter `mode`.

Parameters

- **f** – [in] The function to be scheduled as an HPX thread. Usually this function represents the main entry point of any HPX application. If `f` is `nullptr` the HPX runtime environment will be started without invoking `f`.
- **argc** – [in] The number of command line arguments passed in `argv`. This is usually the unchanged value as passed by the operating system (to `main()`).
- **argv** – [in] The command line arguments for this application, usually that is the value as passed by the operating system (to `main()`).
- **params** – [in] The parameters to the `hpx::start` function (See documentation of `hpx::init_params`)

Returns The function returns `true` if command line processing succeeded and the runtime system was started successfully. It will return `false` otherwise.

```
inline bool start(std::function<int(int, char**)> f, int argc, char **argv, init_params const &params =  
                 init_params())
```

Main non-blocking entry point for launching the HPX runtime system.

This is the main, non-blocking entry point for any HPX application. This function (or one of its overloads below) should be called from the users `main()` function. It will set up the HPX runtime environment and schedule the function given by `f` as a HPX thread. It will return immediately after that. Use `hpx::wait` and `hpx::stop` to synchronize with the runtime system's execution. This overload will not call `hpx_main`.

This is the main, non-blocking entry point for any HPX application. This function (or one of its overloads below) should be called from the users `main()` function. It will set up the HPX runtime environment and schedule the function given by `f` as an HPX thread. It will return immediately after that. Use `hpx::wait` and `hpx::stop` to synchronize with the runtime system's execution.

Note: If the parameter `mode` is not given (defaulted), the created runtime system instance will be executed in console or worker mode depending on the command line arguments passed in `argc/argv`. Otherwise, it will be executed as specified by the parameter `mode`.

Parameters

- **f** – [in] The function to be scheduled as an HPX thread. Usually this function represents the main entry point of any HPX application. If `f` is `nullptr` the HPX runtime environment will be started without invoking `f`.
- **argc** – [in] The number of command line arguments passed in `argv`. This is usually the unchanged value as passed by the operating system (to `main()`).
- **argv** – [in] The command line arguments for this application, usually that is the value as passed by the operating system (to `main()`).
- **params** – [in] The parameters to the `hpx::start` function (See documentation of `hpx::init_params`)

Returns The function returns `true` if command line processing succeeded and the runtime system was started successfully. It will return `false` otherwise.

```
inline bool start(int argc, char **argv, init_params const &params = init_params())
```

Main non-blocking entry point for launching the HPX runtime system.

This is the main, non-blocking entry point for any HPX application. This function (or one of its overloads below) should be called from the users `main()` function. It will set up the HPX runtime environment and schedule the function given by `f` as a HPX thread. It will return immediately after that. Use `hpx::wait` and `hpx::stop` to synchronize with the runtime system's execution. This overload will not call `hpx_main`.

This is the main, non-blocking entry point for any HPX application. This function (or one of its overloads below) should be called from the users `main()` function. It will set up the HPX runtime environment and schedule the function given by `f` as an HPX thread. It will return immediately after that. Use `hpx::wait` and `hpx::stop` to synchronize with the runtime system's execution.

Note: If the parameter `mode` is not given (defaulted), the created runtime system instance will be executed in console or worker mode depending on the command line arguments passed in `argc/argv`. Otherwise, it will be executed as specified by the parameter `mode`.

Parameters

- **argc** – [in] The number of command line arguments passed in `argv`. This is usually the unchanged value as passed by the operating system (to `main()`).
- **argv** – [in] The command line arguments for this application, usually that is the value as passed by the operating system (to `main()`).
- **params** – [in] The parameters to the `hpx::start` function (See documentation of `hpx::init_params`)

Returns The function returns `true` if command line processing succeeded and the runtime system was started successfully. It will return `false` otherwise.

```
inline bool start(std::nullptr_t f, int argc, char **argv, init_params const &params = init_params())
```

Main non-blocking entry point for launching the HPX runtime system.

This is the main, non-blocking entry point for any HPX application. This function (or one of its overloads below) should be called from the users `main()` function. It will set up the HPX runtime environment and schedule the function given by `f` as a HPX thread. It will return immediately after that. Use `hpx::wait` and `hpx::stop` to synchronize with the runtime system's execution. This overload will not call `hpx_main`.

This is the main, non-blocking entry point for any HPX application. This function (or one of its overloads below) should be called from the users `main()` function. It will set up the HPX runtime environment and schedule the function given by `f` as an HPX thread. It will return immediately after that. Use `hpx::wait` and `hpx::stop` to synchronize with the runtime system's execution.

Note: If the parameter `mode` is not given (defaulted), the created runtime system instance will be executed in console or worker mode depending on the command line arguments passed in `argc/argv`. Otherwise, it will be executed as specified by the parameter `mode`.

Parameters

- **f** – [in] The function to be scheduled as an HPX thread. Usually this function represents the main entry point of any HPX application. If `f` is `nullptr` the HPX runtime environment will be started without invoking `f`.
- **argc** – [in] The number of command line arguments passed in `argv`. This is usually the unchanged value as passed by the operating system (to `main()`).
- **argv** – [in] The command line arguments for this application, usually that is the value as passed by the operating system (to `main()`).
- **params** – [in] The parameters to the `hpx::start` function (See documentation of `hpx::init_params`)

Returns The function returns `true` if command line processing succeeded and the runtime system was started successfully. It will return `false` otherwise.

```
inline bool start(init_params const &params = init_params())
```

Main non-blocking entry point for launching the HPX runtime system.

This is a simplified main, non-blocking entry point, which can be used to set up the runtime for an HPX application (the runtime system will be set up in console mode or worker mode depending on the command line settings). It will return immediately after that. Use `hpx::wait` and `hpx::stop` to synchronize with the runtime system's execution.

This is the main, non-blocking entry point for any HPX application. This function (or one of its overloads below) should be called from the users `main()` function. It will set up the HPX runtime environment and schedule the function given by `f` as an HPX thread. It will return immediately after that. Use `hpx::wait` and `hpx::stop` to synchronize with the runtime system's execution.

Note: The created runtime system instance will be executed in console or worker mode depending on the command line arguments passed in `argc/argv`. If not command line arguments are passed, console mode is assumed.

Note: If no command line arguments are passed the HPX runtime system will not support any of the default command line options as described in the section ‘HPX Command Line Options’.

Parameters `params` – [in] The parameters to the `hpx::start` function (See documentation of `hpx::init_params`)

Returns The function returns `true` if command line processing succeeded and the runtime system was started successfully. It will return `false` otherwise.

hpx::suspend, hpx::resume

Defined in header `hpx/init.hpp`⁸⁰⁶.

See *Public API* for a list of names and headers that are part of the public HPX API.

namespace `hpx`

Functions

int `suspend`(*error_code* &ec = *throws*)

Suspend the runtime system.

The function `hpx::suspend` is used to suspend the HPX runtime system. It can only be used when running HPX on a single locality. It will block waiting for all thread pools to be empty. This function only be called when the runtime is running, or already suspended in which case this function will do nothing.

Note: As long as *ec* is not pre-initialized to `hpx::throws` this function doesn’t throw but returns the result code using the parameter *ec*. Otherwise it throws an instance of `hpx::exception`.

Parameters `ec` – [in,out] this represents the error status on exit, if this is pre-initialized to `hpx::throws` the function will throw on error instead.

Returns This function will always return zero.

int `resume`(*error_code* &ec = *throws*)

Resume the HPX runtime system.

The function `hpx::resume` is used to resume the HPX runtime system. It can only be used when running HPX on a single locality. It will block waiting for all thread pools to be resumed. This function only be called when the runtime suspended, or already running in which case this function will do nothing.

Note: As long as *ec* is not pre-initialized to `hpx::throws` this function doesn’t throw but returns the result code using the parameter *ec*. Otherwise it throws an instance of `hpx::exception`.

Parameters `ec` – [in,out] this represents the error status on exit, if this is pre-initialized to `hpx::throws` the function will throw on error instead.

Returns This function will always return zero.

⁸⁰⁶ http://github.com/STELLAR-GROUP/hpx/blob/8a3b7c1a4cb5693b2f7d9f587f759392ed0c51a0/libs/full/init_runtime/include/hpx/init.hpp

naming_base

See *Public API* for a list of names and headers that are part of the public *HPX* API.

hpx/naming_base/unmanaged.hpp

Defined in header `hpx/naming_base/unmanaged.hpp`.

See *Public API* for a list of names and headers that are part of the public *HPX* API.

namespace **hpx**

Functions

`hpx::id_type unmanaged(hpx::id_type const &id)`

The helper function `hpx::unmanaged` can be used to generate a global identifier which does not participate in the automatic garbage collection.

Note: This function allows to apply certain optimizations to the process of memory management in *HPX*. It however requires the user to take full responsibility for keeping the referenced objects alive long enough.

Parameters `id` – [in] The id to generated the unmanaged global id from This parameter can be itself a managed or a unmanaged global id.

Returns This function returns a new global id referencing the same object as the parameter `id`. The only difference is that the returned global identifier does not participate in the automatic garbage collection.

namespace **naming**

parcelset

See *Public API* for a list of names and headers that are part of the public *HPX* API.

hpx/parcelset/connection_cache.hpp

Defined in header `hpx/parcelset/connection_cache.hpp`.

See *Public API* for a list of names and headers that are part of the public *HPX* API.

hpx/parcelset/message_handler_fwd.hpp

Defined in header `hpx/parcelset/message_handler_fwd.hpp`.

See *Public API* for a list of names and headers that are part of the public *HPX* API.

hpx/parcelset/parcelhandler.hpp

Defined in header `hpx/parcelset/parcelhandler.hpp`.

See *Public API* for a list of names and headers that are part of the public *HPX* API.

hpx/parcelset/parcelset_fwd.hpp

Defined in header `hpx/parcelset/parcelset_fwd.hpp`.

See *Public API* for a list of names and headers that are part of the public *HPX* API.

parcelset_base

See *Public API* for a list of names and headers that are part of the public *HPX* API.

hpx/parcelset_base/parcelport.hpp

Defined in header `hpx/parcelset_base/parcelport.hpp`.

See *Public API* for a list of names and headers that are part of the public *HPX* API.

hpx/parcelset_base/parcelset_base_fwd.hpp

Defined in header `hpx/parcelset_base/parcelset_base_fwd.hpp`.

See *Public API* for a list of names and headers that are part of the public *HPX* API.

Defines

HPX_PARCELPORT_BACKGROUND_MODE_ENUM_DEPRECATION_MSG

namespace **hpx**

namespace **parcelset**

Typedefs

using **parcel_write_handler_type** = *hpx::function*<void(*std::error_code* const&, *parcelset::parcel* const&>

The type of the function that can be registered as a parcel write handler using the function *hpx::set_parcel_write_handler*.

Note: A parcel write handler is a function which is called by the parcel layer whenever a parcel has been sent by the underlying networking library and if no explicit parcel handler function was specified for the parcel.

Enums

enum class **parcelport_background_mode** : *std::uint8_t*

Type of background work to perform.

Values:

enumerator **flush_buffers**

perform buffer flush operations

enumerator **send**

perform send operations (includes buffer flush)

enumerator **receive**

perform receive operations

enumerator **all**

perform all operations

Functions

inline bool **operator&**(*parcelport_background_mode* lhs, *parcelport_background_mode* rhs)

char const ***get_parcelport_background_mode_name**(*parcelport_background_mode* mode)

Variables

parcel **empty_parcel**

constexpr *parcelport_background_mode* **parcelport_background_mode_flush_buffers** = *parcelport_background_mode::flush_buffers*

constexpr *parcelport_background_mode* **parcelport_background_mode_send** = *parcelport_background_mode::send*

```
constexpr parcelport_background_mode parcelport_background_mode_receive =
parcelport_background_mode::receive
```

```
constexpr parcelport_background_mode parcelport_background_mode_all =
parcelport_background_mode::all
```

hpx/parcelset_base/set_parcel_write_handler.hpp

Defined in header `hpx/parcelset_base/set_parcel_write_handler.hpp`.

See *Public API* for a list of names and headers that are part of the public *HPX API*.

performance_counters

See *Public API* for a list of names and headers that are part of the public *HPX API*.

hpx/performance_counters/counter_creators.hpp

Defined in header `hpx/performance_counters/counter_creators.hpp`.

See *Public API* for a list of names and headers that are part of the public *HPX API*.

namespace **hpx**

namespace **performance_counters**

Functions

```
bool default_counter_discoverer(counter_info const&, discover_counter_func const&,
discover_counters_mode, error_code&)
```

Default discovery function for performance counters; to be registered with the counter types. It will pass the `counter_info` and the `error_code` to the supplied function.

```
bool locality_counter_discoverer(counter_info const&, discover_counter_func const&,
discover_counters_mode, error_code&)
```

Default discoverer function for performance counters; to be registered with the counter types. It is suitable to be used for all counters following the naming scheme:

```
/<objectname>(locality#<locality_id>/total)/<instancename>
```

```
bool locality_pool_counter_discoverer(counter_info const&, discover_counter_func const&,
discover_counters_mode, error_code&)
```

Default discoverer function for performance counters; to be registered with the counter types. It is suitable to be used for all counters following the naming scheme:

```
/<objectname>(locality#<locality_id>/pool#<pool_name>/total)/<instancename>
```

```
bool locality0_counter_discoverer(counter_info const&, discover_counter_func const&,
                                   discover_counters_mode, error_code&)
```

Default discoverer function for AGAS performance counters; to be registered with the counter types. It is suitable to be used for all counters following the naming scheme:

```
/<objectname>{locality#0/total}/<instancename>
```

```
bool locality_thread_counter_discoverer(counter_info const&, discover_counter_func const&,
                                          discover_counters_mode, error_code&)
```

Default discoverer function for performance counters; to be registered with the counter types. It is suitable to be used for all counters following the naming scheme:

```
/<objectname>(locality#<locality_id>/worker-thread#<threadnum>)/<instancename>
```

```
bool locality_pool_thread_counter_discoverer(counter_info const &info,
                                              discover_counter_func const &f,
                                              discover_counters_mode mode, error_code
                                              &ec)
```

Default discoverer function for performance counters; to be registered with the counter types. It is suitable to be used for all counters following the naming scheme:

```
/<objectname>{locality#<locality_id>/pool#<poolname>/thread#<threadnum>}/<instancename>
```

```
bool locality_pool_thread_no_total_counter_discoverer(counter_info const &info,
                                                       discover_counter_func const &f,
                                                       discover_counters_mode mode,
                                                       error_code &ec)
```

Default discoverer function for performance counters; to be registered with the counter types. It is suitable to be used for all counters following the naming scheme:

```
/<objectname>{locality#<locality_id>/pool#<poolname>/thread#<threadnum>}/<instancename>
```

This is essentially the same as above just that locality#*/total is not supported.

```
bool locality_numa_counter_discoverer(counter_info const&, discover_counter_func const&,
                                        discover_counters_mode, error_code&)
```

Default discoverer function for performance counters; to be registered with the counter types. It is suitable to be used for all counters following the naming scheme:

```
/<objectname>(locality#<locality_id>/numa-node#<threadnum>)/<instancename>
```

```
naming::gid_type locality_raw_counter_creator(counter_info const&,
                                                hpx::function<std::int64_t(bool)> const&,
                                                error_code&)
```

Creation function for raw counters. The passed function is encapsulating the actual value to monitor. This function checks the validity of the supplied counter name, it has to follow the scheme:

```
/<objectname>(locality#<locality_id>/total)/<instancename>
```

```
naming::gid_type locality_raw_values_counter_creator(counter_info const&,
                                                       hpx::function<std::vector<std::int64_t>(bool)>
                                                       const&, error_code&)
```

```
naming::gid_type agas_raw_counter_creator(counter_info const&, error_code&, char const*const)
```

Creation function for raw counters. The passed function is encapsulating the actual value to monitor. This function checks the validity of the supplied counter name, it has to follow the scheme:

```
/agas(<objectinstance>/total)/<instancename>
```

```
bool agas_counter_discoverer(counter_info const&, discover_counter_func const&,
                             discover_counters_mode, error_code&)
```

Default discoverer function for performance counters; to be registered with the counter types. It is suitable to be used for all counters following the naming scheme:

```
/agas(<objectinstance>/total)/<instancename>
```

```
naming::gid_type local_action_invocation_counter_creator(counter_info const&,
                                                         error_code&)
```

```
bool local_action_invocation_counter_discoverer(counter_info const&,
                                                discover_counter_func const&,
                                                discover_counters_mode, error_code&)
```

hpx/performance_counters/counters.hpp

Defined in header `hpx/performance_counters/counters.hpp`.

See *Public API* for a list of names and headers that are part of the public *HPX* API.

```
namespace hpx
```

```
namespace performance_counters
```

Typedefs

```
typedef hpx::function<naming::gid_type(counter_info const&, error_code&)> create_counter_func
```

This declares the type of a function, which will be called by HPX whenever a new performance counter instance of a particular type needs to be created.

```
typedef hpx::function<bool(counter_info const&, error_code&)> discover_counter_func
```

This declares a type of a function, which will be passed to a *discover_counters_func* in order to be called for each discovered performance counter instance.

```
typedef hpx::function<bool(counter_info const&, discover_counter_func const&,
                          discover_counters_mode, error_code&)> discover_counters_func
```

This declares the type of a function, which will be called by HPX whenever it needs to discover all performance counter instances of a particular type.

Enums

```
enum class counter_type
```

Values:

```
enumerator text
```

text shows a variable-length text string. It does not deliver calculated values.

Formula: None Average: None Type: Text

enumerator **raw**

raw shows the last observed value only. It does not deliver an average.

Formula: None. Shows raw data as collected. Average: None Type: Instantaneous

enumerator **monotonically_increasing**

monotonically_increasing shows the cumulatively accumulated observed value. It does not deliver an average.

Formula: None. Shows cumulatively accumulated data as collected. Average: None Type: Instantaneous

enumerator **average_base**

average_base is used as the base data (denominator) in the computation of time or count averages for the *counter_type::average_count* and *counter_type::average_timer* counter types. This counter type collects the last observed value only.

Formula: None. This counter uses raw data in fractional calculations without delivering an output. Average: $SUM(N) / x$ Type: Instantaneous

enumerator **average_count**

average_count shows how many items are processed, on average, during an operation. Counters of this type display a ratio of the items processed (such as bytes sent) to the number of operations completed. The ratio is calculated by comparing the number of items processed during the last interval to the number of operations completed during the last interval.

Formula: $(N1 - N0) / (D1 - D0)$, where the numerator (N) represents the number of items processed during the last sample interval, and the denominator (D) represents the number of operations completed during the last two sample intervals. Average: $(Nx - N0) / (Dx - D0)$ Type: Average

enumerator **aggregating**

aggregating applies a function to an embedded counter instance. The embedded counter is usually evaluated repeatedly after a fixed (but configurable) time interval.

Formula: $F(Nx)$

enumerator **average_timer**

average_timer measures the average time it takes to complete a process or operation. Counters of this type display a ratio of the total elapsed time of the sample interval to the number of processes or operations completed during that time. This counter type measures time in ticks of the system clock. The variable F represents the number of ticks per second. The value of F is factored into the equation so that the result is displayed in seconds.

Formula: $((N1 - N0) / F) / (D1 - D0)$, where the numerator (N) represents the number of ticks counted during the last sample interval, the variable F represents the frequency of the ticks, and the denominator (D) represents the number of operations completed during the last sample interval. Average: $((Nx - N0) / F) / (Dx - D0)$ Type: Average

enumerator **elapsed_time**

elapsed_time shows the total time between when the component or process started and the time when this value is calculated. The variable F represents the number of time units that elapse in one second. The value of F is factored into the equation so that the result is displayed in seconds.

Formula: $(D0 - N0) / F$, where the nominator (D) represents the current time, the numerator (N) represents the time the object was started, and the variable F represents the number of time units that elapse in one second. Average: $(Dx - N0) / F$ Type: Difference

enumerator **histogram**

histogram exposes a histogram of the measured values instead of a single value as many of the other counter types. Counters of this type expose a *counter_value_array* instead of a *counter_value*. Those will also not implement the *get_counter_value()* functionality. The results are exposed through a separate *get_counter_values_array()* function.

The first three values in the returned array represent the lower and upper boundaries, and the size of the histogram buckets. All remaining values in the returned array represent the number of measurements for each of the buckets in the histogram.

enumerator **raw_values**

raw_values exposes an array of measured values instead of a single value as many of the other counter types. Counters of this type expose a *counter_value_array* instead of a *counter_value*. Those will also not implement the *get_counter_value()* functionality. The results are exposed through a separate *get_counter_values_array()* function.

enumerator **text**

enumerator **raw**

enumerator **monotonically_increasing**

enumerator **average_base**

enumerator **average_count**

enumerator **aggregating**

enumerator **average_timer**

enumerator **elapsed_time**

enumerator **histogram**

enumerator **raw_values**

raw_values counter exposes an array of measured values instead of a single value as many of the other counter types. Counters of this type expose a *counter_value_array* instead of a *counter_value*. Those will also not implement the *get_counter_value()* functionality. The results are exposed through a separate *get_counter_values_array()* function.

enum class **counter_status**

Status and error codes used by the functions related to performance counters.

Values:

enumerator **valid_data**

No error occurred, data is valid.

enumerator **new_data**

Data is valid and different from last call.

enumerator **invalid_data**

Some error occurred, data is not value.

enumerator **already_defined**

The type or instance already has been defined.

enumerator **counter_unknown**

The counter instance is unknown.

enumerator **counter_type_unknown**

The counter type is unknown.

enumerator **generic_error**

A unknown error occurred.

enumerator **valid_data**

enumerator **new_data**

enumerator **invalid_data**

enumerator **already_defined**

enumerator **counter_unknown**

enumerator **counter_type_unknown**

enumerator **generic_error**

Functions

```
inline std::string &ensure_counter_prefix(std::string &name)
```

```
inline std::string ensure_counter_prefix(std::string const &counter)
```

```
inline std::string &remove_counter_prefix(std::string &name)
```

```
inline std::string remove_counter_prefix(std::string const &counter)
```

```

char const *get_counter_type_name(counter_type state)
    Return the readable name of a given counter type.

inline bool status_is_valid(counter_status s)

inline counter_status add_counter_type(counter_info const &info, error_code &ec)

inline hpx::id_type get_counter(std::string const &name, error_code &ec)

inline hpx::id_type get_counter(counter_info const &info, error_code &ec)

```

Variables

```

constexpr const char counter_prefix[] = "/counters"

constexpr std::size_t counter_prefix_len = std::size(counter_prefix) - 1

struct counter_info

```

Public Functions

```

inline explicit counter_info(counter_type type = counter_type::raw)

inline explicit counter_info(std::string const &name)

inline counter_info(counter_type type, std::string const &name, std::string const &helptext = "",
                    std::uint32_t version = HPX_PERFORMANCE_COUNTER_V1, std::string
                    const &uom = "")

```

Public Members

```

counter_type type_
    The type of the described counter.

std::uint32_t version_
    The version of the described counter using the 0xMMmmSSSS scheme

counter_status status_
    The status of the counter object.

std::string fullname_
    The full name of this counter.

std::string helptext_
    The full descriptive text for this counter.

std::string unit_of_measure_
    The unit of measure for this counter.

```

Private Functions

```
void serialize(serialization::output_archive &ar, unsigned int) const
```

```
void serialize(serialization::input_archive &ar, unsigned int)
```

Friends

```
friend class hpx::serialization::access
```

```
struct counter_path_elements : public hpx::performance_counters::counter_type_path_elements
```

```
#include <counters.hpp> A counter_path_elements holds the elements of a full name for a counter instance. Generally, a full name of a counter instance has the structure:
```

```
/objectname{parentinstancename::parentindex/instancename#instanceindex} /counter-  
name#parameters
```

```
i.e. /queue{localityprefix/thread#2}/length
```

Public Types

```
using base_type = counter_type_path_elements
```

Public Functions

```
inline counter_path_elements()
```

```
inline counter_path_elements(std::string const &objectname, std::string const &countername,  
 std::string const &parameters, std::string const &parentname,  
 std::string const &instancename, std::int64_t parentindex = -1,  
 std::int64_t instanceindex = -1, bool parentinstance_is_basename  
 = false)
```

```
inline counter_path_elements(std::string const &objectname, std::string const &countername,  
 std::string const &parameters, std::string const &parentname,  
 std::string const &instancename, std::string const  
 &subinstancename, std::int64_t parentindex = -1, std::int64_t  
 instanceindex = -1, std::int64_t subinstanceindex = -1, bool  
 parentinstance_is_basename = false)
```

Public Members

```
std::string parentinstancename_  
 the name of the parent instance
```

```
std::string instancename_  
 the name of the object instance
```

`std::string` **subinstancename_**
the name of the object sub-instance

`std::int64_t` **parentinstanceindex_**
the parent instance index

`std::int64_t` **instanceindex_**
the instance index

`std::int64_t` **subinstanceindex_**
the sub-instance index

bool **parentinstance_is_basename_**
the parentinstancename_

Private Functions

void **serialize**(*serialization::output_archive* &ar, unsigned int)

void **serialize**(*serialization::input_archive* &ar, unsigned int)

Friends

friend class *hpx::serialization::access*

struct **counter_type_path_elements**

#include <counters.hpp> A *counter_type_path_elements* holds the elements of a full name for a counter type. Generally, a full name of a counter type has the structure:

/objectname/countername

i.e. */queue/length*

Subclassed by *hpx::performance_counters::counter_path_elements*

Public Functions

counter_type_path_elements() = default

inline **counter_type_path_elements**(*std::string* const &objectname, *std::string* const &countername, *std::string* const ¶meters)

Public Members

std::string **objectname_**
the name of the performance object

std::string **countername_**
contains the counter name

std::string **parameters_**
optional parameters for the counter instance

Protected Functions

void **serialize**(*serialization::output_archive* &ar, unsigned int) const

void **serialize**(*serialization::input_archive* &ar, unsigned int)

Friends

friend class *hpx::serialization::access*

hpx/performance_counters/counters_fwd.hpp

Defined in header *hpx/performance_counters/counters_fwd.hpp*.

See *Public API* for a list of names and headers that are part of the public *HPX* API.

Defines

HPX_COUNTER_TYPE_UNSCOPED_ENUM_DEPRECATION_MSG

HPX_COUNTER_STATUS_UNSCOPED_ENUM_DEPRECATION_MSG

HPX_PERFORMANCE_COUNTER_V1

HPX_DISCOVER_COUNTERS_MODE_UNSCOPED_ENUM_DEPRECATION_MSG

namespace **hpx**

namespace **performance_counters**

Enums

enum class **counter_type**

Values:

enumerator **text**

text shows a variable-length text string. It does not deliver calculated values.

Formula: None Average: None Type: Text

enumerator **raw**

raw shows the last observed value only. It does not deliver an average.

Formula: None. Shows raw data as collected. Average: None Type: Instantaneous

enumerator **monotonically_increasing**

monotonically_increasing shows the cumulatively accumulated observed value. It does not deliver an average.

Formula: None. Shows cumulatively accumulated data as collected. Average: None Type: Instantaneous

enumerator **average_base**

average_base is used as the base data (denominator) in the computation of time or count averages for the *counter_type::average_count* and *counter_type::average_timer* counter types. This counter type collects the last observed value only.

Formula: None. This counter uses raw data in fractional calculations without delivering an output. Average: $\text{SUM}(N) / x$ Type: Instantaneous

enumerator **average_count**

average_count shows how many items are processed, on average, during an operation. Counters of this type display a ratio of the items processed (such as bytes sent) to the number of operations completed. The ratio is calculated by comparing the number of items processed during the last interval to the number of operations completed during the last interval.

Formula: $(N1 - N0) / (D1 - D0)$, where the numerator (N) represents the number of items processed during the last sample interval, and the denominator (D) represents the number of operations completed during the last two sample intervals. Average: $(Nx - N0) / (Dx - D0)$ Type: Average

enumerator **aggregating**

aggregating applies a function to an embedded counter instance. The embedded counter is usually evaluated repeatedly after a fixed (but configurable) time interval.

Formula: $F(Nx)$

enumerator **average_timer**

average_timer measures the average time it takes to complete a process or operation. Counters of this type display a ratio of the total elapsed time of the sample interval to the number of processes or operations completed during that time. This counter type measures time in ticks of the system clock. The variable F represents the number of ticks per second. The value of F is factored into the equation so that the result is displayed in seconds.

Formula: $((N1 - N0) / F) / (D1 - D0)$, where the numerator (N) represents the number of ticks counted during the last sample interval, the variable F represents the frequency of the ticks, and the denominator (D) represents the number of operations completed during the last sample interval. Average: $((Nx - N0) / F) / (Dx - D0)$ Type: Average

enumerator **elapsed_time**

elapsed_time shows the total time between when the component or process started and the time when this value is calculated. The variable F represents the number of time units that elapse in one second. The value of F is factored into the equation so that the result is displayed in seconds.

Formula: $(D0 - N0) / F$, where the nominator (D) represents the current time, the numerator (N) represents the time the object was started, and the variable F represents the number of time units that elapse in one second. Average: $(Dx - N0) / F$ Type: Difference

enumerator **histogram**

histogram exposes a histogram of the measured values instead of a single value as many of the other counter types. Counters of this type expose a *counter_value_array* instead of a *counter_value*. Those will also not implement the *get_counter_value()* functionality. The results are exposed through a separate *get_counter_values_array()* function.

The first three values in the returned array represent the lower and upper boundaries, and the size of the histogram buckets. All remaining values in the returned array represent the number of measurements for each of the buckets in the histogram.

enumerator **raw_values**

raw_values exposes an array of measured values instead of a single value as many of the other counter types. Counters of this type expose a *counter_value_array* instead of a *counter_value*. Those will also not implement the *get_counter_value()* functionality. The results are exposed through a separate *get_counter_values_array()* function.

enumerator **text**

enumerator **raw**

enumerator **monotonically_increasing**

enumerator **average_base**

enumerator **average_count**

enumerator **aggregating**

enumerator **average_timer**

enumerator **elapsed_time**

enumerator **histogram**

enumerator **raw_values**

raw_values counter exposes an array of measured values instead of a single value as many of the other counter types. Counters of this type expose a *counter_value_array* instead of a *counter_value*. Those will also not implement the *get_counter_value()* functionality. The results are exposed through a separate *get_counter_values_array()* function.

enum class **counter_status**

Values:

enumerator **valid_data**

No error occurred, data is valid.

enumerator **new_data**

Data is valid and different from last call.

enumerator **invalid_data**

Some error occurred, data is not value.

enumerator **already_defined**

The type or instance already has been defined.

enumerator **counter_unknown**

The counter instance is unknown.

enumerator **counter_type_unknown**

The counter type is unknown.

enumerator **generic_error**

A unknown error occurred.

enumerator **valid_data**enumerator **new_data**enumerator **invalid_data**enumerator **already_defined**enumerator **counter_unknown**enumerator **counter_type_unknown**enumerator **generic_error**

enum class **discover_counters_mode**

Values:

enumerator **minimal**

enumerator **full**

Functions

inline constexpr bool **operator<**(*counter_type* lhs, *counter_type* rhs) noexcept

inline constexpr bool **operator>**(*counter_type* lhs, *counter_type* rhs) noexcept

std::ostream &**operator<<**(*std::ostream* &os, *counter_status* rhs)

counter_status **get_counter_type_name**(*counter_type_path_elements* const &path, *std::string* &result, *error_code* &ec = *throws*)

Create a full name of a counter type from the contents of the given *counter_type_path_elements* instance. The generated counter type name will not contain any parameters.

counter_status **get_full_counter_type_name**(*counter_type_path_elements* const &path, *std::string* &result, *error_code* &ec = *throws*)

Create a full name of a counter type from the contents of the given *counter_type_path_elements* instance. The generated counter type name will contain all parameters.

counter_status **get_counter_name**(*counter_path_elements* const &path, *std::string* &result, *error_code* &ec = *throws*)

Create a full name of a counter from the contents of the given *counter_path_elements* instance.

counter_status **get_counter_instance_name**(*counter_path_elements* const &path, *std::string* &result, *error_code* &ec = *throws*)

Create a name of a counter instance from the contents of the given *counter_path_elements* instance.

counter_status **get_counter_type_path_elements**(*std::string* const &name, *counter_type_path_elements* &path, *error_code* &ec = *throws*)

Fill the given *counter_type_path_elements* instance from the given full name of a counter type.

counter_status **get_counter_path_elements**(*std::string* const &name, *counter_path_elements* &path, *error_code* &ec = *throws*)

Fill the given *counter_path_elements* instance from the given full name of a counter.

counter_status **get_counter_name**(*std::string* const &name, *std::string* &countername, *error_code* &ec = *throws*)

Return the canonical counter instance name from a given full instance name.

counter_status **get_counter_type_name**(*std::string* const &name, *std::string* &type_name, *error_code* &ec = *throws*)

Return the canonical counter type name from a given (full) instance name.

HPX_DEPRECATED_V (1, 9, **HPX_DISCOVER_COUNTERS_MODE_UNSCOPED_ENUM_DEPRECATION_MSG**) inline const expr discover_counters_...

```
counter_status complement_counter_info(counter_info &info, counter_info const &type_info,
                                         error_code &ec = throws)
```

Complement the counter info if parent instance name is missing.

```
counter_status complement_counter_info(counter_info &info, error_code &ec = throws)
```

```
counter_status add_counter_type(counter_info const &info, create_counter_func const
                                &create_counter, discover_counters_func const
                                &discover_counters, error_code &ec = throws)
```

```
counter_status discover_counter_types(discover_counter_func const &discover_counter,
                                        discover_counters_mode mode =
                                        discover_counters_mode::minimal, error_code &ec =
                                        throws)
```

Call the supplied function for each registered counter type.

```
counter_status discover_counter_types(std::vector<counter_info> &counters,
                                        discover_counters_mode mode =
                                        discover_counters_mode::minimal, error_code &ec =
                                        throws)
```

Return a list of all available counter descriptions.

```
counter_status discover_counter_type(std::string const &name, discover_counter_func const
                                       &discover_counter, discover_counters_mode mode =
                                       discover_counters_mode::minimal, error_code &ec =
                                       throws)
```

Call the supplied function for the given registered counter type.

```
counter_status discover_counter_type(counter_info const &info, discover_counter_func const
                                       &discover_counter, discover_counters_mode mode =
                                       discover_counters_mode::minimal, error_code &ec =
                                       throws)
```

```
counter_status discover_counter_type(std::string const &name, std::vector<counter_info>
                                       &counters, discover_counters_mode mode =
                                       discover_counters_mode::minimal, error_code &ec =
                                       throws)
```

Return a list of matching counter descriptions for the given registered counter type.

```
counter_status discover_counter_type(counter_info const &info, std::vector<counter_info>
                                       &counters, discover_counters_mode mode =
                                       discover_counters_mode::minimal, error_code &ec =
                                       throws)
```

```
bool expand_counter_info(counter_info const&, discover_counter_func const&, error_code&)
```

call the supplied function will all expanded versions of the supplied counter info.

This function expands all locality#* and worker-thread#* wild cards only.

```
counter_status remove_counter_type(counter_info const &info, error_code &ec = throws)
```

Remove an existing counter type from the (local) registry.

Note: This doesn't remove existing counters of this type, it just inhibits defining new counters using this type.

```
counter_status get_counter_type(std::string const &name, counter_info &info, error_code &ec =  
throws)
```

Retrieve the counter type for the given counter name from the (local) registry.

```
hpx::future<hpx::id_type> get_counter_async(std::string name, error_code &ec = throws)
```

Get the global id of an existing performance counter, if the counter does not exist yet, the function attempts to create the counter based on the given counter name.

```
hpx::future<hpx::id_type> get_counter_async(counter_info const &info, error_code &ec = throws)
```

Get the global id of an existing performance counter, if the counter does not exist yet, the function attempts to create the counter based on the given counter info.

```
void get_counter_infos(counter_info const &info, counter_type &type, std::string &helptext,  
std::uint32_t &version, error_code &ec = throws)
```

Retrieve the meta data specific for the given counter instance.

```
void get_counter_infos(std::string name, counter_type &type, std::string &helptext, std::uint32_t  
&version, error_code &ec = throws)
```

Retrieve the meta data specific for the given counter instance.

Variables

```
constexpr counter_type counter_text = counter_type::text
```

```
constexpr counter_type counter_raw = counter_type::raw
```

```
constexpr counter_type counter_monotonically_increasing =  
counter_type::monotonically_increasing
```

```
constexpr counter_type counter_average_base = counter_type::average_base
```

```
constexpr counter_type counter_average_count = counter_type::average_count
```

```
constexpr counter_type counter_aggregating = counter_type::aggregating
```

```
constexpr counter_type counter_average_timer = counter_type::average_timer
```

```
constexpr counter_type counter_elapsed_time = counter_type::elapsed_time
```

```
constexpr counter_type counter_raw_values = counter_type::raw_values
```

```
constexpr counter_type counter_histogram = counter_type::histogram
```

```
constexpr counter_status status_valid_data = counter_status::valid_data
```

```
constexpr counter_status status_new_data = counter_status::new_data
```

```
constexpr counter_status status_invalid_data = counter_status::invalid_data

constexpr counter_status status_already_defined = counter_status::already_defined

constexpr counter_status status_counter_unknown = counter_status::counter_unknown

constexpr counter_status status_counter_type_unknown = counter_status::counter_type_unknown

constexpr counter_status status_generic_error = counter_status::generic_error

struct counter_value
```

Public Functions

```
inline counter_value(std::int64_t value = 0, std::int64_t scaling = 1, bool scale_inverse = false)
```

```
template<typename T>
```

```
inline T get_value(error_code &ec = throws) const
```

Retrieve the ‘real’ value of the *counter_value*, converted to the requested type *T*.

Public Members

```
std::uint64_t time_
```

The local time when data was collected.

```
std::uint64_t count_
```

The invocation counter for the data.

```
std::int64_t value_
```

The current counter value.

```
std::int64_t scaling_
```

The scaling of the current counter value.

```
counter_status status_
```

The status of the counter value.

```
bool scale_inverse_
```

If true, *value_* needs to be divided by *scaling_*, otherwise it has to be multiplied.

Private Functions

void **serialize**(*serialization::output_archive* &ar, const unsigned int) const

void **serialize**(*serialization::input_archive* &ar, const unsigned int)

Friends

friend class *hpx::serialization::access*

struct **counter_values_array**

Public Functions

inline **counter_values_array**(*std::int64_t* scaling = 1, bool scale_inverse = false)

inline **counter_values_array**(*std::vector<std::int64_t>* &&values, *std::int64_t* scaling = 1, bool scale_inverse = false)

inline **counter_values_array**(*std::vector<std::int64_t>* const &values, *std::int64_t* scaling = 1, bool scale_inverse = false)

template<typename T>

inline T **get_value**(*std::size_t* index, *error_code* &ec = *throws*) const

Retrieve the ‘real’ value of the *counter_value*, converted to the requested type *T*.

Public Members

std::uint64_t **time_**

The local time when data was collected.

std::uint64_t **count_**

The invocation counter for the data.

std::vector<std::int64_t> **values_**

The current counter values.

std::int64_t **scaling_**

The scaling of the current counter values.

counter_status **status_**

The status of the counter value.

bool **scale_inverse_**

If true, *value_* needs to be divided by *scaling_*, otherwise it has to be multiplied.

Private Functions

```
void serialize(serialization::output_archive &ar, const unsigned int) const
```

```
void serialize(serialization::input_archive &ar, const unsigned int)
```

Friends

```
friend class hpx::serialization::access
```

hpx/performance_counters/manage_counter_type.hpp

Defined in header `hpx/performance_counters/manage_counter_type.hpp`.

See *Public API* for a list of names and headers that are part of the public *HPX* API.

```
namespace hpx
```

```
    namespace performance_counters
```

Functions

```
counter_status install_counter_type(std::string const &name, hpx::function<std::int64_t(bool)>
    const &counter_value, std::string const &helptext = "",
    std::string const &uom = "", counter_type type =
    counter_type::raw, error_code &ec = throws)
```

Install a new generic performance counter type in a way, which will uninstall it automatically during shutdown.

The function `install_counter_type` will register a new generic counter type based on the provided function. The counter type will be automatically unregistered during system shutdown. Any consumer querying any instance of this counter type will cause the provided function to be called and the returned value to be exposed as the counter value.

The counter type is registered such that there can be one counter instance per locality. The expected naming scheme for the counter instances is: `/objectname{locality#<*>/total}/countername` where `<*>` is a zero based integer identifying the locality the counter is created on.

Note: As long as `ec` is not pre-initialized to `hpx::throws` this function doesn't throw but returns the result code using the parameter `ec`. Otherwise it throws an instance of `hpx::exception`.

Note: The counter type registry is a locality based service. You will have to register each counter type on every locality where a corresponding performance counter will be created.

Parameters

- **name** – [in] The global virtual name of the counter type. This name is expected to have the format `/objectname/countername`.

- **counter_value** – [in] The function to call whenever the counter value is requested by a consumer.
- **helptext** – [in, optional] A longer descriptive text shown to the user to explain the nature of the counters created from this type.
- **uom** – [in] The unit of measure for the new performance counter type.
- **type** – [in] Type for the new performance counter type.
- **ec** – [in,out] this represents the error status on exit, if this is pre-initialized to *hpx::throws* the function will throw on error instead.

Returns If successful, this function returns *valid_data*, otherwise it will either throw an exception or return an *error_code* from the enum *counter_status* (also, see note related to parameter *ec*).

```
counter_status install_counter_type(std::string const &name,
                                   hpx::function<std::vector<std::int64_t>(bool)> const
                                   &counter_value, std::string const &helptext = "", std::string
                                   const &uom = "", error_code &ec = throws)
```

Install a new generic performance counter type returning an array of values in a way, that will uninstall it automatically during shutdown.

The function *install_counter_type* will register a new generic counter type that returns an array of values based on the provided function. The counter type will be automatically unregistered during system shutdown. Any consumer querying any instance of this counter type will cause the provided function to be called and the returned array value to be exposed as the counter value.

The counter type is registered such that there can be one counter instance per locality. The expected naming scheme for the counter instances is: '/objectname{locality#<*>/total}/countername' where '<*>' is a zero based integer identifying the locality the counter is created on.

Note: As long as *ec* is not pre-initialized to *hpx::throws* this function doesn't throw but returns the result code using the parameter *ec*. Otherwise it throws an instance of *hpx::exception*.

Note: The counter type registry is a locality based service. You will have to register each counter type on every locality where a corresponding performance counter will be created.

Parameters

- **name** – [in] The global virtual name of the counter type. This name is expected to have the format /objectname/countername.
- **counter_value** – [in] The function to call whenever the counter value (array of values) is requested by a consumer.
- **helptext** – [in, optional] A longer descriptive text shown to the user to explain the nature of the counters created from this type.
- **uom** – [in] The unit of measure for the new performance counter type.
- **ec** – [in,out] this represents the error status on exit, if this is pre-initialized to *hpx::throws* the function will throw on error instead.

Returns If successful, this function returns *valid_data*, otherwise it will either throw an exception or return an *error_code* from the enum *counter_status* (also, see note related to parameter *ec*).

```
void install_counter_type(std::string const &name, counter_type type, error_code &ec = throws)
```

Install a new performance counter type in a way, which will uninstall it automatically during shutdown.

The function *install_counter_type* will register a new counter type based on the provided

counter_type_info. The counter type will be automatically unregistered during system shutdown.

Note: The counter type registry is a locality based service. You will have to register each counter type on every locality where a corresponding performance counter will be created.

Note: As long as *ec* is not pre-initialized to *hpx::throws* this function doesn't throw but returns the result code using the parameter *ec*. Otherwise it throws an instance of *hpx::exception*.

Parameters

- **name** – [in] The global virtual name of the counter type. This name is expected to have the format /objectname/countertype.
- **type** – [in] The type of the counters of this counter_type.
- **ec** – [in,out] this represents the error status on exit, if this is pre-initialized to *hpx::throws* the function will throw on error instead.

Returns If successful, this function returns *valid_data*, otherwise it will either throw an exception or return an error_code from the enum *counter_status* (also, see note related to parameter *ec*).

```
counter_status install_counter_type(std::string const &name, counter_type type, std::string const
&helptext, std::string const &uom = "", std::uint32_t version =
HPX_PERFORMANCE_COUNTER_V1, error_code &ec =
throws)
```

Install a new performance counter type in a way, which will uninstall it automatically during shutdown.

The function *install_counter_type* will register a new counter type based on the provided *counter_type_info*. The counter type will be automatically unregistered during system shutdown.

Note: The counter type registry is a locality based service. You will have to register each counter type on every locality where a corresponding performance counter will be created.

Note: As long as *ec* is not pre-initialized to *hpx::throws* this function doesn't throw but returns the result code using the parameter *ec*. Otherwise it throws an instance of *hpx::exception*.

Parameters

- **name** – [in] The global virtual name of the counter type. This name is expected to have the format /objectname/countertype.
- **type** – [in] The type of the counters of this counter_type.
- **helptext** – [in] A longer descriptive text shown to the user to explain the nature of the counters created from this type.
- **uom** – [in] The unit of measure for the new performance counter type.
- **version** – [in] The version of the counter type. This is currently expected to be set to HPX_PERFORMANCE_COUNTER_V1.
- **ec** – [in,out] this represents the error status on exit, if this is pre-initialized to *hpx::throws* the function will throw on error instead.

Returns If successful, this function returns *valid_data*, otherwise it will either throw an exception or return an error_code from the enum *counter_status* (also, see note related to parameter *ec*).

```
counter_status install_counter_type(std::string const &name, counter_type type, std::string const
&helptext, create_counter_func const &create_counter,
discover_counters_func const &discover_counters,
std::uint32_t version =
HPX_PERFORMANCE_COUNTER_V1, std::string const
&uom = "", error_code &ec = throws)
```

Install a new generic performance counter type in a way, which will uninstall it automatically during shutdown.

The function *install_counter_type* will register a new generic counter type based on the provided *counter_type_info*. The counter type will be automatically unregistered during system shutdown.

Note: As long as *ec* is not pre-initialized to *hpx::throws* this function doesn't throw but returns the result code using the parameter *ec*. Otherwise it throws an instance of *hpx::exception*.

Note: The counter type registry is a locality based service. You will have to register each counter type on every locality where a corresponding performance counter will be created.

Parameters

- **name** – [in] The global virtual name of the counter type. This name is expected to have the format /objectname/countertype.
- **type** – [in] The type of the counters of this *counter_type*.
- **helptext** – [in] A longer descriptive text shown to the user to explain the nature of the counters created from this type.
- **version** – [in] The version of the counter type. This is currently expected to be set to *HPX_PERFORMANCE_COUNTER_V1*.
- **create_counter** – [in] The function which will be called to create a new instance of this counter type.
- **discover_counters** – [in] The function will be called to discover counter instances which can be created.
- **uom** – [in] The unit of measure of the counter type (default: “”)
- **ec** – [in,out] this represents the error status on exit, if this is pre-initialized to *hpx::throws* the function will throw on error instead.

Returns If successful, this function returns *valid_data*, otherwise it will either throw an exception or return an *error_code* from the enum *counter_status* (also, see note related to parameter *ec*).

hpx/performance_counters/registry.hpp

Defined in header *hpx/performance_counters/registry.hpp*.

See *Public API* for a list of names and headers that are part of the public *HPX* API.

```
namespace hpx
```

```
    namespace performance_counters
```

```
        class registry
```

Public Functions

registry() = default

void **clear()**

Reset registry by deleting all stored counter types.

counter_status **add_counter_type**(*counter_info* const &info, *create_counter_func* const &create_counter, *discover_counters_func* const &discover_counters, *error_code* &ec = *throws*)

Add a new performance counter type to the (local) registry.

counter_status **discover_counter_types**(*discover_counter_func* discover_counter, *discover_counters_mode* mode, *error_code* &ec = *throws*) const

Call the supplied function for all registered counter types.

counter_status **discover_counter_type**(*std::string* const &fullname, *discover_counter_func* discover_counter, *discover_counters_mode* mode, *error_code* &ec = *throws*)

Call the supplied function for the given registered counter type.

inline *counter_status* **discover_counter_type**(*counter_info* const &info, *discover_counter_func* const &f, *discover_counters_mode* mode, *error_code* &ec = *throws*)

counter_status **get_counter_create_function**(*counter_info* const &info, *create_counter_func* &create_counter, *error_code* &ec = *throws*) const

Retrieve the counter creation function which is associated with a given counter type.

counter_status **get_counter_discovery_function**(*counter_info* const &info, *discover_counters_func* &func, *error_code* &ec) const

Retrieve the counter discovery function which is associated with a given counter type.

counter_status **remove_counter_type**(*counter_info* const &info, *error_code* &ec = *throws*)

Remove an existing counter type from the (local) registry.

Note: This doesn't remove existing counters of this type, it just inhibits defining new counters using this type.

counter_status **create_raw_counter_value**(*counter_info* const &info, *std::int64_t* *countervalue, *naming::gid_type* &id, *error_code* &ec = *throws*)

Create a new performance counter instance of type `raw_counter` based on given counter value.

counter_status **create_raw_counter**(*counter_info* const &info, *hpx::function<std::int64_t()>* const &f, *naming::gid_type* &id, *error_code* &ec = *throws*)

Create a new performance counter instance of type `raw_counter` based on given function returning the counter value.

counter_status **create_raw_counter**(*counter_info* const &info, *hpx::function<std::int64_t(bool)>* const &f, *naming::gid_type* &id, *error_code* &ec = *throws*)

Create a new performance counter instance of type `raw_counter` based on given function returning the counter value.

```
counter_status create_raw_counter(counter_info const &info,  
                                   hpx::function<std::vector<std::int64_t>()> const &f,  
                                   naming::gid_type &id, error_code &ec = throws)
```

Create a new performance counter instance of type `raw_counter` based on given function returning the counter value.

```
counter_status create_raw_counter(counter_info const &info,  
                                   hpx::function<std::vector<std::int64_t>(bool)> const &f,  
                                   naming::gid_type &id, error_code &ec = throws)
```

Create a new performance counter instance of type `raw_counter` based on given function returning the counter value.

```
counter_status create_counter(counter_info const &info, naming::gid_type &id, error_code &ec  
                               = throws)
```

Create a new performance counter instance based on given counter info.

```
counter_status create_statistics_counter(counter_info const &info, std::string const  
                                         &base_counter_name, std::vector<std::size_t>  
                                         const &parameters, naming::gid_type &id,  
                                         error_code &ec = throws)
```

Create a new statistics performance counter instance based on given base counter name and given base time interval (milliseconds).

```
counter_status create_arithmetics_counter(counter_info const &info, std::vector<std::string>  
                                         const &base_counter_names, naming::gid_type  
                                         &id, error_code &ec = throws)
```

Create a new arithmetics performance counter instance based on given base counter names.

```
counter_status create_arithmetics_counter_extended(counter_info const &info,  
                                                    std::vector<std::string> const  
                                                    &base_counter_names,  
                                                    naming::gid_type &id, error_code  
                                                    &ec = throws)
```

Create a new extended arithmetics performance counter instance based on given base counter names.

```
counter_status add_counter(hpx::id_type const &id, counter_info const &info, error_code &ec =  
                           throws)
```

Add an existing performance counter instance to the registry.

```
counter_status remove_counter(counter_info const &info, hpx::id_type const &id, error_code  
                               &ec = throws)
```

remove the existing performance counter from the registry

```
counter_status get_counter_type(std::string const &name, counter_info &info, error_code &ec  
                               = throws)
```

Retrieve counter type information for given counter name.

Public Static Functions

static *registry* &**instance**()

Protected Functions

counter_type_map_type::iterator **locate_counter_type**(*std::string* const &type_name)

counter_type_map_type::const_iterator **locate_counter_type**(*std::string* const &type_name)
const

Private Types

using **counter_type_map_type** = *std::map*<*std::string*, *counter_data*>

Private Members

counter_type_map_type **countertypes_**

struct **counter_data**

Public Functions

inline **counter_data**(*counter_info* const &info, *create_counter_func* const &create_counter,
discover_counters_func const &discover_counters)

Public Members

counter_info **info_**

create_counter_func **create_counter_**

discover_counters_func **discover_counters_**

plugin_factories

See *Public API* for a list of names and headers that are part of the public *HPX* API.

hpx/plugin_factories/binary_filter_factory.hpp

Defined in header hpx/plugin_factories/binary_filter_factory.hpp.

See *Public API* for a list of names and headers that are part of the public *HPX* API.

Defines

HPX_REGISTER_BINARY_FILTER_FACTORY(BinaryFilter, pluginname)

This macro is used create and to register a minimal component factory with Hpx.Plugin.

namespace **hpx**

namespace **plugins**

template<typename **BinaryFilter**>

struct **binary_filter_factory** : public binary_filter_factory_base

#include <binary_filter_factory.hpp> The *message_handler_factory* provides a minimal implementation of a message handler's factory. If no additional functionality is required this type can be used to implement the full set of minimally required functions to be exposed by a message handler's factory instance.

Template Parameters BinaryFilter – The message handler type this factory should be responsible for.

Public Functions

inline **binary_filter_factory**(*util::section* const *global, *util::section* const *local, bool isenabled)

Construct a new factory instance.

Note: The contents of both sections has to be cloned in order to save the configuration setting for later use.

Parameters

- **global** – [in] The pointer to a *hpx::util::section* instance referencing the settings read from the [settings] section of the global configuration file (hpx.ini) This pointer may be nullptr if no such section has been found.
- **local** – [in] The pointer to a *hpx::util::section* instance referencing the settings read from the section describing this component type: [hpx.components.<name>], where <name> is the instance name of the component as given in the configuration files.
- **isenabled** –

~**binary_filter_factory**() override = default

inline *serialization::binary_filter* ***create**(bool compress, *serialization::binary_filter* *next_filter = nullptr) override

Create a new instance of a message handler

return Returns the newly created instance of the message handler supported by this factory

Protected Attributes

util::section `global_settings_`

util::section `local_settings_`

bool `isEnabled_`

hpx/plugin_factories/message_handler_factory.hpp

Defined in header `hpx/plugin_factories/message_handler_factory.hpp`.

See *Public API* for a list of names and headers that are part of the public *HPX* API.

hpx/plugin_factories/parcelport_factory.hpp

Defined in header `hpx/plugin_factories/parcelport_factory.hpp`.

See *Public API* for a list of names and headers that are part of the public *HPX* API.

hpx/plugin_factories/plugin_registry.hpp

Defined in header `hpx/plugin_factories/plugin_registry.hpp`.

See *Public API* for a list of names and headers that are part of the public *HPX* API.

Defines

`HPX_REGISTER_PLUGIN_REGISTRY(...)`

This macro is used create and to register a minimal plugin registry with `Hpx.Plugin`.

`HPX_REGISTER_PLUGIN_REGISTRY_(...)`

`HPX_REGISTER_PLUGIN_REGISTRY_2(PluginType, pluginname)`

`HPX_REGISTER_PLUGIN_REGISTRY_4(PluginType, pluginname, pluginsection, pluginsuffix)`

`HPX_REGISTER_PLUGIN_REGISTRY_5(PluginType, pluginname, pluginstring, pluginsection, pluginsuffix)`

namespace `hpx`

namespace `plugins`

template<typename **Plugin**, char const *const **Name**, char const *const **Section**, char const *const **Suffix**>

struct `plugin_registry` : public `plugin_registry_base`

#include <`plugin_registry.hpp`> The `plugin_registry` provides a minimal implementation of a plugin's registry. If no additional functionality is required this type can be used to implement the full set of minimally required functions to be exposed by a plugin's registry instance.

Template Parameters **Plugin** – The plugin type this registry should be responsible for.

Public Functions

inline bool **get_plugin_info**(*std::vector<std::string>* &fillini) override

Return the ini-information for all contained components.

Parameters *fillini* – [in] The module is expected to fill this vector with the ini-information (one line per vector element) for all components implemented in this module.

Returns Returns *true* if the parameter *fillini* has been successfully initialized with the registry data of all implemented in this module.

runtime_components

See *Public API* for a list of names and headers that are part of the public *HPX* API.

HPX_REGISTER_COMPONENT

Defined in header `hpx/components.hpp`.

See *Public API* for a list of names and headers that are part of the public *HPX* API.

Defines

HPX_REGISTER_COMPONENT(*type*, *name*, *mode*)

Define a component factory for a component type.

This macro is used create and to register a minimal component factory for a component type which allows it to be remotely created using the `hpx::new_<>` function.

This macro can be invoked with one, two or three arguments

Parameters

- **type** – The *type* parameter is a (fully decorated) type of the component type for which a factory should be defined.
- **name** – The *name* parameter specifies the name to use to register the factory. This should uniquely (system-wide) identify the component type. The *name* parameter must conform to the C++ identifier rules (without any namespace). If this parameter is not given, the first parameter is used.
- **mode** – The *mode* parameter has to be one of the defined enumeration values of the enumeration `hpx::components::factory_state`. The default for this parameter is `hpx::components::factory_state::enabled`.

hpx/runtime_components/component_registry.hpp

Defined in header `hpx/runtime_components/component_registry.hpp`.

See *Public API* for a list of names and headers that are part of the public *HPX* API.

Defines

HPX_REGISTER_MINIMAL_COMPONENT_REGISTRY(...)

This macro is used create and to register a minimal component registry with Hpx.Plugin.

HPX_REGISTER_MINIMAL_COMPONENT_REGISTRY_(...)

HPX_REGISTER_MINIMAL_COMPONENT_REGISTRY_2(ComponentType, componentname)

HPX_REGISTER_MINIMAL_COMPONENT_REGISTRY_3(ComponentType, componentname, state)

HPX_REGISTER_MINIMAL_COMPONENT_REGISTRY_DYNAMIC(...)

HPX_REGISTER_MINIMAL_COMPONENT_REGISTRY_DYNAMIC_(...)

HPX_REGISTER_MINIMAL_COMPONENT_REGISTRY_DYNAMIC_2(ComponentType, componentname)

HPX_REGISTER_MINIMAL_COMPONENT_REGISTRY_DYNAMIC_3(ComponentType, componentname, state)

namespace **hpx**

namespace **components**

template<typename **Component**, *factory_state* **state**>

struct **component_registry** : public *component_registry_base*

#include <component_registry.hpp> The **component_registry** provides a minimal implementation of a component's registry. If no additional functionality is required this type can be used to implement the full set of minimally required functions to be exposed by a component's registry instance.

Template Parameters **Component** – The component type this registry should be responsible for.

Public Functions

inline bool **get_component_info**(*std::vector<std::string>* &fillini, *std::string* const &filepath, bool is_static = false) override

Return the ini-information for all contained components.

Parameters

- **fillini** – [in] The module is expected to fill this vector with the ini-information (one line per vector element) for all components implemented in this module.
- **filepath** –
- **is_static** –

Returns Returns *true* if the parameter *fillini* has been successfully initialized with the registry data of all implemented in this module.

inline void **register_component_type**() override

Enables this type of registry and sets its destroy mechanism.

hpx/runtime_components/components_fwd.hpp

Defined in header hpx/runtime_components/components_fwd.hpp.

See *Public API* for a list of names and headers that are part of the public *HPX* API.

namespace **hpx**

Functions

components::server::runtime_support *get_runtime_support_ptr()

namespace **components**

template<typename **Component**>

struct **component_factory**

namespace **server**

namespace **stubs**

namespace **components**

hpx/runtime_components/derived_component_factory.hpp

Defined in header hpx/runtime_components/derived_component_factory.hpp.

See *Public API* for a list of names and headers that are part of the public *HPX* API.

Defines

HPX_REGISTER_DERIVED_COMPONENT_FACTORY(...)

This macro is used create and to register a minimal component factory with Hpx.Plugin. This macro may be used if the registered component factory is the only factory to be exposed from a particular module. If more than one factory needs to be exposed the *HPX_REGISTER_COMPONENT_FACTORY* and *HPX_REGISTER_COMPONENT_MODULE* macros should be used instead.

HPX_REGISTER_DERIVED_COMPONENT_FACTORY_(...)

HPX_REGISTER_DERIVED_COMPONENT_FACTORY_3(ComponentType, componentname, basecomponentname)

HPX_REGISTER_DERIVED_COMPONENT_FACTORY_4(ComponentType, componentname, basecomponentname, state)

HPX_REGISTER_DERIVED_COMPONENT_FACTORY_DYNAMIC(...)

HPX_REGISTER_DERIVED_COMPONENT_FACTORY_DYNAMIC_(...)

HPX_REGISTER_DERIVED_COMPONENT_FACTORY_DYNAMIC_3(ComponentType, componentname,
basecomponentname)

```
HPX_REGISTER_DERIVED_COMPONENT_FACTORY_DYNAMIC_4(ComponentType, componentname,
                                                basecomponentname, state)
```

hpx::new_

Defined in header `hpx/components.hpp`.

See *Public API* for a list of names and headers that are part of the public *HPX* API.

```
namespace hpx
```

Functions

```
template<typename Component, typename ...Ts>
auto new_(id_type const &locality, Ts&&... vs)
```

Create one or more new instances of the given *Component* type on the specified locality.

This function creates one or more new instances of the given *Component* type on the specified locality and returns a future object for the global address which can be used to reference the new component instance.

Note: This function requires to specify an explicit template argument which will define what type of component(s) to create, for instance:

```
hpx::future<hpx::id_type> f =
    hpx::new_<some_component>(hpx::find_here(), ...);
hpx::id_type id = f.get();
```

Parameters

- **locality** – [in] The global address of the locality where the new instance should be created on.
- **vs** – [in] Any number of arbitrary arguments (passed by value, by const reference or by rvalue reference) which will be forwarded to the constructor of the created component instance.

Returns The function returns different types depending on its use:

- If the explicit template argument *Component* represents a component type (`traits::is_component<Component>::value` evaluates to true), the function will return an *hpx::future* object instance which can be used to retrieve the global address of the newly created component.
- If the explicit template argument *Component* represents a client side object (`traits::is_client<Component>::value` evaluates to true), the function will return a new instance of that type which can be used to refer to the newly created component instance.

```
template<typename Component, typename ...Ts>
```

auto **local_new**(*Ts*&&... vs)

Create one new instance of the given Component type on the current locality.

This function creates one new instance of the given Component type on the current locality and returns a future object for the global address which can be used to reference the new component instance.

Note: This function requires to specify an explicit template argument which will define what type of component(s) to create, for instance:

```
hpx::future<hpx::id_type> f =
    hpx::local_new<some_component>(...);
hpx::id_type id = f.get();
```

Note: The difference of this function to *hpx::new_* is that it can be used in cases where the supplied arguments are non-copyable and non-movable. All operations are guaranteed to be local only.

Parameters vs – [in] Any number of arbitrary arguments (passed by value, by const reference or by rvalue reference) which will be forwarded to the constructor of the created component instance.

Returns The function returns different types depending on its use:

- If the explicit template argument *Component* represents a component type (`traits::is_component<Component>::value` evaluates to true), the function will return an *hpx::future* object instance which can be used to retrieve the global address of the newly created component. If the first argument is `hpx::launch::sync` the function will directly return an `hpx::id_type`.
- If the explicit template argument *Component* represents a client side object (`traits::is_client<Component>::value` evaluates to true), the function will return a new instance of that type which can be used to refer to the newly created component instance.

template<typename **Component**, typename ...**Ts**>

auto **new_**(id_type const &locality, *std::size_t* count, *Ts*&&... vs)

Create multiple new instances of the given Component type on the specified locality.

This function creates multiple new instances of the given Component type on the specified locality and returns a future object for the global address which can be used to reference the new component instance.

Note: This function requires to specify an explicit template argument which will define what type of component(s) to create, for instance:

```
hpx::future<std::vector<hpx::id_type> > f =
    hpx::new_<some_component[]>(hpx::find_here(), 10, ...);
hpx::id_type id = f.get();
```

Parameters

- **locality** – [in] The global address of the locality where the new instance should be created on.

- **count** – [in] The number of component instances to create
- **vs** – [in] Any number of arbitrary arguments (passed by value, by const reference or by rvalue reference) which will be forwarded to the constructor of the created component instance.

Returns The function returns different types depending on its use:

- If the explicit template argument *Component* represents an array of a component type (i.e. *Component*[], where `traits::is_component<Component>::value` evaluates to true), the function will return an *hpx::future* object instance which holds a `std::vector<hpx::id_type>`, where each of the items in this vector is a global address of one of the newly created components.
- If the explicit template argument *Component* represents an array of a client side object type (i.e. *Component*[], where `traits::is_client<Component>::value` evaluates to true), the function will return an *hpx::future* object instance which holds a `std::vector<hpx::id_type>`, where each of the items in this vector is a client side instance of the given type, each representing one of the newly created components.

```
template<typename Component, typename DistPolicy, typename ...Ts>
auto new_(DistPolicy const &policy, Ts&&... vs)
```

Create one or more new instances of the given *Component* type based on the given distribution policy.

This function creates one or more new instances of the given *Component* type on the localities defined by the given distribution policy and returns a future object for global address which can be used to reference the new component instance(s).

Note: This function requires to specify an explicit template argument which will define what type of component(s) to create, for instance:

```
hpx::future<hpx::id_type> f =
    hpx::new_<some_component>(hpx::default_layout, ...);
hpx::id_type id = f.get();
```

Parameters

- **policy** – [in] The distribution policy used to decide where to place the newly created.
- **vs** – [in] Any number of arbitrary arguments (passed by value, by const reference or by rvalue reference) which will be forwarded to the constructor of the created component instance.

Returns The function returns different types depending on its use:

- If the explicit template argument *Component* represents a component type (`traits::is_component<Component>::value` evaluates to true), the function will return an *hpx::future* object instance which can be used to retrieve the global address of the newly created component.
- If the explicit template argument *Component* represents a client side object (`traits::is_client<Component>::value` evaluates to true), the function will return a new instance of that type which can be used to refer to the newly created component instance.

```
template<typename Component, typename DistPolicy, typename ...Ts>
```

auto **new_**(*DistPolicy* const &policy, *std::size_t* count, *Ts&&...* vs)

Create multiple new instances of the given Component type on the localities as defined by the given distribution policy.

This function creates multiple new instances of the given Component type on the localities defined by the given distribution policy and returns a future object for the global address which can be used to reference the new component instance.

Note: This function requires to specify an explicit template argument which will define what type of component(s) to create, for instance:

```
hpx::future<std::vector<hpx::id_type> > f =
    hpx::new_<some_component[]>(hpx::default_layout, 10, ...);
hpx::id_type id = f.get();
```

Parameters

- **policy** – [in] The distribution policy used to decide where to place the newly created.
- **count** – [in] The number of component instances to create
- **vs** – [in] Any number of arbitrary arguments (passed by value, by const reference or by rvalue reference) which will be forwarded to the constructor of the created component instance.

Returns The function returns different types depending on its use:

- If the explicit template argument *Component* represents an array of a component type (i.e. *Component[]*, where `traits::is_component<Component>::value` evaluates to true), the function will return an *hpx::future* object instance which holds a `std::vector<hpx::id_type>`, where each of the items in this vector is a global address of one of the newly created components.
- If the explicit template argument *Component* represents an array of a client side object type (i.e. *Component[]*, where `traits::is_client<Component>::value` evaluates to true), the function will return an *hpx::future* object instance which holds a `std::vector<hpx::id_type>`, where each of the items in this vector is a client side instance of the given type, each representing one of the newly created components.

runtime_distributed

See *Public API* for a list of names and headers that are part of the public *HPX* API.

hpx/runtime_distributed.hpp

Defined in header `hpx/runtime_distributed.hpp`.

See *Public API* for a list of names and headers that are part of the public *HPX* API.

namespace **hpx**

class **runtime_distributed** : public *runtime*

#include <*runtime_distributed.hpp*> The *runtime* class encapsulates the HPX runtime system in a simple to use way. It makes sure all required parts of the HPX runtime system are properly initialized.

Public Functions

explicit **runtime_distributed**(*util::runtime_configuration* &rtcfg, int (*pre_main)(*runtime_mode*) = nullptr, void (*post_main)() = nullptr)

Construct a new HPX runtime instance

Parameters

- **rtcfg** – Runtime configuration for this instance
- **pre_main** – Function to be called before running the main action of this instance
- **post_main** – Function to be called after running the main action of this instance

~runtime_distributed()

The destructor makes sure all HPX runtime services are properly shut down before exiting.

int **start**(*hpx::function*<hpx_main_function_type> const &func, bool blocking = false) override

Start the runtime system.

Parameters

- **func** – [in] This is the main function of an HPX application. It will be scheduled for execution by the thread manager as soon as the runtime has been initialized. This function is expected to expose an interface as defined by the typedef *hpx_main_function_type*.
- **blocking** – [in] This allows to control whether this call blocks until the runtime system has been stopped. If this parameter is *true* the function *runtime::start* will call *runtime::wait* internally.

Returns If a blocking is a true, this function will return the value as returned as the result of the invocation of the function object given by the parameter **func**. Otherwise it will return zero.

int **start**(bool blocking = false) override

Start the runtime system.

Parameters **blocking** – [in] This allows to control whether this call blocks until the runtime system has been stopped. If this parameter is *true* the function *runtime::start* will call *runtime::wait* internally .

Returns If a blocking is a true, this function will return the value as returned as the result of the invocation of the function object given by the parameter **func**. Otherwise it will return zero.

int **wait**() override

Wait for the shutdown action to be executed.

Returns This function will return the value as returned as the result of the invocation of the function object given by the parameter **func**.

void **stop**(bool blocking = true) override

Initiate termination of the runtime system.

Parameters **blocking** – [in] This allows to control whether this call blocks until the runtime system has been fully stopped. If this parameter is *false* then this call will initiate the stop action but will return immediately. Use a second call to stop with this parameter set to *true* to wait for all internal work to be completed.

int **finalize**(double shutdown_timeout) override

void **stop_helper**(bool blocking, *std::condition_variable* &cond, *std::mutex* &mtx)

Stop the runtime system, wait for termination.

Parameters

- **blocking** – [in] This allows to control whether this call blocks until the runtime system has been fully stopped. If this parameter is *false* then this call will initiate the stop action but will return immediately. Use a second call to stop with this parameter set to *true* to wait for all internal work to be completed.

- **cond** – Condition used to update all thread when done
- **mtx** – Mutex used by this function to sync all threads

int **suspend**() override

Suspend the runtime system.

int **resume**() override

Resume the runtime system.

bool **report_error**(*std::size_t* num_thread, *std::exception_ptr* const &e, bool terminate_all = true) override

Report a non-recoverable error to the runtime system.

Parameters

- **num_thread** – [in] The number of the operating system thread the error has been detected in.
- **e** – [in] This is an instance encapsulating an exception which lead to this function call.
- **terminate_all** – [in] Kill all localities attached to the currently running application (default: true)

bool **report_error**(*std::exception_ptr* const &e, bool terminate_all = true) override

Report a non-recoverable error to the runtime system.

Note: This function will retrieve the number of the current shepherd thread and forward to the `report_error` function above.

Parameters

- **e** – [in] This is an instance encapsulating an exception which lead to this function call.
- **terminate_all** – [in] Kill all localities attached to the currently running application (default: true)

int **run**(*hpx::function*<hpx_main_function_type> const &func) override

Run the HPX runtime system, use the given function for the main *thread* and block waiting for all threads to finish.

Note: The parameter *func* is optional. If no function is supplied, the runtime system will simply wait for the shutdown action without explicitly executing any main thread.

Parameters **func** – [in] This is the main function of an HPX application. It will be scheduled for execution by the thread manager as soon as the runtime has been initialized. This function is expected to expose an interface as defined by the typedef *hpx_main_function_type*. This parameter is optional and defaults to none main thread function, in which case all threads have to be scheduled explicitly.

Returns This function will return the value as returned as the result of the invocation of the function object given by the parameter **func**.

int **run**() override

Run the HPX runtime system, initially use the given number of (OS) threads in the thread-manager and block waiting for all threads to finish.

Returns This function will always return 0 (zero).

bool **is_networking_enabled**() override

template<typename **F**>

inline *components::server::console_error_dispatcher::sink_type* **set_error_sink**(*F* &&sink)

performance_counters::registry &**get_counter_registry**()

Allow access to the registry counter registry instance used by the HPX runtime.

performance_counters::registry const &**get_counter_registry**() const

Allow access to the registry counter registry instance used by the HPX runtime.

void **register_query_counters**(*std::shared_ptr<util::query_counters>* const &active_counters)

void **start_active_counters**(*error_code* &ec = *throws*) const

void **stop_active_counters**(*error_code* &ec = *throws*) const

void **reset_active_counters**(*error_code* &ec = *throws*) const

void **reinit_active_counters**(bool reset = true, *error_code* &ec = *throws*) const

void **evaluate_active_counters**(bool reset = false, char const *description = nullptr, *error_code* &ec = *throws*) const

void **stop_evaluating_counters**(bool terminate = false) const

naming::resolver_client &**get_agas_client**()

Allow access to the AGAS client instance used by the HPX runtime.

hpx::threads::threadmanager &**get_thread_manager**() override

Allow access to the thread manager instance used by the HPX runtime.

applier::applier &**get_applier**()

Allow access to the applier instance used by the HPX runtime.

std::string **here**() const override

Returns a string of the locality endpoints (usable in debug output)

naming::address_type **get_runtime_support_lva**() const

naming::gid_type **get_next_id**(*std::size_t* count = 1)

void **init_id_pool_range**()

util::unique_id_ranges &**get_id_pool**()

void **initialize_agas**()

Initialize AGAS operation.

void **add_pre_startup_function**(*startup_function_type* f) override

Add a function to be executed inside a HPX thread before `hpx_main` but guaranteed to be executed before any startup function registered with `add_startup_function`.

Note: The difference to a startup function is that all pre-startup functions will be (system-wide) executed before any startup function.

Parameters f – The function ‘f’ will be called from inside a HPX thread before `hpx_main` is executed. This is very useful to setup the runtime environment of the application (install performance counters, etc.)

void **add_startup_function**(*startup_function_type* f) override

Add a function to be executed inside a HPX thread before `hpx_main`

Parameters **f** – The function ‘f’ will be called from inside a HPX thread before `hpx_main` is executed. This is very useful to setup the runtime environment of the application (install performance counters, etc.)

void **add_pre_shutdown_function**(*shutdown_function_type* f) override

Add a function to be executed inside a HPX thread during `hpx::finalize`, but guaranteed before any of the shutdown functions is executed.

Note: The difference to a shutdown function is that all pre-shutdown functions will be (system-wide) executed before any shutdown function.

Parameters **f** – The function ‘f’ will be called from inside a HPX thread while `hpx::finalize` is executed. This is very useful to tear down the runtime environment of the application (uninstall performance counters, etc.)

void **add_shutdown_function**(*shutdown_function_type* f) override

Add a function to be executed inside a HPX thread during `hpx::finalize`

Parameters **f** – The function ‘f’ will be called from inside a HPX thread while `hpx::finalize` is executed. This is very useful to tear down the runtime environment of the application (uninstall performance counters, etc.)

hpx::util::io_service_pool ***get_thread_pool**(char const *name) override

Access one of the internal thread pools (`io_service` instances) HPX is using to perform specific tasks. The three possible values for the argument `name` are “main_pool”, “io_pool”, “parcel_pool”, and “timer_pool”. For any other argument value the function will return zero.

bool **register_thread**(char const *name, *std::size_t* num = 0, bool service_thread = true, *error_code* &ec = *throws*) override

Register an external OS-thread with HPX.

notification_policy_type **get_notification_policy**(char const *prefix, *runtime_local::os_thread_type* type) override

Generate a new notification policy instance for the given thread name prefix

std::uint32_t **get_locality_id**(*error_code* &ec) const override

std::size_t **get_num_worker_threads**() const override

std::uint32_t **get_num_localities**(*hpx::launch::sync_policy*, *error_code* &ec) const override

std::uint32_t **get_initial_num_localities**() const override

hpx::future<*std::uint32_t*> **get_num_localities**() const override

std::string **get_locality_name**() const override

std::uint32_t **get_num_localities**(*hpx::launch::sync_policy*, *components::component_type* type, *error_code* &ec) const

hpx::future<*std::uint32_t*> **get_num_localities**(*components::component_type* type) const

std::uint32_t **assign_cores**(*std::string* const &locality_basename, *std::uint32_t* num_threads) override

std::uint32_t **assign_cores**() override

Public Static Functions

static void **register_counter_types**()

Install all performance counters related to this runtime instance.

Private Types

using **used_cores_map_type** = *std::map*<*std::string*, *std::uint32_t*>

Private Functions

threads::thread_result_type **run_helper**(*hpx::function*<*runtime::hpx_main_function_type*> const &func, int &result)

void **init_global_data**()

void **deinit_global_data**()

void **wait_helper**(*std::mutex* &mtx, *std::condition_variable* &cond, bool &running)

void **init_tss_helper**(char const *context, *runtime_local::os_thread_type* type, *std::size_t* local_thread_num, *std::size_t* global_thread_num, char const *pool_name, char const *postfix, bool service_thread)

void **deinit_tss_helper**(char const *context, *std::size_t* num) const

void **init_tss_ex**(*std::string* const &locality, char const *context, *runtime_local::os_thread_type* type, *std::size_t* local_thread_num, *std::size_t* global_thread_num, char const *pool_name, char const *postfix, bool service_thread, *error_code* &ec) const

Private Members

runtime_mode **mode_**

util::unique_id_ranges **id_pool_**

naming::resolver_client **agas_client_**

applier::applier **applier_**

used_cores_map_type **used_cores_map_**

std::unique_ptr<*components::server::runtime_support*> **runtime_support_**

std::shared_ptr<*util::query_counters*> **active_counters_**

```
int (*pre_main_)(runtime_mode)
```

```
void (*post_main_>()
```

Private Static Functions

```
static void default_errorsink(std::string const&)
```

hpx/runtime_distributed/applier.hpp

Defined in header `hpx/runtime_distributed/applier.hpp`.

See *Public API* for a list of names and headers that are part of the public *HPX* API.

```
namespace hpx
```

```
namespace applier
```

```
class applier
```

#include <applier.hpp> The *applier* class is used to decide whether a particular action has to be issued on a local or a remote resource. If the target component is local a new *thread* will be created, if the target is remote a parcel will be sent.

Public Functions

```
HPX_NON_COPYABLE(applier)
```

```
applier()
```

```
void init(threads::threadmanager &tm)
```

```
~applier() = default
```

```
void initialize(std::uint64_t rts)
```

```
threads::threadmanager &get_thread_manager()
```

Access the *thread-manager* instance associated with this *applier*.

This function returns a reference to the thread manager this *applier* instance has been created with.

```
naming::gid_type const &get_raw_locality(error_code &ec = throws) const
```

Allow access to the locality of the locality this *applier* instance is associated with.

This function returns a reference to the locality this *applier* instance is associated with.

```
std::uint32_t get_locality_id(error_code &ec = throws) const
```

Allow access to the id of the locality this *applier* instance is associated with.

This function returns a reference to the id of the locality this *applier* instance is associated with.

```
bool get_raw_remote_localities(std::vector<naming::gid_type> &locality_ids,
                               components::component_type type =
                               to_int(hpx::components::component_enum_type::invalid),
                               error_code &ec = throws) const
```

Return list of localities of all remote localities registered with the AGAS service for a specific component type.

This function returns a list of all remote localities (all localities known to AGAS except the local one) supporting the given component type.

Parameters

- **locality_ids** – [out] The reference to a vector of id_types filled by the function.
- **type** – [in] The type of the component which needs to exist on the returned localities.

Returns The function returns *true* if there is at least one remote locality known to the AGAS service (!prefixes.empty()).

```
bool get_remote_localities(std::vector<hpx::id_type> &locality_ids,
                           components::component_type type =
                           to_int(hpx::components::component_enum_type::invalid),
                           error_code &ec = throws) const
```

```
bool get_raw_localities(std::vector<naming::gid_type> &locality_ids,
                        components::component_type type =
                        to_int(hpx::components::component_enum_type::invalid)) const
```

Return list of locality_ids of all localities registered with the AGAS service for a specific component type.

This function returns a list of all localities (all localities known to AGAS except the local one) supporting the given component type.

Parameters

- **locality_ids** – [out] The reference to a vector of id_types filled by the function.
- **type** – [in] The type of the component which needs to exist on the returned localities.

Returns The function returns *true* if there is at least one remote locality known to the AGAS service (!prefixes.empty()).

```
bool get_localities(std::vector<hpx::id_type> &locality_ids, error_code &ec = throws) const
```

```
bool get_localities(std::vector<hpx::id_type> &locality_ids, components::component_type
                    type, error_code &ec = throws) const
```

```
inline naming::gid_type const &get_runtime_support_raw_gid() const
```

By convention the runtime_support has a gid identical to the prefix of the locality the runtime_support is responsible for

```
inline hpx::id_type const &get_runtime_support_gid() const
```

By convention the runtime_support has a gid identical to the prefix of the locality the runtime_support is responsible for

Private Members

threads::threadmanager ***thread_manager_**

hpx::id_type **runtime_support_id_**

hpx/runtime_distributed/applier_fwd.hpp

Defined in header `hpx/runtime_distributed/applier_fwd.hpp`.

See *Public API* for a list of names and headers that are part of the public *HPX* API.

namespace **hpx**

namespace **applier**

Functions

applier &**get_applier**()

The function *get_applier* returns a reference to the (thread specific) applier instance.

applier ***get_applier_ptr**()

The function *get_applier* returns a pointer to the (thread specific) applier instance. The returned pointer is NULL if the current thread is not known to HPX or if the runtime system is not active.

namespace **applier**

The namespace *applier* contains all definitions needed for the class `hpx::applier::applier` and its related functionality. This namespace is part of the HPX core module.

hpx/runtime_distributed/copy_component.hpp

Defined in header `hpx/runtime_distributed/copy_component.hpp`.

See *Public API* for a list of names and headers that are part of the public *HPX* API.

namespace **hpx**

namespace **components**

Functions

```
template<typename Component>
future<hpx::id_type> copy(hpx::id_type const &to_copy)
```

Copy given component to the specified target locality.

The function `copy<Component>` will create a copy of the component referenced by `to_copy` on the locality specified with `target_locality`. It returns a future referring to the newly created component instance.

Note: The new component instance is created on the locality of the component instance which is to be copied.

Parameters `to_copy` – [in] The global id of the component to copy
Template Parameters `The` – only template argument specifies the component type to create.
Returns A future representing the global id of the newly (copied) component instance.

```
template<typename Component>
future<hpx::id_type> copy(hpx::id_type const &to_copy, hpx::id_type const &target_locality)
```

Copy given component to the specified target locality.

The function `copy<Component>` will create a copy of the component referenced by `to_copy` on the locality specified with `target_locality`. It returns a future referring to the newly created component instance.

Parameters

- `to_copy` – [in] The global id of the component to copy
- `target_locality` – [in] The locality where the copy should be created.

Template Parameters `The` – only template argument specifies the component type to create.

Returns A future representing the global id of the newly (copied) component instance.

```
template<typename Derived, typename Stub, typename Data>
Derived copy(client_base<Derived, Stub, Data> const &to_copy, hpx::id_type const &target_locality =
             hpx::invalid_id)
```

Copy given component to the specified target locality.

The function `copy` will create a copy of the component referenced by the client side object `to_copy` on the locality specified with `target_locality`. It returns a new client side object future referring to the newly created component instance.

Note: If the second argument is omitted (or is `invalid_id`) the new component instance is created on the locality of the component instance which is to be copied.

Parameters

- `to_copy` – [in] The client side object representing the component to copy
- `target_locality` – [in, optional] The locality where the copy should be created (default is same locality as source).

Template Parameters `The` – only template argument specifies the component type to create.

Returns A future representing the global id of the newly (copied) component instance.

hpx::find_root_locality, hpx::find_all_localities, hpx::find_remote_localities

Defined in header `hpx/runtime.hpp`⁸⁰⁷.

See *Public API* for a list of names and headers that are part of the public *HPX* API.

namespace **hpx**

Functions

`hpx::id_type find_root_locality(error_code &ec = throws)`

Return the global id representing the root locality.

The function `find_root_locality()` can be used to retrieve the global id usable to refer to the root locality. The root locality is the locality where the main AGAS service is hosted.

See also:

`hpx::find_all_localities()`, `hpx::find_locality()`

Note: Generally, the id of a locality can be used for instance to create new instances of components and to invoke plain actions (global functions).

Note: As long as *ec* is not pre-initialized to `hpx::throws` this function doesn't throw but returns the result code using the parameter *ec*. Otherwise it throws an instance of `hpx::exception`.

Note: This function will return meaningful results only if called from an HPX-thread. It will return `hpx::invalid_id` otherwise.

Parameters *ec* – [in,out] this represents the error status on exit, if this is pre-initialized to `hpx::throws` the function will throw on error instead.

Returns The global id representing the root locality for this application.

`std::vector<hpx::id_type> find_all_localities(error_code &ec = throws)`

Return the list of global ids representing all localities available to this application.

The function `find_all_localities()` can be used to retrieve the global ids of all localities currently available to this application.

See also:

`hpx::find_here()`, `hpx::find_locality()`

Note: Generally, the id of a locality can be used for instance to create new instances of components and to invoke plain actions (global functions).

⁸⁰⁷ <http://github.com/STELLAR-GROUP/hpx/blob/8a3b7c1a4cb5693b2f7d9f587f759392ed0c51a0/libs/full/include/include/hpx/runtime.hpp>

Note: As long as *ec* is not pre-initialized to *hpx::throws* this function doesn't throw but returns the result code using the parameter *ec*. Otherwise it throws an instance of *hpx::exception*.

Note: This function will return meaningful results only if called from an HPX-thread. It will return an empty vector otherwise.

Parameters *ec* – [in,out] this represents the error status on exit, if this is pre-initialized to *hpx::throws* the function will throw on error instead.

Returns The global ids representing the localities currently available to this application.

std::vector<hpx::id_type> **find_remote_localities**(*error_code* &*ec* = *throws*)

Return the list of locality ids of remote localities supporting the given component type. By default this function will return the list of all remote localities (all but the current locality).

The function `find_remote_localities()` can be used to retrieve the global ids of all remote localities currently available to this application (i.e. all localities except the current one).

See also:

`hpx::find_here()`, `hpx::find_locality()`

Note: Generally, the id of a locality can be used for instance to create new instances of components and to invoke plain actions (global functions).

Note: As long as *ec* is not pre-initialized to *hpx::throws* this function doesn't throw but returns the result code using the parameter *ec*. Otherwise it throws an instance of *hpx::exception*.

Note: This function will return meaningful results only if called from an HPX-thread. It will return an empty vector otherwise.

Parameters *ec* – [in,out] this represents the error status on exit, if this is pre-initialized to *hpx::throws* the function will throw on error instead.

Returns The global ids representing the remote localities currently available to this application.

hpx/runtime_distributed/find_here.hpp

Defined in header `hpx/runtime_distributed/find_here.hpp`.

See *Public API* for a list of names and headers that are part of the public *HPX* API.

namespace **hpx**

Functions

`hpx::id_type find_here(error_code &ec = throws)`

Return the global id representing this locality.

The function `find_here()` can be used to retrieve the global id usable to refer to the current locality.

See also:

`hpx::find_all_localities()`, `hpx::find_locality()`

Note: Generally, the id of a locality can be used for instance to create new instances of components and to invoke plain actions (global functions).

Note: As long as *ec* is not pre-initialized to `hpx::throws` this function doesn't throw but returns the result code using the parameter *ec*. Otherwise it throws an instance of `hpx::exception`.

Note: This function will return meaningful results only if called from an HPX-thread. It will return `hpx::invalid_id` otherwise.

Parameters *ec* – [in,out] this represents the error status on exit, if this is pre-initialized to `hpx::throws` the function will throw on error instead.

Returns The global id representing the locality this function has been called on.

`hpx::find_locality`

Defined in header `hpx/runtime.hpp`⁸⁰⁸.

See *Public API* for a list of names and headers that are part of the public *HPX* API.

namespace **hpx**

Functions

`std::vector<hpx::id_type> find_all_localities(components::component_type type, error_code &ec = throws)`

Return the list of global ids representing all localities available to this application which support the given component type.

The function `find_all_localities()` can be used to retrieve the global ids of all localities currently available to this application which support the creation of instances of the given component type.

See also:

`hpx::find_here()`, `hpx::find_locality()`

⁸⁰⁸ <http://github.com/STELLAR-GROUP/hpx/blob/8a3b7c1a4cb5693b2f7d9f587f759392ed0c51a0/libs/full/include/include/hpx/runtime.hpp>

Note: Generally, the id of a locality can be used for instance to create new instances of components and to invoke plain actions (global functions).

Note: As long as *ec* is not pre-initialized to *hpx::throws* this function doesn't throw but returns the result code using the parameter *ec*. Otherwise it throws an instance of *hpx::exception*.

Note: This function will return meaningful results only if called from an HPX-thread. It will return an empty vector otherwise.

Parameters

- **type** – [in] The type of the components for which the function should return the available localities.
- **ec** – [in,out] this represents the error status on exit, if this is pre-initialized to *hpx::throws* the function will throw on error instead.

Returns The global ids representing the localities currently available to this application which support the creation of instances of the given component type. If no localities supporting the given component type are currently available, this function will return an empty vector.

std::vector<hpx::id_type> **find_remote_localities**(*components::component_type* type, *error_code* &ec = *throws*)

Return the list of locality ids of remote localities supporting the given component type. By default this function will return the list of all remote localities (all but the current locality).

The function `find_remote_localities()` can be used to retrieve the global ids of all remote localities currently available to this application (i.e. all localities except the current one) which support the creation of instances of the given component type.

See also:

`hpx::find_here()`, `hpx::find_locality()`

Note: Generally, the id of a locality can be used for instance to create new instances of components and to invoke plain actions (global functions).

Note: As long as *ec* is not pre-initialized to *hpx::throws* this function doesn't throw but returns the result code using the parameter *ec*. Otherwise it throws an instance of *hpx::exception*.

Note: This function will return meaningful results only if called from an HPX-thread. It will return an empty vector otherwise.

Parameters

- **type** – [in] The type of the components for which the function should return the available remote localities.
- **ec** – [in,out] this represents the error status on exit, if this is pre-initialized to *hpx::throws* the function will throw on error instead.

Returns The global ids representing the remote localities currently available to this application.

hpx::id_type **find_locality**(*components::component_type* type, *error_code* &ec = *throws*)

Return the global id representing an arbitrary locality which supports the given component type.

The function `find_locality()` can be used to retrieve the global id of an arbitrary locality currently available to this application which supports the creation of instances of the given component type.

See also:

`hpx::find_here()`, `hpx::find_all_localities()`

Note: Generally, the id of a locality can be used for instance to create new instances of components and to invoke plain actions (global functions).

Note: As long as *ec* is not pre-initialized to *hpx::throws* this function doesn't throw but returns the result code using the parameter *ec*. Otherwise it throws an instance of `hpx::exception`.

Note: This function will return meaningful results only if called from an HPX-thread. It will return *hpx::invalid_id* otherwise.

Parameters

- **type** – [in] The type of the components for which the function should return any available locality.
- **ec** – [in,out] this represents the error status on exit, if this is pre-initialized to *hpx::throws* the function will throw on error instead.

Returns The global id representing an arbitrary locality currently available to this application which supports the creation of instances of the given component type. If no locality supporting the given component type is currently available, this function will return *hpx::invalid_id*.

`hpx/runtime_distributed/get_locality_name.hpp`

Defined in header `hpx/runtime_distributed/get_locality_name.hpp`.

See *Public API* for a list of names and headers that are part of the public HPX API.

namespace **hpx**

Functions

future<std::string> **get_locality_name**(*hpx::id_type* const &id)

Return the name of the referenced locality.

This function returns a future referring to the name for the locality of the given id.

See also:

std::string *get_locality_name*()

Parameters **id** – [in] The global id of the locality for which the name should be retrieved

Returns This function returns the name for the locality of the given id. The name is retrieved from the underlying networking layer and may be different for different parcel ports.

hpx/runtime_distributed/get_num_localities.hpp

Defined in header `hpx/runtime_distributed/get_num_localities.hpp`.

See *Public API* for a list of names and headers that are part of the public *HPX* API.

namespace **hpx**

Functions

hpx::future<std::uint32_t> **get_num_localities**(*components::component_type* t)

Asynchronously return the number of localities which are currently registered for the running application.

The function *get_num_localities* asynchronously returns the number of localities currently connected to the console which support the creation of the given component type. The returned future represents the actual result.

See also:

hpx::find_all_localities, *hpx::get_num_localities*

Note: This function will return meaningful results only if called from an HPX-thread. It will return 0 otherwise.

Parameters **t** – The component type for which the number of connected localities should be retrieved.

std::uint32_t **get_num_localities**(*launch::sync_policy*, *components::component_type* t, *error_code* &ec = *throws*)

Synchronously return the number of localities which are currently registered for the running application.

The function *get_num_localities* returns the number of localities currently connected to the console which support the creation of the given component type. The returned future represents the actual result.

See also:

hpx::find_all_localities, *hpx::get_num_localities*

Note: This function will return meaningful results only if called from an HPX-thread. It will return 0 otherwise.

Parameters

- **t** – The component type for which the number of connected localities should be retrieved.
- **ec** – [in,out] this represents the error status on exit, if this is pre-initialized to *hpx::throws* the function will throw on error instead.

hpx/runtime_distributed/migrate_component.hpp

Defined in header *hpx/runtime_distributed/migrate_component.hpp*.

See *Public API* for a list of names and headers that are part of the public *HPX* API.

namespace **hpx**

namespace **components**

Functions

```
template<typename Component, typename DistPolicy>  
future<hpx::id_type> migrate(hpx::id_type const &to_migrate, [[maybe_unused]] DistPolicy const  
&policy)
```

Migrate the given component to the specified target locality

The function *migrate*<*Component*> will migrate the component referenced by *to_migrate* to the locality specified with *target_locality*. It returns a future referring to the migrated component instance.

Parameters

- **to_migrate** – [in] The client side representation of the component to migrate.
- **policy** – [in] A distribution policy which will be used to determine the locality to migrate this object to.

Template Parameters

- **Component** – Specifies the component type of the component to migrate.
- **DistPolicy** – Specifies the distribution policy to use to determine the destination locality.

Returns A future representing the global id of the migrated component instance. This should be the same as *migrate_to*.

```
template<typename Derived, typename Stub, typename Data, typename DistPolicy>  
Derived migrate(client_base<Derived, Stub, Data> const &to_migrate, DistPolicy const &policy)
```

Migrate the given component to the specified target locality

The function *migrate*<*Component*> will migrate the component referenced by *to_migrate* to the locality specified with *target_locality*. It returns a future referring to the migrated component instance.

Parameters

- **to_migrate** – [in] The client side representation of the component to migrate.

- **policy** – [in] A distribution policy which will be used to determine the locality to migrate this object to.

Template Parameters

- **Derived** – Specifies the component type of the component to migrate.
- **DistPolicy** – Specifies the distribution policy to use to determine the destination locality.

Returns A future representing the global id of the migrated component instance. This should be the same as *migrate_to*.

```
template<typename Component>
future<hpx::id_type> migrate(hpx::id_type const &to_migrate, hpx::id_type const &target_locality)
```

Migrate the component with the given id to the specified target locality

The function *migrate<Component>* will migrate the component referenced by *to_migrate* to the locality specified with *target_locality*. It returns a future referring to the migrated component instance.

Parameters

- **to_migrate** – [in] The global id of the component to migrate.
- **target_locality** – [in] The locality where the component should be migrated to.

Template Parameters **Component** – Specifies the component type of the component to migrate.

Returns A future representing the global id of the migrated component instance. This should be the same as *migrate_to*.

```
template<typename Derived, typename Stub, typename Data>
Derived migrate(client_base<Derived, Stub, Data> const &to_migrate, hpx::id_type const
&target_locality)
```

Migrate the given component to the specified target locality

The function *migrate<Component>* will migrate the component referenced by *to_migrate* to the locality specified with *target_locality*. It returns a future referring to the migrated component instance.

Parameters

- **to_migrate** – [in] The client side representation of the component to migrate.
- **target_locality** – [in] The id of the locality to migrate this object to.

Template Parameters **Derived** – Specifies the component type of the component to migrate.

Returns A client side representation of representing of the migrated component instance. This should be the same as *migrate_to*.

hpx/runtime_distributed/runtime_fwd.hpp

Defined in header `hpx/runtime_distributed/runtime_fwd.hpp`.

See *Public API* for a list of names and headers that are part of the public *HPX* API.

namespace **hpx**

Functions

runtime_distributed &get_runtime_distributed()

runtime_distributed *&get_runtime_distributed_ptr()

naming::gid_type const &get_locality()

The function *get_locality* returns a reference to the locality prefix.

void start_active_counters(*error_code* &ec = *throws*)

Start all active performance counters, optionally naming the section of code.

Note: As long as *ec* is not pre-initialized to *hpx::throws* this function doesn't throw but returns the result code using the parameter *ec*. Otherwise it throws an instance of *hpx::exception*.

Note: The active counters are those which have been specified on the command line while executing the application (see command line option `-hpx:print-counter`)

Parameters *ec* – [in,out] this represents the error status on exit, if this is pre-initialized to *hpx::throws* the function will throw on error instead.

void reset_active_counters(*error_code* &ec = *throws*)

Resets all active performance counters.

Note: As long as *ec* is not pre-initialized to *hpx::throws* this function doesn't throw but returns the result code using the parameter *ec*. Otherwise it throws an instance of *hpx::exception*.

Note: The active counters are those which have been specified on the command line while executing the application (see command line option `-hpx:print-counter`)

Parameters *ec* – [in,out] this represents the error status on exit, if this is pre-initialized to *hpx::throws* the function will throw on error instead.

void reinit_active_counters(bool reset = true, *error_code* &ec = *throws*)

Re-initialize all active performance counters.

Note: As long as *ec* is not pre-initialized to *hpx::throws* this function doesn't throw but returns the result code using the parameter *ec*. Otherwise it throws an instance of *hpx::exception*.

Note: The active counters are those which have been specified on the command line while executing the application (see command line option `-hpx:print-counter`)

Parameters

- **reset** – [in] Reset the current values before re-initializing counters (default: true)

- **ec** – [in,out] this represents the error status on exit, if this is pre-initialized to *hpx::throws* the function will throw on error instead.

void **stop_active_counters**(*error_code* &ec = *throws*)

Stop all active performance counters.

Note: As long as *ec* is not pre-initialized to *hpx::throws* this function doesn't throw but returns the result code using the parameter *ec*. Otherwise it throws an instance of *hpx::exception*.

Note: The active counters are those which have been specified on the command line while executing the application (see command line option `-hpx:print-counter`)

Parameters **ec** – [in,out] this represents the error status on exit, if this is pre-initialized to *hpx::throws* the function will throw on error instead.

void **evaluate_active_counters**(bool reset = false, char const *description = nullptr, *error_code* &ec = *throws*)

Evaluate and output all active performance counters, optionally naming the point in code marked by this function.

Note: As long as *ec* is not pre-initialized to *hpx::throws* this function doesn't throw but returns the result code using the parameter *ec*. Otherwise it throws an instance of *hpx::exception*.

Note: The output generated by this function is redirected to the destination specified by the corresponding command line options (see `-hpx:print-counter-destination`).

Note: The active counters are those which have been specified on the command line while executing the application (see command line option `-hpx:print-counter`)

Parameters

- **reset** – [in] this is an optional flag allowing to reset the counter value after it has been evaluated.
- **description** – [in] this is an optional value naming the point in the code marked by the call to this function.
- **ec** – [in,out] this represents the error status on exit, if this is pre-initialized to *hpx::throws* the function will throw on error instead.

serialization::binary_filter ***create_binary_filter**(char const *binary_filter_type, bool compress, *serialization::binary_filter* *next_filter = nullptr, *error_code* &ec = *throws*)

Create an instance of a binary filter plugin.

Note: As long as *ec* is not pre-initialized to *hpx::throws* this function doesn't throw but returns the result code using the parameter *ec*. Otherwise it throws an instance of *hpx::exception*.

Parameters

- **binary_filter_type** – [in] The type of the binary filter to create
- **compress** – [in] The created filter should support compression
- **next_filter** – [in] Use this as the filter to dispatch the invocation into.
- **ec** – [in,out] this represents the error status on exit, if this is pre-initialized to *hpx::throws* the function will throw on error instead.

hpx/runtime_distributed/runtime_support.hpp

Defined in header `hpx/runtime_distributed/runtime_support.hpp`.

See *Public API* for a list of names and headers that are part of the public *HPX* API.

namespace **hpx**

namespace **agas**

Functions

struct runtime_components_init_interface_functions &**runtime_components_init**()

namespace **components**

Functions

struct counter_interface_functions &**counter_init**()

class **runtime_support** : public *hpx::components::stubs::runtime_support*

#include <runtime_support.hpp> The `runtime_support` class is the client side representation of a `server::runtime_support` component

Public Functions

inline **runtime_support**(*hpx::id_type* const &gid = *hpx::invalid_id*)

Create a client side representation for the existing `server::runtime_support` instance with the given global id *gid*.

template<typename **Component**, typename ...**Ts**>
inline *hpx::id_type* **create_component**(*Ts*&&... vs)

Create a new component type using the `runtime_support`.

template<typename **Component**, typename ...**Ts**>

```

inline hpx::future<hpx::id_type> create_component_async(Ts&&... vs)
    Asynchronously create a new component using the runtime_support.

template<bool WithCount, typename Component, typename ...Ts>
inline std::vector<hpx::id_type> bulk_create_component(std::size_t count, Ts&&... vs)
    Asynchronously create N new default constructed components using the runtime_support

template<bool WithCount, typename Component, typename ...Ts>
inline hpx::future<std::vector<hpx::id_type>> bulk_create_components_async(std::size_t
                                                                    count, Ts&&...
                                                                    vs)

    Asynchronously create a new component using the runtime_support.

inline hpx::future<int> load_components_async() const

inline int load_components() const

inline hpx::future<void> call_startup_functions_async(bool pre_startup) const

inline void call_startup_functions(bool pre_startup) const

inline hpx::future<void> shutdown_async(double timeout = -1) const
    Shutdown the given runtime system.

inline void shutdown(double timeout = -1) const

inline void shutdown_all(double timeout = -1) const
    Shutdown the runtime systems of all localities.

inline hpx::future<void> terminate_async() const
    Terminate the given runtime system.

inline void terminate() const

inline void terminate_all() const
    Terminate the runtime systems of all localities.

inline void get_config(util::section &ini) const
    Retrieve configuration information.

inline hpx::id_type const &get_id() const

inline naming::gid_type const &get_raw_gid() const

```

Private Types

```

typedef stubs::runtime_support base_type

```

Private Members

hpx::id_type **gid_**

hpx/runtime_distributed/server/copy_component.hpp

Defined in header `hpx/runtime_distributed/server/copy_component.hpp`.

See *Public API* for a list of names and headers that are part of the public *HPX* API.

namespace **hpx**

namespace **components**

namespace **server**

Functions

```
template<typename Component>
hpx::id_type copy_component_here(hpx::id_type const &to_copy)
```

```
template<typename Component>
future<hpx::id_type> copy_component(hpx::id_type const &to_copy, hpx::id_type const
&target_locality)
```

```
template<typename Component>
struct copy_component_action : public hpx::actions::action<future<hpx::id_type>
(*)(hpx::id_type const&, hpx::id_type const&), &copy_component<Component>,
copy_component_action<Component>>
```

```
template<typename Component>
struct copy_component_action_here : public hpx::actions::action<hpx::id_type (*)(hpx::id_type
const&), &copy_component_here<Component>, copy_component_action_here<Component>>
```

hpx/runtime_distributed/server/runtime_support.hpp

Defined in header `hpx/runtime_distributed/server/runtime_support.hpp`.

See *Public API* for a list of names and headers that are part of the public *HPX* API.

namespace **hpx**

namespace **components**

namespace **server**

class **runtime_support**

Public Types

```
using type_holder = runtime_support
```

Public Functions

```
explicit runtime_support(hpx::util::runtime_configuration &cfg)
```

```
inline ~runtime_support()
```

```
void delete_function_lists()
```

```
void tidy()
```

```
template<typename Component>
naming::gid_type create_component()
```

Actions to create new objects.

```
template<typename Component, typename T, typename ...Ts>
naming::gid_type create_component(T v, Ts... vs)
```

```
template<typename Component, typename ...Ts>
std::vector<naming::gid_type> bulk_create_component(std::size_t count, Ts... vs)
```

```
template<typename Component, typename ...Ts>
std::vector<naming::gid_type> bulk_create_component_with_count(std::size_t count, Ts...
vs)
```

```
template<typename Component>
naming::gid_type copy_create_component(std::shared_ptr<Component> const &p, bool)
```

```
template<typename Component>
naming::gid_type migrate_component_to_here(std::shared_ptr<Component> const &p,
hpx::id_type)
```

```
void shutdown(double timeout, hpx::id_type const &respond_to)
Gracefully shutdown this runtime system instance.
```

```
void shutdown_all(double timeout)
Gracefully shutdown runtime system instances on all localities.
```

```
void terminate(hpx::id_type const &respond_to)
Shutdown this runtime system instance.
```

```
inline void terminate_act(hpx::id_type const &id)
```

```
void terminate_all()
Shutdown runtime system instances on all localities.
```

```
inline void terminate_all_act()
```

```
util::section get_config()
Retrieve configuration information.
```

```
int load_components()
Load all components on this locality.
```

void **call_startup_functions**(bool pre_startup)

void **call_shutdown_functions**(bool pre_shutdown)

void **garbage_collect**()

Force a garbage collection operation in the AGAS layer.

namings::gid_type **create_performance_counter**(*performance_counters::counter_info* const &info)

Create the given performance counter instance.

void **remove_from_connection_cache**(*namings::gid_type* const &gid, *parcelset::endpoints_type* const &eps)

Remove the given locality from our connection cache.

HPX_DEFINE_COMPONENT_ACTION (*runtime_support*, *terminate_act*, *terminate_action*) **HPX_DEFINE_COMPONENT_ACTION**(*runtime_support* termination detection)

terminate_all_action **HPX_DEFINE_COMPONENT_ACTION** (*runtime_support*, *remove_from_connection_cache*) void **run**()

Start the *runtime_support* component.

void **wait**()

Wait for the *runtime_support* component to notify the calling thread.

This function will be called from the main thread, causing it to block while the HPX functionality is executed. The main thread will block until the *shutdown_action* is executed, which in turn notifies all waiting threads.

void **stop**(double timeout, *hpx::id_type* const &respond_to, bool remove_from_remote_caches)

Notify all waiting (blocking) threads allowing the system to be properly stopped.

Note: This function can be called from any thread.

void **stopped**()

called locally only

void **notify_waiting_main**()

inline bool **was_stopped**() const

void **add_pre_startup_function**(*startup_function_type* f)

void **add_startup_function**(*startup_function_type* f)

void **add_pre_shutdown_function**(*shutdown_function_type* f)

void **add_shutdown_function**(*shutdown_function_type* f)

void **remove_here_from_connection_cache**()

void **remove_here_from_console_connection_cache**()

Public Members

terminate_all_act

Public Static Functions

static inline component_type **get_component_type**()

static inline void **set_component_type**(component_type t)

static inline constexpr void **finalize**()

finalize() will be called just before the instance gets destructed

static inline bool **is_target_valid**(hpx::id_type const &id)

Protected Functions

int **load_components**(util::section &ini, naming::gid_type const &prefix,
naming::resolver_client &agas_client,
hpx::program_options::options_description &options,
std::set<std::string> &startup_handled)

bool **load_component**(hpx::util::plugin::dll &d, util::section &ini, std::string const &instance,
std::string const &component, filesystem::path const &lib,
naming::gid_type const &prefix, naming::resolver_client &agas_client,
bool isdefault, bool isenabled,
hpx::program_options::options_description &options,
std::set<std::string> &startup_handled)

bool **load_component_dynamic**(util::section &ini, std::string const &instance, std::string
const &component, filesystem::path lib, naming::gid_type
const &prefix, naming::resolver_client &agas_client, bool
isdefault, bool isenabled,
hpx::program_options::options_description &options,
std::set<std::string> &startup_handled)

bool **load_startup_shutdown_functions**(hpx::util::plugin::dll &d, error_code &ec)

bool **load_commandline_options**(hpx::util::plugin::dll &d,
hpx::program_options::options_description &options,
error_code &ec)

bool **load_component_static**(util::section &ini, std::string const &instance, std::string const
&component, filesystem::path const &lib, naming::gid_type
const &prefix, naming::resolver_client &agas_client, bool
isdefault, bool isenabled,
hpx::program_options::options_description &options,
std::set<std::string> &startup_handled)

bool **load_startup_shutdown_functions_static**(std::string const &mod, error_code
&ec)

```
bool load_commandline_options_static(std::string const &mod,
                                     hpx::program_options::options_description
                                     &options, error_code &ec)

bool load_plugins(util::section &ini, hpx::program_options::options_description &options,
                 std::set<std::string> &startup_handled)

bool load_plugin(hpx::util::plugin::dll &d, util::section &ini, std::string const &instance,
                std::string const &component, filesystem::path const &lib, bool isenabled,
                hpx::program_options::options_description &options, std::set<std::string>
                &startup_handled)

bool load_plugin_dynamic(util::section &ini, std::string const &instance, std::string const
                        &component, filesystem::path lib, bool isenabled,
                        hpx::program_options::options_description &options,
                        std::set<std::string> &startup_handled)

std::size_t dijkstra_termination_detection(std::vector<hpx::id_type> const
                                           &locality_ids)
```

Private Types

```
using plugin_map_mutex_type = hpx::spinlock

using plugin_factory_type = plugin_factory

using plugin_map_type = std::map<std::string, plugin_factory_type>

using modules_map_type = std::map<std::string, hpx::util::plugin::dll>

using static_modules_type = std::vector<static_factory_load_data_type>
```

Private Members

```
std::mutex mtx_

std::condition_variable wait_condition_

std::condition_variable stop_condition_

bool stop_called_

bool stop_done_

bool terminated_
```

```

std::thread::id main_thread_id_

std::atomic<bool> shutdown_all_invoked_

plugin_map_mutex_type p_mtx_

plugin_map_type plugins_

modules_map_type &modules_

static_modules_type static_modules_

hpx::spinlock globals_mtx_

std::list<startup_function_type> pre_startup_functions_

std::list<startup_function_type> startup_functions_

std::list<shutdown_function_type> pre_shutdown_functions_

std::list<shutdown_function_type> shutdown_functions_

struct plugin_factory

```

Public Functions

```

inline plugin_factory(std::shared_ptr<plugins::plugin_factory_base> const &f,
                    hpx::util::plugin::dll const &d, bool enabled)

```

Public Members

```

std::shared_ptr<plugins::plugin_factory_base> first

```

```

hpx::util::plugin::dll const &second

```

```

bool isenabled

```

hpx/runtime_distributed/stubs/runtime_support.hpp

Defined in header `hpx/runtime_distributed/stubs/runtime_support.hpp`.

See *Public API* for a list of names and headers that are part of the public *HPX* API.

```
namespace hpx
```

```
    namespace components
```

```
        namespace stubs
```

```
            struct runtime_support
```

```
                Subclassed by hpx::components::runtime_support
```

Public Static Functions

```
template<typename Component, typename ...Ts>
```

```
static inline hpx::future<hpx::id_type> create_component_async(hpx::id_type const &gid,  
                                                         Ts&&... vs)
```

Create a new component *type* using the *runtime_support* with the given *targetgid*. This is a non-blocking call. The caller needs to call *future::get* on the result of this function to obtain the global id of the newly created object.

```
template<typename Component, typename ...Ts>
```

```
static inline hpx::id_type create_component(hpx::id_type const &gid, Ts&&... vs)
```

Create a new component *type* using the *runtime_support* with the given *targetgid*. Block for the creation to finish.

```
template<bool WithCount, typename Component, typename ...Ts>
```

```
static inline hpx::future<std::vector<hpx::id_type>> bulk_create_component_colocated_async(hpx::id_type  
const  
&gid,  
std::size_t  
count,  
Ts&&...  
vs)
```

Create multiple new components *type* using the *runtime_support* colocated with the given *targetgid*. This is a non-blocking call.

```
template<bool WithCount, typename Component, typename ...Ts>
```

```
static inline std::vector<hpx::id_type> bulk_create_component_colocated(hpx::id_type  
const &gid,  
std::size_t  
count, Ts&&...  
vs)
```

Create multiple new components *type* using the *runtime_support* colocated with the given *targetgid*. Block for the creation to finish.

```
template<bool WithCount, typename Component, typename ...Ts>
```

```
static inline hpx::future<std::vector<hpx::id_type>> bulk_create_component_async(hpx::id_type
                                                                    const
                                                                    &gid,
                                                                    std::size_t
                                                                    count,
                                                                    Ts&&...
                                                                    vs)
```

Create multiple new components *type* using the *runtime_support* on the given locality. This is a non-blocking call.

```
template<bool WithCount, typename Component, typename ...Ts>
static inline std::vector<hpx::id_type> bulk_create_component(hpx::id_type const &gid,
                                                            std::size_t count, Ts&&...
                                                            vs)
```

Create multiple new components *type* using the *runtime_support* on the given locality. Block for the creation to finish.

```
template<typename Component, typename ...Ts>
static inline hpx::future<hpx::id_type> create_component_colocated_async(hpx::id_type
                                                                    const &gid,
                                                                    Ts&&... vs)
```

Create a new component *type* using the *runtime_support* with the given *targetgid*. This is a non-blocking call. The caller needs to call *future::get* on the result of this function to obtain the global id of the newly created object.

```
template<typename Component, typename ...Ts>
static inline hpx::id_type create_component_colocated(hpx::id_type const &gid, Ts&&...
                                                    vs)
```

Create a new component *type* using the *runtime_support* with the given *targetgid*. Block for the creation to finish.

```
template<typename Component>
static inline hpx::future<hpx::id_type> copy_create_component_async(hpx::id_type const
                                                                    &gid,
                                                                    std::shared_ptr<Component>
                                                                    const &p, bool
                                                                    local_op)
```

```
template<typename Component>
static inline hpx::id_type copy_create_component(hpx::id_type const &gid,
                                                  std::shared_ptr<Component> const &p,
                                                  bool local_op)
```

```
template<typename Component>
static inline hpx::future<hpx::id_type> migrate_component_async(hpx::id_type const
                                                                    &target_locality,
                                                                    std::shared_ptr<Component>
                                                                    const &p, hpx::id_type
                                                                    const &to_migrate)
```

```
template<typename Component, typename DistPolicy>
static inline hpx::future<hpx::id_type> migrate_component_async(DistPolicy const &policy,
                                                                    std::shared_ptr<Component>
                                                                    const &p, hpx::id_type
                                                                    const &to_migrate)
```

```
template<typename Component, typename Target>
static inline hpx::id_type migrate_component(Target const &target, hpx::id_type const
                                             &to_migrate, std::shared_ptr<Component>
                                             const &p)

static hpx::future<int> load_components_async(hpx::id_type const &gid)

static int load_components(hpx::id_type const &gid)

static hpx::future<void> call_startup_functions_async(hpx::id_type const &gid, bool
                                                    pre_startup)

static void call_startup_functions(hpx::id_type const &gid, bool pre_startup)

static hpx::future<void> shutdown_async(hpx::id_type const &targetgid, double timeout = -1)
    Shutdown the given runtime system.

static void shutdown(hpx::id_type const &targetgid, double timeout = -1)

static void shutdown_all(hpx::id_type const &targetgid, double timeout = -1)
    Shutdown the runtime systems of all localities.

static void shutdown_all(double timeout = -1)

static hpx::future<void> terminate_async(hpx::id_type const &targetgid)
    Retrieve configuration information.
    Terminate the given runtime system

static void terminate(hpx::id_type const &targetgid)

static void terminate_all(hpx::id_type const &targetgid)
    Terminate the runtime systems of all localities.

static void terminate_all()

static void garbage_collect_non_blocking(hpx::id_type const &targetgid)

static hpx::future<void> garbage_collect_async(hpx::id_type const &targetgid)

static void garbage_collect(hpx::id_type const &targetgid)

static hpx::future<hpx::id_type> create_performance_counter_async(hpx::id_type
                                                                targetgid, perform-
                                                                mance_counters::counter_info
                                                                const &info)

static hpx::id_type create_performance_counter(hpx::id_type targetgid,
                                                performance_counters::counter_info
                                                const &info, error_code &ec = throws)

static hpx::future<util::section> get_config_async(hpx::id_type const &targetgid)
    Retrieve configuration information.

static void get_config(hpx::id_type const &targetgid, util::section &ini)

static void remove_from_connection_cache_async(hpx::id_type const &target,
                                                naming::gid_type const &gid,
                                                parcelset::endpoints_type const
                                                &endpoints)
```

segmented_algorithms

See *Public API* for a list of names and headers that are part of the public *HPX* API.

hpx/parallel/segmented_algorithms/adjacent_difference.hpp

Defined in header `hpx/parallel/segmented_algorithms/adjacent_difference.hpp`.

See *Public API* for a list of names and headers that are part of the public *HPX* API.

namespace **hpx**

namespace **parallel**

namespace **segmented**

Functions

```
template<typename ExPolicy, typename FwdIter1, typename FwdIter2, typename Op>
hpx::parallel::util::detail::algorithm_result_t<ExPolicy, FwdIter2> tag_invoke(hpx::adjacent_difference_t,
ExPolicy &&policy,
FwdIter1 first,
FwdIter1 last, FwdIter2
dest, Op &&op)
```

```
template<typename InIter1, typename InIter2, typename Op>
InIter2 tag_invoke(hpx::adjacent_difference_t, InIter1 first, InIter1 last, InIter2 dest, Op &&op)
```

hpx/parallel/segmented_algorithms/adjacent_find.hpp

Defined in header `hpx/parallel/segmented_algorithms/adjacent_find.hpp`.

See *Public API* for a list of names and headers that are part of the public *HPX* API.

namespace **hpx**

namespace **parallel**

namespace **segmented**

Functions

```
template<typename InIter, typename Pred>  
InIter tag_invoke(hpx::adjacent_find_t, InIter first, InIter last, Pred &&pred = Pred())
```

```
template<typename ExPolicy, typename SegIter, typename Pred>  
hpx::parallel::util::detail::algorithm_result_t<ExPolicy, SegIter>::type tag_invoke(hpx::adjacent_find_t,  
ExPolicy &&policy,  
SegIter first, SegIter  
last, Pred &&pred)
```

hpx/parallel/segmented_algorithms/all_any_none.hpp

Defined in header `hpx/parallel/segmented_algorithms/all_any_none.hpp`.

See *Public API* for a list of names and headers that are part of the public *HPX* API.

```
namespace hpx
```

```
    namespace parallel
```

```
        namespace segmented
```

Functions

```
template<typename InIter, typename F>  
bool tag_invoke(hpx::none_of_t, InIter first, InIter last, F &&f)
```

```
template<typename ExPolicy, typename SegIter, typename F>  
hpx::parallel::util::detail::algorithm_result_t<ExPolicy, bool> tag_invoke(hpx::none_of_t, ExPolicy  
&&policy, SegIter first,  
SegIter last, F &&f)
```

```
template<typename InIter, typename F>  
bool tag_invoke(hpx::any_of_t, InIter first, InIter last, F &&f)
```

```
template<typename ExPolicy, typename SegIter, typename F>  
hpx::parallel::util::detail::algorithm_result_t<ExPolicy, bool> tag_invoke(hpx::any_of_t, ExPolicy  
&&policy, SegIter first,  
SegIter last, F &&f)
```

```
template<typename InIter, typename F>  
bool tag_invoke(hpx::all_of_t, InIter first, InIter last, F &&f)
```

```
template<typename ExPolicy, typename SegIter, typename F>  
hpx::parallel::util::detail::algorithm_result_t<ExPolicy, bool> tag_invoke(hpx::all_of_t, ExPolicy  
&&policy, SegIter first,  
SegIter last, F &&f)
```

hpx/parallel/segmented_algorithms/count.hpp

Defined in header `hpx/parallel/segmented_algorithms/count.hpp`.

See *Public API* for a list of names and headers that are part of the public *HPX* API.

```
namespace hpx
```

```
    namespace parallel
```

```
        namespace segmented
```

Functions

```
template<typename InIter, typename T>
std::iterator_traits<InIter>::difference_type tag_invoke(hpx::count_t, InIter first, InIter last, T const
&value)
```

```
template<typename ExPolicy, typename SegIter, typename T>
hpx::parallel::util::detail::algorithm_result<ExPolicy, typename std::iterator_traits<SegIter>::difference_type>::type tag_i
```

```
template<typename InIter, typename F>
std::iterator_traits<InIter>::difference_type tag_invoke(hpx::count_if_t, InIter first, InIter last, F
&&f)
```

```
template<typename ExPolicy, typename SegIter, typename F>
hpx::parallel::util::detail::algorithm_result<ExPolicy, typename std::iterator_traits<SegIter>::difference_type>::type tag_i
```

hpx/parallel/segmented_algorithms/exclusive_scan.hpp

Defined in header `hpx/parallel/segmented_algorithms/exclusive_scan.hpp`.

See *Public API* for a list of names and headers that are part of the public HPX API.

```
namespace hpx
```

```
    namespace parallel
```

```
        namespace segmented
```

Functions

```
template<typename InIter, typename OutIter, typename T, typename Op = std::plus<T>>>  
OutIter tag_invoke(hpx::exclusive_scan_t, InIter first, InIter last, OutIter dest, T init, Op &&op =  
    Op())
```

```
template<typename ExPolicy, typename FwdIter1, typename FwdIter2, typename T, typename Op =  
std::plus<T>>>  
parallel::util::detail::algorithm_result<ExPolicy, FwdIter2>::type tag_invoke(hpx::exclusive_scan_t,  
    ExPolicy &&policy,  
    FwdIter1 first, FwdIter1  
    last, FwdIter2 dest, T  
    init, Op &&op = Op())
```

hpx/parallel/segmented_algorithms/fill.hpp

Defined in header `hpx/parallel/segmented_algorithms/fill.hpp`.

See *Public API* for a list of names and headers that are part of the public HPX API.

hpx/parallel/segmented_algorithms/for_each.hpp

Defined in header `hpx/parallel/segmented_algorithms/for_each.hpp`.

See *Public API* for a list of names and headers that are part of the public HPX API.

```
namespace hpx
```

```
    namespace parallel
```

```
        namespace segmented
```

Functions

```
template<typename InIter, typename F>
InIter tag_invoke(hpx::for_each_t, InIter first, InIter last, F &&f)
```

```
template<typename ExPolicy, typename SegIter, typename F>
hpx::parallel::util::detail::algorithm_result_t<ExPolicy, SegIter> tag_invoke(hpx::for_each_t, ExPolicy
&&policy, SegIter first,
SegIter last, F &&f)
```

```
template<typename InIter, typename Size, typename F>
InIter tag_invoke(hpx::for_each_n_t, InIter first, Size count, F &&f)
```

```
template<typename ExPolicy, typename SegIter, typename Size, typename F>
hpx::parallel::util::detail::algorithm_result_t<ExPolicy, SegIter> tag_invoke(hpx::for_each_n_t,
ExPolicy &&policy,
SegIter first, Size count,
F &&f)
```

hpx/parallel/segmented_algorithms/generate.hpp

Defined in header `hpx/parallel/segmented_algorithms/generate.hpp`.

See *Public API* for a list of names and headers that are part of the public *HPX* API.

```
namespace hpx
```

```
    namespace parallel
```

```
        namespace segmented
```

Functions

```
template<typename SegIter, typename F>
SegIter tag_invoke(hpx::generate_t, SegIter first, SegIter last, F &&f)
```

```
template<typename ExPolicy, typename SegIter, typename F>
parallel::util::detail::algorithm_result<ExPolicy, SegIter>::type tag_invoke(hpx::generate_t, ExPolicy
&&policy, SegIter first,
SegIter last, F &&f)
```

hpx/parallel/segmented_algorithms/inclusive_scan.hpp

Defined in header `hpx/parallel/segmented_algorithms/inclusive_scan.hpp`.

See *Public API* for a list of names and headers that are part of the public *HPX* API.

```
namespace hpx
```

namespace **parallel**

namespace **segmented**

Functions

```
template<typename InIter, typename OutIter, typename Op = std::plus<typename
std::iterator_traits<InIter>::value_type>>
OutIter tag_invoke(hpx::inclusive_scan_t, InIter first, InIter last, OutIter dest, Op &&op = Op())
```

```
template<typename ExPolicy, typename FwdIter1, typename FwdIter2, typename Op =
std::plus<typename std::iterator_traits<FwdIter1>::value_type>>
parallel::util::detail::algorithm_result<ExPolicy, FwdIter2>::type tag_invoke(hpx::inclusive_scan_t,
                                                                                   ExPolicy &&policy,
                                                                                   FwdIter1 first, FwdIter1
                                                                                   last, FwdIter2 dest, Op
                                                                                   &&op = Op())
```

```
template<typename InIter, typename OutIter, typename Op, typename T>
OutIter tag_invoke(hpx::inclusive_scan_t, InIter first, InIter last, OutIter dest, Op &&op, T &&init)
```

```
template<typename ExPolicy, typename FwdIter1, typename FwdIter2, typename Op, typename T>
parallel::util::detail::algorithm_result<ExPolicy, FwdIter2>::type tag_invoke(hpx::inclusive_scan_t,
                                                                                   ExPolicy &&policy,
                                                                                   FwdIter1 first, FwdIter1
                                                                                   last, FwdIter2 dest, Op
                                                                                   &&op, T &&init)
```

hpx/parallel/segmented_algorithms/minmax.hpp

Defined in header `hpx/parallel/segmented_algorithms/minmax.hpp`.

See [Public API](#) for a list of names and headers that are part of the public HPX API.

namespace **hpx**

namespace **parallel**

Typedefs

```
template<typename T>
using minmax_element_result = hpx::parallel::util::min_max_result<T>
```

namespace **segmented**

Typedefs

```
template<typename T>
```

```
using minmax_element_result = hpx::parallel::util::min_max_result<T>
```

Functions

```
template<typename SegIter, typename F>
```

```
SegIter tag_invoke(hpx::min_element_t, SegIter first, SegIter last, F &&f)
```

```
template<typename ExPolicy, typename SegIter, typename F>
```

```
hpx::parallel::util::detail::algorithm_result_t<ExPolicy, SegIter> tag_invoke(hpx::min_element_t,  
ExPolicy &&policy,  
SegIter first, SegIter last,  
F &&f)
```

```
template<typename SegIter, typename F>
```

```
SegIter tag_invoke(hpx::max_element_t, SegIter first, SegIter last, F &&f)
```

```
template<typename ExPolicy, typename SegIter, typename F>
```

```
hpx::parallel::util::detail::algorithm_result_t<ExPolicy, SegIter> tag_invoke(hpx::max_element_t,  
ExPolicy &&policy,  
SegIter first, SegIter last,  
F &&f)
```

```
template<typename SegIter, typename F>
```

```
minmax_element_result<SegIter> tag_invoke(hpx::minmax_element_t, SegIter first, SegIter last, F  
&&f)
```

```
template<typename ExPolicy, typename SegIter, typename F>
```

```
hpx::parallel::util::detail::algorithm_result_t<ExPolicy, minmax_element_result<SegIter>> tag_invoke(hpx::minmax_ele  
Ex-  
Pol-  
icy  
&&pol-  
icy,  
Se-  
gIter  
first,  
Se-  
gIter  
last,  
F  
&&f)
```

hpx/parallel/segmented_algorithms/reduce.hpp

Defined in header `hpx/parallel/segmented_algorithms/reduce.hpp`.

See *Public API* for a list of names and headers that are part of the public *HPX* API.

```
namespace hpx
```

```
    namespace parallel
```

```
        namespace segmented
```

Functions

```
template<typename InIterB, typename InIterE, typename T, typename F>  
T tag_invoke(hpx::reduce_t, InIterB first, InIterE last, T init, F &&f)
```

```
template<typename ExPolicy, typename InIterB, typename InIterE, typename T, typename F>  
parallel::util::detail::algorithm_result<ExPolicy, T>::type tag_invoke(hpx::reduce_t, ExPolicy  
    &&policy, InIterB first, InIterE  
    last, T init, F &&f)
```

hpx/parallel/segmented_algorithms/transform.hpp

Defined in header `hpx/parallel/segmented_algorithms/transform.hpp`.

See *Public API* for a list of names and headers that are part of the public *HPX* API.

```
namespace hpx
```

```
    namespace parallel
```

```
        namespace segmented
```

Functions

```
template<typename SegIter, typename OutIter, typename F>  
hpx::parallel::util::in_out_result<SegIter, OutIter> tag_invoke(hpx::transform_t, SegIter first, SegIter  
    last, OutIter dest, F &&f)
```

```
template<typename ExPolicy, typename SegIter, typename OutIter, typename F>
```

hpx::parallel::util::detail::algorithm_result<ExPolicy, hpx::parallel::util::in_out_result<SegIter, OutIter>>::type **tag_invoke**

```
template<typename InIter1, typename InIter2, typename OutIter, typename F>
hpx::parallel::util::in_in_out_result<InIter1, InIter2, OutIter> tag_invoke(hpx::transform_t, InIter1
                                                                    first1, InIter1 last1, InIter2
                                                                    first2, OutIter dest, F &&f)
```

```
template<typename ExPolicy, typename InIter1, typename InIter2, typename OutIter, typename
F>
hpx::parallel::util::detail::algorithm_result<ExPolicy, hpx::parallel::util::in_in_out_result<InIter1, InIter2, OutIter>>::type
```

```
template<typename InIter1, typename InIter2, typename OutIter, typename F>
hpx::parallel::util::in_in_out_result<InIter1, InIter2, OutIter> tag_invoke(hpx::transform_t, InIter1
                                                                    first1, InIter1 last1, InIter2
                                                                    first2, InIter2 last2, OutIter
                                                                    dest, F &&f)
```

```
template<typename ExPolicy, typename InIter1, typename InIter2, typename OutIter, typename
F>
```

hpx::parallel::util::detail::algorithm_result<ExPolicy, hpx::parallel::util::in_in_out_result<InIter1, InIter2, OutIter>>::type

hpx/parallel/segmented_algorithms/transform_exclusive_scan.hpp

Defined in header `hpx/parallel/segmented_algorithms/transform_exclusive_scan.hpp`.

See *Public API* for a list of names and headers that are part of the public *HPX* API.

namespace **hpx**

namespace **segmented**

Functions

```
template<typename InIter, typename OutIter, typename T, typename Op, typename Conv>  
OutIter tag_invoke(hpx::transform_exclusive_scan_t, InIter first, InIter last, OutIter dest, T init, Op  
&&op, Conv &&conv)
```

```
template<typename ExPolicy, typename FwdIter1, typename FwdIter2, typename T, typename Op,  
typename Conv>  
parallel::util::detail::algorithm_result<ExPolicy, FwdIter2>::type tag_invoke(hpx::transform_exclusive_scan_t,  
ExPolicy &&policy,  
FwdIter1 first, FwdIter1  
last, FwdIter2 dest, T  
init, Op &&op, Conv  
&&conv)
```

hpx/parallel/segmented_algorithms/transform_inclusive_scan.hpp

Defined in header `hpx/parallel/segmented_algorithms/transform_inclusive_scan.hpp`.

See *Public API* for a list of names and headers that are part of the public *HPX* API.

```
namespace hpx
```

```
    namespace segmented
```

Functions

```
template<typename InIter, typename OutIter, typename Op, typename Conv>
OutIter tag_invoke(hpx::transform_inclusive_scan_t, InIter first, InIter last, OutIter dest, Op &&op,
                    Conv &&conv)
```

```
template<typename ExPolicy, typename FwdIter1, typename FwdIter2, typename Op, typename
Conv>
parallel::util::detail::algorithm_result<ExPolicy, FwdIter2>::type tag_invoke(hpx::transform_inclusive_scan_t,
                                        ExPolicy &&policy,
                                        FwdIter1 first, FwdIter1
                                        last, FwdIter2 dest, Op
                                        &&op, Conv &&conv)
```

```
template<typename InIter, typename OutIter, typename T, typename Op, typename Conv>
OutIter tag_invoke(hpx::transform_inclusive_scan_t, InIter first, InIter last, OutIter dest, Op &&op,
                    Conv &&conv, T init)
```

```
template<typename ExPolicy, typename FwdIter1, typename FwdIter2, typename T, typename Op,
typename Conv>
parallel::util::detail::algorithm_result<ExPolicy, FwdIter2>::type tag_invoke(hpx::transform_inclusive_scan_t,
                                        ExPolicy &&policy,
                                        FwdIter1 first, FwdIter1
                                        last, FwdIter2 dest, Op
                                        &&op, Conv &&conv, T
                                        init)
```

hpx/parallel/segmented_algorithms/transform_reduce.hpp

Defined in header `hpx/parallel/segmented_algorithms/transform_reduce.hpp`.

See *Public API* for a list of names and headers that are part of the public *HPX* API.

```
namespace hpx
```

```
    namespace parallel
```

```
        namespace segmented
```

Functions

```
template<typename SegIter, typename T, typename Reduce, typename Convert>  
std::decay<T> tag_invoke(hpx::transform_reduce_t, SegIter first, SegIter last, T &&init, Reduce  
    &&red_op, Convert &&conv_op)
```

```
template<typename ExPolicy, typename SegIter, typename T, typename Reduce, typename  
Convert>  
parallel::util::detail::algorithm_result<ExPolicy, typename std::decay<T>::type>::type tag_invoke(hpx::transform_reduce_t,  
    Ex-  
    Pol-  
    icy  
    &&pol-  
    icy,  
    Se-  
    gIter  
    first,  
    Se-  
    gIter  
    last,  
    T  
    &&init,  
    Re-  
    duce  
    &&red_op,  
    Con-  
    vert  
    &&conv_op)
```

```
template<typename FwdIter1, typename FwdIter2, typename T, typename Reduce, typename  
Convert>  
T tag_invoke(hpx::transform_reduce_t, FwdIter1 first1, FwdIter1 last1, FwdIter2 first2, T init, Reduce  
    &&red_op, Convert &&conv_op)
```

```
template<typename ExPolicy, typename FwdIter1, typename FwdIter2, typename T, typename  
Reduce, typename Convert>  
parallel::util::detail::algorithm_result<ExPolicy, T>::type tag_invoke(hpx::transform_reduce_t,  
    ExPolicy &&policy, FwdIter1  
    first1, FwdIter1 last1, FwdIter2  
    first2, T init, Reduce &&red_op,  
    Convert &&conv_op)
```

2.9 Contributing to HPX

HPX development happens on Github. The following sections are a collection of useful information related to HPX development.

2.9.1 Contributing to HPX

The main source of information to understand the process of how to contribute to HPX can be found in [this document](#)⁸⁰⁹. This is a living document that is constantly updated with relevant information.

2.9.2 HPX governance model

The HPX project is a meritocratic, consensus-based community project. Anyone with an interest in the project can join the community, contribute to the project design and participate in the decision making process. [This document](#)⁸¹⁰ describes how that participation takes place and how to set about earning merit within the project community.

2.9.3 Release procedure for HPX

Below is a step by step procedure for making an HPX release. We aim to produce two releases per year: one in March-April, and one in September-October.

This is a living document and may not be totally current or accurate. It is an attempt to capture current practices in making an HPX release. Please update it as appropriate.

One way to use this procedure is to print a copy and check off the lines as they are completed to avoid confusion.

1. Notify developers that a release is imminent.
2. For minor and major releases: create and check out a new branch at an appropriate point on master with the name `release-major.minor.X`. `major` and `minor` should be the major and minor versions of the release. For patch releases: check out the corresponding `release-major.minor.X` branch.
3. Write release notes in `docs/sphinx/releases/whats_new_${VERSION}.rst`. Keep adding merged PRs and closed issues to this until just before the release is made. Use `tools/generate_pr_issue_list.sh` to generate the lists. Add the new release notes to the table of contents in `docs/sphinx/releases.rst`.
4. Build the docs, and proof-read them. Update any documentation that may have changed, and correct any typos. Pay special attention to:
 - `$HPX_SOURCE/README.rst`
 - Update grant information
 - `docs/sphinx/releases/whats_new_${VERSION}.rst`
 - `docs/sphinx/about_hpx/people.rst`
 - Update collaborators
 - Update grant information
5. This step does not apply to patch releases. For APEX:
 - Change the release branch to be the most current release tag available in the APEX `git_external` section in the main `CMakeLists.txt`. Please contact the maintainers of the respective packages to generate a new release to synchronize with the HPX release ([APEX](#)⁸¹¹).
6. Make sure `HPX_VERSION_MAJOR/MINOR/SUBMINOR` in `CMakeLists.txt` contain the correct values. Change them if needed.
7. Change version references in `CITATION.cff`. There are two occurrences. Change year in the copyright file under `/libs/core/version/src/version.cpp`.

⁸⁰⁹ <https://github.com/STELLAR-GROUP/hpx/blob/master/.github/CONTRIBUTING.md>

⁸¹⁰ <http://hpx.stellar-group.org/documents/governance/>

⁸¹¹ <http://github.com/UO-OACISS/xpress-apex>

8. This step does not apply to patch releases. Remove features which have been deprecated for at least 2 releases. This involves removing build options which enable those features from the main `CMakeLists.txt` and also deleting all related code and tests from the main source tree.

The general deprecation policy involves a three-step process we have to go through in order to introduce a breaking change:

- a. First release cycle: add a build option that allows for explicitly disabling any old (now deprecated) code.
- b. Second release cycle: turn this build option OFF by default.
- c. Third release cycle: completely remove the old code.

The main `CMakeLists.txt` contains a comment indicating for which version the breaking change was introduced first. In the case of deprecated features which don't have a replacement yet, we keep them around in case (like `Vc` for example).

9. Update the minimum required versions if necessary (compilers, dependencies, etc.) in `prerequisites.rst`. Update latest tested versions.
10. Verify that the Jenkins setups for the release branch on Rostam are running and do not display any errors.
11. Repeat the following steps until satisfied with the release.
 1. Change `HPX_VERSION_TAG` in `CMakeLists.txt` to `-rcN`, where `N` is the current iteration of this step. Start with `-rc1`.
 2. Create a pre-release on GitHub using the script `tools/roll_release.sh`. This script automatically tag with the corresponding release number. The script requires that you have the STELLAR Group signing key.
 3. This step is not necessary for patch releases. Notify `hpx-users@stellar-group.org` of the availability of the release candidate. Ask users to test the candidate by checking out the release candidate tag.
 4. Allow at least a week for testing of the release candidate.
 - Use `git merge` when possible, and fall back to `git cherry-pick` when needed. For patch releases `git cherry-pick` is most likely your only choice if there have been significant unrelated changes on master since the previous release.
 - Go back to the first step when enough patches have been added.
 - If there are no more patches, continue to make the final release.
12. Update any occurrences of the latest stable release to refer to the version about to be released. For example, `quickstart.rst` contains instructions to check out the latest stable tag. Make sure that refers to the new version.
13. Add a new entry to the RPM changelog (`cmake/packaging/rpm/Changelog.txt`) with the new version number and a link to the corresponding changelog.
14. Change `HPX_VERSION_TAG` in `CMakeLists.txt` to an empty string.
15. Add the release date to the caption of the current "What's New" section in the docs, and change the value of `HPX_VERSION_DATE` in `CMakeLists.txt`.
16. Create a release on GitHub using the script `tools/roll_release.sh`. This script automatically tag the with the corresponding release number. The script requires that you have the STELLAR Group signing key.
17. Update the websites (hpx.stellar-group.org⁸¹² and stellar-group.org <<https://stellar-group.org>>). You can login on wordpress through *this page* <<https://hpx.stellar-group.org/wp-login.php>>. You can update the pages with the following:
 - Update links on the downloads page. Link to the release on GitHub.

⁸¹² <https://hpx.stellar-group.org>

- Documentation links on the docs page (link to generated documentation on GitHub Pages). Follow the style of previous releases.
 - A new blog post announcing the release, which links to downloads and the “What’s New” section in the documentation (see previous releases for examples).
18. Merge release branch into master.
 19. Post-release cleanup. Create a new pull request against master with the following changes:
 1. Modify the release procedure if necessary.
 2. Change `HPX_VERSION_TAG` in `CMakeLists.txt` back to `-trunk`.
 3. Increment `HPX_VERSION_MINOR` in `CMakeLists.txt`.
 20. Update Vcpkg (<https://github.com/Microsoft/vcpkg>) to pull from latest release.
 - Update version number in `CONTROL`
 - Update tag and SHA512 to that of the new release
 21. Update spack (<https://github.com/spack/spack>) with the latest HPX package.
 - Update version number in `hpx/package.py` and SHA256 to that of the new release
 22. Announce the release on hpx-users@stellar-group.org, stellar@cct.lsu.edu, allcct@cct.lsu.edu, faculty@csc.lsu.edu, faculty@ece.lsu.edu, the *HPX* Slack channel, the STELLAR-GROUP Discord channel, our list of external collaborators, isocpp.org, reddit.com, HPC Wire, Inside HPC, Heise Online, and a CCT press release.
 23. Beer and pizza.

2.9.4 Testing HPX

To ensure correctness of *HPX*, we ship a large variety of unit and regression tests. The tests are driven by the `CTest`⁸¹³ tool and are executed automatically on each commit to the *HPX Github*⁸¹⁴ repository. In addition, it is encouraged to run the test suite manually to ensure proper operation on your target system. If a test fails for your platform, we highly recommend submitting an issue on our *HPX Issues*⁸¹⁵ tracker with detailed information about the target system.

Running tests manually

Running the tests manually is as easy as typing `make tests && make test`. This will build all tests and run them once the tests are built successfully. After the tests have been built, you can invoke separate tests with the help of the `ctest` command. You can list all available test targets using `make help | grep tests`. Please see the *CTest Documentation*⁸¹⁶ for further details.

⁸¹³ <https://gitlab.kitware.com/cmake/community/wikis/doc/ctest/Testing-With-CTest>

⁸¹⁴ <https://github.com/STELLAR-GROUP/hpx/>

⁸¹⁵ <https://github.com/STELLAR-GROUP/hpx/issues>

⁸¹⁶ <https://www.cmake.org/cmake/help/latest/manual/ctest.1.html>

Running performance tests

We run performance tests on Piz Daint for each pull request using Jenkins. To run those performance tests locally or on Piz Daint, a script is provided under `tools/perftests_ci/local_run.sh` (to be run in the build directory specifying the *HPX* source directory as the argument to the script, default is `$HOME/projects/hpx_perftests_ci`).

Adding new performance tests

To add a new performance test, you need to wrap the portion of code to benchmark with `hpx::util::perftests_report`, passing the test name, the executor name and the function to time (can be a lambda). This facility is used to output the time results in a json format (format needed to compare the results and plot them). To effectively print them at the end of your test, call `hpx::util::perftests_print_times`. To see an example of use, see `future_overhead_report.cpp`. Finally, you can add the test to the CI report editing the `hpx_targets` variable for the executable name and the `hpx_test_options` variable for the corresponding options to use for the run in the performance test script `.jenkins/cscs-perftests/launch_perftests.sh`. And then run the `tools/perftests_ci/local_run.sh` script to get a reference json run (use the name of the test) to be added in the `tools/perftests_ci/perftest/references/daint_default` directory.

Issue tracker

If you stumble over a bug or missing feature in *HPX*, please submit an issue to our [HPX Issues](#)⁸¹⁷ page. For more information on how to submit support requests or other means of getting in contact with the developers, please see the [Support Website](#)⁸¹⁸ page.

Continuous testing

In addition to manual testing, we run automated tests on various platforms. We also run tests on all pull requests using both [CircleCI](#)⁸¹⁹ and a combination of [CDash](#)⁸²⁰ and [pycicle](#)⁸²¹. You can see the dashboards here: [CircleCI HPX dashboard](#)⁸²² and [CDash HPX dashboard](#)⁸²³.

2.9.5 Using docker for development

Although it can often be useful to set up a local development environment with system-provided or self-built dependencies, [Docker](#)⁸²⁴ provides a convenient alternative to quickly get all the dependencies needed to start development of *HPX*. Our testing setup on [CircleCI](#)⁸²⁵ uses a docker image to run all tests.

To get started you need to install [Docker](#)⁸²⁶ using whatever means is most convenient on your system. Once you have [Docker](#)⁸²⁷ installed, you can pull or directly run the docker image. The image is based on Debian and Clang, and can be found on [Docker Hub](#)⁸²⁸. To start a container using the *HPX* build environment, run:

⁸¹⁷ <https://github.com/STELLAR-GROUP/hpx/issues>

⁸¹⁸ <https://stellar.ct.lsu.edu/support/>

⁸¹⁹ <https://circleci.com>

⁸²⁰ <https://www.kitware.com/cdash/project/about.html>

⁸²¹ <https://github.com/biddisco/pycicle/>

⁸²² <https://circleci.com/gh/STELLAR-GROUP/hpx>

⁸²³ <https://cdash.rostam.ct.lsu.edu/index.php?project=HPX>

⁸²⁴ <https://www.docker.com>

⁸²⁵ <https://circleci.com>

⁸²⁶ <https://www.docker.com>

⁸²⁷ <https://www.docker.com>

⁸²⁸ https://hub.docker.com/r/stellargroup/build_env/

```
$ docker run --interactive --tty stellargroup/build_env:latest bash
```

You are now in an environment where all the *HPX* build and runtime dependencies are present. You can install additional packages according to your own needs. Please see the [Docker Documentation](#)⁸²⁹ for more information on using Docker⁸³⁰.

Warning: All changes made within the container are lost when the container is closed. If you want files to persist (e.g., the *HPX* source tree) after closing the container, you can bind directories from the host system into the container (see [Docker Documentation \(Bind mounts\)](#)⁸³¹).

2.9.6 Documentation

This documentation is built using [Sphinx](#)⁸³², and an automatically generated API reference using [Doxygen](#)⁸³³ and [Breathe](#)⁸³⁴.

We always welcome suggestions on how to improve our documentation, as well as pull requests with corrections and additions.

Prerequisites

To build the *HPX* documentation, you need recent versions of the following packages:

- python3
- sphinx 4.5.0 (Python package)
- sphinx-book-theme (Python package)
- breathe 4.33.1 (Python package)
- doxygen
- sphinxcontrib-bibtex
- sphinx-copybutton

If the [Python](#)⁸³⁵ dependencies are not available through your system package manager, you can install them using the Python package manager `pip`:

```
pip install --user "sphinx<5" sphinx-book-theme breathe sphinxcontrib-bibtex sphinx-
↪copybutton
```

You may need to set the following CMake variables to make sure CMake can find the required dependencies.

Doxygen_ROOT:PATH

Specifies where to look for the installation of the [Doxygen](#)⁸³⁶ tool.

⁸²⁹ <https://docs.docker.com/>

⁸³⁰ <https://www.docker.com>

⁸³¹ <https://docs.docker.com/storage/bind-mounts/>

⁸³² <http://www.sphinx-doc.org>

⁸³³ <https://www.doxygen.org>

⁸³⁴ <https://breathe.readthedocs.io/en/latest>

⁸³⁵ <https://www.python.org>

⁸³⁶ <https://www.doxygen.org>

Sphinx_ROOT:PATH

Specifies where to look for the installation of the Sphinx⁸³⁷ tool.

Breathe_APIDOC_ROOT:PATH

Specifies where to look for the installation of the Breathe⁸³⁸ tool.

Building documentation

Enable building of the documentation by setting `HPX_WITH_DOCUMENTATION=ON` during CMake⁸³⁹ configuration. To build the documentation, build the `docs` target using your build tool. The default output format is HTML documentation. You can choose alternative output formats (single-page HTML, PDF, and man) with the `HPX_WITH_DOCUMENTATION_OUTPUT_FORMATS` CMake option.

Note: If you add new source files to the Sphinx documentation, you have to run CMake again to have the files included in the build.

Style guide

The documentation is written using reStructuredText. These are the conventions used for formatting the documentation:

- Use, at most, 80 characters per line.
- Top-level headings use over- and underlines with `=`.
- Sub-headings use only underlines with characters in decreasing level of importance: `=`, `-` and `..`
- Use sentence case in headings.
- Refer to common terminology using `:term: `Component``.
- Indent content of directives (`.. directive::`) by three spaces.
- For C++ code samples at the end of paragraphs, use `::` and indent the code sample by 4 spaces.
 - For other languages (or if you don't want a colon at the end of the paragraph), use `.. code-block:: language` and indent by three spaces as with other directives.
- Use `.. list-table::` to wrap tables with a lot of text in cells.

API documentation

The source code is documented using Doxygen. If you add new API documentation either to existing or new source files, make sure that you add the documented source files to the `doxygen_dependencies` variable in `docs/CMakeLists.txt`.

⁸³⁷ <http://www.sphinx-doc.org>

⁸³⁸ <https://breathe.readthedocs.io/en/latest>

⁸³⁹ <https://www.cmake.org>

2.9.7 Module structure

This section explains the structure of an *HPX* module.

The tool `create_library_skeleton.py`⁸⁴⁰ can be used to generate a basic skeleton. To create a library skeleton, run the tool in the `libs` subdirectory with the module name as an argument:

```
$ ./create_library_skeleton <lib_name>
```

This creates a skeleton with the necessary files for an *HPX* module. It will not create any actual source files. The structure of this skeleton is as follows:

- `<lib_name>/`
 - `README.rst`
 - `CMakeLists.txt`
 - `cmake`
 - `docs/`
 - * `index.rst`
 - `examples/`
 - * `CMakeLists.txt`
 - `include/`
 - * `hpx/`
 - `<lib_name>`
 - `src/`
 - * `CMakeLists.txt`
 - `tests/`
 - * `CMakeLists.txt`
 - * `unit/`
 - `CMakeLists.txt`
 - * `regressions/`
 - `CMakeLists.txt`
 - * `performance/`
 - `CMakeLists.txt`

A `README.rst` should be always included which explains the basic purpose of the library and a link to the generated documentation.

A main `CMakeLists.txt` is created in the root directory of the module. By default it contains a call to `add_hpx_module` which takes care of most of the boilerplate required for a module. You only need to fill in the source and header files in most cases.

`add_hpx_module` requires a module name. Optional flags are:

Optional single-value arguments are:

- `INSTALL_BINARIES`: Install the resulting library.

⁸⁴⁰ https://github.com/STELLAR-GROUP/hpx/blob/master/libs/create_module_skeleton.py

Optional multi-value arguments-are:

- `SOURCES`: List of source files.
- `HEADERS`: List of header files.
- `COMPAT_HEADERS`: List of compatibility header files.
- `DEPENDENCIES`: Libraries that this module depends on, such as other modules.
- `CMAKE_SUBDIRS`: List of subdirectories to add to the module.

The `include` directory should contain only headers that other libraries need. For each of those headers, an automatic header test to check for self containment will be generated. Private headers should be placed under the `src` directory. This allows for clear separation. The `cmake` subdirectory may include additional `CMake`⁸⁴¹ scripts needed to generate the respective build configurations.

Compatibility headers (forwarding headers for headers whose location is changed when creating a module, if moving them from the main library) should be placed in an `include_compatibility` directory. This directory is not created by default.

Documentation is placed in the `docs` folder. A empty skeleton for the index is created, which is picked up by the main build system and will be part of the generated documentation. Each header inside the `include` directory will automatically be processed by Doxygen and included into the documentation.

Tests are placed in suitable subdirectories of `tests`.

When in doubt, consult existing modules for examples on how to structure the module.

Finding circular dependencies

Our CI will perform a check to see if there are circular dependencies between modules. In cases where it's not clear what is causing the circular dependency, running the `cpp-dependencies`⁸⁴² tool manually can be helpful. It can give you detailed information on exactly which files are causing the circular dependency. If you do not have the `cpp-dependencies` tool already installed, one way of obtaining it is by using our docker image. This way you will have exactly the same environment as on the CI. See *Using docker for development* for details on how to use the docker image.

To produce the graph produced by CI run the following command (`HPX_SOURCE` is assumed to hold the path to the `HPX` source directory):

```
$ cpp-dependencies --dir $HPX_SOURCE/libs --graph-cycles circular_dependencies.dot
```

This will produce a `dot` file in the current directory. You can inspect this manually with a text editor. You can also convert this to an image if you have `graphviz` installed:

```
$ dot circular_dependencies.dot -Tsvg -o circular_dependencies.svg
```

This produces an `svg` file in the current directory which shows the circular dependencies. Note that if there are no cycles the image will be empty.

You can use `cpp-dependencies` to print the include paths between two modules.

```
$ cpp-dependencies --dir $HPX_SOURCE/libs --shortest <from> <to>
```

prints all possible paths from the module `<from>` to the module `<to>`. For example, as most modules depend on `config`, the following should give you a long list of paths from `algorithms` to `config`:

⁸⁴¹ <https://www.cmake.org>

⁸⁴² <https://github.com/tomtom-international/cpp-dependencies>

```
$ cpp-dependencies --dir $HPX_SOURCE/libs --shortest algorithms config
```

The following should report that it can't find a path between the two modules:

```
$ cpp-dependencies --dir $HPX_SOURCE/libs --shortest config algorithms
```

2.10 Releases

2.10.1 List of releases

HPX V1.11.1 (TBD)

This is a minor release that fixes some problems that were reported since we have released V1.11.0.

General changes

Breaking changes

No breaking changes are known for this release.

Closed issues

Closed pull requests

HPX V1.11.0 (Jun 30, 2025)

This release is the last version of HPX that supports C++17. Future versions of HPX will require compilation using C++20 or above.

General changes

- Added synchronous versions of all collective operations. Added global predefined communicator objects that are accessible through new APIs: `hpx::collectives::get_world_communicator()` refers to all localities and `hpx::collectives::get_local_communicator()` refers to all threads on the calling locality. We unified the interfaces of the different communicator objects.
- Added `hpx::experimental::run_on_all` allowing to run a given function (possibly concurrently) using a given execution policy.
- Added a helper object `hpx::runtime_manager` that simplifies the initialization of HPX without needing to modify the main function of the application.
- We improved the compatibility with various accelerator frameworks (SYCL, OneAPI).
- Applied build system changes that allow building HPX without any prerequisites. This requires to pass `-DHPX_WITH_FETCH_HWLOC=On` and `-DHPX_WITH_FETCH_BOOST=On` to the `CMake`⁸⁴³ configuration.

⁸⁴³ <https://www.cmake.org>

- We have performed a lot of code cleanup and refactoring to improve the overall code quality and decrease compile times.
- Added the `hpx::contains` and `hpx::contains_subrange` parallel algorithms.
- Adapted many of HPX' parallel algorithms to be usable with senders/receivers.

Breaking changes

- We have moved most of the APIs that were defined in the namespace `hpx::parallel::execution` to the namespace `hpx::execution::experimental`. It was not possible to add compatibility facilities that will allow to continue using the old APIs, applications will have to be changed in order to continue functioning correctly.
- The CMake configuration parameter `HPX_WITH_RUN_MAIN_EVERYWHERE` is now deprecated and will be removed in the future. Use the preprocessor macro `HPX_HAVE_RUN_MAIN_EVERYWHERE` on a target-by-target case instead.
- Removed the dysfunctional libfabric parcelport.
- Removed features that were long deprecated (starting V1.8): - `hpx::flush`, `hpx::endl`, `hpx::async_flush`, `hpx::async_endl` - Various enumerator types are now only available as `class enum` requiring explicit scoped use of the enumerator values - Various non-conforming overloads of parallel algorithms - `hpx::for_loop` and friends (now only available as

`hpx::experimental::for_loop`)

- `hpx::parallel::induction` is now only available as `hpx::experimental::induction`
- `hpx::parallel::reduction` and friends are now only available as `hpx::experimental::reduction`
- `hpx::assertion::source_location` is now only available as `hpx::source_location`
- `hpx::lcos::split_future` is now only available as `hpx::split_future`
- `hpx::lcos::wait` and friends have been removed altogether
- `hpx::lcos::wait_any` and friends are now only available as `hpx::wait_any`
- `hpx::lcos::wait_some` and friends are now only available as `hpx::wait_some`
- `hpx::lcos::wait_each` and friends are now only available as `hpx::wait_each`
- `hpx::lcos::wait_all` and friends are now only available as `hpx::wait_all`
- `hpx::lcos::when_all` and friends are now only available as `hpx::when_all`
- `hpx::lcos::when_any` and friends are now only available as `hpx::when_any`
- `hpx::lcos::when_each` and friends are now only available as `hpx::when_each`
- `hpx::lcos::when_some` and friends are now only available as `hpx::when_some`
- `hpx::util::optional` and related facilities are now only available as `hpx::optional`
- `hpx::util::bind` and related facilities are now only available as `hpx::bind`
- `hpx::util::function` and friends are now only available as `hpx::function`
- `hpx::traits::is_bound_action` and related facilities are now only available as `hpx::is_bound_action`
- `hpx::traits::is_bind_expression` and related facilities are now only available as `hpx::is_bind_expression`

- `hpx::traits::is_placeholder` and related facilities are now only available as `hpx::is_placeholder`
- `hpx::lcos::future` and related facilities are now only available as `hpx::future`
- `hpx::memory::intrusive_ptr` is now only available as `hpx::intrusive_ptr`
- `hpx::lcos::local::barrier` is now only available as `hpx::barrier`
- `hpx::lcos::barrier` is now only available as `hpx::distributed::barrier`
- `hpx::lcos::local::cpp20_binary_semaphore` is now only available as `hpx::detail::binary_semaphore`
- `hpx::lcos::local::condition_variable` and friends are now only available as `hpx::condition_variable`
- `hpx::lcos::local::counting_semaphore` and friends are now only available as `hpx::counting_semaphore`
- `hpx::lcos::local::cpp20_latch` and is now only available as `hpx::latch`
- `hpx::lcos::latch` and is now only available as `hpx::distributed::latch`
- `hpx::lcos::local::upgrade_lock` and friends are now only available as `hpx::upgrade_lock`
- `hpx::lcos::local::mutex` and friends are now only available as `hpx::mutex`
- `hpx::lcos::local::spinlock` and friends are now only available as `hpx::spinlock`
- `hpx::lcos::local::call_once` and friends are now only available as `hpx::call_once`
- `hpx::util::annotated_function` and is now only available as `hpx::annotated_function`
- `hpx::components::abstract_simple_component_base` and is now only available as `hpx::components::abstract_component_base`
- `hpx::naming::id_type` and is now only available as `hpx::id_type`

Closed issues

- [Issue #6699](#)⁸⁴⁴ - Catch lower-level runtime error
- [Issue #6696](#)⁸⁴⁵ - HPX master breaks with Kokkos
- [Issue #6691](#)⁸⁴⁶ - `minimum_category` doesn't work with custom iterator categories
- [Issue #6681](#)⁸⁴⁷ - build break - missing `';`
- [Issue #6658](#)⁸⁴⁸ - CMake error upon building HPX manually
- [Issue #6648](#)⁸⁴⁹ - Asio V1.34 deprecates `io_context::work`
- [Issue #6640](#)⁸⁵⁰ - `iterator_facade` doesn't work with custom iterator categories
- [Issue #6636](#)⁸⁵¹ - problem with `hpx::collectives::exclusive_scan`

⁸⁴⁴ <https://github.com/STELLAR-GROUP/hpx/issues/6699>

⁸⁴⁵ <https://github.com/STELLAR-GROUP/hpx/issues/6696>

⁸⁴⁶ <https://github.com/STELLAR-GROUP/hpx/issues/6691>

⁸⁴⁷ <https://github.com/STELLAR-GROUP/hpx/issues/6681>

⁸⁴⁸ <https://github.com/STELLAR-GROUP/hpx/issues/6658>

⁸⁴⁹ <https://github.com/STELLAR-GROUP/hpx/issues/6648>

⁸⁵⁰ <https://github.com/STELLAR-GROUP/hpx/issues/6640>

⁸⁵¹ <https://github.com/STELLAR-GROUP/hpx/issues/6636>

- Issue #6623⁸⁵² - HPX serialization error with `std::vector<std::vector<std::vector<float>>>`
- Issue #6616⁸⁵³ - Add flux support to HPX to run on El Cap
- Issue #6615⁸⁵⁴ - Too many fails test after installed hpx
- Issue #6605⁸⁵⁵ - Partitionend vector copy constructor is broken
- Issue #6586⁸⁵⁶ - Bullet points in quick start/installing HPX section in documentation incorrectly rendered
- Issue #6563⁸⁵⁷ - Compilation issues on Grace Hopper
- Issue #6544⁸⁵⁸ - Errors in Public Distributed Api for `all_to_all` and `gather_there`
- Issue #6519⁸⁵⁹ - Option `-hpx:queuing=local-priority-lifo` is not configured
- Issue #6501⁸⁶⁰ - HPX 1.10 Failed Linking CXX executable for `arm64-osx`
- Issue #5728⁸⁶¹ - Add optional `fetch_content` support for needed Boost libraries

Closed pull requests

- PR #6716⁸⁶² - Fixing some of the reported linker warnings
- PR #6705⁸⁶³ - Adding `gcc/15` to jenkins
- PR #6701⁸⁶⁴ - Attempting to fix shutdown hang on `exception_info`
- PR #6698⁸⁶⁵ - Making sure `.hpp.in` files are not being installed
- PR #6697⁸⁶⁶ - Minor docs fix
- PR #6695⁸⁶⁷ - Adding missing `‘;`
- PR #6693⁸⁶⁸ - Adding `llvm/19` and `20` and `cmake/4` Jenkins
- PR #6692⁸⁶⁹ - Better implementation of `minimal_category`
- PR #6690⁸⁷⁰ - Fixing bad `#include` in example
- PR #6689⁸⁷¹ - Fix unreachable code warning in `wait_all`
- PR #6687⁸⁷² - lci pp: change default `ndevices=2` and `progress_type=worker`; improve document
- PR #6686⁸⁷³ - lci pp: upgrade LCI autofetch target to 1.7.9

⁸⁵² <https://github.com/STELLAR-GROUP/hpx/issues/6623>

⁸⁵³ <https://github.com/STELLAR-GROUP/hpx/issues/6616>

⁸⁵⁴ <https://github.com/STELLAR-GROUP/hpx/issues/6615>

⁸⁵⁵ <https://github.com/STELLAR-GROUP/hpx/issues/6605>

⁸⁵⁶ <https://github.com/STELLAR-GROUP/hpx/issues/6586>

⁸⁵⁷ <https://github.com/STELLAR-GROUP/hpx/issues/6563>

⁸⁵⁸ <https://github.com/STELLAR-GROUP/hpx/issues/6544>

⁸⁵⁹ <https://github.com/STELLAR-GROUP/hpx/issues/6519>

⁸⁶⁰ <https://github.com/STELLAR-GROUP/hpx/issues/6501>

⁸⁶¹ <https://github.com/STELLAR-GROUP/hpx/issues/5728>

⁸⁶² <https://github.com/STELLAR-GROUP/hpx/pull/6716>

⁸⁶³ <https://github.com/STELLAR-GROUP/hpx/pull/6705>

⁸⁶⁴ <https://github.com/STELLAR-GROUP/hpx/pull/6701>

⁸⁶⁵ <https://github.com/STELLAR-GROUP/hpx/pull/6698>

⁸⁶⁶ <https://github.com/STELLAR-GROUP/hpx/pull/6697>

⁸⁶⁷ <https://github.com/STELLAR-GROUP/hpx/pull/6695>

⁸⁶⁸ <https://github.com/STELLAR-GROUP/hpx/pull/6693>

⁸⁶⁹ <https://github.com/STELLAR-GROUP/hpx/pull/6692>

⁸⁷⁰ <https://github.com/STELLAR-GROUP/hpx/pull/6690>

⁸⁷¹ <https://github.com/STELLAR-GROUP/hpx/pull/6689>

⁸⁷² <https://github.com/STELLAR-GROUP/hpx/pull/6687>

⁸⁷³ <https://github.com/STELLAR-GROUP/hpx/pull/6686>

- PR #6685⁸⁷⁴ - Improve run_on_all implementation and tests
- PR #6683⁸⁷⁵ - Fix bad element comparison for reduce_by_key
- PR #6682⁸⁷⁶ - Add C++23 std::generator equivalence test and fix missing semicolon
- PR #6680⁸⁷⁷ - Add oneapi device init workaround
- PR #6679⁸⁷⁸ - Fix sycl deprecations
- PR #6678⁸⁷⁹ - Fix oneapi overloads
- PR #6677⁸⁸⁰ - Offer a runtime manager object
- PR #6676⁸⁸¹ - Mention the HPX book
- PR #6675⁸⁸² - Bump required version of JSON library
- PR #6674⁸⁸³ - Issue 6631
- PR #6673⁸⁸⁴ - Fix: FindTBB.cmake cannot find correct TBB library. #6504
- PR #6672⁸⁸⁵ - Update modules.rst
- PR #6670⁸⁸⁶ - Add base template template param to execution_policy
- PR #6669⁸⁸⁷ - Add execution policy support to run_on_all
- PR #6667⁸⁸⁸ - Making sure bound threads are rescheduled on their original core
- PR #6666⁸⁸⁹ - Improve documentation for reduction operations
- PR #6664⁸⁹⁰ - Fix CMake template when fetching Boost
- PR #6663⁸⁹¹ - More run_on_all overloads
- PR #6662⁸⁹² - Fix “unary minus operator applied to unsigned type” warning
- PR #6661⁸⁹³ - Adding simple experimental::run_on_all
- PR #6659⁸⁹⁴ - fix(reduce): Initialize accumulator with init instead of first element
- PR #6656⁸⁹⁵ - Add missing channel_communicator::get_info
- PR #6652⁸⁹⁶ - Adding channel-based ping-pong example

⁸⁷⁴ <https://github.com/STELLAR-GROUP/hpx/pull/6685>

⁸⁷⁵ <https://github.com/STELLAR-GROUP/hpx/pull/6683>

⁸⁷⁶ <https://github.com/STELLAR-GROUP/hpx/pull/6682>

⁸⁷⁷ <https://github.com/STELLAR-GROUP/hpx/pull/6680>

⁸⁷⁸ <https://github.com/STELLAR-GROUP/hpx/pull/6679>

⁸⁷⁹ <https://github.com/STELLAR-GROUP/hpx/pull/6678>

⁸⁸⁰ <https://github.com/STELLAR-GROUP/hpx/pull/6677>

⁸⁸¹ <https://github.com/STELLAR-GROUP/hpx/pull/6676>

⁸⁸² <https://github.com/STELLAR-GROUP/hpx/pull/6675>

⁸⁸³ <https://github.com/STELLAR-GROUP/hpx/pull/6674>

⁸⁸⁴ <https://github.com/STELLAR-GROUP/hpx/pull/6673>

⁸⁸⁵ <https://github.com/STELLAR-GROUP/hpx/pull/6672>

⁸⁸⁶ <https://github.com/STELLAR-GROUP/hpx/pull/6670>

⁸⁸⁷ <https://github.com/STELLAR-GROUP/hpx/pull/6669>

⁸⁸⁸ <https://github.com/STELLAR-GROUP/hpx/pull/6667>

⁸⁸⁹ <https://github.com/STELLAR-GROUP/hpx/pull/6666>

⁸⁹⁰ <https://github.com/STELLAR-GROUP/hpx/pull/6664>

⁸⁹¹ <https://github.com/STELLAR-GROUP/hpx/pull/6663>

⁸⁹² <https://github.com/STELLAR-GROUP/hpx/pull/6662>

⁸⁹³ <https://github.com/STELLAR-GROUP/hpx/pull/6661>

⁸⁹⁴ <https://github.com/STELLAR-GROUP/hpx/pull/6659>

⁸⁹⁵ <https://github.com/STELLAR-GROUP/hpx/pull/6656>

⁸⁹⁶ <https://github.com/STELLAR-GROUP/hpx/pull/6652>

- PR #6650⁸⁹⁷ - Adding constructor overloads to `partitioned_vector`
- PR #6649⁸⁹⁸ - Remove the use of deprecated `asio::io_context::work`
- PR #6645⁸⁹⁹ - Fixing `collectives::exclusive_scan`
- PR #6644⁹⁰⁰ - Update `result_type` in `set_union.hpp`
- PR #6643⁹⁰¹ - Update `result_type` in `set_union.hpp`
- PR #6642⁹⁰² - Allowing to use custom iterator tags with `iterator_facade`
- PR #6641⁹⁰³ - Allowing for `zip-iterator` to refer to sequences of different length
- PR #6639⁹⁰⁴ - docs: Fix spelling in example dictionary
- PR #6638⁹⁰⁵ - Update `set_union.hpp`
- PR #6637⁹⁰⁶ - `lci/mpi pp`: fix the case when non-zero-copy data is larger than `INT_MAX`
- PR #6635⁹⁰⁷ - Adding simplified reduction overload
- PR #6634⁹⁰⁸ - Fixed issue 6634: Unqualified calls to `insertion_sort`
- PR #6633⁹⁰⁹ - Increase timeouts for CircleCI tests
- PR #6630⁹¹⁰ - Fix CPUId test
- PR #6628⁹¹¹ - Link `aclocal` with `aclocal-1.16` as `hwloc` asks for it
- PR #6626⁹¹² - Fixing MPI parcel port issue exposed by #6623
- PR #6622⁹¹³ - Newbranch:HPX-Based Task Scheduler with CUDA-Quantum Integration & Benchmarking
- PR #6621⁹¹⁴ - HPX-Based Task Scheduler with CUDA-Quantum Integration & Benchmarking
- PR #6620⁹¹⁵ - new test: very big `tchunk`
- PR #6619⁹¹⁶ - `mpi pp`: fix transmission chunk send
- PR #6617⁹¹⁷ - Adding support for the Flux job scheduling environment
- PR #6614⁹¹⁸ - Fix fallback to module mode for CMake finding Boost
- PR #6613⁹¹⁹ - Fix `partitioned_vector_handle_values` test

⁸⁹⁷ <https://github.com/STELLAR-GROUP/hpx/pull/6650>

⁸⁹⁸ <https://github.com/STELLAR-GROUP/hpx/pull/6649>

⁸⁹⁹ <https://github.com/STELLAR-GROUP/hpx/pull/6645>

⁹⁰⁰ <https://github.com/STELLAR-GROUP/hpx/pull/6644>

⁹⁰¹ <https://github.com/STELLAR-GROUP/hpx/pull/6643>

⁹⁰² <https://github.com/STELLAR-GROUP/hpx/pull/6642>

⁹⁰³ <https://github.com/STELLAR-GROUP/hpx/pull/6641>

⁹⁰⁴ <https://github.com/STELLAR-GROUP/hpx/pull/6639>

⁹⁰⁵ <https://github.com/STELLAR-GROUP/hpx/pull/6638>

⁹⁰⁶ <https://github.com/STELLAR-GROUP/hpx/pull/6637>

⁹⁰⁷ <https://github.com/STELLAR-GROUP/hpx/pull/6635>

⁹⁰⁸ <https://github.com/STELLAR-GROUP/hpx/pull/6634>

⁹⁰⁹ <https://github.com/STELLAR-GROUP/hpx/pull/6633>

⁹¹⁰ <https://github.com/STELLAR-GROUP/hpx/pull/6630>

⁹¹¹ <https://github.com/STELLAR-GROUP/hpx/pull/6628>

⁹¹² <https://github.com/STELLAR-GROUP/hpx/pull/6626>

⁹¹³ <https://github.com/STELLAR-GROUP/hpx/pull/6622>

⁹¹⁴ <https://github.com/STELLAR-GROUP/hpx/pull/6621>

⁹¹⁵ <https://github.com/STELLAR-GROUP/hpx/pull/6620>

⁹¹⁶ <https://github.com/STELLAR-GROUP/hpx/pull/6619>

⁹¹⁷ <https://github.com/STELLAR-GROUP/hpx/pull/6617>

⁹¹⁸ <https://github.com/STELLAR-GROUP/hpx/pull/6614>

⁹¹⁹ <https://github.com/STELLAR-GROUP/hpx/pull/6613>

- PR #6612⁹²⁰ - Fixing naming convention for pp constant
- PR #6611⁹²¹ - Fix Hwloc fetch content
- PR #6610⁹²² - Add docs for synchronous collective operations
- PR #6609⁹²³ - Update perfest CI reference measurements
- PR #6608⁹²⁴ - Partially support data parallel for_loop
- PR #6607⁹²⁵ - Cleaning up copy_component facility
- PR #6606⁹²⁶ - Making sure copy_component creates a new gid
- PR #6600⁹²⁷ - Fixing sync collectives
- PR #6599⁹²⁸ - Make HPX_HAVE_RUN_MAIN_EVERYWHERE application specific
- PR #6598⁹²⁹ - Adding synchronous collective operations
- PR #6596⁹³⁰ - Minor fixes and optimizations
- PR #6595⁹³¹ - Rfa parallel
- PR #6594⁹³² - Move get_stack_ptr to source
- PR #6593⁹³³ - Fix outdated documentation and missing flags
- PR #6592⁹³⁴ - HPX_HAVE_THREADS_GET_STACK_POINTER to match builtin_frame_address feature test
- PR #6591⁹³⁵ - Feature test for __builtin_frame_address
- PR #6590⁹³⁶ - Add device guard for noexcept
- PR #6587⁹³⁷ - Fix bullet points in Quickstart
- PR #6585⁹³⁸ - Fixed escape characters format to handle warning due to misinterpretation of syntax
- PR #6583⁹³⁹ - Execute feature test for at_quick_exit
- PR #6582⁹⁴⁰ - Accommodate for CircleCI reduce available number of cores to two
- PR #6581⁹⁴¹ - Attempting to work around a Boost.Spirit problem
- PR #6580⁹⁴² - mpi pp: fix messages larger than INT_MAX

⁹²⁰ <https://github.com/STELLAR-GROUP/hpx/pull/6612>

⁹²¹ <https://github.com/STELLAR-GROUP/hpx/pull/6611>

⁹²² <https://github.com/STELLAR-GROUP/hpx/pull/6610>

⁹²³ <https://github.com/STELLAR-GROUP/hpx/pull/6609>

⁹²⁴ <https://github.com/STELLAR-GROUP/hpx/pull/6608>

⁹²⁵ <https://github.com/STELLAR-GROUP/hpx/pull/6607>

⁹²⁶ <https://github.com/STELLAR-GROUP/hpx/pull/6606>

⁹²⁷ <https://github.com/STELLAR-GROUP/hpx/pull/6600>

⁹²⁸ <https://github.com/STELLAR-GROUP/hpx/pull/6599>

⁹²⁹ <https://github.com/STELLAR-GROUP/hpx/pull/6598>

⁹³⁰ <https://github.com/STELLAR-GROUP/hpx/pull/6596>

⁹³¹ <https://github.com/STELLAR-GROUP/hpx/pull/6595>

⁹³² <https://github.com/STELLAR-GROUP/hpx/pull/6594>

⁹³³ <https://github.com/STELLAR-GROUP/hpx/pull/6593>

⁹³⁴ <https://github.com/STELLAR-GROUP/hpx/pull/6592>

⁹³⁵ <https://github.com/STELLAR-GROUP/hpx/pull/6591>

⁹³⁶ <https://github.com/STELLAR-GROUP/hpx/pull/6590>

⁹³⁷ <https://github.com/STELLAR-GROUP/hpx/pull/6587>

⁹³⁸ <https://github.com/STELLAR-GROUP/hpx/pull/6585>

⁹³⁹ <https://github.com/STELLAR-GROUP/hpx/pull/6583>

⁹⁴⁰ <https://github.com/STELLAR-GROUP/hpx/pull/6582>

⁹⁴¹ <https://github.com/STELLAR-GROUP/hpx/pull/6581>

⁹⁴² <https://github.com/STELLAR-GROUP/hpx/pull/6580>

- PR #6578⁹⁴³ - Remove leftovers from libfabric parcelport
- PR #6577⁹⁴⁴ - Download Boost from their own archives, not from Sourceforge
- PR #6576⁹⁴⁵ - Fix CMake warning issued since CMake V3.30
- PR #6575⁹⁴⁶ - Replace previously downloaded CDash conv.xml with local version
- PR #6570⁹⁴⁷ - Update exception_list.hpp
- PR #6569⁹⁴⁸ - Update exception_list.hpp
- PR #6567⁹⁴⁹ - Fix vectorization error on copy algorithm
- PR #6566⁹⁵⁰ - lci pp: fix messages larger than INT_MAX
- PR #6565⁹⁵¹ - Moving most of APIs from hpx::parallel::execution to hpx::execution::experimental
- PR #6564⁹⁵² - Remove superfluous HPX_MOVE()
- PR #6562⁹⁵³ - Fix doc return type of broadcast_to
- PR #6560⁹⁵⁴ - Fixes for bit_cast on 32bit systems
- PR #6559⁹⁵⁵ - Making sure that all parcelport counters are unavailable if no networking is needed or configured
- PR #6558⁹⁵⁶ - Remove CSCS CI's
- PR #6556⁹⁵⁷ - Set copyright year in generated files
- PR #6553⁹⁵⁸ - Fix omp vectorization pragma errors
- PR #6551⁹⁵⁹ - Update building_hpx.rst
- PR #6550⁹⁶⁰ - Partitioned vector updates
- PR #6549⁹⁶¹ - Fix CMake conditionals checking ENV variables
- PR #6548⁹⁶² - Update CONTRIBUTING.md
- PR #6546⁹⁶³ - Fix incorrect signature of distributed API functions
- PR #6543⁹⁶⁴ - Throwing an exception derived from std::bad_alloc on OOM conditions
- PR #6539⁹⁶⁵ - Use thread-safe cache in thread_local_caching_allocator

⁹⁴³ <https://github.com/STELLAR-GROUP/hpx/pull/6578>

⁹⁴⁴ <https://github.com/STELLAR-GROUP/hpx/pull/6577>

⁹⁴⁵ <https://github.com/STELLAR-GROUP/hpx/pull/6576>

⁹⁴⁶ <https://github.com/STELLAR-GROUP/hpx/pull/6575>

⁹⁴⁷ <https://github.com/STELLAR-GROUP/hpx/pull/6570>

⁹⁴⁸ <https://github.com/STELLAR-GROUP/hpx/pull/6569>

⁹⁴⁹ <https://github.com/STELLAR-GROUP/hpx/pull/6567>

⁹⁵⁰ <https://github.com/STELLAR-GROUP/hpx/pull/6566>

⁹⁵¹ <https://github.com/STELLAR-GROUP/hpx/pull/6565>

⁹⁵² <https://github.com/STELLAR-GROUP/hpx/pull/6564>

⁹⁵³ <https://github.com/STELLAR-GROUP/hpx/pull/6562>

⁹⁵⁴ <https://github.com/STELLAR-GROUP/hpx/pull/6560>

⁹⁵⁵ <https://github.com/STELLAR-GROUP/hpx/pull/6559>

⁹⁵⁶ <https://github.com/STELLAR-GROUP/hpx/pull/6558>

⁹⁵⁷ <https://github.com/STELLAR-GROUP/hpx/pull/6556>

⁹⁵⁸ <https://github.com/STELLAR-GROUP/hpx/pull/6553>

⁹⁵⁹ <https://github.com/STELLAR-GROUP/hpx/pull/6551>

⁹⁶⁰ <https://github.com/STELLAR-GROUP/hpx/pull/6550>

⁹⁶¹ <https://github.com/STELLAR-GROUP/hpx/pull/6549>

⁹⁶² <https://github.com/STELLAR-GROUP/hpx/pull/6548>

⁹⁶³ <https://github.com/STELLAR-GROUP/hpx/pull/6546>

⁹⁶⁴ <https://github.com/STELLAR-GROUP/hpx/pull/6543>

⁹⁶⁵ <https://github.com/STELLAR-GROUP/hpx/pull/6539>

- PR #6537⁹⁶⁶ - Update README.rst
- PR #6531⁹⁶⁷ - More fixes for the Boost package
- PR #6527⁹⁶⁸ - Improve the LCI parcelport documentation
- PR #6525⁹⁶⁹ - Addressing cmake warnings issued starting V3.30
- PR #6522⁹⁷⁰ - Fixing distance test
- PR #6520⁹⁷¹ - Adding optional handshakes to acknowledge the received data
- PR #6518⁹⁷² - Make sure that `-hpx:ini` log settings take effect
- PR #6512⁹⁷³ - Minor cleanup of `future_data`
- PR #6510⁹⁷⁴ - Include Boost as CMake subproject
- PR #6509⁹⁷⁵ - Add components documentation
- PR #6508⁹⁷⁶ - Fix typo: `s/unititialized/uninitialized/`
- PR #6507⁹⁷⁷ - Update LSU Jenkins libraries to match Rostam 3.0 with RHEL9
- PR #6503⁹⁷⁸ - Fix 2 tests on FreeBSD by initializing `freebsd_environ`
- PR #6499⁹⁷⁹ - Fix crash in `get_executable_filename` on FreeBSD
- PR #6498⁹⁸⁰ - Avoid rewriting `defines.hpp`
- PR #6497⁹⁸¹ - Contains and `contains_subrange` parallel algorithm implementation GSOC 2024
- PR #6496⁹⁸² - Prevent usage of CMake `try_run` on crosscompiling
- PR #6494⁹⁸³ - Add unit test cases and fixes for the S/R versions of the parallel algorithms
- PR #6487⁹⁸⁴ - Fixing security vulnerabilities reported by MSVC security checks
- PR #6486⁹⁸⁵ - Create `codeql.yml`
- PR #6474⁹⁸⁶ - Remove remnants of `libfabric` parcelport
- PR #6473⁹⁸⁷ - Add documentation for distributed implementations of `post`, `async`, `sync` and `dataflow`
- PR #6471⁹⁸⁸ - Add `distance.cpp` test in CMake

⁹⁶⁶ <https://github.com/STELLAR-GROUP/hpx/pull/6537>

⁹⁶⁷ <https://github.com/STELLAR-GROUP/hpx/pull/6531>

⁹⁶⁸ <https://github.com/STELLAR-GROUP/hpx/pull/6527>

⁹⁶⁹ <https://github.com/STELLAR-GROUP/hpx/pull/6525>

⁹⁷⁰ <https://github.com/STELLAR-GROUP/hpx/pull/6522>

⁹⁷¹ <https://github.com/STELLAR-GROUP/hpx/pull/6520>

⁹⁷² <https://github.com/STELLAR-GROUP/hpx/pull/6518>

⁹⁷³ <https://github.com/STELLAR-GROUP/hpx/pull/6512>

⁹⁷⁴ <https://github.com/STELLAR-GROUP/hpx/pull/6510>

⁹⁷⁵ <https://github.com/STELLAR-GROUP/hpx/pull/6509>

⁹⁷⁶ <https://github.com/STELLAR-GROUP/hpx/pull/6508>

⁹⁷⁷ <https://github.com/STELLAR-GROUP/hpx/pull/6507>

⁹⁷⁸ <https://github.com/STELLAR-GROUP/hpx/pull/6503>

⁹⁷⁹ <https://github.com/STELLAR-GROUP/hpx/pull/6499>

⁹⁸⁰ <https://github.com/STELLAR-GROUP/hpx/pull/6498>

⁹⁸¹ <https://github.com/STELLAR-GROUP/hpx/pull/6497>

⁹⁸² <https://github.com/STELLAR-GROUP/hpx/pull/6496>

⁹⁸³ <https://github.com/STELLAR-GROUP/hpx/pull/6494>

⁹⁸⁴ <https://github.com/STELLAR-GROUP/hpx/pull/6487>

⁹⁸⁵ <https://github.com/STELLAR-GROUP/hpx/pull/6486>

⁹⁸⁶ <https://github.com/STELLAR-GROUP/hpx/pull/6474>

⁹⁸⁷ <https://github.com/STELLAR-GROUP/hpx/pull/6473>

⁹⁸⁸ <https://github.com/STELLAR-GROUP/hpx/pull/6471>

- PR #6468⁹⁸⁹ - Small vector relocation
- PR #6448⁹⁹⁰ - Standardising Benchmarks, with support for nanobench as an option for its backend
- PR #6365⁹⁹¹ - Release V1.10.0
- PR #6089⁹⁹² - Implementing p2079

HPX V1.10.0 (May 29, 2024)

General changes

- The HPX documentation has seen a major overhaul for this release. We finished documenting the public local HPX API, we have added migration guides from widely used parallelization platforms to HPX (OpenMP, TBB, and MPI).
- We have added facilities enabling optimizations for trivially-relocatable types (see P1144⁹⁹³ for more details).
- We have added (and use) the `scope_xxx` helper facilities as specified by the C++ library fundamentals TS v3 (see: N4948⁹⁹⁴).
- We have added configuration options that allow to build HPX without pre-installing any prerequisites. Use `HPX_WITH_FETCH_HWLOC=On` to have [Portable Hardware Locality \(HWLOC\)](#)⁹⁹⁵ installed for you. Similarly, setting `HPX_WITH_FETCH_BOOST=On` during configuration time will install the necessary [Boost](#)⁹⁹⁶ libraries (currently V1.84.0).
- We have performed a lot of code cleanup and refactoring to improve the overall code quality and decrease compile times.
- The collective operations APIs have seen an unification, we have fixed issues and performance problems for the collectives.
- The HPX executors have seen a streamlining and some consistency changes. We have applied many performance improvements to the executor implementations that directly positively impact the performance of our parallel algorithms.
- We have added a new parcelport allowing to use Gasnet as a communication platform.
- We have added optimizations to various parcelports improving overall communication performance. This includes - amongst other things - send immediate optimizations and receiver-side zero-copy optimizations.
- Futures will now execute the associated task eagerly and inline on any wait operation if the task has not started running yet. This feature can be enabled using the `HPX_COROUTINES_WITH_THREAD_SCHEDULE_HINT_RUNS_AS_CHILD=On` configuration setting (which is *Off* by default).
- We have enabled using json files to supply configuration information through the command line. This feature can be enabled with the configuration option `HPX_COMMAND_LINE_HANDLING_WITH_JSON_CONFIGURATION_FILES=On`. This functionality depends on the external [JSON library](#)⁹⁹⁷, which can be built at configuration time by supplying `HPX_WITH_FETCH_JSON=On` to `CMake`⁹⁹⁸.

⁹⁸⁹ <https://github.com/STELLAR-GROUP/hpx/pull/6468>

⁹⁹⁰ <https://github.com/STELLAR-GROUP/hpx/pull/6448>

⁹⁹¹ <https://github.com/STELLAR-GROUP/hpx/pull/6365>

⁹⁹² <https://github.com/STELLAR-GROUP/hpx/pull/6089>

⁹⁹³ <https://wg21.link/p1144>

⁹⁹⁴ <http://wg21.link/n4948>

⁹⁹⁵ <https://www.open-mpi.org/projects/hwloc/>

⁹⁹⁶ <https://www.boost.org/>

⁹⁹⁷ <https://github.com/nlohmann/json>

⁹⁹⁸ <https://www.cmake.org>

- We have applied many fixes to our CUDA, ROCm, and SYCL build environments.

Breaking changes

- The CMake⁹⁹⁹ configuration keys SOMELIB_ROOT (e.g., BOOST_ROOT) have been renamed to Somelib_ROOT (e.g., Boost_ROOT) to avoid warnings when using newer versions of CMake¹⁰⁰⁰. Please update your scripts accordingly. For now, the old variable names are re-assigned to the new names and unset in the CMake¹⁰⁰¹ cache.

Closed issues

- Issue #6466¹⁰⁰² - No access limitations to Wiki
- Issue #6461¹⁰⁰³ - handle_received_parcel may never return
- Issue #6459¹⁰⁰⁴ - Building HPX
- Issue #6451¹⁰⁰⁵ - HPX hangs at the very end
- Issue #6446¹⁰⁰⁶ - Issue on page /manual/getting_hpx.html
- Issue #6443¹⁰⁰⁷ - PR #6435 (parcel_layer_tweaks) broke Octo-Tiger
- Issue #6440¹⁰⁰⁸ - HPX does not compile with MSVC of Visual Studio 2022 17.9+
- Issue #6437¹⁰⁰⁹ - HPX 1.9.1 does not compile on Fedora with '#pragma message: [Parallel STL message]: "Vectorized algorithm unimplemented, redirected to serial
- Issue #6419¹⁰¹⁰ - Enhancement of the macro functionalities within hpx
- Issue #6417¹⁰¹¹ - The current HPX master branch is still not compatible with Kokkos 4.0.1
- Issue #6414¹⁰¹² - Current HPX master causes segfaults within Octo-Tiger
- Issue #6412¹⁰¹³ - Clangd (Language Server) throws error for __integer_pack at pack.hpp
- Issue #6407¹⁰¹⁴ - Cannot build Kokkos 4.0.01 with current HPX master
- Issue #6405¹⁰¹⁵ - Spack Build Error with ROCm 5.7.0
- Issue #6398¹⁰¹⁶ - HPX sets affinity wrong with multiple processes per node and LCI parcelport enabled
- Issue #6392¹⁰¹⁷ - [Feature] Install dependencies using CMake

⁹⁹⁹ <https://www.cmake.org>

¹⁰⁰⁰ <https://www.cmake.org>

¹⁰⁰¹ <https://www.cmake.org>

¹⁰⁰² <https://github.com/STELLAR-GROUP/hpx/issues/6466>

¹⁰⁰³ <https://github.com/STELLAR-GROUP/hpx/issues/6461>

¹⁰⁰⁴ <https://github.com/STELLAR-GROUP/hpx/issues/6459>

¹⁰⁰⁵ <https://github.com/STELLAR-GROUP/hpx/issues/6451>

¹⁰⁰⁶ <https://github.com/STELLAR-GROUP/hpx/issues/6446>

¹⁰⁰⁷ <https://github.com/STELLAR-GROUP/hpx/issues/6443>

¹⁰⁰⁸ <https://github.com/STELLAR-GROUP/hpx/issues/6440>

¹⁰⁰⁹ <https://github.com/STELLAR-GROUP/hpx/issues/6437>

¹⁰¹⁰ <https://github.com/STELLAR-GROUP/hpx/issues/6419>

¹⁰¹¹ <https://github.com/STELLAR-GROUP/hpx/issues/6417>

¹⁰¹² <https://github.com/STELLAR-GROUP/hpx/issues/6414>

¹⁰¹³ <https://github.com/STELLAR-GROUP/hpx/issues/6412>

¹⁰¹⁴ <https://github.com/STELLAR-GROUP/hpx/issues/6407>

¹⁰¹⁵ <https://github.com/STELLAR-GROUP/hpx/issues/6405>

¹⁰¹⁶ <https://github.com/STELLAR-GROUP/hpx/issues/6398>

¹⁰¹⁷ <https://github.com/STELLAR-GROUP/hpx/issues/6392>

- Issue #6388¹⁰¹⁸ - HPX error: “Host not found” when running on Expanse with 128 nodes
- Issue #6366¹⁰¹⁹ - serialize_buffer allocator support needs adjustments
- Issue #6361¹⁰²⁰ - HPX 1.9.1 does not compile on Fedora 40
- Issue #6355¹⁰²¹ - Single page documentation is broken
- Issue #6334¹⁰²² - Segmentation fault after adding a padding in one_size_heap_list
- Issue #6329¹⁰²³ - Log hpx threads on forced shutdown
- Issue #6316¹⁰²⁴ - Build breaks on FreeBSD
- Issue #6299¹⁰²⁵ - HPX does not use distributed localities on Fugaku
- Issue #6298¹⁰²⁶ - Update config for coroutines on ARM
- Issue #6291¹⁰²⁷ - Zero-copy receive optimization disabled the invocation of direct actions
- Issue #6261¹⁰²⁸ - Add optional reading of json files for command line options
- Issue #6087¹⁰²⁹ - Support for vcpkg on Linux is broken
- Issue #5921¹⁰³⁰ - hpx::info claims that async_mpi was not built, while cmake assures its existence
- Issue #5893¹⁰³¹ - Tests fail on FreeBSD: Executable copyn_test does not exist
- Issue #5833¹⁰³² - barrier lockup
- Issue #5799¹⁰³³ - Investigate CUDA compilation problems
- Issue #5340¹⁰³⁴ - Examples do not run on Mac OSX using the M1 chip

Closed pull requests

- PR #6493¹⁰³⁵ - Fix distributed latch documentation
- PR #6492¹⁰³⁶ - Fix kokkos hpx nvcc compilation
- PR #6491¹⁰³⁷ - More fixes to handling bool arguments for collective operations
- PR #6490¹⁰³⁸ - Remove the default max cpu count
- PR #6489¹⁰³⁹ - Ensure TCP parcelport is deactivated if not needed

¹⁰¹⁸ <https://github.com/STELLAR-GROUP/hpx/issues/6388>

¹⁰¹⁹ <https://github.com/STELLAR-GROUP/hpx/issues/6366>

¹⁰²⁰ <https://github.com/STELLAR-GROUP/hpx/issues/6361>

¹⁰²¹ <https://github.com/STELLAR-GROUP/hpx/issues/6355>

¹⁰²² <https://github.com/STELLAR-GROUP/hpx/issues/6334>

¹⁰²³ <https://github.com/STELLAR-GROUP/hpx/issues/6329>

¹⁰²⁴ <https://github.com/STELLAR-GROUP/hpx/issues/6316>

¹⁰²⁵ <https://github.com/STELLAR-GROUP/hpx/issues/6299>

¹⁰²⁶ <https://github.com/STELLAR-GROUP/hpx/issues/6298>

¹⁰²⁷ <https://github.com/STELLAR-GROUP/hpx/issues/6291>

¹⁰²⁸ <https://github.com/STELLAR-GROUP/hpx/issues/6261>

¹⁰²⁹ <https://github.com/STELLAR-GROUP/hpx/issues/6087>

¹⁰³⁰ <https://github.com/STELLAR-GROUP/hpx/issues/5921>

¹⁰³¹ <https://github.com/STELLAR-GROUP/hpx/issues/5893>

¹⁰³² <https://github.com/STELLAR-GROUP/hpx/issues/5833>

¹⁰³³ <https://github.com/STELLAR-GROUP/hpx/issues/5799>

¹⁰³⁴ <https://github.com/STELLAR-GROUP/hpx/issues/5340>

¹⁰³⁵ <https://github.com/STELLAR-GROUP/hpx/pull/6493>

¹⁰³⁶ <https://github.com/STELLAR-GROUP/hpx/pull/6492>

¹⁰³⁷ <https://github.com/STELLAR-GROUP/hpx/pull/6491>

¹⁰³⁸ <https://github.com/STELLAR-GROUP/hpx/pull/6490>

¹⁰³⁹ <https://github.com/STELLAR-GROUP/hpx/pull/6489>

- PR #6488¹⁰⁴⁰ - Fixing handling of bool value type for collective operations
- PR #6485¹⁰⁴¹ - Destructive interference size
- PR #6484¹⁰⁴² - Improve performance counter error handling
- PR #6482¹⁰⁴³ - Generalize the notion of bitwise serialization
- PR #6481¹⁰⁴⁴ - Fixing use of HPX_WITH_CXX_STANDARD
- PR #6480¹⁰⁴⁵ - Remove equal_to from hpx::any
- PR #6479¹⁰⁴⁶ - Remove optimizations for certain built-in compiler intrinsics
- PR #6478¹⁰⁴⁷ - Fixing issues on MacOS
- PR #6477¹⁰⁴⁸ - lci pp: lci's github repo name changed from LC to lci
- PR #6476¹⁰⁴⁹ - Fixing binary filter test target names
- PR #6475¹⁰⁵⁰ - Fix mac os github actions
- PR #6472¹⁰⁵¹ - Troubleshoot CI hangs
- PR #6469¹⁰⁵² - improve(lci pp): more options to control the LCI parcelport
- PR #6467¹⁰⁵³ - Bump jwlawson/actions-setup-cmake from 1.14 to 2.0
- PR #6464¹⁰⁵⁴ - Update docs of "Writing distributed applications" page
- PR #6463¹⁰⁵⁵ - Revert "Always return outermost thread id"
- PR #6458¹⁰⁵⁶ - Reduce test workload to fix CI/CD time-out
- PR #6457¹⁰⁵⁷ - replace boost::array with std::array and update file name
- PR #6456¹⁰⁵⁸ - Move APEX CI to rostam
- PR #6455¹⁰⁵⁹ - Fixing compilation if HPX_HAVE_THREAD_QUEUE_WAITTIME is defined
- PR #6454¹⁰⁶⁰ - Update perftests reference measurements
- PR #6453¹⁰⁶¹ - Update supported platforms of Manual/Prerequisites page
- PR #6452¹⁰⁶² - Fix nvcc crashes in transform_stream.cu and synchronize.cu

¹⁰⁴⁰ <https://github.com/STELLAR-GROUP/hpx/pull/6488>

¹⁰⁴¹ <https://github.com/STELLAR-GROUP/hpx/pull/6485>

¹⁰⁴² <https://github.com/STELLAR-GROUP/hpx/pull/6484>

¹⁰⁴³ <https://github.com/STELLAR-GROUP/hpx/pull/6482>

¹⁰⁴⁴ <https://github.com/STELLAR-GROUP/hpx/pull/6481>

¹⁰⁴⁵ <https://github.com/STELLAR-GROUP/hpx/pull/6480>

¹⁰⁴⁶ <https://github.com/STELLAR-GROUP/hpx/pull/6479>

¹⁰⁴⁷ <https://github.com/STELLAR-GROUP/hpx/pull/6478>

¹⁰⁴⁸ <https://github.com/STELLAR-GROUP/hpx/pull/6477>

¹⁰⁴⁹ <https://github.com/STELLAR-GROUP/hpx/pull/6476>

¹⁰⁵⁰ <https://github.com/STELLAR-GROUP/hpx/pull/6475>

¹⁰⁵¹ <https://github.com/STELLAR-GROUP/hpx/pull/6472>

¹⁰⁵² <https://github.com/STELLAR-GROUP/hpx/pull/6469>

¹⁰⁵³ <https://github.com/STELLAR-GROUP/hpx/pull/6467>

¹⁰⁵⁴ <https://github.com/STELLAR-GROUP/hpx/pull/6464>

¹⁰⁵⁵ <https://github.com/STELLAR-GROUP/hpx/pull/6463>

¹⁰⁵⁶ <https://github.com/STELLAR-GROUP/hpx/pull/6458>

¹⁰⁵⁷ <https://github.com/STELLAR-GROUP/hpx/pull/6457>

¹⁰⁵⁸ <https://github.com/STELLAR-GROUP/hpx/pull/6456>

¹⁰⁵⁹ <https://github.com/STELLAR-GROUP/hpx/pull/6455>

¹⁰⁶⁰ <https://github.com/STELLAR-GROUP/hpx/pull/6454>

¹⁰⁶¹ <https://github.com/STELLAR-GROUP/hpx/pull/6453>

¹⁰⁶² <https://github.com/STELLAR-GROUP/hpx/pull/6452>

- PR #6450¹⁰⁶³ - Fix git tag name in Getting HPX page
- PR #6449¹⁰⁶⁴ - LCI parcelport: add yield to potentially infinite retry loop
- PR #6447¹⁰⁶⁵ - Use compressed ptr in schedulers when 128 atomics are not lockfree
- PR #6445¹⁰⁶⁶ - Fix agas addressing cache
- PR #6444¹⁰⁶⁷ - Update CTestConfig.cmake
- PR #6442¹⁰⁶⁸ - Update CMakeLists.txt
- PR #6441¹⁰⁶⁹ - Minor documentation fixes
- PR #6439¹⁰⁷⁰ - Optimizing use of certain #includes
- PR #6438¹⁰⁷¹ - Bump jwlawson/actions-setup-cmake from 1.14 to 2.0
- PR #6436¹⁰⁷² - Update docs
- PR #6435¹⁰⁷³ - Parcel layer tweaks
- PR #6434¹⁰⁷⁴ - improve termination detection: removing lock from critical path
- PR #6433¹⁰⁷⁵ - Use shared mutex for resolve_locality procedure
- PR #6432¹⁰⁷⁶ - Module cleanup up to level 30
- PR #6429¹⁰⁷⁷ - Making sure HPX_WITH_ASYNC_MPI is reported properly
- PR #6427¹⁰⁷⁸ - Modifying CMakeLists to copy libhwloc-15.dll to the binary folder in Windows, independently
- PR #6425¹⁰⁷⁹ - Fix macOS failing test
- PR #6424¹⁰⁸⁰ - Adding option for downloading Boost using CMake FetchContent
- PR #6423¹⁰⁸¹ - Move adjacent_difference to numeric header file
- PR #6422¹⁰⁸² - Adding steal-half functionalities to work-requesting scheduler
- PR #6421¹⁰⁸³ - Bump actions/checkout from 2 to 4
- PR #6418¹⁰⁸⁴ - Working around nvcc problems to use CTAD
- PR #6416¹⁰⁸⁵ - Change run_as_os_thread deprecation forwarding due to hipcc compilation issue

¹⁰⁶³ <https://github.com/STELLAR-GROUP/hpx/pull/6450>

¹⁰⁶⁴ <https://github.com/STELLAR-GROUP/hpx/pull/6449>

¹⁰⁶⁵ <https://github.com/STELLAR-GROUP/hpx/pull/6447>

¹⁰⁶⁶ <https://github.com/STELLAR-GROUP/hpx/pull/6445>

¹⁰⁶⁷ <https://github.com/STELLAR-GROUP/hpx/pull/6444>

¹⁰⁶⁸ <https://github.com/STELLAR-GROUP/hpx/pull/6442>

¹⁰⁶⁹ <https://github.com/STELLAR-GROUP/hpx/pull/6441>

¹⁰⁷⁰ <https://github.com/STELLAR-GROUP/hpx/pull/6439>

¹⁰⁷¹ <https://github.com/STELLAR-GROUP/hpx/pull/6438>

¹⁰⁷² <https://github.com/STELLAR-GROUP/hpx/pull/6436>

¹⁰⁷³ <https://github.com/STELLAR-GROUP/hpx/pull/6435>

¹⁰⁷⁴ <https://github.com/STELLAR-GROUP/hpx/pull/6434>

¹⁰⁷⁵ <https://github.com/STELLAR-GROUP/hpx/pull/6433>

¹⁰⁷⁶ <https://github.com/STELLAR-GROUP/hpx/pull/6432>

¹⁰⁷⁷ <https://github.com/STELLAR-GROUP/hpx/pull/6429>

¹⁰⁷⁸ <https://github.com/STELLAR-GROUP/hpx/pull/6427>

¹⁰⁷⁹ <https://github.com/STELLAR-GROUP/hpx/pull/6425>

¹⁰⁸⁰ <https://github.com/STELLAR-GROUP/hpx/pull/6424>

¹⁰⁸¹ <https://github.com/STELLAR-GROUP/hpx/pull/6423>

¹⁰⁸² <https://github.com/STELLAR-GROUP/hpx/pull/6422>

¹⁰⁸³ <https://github.com/STELLAR-GROUP/hpx/pull/6421>

¹⁰⁸⁴ <https://github.com/STELLAR-GROUP/hpx/pull/6418>

¹⁰⁸⁵ <https://github.com/STELLAR-GROUP/hpx/pull/6416>

- PR #6415¹⁰⁸⁶ - Attempting to avoid segfault in OctoTiger during initialization
- PR #6413¹⁰⁸⁷ - Always return outermost thread id
- PR #6411¹⁰⁸⁸ - Minor refactoring and fixes to the LCI parcelport and pingpong_performance2 benchmark
- PR #6410¹⁰⁸⁹ - Adding scope_xxx from library fundamentals TS v3
- PR #6409¹⁰⁹⁰ - Working around CUDA issue
- PR #6408¹⁰⁹¹ - Tightening up collective operation semantics
- PR #6406¹⁰⁹² - Working around ROCm compiler issue
- PR #6404¹⁰⁹³ - Allow to disable use of [[no_unique_address]] attribute
- PR #6403¹⁰⁹⁴ - Fixing copyright year
- PR #6402¹⁰⁹⁵ - fix(lci pp): fix deadlocks with too many failed sends
- PR #6401¹⁰⁹⁶ - fix(lci pp): fix the null_thread_id bug in the LCI parcelport
- PR #6400¹⁰⁹⁷ - Fix the affinity setting bug when using LCI pp and multiple localities per node
- PR #6397¹⁰⁹⁸ - Change API header titles and info
- PR #6396¹⁰⁹⁹ - Making is_bitwise_serializable SFINAE-friendly
- PR #6395¹¹⁰⁰ - Adapt amount of collective testing
- PR #6394¹¹⁰¹ - Adding option for installing Hwloc using CMake FetchContent
- PR #6393¹¹⁰² - Optionally disable caching allocator
- PR #6391¹¹⁰³ - Cleaning up collective operations
- PR #6390¹¹⁰⁴ - Making function local constexpr variables non-static
- PR #6389¹¹⁰⁵ - Disable resolving hostnames if TCP is disabled
- PR #6387¹¹⁰⁶ - Need to break out of the loop when searching the suffixes.
- PR #6384¹¹⁰⁷ - Fixing allocation/deallocation mismatch in serialize_buffer
- PR #6383¹¹⁰⁸ - Enable fork_join_executor to handle return values from scheduled functions

¹⁰⁸⁶ <https://github.com/STELLAR-GROUP/hpx/pull/6415>

¹⁰⁸⁷ <https://github.com/STELLAR-GROUP/hpx/pull/6413>

¹⁰⁸⁸ <https://github.com/STELLAR-GROUP/hpx/pull/6411>

¹⁰⁸⁹ <https://github.com/STELLAR-GROUP/hpx/pull/6410>

¹⁰⁹⁰ <https://github.com/STELLAR-GROUP/hpx/pull/6409>

¹⁰⁹¹ <https://github.com/STELLAR-GROUP/hpx/pull/6408>

¹⁰⁹² <https://github.com/STELLAR-GROUP/hpx/pull/6406>

¹⁰⁹³ <https://github.com/STELLAR-GROUP/hpx/pull/6404>

¹⁰⁹⁴ <https://github.com/STELLAR-GROUP/hpx/pull/6403>

¹⁰⁹⁵ <https://github.com/STELLAR-GROUP/hpx/pull/6402>

¹⁰⁹⁶ <https://github.com/STELLAR-GROUP/hpx/pull/6401>

¹⁰⁹⁷ <https://github.com/STELLAR-GROUP/hpx/pull/6400>

¹⁰⁹⁸ <https://github.com/STELLAR-GROUP/hpx/pull/6397>

¹⁰⁹⁹ <https://github.com/STELLAR-GROUP/hpx/pull/6396>

¹¹⁰⁰ <https://github.com/STELLAR-GROUP/hpx/pull/6395>

¹¹⁰¹ <https://github.com/STELLAR-GROUP/hpx/pull/6394>

¹¹⁰² <https://github.com/STELLAR-GROUP/hpx/pull/6393>

¹¹⁰³ <https://github.com/STELLAR-GROUP/hpx/pull/6391>

¹¹⁰⁴ <https://github.com/STELLAR-GROUP/hpx/pull/6390>

¹¹⁰⁵ <https://github.com/STELLAR-GROUP/hpx/pull/6389>

¹¹⁰⁶ <https://github.com/STELLAR-GROUP/hpx/pull/6387>

¹¹⁰⁷ <https://github.com/STELLAR-GROUP/hpx/pull/6384>

¹¹⁰⁸ <https://github.com/STELLAR-GROUP/hpx/pull/6383>

- PR #6381¹¹⁰⁹ - Consistently treat conflicting parameters provided by executors and parameter objects
- PR #6380¹¹¹⁰ - Fixing setting an annotation for an execution policy
- PR #6378¹¹¹¹ - Allowing to disable signal handlers
- PR #6377¹¹¹² - Fix gasnet-related test failures
- PR #6375¹¹¹³ - Update LSU Jenkins with 2023-10 libraries
- PR #6374¹¹¹⁴ - Investigate builder gasnet failure
- PR #6373¹¹¹⁵ - Fixing communicator API, adding docs
- PR #6372¹¹¹⁶ - Fix resource partitioner tests for small thread count
- PR #6371¹¹¹⁷ - Fix jacobi omp examples.
- PR #6370¹¹¹⁸ - improve one_size_heap_list: use rwlock to speedup the allocation/free
- PR #6369¹¹¹⁹ - working issue with MPI_CC / CC conflict in automake
- PR #6368¹¹²⁰ - Making sure serialize_buffer properly destroys buffer, if needed.
- PR #6367¹¹²¹ - Fix parallel relocation test
- PR #6364¹¹²² - Relocation variants
- PR #6363¹¹²³ - Update the lci parcelport to use LCI v1.7.6
- PR #6362¹¹²⁴ - Fixing compilation problems on 32 Linux systems
- PR #6360¹¹²⁵ - Fix broken links in docs: PDF, Single HTML page, Dependency report
- PR #6359¹¹²⁶ - Fix header file links in Public API page
- PR #6358¹¹²⁷ - Fix CMake find_library for HWLOC
- PR #6357¹¹²⁸ - Replace Custom Benchmarking Code with Nanobench
- PR #6356¹¹²⁹ - Fixed matrix multiplication example output
- PR #6354¹¹³⁰ - Fix broken links for header files in Public API page
- PR #6353¹¹³¹ - Enable using std::reference_wrapper with executor parameters

¹¹⁰⁹ <https://github.com/STELLAR-GROUP/hpx/pull/6381>

¹¹¹⁰ <https://github.com/STELLAR-GROUP/hpx/pull/6380>

¹¹¹¹ <https://github.com/STELLAR-GROUP/hpx/pull/6378>

¹¹¹² <https://github.com/STELLAR-GROUP/hpx/pull/6377>

¹¹¹³ <https://github.com/STELLAR-GROUP/hpx/pull/6375>

¹¹¹⁴ <https://github.com/STELLAR-GROUP/hpx/pull/6374>

¹¹¹⁵ <https://github.com/STELLAR-GROUP/hpx/pull/6373>

¹¹¹⁶ <https://github.com/STELLAR-GROUP/hpx/pull/6372>

¹¹¹⁷ <https://github.com/STELLAR-GROUP/hpx/pull/6371>

¹¹¹⁸ <https://github.com/STELLAR-GROUP/hpx/pull/6370>

¹¹¹⁹ <https://github.com/STELLAR-GROUP/hpx/pull/6369>

¹¹²⁰ <https://github.com/STELLAR-GROUP/hpx/pull/6368>

¹¹²¹ <https://github.com/STELLAR-GROUP/hpx/pull/6367>

¹¹²² <https://github.com/STELLAR-GROUP/hpx/pull/6364>

¹¹²³ <https://github.com/STELLAR-GROUP/hpx/pull/6363>

¹¹²⁴ <https://github.com/STELLAR-GROUP/hpx/pull/6362>

¹¹²⁵ <https://github.com/STELLAR-GROUP/hpx/pull/6360>

¹¹²⁶ <https://github.com/STELLAR-GROUP/hpx/pull/6359>

¹¹²⁷ <https://github.com/STELLAR-GROUP/hpx/pull/6358>

¹¹²⁸ <https://github.com/STELLAR-GROUP/hpx/pull/6357>

¹¹²⁹ <https://github.com/STELLAR-GROUP/hpx/pull/6356>

¹¹³⁰ <https://github.com/STELLAR-GROUP/hpx/pull/6354>

¹¹³¹ <https://github.com/STELLAR-GROUP/hpx/pull/6353>

- PR #6352¹¹³² - Add Public distributed API documentation
- PR #6350¹¹³³ - Make coverage work with Jenkins Github Branch Source plugin
- PR #6349¹¹³⁴ - Moving hpx::threads::run_as_xxx to namespace hpx
- PR #6348¹¹³⁵ - Adding `-exclusive` to launching tests on rostam
- PR #6346¹¹³⁶ - changed chat link to discord
- PR #6344¹¹³⁷ - uninitialized_relocate w/ type_support primitive
- PR #6343¹¹³⁸ - Bump actions/checkout from 3 to 4
- PR #6342¹¹³⁹ - Fix HPX-APEX cmake integration
- PR #6341¹¹⁴⁰ - Fix shared_future_continuation_order regression test
- PR #6340¹¹⁴¹ - Log alive hpx threads on exit
- PR #6339¹¹⁴² - Add coverage testing on Jenkins
- PR #6338¹¹⁴³ - Fixing HPX_CURRENT_SOURCE_LOCATION when std::source_location exists
- PR #6337¹¹⁴⁴ - Remove aurianer, biddisco, and msimberg from codeowners
- PR #6336¹¹⁴⁵ - More cleaning up for module levels 19-20
- PR #6335¹¹⁴⁶ - Finalize the MPI docs of the Migration Guide
- PR #6332¹¹⁴⁷ - More fixes for CMake V3.27
- PR #6330¹¹⁴⁸ - Adding basic logging to collective operations
- PR #6328¹¹⁴⁹ - Cleanup previous patch adapting to CMake V3.27
- PR #6327¹¹⁵⁰ - Modernize modules in level 17 and 18
- PR #6324¹¹⁵¹ - P1144 Relocation primitives
- PR #6321¹¹⁵² - Ensure hpx_main is a proper thread_function
- PR #6320¹¹⁵³ - Fixing cyclic dependencies in naming and agas modules
- PR #6319¹¹⁵⁴ - Generate git tag if needed but it is not available

¹¹³² <https://github.com/STELLAR-GROUP/hpx/pull/6352>

¹¹³³ <https://github.com/STELLAR-GROUP/hpx/pull/6350>

¹¹³⁴ <https://github.com/STELLAR-GROUP/hpx/pull/6349>

¹¹³⁵ <https://github.com/STELLAR-GROUP/hpx/pull/6348>

¹¹³⁶ <https://github.com/STELLAR-GROUP/hpx/pull/6346>

¹¹³⁷ <https://github.com/STELLAR-GROUP/hpx/pull/6344>

¹¹³⁸ <https://github.com/STELLAR-GROUP/hpx/pull/6343>

¹¹³⁹ <https://github.com/STELLAR-GROUP/hpx/pull/6342>

¹¹⁴⁰ <https://github.com/STELLAR-GROUP/hpx/pull/6341>

¹¹⁴¹ <https://github.com/STELLAR-GROUP/hpx/pull/6340>

¹¹⁴² <https://github.com/STELLAR-GROUP/hpx/pull/6339>

¹¹⁴³ <https://github.com/STELLAR-GROUP/hpx/pull/6338>

¹¹⁴⁴ <https://github.com/STELLAR-GROUP/hpx/pull/6337>

¹¹⁴⁵ <https://github.com/STELLAR-GROUP/hpx/pull/6336>

¹¹⁴⁶ <https://github.com/STELLAR-GROUP/hpx/pull/6335>

¹¹⁴⁷ <https://github.com/STELLAR-GROUP/hpx/pull/6332>

¹¹⁴⁸ <https://github.com/STELLAR-GROUP/hpx/pull/6330>

¹¹⁴⁹ <https://github.com/STELLAR-GROUP/hpx/pull/6328>

¹¹⁵⁰ <https://github.com/STELLAR-GROUP/hpx/pull/6327>

¹¹⁵¹ <https://github.com/STELLAR-GROUP/hpx/pull/6324>

¹¹⁵² <https://github.com/STELLAR-GROUP/hpx/pull/6321>

¹¹⁵³ <https://github.com/STELLAR-GROUP/hpx/pull/6320>

¹¹⁵⁴ <https://github.com/STELLAR-GROUP/hpx/pull/6319>

- PR #6317¹¹⁵⁵ - Fixing linker problem on FreeBSD
- PR #6315¹¹⁵⁶ - acknowledge triv-rel and nothrow-rel types
- PR #6314¹¹⁵⁷ - Relocation algorithms Clean
- PR #6313¹¹⁵⁸ - Trivial relocation of c-v-ref-array types
- PR #6312¹¹⁵⁹ - Fixing warning/error
- PR #6311¹¹⁶⁰ - Adding executor parallel invoke CPOs
- PR #6310¹¹⁶¹ - Define HPX_COMPUTE_CODE in builds with SYCL
- PR #6309¹¹⁶² - Making sure changed number of cores is propagated to executor
- PR #6308¹¹⁶³ - openshmem-parcelport initial import
- PR #6306¹¹⁶⁴ - The hpxcxx script was broken such that it could only compile for _release
- PR #6305¹¹⁶⁵ - Adapting build system for CMake V3.27
- PR #6304¹¹⁶⁶ - Fixing an integral type mismatch warning
- PR #6303¹¹⁶⁷ - omp for default vectorization
- PR #6301¹¹⁶⁸ - Add MPI migration guide
- PR #6294¹¹⁶⁹ - Add internal reference counting to semaphores
- PR #6286¹¹⁷⁰ - Simd helpers
- PR #6280¹¹⁷¹ - Add TBB to HPX documentation in Migration Guide
- PR #6276¹¹⁷² - Add dependabot.yml
- PR #6275¹¹⁷³ - Revert “Move dependabot.yml into correct directory”
- PR #6272¹¹⁷⁴ - set thread name for linux
- PR #6271¹¹⁷⁵ - Uninitialised algorithms, move using std::memcpy
- PR #6270¹¹⁷⁶ - Bump jwlawson/actions-setup-cmake from 1.9 to 1.14
- PR #6269¹¹⁷⁷ - Bump actions/checkout from 2 to 3

¹¹⁵⁵ <https://github.com/STELLAR-GROUP/hpx/pull/6317>

¹¹⁵⁶ <https://github.com/STELLAR-GROUP/hpx/pull/6315>

¹¹⁵⁷ <https://github.com/STELLAR-GROUP/hpx/pull/6314>

¹¹⁵⁸ <https://github.com/STELLAR-GROUP/hpx/pull/6313>

¹¹⁵⁹ <https://github.com/STELLAR-GROUP/hpx/pull/6312>

¹¹⁶⁰ <https://github.com/STELLAR-GROUP/hpx/pull/6311>

¹¹⁶¹ <https://github.com/STELLAR-GROUP/hpx/pull/6310>

¹¹⁶² <https://github.com/STELLAR-GROUP/hpx/pull/6309>

¹¹⁶³ <https://github.com/STELLAR-GROUP/hpx/pull/6308>

¹¹⁶⁴ <https://github.com/STELLAR-GROUP/hpx/pull/6306>

¹¹⁶⁵ <https://github.com/STELLAR-GROUP/hpx/pull/6305>

¹¹⁶⁶ <https://github.com/STELLAR-GROUP/hpx/pull/6304>

¹¹⁶⁷ <https://github.com/STELLAR-GROUP/hpx/pull/6303>

¹¹⁶⁸ <https://github.com/STELLAR-GROUP/hpx/pull/6301>

¹¹⁶⁹ <https://github.com/STELLAR-GROUP/hpx/pull/6294>

¹¹⁷⁰ <https://github.com/STELLAR-GROUP/hpx/pull/6286>

¹¹⁷¹ <https://github.com/STELLAR-GROUP/hpx/pull/6280>

¹¹⁷² <https://github.com/STELLAR-GROUP/hpx/pull/6276>

¹¹⁷³ <https://github.com/STELLAR-GROUP/hpx/pull/6275>

¹¹⁷⁴ <https://github.com/STELLAR-GROUP/hpx/pull/6272>

¹¹⁷⁵ <https://github.com/STELLAR-GROUP/hpx/pull/6271>

¹¹⁷⁶ <https://github.com/STELLAR-GROUP/hpx/pull/6270>

¹¹⁷⁷ <https://github.com/STELLAR-GROUP/hpx/pull/6269>

- PR #6268¹¹⁷⁸ - Move dependabot.yml into correct directory
- PR #6265¹¹⁷⁹ - Create dependabot.yml
- PR #6264¹¹⁸⁰ - hpx::is_trivially_relocatable trait implementation
- PR #6263¹¹⁸¹ - Adding support for reading json configuration files for command line options
- PR #6249¹¹⁸² - Implement the send immediate optimization for the MPI parcelport.
- PR #6237¹¹⁸³ - Improve compilation performance
- PR #6234¹¹⁸⁴ - Adding release notes page for next release
- PR #6233¹¹⁸⁵ - Moving is_relocatable to namespace hpx
- PR #6230¹¹⁸⁶ - gasnet based parcelport
- PR #6226¹¹⁸⁷ - Re-enable dependency on segmented algorithms on CircleCI
- PR #6220¹¹⁸⁸ - Add execution on
- PR #6212¹¹⁸⁹ - Initial trait definition for *relocatable*
- PR #6199¹¹⁹⁰ - added support for unseq, par_unseq for hpx::make_heap algorithm
- PR #6173¹¹⁹¹ - C++ modules
- PR #6122¹¹⁹² - Add Module support
- PR #6099¹¹⁹³ - Futures attempt to execute threads directly if those have not started executing
- PR #6050¹¹⁹⁴ - Investigating partitioned_vector problems
- PR #5988¹¹⁹⁵ - Adding CI configuration for DGX-A100 at LSU
- PR #5910¹¹⁹⁶ - Improve MPI initialization
- PR #5845¹¹⁹⁷ - Adding local work requesting scheduler that is based on message passing internally

¹¹⁷⁸ <https://github.com/STELLAR-GROUP/hpx/pull/6268>

¹¹⁷⁹ <https://github.com/STELLAR-GROUP/hpx/pull/6265>

¹¹⁸⁰ <https://github.com/STELLAR-GROUP/hpx/pull/6264>

¹¹⁸¹ <https://github.com/STELLAR-GROUP/hpx/pull/6263>

¹¹⁸² <https://github.com/STELLAR-GROUP/hpx/pull/6249>

¹¹⁸³ <https://github.com/STELLAR-GROUP/hpx/pull/6237>

¹¹⁸⁴ <https://github.com/STELLAR-GROUP/hpx/pull/6234>

¹¹⁸⁵ <https://github.com/STELLAR-GROUP/hpx/pull/6233>

¹¹⁸⁶ <https://github.com/STELLAR-GROUP/hpx/pull/6230>

¹¹⁸⁷ <https://github.com/STELLAR-GROUP/hpx/pull/6226>

¹¹⁸⁸ <https://github.com/STELLAR-GROUP/hpx/pull/6220>

¹¹⁸⁹ <https://github.com/STELLAR-GROUP/hpx/pull/6212>

¹¹⁹⁰ <https://github.com/STELLAR-GROUP/hpx/pull/6199>

¹¹⁹¹ <https://github.com/STELLAR-GROUP/hpx/pull/6173>

¹¹⁹² <https://github.com/STELLAR-GROUP/hpx/pull/6122>

¹¹⁹³ <https://github.com/STELLAR-GROUP/hpx/pull/6099>

¹¹⁹⁴ <https://github.com/STELLAR-GROUP/hpx/pull/6050>

¹¹⁹⁵ <https://github.com/STELLAR-GROUP/hpx/pull/5988>

¹¹⁹⁶ <https://github.com/STELLAR-GROUP/hpx/pull/5910>

¹¹⁹⁷ <https://github.com/STELLAR-GROUP/hpx/pull/5845>

HPX V1.9.1 (August 4, 2023)

General changes

This point release fixes a couple of problems reported for the V1.9.0 release. Most importantly, we fixed various occasional hanging during startup and shutdown in distributed scenarios. We also added support for zero-copy serialization on the receiving side to the TCP, MPI, and LCI parcelports. Last but not least, we have added support for Visual Studio 2019 and gcc using MINGW on Windows, and also support for gcc V13 and clang V15.

HPX headers are now made consistently named the same as their standard library counterparts, e.g. `#include <thread>` now corresponds to `#include <hpx/thread.hpp>`. This significantly simplifies porting existing standards conforming codes to HPX.

A lot of work has been done to improve and optimize our network communication layers. Primary focus of this work was on the LCI parcelport, but we have also cleaned up and improved the MPI parcelport.

Additionally, we have continued working on our documentation. The main focus here was on completing the API documentation of the most important API functions. We have started adding migration guides for people interested in moving their codes away from other, commonplace parallelization frameworks like OpenMP.

Breaking changes

None

Closed issues

- [Issue #6155](https://github.com/STELLAR-GROUP/hpx/issues/6155)¹¹⁹⁸ - `hpxcxx` and `hpxrun.py` do not work if `HPX_WITH_TESTS=OFF`
- [Issue #6164](https://github.com/STELLAR-GROUP/hpx/issues/6164)¹¹⁹⁹ - `HPX_WITH_DATAPAR_BACKEND=EVE` causes compile errors with C++17
- [Issue #6175](https://github.com/STELLAR-GROUP/hpx/issues/6175)¹²⁰⁰ - Make sure all our parallel algorithms accept the predicates by value
- [Issue #6194](https://github.com/STELLAR-GROUP/hpx/issues/6194)¹²⁰¹ - `tests.regressions.threads.threads_all_1422` failed at Perlmutter
- [Issue #6198](https://github.com/STELLAR-GROUP/hpx/issues/6198)¹²⁰² - `set_intersection/set_difference` fails when run with `execution::par`
- [Issue #6214](https://github.com/STELLAR-GROUP/hpx/issues/6214)¹²⁰³ - Broken Links to the Documentation page in `readme.rst`
- [Issue #6217](https://github.com/STELLAR-GROUP/hpx/issues/6217)¹²⁰⁴ - `hpx::make_heap` does not terminate when `exPolicy` is `par` (or `par_unseq`) and size of vector is 4
- [Issue #6246](https://github.com/STELLAR-GROUP/hpx/issues/6246)¹²⁰⁵ - HPX fails to compile under `cxx 20` (fresh system)
- [Issue #6247](https://github.com/STELLAR-GROUP/hpx/issues/6247)¹²⁰⁶ - HPX 1.9.0 does not compile with GCC on Windows
- [Issue #6282](https://github.com/STELLAR-GROUP/hpx/issues/6282)¹²⁰⁷ - The “attach-debugger” option is broken on the current master branch.

¹¹⁹⁸ <https://github.com/STELLAR-GROUP/hpx/issues/6155>

¹¹⁹⁹ <https://github.com/STELLAR-GROUP/hpx/issues/6164>

¹²⁰⁰ <https://github.com/STELLAR-GROUP/hpx/issues/6175>

¹²⁰¹ <https://github.com/STELLAR-GROUP/hpx/issues/6194>

¹²⁰² <https://github.com/STELLAR-GROUP/hpx/issues/6198>

¹²⁰³ <https://github.com/STELLAR-GROUP/hpx/issues/6214>

¹²⁰⁴ <https://github.com/STELLAR-GROUP/hpx/issues/6217>

¹²⁰⁵ <https://github.com/STELLAR-GROUP/hpx/issues/6246>

¹²⁰⁶ <https://github.com/STELLAR-GROUP/hpx/issues/6247>

¹²⁰⁷ <https://github.com/STELLAR-GROUP/hpx/issues/6282>

Closed pull requests

- PR #6219¹²⁰⁸ - Cleaning up #includes in hpx/ folder
- PR #6223¹²⁰⁹ - Move documentation from README.rst to index.rst files under libs directory
- PR #6229¹²¹⁰ - Adding zero-copy support on the receiving end of the TCP and MPI parcel ports
- PR #6231¹²¹¹ - Remove deprecated email from release procedure
- PR #6235¹²¹² - Modernize more modules (levels 12-16)
- PR #6236¹²¹³ - Attempt to resolve occasional shutdown hangs in distributed operation
- PR #6239¹²¹⁴ - Fix Optimizing HPX applications page of Manual
- PR #6241¹²¹⁵ - LCI parcelport: Refactor, add more variants, zero copy receives.
- PR #6242¹²¹⁶ - updated deprecated headers
- PR #6243¹²¹⁷ - Adding github action builders using VS2019
- PR #6248¹²¹⁸ - Fix CUDA/HIP Jenkins pipelines
- PR #6250¹²¹⁹ - Resolve gcc problems on Windows
- PR #6251¹²²⁰ - Attempting to fix problems in barrier causing hangs
- PR #6253¹²²¹ - Modernize set_thread_name on Windows
- PR #6256¹²²² - Fix nvcc/gcc-10 (Octo-Tiger) compilation issue
- PR #6257¹²²³ - Cmake Tests: Delete operator check for size_t arg
- PR #6258¹²²⁴ - Rewriting wait_some to circumvent data races causing hangs
- PR #6260¹²²⁵ - Add migration guide to manual
- PR #6262¹²²⁶ - Fixing wrong command line options in local command line handling
- PR #6266¹²²⁷ - Attempt to resolve occasional hang in run_loop
- PR #6267¹²²⁸ - Attempting to fix migration tests
- PR #6278¹²²⁹ - Making sure the future's shared state doesn't go out of scope prematurely

¹²⁰⁸ <https://github.com/STELLAR-GROUP/hpx/pull/6219>

¹²⁰⁹ <https://github.com/STELLAR-GROUP/hpx/pull/6223>

¹²¹⁰ <https://github.com/STELLAR-GROUP/hpx/pull/6229>

¹²¹¹ <https://github.com/STELLAR-GROUP/hpx/pull/6231>

¹²¹² <https://github.com/STELLAR-GROUP/hpx/pull/6235>

¹²¹³ <https://github.com/STELLAR-GROUP/hpx/pull/6236>

¹²¹⁴ <https://github.com/STELLAR-GROUP/hpx/pull/6239>

¹²¹⁵ <https://github.com/STELLAR-GROUP/hpx/pull/6241>

¹²¹⁶ <https://github.com/STELLAR-GROUP/hpx/pull/6242>

¹²¹⁷ <https://github.com/STELLAR-GROUP/hpx/pull/6243>

¹²¹⁸ <https://github.com/STELLAR-GROUP/hpx/pull/6248>

¹²¹⁹ <https://github.com/STELLAR-GROUP/hpx/pull/6250>

¹²²⁰ <https://github.com/STELLAR-GROUP/hpx/pull/6251>

¹²²¹ <https://github.com/STELLAR-GROUP/hpx/pull/6253>

¹²²² <https://github.com/STELLAR-GROUP/hpx/pull/6256>

¹²²³ <https://github.com/STELLAR-GROUP/hpx/pull/6257>

¹²²⁴ <https://github.com/STELLAR-GROUP/hpx/pull/6258>

¹²²⁵ <https://github.com/STELLAR-GROUP/hpx/pull/6260>

¹²²⁶ <https://github.com/STELLAR-GROUP/hpx/pull/6262>

¹²²⁷ <https://github.com/STELLAR-GROUP/hpx/pull/6266>

¹²²⁸ <https://github.com/STELLAR-GROUP/hpx/pull/6267>

¹²²⁹ <https://github.com/STELLAR-GROUP/hpx/pull/6278>

- PR #6279¹²³⁰ - Re-expose error names
- PR #6281¹²³¹ - Creating directory for file copy
- PR #6283¹²³² - Consistently #include unistd.h for _POSIX_VERSION

HPX V1.9.0 (May 2, 2023)

General changes

- Added RISC-V 64bit support. HPX is now compatible with RISC-V architectures which have revolutionized the HPC world.
- LCI parcelport has been optimized to transfer parcels with fewer messages and use the HPX resource partitioner for its progress thread allocation. It should generally provide better performance than before. It also removes its dependency on the MPI library.
- HPX dependency on Boost was further relaxed by replacing headers from Boost.Range, Boost.Tokenizer and Boost.Lockfree.
- Improvements took place on our parallel algorithms implementation.
- Our Senders/Receivers (P2300) integration was extended:
 - Coroutines were integrated with senders/receivers.

`get_completion_signatures` now works with awaitable senders. - `with_awaitable_senders` allows the passed senders to retrieve the value i.e. senders are transparently awaitable from within a coroutine. - `when_all_vector` was added.
- `sync_wait` and `sync_wait_with_variant` sender consumers were added. The user can now initiate the execution of their asynchronous pipeline by blocking the current thread that executes the `main()` function until the result is retrieved.
- The combinators for futures (a.k.a. `async_combinators`) `when_*`, `wait_*`, `wait_*_nothrow` were turned into CPOs allowing for end-user customization. For more information on the `async_combinators` refer to the documentation, https://hpx-docs.stellar-group.org/latest/html/libs/core/async_combinators/docs/index.html?highlight=combinators.
- The new datapar backend SVE allows `simd` and `par_simd` execution policies to exploit dataparallelism in the processors that have SVE vector registers like A64FX and Neoverse V1.
- The documentation for parallel algorithms, container algorithms was further improved. The Public API page was vastly enriched.
- Copy button shortkey was added at the top-right of code-blocks.
- Pragma directive that reports warnings as errors on MSVC was fixed.
- Command line argument `--hpx:loopback_network` was added to facilitate debugging with networks.
- We added an HPX-SYCL integration, allowing users to obtain HPX futures for SYCL events. This effectively enables the integration of arbitrary asynchronous SYCL operations into the HPX task graph. Bolted on top of this integration, we further added an HPX-SYCL executor for ease of use.

¹²³⁰ <https://github.com/STELLAR-GROUP/hpx/pull/6279>

¹²³¹ <https://github.com/STELLAR-GROUP/hpx/pull/6281>

¹²³² <https://github.com/STELLAR-GROUP/hpx/pull/6283>

Breaking changes

- Stopped supporting Clang V8, the minimal version supported is now Clang V10.
- Stopped supporting gcc V8, the minimal version supported is now gcc V9.
- Stopped supporting Visual Studio 2015, the minimal version supported is now Visual Studio 2019.
- `tag_policy_tag` et.al. were re-added after HPX V1.8.1 deprecation.
- `get_chunk_size` and `processing_units_count` API is now expecting the time for one iteration as an argument.
- The list of all the namespace changes can be found here: [HPX V1.9.0 Namespace changes](#).

Closed issues

- [Issue #6203](#)¹²³³ - Compilation error with `-mcpu=a64fx` on Oookami
- [Issue #6196](#)¹²³⁴ - Incorrect log destination
- [Issue #6191](#)¹²³⁵ - installing HPX
- [Issue #6184](#)¹²³⁶ - Wrong `processing_units_count` of `restricted_thread_pool_executor`
- [Issue #6171](#)¹²³⁷ - Release Tag Name Request
- [Issue #6162](#)¹²³⁸ - Current master does not compile on ROSTAM
- [Issue #6156](#)¹²³⁹ - `hpxcxx` does not work if `HPX_WITH_PKGCONFIG=OFF`
- [Issue #6108](#)¹²⁴⁰ - `cxx17_aligned_new.cpp` on `msvc` fails due to wrong pragma directive
- [Issue #6045](#)¹²⁴¹ - Can't call nullary callables wrapped with `hpx::unwrapping`
- [Issue #6013](#)¹²⁴² - Unable to build subprojects `hpx_collectives/hpx_compute` with MSVC
- [Issue #6008](#)¹²⁴³ - Missing `constexpr` default constructor for `hpx::mutex`
- [Issue #5999](#)¹²⁴⁴ - Add HPX Conda package to conda-forge
- [Issue #5998](#)¹²⁴⁵ - Serializing multiple arguments when applying distributed action results in segfault
- [Issue #5958](#)¹²⁴⁶ - HPX 1.8.0 and Blaze issues
- [Issue #5908](#)¹²⁴⁷ - Windows: duplicated symbols in static builds
- [Issue #5802](#)¹²⁴⁸ - Lost status `is_ready` from future

¹²³³ <https://github.com/STELLAR-GROUP/hpx/issues/6203>

¹²³⁴ <https://github.com/STELLAR-GROUP/hpx/issues/6196>

¹²³⁵ <https://github.com/STELLAR-GROUP/hpx/issues/6191>

¹²³⁶ <https://github.com/STELLAR-GROUP/hpx/issues/6184>

¹²³⁷ <https://github.com/STELLAR-GROUP/hpx/issues/6171>

¹²³⁸ <https://github.com/STELLAR-GROUP/hpx/issues/6162>

¹²³⁹ <https://github.com/STELLAR-GROUP/hpx/issues/6156>

¹²⁴⁰ <https://github.com/STELLAR-GROUP/hpx/issues/6108>

¹²⁴¹ <https://github.com/STELLAR-GROUP/hpx/issues/6045>

¹²⁴² <https://github.com/STELLAR-GROUP/hpx/issues/6013>

¹²⁴³ <https://github.com/STELLAR-GROUP/hpx/issues/6008>

¹²⁴⁴ <https://github.com/STELLAR-GROUP/hpx/issues/5999>

¹²⁴⁵ <https://github.com/STELLAR-GROUP/hpx/issues/5998>

¹²⁴⁶ <https://github.com/STELLAR-GROUP/hpx/issues/5958>

¹²⁴⁷ <https://github.com/STELLAR-GROUP/hpx/issues/5908>

¹²⁴⁸ <https://github.com/STELLAR-GROUP/hpx/issues/5802>

- Issue #5767¹²⁴⁹ - Performance drop on Piz Daint
- Issue #5752¹²⁵⁰ - Implement stride_view from P1899 (experimental)
- Issue #5744¹²⁵¹ - HPX_WITH_FETCH_ASIO not working on Ookami
- Issue #5561¹²⁵² - Possible race condition in helper thread / hpx::cout

Closed pull requests

- PR #6228¹²⁵³ - Fixing algorithms for zero length sequences when run with s/r scheduler
- PR #6227¹²⁵⁴ - Reliably disable background work when no networking is enabled
- PR #6225¹²⁵⁵ - Make heap fails in par for small sized heaps #6217
- PR #6222¹²⁵⁶ - Add documentation for *hpx::post*
- PR #6221¹²⁵⁷ - Fix segmented algorithms tests
- PR #6218¹²⁵⁸ - Creating INSTALL component 'runtime' to enable installing binaries only
- PR #6216¹²⁵⁹ - added tests for set_difference, updated set_operation.hpp to fix #6198
- PR #6213¹²⁶⁰ - Modernize and streamline MPI parcelport
- PR #6211¹²⁶¹ - Modernize modules of level 11, 12, and 13
- PR #6210¹²⁶² - Fixing MPI parcelport initialization if MPI is initialized outside of HPX
- PR #6209¹²⁶³ - Prevent thread stealing during scheduler shutdown
- PR #6208¹²⁶⁴ - Fix the compilation warning in the MPI parcelport with gcc 11.2
- PR #6207¹²⁶⁵ - Automatically enable Boost.Context when compiling for arm64.
- PR #6206¹²⁶⁶ - Update CMakeLists.txt
- PR #6205¹²⁶⁷ - Do not generate hpxcxx if support for pkgconfig was disabled
- PR #6204¹²⁶⁸ - Use **LRT_** instead of **LAPP_** logging in barrier implementation
- PR #6202¹²⁶⁹ - Fixing Fedora build errors on Power systems
- PR #6201¹²⁷⁰ - Update the LCI parcelport documents

¹²⁴⁹ <https://github.com/STELLAR-GROUP/hpx/issues/5767>

¹²⁵⁰ <https://github.com/STELLAR-GROUP/hpx/issues/5752>

¹²⁵¹ <https://github.com/STELLAR-GROUP/hpx/issues/5744>

¹²⁵² <https://github.com/STELLAR-GROUP/hpx/issues/5561>

¹²⁵³ <https://github.com/STELLAR-GROUP/hpx/pull/6228>

¹²⁵⁴ <https://github.com/STELLAR-GROUP/hpx/pull/6227>

¹²⁵⁵ <https://github.com/STELLAR-GROUP/hpx/pull/6225>

¹²⁵⁶ <https://github.com/STELLAR-GROUP/hpx/pull/6222>

¹²⁵⁷ <https://github.com/STELLAR-GROUP/hpx/pull/6221>

¹²⁵⁸ <https://github.com/STELLAR-GROUP/hpx/pull/6218>

¹²⁵⁹ <https://github.com/STELLAR-GROUP/hpx/pull/6216>

¹²⁶⁰ <https://github.com/STELLAR-GROUP/hpx/pull/6213>

¹²⁶¹ <https://github.com/STELLAR-GROUP/hpx/pull/6211>

¹²⁶² <https://github.com/STELLAR-GROUP/hpx/pull/6210>

¹²⁶³ <https://github.com/STELLAR-GROUP/hpx/pull/6209>

¹²⁶⁴ <https://github.com/STELLAR-GROUP/hpx/pull/6208>

¹²⁶⁵ <https://github.com/STELLAR-GROUP/hpx/pull/6207>

¹²⁶⁶ <https://github.com/STELLAR-GROUP/hpx/pull/6206>

¹²⁶⁷ <https://github.com/STELLAR-GROUP/hpx/pull/6205>

¹²⁶⁸ <https://github.com/STELLAR-GROUP/hpx/pull/6204>

¹²⁶⁹ <https://github.com/STELLAR-GROUP/hpx/pull/6202>

¹²⁷⁰ <https://github.com/STELLAR-GROUP/hpx/pull/6201>

- PR #6200¹²⁷¹ - Par link jobs
- PR #6197¹²⁷² - LCI parcelport: add doc, upgrade to v1.7.4, refactor cmake autofetch.
- PR #6195¹²⁷³ - Change the default tag of autofetch LCI to v1.7.3.
- PR #6192¹²⁷⁴ - Fix page *Writing single-node applications*
- PR #6189¹²⁷⁵ - Making sure restricted_thread_pool_executor properly reports used number of cores
- PR #6187¹²⁷⁶ - Enable using for_loop with range generators
- PR #6186¹²⁷⁷ - thread_support/CMakeLists: Fix build issue
- PR #6185¹²⁷⁸ - Fix EVE datapar with cxx_standard less than 20
- PR #6183¹²⁷⁹ - Update CI integration for EVE
- PR #6182¹²⁸⁰ - Fixing performance regressions
- PR #6181¹²⁸¹ - LCI parcelport: backlog queue, aggregation, separate devices, and more
- PR #6180¹²⁸² - Fixing use of for_loop with rebound execution policy (using *.with()*)
- PR #6179¹²⁸³ - Taking predicates for algorithms by value
- PR #6178¹²⁸⁴ - Changes needed to make chapel_hpx examples work
- PR #6176¹²⁸⁵ - Fixing warnings that were generated by PVS Studio
- PR #6174¹²⁸⁶ - Replace boost::integer::gcd with std::gcd
- PR #6172¹²⁸⁷ - [Docs] Fix example of how to run single/specific test(s)
- PR #6170¹²⁸⁸ - Adding missing fallback for processing_units_count customization point
- PR #6169¹²⁸⁹ - LCI parcelport: bypass the parcel queue and connection cache.
- PR #6167¹²⁹⁰ - Add create_local_communicator API function
- PR #6166¹²⁹¹ - Add missing header for std::intmax_t
- PR #6165¹²⁹² - Attempt to work around MSVC problem
- PR #6161¹²⁹³ - Update EVE integration

¹²⁷¹ <https://github.com/STELLAR-GROUP/hpx/pull/6200>

¹²⁷² <https://github.com/STELLAR-GROUP/hpx/pull/6197>

¹²⁷³ <https://github.com/STELLAR-GROUP/hpx/pull/6195>

¹²⁷⁴ <https://github.com/STELLAR-GROUP/hpx/pull/6192>

¹²⁷⁵ <https://github.com/STELLAR-GROUP/hpx/pull/6189>

¹²⁷⁶ <https://github.com/STELLAR-GROUP/hpx/pull/6187>

¹²⁷⁷ <https://github.com/STELLAR-GROUP/hpx/pull/6186>

¹²⁷⁸ <https://github.com/STELLAR-GROUP/hpx/pull/6185>

¹²⁷⁹ <https://github.com/STELLAR-GROUP/hpx/pull/6183>

¹²⁸⁰ <https://github.com/STELLAR-GROUP/hpx/pull/6182>

¹²⁸¹ <https://github.com/STELLAR-GROUP/hpx/pull/6181>

¹²⁸² <https://github.com/STELLAR-GROUP/hpx/pull/6180>

¹²⁸³ <https://github.com/STELLAR-GROUP/hpx/pull/6179>

¹²⁸⁴ <https://github.com/STELLAR-GROUP/hpx/pull/6178>

¹²⁸⁵ <https://github.com/STELLAR-GROUP/hpx/pull/6176>

¹²⁸⁶ <https://github.com/STELLAR-GROUP/hpx/pull/6174>

¹²⁸⁷ <https://github.com/STELLAR-GROUP/hpx/pull/6172>

¹²⁸⁸ <https://github.com/STELLAR-GROUP/hpx/pull/6170>

¹²⁸⁹ <https://github.com/STELLAR-GROUP/hpx/pull/6169>

¹²⁹⁰ <https://github.com/STELLAR-GROUP/hpx/pull/6167>

¹²⁹¹ <https://github.com/STELLAR-GROUP/hpx/pull/6166>

¹²⁹² <https://github.com/STELLAR-GROUP/hpx/pull/6165>

¹²⁹³ <https://github.com/STELLAR-GROUP/hpx/pull/6161>

- PR #6160¹²⁹⁴ - More cleanup for module levels 0 to 10
- PR #6159¹²⁹⁵ - Fix minor spelling mistake in generate_issue_pr_list.sh
- PR #6158¹²⁹⁶ - Update documentation in *writing single-node applications* page
- PR #6157¹²⁹⁷ - Improve index_queue_spawning
- PR #6154¹²⁹⁸ - Avoid performing late command line handling twice in distributed runtime
- PR #6152¹²⁹⁹ - The -rd and -mr options didn't work, and they should have been -rd and -mr
- PR #6151¹³⁰⁰ - Refactoring the Manual page in documentation
- PR #6148¹³⁰¹ - Investigate the failure of the LCI parcelport.
- PR #6147¹³⁰² - Make posix co-routine stacks non-executable
- PR #6146¹³⁰³ - Avoid ambiguities wrt tag_invoke
- PR #6144¹³⁰⁴ - General improvements to scheduling and related fixes
- PR #6143¹³⁰⁵ - Add list of new namespaces for new release
- PR #6140¹³⁰⁶ - Fixing background scheduler to properly exit in the end
- PR #6139¹³⁰⁷ - [P2300] execution: Cleanup coroutines integration and improve ADL isolation
- PR #6137¹³⁰⁸ - Adding example of a simple master/slave distributed application
- PR #6136¹³⁰⁹ - Deprecate *execution::experimental::task_group* in favor of *experimental::task_group*
- PR #6135¹³¹⁰ - Fixing warnings reported by MSVC analysis
- PR #6134¹³¹¹ - Adding notification function for parcelports to be called after early parcel handling
- PR #6132¹³¹² - Fixing to_non_par() for parallel simd policies
- PR #6131¹³¹³ - modernize modules from level 25
- PR #6130¹³¹⁴ - Remove the mutex lock in the critical path of get_partitioner.
- PR #6129¹³¹⁵ - Modernize module from levels 22, 23
- PR #6127¹³¹⁶ - Working around gccV9 problem that prevent us from storing enum classes in bit fields

¹²⁹⁴ <https://github.com/STELLAR-GROUP/hpx/pull/6160>
¹²⁹⁵ <https://github.com/STELLAR-GROUP/hpx/pull/6159>
¹²⁹⁶ <https://github.com/STELLAR-GROUP/hpx/pull/6158>
¹²⁹⁷ <https://github.com/STELLAR-GROUP/hpx/pull/6157>
¹²⁹⁸ <https://github.com/STELLAR-GROUP/hpx/pull/6154>
¹²⁹⁹ <https://github.com/STELLAR-GROUP/hpx/pull/6152>
¹³⁰⁰ <https://github.com/STELLAR-GROUP/hpx/pull/6151>
¹³⁰¹ <https://github.com/STELLAR-GROUP/hpx/pull/6148>
¹³⁰² <https://github.com/STELLAR-GROUP/hpx/pull/6147>
¹³⁰³ <https://github.com/STELLAR-GROUP/hpx/pull/6146>
¹³⁰⁴ <https://github.com/STELLAR-GROUP/hpx/pull/6144>
¹³⁰⁵ <https://github.com/STELLAR-GROUP/hpx/pull/6143>
¹³⁰⁶ <https://github.com/STELLAR-GROUP/hpx/pull/6140>
¹³⁰⁷ <https://github.com/STELLAR-GROUP/hpx/pull/6139>
¹³⁰⁸ <https://github.com/STELLAR-GROUP/hpx/pull/6137>
¹³⁰⁹ <https://github.com/STELLAR-GROUP/hpx/pull/6136>
¹³¹⁰ <https://github.com/STELLAR-GROUP/hpx/pull/6135>
¹³¹¹ <https://github.com/STELLAR-GROUP/hpx/pull/6134>
¹³¹² <https://github.com/STELLAR-GROUP/hpx/pull/6132>
¹³¹³ <https://github.com/STELLAR-GROUP/hpx/pull/6131>
¹³¹⁴ <https://github.com/STELLAR-GROUP/hpx/pull/6130>
¹³¹⁵ <https://github.com/STELLAR-GROUP/hpx/pull/6129>
¹³¹⁶ <https://github.com/STELLAR-GROUP/hpx/pull/6127>

- PR #6126¹³¹⁷ - Deprecate `hpx::parallel::task_block` in favor of `hpx::experimental::ta?`
- PR #6125¹³¹⁸ - Making sure `sync_wait` compiles when used with an lvalue sender involving bulk
- PR #6124¹³¹⁹ - Fixing use of `any_sender` in combination with `when_all`
- PR #6123¹³²⁰ - Fixed issues found by PVS-Studio
- PR #6121¹³²¹ - Modernize modules of level 21, 22
- PR #6120¹³²² - Use `index_queue` for parallel executors `bulk_async_execute`
- PR #6119¹³²³ - Update `CMakeLists.txt`
- PR #6118¹³²⁴ - Modernize modules from level 17, 18, 19, and 20
- PR #6117¹³²⁵ - Initialize `buffer_allocate_time_` to 0
- PR #6116¹³²⁶ - Add new command line argument `-hpx:loopback_network`
- PR #6115¹³²⁷ - Modernize modules of levels 14, 15, and 16
- PR #6114¹³²⁸ - Enhance the formatting of the documentation
- PR #6113¹³²⁹ - Modernize modules in module level 11, 12, and 13
- PR #6112¹³³⁰ - Modernize modules from levels 9 and 10
- PR #6111¹³³¹ - Modernize all modules from module level 8
- PR #6110¹³³² - Use `pragma error directive` to report warnings as errors on `msvc`
- PR #6109¹³³³ - Modernize serialization module
- PR #6107¹³³⁴ - Modernize error module
- PR #6106¹³³⁵ - Modernizing modules of levels 0 to 5
- PR #6105¹³³⁶ - Optimizations on LCI parcelport: merge small messages; remove sender mutex lock.
- PR #6104¹³³⁷ - Adding parameters API: `measure_iteration`
- PR #6103¹³³⁸ - Document `task_group` and include in Public API
- PR #6102¹³³⁹ - Prevent warnings generated by `clang-cl`

¹³¹⁷ <https://github.com/STELLAR-GROUP/hpx/pull/6126>

¹³¹⁸ <https://github.com/STELLAR-GROUP/hpx/pull/6125>

¹³¹⁹ <https://github.com/STELLAR-GROUP/hpx/pull/6124>

¹³²⁰ <https://github.com/STELLAR-GROUP/hpx/pull/6123>

¹³²¹ <https://github.com/STELLAR-GROUP/hpx/pull/6121>

¹³²² <https://github.com/STELLAR-GROUP/hpx/pull/6120>

¹³²³ <https://github.com/STELLAR-GROUP/hpx/pull/6119>

¹³²⁴ <https://github.com/STELLAR-GROUP/hpx/pull/6118>

¹³²⁵ <https://github.com/STELLAR-GROUP/hpx/pull/6117>

¹³²⁶ <https://github.com/STELLAR-GROUP/hpx/pull/6116>

¹³²⁷ <https://github.com/STELLAR-GROUP/hpx/pull/6115>

¹³²⁸ <https://github.com/STELLAR-GROUP/hpx/pull/6114>

¹³²⁹ <https://github.com/STELLAR-GROUP/hpx/pull/6113>

¹³³⁰ <https://github.com/STELLAR-GROUP/hpx/pull/6112>

¹³³¹ <https://github.com/STELLAR-GROUP/hpx/pull/6111>

¹³³² <https://github.com/STELLAR-GROUP/hpx/pull/6110>

¹³³³ <https://github.com/STELLAR-GROUP/hpx/pull/6109>

¹³³⁴ <https://github.com/STELLAR-GROUP/hpx/pull/6107>

¹³³⁵ <https://github.com/STELLAR-GROUP/hpx/pull/6106>

¹³³⁶ <https://github.com/STELLAR-GROUP/hpx/pull/6105>

¹³³⁷ <https://github.com/STELLAR-GROUP/hpx/pull/6104>

¹³³⁸ <https://github.com/STELLAR-GROUP/hpx/pull/6103>

¹³³⁹ <https://github.com/STELLAR-GROUP/hpx/pull/6102>

- PR #6101¹³⁴⁰ - Using more fold expressions
- PR #6100¹³⁴¹ - Deprecate `hpx::parallel::reduce_by_key` in favor of `hpx::experimental::reduce_by_key`
- PR #6098¹³⁴² - Forking Boost.Lockfree
- PR #6096¹³⁴³ - Forking Boost.Tokenizer
- PR #6095¹³⁴⁴ - Replacing facilities from Boost.Range
- PR #6094¹³⁴⁵ - Removing object_semaphore
- PR #6093¹³⁴⁶ - Replace `boost::string_ref` with `std::string_view`
- PR #6092¹³⁴⁷ - Use C++17 `static_assert` where possible
- PR #6091¹³⁴⁸ - Replace artificial sequencing with fold expressions
- PR #6090¹³⁴⁹ - Fixing use of `get_chunk_size` customization point
- PR #6088¹³⁵⁰ - Add/fix Public API documentation
- PR #6086¹³⁵¹ - Deprecate `hpx::util::unlock_guard` in favor of `hpx::unlock_guard`
- PR #6085¹³⁵² - Add experimental sycl integration/executor
- PR #6084¹³⁵³ - Renaming `hpx::apply` and `friends` to `hpx::post`
- PR #6083¹³⁵⁴ - Using `if constexpr` instead of tag-dispatching, where possible
- PR #6082¹³⁵⁵ - Replace `util::always_void_t` with `std::void_t`
- PR #6081¹³⁵⁶ - Update github actions to avoid warnings
- PR #6080¹³⁵⁷ - Disable some tests that fail on LCI
- PR #6079¹³⁵⁸ - Adding more `natvis` files, correct existing
- PR #6078¹³⁵⁹ - Changing target name of `memory_counters` component
- PR #6077¹³⁶⁰ - Making default constructor of `hpx::mutex constexpr`
- PR #6076¹³⁶¹ - Cleaning up functionality that was deprecated in V1.7
- PR #6075¹³⁶² - Remove conditional code for gcc V7 and below

¹³⁴⁰ <https://github.com/STELLAR-GROUP/hpx/pull/6101>

¹³⁴¹ <https://github.com/STELLAR-GROUP/hpx/pull/6100>

¹³⁴² <https://github.com/STELLAR-GROUP/hpx/pull/6098>

¹³⁴³ <https://github.com/STELLAR-GROUP/hpx/pull/6096>

¹³⁴⁴ <https://github.com/STELLAR-GROUP/hpx/pull/6095>

¹³⁴⁵ <https://github.com/STELLAR-GROUP/hpx/pull/6094>

¹³⁴⁶ <https://github.com/STELLAR-GROUP/hpx/pull/6093>

¹³⁴⁷ <https://github.com/STELLAR-GROUP/hpx/pull/6092>

¹³⁴⁸ <https://github.com/STELLAR-GROUP/hpx/pull/6091>

¹³⁴⁹ <https://github.com/STELLAR-GROUP/hpx/pull/6090>

¹³⁵⁰ <https://github.com/STELLAR-GROUP/hpx/pull/6088>

¹³⁵¹ <https://github.com/STELLAR-GROUP/hpx/pull/6086>

¹³⁵² <https://github.com/STELLAR-GROUP/hpx/pull/6085>

¹³⁵³ <https://github.com/STELLAR-GROUP/hpx/pull/6084>

¹³⁵⁴ <https://github.com/STELLAR-GROUP/hpx/pull/6083>

¹³⁵⁵ <https://github.com/STELLAR-GROUP/hpx/pull/6082>

¹³⁵⁶ <https://github.com/STELLAR-GROUP/hpx/pull/6081>

¹³⁵⁷ <https://github.com/STELLAR-GROUP/hpx/pull/6080>

¹³⁵⁸ <https://github.com/STELLAR-GROUP/hpx/pull/6079>

¹³⁵⁹ <https://github.com/STELLAR-GROUP/hpx/pull/6078>

¹³⁶⁰ <https://github.com/STELLAR-GROUP/hpx/pull/6077>

¹³⁶¹ <https://github.com/STELLAR-GROUP/hpx/pull/6076>

¹³⁶² <https://github.com/STELLAR-GROUP/hpx/pull/6075>

- PR #6074¹³⁶³ - Fixing compilation issues on gcc V8
- PR #6073¹³⁶⁴ - Fixing PAPI counter component compilation
- PR #6072¹³⁶⁵ - Adding `ex::when_all_vector`
- PR #6071¹³⁶⁶ - Making `get_forward_progress_guarantee_t` specializations `constexpr`
- PR #6070¹³⁶⁷ - Implement P2690 for our algorithms
- PR #6069¹³⁶⁸ - Do not check for cancellation during each iteration but only once per partition
- PR #6068¹³⁶⁹ - Prevent using `task` and `non_task` as a CPO
- PR #6067¹³⁷⁰ - Deprecated `hpx::util::mem_fn` in favor of `hpx::mem_fn`
- PR #6066¹³⁷¹ - Create `codeql.yml`
- PR #6064¹³⁷² - Adapting `adjacent_difference` for S/R execution
- PR #6063¹³⁷³ - Modernize `iterator_support` module
- PR #6062¹³⁷⁴ - Make sure wrapping executor does not go out of scope prematurely
- PR #6061¹³⁷⁵ - Minor fix in `small_vector` (from upstream)
- PR #6060¹³⁷⁶ - Allow to disable registering signal handlers
- PR #6059¹³⁷⁷ - [P2300] Fix: `declval` cannot be ODR used
- PR #6058¹³⁷⁸ - Avoid ambiguity for `hpx::get` used with `std::variant`
- PR #6057¹³⁷⁹ - Create a dedicated thread pool to run `LCI_progress`.
- PR #6056¹³⁸⁰ - Fix coroutine test for clang
- PR #6055¹³⁸¹ - Patches needed to be able to build HPX 1.8.1 on various platforms
- PR #6054¹³⁸² - Use MSVC specific attribute `[[msvc::no_unique_address]]`
- PR #6052¹³⁸³ - Deprecated `hpx::util::invoke_fused` in favor of `hpx::invoke_fused`
- PR #6051¹³⁸⁴ - Add non-contiguous index queue and use it in `thread_pool_bulk_scheduler`
- PR #6049¹³⁸⁵ - Crosscompile arm sve

¹³⁶³ <https://github.com/STELLAR-GROUP/hpx/pull/6074>

¹³⁶⁴ <https://github.com/STELLAR-GROUP/hpx/pull/6073>

¹³⁶⁵ <https://github.com/STELLAR-GROUP/hpx/pull/6072>

¹³⁶⁶ <https://github.com/STELLAR-GROUP/hpx/pull/6071>

¹³⁶⁷ <https://github.com/STELLAR-GROUP/hpx/pull/6070>

¹³⁶⁸ <https://github.com/STELLAR-GROUP/hpx/pull/6069>

¹³⁶⁹ <https://github.com/STELLAR-GROUP/hpx/pull/6068>

¹³⁷⁰ <https://github.com/STELLAR-GROUP/hpx/pull/6067>

¹³⁷¹ <https://github.com/STELLAR-GROUP/hpx/pull/6066>

¹³⁷² <https://github.com/STELLAR-GROUP/hpx/pull/6064>

¹³⁷³ <https://github.com/STELLAR-GROUP/hpx/pull/6063>

¹³⁷⁴ <https://github.com/STELLAR-GROUP/hpx/pull/6062>

¹³⁷⁵ <https://github.com/STELLAR-GROUP/hpx/pull/6061>

¹³⁷⁶ <https://github.com/STELLAR-GROUP/hpx/pull/6060>

¹³⁷⁷ <https://github.com/STELLAR-GROUP/hpx/pull/6059>

¹³⁷⁸ <https://github.com/STELLAR-GROUP/hpx/pull/6058>

¹³⁷⁹ <https://github.com/STELLAR-GROUP/hpx/pull/6057>

¹³⁸⁰ <https://github.com/STELLAR-GROUP/hpx/pull/6056>

¹³⁸¹ <https://github.com/STELLAR-GROUP/hpx/pull/6055>

¹³⁸² <https://github.com/STELLAR-GROUP/hpx/pull/6054>

¹³⁸³ <https://github.com/STELLAR-GROUP/hpx/pull/6052>

¹³⁸⁴ <https://github.com/STELLAR-GROUP/hpx/pull/6051>

¹³⁸⁵ <https://github.com/STELLAR-GROUP/hpx/pull/6049>

- PR #6048¹³⁸⁶ - Deprecated `hpx::util::invoke` in favor of `hpx::invoke`
- PR #6047¹³⁸⁷ - Separating `binary_semaphore` into its own file
- PR #6046¹³⁸⁸ - Support using unwrapping with nullary function objects
- PR #6044¹³⁸⁹ - Generalize the use of `then()` and `dataflow`
- PR #6043¹³⁹⁰ - Clean up `scan_partitioner`
- PR #6042¹³⁹¹ - Modernize `dataflow API`
- PR #6041¹³⁹² - docs: document semaphores
- PR #6040¹³⁹³ - Add/Fix documentation of Public API page
- PR #6039¹³⁹⁴ - remove MPI dependency when only using LCI `parcelport`
- PR #6038¹³⁹⁵ - Clean up command line handling
- PR #6037¹³⁹⁶ - Avoid performing parcel related background work if networking is disabled
- PR #6036¹³⁹⁷ - Support new `datapar backend : SVE`
- PR #6035¹³⁹⁸ - Simplify `datapar replace copy if`
- PR #6034¹³⁹⁹ - Add/Fix documentation of Public API
- PR #6033¹⁴⁰⁰ - Support for data-parallelism for `replace`, `replace_if`, `replace_copy`, `replace_copy_if` algorithms
- PR #6032¹⁴⁰¹ - Add documentation in public API
- PR #6031¹⁴⁰² - Expose available cache sizes from `topology object`
- PR #6030¹⁴⁰³ - Adding `parcelport initialization hook` for resource `partitioner operation`
- PR #6029¹⁴⁰⁴ - Simplify startup code
- PR #6027¹⁴⁰⁵ - Add/Fix documentation in Public API page
- PR #6026¹⁴⁰⁶ - add option `hpx:force_ipv4` to force resolving hostnames to `ipv4 addresses`
- PR #6025¹⁴⁰⁷ - `build(docs)`: remove leftover sections
- PR #6023¹⁴⁰⁸ - Minor fixes on “How to build on Windows”

¹³⁸⁶ <https://github.com/STELLAR-GROUP/hpx/pull/6048>
¹³⁸⁷ <https://github.com/STELLAR-GROUP/hpx/pull/6047>
¹³⁸⁸ <https://github.com/STELLAR-GROUP/hpx/pull/6046>
¹³⁸⁹ <https://github.com/STELLAR-GROUP/hpx/pull/6044>
¹³⁹⁰ <https://github.com/STELLAR-GROUP/hpx/pull/6043>
¹³⁹¹ <https://github.com/STELLAR-GROUP/hpx/pull/6042>
¹³⁹² <https://github.com/STELLAR-GROUP/hpx/pull/6041>
¹³⁹³ <https://github.com/STELLAR-GROUP/hpx/pull/6040>
¹³⁹⁴ <https://github.com/STELLAR-GROUP/hpx/pull/6039>
¹³⁹⁵ <https://github.com/STELLAR-GROUP/hpx/pull/6038>
¹³⁹⁶ <https://github.com/STELLAR-GROUP/hpx/pull/6037>
¹³⁹⁷ <https://github.com/STELLAR-GROUP/hpx/pull/6036>
¹³⁹⁸ <https://github.com/STELLAR-GROUP/hpx/pull/6035>
¹³⁹⁹ <https://github.com/STELLAR-GROUP/hpx/pull/6034>
¹⁴⁰⁰ <https://github.com/STELLAR-GROUP/hpx/pull/6033>
¹⁴⁰¹ <https://github.com/STELLAR-GROUP/hpx/pull/6032>
¹⁴⁰² <https://github.com/STELLAR-GROUP/hpx/pull/6031>
¹⁴⁰³ <https://github.com/STELLAR-GROUP/hpx/pull/6030>
¹⁴⁰⁴ <https://github.com/STELLAR-GROUP/hpx/pull/6029>
¹⁴⁰⁵ <https://github.com/STELLAR-GROUP/hpx/pull/6027>
¹⁴⁰⁶ <https://github.com/STELLAR-GROUP/hpx/pull/6026>
¹⁴⁰⁷ <https://github.com/STELLAR-GROUP/hpx/pull/6025>
¹⁴⁰⁸ <https://github.com/STELLAR-GROUP/hpx/pull/6023>

- PR #6022¹⁴⁰⁹ - build(doxy): don't extract private members
- PR #6021¹⁴¹⁰ - Adding pu_mask to thread_pool_bulk_scheduler
- PR #6020¹⁴¹¹ - docs: add cppref NamedRequirements support
- PR #6018¹⁴¹² - Unseq adaptation for for_each, transform, reduce, transform_reduce, etc.
- PR #6017¹⁴¹³ - loop and transform_loop unseq adaptation
- PR #6016¹⁴¹⁴ - Config and structural updates to support unseq implementation
- PR #6015¹⁴¹⁵ - Integrating sync_wait & sync_wait_with_variant
- PR #6012¹⁴¹⁶ - docs: add missing links to public api
- PR #6009¹⁴¹⁷ - Fixing sender&receiver integration with for_each and for_loop
- PR #6007¹⁴¹⁸ - docs: add docs for mutex.hpp
- PR #6006¹⁴¹⁹ - Relax future::is_ready where possible
- PR #6005¹⁴²⁰ - reshuffle header tests to different instances
- PR #6004¹⁴²¹ - Add documentation Public API
- PR #6003¹⁴²² - Always exporting get_component_name implementations
- PR #6002¹⁴²³ - Making sure that default constructible arguments are properly constructed during deserialization
- PR #5996¹⁴²⁴ - Add back explicit template parameters to lock_guards for nvcc
- PR #5994¹⁴²⁵ - Fix CTRL+C on windows
- PR #5993¹⁴²⁶ - Using EVE requires C++20
- PR #5992¹⁴²⁷ - This properly terminates an application on Ctrl-C on Windows
- PR #5991¹⁴²⁸ - Support IPV6 on command line for explicit network initialization
- PR #5990¹⁴²⁹ - P2300 enhancements
- PR #5989¹⁴³⁰ - Fix missing documentation in Public API page
- PR #5987¹⁴³¹ - Attempting to fix timed executor API

¹⁴⁰⁹ <https://github.com/STELLAR-GROUP/hpx/pull/6022>

¹⁴¹⁰ <https://github.com/STELLAR-GROUP/hpx/pull/6021>

¹⁴¹¹ <https://github.com/STELLAR-GROUP/hpx/pull/6020>

¹⁴¹² <https://github.com/STELLAR-GROUP/hpx/pull/6018>

¹⁴¹³ <https://github.com/STELLAR-GROUP/hpx/pull/6017>

¹⁴¹⁴ <https://github.com/STELLAR-GROUP/hpx/pull/6016>

¹⁴¹⁵ <https://github.com/STELLAR-GROUP/hpx/pull/6015>

¹⁴¹⁶ <https://github.com/STELLAR-GROUP/hpx/pull/6012>

¹⁴¹⁷ <https://github.com/STELLAR-GROUP/hpx/pull/6009>

¹⁴¹⁸ <https://github.com/STELLAR-GROUP/hpx/pull/6007>

¹⁴¹⁹ <https://github.com/STELLAR-GROUP/hpx/pull/6006>

¹⁴²⁰ <https://github.com/STELLAR-GROUP/hpx/pull/6005>

¹⁴²¹ <https://github.com/STELLAR-GROUP/hpx/pull/6004>

¹⁴²² <https://github.com/STELLAR-GROUP/hpx/pull/6003>

¹⁴²³ <https://github.com/STELLAR-GROUP/hpx/pull/6002>

¹⁴²⁴ <https://github.com/STELLAR-GROUP/hpx/pull/5996>

¹⁴²⁵ <https://github.com/STELLAR-GROUP/hpx/pull/5994>

¹⁴²⁶ <https://github.com/STELLAR-GROUP/hpx/pull/5993>

¹⁴²⁷ <https://github.com/STELLAR-GROUP/hpx/pull/5992>

¹⁴²⁸ <https://github.com/STELLAR-GROUP/hpx/pull/5991>

¹⁴²⁹ <https://github.com/STELLAR-GROUP/hpx/pull/5990>

¹⁴³⁰ <https://github.com/STELLAR-GROUP/hpx/pull/5989>

¹⁴³¹ <https://github.com/STELLAR-GROUP/hpx/pull/5987>

- PR #5986¹⁴³² - Fix warnings when building docs
- PR #5985¹⁴³³ - Re-add deprecated tag_policy_tag et.al. types that were removed in V1.8.1
- PR #5981¹⁴³⁴ - docs: add docs for condition_variable.hpp
- PR #5980¹⁴³⁵ - More work on execution::read
- PR #5979¹⁴³⁶ - Remove support for clang-v8 and clang-v9, switch LSU clang-v13 to C++17
- PR #5977¹⁴³⁷ - fix: Compilation errors for -std=c++17 builders
- PR #5975¹⁴³⁸ - docs: fix & improve parallel algorithms documentation 5
- PR #5974¹⁴³⁹ - [P2300] Adapt get completion signatures for awaitable senders
- PR #5973¹⁴⁴⁰ - defaults boost.context on riscv64
- PR #5972¹⁴⁴¹ - Fix documentation for container algorithms
- PR #5971¹⁴⁴² - added logic to detect riscv compiler configured for 64 bit target
- PR #5968¹⁴⁴³ - adds risc-v 64 bit support
- PR #5967¹⁴⁴⁴ - Adding missing pieces to sync_wait, adding run_loop
- PR #5966¹⁴⁴⁵ - docs: fix & improve parallel algorithms documentation 4
- PR #5965¹⁴⁴⁶ - Fixing inspect problems, adding missing header file
- PR #5962¹⁴⁴⁷ - Changes in html page of documentation
- PR #5961¹⁴⁴⁸ - Prevent stalling during shutdown when running hello_world_distributed
- PR #5955¹⁴⁴⁹ - Fix documentation for container algorithms
- PR #5952¹⁴⁵⁰ - docs: fix & improve parallel algorithms documentation 3
- PR #5950¹⁴⁵¹ - Change executors to directly implement the executor CPOs
- PR #5949¹⁴⁵² - Converting async combinators into CPOs
- PR #5948¹⁴⁵³ - Adding support for pure sender/receiver based executors to parallel algorithms
- PR #5945¹⁴⁵⁴ - [P2300] Added fundamental coroutine_traits for S/R

¹⁴³² <https://github.com/STELLAR-GROUP/hpx/pull/5986>

¹⁴³³ <https://github.com/STELLAR-GROUP/hpx/pull/5985>

¹⁴³⁴ <https://github.com/STELLAR-GROUP/hpx/pull/5981>

¹⁴³⁵ <https://github.com/STELLAR-GROUP/hpx/pull/5980>

¹⁴³⁶ <https://github.com/STELLAR-GROUP/hpx/pull/5979>

¹⁴³⁷ <https://github.com/STELLAR-GROUP/hpx/pull/5977>

¹⁴³⁸ <https://github.com/STELLAR-GROUP/hpx/pull/5975>

¹⁴³⁹ <https://github.com/STELLAR-GROUP/hpx/pull/5974>

¹⁴⁴⁰ <https://github.com/STELLAR-GROUP/hpx/pull/5973>

¹⁴⁴¹ <https://github.com/STELLAR-GROUP/hpx/pull/5972>

¹⁴⁴² <https://github.com/STELLAR-GROUP/hpx/pull/5971>

¹⁴⁴³ <https://github.com/STELLAR-GROUP/hpx/pull/5968>

¹⁴⁴⁴ <https://github.com/STELLAR-GROUP/hpx/pull/5967>

¹⁴⁴⁵ <https://github.com/STELLAR-GROUP/hpx/pull/5966>

¹⁴⁴⁶ <https://github.com/STELLAR-GROUP/hpx/pull/5965>

¹⁴⁴⁷ <https://github.com/STELLAR-GROUP/hpx/pull/5962>

¹⁴⁴⁸ <https://github.com/STELLAR-GROUP/hpx/pull/5961>

¹⁴⁴⁹ <https://github.com/STELLAR-GROUP/hpx/pull/5955>

¹⁴⁵⁰ <https://github.com/STELLAR-GROUP/hpx/pull/5952>

¹⁴⁵¹ <https://github.com/STELLAR-GROUP/hpx/pull/5950>

¹⁴⁵² <https://github.com/STELLAR-GROUP/hpx/pull/5949>

¹⁴⁵³ <https://github.com/STELLAR-GROUP/hpx/pull/5948>

¹⁴⁵⁴ <https://github.com/STELLAR-GROUP/hpx/pull/5945>

- PR #5883¹⁴⁵⁵ - Optimization on LCI parcelport: uses LCI_putva
- PR #5872¹⁴⁵⁶ - Block fork join executor
- PR #5855¹⁴⁵⁷ - Adding performance test Jenkins builder at LSU

HPX V1.8.1 (Aug 5, 2022)

This is a bugfix release with a few minor additions and resolved problems.

General changes

This patch release adds a number of small new features and fixes a handful of problems discovered since the last release, in particular:

- A lot of work has been done to improve vectorization support for our parallel algorithms. HPX now supports using EVE - the Expressive Vector Engine as a vectorization backend.
- Added a simple average power consumption performance counter.
- Added performance counters related to the use of zero-copy chunks in the networking layer.
- More work was done towards full compatibility with the sender/receivers proposal P2300.
- Fixing `sync_wait` to decay the result types
- Fixed collective operations to properly avoid overlapping consecutive operations on the same communicator.
- Simplified the implementation of our execution policies and added mapping functions between those.
- Fixed performance issues with our implementation of `small_vector`.
- Serialization now works with buffers of unsigned characters.
- Fixing dangling reference in serialization of non-default constructible types
- Fixed static linking on Windows.
- Fixed support for M1/MacOS based architectures.
- Fixed support for gentoo/musl.
- Fixed `hpx::counting_semaphore_var`.
- Properly check start and end bounds for `hpx::for_loop`
- A lot of changes and fixes to the documentation (see <https://hpx-docs.stellar-group.org>).

¹⁴⁵⁵ <https://github.com/STELLAR-GROUP/hpx/pull/5883>

¹⁴⁵⁶ <https://github.com/STELLAR-GROUP/hpx/pull/5872>

¹⁴⁵⁷ <https://github.com/STELLAR-GROUP/hpx/pull/5855>

Breaking changes

- No breaking changes have been introduced.

Closed issues

- [Issue #5964](#)¹⁴⁵⁸ - component with multiple inheritance
- [Issue #5946](#)¹⁴⁵⁹ - dll_dlopen.hpp: error: RTLD_DI_ORIGIN was not declared in this scope with musl libc
- [Issue #5925](#)¹⁴⁶⁰ - Simplify implementation of execution policies
- [Issue #5924](#)¹⁴⁶¹ - {what}: mmap() failed to allocate thread stack: HPX(unhandled_exception)
- [Issue #5912](#)¹⁴⁶² - collectives all gather hangs if rank 0 is not involved
- [Issue #5902](#)¹⁴⁶³ - MPI parcelport issue on Fugaku
- [Issue #5900](#)¹⁴⁶⁴ - Unable to build hello_world_distributed.cpp.
- [Issue #5892](#)¹⁴⁶⁵ - Problems with HPX serialization as a standalone feature. Testcase provided.
- [Issue #5886](#)¹⁴⁶⁶ - Segfault when serializing non default constructible class with stl containers data members
- [Issue #5832](#)¹⁴⁶⁷ - Distributed execution crash
- [Issue #5768](#)¹⁴⁶⁸ - HPX hangs on Perlmutter
- [Issue #5735](#)¹⁴⁶⁹ - hpx::for_loop executes without checking start and end bounds
- [Issue #5700](#)¹⁴⁷⁰ - HPX(serialization_error)

Closed pull requests

- [PR #5970](#)¹⁴⁷¹ - Fixing component multiple inheritance
- [PR #5969](#)¹⁴⁷² - Fixing sync_wait to avoid dangling references
- [PR #5963](#)¹⁴⁷³ - Fixing sync_wait to decay the result types
- [PR #5960](#)¹⁴⁷⁴ - docs: added name to documentation contributors list
- [PR #5959](#)¹⁴⁷⁵ - Fixing sync_wait to decay the result types

¹⁴⁵⁸ <https://github.com/STELLAR-GROUP/hpx/issues/5964>

¹⁴⁵⁹ <https://github.com/STELLAR-GROUP/hpx/issues/5946>

¹⁴⁶⁰ <https://github.com/STELLAR-GROUP/hpx/issues/5925>

¹⁴⁶¹ <https://github.com/STELLAR-GROUP/hpx/issues/5924>

¹⁴⁶² <https://github.com/STELLAR-GROUP/hpx/issues/5912>

¹⁴⁶³ <https://github.com/STELLAR-GROUP/hpx/issues/5902>

¹⁴⁶⁴ <https://github.com/STELLAR-GROUP/hpx/issues/5900>

¹⁴⁶⁵ <https://github.com/STELLAR-GROUP/hpx/issues/5892>

¹⁴⁶⁶ <https://github.com/STELLAR-GROUP/hpx/issues/5886>

¹⁴⁶⁷ <https://github.com/STELLAR-GROUP/hpx/issues/5832>

¹⁴⁶⁸ <https://github.com/STELLAR-GROUP/hpx/issues/5768>

¹⁴⁶⁹ <https://github.com/STELLAR-GROUP/hpx/issues/5735>

¹⁴⁷⁰ <https://github.com/STELLAR-GROUP/hpx/issues/5700>

¹⁴⁷¹ <https://github.com/STELLAR-GROUP/hpx/pull/5970>

¹⁴⁷² <https://github.com/STELLAR-GROUP/hpx/pull/5969>

¹⁴⁷³ <https://github.com/STELLAR-GROUP/hpx/pull/5963>

¹⁴⁷⁴ <https://github.com/STELLAR-GROUP/hpx/pull/5960>

¹⁴⁷⁵ <https://github.com/STELLAR-GROUP/hpx/pull/5959>

- PR #5954¹⁴⁷⁶ - refactor: rename itr to correct type (*reduce*)
- PR #5954¹⁴⁷⁷ - refactor: rename itr to correct type (*reduce*)
- PR #5953¹⁴⁷⁸ - Fixed property handling in hierarchical_spawning
- PR #5951¹⁴⁷⁹ - Fixing static linking (for Windows)
- PR #5947¹⁴⁸⁰ - Fix building on musl.
- PR #5944¹⁴⁸¹ - added adaptive_static_chunk_size
- PR #5943¹⁴⁸² - Fix sync_wait
- PR #5942¹⁴⁸³ - Fix doc warnings
- PR #5941¹⁴⁸⁴ - Fix sync_wait
- PR #5940¹⁴⁸⁵ - Protect collective operations against std::vector<bool> idiosyncrasies
- PR #5939¹⁴⁸⁶ - docs: fix & improve parallel algorithms documentation 2
- PR #5938¹⁴⁸⁷ - Properly implement generation support for collective operations
- PR #5937¹⁴⁸⁸ - Remove leftover files from PMR based small_vector
- PR #5936¹⁴⁸⁹ - Adding mapping functions between execution policies
- PR #5935¹⁴⁹⁰ - Fixing serialization to work with buffers of unsigned chars
- PR #5934¹⁴⁹¹ - Attempting to fix datapar issues on CircleCI
- PR #5933¹⁴⁹² - Fix documentation for ranges algorithms
- PR #5932¹⁴⁹³ - Remove mimalloc version constraint
- PR #5931¹⁴⁹⁴ - docs: fix & improve parallel algorithms documentation
- PR #5930¹⁴⁹⁵ - Add boost to hip builder
- PR #5929¹⁴⁹⁶ - Apply fixes to M1/MacOS related stack allocation to all relevant spots
- PR #5928¹⁴⁹⁷ - updated context_generic_context to accommodate arm64_arch_8/Apple architecture
- PR #5927¹⁴⁹⁸ - Public derivation for counting_semaphore_var

¹⁴⁷⁶ <https://github.com/STELLAR-GROUP/hpx/pull/5954>

¹⁴⁷⁷ <https://github.com/STELLAR-GROUP/hpx/pull/5954>

¹⁴⁷⁸ <https://github.com/STELLAR-GROUP/hpx/pull/5953>

¹⁴⁷⁹ <https://github.com/STELLAR-GROUP/hpx/pull/5951>

¹⁴⁸⁰ <https://github.com/STELLAR-GROUP/hpx/pull/5947>

¹⁴⁸¹ <https://github.com/STELLAR-GROUP/hpx/pull/5944>

¹⁴⁸² <https://github.com/STELLAR-GROUP/hpx/pull/5943>

¹⁴⁸³ <https://github.com/STELLAR-GROUP/hpx/pull/5942>

¹⁴⁸⁴ <https://github.com/STELLAR-GROUP/hpx/pull/5941>

¹⁴⁸⁵ <https://github.com/STELLAR-GROUP/hpx/pull/5940>

¹⁴⁸⁶ <https://github.com/STELLAR-GROUP/hpx/pull/5939>

¹⁴⁸⁷ <https://github.com/STELLAR-GROUP/hpx/pull/5938>

¹⁴⁸⁸ <https://github.com/STELLAR-GROUP/hpx/pull/5937>

¹⁴⁸⁹ <https://github.com/STELLAR-GROUP/hpx/pull/5936>

¹⁴⁹⁰ <https://github.com/STELLAR-GROUP/hpx/pull/5935>

¹⁴⁹¹ <https://github.com/STELLAR-GROUP/hpx/pull/5934>

¹⁴⁹² <https://github.com/STELLAR-GROUP/hpx/pull/5933>

¹⁴⁹³ <https://github.com/STELLAR-GROUP/hpx/pull/5932>

¹⁴⁹⁴ <https://github.com/STELLAR-GROUP/hpx/pull/5931>

¹⁴⁹⁵ <https://github.com/STELLAR-GROUP/hpx/pull/5930>

¹⁴⁹⁶ <https://github.com/STELLAR-GROUP/hpx/pull/5929>

¹⁴⁹⁷ <https://github.com/STELLAR-GROUP/hpx/pull/5928>

¹⁴⁹⁸ <https://github.com/STELLAR-GROUP/hpx/pull/5927>

- PR #5926¹⁴⁹⁹ - Fix doxygen warnings when building documentation
- PR #5923¹⁵⁰⁰ - Fixing git checkout to reflect latest version tag
- PR #5922¹⁵⁰¹ - A couple of unrelated changes in support of implementing P1673
- PR #5920¹⁵⁰² - [P2300] enhancements: receiver_of, sender_of improvements
- PR #5917¹⁵⁰³ - Fixing various ‘held lock while suspending’ problems
- PR #5916¹⁵⁰⁴ - Fix minor doxygen parsing typo
- PR #5915¹⁵⁰⁵ - docs: fix broken api algo links
- PR #5914¹⁵⁰⁶ - Remove CSS rules - update sphinx version
- PR #5911¹⁵⁰⁷ - Removed references to hpx::vector in comments
- PR #5909¹⁵⁰⁸ - Remove stuff which is defined in the header
- PR #5906¹⁵⁰⁹ - Use BUILD_SHARED_LIBS correctly
- PR #5905¹⁵¹⁰ - Fix incorrect usage of generator expressions
- PR #5904¹⁵¹¹ - Delete FindBZip2.cmake
- PR #5901¹⁵¹² - Fix #5900
- PR #5899¹⁵¹³ - Replace PMR based version of small_vector
- PR #5897¹⁵¹⁴ - Add missing “”
- PR #5896¹⁵¹⁵ - Docs: Add serialization tutorial.
- PR #5895¹⁵¹⁶ - Update to V1.9.0 on master
- PR #5894¹⁵¹⁷ - Fix executor_with_thread_hooks example
- PR #5890¹⁵¹⁸ - Adding simple average power consumption performance counter
- PR #5889¹⁵¹⁹ - Par unseq/unseq adding
- PR #5888¹⁵²⁰ - Support for data-parallelism for reduce, transform reduce, transform_binary_reduce algorithms
- PR #5887¹⁵²¹ - Fixing dangling reference in serialization of non-default constructible types

¹⁴⁹⁹ <https://github.com/STELLAR-GROUP/hpx/pull/5926>

¹⁵⁰⁰ <https://github.com/STELLAR-GROUP/hpx/pull/5923>

¹⁵⁰¹ <https://github.com/STELLAR-GROUP/hpx/pull/5922>

¹⁵⁰² <https://github.com/STELLAR-GROUP/hpx/pull/5920>

¹⁵⁰³ <https://github.com/STELLAR-GROUP/hpx/pull/5917>

¹⁵⁰⁴ <https://github.com/STELLAR-GROUP/hpx/pull/5916>

¹⁵⁰⁵ <https://github.com/STELLAR-GROUP/hpx/pull/5915>

¹⁵⁰⁶ <https://github.com/STELLAR-GROUP/hpx/pull/5914>

¹⁵⁰⁷ <https://github.com/STELLAR-GROUP/hpx/pull/5911>

¹⁵⁰⁸ <https://github.com/STELLAR-GROUP/hpx/pull/5909>

¹⁵⁰⁹ <https://github.com/STELLAR-GROUP/hpx/pull/5906>

¹⁵¹⁰ <https://github.com/STELLAR-GROUP/hpx/pull/5905>

¹⁵¹¹ <https://github.com/STELLAR-GROUP/hpx/pull/5904>

¹⁵¹² <https://github.com/STELLAR-GROUP/hpx/pull/5901>

¹⁵¹³ <https://github.com/STELLAR-GROUP/hpx/pull/5899>

¹⁵¹⁴ <https://github.com/STELLAR-GROUP/hpx/pull/5897>

¹⁵¹⁵ <https://github.com/STELLAR-GROUP/hpx/pull/5896>

¹⁵¹⁶ <https://github.com/STELLAR-GROUP/hpx/pull/5895>

¹⁵¹⁷ <https://github.com/STELLAR-GROUP/hpx/pull/5894>

¹⁵¹⁸ <https://github.com/STELLAR-GROUP/hpx/pull/5890>

¹⁵¹⁹ <https://github.com/STELLAR-GROUP/hpx/pull/5889>

¹⁵²⁰ <https://github.com/STELLAR-GROUP/hpx/pull/5888>

¹⁵²¹ <https://github.com/STELLAR-GROUP/hpx/pull/5887>

- PR #5879¹⁵²² - New performance counters related to zero-copy chunks.

HPX V1.8.0 (May 18, 2022)

With HPX parallel algorithms been fully adapted to C++20 the new release achieves full conformance with C++20 concurrency and parallelism facilities. HPX now supports all of the algorithms as specified by C++20. We have added support for vectorization to more of our algorithms. Much work has been done towards implementing P2300 (“std::execution”) and implementing the underlying senders/receivers facilities. Finally, The new release comes with a brand new documentation interface!

General changes

- The new documentation can now be found on our webpage: <https://hpx-docs.stellar-group.org>. This includes a completely new and user-friendly interface environment along with restructuring of certain components. The content in the “Quick start”, “Manual” and “Examples” was improved, while the “Build system” page was adapted to include necessary information for newcomers.
- With the vectorization support available in modern hardware architectures HPX now provides new data-parallel vector execution policies `hpx::execution::simd` and `hpx::execution::par_simd` that enable significant speed-up of our parallel algorithm implementations. The following algorithms now support SIMD execution:
 - `copy`, `copy_n`
 - `generate`
 - `adjacent_difference`, `adjacent_find`
 - `all_of`, `any_of`, `none_of`
 - `equal`, `mismatch`,
 - `inner_product`
 - `count`, `count_if`
 - `fill`, `fill_n`
 - `find`, `find_end`, `find_first_of`, `find_if`, `find_if_not`
 - `for_each`, `for_each_n`
 - `generate`, `generate_n`.
- Based on top of P2300 the HPX parallel algorithms now support the pipeline syntax towards an effort to unify their usage along with senders/receivers. The HPX parallel algorithms can now bind with senders/receivers using the pipeline operator.
- Several changes took place on the executors provided by HPX:
 - The executors now support the `num_cores` options in order for the user to be able to specify the desired number of cores to be used in the corresponding execution.
 - The `scheduler` executor was implemented on top of senders/receivers and can be used with all HPX facilities that schedule new work, such as parallel algorithms, `hpx::async`, `hpx::dataflow`, etc.
 - The performance of `fork_join_executor` was improved.
 - The following algorithms have been added/adapted to be C++20 conformant:
 - `min_element`

¹⁵²² <https://github.com/STELLAR-GROUP/hpx/pull/5879>

- max_element
- minmax_element
- starts_with
- ends_with
- swap_ranges
- unique
- unique_copy
- rotate
- rotate_copy
- sort
- shift_left
- shift_right
- stable_sort
- partition
- partition_copy
- stable_partition
- adjacent_difference
- nth_element
- partial_sort
- partial_sort_copy.

- HPX_FORWARD/HPX_MOVE macros were introduced that replaced the `std::move` and `std::forward` facilities that in the library code.
- Hangs on distributed barrier were fixed.
- The performance of `scan_partitioner` was improved.
- Support was added for `thread_priority` to the `parallel_execution_policy`
- Regarding senders/receivers and the P2300 proposal various actions took place. `stop_token` was adapted to the recent proposal version (`in_place_stop_token` was introduced). Also `hint`, `annotation`, `priority` and `stacksize` properties were added to the scheduler executor. Stop support was added to `when_all`. Support for completion signatures was added. The following schedulers and algorithms were added:
 - `get_completion_scheduler`
 - `any_sender` and `unique_any_sender`
 - `split sender`
 - `transform_mpi sender`
 - `transfer sender`
 - `let_error`, `let_stopped`
 - `get_env` and related environment queries
 - `schedule`, `set_value`, `set_error`, `set_done`, `start` and `connect` are now proper customization points as defined in P2300.

- Several namespaces were altered towards conformance with C++20. Compatibility layers have been added and the old versions will be removed in next releases. The namespace changes are the following:
 - `hpx::parallel::induction/reduction` were moved into namespace `hpx::experimental`
 - `for_loop` and `friends` were moved into namespace `hpx::experimental`.
 - `hpx::util::optional` and `friends` were moved into namespace `hpx`.
 - `hpx::lcos::barrier` has been moved into the `hpx::distributed` namespace and `hpx::lcos::local::cpp20_barrier` has been renamed to `barrier` and moved into the `hpx` namespace.
 - `hpx::lcos::latch` has been moved into the `hpx::distributed` namespace and `lcos::local::latch` has been moved into the `hpx` namespace. The `count_down_and_wait()` functionality of `latch` has been renamed to `arrive_and_wait()`.
 - `hpx::util::unique_function_nonser` has been renamed to `hpx::move_only_function`.
 - `hpx::util::unique_function` has been renamed to `hpx::distributed::move_only_function`.
 - `hpx::util::function` has been renamed to `hpx::distributed::function`.
 - `hpx::util::function_nonser` has been renamed to `hpx::function`.
 - `hpx::util::function_ref` have been moved to namespace `hpx`.
 - `hpx::lcos::split_future` changed namespace and is now used as `hpx::split_future`.
 - `hpx::lcos::local::counting_semaphore` has been deprecated and `hpx::lcos::local::cpp20_counting_semaphore` has been renamed to `hpx::counting_semaphore`.
 - `hpx::lcos::local::cpp20_binary_semaphore` has been renamed to `hpx::binary_semaphore`.
 - `hpx::lcos::local::sliding_semaphore` has been renamed to `hpx::sliding_semaphore` and
 - `hpx::lcos::local::sliding_semaphore_var` has been renamed to `hpx::sliding_semaphore_var`.
 - `hpx::lcos::local::spinlock` has been renamed to `hpx::spinlock`.
 - `hpx::lcos::local::mutex` has been renamed to `hpx::mutex`.
 - `hpx::lcos::local::timed_mutex` has been renamed to `hpx::timed_mutex`.
 - `hpx::lcos::local::no_mutex` has been renamed to `hpx::no_mutex`.
 - `hpx::lcos::local::recursive_mutex` has been renamed to `hpx::recursive_mutex`.
 - `hpx::lcos::local::shared_mutex` has been renamed to `hpx::shared_mutex`.
 - `hpx::lcos::local::upgrade_lock` has been renamed to `hpx::upgrade_lock`.
 - `hpx::lcos::local::upgrade_to_unique_lock` has been renamed to `hpx::upgrade_to_unique_lock`.
 - `hpx::lcos::local::condition_variable` has been renamed to `hpx::condition_variable`. `hpx::lcos::local::condition_variable_var` has been renamed to `hpx::condition_variable_var`.
 - `hpx::lcos::local::once_flag` has been renamed to `hpx::once_flag`, and `hpx::lcos::local::call_once` has been renamed to `hpx::call_once`.
- The new LCI (Lightweight Communication Interface) `parcelexport` was added that supports irregular and asynchronous applications like graph analysis, sparse linear algebra, modern parallel architectures etc. Major features include:

- Support for advanced communication primitives like two sided send/recv and one sided remote put.
- Better multi-threaded performance.
- Explicit user control of communication resource.
- Flexible signaling mechanisms (synchronizer, completion queue, active message handler).
- The following CMake flags were added, mostly to support using HPX as a backend for SHAD (<https://github.com/pnnl/SHAD>). Please note that these options enable questionable functionalities, partially they even enable undefined behavior. Please only use any of them if you know what you're doing:
 - HPX_SERIALIZATION_WITH_ALLOW_RAW_POINTER_SERIALIZATION
 - HPX_SERIALIZATION_WITH_ALL_TYPES_ARE_BITWISE_SERIALIZABLE
 - HPX_SERIALIZATION_WITH_ALLOW_CONST_TUPLE_MEMBERS

Breaking changes

- Minimum required C++ standard library is C++17.
- Support for GCC 7 and Clang 8.0.0 and below has been removed.
- CUDA version required updated to 11.4.
- CMake version required updated to 3.18.
- The default version of Asio used was updated to 1.20.0.
- The default version of APEX used was updated to 2.5.1.
- APEX version was updated to 2.5.1.
- `tagged_pair` and `tagged_tuple` were removed.
- `tag_dispatch` was renamed to `tag_invoke`.
- `hpx.max_background_threads` was renamed to `hpx.parcel.max_background_threads`.
- The following CMake flags were removed after being deprecated for at least two releases:
 - HPX_SCHEDULER_MAX_TERMINATED_THREADS
 - HPX_WITH_GOOGLE_PERFTOOLS
 - HPX_WITH_INIT_START_OVERLOADS_COMPATIBILITY
 - HPX_HAVE_{COROUTINE,PLUGIN}_GCC_HIDDEN_VISIBILITY
 - HPX_TOP_LEVEL
 - HPX_WITH_COMPUTE_CUDA
 - HPX_WITH_ASYNC_CUDA
- `annotate_function` was renamed to `scoped_annotation`.
- `execution::transform` was renamed to `execution::then`.
- `execution::detach` was renamed to `execution::start_detached`.
- `execution::on_sender` was renamed to `execution::schedule_on`.
- `execution::just_on` was renamed to `execution::just_transfer`.
- `execution::set_done` was renamed to `execution::set_stopped`.

Closed issues

- [Issue #5871](#)¹⁵²³ - distributed::channel.regisiter_as terminates the active task.
- [Issue #5856](#)¹⁵²⁴ - Performance counters do not compile
- [Issue #5828](#)¹⁵²⁵ - hpx::distributed:barrier errors
- [Issue #5812](#)¹⁵²⁶ - OctoTiger does not compile with HPX master and CUDA 11.5
- [Issue #5784](#)¹⁵²⁷ - HPX failing with co_await and hpx::when_all(futures)
- [Issue #5774](#)¹⁵²⁸ - CMake can't find HPXCacheVariables.cmake
- [Issue #5764](#)¹⁵²⁹ - Fix HIP problem
- [Issue #5724](#)¹⁵³⁰ - Missing binary filter compression header
- [Issue #5721](#)¹⁵³¹ - Cleanup after repository split
- [Issue #5701](#)¹⁵³² - It seems that the tcp parcelport is running, and the MPI parcelport is ignored
- [Issue #5692](#)¹⁵³³ - Kokkos compilation fails when using both HPX and CUDA execution spaces with gcc 9.3.0
- [Issue #5686](#)¹⁵³⁴ - Rename *annotate_function*
- [Issue #5668](#)¹⁵³⁵ - HPX does not detect the C++ 20 standard using gcc 11.2
- [Issue #5666](#)¹⁵³⁶ - Compilation error using boost 1.76 and gcc 11.2.1
- [Issue #5653](#)¹⁵³⁷ - Implement P2248 for our algorithms
- [Issue #5647](#)¹⁵³⁸ - [User input needed] Remove (CUDA) compute functionality?
- [Issue #5590](#)¹⁵³⁹ - hello_world_distributed fails on startup with HPX stable, MPICH 3.3.2, on Deep Bayou
- [Issue #5570](#)¹⁵⁴⁰ - Rename tag_dispatch to tag_invoke
- [Issue #5566](#)¹⁵⁴¹ - can't build simple example: "Cannot use the dummy implementation of future_then_dispatch"
- [Issue #5565](#)¹⁵⁴² - build failure: hpx::string_util::trim()
- [Issue #5553](#)¹⁵⁴³ - Github action to validate the cff file refs #5471
- [Issue #5504](#)¹⁵⁴⁴ - CMake does not work for HPX 1.7.0 on Piz Daint

¹⁵²³ <https://github.com/STELLAR-GROUP/hpx/issues/5871>

¹⁵²⁴ <https://github.com/STELLAR-GROUP/hpx/issues/5856>

¹⁵²⁵ <https://github.com/STELLAR-GROUP/hpx/issues/5828>

¹⁵²⁶ <https://github.com/STELLAR-GROUP/hpx/issues/5812>

¹⁵²⁷ <https://github.com/STELLAR-GROUP/hpx/issues/5784>

¹⁵²⁸ <https://github.com/STELLAR-GROUP/hpx/issues/5774>

¹⁵²⁹ <https://github.com/STELLAR-GROUP/hpx/issues/5764>

¹⁵³⁰ <https://github.com/STELLAR-GROUP/hpx/issues/5724>

¹⁵³¹ <https://github.com/STELLAR-GROUP/hpx/issues/5721>

¹⁵³² <https://github.com/STELLAR-GROUP/hpx/issues/5701>

¹⁵³³ <https://github.com/STELLAR-GROUP/hpx/issues/5692>

¹⁵³⁴ <https://github.com/STELLAR-GROUP/hpx/issues/5686>

¹⁵³⁵ <https://github.com/STELLAR-GROUP/hpx/issues/5668>

¹⁵³⁶ <https://github.com/STELLAR-GROUP/hpx/issues/5666>

¹⁵³⁷ <https://github.com/STELLAR-GROUP/hpx/issues/5653>

¹⁵³⁸ <https://github.com/STELLAR-GROUP/hpx/issues/5647>

¹⁵³⁹ <https://github.com/STELLAR-GROUP/hpx/issues/5590>

¹⁵⁴⁰ <https://github.com/STELLAR-GROUP/hpx/issues/5570>

¹⁵⁴¹ <https://github.com/STELLAR-GROUP/hpx/issues/5566>

¹⁵⁴² <https://github.com/STELLAR-GROUP/hpx/issues/5565>

¹⁵⁴³ <https://github.com/STELLAR-GROUP/hpx/issues/5553>

¹⁵⁴⁴ <https://github.com/STELLAR-GROUP/hpx/issues/5504>

- [Issue #5503¹⁵⁴⁵](#) - Use contiguous index queue in bulk execution to reduce number of spawned tasks
- [Issue #5502¹⁵⁴⁶](#) - C++20 std::coroutine cmake detection
- [Issue #5478¹⁵⁴⁷](#) - hpx.dll built with vcpkg got functions pointing to the same location
- [Issue #5472¹⁵⁴⁸](#) - Compilation error with cuda/11.3
- [Issue #5469¹⁵⁴⁹](#) - Compiler warning about HPX_NODISCARD when building with APEX
- [Issue #5463¹⁵⁵⁰](#) - Address minor comments of the C++17 PR bump
- [Issue #5456¹⁵⁵¹](#) - Use `std::ranges::iter_swap` where available
- [Issue #5404¹⁵⁵²](#) - Build fails with error “Cannot open include file asio/io_context.hpp”
- [Issue #5381¹⁵⁵³](#) - Add `starts_with` and `ends_with` algorithms
- [Issue #5344¹⁵⁵⁴](#) - Further simplify `tag_invoke` helpers
- [Issue #5269¹⁵⁵⁵](#) - Allow setting a label on executors/policies
- [Issue #5219¹⁵⁵⁶](#) - (Re-)Implement executor API on top of sender/receiver infrastructure
- [Issue #5216¹⁵⁵⁷](#) - Performance counter module not loading
- [Issue #5162¹⁵⁵⁸](#) - Require C++17 support
- [Issue #5156¹⁵⁵⁹](#) - Disentangle segmented algorithms
- [Issue #5118¹⁵⁶⁰](#) - Lock held while suspending
- [Issue #5111¹⁵⁶¹](#) - Tests fail to build with `binary_filter` plugins enabled
- [Issue #5110¹⁵⁶²](#) - Tests don't get built
- [Issue #5105¹⁵⁶³](#) - PAPI performance counters not available
- [Issue #5002¹⁵⁶⁴](#) - `hpx::lcos::barrier()` results in deadlock
- [Issue #4992¹⁵⁶⁵](#) - Clang-format the rest of the files
- [Issue #4987¹⁵⁶⁶](#) - Use `std::function` in public APIs
- [Issue #4871¹⁵⁶⁷](#) - HEP: conformance to C++20

¹⁵⁴⁵ <https://github.com/STELLAR-GROUP/hpx/issues/5503>

¹⁵⁴⁶ <https://github.com/STELLAR-GROUP/hpx/issues/5502>

¹⁵⁴⁷ <https://github.com/STELLAR-GROUP/hpx/issues/5478>

¹⁵⁴⁸ <https://github.com/STELLAR-GROUP/hpx/issues/5472>

¹⁵⁴⁹ <https://github.com/STELLAR-GROUP/hpx/issues/5469>

¹⁵⁵⁰ <https://github.com/STELLAR-GROUP/hpx/issues/5463>

¹⁵⁵¹ <https://github.com/STELLAR-GROUP/hpx/issues/5456>

¹⁵⁵² <https://github.com/STELLAR-GROUP/hpx/issues/5404>

¹⁵⁵³ <https://github.com/STELLAR-GROUP/hpx/issues/5381>

¹⁵⁵⁴ <https://github.com/STELLAR-GROUP/hpx/issues/5344>

¹⁵⁵⁵ <https://github.com/STELLAR-GROUP/hpx/issues/5269>

¹⁵⁵⁶ <https://github.com/STELLAR-GROUP/hpx/issues/5219>

¹⁵⁵⁷ <https://github.com/STELLAR-GROUP/hpx/issues/5216>

¹⁵⁵⁸ <https://github.com/STELLAR-GROUP/hpx/issues/5162>

¹⁵⁵⁹ <https://github.com/STELLAR-GROUP/hpx/issues/5156>

¹⁵⁶⁰ <https://github.com/STELLAR-GROUP/hpx/issues/5118>

¹⁵⁶¹ <https://github.com/STELLAR-GROUP/hpx/issues/5111>

¹⁵⁶² <https://github.com/STELLAR-GROUP/hpx/issues/5110>

¹⁵⁶³ <https://github.com/STELLAR-GROUP/hpx/issues/5105>

¹⁵⁶⁴ <https://github.com/STELLAR-GROUP/hpx/issues/5002>

¹⁵⁶⁵ <https://github.com/STELLAR-GROUP/hpx/issues/4992>

¹⁵⁶⁶ <https://github.com/STELLAR-GROUP/hpx/issues/4987>

¹⁵⁶⁷ <https://github.com/STELLAR-GROUP/hpx/issues/4871>

- Issue #4822¹⁵⁶⁸ - Adapt parallel algorithms to C++20
- Issue #4736¹⁵⁶⁹ - Deprecate `hpx::flush` and `hpx::endl`
- Issue #4558¹⁵⁷⁰ - Prevent work-stealing from stalling
- Issue #4495¹⁵⁷¹ - Add anchor links to table rows in documentation
- Issue #4469¹⁵⁷² - New thread state: *pending_low*
- Issue #4321¹⁵⁷³ - After the modularization the `libfabric` `parcelport` does not compile
- Issue #4308¹⁵⁷⁴ - Using APEX on multinode jobs when `HPX_WITH_NETWORKING = OFF`
- Issue #3995¹⁵⁷⁵ - Use C++20 `std::source_location` where available, adapt ours to conform
- Issue #3861¹⁵⁷⁶ - Selected processor does not support 'yield' in ARM mode
- Issue #3706¹⁵⁷⁷ - Add `shift_left` and `shift_right` algorithms
- Issue #3646¹⁵⁷⁸ - Parallel algorithms should accept iterator/sentinel pairs
- Issue #3636¹⁵⁷⁹ - HPX Modularization
- Issue #3546¹⁵⁸⁰ - Modularization of HPX
- Issue #3474¹⁵⁸¹ - Modernize CMake used in HPX
- Issue #1836¹⁵⁸² - `hpx::parallel` does not have a sort implementation
- Issue #1668¹⁵⁸³ - Adapt all parallel algorithms to Ranges TS
- Issue #1141¹⁵⁸⁴ - Implement N4409 on top of HPX

Closed pull requests

- PR #5885¹⁵⁸⁵ - Testing newer ASIO version
- PR #5884¹⁵⁸⁶ - Fix miscellaneous doc sections
- PR #5882¹⁵⁸⁷ - Fixing OctoTiger incompatibility introduced recently
- PR #5881¹⁵⁸⁸ - Fixing recent patch that disables `ATOMIC_FLAG_INIT` for C++20 and up
- PR #5880¹⁵⁸⁹ - refactor: convert `counter_status` enum to enum class

¹⁵⁶⁸ <https://github.com/STELLAR-GROUP/hpx/issues/4822>

¹⁵⁶⁹ <https://github.com/STELLAR-GROUP/hpx/issues/4736>

¹⁵⁷⁰ <https://github.com/STELLAR-GROUP/hpx/issues/4558>

¹⁵⁷¹ <https://github.com/STELLAR-GROUP/hpx/issues/4495>

¹⁵⁷² <https://github.com/STELLAR-GROUP/hpx/issues/4469>

¹⁵⁷³ <https://github.com/STELLAR-GROUP/hpx/issues/4321>

¹⁵⁷⁴ <https://github.com/STELLAR-GROUP/hpx/issues/4308>

¹⁵⁷⁵ <https://github.com/STELLAR-GROUP/hpx/issues/3995>

¹⁵⁷⁶ <https://github.com/STELLAR-GROUP/hpx/issues/3861>

¹⁵⁷⁷ <https://github.com/STELLAR-GROUP/hpx/issues/3706>

¹⁵⁷⁸ <https://github.com/STELLAR-GROUP/hpx/issues/3646>

¹⁵⁷⁹ <https://github.com/STELLAR-GROUP/hpx/issues/3636>

¹⁵⁸⁰ <https://github.com/STELLAR-GROUP/hpx/issues/3546>

¹⁵⁸¹ <https://github.com/STELLAR-GROUP/hpx/issues/3474>

¹⁵⁸² <https://github.com/STELLAR-GROUP/hpx/issues/1836>

¹⁵⁸³ <https://github.com/STELLAR-GROUP/hpx/issues/1668>

¹⁵⁸⁴ <https://github.com/STELLAR-GROUP/hpx/issues/1141>

¹⁵⁸⁵ <https://github.com/STELLAR-GROUP/hpx/pull/5885>

¹⁵⁸⁶ <https://github.com/STELLAR-GROUP/hpx/pull/5884>

¹⁵⁸⁷ <https://github.com/STELLAR-GROUP/hpx/pull/5882>

¹⁵⁸⁸ <https://github.com/STELLAR-GROUP/hpx/pull/5881>

¹⁵⁸⁹ <https://github.com/STELLAR-GROUP/hpx/pull/5880>

- PR #5878¹⁵⁹⁰ - Docs: Replaced non-existent create_reducer function with create_communicator
- PR #5877¹⁵⁹¹ - Doc updates hpx runtime and resources
- PR #5876¹⁵⁹² - Updates to documentation; grammar edits.
- PR #5875¹⁵⁹³ - Doc updates starting the hpx runtime
- PR #5874¹⁵⁹⁴ - Doc updates launching configuring
- PR #5873¹⁵⁹⁵ - Prevent certain generated files from being deleted on reconfigure
- PR #5870¹⁵⁹⁶ - Adding support for the PJM batch environment
- PR #5867¹⁵⁹⁷ - Update CMakeLists.txt
- PR #5866¹⁵⁹⁸ - add cmake option HPX_WITH_PARCELPORNT_COUNTERS
- PR #5864¹⁵⁹⁹ - ATOMIC_INIT_FLAG is deprecated starting C++20
- PR #5863¹⁶⁰⁰ - Adding llvm 14.0.0 with boost 1.79.0 to Jenkins
- PR #5861¹⁶⁰¹ - Let install step proceed on CircleCI even if the segmented algorithms fail
- PR #5860¹⁶⁰² - Updating APEX tag
- PR #5859¹⁶⁰³ - Splitting documentation generation steps on CircleCI
- PR #5854¹⁶⁰⁴ - Fixing left-overs from changing counter_type to enum class
- PR #5853¹⁶⁰⁵ - Adding HPX dependency tool (adapted from Boostdep tool)
- PR #5852¹⁶⁰⁶ - Optimize LCI parcelport
- PR #5851¹⁶⁰⁷ - Forking dynamic_bitset from Boost
- PR #5850¹⁶⁰⁸ - Convert perf_counters::counter_type enum to enum class.
- PR #5849¹⁶⁰⁹ - Update LCI parcelport to LCI v1.7.1
- PR #5848¹⁶¹⁰ - Fedora related fixes
- PR #5847¹⁶¹¹ - Fix API, troubleshooting & people
- PR #5844¹⁶¹² - Attempting to fix timeouts of segmented iterator tests

¹⁵⁹⁰ <https://github.com/STELLAR-GROUP/hpx/pull/5878>

¹⁵⁹¹ <https://github.com/STELLAR-GROUP/hpx/pull/5877>

¹⁵⁹² <https://github.com/STELLAR-GROUP/hpx/pull/5876>

¹⁵⁹³ <https://github.com/STELLAR-GROUP/hpx/pull/5875>

¹⁵⁹⁴ <https://github.com/STELLAR-GROUP/hpx/pull/5874>

¹⁵⁹⁵ <https://github.com/STELLAR-GROUP/hpx/pull/5873>

¹⁵⁹⁶ <https://github.com/STELLAR-GROUP/hpx/pull/5870>

¹⁵⁹⁷ <https://github.com/STELLAR-GROUP/hpx/pull/5867>

¹⁵⁹⁸ <https://github.com/STELLAR-GROUP/hpx/pull/5866>

¹⁵⁹⁹ <https://github.com/STELLAR-GROUP/hpx/pull/5864>

¹⁶⁰⁰ <https://github.com/STELLAR-GROUP/hpx/pull/5863>

¹⁶⁰¹ <https://github.com/STELLAR-GROUP/hpx/pull/5861>

¹⁶⁰² <https://github.com/STELLAR-GROUP/hpx/pull/5860>

¹⁶⁰³ <https://github.com/STELLAR-GROUP/hpx/pull/5859>

¹⁶⁰⁴ <https://github.com/STELLAR-GROUP/hpx/pull/5854>

¹⁶⁰⁵ <https://github.com/STELLAR-GROUP/hpx/pull/5853>

¹⁶⁰⁶ <https://github.com/STELLAR-GROUP/hpx/pull/5852>

¹⁶⁰⁷ <https://github.com/STELLAR-GROUP/hpx/pull/5851>

¹⁶⁰⁸ <https://github.com/STELLAR-GROUP/hpx/pull/5850>

¹⁶⁰⁹ <https://github.com/STELLAR-GROUP/hpx/pull/5849>

¹⁶¹⁰ <https://github.com/STELLAR-GROUP/hpx/pull/5848>

¹⁶¹¹ <https://github.com/STELLAR-GROUP/hpx/pull/5847>

¹⁶¹² <https://github.com/STELLAR-GROUP/hpx/pull/5844>

- PR #5842¹⁶¹³ - change the default value of HPX_WITH_LCI_TAG to v1.7
- PR #5841¹⁶¹⁴ - Move the split_future facilities into the namespace hpx
- PR #5840¹⁶¹⁵ - wait_XXX_nothrow functions return whether one of the futures is exceptional
- PR #5839¹⁶¹⁶ - Moving a list of synchronization primitives into namespace hpx
- PR #5837¹⁶¹⁷ - Moving latch types to hpx and hpx::distributed namespaces
- PR #5835¹⁶¹⁸ - Add missing compatibility layer for id_type::management_type values
- PR #5834¹⁶¹⁹ - API docs changes
- PR #5831¹⁶²⁰ - Further improvement actions to rotate
- PR #5830¹⁶²¹ - Exposing zero-copy serialization threshold through configuration option
- PR #5829¹⁶²² - Attempting to fix failing barrier test
- PR #5827¹⁶²³ - Add back explicit template parameter to *ignore_while_checking* to compile with nvcc
- PR #5826¹⁶²⁴ - Reduce number of allocations while calling *async_bulk_execute*
- PR #5825¹⁶²⁵ - Steal from neighboring NUMA domain only
- PR #5823¹⁶²⁶ - Remove obsolete directories and adjust build system
- PR #5822¹⁶²⁷ - Clang-format remaining files
- PR #5821¹⁶²⁸ - Enable permissive- flag on Windows GitHub actions builders
- PR #5820¹⁶²⁹ - Convert throwmode enum to enum class
- PR #5819¹⁶³⁰ - Marking customization points for *intrusive_ptr* as noexcept
- PR #5818¹⁶³¹ - Unconditionally use C++17 attributes
- PR #5817¹⁶³² - Modernize naming modules
- PR #5816¹⁶³³ - Modernize cache module
- PR #5815¹⁶³⁴ - Reapply flyby changes from #5467
- PR #5814¹⁶³⁵ - Avoid test timeouts by reducing test sizes

¹⁶¹³ <https://github.com/STELLAR-GROUP/hpx/pull/5842>

¹⁶¹⁴ <https://github.com/STELLAR-GROUP/hpx/pull/5841>

¹⁶¹⁵ <https://github.com/STELLAR-GROUP/hpx/pull/5840>

¹⁶¹⁶ <https://github.com/STELLAR-GROUP/hpx/pull/5839>

¹⁶¹⁷ <https://github.com/STELLAR-GROUP/hpx/pull/5837>

¹⁶¹⁸ <https://github.com/STELLAR-GROUP/hpx/pull/5835>

¹⁶¹⁹ <https://github.com/STELLAR-GROUP/hpx/pull/5834>

¹⁶²⁰ <https://github.com/STELLAR-GROUP/hpx/pull/5831>

¹⁶²¹ <https://github.com/STELLAR-GROUP/hpx/pull/5830>

¹⁶²² <https://github.com/STELLAR-GROUP/hpx/pull/5829>

¹⁶²³ <https://github.com/STELLAR-GROUP/hpx/pull/5827>

¹⁶²⁴ <https://github.com/STELLAR-GROUP/hpx/pull/5826>

¹⁶²⁵ <https://github.com/STELLAR-GROUP/hpx/pull/5825>

¹⁶²⁶ <https://github.com/STELLAR-GROUP/hpx/pull/5823>

¹⁶²⁷ <https://github.com/STELLAR-GROUP/hpx/pull/5822>

¹⁶²⁸ <https://github.com/STELLAR-GROUP/hpx/pull/5821>

¹⁶²⁹ <https://github.com/STELLAR-GROUP/hpx/pull/5820>

¹⁶³⁰ <https://github.com/STELLAR-GROUP/hpx/pull/5819>

¹⁶³¹ <https://github.com/STELLAR-GROUP/hpx/pull/5818>

¹⁶³² <https://github.com/STELLAR-GROUP/hpx/pull/5817>

¹⁶³³ <https://github.com/STELLAR-GROUP/hpx/pull/5816>

¹⁶³⁴ <https://github.com/STELLAR-GROUP/hpx/pull/5815>

¹⁶³⁵ <https://github.com/STELLAR-GROUP/hpx/pull/5814>

- PR #5813¹⁶³⁶ - The CUDA problem is not fixed in V11.5 yet...
- PR #5811¹⁶³⁷ - Make sure reduction value is properly moved, when possible
- PR #5810¹⁶³⁸ - Improve error reporting during device initialization in HIP environments
- PR #5809¹⁶³⁹ - Converting scheduler enums into enum class
- PR #5808¹⁶⁴⁰ - Deprecate hpx::flush and friends
- PR #5807¹⁶⁴¹ - Use C++20 std::source_location, if available
- PR #5806¹⁶⁴² - Moving promise and packaged_task to new namespaces
- PR #5805¹⁶⁴³ - Attempting to fix a test failure when using the LCI parcellpor
- PR #5803¹⁶⁴⁴ - Attempt to fix CUDA related OctoTiger problems
- PR #5800¹⁶⁴⁵ - Add option to restrict MPI background work to subset of cores
- PR #5798¹⁶⁴⁶ - Adding MPI as a dependency to APEX
- PR #5797¹⁶⁴⁷ - Extend Sphinx role to support arbitrary text to display on a link
- PR #5796¹⁶⁴⁸ - Disable CUDA tests that cause NVCC to silently fail without error messages
- PR #5795¹⁶⁴⁹ - Avoid writing path and directories into HPXCacheVariables.cmake
- PR #5793¹⁶⁵⁰ - Remove features that are deprecated since V1.6
- PR #5792¹⁶⁵¹ - Making sure num_cores is properly handled by parallel_executor
- PR #5791¹⁶⁵² - Moving bind, bind_front, bind_back to namespace hpx
- PR #5790¹⁶⁵³ - Moving serializable function/move_only_function into namespace hpx::distributed
- PR #5787¹⁶⁵⁴ - Remove unneeded (and commented) tests
- PR #5786¹⁶⁵⁵ - Attempting to fix hangs in distributed barrier
- PR #5785¹⁶⁵⁶ - add cmake code to detect arm64 on macOS
- PR #5783¹⁶⁵⁷ - Moving function and function_ref into namespace hpx
- PR #5781¹⁶⁵⁸ - Updating used version of Visual Studio

¹⁶³⁶ <https://github.com/STELLAR-GROUP/hpx/pull/5813>

¹⁶³⁷ <https://github.com/STELLAR-GROUP/hpx/pull/5811>

¹⁶³⁸ <https://github.com/STELLAR-GROUP/hpx/pull/5810>

¹⁶³⁹ <https://github.com/STELLAR-GROUP/hpx/pull/5809>

¹⁶⁴⁰ <https://github.com/STELLAR-GROUP/hpx/pull/5808>

¹⁶⁴¹ <https://github.com/STELLAR-GROUP/hpx/pull/5807>

¹⁶⁴² <https://github.com/STELLAR-GROUP/hpx/pull/5806>

¹⁶⁴³ <https://github.com/STELLAR-GROUP/hpx/pull/5805>

¹⁶⁴⁴ <https://github.com/STELLAR-GROUP/hpx/pull/5803>

¹⁶⁴⁵ <https://github.com/STELLAR-GROUP/hpx/pull/5800>

¹⁶⁴⁶ <https://github.com/STELLAR-GROUP/hpx/pull/5798>

¹⁶⁴⁷ <https://github.com/STELLAR-GROUP/hpx/pull/5797>

¹⁶⁴⁸ <https://github.com/STELLAR-GROUP/hpx/pull/5796>

¹⁶⁴⁹ <https://github.com/STELLAR-GROUP/hpx/pull/5795>

¹⁶⁵⁰ <https://github.com/STELLAR-GROUP/hpx/pull/5793>

¹⁶⁵¹ <https://github.com/STELLAR-GROUP/hpx/pull/5792>

¹⁶⁵² <https://github.com/STELLAR-GROUP/hpx/pull/5791>

¹⁶⁵³ <https://github.com/STELLAR-GROUP/hpx/pull/5790>

¹⁶⁵⁴ <https://github.com/STELLAR-GROUP/hpx/pull/5787>

¹⁶⁵⁵ <https://github.com/STELLAR-GROUP/hpx/pull/5786>

¹⁶⁵⁶ <https://github.com/STELLAR-GROUP/hpx/pull/5785>

¹⁶⁵⁷ <https://github.com/STELLAR-GROUP/hpx/pull/5783>

¹⁶⁵⁸ <https://github.com/STELLAR-GROUP/hpx/pull/5781>

- PR #5780¹⁶⁵⁹ - Update Piz Daint Jenkins configurations from gcc/clang 7 to 8
- PR #5778¹⁶⁶⁰ - Updated for_loop.hpp
- PR #5777¹⁶⁶¹ - Update reference for foreach benchmark
- PR #5775¹⁶⁶² - Move optional into namespace hpx
- PR #5773¹⁶⁶³ - Moving barrier to consolidated namespaces
- PR #5772¹⁶⁶⁴ - Adding missing docs for ranges::find_if and find_if_not algorithms
- PR #5771¹⁶⁶⁵ - Moving for_loop into namespace hpx::experimental
- PR #5770¹⁶⁶⁶ - Fixing HIP issues
- PR #5769¹⁶⁶⁷ - Slight improvement of small_vector performance
- PR #5766¹⁶⁶⁸ - Fixing a integral conversion warning
- PR #5765¹⁶⁶⁹ - Adding a sphinx role allowing to link to a file directly in github
- PR #5763¹⁶⁷⁰ - add num_cores facility
- PR #5762¹⁶⁷¹ - Fix Public API main page
- PR #5761¹⁶⁷² - Add missing inline to mpi_exception.hpp error_message function
- PR #5760¹⁶⁷³ - Update cdash build url
- PR #5759¹⁶⁷⁴ - Switch to use generic rostam SLURM partitions
- PR #5758¹⁶⁷⁵ - Adding support for P2300 completion signatures
- PR #5757¹⁶⁷⁶ - Fix missing links in Public API
- PR #5756¹⁶⁷⁷ - Add stop support to when_all
- PR #5755¹⁶⁷⁸ - Support for data-parallelism for mismatch algorithm
- PR #5754¹⁶⁷⁹ - Support for data-parallelism for equal algorithm
- PR #5751¹⁶⁸⁰ - Propagate MPI dependencies to command line handling
- PR #5750¹⁶⁸¹ - Make sure required MPI initialization flags are properly applied and supported

¹⁶⁵⁹ <https://github.com/STELLAR-GROUP/hpx/pull/5780>

¹⁶⁶⁰ <https://github.com/STELLAR-GROUP/hpx/pull/5778>

¹⁶⁶¹ <https://github.com/STELLAR-GROUP/hpx/pull/5777>

¹⁶⁶² <https://github.com/STELLAR-GROUP/hpx/pull/5775>

¹⁶⁶³ <https://github.com/STELLAR-GROUP/hpx/pull/5773>

¹⁶⁶⁴ <https://github.com/STELLAR-GROUP/hpx/pull/5772>

¹⁶⁶⁵ <https://github.com/STELLAR-GROUP/hpx/pull/5771>

¹⁶⁶⁶ <https://github.com/STELLAR-GROUP/hpx/pull/5770>

¹⁶⁶⁷ <https://github.com/STELLAR-GROUP/hpx/pull/5769>

¹⁶⁶⁸ <https://github.com/STELLAR-GROUP/hpx/pull/5766>

¹⁶⁶⁹ <https://github.com/STELLAR-GROUP/hpx/pull/5765>

¹⁶⁷⁰ <https://github.com/STELLAR-GROUP/hpx/pull/5763>

¹⁶⁷¹ <https://github.com/STELLAR-GROUP/hpx/pull/5762>

¹⁶⁷² <https://github.com/STELLAR-GROUP/hpx/pull/5761>

¹⁶⁷³ <https://github.com/STELLAR-GROUP/hpx/pull/5760>

¹⁶⁷⁴ <https://github.com/STELLAR-GROUP/hpx/pull/5759>

¹⁶⁷⁵ <https://github.com/STELLAR-GROUP/hpx/pull/5758>

¹⁶⁷⁶ <https://github.com/STELLAR-GROUP/hpx/pull/5757>

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¹⁶⁷⁸ <https://github.com/STELLAR-GROUP/hpx/pull/5755>

¹⁶⁷⁹ <https://github.com/STELLAR-GROUP/hpx/pull/5754>

¹⁶⁸⁰ <https://github.com/STELLAR-GROUP/hpx/pull/5751>

¹⁶⁸¹ <https://github.com/STELLAR-GROUP/hpx/pull/5750>

- PR #5749¹⁶⁸² - P2300 stop token
- PR #5748¹⁶⁸³ - Adding environmental query CPOs
- PR #5747¹⁶⁸⁴ - Renaming set_done to set_stopped (as per P2300)
- PR #5745¹⁶⁸⁵ - Modernize serialization module
- PR #5743¹⁶⁸⁶ - Add check for MPICH and set the correct env to support multi-threaded
- PR #5742¹⁶⁸⁷ - Remove obsolete files related to cpuid, etc.
- PR #5741¹⁶⁸⁸ - Support for data-parallelism for adjacent find
- PR #5740¹⁶⁸⁹ - Support for data-parallelism for find algorithms
- PR #5739¹⁶⁹⁰ - Enable the option to attach a debugger on a segmentation fault (linux)
- PR #5738¹⁶⁹¹ - Fixing spell-checking errors
- PR #5737¹⁶⁹² - Attempt to fix migrate_component issue
- PR #5736¹⁶⁹³ - Set commit status from Jenkins also for special branches
- PR #5734¹⁶⁹⁴ - Revert #5586
- PR #5732¹⁶⁹⁵ - Attempt to improve build-id reporting to cdash
- PR #5731¹⁶⁹⁶ - Randomly delay execution of bash scripts launched by Jenkins
- PR #5729¹⁶⁹⁷ - Workaround for CMake/Ninja generator OOM problem
- PR #5727¹⁶⁹⁸ - Moving compression plugins to components directory
- PR #5726¹⁶⁹⁹ - Moving/consolidating parcel coalescing plugin sources
- PR #5725¹⁷⁰⁰ - Making sure headers for serialization filters are being installed
- PR #5723¹⁷⁰¹ - Moving more tests to modules
- PR #5722¹⁷⁰² - Removing superfluous semicolons
- PR #5720¹⁷⁰³ - Moving parcelports into modules
- PR #5719¹⁷⁰⁴ - Moving more files to parcelset module

¹⁶⁸² <https://github.com/STELLAR-GROUP/hpx/pull/5749>

¹⁶⁸³ <https://github.com/STELLAR-GROUP/hpx/pull/5748>

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¹⁷⁰⁰ <https://github.com/STELLAR-GROUP/hpx/pull/5725>

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¹⁷⁰² <https://github.com/STELLAR-GROUP/hpx/pull/5722>

¹⁷⁰³ <https://github.com/STELLAR-GROUP/hpx/pull/5720>

¹⁷⁰⁴ <https://github.com/STELLAR-GROUP/hpx/pull/5719>

- PR #5718¹⁷⁰⁵ - build: refactor sphinx config file
- PR #5717¹⁷⁰⁶ - Creating parcelset modules
- PR #5716¹⁷⁰⁷ - Avoid duplicate definition error
- PR #5715¹⁷⁰⁸ - The new LCI parcelport for HPX
- PR #5714¹⁷⁰⁹ - Refine propagation of **HPX_WITH_...** options
- PR #5713¹⁷¹⁰ - Significantly reduce CI jobs run on Piz Daint
- PR #5712¹⁷¹¹ - Updating jenkins configuration for Rostam2.2
- PR #5711¹⁷¹² - Refactor manual sections
- PR #5710¹⁷¹³ - Making task_group serializable
- PR #5709¹⁷¹⁴ - Update the MPI cmake setup
- PR #5707¹⁷¹⁵ - Better diagnose parcel bootstrap problems
- PR #5704¹⁷¹⁶ - Test with hwloc 2.7.0 with GCC 11
- PR #5703¹⁷¹⁷ - Fix *counting_iterator* container tests
- PR #5702¹⁷¹⁸ - Attempting to fix CircleCI timeouts
- PR #5699¹⁷¹⁹ - Update CI to use Boost 1.78.0
- PR #5697¹⁷²⁰ - Adding fork_join_executor to foreach_benchmark
- PR #5696¹⁷²¹ - Modernize when_all and friends (when_any, when_some, when_each)
- PR #5693¹⁷²² - Fix test errors with *_GLIBCXX_DEBUG* defined
- PR #5691¹⁷²³ - Rename *annotate_function* to *scoped_annotation*
- PR #5690¹⁷²⁴ - Replace tag_dispatch with tag_invoke in minmax segmented
- PR #5688¹⁷²⁵ - Remove more deprecated macros
- PR #5687¹⁷²⁶ - Add most important CMake options
- PR #5685¹⁷²⁷ - Fix future API

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¹⁷⁰⁶ <https://github.com/STELLAR-GROUP/hpx/pull/5717>

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¹⁷²⁰ <https://github.com/STELLAR-GROUP/hpx/pull/5697>

¹⁷²¹ <https://github.com/STELLAR-GROUP/hpx/pull/5696>

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- PR #5684¹⁷²⁸ - Move lock registration to separate module and remove global lock registration
- PR #5683¹⁷²⁹ - Make `hpx::wait_all` etc. throw exceptions when waited futures hold exceptions and deprecate `hpx::lcos::wait_all[_n]` in favor of `hpx::wait_all[_n]`
- PR #5682¹⁷³⁰ - Fix macOS test exceptions
- PR #5681¹⁷³¹ - docs: add links to hpx recepies
- PR #5680¹⁷³² - Embed base execution policies to datapar execution policies
- PR #5679¹⁷³³ - Fix `fork_join_executor` with dynamic schedule
- PR #5678¹⁷³⁴ - Fix compilation of service executors with nvcc
- PR #5677¹⁷³⁵ - Remove `compute_cuda` module
- PR #5676¹⁷³⁶ - Don't require up-to-date approvals for bors
- PR #5675¹⁷³⁷ - Add default template type parameters for algorithms
- PR #5674¹⁷³⁸ - Allow using `any_sender` in global variables
- PR #5671¹⁷³⁹ - Making sure `task_group` can be reused
- PR #5670¹⁷⁴⁰ - Relax constraints on `execution::when_all`
- PR #5669¹⁷⁴¹ - Use `HPX_WITH_CXX_STANDARD` for controlling C++ version
- PR #5667¹⁷⁴² - Attempt to fix compilation issues with Boost V1.76
- PR #5664¹⁷⁴³ - Change logging errors to warnings in schedulers
- PR #5663¹⁷⁴⁴ - Use dynamic bitsets by default for CPU masks
- PR #5662¹⁷⁴⁵ - Disambiguate namespace for MSVC
- PR #5660¹⁷⁴⁶ - Replacing remaining `std::forward` and `std::move` with `HPX_FORWARD` and `HPX_MOVE`
- PR #5659¹⁷⁴⁷ - Modernize `hpx::future` and related facilities
- PR #5658¹⁷⁴⁸ - Replace `HPX_INLINE_CONSTEXPR_VARIABLE` with `inline constexpr`
- PR #5657¹⁷⁴⁹ - Remove `tagged`, `tagged_pair` and `tagged_tuple`, remove `tuple/pair` specializations
- PR #5656¹⁷⁵⁰ - Rename `on_execution::schedule_from`, rename `just_on` to `just_transfer`, and add `transfer`

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¹⁷²⁹ <https://github.com/STELLAR-GROUP/hpx/pull/5683>

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¹⁷⁵⁰ <https://github.com/STELLAR-GROUP/hpx/pull/5656>

- PR #5655¹⁷⁵¹ - Avoid for module lists to grow indefinitely in cmake cache
- PR #5649¹⁷⁵² - build: replace usage of Python's reserved words and functions as variable names
- PR #5648¹⁷⁵³ - Modernize action modules and related code
- PR #5646¹⁷⁵⁴ - Fix ends_with test
- PR #5645¹⁷⁵⁵ - Add matrix multiplication example
- PR #5644¹⁷⁵⁶ - Rename execution::transform to execution::then and execution::detach to execution::start_detached
- PR #5643¹⁷⁵⁷ - Update performance test references
- PR #5642¹⁷⁵⁸ - Adapting adjacent_difference to work with proxy iterators
- PR #5641¹⁷⁵⁹ - Factorize perftests scripts
- PR #5640¹⁷⁶⁰ - Fixed links to sources in Sphinx documentation
- PR #5639¹⁷⁶¹ - Fix generate datapar tests for Vc
- PR #5638¹⁷⁶² - Simd all any none
- PR #5637¹⁷⁶³ - Use bors for merging pull requests
- PR #5636¹⁷⁶⁴ - Fix leftover std::holds_alternative usage
- PR #5635¹⁷⁶⁵ - Update container image tag in GitHub actions HIP configuration
- PR #5633¹⁷⁶⁶ - Moving packaged_task to module futures
- PR #5632¹⁷⁶⁷ - Tell asio to use std::aligned_new only if available
- PR #5631¹⁷⁶⁸ - Adding tag parameter to channel communicator get/set
- PR #5630¹⁷⁶⁹ - Add partial_sort_copy and adapt partial sort to c++ 20
- PR #5629¹⁷⁷⁰ - Set HPX_WITH_FETCH_ASIO to OFF as available in the docker image
- PR #5628¹⁷⁷¹ - Add Clang 13 CI configuration
- PR #5627¹⁷⁷² - Replace alternative keyword
- PR #5626¹⁷⁷³ - docs: add support for BibTeX references in Sphinx docs

¹⁷⁵¹ <https://github.com/STELLAR-GROUP/hpx/pull/5655>

¹⁷⁵² <https://github.com/STELLAR-GROUP/hpx/pull/5649>

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¹⁷⁷³ <https://github.com/STELLAR-GROUP/hpx/pull/5626>

- PR #5624¹⁷⁷⁴ - Fix pkgconfig replacements involving CMAKE_INSTALL_PREFIX
- PR #5623¹⁷⁷⁵ - build: remove unused import from conf.py.in
- PR #5622¹⁷⁷⁶ - Remove HPX_WITH_VCPKG CMake option
- PR #5621¹⁷⁷⁷ - Replacing boost::container::small_vector
- PR #5620¹⁷⁷⁸ - Update Asio tag from 1.18.2 to 1.20.0
- PR #5619¹⁷⁷⁹ - Fix block_os_threads_1036 test
- PR #5618¹⁷⁸⁰ - Make sure condition variables are notified under a lock in the thread_pool_scheduler test
- PR #5617¹⁷⁸¹ - Use advance_and_get_distance where required
- PR #5616¹⁷⁸² - Remove separately building segmented algorithms on CircleCI
- PR #5613¹⁷⁸³ - Fix Vc datapar adjacent_difference
- PR #5609¹⁷⁸⁴ - docs: add anchor links to performance counter tables
- PR #5608¹⁷⁸⁵ - Fix header test error by adding missing numeric
- PR #5607¹⁷⁸⁶ - Fix simd adj diff
- PR #5605¹⁷⁸⁷ - Fix usage of HPX_INVOKE macro
- PR #5604¹⁷⁸⁸ - Make use of shell-session to allow non-copyable \$
- PR #5603¹⁷⁸⁹ - Suppress some MSVC warnings in C++20 mode
- PR #5602¹⁷⁹⁰ - Test HPX_DATASTRUCTURES_WITH_ADAPT_STD_TUPLE=OFF to one CI configuration
- PR #5601¹⁷⁹¹ - Test case for any_sender should use hpx::tuple
- PR #5600¹⁷⁹² - Rename tag_dispatch back to tag_invoke
- PR #5599¹⁷⁹³ - Change theme, fix Quickstart & Examples
- PR #5596¹⁷⁹⁴ - Use precompiled headers in tests
- PR #5595¹⁷⁹⁵ - Drop semicolons for macro calls
- PR #5594¹⁷⁹⁶ - Adapt datapar generate

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¹⁷⁷⁵ <https://github.com/STELLAR-GROUP/hpx/pull/5623>

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- PR #5593¹⁷⁹⁷ - Update any_sender to use tag_dispatch for execution customizations
- PR #5592¹⁷⁹⁸ - Add nth_element
- PR #5591¹⁷⁹⁹ - Remove unnecessary checks for C++17 for tests
- PR #5589¹⁸⁰⁰ - Add HPX_FORWARD/HPX_MOVE macros
- PR #5588¹⁸⁰¹ - Fixing the output formatting for id_types
- PR #5586¹⁸⁰² - Remove local functionality
- PR #5585¹⁸⁰³ - Delete GitExternal.cmake
- PR #5584¹⁸⁰⁴ - Serialization of hpx::tuple must use hpx::get
- PR #5583¹⁸⁰⁵ - fix coroutine_traits allocate calls, add unhandled_exception() implementation.
- PR #5582¹⁸⁰⁶ - Make more examples work with local runtime
- PR #5581¹⁸⁰⁷ - Add support for several performance tests in CI
- PR #5580¹⁸⁰⁸ - Adapt simd adj diff
- PR #5579¹⁸⁰⁹ - Split absolute paths for generated pkg-config files into -L/-I parts
- PR #5577¹⁸¹⁰ - fix unit fill test for datapar with Vc
- PR #5576¹⁸¹¹ - Update forgotten “Full” names
- PR #5575¹⁸¹² - Change scan partitioner implementation
- PR #5574¹⁸¹³ - Remove a few deprecated and unused CMake options
- PR #5572¹⁸¹⁴ - Remove more guards for the distributed runtime
- PR #5571¹⁸¹⁵ - Add workaround for libstc++ in string_util trim
- PR #5569¹⁸¹⁶ - Use no_unique_address in sender adaptors
- PR #5568¹⁸¹⁷ - Change try catch block to try_catch_exception_ptr
- PR #5567¹⁸¹⁸ - Make default_agent::yield actually yield
- PR #5564¹⁸¹⁹ - Adjacent

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¹⁷⁹⁸ <https://github.com/STELLAR-GROUP/hpx/pull/5592>

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¹⁸¹⁹ <https://github.com/STELLAR-GROUP/hpx/pull/5564>

- PR #5562¹⁸²⁰ - More changes to overcome build problems on Windows after recent module rearrangements
- PR #5560¹⁸²¹ - Update tests and examples
- PR #5559¹⁸²² - Fixing cmake folder names after module restructuring
- PR #5558¹⁸²³ - Fixing wrong module dependencies
- PR #5557¹⁸²⁴ - Adding an example for the new channel_communicator API
- PR #5556¹⁸²⁵ - Remove leftover thread pool os executor tests
- PR #5555¹⁸²⁶ - Add option enabling serializing raw pointers
- PR #5554¹⁸²⁷ - Make sure command line aliasing is properly handled
- PR #5552¹⁸²⁸ - Modernizing some of the async facilities
- PR #5551¹⁸²⁹ - Fixing for local executions of actions to properly set task names
- PR #5550¹⁸³⁰ - Update CUDA module in clang-cuda configuration
- PR #5549¹⁸³¹ - Fixing agent_ref::yield_k to actually call yield_k
- PR #5548¹⁸³² - Making get_action_name() noexcept
- PR #5547¹⁸³³ - Fixing communication set
- PR #5546¹⁸³⁴ - Fixing shutdown problems caused by missing ref-counting
- PR #5545¹⁸³⁵ - Remove wrong move in thread_pool_scheduler_bulk.hpp
- PR #5543¹⁸³⁶ - Extend launch policy to carry stack size and scheduling hint in addition to priority
- PR #5542¹⁸³⁷ - Simplify execution CPOs
- PR #5540¹⁸³⁸ - Adapt partition, partition_copy and stable_partition to C++ 20
- PR #5539¹⁸³⁹ - Adapt mismatch to support sentinels
- PR #5538¹⁸⁴⁰ - Document specific sphinx version required for the documentation
- PR #5537¹⁸⁴¹ - Test release and debug builds on Piz Daint
- PR #5536¹⁸⁴² - This fixes referencing stale iterators during the execution of binary mismatch

¹⁸²⁰ <https://github.com/STELLAR-GROUP/hpx/pull/5562>

¹⁸²¹ <https://github.com/STELLAR-GROUP/hpx/pull/5560>

¹⁸²² <https://github.com/STELLAR-GROUP/hpx/pull/5559>

¹⁸²³ <https://github.com/STELLAR-GROUP/hpx/pull/5558>

¹⁸²⁴ <https://github.com/STELLAR-GROUP/hpx/pull/5557>

¹⁸²⁵ <https://github.com/STELLAR-GROUP/hpx/pull/5556>

¹⁸²⁶ <https://github.com/STELLAR-GROUP/hpx/pull/5555>

¹⁸²⁷ <https://github.com/STELLAR-GROUP/hpx/pull/5554>

¹⁸²⁸ <https://github.com/STELLAR-GROUP/hpx/pull/5552>

¹⁸²⁹ <https://github.com/STELLAR-GROUP/hpx/pull/5551>

¹⁸³⁰ <https://github.com/STELLAR-GROUP/hpx/pull/5550>

¹⁸³¹ <https://github.com/STELLAR-GROUP/hpx/pull/5549>

¹⁸³² <https://github.com/STELLAR-GROUP/hpx/pull/5548>

¹⁸³³ <https://github.com/STELLAR-GROUP/hpx/pull/5547>

¹⁸³⁴ <https://github.com/STELLAR-GROUP/hpx/pull/5546>

¹⁸³⁵ <https://github.com/STELLAR-GROUP/hpx/pull/5545>

¹⁸³⁶ <https://github.com/STELLAR-GROUP/hpx/pull/5543>

¹⁸³⁷ <https://github.com/STELLAR-GROUP/hpx/pull/5542>

¹⁸³⁸ <https://github.com/STELLAR-GROUP/hpx/pull/5540>

¹⁸³⁹ <https://github.com/STELLAR-GROUP/hpx/pull/5539>

¹⁸⁴⁰ <https://github.com/STELLAR-GROUP/hpx/pull/5538>

¹⁸⁴¹ <https://github.com/STELLAR-GROUP/hpx/pull/5537>

¹⁸⁴² <https://github.com/STELLAR-GROUP/hpx/pull/5536>

- PR #5535¹⁸⁴³ - Rename `simdpar` to `par_simd`
- PR #5534¹⁸⁴⁴ - Fix Quick start & Manual Docs
- PR #5533¹⁸⁴⁵ - Fix `annotate_function` for `std::string`
- PR #5532¹⁸⁴⁶ - Update two remaining apex links from khuck to UO-OACISS
- PR #5531¹⁸⁴⁷ - Use `contiguous_index_queue` in `thread_pool_scheduler`
- PR #5530¹⁸⁴⁸ - Eagerly initialize a configurable number of threads on scheduler/thread queue init
- PR #5529¹⁸⁴⁹ - Update benchmarks and add support for `scheduler_executor`
- PR #5528¹⁸⁵⁰ - Add missing properties to executors/schedulers
- PR #5527¹⁸⁵¹ - Set local thread/pool number in `local/static_queue_scheduler`
- PR #5526¹⁸⁵² - Update Rostam HIP configuration to use 4.3.0
- PR #5525¹⁸⁵³ - Fix Building HPX in Quick start
- PR #5524¹⁸⁵⁴ - Upload image on cdash
- PR #5523¹⁸⁵⁵ - Modernize facilities related to `hpx::sync`
- PR #5522¹⁸⁵⁶ - Add sender overloads for remaining algorithms
- PR #5521¹⁸⁵⁷ - Minor changes that improve performance
- PR #5520¹⁸⁵⁸ - Update reference as perftests failing regularly
- PR #5519¹⁸⁵⁹ - Add `transform_mpi` sender adapter
- PR #5518¹⁸⁶⁰ - Add sender overloads to `rotate/rotate_copy`
- PR #5517¹⁸⁶¹ - Fix coroutine integration
- PR #5515¹⁸⁶² - Avoid deadlock in `ignore_while_locked_1485` test
- PR #5514¹⁸⁶³ - Add split sender adapter
- PR #5512¹⁸⁶⁴ - Update Rostam HIP configuration
- PR #5511¹⁸⁶⁵ - Fix Asio target name for precompiled headers

¹⁸⁴³ <https://github.com/STELLAR-GROUP/hpx/pull/5535>

¹⁸⁴⁴ <https://github.com/STELLAR-GROUP/hpx/pull/5534>

¹⁸⁴⁵ <https://github.com/STELLAR-GROUP/hpx/pull/5533>

¹⁸⁴⁶ <https://github.com/STELLAR-GROUP/hpx/pull/5532>

¹⁸⁴⁷ <https://github.com/STELLAR-GROUP/hpx/pull/5531>

¹⁸⁴⁸ <https://github.com/STELLAR-GROUP/hpx/pull/5530>

¹⁸⁴⁹ <https://github.com/STELLAR-GROUP/hpx/pull/5529>

¹⁸⁵⁰ <https://github.com/STELLAR-GROUP/hpx/pull/5528>

¹⁸⁵¹ <https://github.com/STELLAR-GROUP/hpx/pull/5527>

¹⁸⁵² <https://github.com/STELLAR-GROUP/hpx/pull/5526>

¹⁸⁵³ <https://github.com/STELLAR-GROUP/hpx/pull/5525>

¹⁸⁵⁴ <https://github.com/STELLAR-GROUP/hpx/pull/5524>

¹⁸⁵⁵ <https://github.com/STELLAR-GROUP/hpx/pull/5523>

¹⁸⁵⁶ <https://github.com/STELLAR-GROUP/hpx/pull/5522>

¹⁸⁵⁷ <https://github.com/STELLAR-GROUP/hpx/pull/5521>

¹⁸⁵⁸ <https://github.com/STELLAR-GROUP/hpx/pull/5520>

¹⁸⁵⁹ <https://github.com/STELLAR-GROUP/hpx/pull/5519>

¹⁸⁶⁰ <https://github.com/STELLAR-GROUP/hpx/pull/5518>

¹⁸⁶¹ <https://github.com/STELLAR-GROUP/hpx/pull/5517>

¹⁸⁶² <https://github.com/STELLAR-GROUP/hpx/pull/5515>

¹⁸⁶³ <https://github.com/STELLAR-GROUP/hpx/pull/5514>

¹⁸⁶⁴ <https://github.com/STELLAR-GROUP/hpx/pull/5512>

¹⁸⁶⁵ <https://github.com/STELLAR-GROUP/hpx/pull/5511>

- PR #5510¹⁸⁶⁶ - Add any_sender and unique_any_sender
- PR #5509¹⁸⁶⁷ - Test with Boost 1.77 on gcc/clang-newest configurations
- PR #5508¹⁸⁶⁸ - Minor release changes from 1.7.1
- PR #5507¹⁸⁶⁹ - Add missing commits from scheduler_executor PR
- PR #5506¹⁸⁷⁰ - Fix condition for checking if we should use our own variant
- PR #5501¹⁸⁷¹ - Attempt to fix thread_pool_scheduler test
- PR #5493¹⁸⁷² - Update Jenkins GitHub token to use StellarBot GitHub account
- PR #5490¹⁸⁷³ - Fix clang-format error on master
- PR #5487¹⁸⁷⁴ - Add get_completion_scheduler CPO and customize bulk for thread_pool_scheduler
- PR #5484¹⁸⁷⁵ - Add missing header to jacobi_component/server/solver.hpp
- PR #5481¹⁸⁷⁶ - Changing the APEX repository to the new location
- PR #5479¹⁸⁷⁷ - Fix version check for CUDA noexcept/result_of bug
- PR #5477¹⁸⁷⁸ - Require cxx17 minor comments
- PR #5476¹⁸⁷⁹ - Fix cmake format error
- PR #5475¹⁸⁸⁰ - Require CMake 3.18 as it is already a requirement for CUDA
- PR #5474¹⁸⁸¹ - Make the cuda parameters of try_compile optional
- PR #5473¹⁸⁸² - Update cuda arch and change cuda version
- PR #5471¹⁸⁸³ - Add corrected citation.cff
- PR #5470¹⁸⁸⁴ - Adapt stable_sort to C++ 20
- PR #5468¹⁸⁸⁵ - Experimentation to make the perftest report public
- PR #5466¹⁸⁸⁶ - Add shift_left and shift_right algorithms
- PR #5465¹⁸⁸⁷ - Adapt datapar fill
- PR #5464¹⁸⁸⁸ - Moving tag_dispatch to separate module

¹⁸⁶⁶ <https://github.com/STELLAR-GROUP/hpx/pull/5510>

¹⁸⁶⁷ <https://github.com/STELLAR-GROUP/hpx/pull/5509>

¹⁸⁶⁸ <https://github.com/STELLAR-GROUP/hpx/pull/5508>

¹⁸⁶⁹ <https://github.com/STELLAR-GROUP/hpx/pull/5507>

¹⁸⁷⁰ <https://github.com/STELLAR-GROUP/hpx/pull/5506>

¹⁸⁷¹ <https://github.com/STELLAR-GROUP/hpx/pull/5501>

¹⁸⁷² <https://github.com/STELLAR-GROUP/hpx/pull/5493>

¹⁸⁷³ <https://github.com/STELLAR-GROUP/hpx/pull/5490>

¹⁸⁷⁴ <https://github.com/STELLAR-GROUP/hpx/pull/5487>

¹⁸⁷⁵ <https://github.com/STELLAR-GROUP/hpx/pull/5484>

¹⁸⁷⁶ <https://github.com/STELLAR-GROUP/hpx/pull/5481>

¹⁸⁷⁷ <https://github.com/STELLAR-GROUP/hpx/pull/5479>

¹⁸⁷⁸ <https://github.com/STELLAR-GROUP/hpx/pull/5477>

¹⁸⁷⁹ <https://github.com/STELLAR-GROUP/hpx/pull/5476>

¹⁸⁸⁰ <https://github.com/STELLAR-GROUP/hpx/pull/5475>

¹⁸⁸¹ <https://github.com/STELLAR-GROUP/hpx/pull/5474>

¹⁸⁸² <https://github.com/STELLAR-GROUP/hpx/pull/5473>

¹⁸⁸³ <https://github.com/STELLAR-GROUP/hpx/pull/5471>

¹⁸⁸⁴ <https://github.com/STELLAR-GROUP/hpx/pull/5470>

¹⁸⁸⁵ <https://github.com/STELLAR-GROUP/hpx/pull/5468>

¹⁸⁸⁶ <https://github.com/STELLAR-GROUP/hpx/pull/5466>

¹⁸⁸⁷ <https://github.com/STELLAR-GROUP/hpx/pull/5465>

¹⁸⁸⁸ <https://github.com/STELLAR-GROUP/hpx/pull/5464>

- PR #5461¹⁸⁸⁹ - Rename HPX_WITH_CUDA_COMPUTE with HPX_WITH_COMPUTE_CUDA
- PR #5460¹⁸⁹⁰ - Adapt sort to C++ 20
- PR #5459¹⁸⁹¹ - Adapt rotate/rotate_copy to C++20
- PR #5458¹⁸⁹² - Adapt unique and unique_copy to C++ 20
- PR #5455¹⁸⁹³ - Remove and clean up fallback sender implementations
- PR #5454¹⁸⁹⁴ - Make performance plot show even if similar performance
- PR #5453¹⁸⁹⁵ - Post 1.7.0 version bump
- PR #5452¹⁸⁹⁶ - Fix find_end parallel overload
- PR #5450¹⁸⁹⁷ - Change the print-bind output to be more precise
- PR #5449¹⁸⁹⁸ - Adapt swap_ranges to C++ 20
- PR #5446¹⁸⁹⁹ - Use more verbose names in sender algorithms
- PR #5443¹⁹⁰⁰ - Properly support ASAN with MSVC
- PR #5441¹⁹⁰¹ - Adding reference counting to thread_data
- PR #5429¹⁹⁰² - Scheduler executor
- PR #5428¹⁹⁰³ - Adapt datapar copy
- PR #5421¹⁹⁰⁴ - Update CI base image to use clang-format 11
- PR #5410¹⁹⁰⁵ - Add ranges starts_with and ends_with algorithms
- PR #5383¹⁹⁰⁶ - Tentatively remove runtime_registration_wrapper from cuda futures
- PR #5377¹⁹⁰⁷ - Fewer Asio includes and more precompiled headers
- PR #5329¹⁹⁰⁸ - Sender overloads for parallel algorithms
- PR #5313¹⁹⁰⁹ - Rearrange modules between libraries
- PR #5283¹⁹¹⁰ - Require minimum C++17 and change CUDA handling
- PR #5241¹⁹¹¹ - Adapt min_element, max_element and minmax_element to C++20

¹⁸⁸⁹ <https://github.com/STELLAR-GROUP/hpx/pull/5461>

¹⁸⁹⁰ <https://github.com/STELLAR-GROUP/hpx/pull/5460>

¹⁸⁹¹ <https://github.com/STELLAR-GROUP/hpx/pull/5459>

¹⁸⁹² <https://github.com/STELLAR-GROUP/hpx/pull/5458>

¹⁸⁹³ <https://github.com/STELLAR-GROUP/hpx/pull/5455>

¹⁸⁹⁴ <https://github.com/STELLAR-GROUP/hpx/pull/5454>

¹⁸⁹⁵ <https://github.com/STELLAR-GROUP/hpx/pull/5453>

¹⁸⁹⁶ <https://github.com/STELLAR-GROUP/hpx/pull/5452>

¹⁸⁹⁷ <https://github.com/STELLAR-GROUP/hpx/pull/5450>

¹⁸⁹⁸ <https://github.com/STELLAR-GROUP/hpx/pull/5449>

¹⁸⁹⁹ <https://github.com/STELLAR-GROUP/hpx/pull/5446>

¹⁹⁰⁰ <https://github.com/STELLAR-GROUP/hpx/pull/5443>

¹⁹⁰¹ <https://github.com/STELLAR-GROUP/hpx/pull/5441>

¹⁹⁰² <https://github.com/STELLAR-GROUP/hpx/pull/5429>

¹⁹⁰³ <https://github.com/STELLAR-GROUP/hpx/pull/5428>

¹⁹⁰⁴ <https://github.com/STELLAR-GROUP/hpx/pull/5421>

¹⁹⁰⁵ <https://github.com/STELLAR-GROUP/hpx/pull/5410>

¹⁹⁰⁶ <https://github.com/STELLAR-GROUP/hpx/pull/5383>

¹⁹⁰⁷ <https://github.com/STELLAR-GROUP/hpx/pull/5377>

¹⁹⁰⁸ <https://github.com/STELLAR-GROUP/hpx/pull/5329>

¹⁹⁰⁹ <https://github.com/STELLAR-GROUP/hpx/pull/5313>

¹⁹¹⁰ <https://github.com/STELLAR-GROUP/hpx/pull/5283>

¹⁹¹¹ <https://github.com/STELLAR-GROUP/hpx/pull/5241>

HPX V1.7.1 (Aug 12, 2021)

This is a bugfix release with a few minor fixes.

General changes

- Added a CMake option to assume that all types are bitwise serializable by default: `HPX_SERIALIZATION_WITH_ALL_TYPES_ARE_BITWISE_SERIALIZABLE`. The default value `OFF` corresponds to the old behaviour.
- Added a version check for Asio. The minimum Asio version supported by *HPX* is 1.12.0.
- Fixed a bug affecting usage of actions, where the internals of *HPX* relied on function addresses being unique. This was fixed by relying on variable addresses being unique instead.
- Made `hpx::util::bind` more strict in checking the validity of placeholders.
- Small performance improvement to spinlocks.
- Adapted the following parallel algorithms to C++20: `inclusive_scan`, `exclusive_scan`, `transform_inclusive_scan`, `transform_exclusive_scan`.

Breaking changes

- The experimental `hpx::execution::simdpar` execution policy (introduced in 1.7.0) was renamed to `hpx::execution::par_simd` for consistency with the other parallel policies.

Closed issues

- Issue #5494¹⁹¹² - Rename *simdpar* execution policy to *par_simd*
- Issue #5488¹⁹¹³ - `hpx::util::bind` doesn't bounds-check placeholders
- Issue #5486¹⁹¹⁴ - Possible V1.7.1 release

Closed pull requests

- PR #5500¹⁹¹⁵ - Minor bug fix in transform exclusive and inclusive scan tests
- PR #5499¹⁹¹⁶ - Rename *simdpar* to *par_simd*
- PR #5489¹⁹¹⁷ - Adding bound-checking for bind placeholders
- PR #5485¹⁹¹⁸ - Add Asio version check
- PR #5482¹⁹¹⁹ - Change extra archive data to rely on uniqueness of a variable address, not a function address
- PR #5448¹⁹²⁰ - More fixes to enable for all types to be assumed to be bitwise copyable

¹⁹¹² <https://github.com/STELLAR-GROUP/hpx/issues/5494>

¹⁹¹³ <https://github.com/STELLAR-GROUP/hpx/issues/5488>

¹⁹¹⁴ <https://github.com/STELLAR-GROUP/hpx/issues/5486>

¹⁹¹⁵ <https://github.com/STELLAR-GROUP/hpx/pull/5500>

¹⁹¹⁶ <https://github.com/STELLAR-GROUP/hpx/pull/5499>

¹⁹¹⁷ <https://github.com/STELLAR-GROUP/hpx/pull/5489>

¹⁹¹⁸ <https://github.com/STELLAR-GROUP/hpx/pull/5485>

¹⁹¹⁹ <https://github.com/STELLAR-GROUP/hpx/pull/5482>

¹⁹²⁰ <https://github.com/STELLAR-GROUP/hpx/pull/5448>

- PR #5445¹⁹²¹ - Improve performance of Spinlocks
- PR #5444¹⁹²² - Adapt transform_inclusive_scan to C++ 20
- PR #5440¹⁹²³ - Adapt transform_exclusive_scan to C++ 20
- PR #5439¹⁹²⁴ - Adapt inclusive_scan to C++ 20
- PR #5436¹⁹²⁵ - Adapt exclusive_scan to C++20

HPX V1.7.0 (Jul 14, 2021)

This release is again focused on C++20 conformance of algorithms. Additionally, many new experimental sender-based algorithms have been added based on the latest proposals.

General changes

- The following algorithms have been adapted to be C++20 conformant:
 - remove,
 - remove_if,
 - remove_copy,
 - remove_copy_if,
 - replace,
 - replace_if,
 - reverse, and
 - lexicographical_compare.
- When the compiler and standard library support the standard execution policies `std::execution::seq`, `std::execution::par`, and `std::execution::par_unseq` they can now be used in all *HPX* parallel algorithms with equivalent behaviour to the non-task policies `hpx::execution::seq`, `hpx::execution::par`, and `hpx::execution::par_unseq`.
- Vc support has been fixed, after being broken in 1.6.0. In addition, *HPX* now experimentally supports GCC's SIMD implementation, when available. The implementation can be used through the `hpx::execution::simd` and `hpx::execution::simdpair` execution policies.
- The customization points `sync_execute`, `async_execute`, `then_execute`, `post`, `bulk_sync_execute`, `bulk_async_execute`, and `bulk_then_execute` are now implemented using `tag_dispatch` (previously `tag_invoke`). Executors can still be implemented by providing the aforementioned functions as member functions of an executor.
- New functionality, enhancements, and fixes based on P0443r14 (executors proposal) and P1897 (sender-based algorithms) have been added to the `hpx::execution::experimental` namespace. These can be accessed through the `hpx/execution.hpp` and `hpx/local/execution.hpp` headers. In particular, the following sender-based algorithms have been added:
 - detach,

¹⁹²¹ <https://github.com/STELLAR-GROUP/hpx/pull/5445>

¹⁹²² <https://github.com/STELLAR-GROUP/hpx/pull/5444>

¹⁹²³ <https://github.com/STELLAR-GROUP/hpx/pull/5440>

¹⁹²⁴ <https://github.com/STELLAR-GROUP/hpx/pull/5439>

¹⁹²⁵ <https://github.com/STELLAR-GROUP/hpx/pull/5436>

- `ensure_started`,
- `just`,
- `just_on`,
- `let_error`,
- `let_value`,
- `on`,
- `transform`, and
- `when_all`.

Additionally, futures now implement the sender concept. `make_future` can be used to turn a sender into a future. All functionality is experimental and can change without notice.

- All `hpx::init` and `hpx::start` overloads now take `std::functions` instead of `hpx::util::function_nonser`. No changes should be required in user code to accommodate this change.
- `hpx::util::unwrapping` and other related unwrapping functionality has been moved up into the `hpx` namespace. Names in `hpx::util` are still usable with a deprecation warning. This functionality can now be accessed through the `hpx/unwrap.hpp` and `hpx/local/unwrap.hpp` headers.
- The default tag for APEX has been update from 2.3.1 to 2.4.0. In particular, this fixes a bug which could lead to hangs in distributed runs.
- The dependency on Boost.Asio has been replaced with the standalone Asio available at <https://github.com/chriskohlhoff/asio>. By default, a system-installed Asio will be used. `ASIO_ROOT` can be given as a hint to tell CMake where to find Asio. Alternatively, Asio can be fetched automatically using CMake's `fetchcontent` by setting `HPX_WITH_FETCH_ASIO=ON`. In general, dependencies on Boost have again been reduced.
- Modularization of the library has continued. In this release almost all functionality has been moved into modules. These changes do not generally affect user code. Warnings are still issued for headers that have moved.
- `hipBLAS` is now optional when compiling with `hipcc`. A warning instead of an error will be printed if `hipBLAS` is not found during configuration.
- Previously `HPX_COMPUTE_HOST_CODE` was defined in host code only if HPX was configured with CUDA or HIP. In this release `HPX_COMPUTE_HOST_CODE` is always defined in host code.
- An experimental `HPX_WITH_PRECOMPILED_HEADERS` CMake option has been added to use precompiled headers when building *HPX*. This option should not be used on Windows.
- Numerous bug fixes.

Breaking changes

- The minimum required CMake version is now 3.17.
- The minimum required Boost version is now 1.71.0.
- The customization mechanism used to implement and extend sender functionality and algorithms has been re-named from `tag_invoke` to `tag_dispatch`. All customization of sender functionality should be done by overloading `tag_dispatch`.
- The following compatibility options have been removed, along with their compatibility implementations:
 - `HPX_PROGRAM_OPTIONS_WITH_BOOST_PROGRAM_OPTIONS_COMPATIBILITY`
 - `HPX_WITH_ACTION_BASE_COMPATIBILITY`
 - `HPX_WITH_EMBEDDED_THREAD_POOLS_COMPATIBILITY`
 - `HPX_WITH_POOL_EXECUTOR_COMPATIBILITY`.
 - `HPX_WITH_PROMISE_ALIAS_COMPATIBILITY`

HPX_WITH_REGISTER_THREAD_COMPATIBILITY - HPX_WITH_REGISTER_THREAD_OVERLOADS_COMPATIBILITY
 - HPX_WITH_THREAD_AWARE_TIMER_COMPATIBILITY - HPX_WITH_THREAD_EXECUTORS_COMPATIBILITY -
 HPX_WITH_THREAD_POOL_OS_EXECUTOR_COMPATIBILITY

- The HPX_WITH_THREAD_SCHEDULERS CMake option has been removed. All schedulers are now enabled when possible.
- HPX_WITH_INIT_START_OVERLOADS_COMPATIBILITY has been turned off by default.

Closed issues

- [Issue #5423¹⁹²⁶](#) - Fix lvalue-ref qualified connect for when_all-sender
- [Issue #5412¹⁹²⁷](#) - Link error
- [Issue #5397¹⁹²⁸](#) - Performance regression in thread annotations
- [Issue #5395¹⁹²⁹](#) - HPX 1.7.0-rc1 fails to build icw APEX + OTF2
- [Issue #5385¹⁹³⁰](#) - HPX 1.7 crashes on Piz Daint > 64 nodes
- [Issue #5380¹⁹³¹](#) - CMake should search for asio package installed on the system
- [Issue #5378¹⁹³²](#) - HPX 1.7.0 stopped building on Fedora
- [Issue #5369¹⁹³³](#) - HPX 1.6 and master hangs on Summit for > 64 nodes
- [Issue #5358¹⁹³⁴](#) - HPX init fails for single-core environments
- [Issue #5345¹⁹³⁵](#) - Rename P2220 property CPOs?
- [Issue #5333¹⁹³⁶](#) - HPX does not compile on the new Mac OSX using the M1 chip
- [Issue #5317¹⁹³⁷](#) - Consider making hipblas optional
- [Issue #5306¹⁹³⁸](#) - asio fails to build with CUDA 10.0
- [Issue #5294¹⁹³⁹](#) - `execution::on` should be based on `execution::schedule`
- [Issue #5275¹⁹⁴⁰](#) - HPX V1.6.0 fails on Fedora release
- [Issue #5270¹⁹⁴¹](#) - HPX-1.6.0 fails to build on Windows 10
- [Issue #5257¹⁹⁴²](#) - Allow triggering the output of OS thread affinity from configuration settings
- [Issue #5246¹⁹⁴³](#) - HPX fails to build on ppc64le

¹⁹²⁶ <https://github.com/STELLAR-GROUP/hpx/issues/5423>

¹⁹²⁷ <https://github.com/STELLAR-GROUP/hpx/issues/5412>

¹⁹²⁸ <https://github.com/STELLAR-GROUP/hpx/issues/5397>

¹⁹²⁹ <https://github.com/STELLAR-GROUP/hpx/issues/5395>

¹⁹³⁰ <https://github.com/STELLAR-GROUP/hpx/issues/5385>

¹⁹³¹ <https://github.com/STELLAR-GROUP/hpx/issues/5380>

¹⁹³² <https://github.com/STELLAR-GROUP/hpx/issues/5378>

¹⁹³³ <https://github.com/STELLAR-GROUP/hpx/issues/5369>

¹⁹³⁴ <https://github.com/STELLAR-GROUP/hpx/issues/5358>

¹⁹³⁵ <https://github.com/STELLAR-GROUP/hpx/issues/5345>

¹⁹³⁶ <https://github.com/STELLAR-GROUP/hpx/issues/5333>

¹⁹³⁷ <https://github.com/STELLAR-GROUP/hpx/issues/5317>

¹⁹³⁸ <https://github.com/STELLAR-GROUP/hpx/issues/5306>

¹⁹³⁹ <https://github.com/STELLAR-GROUP/hpx/issues/5294>

¹⁹⁴⁰ <https://github.com/STELLAR-GROUP/hpx/issues/5275>

¹⁹⁴¹ <https://github.com/STELLAR-GROUP/hpx/issues/5270>

¹⁹⁴² <https://github.com/STELLAR-GROUP/hpx/issues/5257>

¹⁹⁴³ <https://github.com/STELLAR-GROUP/hpx/issues/5246>

- [Issue #5232](#)¹⁹⁴⁴ - Annotation using `hpx::util::annotated_function` not working
- [Issue #5222](#)¹⁹⁴⁵ - Build and link errors with `itnotify` enabled
- [Issue #5204](#)¹⁹⁴⁶ - Move algorithms to `tag_fallback_dispatch`
- [Issue #5163](#)¹⁹⁴⁷ - Remove module-specific compatibility and deprecation options
- [Issue #5161](#)¹⁹⁴⁸ - Bump required CMake version to 3.17
- [Issue #5143](#)¹⁹⁴⁹ - Searching for HPX-Application to generate work on multiple Nodes

Closed pull requests

- [PR #5438](#)¹⁹⁵⁰ - Delete `datapar/foreach_tests.hpp`
- [PR #5437](#)¹⁹⁵¹ - Add back explicit `-pthread` flags when available
- [PR #5435](#)¹⁹⁵² - This adds support for systems that assume all types are bitwise serializable by default
- [PR #5434](#)¹⁹⁵³ - Update CUDA polling logging to be more verbose
- [PR #5433](#)¹⁹⁵⁴ - Fix `when_all_sender` connect for references
- [PR #5432](#)¹⁹⁵⁵ - Add deprecation warnings for v1.8
- [PR #5431](#)¹⁹⁵⁶ - Rename the new P0443/P2300 executor to `thread_pool_scheduler`
- [PR #5430](#)¹⁹⁵⁷ - Revert “Adding the missing defined for `HPX_HAVE_DEPRECATED_WARNINGS`”
- [PR #5427](#)¹⁹⁵⁸ - Removing unneeded `typedef`
- [PR #5426](#)¹⁹⁵⁹ - Adding more concept checks for sender/receiver algorithms
- [PR #5425](#)¹⁹⁶⁰ - Adding the missing defined for `HPX_HAVE_DEPRECATED_WARNINGS`
- [PR #5424](#)¹⁹⁶¹ - Disable `Vc` in final docker image created in CI
- [PR #5422](#)¹⁹⁶² - Adding `execution::experimental::bulk` algorithm
- [PR #5420](#)¹⁹⁶³ - Update logic to find threading library
- [PR #5418](#)¹⁹⁶⁴ - Reduce max size and number of files in `ccache` cache

¹⁹⁴⁴ <https://github.com/STELLAR-GROUP/hpx/issues/5232>

¹⁹⁴⁵ <https://github.com/STELLAR-GROUP/hpx/issues/5222>

¹⁹⁴⁶ <https://github.com/STELLAR-GROUP/hpx/issues/5204>

¹⁹⁴⁷ <https://github.com/STELLAR-GROUP/hpx/issues/5163>

¹⁹⁴⁸ <https://github.com/STELLAR-GROUP/hpx/issues/5161>

¹⁹⁴⁹ <https://github.com/STELLAR-GROUP/hpx/issues/5143>

¹⁹⁵⁰ <https://github.com/STELLAR-GROUP/hpx/pull/5438>

¹⁹⁵¹ <https://github.com/STELLAR-GROUP/hpx/pull/5437>

¹⁹⁵² <https://github.com/STELLAR-GROUP/hpx/pull/5435>

¹⁹⁵³ <https://github.com/STELLAR-GROUP/hpx/pull/5434>

¹⁹⁵⁴ <https://github.com/STELLAR-GROUP/hpx/pull/5433>

¹⁹⁵⁵ <https://github.com/STELLAR-GROUP/hpx/pull/5432>

¹⁹⁵⁶ <https://github.com/STELLAR-GROUP/hpx/pull/5431>

¹⁹⁵⁷ <https://github.com/STELLAR-GROUP/hpx/pull/5430>

¹⁹⁵⁸ <https://github.com/STELLAR-GROUP/hpx/pull/5427>

¹⁹⁵⁹ <https://github.com/STELLAR-GROUP/hpx/pull/5426>

¹⁹⁶⁰ <https://github.com/STELLAR-GROUP/hpx/pull/5425>

¹⁹⁶¹ <https://github.com/STELLAR-GROUP/hpx/pull/5424>

¹⁹⁶² <https://github.com/STELLAR-GROUP/hpx/pull/5422>

¹⁹⁶³ <https://github.com/STELLAR-GROUP/hpx/pull/5420>

¹⁹⁶⁴ <https://github.com/STELLAR-GROUP/hpx/pull/5418>

- PR #5417¹⁹⁶⁵ - Final release notes for 1.7.0
- PR #5416¹⁹⁶⁶ - Adapt `uninitialized_value_construct` and `uninitialized_value_construct_n` to C++ 20
- PR #5415¹⁹⁶⁷ - Adapt `uninitialized_default_construct` and `uninitialized_default_construct_n` to C++ 20
- PR #5414¹⁹⁶⁸ - Improve integration of futures and senders
- PR #5413¹⁹⁶⁹ - Fixing sender/receiver code base to compile with MSVC
- PR #5407¹⁹⁷⁰ - Handle exceptions thrown during initialization of parcel handler
- PR #5406¹⁹⁷¹ - Simplify dispatching to annotation handlers
- PR #5405¹⁹⁷² - Fetch Asio automatically in perftests CI
- PR #5403¹⁹⁷³ - Create generic executor that adds annotations to any other executor
- PR #5402¹⁹⁷⁴ - Adapt `uninitialized_fill` and `uninitialized_fill_n` to C++ 20
- PR #5401¹⁹⁷⁵ - Modernize a variety of facilities related to parallel algorithms
- PR #5400¹⁹⁷⁶ - Fix sliding semaphore test
- PR #5399¹⁹⁷⁷ - Rename leftover `tag_fallback_invoke` to `tag_fallback_dispatch`
- PR #5398¹⁹⁷⁸ - Improve logging in AGAS symbol namespace
- PR #5396¹⁹⁷⁹ - Introduce compatibility layer for collective operations
- PR #5394¹⁹⁸⁰ - Enable OTF2 in APEX CI configuration
- PR #5393¹⁹⁸¹ - Update APEX tag
- PR #5392¹⁹⁸² - Fixing wrong usage of `std::forward`
- PR #5391¹⁹⁸³ - Fix forwarding in `transform_receiver` constructor
- PR #5390¹⁹⁸⁴ - Make sure shared priority scheduler steals tasks on the current NUMA domain when (core) stealing is enabled
- PR #5389¹⁹⁸⁵ - Adapt `uninitialized_move` and `uninitialized_move_n` to C++ 20
- PR #5388¹⁹⁸⁶ - Fixing `gather_there` for used with lvalue reference argument

¹⁹⁶⁵ <https://github.com/STELLAR-GROUP/hpx/pull/5417>

¹⁹⁶⁶ <https://github.com/STELLAR-GROUP/hpx/pull/5416>

¹⁹⁶⁷ <https://github.com/STELLAR-GROUP/hpx/pull/5415>

¹⁹⁶⁸ <https://github.com/STELLAR-GROUP/hpx/pull/5414>

¹⁹⁶⁹ <https://github.com/STELLAR-GROUP/hpx/pull/5413>

¹⁹⁷⁰ <https://github.com/STELLAR-GROUP/hpx/pull/5407>

¹⁹⁷¹ <https://github.com/STELLAR-GROUP/hpx/pull/5406>

¹⁹⁷² <https://github.com/STELLAR-GROUP/hpx/pull/5405>

¹⁹⁷³ <https://github.com/STELLAR-GROUP/hpx/pull/5403>

¹⁹⁷⁴ <https://github.com/STELLAR-GROUP/hpx/pull/5402>

¹⁹⁷⁵ <https://github.com/STELLAR-GROUP/hpx/pull/5401>

¹⁹⁷⁶ <https://github.com/STELLAR-GROUP/hpx/pull/5400>

¹⁹⁷⁷ <https://github.com/STELLAR-GROUP/hpx/pull/5399>

¹⁹⁷⁸ <https://github.com/STELLAR-GROUP/hpx/pull/5398>

¹⁹⁷⁹ <https://github.com/STELLAR-GROUP/hpx/pull/5396>

¹⁹⁸⁰ <https://github.com/STELLAR-GROUP/hpx/pull/5394>

¹⁹⁸¹ <https://github.com/STELLAR-GROUP/hpx/pull/5393>

¹⁹⁸² <https://github.com/STELLAR-GROUP/hpx/pull/5392>

¹⁹⁸³ <https://github.com/STELLAR-GROUP/hpx/pull/5391>

¹⁹⁸⁴ <https://github.com/STELLAR-GROUP/hpx/pull/5390>

¹⁹⁸⁵ <https://github.com/STELLAR-GROUP/hpx/pull/5389>

¹⁹⁸⁶ <https://github.com/STELLAR-GROUP/hpx/pull/5388>

- PR #5387¹⁹⁸⁷ - Extend thread state logging and change default stealing parameters
- PR #5386¹⁹⁸⁸ - Attempt to fix the startup hang with nodes > 32
- PR #5384¹⁹⁸⁹ - Remove HPX 1.5.0 deprecations
- PR #5382¹⁹⁹⁰ - Prefer installed Asio before considering FetchContent
- PR #5379¹⁹⁹¹ - Allow using pre-downloaded (not installed) versions of Asio and/or Apex
- PR #5376¹⁹⁹² - Remove unnecessary explicit listing of library modules.rst files in CMakeLists.txt
- PR #5375¹⁹⁹³ - Slight performance improvement for `hpx::copy` and `hpx::move` et.al.
- PR #5374¹⁹⁹⁴ - Remove unnecessary moves from future sender implementations
- PR #5373¹⁹⁹⁵ - More changes to clang-cuda Jenkins configuration
- PR #5372¹⁹⁹⁶ - Slight improvements to `min/max/minmax_element` algorithms
- PR #5371¹⁹⁹⁷ - Adapt `uninitialized_copy` and `uninitialized_copy_n` to C++ 20
- PR #5370¹⁹⁹⁸ - Decay types in `just_sender` `value_types` to match stored types
- PR #5367¹⁹⁹⁹ - Disable `pkgconfig` by default again on macOS
- PR #5365²⁰⁰⁰ - Use `ccache` for Jenkins builds on Piz Daint
- PR #5363²⁰⁰¹ - Update `cuda toolkit` module name in clang-cuda Jenkins configuration
- PR #5362²⁰⁰² - Adding `channel_communicator`
- PR #5361²⁰⁰³ - Fix compilation with MPI enabled
- PR #5360²⁰⁰⁴ - Update APEX and asio tags
- PR #5359²⁰⁰⁵ - Fix check for `pu-step` in single-core case
- PR #5357²⁰⁰⁶ - Making sure collective operations can be reused by preallocating communicator
- PR #5356²⁰⁰⁷ - Update API documentation
- PR #5355²⁰⁰⁸ - Make the `sequenced_executor` `processing_units_count` member function `const`
- PR #5354²⁰⁰⁹ - Making sure `default_stack_size` is defined whenever declared

¹⁹⁸⁷ <https://github.com/STELLAR-GROUP/hpx/pull/5387>
¹⁹⁸⁸ <https://github.com/STELLAR-GROUP/hpx/pull/5386>
¹⁹⁸⁹ <https://github.com/STELLAR-GROUP/hpx/pull/5384>
¹⁹⁹⁰ <https://github.com/STELLAR-GROUP/hpx/pull/5382>
¹⁹⁹¹ <https://github.com/STELLAR-GROUP/hpx/pull/5379>
¹⁹⁹² <https://github.com/STELLAR-GROUP/hpx/pull/5376>
¹⁹⁹³ <https://github.com/STELLAR-GROUP/hpx/pull/5375>
¹⁹⁹⁴ <https://github.com/STELLAR-GROUP/hpx/pull/5374>
¹⁹⁹⁵ <https://github.com/STELLAR-GROUP/hpx/pull/5373>
¹⁹⁹⁶ <https://github.com/STELLAR-GROUP/hpx/pull/5372>
¹⁹⁹⁷ <https://github.com/STELLAR-GROUP/hpx/pull/5371>
¹⁹⁹⁸ <https://github.com/STELLAR-GROUP/hpx/pull/5370>
¹⁹⁹⁹ <https://github.com/STELLAR-GROUP/hpx/pull/5367>
²⁰⁰⁰ <https://github.com/STELLAR-GROUP/hpx/pull/5365>
²⁰⁰¹ <https://github.com/STELLAR-GROUP/hpx/pull/5363>
²⁰⁰² <https://github.com/STELLAR-GROUP/hpx/pull/5362>
²⁰⁰³ <https://github.com/STELLAR-GROUP/hpx/pull/5361>
²⁰⁰⁴ <https://github.com/STELLAR-GROUP/hpx/pull/5360>
²⁰⁰⁵ <https://github.com/STELLAR-GROUP/hpx/pull/5359>
²⁰⁰⁶ <https://github.com/STELLAR-GROUP/hpx/pull/5357>
²⁰⁰⁷ <https://github.com/STELLAR-GROUP/hpx/pull/5356>
²⁰⁰⁸ <https://github.com/STELLAR-GROUP/hpx/pull/5355>
²⁰⁰⁹ <https://github.com/STELLAR-GROUP/hpx/pull/5354>

- PR #5353²⁰¹⁰ - Add CUDA timestamp support to HPX Hardware Clock
- PR #5352²⁰¹¹ - Adding missing includes
- PR #5351²⁰¹² - Adding `enable_logging/disable_logging` API functions
- PR #5350²⁰¹³ - Adapt `lexicographical_compare` to C++20
- PR #5349²⁰¹⁴ - Update minimum boost version needed on the docs
- PR #5348²⁰¹⁵ - Rename `tag_invoke` and related facilities to `tag_dispatch`
- PR #5347²⁰¹⁶ - Remove `make_` prefix for executor properties
- PR #5346²⁰¹⁷ - Remove and disable compatibility options for 1.7.0
- PR #5343²⁰¹⁸ - Fix `timed_executor` static cast conversion
- PR #5342²⁰¹⁹ - Refactor CUDA event polling
- PR #5341²⁰²⁰ - Adding `make_with_annotation` and `get_annotation` properties
- PR #5339²⁰²¹ - Making sure `hpx::util::hardware::timestamp()` is always defined
- PR #5338²⁰²² - Fixing `timed_executor` specializations of customization points
- PR #5335²⁰²³ - Make `partial_algorithm` work with any number of arguments
- PR #5334²⁰²⁴ - Follow up `iter_sent` include on #5225
- PR #5332²⁰²⁵ - Simplify `tag_invoke` and friends
- PR #5331²⁰²⁶ - More work on cleaning up executor CPOs
- PR #5330²⁰²⁷ - Add option to disable `pkgconfig` generation
- PR #5328²⁰²⁸ - Adapt data parallel support using `std-simd`
- PR #5327²⁰²⁹ - Fix missing `ifdef HPX_SMT_PAUSE`
- PR #5326²⁰³⁰ - Adding `resize()` to `serialize_buffer` allowing to shrink its size
- PR #5324²⁰³¹ - Add get member functions to `async_rw_mutex` proxy objects for explicitly getting the wrapped value
- PR #5323²⁰³² - Add `keep_future` algorithm

²⁰¹⁰ <https://github.com/STELLAR-GROUP/hpx/pull/5353>

²⁰¹¹ <https://github.com/STELLAR-GROUP/hpx/pull/5352>

²⁰¹² <https://github.com/STELLAR-GROUP/hpx/pull/5351>

²⁰¹³ <https://github.com/STELLAR-GROUP/hpx/pull/5350>

²⁰¹⁴ <https://github.com/STELLAR-GROUP/hpx/pull/5349>

²⁰¹⁵ <https://github.com/STELLAR-GROUP/hpx/pull/5348>

²⁰¹⁶ <https://github.com/STELLAR-GROUP/hpx/pull/5347>

²⁰¹⁷ <https://github.com/STELLAR-GROUP/hpx/pull/5346>

²⁰¹⁸ <https://github.com/STELLAR-GROUP/hpx/pull/5343>

²⁰¹⁹ <https://github.com/STELLAR-GROUP/hpx/pull/5342>

²⁰²⁰ <https://github.com/STELLAR-GROUP/hpx/pull/5341>

²⁰²¹ <https://github.com/STELLAR-GROUP/hpx/pull/5339>

²⁰²² <https://github.com/STELLAR-GROUP/hpx/pull/5338>

²⁰²³ <https://github.com/STELLAR-GROUP/hpx/pull/5335>

²⁰²⁴ <https://github.com/STELLAR-GROUP/hpx/pull/5334>

²⁰²⁵ <https://github.com/STELLAR-GROUP/hpx/pull/5332>

²⁰²⁶ <https://github.com/STELLAR-GROUP/hpx/pull/5331>

²⁰²⁷ <https://github.com/STELLAR-GROUP/hpx/pull/5330>

²⁰²⁸ <https://github.com/STELLAR-GROUP/hpx/pull/5328>

²⁰²⁹ <https://github.com/STELLAR-GROUP/hpx/pull/5327>

²⁰³⁰ <https://github.com/STELLAR-GROUP/hpx/pull/5326>

²⁰³¹ <https://github.com/STELLAR-GROUP/hpx/pull/5324>

²⁰³² <https://github.com/STELLAR-GROUP/hpx/pull/5323>

- PR #5322²⁰³³ - Replace executor customization point implementations with `tag_invoke`
- PR #5321²⁰³⁴ - Separate segmented algorithms for reduce
- PR #5320²⁰³⁵ - Fix `is_sender` trait and other small fixes to p0443 traits
- PR #5319²⁰³⁶ - gcc 11.1 c++20 build fixes
- PR #5318²⁰³⁷ - Make hipblas dependency optional as not always available
- PR #5316²⁰³⁸ - Attempt to fix checking for libatomic
- PR #5315²⁰³⁹ - Add explicit keyword to fixture constructor
- PR #5314²⁰⁴⁰ - Fix a race condition in async mpi affecting limiting executor
- PR #5312²⁰⁴¹ - Use local runtime and local headers in local-only modules and tests
- PR #5311²⁰⁴² - Add GCC 11 builder to jenkins
- PR #5310²⁰⁴³ - Adding `hpx::execution::experimental::task_group`
- PR #5309²⁰⁴⁴ - Separate datapar
- PR #5308²⁰⁴⁵ - Separate segmented algorithms for `find`, `find_if`, `find_if_not`
- PR #5307²⁰⁴⁶ - Separate segmented algorithms for `fill` and `generate`
- PR #5304²⁰⁴⁷ - Fix compilation of sender CPOs with `nvcc`
- PR #5300²⁰⁴⁸ - Remove PRIVATE flag that was propagated into the LANGUAGES
- PR #5298²⁰⁴⁹ - Separate datapar
- PR #5297²⁰⁵⁰ - Specify exact cmake and ninja versions when loading them in jenkins jobs
- PR #5295²⁰⁵¹ - Update clang-newest configuration to use clang 12 and Boost 1.76.0
- PR #5293²⁰⁵² - Fix Clang 11 `cuda_future` test bug
- PR #5292²⁰⁵³ - Add `async_rw_mutex` based on senders
- PR #5291²⁰⁵⁴ - “Fix” termination detection
- PR #5290²⁰⁵⁵ - Fixed source file line statements in examples documentation

²⁰³³ <https://github.com/STELLAR-GROUP/hpx/pull/5322>

²⁰³⁴ <https://github.com/STELLAR-GROUP/hpx/pull/5321>

²⁰³⁵ <https://github.com/STELLAR-GROUP/hpx/pull/5320>

²⁰³⁶ <https://github.com/STELLAR-GROUP/hpx/pull/5319>

²⁰³⁷ <https://github.com/STELLAR-GROUP/hpx/pull/5318>

²⁰³⁸ <https://github.com/STELLAR-GROUP/hpx/pull/5316>

²⁰³⁹ <https://github.com/STELLAR-GROUP/hpx/pull/5315>

²⁰⁴⁰ <https://github.com/STELLAR-GROUP/hpx/pull/5314>

²⁰⁴¹ <https://github.com/STELLAR-GROUP/hpx/pull/5312>

²⁰⁴² <https://github.com/STELLAR-GROUP/hpx/pull/5311>

²⁰⁴³ <https://github.com/STELLAR-GROUP/hpx/pull/5310>

²⁰⁴⁴ <https://github.com/STELLAR-GROUP/hpx/pull/5309>

²⁰⁴⁵ <https://github.com/STELLAR-GROUP/hpx/pull/5308>

²⁰⁴⁶ <https://github.com/STELLAR-GROUP/hpx/pull/5307>

²⁰⁴⁷ <https://github.com/STELLAR-GROUP/hpx/pull/5304>

²⁰⁴⁸ <https://github.com/STELLAR-GROUP/hpx/pull/5300>

²⁰⁴⁹ <https://github.com/STELLAR-GROUP/hpx/pull/5298>

²⁰⁵⁰ <https://github.com/STELLAR-GROUP/hpx/pull/5297>

²⁰⁵¹ <https://github.com/STELLAR-GROUP/hpx/pull/5295>

²⁰⁵² <https://github.com/STELLAR-GROUP/hpx/pull/5293>

²⁰⁵³ <https://github.com/STELLAR-GROUP/hpx/pull/5292>

²⁰⁵⁴ <https://github.com/STELLAR-GROUP/hpx/pull/5291>

²⁰⁵⁵ <https://github.com/STELLAR-GROUP/hpx/pull/5290>

- PR #5289²⁰⁵⁶ - Allow splitting of futures holding `std::tuple`
- PR #5288²⁰⁵⁷ - Move algorithms to `tag_fallback_invoke`
- PR #5287²⁰⁵⁸ - Move algorithms to `tag_fallback_invoke`
- PR #5285²⁰⁵⁹ - Fix clang-format failure on master
- PR #5284²⁰⁶⁰ - Replacing `util::function_nonser` on `std::function` in `hpx_init`
- PR #5282²⁰⁶¹ - Update Boost for daint 20.11 after update
- PR #5281²⁰⁶² - Fix Segmentation fault on `foreach_datapar_zipiter`
- PR #5280²⁰⁶³ - Avoid modulo by zero in `counting_iterator` test
- PR #5279²⁰⁶⁴ - Fix more GCC 10 deprecation warnings
- PR #5277²⁰⁶⁵ - Small fixes and improvements to CUDA/MPI polling
- PR #5276²⁰⁶⁶ - Fix typo in docs
- PR #5274²⁰⁶⁷ - More P1897 algorithms
- PR #5273²⁰⁶⁸ - Retry CDash submissions on failure
- PR #5272²⁰⁶⁹ - Fix bogus deprecation warnings with GCC 10
- PR #5271²⁰⁷⁰ - Correcting target ids for `symbol_namespace::iterate`
- PR #5268²⁰⁷¹ - Adding generic `require`, `require_concept`, and `query` properties
- PR #5267²⁰⁷² - Support annotations in `hpx::transform_reduce`
- PR #5266²⁰⁷³ - Making late command line options available for local runtime
- PR #5265²⁰⁷⁴ - Leverage `no_unique_address` for `member_pack`
- PR #5264²⁰⁷⁵ - Adopt format in more places
- PR #5262²⁰⁷⁶ - Install HPX in Rostam Jenkins jobs
- PR #5261²⁰⁷⁷ - Limit Rostam Jenkins jobs to marvin partition temporarily
- PR #5260²⁰⁷⁸ - Separate segmented algorithms for `transform_reduce`

²⁰⁵⁶ <https://github.com/STELLAR-GROUP/hpx/pull/5289>

²⁰⁵⁷ <https://github.com/STELLAR-GROUP/hpx/pull/5288>

²⁰⁵⁸ <https://github.com/STELLAR-GROUP/hpx/pull/5287>

²⁰⁵⁹ <https://github.com/STELLAR-GROUP/hpx/pull/5285>

²⁰⁶⁰ <https://github.com/STELLAR-GROUP/hpx/pull/5284>

²⁰⁶¹ <https://github.com/STELLAR-GROUP/hpx/pull/5282>

²⁰⁶² <https://github.com/STELLAR-GROUP/hpx/pull/5281>

²⁰⁶³ <https://github.com/STELLAR-GROUP/hpx/pull/5280>

²⁰⁶⁴ <https://github.com/STELLAR-GROUP/hpx/pull/5279>

²⁰⁶⁵ <https://github.com/STELLAR-GROUP/hpx/pull/5277>

²⁰⁶⁶ <https://github.com/STELLAR-GROUP/hpx/pull/5276>

²⁰⁶⁷ <https://github.com/STELLAR-GROUP/hpx/pull/5274>

²⁰⁶⁸ <https://github.com/STELLAR-GROUP/hpx/pull/5273>

²⁰⁶⁹ <https://github.com/STELLAR-GROUP/hpx/pull/5272>

²⁰⁷⁰ <https://github.com/STELLAR-GROUP/hpx/pull/5271>

²⁰⁷¹ <https://github.com/STELLAR-GROUP/hpx/pull/5268>

²⁰⁷² <https://github.com/STELLAR-GROUP/hpx/pull/5267>

²⁰⁷³ <https://github.com/STELLAR-GROUP/hpx/pull/5266>

²⁰⁷⁴ <https://github.com/STELLAR-GROUP/hpx/pull/5265>

²⁰⁷⁵ <https://github.com/STELLAR-GROUP/hpx/pull/5264>

²⁰⁷⁶ <https://github.com/STELLAR-GROUP/hpx/pull/5262>

²⁰⁷⁷ <https://github.com/STELLAR-GROUP/hpx/pull/5261>

²⁰⁷⁸ <https://github.com/STELLAR-GROUP/hpx/pull/5260>

- PR #5259²⁰⁷⁹ - Making sure late command line options are recognized as configuration options
- PR #5258²⁰⁸⁰ - Allow for HPX algorithms being invoked with std execution policies
- PR #5256²⁰⁸¹ - Separate segmented algorithms for transform
- PR #5255²⁰⁸² - Future/sender adapters
- PR #5254²⁰⁸³ - Fixing datapar
- PR #5253²⁰⁸⁴ - Add utility to format ranges
- PR #5252²⁰⁸⁵ - Remove uses of Boost.Bimap
- PR #5251²⁰⁸⁶ - Banish `<iostream>` from library headers
- PR #5250²⁰⁸⁷ - Try fixing vc circle ci
- PR #5249²⁰⁸⁸ - Adding missing header
- PR #5248²⁰⁸⁹ - Use old Piz Daint modules after upgrade
- PR #5247²⁰⁹⁰ - Significantly speedup simple `for_each`, `for_loop`, and `transform`
- PR #5245²⁰⁹¹ - P1897 `operator|` overloads
- PR #5244²⁰⁹² - P1897 `when_all`
- PR #5243²⁰⁹³ - Make sure `HPX_DEBUG` is set based on HPX's build type, not consuming project's build type
- PR #5242²⁰⁹⁴ - Moving last files unrelated to parcel layer to modules
- PR #5240²⁰⁹⁵ - change namespace for `transform_loop.hpp`
- PR #5238²⁰⁹⁶ - Make sure annotations are used in the binary transform
- PR #5237²⁰⁹⁷ - Add P1897 `just`, `just_on`, and `on` algorithms
- PR #5236²⁰⁹⁸ - Add an example demonstrating the use of the `invoke_function_action` facility
- PR #5235²⁰⁹⁹ - Attempting to fix datapar compilation issues
- PR #5234²¹⁰⁰ - Fix small typo in `--hpx:local` option description
- PR #5233²¹⁰¹ - Only find Boost.Iostreams if required for plugins

²⁰⁷⁹ <https://github.com/STELLAR-GROUP/hpx/pull/5259>

²⁰⁸⁰ <https://github.com/STELLAR-GROUP/hpx/pull/5258>

²⁰⁸¹ <https://github.com/STELLAR-GROUP/hpx/pull/5256>

²⁰⁸² <https://github.com/STELLAR-GROUP/hpx/pull/5255>

²⁰⁸³ <https://github.com/STELLAR-GROUP/hpx/pull/5254>

²⁰⁸⁴ <https://github.com/STELLAR-GROUP/hpx/pull/5253>

²⁰⁸⁵ <https://github.com/STELLAR-GROUP/hpx/pull/5252>

²⁰⁸⁶ <https://github.com/STELLAR-GROUP/hpx/pull/5251>

²⁰⁸⁷ <https://github.com/STELLAR-GROUP/hpx/pull/5250>

²⁰⁸⁸ <https://github.com/STELLAR-GROUP/hpx/pull/5249>

²⁰⁸⁹ <https://github.com/STELLAR-GROUP/hpx/pull/5248>

²⁰⁹⁰ <https://github.com/STELLAR-GROUP/hpx/pull/5247>

²⁰⁹¹ <https://github.com/STELLAR-GROUP/hpx/pull/5245>

²⁰⁹² <https://github.com/STELLAR-GROUP/hpx/pull/5244>

²⁰⁹³ <https://github.com/STELLAR-GROUP/hpx/pull/5243>

²⁰⁹⁴ <https://github.com/STELLAR-GROUP/hpx/pull/5242>

²⁰⁹⁵ <https://github.com/STELLAR-GROUP/hpx/pull/5240>

²⁰⁹⁶ <https://github.com/STELLAR-GROUP/hpx/pull/5238>

²⁰⁹⁷ <https://github.com/STELLAR-GROUP/hpx/pull/5237>

²⁰⁹⁸ <https://github.com/STELLAR-GROUP/hpx/pull/5236>

²⁰⁹⁹ <https://github.com/STELLAR-GROUP/hpx/pull/5235>

²¹⁰⁰ <https://github.com/STELLAR-GROUP/hpx/pull/5234>

²¹⁰¹ <https://github.com/STELLAR-GROUP/hpx/pull/5233>

- PR #5231²¹⁰² - Sort printed config options
- PR #5230²¹⁰³ - Fix C++20 replace algo adaptation misses
- PR #5229²¹⁰⁴ - Remove leftover Boost include from `sync_wait.hpp`
- PR #5228²¹⁰⁵ - Print module name only if it has custom configuration settings
- PR #5227²¹⁰⁶ - Update `.codespell_whitelist`
- PR #5226²¹⁰⁷ - Use new docker image in all CircleCI steps
- PR #5225²¹⁰⁸ - Adapt reverse to C++20
- PR #5224²¹⁰⁹ - Separate segmented algorithms for `none_of`, `any_of` and `all_of`
- PR #5223²¹¹⁰ - Fixing build system for `itnotify`
- PR #5221²¹¹¹ - Moving LCO related files to modules
- PR #5220²¹¹² - Separate segmented algorithms for `count` and `count_if`
- PR #5218²¹¹³ - Separate segmented algorithms for `adjacent_find`
- PR #5217²¹¹⁴ - Add a HIP github action
- PR #5215²¹¹⁵ - Update ROCm to 4.0.1 on Rostam
- PR #5214²¹¹⁶ - Fix clang-format error in `sender.hpp`
- PR #5213²¹¹⁷ - Removing ESSENTIAL option to the doc example
- PR #5212²¹¹⁸ - Separate segmented algorithms for `for_each_n`
- PR #5211²¹¹⁹ - Minor adapted algos fixes
- PR #5210²¹²⁰ - Fixing `is_invocable` deprecation warnings
- PR #5209²¹²¹ - Moving more files into modules (`actions`, `components`, `init_runtime`, etc.)
- PR #5208²¹²² - Add examples and explanation on when `tag_fallback/priority` are useful
- PR #5207²¹²³ - Always define `HPX_COMPUTE_HOST_CODE` for host code
- PR #5206²¹²⁴ - Add formatting exceptions for `libhpx` to `create_module_skeleton.py`

²¹⁰² <https://github.com/STELLAR-GROUP/hpx/pull/5231>

²¹⁰³ <https://github.com/STELLAR-GROUP/hpx/pull/5230>

²¹⁰⁴ <https://github.com/STELLAR-GROUP/hpx/pull/5229>

²¹⁰⁵ <https://github.com/STELLAR-GROUP/hpx/pull/5228>

²¹⁰⁶ <https://github.com/STELLAR-GROUP/hpx/pull/5227>

²¹⁰⁷ <https://github.com/STELLAR-GROUP/hpx/pull/5226>

²¹⁰⁸ <https://github.com/STELLAR-GROUP/hpx/pull/5225>

²¹⁰⁹ <https://github.com/STELLAR-GROUP/hpx/pull/5224>

²¹¹⁰ <https://github.com/STELLAR-GROUP/hpx/pull/5223>

²¹¹¹ <https://github.com/STELLAR-GROUP/hpx/pull/5221>

²¹¹² <https://github.com/STELLAR-GROUP/hpx/pull/5220>

²¹¹³ <https://github.com/STELLAR-GROUP/hpx/pull/5218>

²¹¹⁴ <https://github.com/STELLAR-GROUP/hpx/pull/5217>

²¹¹⁵ <https://github.com/STELLAR-GROUP/hpx/pull/5215>

²¹¹⁶ <https://github.com/STELLAR-GROUP/hpx/pull/5214>

²¹¹⁷ <https://github.com/STELLAR-GROUP/hpx/pull/5213>

²¹¹⁸ <https://github.com/STELLAR-GROUP/hpx/pull/5212>

²¹¹⁹ <https://github.com/STELLAR-GROUP/hpx/pull/5211>

²¹²⁰ <https://github.com/STELLAR-GROUP/hpx/pull/5210>

²¹²¹ <https://github.com/STELLAR-GROUP/hpx/pull/5209>

²¹²² <https://github.com/STELLAR-GROUP/hpx/pull/5208>

²¹²³ <https://github.com/STELLAR-GROUP/hpx/pull/5207>

²¹²⁴ <https://github.com/STELLAR-GROUP/hpx/pull/5206>

- PR #5205²¹²⁵ - Moving all distribution policies into modules
- PR #5203²¹²⁶ - Move copy algorithms to `tag_fallback_invoke`
- PR #5202²¹²⁷ - Make `HPX_WITH_PSEUDO_DEPENDENCIES` a cache variable
- PR #5201²¹²⁸ - Replaced `tag_invoke` with `tag_fallback_invoke` for `adjacent_find` algorithm
- PR #5200²¹²⁹ - Moving files to (distributed) runtime module
- PR #5199²¹³⁰ - Update ICC module name on Piz Daint Jenkins configuration
- PR #5198²¹³¹ - Add doxygen documentation for `thread_schedule_hint`
- PR #5197²¹³² - Attempt to fix compilation of context implementations with unity build enabled
- PR #5196²¹³³ - Re-enable component tests
- PR #5195²¹³⁴ - Moving files related to colocation logic
- PR #5194²¹³⁵ - Another attempt at fixing the Fedora 35 problem
- PR #5193²¹³⁶ - Components module
- PR #5192²¹³⁷ - Adapt `replace(_if)` to C++20
- PR #5190²¹³⁸ - Set compatibility headers by default to on
- PR #5188²¹³⁹ - Bump Boost minimum version to 1.71.0
- PR #5187²¹⁴⁰ - Force CMake to set the `-std=c++XX` flag
- PR #5186²¹⁴¹ - Remove message to print `.cu` extension whenever `.cu` files are encountered
- PR #5185²¹⁴² - Remove some minor unnecessary CMake options
- PR #5184²¹⁴³ - Remove some leftover `HPX_WITH_*_SCHEDULER` uses
- PR #5183²¹⁴⁴ - Remove dependency on `boost/iterators/iterator_categories.hpp`
- PR #5182²¹⁴⁵ - Fixing Fedora 35 for Power architectures
- PR #5181²¹⁴⁶ - Bump version number and tag post 1.6.0 release
- PR #5180²¹⁴⁷ - Fix `htts_v2` tests linking

²¹²⁵ <https://github.com/STELLAR-GROUP/hpx/pull/5205>

²¹²⁶ <https://github.com/STELLAR-GROUP/hpx/pull/5203>

²¹²⁷ <https://github.com/STELLAR-GROUP/hpx/pull/5202>

²¹²⁸ <https://github.com/STELLAR-GROUP/hpx/pull/5201>

²¹²⁹ <https://github.com/STELLAR-GROUP/hpx/pull/5200>

²¹³⁰ <https://github.com/STELLAR-GROUP/hpx/pull/5199>

²¹³¹ <https://github.com/STELLAR-GROUP/hpx/pull/5198>

²¹³² <https://github.com/STELLAR-GROUP/hpx/pull/5197>

²¹³³ <https://github.com/STELLAR-GROUP/hpx/pull/5196>

²¹³⁴ <https://github.com/STELLAR-GROUP/hpx/pull/5195>

²¹³⁵ <https://github.com/STELLAR-GROUP/hpx/pull/5194>

²¹³⁶ <https://github.com/STELLAR-GROUP/hpx/pull/5193>

²¹³⁷ <https://github.com/STELLAR-GROUP/hpx/pull/5192>

²¹³⁸ <https://github.com/STELLAR-GROUP/hpx/pull/5190>

²¹³⁹ <https://github.com/STELLAR-GROUP/hpx/pull/5188>

²¹⁴⁰ <https://github.com/STELLAR-GROUP/hpx/pull/5187>

²¹⁴¹ <https://github.com/STELLAR-GROUP/hpx/pull/5186>

²¹⁴² <https://github.com/STELLAR-GROUP/hpx/pull/5185>

²¹⁴³ <https://github.com/STELLAR-GROUP/hpx/pull/5184>

²¹⁴⁴ <https://github.com/STELLAR-GROUP/hpx/pull/5183>

²¹⁴⁵ <https://github.com/STELLAR-GROUP/hpx/pull/5182>

²¹⁴⁶ <https://github.com/STELLAR-GROUP/hpx/pull/5181>

²¹⁴⁷ <https://github.com/STELLAR-GROUP/hpx/pull/5180>

- PR #5179²¹⁴⁸ - Make sure `--hpx:local` command line option is respected with networking is off but distributed runtime is on
- PR #5177²¹⁴⁹ - Remove module cmake options
- PR #5176²¹⁵⁰ - Starting to separate segmented algorithms: `for_each`
- PR #5174²¹⁵¹ - Don't run segmented algorithms twice on CircleCI
- PR #5173²¹⁵² - Fetching APEX using cmake FetchContent
- PR #5172²¹⁵³ - Add separate local-only entry point
- PR #5171²¹⁵⁴ - Remove `HPX_WITH_THREAD_SCHEDULERS` CMake option
- PR #5170²¹⁵⁵ - Add `HPX_WITH_PRECOMPILED_HEADERS` option
- PR #5166²¹⁵⁶ - Moving some action tests to modules
- PR #5165²¹⁵⁷ - Require cmake 3.17
- PR #5164²¹⁵⁸ - Move `thread_pool_suspension_helper` files to small utility module
- PR #5160²¹⁵⁹ - Adding checks ensuring modules are not cross-referenced from other module categories
- PR #5158²¹⁶⁰ - Replace `boost::asio` with standalone `asio`
- PR #5155²¹⁶¹ - Allow logging when distributed runtime is off
- PR #5153²¹⁶² - Components module
- PR #5152²¹⁶³ - Move more files to performance counter module
- PR #5150²¹⁶⁴ - Adapt `remove_copy(_if)` to C++20
- PR #5144²¹⁶⁵ - AGAS module
- PR #5125²¹⁶⁶ - Adapt `remove` and `remove_if` to C++20
- PR #5117²¹⁶⁷ - Attempt to fix segfaults assumed to be caused by `future_data` instances going out of scope.
- PR #5099²¹⁶⁸ - Allow mixing debug and release builds
- PR #5092²¹⁶⁹ - Replace `spirit.qi` with `x3`
- PR #5053²¹⁷⁰ - Add P0443r14 executor and a few P1897 algorithms

²¹⁴⁸ <https://github.com/STELLAR-GROUP/hpx/pull/5179>

²¹⁴⁹ <https://github.com/STELLAR-GROUP/hpx/pull/5177>

²¹⁵⁰ <https://github.com/STELLAR-GROUP/hpx/pull/5176>

²¹⁵¹ <https://github.com/STELLAR-GROUP/hpx/pull/5174>

²¹⁵² <https://github.com/STELLAR-GROUP/hpx/pull/5173>

²¹⁵³ <https://github.com/STELLAR-GROUP/hpx/pull/5172>

²¹⁵⁴ <https://github.com/STELLAR-GROUP/hpx/pull/5171>

²¹⁵⁵ <https://github.com/STELLAR-GROUP/hpx/pull/5170>

²¹⁵⁶ <https://github.com/STELLAR-GROUP/hpx/pull/5166>

²¹⁵⁷ <https://github.com/STELLAR-GROUP/hpx/pull/5165>

²¹⁵⁸ <https://github.com/STELLAR-GROUP/hpx/pull/5164>

²¹⁵⁹ <https://github.com/STELLAR-GROUP/hpx/pull/5160>

²¹⁶⁰ <https://github.com/STELLAR-GROUP/hpx/pull/5158>

²¹⁶¹ <https://github.com/STELLAR-GROUP/hpx/pull/5155>

²¹⁶² <https://github.com/STELLAR-GROUP/hpx/pull/5153>

²¹⁶³ <https://github.com/STELLAR-GROUP/hpx/pull/5152>

²¹⁶⁴ <https://github.com/STELLAR-GROUP/hpx/pull/5150>

²¹⁶⁵ <https://github.com/STELLAR-GROUP/hpx/pull/5144>

²¹⁶⁶ <https://github.com/STELLAR-GROUP/hpx/pull/5125>

²¹⁶⁷ <https://github.com/STELLAR-GROUP/hpx/pull/5117>

²¹⁶⁸ <https://github.com/STELLAR-GROUP/hpx/pull/5099>

²¹⁶⁹ <https://github.com/STELLAR-GROUP/hpx/pull/5092>

²¹⁷⁰ <https://github.com/STELLAR-GROUP/hpx/pull/5053>

- [PR #5044](#)²¹⁷¹ - Add performance test in Jenkins and reports

HPX V1.6.0 (Feb 17, 2021)

General changes

This release continues the focus on C++20 conformance with multiple new algorithms adapted to be C++20 conformant and becoming customization point objects (CPOs). We have also added experimental support for HIP, allowing previous CUDA features to now be compiled with `hipcc` and run on AMD GPUs.

- The following algorithms have been adapted to be C++20 conformant: `adjacent_find`, `includes`, `inplace_merge`, `is_heap`, `is_heap_until`, `is_partitioned`, `is_sorted`, `is_sorted_until`, `merge`, `set_difference`, `set_intersection`, `set_symmetric_difference`, `set_union`.
- Experimental HIP support can be enabled by compiling *HPX* with `hipcc`. All CUDA functionality in *HPX* can now be used with HIP. The HIP functionality is for the time being exposed through the same API as the CUDA functionality, i.e. no changes are required in user code. The CUDA, and now HIP, functionality is in the `hpx::cuda` namespace.
- We have added `partial_sort` based on Francisco Tapia's implementation.
- `hpx::init` and `hpx::start` gained new overloads taking an `hpx::init_params` struct in 1.5.0. All overloads not taking an `hpx::init_params` are now deprecated.
- We have added an experimental `fork_join_executor`. This executor can be used for OpenMP-style fork-join parallelism, where the latency of a parallel region is important for performance.
- The `parallel_executor` now uses a hierarchical spawning scheme for bulk execution, which improves data locality and performance.
- `hpx::dataflow` can now be used with executors that inject additional parameters into the call of the user-provided function.
- We have added experimental support for properties as proposed in [P2220](#)²¹⁷². Currently the only supported property is the scheduling hint on `parallel_executor`.
- `hpx::util::annotated_function` can now be passed a dynamically generated `std::string`.
- In moving functionality to new namespaces, old names have been deprecated. A deprecation warning will be issued if you are using deprecated functionality, with instructions on how to correct or ignore the warning.
- We have removed all support for C and Fortran from our build system.
- We have further reduced the use of Boost types within *HPX* (`boost::system::error_code` and `boost::detail::spinlock`).
- We have enabled more warnings in our CI builds (unused variables and unused typedefs).

²¹⁷¹ <https://github.com/STELLAR-GROUP/hpx/pull/5044>

²¹⁷² <https://wg21.link/p2220>

Breaking changes

- hpxMP support has been completely removed.
- The verbs parcellport has been removed.
- The following compatibility options have been disabled by default: HPX_WITH_ACTION_BASE_COMPATIBILITY, HPX_WITH_REGISTER_THREAD_COMPATIBILITY, HPX_WITH_PROMISE_ALIAS_COMPATIBILITY, HPX_WITH_UNSCOPED_ENUM_COMPATIBILITY, HPX_PROGRAM_OPTIONS_WITH_BOOST_PROGRAM_OPTIONS_COMPATIBILITY, HPX_WITH_EMBEDDED_THREAD_POOLS_COMPATIBILITY, HPX_WITH_THREAD_POOL_OS_EXECUTOR_COMPATIBILITY, HPX_WITH_THREAD_EXECUTORS_COMPATIBILITY, HPX_THREAD_AWARE_TIMER_COMPATIBILITY, HPX_WITH_POOL_EXECUTOR_COMPATIBILITY. Unless noted here, the above functionalities do not come with replacements. Unscoped enumerations have been replaced by scoped enumerations. Previously deprecated unscoped enumerations are disabled by HPX_WITH_UNSCOPED_ENUM_COMPATIBILITY. Newly deprecated unscoped enumerations have been given deprecation warnings and replaced by scoped enumerations. `hpx::promise` has been replaced with `hpx::distributed::promise`. `hpx::program_options` is a drop-in replacement for `boost::program_options`. `hpx::execution::parallel_executor` now has constructors which take a thread pool, covering the use case of `hpx::threads::executors::pool_executor`. A pool can be supplied with `hpx::resource::get_thread_pool`.

Closed issues

- [Issue #5148²¹⁷³](https://github.com/STELLAR-GROUP/hpx/issues/5148) - `runtime_support.hpp` does not work with newer `clang`
- [Issue #5147²¹⁷⁴](https://github.com/STELLAR-GROUP/hpx/issues/5147) - Wrong results with parallel reduce
- [Issue #5129²¹⁷⁵](https://github.com/STELLAR-GROUP/hpx/issues/5129) - Missing specialization for `std::hash<hpx::thread::id>`
- [Issue #5126²¹⁷⁶](https://github.com/STELLAR-GROUP/hpx/issues/5126) - Use `std::string` for task annotations
- [Issue #5115²¹⁷⁷](https://github.com/STELLAR-GROUP/hpx/issues/5115) - Don't expect `hwloc` to always report Cores
- [Issue #5113²¹⁷⁸](https://github.com/STELLAR-GROUP/hpx/issues/5113) - Handle `threadmanager` exceptions during startup
- [Issue #5112²¹⁷⁹](https://github.com/STELLAR-GROUP/hpx/issues/5112) - libatomic problems causing unexpected fails
- [Issue #5089²¹⁸⁰](https://github.com/STELLAR-GROUP/hpx/issues/5089) - Remove non-BSL files
- [Issue #5088²¹⁸¹](https://github.com/STELLAR-GROUP/hpx/issues/5088) - Unwrapping problem
- [Issue #5087²¹⁸²](https://github.com/STELLAR-GROUP/hpx/issues/5087) - Remove hpxMP support
- [Issue #5077²¹⁸³](https://github.com/STELLAR-GROUP/hpx/issues/5077) - PAPI counters are not accessible when HPX is installed
- [Issue #5075²¹⁸⁴](https://github.com/STELLAR-GROUP/hpx/issues/5075) - Make the structs in all `iter_sent.hpp` lower case
- [Issue #5067²¹⁸⁵](https://github.com/STELLAR-GROUP/hpx/issues/5067) - Bug `string_util/split.hpp`

²¹⁷³ <https://github.com/STELLAR-GROUP/hpx/issues/5148>

²¹⁷⁴ <https://github.com/STELLAR-GROUP/hpx/issues/5147>

²¹⁷⁵ <https://github.com/STELLAR-GROUP/hpx/issues/5129>

²¹⁷⁶ <https://github.com/STELLAR-GROUP/hpx/issues/5126>

²¹⁷⁷ <https://github.com/STELLAR-GROUP/hpx/issues/5115>

²¹⁷⁸ <https://github.com/STELLAR-GROUP/hpx/issues/5113>

²¹⁷⁹ <https://github.com/STELLAR-GROUP/hpx/issues/5112>

²¹⁸⁰ <https://github.com/STELLAR-GROUP/hpx/issues/5089>

²¹⁸¹ <https://github.com/STELLAR-GROUP/hpx/issues/5088>

²¹⁸² <https://github.com/STELLAR-GROUP/hpx/issues/5087>

²¹⁸³ <https://github.com/STELLAR-GROUP/hpx/issues/5077>

²¹⁸⁴ <https://github.com/STELLAR-GROUP/hpx/issues/5075>

²¹⁸⁵ <https://github.com/STELLAR-GROUP/hpx/issues/5067>

- [Issue #5049²¹⁸⁶](#) - Change back the hipcc jenkins config to the fury partition on rostam
- [Issue #5038²¹⁸⁷](#) - Not all examples link in the latest HPX master
- [Issue #5035²¹⁸⁸](#) - Build with HPX_WITH_EXAMPLES fails
- [Issue #5019²¹⁸⁹](#) - Broken help string for hpx
- [Issue #5016²¹⁹⁰](#) - `hpx::parallel::fill` fails compiling
- [Issue #5014²¹⁹¹](#) - Rename all `.cc` to `.cpp` and `.hh` to `.hpp`
- [Issue #4988²¹⁹²](#) - MPI is not finalized if running with only one locality
- [Issue #4978²¹⁹³](#) - Change feature test macros to expand to zero/one
- [Issue #4949²¹⁹⁴](#) - Crash when not enabling TCP parcelport
- [Issue #4933²¹⁹⁵](#) - Improve test coverage for unused variable warnings etc.
- [Issue #4878²¹⁹⁶](#) - HPX mpi async might call `MPI_FINALIZE` before app calls it
- [Issue #4127²¹⁹⁷](#) - Local runtime entry-points

Closed pull requests

- [PR #5178²¹⁹⁸](#) - Fix parallel `remove/remove_copy/transform` namespace references in docs
- [PR #5169²¹⁹⁹](#) - Attempt to get Piz Daint jenkins setup running after maintenance
- [PR #5168²²⁰⁰](#) - Remove include of itself
- [PR #5167²²⁰¹](#) - Fixing deprecation warnings that slipped through the net
- [PR #5159²²⁰²](#) - Update APEX tag to 2.3.1
- [PR #5154²²⁰³](#) - Splitting unit tests on circleci to avoid timeouts
- [PR #5151²²⁰⁴](#) - Use C++20 on `clang-newest` Jenkins CI configuration
- [PR #5149²²⁰⁵](#) - Rename 'module' symbols to avoid keyword conflict
- [PR #5145²²⁰⁶](#) - Adjust handling of CUDA/HIP options in CMake
- [PR #5142²²⁰⁷](#) - Store annotated_function annotations as `std::strings`

²¹⁸⁶ <https://github.com/STELLAR-GROUP/hpx/issues/5049>

²¹⁸⁷ <https://github.com/STELLAR-GROUP/hpx/issues/5038>

²¹⁸⁸ <https://github.com/STELLAR-GROUP/hpx/issues/5035>

²¹⁸⁹ <https://github.com/STELLAR-GROUP/hpx/issues/5019>

²¹⁹⁰ <https://github.com/STELLAR-GROUP/hpx/issues/5016>

²¹⁹¹ <https://github.com/STELLAR-GROUP/hpx/issues/5014>

²¹⁹² <https://github.com/STELLAR-GROUP/hpx/issues/4988>

²¹⁹³ <https://github.com/STELLAR-GROUP/hpx/issues/4978>

²¹⁹⁴ <https://github.com/STELLAR-GROUP/hpx/issues/4949>

²¹⁹⁵ <https://github.com/STELLAR-GROUP/hpx/issues/4933>

²¹⁹⁶ <https://github.com/STELLAR-GROUP/hpx/issues/4878>

²¹⁹⁷ <https://github.com/STELLAR-GROUP/hpx/issues/4127>

²¹⁹⁸ <https://github.com/STELLAR-GROUP/hpx/pull/5178>

²¹⁹⁹ <https://github.com/STELLAR-GROUP/hpx/pull/5169>

²²⁰⁰ <https://github.com/STELLAR-GROUP/hpx/pull/5168>

²²⁰¹ <https://github.com/STELLAR-GROUP/hpx/pull/5167>

²²⁰² <https://github.com/STELLAR-GROUP/hpx/pull/5159>

²²⁰³ <https://github.com/STELLAR-GROUP/hpx/pull/5154>

²²⁰⁴ <https://github.com/STELLAR-GROUP/hpx/pull/5151>

²²⁰⁵ <https://github.com/STELLAR-GROUP/hpx/pull/5149>

²²⁰⁶ <https://github.com/STELLAR-GROUP/hpx/pull/5145>

²²⁰⁷ <https://github.com/STELLAR-GROUP/hpx/pull/5142>

- PR #5140²²⁰⁸ - Scheduler mode
- PR #5139²²⁰⁹ - Fix path problem in pre-commit hook, add summary commit line
- PR #5138²²¹⁰ - Add program options variable map to resource partitioner init
- PR #5137²²¹¹ - Remove the use of `boost::throw_exception`
- PR #5136²²¹² - Make sure codespell checks run on CircleCI
- PR #5132²²¹³ - Fixing spelling errors
- PR #5131²²¹⁴ - Mark `counting_iterator` member functions as `HPX_HOST_DEVICE`
- PR #5130²²¹⁵ - Adding specialization for `std::hash<hpx::thread::id>`
- PR #5128²²¹⁶ - Fixing environment handling for FreeBSD
- PR #5127²²¹⁷ - Fix typo in fibonacci documentation
- PR #5123²²¹⁸ - Reduce vector sizes in partial sort benchmarks when running in debug mode
- PR #5122²²¹⁹ - Making sure exceptions during runtime initialization are correctly reported
- PR #5121²²²⁰ - Working around hwloc limitation on certain platforms
- PR #5120²²²¹ - Fixing compatibility warnings in `hpx::transform` implementation
- PR #5119²²²² - Use `sequential_find` and friends from separate detail header
- PR #5116²²²³ - Fix compilation with timer pool off
- PR #5114²²²⁴ - Fix 5112 - make sure `libatomic` is used when needed
- PR #5109²²²⁵ - Remove default runtime mode argument from `init` overload, again
- PR #5108²²²⁶ - Refactor `iter_sent.hpp` to make structs lowercase
- PR #5107²²²⁷ - Relax `dataflow` internals
- PR #5106²²²⁸ - Change initialization of property CPOs to satisfy older `nvcc` versions
- PR #5104²²²⁹ - Fix regeneration of two files that trigger unnecessary rebuilds
- PR #5103²²³⁰ - Remove default runtime mode argument from `start/init` overloads

²²⁰⁸ <https://github.com/STELLAR-GROUP/hpx/pull/5140>

²²⁰⁹ <https://github.com/STELLAR-GROUP/hpx/pull/5139>

²²¹⁰ <https://github.com/STELLAR-GROUP/hpx/pull/5138>

²²¹¹ <https://github.com/STELLAR-GROUP/hpx/pull/5137>

²²¹² <https://github.com/STELLAR-GROUP/hpx/pull/5136>

²²¹³ <https://github.com/STELLAR-GROUP/hpx/pull/5132>

²²¹⁴ <https://github.com/STELLAR-GROUP/hpx/pull/5131>

²²¹⁵ <https://github.com/STELLAR-GROUP/hpx/pull/5130>

²²¹⁶ <https://github.com/STELLAR-GROUP/hpx/pull/5128>

²²¹⁷ <https://github.com/STELLAR-GROUP/hpx/pull/5127>

²²¹⁸ <https://github.com/STELLAR-GROUP/hpx/pull/5123>

²²¹⁹ <https://github.com/STELLAR-GROUP/hpx/pull/5122>

²²²⁰ <https://github.com/STELLAR-GROUP/hpx/pull/5121>

²²²¹ <https://github.com/STELLAR-GROUP/hpx/pull/5120>

²²²² <https://github.com/STELLAR-GROUP/hpx/pull/5119>

²²²³ <https://github.com/STELLAR-GROUP/hpx/pull/5116>

²²²⁴ <https://github.com/STELLAR-GROUP/hpx/pull/5114>

²²²⁵ <https://github.com/STELLAR-GROUP/hpx/pull/5109>

²²²⁶ <https://github.com/STELLAR-GROUP/hpx/pull/5108>

²²²⁷ <https://github.com/STELLAR-GROUP/hpx/pull/5107>

²²²⁸ <https://github.com/STELLAR-GROUP/hpx/pull/5106>

²²²⁹ <https://github.com/STELLAR-GROUP/hpx/pull/5104>

²²³⁰ <https://github.com/STELLAR-GROUP/hpx/pull/5103>

- PR #5102²²³¹ - Untie deprecated thread enums from the CMake option
- PR #5101²²³² - Update APEX tag for 1.6.0
- PR #5100²²³³ - Bump minimum required Boost version to 1.66 and update CI configurations
- PR #5098²²³⁴ - Minor fixes to public API listing
- PR #5097²²³⁵ - Remove hpxMP support
- PR #5096²²³⁶ - Remove fractals examples
- PR #5095²²³⁷ - Use all AMD nodes again on rostam
- PR #5094²²³⁸ - Attempt to remove macOS workaround for GH actions environment
- PR #5093²²³⁹ - Remove verbs parselport
- PR #5091²²⁴⁰ - Avoid moving from lvalues
- PR #5090²²⁴¹ - Adopt C++20 `std::endian`
- PR #5085²²⁴² - Update daint CI to use Boost 1.75.0
- PR #5084²²⁴³ - Disable compatibility options for 1.6.0 release
- PR #5083²²⁴⁴ - Remove duplicated call to the `limiting_executor` in `future_overhead` test
- PR #5079²²⁴⁵ - Add checks to make sure that MPI/CUDA polling is enabled/not disabled too early
- PR #5078²²⁴⁶ - Add install lib directory to list of component search paths
- PR #5076²²⁴⁷ - Fix a typo in the jenkins `clang-newest` cmake config
- PR #5074²²⁴⁸ - Fixing warnings generated by MSVC
- PR #5073²²⁴⁹ - Allow using noncopyable types with unwrapping
- PR #5072²²⁵⁰ - Fix `is_convertible` args in `result_types`
- PR #5071²²⁵¹ - Fix unused parameters
- PR #5070²²⁵² - Fix unused variables warnings in `hipcc`
- PR #5069²²⁵³ - Add support for sentinels to `adjacent_find`

²²³¹ <https://github.com/STELLAR-GROUP/hpx/pull/5102>

²²³² <https://github.com/STELLAR-GROUP/hpx/pull/5101>

²²³³ <https://github.com/STELLAR-GROUP/hpx/pull/5100>

²²³⁴ <https://github.com/STELLAR-GROUP/hpx/pull/5098>

²²³⁵ <https://github.com/STELLAR-GROUP/hpx/pull/5097>

²²³⁶ <https://github.com/STELLAR-GROUP/hpx/pull/5096>

²²³⁷ <https://github.com/STELLAR-GROUP/hpx/pull/5095>

²²³⁸ <https://github.com/STELLAR-GROUP/hpx/pull/5094>

²²³⁹ <https://github.com/STELLAR-GROUP/hpx/pull/5093>

²²⁴⁰ <https://github.com/STELLAR-GROUP/hpx/pull/5091>

²²⁴¹ <https://github.com/STELLAR-GROUP/hpx/pull/5090>

²²⁴² <https://github.com/STELLAR-GROUP/hpx/pull/5085>

²²⁴³ <https://github.com/STELLAR-GROUP/hpx/pull/5084>

²²⁴⁴ <https://github.com/STELLAR-GROUP/hpx/pull/5083>

²²⁴⁵ <https://github.com/STELLAR-GROUP/hpx/pull/5079>

²²⁴⁶ <https://github.com/STELLAR-GROUP/hpx/pull/5078>

²²⁴⁷ <https://github.com/STELLAR-GROUP/hpx/pull/5076>

²²⁴⁸ <https://github.com/STELLAR-GROUP/hpx/pull/5074>

²²⁴⁹ <https://github.com/STELLAR-GROUP/hpx/pull/5073>

²²⁵⁰ <https://github.com/STELLAR-GROUP/hpx/pull/5072>

²²⁵¹ <https://github.com/STELLAR-GROUP/hpx/pull/5071>

²²⁵² <https://github.com/STELLAR-GROUP/hpx/pull/5070>

²²⁵³ <https://github.com/STELLAR-GROUP/hpx/pull/5069>

- PR #5068²²⁵⁴ - Fix string split function
- PR #5066²²⁵⁵ - Adapt search to C++20 and Range TS
- PR #5065²²⁵⁶ - Fix `hpx::range::adjacent_find` doxygen function signatures
- PR #5064²²⁵⁷ - Refactor runtime configuration, command line handling, and resource partitioner
- PR #5063²²⁵⁸ - Limit the device code guards to the distributed parts of the `future_overhead` bench
- PR #5061²²⁵⁹ - Remove hipcc guards in examples and tests
- PR #5060²²⁶⁰ - Fix deprecation warnings generated by msvc
- PR #5059²²⁶¹ - Add warning about suspending/resuming the runtime in multi-locality scenarios
- PR #5057²²⁶² - Fix unused variable warnings
- PR #5056²²⁶³ - Fix `hpx::util::get`
- PR #5055²²⁶⁴ - Remove hipcc guards
- PR #5054²²⁶⁵ - Fix typo
- PR #5051²²⁶⁶ - Adapt transform to C++20
- PR #5050²²⁶⁷ - Replace old init overloads in tests and examples
- PR #5048²²⁶⁸ - Limit jenkins hipcc to the reno node
- PR #5047²²⁶⁹ - Limit cuda jenkins run to nodes with exclusively Nvidia GPUs
- PR #5046²²⁷⁰ - Convert thread and future enums to class enums
- PR #5043²²⁷¹ - Improve `hpxrun.py` for Phylanx
- PR #5042²²⁷² - Add missing header to partial sort test
- PR #5041²²⁷³ - Adding Francisco Tapia's implementation of `partial_sort`
- PR #5040²²⁷⁴ - Remove generated headers left behind from a previous configuration
- PR #5039²²⁷⁵ - Fix GCC 10 release builds
- PR #5037²²⁷⁶ - Add `is_invocable` typedefs to top-level `hpx` namespace and public API list

²²⁵⁴ <https://github.com/STELLAR-GROUP/hpx/pull/5068>

²²⁵⁵ <https://github.com/STELLAR-GROUP/hpx/pull/5066>

²²⁵⁶ <https://github.com/STELLAR-GROUP/hpx/pull/5065>

²²⁵⁷ <https://github.com/STELLAR-GROUP/hpx/pull/5064>

²²⁵⁸ <https://github.com/STELLAR-GROUP/hpx/pull/5063>

²²⁵⁹ <https://github.com/STELLAR-GROUP/hpx/pull/5061>

²²⁶⁰ <https://github.com/STELLAR-GROUP/hpx/pull/5060>

²²⁶¹ <https://github.com/STELLAR-GROUP/hpx/pull/5059>

²²⁶² <https://github.com/STELLAR-GROUP/hpx/pull/5057>

²²⁶³ <https://github.com/STELLAR-GROUP/hpx/pull/5056>

²²⁶⁴ <https://github.com/STELLAR-GROUP/hpx/pull/5055>

²²⁶⁵ <https://github.com/STELLAR-GROUP/hpx/pull/5054>

²²⁶⁶ <https://github.com/STELLAR-GROUP/hpx/pull/5051>

²²⁶⁷ <https://github.com/STELLAR-GROUP/hpx/pull/5050>

²²⁶⁸ <https://github.com/STELLAR-GROUP/hpx/pull/5048>

²²⁶⁹ <https://github.com/STELLAR-GROUP/hpx/pull/5047>

²²⁷⁰ <https://github.com/STELLAR-GROUP/hpx/pull/5046>

²²⁷¹ <https://github.com/STELLAR-GROUP/hpx/pull/5043>

²²⁷² <https://github.com/STELLAR-GROUP/hpx/pull/5042>

²²⁷³ <https://github.com/STELLAR-GROUP/hpx/pull/5041>

²²⁷⁴ <https://github.com/STELLAR-GROUP/hpx/pull/5040>

²²⁷⁵ <https://github.com/STELLAR-GROUP/hpx/pull/5039>

²²⁷⁶ <https://github.com/STELLAR-GROUP/hpx/pull/5037>

- PR #5036²²⁷⁷ - Deprecate `hpx::util::decay` in favor of `std::decay`
- PR #5034²²⁷⁸ - Use versioned container image on CircleCI
- PR #5033²²⁷⁹ - Implement P2220 properties module
- PR #5032²²⁸⁰ - Do codespell comparison only on files changed from common ancestor
- PR #5031²²⁸¹ - Moving traits files to `actions_base`
- PR #5030²²⁸² - Add codespell version print in `circleci`
- PR #5029²²⁸³ - Work around problems in GitHub actions macOS builder
- PR #5028²²⁸⁴ - Moving move files to `naming` and `naming_base`
- PR #5027²²⁸⁵ - Lessen constraints on certain algorithm arguments
- PR #5025²²⁸⁶ - Adapt `is_sorted` and `is_sorted_until` to C++20
- PR #5024²²⁸⁷ - Moving `naming_base` to full modules
- PR #5022²²⁸⁸ - Remove C language from `CMakeLists.txt`
- PR #5021²²⁸⁹ - Warn about unused arguments given to `add_hpx_module`
- PR #5020²²⁹⁰ - Fixing help string
- PR #5018²²⁹¹ - Update CSCS jenkins configuration to clang 11
- PR #5017²²⁹² - Fixing broken backwards compatibility for `hpx::parallel::fill`
- PR #5015²²⁹³ - Detect if generated global header conflicts with explicitly listed module headers
- PR #5012²²⁹⁴ - Properly reset pointer tracking data in `output_archive`
- PR #5011²²⁹⁵ - Inspect command line tweaks
- PR #5010²²⁹⁶ - Creating AGAS module
- PR #5009²²⁹⁷ - Replace `boost::system::error_code` with `std::error_code`
- PR #5008²²⁹⁸ - Replace uses of `boost::detail::spinlock`
- PR #5007²²⁹⁹ - Bump minimal Boost version to 1.65.0

2277 <https://github.com/STELLAR-GROUP/hpx/pull/5036>
 2278 <https://github.com/STELLAR-GROUP/hpx/pull/5034>
 2279 <https://github.com/STELLAR-GROUP/hpx/pull/5033>
 2280 <https://github.com/STELLAR-GROUP/hpx/pull/5032>
 2281 <https://github.com/STELLAR-GROUP/hpx/pull/5031>
 2282 <https://github.com/STELLAR-GROUP/hpx/pull/5030>
 2283 <https://github.com/STELLAR-GROUP/hpx/pull/5029>
 2284 <https://github.com/STELLAR-GROUP/hpx/pull/5028>
 2285 <https://github.com/STELLAR-GROUP/hpx/pull/5027>
 2286 <https://github.com/STELLAR-GROUP/hpx/pull/5025>
 2287 <https://github.com/STELLAR-GROUP/hpx/pull/5024>
 2288 <https://github.com/STELLAR-GROUP/hpx/pull/5022>
 2289 <https://github.com/STELLAR-GROUP/hpx/pull/5021>
 2290 <https://github.com/STELLAR-GROUP/hpx/pull/5020>
 2291 <https://github.com/STELLAR-GROUP/hpx/pull/5018>
 2292 <https://github.com/STELLAR-GROUP/hpx/pull/5017>
 2293 <https://github.com/STELLAR-GROUP/hpx/pull/5015>
 2294 <https://github.com/STELLAR-GROUP/hpx/pull/5012>
 2295 <https://github.com/STELLAR-GROUP/hpx/pull/5011>
 2296 <https://github.com/STELLAR-GROUP/hpx/pull/5010>
 2297 <https://github.com/STELLAR-GROUP/hpx/pull/5009>
 2298 <https://github.com/STELLAR-GROUP/hpx/pull/5008>
 2299 <https://github.com/STELLAR-GROUP/hpx/pull/5007>

- PR #5006²³⁰⁰ - Adapt `is_partitioned` to C++20
- PR #5005²³⁰¹ - Making sure `reduce_by_key` compiles again
- PR #5004²³⁰² - Fixing template specializations that make extra archive data types unique across module boundaries
- PR #5003²³⁰³ - Relax `dataflow` argument constraints
- PR #5001²³⁰⁴ - Add `<random>` inspect check
- PR #4999²³⁰⁵ - Attempt to fix MacOS Github action error
- PR #4997²³⁰⁶ - Fix unused variable and typedef warnings
- PR #4996²³⁰⁷ - Adapt `adjacent_find` to C++20
- PR #4995²³⁰⁸ - Test all schedulers in `cross_pool_injection` test except `shared_priority_queue_scheduler`
- PR #4993²³⁰⁹ - Fix deprecation warnings
- PR #4991²³¹⁰ - Avoid unnecessarily including entire modules
- PR #4990²³¹¹ - Fixing some warnings from HPX complaining about use of obsolete types
- PR #4989²³¹² - add a `*destroy*` trait for `ParcelPort` plugins
- PR #4986²³¹³ - Remove serialization to functional module dependency
- PR #4985²³¹⁴ - Compatibility header generation
- PR #4980²³¹⁵ - Add ranges overloads to `for_loop` (and variants)
- PR #4979²³¹⁶ - Actually enable unity builds on Jenkins
- PR #4977²³¹⁷ - Cleaning up `debug::print` functionalities
- PR #4976²³¹⁸ - Remove indirection layer in `at_index_impl`
- PR #4975²³¹⁹ - Remove indirection layer in `at_index_impl`
- PR #4973²³²⁰ - Avoid warnings/errors for older gcc complaining about multi-line comments
- PR #4970²³²¹ - Making set algorithms conform to C++20

²³⁰⁰ <https://github.com/STELLAR-GROUP/hpx/pull/5006>

²³⁰¹ <https://github.com/STELLAR-GROUP/hpx/pull/5005>

²³⁰² <https://github.com/STELLAR-GROUP/hpx/pull/5004>

²³⁰³ <https://github.com/STELLAR-GROUP/hpx/pull/5003>

²³⁰⁴ <https://github.com/STELLAR-GROUP/hpx/pull/5001>

²³⁰⁵ <https://github.com/STELLAR-GROUP/hpx/pull/4999>

²³⁰⁶ <https://github.com/STELLAR-GROUP/hpx/pull/4997>

²³⁰⁷ <https://github.com/STELLAR-GROUP/hpx/pull/4996>

²³⁰⁸ <https://github.com/STELLAR-GROUP/hpx/pull/4995>

²³⁰⁹ <https://github.com/STELLAR-GROUP/hpx/pull/4993>

²³¹⁰ <https://github.com/STELLAR-GROUP/hpx/pull/4991>

²³¹¹ <https://github.com/STELLAR-GROUP/hpx/pull/4990>

²³¹² <https://github.com/STELLAR-GROUP/hpx/pull/4989>

²³¹³ <https://github.com/STELLAR-GROUP/hpx/pull/4986>

²³¹⁴ <https://github.com/STELLAR-GROUP/hpx/pull/4985>

²³¹⁵ <https://github.com/STELLAR-GROUP/hpx/pull/4980>

²³¹⁶ <https://github.com/STELLAR-GROUP/hpx/pull/4979>

²³¹⁷ <https://github.com/STELLAR-GROUP/hpx/pull/4977>

²³¹⁸ <https://github.com/STELLAR-GROUP/hpx/pull/4976>

²³¹⁹ <https://github.com/STELLAR-GROUP/hpx/pull/4975>

²³²⁰ <https://github.com/STELLAR-GROUP/hpx/pull/4973>

²³²¹ <https://github.com/STELLAR-GROUP/hpx/pull/4970>

- PR #4969²³²² - Moving `is_execution_policy` and friends into namespace `hpx`
- PR #4968²³²³ - Enable deprecation warnings for 1.6.0 and move any functionality to `hpx` namespace
- PR #4967²³²⁴ - Define deprecation macros conditionally
- PR #4966²³²⁵ - Add `clang-format` and `cmake-format` version prints
- PR #4965²³²⁶ - Making `is_heap` and `is_heap_until` conforming to C++20
- PR #4964²³²⁷ - Adding parallel `make_heap`
- PR #4962²³²⁸ - Fix external timer function pointer exports
- PR #4960²³²⁹ - Fixing folder names for module tests and examples
- PR #4959²³³⁰ - Adding communications set
- PR #4958²³³¹ - Deprecate tuple and timing functionality in `hpx::util`
- PR #4957²³³² - Fixing unity build option for parcelports
- PR #4953²³³³ - Fixing MSVC problems after recent restructurings
- PR #4952²³³⁴ - Make `parallel_executor` use `thread_pool_executor` spawning mechanism
- PR #4948²³³⁵ - Clean up old artifacts better and more aggressively on Jenkins
- PR #4947²³³⁶ - Add HIP support for AMD GPUs
- PR #4945²³³⁷ - Enable `HPX_WITH_UNITY_BUILD` option on one of the Jenkins configurations
- PR #4943²³³⁸ - Move public `hpx::parallel::execution` functionality to `hpx::execution`
- PR #4938²³³⁹ - Post release cleanup
- PR #4858²³⁴⁰ - Extending resilience APIs to support distributed invocations
- PR #4744²³⁴¹ - Fork-join executor
- PR #4665²³⁴² - Implementing sender, receiver, and `operation_state` concepts in terms of P0443r13
- PR #4649²³⁴³ - Split `libhpx` into multiple libraries
- PR #4642²³⁴⁴ - Implementing `operation_state` concept in terms of P0443r13

²³²² <https://github.com/STELLAR-GROUP/hpx/pull/4969>
²³²³ <https://github.com/STELLAR-GROUP/hpx/pull/4968>
²³²⁴ <https://github.com/STELLAR-GROUP/hpx/pull/4967>
²³²⁵ <https://github.com/STELLAR-GROUP/hpx/pull/4966>
²³²⁶ <https://github.com/STELLAR-GROUP/hpx/pull/4965>
²³²⁷ <https://github.com/STELLAR-GROUP/hpx/pull/4964>
²³²⁸ <https://github.com/STELLAR-GROUP/hpx/pull/4962>
²³²⁹ <https://github.com/STELLAR-GROUP/hpx/pull/4960>
²³³⁰ <https://github.com/STELLAR-GROUP/hpx/pull/4959>
²³³¹ <https://github.com/STELLAR-GROUP/hpx/pull/4958>
²³³² <https://github.com/STELLAR-GROUP/hpx/pull/4957>
²³³³ <https://github.com/STELLAR-GROUP/hpx/pull/4953>
²³³⁴ <https://github.com/STELLAR-GROUP/hpx/pull/4952>
²³³⁵ <https://github.com/STELLAR-GROUP/hpx/pull/4948>
²³³⁶ <https://github.com/STELLAR-GROUP/hpx/pull/4947>
²³³⁷ <https://github.com/STELLAR-GROUP/hpx/pull/4945>
²³³⁸ <https://github.com/STELLAR-GROUP/hpx/pull/4943>
²³³⁹ <https://github.com/STELLAR-GROUP/hpx/pull/4938>
²³⁴⁰ <https://github.com/STELLAR-GROUP/hpx/pull/4858>
²³⁴¹ <https://github.com/STELLAR-GROUP/hpx/pull/4744>
²³⁴² <https://github.com/STELLAR-GROUP/hpx/pull/4665>
²³⁴³ <https://github.com/STELLAR-GROUP/hpx/pull/4649>
²³⁴⁴ <https://github.com/STELLAR-GROUP/hpx/pull/4642>

- PR #4640²³⁴⁵ - Implementing receiver concept in terms of P0443r13
- PR #4622²³⁴⁶ - Sanitizer fixes

HPX V1.5.1 (Sep 30, 2020)

General changes

This is a patch release. It contains the following changes:

- Remove restriction on suspending runtime with multiple localities, users are now responsible for synchronizing work between localities before suspending.
- Fixes several compilation problems and warnings.
- Adds notes in the documentation explaining how to cite HPX.

Closed issues

- Issue #4971²³⁴⁷ - Parallel sort fails to compile with C++20
- Issue #4950²³⁴⁸ - Build with `HPX_WITH_PARCELPORT_ACTION_COUNTERS_ON` fails
- Issue #4940²³⁴⁹ - Codespell report for “HPX” (on fossies.org)
- Issue #4937²³⁵⁰ - Allow suspension of runtime for multiple localities

Closed pull requests

- PR #4982²³⁵¹ - Add page about citing HPX to documentation
- PR #4981²³⁵² - Adding the missing include
- PR #4974²³⁵³ - Remove leftover format export hack
- PR #4972²³⁵⁴ - Removing use of `get_temporary_buffer` and `return_temporary_buffer`
- PR #4963²³⁵⁵ - Renaming files to avoid warnings from the vs build system
- PR #4951²³⁵⁶ - Fixing build if `HPX_WITH_PARCELPORT_ACTION_COUNTERS=On`
- PR #4946²³⁵⁷ - Allow suspension on multiple localities
- PR #4944²³⁵⁸ - Fix typos reported by fossies codespell report
- PR #4941²³⁵⁹ - Adding some explanation to README about how to cite HPX

²³⁴⁵ <https://github.com/STELLAR-GROUP/hpx/pull/4640>

²³⁴⁶ <https://github.com/STELLAR-GROUP/hpx/pull/4622>

²³⁴⁷ <https://github.com/STELLAR-GROUP/hpx/issues/4971>

²³⁴⁸ <https://github.com/STELLAR-GROUP/hpx/issues/4950>

²³⁴⁹ <https://github.com/STELLAR-GROUP/hpx/issues/4940>

²³⁵⁰ <https://github.com/STELLAR-GROUP/hpx/issues/4937>

²³⁵¹ <https://github.com/STELLAR-GROUP/hpx/pull/4982>

²³⁵² <https://github.com/STELLAR-GROUP/hpx/pull/4981>

²³⁵³ <https://github.com/STELLAR-GROUP/hpx/pull/4974>

²³⁵⁴ <https://github.com/STELLAR-GROUP/hpx/pull/4972>

²³⁵⁵ <https://github.com/STELLAR-GROUP/hpx/pull/4963>

²³⁵⁶ <https://github.com/STELLAR-GROUP/hpx/pull/4951>

²³⁵⁷ <https://github.com/STELLAR-GROUP/hpx/pull/4946>

²³⁵⁸ <https://github.com/STELLAR-GROUP/hpx/pull/4944>

²³⁵⁹ <https://github.com/STELLAR-GROUP/hpx/pull/4941>

- PR #4939²³⁶⁰ - Small changes

HPX V1.5.0 (Sep 02, 2020)

General changes

The main focus of this release is on APIs and C++20 conformance. We have added many new C++20 features and adapted multiple algorithms to be fully C++20 conformant. As part of the modularization we have begun specifying the public API of *HPX* in terms of headers and functionality, and aligning it more closely to the C++ standard. All non-distributed modules are now in place, along with an experimental option to completely disable distributed features in *HPX*. We have also added experimental asynchronous MPI and CUDA executors. Lastly this release introduces CMake targets for depending projects, performance improvements, and many bug fixes.

- We have added the C++20 features `hpx::jthread` and `hpx::stop_token`. `hpx::condition_variable_any` now exposes new functions supporting `hpx::stop_token`.
- We have added `hpx::stable_sort` based on Francisco Tapia's implementation.
- We have adapted existing synchronization primitives to be fully conformant C++20: `hpx::barrier`, `hpx::latch`, `hpx::counting_semaphore`, and `hpx::binary_semaphore`.
- We have started using customization point objects (CPOs) to make the corresponding algorithms fully conformant to C++20 as well as to make algorithm extension easier for the user. `all_of/any_of/none_of`, `copy`, `count`, `destroy`, `equal`, `fill`, `find`, `for_each`, `generate`, `mismatch`, `move`, `reduce`, `transform_reduce` are using those CPOs (all in namespace `hpx`). We also have adapted their corresponding `hpx::ranges` versions to be conforming to C++20 in this release.
- We have adapted support for `co_await` to C++20, in addition to `hpx::future` it now also supports `hpx::shared_future`. We have also added allocator support for futures returned by `co_return`. It is no longer in the `experimental` namespace.
- We added serialization support for `std::variant` and `std::tuple`.
- `result_of` and `is_callable` are now deprecated and replaced by `invoke_result` and `is_invocable` to conform to C++20.
- We continued with the modularization, making it easier for us to add the new experimental `HPX_WITH_DISTRIBUTED_RUNTIME` CMake option (see below) . A significant amount of headers have been deprecated. We adapted the namespaces and headers we could to be closer to the standard ones (*Public API*). Depending code should still compile, however warnings are now generated instructing to change the include statements accordingly.
- It is now possible to have a basic CUDA support including a helper function to get a future from a CUDA stream and target handling. They are available under the `hpx::cuda::experimental` namespace and they can be enabled with the `-DHPX_WITH_ASYNC_CUDA=ON` CMake option.
- We added a new `hpx::mpi::experimental` namespace for getting futures from an asynchronous MPI call and a new minimal MPI executor `hpx::mpi::experimental::executor`. These can be enabled with the `-DHPX_WITH_ASYNC_MPI=On` CMake option.
- A polymorphic executor has been implemented to reduce compile times as a function accepting executors can potentially be instantiated only once instead of multiple times with different executors. It accepts the function signature as a template argument. It needs to be constructed from any other executor. Please note, that the function signatures that can be scheduled using `then_execute`, `bulk_sync_execute`, `bulk_async_execute` and `bulk_then_execute` are slightly different (See the comment in PR #4514²³⁶¹ for more details).
- The underlying executor of `block_executor` has been updated to a newer one.

²³⁶⁰ <https://github.com/STELLAR-GROUP/hpx/pull/4939>

²³⁶¹ <https://github.com/STELLAR-GROUP/hpx/pull/4514>

- We have added a parameter to `auto_chunk_size` to control the amount of iterations to measure.
- All executor parameter hooks can now be exposed through the executor itself. This will allow to deprecate the `.with()` functionality on execution policies in the future. This is also a first step towards simplifying our executor APIs in preparation for the upcoming C++23 executors (senders/receivers).
- We have moved all of the existing APIs related to resiliency into the namespace `hpx::resiliency::experimental`. Please note this is a breaking change without backwards-compatibility option. We have converted all of those APIs to be based on customization point objects. Two new executors have been added to enable easy integration of the existing resiliency features with other facilities (like the parallel algorithms): `replay_executor` and `replicate_executor`.
- We have added performance counters type information (aggregating, monotonically increasing, average count, average timer, etc.).
- HPX threads are now re-scheduled on the same worker thread they were suspended on to avoid cache misses from moving from one thread to the other. This behavior doesn't prevent the thread from being stolen, however.
- We have added a new configuration option `hpx.exception_verbosity` to allow to control the level of verbosity of the exceptions (3 levels available).
- `broadcast_to`, `broadcast_from`, `scatter_to` and `scatter_from` have been added to the collectives, modernization of `gather_here` and `gather_there` with futures taken by rvalue references. See the breaking change on `all_to_all` in the next section. None of the collectives need supporting macros anymore (e.g. specifying the data types used for a collective operation using `HPX_REGISTER_ALLGATHER` and similar is not needed anymore).
- New API functions have been added: a) to get the number of cores which are idle (`hpx::get_idle_core_count`) and b) returning a bitmask representing the currently idle cores (`hpx::get_idle_core_mask`).
- We have added an experimental option to only enable the local runtime, you can disable the distributed runtime with `HPX_WITH_DISTRIBUTED_RUNTIME=OFF`. You can also enable the local runtime by using the `--hpx:local` runtime option.
- We fixed task annotations for actions.
- The alias `hpx::promise` to `hpx::lcos::promise` is now deprecated. You can use `hpx::lcos::promise` directly instead. `hpx::promise` will refer to the local-only promise in the future.
- We have added a `prepare_checkpoint` API function that calculates the amount of necessary buffer space for a particular set of arguments checkpointed.
- We have added `hpx::upgrade_lock` and `hpx::upgrade_to_unique_lock`, which make `hpx::shared_mutex` (and similar) usable in more flexible ways.
- We have changed the CMake targets exposed to the user, it now includes `HPX::hpx`, `HPX::wrap_main` (int main as the first *HPX* thread of the application, see *Starting the HPX runtime*), `HPX::plugin`, `HPX::component`. The CMake variables `HPX_INCLUDE_DIRS` and `HPX_LIBRARIES` are deprecated and will be removed in a future release, you should now link directly to the `HPX::hpx` CMake target.
- A new example is demonstrating how to create and use a wrapping executor (`quickstart/executor_with_thread_hooks.cpp`)
- A new example is demonstrating how to disable thread stealing during the execution of parallel algorithms (`quickstart/disable_thread_stealing_executor.cpp`)
- We now require for our CMake build system configuration files to be formatted using `cmake-format`.
- We have removed more dependencies on various Boost libraries.
- We have added an experimental option enabling unity builds of HPX using the `-DHPX_WITH_UNITY_BUILD=On` CMake option.

- Many bug fixes.

Breaking changes

- *HPX* now requires a C++14 capable compiler. We have set the *HPX* C++ standard automatically to C++14 and if it needs to be set explicitly, it should be specified through the `CMAKE_CXX_STANDARD` setting as mandated by CMake. The `HPX_WITH_CXX*` variables are now deprecated and will be removed in the future.
- Building and using *HPX* is now supported only when using CMake V3.13 or later, Boost V1.64 or newer, and when compiling with clang V5, gcc V7, or VS2019, or later. Other compilers might still work but have not been tested thoroughly.
- We have added a `hpx::init_params` struct to pass parameters for *HPX* initialization e.g. the resource partitioner callback to initialize thread pools (*Using the resource partitioner*).
- The `all_to_all` algorithm is renamed to `all_gather`, and the new `all_to_all` algorithm is not compatible with the old one.
- We have moved all of the existing APIs related to resiliency into the namespace `hpx::resiliency::experimental`.

Closed issues

- Issue #4918²³⁶² - Rename `distributed_executors` module
- Issue #4900²³⁶³ - Adding JOSS status badge to README
- Issue #4897²³⁶⁴ - Compiler warning, deprecated header used by *HPX* itself
- Issue #4886²³⁶⁵ - A future bound to an action executing on a different locality doesn't capture exception state
- Issue #4880²³⁶⁶ - Undefined reference to main build error when `HPX_WITH_DYNAMIC_HPX_MAIN=OFF`
- Issue #4877²³⁶⁷ - `hpx_main` might not able to start *hpx* runtime properly
- Issue #4850²³⁶⁸ - Issues creating templated component
- Issue #4829²³⁶⁹ - Spack package & `HPX_WITH_GENERIC_CONTEXT_COROUTINES`
- Issue #4820²³⁷⁰ - PAPI counters don't work
- Issue #4818²³⁷¹ - *HPX* can't be used with IO pool turned off
- Issue #4816²³⁷² - Build of *HPX* fails when `find_package(Boost)` is called before `FetchContent_MakeAvailable(hpx)`
- Issue #4813²³⁷³ - *HPX* MPI Future failed
- Issue #4811²³⁷⁴ - Remove `HPX::hpx_no_wrap_main` target before 1.5.0 release

²³⁶² <https://github.com/STELLAR-GROUP/hpx/issues/4918>

²³⁶³ <https://github.com/STELLAR-GROUP/hpx/issues/4900>

²³⁶⁴ <https://github.com/STELLAR-GROUP/hpx/issues/4897>

²³⁶⁵ <https://github.com/STELLAR-GROUP/hpx/issues/4886>

²³⁶⁶ <https://github.com/STELLAR-GROUP/hpx/issues/4880>

²³⁶⁷ <https://github.com/STELLAR-GROUP/hpx/issues/4877>

²³⁶⁸ <https://github.com/STELLAR-GROUP/hpx/issues/4850>

²³⁶⁹ <https://github.com/STELLAR-GROUP/hpx/issues/4829>

²³⁷⁰ <https://github.com/STELLAR-GROUP/hpx/issues/4820>

²³⁷¹ <https://github.com/STELLAR-GROUP/hpx/issues/4818>

²³⁷² <https://github.com/STELLAR-GROUP/hpx/issues/4816>

²³⁷³ <https://github.com/STELLAR-GROUP/hpx/issues/4813>

²³⁷⁴ <https://github.com/STELLAR-GROUP/hpx/issues/4811>

- Issue #4810²³⁷⁵ - In `hpx::for_each::invoke_projected` the `hpx::util::decay` is misguided
- Issue #4787²³⁷⁶ - `transform_inclusive_scan` gives incorrect results for non-commutative operator
- Issue #4786²³⁷⁷ - `transform_inclusive_scan` tries to implicitly convert between types, instead of using the provided `conv` function
- Issue #4779²³⁷⁸ - HPX build error with GCC 10.1
- Issue #4766²³⁷⁹ - Move HPX.Compute functionality to experimental namespace
- Issue #4763²³⁸⁰ - License file name
- Issue #4758²³⁸¹ - CMake profiling results
- Issue #4755²³⁸² - Building HPX with support for PAPI fails
- Issue #4754²³⁸³ - CMake cache creation breaks when using HPX with `mimalloc`
- Issue #4752²³⁸⁴ - HPX MPI Future build failed
- Issue #4746²³⁸⁵ - Memory leak when using dataflow icw components
- Issue #4731²³⁸⁶ - Bug in stencil example, calculation of locality IDs
- Issue #4723²³⁸⁷ - Build fail with NETWORKING OFF
- Issue #4720²³⁸⁸ - Add compatibility headers for modules that had their module headers implicitly generated in 1.4.1
- Issue #4719²³⁸⁹ - Undeprecate some module headers
- Issue #4712²³⁹⁰ - Rename `HPX_MPI_WITH_FUTURES` option
- Issue #4709²³⁹¹ - Make deprecation warnings overridable in dependent projects
- Issue #4691²³⁹² - Suggestion to fix and enhance the `thread_mapper` API
- Issue #4686²³⁹³ - Fix tutorials examples
- Issue #4685²³⁹⁴ - HPX distributed map fails to compile
- Issue #4680²³⁹⁵ - Build error with `HPX_WITH_DYNAMIC_HPX_MAIN=OFF`
- Issue #4679²³⁹⁶ - Build error for `hpx w/ Apex` on Summit

²³⁷⁵ <https://github.com/STELLAR-GROUP/hpx/issues/4810>

²³⁷⁶ <https://github.com/STELLAR-GROUP/hpx/issues/4787>

²³⁷⁷ <https://github.com/STELLAR-GROUP/hpx/issues/4786>

²³⁷⁸ <https://github.com/STELLAR-GROUP/hpx/issues/4779>

²³⁷⁹ <https://github.com/STELLAR-GROUP/hpx/issues/4766>

²³⁸⁰ <https://github.com/STELLAR-GROUP/hpx/issues/4763>

²³⁸¹ <https://github.com/STELLAR-GROUP/hpx/issues/4758>

²³⁸² <https://github.com/STELLAR-GROUP/hpx/issues/4755>

²³⁸³ <https://github.com/STELLAR-GROUP/hpx/issues/4754>

²³⁸⁴ <https://github.com/STELLAR-GROUP/hpx/issues/4752>

²³⁸⁵ <https://github.com/STELLAR-GROUP/hpx/issues/4746>

²³⁸⁶ <https://github.com/STELLAR-GROUP/hpx/issues/4731>

²³⁸⁷ <https://github.com/STELLAR-GROUP/hpx/issues/4723>

²³⁸⁸ <https://github.com/STELLAR-GROUP/hpx/issues/4720>

²³⁸⁹ <https://github.com/STELLAR-GROUP/hpx/issues/4719>

²³⁹⁰ <https://github.com/STELLAR-GROUP/hpx/issues/4712>

²³⁹¹ <https://github.com/STELLAR-GROUP/hpx/issues/4709>

²³⁹² <https://github.com/STELLAR-GROUP/hpx/issues/4691>

²³⁹³ <https://github.com/STELLAR-GROUP/hpx/issues/4686>

²³⁹⁴ <https://github.com/STELLAR-GROUP/hpx/issues/4685>

²³⁹⁵ <https://github.com/STELLAR-GROUP/hpx/issues/4680>

²³⁹⁶ <https://github.com/STELLAR-GROUP/hpx/issues/4679>

- [Issue #4675²³⁹⁷](#) - build error with `HPX_WITH_NETWORKING=OFF`
- [Issue #4674²³⁹⁸](#) - Error running Quickstart tests on OS X
- [Issue #4662²³⁹⁹](#) - MPI initialization broken when networking off
- [Issue #4652²⁴⁰⁰](#) - How to fix distributed action annotation
- [Issue #4650²⁴⁰¹](#) - thread descriptions are broken. ... again
- [Issue #4648²⁴⁰²](#) - Thread stacksize not properly set
- [Issue #4647²⁴⁰³](#) - Rename generated collective headers in modules
- [Issue #4639²⁴⁰⁴](#) - Update deprecation warnings in compatibility headers to point to collective headers
- [Issue #4628²⁴⁰⁵](#) - mpi parcellport totally broken
- [Issue #4619²⁴⁰⁶](#) - Fully document `hpx_wrap` behaviour and targets
- [Issue #4612²⁴⁰⁷](#) - Compilation issue with HPX 1.4.1 and 1.4.0
- [Issue #4594²⁴⁰⁸](#) - Rename modules
- [Issue #4578²⁴⁰⁹](#) - Default value for `HPX_WITH_THREAD_BACKTRACE_DEPTH`
- [Issue #4572²⁴¹⁰](#) - Thread manager should be given a `runtime_configuration`
- [Issue #4571²⁴¹¹](#) - Add high-level documentation to new modules
- [Issue #4569²⁴¹²](#) - Annoying warning when compiling - pls suppress or fix it.
- [Issue #4555²⁴¹³](#) - `HPX_HAVE_THREAD_BACKTRACE_ON_SUSPENSION` compilation error
- [Issue #4543²⁴¹⁴](#) - Segfaults in Release builds using `sleep_for`
- [Issue #4539²⁴¹⁵](#) - Compilation Error when `HPX_MPI_WITH_FUTURES=ON`
- [Issue #4537²⁴¹⁶](#) - Linking issue with `libhpx_initd.a`
- [Issue #4535²⁴¹⁷](#) - API for checking if pool with a given name exists
- [Issue #4523²⁴¹⁸](#) - Build of PR #4311 (git tag 9955e8e) fails
- [Issue #4519²⁴¹⁹](#) - Documentation problem

²³⁹⁷ <https://github.com/STELLAR-GROUP/hpx/issues/4675>

²³⁹⁸ <https://github.com/STELLAR-GROUP/hpx/issues/4674>

²³⁹⁹ <https://github.com/STELLAR-GROUP/hpx/issues/4662>

²⁴⁰⁰ <https://github.com/STELLAR-GROUP/hpx/issues/4652>

²⁴⁰¹ <https://github.com/STELLAR-GROUP/hpx/issues/4650>

²⁴⁰² <https://github.com/STELLAR-GROUP/hpx/issues/4648>

²⁴⁰³ <https://github.com/STELLAR-GROUP/hpx/issues/4647>

²⁴⁰⁴ <https://github.com/STELLAR-GROUP/hpx/issues/4639>

²⁴⁰⁵ <https://github.com/STELLAR-GROUP/hpx/issues/4628>

²⁴⁰⁶ <https://github.com/STELLAR-GROUP/hpx/issues/4619>

²⁴⁰⁷ <https://github.com/STELLAR-GROUP/hpx/issues/4612>

²⁴⁰⁸ <https://github.com/STELLAR-GROUP/hpx/issues/4594>

²⁴⁰⁹ <https://github.com/STELLAR-GROUP/hpx/issues/4578>

²⁴¹⁰ <https://github.com/STELLAR-GROUP/hpx/issues/4572>

²⁴¹¹ <https://github.com/STELLAR-GROUP/hpx/issues/4571>

²⁴¹² <https://github.com/STELLAR-GROUP/hpx/issues/4569>

²⁴¹³ <https://github.com/STELLAR-GROUP/hpx/issues/4555>

²⁴¹⁴ <https://github.com/STELLAR-GROUP/hpx/issues/4543>

²⁴¹⁵ <https://github.com/STELLAR-GROUP/hpx/issues/4539>

²⁴¹⁶ <https://github.com/STELLAR-GROUP/hpx/issues/4537>

²⁴¹⁷ <https://github.com/STELLAR-GROUP/hpx/issues/4535>

²⁴¹⁸ <https://github.com/STELLAR-GROUP/hpx/issues/4523>

²⁴¹⁹ <https://github.com/STELLAR-GROUP/hpx/issues/4519>

- Issue #4513²⁴²⁰ - HPXConfig.cmake contains ill-formed paths when library paths use backslashes
- Issue #4507²⁴²¹ - User-polling introduced by MPI futures module should be more generally usable
- Issue #4506²⁴²² - Make sure force_linking.hpp is not included in main module header
- Issue #4501²⁴²³ - Fix compilation of PAPI tests
- Issue #4497²⁴²⁴ - Add modules CI checks
- Issue #4489²⁴²⁵ - Polymorphic executor
- Issue #4476²⁴²⁶ - Use CMake targets defined by FindBoost
- Issue #4473²⁴²⁷ - Add vcpkg installation instructions
- Issue #4470²⁴²⁸ - Adapt hpx::future to C++20 co_await
- Issue #4468²⁴²⁹ - Compile error on Raspberry Pi 4
- Issue #4466²⁴³⁰ - Compile error on Windows, current stable:
- Issue #4453²⁴³¹ - Installing HPX on fedora with dnf is not adding cmake files
- Issue #4448²⁴³² - New std::variant serialization broken
- Issue #4438²⁴³³ - Add performance counter flag is monotonically increasing
- Issue #4436²⁴³⁴ - Build problem: same code build and works with 1.4.0 but it doesn't with 1.4.1
- Issue #4429²⁴³⁵ - Function descriptions not supported in distributed
- Issue #4423²⁴³⁶ - `-hpx:ini=hpx.lock_detection=0` has no effect
- Issue #4422²⁴³⁷ - Add performance counter metadata
- Issue #4419²⁴³⁸ - Weird behavior for `-hpx:print-counter-interval` with large numbers
- Issue #4401²⁴³⁹ - Create module repository
- Issue #4400²⁴⁴⁰ - Command line options conflict related to performance counters
- Issue #4349²⁴⁴¹ - `-hpx:use-process-mask` option throw an exception on OS X
- Issue #4345²⁴⁴² - Move gh-pages branch out of hpx repo

²⁴²⁰ <https://github.com/STELLAR-GROUP/hpx/issues/4513>

²⁴²¹ <https://github.com/STELLAR-GROUP/hpx/issues/4507>

²⁴²² <https://github.com/STELLAR-GROUP/hpx/issues/4506>

²⁴²³ <https://github.com/STELLAR-GROUP/hpx/issues/4501>

²⁴²⁴ <https://github.com/STELLAR-GROUP/hpx/issues/4497>

²⁴²⁵ <https://github.com/STELLAR-GROUP/hpx/issues/4489>

²⁴²⁶ <https://github.com/STELLAR-GROUP/hpx/issues/4476>

²⁴²⁷ <https://github.com/STELLAR-GROUP/hpx/issues/4473>

²⁴²⁸ <https://github.com/STELLAR-GROUP/hpx/issues/4470>

²⁴²⁹ <https://github.com/STELLAR-GROUP/hpx/issues/4468>

²⁴³⁰ <https://github.com/STELLAR-GROUP/hpx/issues/4466>

²⁴³¹ <https://github.com/STELLAR-GROUP/hpx/issues/4453>

²⁴³² <https://github.com/STELLAR-GROUP/hpx/issues/4448>

²⁴³³ <https://github.com/STELLAR-GROUP/hpx/issues/4438>

²⁴³⁴ <https://github.com/STELLAR-GROUP/hpx/issues/4436>

²⁴³⁵ <https://github.com/STELLAR-GROUP/hpx/issues/4429>

²⁴³⁶ <https://github.com/STELLAR-GROUP/hpx/issues/4423>

²⁴³⁷ <https://github.com/STELLAR-GROUP/hpx/issues/4422>

²⁴³⁸ <https://github.com/STELLAR-GROUP/hpx/issues/4419>

²⁴³⁹ <https://github.com/STELLAR-GROUP/hpx/issues/4401>

²⁴⁴⁰ <https://github.com/STELLAR-GROUP/hpx/issues/4400>

²⁴⁴¹ <https://github.com/STELLAR-GROUP/hpx/issues/4349>

²⁴⁴² <https://github.com/STELLAR-GROUP/hpx/issues/4345>

- Issue #4323²⁴⁴³ - Const-correctness error in assignment operator of `compute::vector`
- Issue #4318²⁴⁴⁴ - ASIO breaks with C++2a concepts
- Issue #4317²⁴⁴⁵ - Application runs even if `-hpx:help` is specified
- Issue #4063²⁴⁴⁶ - Document `hpxcxx` compiler wrapper
- Issue #3983²⁴⁴⁷ - Implement the C++20 Synchronization Library
- Issue #3696²⁴⁴⁸ - C++11 `constexpr` support is now required
- Issue #3623²⁴⁴⁹ - Modular HPX branch and an alternative project layout
- Issue #2836²⁴⁵⁰ - The worst-case time complexity of `parallel::sort` seems to be $O(N^2)$.

Closed pull requests

- PR #4936²⁴⁵¹ - Minor documentation fixes part 2
- PR #4935²⁴⁵² - Add copyright and license to joss paper file
- PR #4934²⁴⁵³ - Adding Semicolon in Documentation
- PR #4932²⁴⁵⁴ - Fixing compiler warnings
- PR #4931²⁴⁵⁵ - Small documentation formatting fixes
- PR #4930²⁴⁵⁶ - Documentation Distributed HPX applications `localvv` with `local_vv`
- PR #4929²⁴⁵⁷ - Add final version of the JOSS paper
- PR #4928²⁴⁵⁸ - Add `HPX_NODISCARD` to `enable_user_polling` structs
- PR #4926²⁴⁵⁹ - Rename `distributed_executors` module to `executors_distributed`
- PR #4925²⁴⁶⁰ - Making `transform_reduce` conforming to C++20
- PR #4923²⁴⁶¹ - Don't acquire lock if not needed
- PR #4921²⁴⁶² - Update the release notes for the release candidate 3
- PR #4920²⁴⁶³ - Disable `libcds` release
- PR #4919²⁴⁶⁴ - Make `cuda` event pool dynamic instead of fixed size

²⁴⁴³ <https://github.com/STELLAR-GROUP/hpx/issues/4323>

²⁴⁴⁴ <https://github.com/STELLAR-GROUP/hpx/issues/4318>

²⁴⁴⁵ <https://github.com/STELLAR-GROUP/hpx/issues/4317>

²⁴⁴⁶ <https://github.com/STELLAR-GROUP/hpx/issues/4063>

²⁴⁴⁷ <https://github.com/STELLAR-GROUP/hpx/issues/3983>

²⁴⁴⁸ <https://github.com/STELLAR-GROUP/hpx/issues/3696>

²⁴⁴⁹ <https://github.com/STELLAR-GROUP/hpx/issues/3623>

²⁴⁵⁰ <https://github.com/STELLAR-GROUP/hpx/issues/2836>

²⁴⁵¹ <https://github.com/STELLAR-GROUP/hpx/pull/4936>

²⁴⁵² <https://github.com/STELLAR-GROUP/hpx/pull/4935>

²⁴⁵³ <https://github.com/STELLAR-GROUP/hpx/pull/4934>

²⁴⁵⁴ <https://github.com/STELLAR-GROUP/hpx/pull/4932>

²⁴⁵⁵ <https://github.com/STELLAR-GROUP/hpx/pull/4931>

²⁴⁵⁶ <https://github.com/STELLAR-GROUP/hpx/pull/4930>

²⁴⁵⁷ <https://github.com/STELLAR-GROUP/hpx/pull/4929>

²⁴⁵⁸ <https://github.com/STELLAR-GROUP/hpx/pull/4928>

²⁴⁵⁹ <https://github.com/STELLAR-GROUP/hpx/pull/4926>

²⁴⁶⁰ <https://github.com/STELLAR-GROUP/hpx/pull/4925>

²⁴⁶¹ <https://github.com/STELLAR-GROUP/hpx/pull/4923>

²⁴⁶² <https://github.com/STELLAR-GROUP/hpx/pull/4921>

²⁴⁶³ <https://github.com/STELLAR-GROUP/hpx/pull/4920>

²⁴⁶⁴ <https://github.com/STELLAR-GROUP/hpx/pull/4919>

- PR #4917²⁴⁶⁵ - Move chrono functionality to hpx::chrono namespace
- PR #4916²⁴⁶⁶ - HPX_HAVE_DEPRECATED_WARNINGS needs to be set even when disabled
- PR #4915²⁴⁶⁷ - Moving more action related files to actions modules
- PR #4914²⁴⁶⁸ - Add alias targets with namespaces used for exporting
- PR #4912²⁴⁶⁹ - Aggregate initialize CPOs
- PR #4910²⁴⁷⁰ - Explicitly specify hwloc root on Jenkins CSCS builds
- PR #4908²⁴⁷¹ - Fix algorithms documentation
- PR #4907²⁴⁷² - Remove HPX::hpx_no_wrap_main target
- PR #4906²⁴⁷³ - Fixing unused variable warning
- PR #4905²⁴⁷⁴ - Adding specializations for simple for_loops
- PR #4904²⁴⁷⁵ - Update boost to 1.74.0 for the newest jenkins configs
- PR #4903²⁴⁷⁶ - Hide GITHUB_TOKEN environment variables from environment variable output
- PR #4902²⁴⁷⁷ - Cancel previous pull requests builds before starting a new one with Jenkins
- PR #4901²⁴⁷⁸ - Update public API list with updated algorithms
- PR #4899²⁴⁷⁹ - Suggested changes for HPX V1.5 release notes
- PR #4898²⁴⁸⁰ - Minor tweak to hpx::equal implementation
- PR #4896²⁴⁸¹ - Making generate() and generate_n conforming to C++20
- PR #4895²⁴⁸² - Update apex tag
- PR #4894²⁴⁸³ - Fix exception handling for tasks
- PR #4893²⁴⁸⁴ - Remove last use of std::result_of, removed in C++20
- PR #4892²⁴⁸⁵ - Adding replay_executor and replicate_executor
- PR #4889²⁴⁸⁶ - Restore old behaviour of not requiring linking to hpx_wrap when HPX_WITH_DYNAMIC_HPX_MAIN=OFF
- PR #4887²⁴⁸⁷ - Making sure remotely thrown (non-hpx) exceptions are properly marshaled back to invocation

²⁴⁶⁵ <https://github.com/STELLAR-GROUP/hpx/pull/4917>

²⁴⁶⁶ <https://github.com/STELLAR-GROUP/hpx/pull/4916>

²⁴⁶⁷ <https://github.com/STELLAR-GROUP/hpx/pull/4915>

²⁴⁶⁸ <https://github.com/STELLAR-GROUP/hpx/pull/4914>

²⁴⁶⁹ <https://github.com/STELLAR-GROUP/hpx/pull/4912>

²⁴⁷⁰ <https://github.com/STELLAR-GROUP/hpx/pull/4910>

²⁴⁷¹ <https://github.com/STELLAR-GROUP/hpx/pull/4908>

²⁴⁷² <https://github.com/STELLAR-GROUP/hpx/pull/4907>

²⁴⁷³ <https://github.com/STELLAR-GROUP/hpx/pull/4906>

²⁴⁷⁴ <https://github.com/STELLAR-GROUP/hpx/pull/4905>

²⁴⁷⁵ <https://github.com/STELLAR-GROUP/hpx/pull/4904>

²⁴⁷⁶ <https://github.com/STELLAR-GROUP/hpx/pull/4903>

²⁴⁷⁷ <https://github.com/STELLAR-GROUP/hpx/pull/4902>

²⁴⁷⁸ <https://github.com/STELLAR-GROUP/hpx/pull/4901>

²⁴⁷⁹ <https://github.com/STELLAR-GROUP/hpx/pull/4899>

²⁴⁸⁰ <https://github.com/STELLAR-GROUP/hpx/pull/4898>

²⁴⁸¹ <https://github.com/STELLAR-GROUP/hpx/pull/4896>

²⁴⁸² <https://github.com/STELLAR-GROUP/hpx/pull/4895>

²⁴⁸³ <https://github.com/STELLAR-GROUP/hpx/pull/4894>

²⁴⁸⁴ <https://github.com/STELLAR-GROUP/hpx/pull/4893>

²⁴⁸⁵ <https://github.com/STELLAR-GROUP/hpx/pull/4892>

²⁴⁸⁶ <https://github.com/STELLAR-GROUP/hpx/pull/4889>

²⁴⁸⁷ <https://github.com/STELLAR-GROUP/hpx/pull/4887>

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- PR #4885²⁴⁸⁸ - Adapting `hpx::find` and `friends` to C++20
- PR #4884²⁴⁸⁹ - Adapting `mismatch` to C++20
- PR #4883²⁴⁹⁰ - Adapting `hpx::equal` to be conforming to C++20
- PR #4882²⁴⁹¹ - Fixing exception handling for `hpx::copy` and adding missing tests
- PR #4881²⁴⁹² - Adds different runtime exception when registering thread with the HPX runtime
- PR #4876²⁴⁹³ - Adding example demonstrating how to disable thread stealing during the execution of parallel algorithms
- PR #4874²⁴⁹⁴ - Adding non-policy tests to `all_of`, `any_of`, and `none_of`
- PR #4873²⁴⁹⁵ - Set CUDA compute capability on rostam Jenkins builds
- PR #4872²⁴⁹⁶ - Force partitioned vector scan tests to run serially
- PR #4870²⁴⁹⁷ - Making `move` conforming with C++20
- PR #4869²⁴⁹⁸ - Making `destroy` and `destroy_n` conforming to C++20
- PR #4868²⁴⁹⁹ - Fix miscellaneous header problems
- PR #4867²⁵⁰⁰ - Add CPOs for `for_each`
- PR #4865²⁵⁰¹ - Adapting `count` and `count_if` to be conforming to C++20
- PR #4864²⁵⁰² - Release notes 1.5.0
- PR #4863²⁵⁰³ - adding `libcds-hpx` tag to prepare for `hpx1.5` release
- PR #4862²⁵⁰⁴ - Adding version specific deprecation options
- PR #4861²⁵⁰⁵ - Limiting executor improvements
- PR #4860²⁵⁰⁶ - Making `fill` and `fill_n` compatible with C++20
- PR #4859²⁵⁰⁷ - Adapting `all_of`, `any_of`, and `none_of` to C++20
- PR #4857²⁵⁰⁸ - Improve `libCDS` integration
- PR #4856²⁵⁰⁹ - Correct typos in the documentation of the `hpx` performance counters

²⁴⁸⁸ <https://github.com/STELLAR-GROUP/hpx/pull/4885>

²⁴⁸⁹ <https://github.com/STELLAR-GROUP/hpx/pull/4884>

²⁴⁹⁰ <https://github.com/STELLAR-GROUP/hpx/pull/4883>

²⁴⁹¹ <https://github.com/STELLAR-GROUP/hpx/pull/4882>

²⁴⁹² <https://github.com/STELLAR-GROUP/hpx/pull/4881>

²⁴⁹³ <https://github.com/STELLAR-GROUP/hpx/pull/4876>

²⁴⁹⁴ <https://github.com/STELLAR-GROUP/hpx/pull/4874>

²⁴⁹⁵ <https://github.com/STELLAR-GROUP/hpx/pull/4873>

²⁴⁹⁶ <https://github.com/STELLAR-GROUP/hpx/pull/4872>

²⁴⁹⁷ <https://github.com/STELLAR-GROUP/hpx/pull/4870>

²⁴⁹⁸ <https://github.com/STELLAR-GROUP/hpx/pull/4869>

²⁴⁹⁹ <https://github.com/STELLAR-GROUP/hpx/pull/4868>

²⁵⁰⁰ <https://github.com/STELLAR-GROUP/hpx/pull/4867>

²⁵⁰¹ <https://github.com/STELLAR-GROUP/hpx/pull/4865>

²⁵⁰² <https://github.com/STELLAR-GROUP/hpx/pull/4864>

²⁵⁰³ <https://github.com/STELLAR-GROUP/hpx/pull/4863>

²⁵⁰⁴ <https://github.com/STELLAR-GROUP/hpx/pull/4862>

²⁵⁰⁵ <https://github.com/STELLAR-GROUP/hpx/pull/4861>

²⁵⁰⁶ <https://github.com/STELLAR-GROUP/hpx/pull/4860>

²⁵⁰⁷ <https://github.com/STELLAR-GROUP/hpx/pull/4859>

²⁵⁰⁸ <https://github.com/STELLAR-GROUP/hpx/pull/4857>

²⁵⁰⁹ <https://github.com/STELLAR-GROUP/hpx/pull/4856>

- PR #4854²⁵¹⁰ - Removing obsolete code
- PR #4853²⁵¹¹ - Adding test that derives component from two other components
- PR #4852²⁵¹² - Fix mpi_ring test in distributed mode by ensuring all ranks run hpx_main
- PR #4851²⁵¹³ - Converting resiliency APIs to tag_invoke based CPOs
- PR #4849²⁵¹⁴ - Enable use of future_overhead test when DISTRIBUTED_RUNTIME is OFF
- PR #4847²⁵¹⁵ - Fixing 'error prone' constructs as reported by Codacy
- PR #4846²⁵¹⁶ - Disable Boost.Asio concepts support
- PR #4845²⁵¹⁷ - Fix PAPI counters
- PR #4843²⁵¹⁸ - Remove dependency on various Boost headers
- PR #4841²⁵¹⁹ - Rearrange public API headers
- PR #4840²⁵²⁰ - Fixing TSS problems during thread termination
- PR #4839²⁵²¹ - Fix async_cuda build problems when distributed runtime is disabled
- PR #4837²⁵²² - Restore compatibility for old (now deprecated) copy algorithms
- PR #4836²⁵²³ - Adding CPOs for hpx::reduce
- PR #4835²⁵²⁴ - Remove *using util::result_of* from namespace hpx
- PR #4834²⁵²⁵ - Fixing the calculation of the number of idle cores and the corresponding idle masks
- PR #4833²⁵²⁶ - Allow thread function destructors to yield
- PR #4832²⁵²⁷ - Fixing assertion in split_gids and memory leaks in 1d_stencil_7
- PR #4831²⁵²⁸ - Making sure MPI_CXX_COMPILE_FLAGS is interpreted as a sequence of options
- PR #4830²⁵²⁹ - Update documentation on using HPX::wrap_main
- PR #4827²⁵³⁰ - Update clang-newest configuration to use clang 10
- PR #4826²⁵³¹ - Add Jenkins configuration for rostam
- PR #4825²⁵³² - Move all CUDA functionality to hpx::cuda::experimental namespace

²⁵¹⁰ <https://github.com/STELLAR-GROUP/hpx/pull/4854>

²⁵¹¹ <https://github.com/STELLAR-GROUP/hpx/pull/4853>

²⁵¹² <https://github.com/STELLAR-GROUP/hpx/pull/4852>

²⁵¹³ <https://github.com/STELLAR-GROUP/hpx/pull/4851>

²⁵¹⁴ <https://github.com/STELLAR-GROUP/hpx/pull/4849>

²⁵¹⁵ <https://github.com/STELLAR-GROUP/hpx/pull/4847>

²⁵¹⁶ <https://github.com/STELLAR-GROUP/hpx/pull/4846>

²⁵¹⁷ <https://github.com/STELLAR-GROUP/hpx/pull/4845>

²⁵¹⁸ <https://github.com/STELLAR-GROUP/hpx/pull/4843>

²⁵¹⁹ <https://github.com/STELLAR-GROUP/hpx/pull/4841>

²⁵²⁰ <https://github.com/STELLAR-GROUP/hpx/pull/4840>

²⁵²¹ <https://github.com/STELLAR-GROUP/hpx/pull/4839>

²⁵²² <https://github.com/STELLAR-GROUP/hpx/pull/4837>

²⁵²³ <https://github.com/STELLAR-GROUP/hpx/pull/4836>

²⁵²⁴ <https://github.com/STELLAR-GROUP/hpx/pull/4835>

²⁵²⁵ <https://github.com/STELLAR-GROUP/hpx/pull/4834>

²⁵²⁶ <https://github.com/STELLAR-GROUP/hpx/pull/4833>

²⁵²⁷ <https://github.com/STELLAR-GROUP/hpx/pull/4832>

²⁵²⁸ <https://github.com/STELLAR-GROUP/hpx/pull/4831>

²⁵²⁹ <https://github.com/STELLAR-GROUP/hpx/pull/4830>

²⁵³⁰ <https://github.com/STELLAR-GROUP/hpx/pull/4827>

²⁵³¹ <https://github.com/STELLAR-GROUP/hpx/pull/4826>

²⁵³² <https://github.com/STELLAR-GROUP/hpx/pull/4825>

- PR #4824²⁵³³ - Add support for building master/release branches to Jenkins configuration
- PR #4821²⁵³⁴ - Implement customization point for `hpx::copy` and `hpx::ranges::copy`
- PR #4819²⁵³⁵ - Allow finding Boost components before finding HPX
- PR #4817²⁵³⁶ - Adding range version of stable sort
- PR #4815²⁵³⁷ - Fix a wrong `#ifdef` for IO/TIMER pools causing build errors
- PR #4814²⁵³⁸ - Replace `hpx::function_nonser` with `std::function` in error module
- PR #4809²⁵³⁹ - Foreach adapt
- PR #4808²⁵⁴⁰ - Make internal algorithms functions const
- PR #4807²⁵⁴¹ - Add Jenkins configuration for running on Piz Daint
- PR #4806²⁵⁴² - Update documentation links to new domain name
- PR #4805²⁵⁴³ - Applying changes that resolve time complexity issues in sort
- PR #4803²⁵⁴⁴ - Adding implementation of `stable_sort`
- PR #4802²⁵⁴⁵ - Fix datapar header paths
- PR #4801²⁵⁴⁶ - Replace `boost::shared_array<T>` with `std::shared_ptr<T[]>` if supported
- PR #4799²⁵⁴⁷ - Fixing `#include` paths in compatibility headers
- PR #4798²⁵⁴⁸ - Include the main module header (fixes partially #4488)
- PR #4797²⁵⁴⁹ - Change cmake targets
- PR #4794²⁵⁵⁰ - Removing 128bit integer emulation
- PR #4793²⁵⁵¹ - Make sure global variable is handled properly
- PR #4792²⁵⁵² - Replace `enable_if` with **HPX_CONCEPT_REQUIRES_** and add `is_sentinel_for` constraint
- PR #4790²⁵⁵³ - Move deprecation warnings from base template to template specializations for `result_of` etc. structs
- PR #4789²⁵⁵⁴ - Fix hangs during assertion handling and distributed runtime construction
- PR #4788²⁵⁵⁵ - Fixing inclusive transform scan algorithm to properly handle initial value

²⁵³³ <https://github.com/STELLAR-GROUP/hpx/pull/4824>

²⁵³⁴ <https://github.com/STELLAR-GROUP/hpx/pull/4821>

²⁵³⁵ <https://github.com/STELLAR-GROUP/hpx/pull/4819>

²⁵³⁶ <https://github.com/STELLAR-GROUP/hpx/pull/4817>

²⁵³⁷ <https://github.com/STELLAR-GROUP/hpx/pull/4815>

²⁵³⁸ <https://github.com/STELLAR-GROUP/hpx/pull/4814>

²⁵³⁹ <https://github.com/STELLAR-GROUP/hpx/pull/4809>

²⁵⁴⁰ <https://github.com/STELLAR-GROUP/hpx/pull/4808>

²⁵⁴¹ <https://github.com/STELLAR-GROUP/hpx/pull/4807>

²⁵⁴² <https://github.com/STELLAR-GROUP/hpx/pull/4806>

²⁵⁴³ <https://github.com/STELLAR-GROUP/hpx/pull/4805>

²⁵⁴⁴ <https://github.com/STELLAR-GROUP/hpx/pull/4803>

²⁵⁴⁵ <https://github.com/STELLAR-GROUP/hpx/pull/4802>

²⁵⁴⁶ <https://github.com/STELLAR-GROUP/hpx/pull/4801>

²⁵⁴⁷ <https://github.com/STELLAR-GROUP/hpx/pull/4799>

²⁵⁴⁸ <https://github.com/STELLAR-GROUP/hpx/pull/4798>

²⁵⁴⁹ <https://github.com/STELLAR-GROUP/hpx/pull/4797>

²⁵⁵⁰ <https://github.com/STELLAR-GROUP/hpx/pull/4794>

²⁵⁵¹ <https://github.com/STELLAR-GROUP/hpx/pull/4793>

²⁵⁵² <https://github.com/STELLAR-GROUP/hpx/pull/4792>

²⁵⁵³ <https://github.com/STELLAR-GROUP/hpx/pull/4790>

²⁵⁵⁴ <https://github.com/STELLAR-GROUP/hpx/pull/4789>

²⁵⁵⁵ <https://github.com/STELLAR-GROUP/hpx/pull/4788>

- PR #4785²⁵⁵⁶ - Fixing barrier test
- PR #4784²⁵⁵⁷ - Fixing deleter argument bindings in `serialize_buffer`
- PR #4783²⁵⁵⁸ - Add coveralls badge
- PR #4782²⁵⁵⁹ - Make header tests parallel again
- PR #4780²⁵⁶⁰ - Remove outdated comment about `hpx::stop` in documentation
- PR #4776²⁵⁶¹ - debug print improvements
- PR #4775²⁵⁶² - Checkpoint cleanup
- PR #4771²⁵⁶³ - Fix compilation with `HPX_WITH_NETWORKING=OFF`
- PR #4767²⁵⁶⁴ - Remove all force linking leftovers
- PR #4765²⁵⁶⁵ - Fix 1d stencil index calculation
- PR #4764²⁵⁶⁶ - Force some tests to run serially
- PR #4762²⁵⁶⁷ - Update pointees in compatibility headers
- PR #4761²⁵⁶⁸ - Fix running and building of execution module tests on CircleCI
- PR #4760²⁵⁶⁹ - Storing `hpx_options` in global property to speed up summary report
- PR #4759²⁵⁷⁰ - Reduce memory requirements for our main shared state
- PR #4757²⁵⁷¹ - Fix `mimalloc` linking on Windows
- PR #4756²⁵⁷² - Fix compilation issues
- PR #4753²⁵⁷³ - Re-adding API functions that were lost during merges
- PR #4751²⁵⁷⁴ - Revert “Create coverage reports and upload them to `codecov.io`”
- PR #4750²⁵⁷⁵ - Fixing possible race condition during termination detection
- PR #4749²⁵⁷⁶ - Deprecate `result_of` and friends
- PR #4748²⁵⁷⁷ - Create coverage reports and upload them to `codecov.io`
- PR #4747²⁵⁷⁸ - Changing `#include` for MPI `parcelport`

²⁵⁵⁶ <https://github.com/STELLAR-GROUP/hpx/pull/4785>

²⁵⁵⁷ <https://github.com/STELLAR-GROUP/hpx/pull/4784>

²⁵⁵⁸ <https://github.com/STELLAR-GROUP/hpx/pull/4783>

²⁵⁵⁹ <https://github.com/STELLAR-GROUP/hpx/pull/4782>

²⁵⁶⁰ <https://github.com/STELLAR-GROUP/hpx/pull/4780>

²⁵⁶¹ <https://github.com/STELLAR-GROUP/hpx/pull/4776>

²⁵⁶² <https://github.com/STELLAR-GROUP/hpx/pull/4775>

²⁵⁶³ <https://github.com/STELLAR-GROUP/hpx/pull/4771>

²⁵⁶⁴ <https://github.com/STELLAR-GROUP/hpx/pull/4767>

²⁵⁶⁵ <https://github.com/STELLAR-GROUP/hpx/pull/4765>

²⁵⁶⁶ <https://github.com/STELLAR-GROUP/hpx/pull/4764>

²⁵⁶⁷ <https://github.com/STELLAR-GROUP/hpx/pull/4762>

²⁵⁶⁸ <https://github.com/STELLAR-GROUP/hpx/pull/4761>

²⁵⁶⁹ <https://github.com/STELLAR-GROUP/hpx/pull/4760>

²⁵⁷⁰ <https://github.com/STELLAR-GROUP/hpx/pull/4759>

²⁵⁷¹ <https://github.com/STELLAR-GROUP/hpx/pull/4757>

²⁵⁷² <https://github.com/STELLAR-GROUP/hpx/pull/4756>

²⁵⁷³ <https://github.com/STELLAR-GROUP/hpx/pull/4753>

²⁵⁷⁴ <https://github.com/STELLAR-GROUP/hpx/pull/4751>

²⁵⁷⁵ <https://github.com/STELLAR-GROUP/hpx/pull/4750>

²⁵⁷⁶ <https://github.com/STELLAR-GROUP/hpx/pull/4749>

²⁵⁷⁷ <https://github.com/STELLAR-GROUP/hpx/pull/4748>

²⁵⁷⁸ <https://github.com/STELLAR-GROUP/hpx/pull/4747>

- PR #4745²⁵⁷⁹ - Add *is_sentinel_for* trait implementation and test
- PR #4743²⁵⁸⁰ - Fix *init_globally* example after runtime mode changes
- PR #4742²⁵⁸¹ - Update SUPPORT.md
- PR #4741²⁵⁸² - Fixing a warning generated for unity builds with msvc
- PR #4740²⁵⁸³ - Rename *local_lcos* and *basic_execution* modules
- PR #4739²⁵⁸⁴ - Undeprecate a couple of *hpx/modulename.hpp* headers
- PR #4738²⁵⁸⁵ - Conditionally test schedulers in *thread_stacksize_current* test
- PR #4734²⁵⁸⁶ - Fixing a bunch of codacy warnings
- PR #4733²⁵⁸⁷ - Add experimental unity build option to CMake configuration
- PR #4730²⁵⁸⁸ - Fixing compilation problems with *unordered_map*
- PR #4729²⁵⁸⁹ - Fix APEX build
- PR #4727²⁵⁹⁰ - Fix missing runtime includes for distributed runtime
- PR #4726²⁵⁹¹ - Add more API headers
- PR #4725²⁵⁹² - Add more compatibility headers for deprecated module headers
- PR #4724²⁵⁹³ - Fix 4723
- PR #4721²⁵⁹⁴ - Attempt to fixing migration tests
- PR #4717²⁵⁹⁵ - Make the compatibility headers macro conditional
- PR #4716²⁵⁹⁶ - Add *hpx/runtime.hpp* and *hpx/distributed/runtime.hpp* API headers
- PR #4714²⁵⁹⁷ - Add *hpx/future.hpp* header
- PR #4713²⁵⁹⁸ - Remove *hpx/runtime/threads_fwd.hpp* and *hpx/util_fwd.hpp*
- PR #4711²⁵⁹⁹ - Make module deprecation warnings overridable
- PR #4710²⁶⁰⁰ - Add compatibility headers and other fixes after module header renaming
- PR #4708²⁶⁰¹ - Add termination handler for parallel algorithms

²⁵⁷⁹ <https://github.com/STELLAR-GROUP/hpx/pull/4745>
²⁵⁸⁰ <https://github.com/STELLAR-GROUP/hpx/pull/4743>
²⁵⁸¹ <https://github.com/STELLAR-GROUP/hpx/pull/4742>
²⁵⁸² <https://github.com/STELLAR-GROUP/hpx/pull/4741>
²⁵⁸³ <https://github.com/STELLAR-GROUP/hpx/pull/4740>
²⁵⁸⁴ <https://github.com/STELLAR-GROUP/hpx/pull/4739>
²⁵⁸⁵ <https://github.com/STELLAR-GROUP/hpx/pull/4738>
²⁵⁸⁶ <https://github.com/STELLAR-GROUP/hpx/pull/4734>
²⁵⁸⁷ <https://github.com/STELLAR-GROUP/hpx/pull/4733>
²⁵⁸⁸ <https://github.com/STELLAR-GROUP/hpx/pull/4730>
²⁵⁸⁹ <https://github.com/STELLAR-GROUP/hpx/pull/4729>
²⁵⁹⁰ <https://github.com/STELLAR-GROUP/hpx/pull/4727>
²⁵⁹¹ <https://github.com/STELLAR-GROUP/hpx/pull/4726>
²⁵⁹² <https://github.com/STELLAR-GROUP/hpx/pull/4725>
²⁵⁹³ <https://github.com/STELLAR-GROUP/hpx/pull/4724>
²⁵⁹⁴ <https://github.com/STELLAR-GROUP/hpx/pull/4721>
²⁵⁹⁵ <https://github.com/STELLAR-GROUP/hpx/pull/4717>
²⁵⁹⁶ <https://github.com/STELLAR-GROUP/hpx/pull/4716>
²⁵⁹⁷ <https://github.com/STELLAR-GROUP/hpx/pull/4714>
²⁵⁹⁸ <https://github.com/STELLAR-GROUP/hpx/pull/4713>
²⁵⁹⁹ <https://github.com/STELLAR-GROUP/hpx/pull/4711>
²⁶⁰⁰ <https://github.com/STELLAR-GROUP/hpx/pull/4710>
²⁶⁰¹ <https://github.com/STELLAR-GROUP/hpx/pull/4708>

- PR #4707²⁶⁰² - Use `hpx::function_nonser` instead of `std::function` internally
- PR #4706²⁶⁰³ - Move header file to module
- PR #4705²⁶⁰⁴ - Fix incorrect behaviour of `cmake-format` check
- PR #4704²⁶⁰⁵ - Fix resource tests
- PR #4701²⁶⁰⁶ - Fix missing includes for `future::then` specializations
- PR #4700²⁶⁰⁷ - Removing obsolete memory component
- PR #4699²⁶⁰⁸ - Add short descriptions to modules missing documentation
- PR #4696²⁶⁰⁹ - Rename generated modules headers
- PR #4693²⁶¹⁰ - Overhauling `thread_mapper` for public consumption
- PR #4688²⁶¹¹ - Fix thread stack size handling
- PR #4687²⁶¹² - Adding `all_gather` and fixing `all_to_all`
- PR #4684²⁶¹³ - Miscellaneous compilation fixes
- PR #4683²⁶¹⁴ - Fix `HPX_WITH_DYNAMIC_HPX_MAIN=OFF`
- PR #4682²⁶¹⁵ - Fix compilation of `pack_traversal_rebind_container.hpp`
- PR #4681²⁶¹⁶ - Add missing `hpx/execution.hpp` includes for `future::then`
- PR #4678²⁶¹⁷ - Typeless communicator
- PR #4677²⁶¹⁸ - Forcing registry option to be accepted without checks.
- PR #4676²⁶¹⁹ - Adding `scatter_to/scatter_from` collective operations
- PR #4673²⁶²⁰ - Fix PAPI counters compilation
- PR #4671²⁶²¹ - Deprecate `hpx::promise` alias to `hpx::lcos::promise`
- PR #4670²⁶²² - Explicitly instantiate `get_exception`
- PR #4667²⁶²³ - Add `stopValue` in *Sentinel* struct instead of *Iterator*
- PR #4666²⁶²⁴ - Add release build on Windows to GitHub actions

²⁶⁰² <https://github.com/STELLAR-GROUP/hpx/pull/4707>

²⁶⁰³ <https://github.com/STELLAR-GROUP/hpx/pull/4706>

²⁶⁰⁴ <https://github.com/STELLAR-GROUP/hpx/pull/4705>

²⁶⁰⁵ <https://github.com/STELLAR-GROUP/hpx/pull/4704>

²⁶⁰⁶ <https://github.com/STELLAR-GROUP/hpx/pull/4701>

²⁶⁰⁷ <https://github.com/STELLAR-GROUP/hpx/pull/4700>

²⁶⁰⁸ <https://github.com/STELLAR-GROUP/hpx/pull/4699>

²⁶⁰⁹ <https://github.com/STELLAR-GROUP/hpx/pull/4696>

²⁶¹⁰ <https://github.com/STELLAR-GROUP/hpx/pull/4693>

²⁶¹¹ <https://github.com/STELLAR-GROUP/hpx/pull/4688>

²⁶¹² <https://github.com/STELLAR-GROUP/hpx/pull/4687>

²⁶¹³ <https://github.com/STELLAR-GROUP/hpx/pull/4684>

²⁶¹⁴ <https://github.com/STELLAR-GROUP/hpx/pull/4683>

²⁶¹⁵ <https://github.com/STELLAR-GROUP/hpx/pull/4682>

²⁶¹⁶ <https://github.com/STELLAR-GROUP/hpx/pull/4681>

²⁶¹⁷ <https://github.com/STELLAR-GROUP/hpx/pull/4678>

²⁶¹⁸ <https://github.com/STELLAR-GROUP/hpx/pull/4677>

²⁶¹⁹ <https://github.com/STELLAR-GROUP/hpx/pull/4676>

²⁶²⁰ <https://github.com/STELLAR-GROUP/hpx/pull/4673>

²⁶²¹ <https://github.com/STELLAR-GROUP/hpx/pull/4671>

²⁶²² <https://github.com/STELLAR-GROUP/hpx/pull/4670>

²⁶²³ <https://github.com/STELLAR-GROUP/hpx/pull/4667>

²⁶²⁴ <https://github.com/STELLAR-GROUP/hpx/pull/4666>

- PR #4664²⁶²⁵ - Creating itt_notify module.
- PR #4663²⁶²⁶ - Mpi fixes
- PR #4659²⁶²⁷ - Making sure declarations match definitions in register_locks implementation
- PR #4655²⁶²⁸ - Fixing task annotations for actions
- PR #4653²⁶²⁹ - Making sure APEX is linked into every application, if needed
- PR #4651²⁶³⁰ - Update get_function_annotation.hpp
- PR #4646²⁶³¹ - Runtime type
- PR #4645²⁶³² - Add a few more API headers
- PR #4644²⁶³³ - Fixing support for mpirun (and similar)
- PR #4643²⁶³⁴ - Fixing the fix for get_idle_core_count() API
- PR #4638²⁶³⁵ - Remove HPX_API_EXPORT missed in previous cleanup
- PR #4636²⁶³⁶ - Adding C++20 barrier
- PR #4635²⁶³⁷ - Adding C++20 latch API
- PR #4634²⁶³⁸ - Adding C++20 counting semaphore API
- PR #4633²⁶³⁹ - Unify execution parameters customization points
- PR #4632²⁶⁴⁰ - Adding missing bulk_sync_execute wrapper to example executor
- PR #4631²⁶⁴¹ - Updates to documentation; grammar edits.
- PR #4630²⁶⁴² - Updates to documentation; moved hyperlink
- PR #4624²⁶⁴³ - Export set_self_ptr in thread_data.hpp instead of with forward declarations where used
- PR #4623²⁶⁴⁴ - Clean up export macros
- PR #4621²⁶⁴⁵ - Trigger an error for older boost versions on power architectures
- PR #4617²⁶⁴⁶ - Ignore user-set compatibility header options if the module does not have compatibility headers
- PR #4616²⁶⁴⁷ - Fix cmake-format warning

²⁶²⁵ <https://github.com/STELLAR-GROUP/hpx/pull/4664>

²⁶²⁶ <https://github.com/STELLAR-GROUP/hpx/pull/4663>

²⁶²⁷ <https://github.com/STELLAR-GROUP/hpx/pull/4659>

²⁶²⁸ <https://github.com/STELLAR-GROUP/hpx/pull/4655>

²⁶²⁹ <https://github.com/STELLAR-GROUP/hpx/pull/4653>

²⁶³⁰ <https://github.com/STELLAR-GROUP/hpx/pull/4651>

²⁶³¹ <https://github.com/STELLAR-GROUP/hpx/pull/4646>

²⁶³² <https://github.com/STELLAR-GROUP/hpx/pull/4645>

²⁶³³ <https://github.com/STELLAR-GROUP/hpx/pull/4644>

²⁶³⁴ <https://github.com/STELLAR-GROUP/hpx/pull/4643>

²⁶³⁵ <https://github.com/STELLAR-GROUP/hpx/pull/4638>

²⁶³⁶ <https://github.com/STELLAR-GROUP/hpx/pull/4636>

²⁶³⁷ <https://github.com/STELLAR-GROUP/hpx/pull/4635>

²⁶³⁸ <https://github.com/STELLAR-GROUP/hpx/pull/4634>

²⁶³⁹ <https://github.com/STELLAR-GROUP/hpx/pull/4633>

²⁶⁴⁰ <https://github.com/STELLAR-GROUP/hpx/pull/4632>

²⁶⁴¹ <https://github.com/STELLAR-GROUP/hpx/pull/4631>

²⁶⁴² <https://github.com/STELLAR-GROUP/hpx/pull/4630>

²⁶⁴³ <https://github.com/STELLAR-GROUP/hpx/pull/4624>

²⁶⁴⁴ <https://github.com/STELLAR-GROUP/hpx/pull/4623>

²⁶⁴⁵ <https://github.com/STELLAR-GROUP/hpx/pull/4621>

²⁶⁴⁶ <https://github.com/STELLAR-GROUP/hpx/pull/4617>

²⁶⁴⁷ <https://github.com/STELLAR-GROUP/hpx/pull/4616>

- PR #4615²⁶⁴⁸ - Add handler for serializing custom exceptions
- PR #4614²⁶⁴⁹ - Fix error message when HPX_IGNORE_CMAKE_BUILD_TYPE_COMPATIBILITY=OFF
- PR #4613²⁶⁵⁰ - Make partitioner constructor private
- PR #4611²⁶⁵¹ - Making auto_chunk_size execute the given function using the given executor
- PR #4610²⁶⁵² - Making sure the thread-local lock registration data is moving to the core the suspended HPX thread is resumed on
- PR #4609²⁶⁵³ - Adding an API function that exposes the number of idle cores
- PR #4608²⁶⁵⁴ - Fixing moodycamel namespace
- PR #4607²⁶⁵⁵ - Moving winsocket initialization to core library
- PR #4606²⁶⁵⁶ - Local runtime module etc.
- PR #4604²⁶⁵⁷ - Add config_registry module
- PR #4603²⁶⁵⁸ - Deal with distributed modules in their respective CMakeLists.txt
- PR #4602²⁶⁵⁹ - Small module fixes
- PR #4598²⁶⁶⁰ - Making sure current_executor and service_executor functions are linked into the core library
- PR #4597²⁶⁶¹ - Adding broadcast_to/broadcast_from to collectives module
- PR #4596²⁶⁶² - Fix performance regression in block_executor
- PR #4595²⁶⁶³ - Making sure main.cpp is built as a library if HPX_WITH_DYNAMIC_MAIN=OFF
- PR #4592²⁶⁶⁴ - Futures module
- PR #4591²⁶⁶⁵ - Adapting co_await support for C++20
- PR #4590²⁶⁶⁶ - Adding missing exception test for for_loop()
- PR #4587²⁶⁶⁷ - Move traits headers to hpx/modulename/traits directory
- PR #4586²⁶⁶⁸ - Remove Travis CI config
- PR #4585²⁶⁶⁹ - Update macOS test blacklist
- PR #4584²⁶⁷⁰ - Attempting to fix missing symbols in stack trace

²⁶⁴⁸ <https://github.com/STELLAR-GROUP/hpx/pull/4615>

²⁶⁴⁹ <https://github.com/STELLAR-GROUP/hpx/pull/4614>

²⁶⁵⁰ <https://github.com/STELLAR-GROUP/hpx/pull/4613>

²⁶⁵¹ <https://github.com/STELLAR-GROUP/hpx/pull/4611>

²⁶⁵² <https://github.com/STELLAR-GROUP/hpx/pull/4610>

²⁶⁵³ <https://github.com/STELLAR-GROUP/hpx/pull/4609>

²⁶⁵⁴ <https://github.com/STELLAR-GROUP/hpx/pull/4608>

²⁶⁵⁵ <https://github.com/STELLAR-GROUP/hpx/pull/4607>

²⁶⁵⁶ <https://github.com/STELLAR-GROUP/hpx/pull/4606>

²⁶⁵⁷ <https://github.com/STELLAR-GROUP/hpx/pull/4604>

²⁶⁵⁸ <https://github.com/STELLAR-GROUP/hpx/pull/4603>

²⁶⁵⁹ <https://github.com/STELLAR-GROUP/hpx/pull/4602>

²⁶⁶⁰ <https://github.com/STELLAR-GROUP/hpx/pull/4598>

²⁶⁶¹ <https://github.com/STELLAR-GROUP/hpx/pull/4597>

²⁶⁶² <https://github.com/STELLAR-GROUP/hpx/pull/4596>

²⁶⁶³ <https://github.com/STELLAR-GROUP/hpx/pull/4595>

²⁶⁶⁴ <https://github.com/STELLAR-GROUP/hpx/pull/4592>

²⁶⁶⁵ <https://github.com/STELLAR-GROUP/hpx/pull/4591>

²⁶⁶⁶ <https://github.com/STELLAR-GROUP/hpx/pull/4590>

²⁶⁶⁷ <https://github.com/STELLAR-GROUP/hpx/pull/4587>

²⁶⁶⁸ <https://github.com/STELLAR-GROUP/hpx/pull/4586>

²⁶⁶⁹ <https://github.com/STELLAR-GROUP/hpx/pull/4585>

²⁶⁷⁰ <https://github.com/STELLAR-GROUP/hpx/pull/4584>

- PR #4583²⁶⁷¹ - Fixing bad static_cast
- PR #4582²⁶⁷² - Changing download url for Windows prerequisites to circumvent bandwidth limitations
- PR #4581²⁶⁷³ - Adding missing using placeholder::_X
- PR #4579²⁶⁷⁴ - Move get_stack_size_name and related functions
- PR #4575²⁶⁷⁵ - Excluding unconditional definition of class backtrace from global header
- PR #4574²⁶⁷⁶ - Changing return type of hardware_concurrency() to unsigned int
- PR #4570²⁶⁷⁷ - Move tests to modules
- PR #4564²⁶⁷⁸ - Reshuffle internal targets and add HPX::hpx_no_wrap_main target
- PR #4563²⁶⁷⁹ - fix CMake option typo
- PR #4562²⁶⁸⁰ - Unregister lock earlier to avoid holding it while suspending
- PR #4561²⁶⁸¹ - Adding test macros supporting custom output stream
- PR #4560²⁶⁸² - Making sure hash_any::operator() is linked into core library
- PR #4559²⁶⁸³ - Fixing compilation if HPX_WITH_THREAD_BACKTRACE_ON_SUSPENSION=On
- PR #4557²⁶⁸⁴ - Improve spinlock implementation to perform better in high-contention situations
- PR #4553²⁶⁸⁵ - Fix a runtime_ptr problem at shutdown when apex is enabled
- PR #4552²⁶⁸⁶ - Add configuration option for making exceptions less noisy
- PR #4551²⁶⁸⁷ - Clean up thread creation parameters
- PR #4549²⁶⁸⁸ - Test FetchContent build on GitHub actions
- PR #4548²⁶⁸⁹ - Fix stack size
- PR #4545²⁶⁹⁰ - Fix header tests
- PR #4544²⁶⁹¹ - Fix a typo in sanitizer build
- PR #4541²⁶⁹² - Add API to check if a thread pool exists
- PR #4540²⁶⁹³ - Making sure MPI support is enabled if MPI futures are used but networking is disabled

²⁶⁷¹ <https://github.com/STELLAR-GROUP/hpx/pull/4583>

²⁶⁷² <https://github.com/STELLAR-GROUP/hpx/pull/4582>

²⁶⁷³ <https://github.com/STELLAR-GROUP/hpx/pull/4581>

²⁶⁷⁴ <https://github.com/STELLAR-GROUP/hpx/pull/4579>

²⁶⁷⁵ <https://github.com/STELLAR-GROUP/hpx/pull/4575>

²⁶⁷⁶ <https://github.com/STELLAR-GROUP/hpx/pull/4574>

²⁶⁷⁷ <https://github.com/STELLAR-GROUP/hpx/pull/4570>

²⁶⁷⁸ <https://github.com/STELLAR-GROUP/hpx/pull/4564>

²⁶⁷⁹ <https://github.com/STELLAR-GROUP/hpx/pull/4563>

²⁶⁸⁰ <https://github.com/STELLAR-GROUP/hpx/pull/4562>

²⁶⁸¹ <https://github.com/STELLAR-GROUP/hpx/pull/4561>

²⁶⁸² <https://github.com/STELLAR-GROUP/hpx/pull/4560>

²⁶⁸³ <https://github.com/STELLAR-GROUP/hpx/pull/4559>

²⁶⁸⁴ <https://github.com/STELLAR-GROUP/hpx/pull/4557>

²⁶⁸⁵ <https://github.com/STELLAR-GROUP/hpx/pull/4553>

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²⁶⁸⁸ <https://github.com/STELLAR-GROUP/hpx/pull/4549>

²⁶⁸⁹ <https://github.com/STELLAR-GROUP/hpx/pull/4548>

²⁶⁹⁰ <https://github.com/STELLAR-GROUP/hpx/pull/4545>

²⁶⁹¹ <https://github.com/STELLAR-GROUP/hpx/pull/4544>

²⁶⁹² <https://github.com/STELLAR-GROUP/hpx/pull/4541>

²⁶⁹³ <https://github.com/STELLAR-GROUP/hpx/pull/4540>

- PR #4538²⁶⁹⁴ - Move channel documentation examples to examples directory
- PR #4536²⁶⁹⁵ - Add generic allocator for execution policies
- PR #4534²⁶⁹⁶ - Enable compatibility headers for thread_executors module
- PR #4532²⁶⁹⁷ - Fixing broken url in README.rst
- PR #4531²⁶⁹⁸ - Update scripts
- PR #4530²⁶⁹⁹ - Make sure module API docs show up in correct order
- PR #4529²⁷⁰⁰ - Adding missing template code to module creation script
- PR #4528²⁷⁰¹ - Make sure version module uses HPX's binary dir, not the parent's
- PR #4527²⁷⁰² - Creating actions_base and actions module
- PR #4526²⁷⁰³ - Shared state for cv
- PR #4525²⁷⁰⁴ - Changing sub-name sequencing for experimental namespace
- PR #4524²⁷⁰⁵ - Add API guarantee notes to API reference documentation
- PR #4522²⁷⁰⁶ - Enable and fix deprecation warnings in execution module
- PR #4521²⁷⁰⁷ - Moves more miscellaneous files to modules
- PR #4520²⁷⁰⁸ - Skip execution customization points when executor is known
- PR #4518²⁷⁰⁹ - Module distributed lcos
- PR #4516²⁷¹⁰ - Fix various builds
- PR #4515²⁷¹¹ - Replace backslashes by slashes in windows paths
- PR #4514²⁷¹² - Adding polymorphic_executor
- PR #4512²⁷¹³ - Adding C++20 jthread and stop_token
- PR #4510²⁷¹⁴ - Attempt to fix APEX linking in external packages again
- PR #4508²⁷¹⁵ - Only test pull requests (not all branches) with GitHub actions
- PR #4505²⁷¹⁶ - Fix duplicate linking in tests (ODR violations)

²⁶⁹⁴ <https://github.com/STELLAR-GROUP/hpx/pull/4538>

²⁶⁹⁵ <https://github.com/STELLAR-GROUP/hpx/pull/4536>

²⁶⁹⁶ <https://github.com/STELLAR-GROUP/hpx/pull/4534>

²⁶⁹⁷ <https://github.com/STELLAR-GROUP/hpx/pull/4532>

²⁶⁹⁸ <https://github.com/STELLAR-GROUP/hpx/pull/4531>

²⁶⁹⁹ <https://github.com/STELLAR-GROUP/hpx/pull/4530>

²⁷⁰⁰ <https://github.com/STELLAR-GROUP/hpx/pull/4529>

²⁷⁰¹ <https://github.com/STELLAR-GROUP/hpx/pull/4528>

²⁷⁰² <https://github.com/STELLAR-GROUP/hpx/pull/4527>

²⁷⁰³ <https://github.com/STELLAR-GROUP/hpx/pull/4526>

²⁷⁰⁴ <https://github.com/STELLAR-GROUP/hpx/pull/4525>

²⁷⁰⁵ <https://github.com/STELLAR-GROUP/hpx/pull/4524>

²⁷⁰⁶ <https://github.com/STELLAR-GROUP/hpx/pull/4522>

²⁷⁰⁷ <https://github.com/STELLAR-GROUP/hpx/pull/4521>

²⁷⁰⁸ <https://github.com/STELLAR-GROUP/hpx/pull/4520>

²⁷⁰⁹ <https://github.com/STELLAR-GROUP/hpx/pull/4518>

²⁷¹⁰ <https://github.com/STELLAR-GROUP/hpx/pull/4516>

²⁷¹¹ <https://github.com/STELLAR-GROUP/hpx/pull/4515>

²⁷¹² <https://github.com/STELLAR-GROUP/hpx/pull/4514>

²⁷¹³ <https://github.com/STELLAR-GROUP/hpx/pull/4512>

²⁷¹⁴ <https://github.com/STELLAR-GROUP/hpx/pull/4510>

²⁷¹⁵ <https://github.com/STELLAR-GROUP/hpx/pull/4508>

²⁷¹⁶ <https://github.com/STELLAR-GROUP/hpx/pull/4505>

- PR #4504²⁷¹⁷ - Fix C++ standard handling
- PR #4503²⁷¹⁸ - Add CMakeLists file check
- PR #4500²⁷¹⁹ - Fix .clang-format version requirement comment
- PR #4499²⁷²⁰ - Attempting to fix hpx_init linking on macOS
- PR #4498²⁷²¹ - Fix compatibility of *pool_executor*
- PR #4496²⁷²² - Removing superfluous SPDX tags
- PR #4494²⁷²³ - Module executors
- PR #4493²⁷²⁴ - Pack traversal module
- PR #4492²⁷²⁵ - Update copyright year in documentation
- PR #4491²⁷²⁶ - Add missing current_executor header
- PR #4490²⁷²⁷ - Update GitHub actions configs
- PR #4487²⁷²⁸ - Properly dispatch exceptions thrown from hpx_main to be rethrown from hpx::init/hpx::stop
- PR #4486²⁷²⁹ - Fixing an initialization order problem
- PR #4485²⁷³⁰ - Move miscellaneous files to their rightful modules
- PR #4483²⁷³¹ - Clean up imported CMake target naming
- PR #4481²⁷³² - Add vcpkg installation instructions
- PR #4479²⁷³³ - Add hints to allow to specify MIMALLOC_ROOT
- PR #4478²⁷³⁴ - Async modules
- PR #4475²⁷³⁵ - Fix rp init changes
- PR #4474²⁷³⁶ - Use #pragma once in headers
- PR #4472²⁷³⁷ - Add more descriptive error message when using x86 coroutines on non-x86 platforms
- PR #4467²⁷³⁸ - Add mimalloc find cmake script
- PR #4465²⁷³⁹ - Add thread_executors module

²⁷¹⁷ <https://github.com/STELLAR-GROUP/hpx/pull/4504>

²⁷¹⁸ <https://github.com/STELLAR-GROUP/hpx/pull/4503>

²⁷¹⁹ <https://github.com/STELLAR-GROUP/hpx/pull/4500>

²⁷²⁰ <https://github.com/STELLAR-GROUP/hpx/pull/4499>

²⁷²¹ <https://github.com/STELLAR-GROUP/hpx/pull/4498>

²⁷²² <https://github.com/STELLAR-GROUP/hpx/pull/4496>

²⁷²³ <https://github.com/STELLAR-GROUP/hpx/pull/4494>

²⁷²⁴ <https://github.com/STELLAR-GROUP/hpx/pull/4493>

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²⁷²⁸ <https://github.com/STELLAR-GROUP/hpx/pull/4487>

²⁷²⁹ <https://github.com/STELLAR-GROUP/hpx/pull/4486>

²⁷³⁰ <https://github.com/STELLAR-GROUP/hpx/pull/4485>

²⁷³¹ <https://github.com/STELLAR-GROUP/hpx/pull/4483>

²⁷³² <https://github.com/STELLAR-GROUP/hpx/pull/4481>

²⁷³³ <https://github.com/STELLAR-GROUP/hpx/pull/4479>

²⁷³⁴ <https://github.com/STELLAR-GROUP/hpx/pull/4478>

²⁷³⁵ <https://github.com/STELLAR-GROUP/hpx/pull/4475>

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²⁷³⁷ <https://github.com/STELLAR-GROUP/hpx/pull/4472>

²⁷³⁸ <https://github.com/STELLAR-GROUP/hpx/pull/4467>

²⁷³⁹ <https://github.com/STELLAR-GROUP/hpx/pull/4465>

- PR #4464²⁷⁴⁰ - Include module
- PR #4462²⁷⁴¹ - Merge hpx_init and hpx_wrap into one static library
- PR #4461²⁷⁴² - Making thread_data test more realistic
- PR #4460²⁷⁴³ - Suppress MPI warnings in version.cpp
- PR #4459²⁷⁴⁴ - Make sure pkgconfig applications link with hpx_init
- PR #4458²⁷⁴⁵ - Added example demonstrating how to create and use a wrapping executor
- PR #4457²⁷⁴⁶ - Fixing execution of thread exit functions
- PR #4456²⁷⁴⁷ - Move backtrace files to debugging module
- PR #4455²⁷⁴⁸ - Move deadlock_detection and maintain_queue_wait_times source files into schedulers module
- PR #4450²⁷⁴⁹ - Fixing compilation with std::filesystem enabled
- PR #4449²⁷⁵⁰ - Fixing build system to actually build variant test
- PR #4447²⁷⁵¹ - This fixes an obsolete #include
- PR #4446²⁷⁵² - Resume tasks where they were suspended
- PR #4444²⁷⁵³ - Minor CUDA fixes
- PR #4443²⁷⁵⁴ - Add missing tests to CircleCI config
- PR #4442²⁷⁵⁵ - Adding a tag to all auto-generated files allowing for tools to visually distinguish those
- PR #4441²⁷⁵⁶ - Adding performance counter type information
- PR #4440²⁷⁵⁷ - Fixing MSVC build
- PR #4439²⁷⁵⁸ - Link HPX::plugin and component privately in hpx_setup_target
- PR #4437²⁷⁵⁹ - Adding a test that verifies the problem can be solved using a trait specialization
- PR #4434²⁷⁶⁰ - Clean up Boost dependencies and copy string algorithms to new module
- PR #4433²⁷⁶¹ - Fixing compilation issues (!) if MPI parcelport is enabled
- PR #4431²⁷⁶² - Ignore warnings about name mangling changing

²⁷⁴⁰ <https://github.com/STELLAR-GROUP/hpx/pull/4464>

²⁷⁴¹ <https://github.com/STELLAR-GROUP/hpx/pull/4462>

²⁷⁴² <https://github.com/STELLAR-GROUP/hpx/pull/4461>

²⁷⁴³ <https://github.com/STELLAR-GROUP/hpx/pull/4460>

²⁷⁴⁴ <https://github.com/STELLAR-GROUP/hpx/pull/4459>

²⁷⁴⁵ <https://github.com/STELLAR-GROUP/hpx/pull/4458>

²⁷⁴⁶ <https://github.com/STELLAR-GROUP/hpx/pull/4457>

²⁷⁴⁷ <https://github.com/STELLAR-GROUP/hpx/pull/4456>

²⁷⁴⁸ <https://github.com/STELLAR-GROUP/hpx/pull/4455>

²⁷⁴⁹ <https://github.com/STELLAR-GROUP/hpx/pull/4450>

²⁷⁵⁰ <https://github.com/STELLAR-GROUP/hpx/pull/4449>

²⁷⁵¹ <https://github.com/STELLAR-GROUP/hpx/pull/4447>

²⁷⁵² <https://github.com/STELLAR-GROUP/hpx/pull/4446>

²⁷⁵³ <https://github.com/STELLAR-GROUP/hpx/pull/4444>

²⁷⁵⁴ <https://github.com/STELLAR-GROUP/hpx/pull/4443>

²⁷⁵⁵ <https://github.com/STELLAR-GROUP/hpx/pull/4442>

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²⁷⁵⁷ <https://github.com/STELLAR-GROUP/hpx/pull/4440>

²⁷⁵⁸ <https://github.com/STELLAR-GROUP/hpx/pull/4439>

²⁷⁵⁹ <https://github.com/STELLAR-GROUP/hpx/pull/4437>

²⁷⁶⁰ <https://github.com/STELLAR-GROUP/hpx/pull/4434>

²⁷⁶¹ <https://github.com/STELLAR-GROUP/hpx/pull/4433>

²⁷⁶² <https://github.com/STELLAR-GROUP/hpx/pull/4431>

- PR #4430²⁷⁶³ - Add performance_counters module
- PR #4428²⁷⁶⁴ - Don't add compatibility headers to module API reference
- PR #4426²⁷⁶⁵ - Add currently failing tests on GitHub actions to blacklist
- PR #4425²⁷⁶⁶ - Clean up and correct minimum required versions
- PR #4424²⁷⁶⁷ - Making sure hpx.lock_detection=0 works as advertized
- PR #4421²⁷⁶⁸ - Making sure interval time stops underlying timer thread on termination
- PR #4417²⁷⁶⁹ - Adding serialization support for std::variant (if available) and std::tuple
- PR #4415²⁷⁷⁰ - Partially reverting changes applied by PR 4373
- PR #4414²⁷⁷¹ - Added documentation for the compiler-wrapper script hpxcxx.in in creating_hpx_projects.rst
- PR #4413²⁷⁷² - Merging from V1.4.1 release
- PR #4412²⁷⁷³ - Making sure to issue a warning if a file specified using -hpx:options-file is not found
- PR #4411²⁷⁷⁴ - Make test specific to HPX_WITH_SHARED_PRIORITY_SCHEDULER
- PR #4407²⁷⁷⁵ - Adding minimal MPI executor
- PR #4405²⁷⁷⁶ - Fix cross pool injection test, use default scheduler as fallback
- PR #4404²⁷⁷⁷ - Fix a race condition and clean-up usage of scheduler mode
- PR #4399²⁷⁷⁸ - Add more threading modules
- PR #4398²⁷⁷⁹ - Add CODEOWNERS file
- PR #4395²⁷⁸⁰ - Adding a parameter to auto_chunk_size allowing to control the amount of iterations to measure
- PR #4393²⁷⁸¹ - Use appropriate cache-line size defaults for different platforms
- PR #4391²⁷⁸² - Fixing use of allocator for C++20
- PR #4390²⁷⁸³ - Making -hpx:help behavior consistent
- PR #4388²⁷⁸⁴ - Change the resource partitioner initialization
- PR #4387²⁷⁸⁵ - Fix roll_release.sh

²⁷⁶³ <https://github.com/STELLAR-GROUP/hpx/pull/4430>

²⁷⁶⁴ <https://github.com/STELLAR-GROUP/hpx/pull/4428>

²⁷⁶⁵ <https://github.com/STELLAR-GROUP/hpx/pull/4426>

²⁷⁶⁶ <https://github.com/STELLAR-GROUP/hpx/pull/4425>

²⁷⁶⁷ <https://github.com/STELLAR-GROUP/hpx/pull/4424>

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²⁷⁷⁰ <https://github.com/STELLAR-GROUP/hpx/pull/4415>

²⁷⁷¹ <https://github.com/STELLAR-GROUP/hpx/pull/4414>

²⁷⁷² <https://github.com/STELLAR-GROUP/hpx/pull/4413>

²⁷⁷³ <https://github.com/STELLAR-GROUP/hpx/pull/4412>

²⁷⁷⁴ <https://github.com/STELLAR-GROUP/hpx/pull/4411>

²⁷⁷⁵ <https://github.com/STELLAR-GROUP/hpx/pull/4407>

²⁷⁷⁶ <https://github.com/STELLAR-GROUP/hpx/pull/4405>

²⁷⁷⁷ <https://github.com/STELLAR-GROUP/hpx/pull/4404>

²⁷⁷⁸ <https://github.com/STELLAR-GROUP/hpx/pull/4399>

²⁷⁷⁹ <https://github.com/STELLAR-GROUP/hpx/pull/4398>

²⁷⁸⁰ <https://github.com/STELLAR-GROUP/hpx/pull/4395>

²⁷⁸¹ <https://github.com/STELLAR-GROUP/hpx/pull/4393>

²⁷⁸² <https://github.com/STELLAR-GROUP/hpx/pull/4391>

²⁷⁸³ <https://github.com/STELLAR-GROUP/hpx/pull/4390>

²⁷⁸⁴ <https://github.com/STELLAR-GROUP/hpx/pull/4388>

²⁷⁸⁵ <https://github.com/STELLAR-GROUP/hpx/pull/4387>

- PR #4386²⁷⁸⁶ - Add warning messages for using thread binding options on macOS
- PR #4385²⁷⁸⁷ - Cuda futures
- PR #4384²⁷⁸⁸ - Make enabling dynamic hpx_main on non-Linux systems a configuration error
- PR #4383²⁷⁸⁹ - Use configure_file for HPXCacheVariables.cmake
- PR #4382²⁷⁹⁰ - Update spellchecking whitelist and fix more typos
- PR #4380²⁷⁹¹ - Add a helper function to get a future from a cuda stream
- PR #4379²⁷⁹² - Add Windows and macOS CI with GitHub actions
- PR #4378²⁷⁹³ - Change C++ standard handling
- PR #4377²⁷⁹⁴ - Remove Python scripts
- PR #4374²⁷⁹⁵ - Adding overload for `hpx::init/hpx::start` for use with resource partitioner
- PR #4373²⁷⁹⁶ - Adding test that verifies for 4369 to be fixed
- PR #4372²⁷⁹⁷ - Another attempt at fixing the integral mismatch and conversion warnings
- PR #4370²⁷⁹⁸ - Doc updates quick start
- PR #4368²⁷⁹⁹ - Add a whitelist of words for weird spelling suggestions
- PR #4366²⁸⁰⁰ - Suppress or fix clang-tidy-9 warnings
- PR #4365²⁸⁰¹ - Removing more Boost dependencies
- PR #4363²⁸⁰² - Update clang-format config file for version 9
- PR #4362²⁸⁰³ - Fix indices typo
- PR #4361²⁸⁰⁴ - Boost cleanup
- PR #4360²⁸⁰⁵ - Move plugins
- PR #4358²⁸⁰⁶ - Doc updates; generating documentation. Will likely need heavy editing.
- PR #4356²⁸⁰⁷ - Remove some minor unused and unnecessary Boost includes
- PR #4355²⁸⁰⁸ - Fix spellcheck step in CircleCI config

²⁷⁸⁶ <https://github.com/STELLAR-GROUP/hpx/pull/4386>

²⁷⁸⁷ <https://github.com/STELLAR-GROUP/hpx/pull/4385>

²⁷⁸⁸ <https://github.com/STELLAR-GROUP/hpx/pull/4384>

²⁷⁸⁹ <https://github.com/STELLAR-GROUP/hpx/pull/4383>

²⁷⁹⁰ <https://github.com/STELLAR-GROUP/hpx/pull/4382>

²⁷⁹¹ <https://github.com/STELLAR-GROUP/hpx/pull/4380>

²⁷⁹² <https://github.com/STELLAR-GROUP/hpx/pull/4379>

²⁷⁹³ <https://github.com/STELLAR-GROUP/hpx/pull/4378>

²⁷⁹⁴ <https://github.com/STELLAR-GROUP/hpx/pull/4377>

²⁷⁹⁵ <https://github.com/STELLAR-GROUP/hpx/pull/4374>

²⁷⁹⁶ <https://github.com/STELLAR-GROUP/hpx/pull/4373>

²⁷⁹⁷ <https://github.com/STELLAR-GROUP/hpx/pull/4372>

²⁷⁹⁸ <https://github.com/STELLAR-GROUP/hpx/pull/4370>

²⁷⁹⁹ <https://github.com/STELLAR-GROUP/hpx/pull/4368>

²⁸⁰⁰ <https://github.com/STELLAR-GROUP/hpx/pull/4366>

²⁸⁰¹ <https://github.com/STELLAR-GROUP/hpx/pull/4365>

²⁸⁰² <https://github.com/STELLAR-GROUP/hpx/pull/4363>

²⁸⁰³ <https://github.com/STELLAR-GROUP/hpx/pull/4362>

²⁸⁰⁴ <https://github.com/STELLAR-GROUP/hpx/pull/4361>

²⁸⁰⁵ <https://github.com/STELLAR-GROUP/hpx/pull/4360>

²⁸⁰⁶ <https://github.com/STELLAR-GROUP/hpx/pull/4358>

²⁸⁰⁷ <https://github.com/STELLAR-GROUP/hpx/pull/4356>

²⁸⁰⁸ <https://github.com/STELLAR-GROUP/hpx/pull/4355>

- PR #4354²⁸⁰⁹ - Lightweight utility to hold a pack as members
- PR #4352²⁸¹⁰ - Minor fixes to the C++ standard detection for MSVC
- PR #4351²⁸¹¹ - Move generated documentation to hpx-docs repo
- PR #4347²⁸¹² - Add cmake policy - CMP0074
- PR #4346²⁸¹³ - Remove file committed by mistake
- PR #4342²⁸¹⁴ - Remove HCC and SYCL options from CMakeLists.txt
- PR #4341²⁸¹⁵ - Fix launch process test with APEX enabled
- PR #4340²⁸¹⁶ - Testing Cirrus CI
- PR #4339²⁸¹⁷ - Post 1.4.0 updates
- PR #4338²⁸¹⁸ - Spelling corrections and CircleCI spell check
- PR #4333²⁸¹⁹ - Flatten bound callables
- PR #4332²⁸²⁰ - This is a collection of mostly minor (cleanup) fixes
- PR #4331²⁸²¹ - This adds the missing tests for `async_colocated` and `async_continue_colocated`
- PR #4330²⁸²² - Remove `HPX.Compute` host default_executor
- PR #4328²⁸²³ - Generate global header for `basic_execution` module
- PR #4327²⁸²⁴ - Use `INTERNAL_FLAGS` option for all examples and components
- PR #4326²⁸²⁵ - Usage of temporary allocator in assignment operator of `compute::vector`
- PR #4325²⁸²⁶ - Use `hpx::threads::get_cache_line_size` in `prefetching.hpp`
- PR #4324²⁸²⁷ - Enable compatibility headers option for execution module
- PR #4316²⁸²⁸ - Add clang format indentppdirectives
- PR #4313²⁸²⁹ - Introduce `index_pack` alias to pack of `size_t`
- PR #4312²⁸³⁰ - Fixing compatibility header for `pack.hpp`
- PR #4311²⁸³¹ - Dataflow annotations for APEX

²⁸⁰⁹ <https://github.com/STELLAR-GROUP/hpx/pull/4354>

²⁸¹⁰ <https://github.com/STELLAR-GROUP/hpx/pull/4352>

²⁸¹¹ <https://github.com/STELLAR-GROUP/hpx/pull/4351>

²⁸¹² <https://github.com/STELLAR-GROUP/hpx/pull/4347>

²⁸¹³ <https://github.com/STELLAR-GROUP/hpx/pull/4346>

²⁸¹⁴ <https://github.com/STELLAR-GROUP/hpx/pull/4342>

²⁸¹⁵ <https://github.com/STELLAR-GROUP/hpx/pull/4341>

²⁸¹⁶ <https://github.com/STELLAR-GROUP/hpx/pull/4340>

²⁸¹⁷ <https://github.com/STELLAR-GROUP/hpx/pull/4339>

²⁸¹⁸ <https://github.com/STELLAR-GROUP/hpx/pull/4338>

²⁸¹⁹ <https://github.com/STELLAR-GROUP/hpx/pull/4333>

²⁸²⁰ <https://github.com/STELLAR-GROUP/hpx/pull/4332>

²⁸²¹ <https://github.com/STELLAR-GROUP/hpx/pull/4331>

²⁸²² <https://github.com/STELLAR-GROUP/hpx/pull/4330>

²⁸²³ <https://github.com/STELLAR-GROUP/hpx/pull/4328>

²⁸²⁴ <https://github.com/STELLAR-GROUP/hpx/pull/4327>

²⁸²⁵ <https://github.com/STELLAR-GROUP/hpx/pull/4326>

²⁸²⁶ <https://github.com/STELLAR-GROUP/hpx/pull/4325>

²⁸²⁷ <https://github.com/STELLAR-GROUP/hpx/pull/4324>

²⁸²⁸ <https://github.com/STELLAR-GROUP/hpx/pull/4316>

²⁸²⁹ <https://github.com/STELLAR-GROUP/hpx/pull/4313>

²⁸³⁰ <https://github.com/STELLAR-GROUP/hpx/pull/4312>

²⁸³¹ <https://github.com/STELLAR-GROUP/hpx/pull/4311>

- PR #4309²⁸³² - Update launching_and_configuring_hpx_applications.rst
- PR #4306²⁸³³ - Fix schedule hint not being taken from executor
- PR #4305²⁸³⁴ - Implementing *hpx::functional::tag_invoke*
- PR #4304²⁸³⁵ - Improve pack support utilities
- PR #4303²⁸³⁶ - Remove errors module dependency on datastructures
- PR #4301²⁸³⁷ - Clean up thread executors
- PR #4294²⁸³⁸ - Logging revamp
- PR #4292²⁸³⁹ - Remove SPDX tag from Boost License file to allow for github to recognize it
- PR #4291²⁸⁴⁰ - Add format support for std::tm
- PR #4290²⁸⁴¹ - Simplify compatible tuples check
- PR #4288²⁸⁴² - A lightweight take on boost::lexical_cast
- PR #4287²⁸⁴³ - Forking boost::lexical_cast as a new module
- PR #4277²⁸⁴⁴ - MPI_futures
- PR #4270²⁸⁴⁵ - Refactor future implementation
- PR #4265²⁸⁴⁶ - Threading module
- PR #4259²⁸⁴⁷ - Module naming base
- PR #4251²⁸⁴⁸ - Local workrequesting scheduler
- PR #4250²⁸⁴⁹ - Inline execution of scoped tasks, if possible
- PR #4247²⁸⁵⁰ - Add execution in module headers
- PR #4246²⁸⁵¹ - Expose CMake targets officially
- PR #4239²⁸⁵² - Doc updates miscellaneous (partially completed during Google Season of Docs)
- PR #4233²⁸⁵³ - Remove project() from modules + fix CMAKE_SOURCE_DIR issue
- PR #4231²⁸⁵⁴ - Module local lcos

²⁸³² <https://github.com/STELLAR-GROUP/hpx/pull/4309>

²⁸³³ <https://github.com/STELLAR-GROUP/hpx/pull/4306>

²⁸³⁴ <https://github.com/STELLAR-GROUP/hpx/pull/4305>

²⁸³⁵ <https://github.com/STELLAR-GROUP/hpx/pull/4304>

²⁸³⁶ <https://github.com/STELLAR-GROUP/hpx/pull/4303>

²⁸³⁷ <https://github.com/STELLAR-GROUP/hpx/pull/4301>

²⁸³⁸ <https://github.com/STELLAR-GROUP/hpx/pull/4294>

²⁸³⁹ <https://github.com/STELLAR-GROUP/hpx/pull/4292>

²⁸⁴⁰ <https://github.com/STELLAR-GROUP/hpx/pull/4291>

²⁸⁴¹ <https://github.com/STELLAR-GROUP/hpx/pull/4290>

²⁸⁴² <https://github.com/STELLAR-GROUP/hpx/pull/4288>

²⁸⁴³ <https://github.com/STELLAR-GROUP/hpx/pull/4287>

²⁸⁴⁴ <https://github.com/STELLAR-GROUP/hpx/pull/4277>

²⁸⁴⁵ <https://github.com/STELLAR-GROUP/hpx/pull/4270>

²⁸⁴⁶ <https://github.com/STELLAR-GROUP/hpx/pull/4265>

²⁸⁴⁷ <https://github.com/STELLAR-GROUP/hpx/pull/4259>

²⁸⁴⁸ <https://github.com/STELLAR-GROUP/hpx/pull/4251>

²⁸⁴⁹ <https://github.com/STELLAR-GROUP/hpx/pull/4250>

²⁸⁵⁰ <https://github.com/STELLAR-GROUP/hpx/pull/4247>

²⁸⁵¹ <https://github.com/STELLAR-GROUP/hpx/pull/4246>

²⁸⁵² <https://github.com/STELLAR-GROUP/hpx/pull/4239>

²⁸⁵³ <https://github.com/STELLAR-GROUP/hpx/pull/4233>

²⁸⁵⁴ <https://github.com/STELLAR-GROUP/hpx/pull/4231>

- PR #4207²⁸⁵⁵ - Command line handling module
- PR #4206²⁸⁵⁶ - Runtime configuration module
- PR #4141²⁸⁵⁷ - Doc updates examples local to remote (partially completed during Google Season of Docs)
- PR #4091²⁸⁵⁸ - Split runtime into local and distributed parts
- PR #4017²⁸⁵⁹ - Require C++14

HPX V1.4.1 (Feb 12, 2020)

General changes

This is a bugfix release. It contains the following changes:

- Fix compilation issues on Windows, macOS, FreeBSD, and with gcc 10
- Install missing pdb files on Windows
- Allow running tests using an installed version of *HPX*
- Skip MPI finalization if HPX has not initialized MPI
- Give a hard error when attempting to use IO counters on Windows

Closed issues

- Issue #4320²⁸⁶⁰ - HPX 1.4.0 does not compile with gcc 10
- Issue #4336²⁸⁶¹ - Building HPX 1.4.0 with IO Counters breaks (Windows)
- Issue #4334²⁸⁶² - HPX Debug and RelWithDebinfo builds on Windows not installing .pdb files
- Issue #4322²⁸⁶³ - Undefine VT1 and VT2 after boost includes
- Issue #4314²⁸⁶⁴ - Compile error on 1.4.0
- Issue #4307²⁸⁶⁵ - ld: error: duplicate symbol: freebsd_environ

²⁸⁵⁵ <https://github.com/STELLAR-GROUP/hpx/pull/4207>

²⁸⁵⁶ <https://github.com/STELLAR-GROUP/hpx/pull/4206>

²⁸⁵⁷ <https://github.com/STELLAR-GROUP/hpx/pull/4141>

²⁸⁵⁸ <https://github.com/STELLAR-GROUP/hpx/pull/4091>

²⁸⁵⁹ <https://github.com/STELLAR-GROUP/hpx/pull/4017>

²⁸⁶⁰ <https://github.com/STELLAR-GROUP/hpx/issues/4320>

²⁸⁶¹ <https://github.com/STELLAR-GROUP/hpx/issues/4336>

²⁸⁶² <https://github.com/STELLAR-GROUP/hpx/issues/4334>

²⁸⁶³ <https://github.com/STELLAR-GROUP/hpx/issues/4322>

²⁸⁶⁴ <https://github.com/STELLAR-GROUP/hpx/issues/4314>

²⁸⁶⁵ <https://github.com/STELLAR-GROUP/hpx/issues/4307>

Closed pull requests

- PR #4376²⁸⁶⁶ - Attempt to fix some test build errors on Windows
- PR #4357²⁸⁶⁷ - Adding missing `#includes` to fix gcc V10 linker problems
- PR #4353²⁸⁶⁸ - Skip `MPI_Finalize` if `MPI_Init` is not called from HPX
- PR #4343²⁸⁶⁹ - Give a hard error if IO counters are enabled on non-Linux systems
- PR #4337²⁸⁷⁰ - Installing `pdb` files on Windows
- PR #4335²⁸⁷¹ - Adding capability to `buildsystem` to use an installed version of HPX
- PR #4315²⁸⁷² - Forcing exported symbols from `composable_guard` to be linked into core library
- PR #4310²⁸⁷³ - Remove environment handling from `exception.cpp`

HPX V1.4.0 (January 15, 2020)

General changes

- We have added the collectives `all_to_all` and `all_reduce`.
- We have added APIs for resiliency, which allows replication and replay for failed tasks. See the *documentation* for more details.
- Components can now be checkpointed.
- Performance improvements to schedulers and coroutines. A significant change is the addition of stackless coroutines. These are to be used for tasks that do not need to be suspended and can reduce overheads noticeably in applications with short tasks. A stackless coroutine can be created with the new `stack_size` `thread_stacksize_nostack`.
- We have added an implementation of `unique_any`, which is a non-copyable version of `any`.
- The `shared_priority_queue_scheduler` has been improved. It now has lower overheads than the default scheduler in many situations. Unlike the default scheduler it fully supports NUMA scheduling hints. Enable it with the command line option `--hpx:queuing=shared-priority`. This scheduler should still be considered experimental, but its use is encouraged in real applications to help us make it production ready.
- We have added the performance counters `background-receive-duration` and `background-receive-overhead` for inspecting the time and overhead spent on receiving parcels in the background.
- Compilation time has been further improved when `HPX_WITH_NETWORKING=OFF`.
- We no longer require compiled Boost dependencies in certain configurations. This requires at least Boost 1.70, compiling on x86 with GCC 9, clang (libc++) 9, or VS2019 in C++17 mode. The dependency on `Boost.Filesystem` can explicitly be turned on with `HPX_FILESYSTEM_WITH_BOOST_FILESYSTEM_COMPATIBILITY=ON` (it is off by default if the standard library supports `std::filesystem`). `Boost.ProgramOptions` has been copied into the HPX repository. We have a compatibility layer for users who must explicitly use

²⁸⁶⁶ <https://github.com/STELLAR-GROUP/hpx/pull/4376>

²⁸⁶⁷ <https://github.com/STELLAR-GROUP/hpx/pull/4357>

²⁸⁶⁸ <https://github.com/STELLAR-GROUP/hpx/pull/4353>

²⁸⁶⁹ <https://github.com/STELLAR-GROUP/hpx/pull/4343>

²⁸⁷⁰ <https://github.com/STELLAR-GROUP/hpx/pull/4337>

²⁸⁷¹ <https://github.com/STELLAR-GROUP/hpx/pull/4335>

²⁸⁷² <https://github.com/STELLAR-GROUP/hpx/pull/4315>

²⁸⁷³ <https://github.com/STELLAR-GROUP/hpx/pull/4310>

Boost.ProgramOptions instead of the ProgramOptions provided by HPX. To remove the dependency HPX_PROGRAM_OPTIONS_WITH_BOOST_PROGRAM_OPTIONS_COMPATIBILITY must be explicitly set to OFF. This option will be removed in a future release. We have also removed several other header-only dependencies on Boost.

- It is now possible to use the process affinity mask set by tools like `numactl` and various batch environments with the command line option `--hpx:use-process-mask`. Enabling this option implies `--hpx:ignore-batch-env`.
- It is now possible to create standalone thread pools without starting the runtime. See the `standalone_thread_pool_executor.cpp` test in the `execution` module for an example.
- Tasks annotated with `hpx::util::annotated_function` now have their correct name when using APEX to generate OTF2 files.
- Cloning of APEX was defective in previous releases (it required manual intervention to check out the correct tag or branch). This has been fixed.
- The option `HPX_WITH_MORE_THAN_64_THREADS` is now ignored and will be removed in a future release. The value is instead derived directly from `HPX_WITH_MAX_CPU_COUNT` option.
- We have deprecated compiling in C++11 mode. The next release will require a C++14 capable compiler.
- We have deprecated support for the `Vc` library. This option will be replaced with SIMD support from the standard library in a future release.
- We have significantly refactored our CMake setup. This is intended to be a non-breaking change and will allow for using HPX through CMake targets in the future.
- We have continued modularizing the HPX library. In the process we have rearranged many header files into module-specific directories. All moved headers have compatibility headers which forward from the old location to the new location, together with a deprecation warning. The compatibility headers will eventually be removed.
- We now enforce formatting with `clang-format` on the majority of our source files.
- We have added SPDX license tags to all files.
- Many bugfixes.

Breaking changes

- The `HPX_WITH_THREAD_COMPATIBILITY` option and the associated compatibility layer has been removed.
- The `HPX_WITH_INCLUSIVE_SCAN_COMPATIBILITY` option and the associated compatibility layer has been removed.
- The `HPX_WITH_UNWRAPPED_COMPATIBILITY` option and the associated compatibility layer has been removed.

Closed issues

- [Issue #4282²⁸⁷⁴](https://github.com/STELLAR-GROUP/hpx/issues/4282) - Build Issues with Release on Windows
- [Issue #4278²⁸⁷⁵](https://github.com/STELLAR-GROUP/hpx/issues/4278) - Build Issues with CMake 3.14.4
- [Issue #4273²⁸⁷⁶](https://github.com/STELLAR-GROUP/hpx/issues/4273) - Clients of HPX 1.4.0-rc2 with APEX are not linked to `libhpx-apex`
- [Issue #4269²⁸⁷⁷](https://github.com/STELLAR-GROUP/hpx/issues/4269) - Building HPX 1.4.0-rc2 with support for APEX fails

²⁸⁷⁴ <https://github.com/STELLAR-GROUP/hpx/issues/4282>

²⁸⁷⁵ <https://github.com/STELLAR-GROUP/hpx/issues/4278>

²⁸⁷⁶ <https://github.com/STELLAR-GROUP/hpx/issues/4273>

²⁸⁷⁷ <https://github.com/STELLAR-GROUP/hpx/issues/4269>

- [Issue #4263²⁸⁷⁸](#) - Compilation fail on latest master
- [Issue #4232²⁸⁷⁹](#) - Configure of HPX project using CMake FetchContent fails
- [Issue #4223²⁸⁸⁰](#) - “Re-using the main() function as the main HPX entry point” doesn’t work
- [Issue #4220²⁸⁸¹](#) - HPX won’t compile - error building resource_partitioner
- [Issue #4215²⁸⁸²](#) - HPX 1.4.0rc1 does not link on s390x
- [Issue #4204²⁸⁸³](#) - Trouble compiling HPX with Intel compiler
- [Issue #4199²⁸⁸⁴](#) - Refactor APEX to eliminate circular dependency
- [Issue #4187²⁸⁸⁵](#) - HPX can’t build on OSX
- [Issue #4185²⁸⁸⁶](#) - Simple debug output for development
- [Issue #4182²⁸⁸⁷](#) - @HPX_CONF_PREFIX@ is the empty string
- [Issue #4169²⁸⁸⁸](#) - HPX won’t build with APEX
- [Issue #4163²⁸⁸⁹](#) - Add back HPX_LIBRARIES and HPX_INCLUDE_DIRS
- [Issue #4161²⁸⁹⁰](#) - It should be possible to call find_package(HPX) multiple times
- [Issue #4155²⁸⁹¹](#) - get_self_id() for stackless threads returns invalid_thread_id
- [Issue #4151²⁸⁹²](#) - build error with MPI code
- [Issue #4150²⁸⁹³](#) - hpx won’t build on POWER9 with clang 8
- [Issue #4148²⁸⁹⁴](#) - cacheline_data delivers poor performance with C++17 compared to C++14
- [Issue #4144²⁸⁹⁵](#) - target general in HPX_LIBRARIES does not exist
- [Issue #4134²⁸⁹⁶](#) - CMake Error when -DHPX_WITH_HPXP=ON
- [Issue #4132²⁸⁹⁷](#) - parallel fill leaves elements unfilled
- [Issue #4123²⁸⁹⁸](#) - PAPI performance counters are inaccessible
- [Issue #4118²⁸⁹⁹](#) - static_chunk_size is not obeyed in scan algorithms
- [Issue #4115²⁹⁰⁰](#) - dependency chaining error with APEX

²⁸⁷⁸ <https://github.com/STELLAR-GROUP/hpx/issues/4263>

²⁸⁷⁹ <https://github.com/STELLAR-GROUP/hpx/issues/4232>

²⁸⁸⁰ <https://github.com/STELLAR-GROUP/hpx/issues/4223>

²⁸⁸¹ <https://github.com/STELLAR-GROUP/hpx/issues/4220>

²⁸⁸² <https://github.com/STELLAR-GROUP/hpx/issues/4215>

²⁸⁸³ <https://github.com/STELLAR-GROUP/hpx/issues/4204>

²⁸⁸⁴ <https://github.com/STELLAR-GROUP/hpx/issues/4199>

²⁸⁸⁵ <https://github.com/STELLAR-GROUP/hpx/issues/4187>

²⁸⁸⁶ <https://github.com/STELLAR-GROUP/hpx/issues/4185>

²⁸⁸⁷ <https://github.com/STELLAR-GROUP/hpx/issues/4182>

²⁸⁸⁸ <https://github.com/STELLAR-GROUP/hpx/issues/4169>

²⁸⁸⁹ <https://github.com/STELLAR-GROUP/hpx/issues/4163>

²⁸⁹⁰ <https://github.com/STELLAR-GROUP/hpx/issues/4161>

²⁸⁹¹ <https://github.com/STELLAR-GROUP/hpx/issues/4155>

²⁸⁹² <https://github.com/STELLAR-GROUP/hpx/issues/4151>

²⁸⁹³ <https://github.com/STELLAR-GROUP/hpx/issues/4150>

²⁸⁹⁴ <https://github.com/STELLAR-GROUP/hpx/issues/4148>

²⁸⁹⁵ <https://github.com/STELLAR-GROUP/hpx/issues/4144>

²⁸⁹⁶ <https://github.com/STELLAR-GROUP/hpx/issues/4134>

²⁸⁹⁷ <https://github.com/STELLAR-GROUP/hpx/issues/4132>

²⁸⁹⁸ <https://github.com/STELLAR-GROUP/hpx/issues/4123>

²⁸⁹⁹ <https://github.com/STELLAR-GROUP/hpx/issues/4118>

²⁹⁰⁰ <https://github.com/STELLAR-GROUP/hpx/issues/4115>

- [Issue #4107²⁹⁰¹](#) - Initializing runtime without entry point function and command line arguments
- [Issue #4105²⁹⁰²](#) - Bug in `hpx:bind=numa-balanced`
- [Issue #4101²⁹⁰³](#) - Bound tasks
- [Issue #4100²⁹⁰⁴](#) - Add SPDX identifier to all files
- [Issue #4085²⁹⁰⁵](#) - `hpx_topology` library should depend on `hwloc`
- [Issue #4067²⁹⁰⁶](#) - HPX fails to build on macOS
- [Issue #4056²⁹⁰⁷](#) - Building without thread manager idle backoff fails
- [Issue #4052²⁹⁰⁸](#) - Enforce `clang-format` style for modules
- [Issue #4032²⁹⁰⁹](#) - Simple hello world fails to launch correctly
- [Issue #4030²⁹¹⁰](#) - Allow threads to skip context switching
- [Issue #4029²⁹¹¹](#) - Add support for `mimalloc`
- [Issue #4005²⁹¹²](#) - Can't link HPX when APEX enabled
- [Issue #4002²⁹¹³](#) - Missing header for algorithm module
- [Issue #3989²⁹¹⁴](#) - conversion from `long` to `unsigned int` requires a narrowing conversion on MSVC
- [Issue #3958²⁹¹⁵](#) - `/statistics/average@` perf counter can't be created
- [Issue #3953²⁹¹⁶](#) - CMake errors from `HPX_AddPseudoDependencies`
- [Issue #3941²⁹¹⁷](#) - CMake error for APEX install target
- [Issue #3940²⁹¹⁸](#) - Convert pseudo-doxygen function documentation into actual doxygen documentation
- [Issue #3935²⁹¹⁹](#) - HPX compiler match too strict?
- [Issue #3929²⁹²⁰](#) - Buildbot failures on latest HPX stable
- [Issue #3912²⁹²¹](#) - I recommend publishing a version that does not depend on the boost library
- [Issue #3890²⁹²²](#) - `hpx.ini` not working
- [Issue #3883²⁹²³](#) - cuda compilation fails because of `-faligned-new`

²⁹⁰¹ <https://github.com/STELLAR-GROUP/hpx/issues/4107>

²⁹⁰² <https://github.com/STELLAR-GROUP/hpx/issues/4105>

²⁹⁰³ <https://github.com/STELLAR-GROUP/hpx/issues/4101>

²⁹⁰⁴ <https://github.com/STELLAR-GROUP/hpx/issues/4100>

²⁹⁰⁵ <https://github.com/STELLAR-GROUP/hpx/issues/4085>

²⁹⁰⁶ <https://github.com/STELLAR-GROUP/hpx/issues/4067>

²⁹⁰⁷ <https://github.com/STELLAR-GROUP/hpx/issues/4056>

²⁹⁰⁸ <https://github.com/STELLAR-GROUP/hpx/issues/4052>

²⁹⁰⁹ <https://github.com/STELLAR-GROUP/hpx/issues/4032>

²⁹¹⁰ <https://github.com/STELLAR-GROUP/hpx/issues/4030>

²⁹¹¹ <https://github.com/STELLAR-GROUP/hpx/issues/4029>

²⁹¹² <https://github.com/STELLAR-GROUP/hpx/issues/4005>

²⁹¹³ <https://github.com/STELLAR-GROUP/hpx/issues/4002>

²⁹¹⁴ <https://github.com/STELLAR-GROUP/hpx/issues/3989>

²⁹¹⁵ <https://github.com/STELLAR-GROUP/hpx/issues/3958>

²⁹¹⁶ <https://github.com/STELLAR-GROUP/hpx/issues/3953>

²⁹¹⁷ <https://github.com/STELLAR-GROUP/hpx/issues/3941>

²⁹¹⁸ <https://github.com/STELLAR-GROUP/hpx/issues/3940>

²⁹¹⁹ <https://github.com/STELLAR-GROUP/hpx/issues/3935>

²⁹²⁰ <https://github.com/STELLAR-GROUP/hpx/issues/3929>

²⁹²¹ <https://github.com/STELLAR-GROUP/hpx/issues/3912>

²⁹²² <https://github.com/STELLAR-GROUP/hpx/issues/3890>

²⁹²³ <https://github.com/STELLAR-GROUP/hpx/issues/3883>

- Issue #3879²⁹²⁴ - HPX fails to configure with `-DHPX_WITH_TESTS=OFF`
- Issue #3871²⁹²⁵ - `dataflow` does not support void allocators
- Issue #3867²⁹²⁶ - Latest HTML docs placed in wrong directory on GitHub pages
- Issue #3866²⁹²⁷ - Make sure all tests use `HPX_TEST*` macros and not `HPX_ASSERT`
- Issue #3857²⁹²⁸ - CMake all-keyword or all-plain for `target_link_libraries`
- Issue #3856²⁹²⁹ - `hpx_setup_target` adds rogue flags
- Issue #3850²⁹³⁰ - HPX fails to build on POWER8 with Clang7
- Issue #3848²⁹³¹ - Remove `lva` member from `thread_init_data`
- Issue #3838²⁹³² - `hpx::parallel::count/count_if` failing tests
- Issue #3651²⁹³³ - `hpx::parallel::transform_reduce` with non const reference as lambda parameter
- Issue #3560²⁹³⁴ - Apex integration with HPX not working properly
- Issue #3322²⁹³⁵ - No warning when mixing debug/release builds

Closed pull requests

- PR #4300²⁹³⁶ - Checks for `MPI_Init` being called twice
- PR #4299²⁹³⁷ - Small CMake fixes
- PR #4298²⁹³⁸ - Remove extra call to annotate function that messes up traces
- PR #4296²⁹³⁹ - Fixing collectives locking problem
- PR #4295²⁹⁴⁰ - Do not check `LICENSE_1_0.txt` for inspect violations
- PR #4293²⁹⁴¹ - Applying two small changes fixing carious MSVC/Windows problems
- PR #4285²⁹⁴² - Delete `apex.hpp`
- PR #4276²⁹⁴³ - Disable doxygen generation for `hpx/debugging/print.hpp` file
- PR #4275²⁹⁴⁴ - Make sure APEX is linked to even when not explicitly referenced
- PR #4272²⁹⁴⁵ - Fix pushing of documentation

²⁹²⁴ <https://github.com/STELLAR-GROUP/hpx/issues/3879>

²⁹²⁵ <https://github.com/STELLAR-GROUP/hpx/issues/3871>

²⁹²⁶ <https://github.com/STELLAR-GROUP/hpx/issues/3867>

²⁹²⁷ <https://github.com/STELLAR-GROUP/hpx/issues/3866>

²⁹²⁸ <https://github.com/STELLAR-GROUP/hpx/issues/3857>

²⁹²⁹ <https://github.com/STELLAR-GROUP/hpx/issues/3856>

²⁹³⁰ <https://github.com/STELLAR-GROUP/hpx/issues/3850>

²⁹³¹ <https://github.com/STELLAR-GROUP/hpx/issues/3848>

²⁹³² <https://github.com/STELLAR-GROUP/hpx/issues/3838>

²⁹³³ <https://github.com/STELLAR-GROUP/hpx/issues/3651>

²⁹³⁴ <https://github.com/STELLAR-GROUP/hpx/issues/3560>

²⁹³⁵ <https://github.com/STELLAR-GROUP/hpx/issues/3322>

²⁹³⁶ <https://github.com/STELLAR-GROUP/hpx/pull/4300>

²⁹³⁷ <https://github.com/STELLAR-GROUP/hpx/pull/4299>

²⁹³⁸ <https://github.com/STELLAR-GROUP/hpx/pull/4298>

²⁹³⁹ <https://github.com/STELLAR-GROUP/hpx/pull/4296>

²⁹⁴⁰ <https://github.com/STELLAR-GROUP/hpx/pull/4295>

²⁹⁴¹ <https://github.com/STELLAR-GROUP/hpx/pull/4293>

²⁹⁴² <https://github.com/STELLAR-GROUP/hpx/pull/4285>

²⁹⁴³ <https://github.com/STELLAR-GROUP/hpx/pull/4276>

²⁹⁴⁴ <https://github.com/STELLAR-GROUP/hpx/pull/4275>

²⁹⁴⁵ <https://github.com/STELLAR-GROUP/hpx/pull/4272>

- PR #4271²⁹⁴⁶ - Updating APEX tag, don't create new task_wrapper on operator= of hpx_thread object
- PR #4268²⁹⁴⁷ - Testing for noexcept function specializations in C++11/14 mode
- PR #4267²⁹⁴⁸ - Fixing MSVC warning
- PR #4266²⁹⁴⁹ - Make sure macOS Travis CI fails if build step fails
- PR #4264²⁹⁵⁰ - Clean up compatibility header options
- PR #4262²⁹⁵¹ - Cleanup modules CMakeLists.txt
- PR #4261²⁹⁵² - Fixing HPX/APEX linking and dependencies for external projects like Phylanx
- PR #4260²⁹⁵³ - Fix docs compilation problems
- PR #4258²⁹⁵⁴ - Couple of minor changes
- PR #4257²⁹⁵⁵ - Fix apex annotation for async dispatch
- PR #4256²⁹⁵⁶ - Remove lambdas from assert expressions
- PR #4255²⁹⁵⁷ - Ignoring lock in all_to_all and all_reduce
- PR #4254²⁹⁵⁸ - Adding action specializations for noexcept functions
- PR #4253²⁹⁵⁹ - Move partlit.hpp to affinity module
- PR #4252²⁹⁶⁰ - Make mismatching build types a hard error in CMake
- PR #4249²⁹⁶¹ - Scheduler improvement
- PR #4248²⁹⁶² - update hpxmp tag to v0.3.0
- PR #4245²⁹⁶³ - Adding high performance channels
- PR #4244²⁹⁶⁴ - Ignore lock in ignore_while_locked_1485 test
- PR #4243²⁹⁶⁵ - Fix PAPI command line option documentation
- PR #4242²⁹⁶⁶ - Ignore lock in target_distribution_policy
- PR #4241²⁹⁶⁷ - Fix start_stop_callbacks test
- PR #4240²⁹⁶⁸ - Mostly fix clang CUDA compilation

²⁹⁴⁶ <https://github.com/STELLAR-GROUP/hpx/pull/4271>

²⁹⁴⁷ <https://github.com/STELLAR-GROUP/hpx/pull/4268>

²⁹⁴⁸ <https://github.com/STELLAR-GROUP/hpx/pull/4267>

²⁹⁴⁹ <https://github.com/STELLAR-GROUP/hpx/pull/4266>

²⁹⁵⁰ <https://github.com/STELLAR-GROUP/hpx/pull/4264>

²⁹⁵¹ <https://github.com/STELLAR-GROUP/hpx/pull/4262>

²⁹⁵² <https://github.com/STELLAR-GROUP/hpx/pull/4261>

²⁹⁵³ <https://github.com/STELLAR-GROUP/hpx/pull/4260>

²⁹⁵⁴ <https://github.com/STELLAR-GROUP/hpx/pull/4258>

²⁹⁵⁵ <https://github.com/STELLAR-GROUP/hpx/pull/4257>

²⁹⁵⁶ <https://github.com/STELLAR-GROUP/hpx/pull/4256>

²⁹⁵⁷ <https://github.com/STELLAR-GROUP/hpx/pull/4255>

²⁹⁵⁸ <https://github.com/STELLAR-GROUP/hpx/pull/4254>

²⁹⁵⁹ <https://github.com/STELLAR-GROUP/hpx/pull/4253>

²⁹⁶⁰ <https://github.com/STELLAR-GROUP/hpx/pull/4252>

²⁹⁶¹ <https://github.com/STELLAR-GROUP/hpx/pull/4249>

²⁹⁶² <https://github.com/STELLAR-GROUP/hpx/pull/4248>

²⁹⁶³ <https://github.com/STELLAR-GROUP/hpx/pull/4245>

²⁹⁶⁴ <https://github.com/STELLAR-GROUP/hpx/pull/4244>

²⁹⁶⁵ <https://github.com/STELLAR-GROUP/hpx/pull/4243>

²⁹⁶⁶ <https://github.com/STELLAR-GROUP/hpx/pull/4242>

²⁹⁶⁷ <https://github.com/STELLAR-GROUP/hpx/pull/4241>

²⁹⁶⁸ <https://github.com/STELLAR-GROUP/hpx/pull/4240>

- PR #4238²⁹⁶⁹ - Google Season of Docs updates to documentation; grammar edits.
- PR #4237²⁹⁷⁰ - fixing annotated task to use the name, not the desc
- PR #4236²⁹⁷¹ - Move module print summary to modules
- PR #4235²⁹⁷² - Don't use alignas in cache_{aligned,line}_data
- PR #4234²⁹⁷³ - Add basic overview sentence to all modules
- PR #4230²⁹⁷⁴ - Add OS X builds to Travis CI
- PR #4229²⁹⁷⁵ - Remove leftover queue compatibility checks
- PR #4226²⁹⁷⁶ - Fixing APEX shutdown by explicitly shutting down throttling
- PR #4225²⁹⁷⁷ - Allow CMAKE_INSTALL_PREFIX to be a relative path
- PR #4224²⁹⁷⁸ - Deprecate verbs parcelport
- PR #4222²⁹⁷⁹ - Update register_{thread,work} namespaces
- PR #4221²⁹⁸⁰ - Changing HPX_GCC_VERSION check from 70000 to 70300
- PR #4218²⁹⁸¹ - Google Season of Docs updates to documentation; grammar edits.
- PR #4217²⁹⁸² - Google Season of Docs updates to documentation; grammar edits.
- PR #4216²⁹⁸³ - Fixing gcc warning on 32bit platforms (integer truncation)
- PR #4214²⁹⁸⁴ - Apex callback refactoring
- PR #4213²⁹⁸⁵ - Clean up allocator checks for dependent projects
- PR #4212²⁹⁸⁶ - Google Season of Docs updates to documentation; grammar edits.
- PR #4211²⁹⁸⁷ - Google Season of Docs updates to documentation; contributing to hpx
- PR #4210²⁹⁸⁸ - Attempting to fix Intel compilation
- PR #4209²⁹⁸⁹ - Fix CUDA 10 build
- PR #4205²⁹⁹⁰ - Making sure that differences in CMAKE_BUILD_TYPE are not reported on multi-configuration cmake generators
- PR #4203²⁹⁹¹ - Deprecate Vc

²⁹⁶⁹ <https://github.com/STELLAR-GROUP/hpx/pull/4238>

²⁹⁷⁰ <https://github.com/STELLAR-GROUP/hpx/pull/4237>

²⁹⁷¹ <https://github.com/STELLAR-GROUP/hpx/pull/4236>

²⁹⁷² <https://github.com/STELLAR-GROUP/hpx/pull/4235>

²⁹⁷³ <https://github.com/STELLAR-GROUP/hpx/pull/4234>

²⁹⁷⁴ <https://github.com/STELLAR-GROUP/hpx/pull/4230>

²⁹⁷⁵ <https://github.com/STELLAR-GROUP/hpx/pull/4229>

²⁹⁷⁶ <https://github.com/STELLAR-GROUP/hpx/pull/4226>

²⁹⁷⁷ <https://github.com/STELLAR-GROUP/hpx/pull/4225>

²⁹⁷⁸ <https://github.com/STELLAR-GROUP/hpx/pull/4224>

²⁹⁷⁹ <https://github.com/STELLAR-GROUP/hpx/pull/4222>

²⁹⁸⁰ <https://github.com/STELLAR-GROUP/hpx/pull/4221>

²⁹⁸¹ <https://github.com/STELLAR-GROUP/hpx/pull/4218>

²⁹⁸² <https://github.com/STELLAR-GROUP/hpx/pull/4217>

²⁹⁸³ <https://github.com/STELLAR-GROUP/hpx/pull/4216>

²⁹⁸⁴ <https://github.com/STELLAR-GROUP/hpx/pull/4214>

²⁹⁸⁵ <https://github.com/STELLAR-GROUP/hpx/pull/4213>

²⁹⁸⁶ <https://github.com/STELLAR-GROUP/hpx/pull/4212>

²⁹⁸⁷ <https://github.com/STELLAR-GROUP/hpx/pull/4211>

²⁹⁸⁸ <https://github.com/STELLAR-GROUP/hpx/pull/4210>

²⁹⁸⁹ <https://github.com/STELLAR-GROUP/hpx/pull/4209>

²⁹⁹⁰ <https://github.com/STELLAR-GROUP/hpx/pull/4205>

²⁹⁹¹ <https://github.com/STELLAR-GROUP/hpx/pull/4203>

- PR #4202²⁹⁹² - Fix CUDA configuration
- PR #4200²⁹⁹³ - Making sure `hpx_wrap` is not passed on to linker on non-Linux systems
- PR #4198²⁹⁹⁴ - Fix `execution_agent.cpp` compilation with GCC 5
- PR #4197²⁹⁹⁵ - Remove deprecated options for 1.4.0 release
- PR #4196²⁹⁹⁶ - minor fixes for building on OSX Darwin
- PR #4195²⁹⁹⁷ - Use full clone on CircleCI for pushing stable tag
- PR #4193²⁹⁹⁸ - Add scheduling hints to `hello_world_distributed`
- PR #4192²⁹⁹⁹ - Set up CUDA in `HPXConfig.cmake`
- PR #4191³⁰⁰⁰ - Export allocators root variables
- PR #4190³⁰⁰¹ - Don't use `constexpr` in `thread_data` with GCC <= 6
- PR #4189³⁰⁰² - Only use `quick_exit` if available
- PR #4188³⁰⁰³ - Google Season of Docs updates to documentation; writing single node hpx applications
- PR #4186³⁰⁰⁴ - correct `vc` to `cuda` in `cuda.cmake`
- PR #4184³⁰⁰⁵ - Resetting some cached variables to make sure those are re-filled
- PR #4183³⁰⁰⁶ - Fix `hpxcxx` configuration
- PR #4181³⁰⁰⁷ - Rename base libraries var
- PR #4180³⁰⁰⁸ - Move header left behind earlier to plugin module
- PR #4179³⁰⁰⁹ - Moving `zip_iterator` and `transform_iterator` to `iterator_support` module
- PR #4178³⁰¹⁰ - Move checkpointing support to its own module
- PR #4177³⁰¹¹ - Small const fix to `basic_execution` module
- PR #4176³⁰¹² - Add back `HPX_LIBRARIES` and friends to `HPXConfig.cmake`
- PR #4175³⁰¹³ - Make `Vc` public and add it to `HPXConfig.cmake`
- PR #4173³⁰¹⁴ - Wait for runtime to be running before returning from `hpx::start`

2992 <https://github.com/STELLAR-GROUP/hpx/pull/4202>
 2993 <https://github.com/STELLAR-GROUP/hpx/pull/4200>
 2994 <https://github.com/STELLAR-GROUP/hpx/pull/4198>
 2995 <https://github.com/STELLAR-GROUP/hpx/pull/4197>
 2996 <https://github.com/STELLAR-GROUP/hpx/pull/4196>
 2997 <https://github.com/STELLAR-GROUP/hpx/pull/4195>
 2998 <https://github.com/STELLAR-GROUP/hpx/pull/4193>
 2999 <https://github.com/STELLAR-GROUP/hpx/pull/4192>
 3000 <https://github.com/STELLAR-GROUP/hpx/pull/4191>
 3001 <https://github.com/STELLAR-GROUP/hpx/pull/4190>
 3002 <https://github.com/STELLAR-GROUP/hpx/pull/4189>
 3003 <https://github.com/STELLAR-GROUP/hpx/pull/4188>
 3004 <https://github.com/STELLAR-GROUP/hpx/pull/4186>
 3005 <https://github.com/STELLAR-GROUP/hpx/pull/4184>
 3006 <https://github.com/STELLAR-GROUP/hpx/pull/4183>
 3007 <https://github.com/STELLAR-GROUP/hpx/pull/4181>
 3008 <https://github.com/STELLAR-GROUP/hpx/pull/4180>
 3009 <https://github.com/STELLAR-GROUP/hpx/pull/4179>
 3010 <https://github.com/STELLAR-GROUP/hpx/pull/4178>
 3011 <https://github.com/STELLAR-GROUP/hpx/pull/4177>
 3012 <https://github.com/STELLAR-GROUP/hpx/pull/4176>
 3013 <https://github.com/STELLAR-GROUP/hpx/pull/4175>
 3014 <https://github.com/STELLAR-GROUP/hpx/pull/4173>

- PR #4172³⁰¹⁵ - More protection against shutdown problems in error handling scenarios.
- PR #4171³⁰¹⁶ - Ignore lock in `condition_variable::wait`
- PR #4170³⁰¹⁷ - Adding APEX dependency to MPI parcelport
- PR #4168³⁰¹⁸ - Adding utility include
- PR #4167³⁰¹⁹ - Add a condition to setup the external libraries
- PR #4166³⁰²⁰ - Add an `INTERNAL_FLAGS` option to link to `hpx_internal_flags`
- PR #4165³⁰²¹ - Forward `HPX_*` cmake cache variables to external projects
- PR #4164³⁰²² - Affinity and batch environment modules
- PR #4162³⁰²³ - Handle `quick_exit`
- PR #4160³⁰²⁴ - Using `target_link_libraries` for cmake versions ≥ 3.12
- PR #4159³⁰²⁵ - Make sure `HPX_WITH_NATIVE_TLS` is forwarded to dependent projects
- PR #4158³⁰²⁶ - Adding allocator imported target as a dependency of allocator module
- PR #4157³⁰²⁷ - Add `hpx_memory` as a dependency of parcelport plugins
- PR #4156³⁰²⁸ - Stackless coroutines now can refer to themselves (through `get_self()` and friends)
- PR #4154³⁰²⁹ - Added CMake policy CMP0060 for HPX applications.
- PR #4153³⁰³⁰ - add header `iomaniip` to tests and tool
- PR #4152³⁰³¹ - Casting MPI tag value
- PR #4149³⁰³² - Add back private `m_desc` member variable in `program_options` module
- PR #4147³⁰³³ - Resource partitioner and threadmanager modules
- PR #4146³⁰³⁴ - Google Season of Docs updates to documentation; creating hpx projects
- PR #4145³⁰³⁵ - Adding basic support for stackless threads
- PR #4143³⁰³⁶ - Exclude `test_client_1950` from all target
- PR #4142³⁰³⁷ - Add a new `thread_pool_executor`

³⁰¹⁵ <https://github.com/STELLAR-GROUP/hpx/pull/4172>

³⁰¹⁶ <https://github.com/STELLAR-GROUP/hpx/pull/4171>

³⁰¹⁷ <https://github.com/STELLAR-GROUP/hpx/pull/4170>

³⁰¹⁸ <https://github.com/STELLAR-GROUP/hpx/pull/4168>

³⁰¹⁹ <https://github.com/STELLAR-GROUP/hpx/pull/4167>

³⁰²⁰ <https://github.com/STELLAR-GROUP/hpx/pull/4166>

³⁰²¹ <https://github.com/STELLAR-GROUP/hpx/pull/4165>

³⁰²² <https://github.com/STELLAR-GROUP/hpx/pull/4164>

³⁰²³ <https://github.com/STELLAR-GROUP/hpx/pull/4162>

³⁰²⁴ <https://github.com/STELLAR-GROUP/hpx/pull/4160>

³⁰²⁵ <https://github.com/STELLAR-GROUP/hpx/pull/4159>

³⁰²⁶ <https://github.com/STELLAR-GROUP/hpx/pull/4158>

³⁰²⁷ <https://github.com/STELLAR-GROUP/hpx/pull/4157>

³⁰²⁸ <https://github.com/STELLAR-GROUP/hpx/pull/4156>

³⁰²⁹ <https://github.com/STELLAR-GROUP/hpx/pull/4154>

³⁰³⁰ <https://github.com/STELLAR-GROUP/hpx/pull/4153>

³⁰³¹ <https://github.com/STELLAR-GROUP/hpx/pull/4152>

³⁰³² <https://github.com/STELLAR-GROUP/hpx/pull/4149>

³⁰³³ <https://github.com/STELLAR-GROUP/hpx/pull/4147>

³⁰³⁴ <https://github.com/STELLAR-GROUP/hpx/pull/4146>

³⁰³⁵ <https://github.com/STELLAR-GROUP/hpx/pull/4145>

³⁰³⁶ <https://github.com/STELLAR-GROUP/hpx/pull/4143>

³⁰³⁷ <https://github.com/STELLAR-GROUP/hpx/pull/4142>

- PR #4140³⁰³⁸ - Google Season of Docs updates to documentation; why hpx
- PR #4139³⁰³⁹ - Remove runtime includes from coroutines module
- PR #4138³⁰⁴⁰ - Forking boost::intrusive_ptr and adding it as hpx::intrusive_ptr
- PR #4137³⁰⁴¹ - Fixing TSS destruction
- PR #4136³⁰⁴² - HPX.Compute modules
- PR #4133³⁰⁴³ - Fix block_executor
- PR #4131³⁰⁴⁴ - Applying fixes based on reports from PVS Studio
- PR #4130³⁰⁴⁵ - Adding missing header to build system
- PR #4129³⁰⁴⁶ - Fixing compilation if HPX_WITH_DATAPAR_VC is enabled
- PR #4128³⁰⁴⁷ - Renaming moveonly_any to unique_any
- PR #4126³⁰⁴⁸ - Attempt to fix basic_any constructor for gcc 7
- PR #4125³⁰⁴⁹ - Changing extra_archive_data implementation
- PR #4124³⁰⁵⁰ - Don't link to Boost.System unless required
- PR #4122³⁰⁵¹ - Add kernel launch helper utility (+saxpy demo) and merge in octotiger changes
- PR #4121³⁰⁵² - Fixing migration test if networking is disabled.
- PR #4120³⁰⁵³ - Google Season of Docs updates to documentation; hpx build system v1
- PR #4119³⁰⁵⁴ - Making sure chunk_size and max_chunk are actually applied to parallel algorithms if specified
- PR #4117³⁰⁵⁵ - Make CircleCI formatting check store diff
- PR #4116³⁰⁵⁶ - Fix automatically setting C++ standard
- PR #4114³⁰⁵⁷ - Module serialization
- PR #4113³⁰⁵⁸ - Module datastructures
- PR #4111³⁰⁵⁹ - Fixing performance regression introduced earlier
- PR #4110³⁰⁶⁰ - Adding missing SPDX tags

³⁰³⁸ <https://github.com/STELLAR-GROUP/hpx/pull/4140>

³⁰³⁹ <https://github.com/STELLAR-GROUP/hpx/pull/4139>

³⁰⁴⁰ <https://github.com/STELLAR-GROUP/hpx/pull/4138>

³⁰⁴¹ <https://github.com/STELLAR-GROUP/hpx/pull/4137>

³⁰⁴² <https://github.com/STELLAR-GROUP/hpx/pull/4136>

³⁰⁴³ <https://github.com/STELLAR-GROUP/hpx/pull/4133>

³⁰⁴⁴ <https://github.com/STELLAR-GROUP/hpx/pull/4131>

³⁰⁴⁵ <https://github.com/STELLAR-GROUP/hpx/pull/4130>

³⁰⁴⁶ <https://github.com/STELLAR-GROUP/hpx/pull/4129>

³⁰⁴⁷ <https://github.com/STELLAR-GROUP/hpx/pull/4128>

³⁰⁴⁸ <https://github.com/STELLAR-GROUP/hpx/pull/4126>

³⁰⁴⁹ <https://github.com/STELLAR-GROUP/hpx/pull/4125>

³⁰⁵⁰ <https://github.com/STELLAR-GROUP/hpx/pull/4124>

³⁰⁵¹ <https://github.com/STELLAR-GROUP/hpx/pull/4122>

³⁰⁵² <https://github.com/STELLAR-GROUP/hpx/pull/4121>

³⁰⁵³ <https://github.com/STELLAR-GROUP/hpx/pull/4120>

³⁰⁵⁴ <https://github.com/STELLAR-GROUP/hpx/pull/4119>

³⁰⁵⁵ <https://github.com/STELLAR-GROUP/hpx/pull/4117>

³⁰⁵⁶ <https://github.com/STELLAR-GROUP/hpx/pull/4116>

³⁰⁵⁷ <https://github.com/STELLAR-GROUP/hpx/pull/4114>

³⁰⁵⁸ <https://github.com/STELLAR-GROUP/hpx/pull/4113>

³⁰⁵⁹ <https://github.com/STELLAR-GROUP/hpx/pull/4111>

³⁰⁶⁰ <https://github.com/STELLAR-GROUP/hpx/pull/4110>

- PR #4109³⁰⁶¹ - Overload for start without entry point/argv.
- PR #4108³⁰⁶² - Making sure C++ standard is properly detected and propagated
- PR #4106³⁰⁶³ - use `std::round` for guaranteed rounding without errors
- PR #4104³⁰⁶⁴ - Extend `scheduler_mode` with new `work_stealing` and task assignment modes
- PR #4103³⁰⁶⁵ - Add this to lambda capture list
- PR #4102³⁰⁶⁶ - Add spdx license and check
- PR #4099³⁰⁶⁷ - Module coroutines
- PR #4098³⁰⁶⁸ - Fix append module path in module CMakeLists template
- PR #4097³⁰⁶⁹ - Function tests
- PR #4096³⁰⁷⁰ - Removing return of `thread_result_type` from functions not needing them
- PR #4095³⁰⁷¹ - Stop-gap measure until cmake overhaul is in place
- PR #4094³⁰⁷² - Deprecate `HPX_WITH_MORE_THAN_64_THREADS`
- PR #4093³⁰⁷³ - Fix initialization of `global_num_tasks` in `parallel_executor`
- PR #4092³⁰⁷⁴ - Add support for mi-malloc
- PR #4090³⁰⁷⁵ - Execution context
- PR #4089³⁰⁷⁶ - Make counters in coroutines optional
- PR #4087³⁰⁷⁷ - Making `hpx::util::any` compatible with C++17
- PR #4084³⁰⁷⁸ - Making sure destination array for `std::transform` is properly resized
- PR #4083³⁰⁷⁹ - Adapting `thread_queue_mc` to behave even if no 128bit atomics are available
- PR #4082³⁰⁸⁰ - Fix compilation on GCC 5
- PR #4081³⁰⁸¹ - Adding option allowing to force using `Boost.FileSystem`
- PR #4080³⁰⁸² - Updating module dependencies
- PR #4079³⁰⁸³ - Add missing tests for `iterator_support` module

³⁰⁶¹ <https://github.com/STELLAR-GROUP/hpx/pull/4109>

³⁰⁶² <https://github.com/STELLAR-GROUP/hpx/pull/4108>

³⁰⁶³ <https://github.com/STELLAR-GROUP/hpx/pull/4106>

³⁰⁶⁴ <https://github.com/STELLAR-GROUP/hpx/pull/4104>

³⁰⁶⁵ <https://github.com/STELLAR-GROUP/hpx/pull/4103>

³⁰⁶⁶ <https://github.com/STELLAR-GROUP/hpx/pull/4102>

³⁰⁶⁷ <https://github.com/STELLAR-GROUP/hpx/pull/4099>

³⁰⁶⁸ <https://github.com/STELLAR-GROUP/hpx/pull/4098>

³⁰⁶⁹ <https://github.com/STELLAR-GROUP/hpx/pull/4097>

³⁰⁷⁰ <https://github.com/STELLAR-GROUP/hpx/pull/4096>

³⁰⁷¹ <https://github.com/STELLAR-GROUP/hpx/pull/4095>

³⁰⁷² <https://github.com/STELLAR-GROUP/hpx/pull/4094>

³⁰⁷³ <https://github.com/STELLAR-GROUP/hpx/pull/4093>

³⁰⁷⁴ <https://github.com/STELLAR-GROUP/hpx/pull/4092>

³⁰⁷⁵ <https://github.com/STELLAR-GROUP/hpx/pull/4090>

³⁰⁷⁶ <https://github.com/STELLAR-GROUP/hpx/pull/4089>

³⁰⁷⁷ <https://github.com/STELLAR-GROUP/hpx/pull/4087>

³⁰⁷⁸ <https://github.com/STELLAR-GROUP/hpx/pull/4084>

³⁰⁷⁹ <https://github.com/STELLAR-GROUP/hpx/pull/4083>

³⁰⁸⁰ <https://github.com/STELLAR-GROUP/hpx/pull/4082>

³⁰⁸¹ <https://github.com/STELLAR-GROUP/hpx/pull/4081>

³⁰⁸² <https://github.com/STELLAR-GROUP/hpx/pull/4080>

³⁰⁸³ <https://github.com/STELLAR-GROUP/hpx/pull/4079>

- PR #4078³⁰⁸⁴ - Disable parcel-layer if networking is disabled
- PR #4077³⁰⁸⁵ - Add missing include that causes build fails
- PR #4076³⁰⁸⁶ - Enable compatibility headers for functional module
- PR #4075³⁰⁸⁷ - Coroutines module
- PR #4073³⁰⁸⁸ - Use `configure_file` for generated files in modules
- PR #4071³⁰⁸⁹ - Fixing MPI detection for PMIx
- PR #4070³⁰⁹⁰ - Fix macOS builds
- PR #4069³⁰⁹¹ - Moving more facilities to the collectives module
- PR #4068³⁰⁹² - Adding main HPX `#include` directory to modules
- PR #4066³⁰⁹³ - Switching the use of `message(STATUS "...")` to `hpx_info`
- PR #4065³⁰⁹⁴ - Move Boost.Filesystem handling to filesystem module
- PR #4064³⁰⁹⁵ - Fix `program_options` test with older boost versions
- PR #4062³⁰⁹⁶ - The `cpu_features` tool fails to compile on anything but x86 architectures
- PR #4061³⁰⁹⁷ - Add `clang-format` checking step for modules
- PR #4060³⁰⁹⁸ - Making sure `HPX_IDLE_BACKOFF_TIME_MAX` is always defined (even if its unused)
- PR #4059³⁰⁹⁹ - Renaming module `hpx_parallel_executors` into `hpx_execution`
- PR #4058³¹⁰⁰ - Do not build networking tests when networking disabled
- PR #4057³¹⁰¹ - Printing configuration summary for modules as well
- PR #4055³¹⁰² - Google Season of Docs updates to documentation; hpx build systems
- PR #4054³¹⁰³ - Add troubleshooting section to manual
- PR #4051³¹⁰⁴ - Add more variations to `future_overhead` test
- PR #4050³¹⁰⁵ - Creating plugin module
- PR #4049³¹⁰⁶ - Move missing modules tests

³⁰⁸⁴ <https://github.com/STELLAR-GROUP/hpx/pull/4078>

³⁰⁸⁵ <https://github.com/STELLAR-GROUP/hpx/pull/4077>

³⁰⁸⁶ <https://github.com/STELLAR-GROUP/hpx/pull/4076>

³⁰⁸⁷ <https://github.com/STELLAR-GROUP/hpx/pull/4075>

³⁰⁸⁸ <https://github.com/STELLAR-GROUP/hpx/pull/4073>

³⁰⁸⁹ <https://github.com/STELLAR-GROUP/hpx/pull/4071>

³⁰⁹⁰ <https://github.com/STELLAR-GROUP/hpx/pull/4070>

³⁰⁹¹ <https://github.com/STELLAR-GROUP/hpx/pull/4069>

³⁰⁹² <https://github.com/STELLAR-GROUP/hpx/pull/4068>

³⁰⁹³ <https://github.com/STELLAR-GROUP/hpx/pull/4066>

³⁰⁹⁴ <https://github.com/STELLAR-GROUP/hpx/pull/4065>

³⁰⁹⁵ <https://github.com/STELLAR-GROUP/hpx/pull/4064>

³⁰⁹⁶ <https://github.com/STELLAR-GROUP/hpx/pull/4062>

³⁰⁹⁷ <https://github.com/STELLAR-GROUP/hpx/pull/4061>

³⁰⁹⁸ <https://github.com/STELLAR-GROUP/hpx/pull/4060>

³⁰⁹⁹ <https://github.com/STELLAR-GROUP/hpx/pull/4059>

³¹⁰⁰ <https://github.com/STELLAR-GROUP/hpx/pull/4058>

³¹⁰¹ <https://github.com/STELLAR-GROUP/hpx/pull/4057>

³¹⁰² <https://github.com/STELLAR-GROUP/hpx/pull/4055>

³¹⁰³ <https://github.com/STELLAR-GROUP/hpx/pull/4054>

³¹⁰⁴ <https://github.com/STELLAR-GROUP/hpx/pull/4051>

³¹⁰⁵ <https://github.com/STELLAR-GROUP/hpx/pull/4050>

³¹⁰⁶ <https://github.com/STELLAR-GROUP/hpx/pull/4049>

- PR #4047³¹⁰⁷ - Add boost/filesystem headers to inspect deprecated headers
- PR #4045³¹⁰⁸ - Module functional
- PR #4043³¹⁰⁹ - Fix preconditions and error messages for suspension functions
- PR #4041³¹¹⁰ - Pass HPX_STANDARD on to dependent projects via HPXConfig.cmake
- PR #4040³¹¹¹ - Program options module
- PR #4039³¹¹² - Moving non-serializable any (any_nonser) to datastructures module
- PR #4038³¹¹³ - Adding MPark's variant (V1.4.0) to HPX
- PR #4037³¹¹⁴ - Adding resiliency module
- PR #4036³¹¹⁵ - Add C++17 filesystem compatibility header
- PR #4035³¹¹⁶ - Fixing support for mpirun
- PR #4028³¹¹⁷ - CMake to target based directives
- PR #4027³¹¹⁸ - Remove GitLab CI configuration
- PR #4026³¹¹⁹ - Threading refactoring
- PR #4025³¹²⁰ - Refactoring thread queue configuration options
- PR #4024³¹²¹ - Fix padding calculation in cache_aligned_data.hpp
- PR #4023³¹²² - Fixing Codacy issues
- PR #4022³¹²³ - Make sure process mask option is passed to affinity_data
- PR #4021³¹²⁴ - Warn about compiling in C++11 mode
- PR #4020³¹²⁵ - Module concurrency
- PR #4019³¹²⁶ - Module topology
- PR #4018³¹²⁷ - Update deprecated header in thread_queue_mc.hpp
- PR #4015³¹²⁸ - Avoid overwriting artifacts
- PR #4014³¹²⁹ - Future overheads

³¹⁰⁷ <https://github.com/STELLAR-GROUP/hpx/pull/4047>

³¹⁰⁸ <https://github.com/STELLAR-GROUP/hpx/pull/4045>

³¹⁰⁹ <https://github.com/STELLAR-GROUP/hpx/pull/4043>

³¹¹⁰ <https://github.com/STELLAR-GROUP/hpx/pull/4041>

³¹¹¹ <https://github.com/STELLAR-GROUP/hpx/pull/4040>

³¹¹² <https://github.com/STELLAR-GROUP/hpx/pull/4039>

³¹¹³ <https://github.com/STELLAR-GROUP/hpx/pull/4038>

³¹¹⁴ <https://github.com/STELLAR-GROUP/hpx/pull/4037>

³¹¹⁵ <https://github.com/STELLAR-GROUP/hpx/pull/4036>

³¹¹⁶ <https://github.com/STELLAR-GROUP/hpx/pull/4035>

³¹¹⁷ <https://github.com/STELLAR-GROUP/hpx/pull/4028>

³¹¹⁸ <https://github.com/STELLAR-GROUP/hpx/pull/4027>

³¹¹⁹ <https://github.com/STELLAR-GROUP/hpx/pull/4026>

³¹²⁰ <https://github.com/STELLAR-GROUP/hpx/pull/4025>

³¹²¹ <https://github.com/STELLAR-GROUP/hpx/pull/4024>

³¹²² <https://github.com/STELLAR-GROUP/hpx/pull/4023>

³¹²³ <https://github.com/STELLAR-GROUP/hpx/pull/4022>

³¹²⁴ <https://github.com/STELLAR-GROUP/hpx/pull/4021>

³¹²⁵ <https://github.com/STELLAR-GROUP/hpx/pull/4020>

³¹²⁶ <https://github.com/STELLAR-GROUP/hpx/pull/4019>

³¹²⁷ <https://github.com/STELLAR-GROUP/hpx/pull/4018>

³¹²⁸ <https://github.com/STELLAR-GROUP/hpx/pull/4015>

³¹²⁹ <https://github.com/STELLAR-GROUP/hpx/pull/4014>

- PR #4013³¹³⁰ - Update URL to test output conversion script
- PR #4012³¹³¹ - Fix CUDA compilation
- PR #4011³¹³² - Fixing cyclic dependencies between modules
- PR #4010³¹³³ - Ignore stable tag on CircleCI
- PR #4009³¹³⁴ - Check circular dependencies in a circle ci step
- PR #4008³¹³⁵ - Extend cache aligned data to handle tuple-like data
- PR #4007³¹³⁶ - Fixing migration for components that have actions returning a client
- PR #4006³¹³⁷ - Move is_value_proxy.hpp to algorithms module
- PR #4004³¹³⁸ - Shorten CTest timeout on CircleCI
- PR #4003³¹³⁹ - Refactoring to remove (internal) dependencies
- PR #4001³¹⁴⁰ - Exclude tests from all target
- PR #4000³¹⁴¹ - Module errors
- PR #3999³¹⁴² - Enable support for compatibility headers for logging module
- PR #3998³¹⁴³ - Add process thread binding option
- PR #3997³¹⁴⁴ - Export handle_assert function
- PR #3996³¹⁴⁵ - Attempt to solve issue where -latomic does not support 128bit atomics
- PR #3993³¹⁴⁶ - Make sure __LINE__ is an unsigned
- PR #3991³¹⁴⁷ - Fix dependencies and flags for header tests
- PR #3990³¹⁴⁸ - Documentation tags fixes
- PR #3988³¹⁴⁹ - Adding missing solution folder for format module test
- PR #3987³¹⁵⁰ - Move runtime-dependent functions out of command line handling
- PR #3986³¹⁵¹ - Fix CMake configuration with PAPI on
- PR #3985³¹⁵² - Module timing

³¹³⁰ <https://github.com/STELLAR-GROUP/hpx/pull/4013>

³¹³¹ <https://github.com/STELLAR-GROUP/hpx/pull/4012>

³¹³² <https://github.com/STELLAR-GROUP/hpx/pull/4011>

³¹³³ <https://github.com/STELLAR-GROUP/hpx/pull/4010>

³¹³⁴ <https://github.com/STELLAR-GROUP/hpx/pull/4009>

³¹³⁵ <https://github.com/STELLAR-GROUP/hpx/pull/4008>

³¹³⁶ <https://github.com/STELLAR-GROUP/hpx/pull/4007>

³¹³⁷ <https://github.com/STELLAR-GROUP/hpx/pull/4006>

³¹³⁸ <https://github.com/STELLAR-GROUP/hpx/pull/4004>

³¹³⁹ <https://github.com/STELLAR-GROUP/hpx/pull/4003>

³¹⁴⁰ <https://github.com/STELLAR-GROUP/hpx/pull/4001>

³¹⁴¹ <https://github.com/STELLAR-GROUP/hpx/pull/4000>

³¹⁴² <https://github.com/STELLAR-GROUP/hpx/pull/3999>

³¹⁴³ <https://github.com/STELLAR-GROUP/hpx/pull/3998>

³¹⁴⁴ <https://github.com/STELLAR-GROUP/hpx/pull/3997>

³¹⁴⁵ <https://github.com/STELLAR-GROUP/hpx/pull/3996>

³¹⁴⁶ <https://github.com/STELLAR-GROUP/hpx/pull/3993>

³¹⁴⁷ <https://github.com/STELLAR-GROUP/hpx/pull/3991>

³¹⁴⁸ <https://github.com/STELLAR-GROUP/hpx/pull/3990>

³¹⁴⁹ <https://github.com/STELLAR-GROUP/hpx/pull/3988>

³¹⁵⁰ <https://github.com/STELLAR-GROUP/hpx/pull/3987>

³¹⁵¹ <https://github.com/STELLAR-GROUP/hpx/pull/3986>

³¹⁵² <https://github.com/STELLAR-GROUP/hpx/pull/3985>

- PR #3984³¹⁵³ - Fix default behaviour of paths in `add_hpx_component`
- PR #3982³¹⁵⁴ - Parallel executors module
- PR #3981³¹⁵⁵ - Segmented algorithms module
- PR #3980³¹⁵⁶ - Module logging
- PR #3979³¹⁵⁷ - Module util
- PR #3978³¹⁵⁸ - Fix `clang-tidy` step on CircleCI
- PR #3977³¹⁵⁹ - Fixing solution folders for moved components
- PR #3976³¹⁶⁰ - Module format
- PR #3975³¹⁶¹ - Enable deprecation warnings on CircleCI
- PR #3974³¹⁶² - Fix typos in documentation
- PR #3973³¹⁶³ - Fix compilation with GCC 9
- PR #3972³¹⁶⁴ - Add condition to clone apex + use of new cmake var `APEX_ROOT`
- PR #3971³¹⁶⁵ - Add testing module
- PR #3968³¹⁶⁶ - Remove unneeded file in hardware module
- PR #3967³¹⁶⁷ - Remove leftover PIC settings from main `CMakeLists.txt`
- PR #3966³¹⁶⁸ - Add missing export option in `add_hpx_module`
- PR #3965³¹⁶⁹ - Change `current_function_helper` back to non-constexpr
- PR #3964³¹⁷⁰ - Fixing merge problems
- PR #3962³¹⁷¹ - Add a trait for `std::array` for unwrapping
- PR #3961³¹⁷² - Making `hpx::util::tuple<Ts...>` and `std::tuple<Ts...>` convertible
- PR #3960³¹⁷³ - fix compilation with CUDA 10 and GCC 6
- PR #3959³¹⁷⁴ - Fix C++11 incompatibility
- PR #3957³¹⁷⁵ - Algorithms module

³¹⁵³ <https://github.com/STELLAR-GROUP/hpx/pull/3984>

³¹⁵⁴ <https://github.com/STELLAR-GROUP/hpx/pull/3982>

³¹⁵⁵ <https://github.com/STELLAR-GROUP/hpx/pull/3981>

³¹⁵⁶ <https://github.com/STELLAR-GROUP/hpx/pull/3980>

³¹⁵⁷ <https://github.com/STELLAR-GROUP/hpx/pull/3979>

³¹⁵⁸ <https://github.com/STELLAR-GROUP/hpx/pull/3978>

³¹⁵⁹ <https://github.com/STELLAR-GROUP/hpx/pull/3977>

³¹⁶⁰ <https://github.com/STELLAR-GROUP/hpx/pull/3976>

³¹⁶¹ <https://github.com/STELLAR-GROUP/hpx/pull/3975>

³¹⁶² <https://github.com/STELLAR-GROUP/hpx/pull/3974>

³¹⁶³ <https://github.com/STELLAR-GROUP/hpx/pull/3973>

³¹⁶⁴ <https://github.com/STELLAR-GROUP/hpx/pull/3972>

³¹⁶⁵ <https://github.com/STELLAR-GROUP/hpx/pull/3971>

³¹⁶⁶ <https://github.com/STELLAR-GROUP/hpx/pull/3968>

³¹⁶⁷ <https://github.com/STELLAR-GROUP/hpx/pull/3967>

³¹⁶⁸ <https://github.com/STELLAR-GROUP/hpx/pull/3966>

³¹⁶⁹ <https://github.com/STELLAR-GROUP/hpx/pull/3965>

³¹⁷⁰ <https://github.com/STELLAR-GROUP/hpx/pull/3964>

³¹⁷¹ <https://github.com/STELLAR-GROUP/hpx/pull/3962>

³¹⁷² <https://github.com/STELLAR-GROUP/hpx/pull/3961>

³¹⁷³ <https://github.com/STELLAR-GROUP/hpx/pull/3960>

³¹⁷⁴ <https://github.com/STELLAR-GROUP/hpx/pull/3959>

³¹⁷⁵ <https://github.com/STELLAR-GROUP/hpx/pull/3957>

- PR #3956³¹⁷⁶ - [HPX_AddModule] Fix lower name var to upper
- PR #3955³¹⁷⁷ - Fix CMake configuration with examples off and tests on
- PR #3954³¹⁷⁸ - Move components to separate subdirectory in root of repository
- PR #3952³¹⁷⁹ - Update `papi.cpp`
- PR #3951³¹⁸⁰ - Exclude modules header tests from all target
- PR #3950³¹⁸¹ - Adding `all_reduce` facility to collectives module
- PR #3949³¹⁸² - This adds a configuration file that will cause for stale issues to be automatically closed
- PR #3948³¹⁸³ - Fixing ALPS environment
- PR #3947³¹⁸⁴ - Add major compiler version check for building hpx as a binary package
- PR #3946³¹⁸⁵ - [Modules] Move the location of the generated headers
- PR #3945³¹⁸⁶ - Simplify tests and examples cmake
- PR #3943³¹⁸⁷ - Remove example module
- PR #3942³¹⁸⁸ - Add `NOEXPORT` option to `add_hpx_{component,library}`
- PR #3938³¹⁸⁹ - Use https for CDash submissions
- PR #3937³¹⁹⁰ - Add `HPX_WITH_BUILD_BINARY_PACKAGE` to the compiler check (refs #3935)
- PR #3936³¹⁹¹ - Fixing installation of binaries on windows
- PR #3934³¹⁹² - Add set function for `sliding_semaphore_max_difference`
- PR #3933³¹⁹³ - Remove `cudaDeviceRT` from compile/link flags as it breaks downstream projects
- PR #3932³¹⁹⁴ - Fixing 3929
- PR #3931³¹⁹⁵ - Adding `all_to_all`
- PR #3930³¹⁹⁶ - Add test demonstrating the use of broadcast with component actions
- PR #3928³¹⁹⁷ - fixed number of tasks and number of threads for heterogeneous slurm environments
- PR #3927³¹⁹⁸ - Moving Cache module's tests into separate solution folder

³¹⁷⁶ <https://github.com/STELLAR-GROUP/hpx/pull/3956>

³¹⁷⁷ <https://github.com/STELLAR-GROUP/hpx/pull/3955>

³¹⁷⁸ <https://github.com/STELLAR-GROUP/hpx/pull/3954>

³¹⁷⁹ <https://github.com/STELLAR-GROUP/hpx/pull/3952>

³¹⁸⁰ <https://github.com/STELLAR-GROUP/hpx/pull/3951>

³¹⁸¹ <https://github.com/STELLAR-GROUP/hpx/pull/3950>

³¹⁸² <https://github.com/STELLAR-GROUP/hpx/pull/3949>

³¹⁸³ <https://github.com/STELLAR-GROUP/hpx/pull/3948>

³¹⁸⁴ <https://github.com/STELLAR-GROUP/hpx/pull/3947>

³¹⁸⁵ <https://github.com/STELLAR-GROUP/hpx/pull/3946>

³¹⁸⁶ <https://github.com/STELLAR-GROUP/hpx/pull/3945>

³¹⁸⁷ <https://github.com/STELLAR-GROUP/hpx/pull/3943>

³¹⁸⁸ <https://github.com/STELLAR-GROUP/hpx/pull/3942>

³¹⁸⁹ <https://github.com/STELLAR-GROUP/hpx/pull/3938>

³¹⁹⁰ <https://github.com/STELLAR-GROUP/hpx/pull/3937>

³¹⁹¹ <https://github.com/STELLAR-GROUP/hpx/pull/3936>

³¹⁹² <https://github.com/STELLAR-GROUP/hpx/pull/3934>

³¹⁹³ <https://github.com/STELLAR-GROUP/hpx/pull/3933>

³¹⁹⁴ <https://github.com/STELLAR-GROUP/hpx/pull/3932>

³¹⁹⁵ <https://github.com/STELLAR-GROUP/hpx/pull/3931>

³¹⁹⁶ <https://github.com/STELLAR-GROUP/hpx/pull/3930>

³¹⁹⁷ <https://github.com/STELLAR-GROUP/hpx/pull/3928>

³¹⁹⁸ <https://github.com/STELLAR-GROUP/hpx/pull/3927>

- PR #3926³¹⁹⁹ - Move unit tests to cache module
- PR #3925³²⁰⁰ - Move version check to config module
- PR #3924³²⁰¹ - Add schedule hint executor parameters
- PR #3923³²⁰² - Allow aligning objects bigger than the cache line size
- PR #3922³²⁰³ - Add Windows builds with Travis CI
- PR #3921³²⁰⁴ - Add ccls cache directory to gitignore
- PR #3920³²⁰⁵ - Fix `git_external` fetching of tags
- PR #3905³²⁰⁶ - Correct rostambod url. Fix typo in doc
- PR #3904³²⁰⁷ - Fix bug in `context_base.hpp`
- PR #3903³²⁰⁸ - Adding new performance counters
- PR #3902³²⁰⁹ - Add `add_hpx_module` function
- PR #3901³²¹⁰ - Factoring out container remapping into a separate trait
- PR #3900³²¹¹ - Making sure errors during command line processing are properly reported and will not cause assertions
- PR #3899³²¹² - Remove old compatibility bases from `make_action`
- PR #3898³²¹³ - Make parameter size be of type `size_t`
- PR #3897³²¹⁴ - Making sure all tests are disabled if `HPX_WITH_TESTS=OFF`
- PR #3895³²¹⁵ - Add documentation for `annotated_function`
- PR #3894³²¹⁶ - Working around VS2019 problem with `make_action`
- PR #3892³²¹⁷ - Avoid MSVC compatibility warning in internal allocator
- PR #3891³²¹⁸ - Removal of the default intel config include
- PR #3888³²¹⁹ - Fix `async_customization` dataflow example and Clarify what's being tested
- PR #3887³²²⁰ - Add Doxygen documentation
- PR #3882³²²¹ - Minor docs fixes

³¹⁹⁹ <https://github.com/STELLAR-GROUP/hpx/pull/3926>

³²⁰⁰ <https://github.com/STELLAR-GROUP/hpx/pull/3925>

³²⁰¹ <https://github.com/STELLAR-GROUP/hpx/pull/3924>

³²⁰² <https://github.com/STELLAR-GROUP/hpx/pull/3923>

³²⁰³ <https://github.com/STELLAR-GROUP/hpx/pull/3922>

³²⁰⁴ <https://github.com/STELLAR-GROUP/hpx/pull/3921>

³²⁰⁵ <https://github.com/STELLAR-GROUP/hpx/pull/3920>

³²⁰⁶ <https://github.com/STELLAR-GROUP/hpx/pull/3905>

³²⁰⁷ <https://github.com/STELLAR-GROUP/hpx/pull/3904>

³²⁰⁸ <https://github.com/STELLAR-GROUP/hpx/pull/3903>

³²⁰⁹ <https://github.com/STELLAR-GROUP/hpx/pull/3902>

³²¹⁰ <https://github.com/STELLAR-GROUP/hpx/pull/3901>

³²¹¹ <https://github.com/STELLAR-GROUP/hpx/pull/3900>

³²¹² <https://github.com/STELLAR-GROUP/hpx/pull/3899>

³²¹³ <https://github.com/STELLAR-GROUP/hpx/pull/3898>

³²¹⁴ <https://github.com/STELLAR-GROUP/hpx/pull/3897>

³²¹⁵ <https://github.com/STELLAR-GROUP/hpx/pull/3895>

³²¹⁶ <https://github.com/STELLAR-GROUP/hpx/pull/3894>

³²¹⁷ <https://github.com/STELLAR-GROUP/hpx/pull/3892>

³²¹⁸ <https://github.com/STELLAR-GROUP/hpx/pull/3891>

³²¹⁹ <https://github.com/STELLAR-GROUP/hpx/pull/3888>

³²²⁰ <https://github.com/STELLAR-GROUP/hpx/pull/3887>

³²²¹ <https://github.com/STELLAR-GROUP/hpx/pull/3882>

- PR #3880³²²² - Updating APEX version tag
- PR #3878³²²³ - Making sure symbols are properly exported from modules (needed for Windows/MacOS)
- PR #3877³²²⁴ - Documentation
- PR #3876³²²⁵ - Module hardware
- PR #3875³²²⁶ - Converted typedefs in actions submodule to using directives
- PR #3874³²²⁷ - Allow one to suppress target keywords in `hpx_setup_target` for backwards compatibility
- PR #3873³²²⁸ - Add scripts to create releases and generate lists of PRs and issues
- PR #3872³²²⁹ - Fix latest HTML docs location
- PR #3870³²³⁰ - Module cache
- PR #3869³²³¹ - Post 1.3.0 version bumps
- PR #3868³²³² - Replace the macro `HPX_ASSERT` by `HPX_TEST` in tests
- PR #3845³²³³ - Assertion module
- PR #3839³²³⁴ - Make tuple serialization non-intrusive
- PR #3832³²³⁵ - Config module
- PR #3799³²³⁶ - Remove compat namespace and its contents
- PR #3701³²³⁷ - MoodyCamel lockfree
- PR #3496³²³⁸ - Disabling MPI's (deprecated) C++ interface
- PR #3192³²³⁹ - Move type info into `hpx::debug` namespace and add print helper functions
- PR #3159³²⁴⁰ - Support Checkpointing Components

³²²² <https://github.com/STELLAR-GROUP/hpx/pull/3880>

³²²³ <https://github.com/STELLAR-GROUP/hpx/pull/3878>

³²²⁴ <https://github.com/STELLAR-GROUP/hpx/pull/3877>

³²²⁵ <https://github.com/STELLAR-GROUP/hpx/pull/3876>

³²²⁶ <https://github.com/STELLAR-GROUP/hpx/pull/3875>

³²²⁷ <https://github.com/STELLAR-GROUP/hpx/pull/3874>

³²²⁸ <https://github.com/STELLAR-GROUP/hpx/pull/3873>

³²²⁹ <https://github.com/STELLAR-GROUP/hpx/pull/3872>

³²³⁰ <https://github.com/STELLAR-GROUP/hpx/pull/3870>

³²³¹ <https://github.com/STELLAR-GROUP/hpx/pull/3869>

³²³² <https://github.com/STELLAR-GROUP/hpx/pull/3868>

³²³³ <https://github.com/STELLAR-GROUP/hpx/pull/3845>

³²³⁴ <https://github.com/STELLAR-GROUP/hpx/pull/3839>

³²³⁵ <https://github.com/STELLAR-GROUP/hpx/pull/3832>

³²³⁶ <https://github.com/STELLAR-GROUP/hpx/pull/3799>

³²³⁷ <https://github.com/STELLAR-GROUP/hpx/pull/3701>

³²³⁸ <https://github.com/STELLAR-GROUP/hpx/pull/3496>

³²³⁹ <https://github.com/STELLAR-GROUP/hpx/pull/3192>

³²⁴⁰ <https://github.com/STELLAR-GROUP/hpx/pull/3159>

HPX V1.3.0 (May 23, 2019)

General changes

- Performance improvements: the schedulers have significantly reduced overheads from removing false sharing and the parallel executor has been updated to create fewer futures.
- HPX now defaults to not turning on networking when running on one locality. This means that you can run multiple instances on the same system without adding command line options.
- Multiple issues reported by Clang sanitizers have been fixed.
- We have added (back) single-page HTML documentation and PDF documentation.
- We have started modularizing the HPX library. This is useful both for developers and users. In the long term users will be able to consume only parts of the HPX libraries if they do not require all the functionality that HPX currently provides.
- We have added an implementation of `function_ref`.
- The `barrier` and `latch` classes have gained a few additional member functions.

Breaking changes

- Executable and library targets are now created without the `_exe` and `_lib` suffix respectively. For example, the target `1d_stencil_1_exe` is now simply called `1d_stencil_1`.
- We have removed the following deprecated functionality: `queue`, `scoped_unlock`, and support for input iterators in algorithms.
- We have turned off the compatibility layer for `unwrapped` by default. The functionality will be removed in the next release. The option can still be turned on using the `CMake`³²⁴¹ option `HPX_WITH_UNWRAPPED_SUPPORT`. Likewise, `inclusive_scan` compatibility overloads have been turned off by default. They can still be turned on with `HPX_WITH_INCLUSIVE_SCAN_COMPATIBILITY`.
- The minimum compiler and dependency versions have been updated. We now support GCC from version 5 onwards, Clang from version 4 onwards, and Boost from version 1.61.0 onwards.
- The headers for preprocessor macros have moved as a result of the functionality being moved to a separate module. The old headers are deprecated and will be removed in a future version of HPX. You can turn off the warnings by setting `HPX_PREPROCESSOR_WITH_DEPRECATION_WARNINGS=OFF` or turn off the compatibility headers completely with `HPX_PREPROCESSOR_WITH_COMPATIBILITY_HEADERS=OFF`.

Closed issues

- [Issue #3863](#)³²⁴² - shouldn't “-faligned-new” be a usage requirement?
- [Issue #3841](#)³²⁴³ - Build error with msvc 19 caused by SFINAE and C++17
- [Issue #3836](#)³²⁴⁴ - master branch does not build with idle rate counters enabled
- [Issue #3819](#)³²⁴⁵ - Add debug suffix to modules built in debug mode

³²⁴¹ <https://www.cmake.org>

³²⁴² <https://github.com/STELLAR-GROUP/hpx/issues/3863>

³²⁴³ <https://github.com/STELLAR-GROUP/hpx/issues/3841>

³²⁴⁴ <https://github.com/STELLAR-GROUP/hpx/issues/3836>

³²⁴⁵ <https://github.com/STELLAR-GROUP/hpx/issues/3819>

- Issue #3817³²⁴⁶ - HPX_INCLUDE_DIRS contains non-existent directory
- Issue #3810³²⁴⁷ - Source groups are not created for files in modules
- Issue #3805³²⁴⁸ - HPX won't compile with -DHPX_WITH_APEX=TRUE
- Issue #3792³²⁴⁹ - Barrier Hangs When Locality Zero not included
- Issue #3778³²⁵⁰ - Replace throw() with noexcept
- Issue #3763³²⁵¹ - configurable sort limit per task
- Issue #3758³²⁵² - dataflow doesn't convert future<future<T>> to future<T>
- Issue #3757³²⁵³ - When compiling undefined reference to hpx::hpx_check_version_1_2 HPX V1.2.1, Ubuntu 18.04.01 Server Edition
- Issue #3753³²⁵⁴ - --hpx:list-counters=full crashes
- Issue #3746³²⁵⁵ - Detection of MPI with pmix
- Issue #3744³²⁵⁶ - Separate spinlock from same cacheline as internal data for all LCOs
- Issue #3743³²⁵⁷ - hpxcxx's shebang doesn't specify the python version
- Issue #3738³²⁵⁸ - Unable to debug parcelport on a single node
- Issue #3735³²⁵⁹ - Latest master: Can't compile in MSVC
- Issue #3731³²⁶⁰ - util::bound seems broken on Clang with older libstdc++
- Issue #3724³²⁶¹ - Allow to pre-set command line options through environment
- Issue #3723³²⁶² - examples/resource_partitioner build issue on master branch / ubuntu 18
- Issue #3721³²⁶³ - faced a building error
- Issue #3720³²⁶⁴ - Hello World example fails to link
- Issue #3719³²⁶⁵ - pkg-config produces invalid output: -l-pthread
- Issue #3718³²⁶⁶ - Please make the python executable configurable through cmake
- Issue #3717³²⁶⁷ - interested to contribute to the organisation
- Issue #3699³²⁶⁸ - Remove 'HPX runtime' executable

³²⁴⁶ <https://github.com/STELLAR-GROUP/hpx/issues/3817>

³²⁴⁷ <https://github.com/STELLAR-GROUP/hpx/issues/3810>

³²⁴⁸ <https://github.com/STELLAR-GROUP/hpx/issues/3805>

³²⁴⁹ <https://github.com/STELLAR-GROUP/hpx/issues/3792>

³²⁵⁰ <https://github.com/STELLAR-GROUP/hpx/issues/3778>

³²⁵¹ <https://github.com/STELLAR-GROUP/hpx/issues/3763>

³²⁵² <https://github.com/STELLAR-GROUP/hpx/issues/3758>

³²⁵³ <https://github.com/STELLAR-GROUP/hpx/issues/3757>

³²⁵⁴ <https://github.com/STELLAR-GROUP/hpx/issues/3753>

³²⁵⁵ <https://github.com/STELLAR-GROUP/hpx/issues/3746>

³²⁵⁶ <https://github.com/STELLAR-GROUP/hpx/issues/3744>

³²⁵⁷ <https://github.com/STELLAR-GROUP/hpx/issues/3743>

³²⁵⁸ <https://github.com/STELLAR-GROUP/hpx/issues/3738>

³²⁵⁹ <https://github.com/STELLAR-GROUP/hpx/issues/3735>

³²⁶⁰ <https://github.com/STELLAR-GROUP/hpx/issues/3731>

³²⁶¹ <https://github.com/STELLAR-GROUP/hpx/issues/3724>

³²⁶² <https://github.com/STELLAR-GROUP/hpx/issues/3723>

³²⁶³ <https://github.com/STELLAR-GROUP/hpx/issues/3721>

³²⁶⁴ <https://github.com/STELLAR-GROUP/hpx/issues/3720>

³²⁶⁵ <https://github.com/STELLAR-GROUP/hpx/issues/3719>

³²⁶⁶ <https://github.com/STELLAR-GROUP/hpx/issues/3718>

³²⁶⁷ <https://github.com/STELLAR-GROUP/hpx/issues/3717>

³²⁶⁸ <https://github.com/STELLAR-GROUP/hpx/issues/3699>

- Issue #3698³²⁶⁹ - Ignore all locks while handling asserts
- Issue #3689³²⁷⁰ - Incorrect and inconsistent website structure <http://stellar.cct.lsu.edu/downloads/>.
- Issue #3681³²⁷¹ - Broken links on <http://stellar.cct.lsu.edu/2015/05/hpx-archives-now-on-gmane/>
- Issue #3676³²⁷² - HPX master built from source, cmake fails to link main.cpp example in docs
- Issue #3673³²⁷³ - HPX build fails with `std::atomic` missing error
- Issue #3670³²⁷⁴ - Generate PDF again from documentation (with Sphinx)
- Issue #3643³²⁷⁵ - Warnings when compiling HPX 1.2.1 with gcc 9
- Issue #3641³²⁷⁶ - Trouble with using ranges-v3 and `hpx::parallel::reduce`
- Issue #3639³²⁷⁷ - `util::unwrapping` does not work well with member functions
- Issue #3634³²⁷⁸ - The build fails if `shared_future<>::then` is called with a thread executor
- Issue #3622³²⁷⁹ - VTune Amplifier 2019 not working with `use_itt_notify=1`
- Issue #3616³²⁸⁰ - HPX Fails to Build with CUDA 10
- Issue #3612³²⁸¹ - False sharing of scheduling counters
- Issue #3609³²⁸² - `executor_parameters` timeout with gcc `<= 7` and Debug mode
- Issue #3601³²⁸³ - Misleading error message on power pc for `rdtsc` and `rdtscp`
- Issue #3598³²⁸⁴ - Build of some examples fails when using `Vc`
- Issue #3594³²⁸⁵ - Error: The number of OS threads requested (20) does not match the number of threads to bind (12): `HPX(bad_parameter)`
- Issue #3592³²⁸⁶ - Undefined Reference Error
- Issue #3589³²⁸⁷ - `include` could not find load file: `HPX_Utils.cmake`
- Issue #3587³²⁸⁸ - HPX won't compile on POWER8 with Clang 7
- Issue #3583³²⁸⁹ - Fedora and openSUSE instructions missing on “Distribution Packages” page
- Issue #3578³²⁹⁰ - Build error when configuring with `HPX_HAVE_ALGORITHM_INPUT_ITERATOR_SUPPORT=ON`
- Issue #3575³²⁹¹ - Merge openSUSE reproducible patch

³²⁶⁹ <https://github.com/STELLAR-GROUP/hpx/issues/3698>

³²⁷⁰ <https://github.com/STELLAR-GROUP/hpx/issues/3689>

³²⁷¹ <https://github.com/STELLAR-GROUP/hpx/issues/3681>

³²⁷² <https://github.com/STELLAR-GROUP/hpx/issues/3676>

³²⁷³ <https://github.com/STELLAR-GROUP/hpx/issues/3673>

³²⁷⁴ <https://github.com/STELLAR-GROUP/hpx/issues/3670>

³²⁷⁵ <https://github.com/STELLAR-GROUP/hpx/issues/3643>

³²⁷⁶ <https://github.com/STELLAR-GROUP/hpx/issues/3641>

³²⁷⁷ <https://github.com/STELLAR-GROUP/hpx/issues/3639>

³²⁷⁸ <https://github.com/STELLAR-GROUP/hpx/issues/3634>

³²⁷⁹ <https://github.com/STELLAR-GROUP/hpx/issues/3622>

³²⁸⁰ <https://github.com/STELLAR-GROUP/hpx/issues/3616>

³²⁸¹ <https://github.com/STELLAR-GROUP/hpx/issues/3612>

³²⁸² <https://github.com/STELLAR-GROUP/hpx/issues/3609>

³²⁸³ <https://github.com/STELLAR-GROUP/hpx/issues/3601>

³²⁸⁴ <https://github.com/STELLAR-GROUP/hpx/issues/3598>

³²⁸⁵ <https://github.com/STELLAR-GROUP/hpx/issues/3594>

³²⁸⁶ <https://github.com/STELLAR-GROUP/hpx/issues/3592>

³²⁸⁷ <https://github.com/STELLAR-GROUP/hpx/issues/3589>

³²⁸⁸ <https://github.com/STELLAR-GROUP/hpx/issues/3587>

³²⁸⁹ <https://github.com/STELLAR-GROUP/hpx/issues/3583>

³²⁹⁰ <https://github.com/STELLAR-GROUP/hpx/issues/3578>

³²⁹¹ <https://github.com/STELLAR-GROUP/hpx/issues/3575>

- Issue #3570³²⁹² - Update HPX to work with the latest VC version
- Issue #3567³²⁹³ - Build succeed and make failed for `hpx : cout`
- Issue #3565³²⁹⁴ - Polymorphic simple component destructor not getting called
- Issue #3559³²⁹⁵ - 1.2.0 is missing from download page
- Issue #3554³²⁹⁶ - Clang 6.0 warning of hiding overloaded virtual function
- Issue #3510³²⁹⁷ - Build on ppc64 fails
- Issue #3482³²⁹⁸ - Improve error message when `HPX_WITH_MAX_CPU_COUNT` is too low for given system
- Issue #3453³²⁹⁹ - Two HPX applications can't run at the same time.
- Issue #3452³³⁰⁰ - Scaling issue on the change to 2 NUMA domains
- Issue #3442³³⁰¹ - HPX `set_difference`, `set_intersection` failure cases
- Issue #3437³³⁰² - Ensure `parent_task` pointer when child task is created and child/parent are on same locality
- Issue #3255³³⁰³ - Suspension with lock for `--hpx:list-component-types`
- Issue #3034³³⁰⁴ - Use C++17 structured bindings for serialization
- Issue #2999³³⁰⁵ - Change thread scheduling use of `size_t` for thread indexing

Closed pull requests

- PR #3865³³⁰⁶ - adds `hpx_target_compile_option_if_available`
- PR #3864³³⁰⁷ - Helper functions that are useful in numa binding and testing of allocator
- PR #3862³³⁰⁸ - Temporary fix to `local_dataflow_boost_small_vector` test
- PR #3860³³⁰⁹ - Add cache line padding to intermediate results in for loop reduction
- PR #3859³³¹⁰ - Remove `HPX_TLL_PUBLIC` and `HPX_TLL_PRIVATE` from CMake files
- PR #3858³³¹¹ - Add compile flags and definitions to modules
- PR #3851³³¹² - update `hpxmp` release tag to v0.2.0
- PR #3849³³¹³ - Correct `BOOST_ROOT` variable name in quick start guide

³²⁹² <https://github.com/STELLAR-GROUP/hpx/issues/3570>

³²⁹³ <https://github.com/STELLAR-GROUP/hpx/issues/3567>

³²⁹⁴ <https://github.com/STELLAR-GROUP/hpx/issues/3565>

³²⁹⁵ <https://github.com/STELLAR-GROUP/hpx/issues/3559>

³²⁹⁶ <https://github.com/STELLAR-GROUP/hpx/issues/3554>

³²⁹⁷ <https://github.com/STELLAR-GROUP/hpx/issues/3510>

³²⁹⁸ <https://github.com/STELLAR-GROUP/hpx/issues/3482>

³²⁹⁹ <https://github.com/STELLAR-GROUP/hpx/issues/3453>

³³⁰⁰ <https://github.com/STELLAR-GROUP/hpx/issues/3452>

³³⁰¹ <https://github.com/STELLAR-GROUP/hpx/issues/3442>

³³⁰² <https://github.com/STELLAR-GROUP/hpx/issues/3437>

³³⁰³ <https://github.com/STELLAR-GROUP/hpx/issues/3255>

³³⁰⁴ <https://github.com/STELLAR-GROUP/hpx/issues/3034>

³³⁰⁵ <https://github.com/STELLAR-GROUP/hpx/issues/2999>

³³⁰⁶ <https://github.com/STELLAR-GROUP/hpx/pull/3865>

³³⁰⁷ <https://github.com/STELLAR-GROUP/hpx/pull/3864>

³³⁰⁸ <https://github.com/STELLAR-GROUP/hpx/pull/3862>

³³⁰⁹ <https://github.com/STELLAR-GROUP/hpx/pull/3860>

³³¹⁰ <https://github.com/STELLAR-GROUP/hpx/pull/3859>

³³¹¹ <https://github.com/STELLAR-GROUP/hpx/pull/3858>

³³¹² <https://github.com/STELLAR-GROUP/hpx/pull/3851>

³³¹³ <https://github.com/STELLAR-GROUP/hpx/pull/3849>

- PR #3847³³¹⁴ - Fix attach_debugger configuration option
- PR #3846³³¹⁵ - Add tests for libs header tests
- PR #3844³³¹⁶ - Fixing source_groups in preprocessor module to properly handle compatibility headers
- PR #3843³³¹⁷ - This fixes the launch_process/launched_process pair of tests
- PR #3842³³¹⁸ - Fix macro call with ITTNOTIFY enabled
- PR #3840³³¹⁹ - Fixing SLURM environment parsing
- PR #3837³³²⁰ - Fixing misplaced #endif
- PR #3835³³²¹ - make all latch members protected for consistency
- PR #3834³³²² - Disable transpose_block_numa example on CircleCI
- PR #3833³³²³ - make latch **counter_** protected for deriving latch in hpxmp
- PR #3831³³²⁴ - Fix CircleCI config for modules
- PR #3830³³²⁵ - minor fix: option HPX_WITH_TEST was not working correctly
- PR #3828³³²⁶ - Avoid for binaries that depend on HPX to directly link against internal modules
- PR #3827³³²⁷ - Adding shortcut for `hpx::get_ptr<>(sync, id)` for a local, non-migratable objects
- PR #3826³³²⁸ - Fix and update modules documentation
- PR #3825³³²⁹ - Updating default APEX version to 2.1.3 with HPX
- PR #3823³³³⁰ - Fix pkgconfig libs handling
- PR #3822³³³¹ - Change includes in hpx_wrap.cpp to more specific includes
- PR #3821³³³² - Disable barrier_3792 test when networking is disabled
- PR #3820³³³³ - Assorted CMake fixes
- PR #3815³³³⁴ - Removing left-over debug output
- PR #3814³³³⁵ - Allow setting default scheduler mode via the configuration database
- PR #3813³³³⁶ - Make the deprecation warnings issued by the old pp headers optional

³³¹⁴ <https://github.com/STELLAR-GROUP/hpx/pull/3847>

³³¹⁵ <https://github.com/STELLAR-GROUP/hpx/pull/3846>

³³¹⁶ <https://github.com/STELLAR-GROUP/hpx/pull/3844>

³³¹⁷ <https://github.com/STELLAR-GROUP/hpx/pull/3843>

³³¹⁸ <https://github.com/STELLAR-GROUP/hpx/pull/3842>

³³¹⁹ <https://github.com/STELLAR-GROUP/hpx/pull/3840>

³³²⁰ <https://github.com/STELLAR-GROUP/hpx/pull/3837>

³³²¹ <https://github.com/STELLAR-GROUP/hpx/pull/3835>

³³²² <https://github.com/STELLAR-GROUP/hpx/pull/3834>

³³²³ <https://github.com/STELLAR-GROUP/hpx/pull/3833>

³³²⁴ <https://github.com/STELLAR-GROUP/hpx/pull/3831>

³³²⁵ <https://github.com/STELLAR-GROUP/hpx/pull/3830>

³³²⁶ <https://github.com/STELLAR-GROUP/hpx/pull/3828>

³³²⁷ <https://github.com/STELLAR-GROUP/hpx/pull/3827>

³³²⁸ <https://github.com/STELLAR-GROUP/hpx/pull/3826>

³³²⁹ <https://github.com/STELLAR-GROUP/hpx/pull/3825>

³³³⁰ <https://github.com/STELLAR-GROUP/hpx/pull/3823>

³³³¹ <https://github.com/STELLAR-GROUP/hpx/pull/3822>

³³³² <https://github.com/STELLAR-GROUP/hpx/pull/3821>

³³³³ <https://github.com/STELLAR-GROUP/hpx/pull/3820>

³³³⁴ <https://github.com/STELLAR-GROUP/hpx/pull/3815>

³³³⁵ <https://github.com/STELLAR-GROUP/hpx/pull/3814>

³³³⁶ <https://github.com/STELLAR-GROUP/hpx/pull/3813>

- PR #3812³³³⁷ - Windows requires to handle symlinks to directories differently from those linking files
- PR #3811³³³⁸ - Clean up PP module and library skeleton
- PR #3806³³³⁹ - Moving include path configuration to before APEX
- PR #3804³³⁴⁰ - Fix latch
- PR #3803³³⁴¹ - Update hpxcxx to look at lib64 and use python3
- PR #3802³³⁴² - Numa binding allocator
- PR #3801³³⁴³ - Remove duplicated includes
- PR #3800³³⁴⁴ - Attempt to fix Posix context switching after lazy init changes
- PR #3798³³⁴⁵ - count and count_if accepts different iterator types
- PR #3797³³⁴⁶ - Adding a couple of override keywords to overloaded virtual functions
- PR #3796³³⁴⁷ - Re-enable testing all schedulers in shutdown_suspended_test
- PR #3795³³⁴⁸ - Change std::terminate to std::abort in SIGSEGV handler
- PR #3794³³⁴⁹ - Fixing #3792
- PR #3793³³⁵⁰ - Extending migrate_polymorphic_component unit test
- PR #3791³³⁵¹ - Change throw() to noexcept
- PR #3790³³⁵² - Remove deprecated options for 1.3.0 release
- PR #3789³³⁵³ - Remove Boost filesystem compatibility header
- PR #3788³³⁵⁴ - Disabled even more spots that should not execute if networking is disabled
- PR #3787³³⁵⁵ - Bump minimal boost supported version to 1.61.0
- PR #3786³³⁵⁶ - Bump minimum required versions for 1.3.0 release
- PR #3785³³⁵⁷ - Explicitly set number of jobs for all ninja invocations on CircleCI
- PR #3784³³⁵⁸ - Fix leak and address sanitizer problems
- PR #3783³³⁵⁹ - Disabled even more spots that should not execute is networking is disabled

³³³⁷ <https://github.com/STELLAR-GROUP/hpx/pull/3812>

³³³⁸ <https://github.com/STELLAR-GROUP/hpx/pull/3811>

³³³⁹ <https://github.com/STELLAR-GROUP/hpx/pull/3806>

³³⁴⁰ <https://github.com/STELLAR-GROUP/hpx/pull/3804>

³³⁴¹ <https://github.com/STELLAR-GROUP/hpx/pull/3803>

³³⁴² <https://github.com/STELLAR-GROUP/hpx/pull/3802>

³³⁴³ <https://github.com/STELLAR-GROUP/hpx/pull/3801>

³³⁴⁴ <https://github.com/STELLAR-GROUP/hpx/pull/3800>

³³⁴⁵ <https://github.com/STELLAR-GROUP/hpx/pull/3798>

³³⁴⁶ <https://github.com/STELLAR-GROUP/hpx/pull/3797>

³³⁴⁷ <https://github.com/STELLAR-GROUP/hpx/pull/3796>

³³⁴⁸ <https://github.com/STELLAR-GROUP/hpx/pull/3795>

³³⁴⁹ <https://github.com/STELLAR-GROUP/hpx/pull/3794>

³³⁵⁰ <https://github.com/STELLAR-GROUP/hpx/pull/3793>

³³⁵¹ <https://github.com/STELLAR-GROUP/hpx/pull/3791>

³³⁵² <https://github.com/STELLAR-GROUP/hpx/pull/3790>

³³⁵³ <https://github.com/STELLAR-GROUP/hpx/pull/3789>

³³⁵⁴ <https://github.com/STELLAR-GROUP/hpx/pull/3788>

³³⁵⁵ <https://github.com/STELLAR-GROUP/hpx/pull/3787>

³³⁵⁶ <https://github.com/STELLAR-GROUP/hpx/pull/3786>

³³⁵⁷ <https://github.com/STELLAR-GROUP/hpx/pull/3785>

³³⁵⁸ <https://github.com/STELLAR-GROUP/hpx/pull/3784>

³³⁵⁹ <https://github.com/STELLAR-GROUP/hpx/pull/3783>

- PR #3782³³⁶⁰ - Cherry-picked tuple and thread_init_data fixes from #3701
- PR #3781³³⁶¹ - Fix generic context coroutines after lazy stack allocation changes
- PR #3780³³⁶² - Rename hello world examples
- PR #3776³³⁶³ - Sort algorithms now use the supplied chunker to determine the required minimal chunk size
- PR #3775³³⁶⁴ - Disable Boost auto-linking
- PR #3774³³⁶⁵ - Tag and push stable builds
- PR #3773³³⁶⁶ - Enable migration of polymorphic components
- PR #3771³³⁶⁷ - Fix link to stackoverflow in documentation
- PR #3770³³⁶⁸ - Replacing constexpr if in brace-serialization code
- PR #3769³³⁶⁹ - Fix SIGSEGV handler
- PR #3768³³⁷⁰ - Adding flags to scheduler allowing to control thread stealing and idle back-off
- PR #3767³³⁷¹ - Fix help formatting in hpxrun.py
- PR #3765³³⁷² - Fix a couple of bugs in the thread test
- PR #3764³³⁷³ - Workaround for SFINAE regression in msvc14.2
- PR #3762³³⁷⁴ - Prevent MSVC from prematurely instantiating things
- PR #3761³³⁷⁵ - Update python scripts to work with python 3
- PR #3760³³⁷⁶ - Fix callable vtable for GCC4.9
- PR #3759³³⁷⁷ - Rename PAGE_SIZE to PAGE_SIZE_ because AppleClang
- PR #3755³³⁷⁸ - Making sure locks are not held during suspension
- PR #3754³³⁷⁹ - Disable more code if networking is not available/not enabled
- PR #3752³³⁸⁰ - Move util::format implementation to source file
- PR #3751³³⁸¹ - Fixing problems with lcos::barrier and iostreams
- PR #3750³³⁸² - Change error message to take into account use_guard_page setting

³³⁶⁰ <https://github.com/STELLAR-GROUP/hpx/pull/3782>

³³⁶¹ <https://github.com/STELLAR-GROUP/hpx/pull/3781>

³³⁶² <https://github.com/STELLAR-GROUP/hpx/pull/3780>

³³⁶³ <https://github.com/STELLAR-GROUP/hpx/pull/3776>

³³⁶⁴ <https://github.com/STELLAR-GROUP/hpx/pull/3775>

³³⁶⁵ <https://github.com/STELLAR-GROUP/hpx/pull/3774>

³³⁶⁶ <https://github.com/STELLAR-GROUP/hpx/pull/3773>

³³⁶⁷ <https://github.com/STELLAR-GROUP/hpx/pull/3771>

³³⁶⁸ <https://github.com/STELLAR-GROUP/hpx/pull/3770>

³³⁶⁹ <https://github.com/STELLAR-GROUP/hpx/pull/3769>

³³⁷⁰ <https://github.com/STELLAR-GROUP/hpx/pull/3768>

³³⁷¹ <https://github.com/STELLAR-GROUP/hpx/pull/3767>

³³⁷² <https://github.com/STELLAR-GROUP/hpx/pull/3765>

³³⁷³ <https://github.com/STELLAR-GROUP/hpx/pull/3764>

³³⁷⁴ <https://github.com/STELLAR-GROUP/hpx/pull/3762>

³³⁷⁵ <https://github.com/STELLAR-GROUP/hpx/pull/3761>

³³⁷⁶ <https://github.com/STELLAR-GROUP/hpx/pull/3760>

³³⁷⁷ <https://github.com/STELLAR-GROUP/hpx/pull/3759>

³³⁷⁸ <https://github.com/STELLAR-GROUP/hpx/pull/3755>

³³⁷⁹ <https://github.com/STELLAR-GROUP/hpx/pull/3754>

³³⁸⁰ <https://github.com/STELLAR-GROUP/hpx/pull/3752>

³³⁸¹ <https://github.com/STELLAR-GROUP/hpx/pull/3751>

³³⁸² <https://github.com/STELLAR-GROUP/hpx/pull/3750>

- PR #3749³³⁸³ - Fix lifetime problem in `run_as_hpx_thread`
- PR #3748³³⁸⁴ - Fixed unusable behavior of the clang code analyzer.
- PR #3747³³⁸⁵ - Added `PMIX_RANK` to the defaults of `HPX_WITH_PARCELPOR_T_MPI_ENV`.
- PR #3745³³⁸⁶ - Introduced `cache_aligned_data` and `cache_line_data` helper structure
- PR #3742³³⁸⁷ - Remove more unused functionality from `util/logging`
- PR #3740³³⁸⁸ - Fix includes in partitioned vector tests
- PR #3739³³⁸⁹ - More fixes to make sure that `std::flush` really flushes all output
- PR #3737³³⁹⁰ - Fix potential shutdown problems
- PR #3736³³⁹¹ - Fix `guided_pool_executor` after dataflow changes caused compilation fail
- PR #3734³³⁹² - Limiting executor
- PR #3732³³⁹³ - More constrained bound constructors
- PR #3730³³⁹⁴ - Attempt to fix deadlocks during component loading
- PR #3729³³⁹⁵ - Add latch member function `count_up` and `reset`, requested by `hpxMP`
- PR #3728³³⁹⁶ - Send even empty buffers on `hpx::endl` and `hpx::flush`
- PR #3727³³⁹⁷ - Adding example demonstrating how to customize the memory management for a component
- PR #3726³³⁹⁸ - Adding support for passing command line options through the `HPX_COMMANDLINE_OPTIONS` environment variable
- PR #3722³³⁹⁹ - Document known broken OpenMPI builds
- PR #3716³⁴⁰⁰ - Add barrier reset function, requested by `hpxMP` for reusing barrier
- PR #3715³⁴⁰¹ - More work on functions and `vtables`
- PR #3714³⁴⁰² - Generate single-page HTML, PDF, manpage from documentation
- PR #3713³⁴⁰³ - Updating default APEX version to 2.1.2
- PR #3712³⁴⁰⁴ - Update release procedure
- PR #3710³⁴⁰⁵ - Fix the C++11 build, after #3704

3383 <https://github.com/STELLAR-GROUP/hpx/pull/3749>

3384 <https://github.com/STELLAR-GROUP/hpx/pull/3748>

3385 <https://github.com/STELLAR-GROUP/hpx/pull/3747>

3386 <https://github.com/STELLAR-GROUP/hpx/pull/3745>

3387 <https://github.com/STELLAR-GROUP/hpx/pull/3742>

3388 <https://github.com/STELLAR-GROUP/hpx/pull/3740>

3389 <https://github.com/STELLAR-GROUP/hpx/pull/3739>

3390 <https://github.com/STELLAR-GROUP/hpx/pull/3737>

3391 <https://github.com/STELLAR-GROUP/hpx/pull/3736>

3392 <https://github.com/STELLAR-GROUP/hpx/pull/3734>

3393 <https://github.com/STELLAR-GROUP/hpx/pull/3732>

3394 <https://github.com/STELLAR-GROUP/hpx/pull/3730>

3395 <https://github.com/STELLAR-GROUP/hpx/pull/3729>

3396 <https://github.com/STELLAR-GROUP/hpx/pull/3728>

3397 <https://github.com/STELLAR-GROUP/hpx/pull/3727>

3398 <https://github.com/STELLAR-GROUP/hpx/pull/3726>

3399 <https://github.com/STELLAR-GROUP/hpx/pull/3722>

3400 <https://github.com/STELLAR-GROUP/hpx/pull/3716>

3401 <https://github.com/STELLAR-GROUP/hpx/pull/3715>

3402 <https://github.com/STELLAR-GROUP/hpx/pull/3714>

3403 <https://github.com/STELLAR-GROUP/hpx/pull/3713>

3404 <https://github.com/STELLAR-GROUP/hpx/pull/3712>

3405 <https://github.com/STELLAR-GROUP/hpx/pull/3710>

- PR #3709³⁴⁰⁶ - Move some component_registry functionality to source file
- PR #3708³⁴⁰⁷ - Ignore all locks while handling assertions
- PR #3707³⁴⁰⁸ - Remove obsolete hpx runtime executable
- PR #3705³⁴⁰⁹ - Fix and simplify make_ready_future overload sets
- PR #3704³⁴¹⁰ - Reduce use of binders
- PR #3703³⁴¹¹ - Ini
- PR #3702³⁴¹² - Fixing CUDA compiler errors
- PR #3700³⁴¹³ - Added barrier::increment function to increase total number of thread
- PR #3697³⁴¹⁴ - One more attempt to fix migration...
- PR #3694³⁴¹⁵ - Fixing component migration
- PR #3693³⁴¹⁶ - Print thread state when getting disallowed value in set_thread_state
- PR #3692³⁴¹⁷ - Only disable constexpr with clang-cuda, not nvcc+gcc
- PR #3691³⁴¹⁸ - Link with libsupc++ if needed for thread_local
- PR #3690³⁴¹⁹ - Remove thousands separators in set_operations_3442 to comply with C++11
- PR #3688³⁴²⁰ - Decouple serialization from function vtables
- PR #3687³⁴²¹ - Fix a couple of test failures
- PR #3686³⁴²² - Make sure tests.unit.build are run after install on CircleCI
- PR #3685³⁴²³ - Revise quickstart CMakeLists.txt explanation
- PR #3684³⁴²⁴ - Provide concept emulation for Ranges-TS concepts
- PR #3683³⁴²⁵ - Ignore uninitialized chunks
- PR #3682³⁴²⁶ - Ignore uninitialized chunks. Check proper indices.
- PR #3680³⁴²⁷ - Ignore uninitialized chunks. Check proper range indices
- PR #3679³⁴²⁸ - Simplify basic action implementations

³⁴⁰⁶ <https://github.com/STELLAR-GROUP/hpx/pull/3709>

³⁴⁰⁷ <https://github.com/STELLAR-GROUP/hpx/pull/3708>

³⁴⁰⁸ <https://github.com/STELLAR-GROUP/hpx/pull/3707>

³⁴⁰⁹ <https://github.com/STELLAR-GROUP/hpx/pull/3705>

³⁴¹⁰ <https://github.com/STELLAR-GROUP/hpx/pull/3704>

³⁴¹¹ <https://github.com/STELLAR-GROUP/hpx/pull/3703>

³⁴¹² <https://github.com/STELLAR-GROUP/hpx/pull/3702>

³⁴¹³ <https://github.com/STELLAR-GROUP/hpx/pull/3700>

³⁴¹⁴ <https://github.com/STELLAR-GROUP/hpx/pull/3697>

³⁴¹⁵ <https://github.com/STELLAR-GROUP/hpx/pull/3694>

³⁴¹⁶ <https://github.com/STELLAR-GROUP/hpx/pull/3693>

³⁴¹⁷ <https://github.com/STELLAR-GROUP/hpx/pull/3692>

³⁴¹⁸ <https://github.com/STELLAR-GROUP/hpx/pull/3691>

³⁴¹⁹ <https://github.com/STELLAR-GROUP/hpx/pull/3690>

³⁴²⁰ <https://github.com/STELLAR-GROUP/hpx/pull/3688>

³⁴²¹ <https://github.com/STELLAR-GROUP/hpx/pull/3687>

³⁴²² <https://github.com/STELLAR-GROUP/hpx/pull/3686>

³⁴²³ <https://github.com/STELLAR-GROUP/hpx/pull/3685>

³⁴²⁴ <https://github.com/STELLAR-GROUP/hpx/pull/3684>

³⁴²⁵ <https://github.com/STELLAR-GROUP/hpx/pull/3683>

³⁴²⁶ <https://github.com/STELLAR-GROUP/hpx/pull/3682>

³⁴²⁷ <https://github.com/STELLAR-GROUP/hpx/pull/3680>

³⁴²⁸ <https://github.com/STELLAR-GROUP/hpx/pull/3679>

- PR #3678³⁴²⁹ - Making sure HPX_HAVE_LIBATOMIC is unset before checking
- PR #3677³⁴³⁰ - Fix generated full version number to be usable in expressions
- PR #3674³⁴³¹ - Reduce functional utilities call depth
- PR #3672³⁴³² - Change new build system to use existing macros related to pseudo dependencies
- PR #3669³⁴³³ - Remove indirection in `function_ref` when thread description is disabled
- PR #3668³⁴³⁴ - Unbreaking `async_*cb*` tests
- PR #3667³⁴³⁵ - Generate `version.hpp`
- PR #3665³⁴³⁶ - Enabling MPI parcellport for gitlab runners
- PR #3664³⁴³⁷ - making clang-tidy work properly again
- PR #3662³⁴³⁸ - Attempt to fix exception handling
- PR #3661³⁴³⁹ - Move `lcos::latch` to source file
- PR #3660³⁴⁴⁰ - Fix accidentally explicit `gid_type` default constructor
- PR #3659³⁴⁴¹ - Parallel executor latch
- PR #3658³⁴⁴² - Fixing `execution_parameters`
- PR #3657³⁴⁴³ - Avoid dangling references in `wait_all`
- PR #3656³⁴⁴⁴ - Avoiding lifetime problems with `sync_put_parcel`
- PR #3655³⁴⁴⁵ - Fixing `nullptr` dereference inside of function
- PR #3652³⁴⁴⁶ - Attempt to fix `thread_map_type` definition with C++11
- PR #3650³⁴⁴⁷ - Allowing for end iterator being different from begin iterator
- PR #3649³⁴⁴⁸ - Added architecture identification to `cmake` to be able to detect timestamp support
- PR #3645³⁴⁴⁹ - Enabling sanitizers on gitlab runner
- PR #3644³⁴⁵⁰ - Attempt to tackle timeouts during startup
- PR #3642³⁴⁵¹ - Cleanup parallel partitioners

³⁴²⁹ <https://github.com/STELLAR-GROUP/hpx/pull/3678>
³⁴³⁰ <https://github.com/STELLAR-GROUP/hpx/pull/3677>
³⁴³¹ <https://github.com/STELLAR-GROUP/hpx/pull/3674>
³⁴³² <https://github.com/STELLAR-GROUP/hpx/pull/3672>
³⁴³³ <https://github.com/STELLAR-GROUP/hpx/pull/3669>
³⁴³⁴ <https://github.com/STELLAR-GROUP/hpx/pull/3668>
³⁴³⁵ <https://github.com/STELLAR-GROUP/hpx/pull/3667>
³⁴³⁶ <https://github.com/STELLAR-GROUP/hpx/pull/3665>
³⁴³⁷ <https://github.com/STELLAR-GROUP/hpx/pull/3664>
³⁴³⁸ <https://github.com/STELLAR-GROUP/hpx/pull/3662>
³⁴³⁹ <https://github.com/STELLAR-GROUP/hpx/pull/3661>
³⁴⁴⁰ <https://github.com/STELLAR-GROUP/hpx/pull/3660>
³⁴⁴¹ <https://github.com/STELLAR-GROUP/hpx/pull/3659>
³⁴⁴² <https://github.com/STELLAR-GROUP/hpx/pull/3658>
³⁴⁴³ <https://github.com/STELLAR-GROUP/hpx/pull/3657>
³⁴⁴⁴ <https://github.com/STELLAR-GROUP/hpx/pull/3656>
³⁴⁴⁵ <https://github.com/STELLAR-GROUP/hpx/pull/3655>
³⁴⁴⁶ <https://github.com/STELLAR-GROUP/hpx/pull/3652>
³⁴⁴⁷ <https://github.com/STELLAR-GROUP/hpx/pull/3650>
³⁴⁴⁸ <https://github.com/STELLAR-GROUP/hpx/pull/3649>
³⁴⁴⁹ <https://github.com/STELLAR-GROUP/hpx/pull/3645>
³⁴⁵⁰ <https://github.com/STELLAR-GROUP/hpx/pull/3644>
³⁴⁵¹ <https://github.com/STELLAR-GROUP/hpx/pull/3642>

- PR #3640³⁴⁵² - Dataflow now works with functions that return a reference
- PR #3637³⁴⁵³ - Merging the executor-enabled overloads of `shared_future<>::then`
- PR #3633³⁴⁵⁴ - Replace deprecated boost endian macros
- PR #3632³⁴⁵⁵ - Add instructions on getting HPX to documentation
- PR #3631³⁴⁵⁶ - Simplify parcel creation
- PR #3630³⁴⁵⁷ - Small additions and fixes to release procedure
- PR #3629³⁴⁵⁸ - Modular pp
- PR #3627³⁴⁵⁹ - Implement `util::function_ref`
- PR #3626³⁴⁶⁰ - Fix cancelable_action_client example
- PR #3625³⁴⁶¹ - Added automatic serialization for simple structs (see #3034)
- PR #3624³⁴⁶² - Updating the default order of priority for `thread_description`
- PR #3621³⁴⁶³ - Update copyright year and other small formatting fixes
- PR #3620³⁴⁶⁴ - Adding support for gitlab runner
- PR #3619³⁴⁶⁵ - Store debug logs and core dumps on CircleCI
- PR #3618³⁴⁶⁶ - Various optimizations
- PR #3617³⁴⁶⁷ - Fix link to the gpg key (#2)
- PR #3615³⁴⁶⁸ - Fix unused variable warnings with networking off
- PR #3614³⁴⁶⁹ - Restructuring counter data in scheduler to reduce false sharing
- PR #3613³⁴⁷⁰ - Adding support for gitlab runners
- PR #3610³⁴⁷¹ - Don't wait for `stop_condition` in main thread
- PR #3608³⁴⁷² - Add inline keyword to `invalid_thread_id` definition for nvcc
- PR #3607³⁴⁷³ - Adding configuration key that allows one to explicitly add a directory to the component search path
- PR #3606³⁴⁷⁴ - Add nvcc to exclude constexpress since is it not supported by nvcc

³⁴⁵² <https://github.com/STELLAR-GROUP/hpx/pull/3640>

³⁴⁵³ <https://github.com/STELLAR-GROUP/hpx/pull/3637>

³⁴⁵⁴ <https://github.com/STELLAR-GROUP/hpx/pull/3633>

³⁴⁵⁵ <https://github.com/STELLAR-GROUP/hpx/pull/3632>

³⁴⁵⁶ <https://github.com/STELLAR-GROUP/hpx/pull/3631>

³⁴⁵⁷ <https://github.com/STELLAR-GROUP/hpx/pull/3630>

³⁴⁵⁸ <https://github.com/STELLAR-GROUP/hpx/pull/3629>

³⁴⁵⁹ <https://github.com/STELLAR-GROUP/hpx/pull/3627>

³⁴⁶⁰ <https://github.com/STELLAR-GROUP/hpx/pull/3626>

³⁴⁶¹ <https://github.com/STELLAR-GROUP/hpx/pull/3625>

³⁴⁶² <https://github.com/STELLAR-GROUP/hpx/pull/3624>

³⁴⁶³ <https://github.com/STELLAR-GROUP/hpx/pull/3621>

³⁴⁶⁴ <https://github.com/STELLAR-GROUP/hpx/pull/3620>

³⁴⁶⁵ <https://github.com/STELLAR-GROUP/hpx/pull/3619>

³⁴⁶⁶ <https://github.com/STELLAR-GROUP/hpx/pull/3618>

³⁴⁶⁷ <https://github.com/STELLAR-GROUP/hpx/pull/3617>

³⁴⁶⁸ <https://github.com/STELLAR-GROUP/hpx/pull/3615>

³⁴⁶⁹ <https://github.com/STELLAR-GROUP/hpx/pull/3614>

³⁴⁷⁰ <https://github.com/STELLAR-GROUP/hpx/pull/3613>

³⁴⁷¹ <https://github.com/STELLAR-GROUP/hpx/pull/3610>

³⁴⁷² <https://github.com/STELLAR-GROUP/hpx/pull/3608>

³⁴⁷³ <https://github.com/STELLAR-GROUP/hpx/pull/3607>

³⁴⁷⁴ <https://github.com/STELLAR-GROUP/hpx/pull/3606>

- PR #3605³⁴⁷⁵ - Add `inline` to definition of checkpoint stream operators to fix link error
- PR #3604³⁴⁷⁶ - Use format for string formatting
- PR #3603³⁴⁷⁷ - Improve the error message for using to less `MAX_CPU_COUNT`
- PR #3602³⁴⁷⁸ - Improve the error message for to small values of `MAX_CPU_COUNT`
- PR #3600³⁴⁷⁹ - Parallel executor aggregated
- PR #3599³⁴⁸⁰ - Making sure networking is disabled for default one-locality-runs
- PR #3596³⁴⁸¹ - Store thread exit functions in `forward_list` instead of `deque` to avoid allocations
- PR #3590³⁴⁸² - Fix typo/mistake in thread queue `cleanup_terminated`
- PR #3588³⁴⁸³ - Fix formatting errors in `launching_and_configuring_hpx_applications.rst`
- PR #3586³⁴⁸⁴ - Make `bind` propagate value category
- PR #3585³⁴⁸⁵ - Extend Cmake for building hpx as distribution packages (refs #3575)
- PR #3584³⁴⁸⁶ - Untangle function storage from object pointer
- PR #3582³⁴⁸⁷ - Towards Modularized HPX
- PR #3580³⁴⁸⁸ - Remove extra `||` in `merge.hpp`
- PR #3577³⁴⁸⁹ - Partially revert “Remove vtable empty flag”
- PR #3576³⁴⁹⁰ - Make sure empty startup/shutdown functions are not being used
- PR #3574³⁴⁹¹ - Make sure `DATAPAR` settings are conveyed to depending projects
- PR #3573³⁴⁹² - Make sure HPX is usable with latest released version of Vc (V1.4.1)
- PR #3572³⁴⁹³ - Adding test ensuring ticket 3565 is fixed
- PR #3571³⁴⁹⁴ - Make empty `[unique_]function` vtable non-dependent
- PR #3566³⁴⁹⁵ - Fix compilation with dynamic bitset for CPU masks
- PR #3563³⁴⁹⁶ - Drop `util::[unique_]function` `target_type`
- PR #3562³⁴⁹⁷ - Removing the target suffixes

³⁴⁷⁵ <https://github.com/STELLAR-GROUP/hpx/pull/3605>

³⁴⁷⁶ <https://github.com/STELLAR-GROUP/hpx/pull/3604>

³⁴⁷⁷ <https://github.com/STELLAR-GROUP/hpx/pull/3603>

³⁴⁷⁸ <https://github.com/STELLAR-GROUP/hpx/pull/3602>

³⁴⁷⁹ <https://github.com/STELLAR-GROUP/hpx/pull/3600>

³⁴⁸⁰ <https://github.com/STELLAR-GROUP/hpx/pull/3599>

³⁴⁸¹ <https://github.com/STELLAR-GROUP/hpx/pull/3596>

³⁴⁸² <https://github.com/STELLAR-GROUP/hpx/pull/3590>

³⁴⁸³ <https://github.com/STELLAR-GROUP/hpx/pull/3588>

³⁴⁸⁴ <https://github.com/STELLAR-GROUP/hpx/pull/3586>

³⁴⁸⁵ <https://github.com/STELLAR-GROUP/hpx/pull/3585>

³⁴⁸⁶ <https://github.com/STELLAR-GROUP/hpx/pull/3584>

³⁴⁸⁷ <https://github.com/STELLAR-GROUP/hpx/pull/3582>

³⁴⁸⁸ <https://github.com/STELLAR-GROUP/hpx/pull/3580>

³⁴⁸⁹ <https://github.com/STELLAR-GROUP/hpx/pull/3577>

³⁴⁹⁰ <https://github.com/STELLAR-GROUP/hpx/pull/3576>

³⁴⁹¹ <https://github.com/STELLAR-GROUP/hpx/pull/3574>

³⁴⁹² <https://github.com/STELLAR-GROUP/hpx/pull/3573>

³⁴⁹³ <https://github.com/STELLAR-GROUP/hpx/pull/3572>

³⁴⁹⁴ <https://github.com/STELLAR-GROUP/hpx/pull/3571>

³⁴⁹⁵ <https://github.com/STELLAR-GROUP/hpx/pull/3566>

³⁴⁹⁶ <https://github.com/STELLAR-GROUP/hpx/pull/3563>

³⁴⁹⁷ <https://github.com/STELLAR-GROUP/hpx/pull/3562>

- PR #3561³⁴⁹⁸ - Replace executor traits return type deduction (keep non-SFINAE)
- PR #3557³⁴⁹⁹ - Replace the last usages of boost::atomic
- PR #3556³⁵⁰⁰ - Replace boost::scoped_array with std::unique_ptr
- PR #3552³⁵⁰¹ - (Re)move APEX readme
- PR #3548³⁵⁰² - Replace boost::scoped_ptr with std::unique_ptr
- PR #3547³⁵⁰³ - Remove last use of Boost.Signals2
- PR #3544³⁵⁰⁴ - Post 1.2.0 version bumps
- PR #3543³⁵⁰⁵ - added Ubuntu dependency list to readme
- PR #3531³⁵⁰⁶ - Warnings, warnings...
- PR #3527³⁵⁰⁷ - Add CircleCI filter for building all tags
- PR #3525³⁵⁰⁸ - Segmented algorithms
- PR #3517³⁵⁰⁹ - Replace boost::regex with C++11 <regex>
- PR #3514³⁵¹⁰ - Cleaning up the build system
- PR #3505³⁵¹¹ - Fixing type attribute warning for transfer_action
- PR #3504³⁵¹² - Add support for rpm packaging
- PR #3499³⁵¹³ - Improving spinlock pools
- PR #3498³⁵¹⁴ - Remove thread specific ptr
- PR #3486³⁵¹⁵ - Fix comparison for expect_connecting_localities config entry
- PR #3469³⁵¹⁶ - Enable (existing) code for extracting stack pointer on Power platform

³⁴⁹⁸ <https://github.com/STELLAR-GROUP/hpx/pull/3561>

³⁴⁹⁹ <https://github.com/STELLAR-GROUP/hpx/pull/3557>

³⁵⁰⁰ <https://github.com/STELLAR-GROUP/hpx/pull/3556>

³⁵⁰¹ <https://github.com/STELLAR-GROUP/hpx/pull/3552>

³⁵⁰² <https://github.com/STELLAR-GROUP/hpx/pull/3548>

³⁵⁰³ <https://github.com/STELLAR-GROUP/hpx/pull/3547>

³⁵⁰⁴ <https://github.com/STELLAR-GROUP/hpx/pull/3544>

³⁵⁰⁵ <https://github.com/STELLAR-GROUP/hpx/pull/3543>

³⁵⁰⁶ <https://github.com/STELLAR-GROUP/hpx/pull/3531>

³⁵⁰⁷ <https://github.com/STELLAR-GROUP/hpx/pull/3527>

³⁵⁰⁸ <https://github.com/STELLAR-GROUP/hpx/pull/3525>

³⁵⁰⁹ <https://github.com/STELLAR-GROUP/hpx/pull/3517>

³⁵¹⁰ <https://github.com/STELLAR-GROUP/hpx/pull/3514>

³⁵¹¹ <https://github.com/STELLAR-GROUP/hpx/pull/3505>

³⁵¹² <https://github.com/STELLAR-GROUP/hpx/pull/3504>

³⁵¹³ <https://github.com/STELLAR-GROUP/hpx/pull/3499>

³⁵¹⁴ <https://github.com/STELLAR-GROUP/hpx/pull/3498>

³⁵¹⁵ <https://github.com/STELLAR-GROUP/hpx/pull/3486>

³⁵¹⁶ <https://github.com/STELLAR-GROUP/hpx/pull/3469>

HPX V1.2.1 (Feb 19, 2019)

General changes

This is a bugfix release. It contains the following changes:

- Fix compilation on ARM, s390x and 32-bit architectures.
- Fix a critical bug in the `future` implementation.
- Fix several problems in the CMake configuration which affects external projects.
- Add support for Boost 1.69.0.

Closed issues

- Issue #3638³⁵¹⁷ - Build HPX 1.2 with boost 1.69
- Issue #3635³⁵¹⁸ - Non-deterministic crashing on Stampede2
- Issue #3550³⁵¹⁹ - `1>e:000workhpxsrcthrw_exception.cpp(54): error C2440: '<function-style-cast>': cannot convert from 'boost::system::error_code' to 'hpx::exception'`
- Issue #3549³⁵²⁰ - HPX 1.2.0 does not build on i686, but release candidate did
- Issue #3511³⁵²¹ - Build on s390x fails
- Issue #3509³⁵²² - Build on armv7l fails

Closed pull requests

- PR #3695³⁵²³ - Don't install CMake templates and packaging files
- PR #3666³⁵²⁴ - Fixing yet another race in `future_data`
- PR #3663³⁵²⁵ - Fixing race between setting and getting the value inside `future_data`
- PR #3648³⁵²⁶ - Adding timestamp option for S390x platform
- PR #3647³⁵²⁷ - Blind attempt to fix warnings issued by gcc V9
- PR #3611³⁵²⁸ - Include `GNUInstallDirs` earlier to have it available for subdirectories
- PR #3595³⁵²⁹ - Use `GNUInstallDirs` lib path in `pkgconfig` config file
- PR #3593³⁵³⁰ - Add `include(GNUInstallDirs)` to `HPXMacros.cmake`

³⁵¹⁷ <https://github.com/STELLAR-GROUP/hpx/issues/3638>

³⁵¹⁸ <https://github.com/STELLAR-GROUP/hpx/issues/3635>

³⁵¹⁹ <https://github.com/STELLAR-GROUP/hpx/issues/3550>

³⁵²⁰ <https://github.com/STELLAR-GROUP/hpx/issues/3549>

³⁵²¹ <https://github.com/STELLAR-GROUP/hpx/issues/3511>

³⁵²² <https://github.com/STELLAR-GROUP/hpx/issues/3509>

³⁵²³ <https://github.com/STELLAR-GROUP/hpx/pull/3695>

³⁵²⁴ <https://github.com/STELLAR-GROUP/hpx/pull/3666>

³⁵²⁵ <https://github.com/STELLAR-GROUP/hpx/pull/3663>

³⁵²⁶ <https://github.com/STELLAR-GROUP/hpx/pull/3648>

³⁵²⁷ <https://github.com/STELLAR-GROUP/hpx/pull/3647>

³⁵²⁸ <https://github.com/STELLAR-GROUP/hpx/pull/3611>

³⁵²⁹ <https://github.com/STELLAR-GROUP/hpx/pull/3595>

³⁵³⁰ <https://github.com/STELLAR-GROUP/hpx/pull/3593>

- PR #3591³⁵³¹ - Fix compilation error on arm7 architecture. Compiles and runs on Fedora 29 on Pi 3.
- PR #3558³⁵³² - Adding constructor *exception(boost::system::error_code const&)*
- PR #3555³⁵³³ - cmake: make install locations configurable
- PR #3551³⁵³⁴ - Fix uint64_t causing compilation fail on i686

HPX V1.2.0 (Nov 12, 2018)

General changes

Here are some of the main highlights and changes for this release:

- Thanks to the work of our Google Summer of Code student, Nikunj Gupta, we now have a new implementation of `hpx_main.hpp` on supported platforms (Linux, BSD and MacOS). This is intended to be a less fragile drop-in replacement for the old implementation relying on preprocessor macros. The new implementation does not require changes if you are using the `CMake`³⁵³⁵ or `pkg-config`. The old behaviour can be restored by setting `HPX_WITH_DYNAMIC_HPX_MAIN=OFF` during `CMake`³⁵³⁶ configuration. The implementation on Windows is unchanged.
- We have added functionality to allow passing scheduling hints to our schedulers. These will allow us to create executors that for example target a specific NUMA domain or allow for *HPX* threads to be pinned to a particular worker thread.
- We have significantly improved the performance of our futures implementation by making the shared state atomic.
- We have replaced Boostbook by Sphinx for our documentation. This means the documentation is easier to navigate with built-in search and table of contents. We have also added a quick start section and restructured the documentation to be easier to follow for new users.
- We have added a new option to the `--hpx:threads` command line option. It is now possible to use `cores` to tell *HPX* to only use one worker thread per core, unlike the existing option `all` which uses one worker thread per processing unit (processing unit can be a hyperthread if hyperthreads are available). The default value of `--hpx:threads` has also been changed to `cores` as this leads to better performance in most cases.
- All command line options can now be passed alongside configuration options when initializing *HPX*. This means that some options that were previously only available on the command line can now be set as configuration options.
- *HPXMP* is a portable, scalable, and flexible application programming interface using the OpenMP specification that supports multi-platform shared memory multiprocessing programming in C and C++. *HPXMP* can be enabled within *HPX* by setting `DHPX_WITH_HPMP=ON` during `CMake`³⁵³⁷ configuration.
- Two new performance counters were added for measuring the time spent doing background work. `/threads/time/background-work-duration` returns the time spent doing background on a given thread or locality, while `/threads/time/background-overhead` returns the fraction of time spent doing background work with respect to the overall time spent running the scheduler. The new performance counters are disabled by default and can be turned on by setting `HPX_WITH_BACKGROUND_THREAD_COUNTERS=ON` during `CMake`³⁵³⁸ configuration.

³⁵³¹ <https://github.com/STELLAR-GROUP/hpx/pull/3591>

³⁵³² <https://github.com/STELLAR-GROUP/hpx/pull/3558>

³⁵³³ <https://github.com/STELLAR-GROUP/hpx/pull/3555>

³⁵³⁴ <https://github.com/STELLAR-GROUP/hpx/pull/3551>

³⁵³⁵ <https://www.cmake.org>

³⁵³⁶ <https://www.cmake.org>

³⁵³⁷ <https://www.cmake.org>

³⁵³⁸ <https://www.cmake.org>

- The idling behaviour of *HPX* has been tweaked to allow for faster idling. This is useful in interactive applications where the *HPX* worker threads may not have work all the time. This behaviour can be tweaked and turned off as before with `HPX_WITH_THREAD_MANAGER_IDLE_BACKOFF=OFF` during `CMake`³⁵³⁹ configuration.
- It is now possible to register callback functions for *HPX* worker thread events. Callbacks can be registered for starting and stopping worker threads, and for when errors occur.

Breaking changes

- The implementation of `hpx_main.hpp` has changed. If you are using custom Makefiles you will need to make changes. Please see the documentation on *using Makefiles* for more details.
- The default value of `--hpx:threads` has changed from `all` to `cores`. The new option `cores` only starts one worker thread per core.
- We have dropped support for Boost 1.56 and 1.57. The minimal version of Boost we now test is 1.58.
- Our `boost::format`-based formatting implementation has been revised and replaced with a custom implementation. This changes the formatting syntax and requires changes if you are relying on `hpx::util::format` or `hpx::util::format_to`. The pull request for this change contains more information: [PR #3266](#)³⁵⁴⁰.
- The following deprecated options have now been completely removed:
`HPX_WITH_ASYNC_FUNCTION_COMPATIBILITY`, `HPX_WITH_LOCAL_DATAFLOW`,
`HPX_WITH_GENERIC_EXECUTION_POLICY`, `HPX_WITH_BOOST_CHRONO_COMPATIBILITY`,
`HPX_WITH_EXECUTOR_COMPATIBILITY`, `HPX_WITH_EXECUTION_POLICY_COMPATIBILITY`, and
`HPX_WITH_TRANSFORM_REDUCE_COMPATIBILITY`.

Closed issues

- [Issue #3538](#)³⁵⁴¹ - numa handling incorrect for hwloc 2
- [Issue #3533](#)³⁵⁴² - Cmake version 3.5.1 does not work (git ff26b35 2018-11-06)
- [Issue #3526](#)³⁵⁴³ - Failed building hpx-1.2.0-rc1 on Ubuntu16.04 x86-64 Virtualbox VM
- [Issue #3512](#)³⁵⁴⁴ - Build on aarch64 fails
- [Issue #3475](#)³⁵⁴⁵ - HPX fails to link if the MPI parcelport is enabled
- [Issue #3462](#)³⁵⁴⁶ - CMake configuration shows a minor and inconsequential failure to create a symlink
- [Issue #3461](#)³⁵⁴⁷ - Compilation Problems with the most recent Clang
- [Issue #3460](#)³⁵⁴⁸ - Deadlock when `create_partitioner` fails (assertion fails) in debug mode
- [Issue #3455](#)³⁵⁴⁹ - HPX build failing with HWLOC errors on POWER8 with hwloc 1.8
- [Issue #3438](#)³⁵⁵⁰ - HPX no longer builds on IBM POWER8

³⁵³⁹ <https://www.cmake.org>

³⁵⁴⁰ <https://github.com/STELLAR-GROUP/hpx/pull/3266>

³⁵⁴¹ <https://github.com/STELLAR-GROUP/hpx/issues/3538>

³⁵⁴² <https://github.com/STELLAR-GROUP/hpx/issues/3533>

³⁵⁴³ <https://github.com/STELLAR-GROUP/hpx/issues/3526>

³⁵⁴⁴ <https://github.com/STELLAR-GROUP/hpx/issues/3512>

³⁵⁴⁵ <https://github.com/STELLAR-GROUP/hpx/issues/3475>

³⁵⁴⁶ <https://github.com/STELLAR-GROUP/hpx/issues/3462>

³⁵⁴⁷ <https://github.com/STELLAR-GROUP/hpx/issues/3461>

³⁵⁴⁸ <https://github.com/STELLAR-GROUP/hpx/issues/3460>

³⁵⁴⁹ <https://github.com/STELLAR-GROUP/hpx/issues/3455>

³⁵⁵⁰ <https://github.com/STELLAR-GROUP/hpx/issues/3438>

- Issue #3426³⁵⁵¹ - hpx build failed on MacOS
- Issue #3424³⁵⁵² - CircleCI builds broken for forked repositories
- Issue #3422³⁵⁵³ - Benchmarks in tests.performance.local are not run nightly
- Issue #3408³⁵⁵⁴ - CMake Targets for HPX
- Issue #3399³⁵⁵⁵ - processing unit out of bounds
- Issue #3395³⁵⁵⁶ - Floating point bug in hpx/runtime/threads/policies/scheduler_base.hpp
- Issue #3378³⁵⁵⁷ - compile error with lcos::communicator
- Issue #3376³⁵⁵⁸ - Failed to build HPX with APEX using clang
- Issue #3366³⁵⁵⁹ - Adapted Safe_Object example fails for `-hpx:threads > 1`
- Issue #3360³⁵⁶⁰ - Segmentation fault when passing component id as parameter
- Issue #3358³⁵⁶¹ - HPX runtime hangs after multiple (~thousands) start-stop sequences
- Issue #3352³⁵⁶² - Support TCP provider in libfabric ParcelPort
- Issue #3342³⁵⁶³ - undefined reference to `__atomic_load_16`
- Issue #3339³⁵⁶⁴ - setting command line options/flags from init cfg is not obvious
- Issue #3325³⁵⁶⁵ - AGAS migrates components prematurely
- Issue #3321³⁵⁶⁶ - hpx bad_parameter handling is awful
- Issue #3318³⁵⁶⁷ - Benchmarks fail to build with C++11
- Issue #3304³⁵⁶⁸ - `hpx::threads::run_as_hpx_thread` does not properly handle exceptions
- Issue #3300³⁵⁶⁹ - Setting pu step or offset results in no threads in default pool
- Issue #3297³⁵⁷⁰ - Crash with APEX when running Phylax Ira_csv with > 1 thread
- Issue #3296³⁵⁷¹ - Building HPX with APEX configuration gives compiler warnings
- Issue #3290³⁵⁷² - make tests failing at hello_world_component
- Issue #3285³⁵⁷³ - possible compilation error when “using namespace std;” is defined before including “hpx” headers files

³⁵⁵¹ <https://github.com/STELLAR-GROUP/hpx/issues/3426>

³⁵⁵² <https://github.com/STELLAR-GROUP/hpx/issues/3424>

³⁵⁵³ <https://github.com/STELLAR-GROUP/hpx/issues/3422>

³⁵⁵⁴ <https://github.com/STELLAR-GROUP/hpx/issues/3408>

³⁵⁵⁵ <https://github.com/STELLAR-GROUP/hpx/issues/3399>

³⁵⁵⁶ <https://github.com/STELLAR-GROUP/hpx/issues/3395>

³⁵⁵⁷ <https://github.com/STELLAR-GROUP/hpx/issues/3378>

³⁵⁵⁸ <https://github.com/STELLAR-GROUP/hpx/issues/3376>

³⁵⁵⁹ <https://github.com/STELLAR-GROUP/hpx/issues/3366>

³⁵⁶⁰ <https://github.com/STELLAR-GROUP/hpx/issues/3360>

³⁵⁶¹ <https://github.com/STELLAR-GROUP/hpx/issues/3358>

³⁵⁶² <https://github.com/STELLAR-GROUP/hpx/issues/3352>

³⁵⁶³ <https://github.com/STELLAR-GROUP/hpx/issues/3342>

³⁵⁶⁴ <https://github.com/STELLAR-GROUP/hpx/issues/3339>

³⁵⁶⁵ <https://github.com/STELLAR-GROUP/hpx/issues/3325>

³⁵⁶⁶ <https://github.com/STELLAR-GROUP/hpx/issues/3321>

³⁵⁶⁷ <https://github.com/STELLAR-GROUP/hpx/issues/3318>

³⁵⁶⁸ <https://github.com/STELLAR-GROUP/hpx/issues/3304>

³⁵⁶⁹ <https://github.com/STELLAR-GROUP/hpx/issues/3300>

³⁵⁷⁰ <https://github.com/STELLAR-GROUP/hpx/issues/3297>

³⁵⁷¹ <https://github.com/STELLAR-GROUP/hpx/issues/3296>

³⁵⁷² <https://github.com/STELLAR-GROUP/hpx/issues/3290>

³⁵⁷³ <https://github.com/STELLAR-GROUP/hpx/issues/3285>

- Issue #3280³⁵⁷⁴ - HPX fails on OSX
- Issue #3272³⁵⁷⁵ - CircleCI does not upload generated docker image any more
- Issue #3270³⁵⁷⁶ - Error when compiling CUDA examples
- Issue #3267³⁵⁷⁷ - `tests.unit.host_.block_allocator` fails occasionally
- Issue #3264³⁵⁷⁸ - Possible move to Sphinx for documentation
- Issue #3263³⁵⁷⁹ - Documentation improvements
- Issue #3259³⁵⁸⁰ - `set_parcel_write_handler` test fails occasionally
- Issue #3258³⁵⁸¹ - Links to source code in documentation are broken
- Issue #3247³⁵⁸² - Rare `tests.unit.host_.block_allocator` test failure on 1.1.0-rc1
- Issue #3244³⁵⁸³ - Slowing down and speeding up an `interval_timer`
- Issue #3215³⁵⁸⁴ - Cannot build both tests and examples on MSVC with pseudo-dependencies enabled
- Issue #3195³⁵⁸⁵ - Unnecessary customization point route causing performance penalty
- Issue #3088³⁵⁸⁶ - A strange thing in `parallel::sort`.
- Issue #2650³⁵⁸⁷ - libfabric support for passive endpoints
- Issue #1205³⁵⁸⁸ - TSS is broken

Closed pull requests

- PR #3542³⁵⁸⁹ - Fix numa lookup from pu when using hwloc 2.x
- PR #3541³⁵⁹⁰ - Fixing the build system of the MPI parcelport
- PR #3540³⁵⁹¹ - Updating HPX people section
- PR #3539³⁵⁹² - Splitting test to avoid OOM on CircleCI
- PR #3537³⁵⁹³ - Fix guided exec
- PR #3536³⁵⁹⁴ - Updating grants which support the LSU team
- PR #3535³⁵⁹⁵ - Fix hiding of docker credentials

³⁵⁷⁴ <https://github.com/STELLAR-GROUP/hpx/issues/3280>

³⁵⁷⁵ <https://github.com/STELLAR-GROUP/hpx/issues/3272>

³⁵⁷⁶ <https://github.com/STELLAR-GROUP/hpx/issues/3270>

³⁵⁷⁷ <https://github.com/STELLAR-GROUP/hpx/issues/3267>

³⁵⁷⁸ <https://github.com/STELLAR-GROUP/hpx/issues/3264>

³⁵⁷⁹ <https://github.com/STELLAR-GROUP/hpx/issues/3263>

³⁵⁸⁰ <https://github.com/STELLAR-GROUP/hpx/issues/3259>

³⁵⁸¹ <https://github.com/STELLAR-GROUP/hpx/issues/3258>

³⁵⁸² <https://github.com/STELLAR-GROUP/hpx/issues/3247>

³⁵⁸³ <https://github.com/STELLAR-GROUP/hpx/issues/3244>

³⁵⁸⁴ <https://github.com/STELLAR-GROUP/hpx/issues/3215>

³⁵⁸⁵ <https://github.com/STELLAR-GROUP/hpx/issues/3195>

³⁵⁸⁶ <https://github.com/STELLAR-GROUP/hpx/issues/3088>

³⁵⁸⁷ <https://github.com/STELLAR-GROUP/hpx/issues/2650>

³⁵⁸⁸ <https://github.com/STELLAR-GROUP/hpx/issues/1205>

³⁵⁸⁹ <https://github.com/STELLAR-GROUP/hpx/pull/3542>

³⁵⁹⁰ <https://github.com/STELLAR-GROUP/hpx/pull/3541>

³⁵⁹¹ <https://github.com/STELLAR-GROUP/hpx/pull/3540>

³⁵⁹² <https://github.com/STELLAR-GROUP/hpx/pull/3539>

³⁵⁹³ <https://github.com/STELLAR-GROUP/hpx/pull/3537>

³⁵⁹⁴ <https://github.com/STELLAR-GROUP/hpx/pull/3536>

³⁵⁹⁵ <https://github.com/STELLAR-GROUP/hpx/pull/3535>

- PR #3534³⁵⁹⁶ - Fixing #3533
- PR #3532³⁵⁹⁷ - fixing minor doc typo `-hpx:print-counter-at` arg
- PR #3530³⁵⁹⁸ - Changing APEX default tag to v2.1.0
- PR #3529³⁵⁹⁹ - Remove leftover security options and documentation
- PR #3528³⁶⁰⁰ - Fix hwloc version check
- PR #3524³⁶⁰¹ - Do not build guided pool examples with older GCC compilers
- PR #3523³⁶⁰² - Fix logging regression
- PR #3522³⁶⁰³ - Fix more warnings
- PR #3521³⁶⁰⁴ - Fixing argument handling in induction and reduction clauses for `parallel::for_loop`
- PR #3520³⁶⁰⁵ - Remove docs symlink and versioned docs folders
- PR #3519³⁶⁰⁶ - hpxMP release
- PR #3518³⁶⁰⁷ - Change all steps to use new docker image on CircleCI
- PR #3516³⁶⁰⁸ - Drop usage of deprecated facilities removed in C++17
- PR #3515³⁶⁰⁹ - Remove remaining uses of `Boost.TypeTraits`
- PR #3513³⁶¹⁰ - Fixing a CMake problem when trying to use `libfabric`
- PR #3508³⁶¹¹ - Remove `memory_block` component
- PR #3507³⁶¹² - Propagating the MPI compile definitions to all relevant targets
- PR #3503³⁶¹³ - Update documentation colors and logo
- PR #3502³⁶¹⁴ - Fix bogus ``throws`` bindings in `scheduled_thread_pool_impl`
- PR #3501³⁶¹⁵ - Split `parallel::remove_if` tests to avoid OOM on CircleCI
- PR #3500³⁶¹⁶ - Support `NONAMEPREFIX` in `add_hpx_library()`
- PR #3497³⁶¹⁷ - Note that cuda support requires cmake 3.9
- PR #3495³⁶¹⁸ - Fixing dataflow

³⁵⁹⁶ <https://github.com/STELLAR-GROUP/hpx/pull/3534>

³⁵⁹⁷ <https://github.com/STELLAR-GROUP/hpx/pull/3532>

³⁵⁹⁸ <https://github.com/STELLAR-GROUP/hpx/pull/3530>

³⁵⁹⁹ <https://github.com/STELLAR-GROUP/hpx/pull/3529>

³⁶⁰⁰ <https://github.com/STELLAR-GROUP/hpx/pull/3528>

³⁶⁰¹ <https://github.com/STELLAR-GROUP/hpx/pull/3524>

³⁶⁰² <https://github.com/STELLAR-GROUP/hpx/pull/3523>

³⁶⁰³ <https://github.com/STELLAR-GROUP/hpx/pull/3522>

³⁶⁰⁴ <https://github.com/STELLAR-GROUP/hpx/pull/3521>

³⁶⁰⁵ <https://github.com/STELLAR-GROUP/hpx/pull/3520>

³⁶⁰⁶ <https://github.com/STELLAR-GROUP/hpx/pull/3519>

³⁶⁰⁷ <https://github.com/STELLAR-GROUP/hpx/pull/3518>

³⁶⁰⁸ <https://github.com/STELLAR-GROUP/hpx/pull/3516>

³⁶⁰⁹ <https://github.com/STELLAR-GROUP/hpx/pull/3515>

³⁶¹⁰ <https://github.com/STELLAR-GROUP/hpx/pull/3513>

³⁶¹¹ <https://github.com/STELLAR-GROUP/hpx/pull/3508>

³⁶¹² <https://github.com/STELLAR-GROUP/hpx/pull/3507>

³⁶¹³ <https://github.com/STELLAR-GROUP/hpx/pull/3503>

³⁶¹⁴ <https://github.com/STELLAR-GROUP/hpx/pull/3502>

³⁶¹⁵ <https://github.com/STELLAR-GROUP/hpx/pull/3501>

³⁶¹⁶ <https://github.com/STELLAR-GROUP/hpx/pull/3500>

³⁶¹⁷ <https://github.com/STELLAR-GROUP/hpx/pull/3497>

³⁶¹⁸ <https://github.com/STELLAR-GROUP/hpx/pull/3495>

- PR #3493³⁶¹⁹ - Remove deprecated options for 1.2.0 part 2
- PR #3492³⁶²⁰ - Add CUDA_LINK_LIBRARIES_KEYWORD to allow PRIVATE keyword in linkage t...
- PR #3491³⁶²¹ - Changing Base docker image
- PR #3490³⁶²² - Don't create tasks immediately with hpx::apply
- PR #3489³⁶²³ - Remove deprecated options for 1.2.0
- PR #3488³⁶²⁴ - Revert "Use BUILD_INTERFACE generator expression to fix cmake flag exports"
- PR #3487³⁶²⁵ - Revert "Fixing type attribute warning for transfer_action"
- PR #3485³⁶²⁶ - Use BUILD_INTERFACE generator expression to fix cmake flag exports
- PR #3483³⁶²⁷ - Fixing type attribute warning for transfer_action
- PR #3481³⁶²⁸ - Remove unused variables
- PR #3480³⁶²⁹ - Towards a more lightweight transfer action
- PR #3479³⁶³⁰ - Fix FLAGS - Use correct version of target_compile_options
- PR #3478³⁶³¹ - Making sure the application's exit code is properly propagated back to the OS
- PR #3476³⁶³² - Don't print docker credentials as part of the environment.
- PR #3473³⁶³³ - Fixing invalid cmake code if no jemalloc prefix was given
- PR #3472³⁶³⁴ - Attempting to work around recent clang test compilation failures
- PR #3471³⁶³⁵ - Enable jemalloc on windows
- PR #3470³⁶³⁶ - Updates readme
- PR #3468³⁶³⁷ - Avoid hang if there is an exception thrown during startup
- PR #3467³⁶³⁸ - Add compiler specific fallback attributes if C++17 attribute is not available
- PR #3466³⁶³⁹ - - bugfix : fix compilation with llvm-7.0
- PR #3465³⁶⁴⁰ - This patch adds various optimizations extracted from the thread_local_allocator work
- PR #3464³⁶⁴¹ - Check for forked repos in CircleCI docker push step

³⁶¹⁹ <https://github.com/STELLAR-GROUP/hpx/pull/3493>

³⁶²⁰ <https://github.com/STELLAR-GROUP/hpx/pull/3492>

³⁶²¹ <https://github.com/STELLAR-GROUP/hpx/pull/3491>

³⁶²² <https://github.com/STELLAR-GROUP/hpx/pull/3490>

³⁶²³ <https://github.com/STELLAR-GROUP/hpx/pull/3489>

³⁶²⁴ <https://github.com/STELLAR-GROUP/hpx/pull/3488>

³⁶²⁵ <https://github.com/STELLAR-GROUP/hpx/pull/3487>

³⁶²⁶ <https://github.com/STELLAR-GROUP/hpx/pull/3485>

³⁶²⁷ <https://github.com/STELLAR-GROUP/hpx/pull/3483>

³⁶²⁸ <https://github.com/STELLAR-GROUP/hpx/pull/3481>

³⁶²⁹ <https://github.com/STELLAR-GROUP/hpx/pull/3480>

³⁶³⁰ <https://github.com/STELLAR-GROUP/hpx/pull/3479>

³⁶³¹ <https://github.com/STELLAR-GROUP/hpx/pull/3478>

³⁶³² <https://github.com/STELLAR-GROUP/hpx/pull/3476>

³⁶³³ <https://github.com/STELLAR-GROUP/hpx/pull/3473>

³⁶³⁴ <https://github.com/STELLAR-GROUP/hpx/pull/3472>

³⁶³⁵ <https://github.com/STELLAR-GROUP/hpx/pull/3471>

³⁶³⁶ <https://github.com/STELLAR-GROUP/hpx/pull/3470>

³⁶³⁷ <https://github.com/STELLAR-GROUP/hpx/pull/3468>

³⁶³⁸ <https://github.com/STELLAR-GROUP/hpx/pull/3467>

³⁶³⁹ <https://github.com/STELLAR-GROUP/hpx/pull/3466>

³⁶⁴⁰ <https://github.com/STELLAR-GROUP/hpx/pull/3465>

³⁶⁴¹ <https://github.com/STELLAR-GROUP/hpx/pull/3464>

- PR #3463³⁶⁴² - - cmake : create the parent directory before symlinking
- PR #3459³⁶⁴³ - Remove unused/incomplete functionality from util/logging
- PR #3458³⁶⁴⁴ - Fix a problem with scope of CMAKE_CXX_FLAGS and hpx_add_compile_flag
- PR #3457³⁶⁴⁵ - Fixing more size_t -> int16_t (and similar) warnings
- PR #3456³⁶⁴⁶ - Add #ifdefs to topology.cpp to support old hwloc versions again
- PR #3454³⁶⁴⁷ - Fixing warnings related to silent conversion of size_t -> int16_t
- PR #3451³⁶⁴⁸ - Add examples as unit tests
- PR #3450³⁶⁴⁹ - Constexpr-fying bind and other functional facilities
- PR #3446³⁶⁵⁰ - Fix some thread suspension timeouts
- PR #3445³⁶⁵¹ - Fix various warnings
- PR #3443³⁶⁵² - Only enable service pool config options if pools are enabled
- PR #3441³⁶⁵³ - Fix missing closing brackets in documentation
- PR #3439³⁶⁵⁴ - Use correct MPI CXX libraries for MPI parcelport
- PR #3436³⁶⁵⁵ - Add projection function to find_* (and fix very bad bug)
- PR #3435³⁶⁵⁶ - Fixing 1205
- PR #3434³⁶⁵⁷ - Fix threads cores
- PR #3433³⁶⁵⁸ - Add Heise Online to release announcement list
- PR #3432³⁶⁵⁹ - Don't track task dependencies for distributed runs
- PR #3431³⁶⁶⁰ - Circle CI setting changes for hpxMP
- PR #3430³⁶⁶¹ - Fix unused params warning
- PR #3429³⁶⁶² - One thread per core
- PR #3428³⁶⁶³ - This suppresses a deprecation warning that is being issued by MSVC 19.15.26726
- PR #3427³⁶⁶⁴ - Fixes #3426

³⁶⁴² <https://github.com/STELLAR-GROUP/hpx/pull/3463>

³⁶⁴³ <https://github.com/STELLAR-GROUP/hpx/pull/3459>

³⁶⁴⁴ <https://github.com/STELLAR-GROUP/hpx/pull/3458>

³⁶⁴⁵ <https://github.com/STELLAR-GROUP/hpx/pull/3457>

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³⁶⁴⁷ <https://github.com/STELLAR-GROUP/hpx/pull/3454>

³⁶⁴⁸ <https://github.com/STELLAR-GROUP/hpx/pull/3451>

³⁶⁴⁹ <https://github.com/STELLAR-GROUP/hpx/pull/3450>

³⁶⁵⁰ <https://github.com/STELLAR-GROUP/hpx/pull/3446>

³⁶⁵¹ <https://github.com/STELLAR-GROUP/hpx/pull/3445>

³⁶⁵² <https://github.com/STELLAR-GROUP/hpx/pull/3443>

³⁶⁵³ <https://github.com/STELLAR-GROUP/hpx/pull/3441>

³⁶⁵⁴ <https://github.com/STELLAR-GROUP/hpx/pull/3439>

³⁶⁵⁵ <https://github.com/STELLAR-GROUP/hpx/pull/3436>

³⁶⁵⁶ <https://github.com/STELLAR-GROUP/hpx/pull/3435>

³⁶⁵⁷ <https://github.com/STELLAR-GROUP/hpx/pull/3434>

³⁶⁵⁸ <https://github.com/STELLAR-GROUP/hpx/pull/3433>

³⁶⁵⁹ <https://github.com/STELLAR-GROUP/hpx/pull/3432>

³⁶⁶⁰ <https://github.com/STELLAR-GROUP/hpx/pull/3431>

³⁶⁶¹ <https://github.com/STELLAR-GROUP/hpx/pull/3430>

³⁶⁶² <https://github.com/STELLAR-GROUP/hpx/pull/3429>

³⁶⁶³ <https://github.com/STELLAR-GROUP/hpx/pull/3428>

³⁶⁶⁴ <https://github.com/STELLAR-GROUP/hpx/pull/3427>

- PR #3425³⁶⁶⁵ - Use source cache and workspace between job steps on CircleCI
- PR #3421³⁶⁶⁶ - Add CDash timing output to future overhead test (for graphs)
- PR #3420³⁶⁶⁷ - Add guided_pool_executor
- PR #3419³⁶⁶⁸ - Fix typo in CircleCI config
- PR #3418³⁶⁶⁹ - Add sphinx documentation
- PR #3415³⁶⁷⁰ - Scheduler NUMA hint and shared priority scheduler
- PR #3414³⁶⁷¹ - Adding step to synchronize the APEX release
- PR #3413³⁶⁷² - Fixing multiple defines of APEX_HAVE_HPX
- PR #3412³⁶⁷³ - Fixes linking with libhpx_wrap error with BSD and Windows based systems
- PR #3410³⁶⁷⁴ - Fix typo in CMakeLists.txt
- PR #3409³⁶⁷⁵ - Fix brackets and indentation in existing_performance_counters.qbk
- PR #3407³⁶⁷⁶ - Fix unused param and extra ; warnings emitted by gcc 8.x
- PR #3406³⁶⁷⁷ - Adding thread local allocator and use it for future shared states
- PR #3405³⁶⁷⁸ - Adding DHPX_HAVE_THREAD_LOCAL_STORAGE=ON to builds
- PR #3404³⁶⁷⁹ - fixing multiple definition of main() in linux
- PR #3402³⁶⁸⁰ - Allow debug option to be enabled only for Linux systems with dynamic main on
- PR #3401³⁶⁸¹ - Fix cuda_future_helper.h when compiling with C++11
- PR #3400³⁶⁸² - Fix floating point exception scheduler_base idle backoff
- PR #3398³⁶⁸³ - Atomic future state
- PR #3397³⁶⁸⁴ - Fixing code for older gcc versions
- PR #3396³⁶⁸⁵ - Allowing to register thread event functions (start/stop/error)
- PR #3394³⁶⁸⁶ - Fix small mistake in primary_namespace_server.cpp
- PR #3393³⁶⁸⁷ - Explicitly instantiate configured schedulers

³⁶⁶⁵ <https://github.com/STELLAR-GROUP/hpx/pull/3425>

³⁶⁶⁶ <https://github.com/STELLAR-GROUP/hpx/pull/3421>

³⁶⁶⁷ <https://github.com/STELLAR-GROUP/hpx/pull/3420>

³⁶⁶⁸ <https://github.com/STELLAR-GROUP/hpx/pull/3419>

³⁶⁶⁹ <https://github.com/STELLAR-GROUP/hpx/pull/3418>

³⁶⁷⁰ <https://github.com/STELLAR-GROUP/hpx/pull/3415>

³⁶⁷¹ <https://github.com/STELLAR-GROUP/hpx/pull/3414>

³⁶⁷² <https://github.com/STELLAR-GROUP/hpx/pull/3413>

³⁶⁷³ <https://github.com/STELLAR-GROUP/hpx/pull/3412>

³⁶⁷⁴ <https://github.com/STELLAR-GROUP/hpx/pull/3410>

³⁶⁷⁵ <https://github.com/STELLAR-GROUP/hpx/pull/3409>

³⁶⁷⁶ <https://github.com/STELLAR-GROUP/hpx/pull/3407>

³⁶⁷⁷ <https://github.com/STELLAR-GROUP/hpx/pull/3406>

³⁶⁷⁸ <https://github.com/STELLAR-GROUP/hpx/pull/3405>

³⁶⁷⁹ <https://github.com/STELLAR-GROUP/hpx/pull/3404>

³⁶⁸⁰ <https://github.com/STELLAR-GROUP/hpx/pull/3402>

³⁶⁸¹ <https://github.com/STELLAR-GROUP/hpx/pull/3401>

³⁶⁸² <https://github.com/STELLAR-GROUP/hpx/pull/3400>

³⁶⁸³ <https://github.com/STELLAR-GROUP/hpx/pull/3398>

³⁶⁸⁴ <https://github.com/STELLAR-GROUP/hpx/pull/3397>

³⁶⁸⁵ <https://github.com/STELLAR-GROUP/hpx/pull/3396>

³⁶⁸⁶ <https://github.com/STELLAR-GROUP/hpx/pull/3394>

³⁶⁸⁷ <https://github.com/STELLAR-GROUP/hpx/pull/3393>

- PR #3392³⁶⁸⁸ - Add performance counters background overhead and background work duration
- PR #3391³⁶⁸⁹ - Adapt integration of HPXMP to latest build system changes
- PR #3390³⁶⁹⁰ - Make AGAS measurements optional
- PR #3389³⁶⁹¹ - Fix deadlock during shutdown
- PR #3388³⁶⁹² - Add several functionalities allowing to optimize synchronous action invocation
- PR #3387³⁶⁹³ - Add cmake option to opt out of fail-compile tests
- PR #3386³⁶⁹⁴ - Adding support for boost::container::small_vector to dataflow
- PR #3385³⁶⁹⁵ - Adds Debug option for hpx initializing from main
- PR #3384³⁶⁹⁶ - This hopefully fixes two tests that occasionally fail
- PR #3383³⁶⁹⁷ - Making sure thread local storage is enable for hpxMP
- PR #3382³⁶⁹⁸ - Fix usage of HPX_CAPTURE together with default value capture [=]
- PR #3381³⁶⁹⁹ - Replace undefined instantiations of uniform_int_distribution
- PR #3380³⁷⁰⁰ - Add missing semicolons to uses of HPX_COMPILER_FENCE
- PR #3379³⁷⁰¹ - Fixing #3378
- PR #3377³⁷⁰² - Adding build system support to integrate hpxmp into hpx at the user's machine
- PR #3375³⁷⁰³ - Replacing wrapper for __libc_start_main with main
- PR #3374³⁷⁰⁴ - Adds hpx_wrap to HPX_LINK_LIBRARIES which links only when specified.
- PR #3373³⁷⁰⁵ - Forcing cache settings in HPXConfig.cmake to guarantee updated values
- PR #3372³⁷⁰⁶ - Fix some more c++11 build problems
- PR #3371³⁷⁰⁷ - Adds HPX_LINKER_FLAGS to HPX applications without editing their source codes
- PR #3370³⁷⁰⁸ - util::format: add type_specifier<> specializations for %!s(MISSING) and %!(MISSING)s
- PR #3369³⁷⁰⁹ - Adding configuration option to allow explicit disable of the new hpx_main feature on Linux
- PR #3368³⁷¹⁰ - Updates doc with recent hpx_wrap implementation

³⁶⁸⁸ <https://github.com/STELLAR-GROUP/hpx/pull/3392>

³⁶⁸⁹ <https://github.com/STELLAR-GROUP/hpx/pull/3391>

³⁶⁹⁰ <https://github.com/STELLAR-GROUP/hpx/pull/3390>

³⁶⁹¹ <https://github.com/STELLAR-GROUP/hpx/pull/3389>

³⁶⁹² <https://github.com/STELLAR-GROUP/hpx/pull/3388>

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³⁶⁹⁴ <https://github.com/STELLAR-GROUP/hpx/pull/3386>

³⁶⁹⁵ <https://github.com/STELLAR-GROUP/hpx/pull/3385>

³⁶⁹⁶ <https://github.com/STELLAR-GROUP/hpx/pull/3384>

³⁶⁹⁷ <https://github.com/STELLAR-GROUP/hpx/pull/3383>

³⁶⁹⁸ <https://github.com/STELLAR-GROUP/hpx/pull/3382>

³⁶⁹⁹ <https://github.com/STELLAR-GROUP/hpx/pull/3381>

³⁷⁰⁰ <https://github.com/STELLAR-GROUP/hpx/pull/3380>

³⁷⁰¹ <https://github.com/STELLAR-GROUP/hpx/pull/3379>

³⁷⁰² <https://github.com/STELLAR-GROUP/hpx/pull/3377>

³⁷⁰³ <https://github.com/STELLAR-GROUP/hpx/pull/3375>

³⁷⁰⁴ <https://github.com/STELLAR-GROUP/hpx/pull/3374>

³⁷⁰⁵ <https://github.com/STELLAR-GROUP/hpx/pull/3373>

³⁷⁰⁶ <https://github.com/STELLAR-GROUP/hpx/pull/3372>

³⁷⁰⁷ <https://github.com/STELLAR-GROUP/hpx/pull/3371>

³⁷⁰⁸ <https://github.com/STELLAR-GROUP/hpx/pull/3370>

³⁷⁰⁹ <https://github.com/STELLAR-GROUP/hpx/pull/3369>

³⁷¹⁰ <https://github.com/STELLAR-GROUP/hpx/pull/3368>

- PR #3367³⁷¹¹ - Adds Mac OS implementation to hpx_main.hpp
- PR #3365³⁷¹² - Fix order of hpx libs in HPX_CONF_LIBRARIES.
- PR #3363³⁷¹³ - Apex fixing null wrapper
- PR #3361³⁷¹⁴ - Making sure all parcels get destroyed on an HPX thread (TCP pp)
- PR #3359³⁷¹⁵ - Feature/improveerrorforcompiler
- PR #3357³⁷¹⁶ - Static/dynamic executable implementation
- PR #3355³⁷¹⁷ - Reverting changes introduced by #3283 as those make applications hang
- PR #3354³⁷¹⁸ - Add external dependencies to HPX_LIBRARY_DIR
- PR #3353³⁷¹⁹ - Fix libfabric tcp
- PR #3351³⁷²⁰ - Move obsolete header to tests directory.
- PR #3350³⁷²¹ - Renaming two functions to avoid problem described in #3285
- PR #3349³⁷²² - Make idle backoff exponential with maximum sleep time
- PR #3347³⁷²³ - Replace *simple_component** with *component** in the Documentation
- PR #3346³⁷²⁴ - Fix CMakeLists.txt example in quick start
- PR #3345³⁷²⁵ - Fix automatic setting of HPX_MORE_THAN_64_THREADS
- PR #3344³⁷²⁶ - Reduce amount of information printed for unknown command line options
- PR #3343³⁷²⁷ - Safeguard HPX against destruction in global contexts
- PR #3341³⁷²⁸ - Allowing for all command line options to be used as configuration settings
- PR #3340³⁷²⁹ - Always convert inspect results to JUnit XML
- PR #3336³⁷³⁰ - Only run docker push on master on CircleCI
- PR #3335³⁷³¹ - Update description of hpx.os_threads config parameter.
- PR #3334³⁷³² - Making sure early logging settings don't get mixed with others
- PR #3333³⁷³³ - Update CMake links and versions in documentation

³⁷¹¹ <https://github.com/STELLAR-GROUP/hpx/pull/3367>

³⁷¹² <https://github.com/STELLAR-GROUP/hpx/pull/3365>

³⁷¹³ <https://github.com/STELLAR-GROUP/hpx/pull/3363>

³⁷¹⁴ <https://github.com/STELLAR-GROUP/hpx/pull/3361>

³⁷¹⁵ <https://github.com/STELLAR-GROUP/hpx/pull/3359>

³⁷¹⁶ <https://github.com/STELLAR-GROUP/hpx/pull/3357>

³⁷¹⁷ <https://github.com/STELLAR-GROUP/hpx/pull/3355>

³⁷¹⁸ <https://github.com/STELLAR-GROUP/hpx/pull/3354>

³⁷¹⁹ <https://github.com/STELLAR-GROUP/hpx/pull/3353>

³⁷²⁰ <https://github.com/STELLAR-GROUP/hpx/pull/3351>

³⁷²¹ <https://github.com/STELLAR-GROUP/hpx/pull/3350>

³⁷²² <https://github.com/STELLAR-GROUP/hpx/pull/3349>

³⁷²³ <https://github.com/STELLAR-GROUP/hpx/pull/3347>

³⁷²⁴ <https://github.com/STELLAR-GROUP/hpx/pull/3346>

³⁷²⁵ <https://github.com/STELLAR-GROUP/hpx/pull/3345>

³⁷²⁶ <https://github.com/STELLAR-GROUP/hpx/pull/3344>

³⁷²⁷ <https://github.com/STELLAR-GROUP/hpx/pull/3343>

³⁷²⁸ <https://github.com/STELLAR-GROUP/hpx/pull/3341>

³⁷²⁹ <https://github.com/STELLAR-GROUP/hpx/pull/3340>

³⁷³⁰ <https://github.com/STELLAR-GROUP/hpx/pull/3336>

³⁷³¹ <https://github.com/STELLAR-GROUP/hpx/pull/3335>

³⁷³² <https://github.com/STELLAR-GROUP/hpx/pull/3334>

³⁷³³ <https://github.com/STELLAR-GROUP/hpx/pull/3333>

- PR #3332³⁷³⁴ - Add notes on target suffixes to CMake documentation
- PR #3331³⁷³⁵ - Add quickstart section to documentation
- PR #3330³⁷³⁶ - Rename resource_partitioner test to avoid conflicts with pseudodependencies
- PR #3328³⁷³⁷ - Making sure object is pinned while executing actions, even if action returns a future
- PR #3327³⁷³⁸ - Add missing std::forward to tuple.hpp
- PR #3326³⁷³⁹ - Make sure logging is up and running while modules are being discovered.
- PR #3324³⁷⁴⁰ - Replace C++14 overload of std::equal with C++11 code.
- PR #3323³⁷⁴¹ - Fix a missing apex thread data (wrapper) initialization
- PR #3320³⁷⁴² - Adding support for -std=c++2a (define *HPX_WITH_CXX2A=On*)
- PR #3319³⁷⁴³ - Replacing C++14 feature with equivalent C++11 code
- PR #3317³⁷⁴⁴ - Fix compilation with VS 15.7.1 and /std:c++latest
- PR #3316³⁷⁴⁵ - Fix includes for 1d_stencil*_omp examples
- PR #3314³⁷⁴⁶ - Remove some unused parameter warnings
- PR #3313³⁷⁴⁷ - Fix pu-step and pu-offset command line options
- PR #3312³⁷⁴⁸ - Add conversion of inspect reports to JUnit XML
- PR #3311³⁷⁴⁹ - Fix escaping of closing braces in format specification syntax
- PR #3310³⁷⁵⁰ - Don't overwrite user settings with defaults in registration database
- PR #3309³⁷⁵¹ - Fixing potential stack overflow for dataflow
- PR #3308³⁷⁵² - This updates the .clang-format configuration file to utilize newer features
- PR #3306³⁷⁵³ - Marking migratable objects in their gid to allow not handling migration in AGAS
- PR #3305³⁷⁵⁴ - Add proper exception handling to run_as_hpx_thread
- PR #3303³⁷⁵⁵ - Changed std::rand to a better inbuilt PRNG Generator
- PR #3302³⁷⁵⁶ - All non-migratable (simple) components now encode their lva and component type in their gid

³⁷³⁴ <https://github.com/STELLAR-GROUP/hpx/pull/3332>

³⁷³⁵ <https://github.com/STELLAR-GROUP/hpx/pull/3331>

³⁷³⁶ <https://github.com/STELLAR-GROUP/hpx/pull/3330>

³⁷³⁷ <https://github.com/STELLAR-GROUP/hpx/pull/3328>

³⁷³⁸ <https://github.com/STELLAR-GROUP/hpx/pull/3327>

³⁷³⁹ <https://github.com/STELLAR-GROUP/hpx/pull/3326>

³⁷⁴⁰ <https://github.com/STELLAR-GROUP/hpx/pull/3324>

³⁷⁴¹ <https://github.com/STELLAR-GROUP/hpx/pull/3323>

³⁷⁴² <https://github.com/STELLAR-GROUP/hpx/pull/3320>

³⁷⁴³ <https://github.com/STELLAR-GROUP/hpx/pull/3319>

³⁷⁴⁴ <https://github.com/STELLAR-GROUP/hpx/pull/3317>

³⁷⁴⁵ <https://github.com/STELLAR-GROUP/hpx/pull/3316>

³⁷⁴⁶ <https://github.com/STELLAR-GROUP/hpx/pull/3314>

³⁷⁴⁷ <https://github.com/STELLAR-GROUP/hpx/pull/3313>

³⁷⁴⁸ <https://github.com/STELLAR-GROUP/hpx/pull/3312>

³⁷⁴⁹ <https://github.com/STELLAR-GROUP/hpx/pull/3311>

³⁷⁵⁰ <https://github.com/STELLAR-GROUP/hpx/pull/3310>

³⁷⁵¹ <https://github.com/STELLAR-GROUP/hpx/pull/3309>

³⁷⁵² <https://github.com/STELLAR-GROUP/hpx/pull/3308>

³⁷⁵³ <https://github.com/STELLAR-GROUP/hpx/pull/3306>

³⁷⁵⁴ <https://github.com/STELLAR-GROUP/hpx/pull/3305>

³⁷⁵⁵ <https://github.com/STELLAR-GROUP/hpx/pull/3303>

³⁷⁵⁶ <https://github.com/STELLAR-GROUP/hpx/pull/3302>

- PR #3301³⁷⁵⁷ - Add nullptr_t overloads to resource partitioner
- PR #3298³⁷⁵⁸ - Apex task wrapper memory bug
- PR #3295³⁷⁵⁹ - Fix mistakes after merge of CircleCI config
- PR #3294³⁷⁶⁰ - Fix partitioned vector include in partitioned_vector_find tests
- PR #3293³⁷⁶¹ - Adding emplace support to promise and make_ready_future
- PR #3292³⁷⁶² - Add new cuda kernel synchronization with hpx::future demo
- PR #3291³⁷⁶³ - Fixes #3290
- PR #3289³⁷⁶⁴ - Fixing Docker image creation
- PR #3288³⁷⁶⁵ - Avoid allocating shared state for wait_all
- PR #3287³⁷⁶⁶ - Fixing /scheduler/utilization/instantaneous performance counter
- PR #3286³⁷⁶⁷ - dataflow() and future::then() use sync policy where possible
- PR #3284³⁷⁶⁸ - Background thread can use relaxed atomics to manipulate thread state
- PR #3283³⁷⁶⁹ - Do not unwrap ready future
- PR #3282³⁷⁷⁰ - Fix virtual method override warnings in static schedulers
- PR #3281³⁷⁷¹ - Disable set_area_membind_nodeset for OSX
- PR #3279³⁷⁷² - Add two variations to the future_overhead benchmark
- PR #3278³⁷⁷³ - Fix circleci workspace
- PR #3277³⁷⁷⁴ - Support external plugins
- PR #3276³⁷⁷⁵ - Fix missing parenthesis in hello_compute.cu.
- PR #3274³⁷⁷⁶ - Reinit counters synchronously in reinit_counters test
- PR #3273³⁷⁷⁷ - Splitting tests to avoid compiler OOM
- PR #3271³⁷⁷⁸ - Remove leftover code from context_generic_context.hpp
- PR #3269³⁷⁷⁹ - Fix bulk_construct with count = 0

³⁷⁵⁷ <https://github.com/STELLAR-GROUP/hpx/pull/3301>
³⁷⁵⁸ <https://github.com/STELLAR-GROUP/hpx/pull/3298>
³⁷⁵⁹ <https://github.com/STELLAR-GROUP/hpx/pull/3295>
³⁷⁶⁰ <https://github.com/STELLAR-GROUP/hpx/pull/3294>
³⁷⁶¹ <https://github.com/STELLAR-GROUP/hpx/pull/3293>
³⁷⁶² <https://github.com/STELLAR-GROUP/hpx/pull/3292>
³⁷⁶³ <https://github.com/STELLAR-GROUP/hpx/pull/3291>
³⁷⁶⁴ <https://github.com/STELLAR-GROUP/hpx/pull/3289>
³⁷⁶⁵ <https://github.com/STELLAR-GROUP/hpx/pull/3288>
³⁷⁶⁶ <https://github.com/STELLAR-GROUP/hpx/pull/3287>
³⁷⁶⁷ <https://github.com/STELLAR-GROUP/hpx/pull/3286>
³⁷⁶⁸ <https://github.com/STELLAR-GROUP/hpx/pull/3284>
³⁷⁶⁹ <https://github.com/STELLAR-GROUP/hpx/pull/3283>
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³⁷⁷¹ <https://github.com/STELLAR-GROUP/hpx/pull/3281>
³⁷⁷² <https://github.com/STELLAR-GROUP/hpx/pull/3279>
³⁷⁷³ <https://github.com/STELLAR-GROUP/hpx/pull/3278>
³⁷⁷⁴ <https://github.com/STELLAR-GROUP/hpx/pull/3277>
³⁷⁷⁵ <https://github.com/STELLAR-GROUP/hpx/pull/3276>
³⁷⁷⁶ <https://github.com/STELLAR-GROUP/hpx/pull/3274>
³⁷⁷⁷ <https://github.com/STELLAR-GROUP/hpx/pull/3273>
³⁷⁷⁸ <https://github.com/STELLAR-GROUP/hpx/pull/3271>
³⁷⁷⁹ <https://github.com/STELLAR-GROUP/hpx/pull/3269>

- PR #3268³⁷⁸⁰ - Replace constexpr with HPX_CXX14_CONSTEXPR and HPX_CONSTEXPR
- PR #3266³⁷⁸¹ - Replace boost::format with custom printf-based implementation
- PR #3265³⁷⁸² - Split parallel tests on CircleCI
- PR #3262³⁷⁸³ - Making sure documentation correctly links to source files
- PR #3261³⁷⁸⁴ - Apex refactoring fix rebind
- PR #3260³⁷⁸⁵ - Isolate performance counter parser into a separate TU
- PR #3256³⁷⁸⁶ - Post 1.1.0 version bumps
- PR #3254³⁷⁸⁷ - Adding trait for actions allowing to make runtime decision on whether to execute it directly
- PR #3253³⁷⁸⁸ - Bump minimal supported Boost to 1.58.0
- PR #3251³⁷⁸⁹ - Adds new feature: changing interval used in interval_timer (issue 3244)
- PR #3239³⁷⁹⁰ - Changing std::rand() to a better inbuilt PRNG generator.
- PR #3234³⁷⁹¹ - Disable background thread when networking is off
- PR #3232³⁷⁹² - Clean up suspension tests
- PR #3230³⁷⁹³ - Add optional scheduler mode parameter to create_thread_pool function
- PR #3228³⁷⁹⁴ - Allow suspension also on static schedulers
- PR #3163³⁷⁹⁵ - libfabric parcelport w/o HPX_PARCELPOR_T_LIBFABRIC_ENDPOINT_RDM
- PR #3036³⁷⁹⁶ - Switching to CircleCI 2.0

HPX V1.1.0 (Mar 24, 2018)

General changes

Here are some of the main highlights and changes for this release (in no particular order):

- We have changed the way *HPX* manages the processing units on a node. We do not longer implicitly bind all available cores to a single thread pool. The user has now full control over what processing units are bound to what thread pool, each with a separate scheduler. It is now also possible to create your own scheduler implementation and control what processing units this scheduler should use. We added the `hpx::resource::partitioner` that manages all available processing units and assigns resources to the used thread pools. Thread pools can be

³⁷⁸⁰ <https://github.com/STELLAR-GROUP/hpx/pull/3268>
³⁷⁸¹ <https://github.com/STELLAR-GROUP/hpx/pull/3266>
³⁷⁸² <https://github.com/STELLAR-GROUP/hpx/pull/3265>
³⁷⁸³ <https://github.com/STELLAR-GROUP/hpx/pull/3262>
³⁷⁸⁴ <https://github.com/STELLAR-GROUP/hpx/pull/3261>
³⁷⁸⁵ <https://github.com/STELLAR-GROUP/hpx/pull/3260>
³⁷⁸⁶ <https://github.com/STELLAR-GROUP/hpx/pull/3256>
³⁷⁸⁷ <https://github.com/STELLAR-GROUP/hpx/pull/3254>
³⁷⁸⁸ <https://github.com/STELLAR-GROUP/hpx/pull/3253>
³⁷⁸⁹ <https://github.com/STELLAR-GROUP/hpx/pull/3251>
³⁷⁹⁰ <https://github.com/STELLAR-GROUP/hpx/pull/3239>
³⁷⁹¹ <https://github.com/STELLAR-GROUP/hpx/pull/3234>
³⁷⁹² <https://github.com/STELLAR-GROUP/hpx/pull/3232>
³⁷⁹³ <https://github.com/STELLAR-GROUP/hpx/pull/3230>
³⁷⁹⁴ <https://github.com/STELLAR-GROUP/hpx/pull/3228>
³⁷⁹⁵ <https://github.com/STELLAR-GROUP/hpx/pull/3163>
³⁷⁹⁶ <https://github.com/STELLAR-GROUP/hpx/pull/3036>

now be suspended/resumed independently. This functionality helps in running *HPX* concurrently to code that is directly relying on [OpenMP](https://openmp.org/wp/)³⁷⁹⁷ and/or [MPI](https://en.wikipedia.org/wiki/Message_Passing_Interface)³⁷⁹⁸.

- We have continued to implement various parallel algorithms. *HPX* now almost completely implements all of the parallel algorithms as specified by the [C++17 Standard](http://www.open-std.org/jtc1/sc22/wg21)³⁷⁹⁹. We have also continued to implement these algorithms for the distributed use case (for segmented data structures, such as `hpx::partitioned_vector`).
- Added a compatibility layer for `std::thread`, `std::mutex`, and `std::condition_variable` allowing for the code to use those facilities where available and to fall back to the corresponding Boost facilities otherwise. The [CMake](https://www.cmake.org)³⁸⁰⁰ configuration option `-DHPX_WITH_THREAD_COMPATIBILITY=On` can be used to force using the Boost equivalents.
- The parameter sequence for the `hpx::parallel::transform_inclusive_scan` overload taking one iterator range has changed (again) to match the changes this algorithm has undergone while being moved to C++17. The old overloads can be still enabled at configure time by passing `-DHPX_WITH_TRANSFORM_REDUCE_COMPATIBILITY=On` to [CMake](https://www.cmake.org)³⁸⁰¹.
- The parameter sequence for the `hpx::parallel::inclusive_scan` overload taking one iterator range has changed to match the changes this algorithm has undergone while being moved to C++17. The old overloads can be still enabled at configure time by passing `-DHPX_WITH_INCLUSIVE_SCAN_COMPATIBILITY=On` to [CMake](https://www.cmake.org).
- Added a helper facility `hpx::local_new` which is equivalent to `hpx::new_` except that it creates components locally only. As a consequence, the used component constructor may accept non-serializable argument types and/or non-const references or pointers.
- Removed the (broken) component type `hpx::lcos::queue<T>`. The old type is still available at configure time by passing `-DHPX_WITH_QUEUE_COMPATIBILITY=On` to [CMake](https://www.cmake.org).
- The parallel algorithms adopted for C++17 restrict the iterator categories usable with those to at least forward iterators. Our implementation of the parallel algorithms was supporting input iterators (and output iterators) as well by simply falling back to sequential execution. We have now made our implementations conforming by requiring at least forward iterators. In order to enable the old behavior use the compatibility option `-DHPX_WITH_ALGORITHM_INPUT_ITERATOR_SUPPORT=On` on the [CMake](https://www.cmake.org)³⁸⁰² command line.
- We have added the functionalities allowing for LCOs being implemented using (simple) components. Before LCOs had to always be implemented using managed components.
- User defined components don't have to be default-constructible anymore. Return types from actions don't have to be default-constructible anymore either. Our serialization layer now in general supports non-default-constructible types.
- We have added a new launch policy `hpx::launch::lazy` that allows one to defer the decision on what launch policy to use to the point of execution. This policy is initialized with a function (object) that – when invoked – is expected to produce the desired launch policy.

³⁷⁹⁷ <https://openmp.org/wp/>

³⁷⁹⁸ https://en.wikipedia.org/wiki/Message_Passing_Interface

³⁷⁹⁹ <http://www.open-std.org/jtc1/sc22/wg21>

³⁸⁰⁰ <https://www.cmake.org>

³⁸⁰¹ <https://www.cmake.org>

³⁸⁰² <https://www.cmake.org>

Breaking changes

- We have dropped support for the gcc compiler version V4.8. The minimal gcc version we now test on is gcc V4.9. The minimally required version of CMake³⁸⁰³ is now V3.3.2.
- We have dropped support for the Visual Studio 2013 compiler version. The minimal Visual Studio version we now test on is Visual Studio 2015.5.
- We have dropped support for the Boost V1.51-V1.54. The minimal version of Boost we now test is Boost V1.55.
- We have dropped support for the `hpx::util::unwrapped` API. `hpx::util::unwrapped` will stay functional to some degree, until it finally gets removed in a later version of HPX. The functional usage of `hpx::util::unwrapped` should be changed to the new `hpx::util::unwrapping` function whereas the immediate usage should be replaced to `hpx::util::unwrap`.
- The performance counter names referring to properties as exposed by the threading subsystem have changes as those now additionally have to specify the thread-pool. See the corresponding documentation for more details.
- The overloads of `hpx::async` that invoke an action do not perform implicit unwrapping of the returned future anymore in case the invoked function does return a future in the first place. In this case `hpx::async` now returns a `hpx::future<future<T>>` making its behavior conforming to its local counterpart.
- We have replaced the use of `boost::exception_ptr` in our APIs with the equivalent `std::exception_ptr`. Please change your codes accordingly. No compatibility settings are provided.
- We have removed the compatibility settings for `HPX_WITH_COLOCATED_BACKWARDS_COMPATIBILITY` and `HPX_WITH_COMPONENT_GET_GID_COMPATIBILITY` as their life-cycle has reached its end.
- We have removed the experimental thread schedulers `hierarchy_scheduler`, `periodic_priority_scheduler` and `throttling_scheduler` in an effort to clean up and consolidate our thread schedulers.

Bug fixes (closed tickets)

Here is a list of the important tickets we closed for this release.

- PR #3250³⁸⁰⁴ - Apex refactoring with guides
- PR #3249³⁸⁰⁵ - Updating People.qbk
- PR #3246³⁸⁰⁶ - Assorted fixes for CUDA
- PR #3245³⁸⁰⁷ - Apex refactoring with guides
- PR #3242³⁸⁰⁸ - Modify task counting in `thread_queue.hpp`
- PR #3240³⁸⁰⁹ - Fixed typos
- PR #3238³⁸¹⁰ - Readding accidentally removed `std::abort`
- PR #3237³⁸¹¹ - Adding Pipeline example
- PR #3236³⁸¹² - Fixing `memory_block`

³⁸⁰³ <https://www.cmake.org>

³⁸⁰⁴ <https://github.com/STELLAR-GROUP/hpx/pull/3250>

³⁸⁰⁵ <https://github.com/STELLAR-GROUP/hpx/pull/3249>

³⁸⁰⁶ <https://github.com/STELLAR-GROUP/hpx/pull/3246>

³⁸⁰⁷ <https://github.com/STELLAR-GROUP/hpx/pull/3245>

³⁸⁰⁸ <https://github.com/STELLAR-GROUP/hpx/pull/3242>

³⁸⁰⁹ <https://github.com/STELLAR-GROUP/hpx/pull/3240>

³⁸¹⁰ <https://github.com/STELLAR-GROUP/hpx/pull/3238>

³⁸¹¹ <https://github.com/STELLAR-GROUP/hpx/pull/3237>

³⁸¹² <https://github.com/STELLAR-GROUP/hpx/pull/3236>

- PR #3233³⁸¹³ - Make schedule_thread take suspended threads into account
- Issue #3226³⁸¹⁴ - memory_block is breaking, signaling SIGSEGV on a thread on creation and freeing
- PR #3225³⁸¹⁵ - Applying quick fix for hwloc-2.0
- Issue #3224³⁸¹⁶ - HPX counters crashing the application
- PR #3223³⁸¹⁷ - Fix returns when setting config entries
- Issue #3222³⁸¹⁸ - Errors linking libhpx.so
- Issue #3221³⁸¹⁹ - HPX on Mac OS X with HWLoc 2.0.0 fails to run
- PR #3216³⁸²⁰ - Reorder a variadic array to satisfy VS 2017 15.6
- PR #3214³⁸²¹ - Changed prerequisites.qbk to avoid confusion while building boost
- PR #3213³⁸²² - Relax locks for thread suspension to avoid holding locks when yielding
- PR #3212³⁸²³ - Fix check in sequenced_executor test
- PR #3211³⁸²⁴ - Use preinit_array to set argc/argv in init_globally example
- PR #3210³⁸²⁵ - Adapted parallel::{search | search_n} for Ranges TS (see #1668)
- PR #3209³⁸²⁶ - Fix locking problems during shutdown
- Issue #3208³⁸²⁷ - init_globally throwing a run-time error
- PR #3206³⁸²⁸ - Addition of new arithmetic performance counter “Count”
- PR #3205³⁸²⁹ - Fixing return type calculation for bulk_then_execute
- PR #3204³⁸³⁰ - Changing std::rand() to a better inbuilt PRNG generator
- PR #3203³⁸³¹ - Resolving problems during shutdown for VS2015
- PR #3202³⁸³² - Making sure resource partitioner is not accessed if its not valid
- PR #3201³⁸³³ - Fixing optional::swap
- Issue #3200³⁸³⁴ - hpx::util::optional fails
- PR #3199³⁸³⁵ - Fix sliding_semaphore test

³⁸¹³ <https://github.com/STELLAR-GROUP/hpx/pull/3233>
³⁸¹⁴ <https://github.com/STELLAR-GROUP/hpx/issues/3226>
³⁸¹⁵ <https://github.com/STELLAR-GROUP/hpx/pull/3225>
³⁸¹⁶ <https://github.com/STELLAR-GROUP/hpx/issues/3224>
³⁸¹⁷ <https://github.com/STELLAR-GROUP/hpx/pull/3223>
³⁸¹⁸ <https://github.com/STELLAR-GROUP/hpx/issues/3222>
³⁸¹⁹ <https://github.com/STELLAR-GROUP/hpx/issues/3221>
³⁸²⁰ <https://github.com/STELLAR-GROUP/hpx/pull/3216>
³⁸²¹ <https://github.com/STELLAR-GROUP/hpx/pull/3214>
³⁸²² <https://github.com/STELLAR-GROUP/hpx/pull/3213>
³⁸²³ <https://github.com/STELLAR-GROUP/hpx/pull/3212>
³⁸²⁴ <https://github.com/STELLAR-GROUP/hpx/pull/3211>
³⁸²⁵ <https://github.com/STELLAR-GROUP/hpx/pull/3210>
³⁸²⁶ <https://github.com/STELLAR-GROUP/hpx/pull/3209>
³⁸²⁷ <https://github.com/STELLAR-GROUP/hpx/issues/3208>
³⁸²⁸ <https://github.com/STELLAR-GROUP/hpx/pull/3206>
³⁸²⁹ <https://github.com/STELLAR-GROUP/hpx/pull/3205>
³⁸³⁰ <https://github.com/STELLAR-GROUP/hpx/pull/3204>
³⁸³¹ <https://github.com/STELLAR-GROUP/hpx/pull/3203>
³⁸³² <https://github.com/STELLAR-GROUP/hpx/pull/3202>
³⁸³³ <https://github.com/STELLAR-GROUP/hpx/pull/3201>
³⁸³⁴ <https://github.com/STELLAR-GROUP/hpx/issues/3200>
³⁸³⁵ <https://github.com/STELLAR-GROUP/hpx/pull/3199>

- PR #3198³⁸³⁶ - Set pre_main status before launching run_helper
- PR #3197³⁸³⁷ - Update README.rst
- PR #3194³⁸³⁸ - parallel::{fill|fill_n} updated for Ranges TS
- PR #3193³⁸³⁹ - Updating Runtime.cpp by adding correct description of Performance counters during register
- PR #3191³⁸⁴⁰ - Fix sliding_semaphore_2338 test
- PR #3190³⁸⁴¹ - Topology improvements
- PR #3189³⁸⁴² - Deleting one include of median from BOOST library to arithmetics_counter file
- PR #3188³⁸⁴³ - Optionally disable printing of diagnostics during terminate
- PR #3187³⁸⁴⁴ - Suppressing cmake warning issued by cmake > V3.11
- PR #3185³⁸⁴⁵ - Remove unused scoped_unlock, unlock_guard_try
- PR #3184³⁸⁴⁶ - Fix nqueen example
- PR #3183³⁸⁴⁷ - Add runtime start/stop, resume/suspend and OpenMP benchmarks
- Issue #3182³⁸⁴⁸ - bulk_then_execute has unexpected return type/does not compile
- Issue #3181³⁸⁴⁹ - hwloc 2.0 breaks topo class and cannot be used
- Issue #3180³⁸⁵⁰ - Schedulers that don't support suspend/resume are unusable
- PR #3179³⁸⁵¹ - Various minor changes to support FLeCSI
- PR #3178³⁸⁵² - Fix #3124
- PR #3177³⁸⁵³ - Removed allgather
- PR #3176³⁸⁵⁴ - Fixed Documentation for "using_hpx_pkgconfig"
- PR #3174³⁸⁵⁵ - Add hpx::iostreams::ostream overload to format_to
- PR #3172³⁸⁵⁶ - Fix lifo queue backend
- PR #3171³⁸⁵⁷ - adding the missing unset() function to cpu_mask() for case of more than 64 threads
- PR #3170³⁸⁵⁸ - Add cmake flag -DHPX_WITH_FAULT_TOLERANCE=ON (OFF by default)

³⁸³⁶ <https://github.com/STELLAR-GROUP/hpx/pull/3198>

³⁸³⁷ <https://github.com/STELLAR-GROUP/hpx/pull/3197>

³⁸³⁸ <https://github.com/STELLAR-GROUP/hpx/pull/3194>

³⁸³⁹ <https://github.com/STELLAR-GROUP/hpx/pull/3193>

³⁸⁴⁰ <https://github.com/STELLAR-GROUP/hpx/pull/3191>

³⁸⁴¹ <https://github.com/STELLAR-GROUP/hpx/pull/3190>

³⁸⁴² <https://github.com/STELLAR-GROUP/hpx/pull/3189>

³⁸⁴³ <https://github.com/STELLAR-GROUP/hpx/pull/3188>

³⁸⁴⁴ <https://github.com/STELLAR-GROUP/hpx/pull/3187>

³⁸⁴⁵ <https://github.com/STELLAR-GROUP/hpx/pull/3185>

³⁸⁴⁶ <https://github.com/STELLAR-GROUP/hpx/pull/3184>

³⁸⁴⁷ <https://github.com/STELLAR-GROUP/hpx/pull/3183>

³⁸⁴⁸ <https://github.com/STELLAR-GROUP/hpx/issues/3182>

³⁸⁴⁹ <https://github.com/STELLAR-GROUP/hpx/issues/3181>

³⁸⁵⁰ <https://github.com/STELLAR-GROUP/hpx/issues/3180>

³⁸⁵¹ <https://github.com/STELLAR-GROUP/hpx/pull/3179>

³⁸⁵² <https://github.com/STELLAR-GROUP/hpx/pull/3178>

³⁸⁵³ <https://github.com/STELLAR-GROUP/hpx/pull/3177>

³⁸⁵⁴ <https://github.com/STELLAR-GROUP/hpx/pull/3176>

³⁸⁵⁵ <https://github.com/STELLAR-GROUP/hpx/pull/3174>

³⁸⁵⁶ <https://github.com/STELLAR-GROUP/hpx/pull/3172>

³⁸⁵⁷ <https://github.com/STELLAR-GROUP/hpx/pull/3171>

³⁸⁵⁸ <https://github.com/STELLAR-GROUP/hpx/pull/3170>

- PR #3169³⁸⁵⁹ - Adapted parallel::`{count|count_if}` for Ranges TS (see #1668)
- PR #3168³⁸⁶⁰ - Changing used namespace for seq execution policy
- Issue #3167³⁸⁶¹ - Update GSoC projects
- Issue #3166³⁸⁶² - Application (Octotiger) gets stuck on `hpx::finalize` when only using one thread
- Issue #3165³⁸⁶³ - Compilation of parallel algorithms with `HPX_WITH_DATAPAR` is broken
- PR #3164³⁸⁶⁴ - Fixing component migration
- PR #3162³⁸⁶⁵ - `regex_from_pattern`: escape regex special characters to avoid misinterpretation
- Issue #3161³⁸⁶⁶ - Building HPX with `hwloc 2.0.0` fails
- PR #3160³⁸⁶⁷ - Fixing the handling of quoted command line arguments.
- PR #3158³⁸⁶⁸ - Fixing a race with timed suspension (second attempt)
- PR #3157³⁸⁶⁹ - Revert “Fixing a race with timed suspension”
- PR #3156³⁸⁷⁰ - Fixing serialization of classes with incompatible `serialize` signature
- PR #3154³⁸⁷¹ - More refactorings based on clang-tidy reports
- PR #3153³⁸⁷² - Fixing a race with timed suspension
- PR #3152³⁸⁷³ - Documentation for runtime suspension
- PR #3151³⁸⁷⁴ - Use `small_vector` only from boost version 1.59 onwards
- PR #3150³⁸⁷⁵ - Avoiding more stack overflows
- PR #3148³⁸⁷⁶ - Refactoring `component_base` and `base_action/transfer_base_action`
- PR #3147³⁸⁷⁷ - Move `yield_while` out of detail namespace and into own file
- PR #3145³⁸⁷⁸ - Remove a leftover of the `cxx11` std array cleanup
- PR #3144³⁸⁷⁹ - Minor changes to how actions are executed
- PR #3143³⁸⁸⁰ - Fix stack overhead
- PR #3142³⁸⁸¹ - Fix typo in `config.hpp`

3859 <https://github.com/STELLAR-GROUP/hpx/pull/3169>
3860 <https://github.com/STELLAR-GROUP/hpx/pull/3168>
3861 <https://github.com/STELLAR-GROUP/hpx/issues/3167>
3862 <https://github.com/STELLAR-GROUP/hpx/issues/3166>
3863 <https://github.com/STELLAR-GROUP/hpx/issues/3165>
3864 <https://github.com/STELLAR-GROUP/hpx/pull/3164>
3865 <https://github.com/STELLAR-GROUP/hpx/pull/3162>
3866 <https://github.com/STELLAR-GROUP/hpx/issues/3161>
3867 <https://github.com/STELLAR-GROUP/hpx/pull/3160>
3868 <https://github.com/STELLAR-GROUP/hpx/pull/3158>
3869 <https://github.com/STELLAR-GROUP/hpx/pull/3157>
3870 <https://github.com/STELLAR-GROUP/hpx/pull/3156>
3871 <https://github.com/STELLAR-GROUP/hpx/pull/3154>
3872 <https://github.com/STELLAR-GROUP/hpx/pull/3153>
3873 <https://github.com/STELLAR-GROUP/hpx/pull/3152>
3874 <https://github.com/STELLAR-GROUP/hpx/pull/3151>
3875 <https://github.com/STELLAR-GROUP/hpx/pull/3150>
3876 <https://github.com/STELLAR-GROUP/hpx/pull/3148>
3877 <https://github.com/STELLAR-GROUP/hpx/pull/3147>
3878 <https://github.com/STELLAR-GROUP/hpx/pull/3145>
3879 <https://github.com/STELLAR-GROUP/hpx/pull/3144>
3880 <https://github.com/STELLAR-GROUP/hpx/pull/3143>
3881 <https://github.com/STELLAR-GROUP/hpx/pull/3142>

- PR #3141³⁸⁸² - Fixing small_vector compatibility with older boost version
- PR #3140³⁸⁸³ - is_heap_text fix
- Issue #3139³⁸⁸⁴ - Error in is_heap_tests.hpp
- PR #3138³⁸⁸⁵ - Partially reverting #3126
- PR #3137³⁸⁸⁶ - Suspend speedup
- PR #3136³⁸⁸⁷ - Revert “Fixing #2325”
- PR #3135³⁸⁸⁸ - Improving destruction of threads
- Issue #3134³⁸⁸⁹ - HPX_SERIALIZATION_SPLIT_FREE does not stop compiler from looking for serialize() method
- PR #3133³⁸⁹⁰ - Make hwloc compulsory
- PR #3132³⁸⁹¹ - Update CXX14 constexpr feature test
- PR #3131³⁸⁹² - Fixing #2325
- PR #3130³⁸⁹³ - Avoid completion handler allocation
- PR #3129³⁸⁹⁴ - Suspend runtime
- PR #3128³⁸⁹⁵ - Make docbook dtd and xsl path names consistent
- PR #3127³⁸⁹⁶ - Add hpx::start nullptr overloads
- PR #3126³⁸⁹⁷ - Cleaning up coroutine implementation
- PR #3125³⁸⁹⁸ - Replacing nullptr with hpx::threads::invalid_thread_id
- Issue #3124³⁸⁹⁹ - Add hello_world_component to CI builds
- PR #3123³⁹⁰⁰ - Add new constructor.
- PR #3122³⁹⁰¹ - Fixing #3121
- Issue #3121³⁹⁰² - HPX_SMT_PAUSE is broken on non-x86 platforms when __GNUC__ is defined
- PR #3120³⁹⁰³ - Don't use boost::intrusive_ptr for thread_id_type
- PR #3119³⁹⁰⁴ - Disable default executor compatibility with V1 executors

³⁸⁸² <https://github.com/STELLAR-GROUP/hpx/pull/3141>

³⁸⁸³ <https://github.com/STELLAR-GROUP/hpx/pull/3140>

³⁸⁸⁴ <https://github.com/STELLAR-GROUP/hpx/issues/3139>

³⁸⁸⁵ <https://github.com/STELLAR-GROUP/hpx/pull/3138>

³⁸⁸⁶ <https://github.com/STELLAR-GROUP/hpx/pull/3137>

³⁸⁸⁷ <https://github.com/STELLAR-GROUP/hpx/pull/3136>

³⁸⁸⁸ <https://github.com/STELLAR-GROUP/hpx/pull/3135>

³⁸⁸⁹ <https://github.com/STELLAR-GROUP/hpx/issues/3134>

³⁸⁹⁰ <https://github.com/STELLAR-GROUP/hpx/pull/3133>

³⁸⁹¹ <https://github.com/STELLAR-GROUP/hpx/pull/3132>

³⁸⁹² <https://github.com/STELLAR-GROUP/hpx/pull/3131>

³⁸⁹³ <https://github.com/STELLAR-GROUP/hpx/pull/3130>

³⁸⁹⁴ <https://github.com/STELLAR-GROUP/hpx/pull/3129>

³⁸⁹⁵ <https://github.com/STELLAR-GROUP/hpx/pull/3128>

³⁸⁹⁶ <https://github.com/STELLAR-GROUP/hpx/pull/3127>

³⁸⁹⁷ <https://github.com/STELLAR-GROUP/hpx/pull/3126>

³⁸⁹⁸ <https://github.com/STELLAR-GROUP/hpx/pull/3125>

³⁸⁹⁹ <https://github.com/STELLAR-GROUP/hpx/issues/3124>

³⁹⁰⁰ <https://github.com/STELLAR-GROUP/hpx/pull/3123>

³⁹⁰¹ <https://github.com/STELLAR-GROUP/hpx/pull/3122>

³⁹⁰² <https://github.com/STELLAR-GROUP/hpx/issues/3121>

³⁹⁰³ <https://github.com/STELLAR-GROUP/hpx/pull/3120>

³⁹⁰⁴ <https://github.com/STELLAR-GROUP/hpx/pull/3119>

- PR #3118³⁹⁰⁵ - Adding performance_counter::reinit to allow for dynamically changing counter sets
- PR #3117³⁹⁰⁶ - Replace uses of boost/experimental::optional with util::optional
- PR #3116³⁹⁰⁷ - Moving background thread APEX timer #2980
- PR #3115³⁹⁰⁸ - Fixing race condition in channel test
- PR #3114³⁹⁰⁹ - Avoid using util::function for thread function wrappers
- PR #3113³⁹¹⁰ - cmake V3.10.2 has changed the variable names used for MPI
- PR #3112³⁹¹¹ - Minor fixes to exclusive_scan algorithm
- PR #3111³⁹¹² - Revert “fix detection of cxx11_std_atomic”
- PR #3110³⁹¹³ - Suspend thread pool
- PR #3109³⁹¹⁴ - Fixing thread scheduling when yielding a thread id
- PR #3108³⁹¹⁵ - Revert “Suspend thread pool”
- PR #3107³⁹¹⁶ - Remove UB from thread::id relational operators
- PR #3106³⁹¹⁷ - Add cmake test for std::decay_t to fix cuda build
- PR #3105³⁹¹⁸ - Fixing refcount for async traversal frame
- PR #3104³⁹¹⁹ - Local execution of direct actions is now actually performed directly
- PR #3103³⁹²⁰ - Adding support for generic counter_raw_values performance counter type
- Issue #3102³⁹²¹ - Introduce generic performance counter type returning an array of values
- PR #3101³⁹²² - Revert “Adapting stack overhead limit for gcc 4.9”
- PR #3100³⁹²³ - Fix #3068 (condition_variable deadlock)
- PR #3099³⁹²⁴ - Fixing lock held during suspension in papi counter component
- PR #3098³⁹²⁵ - Unbreak broadcast_wait_for_2822 test
- PR #3097³⁹²⁶ - Adapting stack overhead limit for gcc 4.9
- PR #3096³⁹²⁷ - fix detection of cxx11_std_atomic

³⁹⁰⁵ <https://github.com/STELLAR-GROUP/hpx/pull/3118>
³⁹⁰⁶ <https://github.com/STELLAR-GROUP/hpx/pull/3117>
³⁹⁰⁷ <https://github.com/STELLAR-GROUP/hpx/pull/3116>
³⁹⁰⁸ <https://github.com/STELLAR-GROUP/hpx/pull/3115>
³⁹⁰⁹ <https://github.com/STELLAR-GROUP/hpx/pull/3114>
³⁹¹⁰ <https://github.com/STELLAR-GROUP/hpx/pull/3113>
³⁹¹¹ <https://github.com/STELLAR-GROUP/hpx/pull/3112>
³⁹¹² <https://github.com/STELLAR-GROUP/hpx/pull/3111>
³⁹¹³ <https://github.com/STELLAR-GROUP/hpx/pull/3110>
³⁹¹⁴ <https://github.com/STELLAR-GROUP/hpx/pull/3109>
³⁹¹⁵ <https://github.com/STELLAR-GROUP/hpx/pull/3108>
³⁹¹⁶ <https://github.com/STELLAR-GROUP/hpx/pull/3107>
³⁹¹⁷ <https://github.com/STELLAR-GROUP/hpx/pull/3106>
³⁹¹⁸ <https://github.com/STELLAR-GROUP/hpx/pull/3105>
³⁹¹⁹ <https://github.com/STELLAR-GROUP/hpx/pull/3104>
³⁹²⁰ <https://github.com/STELLAR-GROUP/hpx/pull/3103>
³⁹²¹ <https://github.com/STELLAR-GROUP/hpx/issues/3102>
³⁹²² <https://github.com/STELLAR-GROUP/hpx/pull/3101>
³⁹²³ <https://github.com/STELLAR-GROUP/hpx/pull/3100>
³⁹²⁴ <https://github.com/STELLAR-GROUP/hpx/pull/3099>
³⁹²⁵ <https://github.com/STELLAR-GROUP/hpx/pull/3098>
³⁹²⁶ <https://github.com/STELLAR-GROUP/hpx/pull/3097>
³⁹²⁷ <https://github.com/STELLAR-GROUP/hpx/pull/3096>

- PR #3095³⁹²⁸ - Add ciso646 header to get `_LIBCPP_VERSION` for testing inplace merge
- PR #3094³⁹²⁹ - Relax atomic operations on performance counter values
- PR #3093³⁹³⁰ - Short-circuit `all_of/any_of/none_of` instantiations
- PR #3092³⁹³¹ - Take advantage of C++14 lambda capture initialization syntax, where possible
- PR #3091³⁹³² - Remove more references to Boost from logging code
- PR #3090³⁹³³ - Unify use of `yield/yield_k`
- PR #3089³⁹³⁴ - Fix a strange thing in `parallel::detail::handle_exception`. (Fix #2834.)
- Issue #3088³⁹³⁵ - A strange thing in `parallel::sort`.
- PR #3087³⁹³⁶ - Fixing assertion in `default_distribution_policy`
- PR #3086³⁹³⁷ - Implement `parallel::remove` and `parallel::remove_if`
- PR #3085³⁹³⁸ - Addressing breaking changes in Boost V1.66
- PR #3084³⁹³⁹ - Ignore build warnings round 2
- PR #3083³⁹⁴⁰ - Fix typo `HPX_WITH_MM_PREFECTH`
- PR #3081³⁹⁴¹ - Pre-decay template arguments early
- PR #3080³⁹⁴² - Suspend thread pool
- PR #3079³⁹⁴³ - Ignore build warnings
- PR #3078³⁹⁴⁴ - Don't test `inplace_merge` with `libc++`
- PR #3076³⁹⁴⁵ - Fixing 3075: Part 1
- PR #3074³⁹⁴⁶ - Fix more build warnings
- PR #3073³⁹⁴⁷ - Suspend thread cleanup
- PR #3072³⁹⁴⁸ - Change existing `symbol_namespace::iterate` to return all data instead of invoking a callback
- PR #3071³⁹⁴⁹ - Fixing `pack_traversal_async` test
- PR #3070³⁹⁵⁰ - Fix `dynamic_counters_loaded_1508` test by adding dependency to `memory_component`

³⁹²⁸ <https://github.com/STELLAR-GROUP/hpx/pull/3095>

³⁹²⁹ <https://github.com/STELLAR-GROUP/hpx/pull/3094>

³⁹³⁰ <https://github.com/STELLAR-GROUP/hpx/pull/3093>

³⁹³¹ <https://github.com/STELLAR-GROUP/hpx/pull/3092>

³⁹³² <https://github.com/STELLAR-GROUP/hpx/pull/3091>

³⁹³³ <https://github.com/STELLAR-GROUP/hpx/pull/3090>

³⁹³⁴ <https://github.com/STELLAR-GROUP/hpx/pull/3089>

³⁹³⁵ <https://github.com/STELLAR-GROUP/hpx/issues/3088>

³⁹³⁶ <https://github.com/STELLAR-GROUP/hpx/pull/3087>

³⁹³⁷ <https://github.com/STELLAR-GROUP/hpx/pull/3086>

³⁹³⁸ <https://github.com/STELLAR-GROUP/hpx/pull/3085>

³⁹³⁹ <https://github.com/STELLAR-GROUP/hpx/pull/3084>

³⁹⁴⁰ <https://github.com/STELLAR-GROUP/hpx/pull/3083>

³⁹⁴¹ <https://github.com/STELLAR-GROUP/hpx/pull/3081>

³⁹⁴² <https://github.com/STELLAR-GROUP/hpx/pull/3080>

³⁹⁴³ <https://github.com/STELLAR-GROUP/hpx/pull/3079>

³⁹⁴⁴ <https://github.com/STELLAR-GROUP/hpx/pull/3078>

³⁹⁴⁵ <https://github.com/STELLAR-GROUP/hpx/pull/3076>

³⁹⁴⁶ <https://github.com/STELLAR-GROUP/hpx/pull/3074>

³⁹⁴⁷ <https://github.com/STELLAR-GROUP/hpx/pull/3073>

³⁹⁴⁸ <https://github.com/STELLAR-GROUP/hpx/pull/3072>

³⁹⁴⁹ <https://github.com/STELLAR-GROUP/hpx/pull/3071>

³⁹⁵⁰ <https://github.com/STELLAR-GROUP/hpx/pull/3070>

- PR #3069³⁹⁵¹ - Fix scheduling loop exit
- Issue #3068³⁹⁵² - `hpx::lcos::condition_variable` could be suspect to deadlocks
- PR #3067³⁹⁵³ - `#ifdef` out `random_shuffle` deprecated in later c++
- PR #3066³⁹⁵⁴ - Make coalescing test depend on coalescing library to ensure it gets built
- PR #3065³⁹⁵⁵ - Workaround for `minimal_timed_async_executor_test` compilation failures, attempts to copy a deferred call (in unevaluated context)
- PR #3064³⁹⁵⁶ - Fixing wrong condition in `wrapper_heap`
- PR #3062³⁹⁵⁷ - Fix exception handling for `execution::seq`
- PR #3061³⁹⁵⁸ - Adapt MSVC C++ mode handling to VS15.5
- PR #3060³⁹⁵⁹ - Fix compiler problem in MSVC release mode
- PR #3059³⁹⁶⁰ - Fixing #2931
- Issue #3058³⁹⁶¹ - `minimal_timed_async_executor_test_exe` fails to compile on master (d6f505c)
- PR #3057³⁹⁶² - Fix `stable_merge_2964` compilation problems
- PR #3056³⁹⁶³ - Fix some build warnings caused by unused variables/unnecessary tests
- PR #3055³⁹⁶⁴ - Update documentation for running tests
- Issue #3054³⁹⁶⁵ - Assertion failure when using bulk `hpx::new_` in asynchronous mode
- PR #3052³⁹⁶⁶ - Do not bind test running to `cmake` test build rule
- PR #3051³⁹⁶⁷ - Fix HPX-Qt interaction in Qt example.
- Issue #3048³⁹⁶⁸ - `nqueen` example fails occasionally
- PR #3047³⁹⁶⁹ - Fixing #3044
- PR #3046³⁹⁷⁰ - Add OS thread suspension
- PR #3042³⁹⁷¹ - PyCicle - first attempt at a build tool for checking PR's
- PR #3041³⁹⁷² - Fix a problem about asynchronous execution of `parallel::merge` and `parallel::partition`.
- PR #3040³⁹⁷³ - Fix a mistake about exception handling in asynchronous execution of `scan_partitioner`.

³⁹⁵¹ <https://github.com/STELLAR-GROUP/hpx/pull/3069>

³⁹⁵² <https://github.com/STELLAR-GROUP/hpx/issues/3068>

³⁹⁵³ <https://github.com/STELLAR-GROUP/hpx/pull/3067>

³⁹⁵⁴ <https://github.com/STELLAR-GROUP/hpx/pull/3066>

³⁹⁵⁵ <https://github.com/STELLAR-GROUP/hpx/pull/3065>

³⁹⁵⁶ <https://github.com/STELLAR-GROUP/hpx/pull/3064>

³⁹⁵⁷ <https://github.com/STELLAR-GROUP/hpx/pull/3062>

³⁹⁵⁸ <https://github.com/STELLAR-GROUP/hpx/pull/3061>

³⁹⁵⁹ <https://github.com/STELLAR-GROUP/hpx/pull/3060>

³⁹⁶⁰ <https://github.com/STELLAR-GROUP/hpx/pull/3059>

³⁹⁶¹ <https://github.com/STELLAR-GROUP/hpx/issues/3058>

³⁹⁶² <https://github.com/STELLAR-GROUP/hpx/pull/3057>

³⁹⁶³ <https://github.com/STELLAR-GROUP/hpx/pull/3056>

³⁹⁶⁴ <https://github.com/STELLAR-GROUP/hpx/pull/3055>

³⁹⁶⁵ <https://github.com/STELLAR-GROUP/hpx/issues/3054>

³⁹⁶⁶ <https://github.com/STELLAR-GROUP/hpx/pull/3052>

³⁹⁶⁷ <https://github.com/STELLAR-GROUP/hpx/pull/3051>

³⁹⁶⁸ <https://github.com/STELLAR-GROUP/hpx/issues/3048>

³⁹⁶⁹ <https://github.com/STELLAR-GROUP/hpx/pull/3047>

³⁹⁷⁰ <https://github.com/STELLAR-GROUP/hpx/pull/3046>

³⁹⁷¹ <https://github.com/STELLAR-GROUP/hpx/pull/3042>

³⁹⁷² <https://github.com/STELLAR-GROUP/hpx/pull/3041>

³⁹⁷³ <https://github.com/STELLAR-GROUP/hpx/pull/3040>

- PR #3039³⁹⁷⁴ - Consistently use executors to schedule work
- PR #3038³⁹⁷⁵ - Fixing local direct function execution and lambda actions perfect forwarding
- PR #3035³⁹⁷⁶ - Make parallel unit test names match build target/folder names
- PR #3033³⁹⁷⁷ - Fix setting of default build type
- Issue #3032³⁹⁷⁸ - Fix partitioner arg copy found in #2982
- Issue #3031³⁹⁷⁹ - Errors linking libhpx.so due to missing references (master branch, commit 6679a8882)
- PR #3030³⁹⁸⁰ - Revert “implement executor then interface with && forwarding reference”
- PR #3029³⁹⁸¹ - Run CI inspect checks before building
- PR #3028³⁹⁸² - Added range version of parallel::move
- Issue #3027³⁹⁸³ - Implement all scheduling APIs in terms of executors
- PR #3026³⁹⁸⁴ - implement executor then interface with && forwarding reference
- PR #3025³⁹⁸⁵ - Fix typo uninitialized to unitialized
- PR #3024³⁹⁸⁶ - Inspect fixes
- PR #3023³⁹⁸⁷ - P0356 Simplified partial function application
- PR #3022³⁹⁸⁸ - Master fixes
- PR #3021³⁹⁸⁹ - Segfault fix
- PR #3020³⁹⁹⁰ - Disable command-line aliasing for applications that use user_main
- PR #3019³⁹⁹¹ - Adding enable_elasticity option to pool configuration
- PR #3018³⁹⁹² - Fix stack overflow detection configuration in header files
- PR #3017³⁹⁹³ - Speed up local action execution
- PR #3016³⁹⁹⁴ - Unify stack-overflow detection options, remove reference to libsigsegv
- PR #3015³⁹⁹⁵ - Speeding up accessing the resource partitioner and the topology info
- Issue #3014³⁹⁹⁶ - HPX does not compile on POWER8 with gcc 5.4

³⁹⁷⁴ <https://github.com/STELLAR-GROUP/hpx/pull/3039>

³⁹⁷⁵ <https://github.com/STELLAR-GROUP/hpx/pull/3038>

³⁹⁷⁶ <https://github.com/STELLAR-GROUP/hpx/pull/3035>

³⁹⁷⁷ <https://github.com/STELLAR-GROUP/hpx/pull/3033>

³⁹⁷⁸ <https://github.com/STELLAR-GROUP/hpx/issues/3032>

³⁹⁷⁹ <https://github.com/STELLAR-GROUP/hpx/issues/3031>

³⁹⁸⁰ <https://github.com/STELLAR-GROUP/hpx/pull/3030>

³⁹⁸¹ <https://github.com/STELLAR-GROUP/hpx/pull/3029>

³⁹⁸² <https://github.com/STELLAR-GROUP/hpx/pull/3028>

³⁹⁸³ <https://github.com/STELLAR-GROUP/hpx/issues/3027>

³⁹⁸⁴ <https://github.com/STELLAR-GROUP/hpx/pull/3026>

³⁹⁸⁵ <https://github.com/STELLAR-GROUP/hpx/pull/3025>

³⁹⁸⁶ <https://github.com/STELLAR-GROUP/hpx/pull/3024>

³⁹⁸⁷ <https://github.com/STELLAR-GROUP/hpx/pull/3023>

³⁹⁸⁸ <https://github.com/STELLAR-GROUP/hpx/pull/3022>

³⁹⁸⁹ <https://github.com/STELLAR-GROUP/hpx/pull/3021>

³⁹⁹⁰ <https://github.com/STELLAR-GROUP/hpx/pull/3020>

³⁹⁹¹ <https://github.com/STELLAR-GROUP/hpx/pull/3019>

³⁹⁹² <https://github.com/STELLAR-GROUP/hpx/pull/3018>

³⁹⁹³ <https://github.com/STELLAR-GROUP/hpx/pull/3017>

³⁹⁹⁴ <https://github.com/STELLAR-GROUP/hpx/pull/3016>

³⁹⁹⁵ <https://github.com/STELLAR-GROUP/hpx/pull/3015>

³⁹⁹⁶ <https://github.com/STELLAR-GROUP/hpx/issues/3014>

- [Issue #3013³⁹⁹⁷](#) - hello_world occasionally prints multiple lines from a single OS-thread
- [PR #3012³⁹⁹⁸](#) - Silence warning about casting away qualifiers in itt_notify.hpp
- [PR #3011³⁹⁹⁹](#) - Fix cpuset leak in hwloc_topology_info.cpp
- [PR #3010⁴⁰⁰⁰](#) - Remove useless decay_copy
- [PR #3009⁴⁰⁰¹](#) - Fixing 2996
- [PR #3008⁴⁰⁰²](#) - Remove unused internal function
- [PR #3007⁴⁰⁰³](#) - Fixing wrapper_heap alignment problems
- [Issue #3006⁴⁰⁰⁴](#) - hwloc memory leak
- [PR #3004⁴⁰⁰⁵](#) - Silence C4251 (needs to have dll-interface) for future_data_void
- [Issue #3003⁴⁰⁰⁶](#) - Suspension of runtime
- [PR #3001⁴⁰⁰⁷](#) - Attempting to avoid data races in async_traversal while evaluating dataflow()
- [PR #3000⁴⁰⁰⁸](#) - Adding hpx::util::optional as a first step to replace experimental::optional
- [PR #2998⁴⁰⁰⁹](#) - Cleanup up and Fixing component creation and deletion
- [Issue #2996⁴⁰¹⁰](#) - Build fails with HPX_WITH_HWLOC=OFF
- [PR #2995⁴⁰¹¹](#) - Push more future_data functionality to source file
- [PR #2994⁴⁰¹²](#) - WIP: Fix throttle test
- [PR #2993⁴⁰¹³](#) - Making sure -hpx:help does not throw for required (but missing) arguments
- [PR #2992⁴⁰¹⁴](#) - Adding non-blocking (on destruction) service executors
- [Issue #2991⁴⁰¹⁵](#) - run_as_os_thread locks up
- [Issue #2990⁴⁰¹⁶](#) - -help will not work until all required options are provided
- [PR #2989⁴⁰¹⁷](#) - Improve error messages caused by misuse of dataflow
- [PR #2988⁴⁰¹⁸](#) - Improve error messages caused by misuse of .then
- [Issue #2987⁴⁰¹⁹](#) - stack overflow detection producing false positives

³⁹⁹⁷ <https://github.com/STELLAR-GROUP/hpx/issues/3013>

³⁹⁹⁸ <https://github.com/STELLAR-GROUP/hpx/pull/3012>

³⁹⁹⁹ <https://github.com/STELLAR-GROUP/hpx/pull/3011>

⁴⁰⁰⁰ <https://github.com/STELLAR-GROUP/hpx/pull/3010>

⁴⁰⁰¹ <https://github.com/STELLAR-GROUP/hpx/pull/3009>

⁴⁰⁰² <https://github.com/STELLAR-GROUP/hpx/pull/3008>

⁴⁰⁰³ <https://github.com/STELLAR-GROUP/hpx/pull/3007>

⁴⁰⁰⁴ <https://github.com/STELLAR-GROUP/hpx/issues/3006>

⁴⁰⁰⁵ <https://github.com/STELLAR-GROUP/hpx/pull/3004>

⁴⁰⁰⁶ <https://github.com/STELLAR-GROUP/hpx/issues/3003>

⁴⁰⁰⁷ <https://github.com/STELLAR-GROUP/hpx/pull/3001>

⁴⁰⁰⁸ <https://github.com/STELLAR-GROUP/hpx/pull/3000>

⁴⁰⁰⁹ <https://github.com/STELLAR-GROUP/hpx/pull/2998>

⁴⁰¹⁰ <https://github.com/STELLAR-GROUP/hpx/issues/2996>

⁴⁰¹¹ <https://github.com/STELLAR-GROUP/hpx/pull/2995>

⁴⁰¹² <https://github.com/STELLAR-GROUP/hpx/pull/2994>

⁴⁰¹³ <https://github.com/STELLAR-GROUP/hpx/pull/2993>

⁴⁰¹⁴ <https://github.com/STELLAR-GROUP/hpx/pull/2992>

⁴⁰¹⁵ <https://github.com/STELLAR-GROUP/hpx/issues/2991>

⁴⁰¹⁶ <https://github.com/STELLAR-GROUP/hpx/issues/2990>

⁴⁰¹⁷ <https://github.com/STELLAR-GROUP/hpx/pull/2989>

⁴⁰¹⁸ <https://github.com/STELLAR-GROUP/hpx/pull/2988>

⁴⁰¹⁹ <https://github.com/STELLAR-GROUP/hpx/issues/2987>

- [PR #2986](#)⁴⁰²⁰ - Deduplicate non-dependent thread_info logging types
- [PR #2985](#)⁴⁰²¹ - Adapted parallel::{all_of|any_of|none_of} for Ranges TS (see #1668)
- [PR #2984](#)⁴⁰²² - Refactor one_size_heap code to simplify code
- [PR #2983](#)⁴⁰²³ - Fixing local_new_component
- [PR #2982](#)⁴⁰²⁴ - Clang tidy
- [PR #2981](#)⁴⁰²⁵ - Simplify allocator rebinding in pack traversal
- [PR #2979](#)⁴⁰²⁶ - Fixing integer overflows
- [PR #2978](#)⁴⁰²⁷ - Implement parallel::inplace_merge
- [Issue #2977](#)⁴⁰²⁸ - Make hwloc compulsory instead of optional
- [PR #2976](#)⁴⁰²⁹ - Making sure client_base instance that registered the component does not unregister it when being destructed
- [PR #2975](#)⁴⁰³⁰ - Change version of pulled APEX to master
- [PR #2974](#)⁴⁰³¹ - Fix domain not being freed at the end of scheduling loop
- [PR #2973](#)⁴⁰³² - Fix small typos
- [PR #2972](#)⁴⁰³³ - Adding uintstd.h header
- [PR #2971](#)⁴⁰³⁴ - Fall back to creating local components using local_new
- [PR #2970](#)⁴⁰³⁵ - Improve is_tuple_like trait
- [PR #2969](#)⁴⁰³⁶ - Fix HPX_WITH_MORE_THAN_64_THREADS default value
- [PR #2968](#)⁴⁰³⁷ - Cleaning up dataflow overload set
- [PR #2967](#)⁴⁰³⁸ - Make parallel::merge is stable. (Fix #2964.)
- [PR #2966](#)⁴⁰³⁹ - Fixing a couple of held locks during exception handling
- [PR #2965](#)⁴⁰⁴⁰ - Adding missing #include
- [Issue #2964](#)⁴⁰⁴¹ - parallel merge is not stable
- [PR #2963](#)⁴⁰⁴² - Making sure any function object passed to dataflow is released after being invoked

⁴⁰²⁰ <https://github.com/STELLAR-GROUP/hpx/pull/2986>

⁴⁰²¹ <https://github.com/STELLAR-GROUP/hpx/pull/2985>

⁴⁰²² <https://github.com/STELLAR-GROUP/hpx/pull/2984>

⁴⁰²³ <https://github.com/STELLAR-GROUP/hpx/pull/2983>

⁴⁰²⁴ <https://github.com/STELLAR-GROUP/hpx/pull/2982>

⁴⁰²⁵ <https://github.com/STELLAR-GROUP/hpx/pull/2981>

⁴⁰²⁶ <https://github.com/STELLAR-GROUP/hpx/pull/2979>

⁴⁰²⁷ <https://github.com/STELLAR-GROUP/hpx/pull/2978>

⁴⁰²⁸ <https://github.com/STELLAR-GROUP/hpx/issues/2977>

⁴⁰²⁹ <https://github.com/STELLAR-GROUP/hpx/pull/2976>

⁴⁰³⁰ <https://github.com/STELLAR-GROUP/hpx/pull/2975>

⁴⁰³¹ <https://github.com/STELLAR-GROUP/hpx/pull/2974>

⁴⁰³² <https://github.com/STELLAR-GROUP/hpx/pull/2973>

⁴⁰³³ <https://github.com/STELLAR-GROUP/hpx/pull/2972>

⁴⁰³⁴ <https://github.com/STELLAR-GROUP/hpx/pull/2971>

⁴⁰³⁵ <https://github.com/STELLAR-GROUP/hpx/pull/2970>

⁴⁰³⁶ <https://github.com/STELLAR-GROUP/hpx/pull/2969>

⁴⁰³⁷ <https://github.com/STELLAR-GROUP/hpx/pull/2968>

⁴⁰³⁸ <https://github.com/STELLAR-GROUP/hpx/pull/2967>

⁴⁰³⁹ <https://github.com/STELLAR-GROUP/hpx/pull/2966>

⁴⁰⁴⁰ <https://github.com/STELLAR-GROUP/hpx/pull/2965>

⁴⁰⁴¹ <https://github.com/STELLAR-GROUP/hpx/issues/2964>

⁴⁰⁴² <https://github.com/STELLAR-GROUP/hpx/pull/2963>

- [PR #2962⁴⁰⁴³](#) - Partially reverting #2891
- [PR #2961⁴⁰⁴⁴](#) - Attempt to fix the gcc 4.9 problem with the async pack traversal
- [Issue #2959⁴⁰⁴⁵](#) - Program terminates during error handling
- [Issue #2958⁴⁰⁴⁶](#) - HPX_PLAIN_ACTION breaks due to missing include
- [PR #2957⁴⁰⁴⁷](#) - Fixing errors generated by mixing different attribute syntaxes
- [Issue #2956⁴⁰⁴⁸](#) - Mixing attribute syntaxes leads to compiler errors
- [Issue #2955⁴⁰⁴⁹](#) - Fix OS-Thread throttling
- [PR #2953⁴⁰⁵⁰](#) - Making sure any hpx.os_threads=N supplied through a -hpx::config file is taken into account
- [PR #2952⁴⁰⁵¹](#) - Removing wrong call to cleanup_terminated_locked
- [PR #2951⁴⁰⁵²](#) - Revert “Make sure the function vtables are initialized before use”
- [PR #2950⁴⁰⁵³](#) - Fix a namespace compilation error when some schedulers are disabled
- [Issue #2949⁴⁰⁵⁴](#) - master branch giving lockups on shutdown
- [Issue #2947⁴⁰⁵⁵](#) - hpx.ini is not used correctly at initialization
- [PR #2946⁴⁰⁵⁶](#) - Adding explicit feature test for thread_local
- [PR #2945⁴⁰⁵⁷](#) - Make sure the function vtables are initialized before use
- [PR #2944⁴⁰⁵⁸](#) - Attempting to solve affinity problems on CircleCI
- [PR #2943⁴⁰⁵⁹](#) - Changing channel actions to be direct
- [PR #2942⁴⁰⁶⁰](#) - Adding split_future for std::vector
- [PR #2941⁴⁰⁶¹](#) - Add a feature test to test for CXX11 override
- [Issue #2940⁴⁰⁶²](#) - Add split_future for future<vector<T>>
- [PR #2939⁴⁰⁶³](#) - Making error reporting during problems with setting affinity masks more verbose
- [PR #2938⁴⁰⁶⁴](#) - Fix this various executors
- [PR #2937⁴⁰⁶⁵](#) - Fix some typos in documentation

⁴⁰⁴³ <https://github.com/STELLAR-GROUP/hpx/pull/2962>

⁴⁰⁴⁴ <https://github.com/STELLAR-GROUP/hpx/pull/2961>

⁴⁰⁴⁵ <https://github.com/STELLAR-GROUP/hpx/issues/2959>

⁴⁰⁴⁶ <https://github.com/STELLAR-GROUP/hpx/issues/2958>

⁴⁰⁴⁷ <https://github.com/STELLAR-GROUP/hpx/pull/2957>

⁴⁰⁴⁸ <https://github.com/STELLAR-GROUP/hpx/issues/2956>

⁴⁰⁴⁹ <https://github.com/STELLAR-GROUP/hpx/issues/2955>

⁴⁰⁵⁰ <https://github.com/STELLAR-GROUP/hpx/pull/2953>

⁴⁰⁵¹ <https://github.com/STELLAR-GROUP/hpx/pull/2952>

⁴⁰⁵² <https://github.com/STELLAR-GROUP/hpx/pull/2951>

⁴⁰⁵³ <https://github.com/STELLAR-GROUP/hpx/pull/2950>

⁴⁰⁵⁴ <https://github.com/STELLAR-GROUP/hpx/issues/2949>

⁴⁰⁵⁵ <https://github.com/STELLAR-GROUP/hpx/issues/2947>

⁴⁰⁵⁶ <https://github.com/STELLAR-GROUP/hpx/pull/2946>

⁴⁰⁵⁷ <https://github.com/STELLAR-GROUP/hpx/pull/2945>

⁴⁰⁵⁸ <https://github.com/STELLAR-GROUP/hpx/pull/2944>

⁴⁰⁵⁹ <https://github.com/STELLAR-GROUP/hpx/pull/2943>

⁴⁰⁶⁰ <https://github.com/STELLAR-GROUP/hpx/pull/2942>

⁴⁰⁶¹ <https://github.com/STELLAR-GROUP/hpx/pull/2941>

⁴⁰⁶² <https://github.com/STELLAR-GROUP/hpx/issues/2940>

⁴⁰⁶³ <https://github.com/STELLAR-GROUP/hpx/pull/2939>

⁴⁰⁶⁴ <https://github.com/STELLAR-GROUP/hpx/pull/2938>

⁴⁰⁶⁵ <https://github.com/STELLAR-GROUP/hpx/pull/2937>

- PR #2934⁴⁰⁶⁶ - Remove the need for “complete” SFINAE checks
- PR #2933⁴⁰⁶⁷ - Making sure parallel::for_loop is executed in parallel if requested
- PR #2932⁴⁰⁶⁸ - Classify chunk_size_iterator to input iterator tag. (Fix #2866)
- Issue #2931⁴⁰⁶⁹ - --hpx:help triggers unusual error with clang build
- PR #2930⁴⁰⁷⁰ - Add #include files needed to set _POSIX_VERSION for debug check
- PR #2929⁴⁰⁷¹ - Fix a couple of deprecated c++ features
- PR #2928⁴⁰⁷² - Fixing execution parameters
- Issue #2927⁴⁰⁷³ - CMake warning: ... cycle in constraint graph
- PR #2926⁴⁰⁷⁴ - Default pool rename
- Issue #2925⁴⁰⁷⁵ - Default pool cannot be renamed
- Issue #2924⁴⁰⁷⁶ - hpx:attach-debugger=startup does not work any more
- PR #2923⁴⁰⁷⁷ - Alloc membind
- PR #2922⁴⁰⁷⁸ - This fixes CircleCI errors when running with --hpx:bind=none
- PR #2921⁴⁰⁷⁹ - Custom pool executor was missing priority and stacksize options
- PR #2920⁴⁰⁸⁰ - Adding test to trigger problem reported in #2916
- PR #2919⁴⁰⁸¹ - Make sure the resource_partitioner is properly destructed on hpx::finalize
- Issue #2918⁴⁰⁸² - hpx::init calls wrong (first) callback when called multiple times
- PR #2917⁴⁰⁸³ - Adding util::checkpoint
- Issue #2916⁴⁰⁸⁴ - Weird runtime failures when using a channel and chained continuations
- PR #2915⁴⁰⁸⁵ - Introduce executor parameters customization points
- Issue #2914⁴⁰⁸⁶ - Task assignment to current Pool has unintended consequences
- PR #2913⁴⁰⁸⁷ - Fix rp hang
- PR #2912⁴⁰⁸⁸ - Update contributors

⁴⁰⁶⁶ <https://github.com/STELLAR-GROUP/hpx/pull/2934>

⁴⁰⁶⁷ <https://github.com/STELLAR-GROUP/hpx/pull/2933>

⁴⁰⁶⁸ <https://github.com/STELLAR-GROUP/hpx/pull/2932>

⁴⁰⁶⁹ <https://github.com/STELLAR-GROUP/hpx/issues/2931>

⁴⁰⁷⁰ <https://github.com/STELLAR-GROUP/hpx/pull/2930>

⁴⁰⁷¹ <https://github.com/STELLAR-GROUP/hpx/pull/2929>

⁴⁰⁷² <https://github.com/STELLAR-GROUP/hpx/pull/2928>

⁴⁰⁷³ <https://github.com/STELLAR-GROUP/hpx/issues/2927>

⁴⁰⁷⁴ <https://github.com/STELLAR-GROUP/hpx/pull/2926>

⁴⁰⁷⁵ <https://github.com/STELLAR-GROUP/hpx/issues/2925>

⁴⁰⁷⁶ <https://github.com/STELLAR-GROUP/hpx/issues/2924>

⁴⁰⁷⁷ <https://github.com/STELLAR-GROUP/hpx/pull/2923>

⁴⁰⁷⁸ <https://github.com/STELLAR-GROUP/hpx/pull/2922>

⁴⁰⁷⁹ <https://github.com/STELLAR-GROUP/hpx/pull/2921>

⁴⁰⁸⁰ <https://github.com/STELLAR-GROUP/hpx/pull/2920>

⁴⁰⁸¹ <https://github.com/STELLAR-GROUP/hpx/pull/2919>

⁴⁰⁸² <https://github.com/STELLAR-GROUP/hpx/issues/2918>

⁴⁰⁸³ <https://github.com/STELLAR-GROUP/hpx/pull/2917>

⁴⁰⁸⁴ <https://github.com/STELLAR-GROUP/hpx/issues/2916>

⁴⁰⁸⁵ <https://github.com/STELLAR-GROUP/hpx/pull/2915>

⁴⁰⁸⁶ <https://github.com/STELLAR-GROUP/hpx/issues/2914>

⁴⁰⁸⁷ <https://github.com/STELLAR-GROUP/hpx/pull/2913>

⁴⁰⁸⁸ <https://github.com/STELLAR-GROUP/hpx/pull/2912>

- [PR #2911⁴⁰⁸⁹](#) - Fixing CUDA problems
- [PR #2910⁴⁰⁹⁰](#) - Improve error reporting for process component on POSIX systems
- [PR #2909⁴⁰⁹¹](#) - Fix typo in include path
- [PR #2908⁴⁰⁹²](#) - Use proper container according to iterator tag in benchmarks of parallel algorithms
- [PR #2907⁴⁰⁹³](#) - Optionally force-delete remaining channel items on close
- [PR #2906⁴⁰⁹⁴](#) - Making sure generated performance counter names are correct
- [Issue #2905⁴⁰⁹⁵](#) - collecting idle-rate performance counters on multiple localities produces an error
- [Issue #2904⁴⁰⁹⁶](#) - build broken for Intel 17 compilers
- [PR #2903⁴⁰⁹⁷](#) - Documentation Updates– Adding New People
- [PR #2902⁴⁰⁹⁸](#) - Fixing service_executor
- [PR #2901⁴⁰⁹⁹](#) - Fixing partitioned_vector creation
- [PR #2900⁴¹⁰⁰](#) - Add numa-balanced mode to hpx::bind, spread cores over numa domains
- [Issue #2899⁴¹⁰¹](#) - hpx::bind does not have a mode that balances cores over numa domains
- [PR #2898⁴¹⁰²](#) - Adding missing #include and missing guard for optional code section
- [PR #2897⁴¹⁰³](#) - Removing dependency on Boost.ICL
- [Issue #2896⁴¹⁰⁴](#) - Debug build fails without -fpermissive with GCC 7.1 and Boost 1.65
- [PR #2895⁴¹⁰⁵](#) - Fixing SLURM environment parsing
- [PR #2894⁴¹⁰⁶](#) - Fix incorrect handling of compile definition with value 0
- [Issue #2893⁴¹⁰⁷](#) - Disabling schedulers causes build errors
- [PR #2892⁴¹⁰⁸](#) - added list serializer
- [PR #2891⁴¹⁰⁹](#) - Resource Partitioner Fixes
- [Issue #2890⁴¹¹⁰](#) - Destroying a non-empty channel causes an assertion failure
- [PR #2889⁴¹¹¹](#) - Add check for libatomic

⁴⁰⁸⁹ <https://github.com/STELLAR-GROUP/hpx/pull/2911>
⁴⁰⁹⁰ <https://github.com/STELLAR-GROUP/hpx/pull/2910>
⁴⁰⁹¹ <https://github.com/STELLAR-GROUP/hpx/pull/2909>
⁴⁰⁹² <https://github.com/STELLAR-GROUP/hpx/pull/2908>
⁴⁰⁹³ <https://github.com/STELLAR-GROUP/hpx/pull/2907>
⁴⁰⁹⁴ <https://github.com/STELLAR-GROUP/hpx/pull/2906>
⁴⁰⁹⁵ <https://github.com/STELLAR-GROUP/hpx/issues/2905>
⁴⁰⁹⁶ <https://github.com/STELLAR-GROUP/hpx/issues/2904>
⁴⁰⁹⁷ <https://github.com/STELLAR-GROUP/hpx/pull/2903>
⁴⁰⁹⁸ <https://github.com/STELLAR-GROUP/hpx/pull/2902>
⁴⁰⁹⁹ <https://github.com/STELLAR-GROUP/hpx/pull/2901>
⁴¹⁰⁰ <https://github.com/STELLAR-GROUP/hpx/pull/2900>
⁴¹⁰¹ <https://github.com/STELLAR-GROUP/hpx/issues/2899>
⁴¹⁰² <https://github.com/STELLAR-GROUP/hpx/pull/2898>
⁴¹⁰³ <https://github.com/STELLAR-GROUP/hpx/pull/2897>
⁴¹⁰⁴ <https://github.com/STELLAR-GROUP/hpx/issues/2896>
⁴¹⁰⁵ <https://github.com/STELLAR-GROUP/hpx/pull/2895>
⁴¹⁰⁶ <https://github.com/STELLAR-GROUP/hpx/pull/2894>
⁴¹⁰⁷ <https://github.com/STELLAR-GROUP/hpx/issues/2893>
⁴¹⁰⁸ <https://github.com/STELLAR-GROUP/hpx/pull/2892>
⁴¹⁰⁹ <https://github.com/STELLAR-GROUP/hpx/pull/2891>
⁴¹¹⁰ <https://github.com/STELLAR-GROUP/hpx/issues/2890>
⁴¹¹¹ <https://github.com/STELLAR-GROUP/hpx/pull/2889>

- PR #2888⁴¹¹² - Fix compilation problems if HPX_WITH_ITT_NOTIFY=ON
- PR #2887⁴¹¹³ - Adapt broadcast() to non-unwrapping async<Action>
- PR #2886⁴¹¹⁴ - Replace Boost.Random with C++11 <random>
- Issue #2885⁴¹¹⁵ - regression in broadcast?
- Issue #2884⁴¹¹⁶ - linking -latomic is not portable
- PR #2883⁴¹¹⁷ - Explicitly set -pthread flag if available
- PR #2882⁴¹¹⁸ - Wrap boost::format uses
- Issue #2881⁴¹¹⁹ - hpx not compiling with HPX_WITH_ITTNOTIFY=On
- Issue #2880⁴¹²⁰ - hpx::bind scatter/balanced give wrong pu masks
- PR #2878⁴¹²¹ - Fix incorrect pool usage masks setup in RP/thread manager
- PR #2877⁴¹²² - Require std::array by default
- PR #2875⁴¹²³ - Deprecate use of BOOST_ASSERT
- PR #2874⁴¹²⁴ - Changed serialization of boost.variant to use variadic templates
- Issue #2873⁴¹²⁵ - building with parcelport_mpi fails on cori
- PR #2871⁴¹²⁶ - Adding missing support for throttling scheduler
- PR #2870⁴¹²⁷ - Disambiguate use of base_lco_with_value macros with channel
- Issue #2869⁴¹²⁸ - Difficulty compiling HPX_REGISTER_CHANNEL_DECLARATION(double)
- PR #2868⁴¹²⁹ - Removing unneeded assert
- PR #2867⁴¹³⁰ - Implement parallel::unique
- Issue #2866⁴¹³¹ - The chunk_size_iterator violates multipass guarantee
- PR #2865⁴¹³² - Only use sched_getcpu on linux machines
- PR #2864⁴¹³³ - Create redistribution archive for successful builds
- PR #2863⁴¹³⁴ - Replace casts/assignments with hard-coded memcopy operations

⁴¹¹² <https://github.com/STELLAR-GROUP/hpx/pull/2888>

⁴¹¹³ <https://github.com/STELLAR-GROUP/hpx/pull/2887>

⁴¹¹⁴ <https://github.com/STELLAR-GROUP/hpx/pull/2886>

⁴¹¹⁵ <https://github.com/STELLAR-GROUP/hpx/issues/2885>

⁴¹¹⁶ <https://github.com/STELLAR-GROUP/hpx/issues/2884>

⁴¹¹⁷ <https://github.com/STELLAR-GROUP/hpx/pull/2883>

⁴¹¹⁸ <https://github.com/STELLAR-GROUP/hpx/pull/2882>

⁴¹¹⁹ <https://github.com/STELLAR-GROUP/hpx/issues/2881>

⁴¹²⁰ <https://github.com/STELLAR-GROUP/hpx/issues/2880>

⁴¹²¹ <https://github.com/STELLAR-GROUP/hpx/pull/2878>

⁴¹²² <https://github.com/STELLAR-GROUP/hpx/pull/2877>

⁴¹²³ <https://github.com/STELLAR-GROUP/hpx/pull/2875>

⁴¹²⁴ <https://github.com/STELLAR-GROUP/hpx/pull/2874>

⁴¹²⁵ <https://github.com/STELLAR-GROUP/hpx/issues/2873>

⁴¹²⁶ <https://github.com/STELLAR-GROUP/hpx/pull/2871>

⁴¹²⁷ <https://github.com/STELLAR-GROUP/hpx/pull/2870>

⁴¹²⁸ <https://github.com/STELLAR-GROUP/hpx/issues/2869>

⁴¹²⁹ <https://github.com/STELLAR-GROUP/hpx/pull/2868>

⁴¹³⁰ <https://github.com/STELLAR-GROUP/hpx/pull/2867>

⁴¹³¹ <https://github.com/STELLAR-GROUP/hpx/issues/2866>

⁴¹³² <https://github.com/STELLAR-GROUP/hpx/pull/2865>

⁴¹³³ <https://github.com/STELLAR-GROUP/hpx/pull/2864>

⁴¹³⁴ <https://github.com/STELLAR-GROUP/hpx/pull/2863>

- Issue #2862⁴¹³⁵ - sched_getcpu not available on MacOS
- PR #2861⁴¹³⁶ - Fixing unmatched header defines and recursive inclusion of threadmanager
- Issue #2860⁴¹³⁷ - Master program fails with assertion 'type == data_type_address' failed: HPX(assertion_failure)
- Issue #2852⁴¹³⁸ - Support for ARM64
- PR #2858⁴¹³⁹ - Fix misplaced #if #endif's that cause build failure without THREAD_CUMULATIVE_COUNTS
- PR #2857⁴¹⁴⁰ - Fix some listing in documentation
- PR #2856⁴¹⁴¹ - Fixing component handling for lcos
- PR #2855⁴¹⁴² - Add documentation for coarrays
- PR #2854⁴¹⁴³ - Support ARM64 in timestamps
- PR #2853⁴¹⁴⁴ - Update Table 17. Non-modifying Parallel Algorithms in Documentation
- PR #2851⁴¹⁴⁵ - Allowing for non-default-constructible component types
- PR #2850⁴¹⁴⁶ - Enable returning future<R> from actions where R is not default-constructible
- PR #2849⁴¹⁴⁷ - Unify serialization of non-default-constructable types
- Issue #2848⁴¹⁴⁸ - Components have to be default constructible
- Issue #2847⁴¹⁴⁹ - Returning a future<R> where R is not default-constructable broken
- Issue #2846⁴¹⁵⁰ - Unify serialization of non-default-constructible types
- PR #2845⁴¹⁵¹ - Add Visual Studio 2015 to the tested toolchains in Appveyor
- Issue #2844⁴¹⁵² - Change the appveyor build to use the minimal required MSVC version
- Issue #2843⁴¹⁵³ - multi node hello_world hangs
- PR #2842⁴¹⁵⁴ - Correcting Spelling mistake in docs
- PR #2841⁴¹⁵⁵ - Fix usage of std::aligned_storage
- PR #2840⁴¹⁵⁶ - Remove constexpr from a void function
- Issue #2839⁴¹⁵⁷ - memcpy buffer overflow: load_construct_data() and std::complex members

⁴¹³⁵ <https://github.com/STELLAR-GROUP/hpx/issues/2862>

⁴¹³⁶ <https://github.com/STELLAR-GROUP/hpx/pull/2861>

⁴¹³⁷ <https://github.com/STELLAR-GROUP/hpx/issues/2860>

⁴¹³⁸ <https://github.com/STELLAR-GROUP/hpx/issues/2852>

⁴¹³⁹ <https://github.com/STELLAR-GROUP/hpx/pull/2858>

⁴¹⁴⁰ <https://github.com/STELLAR-GROUP/hpx/pull/2857>

⁴¹⁴¹ <https://github.com/STELLAR-GROUP/hpx/pull/2856>

⁴¹⁴² <https://github.com/STELLAR-GROUP/hpx/pull/2855>

⁴¹⁴³ <https://github.com/STELLAR-GROUP/hpx/pull/2854>

⁴¹⁴⁴ <https://github.com/STELLAR-GROUP/hpx/pull/2853>

⁴¹⁴⁵ <https://github.com/STELLAR-GROUP/hpx/pull/2851>

⁴¹⁴⁶ <https://github.com/STELLAR-GROUP/hpx/pull/2850>

⁴¹⁴⁷ <https://github.com/STELLAR-GROUP/hpx/pull/2849>

⁴¹⁴⁸ <https://github.com/STELLAR-GROUP/hpx/issues/2848>

⁴¹⁴⁹ <https://github.com/STELLAR-GROUP/hpx/issues/2847>

⁴¹⁵⁰ <https://github.com/STELLAR-GROUP/hpx/issues/2846>

⁴¹⁵¹ <https://github.com/STELLAR-GROUP/hpx/pull/2845>

⁴¹⁵² <https://github.com/STELLAR-GROUP/hpx/issues/2844>

⁴¹⁵³ <https://github.com/STELLAR-GROUP/hpx/issues/2843>

⁴¹⁵⁴ <https://github.com/STELLAR-GROUP/hpx/pull/2842>

⁴¹⁵⁵ <https://github.com/STELLAR-GROUP/hpx/pull/2841>

⁴¹⁵⁶ <https://github.com/STELLAR-GROUP/hpx/pull/2840>

⁴¹⁵⁷ <https://github.com/STELLAR-GROUP/hpx/issues/2839>

- [Issue #2835](#)⁴¹⁵⁸ - `constexpr` functions with `void` return type break compilation with CUDA 8.0
- [Issue #2834](#)⁴¹⁵⁹ - One suspicion in `parallel::detail::handle_exception`
- [PR #2833](#)⁴¹⁶⁰ - Implement `parallel::merge`
- [PR #2832](#)⁴¹⁶¹ - Fix a strange thing in `parallel::util::detail::handle_local_exceptions`. (Fix #2818)
- [PR #2830](#)⁴¹⁶² - Break the debugger when a test failed
- [Issue #2831](#)⁴¹⁶³ - `parallel/executors/execution_fwd.hpp` causes compilation failure in C++11 mode.
- [PR #2829](#)⁴¹⁶⁴ - Implement an API for asynchronous pack traversal
- [PR #2828](#)⁴¹⁶⁵ - Split unit test builds on CircleCI to avoid timeouts
- [Issue #2827](#)⁴¹⁶⁶ - failure to compile `hello_world` example with `-Werror`
- [PR #2824](#)⁴¹⁶⁷ - Making sure promises are marked as started when used as continuations
- [PR #2823](#)⁴¹⁶⁸ - Add documentation for `partitioned_vector_view`
- [Issue #2822](#)⁴¹⁶⁹ - Yet another issue with `wait_for` similar to #2796
- [PR #2821](#)⁴¹⁷⁰ - Fix bugs and improve that about `HPX_HAVE_CXX11_AUTO_RETURN_VALUE` of CMake
- [PR #2820](#)⁴¹⁷¹ - Support C++11 in benchmark codes of `parallel::partition` and `parallel::partition_copy`
- [PR #2819](#)⁴¹⁷² - Fix compile errors in unit test of container version of `parallel::partition`
- [Issue #2818](#)⁴¹⁷³ - A strange thing in `parallel::util::detail::handle_local_exceptions`
- [Issue #2815](#)⁴¹⁷⁴ - HPX fails to compile with `HPX_WITH_CUDA=ON` and the new CUDA 9.0 RC
- [Issue #2814](#)⁴¹⁷⁵ - Using 'gmakeN' after 'cmake' produces error in `src/CMakeFiles/hpx.dir/runtime/agas/addressing_service.cpp.o`
- [PR #2813](#)⁴¹⁷⁶ - Properly support `[[noreturn]]` attribute if available
- [Issue #2812](#)⁴¹⁷⁷ - Compilation fails with `gcc 7.1.1`
- [PR #2811](#)⁴¹⁷⁸ - Adding `hpx::launch::lazy` and support for `async`, `dataflow`, and `future::then`
- [PR #2810](#)⁴¹⁷⁹ - Add option allowing to disable deprecation warning
- [PR #2809](#)⁴¹⁸⁰ - Disable throttling scheduler if `HWLOC` is not found/used

⁴¹⁵⁸ <https://github.com/STELLAR-GROUP/hpx/issues/2835>

⁴¹⁵⁹ <https://github.com/STELLAR-GROUP/hpx/issues/2834>

⁴¹⁶⁰ <https://github.com/STELLAR-GROUP/hpx/pull/2833>

⁴¹⁶¹ <https://github.com/STELLAR-GROUP/hpx/pull/2832>

⁴¹⁶² <https://github.com/STELLAR-GROUP/hpx/pull/2830>

⁴¹⁶³ <https://github.com/STELLAR-GROUP/hpx/issues/2831>

⁴¹⁶⁴ <https://github.com/STELLAR-GROUP/hpx/pull/2829>

⁴¹⁶⁵ <https://github.com/STELLAR-GROUP/hpx/pull/2828>

⁴¹⁶⁶ <https://github.com/STELLAR-GROUP/hpx/issues/2827>

⁴¹⁶⁷ <https://github.com/STELLAR-GROUP/hpx/pull/2824>

⁴¹⁶⁸ <https://github.com/STELLAR-GROUP/hpx/pull/2823>

⁴¹⁶⁹ <https://github.com/STELLAR-GROUP/hpx/issues/2822>

⁴¹⁷⁰ <https://github.com/STELLAR-GROUP/hpx/pull/2821>

⁴¹⁷¹ <https://github.com/STELLAR-GROUP/hpx/pull/2820>

⁴¹⁷² <https://github.com/STELLAR-GROUP/hpx/pull/2819>

⁴¹⁷³ <https://github.com/STELLAR-GROUP/hpx/issues/2818>

⁴¹⁷⁴ <https://github.com/STELLAR-GROUP/hpx/issues/2815>

⁴¹⁷⁵ <https://github.com/STELLAR-GROUP/hpx/issues/2814>

⁴¹⁷⁶ <https://github.com/STELLAR-GROUP/hpx/pull/2813>

⁴¹⁷⁷ <https://github.com/STELLAR-GROUP/hpx/issues/2812>

⁴¹⁷⁸ <https://github.com/STELLAR-GROUP/hpx/pull/2811>

⁴¹⁷⁹ <https://github.com/STELLAR-GROUP/hpx/pull/2810>

⁴¹⁸⁰ <https://github.com/STELLAR-GROUP/hpx/pull/2809>

- PR #2808⁴¹⁸¹ - Fix compile errors on some environments of `parallel::partition`
- Issue #2807⁴¹⁸² - Difficulty building with `HPX_WITH_HWLOC=Off`
- PR #2806⁴¹⁸³ - Partitioned vector
- PR #2805⁴¹⁸⁴ - Serializing collections with non-default constructible data
- PR #2802⁴¹⁸⁵ - Fix FreeBSD 11
- Issue #2801⁴¹⁸⁶ - Rate limiting techniques in `io_service`
- Issue #2800⁴¹⁸⁷ - New Launch Policy: `async_if`
- PR #2799⁴¹⁸⁸ - Fix a unit test failure on GCC in `tuple_cat`
- PR #2798⁴¹⁸⁹ - bump minimum required cmake to 3.0 in test
- PR #2797⁴¹⁹⁰ - Making sure `future::wait_for` et.al. work properly for action results
- Issue #2796⁴¹⁹¹ - `wait_for` does always in “deferred” state for calls on remote localities
- Issue #2795⁴¹⁹² - Serialization of types without default constructor
- PR #2794⁴¹⁹³ - Fixing test for `partitioned_vector` iteration
- PR #2792⁴¹⁹⁴ - Implemented segmented find and its variations for partitioned vector
- PR #2791⁴¹⁹⁵ - Circumvent scary warning about placement new
- PR #2790⁴¹⁹⁶ - Fix OSX build
- PR #2789⁴¹⁹⁷ - Resource partitioner
- PR #2788⁴¹⁹⁸ - Adapt `parallel::is_heap` and `parallel::is_heap_until` to Ranges TS
- PR #2787⁴¹⁹⁹ - Unwrap hotfixes
- PR #2786⁴²⁰⁰ - Update CMake Minimum Version to 3.3.2 (refs #2565)
- Issue #2785⁴²⁰¹ - Issues with masks and `cpuset`
- PR #2784⁴²⁰² - Error with reduce and transform reduce fixed
- PR #2783⁴²⁰³ - StackOverflow integration with `libsigsigv`

⁴¹⁸¹ <https://github.com/STELLAR-GROUP/hpx/pull/2808>

⁴¹⁸² <https://github.com/STELLAR-GROUP/hpx/issues/2807>

⁴¹⁸³ <https://github.com/STELLAR-GROUP/hpx/pull/2806>

⁴¹⁸⁴ <https://github.com/STELLAR-GROUP/hpx/pull/2805>

⁴¹⁸⁵ <https://github.com/STELLAR-GROUP/hpx/pull/2802>

⁴¹⁸⁶ <https://github.com/STELLAR-GROUP/hpx/issues/2801>

⁴¹⁸⁷ <https://github.com/STELLAR-GROUP/hpx/issues/2800>

⁴¹⁸⁸ <https://github.com/STELLAR-GROUP/hpx/pull/2799>

⁴¹⁸⁹ <https://github.com/STELLAR-GROUP/hpx/pull/2798>

⁴¹⁹⁰ <https://github.com/STELLAR-GROUP/hpx/pull/2797>

⁴¹⁹¹ <https://github.com/STELLAR-GROUP/hpx/issues/2796>

⁴¹⁹² <https://github.com/STELLAR-GROUP/hpx/issues/2795>

⁴¹⁹³ <https://github.com/STELLAR-GROUP/hpx/pull/2794>

⁴¹⁹⁴ <https://github.com/STELLAR-GROUP/hpx/pull/2792>

⁴¹⁹⁵ <https://github.com/STELLAR-GROUP/hpx/pull/2791>

⁴¹⁹⁶ <https://github.com/STELLAR-GROUP/hpx/pull/2790>

⁴¹⁹⁷ <https://github.com/STELLAR-GROUP/hpx/pull/2789>

⁴¹⁹⁸ <https://github.com/STELLAR-GROUP/hpx/pull/2788>

⁴¹⁹⁹ <https://github.com/STELLAR-GROUP/hpx/pull/2787>

⁴²⁰⁰ <https://github.com/STELLAR-GROUP/hpx/pull/2786>

⁴²⁰¹ <https://github.com/STELLAR-GROUP/hpx/issues/2785>

⁴²⁰² <https://github.com/STELLAR-GROUP/hpx/pull/2784>

⁴²⁰³ <https://github.com/STELLAR-GROUP/hpx/pull/2783>

- PR #2782⁴²⁰⁴ - Replace boost::atomic with std::atomic (where possible)
- PR #2781⁴²⁰⁵ - Check for and optionally use [[deprecated]] attribute
- PR #2780⁴²⁰⁶ - Adding empty (but non-trivial) destructor to circumvent warnings
- PR #2779⁴²⁰⁷ - Exception info tweaks
- PR #2778⁴²⁰⁸ - Implement parallel::partition
- PR #2777⁴²⁰⁹ - Improve error handling in gather_here/gather_there
- PR #2776⁴²¹⁰ - Fix a bug in compiler version check
- PR #2775⁴²¹¹ - Fix compilation when HPX_WITH_LOGGING is OFF
- PR #2774⁴²¹² - Removing dependency on Boost.Date_Time
- PR #2773⁴²¹³ - Add sync_images() method to spmd_block class
- PR #2772⁴²¹⁴ - Adding documentation for PAPI counters
- PR #2771⁴²¹⁵ - Removing boost preprocessor dependency
- PR #2770⁴²¹⁶ - Adding test, fixing deadlock in config registry
- PR #2769⁴²¹⁷ - Remove some other warnings and errors detected by clang 5.0
- Issue #2768⁴²¹⁸ - Is there iterator tag for HPX?
- PR #2767⁴²¹⁹ - Improvements to continuation annotation
- PR #2765⁴²²⁰ - gcc split stack support for HPX threads #620
- PR #2764⁴²²¹ - Fix some uses of begin/end, remove unnecessary includes
- PR #2763⁴²²² - Bump minimal Boost version to 1.55.0
- PR #2762⁴²²³ - hpx::partitioned_vector serializer
- PR #2761⁴²²⁴ - Adding configuration summary to cmake output and -hpx:info
- PR #2760⁴²²⁵ - Removing 1d_hydro example as it is broken
- PR #2758⁴²²⁶ - Remove various warnings detected by clang 5.0

⁴²⁰⁴ <https://github.com/STELLAR-GROUP/hpx/pull/2782>

⁴²⁰⁵ <https://github.com/STELLAR-GROUP/hpx/pull/2781>

⁴²⁰⁶ <https://github.com/STELLAR-GROUP/hpx/pull/2780>

⁴²⁰⁷ <https://github.com/STELLAR-GROUP/hpx/pull/2779>

⁴²⁰⁸ <https://github.com/STELLAR-GROUP/hpx/pull/2778>

⁴²⁰⁹ <https://github.com/STELLAR-GROUP/hpx/pull/2777>

⁴²¹⁰ <https://github.com/STELLAR-GROUP/hpx/pull/2776>

⁴²¹¹ <https://github.com/STELLAR-GROUP/hpx/pull/2775>

⁴²¹² <https://github.com/STELLAR-GROUP/hpx/pull/2774>

⁴²¹³ <https://github.com/STELLAR-GROUP/hpx/pull/2773>

⁴²¹⁴ <https://github.com/STELLAR-GROUP/hpx/pull/2772>

⁴²¹⁵ <https://github.com/STELLAR-GROUP/hpx/pull/2771>

⁴²¹⁶ <https://github.com/STELLAR-GROUP/hpx/pull/2770>

⁴²¹⁷ <https://github.com/STELLAR-GROUP/hpx/pull/2769>

⁴²¹⁸ <https://github.com/STELLAR-GROUP/hpx/issues/2768>

⁴²¹⁹ <https://github.com/STELLAR-GROUP/hpx/pull/2767>

⁴²²⁰ <https://github.com/STELLAR-GROUP/hpx/pull/2765>

⁴²²¹ <https://github.com/STELLAR-GROUP/hpx/pull/2764>

⁴²²² <https://github.com/STELLAR-GROUP/hpx/pull/2763>

⁴²²³ <https://github.com/STELLAR-GROUP/hpx/pull/2762>

⁴²²⁴ <https://github.com/STELLAR-GROUP/hpx/pull/2761>

⁴²²⁵ <https://github.com/STELLAR-GROUP/hpx/pull/2760>

⁴²²⁶ <https://github.com/STELLAR-GROUP/hpx/pull/2758>

- [Issue #2757⁴²²⁷](#) - In case of a “raw thread” is needed per core for implementing parallel algorithm, what is good practice in HPX?
- [PR #2756⁴²²⁸](#) - Allowing for LCOs to be simple components
- [PR #2755⁴²²⁹](#) - Removing make_index_pack_unrolled
- [PR #2754⁴²³⁰](#) - Implement parallel::unique_copy
- [PR #2753⁴²³¹](#) - Fixing detection of [[fallthrough]] attribute
- [PR #2752⁴²³²](#) - New thread priority names
- [PR #2751⁴²³³](#) - Replace boost::exception with proposed exception_info
- [PR #2750⁴²³⁴](#) - Replace boost::iterator_range
- [PR #2749⁴²³⁵](#) - Fixing hdf5 examples
- [Issue #2748⁴²³⁶](#) - HPX fails to build with enabled hdf5 examples
- [Issue #2747⁴²³⁷](#) - Inherited task priorities break certain DAG optimizations
- [Issue #2746⁴²³⁸](#) - HPX segfaulting with valgrind
- [PR #2745⁴²³⁹](#) - Adding extended arithmetic performance counters
- [PR #2744⁴²⁴⁰](#) - Adding ability to statistics counters to reset base counter
- [Issue #2743⁴²⁴¹](#) - Statistics counter does not support resetting
- [PR #2742⁴²⁴²](#) - Making sure Vc V2 builds without additional HPX configuration flags
- [PR #2741⁴²⁴³](#) - Deprecate unwrapped and implement unwrap and unwrapping
- [PR #2740⁴²⁴⁴](#) - Coroutine stackoverflow detection for linux/posix; Issue #2408
- [PR #2739⁴²⁴⁵](#) - Add files via upload
- [PR #2738⁴²⁴⁶](#) - Appveyor support
- [PR #2737⁴²⁴⁷](#) - Fixing 2735
- [Issue #2736⁴²⁴⁸](#) - 1d_hydro example doesn't work
- [Issue #2735⁴²⁴⁹](#) - partitioned_vector_subview test failing

⁴²²⁷ <https://github.com/STELLAR-GROUP/hpx/issues/2757>

⁴²²⁸ <https://github.com/STELLAR-GROUP/hpx/pull/2756>

⁴²²⁹ <https://github.com/STELLAR-GROUP/hpx/pull/2755>

⁴²³⁰ <https://github.com/STELLAR-GROUP/hpx/pull/2754>

⁴²³¹ <https://github.com/STELLAR-GROUP/hpx/pull/2753>

⁴²³² <https://github.com/STELLAR-GROUP/hpx/pull/2752>

⁴²³³ <https://github.com/STELLAR-GROUP/hpx/pull/2751>

⁴²³⁴ <https://github.com/STELLAR-GROUP/hpx/pull/2750>

⁴²³⁵ <https://github.com/STELLAR-GROUP/hpx/pull/2749>

⁴²³⁶ <https://github.com/STELLAR-GROUP/hpx/issues/2748>

⁴²³⁷ <https://github.com/STELLAR-GROUP/hpx/issues/2747>

⁴²³⁸ <https://github.com/STELLAR-GROUP/hpx/issues/2746>

⁴²³⁹ <https://github.com/STELLAR-GROUP/hpx/pull/2745>

⁴²⁴⁰ <https://github.com/STELLAR-GROUP/hpx/pull/2744>

⁴²⁴¹ <https://github.com/STELLAR-GROUP/hpx/issues/2743>

⁴²⁴² <https://github.com/STELLAR-GROUP/hpx/pull/2742>

⁴²⁴³ <https://github.com/STELLAR-GROUP/hpx/pull/2741>

⁴²⁴⁴ <https://github.com/STELLAR-GROUP/hpx/pull/2740>

⁴²⁴⁵ <https://github.com/STELLAR-GROUP/hpx/pull/2739>

⁴²⁴⁶ <https://github.com/STELLAR-GROUP/hpx/pull/2738>

⁴²⁴⁷ <https://github.com/STELLAR-GROUP/hpx/pull/2737>

⁴²⁴⁸ <https://github.com/STELLAR-GROUP/hpx/issues/2736>

⁴²⁴⁹ <https://github.com/STELLAR-GROUP/hpx/issues/2735>

- PR #2734⁴²⁵⁰ - Add C++11 range utilities
- PR #2733⁴²⁵¹ - Adapting iterator requirements for parallel algorithms
- PR #2732⁴²⁵² - Integrate C++ Co-arrays
- PR #2731⁴²⁵³ - Adding on_migrated event handler to migratable component instances
- Issue #2729⁴²⁵⁴ - Add on_migrated() event handler to migratable components
- Issue #2728⁴²⁵⁵ - Why Projection is needed in parallel algorithms?
- PR #2727⁴²⁵⁶ - Cmake files for StackOverflow Detection
- PR #2726⁴²⁵⁷ - CMake for Stack Overflow Detection
- PR #2725⁴²⁵⁸ - Implemented segmented algorithms for partitioned vector
- PR #2724⁴²⁵⁹ - Fix examples in Action documentation
- PR #2723⁴²⁶⁰ - Enable lcos::channel<T>::register_as
- Issue #2722⁴²⁶¹ - channel register_as() failing on compilation
- PR #2721⁴²⁶² - Mind map
- PR #2720⁴²⁶³ - reorder forward declarations to get rid of C++14-only auto return types
- PR #2719⁴²⁶⁴ - Add documentation for partitioned_vector and add features in pack.hpp
- Issue #2718⁴²⁶⁵ - Some forward declarations in execution_fwd.hpp aren't C++11-compatible
- PR #2717⁴²⁶⁶ - Config support for fallthrough attribute
- PR #2716⁴²⁶⁷ - Implement parallel::partition_copy
- PR #2715⁴²⁶⁸ - initial import of icu string serializer
- PR #2714⁴²⁶⁹ - initial import of valarray serializer
- PR #2713⁴²⁷⁰ - Remove slashes before CMAKE_FILES_DIRECTORY variables
- PR #2712⁴²⁷¹ - Fixing wait for 1751
- PR #2711⁴²⁷² - Adjust code for minimal supported GCC having being bumped to 4.9

⁴²⁵⁰ <https://github.com/STELLAR-GROUP/hpx/pull/2734>

⁴²⁵¹ <https://github.com/STELLAR-GROUP/hpx/pull/2733>

⁴²⁵² <https://github.com/STELLAR-GROUP/hpx/pull/2732>

⁴²⁵³ <https://github.com/STELLAR-GROUP/hpx/pull/2731>

⁴²⁵⁴ <https://github.com/STELLAR-GROUP/hpx/issues/2729>

⁴²⁵⁵ <https://github.com/STELLAR-GROUP/hpx/issues/2728>

⁴²⁵⁶ <https://github.com/STELLAR-GROUP/hpx/pull/2727>

⁴²⁵⁷ <https://github.com/STELLAR-GROUP/hpx/pull/2726>

⁴²⁵⁸ <https://github.com/STELLAR-GROUP/hpx/pull/2725>

⁴²⁵⁹ <https://github.com/STELLAR-GROUP/hpx/pull/2724>

⁴²⁶⁰ <https://github.com/STELLAR-GROUP/hpx/pull/2723>

⁴²⁶¹ <https://github.com/STELLAR-GROUP/hpx/issues/2722>

⁴²⁶² <https://github.com/STELLAR-GROUP/hpx/pull/2721>

⁴²⁶³ <https://github.com/STELLAR-GROUP/hpx/pull/2720>

⁴²⁶⁴ <https://github.com/STELLAR-GROUP/hpx/pull/2719>

⁴²⁶⁵ <https://github.com/STELLAR-GROUP/hpx/issues/2718>

⁴²⁶⁶ <https://github.com/STELLAR-GROUP/hpx/pull/2717>

⁴²⁶⁷ <https://github.com/STELLAR-GROUP/hpx/pull/2716>

⁴²⁶⁸ <https://github.com/STELLAR-GROUP/hpx/pull/2715>

⁴²⁶⁹ <https://github.com/STELLAR-GROUP/hpx/pull/2714>

⁴²⁷⁰ <https://github.com/STELLAR-GROUP/hpx/pull/2713>

⁴²⁷¹ <https://github.com/STELLAR-GROUP/hpx/pull/2712>

⁴²⁷² <https://github.com/STELLAR-GROUP/hpx/pull/2711>

- PR #2710⁴²⁷³ - Adding code of conduct
- PR #2709⁴²⁷⁴ - Fixing UB in destroy tests
- PR #2708⁴²⁷⁵ - Add inline to prevent multiple definition issue
- Issue #2707⁴²⁷⁶ - Multiple defined symbols for task_block.hpp in VS2015
- PR #2706⁴²⁷⁷ - Adding .clang-format file
- PR #2704⁴²⁷⁸ - Add a synchronous mapping API
- Issue #2703⁴²⁷⁹ - Request: Add the .clang-format file to the repository
- Issue #2702⁴²⁸⁰ - STELLAR-GROUP/Vc slower than VCv1 possibly due to wrong instructions generated
- Issue #2701⁴²⁸¹ - Datapar with STELLAR-GROUP/Vc requires obscure flag
- Issue #2700⁴²⁸² - Naming inconsistency in parallel algorithms
- Issue #2699⁴²⁸³ - Iterator requirements are different from standard in parallel copy_if.
- PR #2698⁴²⁸⁴ - Properly releasing parcelport write handlers
- Issue #2697⁴²⁸⁵ - Compile error in addressing_service.cpp
- Issue #2696⁴²⁸⁶ - Building and using HPX statically: undefined references from runtime_support_server.cpp
- Issue #2695⁴²⁸⁷ - Executor changes cause compilation failures
- PR #2694⁴²⁸⁸ - Refining C++ language mode detection for MSVC
- PR #2693⁴²⁸⁹ - P0443 r2
- PR #2692⁴²⁹⁰ - Partially reverting changes to parcel_await
- Issue #2689⁴²⁹¹ - HPX build fails when HPX_WITH_CUDA is enabled
- PR #2688⁴²⁹² - Make Cuda Clang builds pass
- PR #2687⁴²⁹³ - Add an is_tuple_like trait for sequenceable type detection
- PR #2686⁴²⁹⁴ - Allowing throttling scheduler to be used without idle backoff
- PR #2685⁴²⁹⁵ - Add support of std::array to hpx::util::tuple_size and tuple_element

⁴²⁷³ <https://github.com/STELLAR-GROUP/hpx/pull/2710>

⁴²⁷⁴ <https://github.com/STELLAR-GROUP/hpx/pull/2709>

⁴²⁷⁵ <https://github.com/STELLAR-GROUP/hpx/pull/2708>

⁴²⁷⁶ <https://github.com/STELLAR-GROUP/hpx/issues/2707>

⁴²⁷⁷ <https://github.com/STELLAR-GROUP/hpx/pull/2706>

⁴²⁷⁸ <https://github.com/STELLAR-GROUP/hpx/pull/2704>

⁴²⁷⁹ <https://github.com/STELLAR-GROUP/hpx/issues/2703>

⁴²⁸⁰ <https://github.com/STELLAR-GROUP/hpx/issues/2702>

⁴²⁸¹ <https://github.com/STELLAR-GROUP/hpx/issues/2701>

⁴²⁸² <https://github.com/STELLAR-GROUP/hpx/issues/2700>

⁴²⁸³ <https://github.com/STELLAR-GROUP/hpx/issues/2699>

⁴²⁸⁴ <https://github.com/STELLAR-GROUP/hpx/pull/2698>

⁴²⁸⁵ <https://github.com/STELLAR-GROUP/hpx/issues/2697>

⁴²⁸⁶ <https://github.com/STELLAR-GROUP/hpx/issues/2696>

⁴²⁸⁷ <https://github.com/STELLAR-GROUP/hpx/issues/2695>

⁴²⁸⁸ <https://github.com/STELLAR-GROUP/hpx/pull/2694>

⁴²⁸⁹ <https://github.com/STELLAR-GROUP/hpx/pull/2693>

⁴²⁹⁰ <https://github.com/STELLAR-GROUP/hpx/pull/2692>

⁴²⁹¹ <https://github.com/STELLAR-GROUP/hpx/issues/2689>

⁴²⁹² <https://github.com/STELLAR-GROUP/hpx/pull/2688>

⁴²⁹³ <https://github.com/STELLAR-GROUP/hpx/pull/2687>

⁴²⁹⁴ <https://github.com/STELLAR-GROUP/hpx/pull/2686>

⁴²⁹⁵ <https://github.com/STELLAR-GROUP/hpx/pull/2685>

- PR #2684⁴²⁹⁶ - Adding new statistics performance counters
- PR #2683⁴²⁹⁷ - Replace boost::exception_ptr with std::exception_ptr
- Issue #2682⁴²⁹⁸ - HPX does not compile with HPX_WITH_THREAD_MANAGER_IDLE_BACKOFF=OFF
- PR #2681⁴²⁹⁹ - Attempt to fix problem in managed_component_base
- PR #2680⁴³⁰⁰ - Fix bad size during archive creation
- Issue #2679⁴³⁰¹ - Mismatch between size of archive and container
- Issue #2678⁴³⁰² - In parallel algorithm, other tasks are executed to the end even if an exception occurs in any task.
- PR #2677⁴³⁰³ - Adding include check for std::addressof
- PR #2676⁴³⁰⁴ - Adding parallel::destroy and destroy_n
- PR #2675⁴³⁰⁵ - Making sure statistics counters work as expected
- PR #2674⁴³⁰⁶ - Turning assertions into exceptions
- PR #2673⁴³⁰⁷ - Inhibit direct conversion from future<future<T>> -> future<void>
- PR #2672⁴³⁰⁸ - C++17 invoke forms
- PR #2671⁴³⁰⁹ - Adding uninitialized_value_construct and uninitialized_value_construct_n
- PR #2670⁴³¹⁰ - Integrate spmd multidimensional views for partitioned_vectors
- PR #2669⁴³¹¹ - Adding uninitialized_default_construct and uninitialized_default_construct_n
- PR #2668⁴³¹² - Fixing documentation index
- Issue #2667⁴³¹³ - Ambiguity of nested hpx::future<void>'s
- Issue #2666⁴³¹⁴ - Statistics Performance counter is not working
- PR #2664⁴³¹⁵ - Adding uninitialized_move and uninitialized_move_n
- Issue #2663⁴³¹⁶ - Seg fault in managed_component::get_base_gid, possibly cause by util::reinitializable_static
- Issue #2662⁴³¹⁷ - Crash in managed_component::get_base_gid due to problem with util::reinitializable_static
- PR #2665⁴³¹⁸ - Hide the detail namespace in doxygen per default

⁴²⁹⁶ <https://github.com/STELLAR-GROUP/hpx/pull/2684>

⁴²⁹⁷ <https://github.com/STELLAR-GROUP/hpx/pull/2683>

⁴²⁹⁸ <https://github.com/STELLAR-GROUP/hpx/issues/2682>

⁴²⁹⁹ <https://github.com/STELLAR-GROUP/hpx/pull/2681>

⁴³⁰⁰ <https://github.com/STELLAR-GROUP/hpx/pull/2680>

⁴³⁰¹ <https://github.com/STELLAR-GROUP/hpx/issues/2679>

⁴³⁰² <https://github.com/STELLAR-GROUP/hpx/issues/2678>

⁴³⁰³ <https://github.com/STELLAR-GROUP/hpx/pull/2677>

⁴³⁰⁴ <https://github.com/STELLAR-GROUP/hpx/pull/2676>

⁴³⁰⁵ <https://github.com/STELLAR-GROUP/hpx/pull/2675>

⁴³⁰⁶ <https://github.com/STELLAR-GROUP/hpx/pull/2674>

⁴³⁰⁷ <https://github.com/STELLAR-GROUP/hpx/pull/2673>

⁴³⁰⁸ <https://github.com/STELLAR-GROUP/hpx/pull/2672>

⁴³⁰⁹ <https://github.com/STELLAR-GROUP/hpx/pull/2671>

⁴³¹⁰ <https://github.com/STELLAR-GROUP/hpx/pull/2670>

⁴³¹¹ <https://github.com/STELLAR-GROUP/hpx/pull/2669>

⁴³¹² <https://github.com/STELLAR-GROUP/hpx/pull/2668>

⁴³¹³ <https://github.com/STELLAR-GROUP/hpx/issues/2667>

⁴³¹⁴ <https://github.com/STELLAR-GROUP/hpx/issues/2666>

⁴³¹⁵ <https://github.com/STELLAR-GROUP/hpx/pull/2664>

⁴³¹⁶ <https://github.com/STELLAR-GROUP/hpx/issues/2663>

⁴³¹⁷ <https://github.com/STELLAR-GROUP/hpx/issues/2662>

⁴³¹⁸ <https://github.com/STELLAR-GROUP/hpx/pull/2665>

- PR #2660⁴³¹⁹ - Add documentation to `hpx::util::unwrapped` and `hpx::util::unwrapped2`
- PR #2659⁴³²⁰ - Improve integration with `vcpkg`
- PR #2658⁴³²¹ - Unify `access_data` trait for use in both, serialization and de-serialization
- PR #2657⁴³²² - Removing `hpx::lcos::queue<T>`
- PR #2656⁴³²³ - Reduce `MAX_TERMINATED_THREADS` default, improve memory use on manycore cpus
- PR #2655⁴³²⁴ - Maintenance for emulate-deleted macros
- PR #2654⁴³²⁵ - Implement parallel `is_heap` and `is_heap_until`
- PR #2653⁴³²⁶ - Drop support for VS2013
- PR #2652⁴³²⁷ - This patch makes sure that all parcels in a batch are properly handled
- PR #2649⁴³²⁸ - Update docs (Table 18) - move `transform` to end
- Issue #2647⁴³²⁹ - `hpx::parcelset::detail::parcel_data::has_continuation_` is uninitialized
- Issue #2644⁴³³⁰ - Some `.vcxproj` in the `HPX.sln` fail to build
- Issue #2641⁴³³¹ - `hpx::lcos::queue` should be deprecated
- PR #2640⁴³³² - A new throttling policy with public APIs to suspend/resume
- PR #2639⁴³³³ - Fix a tiny typo in tutorial.
- Issue #2638⁴³³⁴ - Invalid return type 'void' of `constexpr` function
- PR #2636⁴³³⁵ - Add and use `HPX_MSVC_WARNING_PRAGMA` for `#pragma` warning
- PR #2633⁴³³⁶ - Distributed `define_spmc_block`
- PR #2632⁴³³⁷ - Making sure container serialization uses size-compatible types
- PR #2631⁴³³⁸ - Add `lcos::local::one_element_channel`
- PR #2629⁴³³⁹ - Move `unordered_map` out of `parcelport` into `hpx/concurrent`
- PR #2628⁴³⁴⁰ - Making sure that shutdown does not hang
- PR #2627⁴³⁴¹ - Fix serialization

⁴³¹⁹ <https://github.com/STELLAR-GROUP/hpx/pull/2660>
⁴³²⁰ <https://github.com/STELLAR-GROUP/hpx/pull/2659>
⁴³²¹ <https://github.com/STELLAR-GROUP/hpx/pull/2658>
⁴³²² <https://github.com/STELLAR-GROUP/hpx/pull/2657>
⁴³²³ <https://github.com/STELLAR-GROUP/hpx/pull/2656>
⁴³²⁴ <https://github.com/STELLAR-GROUP/hpx/pull/2655>
⁴³²⁵ <https://github.com/STELLAR-GROUP/hpx/pull/2654>
⁴³²⁶ <https://github.com/STELLAR-GROUP/hpx/pull/2653>
⁴³²⁷ <https://github.com/STELLAR-GROUP/hpx/pull/2652>
⁴³²⁸ <https://github.com/STELLAR-GROUP/hpx/pull/2649>
⁴³²⁹ <https://github.com/STELLAR-GROUP/hpx/issues/2647>
⁴³³⁰ <https://github.com/STELLAR-GROUP/hpx/issues/2644>
⁴³³¹ <https://github.com/STELLAR-GROUP/hpx/issues/2641>
⁴³³² <https://github.com/STELLAR-GROUP/hpx/pull/2640>
⁴³³³ <https://github.com/STELLAR-GROUP/hpx/pull/2639>
⁴³³⁴ <https://github.com/STELLAR-GROUP/hpx/issues/2638>
⁴³³⁵ <https://github.com/STELLAR-GROUP/hpx/pull/2636>
⁴³³⁶ <https://github.com/STELLAR-GROUP/hpx/pull/2633>
⁴³³⁷ <https://github.com/STELLAR-GROUP/hpx/pull/2632>
⁴³³⁸ <https://github.com/STELLAR-GROUP/hpx/pull/2631>
⁴³³⁹ <https://github.com/STELLAR-GROUP/hpx/pull/2629>
⁴³⁴⁰ <https://github.com/STELLAR-GROUP/hpx/pull/2628>
⁴³⁴¹ <https://github.com/STELLAR-GROUP/hpx/pull/2627>

- PR #2626⁴³⁴² - Generate `cmake_variables.qbk` and `cmake_toolchains.qbk` outside of the source tree
- PR #2625⁴³⁴³ - Supporting `-std=c++17` flag
- PR #2624⁴³⁴⁴ - Fixing a small `cmake` typo
- PR #2622⁴³⁴⁵ - Update CMake minimum required version to 3.0.2 (closes #2621)
- Issue #2621⁴³⁴⁶ - Compiling `hpx` master fails with `/usr/bin/ld: final link failed: Bad value`
- PR #2620⁴³⁴⁷ - Remove warnings due to some captured variables
- PR #2619⁴³⁴⁸ - LF multiple parcels
- PR #2618⁴³⁴⁹ - Some fixes to `libfabric` that didn't get caught before the merge
- PR #2617⁴³⁵⁰ - Adding `hpx::local_new`
- PR #2616⁴³⁵¹ - Documentation: Extract all entities in order to autolink functions correctly
- Issue #2615⁴³⁵² - Documentation: Linking functions is broken
- PR #2614⁴³⁵³ - Adding serialization for `std::deque`
- PR #2613⁴³⁵⁴ - We need to link with `boost.thread` and `boost.chrono` if we use `boost.context`
- PR #2612⁴³⁵⁵ - Making sure `for_loop_n(par, ...)` is actually executed in parallel
- PR #2611⁴³⁵⁶ - Add documentation to `invoke_fused` and `friends NFC`
- PR #2610⁴³⁵⁷ - Added reduction templates using an identity value
- PR #2608⁴³⁵⁸ - Fixing some unused vars in `inspect`
- PR #2607⁴³⁵⁹ - Fixed build for `mingw`
- PR #2606⁴³⁶⁰ - Supporting generic context for `boost >= 1.61`
- PR #2605⁴³⁶¹ - Parcelport `libfabric3`
- PR #2604⁴³⁶² - Adding allocator support to `promise` and `friends`
- PR #2603⁴³⁶³ - Barrier hang
- PR #2602⁴³⁶⁴ - Changes to scheduler to steal from one high-priority queue

⁴³⁴² <https://github.com/STELLAR-GROUP/hpx/pull/2626>

⁴³⁴³ <https://github.com/STELLAR-GROUP/hpx/pull/2625>

⁴³⁴⁴ <https://github.com/STELLAR-GROUP/hpx/pull/2624>

⁴³⁴⁵ <https://github.com/STELLAR-GROUP/hpx/pull/2622>

⁴³⁴⁶ <https://github.com/STELLAR-GROUP/hpx/issues/2621>

⁴³⁴⁷ <https://github.com/STELLAR-GROUP/hpx/pull/2620>

⁴³⁴⁸ <https://github.com/STELLAR-GROUP/hpx/pull/2619>

⁴³⁴⁹ <https://github.com/STELLAR-GROUP/hpx/pull/2618>

⁴³⁵⁰ <https://github.com/STELLAR-GROUP/hpx/pull/2617>

⁴³⁵¹ <https://github.com/STELLAR-GROUP/hpx/pull/2616>

⁴³⁵² <https://github.com/STELLAR-GROUP/hpx/issues/2615>

⁴³⁵³ <https://github.com/STELLAR-GROUP/hpx/pull/2614>

⁴³⁵⁴ <https://github.com/STELLAR-GROUP/hpx/pull/2613>

⁴³⁵⁵ <https://github.com/STELLAR-GROUP/hpx/pull/2612>

⁴³⁵⁶ <https://github.com/STELLAR-GROUP/hpx/pull/2611>

⁴³⁵⁷ <https://github.com/STELLAR-GROUP/hpx/pull/2610>

⁴³⁵⁸ <https://github.com/STELLAR-GROUP/hpx/pull/2608>

⁴³⁵⁹ <https://github.com/STELLAR-GROUP/hpx/pull/2607>

⁴³⁶⁰ <https://github.com/STELLAR-GROUP/hpx/pull/2606>

⁴³⁶¹ <https://github.com/STELLAR-GROUP/hpx/pull/2605>

⁴³⁶² <https://github.com/STELLAR-GROUP/hpx/pull/2604>

⁴³⁶³ <https://github.com/STELLAR-GROUP/hpx/pull/2603>

⁴³⁶⁴ <https://github.com/STELLAR-GROUP/hpx/pull/2602>

- [Issue #2601⁴³⁶⁵](#) - High priority tasks are not executed first
- [PR #2600⁴³⁶⁶](#) - Compat fixes
- [PR #2599⁴³⁶⁷](#) - Compatibility layer for threading support
- [PR #2598⁴³⁶⁸](#) - V1.1
- [PR #2597⁴³⁶⁹](#) - Release V1.0
- [PR #2592⁴³⁷⁰](#) - First attempt to introduce `spmd_block` in `hpx`
- [PR #2586⁴³⁷¹](#) - `local_segment` in `segmented_iterator_traits`
- [Issue #2584⁴³⁷²](#) - Add allocator support to `promise`, `packaged_task` and friends
- [PR #2576⁴³⁷³](#) - Add missing dependencies of `cuda` based tests
- [PR #2575⁴³⁷⁴](#) - Remove warnings due to some captured variables
- [Issue #2574⁴³⁷⁵](#) - MSVC 2015 Compiler crash when building HPX
- [Issue #2568⁴³⁷⁶](#) - Remove `throttle_scheduler` as it has been abandoned
- [Issue #2566⁴³⁷⁷](#) - Add an inline versioning namespace before 1.0 release
- [Issue #2565⁴³⁷⁸](#) - Raise minimal `cmake` version requirement
- [PR #2556⁴³⁷⁹](#) - Fixing scan partitioner
- [PR #2546⁴³⁸⁰](#) - Broadcast `async`
- [Issue #2543⁴³⁸¹](#) - make install fails due to a non-existing `.so` file
- [PR #2495⁴³⁸²](#) - `wait_or_add_new` returning `thread_id_type`
- [Issue #2480⁴³⁸³](#) - Unable to register new performance counter
- [Issue #2471⁴³⁸⁴](#) - no type named `'fcontext_t'` in namespace
- [Issue #2456⁴³⁸⁵](#) - Re-implement `hpx::util::unwrapped`
- [Issue #2455⁴³⁸⁶](#) - Add more arithmetic performance counters
- [PR #2454⁴³⁸⁷](#) - Fix a couple of warnings and compiler errors

⁴³⁶⁵ <https://github.com/STELLAR-GROUP/hpx/issues/2601>

⁴³⁶⁶ <https://github.com/STELLAR-GROUP/hpx/pull/2600>

⁴³⁶⁷ <https://github.com/STELLAR-GROUP/hpx/pull/2599>

⁴³⁶⁸ <https://github.com/STELLAR-GROUP/hpx/pull/2598>

⁴³⁶⁹ <https://github.com/STELLAR-GROUP/hpx/pull/2597>

⁴³⁷⁰ <https://github.com/STELLAR-GROUP/hpx/pull/2592>

⁴³⁷¹ <https://github.com/STELLAR-GROUP/hpx/pull/2586>

⁴³⁷² <https://github.com/STELLAR-GROUP/hpx/issues/2584>

⁴³⁷³ <https://github.com/STELLAR-GROUP/hpx/pull/2576>

⁴³⁷⁴ <https://github.com/STELLAR-GROUP/hpx/pull/2575>

⁴³⁷⁵ <https://github.com/STELLAR-GROUP/hpx/issues/2574>

⁴³⁷⁶ <https://github.com/STELLAR-GROUP/hpx/issues/2568>

⁴³⁷⁷ <https://github.com/STELLAR-GROUP/hpx/issues/2566>

⁴³⁷⁸ <https://github.com/STELLAR-GROUP/hpx/issues/2565>

⁴³⁷⁹ <https://github.com/STELLAR-GROUP/hpx/pull/2556>

⁴³⁸⁰ <https://github.com/STELLAR-GROUP/hpx/pull/2546>

⁴³⁸¹ <https://github.com/STELLAR-GROUP/hpx/issues/2543>

⁴³⁸² <https://github.com/STELLAR-GROUP/hpx/pull/2495>

⁴³⁸³ <https://github.com/STELLAR-GROUP/hpx/issues/2480>

⁴³⁸⁴ <https://github.com/STELLAR-GROUP/hpx/issues/2471>

⁴³⁸⁵ <https://github.com/STELLAR-GROUP/hpx/issues/2456>

⁴³⁸⁶ <https://github.com/STELLAR-GROUP/hpx/issues/2455>

⁴³⁸⁷ <https://github.com/STELLAR-GROUP/hpx/pull/2454>

- PR #2453⁴³⁸⁸ - Timed executor support
- PR #2447⁴³⁸⁹ - Implementing new executor API (P0443)
- Issue #2439⁴³⁹⁰ - Implement executor proposal
- Issue #2408⁴³⁹¹ - Stackoverflow detection for linux, e.g. based on libsigsegv
- PR #2377⁴³⁹² - Add a customization point for put_parcel so we can override actions
- Issue #2368⁴³⁹³ - HPX_ASSERT problem
- Issue #2324⁴³⁹⁴ - Change default number of threads used to the maximum of the system
- Issue #2266⁴³⁹⁵ - hpx_0.9.99 make tests fail
- PR #2195⁴³⁹⁶ - Support for code completion in VIM
- Issue #2137⁴³⁹⁷ - Hpx does not compile over osx
- Issue #2092⁴³⁹⁸ - make tests should just build the tests
- Issue #2026⁴³⁹⁹ - Build HPX with Apple's clang
- Issue #1932⁴⁴⁰⁰ - hpx with PBS fails on multiple localities
- PR #1914⁴⁴⁰¹ - Parallel heap algorithm implementations WIP
- Issue #1598⁴⁴⁰² - Disconnecting a locality results in segfault using heartbeat example
- Issue #1404⁴⁴⁰³ - unwrapped doesn't work with movable only types
- Issue #1400⁴⁴⁰⁴ - hpx::util::unwrapped doesn't work with non-future types
- Issue #1205⁴⁴⁰⁵ - TSS is broken
- Issue #1126⁴⁴⁰⁶ - vector<future<T> > does not work gracefully with dataflow, when_all and unwrapped
- Issue #1056⁴⁴⁰⁷ - Thread manager cleanup
- Issue #863⁴⁴⁰⁸ - Futures should not require a default constructor
- Issue #856⁴⁴⁰⁹ - Allow runtime_mode_connect to be used with security enabled
- Issue #726⁴⁴¹⁰ - Valgrind

⁴³⁸⁸ <https://github.com/STELLAR-GROUP/hpx/pull/2453>

⁴³⁸⁹ <https://github.com/STELLAR-GROUP/hpx/pull/2447>

⁴³⁹⁰ <https://github.com/STELLAR-GROUP/hpx/issues/2439>

⁴³⁹¹ <https://github.com/STELLAR-GROUP/hpx/issues/2408>

⁴³⁹² <https://github.com/STELLAR-GROUP/hpx/pull/2377>

⁴³⁹³ <https://github.com/STELLAR-GROUP/hpx/issues/2368>

⁴³⁹⁴ <https://github.com/STELLAR-GROUP/hpx/issues/2324>

⁴³⁹⁵ <https://github.com/STELLAR-GROUP/hpx/issues/2266>

⁴³⁹⁶ <https://github.com/STELLAR-GROUP/hpx/pull/2195>

⁴³⁹⁷ <https://github.com/STELLAR-GROUP/hpx/issues/2137>

⁴³⁹⁸ <https://github.com/STELLAR-GROUP/hpx/issues/2092>

⁴³⁹⁹ <https://github.com/STELLAR-GROUP/hpx/issues/2026>

⁴⁴⁰⁰ <https://github.com/STELLAR-GROUP/hpx/issues/1932>

⁴⁴⁰¹ <https://github.com/STELLAR-GROUP/hpx/pull/1914>

⁴⁴⁰² <https://github.com/STELLAR-GROUP/hpx/issues/1598>

⁴⁴⁰³ <https://github.com/STELLAR-GROUP/hpx/issues/1404>

⁴⁴⁰⁴ <https://github.com/STELLAR-GROUP/hpx/issues/1400>

⁴⁴⁰⁵ <https://github.com/STELLAR-GROUP/hpx/issues/1205>

⁴⁴⁰⁶ <https://github.com/STELLAR-GROUP/hpx/issues/1126>

⁴⁴⁰⁷ <https://github.com/STELLAR-GROUP/hpx/issues/1056>

⁴⁴⁰⁸ <https://github.com/STELLAR-GROUP/hpx/issues/863>

⁴⁴⁰⁹ <https://github.com/STELLAR-GROUP/hpx/issues/856>

⁴⁴¹⁰ <https://github.com/STELLAR-GROUP/hpx/issues/726>

- [Issue #701](#)⁴⁴¹¹ - Add RCR performance counter component
- [Issue #528](#)⁴⁴¹² - Add support for known failures and warning count/comparisons to `hpx_run_tests.py`

HPX V1.0.0 (Apr 24, 2017)

General changes

Here are some of the main highlights and changes for this release (in no particular order):

- Added the facility `hpx::split_future` which allows one to convert a `future<tuple<Ts...>>` into a `tuple<future<Ts>...>`. This functionality is not available when compiling *HPX* with VS2012.
- Added a new type of performance counter which allows one to return a list of values for each invocation. We also added a first counter of this type which collects a histogram of the times between parcels being created.
- Added new LCOs: `hpx::lcos::channel` and `hpx::lcos::local::channel` which are very similar to the well known channel constructs used in the Go language.
- Added new performance counters reporting the amount of data handled by the networking layer on a action-by-action basis (please see [PR #2289](#)⁴⁴¹³ for more details).
- Added a new facility `hpx::lcos::barrier`, replacing the equally named older one. The new facility has a slightly changed API and is much more efficient. Most notable, the new facility exposes a (global) function `hpx::lcos::barrier::synchronize()` which represents a global barrier across all localities.
- We have started to add support for vectorization to our parallel algorithm implementations. This support depends on using an external library, currently either Vc Library or `|boost_simd|`. Please see [Issue #2333](#)⁴⁴¹⁴ for a list of currently supported algorithms. This is an experimental feature and its implementation and/or API might change in the future. Please see this [blog-post](#)⁴⁴¹⁵ for more information.
- The parameter sequence for the `hpx::parallel::transform_reduce` overload taking one iterator range has changed to match the changes this algorithm has undergone while being moved to C++17. The old overload can be still enabled at configure time by specifying `-DHPX_WITH_TRANSFORM_REDUCE_COMPATIBILITY=On` to CMake.
- The algorithm `hpx::parallel::inner_product` has been renamed to `hpx::parallel::transform_reduce` to match the changes this algorithm has undergone while being moved to C++17. The old `inner_product` names can be still enabled at configure time by specifying `-DHPX_WITH_TRANSFORM_REDUCE_COMPATIBILITY=On` to CMake.
- Added versions of `hpx::get_ptr` taking client side representations for component instances as their parameter (instead of a global id).
- Added the helper utility `hpx::performance_counters::performance_counter_set` helping to encapsulate a set of performance counters to be managed concurrently.
- All execution policies and related classes have been renamed to be consistent with the naming changes applied for C++17. All policies now live in the namespace `hpx::parallel::execution`. The old names can be still enabled at configure time by specifying `-DHPX_WITH_EXECUTION_POLICY_COMPATIBILITY=On` to CMake.
- The thread scheduling subsystem has undergone a major refactoring which results in significant performance improvements. We have also improved the performance of creating `hpx::future` and of various facilities handling those.

⁴⁴¹¹ <https://github.com/STELLAR-GROUP/hpx/issues/701>

⁴⁴¹² <https://github.com/STELLAR-GROUP/hpx/issues/528>

⁴⁴¹³ <https://github.com/STELLAR-GROUP/hpx/pull/2289>

⁴⁴¹⁴ <https://github.com/STELLAR-GROUP/hpx/issues/2333>

⁴⁴¹⁵ <http://stellar-group.org/2016/09/vectorized-cpp-parallel-algorithms-with-hpx/>

- We have consolidated all of the code in `HPX.Compute` related to the integration of CUDA. `hpx::partitioned_vector` has been enabled to be usable with `hpx::compute::vector` which allows one to place the partitions on one or more GPU devices.
- Added new performance counters exposing various internals of the thread scheduling subsystem, such as the current idle- and busy-loop counters and instantaneous scheduler utilization.
- Extended and improved the use of the ITTNotify hooks allowing to collect performance counter data and function annotation information from within the Intel Amplifier tool.

Breaking changes

- We have dropped support for the gcc compiler versions V4.6 and 4.7. The minimal gcc version we now test on is gcc V4.8.
- We have removed (default) support for `boost::chrono` in interfaces, uses of it have been replaced with `std::chrono`. This facility can be still enabled at configure time by specifying `-DHPX_WITH_BOOST_CHRONO_COMPATIBILITY=On` to CMake.
- The parameter sequence for the `hpx::parallel::transform_reduce` overload taking one iterator range has changed to match the changes this algorithm has undergone while being moved to C++17.
- The algorithm `hpx::parallel::inner_product` has been renamed to `hpx::parallel::transform_reduce` to match the changes this algorithm has undergone while being moved to C++17.
- the build options `HPX_WITH_COLOCATED_BACKWARDS_COMPATIBILITY` and `HPX_WITH_COMPONENT_GET_GID_COMPATIBILITY` are now disabled by default. Please change your code still depending on the deprecated interfaces.

Bug fixes (closed tickets)

Here is a list of the important tickets we closed for this release.

- [PR #2596⁴⁴¹⁶](#) - Adding apex data
- [PR #2595⁴⁴¹⁷](#) - Remove obsolete file
- [Issue #2594⁴⁴¹⁸](#) - FindOpenCL.cmake mismatch with the official cmake module
- [PR #2592⁴⁴¹⁹](#) - First attempt to introduce `spmd_block` in `hpx`
- [Issue #2591⁴⁴²⁰](#) - Feature request: continuation (then) which does not require the callable object to take a future<R> as parameter
- [PR #2588⁴⁴²¹](#) - Daint fixes
- [PR #2587⁴⁴²²](#) - Fixing `transfer_(continuation)_action::schedule`
- [PR #2585⁴⁴²³](#) - Work around MSVC having an ICE when compiling with `-Ob2`
- [PR #2583⁴⁴²⁴](#) - changing `7zip` command to `7za` in `roll_release.sh`

⁴⁴¹⁶ <https://github.com/STELLAR-GROUP/hpx/pull/2596>

⁴⁴¹⁷ <https://github.com/STELLAR-GROUP/hpx/pull/2595>

⁴⁴¹⁸ <https://github.com/STELLAR-GROUP/hpx/issues/2594>

⁴⁴¹⁹ <https://github.com/STELLAR-GROUP/hpx/pull/2592>

⁴⁴²⁰ <https://github.com/STELLAR-GROUP/hpx/issues/2591>

⁴⁴²¹ <https://github.com/STELLAR-GROUP/hpx/pull/2588>

⁴⁴²² <https://github.com/STELLAR-GROUP/hpx/pull/2587>

⁴⁴²³ <https://github.com/STELLAR-GROUP/hpx/pull/2585>

⁴⁴²⁴ <https://github.com/STELLAR-GROUP/hpx/pull/2583>

- PR #2582⁴⁴²⁵ - First attempt to introduce `spmd_block` in `hpx`
- PR #2581⁴⁴²⁶ - Enable annotated function for parallel algorithms
- PR #2580⁴⁴²⁷ - First attempt to introduce `spmd_block` in `hpx`
- PR #2579⁴⁴²⁸ - Make thread NICE level setting an option
- PR #2578⁴⁴²⁹ - Implementing `enqueue` instead of busy wait when no sender is available
- PR #2577⁴⁴³⁰ - Retrieve `-std=c++11` consistent `nvcc` flag
- PR #2576⁴⁴³¹ - Add missing dependencies of `cuda` based tests
- PR #2575⁴⁴³² - Remove warnings due to some captured variables
- PR #2573⁴⁴³³ - Attempt to resolve `resolve_locality`
- PR #2572⁴⁴³⁴ - Adding APEX hooks to background thread
- PR #2571⁴⁴³⁵ - Pick up `hpx.ignore_batch_env` from config map
- PR #2570⁴⁴³⁶ - Add cmdline options `-hpx:print-counters-locally`
- PR #2569⁴⁴³⁷ - Fix `computeapi` unit tests
- PR #2567⁴⁴³⁸ - This adds another `barrier::synchronize` before registering performance counters
- PR #2564⁴⁴³⁹ - Cray static toolchain support
- PR #2563⁴⁴⁴⁰ - Fixed unhandled exception during startup
- PR #2562⁴⁴⁴¹ - Remove `partitioned_vector.cu` from build tree when `nvcc` is used
- Issue #2561⁴⁴⁴² - octo-tiger crash with commit `6e921495ff6c26f125d62629cbaad0525f14f7ab`
- PR #2560⁴⁴⁴³ - Prevent `-Wundef` warnings on `Vc` version checks
- PR #2559⁴⁴⁴⁴ - Allowing `CUDA` callback to set the future directly from an OS thread
- PR #2558⁴⁴⁴⁵ - Remove warnings due to float precisions
- PR #2557⁴⁴⁴⁶ - Removing bogus handling of compile flags for `CUDA`
- PR #2556⁴⁴⁴⁷ - Fixing scan partitioner

⁴⁴²⁵ <https://github.com/STELLAR-GROUP/hpx/pull/2582>

⁴⁴²⁶ <https://github.com/STELLAR-GROUP/hpx/pull/2581>

⁴⁴²⁷ <https://github.com/STELLAR-GROUP/hpx/pull/2580>

⁴⁴²⁸ <https://github.com/STELLAR-GROUP/hpx/pull/2579>

⁴⁴²⁹ <https://github.com/STELLAR-GROUP/hpx/pull/2578>

⁴⁴³⁰ <https://github.com/STELLAR-GROUP/hpx/pull/2577>

⁴⁴³¹ <https://github.com/STELLAR-GROUP/hpx/pull/2576>

⁴⁴³² <https://github.com/STELLAR-GROUP/hpx/pull/2575>

⁴⁴³³ <https://github.com/STELLAR-GROUP/hpx/pull/2573>

⁴⁴³⁴ <https://github.com/STELLAR-GROUP/hpx/pull/2572>

⁴⁴³⁵ <https://github.com/STELLAR-GROUP/hpx/pull/2571>

⁴⁴³⁶ <https://github.com/STELLAR-GROUP/hpx/pull/2570>

⁴⁴³⁷ <https://github.com/STELLAR-GROUP/hpx/pull/2569>

⁴⁴³⁸ <https://github.com/STELLAR-GROUP/hpx/pull/2567>

⁴⁴³⁹ <https://github.com/STELLAR-GROUP/hpx/pull/2564>

⁴⁴⁴⁰ <https://github.com/STELLAR-GROUP/hpx/pull/2563>

⁴⁴⁴¹ <https://github.com/STELLAR-GROUP/hpx/pull/2562>

⁴⁴⁴² <https://github.com/STELLAR-GROUP/hpx/issues/2561>

⁴⁴⁴³ <https://github.com/STELLAR-GROUP/hpx/pull/2560>

⁴⁴⁴⁴ <https://github.com/STELLAR-GROUP/hpx/pull/2559>

⁴⁴⁴⁵ <https://github.com/STELLAR-GROUP/hpx/pull/2558>

⁴⁴⁴⁶ <https://github.com/STELLAR-GROUP/hpx/pull/2557>

⁴⁴⁴⁷ <https://github.com/STELLAR-GROUP/hpx/pull/2556>

- PR #2554⁴⁴⁴⁸ - Add more diagnostics to error thrown from `find_appropriate_destination`
- Issue #2555⁴⁴⁴⁹ - No valid parcellport configured
- PR #2553⁴⁴⁵⁰ - Add `cmake cuda_arch` option
- PR #2552⁴⁴⁵¹ - Remove incomplete datapar bindings to `libflatarray`
- PR #2551⁴⁴⁵² - Rename `hwloc_topology` to `hwloc_topology_info`
- PR #2550⁴⁴⁵³ - Apex api updates
- PR #2549⁴⁴⁵⁴ - Pre-include `defines.hpp` to get the macro `HPX_HAVE_CUDA` value
- PR #2548⁴⁴⁵⁵ - Fixing issue with `disconnect`
- PR #2546⁴⁴⁵⁶ - Some fixes around `cuda clang partitioned_vector` example
- PR #2545⁴⁴⁵⁷ - Fix uses of the `Vc2` datapar flags; the value, not the type, should be passed to functions
- PR #2542⁴⁴⁵⁸ - Make `HPX_WITH_MALLOC` easier to use
- PR #2541⁴⁴⁵⁹ - avoid recompiles when enabling/disabling examples
- PR #2540⁴⁴⁶⁰ - Fixing usage of `target_link_libraries()`
- PR #2539⁴⁴⁶¹ - fix `RPATH` behaviour
- Issue #2538⁴⁴⁶² - `HPX_WITH_CUDA` corrupts compilation flags
- PR #2537⁴⁴⁶³ - Add output of a Bazel Skylark extension for paths and compile options
- PR #2536⁴⁴⁶⁴ - Add counter exposing total available memory to Windows as well
- PR #2535⁴⁴⁶⁵ - Remove obsolete support for security
- Issue #2534⁴⁴⁶⁶ - Remove command line option `--hpx:run-agas-server`
- PR #2533⁴⁴⁶⁷ - Pre-cache locality endpoints during bootstrap
- PR #2532⁴⁴⁶⁸ - Fixing handling of GIDs during serialization preprocessing
- PR #2531⁴⁴⁶⁹ - Amend uses of the term “functor”
- PR #2529⁴⁴⁷⁰ - added counter for reading available memory

⁴⁴⁴⁸ <https://github.com/STELLAR-GROUP/hpx/pull/2554>

⁴⁴⁴⁹ <https://github.com/STELLAR-GROUP/hpx/issues/2555>

⁴⁴⁵⁰ <https://github.com/STELLAR-GROUP/hpx/pull/2553>

⁴⁴⁵¹ <https://github.com/STELLAR-GROUP/hpx/pull/2552>

⁴⁴⁵² <https://github.com/STELLAR-GROUP/hpx/pull/2551>

⁴⁴⁵³ <https://github.com/STELLAR-GROUP/hpx/pull/2550>

⁴⁴⁵⁴ <https://github.com/STELLAR-GROUP/hpx/pull/2549>

⁴⁴⁵⁵ <https://github.com/STELLAR-GROUP/hpx/pull/2548>

⁴⁴⁵⁶ <https://github.com/STELLAR-GROUP/hpx/pull/2546>

⁴⁴⁵⁷ <https://github.com/STELLAR-GROUP/hpx/pull/2545>

⁴⁴⁵⁸ <https://github.com/STELLAR-GROUP/hpx/pull/2542>

⁴⁴⁵⁹ <https://github.com/STELLAR-GROUP/hpx/pull/2541>

⁴⁴⁶⁰ <https://github.com/STELLAR-GROUP/hpx/pull/2540>

⁴⁴⁶¹ <https://github.com/STELLAR-GROUP/hpx/pull/2539>

⁴⁴⁶² <https://github.com/STELLAR-GROUP/hpx/issues/2538>

⁴⁴⁶³ <https://github.com/STELLAR-GROUP/hpx/pull/2537>

⁴⁴⁶⁴ <https://github.com/STELLAR-GROUP/hpx/pull/2536>

⁴⁴⁶⁵ <https://github.com/STELLAR-GROUP/hpx/pull/2535>

⁴⁴⁶⁶ <https://github.com/STELLAR-GROUP/hpx/issues/2534>

⁴⁴⁶⁷ <https://github.com/STELLAR-GROUP/hpx/pull/2533>

⁴⁴⁶⁸ <https://github.com/STELLAR-GROUP/hpx/pull/2532>

⁴⁴⁶⁹ <https://github.com/STELLAR-GROUP/hpx/pull/2531>

⁴⁴⁷⁰ <https://github.com/STELLAR-GROUP/hpx/pull/2529>

- PR #2527⁴⁴⁷¹ - Facilities to create actions from lambdas
- PR #2526⁴⁴⁷² - Updated docs: HPX_WITH_EXAMPLES
- PR #2525⁴⁴⁷³ - Remove warnings related to unused captured variables
- Issue #2524⁴⁴⁷⁴ - CMAKE failed because it is missing: TCMALLOC_LIBRARY TCMALLOC_INCLUDE_DIR
- PR #2523⁴⁴⁷⁵ - Fixing compose_cb stack overflow
- PR #2522⁴⁴⁷⁶ - Instead of unlocking, ignore the lock while creating the message handler
- PR #2521⁴⁴⁷⁷ - Create LPROGRESS_ logging macro to simplify progress tracking and timings
- PR #2520⁴⁴⁷⁸ - Intel 17 support
- PR #2519⁴⁴⁷⁹ - Fix components example
- PR #2518⁴⁴⁸⁰ - Fixing parcel scheduling
- Issue #2517⁴⁴⁸¹ - Race condition during Parcel Coalescing Handler creation
- Issue #2516⁴⁴⁸² - HPX locks up when using at least 256 localities
- Issue #2515⁴⁴⁸³ - error: Install cannot find “/lib/hpx/libparcel_coalescing.so.0.9.99” but I can see that file
- PR #2514⁴⁴⁸⁴ - Making sure that all continuations of a shared_future are invoked in order
- PR #2513⁴⁴⁸⁵ - Fixing locks held during suspension
- PR #2512⁴⁴⁸⁶ - MPI Parcelport improvements and fixes related to the background work changes
- PR #2511⁴⁴⁸⁷ - Fixing bit-wise (zero-copy) serialization
- Issue #2509⁴⁴⁸⁸ - Linking errors in hwloc_topology
- PR #2508⁴⁴⁸⁹ - Added documentation for debugging with core files
- PR #2506⁴⁴⁹⁰ - Fixing background work invocations
- PR #2505⁴⁴⁹¹ - Fix tuple serialization
- Issue #2504⁴⁴⁹² - Ensure continuations are called in the order they have been attached
- PR #2503⁴⁴⁹³ - Adding serialization support for Vc v2 (datapar)

4471 <https://github.com/STELLAR-GROUP/hpx/pull/2527>
4472 <https://github.com/STELLAR-GROUP/hpx/pull/2526>
4473 <https://github.com/STELLAR-GROUP/hpx/pull/2525>
4474 <https://github.com/STELLAR-GROUP/hpx/issues/2524>
4475 <https://github.com/STELLAR-GROUP/hpx/pull/2523>
4476 <https://github.com/STELLAR-GROUP/hpx/pull/2522>
4477 <https://github.com/STELLAR-GROUP/hpx/pull/2521>
4478 <https://github.com/STELLAR-GROUP/hpx/pull/2520>
4479 <https://github.com/STELLAR-GROUP/hpx/pull/2519>
4480 <https://github.com/STELLAR-GROUP/hpx/pull/2518>
4481 <https://github.com/STELLAR-GROUP/hpx/issues/2517>
4482 <https://github.com/STELLAR-GROUP/hpx/issues/2516>
4483 <https://github.com/STELLAR-GROUP/hpx/issues/2515>
4484 <https://github.com/STELLAR-GROUP/hpx/pull/2514>
4485 <https://github.com/STELLAR-GROUP/hpx/pull/2513>
4486 <https://github.com/STELLAR-GROUP/hpx/pull/2512>
4487 <https://github.com/STELLAR-GROUP/hpx/pull/2511>
4488 <https://github.com/STELLAR-GROUP/hpx/issues/2509>
4489 <https://github.com/STELLAR-GROUP/hpx/pull/2508>
4490 <https://github.com/STELLAR-GROUP/hpx/pull/2506>
4491 <https://github.com/STELLAR-GROUP/hpx/pull/2505>
4492 <https://github.com/STELLAR-GROUP/hpx/issues/2504>
4493 <https://github.com/STELLAR-GROUP/hpx/pull/2503>

- PR #2502⁴⁴⁹⁴ - Resolve various, minor compiler warnings
- PR #2501⁴⁴⁹⁵ - Some other fixes around cuda examples
- Issue #2500⁴⁴⁹⁶ - nvcc / cuda clang issue due to a missing -DHPX_WITH_CUDA flag
- PR #2499⁴⁴⁹⁷ - Adding support for std::array to wait_all and friends
- PR #2498⁴⁴⁹⁸ - Execute background work as HPX thread
- PR #2497⁴⁴⁹⁹ - Fixing configuration options for spinlock-deadlock detection
- PR #2496⁴⁵⁰⁰ - Accounting for different compilers in CrayKNL toolchain file
- PR #2494⁴⁵⁰¹ - Adding component base class which ties a component instance to a given executor
- PR #2493⁴⁵⁰² - Enable controlling amount of pending threads which must be available to allow thread stealing
- PR #2492⁴⁵⁰³ - Adding new command line option -hpx:print-counter-reset
- PR #2491⁴⁵⁰⁴ - Resolve ambiguities when compiling with APEX
- PR #2490⁴⁵⁰⁵ - Resuming threads waiting on future with higher priority
- Issue #2489⁴⁵⁰⁶ - nvcc issue because -std=c++11 appears twice
- PR #2488⁴⁵⁰⁷ - Adding performance counters exposing the internal idle and busy-loop counters
- PR #2487⁴⁵⁰⁸ - Allowing for plain suspend to reschedule thread right away
- PR #2486⁴⁵⁰⁹ - Only flag HPX code for CUDA if HPX_WITH_CUDA is set
- PR #2485⁴⁵¹⁰ - Making thread-queue parameters runtime-configurable
- PR #2484⁴⁵¹¹ - Added atomic counter for parcel-destinations
- PR #2483⁴⁵¹² - Added priority-queue lifo scheduler
- PR #2482⁴⁵¹³ - Changing scheduler to steal only if more than a minimal number of tasks are available
- PR #2481⁴⁵¹⁴ - Extending command line option -hpx:print-counter-destination to support value 'none'
- PR #2479⁴⁵¹⁵ - Added option to disable signal handler
- PR #2478⁴⁵¹⁶ - Making sure the sine performance counter module gets loaded only for the corresponding example

⁴⁴⁹⁴ <https://github.com/STELLAR-GROUP/hpx/pull/2502>

⁴⁴⁹⁵ <https://github.com/STELLAR-GROUP/hpx/pull/2501>

⁴⁴⁹⁶ <https://github.com/STELLAR-GROUP/hpx/issues/2500>

⁴⁴⁹⁷ <https://github.com/STELLAR-GROUP/hpx/pull/2499>

⁴⁴⁹⁸ <https://github.com/STELLAR-GROUP/hpx/pull/2498>

⁴⁴⁹⁹ <https://github.com/STELLAR-GROUP/hpx/pull/2497>

⁴⁵⁰⁰ <https://github.com/STELLAR-GROUP/hpx/pull/2496>

⁴⁵⁰¹ <https://github.com/STELLAR-GROUP/hpx/pull/2494>

⁴⁵⁰² <https://github.com/STELLAR-GROUP/hpx/pull/2493>

⁴⁵⁰³ <https://github.com/STELLAR-GROUP/hpx/pull/2492>

⁴⁵⁰⁴ <https://github.com/STELLAR-GROUP/hpx/pull/2491>

⁴⁵⁰⁵ <https://github.com/STELLAR-GROUP/hpx/pull/2490>

⁴⁵⁰⁶ <https://github.com/STELLAR-GROUP/hpx/issues/2489>

⁴⁵⁰⁷ <https://github.com/STELLAR-GROUP/hpx/pull/2488>

⁴⁵⁰⁸ <https://github.com/STELLAR-GROUP/hpx/pull/2487>

⁴⁵⁰⁹ <https://github.com/STELLAR-GROUP/hpx/pull/2486>

⁴⁵¹⁰ <https://github.com/STELLAR-GROUP/hpx/pull/2485>

⁴⁵¹¹ <https://github.com/STELLAR-GROUP/hpx/pull/2484>

⁴⁵¹² <https://github.com/STELLAR-GROUP/hpx/pull/2483>

⁴⁵¹³ <https://github.com/STELLAR-GROUP/hpx/pull/2482>

⁴⁵¹⁴ <https://github.com/STELLAR-GROUP/hpx/pull/2481>

⁴⁵¹⁵ <https://github.com/STELLAR-GROUP/hpx/pull/2479>

⁴⁵¹⁶ <https://github.com/STELLAR-GROUP/hpx/pull/2478>

- Issue #2477⁴⁵¹⁷ - Breaking at a throw statement
- PR #2476⁴⁵¹⁸ - Annotated function
- PR #2475⁴⁵¹⁹ - Ensure that using `%osthread%` during logging will not throw for non-hpx threads
- PR #2474⁴⁵²⁰ - Remove now superficial `non_direct` actions from `base_lco` and friends
- PR #2473⁴⁵²¹ - Refining support for ITTNotify
- PR #2472⁴⁵²² - Some fixes around hpx compute
- Issue #2470⁴⁵²³ - redefinition of `boost::detail::spinlock`
- Issue #2469⁴⁵²⁴ - Dataflow performance issue
- PR #2468⁴⁵²⁵ - Perf docs update
- PR #2466⁴⁵²⁶ - Guarantee to execute remote direct actions on HPX-thread
- PR #2465⁴⁵²⁷ - Improve demo : Async copy and fixed device handling
- PR #2464⁴⁵²⁸ - Adding performance counter exposing instantaneous scheduler utilization
- PR #2463⁴⁵²⁹ - Downcast to `future<void>`
- PR #2462⁴⁵³⁰ - Fixed usage of ITT-Notify API with Intel Amplifier
- PR #2461⁴⁵³¹ - Cublas demo
- PR #2460⁴⁵³² - Fixing thread bindings
- PR #2459⁴⁵³³ - Make `-std=c++11` nvcc flag consistent for in-build and installed versions
- Issue #2457⁴⁵³⁴ - Segmentation fault when registering a partitioned vector
- PR #2452⁴⁵³⁵ - Properly releasing global barrier for unhandled exceptions
- PR #2451⁴⁵³⁶ - Fixing long shutdown times
- PR #2450⁴⁵³⁷ - Attempting to fix initialization errors on newer platforms (Boost V1.63)
- PR #2449⁴⁵³⁸ - Replace `BOOST_COMPILER_FENCE` with an HPX version
- PR #2448⁴⁵³⁹ - This fixes a possible race in the migration code

⁴⁵¹⁷ <https://github.com/STELLAR-GROUP/hpx/issues/2477>

⁴⁵¹⁸ <https://github.com/STELLAR-GROUP/hpx/pull/2476>

⁴⁵¹⁹ <https://github.com/STELLAR-GROUP/hpx/pull/2475>

⁴⁵²⁰ <https://github.com/STELLAR-GROUP/hpx/pull/2474>

⁴⁵²¹ <https://github.com/STELLAR-GROUP/hpx/pull/2473>

⁴⁵²² <https://github.com/STELLAR-GROUP/hpx/pull/2472>

⁴⁵²³ <https://github.com/STELLAR-GROUP/hpx/issues/2470>

⁴⁵²⁴ <https://github.com/STELLAR-GROUP/hpx/issues/2469>

⁴⁵²⁵ <https://github.com/STELLAR-GROUP/hpx/pull/2468>

⁴⁵²⁶ <https://github.com/STELLAR-GROUP/hpx/pull/2466>

⁴⁵²⁷ <https://github.com/STELLAR-GROUP/hpx/pull/2465>

⁴⁵²⁸ <https://github.com/STELLAR-GROUP/hpx/pull/2464>

⁴⁵²⁹ <https://github.com/STELLAR-GROUP/hpx/pull/2463>

⁴⁵³⁰ <https://github.com/STELLAR-GROUP/hpx/pull/2462>

⁴⁵³¹ <https://github.com/STELLAR-GROUP/hpx/pull/2461>

⁴⁵³² <https://github.com/STELLAR-GROUP/hpx/pull/2460>

⁴⁵³³ <https://github.com/STELLAR-GROUP/hpx/pull/2459>

⁴⁵³⁴ <https://github.com/STELLAR-GROUP/hpx/issues/2457>

⁴⁵³⁵ <https://github.com/STELLAR-GROUP/hpx/pull/2452>

⁴⁵³⁶ <https://github.com/STELLAR-GROUP/hpx/pull/2451>

⁴⁵³⁷ <https://github.com/STELLAR-GROUP/hpx/pull/2450>

⁴⁵³⁸ <https://github.com/STELLAR-GROUP/hpx/pull/2449>

⁴⁵³⁹ <https://github.com/STELLAR-GROUP/hpx/pull/2448>

- **PR #2445**^{Page 1737, 4540} - **Fixing dataflow et.al. for futures or future-ranges wrapped** into ref()
- **PR #2444**⁴⁵⁴¹ - Fix segfaults
- **PR #2443**⁴⁵⁴² - Issue 2442
- **Issue #2442**⁴⁵⁴³ - Mismatch between #if/#endif and namespace scope brackets in this_thread_executors.hpp
- **Issue #2441**⁴⁵⁴⁴ - undeclared identifier BOOST_COMPILER_FENCE
- **PR #2440**⁴⁵⁴⁵ - Knl build
- **PR #2438**⁴⁵⁴⁶ - Datapar backend
- **PR #2437**⁴⁵⁴⁷ - Adapt algorithm parameter sequence changes from C++17
- **PR #2436**⁴⁵⁴⁸ - Adapt execution policy name changes from C++17
- **Issue #2435**⁴⁵⁴⁹ - Trunk broken, undefined reference to hpx::thread::interrupt(hpx::thread::id, bool)
- **PR #2434**⁴⁵⁵⁰ - More fixes to resource manager
- **PR #2433**⁴⁵⁵¹ - Added versions of hpx::get_ptr taking client side representations
- **PR #2432**⁴⁵⁵² - Warning fixes
- **PR #2431**⁴⁵⁵³ - Adding facility representing set of performance counters
- **PR #2430**⁴⁵⁵⁴ - Fix parallel_executor thread spawning
- **PR #2429**⁴⁵⁵⁵ - Fix attribute warning for gcc
- **Issue #2427**⁴⁵⁵⁶ - Seg fault running octo-tiger with latest HPX commit
- **Issue #2426**⁴⁵⁵⁷ - Bug in 9592f5c0bc29806fce0dbe73f35b6ca7e027edcb causes immediate crash in Octo-tiger
- **PR #2425**⁴⁵⁵⁸ - Fix nvcc errors due to constexpr specifier
- **Issue #2424**⁴⁵⁵⁹ - Async action on component present on hpx::find_here is executing synchronously
- **PR #2423**⁴⁵⁶⁰ - Fix nvcc errors due to constexpr specifier
- **PR #2422**⁴⁵⁶¹ - Implementing hpx::this_thread thread data functions
- **PR #2421**⁴⁵⁶² - Adding benchmark for wait_all

⁴⁵⁴⁰ <https://github.com/STELLAR-GROUP/hpx/pull/2445>

⁴⁵⁴¹ <https://github.com/STELLAR-GROUP/hpx/pull/2444>

⁴⁵⁴² <https://github.com/STELLAR-GROUP/hpx/pull/2443>

⁴⁵⁴³ <https://github.com/STELLAR-GROUP/hpx/issues/2442>

⁴⁵⁴⁴ <https://github.com/STELLAR-GROUP/hpx/issues/2441>

⁴⁵⁴⁵ <https://github.com/STELLAR-GROUP/hpx/pull/2440>

⁴⁵⁴⁶ <https://github.com/STELLAR-GROUP/hpx/pull/2438>

⁴⁵⁴⁷ <https://github.com/STELLAR-GROUP/hpx/pull/2437>

⁴⁵⁴⁸ <https://github.com/STELLAR-GROUP/hpx/pull/2436>

⁴⁵⁴⁹ <https://github.com/STELLAR-GROUP/hpx/issues/2435>

⁴⁵⁵⁰ <https://github.com/STELLAR-GROUP/hpx/pull/2434>

⁴⁵⁵¹ <https://github.com/STELLAR-GROUP/hpx/pull/2433>

⁴⁵⁵² <https://github.com/STELLAR-GROUP/hpx/pull/2432>

⁴⁵⁵³ <https://github.com/STELLAR-GROUP/hpx/pull/2431>

⁴⁵⁵⁴ <https://github.com/STELLAR-GROUP/hpx/pull/2430>

⁴⁵⁵⁵ <https://github.com/STELLAR-GROUP/hpx/pull/2429>

⁴⁵⁵⁶ <https://github.com/STELLAR-GROUP/hpx/issues/2427>

⁴⁵⁵⁷ <https://github.com/STELLAR-GROUP/hpx/issues/2426>

⁴⁵⁵⁸ <https://github.com/STELLAR-GROUP/hpx/pull/2425>

⁴⁵⁵⁹ <https://github.com/STELLAR-GROUP/hpx/issues/2424>

⁴⁵⁶⁰ <https://github.com/STELLAR-GROUP/hpx/pull/2423>

⁴⁵⁶¹ <https://github.com/STELLAR-GROUP/hpx/pull/2422>

⁴⁵⁶² <https://github.com/STELLAR-GROUP/hpx/pull/2421>

- Issue #2420⁴⁵⁶³ - Returning object of a component client from another component action fails
- PR #2419⁴⁵⁶⁴ - Infiniband parcellport
- Issue #2418⁴⁵⁶⁵ - gcc + nvcc fails to compile code that uses partitioned_vector
- PR #2417⁴⁵⁶⁶ - Fixing context switching
- PR #2416⁴⁵⁶⁷ - Adding fixes and workarounds to allow compilation with nvcc/msvc (VS2015up3)
- PR #2415⁴⁵⁶⁸ - Fix errors coming from hpx compute examples
- PR #2414⁴⁵⁶⁹ - Fixing msvc12
- PR #2413⁴⁵⁷⁰ - Enable cuda/nvcc or cuda/clang when using add_hpx_executable()
- PR #2412⁴⁵⁷¹ - Fix issue in HPX_SetupTarget.cmake when cuda is used
- PR #2411⁴⁵⁷² - This fixes the core compilation issues with MSVC12
- Issue #2410⁴⁵⁷³ - undefined reference to opal_hwloc191_hwloc_.....
- PR #2409⁴⁵⁷⁴ - Fixing locking for channel and receive_buffer
- PR #2407⁴⁵⁷⁵ - Solving #2402 and #2403
- PR #2406⁴⁵⁷⁶ - Improve guards
- PR #2405⁴⁵⁷⁷ - Enable parallel::for_each for iterators returning proxy types
- PR #2404⁴⁵⁷⁸ - Forward the explicitly given result_type in the hpx invoke
- Issue #2403⁴⁵⁷⁹ - datapar_execution + zip iterator: lambda arguments aren't references
- Issue #2402⁴⁵⁸⁰ - datapar algorithm instantiated with wrong type #2402
- PR #2401⁴⁵⁸¹ - Added support for imported libraries to HPX_Libraries.cmake
- PR #2400⁴⁵⁸² - Use CMake policy CMP0060
- Issue #2399⁴⁵⁸³ - Error trying to push back vector of futures to vector
- PR #2398⁴⁵⁸⁴ - Allow config #defines to be written out to custom config/defines.hpp
- Issue #2397⁴⁵⁸⁵ - CMake generated config defines can cause tedious rebuilds category

⁴⁵⁶³ <https://github.com/STELLAR-GROUP/hpx/issues/2420>

⁴⁵⁶⁴ <https://github.com/STELLAR-GROUP/hpx/pull/2419>

⁴⁵⁶⁵ <https://github.com/STELLAR-GROUP/hpx/issues/2418>

⁴⁵⁶⁶ <https://github.com/STELLAR-GROUP/hpx/pull/2417>

⁴⁵⁶⁷ <https://github.com/STELLAR-GROUP/hpx/pull/2416>

⁴⁵⁶⁸ <https://github.com/STELLAR-GROUP/hpx/pull/2415>

⁴⁵⁶⁹ <https://github.com/STELLAR-GROUP/hpx/pull/2414>

⁴⁵⁷⁰ <https://github.com/STELLAR-GROUP/hpx/pull/2413>

⁴⁵⁷¹ <https://github.com/STELLAR-GROUP/hpx/pull/2412>

⁴⁵⁷² <https://github.com/STELLAR-GROUP/hpx/pull/2411>

⁴⁵⁷³ <https://github.com/STELLAR-GROUP/hpx/issues/2410>

⁴⁵⁷⁴ <https://github.com/STELLAR-GROUP/hpx/pull/2409>

⁴⁵⁷⁵ <https://github.com/STELLAR-GROUP/hpx/pull/2407>

⁴⁵⁷⁶ <https://github.com/STELLAR-GROUP/hpx/pull/2406>

⁴⁵⁷⁷ <https://github.com/STELLAR-GROUP/hpx/pull/2405>

⁴⁵⁷⁸ <https://github.com/STELLAR-GROUP/hpx/pull/2404>

⁴⁵⁷⁹ <https://github.com/STELLAR-GROUP/hpx/issues/2403>

⁴⁵⁸⁰ <https://github.com/STELLAR-GROUP/hpx/issues/2402>

⁴⁵⁸¹ <https://github.com/STELLAR-GROUP/hpx/pull/2401>

⁴⁵⁸² <https://github.com/STELLAR-GROUP/hpx/pull/2400>

⁴⁵⁸³ <https://github.com/STELLAR-GROUP/hpx/issues/2399>

⁴⁵⁸⁴ <https://github.com/STELLAR-GROUP/hpx/pull/2398>

⁴⁵⁸⁵ <https://github.com/STELLAR-GROUP/hpx/issues/2397>

- Issue #2396⁴⁵⁸⁶ - BOOST_ROOT paths are not used at link time
- PR #2395⁴⁵⁸⁷ - Fix target_link_libraries() issue when HPX Cuda is enabled
- Issue #2394⁴⁵⁸⁸ - Template compilation error using HPX_WITH_DATAPAR_LIBFLATARRAY
- PR #2393⁴⁵⁸⁹ - Fixing lock registration for recursive mutex
- PR #2392⁴⁵⁹⁰ - Add keywords in target_link_libraries in hpx_setup_target
- PR #2391⁴⁵⁹¹ - Clang goroutines
- Issue #2390⁴⁵⁹² - Adapt execution policy name changes from C++17
- PR #2389⁴⁵⁹³ - Chunk allocator and pool are not used and are obsolete
- PR #2388⁴⁵⁹⁴ - Adding functionalities to datapar needed by octotiger
- PR #2387⁴⁵⁹⁵ - Fixing race condition for early parcels
- Issue #2386⁴⁵⁹⁶ - Lock registration broken for recursive_mutex
- PR #2385⁴⁵⁹⁷ - Datapar zip iterator
- PR #2384⁴⁵⁹⁸ - Fixing race condition in for_loop_reduction
- PR #2383⁴⁵⁹⁹ - Continuations
- PR #2382⁴⁶⁰⁰ - add LibFlatArray-based backend for datapar
- PR #2381⁴⁶⁰¹ - remove unused typedef to get rid of compiler warnings
- PR #2380⁴⁶⁰² - Tau cleanup
- PR #2379⁴⁶⁰³ - Can send immediate
- PR #2378⁴⁶⁰⁴ - Renaming copy_helper/copy_n_helper/move_helper/move_n_helper
- Issue #2376⁴⁶⁰⁵ - Boost trunk's spinlock initializer fails to compile
- PR #2375⁴⁶⁰⁶ - Add support for minimal thread local data
- PR #2374⁴⁶⁰⁷ - Adding API functions set_config_entry_callback
- PR #2373⁴⁶⁰⁸ - Add a simple utility for debugging that gives suspended task backtraces

⁴⁵⁸⁶ <https://github.com/STELLAR-GROUP/hpx/issues/2396>

⁴⁵⁸⁷ <https://github.com/STELLAR-GROUP/hpx/pull/2395>

⁴⁵⁸⁸ <https://github.com/STELLAR-GROUP/hpx/issues/2394>

⁴⁵⁸⁹ <https://github.com/STELLAR-GROUP/hpx/pull/2393>

⁴⁵⁹⁰ <https://github.com/STELLAR-GROUP/hpx/pull/2392>

⁴⁵⁹¹ <https://github.com/STELLAR-GROUP/hpx/pull/2391>

⁴⁵⁹² <https://github.com/STELLAR-GROUP/hpx/issues/2390>

⁴⁵⁹³ <https://github.com/STELLAR-GROUP/hpx/pull/2389>

⁴⁵⁹⁴ <https://github.com/STELLAR-GROUP/hpx/pull/2388>

⁴⁵⁹⁵ <https://github.com/STELLAR-GROUP/hpx/pull/2387>

⁴⁵⁹⁶ <https://github.com/STELLAR-GROUP/hpx/issues/2386>

⁴⁵⁹⁷ <https://github.com/STELLAR-GROUP/hpx/pull/2385>

⁴⁵⁹⁸ <https://github.com/STELLAR-GROUP/hpx/pull/2384>

⁴⁵⁹⁹ <https://github.com/STELLAR-GROUP/hpx/pull/2383>

⁴⁶⁰⁰ <https://github.com/STELLAR-GROUP/hpx/pull/2382>

⁴⁶⁰¹ <https://github.com/STELLAR-GROUP/hpx/pull/2381>

⁴⁶⁰² <https://github.com/STELLAR-GROUP/hpx/pull/2380>

⁴⁶⁰³ <https://github.com/STELLAR-GROUP/hpx/pull/2379>

⁴⁶⁰⁴ <https://github.com/STELLAR-GROUP/hpx/pull/2378>

⁴⁶⁰⁵ <https://github.com/STELLAR-GROUP/hpx/issues/2376>

⁴⁶⁰⁶ <https://github.com/STELLAR-GROUP/hpx/pull/2375>

⁴⁶⁰⁷ <https://github.com/STELLAR-GROUP/hpx/pull/2374>

⁴⁶⁰⁸ <https://github.com/STELLAR-GROUP/hpx/pull/2373>

- PR #2372⁴⁶⁰⁹ - Barrier Fixes
- Issue #2370⁴⁶¹⁰ - Can't wait on a wrapped future
- PR #2369⁴⁶¹¹ - Fixing stable_partition
- PR #2367⁴⁶¹² - Fixing find_prefixes for Windows platforms
- PR #2366⁴⁶¹³ - Testing for experimental/optional only in C++14 mode
- PR #2364⁴⁶¹⁴ - Adding set_config_entry
- PR #2363⁴⁶¹⁵ - Fix papi
- PR #2362⁴⁶¹⁶ - Adding missing macros for new non-direct actions
- PR #2361⁴⁶¹⁷ - Improve cmake output to help debug compiler incompatibility check
- PR #2360⁴⁶¹⁸ - Fixing race condition in condition_variable
- PR #2359⁴⁶¹⁹ - Fixing shutdown when parcels are still in flight
- Issue #2357⁴⁶²⁰ - failed to insert console_print_action into typename_to_id_t registry
- PR #2356⁴⁶²¹ - Fixing return type of get_iterator_tuple
- PR #2355⁴⁶²² - Fixing compilation against Boost 1.62
- PR #2354⁴⁶²³ - Adding serialization for mask_type if CPU_COUNT > 64
- PR #2353⁴⁶²⁴ - Adding hooks to tie in APEX into the parcel layer
- Issue #2352⁴⁶²⁵ - Compile errors when using intel 17 beta (for KNL) on edison
- PR #2351⁴⁶²⁶ - Fix function vtable get_function_address implementation
- Issue #2350⁴⁶²⁷ - Build failure - master branch (4de09f5) with Intel Compiler v17
- PR #2349⁴⁶²⁸ - Enabling zero-copy serialization support for std::vector<>
- PR #2348⁴⁶²⁹ - Adding test to verify #2334 is fixed
- PR #2347⁴⁶³⁰ - Bug fixes for hpx.compute and hpx::lcos::channel
- PR #2346⁴⁶³¹ - Removing cmake "find" files that are in the APEX cmake Modules

⁴⁶⁰⁹ <https://github.com/STELLAR-GROUP/hpx/pull/2372>
⁴⁶¹⁰ <https://github.com/STELLAR-GROUP/hpx/issues/2370>
⁴⁶¹¹ <https://github.com/STELLAR-GROUP/hpx/pull/2369>
⁴⁶¹² <https://github.com/STELLAR-GROUP/hpx/pull/2367>
⁴⁶¹³ <https://github.com/STELLAR-GROUP/hpx/pull/2366>
⁴⁶¹⁴ <https://github.com/STELLAR-GROUP/hpx/pull/2364>
⁴⁶¹⁵ <https://github.com/STELLAR-GROUP/hpx/pull/2363>
⁴⁶¹⁶ <https://github.com/STELLAR-GROUP/hpx/pull/2362>
⁴⁶¹⁷ <https://github.com/STELLAR-GROUP/hpx/pull/2361>
⁴⁶¹⁸ <https://github.com/STELLAR-GROUP/hpx/pull/2360>
⁴⁶¹⁹ <https://github.com/STELLAR-GROUP/hpx/pull/2359>
⁴⁶²⁰ <https://github.com/STELLAR-GROUP/hpx/issues/2357>
⁴⁶²¹ <https://github.com/STELLAR-GROUP/hpx/pull/2356>
⁴⁶²² <https://github.com/STELLAR-GROUP/hpx/pull/2355>
⁴⁶²³ <https://github.com/STELLAR-GROUP/hpx/pull/2354>
⁴⁶²⁴ <https://github.com/STELLAR-GROUP/hpx/pull/2353>
⁴⁶²⁵ <https://github.com/STELLAR-GROUP/hpx/issues/2352>
⁴⁶²⁶ <https://github.com/STELLAR-GROUP/hpx/pull/2351>
⁴⁶²⁷ <https://github.com/STELLAR-GROUP/hpx/issues/2350>
⁴⁶²⁸ <https://github.com/STELLAR-GROUP/hpx/pull/2349>
⁴⁶²⁹ <https://github.com/STELLAR-GROUP/hpx/pull/2348>
⁴⁶³⁰ <https://github.com/STELLAR-GROUP/hpx/pull/2347>
⁴⁶³¹ <https://github.com/STELLAR-GROUP/hpx/pull/2346>

- PR #2345⁴⁶³² - Implemented parallel::stable_partition
- PR #2344⁴⁶³³ - Making hpx::lcos::channel usable with basename registration
- PR #2343⁴⁶³⁴ - Fix a couple of examples that failed to compile after recent api changes
- Issue #2342⁴⁶³⁵ - Enabling APEX causes link errors
- PR #2341⁴⁶³⁶ - Removing cmake “find” files that are in the APEX cmake Modules
- PR #2340⁴⁶³⁷ - Implemented all existing datapar algorithms using Boost.SIMD
- PR #2339⁴⁶³⁸ - Fixing 2338
- PR #2338⁴⁶³⁹ - Possible race in sliding semaphore
- PR #2337⁴⁶⁴⁰ - Adjust osu_latency test to measure window_size parcels in flight at once
- PR #2336⁴⁶⁴¹ - Allowing remote direct actions to be executed without spawning a task
- PR #2335⁴⁶⁴² - Making sure multiple components are properly initialized from arguments
- Issue #2334⁴⁶⁴³ - Cannot construct component with large vector on a remote locality
- PR #2332⁴⁶⁴⁴ - Fixing hpx::lcos::local::barrier
- PR #2331⁴⁶⁴⁵ - Updating APEX support to include OTF2
- PR #2330⁴⁶⁴⁶ - Support for data-parallelism for parallel algorithms
- Issue #2329⁴⁶⁴⁷ - Coordinate settings in cmake
- PR #2328⁴⁶⁴⁸ - fix LibGeoDecomp builds with HPX + GCC 5.3.0 + CUDA 8RC
- PR #2326⁴⁶⁴⁹ - Making scan_partitioner work (for now)
- Issue #2323⁴⁶⁵⁰ - Constructing a vector of components only correctly initializes the first component
- PR #2322⁴⁶⁵¹ - Fix problems that bubbled up after merging #2278
- PR #2321⁴⁶⁵² - Scalable barrier
- PR #2320⁴⁶⁵³ - Std flag fixes
- Issue #2319⁴⁶⁵⁴ - -std=c++14 and -std=c++1y with Intel can't build recent Boost builds due to insufficient C++14 support; don't enable these flags by default for Intel

⁴⁶³² <https://github.com/STELLAR-GROUP/hpx/pull/2345>

⁴⁶³³ <https://github.com/STELLAR-GROUP/hpx/pull/2344>

⁴⁶³⁴ <https://github.com/STELLAR-GROUP/hpx/pull/2343>

⁴⁶³⁵ <https://github.com/STELLAR-GROUP/hpx/issues/2342>

⁴⁶³⁶ <https://github.com/STELLAR-GROUP/hpx/pull/2341>

⁴⁶³⁷ <https://github.com/STELLAR-GROUP/hpx/pull/2340>

⁴⁶³⁸ <https://github.com/STELLAR-GROUP/hpx/pull/2339>

⁴⁶³⁹ <https://github.com/STELLAR-GROUP/hpx/pull/2338>

⁴⁶⁴⁰ <https://github.com/STELLAR-GROUP/hpx/pull/2337>

⁴⁶⁴¹ <https://github.com/STELLAR-GROUP/hpx/pull/2336>

⁴⁶⁴² <https://github.com/STELLAR-GROUP/hpx/pull/2335>

⁴⁶⁴³ <https://github.com/STELLAR-GROUP/hpx/issues/2334>

⁴⁶⁴⁴ <https://github.com/STELLAR-GROUP/hpx/pull/2332>

⁴⁶⁴⁵ <https://github.com/STELLAR-GROUP/hpx/pull/2331>

⁴⁶⁴⁶ <https://github.com/STELLAR-GROUP/hpx/pull/2330>

⁴⁶⁴⁷ <https://github.com/STELLAR-GROUP/hpx/issues/2329>

⁴⁶⁴⁸ <https://github.com/STELLAR-GROUP/hpx/pull/2328>

⁴⁶⁴⁹ <https://github.com/STELLAR-GROUP/hpx/pull/2326>

⁴⁶⁵⁰ <https://github.com/STELLAR-GROUP/hpx/issues/2323>

⁴⁶⁵¹ <https://github.com/STELLAR-GROUP/hpx/pull/2322>

⁴⁶⁵² <https://github.com/STELLAR-GROUP/hpx/pull/2321>

⁴⁶⁵³ <https://github.com/STELLAR-GROUP/hpx/pull/2320>

⁴⁶⁵⁴ <https://github.com/STELLAR-GROUP/hpx/issues/2319>

- PR #2318⁴⁶⁵⁵ - Improve handling of `-hpx:bind=<bind-spec>`
- PR #2317⁴⁶⁵⁶ - Making sure command line warnings are printed once only
- PR #2316⁴⁶⁵⁷ - Fixing command line handling for default bind mode
- PR #2315⁴⁶⁵⁸ - Set `id_retrieved` if `set_id` is present
- Issue #2314⁴⁶⁵⁹ - Warning for requested/allocated thread discrepancy is printed twice
- Issue #2313⁴⁶⁶⁰ - `-hpx:print-bind` doesn't work with `-hpx:pu-step`
- Issue #2312⁴⁶⁶¹ - `-hpx:bind` range specifier restrictions are overly restrictive
- Issue #2311⁴⁶⁶² - `hpx_0.9.99` out of project build fails
- PR #2310⁴⁶⁶³ - Simplify function registration
- PR #2309⁴⁶⁶⁴ - Spelling and grammar revisions in documentation (and some code)
- PR #2306⁴⁶⁶⁵ - Correct minor typo in the documentation
- PR #2305⁴⁶⁶⁶ - Cleaning up and fixing parcel coalescing
- PR #2304⁴⁶⁶⁷ - Inspect checks for stream related includes
- PR #2303⁴⁶⁶⁸ - Add functionality allowing to enumerate threads of given state
- PR #2301⁴⁶⁶⁹ - Algorithm overloads fix for VS2013
- PR #2300⁴⁶⁷⁰ - Use `<cstdlib>`, add inspect checks
- PR #2299⁴⁶⁷¹ - Replace `boost::[c]ref` with `std::[c]ref`, add inspect checks
- PR #2297⁴⁶⁷² - Fixing compilation with `no_hw_loc`
- PR #2296⁴⁶⁷³ - Hpx compute
- PR #2295⁴⁶⁷⁴ - Making sure `for_loop(execution::par, 0, N, ...)` is actually executed in parallel
- PR #2294⁴⁶⁷⁵ - Throwing exceptions if the runtime is not up and running
- PR #2293⁴⁶⁷⁶ - Removing unused parcel port code
- PR #2292⁴⁶⁷⁷ - Refactor function vtables

⁴⁶⁵⁵ <https://github.com/STELLAR-GROUP/hpx/pull/2318>
⁴⁶⁵⁶ <https://github.com/STELLAR-GROUP/hpx/pull/2317>
⁴⁶⁵⁷ <https://github.com/STELLAR-GROUP/hpx/pull/2316>
⁴⁶⁵⁸ <https://github.com/STELLAR-GROUP/hpx/pull/2315>
⁴⁶⁵⁹ <https://github.com/STELLAR-GROUP/hpx/issues/2314>
⁴⁶⁶⁰ <https://github.com/STELLAR-GROUP/hpx/issues/2313>
⁴⁶⁶¹ <https://github.com/STELLAR-GROUP/hpx/issues/2312>
⁴⁶⁶² <https://github.com/STELLAR-GROUP/hpx/issues/2311>
⁴⁶⁶³ <https://github.com/STELLAR-GROUP/hpx/pull/2310>
⁴⁶⁶⁴ <https://github.com/STELLAR-GROUP/hpx/pull/2309>
⁴⁶⁶⁵ <https://github.com/STELLAR-GROUP/hpx/pull/2306>
⁴⁶⁶⁶ <https://github.com/STELLAR-GROUP/hpx/pull/2305>
⁴⁶⁶⁷ <https://github.com/STELLAR-GROUP/hpx/pull/2304>
⁴⁶⁶⁸ <https://github.com/STELLAR-GROUP/hpx/pull/2303>
⁴⁶⁶⁹ <https://github.com/STELLAR-GROUP/hpx/pull/2301>
⁴⁶⁷⁰ <https://github.com/STELLAR-GROUP/hpx/pull/2300>
⁴⁶⁷¹ <https://github.com/STELLAR-GROUP/hpx/pull/2299>
⁴⁶⁷² <https://github.com/STELLAR-GROUP/hpx/pull/2297>
⁴⁶⁷³ <https://github.com/STELLAR-GROUP/hpx/pull/2296>
⁴⁶⁷⁴ <https://github.com/STELLAR-GROUP/hpx/pull/2295>
⁴⁶⁷⁵ <https://github.com/STELLAR-GROUP/hpx/pull/2294>
⁴⁶⁷⁶ <https://github.com/STELLAR-GROUP/hpx/pull/2293>
⁴⁶⁷⁷ <https://github.com/STELLAR-GROUP/hpx/pull/2292>

- PR #2291⁴⁶⁷⁸ - Fixing 2286
- PR #2290⁴⁶⁷⁹ - Simplify algorithm overloads
- PR #2289⁴⁶⁸⁰ - Adding performance counters reporting parcel related data on a per-action basis
- Issue #2288⁴⁶⁸¹ - Remove dormant parcelports
- Issue #2286⁴⁶⁸² - adjustments to parcel handling to support parcelports that do not need a connection cache
- PR #2285⁴⁶⁸³ - add CMake option to disable package export
- PR #2283⁴⁶⁸⁴ - Add more inspect checks for use of deprecated components
- Issue #2282⁴⁶⁸⁵ - Arithmetic exception in executor static chunker
- Issue #2281⁴⁶⁸⁶ - For loop doesn't parallelize
- PR #2280⁴⁶⁸⁷ - Fixing 2277: build failure with PAPI
- PR #2279⁴⁶⁸⁸ - Child vs parent stealing
- Issue #2277⁴⁶⁸⁹ - master branch build failure (53c5b4f) with papi
- PR #2276⁴⁶⁹⁰ - Compile time launch policies
- PR #2275⁴⁶⁹¹ - Replace boost::chrono with std::chrono in interfaces
- PR #2274⁴⁶⁹² - Replace most uses of Boost.Assign with initializer list
- PR #2273⁴⁶⁹³ - Fixed typos
- PR #2272⁴⁶⁹⁴ - Inspect checks
- PR #2270⁴⁶⁹⁵ - Adding test verifying -lhp.os_threads=all
- PR #2269⁴⁶⁹⁶ - Added inspect check for now obsolete boost type traits
- PR #2268⁴⁶⁹⁷ - Moving more code into source files
- Issue #2267⁴⁶⁹⁸ - Add inspect support to deprecate Boost.TypeTraits
- PR #2265⁴⁶⁹⁹ - Adding channel LCO
- PR #2264⁴⁷⁰⁰ - Make support for std::ref mandatory

⁴⁶⁷⁸ <https://github.com/STELLAR-GROUP/hpx/pull/2291>

⁴⁶⁷⁹ <https://github.com/STELLAR-GROUP/hpx/pull/2290>

⁴⁶⁸⁰ <https://github.com/STELLAR-GROUP/hpx/pull/2289>

⁴⁶⁸¹ <https://github.com/STELLAR-GROUP/hpx/issues/2288>

⁴⁶⁸² <https://github.com/STELLAR-GROUP/hpx/issues/2286>

⁴⁶⁸³ <https://github.com/STELLAR-GROUP/hpx/pull/2285>

⁴⁶⁸⁴ <https://github.com/STELLAR-GROUP/hpx/pull/2283>

⁴⁶⁸⁵ <https://github.com/STELLAR-GROUP/hpx/issues/2282>

⁴⁶⁸⁶ <https://github.com/STELLAR-GROUP/hpx/issues/2281>

⁴⁶⁸⁷ <https://github.com/STELLAR-GROUP/hpx/pull/2280>

⁴⁶⁸⁸ <https://github.com/STELLAR-GROUP/hpx/pull/2279>

⁴⁶⁸⁹ <https://github.com/STELLAR-GROUP/hpx/issues/2277>

⁴⁶⁹⁰ <https://github.com/STELLAR-GROUP/hpx/pull/2276>

⁴⁶⁹¹ <https://github.com/STELLAR-GROUP/hpx/pull/2275>

⁴⁶⁹² <https://github.com/STELLAR-GROUP/hpx/pull/2274>

⁴⁶⁹³ <https://github.com/STELLAR-GROUP/hpx/pull/2273>

⁴⁶⁹⁴ <https://github.com/STELLAR-GROUP/hpx/pull/2272>

⁴⁶⁹⁵ <https://github.com/STELLAR-GROUP/hpx/pull/2270>

⁴⁶⁹⁶ <https://github.com/STELLAR-GROUP/hpx/pull/2269>

⁴⁶⁹⁷ <https://github.com/STELLAR-GROUP/hpx/pull/2268>

⁴⁶⁹⁸ <https://github.com/STELLAR-GROUP/hpx/issues/2267>

⁴⁶⁹⁹ <https://github.com/STELLAR-GROUP/hpx/pull/2265>

⁴⁷⁰⁰ <https://github.com/STELLAR-GROUP/hpx/pull/2264>

- PR #2263⁴⁷⁰¹ - Constrain tuple_member forwarding constructor
- Issue #2262⁴⁷⁰² - Test hpx.os_threads=all
- Issue #2261⁴⁷⁰³ - OS X: Error: no matching constructor for initialization of 'hpx::lcos::local::condition_variable_any'
- Issue #2260⁴⁷⁰⁴ - Make support for std::ref mandatory
- PR #2259⁴⁷⁰⁵ - Remove most of Boost.MPL, Boost.EnableIf and Boost.TypeTraits
- PR #2258⁴⁷⁰⁶ - Fixing #2256
- PR #2257⁴⁷⁰⁷ - Fixing launch process
- Issue #2256⁴⁷⁰⁸ - Actions are not registered if not invoked
- PR #2255⁴⁷⁰⁹ - Coalescing histogram
- PR #2254⁴⁷¹⁰ - Silence explicit initialization in copy-constructor warnings
- PR #2253⁴⁷¹¹ - Drop support for GCC 4.6 and 4.7
- PR #2252⁴⁷¹² - Prepare V1.0
- PR #2251⁴⁷¹³ - Convert to 0.9.99
- PR #2249⁴⁷¹⁴ - Adding iterator_facade and iterator_adaptor
- Issue #2248⁴⁷¹⁵ - Need a feature to yield to a new task immediately
- PR #2246⁴⁷¹⁶ - Adding split_future
- PR #2245⁴⁷¹⁷ - Add an example for handing over a component instance to a dynamically launched locality
- Issue #2243⁴⁷¹⁸ - Add example demonstrating AGAS symbolic name registration
- Issue #2242⁴⁷¹⁹ - pkgconfig test broken on CentOS 7 / Boost 1.61
- Issue #2241⁴⁷²⁰ - Compilation error for partitioned vector in hpx_compute branch
- PR #2240⁴⁷²¹ - Fixing termination detection on one locality
- Issue #2239⁴⁷²² - Create a new facility lcos::split_all
- Issue #2236⁴⁷²³ - hpx::cout vs. std::cout

⁴⁷⁰¹ <https://github.com/STELLAR-GROUP/hpx/pull/2263>
⁴⁷⁰² <https://github.com/STELLAR-GROUP/hpx/issues/2262>
⁴⁷⁰³ <https://github.com/STELLAR-GROUP/hpx/issues/2261>
⁴⁷⁰⁴ <https://github.com/STELLAR-GROUP/hpx/issues/2260>
⁴⁷⁰⁵ <https://github.com/STELLAR-GROUP/hpx/pull/2259>
⁴⁷⁰⁶ <https://github.com/STELLAR-GROUP/hpx/pull/2258>
⁴⁷⁰⁷ <https://github.com/STELLAR-GROUP/hpx/pull/2257>
⁴⁷⁰⁸ <https://github.com/STELLAR-GROUP/hpx/issues/2256>
⁴⁷⁰⁹ <https://github.com/STELLAR-GROUP/hpx/pull/2255>
⁴⁷¹⁰ <https://github.com/STELLAR-GROUP/hpx/pull/2254>
⁴⁷¹¹ <https://github.com/STELLAR-GROUP/hpx/pull/2253>
⁴⁷¹² <https://github.com/STELLAR-GROUP/hpx/pull/2252>
⁴⁷¹³ <https://github.com/STELLAR-GROUP/hpx/pull/2251>
⁴⁷¹⁴ <https://github.com/STELLAR-GROUP/hpx/pull/2249>
⁴⁷¹⁵ <https://github.com/STELLAR-GROUP/hpx/issues/2248>
⁴⁷¹⁶ <https://github.com/STELLAR-GROUP/hpx/pull/2246>
⁴⁷¹⁷ <https://github.com/STELLAR-GROUP/hpx/pull/2245>
⁴⁷¹⁸ <https://github.com/STELLAR-GROUP/hpx/issues/2243>
⁴⁷¹⁹ <https://github.com/STELLAR-GROUP/hpx/issues/2242>
⁴⁷²⁰ <https://github.com/STELLAR-GROUP/hpx/issues/2241>
⁴⁷²¹ <https://github.com/STELLAR-GROUP/hpx/pull/2240>
⁴⁷²² <https://github.com/STELLAR-GROUP/hpx/issues/2239>
⁴⁷²³ <https://github.com/STELLAR-GROUP/hpx/issues/2236>

- PR #2232⁴⁷²⁴ - Implement local-only primary namespace service
- Issue #2147⁴⁷²⁵ - would like to know how much data is being routed by particular actions
- Issue #2109⁴⁷²⁶ - Warning while compiling hpx
- Issue #1973⁴⁷²⁷ - Setting INTERFACE_COMPILE_OPTIONS for hpx_init in CMake taints Fortran_FLAGS
- Issue #1864⁴⁷²⁸ - run_guarded using bound function ignores reference
- Issue #1754⁴⁷²⁹ - Running with TCP parcelport causes immediate crash or freeze
- Issue #1655⁴⁷³⁰ - Enable zip_iterator to be used with Boost traversal iterator categories
- Issue #1591⁴⁷³¹ - Optimize AGAS for shared memory only operation
- Issue #1401⁴⁷³² - Need an efficient infiniband parcelport
- Issue #1125⁴⁷³³ - Fix the IPC parcelport
- Issue #839⁴⁷³⁴ - Refactor ibverbs and shmем parcelport
- Issue #702⁴⁷³⁵ - Add instrumentation of parcel layer
- Issue #668⁴⁷³⁶ - Implement ispc task interface
- Issue #533⁴⁷³⁷ - Thread queue/dequeue internal parameters should be runtime configurable
- Issue #475⁴⁷³⁸ - Create a means of combining performance counters into querysets

HPX V0.9.99 (Jul 15, 2016)

General changes

As the version number of this release hints, we consider this release to be a preview for the upcoming *HPX* V1.0. All of the functionalities we set out to implement for V1.0 are in place; all of the features we wanted to have exposed are ready. We are very happy with the stability and performance of *HPX* and we would like to present this release to the community in order for us to gather broad feedback before releasing V1.0. We still expect for some minor details to change, but on the whole this release represents what we would like to have in a V1.0.

Overall, since the last release we have had almost 1600 commits while closing almost 400 tickets. These numbers reflect the incredible development activity we have seen over the last couple of months. We would like to express a big ‘Thank you!’ to all contributors and those who helped to make this release happen.

The most notable addition in terms of new functionality available with this release is the full implementation of object migration (i.e. the ability to transparently move *HPX* components to a different compute node). Additionally, this release of *HPX* cleans up many minor issues and some API inconsistencies.

Here are some of the main highlights and changes for this release (in no particular order):

- ⁴⁷²⁴ <https://github.com/STELLAR-GROUP/hpx/pull/2232>
- ⁴⁷²⁵ <https://github.com/STELLAR-GROUP/hpx/issues/2147>
- ⁴⁷²⁶ <https://github.com/STELLAR-GROUP/hpx/issues/2109>
- ⁴⁷²⁷ <https://github.com/STELLAR-GROUP/hpx/issues/1973>
- ⁴⁷²⁸ <https://github.com/STELLAR-GROUP/hpx/issues/1864>
- ⁴⁷²⁹ <https://github.com/STELLAR-GROUP/hpx/issues/1754>
- ⁴⁷³⁰ <https://github.com/STELLAR-GROUP/hpx/issues/1655>
- ⁴⁷³¹ <https://github.com/STELLAR-GROUP/hpx/issues/1591>
- ⁴⁷³² <https://github.com/STELLAR-GROUP/hpx/issues/1401>
- ⁴⁷³³ <https://github.com/STELLAR-GROUP/hpx/issues/1125>
- ⁴⁷³⁴ <https://github.com/STELLAR-GROUP/hpx/issues/839>
- ⁴⁷³⁵ <https://github.com/STELLAR-GROUP/hpx/issues/702>
- ⁴⁷³⁶ <https://github.com/STELLAR-GROUP/hpx/issues/668>
- ⁴⁷³⁷ <https://github.com/STELLAR-GROUP/hpx/issues/533>
- ⁴⁷³⁸ <https://github.com/STELLAR-GROUP/hpx/issues/475>

- We have fixed a couple of issues in AGAS and the parcel layer which have caused hangs, segmentation faults at exit, and a slowdown of applications over time. Fixing those has significantly increased the overall stability and performance of distributed runs.
- We have started to add parallel algorithm overloads based on the C++ Extensions for Ranges (N4560⁴⁷³⁹) proposal. This also includes the addition of projections to the existing algorithms. Please see Issue #1668⁴⁷⁴⁰ for a list of algorithms which have been adapted to N4560⁴⁷⁴¹.
- We have implemented index-based parallel for-loops based on a corresponding standardization proposal (P0075R1⁴⁷⁴²). Please see Issue #2016⁴⁷⁴³ for a list of available algorithms.
- We have added implementations for more parallel algorithms as proposed for the upcoming C++ 17 Standard. See Issue #1141⁴⁷⁴⁴ for an overview of which algorithms are available by now.
- We have started to implement a new prototypical functionality with *HPX.Compute* which uniformly exposes some of the higher level APIs to heterogeneous architectures (currently CUDA). This functionality is an early preview and should not be considered stable. It may change considerably in the future.
- We have pervasively added (optional) executor arguments to all API functions which schedule new work. Executors are now used throughout the code base as the main means of executing tasks.
- Added `hpx::make_future<R>(future<T> &&)` allowing to convert a future of any type T into a future of any other type R, either based on default conversion rules of the embedded types or using a given explicit conversion function.
- We finally finished the implementation of transparent migration of components to another locality. It is now possible to trigger a migration operation without ‘stopping the world’ for the object to migrate. *HPX* will make sure that no work is being performed on an object before it is migrated and that all subsequently scheduled work for the migrated object will be transparently forwarded to the new locality. Please note that the global id of the migrated object does not change, thus the application will not have to be changed in any way to support this new functionality. Please note that this feature is currently considered experimental. See Issue #559⁴⁷⁴⁵ and PR #1966⁴⁷⁴⁶ for more details.
- The `hpx::dataflow` facility is now usable with actions. Similarly to `hpx::async`, actions can be specified as an explicit template argument (`hpx::dataflow<Action>(target, ...)`) or as the first argument (`hpx::dataflow(Action(), target, ...)`). We have also enabled the use of distribution policies as the target for dataflow invocations. Please see Issue #1265⁴⁷⁴⁷ and PR #1912⁴⁷⁴⁸ for more information.
- Adding overloads of `gather_here` and `gather_there` to accept the plain values of the data to gather (in addition to the existing overloads expecting futures).
- We have cleaned up and refactored large parts of the code base. This helped reducing compile and link times of *HPX* itself and also of applications depending on it. We have further decreased the dependency of *HPX* on the Boost libraries by replacing part of those with facilities available from the standard libraries.
- Wherever possible we have removed dependencies of our API on Boost by replacing those with the equivalent facility from the C++11 standard library.
- We have added new performance counters for parcel coalescing, file-IO, the AGAS cache, and overall scheduler time. Resetting performance counters has been overhauled and fixed.

⁴⁷³⁹ <http://wg21.link/n4560>

⁴⁷⁴⁰ <https://github.com/STELLAR-GROUP/hpx/issues/1668>

⁴⁷⁴¹ <http://wg21.link/n4560>

⁴⁷⁴² <http://wg21.link/p0075r1>

⁴⁷⁴³ <https://github.com/STELLAR-GROUP/hpx/issues/2016>

⁴⁷⁴⁴ <https://github.com/STELLAR-GROUP/hpx/issues/1141>

⁴⁷⁴⁵ <https://github.com/STELLAR-GROUP/hpx/issues/559>

⁴⁷⁴⁶ <https://github.com/STELLAR-GROUP/hpx/pull/1966>

⁴⁷⁴⁷ <https://github.com/STELLAR-GROUP/hpx/issues/1265>

⁴⁷⁴⁸ <https://github.com/STELLAR-GROUP/hpx/pull/1912>

- We have introduced a generic client type `hpx::components::client<>` and added support for using it with `hpx::async`. This removes the necessity to implement specific client types for every component type without losing type safety. This deemphasizes the need for using the low level `hpx::id_type` for referencing (possibly remote) component instances. The plan is to deprecate the direct use of `hpx::id_type` in user code in the future.
- We have added a special iterator which supports automatic prefetching of one or more arrays for speeding up loop-like code (see `hpx::parallel::util::make_prefetcher_context()`).
- We have extended the interfaces exposed from executors (as proposed by [N4406](#)⁴⁷⁴⁹) to accept an arbitrary number of arguments.

Breaking changes

- In order to move the dataflow facility to namespace `hpx` we added a definition of `hpx::dataflow` which might create ambiguities in existing codes. The previous definition of this facility (`hpx::lcos::local::dataflow`) has been deprecated and is available only if the constant `-DHPX_WITH_LOCAL_DATAFLOW_COMPATIBILITY=On` to `CMake`⁴⁷⁵⁰ is defined at configuration time. Please explicitly qualify all uses of the dataflow facility if you enable this compatibility setting and encounter ambiguities.
- The adaptation of the C++ Extensions for Ranges ([N4560](#)⁴⁷⁵¹) proposal imposes some breaking changes related to the return types of some of the parallel algorithms. Please see [Issue #1668](#)⁴⁷⁵² for a list of algorithms which have already been adapted.
- The facility `hpx::lcos::make_future_void()` has been replaced by `hpx::make_future<void>()`.
- We have removed support for Intel V13 and gcc 4.4.x.
- We have removed (default) support for the generic `hpx::parallel::execution_policy` because it was removed from the Parallelism TS (`__cpp11_n4104__`) while it was being added to the upcoming C++17 Standard. This facility can be still enabled at configure time by specifying `-DHPX_WITH_GENERIC_EXECUTION_POLICY=On` to `CMake`.
- Uses of `boost::shared_ptr` and related facilities have been replaced with `std::shared_ptr` and friends. Uses of `boost::unique_lock`, `boost::lock_guard` etc. have also been replaced by the equivalent (and equally named) tools available from the C++11 standard library.
- Facilities that used to expect an explicit `boost::unique_lock` now take an `std::unique_lock`. Additionally, `condition_variable` no longer aliases `condition_variable_any`; its interface now only works with `std::unique_lock<local::mutex>`.
- Uses of `boost::function`, `boost::bind`, `boost::tuple` have been replaced by the corresponding facilities in *HPX* (`hpx::util::function`, `hpx::util::bind`, and `hpx::util::tuple`, respectively).

⁴⁷⁴⁹ <http://wg21.link/n4406>

⁴⁷⁵⁰ <https://www.cmake.org>

⁴⁷⁵¹ <http://wg21.link/n4560>

⁴⁷⁵² <https://github.com/STELLAR-GROUP/hpx/issues/1668>

Bug fixes (closed tickets)

Here is a list of the important tickets we closed for this release.

- [PR #2250⁴⁷⁵³](#) - change default chunker of parallel executor to static one
- [PR #2247⁴⁷⁵⁴](#) - HPX on ppc64le
- [PR #2244⁴⁷⁵⁵](#) - Fixing MSVC problems
- [PR #2238⁴⁷⁵⁶](#) - Fixing small typos
- [PR #2237⁴⁷⁵⁷](#) - Fixing small typos
- [PR #2234⁴⁷⁵⁸](#) - Fix broken add test macro when extra args are passed in
- [PR #2231⁴⁷⁵⁹](#) - Fixing possible race during future awaiting in serialization
- [PR #2230⁴⁷⁶⁰](#) - Fix stream nvcc
- [PR #2229⁴⁷⁶¹](#) - Fixed run_as_hpx_thread
- [PR #2228⁴⁷⁶²](#) - On prefetching_test branch : adding prefetching_iterator and related tests used for prefetching containers within lambda functions
- [PR #2227⁴⁷⁶³](#) - Support for HPXCL's opencil::event
- [PR #2226⁴⁷⁶⁴](#) - Preparing for release of V0.9.99
- [PR #2225⁴⁷⁶⁵](#) - fix issue when compiling components with hpxcxx
- [PR #2224⁴⁷⁶⁶](#) - Compute alloc fix
- [PR #2223⁴⁷⁶⁷](#) - Simplify promise
- [PR #2222⁴⁷⁶⁸](#) - Replace last uses of boost::function by util::function_nonser
- [PR #2221⁴⁷⁶⁹](#) - Fix config tests
- [PR #2220⁴⁷⁷⁰](#) - Fixing gcc 4.6 compilation issues
- [PR #2219⁴⁷⁷¹](#) - nullptr support for [unique_] function
- [PR #2218⁴⁷⁷²](#) - Introducing clang tidy
- [PR #2216⁴⁷⁷³](#) - Replace NULL with nullptr

⁴⁷⁵³ <https://github.com/STELLAR-GROUP/hpx/pull/2250>

⁴⁷⁵⁴ <https://github.com/STELLAR-GROUP/hpx/pull/2247>

⁴⁷⁵⁵ <https://github.com/STELLAR-GROUP/hpx/pull/2244>

⁴⁷⁵⁶ <https://github.com/STELLAR-GROUP/hpx/pull/2238>

⁴⁷⁵⁷ <https://github.com/STELLAR-GROUP/hpx/pull/2237>

⁴⁷⁵⁸ <https://github.com/STELLAR-GROUP/hpx/pull/2234>

⁴⁷⁵⁹ <https://github.com/STELLAR-GROUP/hpx/pull/2231>

⁴⁷⁶⁰ <https://github.com/STELLAR-GROUP/hpx/pull/2230>

⁴⁷⁶¹ <https://github.com/STELLAR-GROUP/hpx/pull/2229>

⁴⁷⁶² <https://github.com/STELLAR-GROUP/hpx/pull/2228>

⁴⁷⁶³ <https://github.com/STELLAR-GROUP/hpx/pull/2227>

⁴⁷⁶⁴ <https://github.com/STELLAR-GROUP/hpx/pull/2226>

⁴⁷⁶⁵ <https://github.com/STELLAR-GROUP/hpx/pull/2225>

⁴⁷⁶⁶ <https://github.com/STELLAR-GROUP/hpx/pull/2224>

⁴⁷⁶⁷ <https://github.com/STELLAR-GROUP/hpx/pull/2223>

⁴⁷⁶⁸ <https://github.com/STELLAR-GROUP/hpx/pull/2222>

⁴⁷⁶⁹ <https://github.com/STELLAR-GROUP/hpx/pull/2221>

⁴⁷⁷⁰ <https://github.com/STELLAR-GROUP/hpx/pull/2220>

⁴⁷⁷¹ <https://github.com/STELLAR-GROUP/hpx/pull/2219>

⁴⁷⁷² <https://github.com/STELLAR-GROUP/hpx/pull/2218>

⁴⁷⁷³ <https://github.com/STELLAR-GROUP/hpx/pull/2216>

- Issue #2214⁴⁷⁷⁴ - Let inspect flag use of NULL, suggest nullptr instead
- PR #2213⁴⁷⁷⁵ - Require support for nullptr
- PR #2212⁴⁷⁷⁶ - Properly find jemalloc through pkg-config
- PR #2211⁴⁷⁷⁷ - Disable a couple of warnings reported by Intel on Windows
- PR #2210⁴⁷⁷⁸ - Fixed host::block_allocator::bulk_construct
- PR #2209⁴⁷⁷⁹ - Started to clean up new sort algorithms, made things compile for sort_by_key
- PR #2208⁴⁷⁸⁰ - A couple of fixes that were exposed by a new sort algorithm
- PR #2207⁴⁷⁸¹ - Adding missing includes in /hpx/include/serialization.hpp
- PR #2206⁴⁷⁸² - Call package_action::get_future before package_action::apply
- PR #2205⁴⁷⁸³ - The indirect_packaged_task::operator() needs to be run on a HPX thread
- PR #2204⁴⁷⁸⁴ - Variadic executor parameters
- PR #2203⁴⁷⁸⁵ - Delay-initialize members of partitioned iterator
- PR #2202⁴⁷⁸⁶ - Added segmented fill for hpx::vector
- Issue #2201⁴⁷⁸⁷ - Null Thread id encountered on partitioned_vector
- PR #2200⁴⁷⁸⁸ - Fix hangs
- PR #2199⁴⁷⁸⁹ - Deprecating hpx/traits.hpp
- PR #2198⁴⁷⁹⁰ - Making explicit inclusion of external libraries into build
- PR #2197⁴⁷⁹¹ - Fix typo in QT CMakeLists
- PR #2196⁴⁷⁹² - Fixing a gcc warning about attributes being ignored
- PR #2194⁴⁷⁹³ - Fixing partitioned_vector_spmf_foreach example
- Issue #2193⁴⁷⁹⁴ - partitioned_vector_spmf_foreach seg faults
- PR #2192⁴⁷⁹⁵ - Support Boost.Thread v4
- PR #2191⁴⁷⁹⁶ - HPX.Compute prototype

⁴⁷⁷⁴ <https://github.com/STELLAR-GROUP/hpx/issues/2214>

⁴⁷⁷⁵ <https://github.com/STELLAR-GROUP/hpx/pull/2213>

⁴⁷⁷⁶ <https://github.com/STELLAR-GROUP/hpx/pull/2212>

⁴⁷⁷⁷ <https://github.com/STELLAR-GROUP/hpx/pull/2211>

⁴⁷⁷⁸ <https://github.com/STELLAR-GROUP/hpx/pull/2210>

⁴⁷⁷⁹ <https://github.com/STELLAR-GROUP/hpx/pull/2209>

⁴⁷⁸⁰ <https://github.com/STELLAR-GROUP/hpx/pull/2208>

⁴⁷⁸¹ <https://github.com/STELLAR-GROUP/hpx/pull/2207>

⁴⁷⁸² <https://github.com/STELLAR-GROUP/hpx/pull/2206>

⁴⁷⁸³ <https://github.com/STELLAR-GROUP/hpx/pull/2205>

⁴⁷⁸⁴ <https://github.com/STELLAR-GROUP/hpx/pull/2204>

⁴⁷⁸⁵ <https://github.com/STELLAR-GROUP/hpx/pull/2203>

⁴⁷⁸⁶ <https://github.com/STELLAR-GROUP/hpx/pull/2202>

⁴⁷⁸⁷ <https://github.com/STELLAR-GROUP/hpx/issues/2201>

⁴⁷⁸⁸ <https://github.com/STELLAR-GROUP/hpx/pull/2200>

⁴⁷⁸⁹ <https://github.com/STELLAR-GROUP/hpx/pull/2199>

⁴⁷⁹⁰ <https://github.com/STELLAR-GROUP/hpx/pull/2198>

⁴⁷⁹¹ <https://github.com/STELLAR-GROUP/hpx/pull/2197>

⁴⁷⁹² <https://github.com/STELLAR-GROUP/hpx/pull/2196>

⁴⁷⁹³ <https://github.com/STELLAR-GROUP/hpx/pull/2194>

⁴⁷⁹⁴ <https://github.com/STELLAR-GROUP/hpx/issues/2193>

⁴⁷⁹⁵ <https://github.com/STELLAR-GROUP/hpx/pull/2192>

⁴⁷⁹⁶ <https://github.com/STELLAR-GROUP/hpx/pull/2191>

- [PR #2190⁴⁷⁹⁷](#) - Spawning operation on new thread if remaining stack space becomes too small
- [PR #2189⁴⁷⁹⁸](#) - Adding callback taking index and future to when_each
- [PR #2188⁴⁷⁹⁹](#) - Adding new example demonstrating receive_buffer
- [PR #2187⁴⁸⁰⁰](#) - Mask 128-bit ints if CUDA is being used
- [PR #2186⁴⁸⁰¹](#) - Make startup & shutdown functions unique_function
- [PR #2185⁴⁸⁰²](#) - Fixing logging output not to cause hang on shutdown
- [PR #2184⁴⁸⁰³](#) - Allowing component clients as action return types
- [Issue #2183⁴⁸⁰⁴](#) - Enabling logging output causes hang on shutdown
- [Issue #2182⁴⁸⁰⁵](#) - 1d_stencil seg fault
- [Issue #2181⁴⁸⁰⁶](#) - Setting small stack size does not change default
- [PR #2180⁴⁸⁰⁷](#) - Changing default bind mode to balanced
- [PR #2179⁴⁸⁰⁸](#) - adding prefetching_iterator and related tests used for prefetching containers within lambda functions
- [PR #2177⁴⁸⁰⁹](#) - Fixing 2176
- [Issue #2176⁴⁸¹⁰](#) - Launch process test fails on OSX
- [PR #2175⁴⁸¹¹](#) - Fix unbalanced config/warnings includes, add some new ones
- [PR #2174⁴⁸¹²](#) - Fix test categorization : regression not unit
- [Issue #2172⁴⁸¹³](#) - Different performance results
- [Issue #2171⁴⁸¹⁴](#) - “negative entry in reference count table” running octotiger on 32 nodes on queenbee
- [Issue #2170⁴⁸¹⁵](#) - Error while compiling on Mac + boost 1.60
- [PR #2168⁴⁸¹⁶](#) - Fixing problems with is_bitwise_serializable
- [Issue #2167⁴⁸¹⁷](#) - startup & shutdown function should accept unique_function
- [Issue #2166⁴⁸¹⁸](#) - Simple receive_buffer example
- [PR #2165⁴⁸¹⁹](#) - Fix wait all

⁴⁷⁹⁷ <https://github.com/STELLAR-GROUP/hpx/pull/2190>
⁴⁷⁹⁸ <https://github.com/STELLAR-GROUP/hpx/pull/2189>
⁴⁷⁹⁹ <https://github.com/STELLAR-GROUP/hpx/pull/2188>
⁴⁸⁰⁰ <https://github.com/STELLAR-GROUP/hpx/pull/2187>
⁴⁸⁰¹ <https://github.com/STELLAR-GROUP/hpx/pull/2186>
⁴⁸⁰² <https://github.com/STELLAR-GROUP/hpx/pull/2185>
⁴⁸⁰³ <https://github.com/STELLAR-GROUP/hpx/pull/2184>
⁴⁸⁰⁴ <https://github.com/STELLAR-GROUP/hpx/issues/2183>
⁴⁸⁰⁵ <https://github.com/STELLAR-GROUP/hpx/issues/2182>
⁴⁸⁰⁶ <https://github.com/STELLAR-GROUP/hpx/issues/2181>
⁴⁸⁰⁷ <https://github.com/STELLAR-GROUP/hpx/pull/2180>
⁴⁸⁰⁸ <https://github.com/STELLAR-GROUP/hpx/pull/2179>
⁴⁸⁰⁹ <https://github.com/STELLAR-GROUP/hpx/pull/2177>
⁴⁸¹⁰ <https://github.com/STELLAR-GROUP/hpx/issues/2176>
⁴⁸¹¹ <https://github.com/STELLAR-GROUP/hpx/pull/2175>
⁴⁸¹² <https://github.com/STELLAR-GROUP/hpx/pull/2174>
⁴⁸¹³ <https://github.com/STELLAR-GROUP/hpx/issues/2172>
⁴⁸¹⁴ <https://github.com/STELLAR-GROUP/hpx/issues/2171>
⁴⁸¹⁵ <https://github.com/STELLAR-GROUP/hpx/issues/2170>
⁴⁸¹⁶ <https://github.com/STELLAR-GROUP/hpx/pull/2168>
⁴⁸¹⁷ <https://github.com/STELLAR-GROUP/hpx/issues/2167>
⁴⁸¹⁸ <https://github.com/STELLAR-GROUP/hpx/issues/2166>
⁴⁸¹⁹ <https://github.com/STELLAR-GROUP/hpx/pull/2165>

- PR #2164⁴⁸²⁰ - Fix wait all
- PR #2163⁴⁸²¹ - Fix some typos in config tests
- PR #2162⁴⁸²² - Improve #includes
- PR #2160⁴⁸²³ - Add inspect check for missing #include <list>
- PR #2159⁴⁸²⁴ - Add missing finalize call to stop test hanging
- PR #2158⁴⁸²⁵ - Algo fixes
- PR #2157⁴⁸²⁶ - Stack check
- Issue #2156⁴⁸²⁷ - OSX reports stack space incorrectly (generic context coroutines)
- Issue #2155⁴⁸²⁸ - Race condition suspected in runtime
- PR #2154⁴⁸²⁹ - Replace boost::detail::atomic_count with the new util::atomic_count
- PR #2153⁴⁸³⁰ - Fix stack overflow on OSX
- PR #2152⁴⁸³¹ - Define is_bitwise_serializable as is_trivially_copyable when available
- PR #2151⁴⁸³² - Adding missing <cstring> for std::mem* functions
- Issue #2150⁴⁸³³ - Unable to use component clients as action return types
- PR #2149⁴⁸³⁴ - std::memmove copies bytes, use bytes*sizeof(type) when copying larger types
- PR #2146⁴⁸³⁵ - Adding customization point for parallel copy/move
- PR #2145⁴⁸³⁶ - Applying changes to address warnings issued by latest version of PVS Studio
- Issue #2148⁴⁸³⁷ - hpx::parallel::copy is broken after trivially copyable changes
- PR #2144⁴⁸³⁸ - Some minor tweaks to compute prototype
- PR #2143⁴⁸³⁹ - Added Boost version support information over OSX platform
- PR #2142⁴⁸⁴⁰ - Fixing memory leak in example
- PR #2141⁴⁸⁴¹ - Add missing specializations in execution policies
- PR #2139⁴⁸⁴² - This PR fixes a few problems reported by Clang's Undefined Behavior sanitizer

4820 <https://github.com/STELLAR-GROUP/hpx/pull/2164>

4821 <https://github.com/STELLAR-GROUP/hpx/pull/2163>

4822 <https://github.com/STELLAR-GROUP/hpx/pull/2162>

4823 <https://github.com/STELLAR-GROUP/hpx/pull/2160>

4824 <https://github.com/STELLAR-GROUP/hpx/pull/2159>

4825 <https://github.com/STELLAR-GROUP/hpx/pull/2158>

4826 <https://github.com/STELLAR-GROUP/hpx/pull/2157>

4827 <https://github.com/STELLAR-GROUP/hpx/issues/2156>

4828 <https://github.com/STELLAR-GROUP/hpx/issues/2155>

4829 <https://github.com/STELLAR-GROUP/hpx/pull/2154>

4830 <https://github.com/STELLAR-GROUP/hpx/pull/2153>

4831 <https://github.com/STELLAR-GROUP/hpx/pull/2152>

4832 <https://github.com/STELLAR-GROUP/hpx/pull/2151>

4833 <https://github.com/STELLAR-GROUP/hpx/issues/2150>

4834 <https://github.com/STELLAR-GROUP/hpx/pull/2149>

4835 <https://github.com/STELLAR-GROUP/hpx/pull/2146>

4836 <https://github.com/STELLAR-GROUP/hpx/pull/2145>

4837 <https://github.com/STELLAR-GROUP/hpx/issues/2148>

4838 <https://github.com/STELLAR-GROUP/hpx/pull/2144>

4839 <https://github.com/STELLAR-GROUP/hpx/pull/2143>

4840 <https://github.com/STELLAR-GROUP/hpx/pull/2142>

4841 <https://github.com/STELLAR-GROUP/hpx/pull/2141>

4842 <https://github.com/STELLAR-GROUP/hpx/pull/2139>

- PR #2138⁴⁸⁴³ - Revert “Adding fedora docs”
- PR #2136⁴⁸⁴⁴ - Removed double semicolon
- PR #2135⁴⁸⁴⁵ - Add deprecated #include check for hpx_fwd.hpp
- PR #2134⁴⁸⁴⁶ - Resolved memory leak in stencil_8
- PR #2133⁴⁸⁴⁷ - Replace uses of boost pointer containers
- PR #2132⁴⁸⁴⁸ - Removing unused typedef
- PR #2131⁴⁸⁴⁹ - Add several include checks for std facilities
- PR #2130⁴⁸⁵⁰ - Fixing parcel compression, adding test
- PR #2129⁴⁸⁵¹ - Fix invalid attribute warnings
- Issue #2128⁴⁸⁵² - hpx::init seems to segfault
- PR #2127⁴⁸⁵³ - Making executor_traits N-nary
- PR #2126⁴⁸⁵⁴ - GCC 4.6 fails to deduce the correct type in lambda
- PR #2125⁴⁸⁵⁵ - Making parcel coalescing test actually test something
- Issue #2124⁴⁸⁵⁶ - Make a testcase for parcel compression
- Issue #2123⁴⁸⁵⁷ - hpx/hpx/runtime/applier_fwd.hpp - Multiple defined types
- Issue #2122⁴⁸⁵⁸ - Exception in primary_namespace::resolve_free_list
- Issue #2121⁴⁸⁵⁹ - Possible memory leak in 1d_stencil_8
- PR #2120⁴⁸⁶⁰ - Fixing 2119
- Issue #2119⁴⁸⁶¹ - reduce_by_key compilation problems
- Issue #2118⁴⁸⁶² - Premature unwrapping of boost::ref'ed arguments
- PR #2117⁴⁸⁶³ - Added missing initializer on last constructor for thread_description
- PR #2116⁴⁸⁶⁴ - Use a lightweight bind implementation when no placeholders are given
- PR #2115⁴⁸⁶⁵ - Replace boost::shared_ptr with std::shared_ptr

4843 <https://github.com/STELLAR-GROUP/hpx/pull/2138>

4844 <https://github.com/STELLAR-GROUP/hpx/pull/2136>

4845 <https://github.com/STELLAR-GROUP/hpx/pull/2135>

4846 <https://github.com/STELLAR-GROUP/hpx/pull/2134>

4847 <https://github.com/STELLAR-GROUP/hpx/pull/2133>

4848 <https://github.com/STELLAR-GROUP/hpx/pull/2132>

4849 <https://github.com/STELLAR-GROUP/hpx/pull/2131>

4850 <https://github.com/STELLAR-GROUP/hpx/pull/2130>

4851 <https://github.com/STELLAR-GROUP/hpx/pull/2129>

4852 <https://github.com/STELLAR-GROUP/hpx/issues/2128>

4853 <https://github.com/STELLAR-GROUP/hpx/pull/2127>

4854 <https://github.com/STELLAR-GROUP/hpx/pull/2126>

4855 <https://github.com/STELLAR-GROUP/hpx/pull/2125>

4856 <https://github.com/STELLAR-GROUP/hpx/issues/2124>

4857 <https://github.com/STELLAR-GROUP/hpx/issues/2123>

4858 <https://github.com/STELLAR-GROUP/hpx/issues/2122>

4859 <https://github.com/STELLAR-GROUP/hpx/issues/2121>

4860 <https://github.com/STELLAR-GROUP/hpx/pull/2120>

4861 <https://github.com/STELLAR-GROUP/hpx/issues/2119>

4862 <https://github.com/STELLAR-GROUP/hpx/issues/2118>

4863 <https://github.com/STELLAR-GROUP/hpx/pull/2117>

4864 <https://github.com/STELLAR-GROUP/hpx/pull/2116>

4865 <https://github.com/STELLAR-GROUP/hpx/pull/2115>

- PR #2114⁴⁸⁶⁶ - Adding hook functions for executor_parameter_traits supporting timers
- Issue #2113⁴⁸⁶⁷ - Compilation error with gcc version 4.9.3 (MacPorts gcc49 4.9.3_0)
- PR #2112⁴⁸⁶⁸ - Replace uses of safe_bool with explicit operator bool
- Issue #2111⁴⁸⁶⁹ - Compilation error on QT example
- Issue #2110⁴⁸⁷⁰ - Compilation error when passing non-future argument to unwrapped continuation in dataflow
- Issue #2109⁴⁸⁷¹ - Warning while compiling hpx
- Issue #2109⁴⁸⁷² - Stack trace of last bug causing issues with octotiger
- Issue #2108⁴⁸⁷³ - Stack trace of last bug causing issues with octotiger
- PR #2107⁴⁸⁷⁴ - Making sure that a missing parcel_coalescing module does not cause startup exceptions
- PR #2106⁴⁸⁷⁵ - Stop using hpx_fwd.hpp
- Issue #2105⁴⁸⁷⁶ - coalescing plugin handler is not optional any more
- Issue #2104⁴⁸⁷⁷ - Make executor_traits N-nary
- Issue #2103⁴⁸⁷⁸ - Build error with octotiger and hpx commit e657426d
- PR #2102⁴⁸⁷⁹ - Combining thread data storage
- PR #2101⁴⁸⁸⁰ - Added repartition version of 1d stencil that uses any performance counter
- PR #2100⁴⁸⁸¹ - Drop obsolete TR1 result_of protocol
- PR #2099⁴⁸⁸² - Replace uses of boost::bind with util::bind
- PR #2098⁴⁸⁸³ - Deprecated inspect checks
- PR #2097⁴⁸⁸⁴ - Reduce by key, extends #1141
- PR #2096⁴⁸⁸⁵ - Moving local cache from external to hpx/util
- PR #2095⁴⁸⁸⁶ - Bump minimum required Boost to 1.50.0
- PR #2094⁴⁸⁸⁷ - Add include checks for several Boost utilities
- Issue #2093⁴⁸⁸⁸ - ./.../local_cache.hpp(89): error #303: explicit type is missing (“int” assumed)

4866 <https://github.com/STELLAR-GROUP/hpx/pull/2114>
4867 <https://github.com/STELLAR-GROUP/hpx/issues/2113>
4868 <https://github.com/STELLAR-GROUP/hpx/pull/2112>
4869 <https://github.com/STELLAR-GROUP/hpx/issues/2111>
4870 <https://github.com/STELLAR-GROUP/hpx/issues/2110>
4871 <https://github.com/STELLAR-GROUP/hpx/issues/2109>
4872 <https://github.com/STELLAR-GROUP/hpx/issues/2109>
4873 <https://github.com/STELLAR-GROUP/hpx/issues/2108>
4874 <https://github.com/STELLAR-GROUP/hpx/pull/2107>
4875 <https://github.com/STELLAR-GROUP/hpx/pull/2106>
4876 <https://github.com/STELLAR-GROUP/hpx/issues/2105>
4877 <https://github.com/STELLAR-GROUP/hpx/issues/2104>
4878 <https://github.com/STELLAR-GROUP/hpx/issues/2103>
4879 <https://github.com/STELLAR-GROUP/hpx/pull/2102>
4880 <https://github.com/STELLAR-GROUP/hpx/pull/2101>
4881 <https://github.com/STELLAR-GROUP/hpx/pull/2100>
4882 <https://github.com/STELLAR-GROUP/hpx/pull/2099>
4883 <https://github.com/STELLAR-GROUP/hpx/pull/2098>
4884 <https://github.com/STELLAR-GROUP/hpx/pull/2097>
4885 <https://github.com/STELLAR-GROUP/hpx/pull/2096>
4886 <https://github.com/STELLAR-GROUP/hpx/pull/2095>
4887 <https://github.com/STELLAR-GROUP/hpx/pull/2094>
4888 <https://github.com/STELLAR-GROUP/hpx/issues/2093>

- PR #2091⁴⁸⁸⁹ - Fix for Raspberry pi build
- PR #2090⁴⁸⁹⁰ - Fix storage size for util::function<>
- PR #2089⁴⁸⁹¹ - Fix #2088
- Issue #2088⁴⁸⁹² - More verbose output from cmake configuration
- PR #2087⁴⁸⁹³ - Making sure init_globally always executes hpx_main
- Issue #2086⁴⁸⁹⁴ - Race condition with recent HPX
- PR #2085⁴⁸⁹⁵ - Adding #include checker
- PR #2084⁴⁸⁹⁶ - Replace boost lock types with standard library ones
- PR #2083⁴⁸⁹⁷ - Simplify packaged task
- PR #2082⁴⁸⁹⁸ - Updating APEX version for testing
- PR #2081⁴⁸⁹⁹ - Cleanup exception headers
- PR #2080⁴⁹⁰⁰ - Make call_once variadic
- Issue #2079⁴⁹⁰¹ - With GNU C++, line 85 of hpx/config/version.hpp causes link failure when linking application
- Issue #2078⁴⁹⁰² - Simple test fails with _GLIBCXX_DEBUG defined
- PR #2077⁴⁹⁰³ - Instantiate board in nqueen client
- PR #2076⁴⁹⁰⁴ - Moving coalescing registration to TUs
- PR #2075⁴⁹⁰⁵ - Fixed some documentation typos
- PR #2074⁴⁹⁰⁶ - Adding flush-mode to message handler flush
- PR #2073⁴⁹⁰⁷ - Fixing performance regression introduced lately
- PR #2072⁴⁹⁰⁸ - Refactor local::condition_variable
- PR #2071⁴⁹⁰⁹ - Timer based on boost::asio::deadline_timer
- PR #2070⁴⁹¹⁰ - Refactor tuple based functionality
- PR #2069⁴⁹¹¹ - Fixed typos

4889 <https://github.com/STELLAR-GROUP/hpx/pull/2091>
4890 <https://github.com/STELLAR-GROUP/hpx/pull/2090>
4891 <https://github.com/STELLAR-GROUP/hpx/pull/2089>
4892 <https://github.com/STELLAR-GROUP/hpx/issues/2088>
4893 <https://github.com/STELLAR-GROUP/hpx/pull/2087>
4894 <https://github.com/STELLAR-GROUP/hpx/issues/2086>
4895 <https://github.com/STELLAR-GROUP/hpx/pull/2085>
4896 <https://github.com/STELLAR-GROUP/hpx/pull/2084>
4897 <https://github.com/STELLAR-GROUP/hpx/pull/2083>
4898 <https://github.com/STELLAR-GROUP/hpx/pull/2082>
4899 <https://github.com/STELLAR-GROUP/hpx/pull/2081>
4900 <https://github.com/STELLAR-GROUP/hpx/pull/2080>
4901 <https://github.com/STELLAR-GROUP/hpx/issues/2079>
4902 <https://github.com/STELLAR-GROUP/hpx/issues/2078>
4903 <https://github.com/STELLAR-GROUP/hpx/pull/2077>
4904 <https://github.com/STELLAR-GROUP/hpx/pull/2076>
4905 <https://github.com/STELLAR-GROUP/hpx/pull/2075>
4906 <https://github.com/STELLAR-GROUP/hpx/pull/2074>
4907 <https://github.com/STELLAR-GROUP/hpx/pull/2073>
4908 <https://github.com/STELLAR-GROUP/hpx/pull/2072>
4909 <https://github.com/STELLAR-GROUP/hpx/pull/2071>
4910 <https://github.com/STELLAR-GROUP/hpx/pull/2070>
4911 <https://github.com/STELLAR-GROUP/hpx/pull/2069>

- Issue #2068⁴⁹¹² - Seg fault with octotiger
- PR #2067⁴⁹¹³ - Algorithm cleanup
- PR #2066⁴⁹¹⁴ - Split credit fixes
- PR #2065⁴⁹¹⁵ - Rename HPX_MOVABLE_BUT_NOT_COPYABLE to HPX_MOVABLE_ONLY
- PR #2064⁴⁹¹⁶ - Fixed some typos in docs
- PR #2063⁴⁹¹⁷ - Adding example demonstrating template components
- Issue #2062⁴⁹¹⁸ - Support component templates
- PR #2061⁴⁹¹⁹ - Replace some uses of lexical_cast<string> with C++11 std::to_string
- PR #2060⁴⁹²⁰ - Replace uses of boost::noncopyable with HPX_NON_COPYABLE
- PR #2059⁴⁹²¹ - Adding missing for_loop algorithms
- PR #2058⁴⁹²² - Move several definitions to more appropriate headers
- PR #2057⁴⁹²³ - Simplify assert_owns_lock and ignore_while_checking
- PR #2056⁴⁹²⁴ - Replacing std::result_of with util::result_of
- PR #2055⁴⁹²⁵ - Fix process launching/connecting back
- PR #2054⁴⁹²⁶ - Add a forwarding coroutine header
- PR #2053⁴⁹²⁷ - Replace uses of boost::unordered_map with std::unordered_map
- PR #2052⁴⁹²⁸ - Rewrite tuple unwrap
- PR #2050⁴⁹²⁹ - Replace uses of BOOST_SCOPED_ENUM with C++11 scoped enums
- PR #2049⁴⁹³⁰ - Attempt to narrow down split_credit problem
- PR #2048⁴⁹³¹ - Fixing gcc startup hangs
- PR #2047⁴⁹³² - Fixing when_xxx and wait_xxx for MSVC12
- PR #2046⁴⁹³³ - adding persistent_auto_chunk_size and related tests for for_each
- PR #2045⁴⁹³⁴ - Fixing HPX_HAVE_THREAD_BACKTRACE_DEPTH build time configuration

⁴⁹¹² <https://github.com/STELLAR-GROUP/hpx/issues/2068>

⁴⁹¹³ <https://github.com/STELLAR-GROUP/hpx/pull/2067>

⁴⁹¹⁴ <https://github.com/STELLAR-GROUP/hpx/pull/2066>

⁴⁹¹⁵ <https://github.com/STELLAR-GROUP/hpx/pull/2065>

⁴⁹¹⁶ <https://github.com/STELLAR-GROUP/hpx/pull/2064>

⁴⁹¹⁷ <https://github.com/STELLAR-GROUP/hpx/pull/2063>

⁴⁹¹⁸ <https://github.com/STELLAR-GROUP/hpx/issues/2062>

⁴⁹¹⁹ <https://github.com/STELLAR-GROUP/hpx/pull/2061>

⁴⁹²⁰ <https://github.com/STELLAR-GROUP/hpx/pull/2060>

⁴⁹²¹ <https://github.com/STELLAR-GROUP/hpx/pull/2059>

⁴⁹²² <https://github.com/STELLAR-GROUP/hpx/pull/2058>

⁴⁹²³ <https://github.com/STELLAR-GROUP/hpx/pull/2057>

⁴⁹²⁴ <https://github.com/STELLAR-GROUP/hpx/pull/2056>

⁴⁹²⁵ <https://github.com/STELLAR-GROUP/hpx/pull/2055>

⁴⁹²⁶ <https://github.com/STELLAR-GROUP/hpx/pull/2054>

⁴⁹²⁷ <https://github.com/STELLAR-GROUP/hpx/pull/2053>

⁴⁹²⁸ <https://github.com/STELLAR-GROUP/hpx/pull/2052>

⁴⁹²⁹ <https://github.com/STELLAR-GROUP/hpx/pull/2050>

⁴⁹³⁰ <https://github.com/STELLAR-GROUP/hpx/pull/2049>

⁴⁹³¹ <https://github.com/STELLAR-GROUP/hpx/pull/2048>

⁴⁹³² <https://github.com/STELLAR-GROUP/hpx/pull/2047>

⁴⁹³³ <https://github.com/STELLAR-GROUP/hpx/pull/2046>

⁴⁹³⁴ <https://github.com/STELLAR-GROUP/hpx/pull/2045>

- PR #2044⁴⁹³⁵ - Adding missing service executor types
- PR #2043⁴⁹³⁶ - Removing ambiguous definitions for `is_future_range` and `future_range_traits`
- PR #2042⁴⁹³⁷ - Clarify that HPX builds can use (much) more than 2GB per process
- PR #2041⁴⁹³⁸ - Changing `future_iterator_traits` to support pointers
- Issue #2040⁴⁹³⁹ - Improve documentation memory usage warning?
- PR #2039⁴⁹⁴⁰ - Coroutine cleanup
- PR #2038⁴⁹⁴¹ - Fix `cmake` policy `CMP0042` warning `MACOSX_RPATH`
- PR #2037⁴⁹⁴² - Avoid redundant specialization of `[unique_]function_nonser`
- PR #2036⁴⁹⁴³ - `nvcc` dies with an internal error upon pushing/popping warnings inside templates
- Issue #2035⁴⁹⁴⁴ - Use a less restrictive iterator definition in `hpx::lcos::detail::future_iterator_traits`
- PR #2034⁴⁹⁴⁵ - Fixing compilation error with thread queue wait time performance counter
- Issue #2033⁴⁹⁴⁶ - Compilation error when compiling with thread queue waittime performance counter
- Issue #2032⁴⁹⁴⁷ - Ambiguous template instantiation for `is_future_range` and `future_range_traits`.
- PR #2031⁴⁹⁴⁸ - Don't restart timer on every incoming parcel
- PR #2030⁴⁹⁴⁹ - Unify handling of execution policies in parallel algorithms
- PR #2029⁴⁹⁵⁰ - Make `pkg-config` `.pc` files use `.dylib` on OSX
- PR #2028⁴⁹⁵¹ - Adding process component
- PR #2027⁴⁹⁵² - Making check for compiler compatibility independent on compiler path
- PR #2025⁴⁹⁵³ - Fixing inspect tool
- PR #2024⁴⁹⁵⁴ - Intel13 removal
- PR #2023⁴⁹⁵⁵ - Fix errors related to older boost versions and parameter pack expansions in lambdas
- Issue #2022⁴⁹⁵⁶ - `gmake` fail: "No rule to make target `/usr/lib46/libboost_context-mt.so`"
- PR #2021⁴⁹⁵⁷ - Added Sudoku example

⁴⁹³⁵ <https://github.com/STELLAR-GROUP/hpx/pull/2044>
⁴⁹³⁶ <https://github.com/STELLAR-GROUP/hpx/pull/2043>
⁴⁹³⁷ <https://github.com/STELLAR-GROUP/hpx/pull/2042>
⁴⁹³⁸ <https://github.com/STELLAR-GROUP/hpx/pull/2041>
⁴⁹³⁹ <https://github.com/STELLAR-GROUP/hpx/issues/2040>
⁴⁹⁴⁰ <https://github.com/STELLAR-GROUP/hpx/pull/2039>
⁴⁹⁴¹ <https://github.com/STELLAR-GROUP/hpx/pull/2038>
⁴⁹⁴² <https://github.com/STELLAR-GROUP/hpx/pull/2037>
⁴⁹⁴³ <https://github.com/STELLAR-GROUP/hpx/pull/2036>
⁴⁹⁴⁴ <https://github.com/STELLAR-GROUP/hpx/issues/2035>
⁴⁹⁴⁵ <https://github.com/STELLAR-GROUP/hpx/pull/2034>
⁴⁹⁴⁶ <https://github.com/STELLAR-GROUP/hpx/issues/2033>
⁴⁹⁴⁷ <https://github.com/STELLAR-GROUP/hpx/issues/2032>
⁴⁹⁴⁸ <https://github.com/STELLAR-GROUP/hpx/pull/2031>
⁴⁹⁴⁹ <https://github.com/STELLAR-GROUP/hpx/pull/2030>
⁴⁹⁵⁰ <https://github.com/STELLAR-GROUP/hpx/pull/2029>
⁴⁹⁵¹ <https://github.com/STELLAR-GROUP/hpx/pull/2028>
⁴⁹⁵² <https://github.com/STELLAR-GROUP/hpx/pull/2027>
⁴⁹⁵³ <https://github.com/STELLAR-GROUP/hpx/pull/2025>
⁴⁹⁵⁴ <https://github.com/STELLAR-GROUP/hpx/pull/2024>
⁴⁹⁵⁵ <https://github.com/STELLAR-GROUP/hpx/pull/2023>
⁴⁹⁵⁶ <https://github.com/STELLAR-GROUP/hpx/issues/2022>
⁴⁹⁵⁷ <https://github.com/STELLAR-GROUP/hpx/pull/2021>

- [Issue #2020⁴⁹⁵⁸](#) - Make errors related to `init_globally.cpp` example while building HPX out of the box
- [PR #2019⁴⁹⁵⁹](#) - Fixed some compilation and `cmake` errors encountered in `nqueen` example
- [PR #2018⁴⁹⁶⁰](#) - For loop algorithms
- [PR #2017⁴⁹⁶¹](#) - Non-recursive `at_index` implementation
- [Issue #2016⁴⁹⁶²](#) - Add index-based for-loops
- [Issue #2015⁴⁹⁶³](#) - Change default `bind-mode` to `balanced`
- [PR #2014⁴⁹⁶⁴](#) - Fixed dataflow if invoked action returns a future
- [PR #2013⁴⁹⁶⁵](#) - Fixing compilation issues with external example
- [PR #2012⁴⁹⁶⁶](#) - Added Sierpinski Triangle example
- [Issue #2011⁴⁹⁶⁷](#) - Compilation error while running sample `hello_world_component` code
- [PR #2010⁴⁹⁶⁸](#) - Segmented move implemented for `hpx::vector`
- [Issue #2009⁴⁹⁶⁹](#) - `pkg-config` order incorrect on 14.04 / GCC 4.8
- [Issue #2008⁴⁹⁷⁰](#) - Compilation error in dataflow of action returning a future
- [PR #2007⁴⁹⁷¹](#) - Adding new performance counter exposing overall scheduler time
- [PR #2006⁴⁹⁷²](#) - Function includes
- [PR #2005⁴⁹⁷³](#) - Adding an example demonstrating how to initialize HPX from a global object
- [PR #2004⁴⁹⁷⁴](#) - Fixing 2000
- [PR #2003⁴⁹⁷⁵](#) - Adding generation parameter to `gather` to enable using it more than once
- [PR #2002⁴⁹⁷⁶](#) - Turn on position independent code to solve link problem with `hpx_init`
- [Issue #2001⁴⁹⁷⁷](#) - Gathering more than once segfaults
- [Issue #2000⁴⁹⁷⁸](#) - Undefined reference to `hpx::assertion_failed`
- [Issue #1999⁴⁹⁷⁹](#) - Seg fault in `hpx::lcos::base_lco_with_value<*>::set_value_nonvirt()` when running `octo-tiger`
- [PR #1998⁴⁹⁸⁰](#) - Detect unknown command line options

⁴⁹⁵⁸ <https://github.com/STELLAR-GROUP/hpx/issues/2020>

⁴⁹⁵⁹ <https://github.com/STELLAR-GROUP/hpx/pull/2019>

⁴⁹⁶⁰ <https://github.com/STELLAR-GROUP/hpx/pull/2018>

⁴⁹⁶¹ <https://github.com/STELLAR-GROUP/hpx/pull/2017>

⁴⁹⁶² <https://github.com/STELLAR-GROUP/hpx/issues/2016>

⁴⁹⁶³ <https://github.com/STELLAR-GROUP/hpx/issues/2015>

⁴⁹⁶⁴ <https://github.com/STELLAR-GROUP/hpx/pull/2014>

⁴⁹⁶⁵ <https://github.com/STELLAR-GROUP/hpx/pull/2013>

⁴⁹⁶⁶ <https://github.com/STELLAR-GROUP/hpx/pull/2012>

⁴⁹⁶⁷ <https://github.com/STELLAR-GROUP/hpx/issues/2011>

⁴⁹⁶⁸ <https://github.com/STELLAR-GROUP/hpx/pull/2010>

⁴⁹⁶⁹ <https://github.com/STELLAR-GROUP/hpx/issues/2009>

⁴⁹⁷⁰ <https://github.com/STELLAR-GROUP/hpx/issues/2008>

⁴⁹⁷¹ <https://github.com/STELLAR-GROUP/hpx/pull/2007>

⁴⁹⁷² <https://github.com/STELLAR-GROUP/hpx/pull/2006>

⁴⁹⁷³ <https://github.com/STELLAR-GROUP/hpx/pull/2005>

⁴⁹⁷⁴ <https://github.com/STELLAR-GROUP/hpx/pull/2004>

⁴⁹⁷⁵ <https://github.com/STELLAR-GROUP/hpx/pull/2003>

⁴⁹⁷⁶ <https://github.com/STELLAR-GROUP/hpx/pull/2002>

⁴⁹⁷⁷ <https://github.com/STELLAR-GROUP/hpx/issues/2001>

⁴⁹⁷⁸ <https://github.com/STELLAR-GROUP/hpx/issues/2000>

⁴⁹⁷⁹ <https://github.com/STELLAR-GROUP/hpx/issues/1999>

⁴⁹⁸⁰ <https://github.com/STELLAR-GROUP/hpx/pull/1998>

- PR #1997⁴⁹⁸¹ - Extending thread description
- PR #1996⁴⁹⁸² - Adding natvis files to solution (MSVC only)
- Issue #1995⁴⁹⁸³ - Command line handling does not produce error
- PR #1994⁴⁹⁸⁴ - Possible missing include in test_utils.hpp
- PR #1993⁴⁹⁸⁵ - Add missing LANGUAGES tag to a hpx_add_compile_flag_if_available() call in CMakeLists.txt
- PR #1992⁴⁹⁸⁶ - Fixing shared_executor_test
- PR #1991⁴⁹⁸⁷ - Making sure the winsock library is properly initialized
- PR #1990⁴⁹⁸⁸ - Fixing bind_test placeholder ambiguity coming from boost-1.60
- PR #1989⁴⁹⁸⁹ - Performance tuning
- PR #1987⁴⁹⁹⁰ - Make configurable size of internal storage in util::function
- PR #1986⁴⁹⁹¹ - AGAS Refactoring+1753 Cache mods
- PR #1985⁴⁹⁹² - Adding missing task_block::run() overload taking an executor
- PR #1984⁴⁹⁹³ - Adding an optimized LRU Cache implementation (for AGAS)
- PR #1983⁴⁹⁹⁴ - Avoid invoking migration table look up for all objects
- PR #1981⁴⁹⁹⁵ - Replacing uintptr_t (which is not defined everywhere) with std::size_t
- PR #1980⁴⁹⁹⁶ - Optimizing LCO continuations
- PR #1979⁴⁹⁹⁷ - Fixing Cori
- PR #1978⁴⁹⁹⁸ - Fix test check that got broken in hasty fix to memory overflow
- PR #1977⁴⁹⁹⁹ - Refactor action traits
- PR #1976⁵⁰⁰⁰ - Fixes typo in README.rst
- PR #1975⁵⁰⁰¹ - Reduce size of benchmark timing arrays to fix test failures
- PR #1974⁵⁰⁰² - Add action to update data owned by the partitioned_vector component
- PR #1972⁵⁰⁰³ - Adding partitioned_vector SPMD example

⁴⁹⁸¹ <https://github.com/STELLAR-GROUP/hpx/pull/1997>
⁴⁹⁸² <https://github.com/STELLAR-GROUP/hpx/pull/1996>
⁴⁹⁸³ <https://github.com/STELLAR-GROUP/hpx/issues/1995>
⁴⁹⁸⁴ <https://github.com/STELLAR-GROUP/hpx/pull/1994>
⁴⁹⁸⁵ <https://github.com/STELLAR-GROUP/hpx/pull/1993>
⁴⁹⁸⁶ <https://github.com/STELLAR-GROUP/hpx/pull/1992>
⁴⁹⁸⁷ <https://github.com/STELLAR-GROUP/hpx/pull/1991>
⁴⁹⁸⁸ <https://github.com/STELLAR-GROUP/hpx/pull/1990>
⁴⁹⁸⁹ <https://github.com/STELLAR-GROUP/hpx/pull/1989>
⁴⁹⁹⁰ <https://github.com/STELLAR-GROUP/hpx/pull/1987>
⁴⁹⁹¹ <https://github.com/STELLAR-GROUP/hpx/pull/1986>
⁴⁹⁹² <https://github.com/STELLAR-GROUP/hpx/pull/1985>
⁴⁹⁹³ <https://github.com/STELLAR-GROUP/hpx/pull/1984>
⁴⁹⁹⁴ <https://github.com/STELLAR-GROUP/hpx/pull/1983>
⁴⁹⁹⁵ <https://github.com/STELLAR-GROUP/hpx/pull/1981>
⁴⁹⁹⁶ <https://github.com/STELLAR-GROUP/hpx/pull/1980>
⁴⁹⁹⁷ <https://github.com/STELLAR-GROUP/hpx/pull/1979>
⁴⁹⁹⁸ <https://github.com/STELLAR-GROUP/hpx/pull/1978>
⁴⁹⁹⁹ <https://github.com/STELLAR-GROUP/hpx/pull/1977>
⁵⁰⁰⁰ <https://github.com/STELLAR-GROUP/hpx/pull/1976>
⁵⁰⁰¹ <https://github.com/STELLAR-GROUP/hpx/pull/1975>
⁵⁰⁰² <https://github.com/STELLAR-GROUP/hpx/pull/1974>
⁵⁰⁰³ <https://github.com/STELLAR-GROUP/hpx/pull/1972>

- PR #1971⁵⁰⁰⁴ - Fixing 1965
- PR #1970⁵⁰⁰⁵ - Papi fixes
- PR #1969⁵⁰⁰⁶ - Fixing continuation recursions to not depend on fixed amount of recursions
- PR #1968⁵⁰⁰⁷ - More segmented algorithms
- Issue #1967⁵⁰⁰⁸ - Simplify component implementations
- PR #1966⁵⁰⁰⁹ - Migrate components
- Issue #1964⁵⁰¹⁰ - fatal error: 'boost/lockfree/detail/branch_hints.hpp' file not found
- Issue #1962⁵⁰¹¹ - parallel::copy_if has race condition when used on in place arrays
- PR #1963⁵⁰¹² - Fixing Static Parcelport initialization
- PR #1961⁵⁰¹³ - Fix function target
- Issue #1960⁵⁰¹⁴ - Papi counters don't reset
- PR #1959⁵⁰¹⁵ - Fixing 1958
- Issue #1958⁵⁰¹⁶ - inclusive_scan gives incorrect results with non-commutative operator
- PR #1957⁵⁰¹⁷ - Fixing #1950
- PR #1956⁵⁰¹⁸ - Sort by key example
- PR #1955⁵⁰¹⁹ - Adding regression test for #1946: Hang in wait_all() in distributed run
- Issue #1954⁵⁰²⁰ - HPX releases should not use -Werror
- PR #1953⁵⁰²¹ - Adding performance analysis for AGAS cache
- PR #1952⁵⁰²² - Adapting test for explicit variadics to fail for gcc 4.6
- PR #1951⁵⁰²³ - Fixing memory leak
- Issue #1950⁵⁰²⁴ - Simplify external builds
- PR #1949⁵⁰²⁵ - Fixing yet another lock that is being held during suspension
- PR #1948⁵⁰²⁶ - Fixed container algorithms for Intel

⁵⁰⁰⁴ <https://github.com/STELLAR-GROUP/hpx/pull/1971>

⁵⁰⁰⁵ <https://github.com/STELLAR-GROUP/hpx/pull/1970>

⁵⁰⁰⁶ <https://github.com/STELLAR-GROUP/hpx/pull/1969>

⁵⁰⁰⁷ <https://github.com/STELLAR-GROUP/hpx/pull/1968>

⁵⁰⁰⁸ <https://github.com/STELLAR-GROUP/hpx/issues/1967>

⁵⁰⁰⁹ <https://github.com/STELLAR-GROUP/hpx/pull/1966>

⁵⁰¹⁰ <https://github.com/STELLAR-GROUP/hpx/issues/1964>

⁵⁰¹¹ <https://github.com/STELLAR-GROUP/hpx/issues/1962>

⁵⁰¹² <https://github.com/STELLAR-GROUP/hpx/pull/1963>

⁵⁰¹³ <https://github.com/STELLAR-GROUP/hpx/pull/1961>

⁵⁰¹⁴ <https://github.com/STELLAR-GROUP/hpx/issues/1960>

⁵⁰¹⁵ <https://github.com/STELLAR-GROUP/hpx/pull/1959>

⁵⁰¹⁶ <https://github.com/STELLAR-GROUP/hpx/issues/1958>

⁵⁰¹⁷ <https://github.com/STELLAR-GROUP/hpx/pull/1957>

⁵⁰¹⁸ <https://github.com/STELLAR-GROUP/hpx/pull/1956>

⁵⁰¹⁹ <https://github.com/STELLAR-GROUP/hpx/pull/1955>

⁵⁰²⁰ <https://github.com/STELLAR-GROUP/hpx/issues/1954>

⁵⁰²¹ <https://github.com/STELLAR-GROUP/hpx/pull/1953>

⁵⁰²² <https://github.com/STELLAR-GROUP/hpx/pull/1952>

⁵⁰²³ <https://github.com/STELLAR-GROUP/hpx/pull/1951>

⁵⁰²⁴ <https://github.com/STELLAR-GROUP/hpx/issues/1950>

⁵⁰²⁵ <https://github.com/STELLAR-GROUP/hpx/pull/1949>

⁵⁰²⁶ <https://github.com/STELLAR-GROUP/hpx/pull/1948>

- PR #1947⁵⁰²⁷ - Adding workaround for tagged_tuple
- Issue #1946⁵⁰²⁸ - Hang in wait_all() in distributed run
- PR #1945⁵⁰²⁹ - Fixed container algorithm tests
- Issue #1944⁵⁰³⁰ - assertion 'p.destination_locality() == hpx::get_locality()' failed
- PR #1943⁵⁰³¹ - Fix a couple of compile errors with clang
- PR #1942⁵⁰³² - Making parcel coalescing functional
- Issue #1941⁵⁰³³ - Re-enable parcel coalescing
- PR #1940⁵⁰³⁴ - Touching up make_future
- PR #1939⁵⁰³⁵ - Fixing problems in over-subscription management in the resource manager
- PR #1938⁵⁰³⁶ - Removing use of unified Boost.Thread header
- PR #1937⁵⁰³⁷ - Cleaning up the use of Boost.Accumulator headers
- PR #1936⁵⁰³⁸ - Making sure interval timer is started for aggregating performance counters
- PR #1935⁵⁰³⁹ - Tagged results
- PR #1934⁵⁰⁴⁰ - Fix remote async with deferred launch policy
- Issue #1933⁵⁰⁴¹ - Floating point exception in statistics_counter<boost::accumulators::tag::mean>::get_counter_v
- PR #1932⁵⁰⁴² - Removing superfluous includes of boost/lockfree/detail/branch_hints.hpp
- PR #1931⁵⁰⁴³ - fix compilation with clang 3.8.0
- Issue #1930⁵⁰⁴⁴ - Missing online documentation for HPX 0.9.11
- PR #1929⁵⁰⁴⁵ - LWG2485: get() should be overloaded for const tuple&&
- PR #1928⁵⁰⁴⁶ - Revert "Using ninja for circle-ci builds"
- PR #1927⁵⁰⁴⁷ - Using ninja for circle-ci builds
- PR #1926⁵⁰⁴⁸ - Fixing serialization of std::array
- Issue #1925⁵⁰⁴⁹ - Issues with static HPX libraries

⁵⁰²⁷ <https://github.com/STELLAR-GROUP/hpx/pull/1947>

⁵⁰²⁸ <https://github.com/STELLAR-GROUP/hpx/issues/1946>

⁵⁰²⁹ <https://github.com/STELLAR-GROUP/hpx/pull/1945>

⁵⁰³⁰ <https://github.com/STELLAR-GROUP/hpx/issues/1944>

⁵⁰³¹ <https://github.com/STELLAR-GROUP/hpx/pull/1943>

⁵⁰³² <https://github.com/STELLAR-GROUP/hpx/pull/1942>

⁵⁰³³ <https://github.com/STELLAR-GROUP/hpx/issues/1941>

⁵⁰³⁴ <https://github.com/STELLAR-GROUP/hpx/pull/1940>

⁵⁰³⁵ <https://github.com/STELLAR-GROUP/hpx/pull/1939>

⁵⁰³⁶ <https://github.com/STELLAR-GROUP/hpx/pull/1938>

⁵⁰³⁷ <https://github.com/STELLAR-GROUP/hpx/pull/1937>

⁵⁰³⁸ <https://github.com/STELLAR-GROUP/hpx/pull/1936>

⁵⁰³⁹ <https://github.com/STELLAR-GROUP/hpx/pull/1935>

⁵⁰⁴⁰ <https://github.com/STELLAR-GROUP/hpx/pull/1934>

⁵⁰⁴¹ <https://github.com/STELLAR-GROUP/hpx/issues/1933>

⁵⁰⁴² <https://github.com/STELLAR-GROUP/hpx/pull/1932>

⁵⁰⁴³ <https://github.com/STELLAR-GROUP/hpx/pull/1931>

⁵⁰⁴⁴ <https://github.com/STELLAR-GROUP/hpx/issues/1930>

⁵⁰⁴⁵ <https://github.com/STELLAR-GROUP/hpx/pull/1929>

⁵⁰⁴⁶ <https://github.com/STELLAR-GROUP/hpx/pull/1928>

⁵⁰⁴⁷ <https://github.com/STELLAR-GROUP/hpx/pull/1927>

⁵⁰⁴⁸ <https://github.com/STELLAR-GROUP/hpx/pull/1926>

⁵⁰⁴⁹ <https://github.com/STELLAR-GROUP/hpx/issues/1925>

- [Issue #1924⁵⁰⁵⁰](#) - Performance degrading over time
- [Issue #1923⁵⁰⁵¹](#) - serialization of std::array appears broken in latest commit
- [PR #1922⁵⁰⁵²](#) - Container algorithms
- [PR #1921⁵⁰⁵³](#) - Tons of smaller quality improvements
- [Issue #1920⁵⁰⁵⁴](#) - Seg fault in hpx::serialization::output_archive::add_gid when running octotiger
- [Issue #1919⁵⁰⁵⁵](#) - Intel 15 compiler bug preventing HPX build
- [PR #1918⁵⁰⁵⁶](#) - Address sanitizer fixes
- [PR #1917⁵⁰⁵⁷](#) - Fixing compilation problems of parallel::sort with Intel compilers
- [PR #1916⁵⁰⁵⁸](#) - Making sure code compiles if HPX_WITH_HWLOC=Off
- [Issue #1915⁵⁰⁵⁹](#) - max_cores undefined if HPX_WITH_HWLOC=Off
- [PR #1913⁵⁰⁶⁰](#) - Add utility member functions for partitioned_vector
- [PR #1912⁵⁰⁶¹](#) - Adding support for invoking actions to dataflow
- [PR #1911⁵⁰⁶²](#) - Adding first batch of container algorithms
- [PR #1910⁵⁰⁶³](#) - Keep cmake_module_path
- [PR #1909⁵⁰⁶⁴](#) - Fix mpirun with pbs
- [PR #1908⁵⁰⁶⁵](#) - Changing parallel::sort to return the last iterator as proposed by N4560
- [PR #1907⁵⁰⁶⁶](#) - Adding a minimum version for Open MPI
- [PR #1906⁵⁰⁶⁷](#) - Updates to the Release Procedure
- [PR #1905⁵⁰⁶⁸](#) - Fixing #1903
- [PR #1904⁵⁰⁶⁹](#) - Making sure std containers are cleared before serialization loads data
- [Issue #1903⁵⁰⁷⁰](#) - When running octotiger, I get: assertion '(*new_gids_)[gid].size() == 1' failed: HPX(assertion_failure)
- [Issue #1902⁵⁰⁷¹](#) - Immediate crash when running hpx/octotiger with _GLIBCXX_DEBUG defined.
- [PR #1901⁵⁰⁷²](#) - Making non-serializable classes non-serializable

⁵⁰⁵⁰ <https://github.com/STELLAR-GROUP/hpx/issues/1924>

⁵⁰⁵¹ <https://github.com/STELLAR-GROUP/hpx/issues/1923>

⁵⁰⁵² <https://github.com/STELLAR-GROUP/hpx/pull/1922>

⁵⁰⁵³ <https://github.com/STELLAR-GROUP/hpx/pull/1921>

⁵⁰⁵⁴ <https://github.com/STELLAR-GROUP/hpx/issues/1920>

⁵⁰⁵⁵ <https://github.com/STELLAR-GROUP/hpx/issues/1919>

⁵⁰⁵⁶ <https://github.com/STELLAR-GROUP/hpx/pull/1918>

⁵⁰⁵⁷ <https://github.com/STELLAR-GROUP/hpx/pull/1917>

⁵⁰⁵⁸ <https://github.com/STELLAR-GROUP/hpx/pull/1916>

⁵⁰⁵⁹ <https://github.com/STELLAR-GROUP/hpx/issues/1915>

⁵⁰⁶⁰ <https://github.com/STELLAR-GROUP/hpx/pull/1913>

⁵⁰⁶¹ <https://github.com/STELLAR-GROUP/hpx/pull/1912>

⁵⁰⁶² <https://github.com/STELLAR-GROUP/hpx/pull/1911>

⁵⁰⁶³ <https://github.com/STELLAR-GROUP/hpx/pull/1910>

⁵⁰⁶⁴ <https://github.com/STELLAR-GROUP/hpx/pull/1909>

⁵⁰⁶⁵ <https://github.com/STELLAR-GROUP/hpx/pull/1908>

⁵⁰⁶⁶ <https://github.com/STELLAR-GROUP/hpx/pull/1907>

⁵⁰⁶⁷ <https://github.com/STELLAR-GROUP/hpx/pull/1906>

⁵⁰⁶⁸ <https://github.com/STELLAR-GROUP/hpx/pull/1905>

⁵⁰⁶⁹ <https://github.com/STELLAR-GROUP/hpx/pull/1904>

⁵⁰⁷⁰ <https://github.com/STELLAR-GROUP/hpx/issues/1903>

⁵⁰⁷¹ <https://github.com/STELLAR-GROUP/hpx/issues/1902>

⁵⁰⁷² <https://github.com/STELLAR-GROUP/hpx/pull/1901>

- [Issue #1900⁵⁰⁷³](#) - Two possible issues with std::list serialization
- [PR #1899⁵⁰⁷⁴](#) - Fixing a problem with credit splitting as revealed by #1898
- [Issue #1898⁵⁰⁷⁵](#) - Accessing component from locality where it was not created segfaults
- [PR #1897⁵⁰⁷⁶](#) - Changing parallel::sort to return the last iterator as proposed by N4560
- [Issue #1896⁵⁰⁷⁷](#) - version 1.0?
- [Issue #1895⁵⁰⁷⁸](#) - Warning comment on numa_allocator is not very clear
- [PR #1894⁵⁰⁷⁹](#) - Add support for compilers that have thread_local
- [PR #1893⁵⁰⁸⁰](#) - Fixing 1890
- [PR #1892⁵⁰⁸¹](#) - Adds typed future_type for executor_traits
- [PR #1891⁵⁰⁸²](#) - Fix wording in certain parallel algorithm docs
- [Issue #1890⁵⁰⁸³](#) - Invoking papi counters give segfault
- [PR #1889⁵⁰⁸⁴](#) - Fixing problems as reported by clang-check
- [PR #1888⁵⁰⁸⁵](#) - WIP parallel is_heap
- [PR #1887⁵⁰⁸⁶](#) - Fixed resetting performance counters related to idle-rate, etc
- [Issue #1886⁵⁰⁸⁷](#) - Run hpx with qsub does not work
- [PR #1885⁵⁰⁸⁸](#) - Warning cleaning pass
- [PR #1884⁵⁰⁸⁹](#) - Add missing parallel algorithm header
- [PR #1883⁵⁰⁹⁰](#) - Add feature test for thread_local on Clang for TLS
- [PR #1882⁵⁰⁹¹](#) - Fix some redundant qualifiers
- [Issue #1881⁵⁰⁹²](#) - Unable to compile Octotiger using HPX and Intel MPI on SuperMIC
- [Issue #1880⁵⁰⁹³](#) - clang with libc++ on Linux needs TLS case
- [PR #1879⁵⁰⁹⁴](#) - Doc fixes for #1868
- [PR #1878⁵⁰⁹⁵](#) - Simplify functions

⁵⁰⁷³ <https://github.com/STELLAR-GROUP/hpx/issues/1900>
⁵⁰⁷⁴ <https://github.com/STELLAR-GROUP/hpx/pull/1899>
⁵⁰⁷⁵ <https://github.com/STELLAR-GROUP/hpx/issues/1898>
⁵⁰⁷⁶ <https://github.com/STELLAR-GROUP/hpx/pull/1897>
⁵⁰⁷⁷ <https://github.com/STELLAR-GROUP/hpx/issues/1896>
⁵⁰⁷⁸ <https://github.com/STELLAR-GROUP/hpx/issues/1895>
⁵⁰⁷⁹ <https://github.com/STELLAR-GROUP/hpx/pull/1894>
⁵⁰⁸⁰ <https://github.com/STELLAR-GROUP/hpx/pull/1893>
⁵⁰⁸¹ <https://github.com/STELLAR-GROUP/hpx/pull/1892>
⁵⁰⁸² <https://github.com/STELLAR-GROUP/hpx/pull/1891>
⁵⁰⁸³ <https://github.com/STELLAR-GROUP/hpx/issues/1890>
⁵⁰⁸⁴ <https://github.com/STELLAR-GROUP/hpx/pull/1889>
⁵⁰⁸⁵ <https://github.com/STELLAR-GROUP/hpx/pull/1888>
⁵⁰⁸⁶ <https://github.com/STELLAR-GROUP/hpx/pull/1887>
⁵⁰⁸⁷ <https://github.com/STELLAR-GROUP/hpx/issues/1886>
⁵⁰⁸⁸ <https://github.com/STELLAR-GROUP/hpx/pull/1885>
⁵⁰⁸⁹ <https://github.com/STELLAR-GROUP/hpx/pull/1884>
⁵⁰⁹⁰ <https://github.com/STELLAR-GROUP/hpx/pull/1883>
⁵⁰⁹¹ <https://github.com/STELLAR-GROUP/hpx/pull/1882>
⁵⁰⁹² <https://github.com/STELLAR-GROUP/hpx/issues/1881>
⁵⁰⁹³ <https://github.com/STELLAR-GROUP/hpx/issues/1880>
⁵⁰⁹⁴ <https://github.com/STELLAR-GROUP/hpx/pull/1879>
⁵⁰⁹⁵ <https://github.com/STELLAR-GROUP/hpx/pull/1878>

- PR #1877⁵⁰⁹⁶ - Removing most usage of Boost.Config
- PR #1876⁵⁰⁹⁷ - Add missing parallel algorithms to algorithm.hpp
- PR #1875⁵⁰⁹⁸ - Simplify callables
- PR #1874⁵⁰⁹⁹ - Address long standing FIXME on using `std::unique_ptr` with incomplete types
- PR #1873⁵¹⁰⁰ - Fixing 1871
- PR #1872⁵¹⁰¹ - Making sure PBS environment uses specified node list even if no PBS_NODEFILE env is available
- Issue #1871⁵¹⁰² - Fortran checks should be optional
- PR #1870⁵¹⁰³ - Touch local::mutex
- PR #1869⁵¹⁰⁴ - Documentation refactoring based off #1868
- PR #1867⁵¹⁰⁵ - Embrace static_assert
- PR #1866⁵¹⁰⁶ - Fix #1803 with documentation refactoring
- PR #1865⁵¹⁰⁷ - Setting OUTPUT_NAME as target properties
- PR #1863⁵¹⁰⁸ - Use SYSTEM for boost includes
- PR #1862⁵¹⁰⁹ - Minor cleanups
- PR #1861⁵¹¹⁰ - Minor Corrections for Release
- PR #1860⁵¹¹¹ - Fixing hpx gdb script
- Issue #1859⁵¹¹² - reset_active_counters resets times and thread counts before some of the counters are evaluated
- PR #1858⁵¹¹³ - Release V0.9.11
- PR #1857⁵¹¹⁴ - removing diskperf example from 9.11 release
- PR #1856⁵¹¹⁵ - fix return in packaged_task_base::reset()
- Issue #1842⁵¹¹⁶ - Install error: file INSTALL cannot find libhpx_parcel_coalescing.so.0.9.11
- PR #1839⁵¹¹⁷ - Adding fedora docs
- PR #1824⁵¹¹⁸ - Changing version on master to V0.9.12

⁵⁰⁹⁶ <https://github.com/STELLAR-GROUP/hpx/pull/1877>

⁵⁰⁹⁷ <https://github.com/STELLAR-GROUP/hpx/pull/1876>

⁵⁰⁹⁸ <https://github.com/STELLAR-GROUP/hpx/pull/1875>

⁵⁰⁹⁹ <https://github.com/STELLAR-GROUP/hpx/pull/1874>

⁵¹⁰⁰ <https://github.com/STELLAR-GROUP/hpx/pull/1873>

⁵¹⁰¹ <https://github.com/STELLAR-GROUP/hpx/pull/1872>

⁵¹⁰² <https://github.com/STELLAR-GROUP/hpx/issues/1871>

⁵¹⁰³ <https://github.com/STELLAR-GROUP/hpx/pull/1870>

⁵¹⁰⁴ <https://github.com/STELLAR-GROUP/hpx/pull/1869>

⁵¹⁰⁵ <https://github.com/STELLAR-GROUP/hpx/pull/1867>

⁵¹⁰⁶ <https://github.com/STELLAR-GROUP/hpx/pull/1866>

⁵¹⁰⁷ <https://github.com/STELLAR-GROUP/hpx/pull/1865>

⁵¹⁰⁸ <https://github.com/STELLAR-GROUP/hpx/pull/1863>

⁵¹⁰⁹ <https://github.com/STELLAR-GROUP/hpx/pull/1862>

⁵¹¹⁰ <https://github.com/STELLAR-GROUP/hpx/pull/1861>

⁵¹¹¹ <https://github.com/STELLAR-GROUP/hpx/pull/1860>

⁵¹¹² <https://github.com/STELLAR-GROUP/hpx/issues/1859>

⁵¹¹³ <https://github.com/STELLAR-GROUP/hpx/pull/1858>

⁵¹¹⁴ <https://github.com/STELLAR-GROUP/hpx/pull/1857>

⁵¹¹⁵ <https://github.com/STELLAR-GROUP/hpx/pull/1856>

⁵¹¹⁶ <https://github.com/STELLAR-GROUP/hpx/issues/1842>

⁵¹¹⁷ <https://github.com/STELLAR-GROUP/hpx/pull/1839>

⁵¹¹⁸ <https://github.com/STELLAR-GROUP/hpx/pull/1824>

- [PR #1818⁵¹¹⁹](#) - Fixing #1748
- [Issue #1815⁵¹²⁰](#) - seg fault in AGAS
- [Issue #1803⁵¹²¹](#) - wait_all documentation
- [Issue #1796⁵¹²²](#) - Outdated documentation to be revised
- [Issue #1759⁵¹²³](#) - glibc munmap_chunk or free(): invalid pointer on SuperMIC
- [Issue #1753⁵¹²⁴](#) - HPX performance degrades with time since execution begins
- [Issue #1748⁵¹²⁵](#) - All public HPX headers need to be self contained
- [PR #1719⁵¹²⁶](#) - How to build HPX with Visual Studio
- [Issue #1684⁵¹²⁷](#) - Race condition when using `-hpx:connect?`
- [PR #1658⁵¹²⁸](#) - Add serialization for `std::set` (as there is for `std::vector` and `std::map`)
- [PR #1641⁵¹²⁹](#) - Generic client
- [Issue #1632⁵¹³⁰](#) - heartbeat example fails on separate nodes
- [PR #1603⁵¹³¹](#) - Adds preferred namespace check to inspect tool
- [Issue #1559⁵¹³²](#) - Extend inspect tool
- [Issue #1523⁵¹³³](#) - Remote async with deferred launch policy never executes
- [Issue #1472⁵¹³⁴](#) - Serialization issues
- [Issue #1457⁵¹³⁵](#) - Implement N4392: C++ Latches and Barriers
- [PR #1444⁵¹³⁶](#) - Enabling usage of moveonly types for component construction
- [Issue #1407⁵¹³⁷](#) - The Intel 13 compiler has failing unit tests
- [Issue #1405⁵¹³⁸](#) - Allow component constructors to take movable only types
- [Issue #1265⁵¹³⁹](#) - Enable `dataflow()` to be usable with actions
- [Issue #1236⁵¹⁴⁰](#) - NUMA aware allocators
- [Issue #802⁵¹⁴¹](#) - Fix Broken Examples

⁵¹¹⁹ <https://github.com/STELLAR-GROUP/hpx/pull/1818>

⁵¹²⁰ <https://github.com/STELLAR-GROUP/hpx/issues/1815>

⁵¹²¹ <https://github.com/STELLAR-GROUP/hpx/issues/1803>

⁵¹²² <https://github.com/STELLAR-GROUP/hpx/issues/1796>

⁵¹²³ <https://github.com/STELLAR-GROUP/hpx/issues/1759>

⁵¹²⁴ <https://github.com/STELLAR-GROUP/hpx/issues/1753>

⁵¹²⁵ <https://github.com/STELLAR-GROUP/hpx/issues/1748>

⁵¹²⁶ <https://github.com/STELLAR-GROUP/hpx/pull/1719>

⁵¹²⁷ <https://github.com/STELLAR-GROUP/hpx/issues/1684>

⁵¹²⁸ <https://github.com/STELLAR-GROUP/hpx/pull/1658>

⁵¹²⁹ <https://github.com/STELLAR-GROUP/hpx/pull/1641>

⁵¹³⁰ <https://github.com/STELLAR-GROUP/hpx/issues/1632>

⁵¹³¹ <https://github.com/STELLAR-GROUP/hpx/pull/1603>

⁵¹³² <https://github.com/STELLAR-GROUP/hpx/issues/1559>

⁵¹³³ <https://github.com/STELLAR-GROUP/hpx/issues/1523>

⁵¹³⁴ <https://github.com/STELLAR-GROUP/hpx/issues/1472>

⁵¹³⁵ <https://github.com/STELLAR-GROUP/hpx/issues/1457>

⁵¹³⁶ <https://github.com/STELLAR-GROUP/hpx/pull/1444>

⁵¹³⁷ <https://github.com/STELLAR-GROUP/hpx/issues/1407>

⁵¹³⁸ <https://github.com/STELLAR-GROUP/hpx/issues/1405>

⁵¹³⁹ <https://github.com/STELLAR-GROUP/hpx/issues/1265>

⁵¹⁴⁰ <https://github.com/STELLAR-GROUP/hpx/issues/1236>

⁵¹⁴¹ <https://github.com/STELLAR-GROUP/hpx/issues/802>

- Issue #559⁵¹⁴² - Add `hpx::migrate` facility
- Issue #449⁵¹⁴³ - Make actions with template arguments usable and add documentation
- Issue #279⁵¹⁴⁴ - Refactor `addressing_service` into a base class and two derived classes
- Issue #224⁵¹⁴⁵ - Changing thread state metadata is not thread safe
- Issue #55⁵¹⁴⁶ - Uniform syntax for enums should be implemented

HPX V0.9.11 (Nov 11, 2015)

Our main focus for this release was the design and development of a coherent set of higher-level APIs exposing various types of parallelism to the application programmer. We introduced the concepts of an `executor`, which can be used to customize the `where` and `when` of execution of tasks in the context of parallelizing codes. We extended all APIs related to managing parallel tasks to support executors which gives the user the choice of either using one of the predefined executor types or to provide its own, possibly application specific, executor. We paid very close attention to align all of these changes with the existing C++ Standards documents or with the ongoing proposals for standardization.

This release is the first after our change to a new development policy. We switched all development to be strictly performed on branches only, all direct commits to our main branch (`master`) are prohibited. Any change has to go through a peer review before it will be merged to `master`. As a result the overall stability of our code base has significantly increased, the development process itself has been simplified. This change manifests itself in a large number of pull-requests which have been merged (please see below for a full list of closed issues and pull-requests). All in all for this release, we closed almost 100 issues and merged over 290 pull-requests. There have been over 1600 commits to the master branch since the last release.

General changes

- We are moving into the direction of unifying managed and simple components. As such, the classes `hpx::components::component` and `hpx::components::component_base` have been added which currently just forward to the currently existing simple component facilities. The examples have been converted to only use those two classes.
- Added integration with the [CircleCI](https://circleci.com/gh/STELLAR-GROUP/hpx)⁵¹⁴⁷ hosted continuous integration service. This gives us constant and immediate feedback on the health of our master branch.
- The compiler configuration subsystem in the build system has been reimplemented. Instead of using `Boost.Config` we now use our own lightweight set of `cmake` scripts to determine the available language and library features supported by the used compiler.
- The API for creating instances of components has been consolidated. All component instances should be created using the `hpx::new_` only. It allows one to instantiate both, single component instances and multiple component instances. The placement of the created components can be controlled by special distribution policies. Please see the corresponding documentation outlining the use of `hpx::new_`.
- Introduced four new distribution policies which can be used with many API functions which traditionally expected to be used with a locality id. The new distribution policies are:
 - `hpx::components::default_distribution_policy` which tries to place multiple component instances as evenly as possible.

⁵¹⁴² <https://github.com/STELLAR-GROUP/hpx/issues/559>

⁵¹⁴³ <https://github.com/STELLAR-GROUP/hpx/issues/449>

⁵¹⁴⁴ <https://github.com/STELLAR-GROUP/hpx/issues/279>

⁵¹⁴⁵ <https://github.com/STELLAR-GROUP/hpx/issues/224>

⁵¹⁴⁶ <https://github.com/STELLAR-GROUP/hpx/issues/55>

⁵¹⁴⁷ <https://circleci.com/gh/STELLAR-GROUP/hpx>

- `hpx::components::colocating_distribution_policy` which will refer to the locality where a given component instance is currently placed.
 - `hpx::components::binpacking_distribution_policy` which will place multiple component instances as evenly as possible based on any performance counter.
 - `hpx::components::target_distribution_policy` which allows one to represent a given locality in the context of a distribution policy.
- The new distribution policies can now be also used with `hpx::async`. This change also deprecates `hpx::async_colocated(id, ...)` which now is replaced by a distribution policy: `hpx::async(hpx::colocated(id), ...)`.
 - The `hpx::vector` and `hpx::unordered_map` data structures can now be used with the new distribution policies as well.
 - The parallel facility `hpx::parallel::task_region` has been renamed to `hpx::parallel::task_block` based on the changes in the corresponding standardization proposal N4411⁵¹⁴⁸.
 - Added extensions to the parallel facility `hpx::parallel::task_block` allowing to combine a `task_block` with an execution policy. This implies a minor breaking change as the `hpx::parallel::task_block` is now a template.
 - Added new LCOs: `hpx::lcos::latch` and `hpx::lcos::local::latch` which semantically conform to the proposed `std::latch` (see N4399⁵¹⁴⁹).
 - Added performance counters exposing data related to data transferred by input/output (filesystem) operations (thanks to Maciej Brodowicz).
 - Added performance counters allowing to track the number of action invocations (local and remote invocations).
 - Added new command line options `-hpx:print-counter-at` and `-hpx:reset-counters`.
 - The `hpx::vector` component has been renamed to `hpx::partitioned_vector` to make it explicit that the underlying memory is not contiguous.
 - Introduced a completely new and uniform higher-level parallelism API which is based on executors. All existing parallelism APIs have been adapted to this. We have added a large number of different executor types, such as a numa-aware executor, a this-thread executor, etc.
 - Added support for the MingW toolchain on Windows (thanks to Eric Lemanissier).
 - HPX now includes support for APEX, (Autonomic Performance Environment for eXascale). APEX is an instrumentation and software adaptation library that provides an interface to TAU profiling / tracing as well as runtime adaptation of HPX applications through policy definitions. For more information and documentation, please see <https://github.com/UO-OACISS/xpress-apex>. To enable APEX at configuration time, specify `-DHPX_WITH_APEX=On`. To also include support for TAU profiling, specify `-DHPX_WITH_TAU=On` and specify the `-DTAU_ROOT`, `-DTAU_ARCH` and `-DTAU_OPTIONS` cmake parameters.
 - We have implemented many more of the *Using parallel algorithms*. Please see [Issue #1141](#)⁵¹⁵⁰ for the list of all available parallel algorithms (thanks to Daniel Bourgeois and John Biddiscombe for contributing their work).

⁵¹⁴⁸ <http://wg21.link/n4411>

⁵¹⁴⁹ <http://wg21.link/n4399>

⁵¹⁵⁰ <https://github.com/STELLAR-GROUP/hpx/issues/1141>

Breaking changes

- We are moving into the direction of unifying managed and simple components. In order to stop exposing the old facilities, all examples have been converted to use the new classes. The breaking change in this release is that performance counters are now a `hpx::components::component_base` instead of `hpx::components::managed_component_base`.
- We removed the support for stackless threads. It turned out that there was no performance benefit when using stackless threads. As such, we decided to clean up our codebase. This feature was not documented.
- The CMake project name has changed from 'hpx' to 'HPX' for consistency and compatibility with naming conventions and other CMake projects. Generated config files go into `<prefix>/lib/cmake/HPX` and not `<prefix>/lib/cmake/hpx`.
- The macro `HPX_REGISTER_MINIMAL_COMPONENT_FACTORY` has been deprecated. Please use `HPX_REGISTER_COMPONENT` instead. The old macro will be removed in the next release.
- The obsolete `distributing_factory` and `binpacking_factory` components have been removed. The corresponding functionality is now provided by the `hpx::new_` API function in conjunction with the `hpx::default_layout` and `hpx::binpacking` distribution policies (`hpx::components::default_distribution_policy` and `hpx::components::binpacking_distribution_policy`)
- The API function `hpx::new_colocated` has been deprecated. Please use the consolidated API `hpx::new_` in conjunction with the new `hpx::colocated` distribution policy (`hpx::components::colocating_distribution_policy`) instead. The old API function will still be available for at least one release of *HPX* if the configuration variable `HPX_WITH_COLOCATED_BACKWARDS_COMPATIBILITY` is enabled.
- The API function `hpx::async_colocated` has been deprecated. Please use the consolidated API `hpx::async` in conjunction with the new `hpx::colocated` distribution policy (`hpx::components::colocating_distribution_policy`) instead. The old API function will still be available for at least one release of *HPX* if the configuration variable `HPX_WITH_COLOCATED_BACKWARDS_COMPATIBILITY` is enabled.
- The obsolete `remote_object` component has been removed.
- Replaced the use of `Boost.Serialization` with our own solution. While the new version is mostly compatible with `Boost.Serialization`, this change requires some minor code modifications in user code. For more information, please see the corresponding [announcement](#)⁵¹⁵¹ on the `hpx-users@stellar.cct.lsu.edu` mailing list.
- The names used by `cmake` to influence various configuration options have been unified. The new naming scheme relies on all configuration constants to start with `HPX_WITH_...`, while the preprocessor constant which is used at build time starts with `HPX_HAVE_...`. For instance, the former `cmake` command line `-DHPX_MALLOC=...` now has to be specified a `-DHPX_WITH_MALLOC=...` and will cause the preprocessor constant `HPX_HAVE_MALLOC` to be defined. The actual name of the constant (i.e. `MALLOC`) has not changed. Please see the corresponding documentation for more details (*CMake options*).
- The `get_gid()` functions exposed by the component base classes `hpx::components::server::simple_component_base`, `hpx::components::server::managed_component_base`, and `hpx::components::server::fixed_component_base` have been replaced by two new functions: `get_unmanaged_id()` and `get_id()`. To enable the old function name for backwards compatibility, use the `cmake` configuration option `HPX_WITH_COMPONENT_GET_GID_COMPATIBILITY=On`.
- All functions which were named `get_gid()` but were returning `hpx::id_type` have been renamed to `get_id()`. To enable the old function names for backwards compatibility, use the `cmake` configuration option `HPX_WITH_COMPONENT_GET_GID_COMPATIBILITY=On`.

⁵¹⁵¹ <http://thread.gmane.org/gmane.comp.lib.hpx.devel/196>

Bug fixes (closed tickets)

Here is a list of the important tickets we closed for this release.

- PR #1855⁵¹⁵² - Completely removing external/endian
- PR #1854⁵¹⁵³ - Don't pollute CMAKE_CXX_FLAGS through find_package()
- PR #1853⁵¹⁵⁴ - Updating CMake configuration to get correct version of TAU library
- PR #1852⁵¹⁵⁵ - Fixing Performance Problems with MPI Parcelport
- PR #1851⁵¹⁵⁶ - Fixing hpx_add_link_flag() and hpx_remove_link_flag()
- PR #1850⁵¹⁵⁷ - Fixing 1836, adding parallel::sort
- PR #1849⁵¹⁵⁸ - Fixing configuration for use of more than 64 cores
- PR #1848⁵¹⁵⁹ - Change default APEX version for release
- PR #1847⁵¹⁶⁰ - Fix client_base::then on release
- PR #1846⁵¹⁶¹ - Removing broken lcos::local::channel from release
- PR #1845⁵¹⁶² - Adding example demonstrating a possible safe-object implementation to release
- PR #1844⁵¹⁶³ - Removing stubs from accumulator examples
- PR #1843⁵¹⁶⁴ - Don't pollute CMAKE_CXX_FLAGS through find_package()
- PR #1841⁵¹⁶⁵ - Fixing client_base<>::then
- PR #1840⁵¹⁶⁶ - Adding example demonstrating a possible safe-object implementation
- PR #1838⁵¹⁶⁷ - Update version rc1
- PR #1837⁵¹⁶⁸ - Removing broken lcos::local::channel
- PR #1835⁵¹⁶⁹ - Adding explicit move constructor and assignment operator to hpx::lcos::promise
- PR #1834⁵¹⁷⁰ - Making hpx::lcos::promise move-only
- PR #1833⁵¹⁷¹ - Adding fedora docs
- Issue #1832⁵¹⁷² - hpx::lcos::promise<> must be move-only

⁵¹⁵² <https://github.com/STELLAR-GROUP/hpx/pull/1855>

⁵¹⁵³ <https://github.com/STELLAR-GROUP/hpx/pull/1854>

⁵¹⁵⁴ <https://github.com/STELLAR-GROUP/hpx/pull/1853>

⁵¹⁵⁵ <https://github.com/STELLAR-GROUP/hpx/pull/1852>

⁵¹⁵⁶ <https://github.com/STELLAR-GROUP/hpx/pull/1851>

⁵¹⁵⁷ <https://github.com/STELLAR-GROUP/hpx/pull/1850>

⁵¹⁵⁸ <https://github.com/STELLAR-GROUP/hpx/pull/1849>

⁵¹⁵⁹ <https://github.com/STELLAR-GROUP/hpx/pull/1848>

⁵¹⁶⁰ <https://github.com/STELLAR-GROUP/hpx/pull/1847>

⁵¹⁶¹ <https://github.com/STELLAR-GROUP/hpx/pull/1846>

⁵¹⁶² <https://github.com/STELLAR-GROUP/hpx/pull/1845>

⁵¹⁶³ <https://github.com/STELLAR-GROUP/hpx/pull/1844>

⁵¹⁶⁴ <https://github.com/STELLAR-GROUP/hpx/pull/1843>

⁵¹⁶⁵ <https://github.com/STELLAR-GROUP/hpx/pull/1841>

⁵¹⁶⁶ <https://github.com/STELLAR-GROUP/hpx/pull/1840>

⁵¹⁶⁷ <https://github.com/STELLAR-GROUP/hpx/pull/1838>

⁵¹⁶⁸ <https://github.com/STELLAR-GROUP/hpx/pull/1837>

⁵¹⁶⁹ <https://github.com/STELLAR-GROUP/hpx/pull/1835>

⁵¹⁷⁰ <https://github.com/STELLAR-GROUP/hpx/pull/1834>

⁵¹⁷¹ <https://github.com/STELLAR-GROUP/hpx/pull/1833>

⁵¹⁷² <https://github.com/STELLAR-GROUP/hpx/issues/1832>

- PR #1831⁵¹⁷³ - Fixing resource manager gcc5.2
- PR #1830⁵¹⁷⁴ - Fix intel13
- PR #1829⁵¹⁷⁵ - Unbreaking thread test
- PR #1828⁵¹⁷⁶ - Fixing #1620
- PR #1827⁵¹⁷⁷ - Fixing a memory management issue for the Parquet application
- Issue #1826⁵¹⁷⁸ - Memory management issue in hpx::lcos::promise
- PR #1825⁵¹⁷⁹ - Adding hpx::components::component and hpx::components::component_base
- PR #1823⁵¹⁸⁰ - Adding git commit id to circleci build
- PR #1822⁵¹⁸¹ - applying fixes suggested by clang 3.7
- PR #1821⁵¹⁸² - Hyperlink fixes
- PR #1820⁵¹⁸³ - added parallel multi-locality sanity test
- PR #1819⁵¹⁸⁴ - Fixing #1667
- Issue #1817⁵¹⁸⁵ - Hyperlinks generated by inspect tool are wrong
- PR #1816⁵¹⁸⁶ - Support hpxrx
- PR #1814⁵¹⁸⁷ - Fix async to dispatch to the correct locality in all cases
- Issue #1813⁵¹⁸⁸ - async(launch::..., action(), ...) always invokes locally
- PR #1812⁵¹⁸⁹ - fixed syntax error in CMakeLists.txt
- PR #1811⁵¹⁹⁰ - Agas optimizations
- PR #1810⁵¹⁹¹ - drop superfluous typedefs
- PR #1809⁵¹⁹² - Allow HPX to be used as an optional package in 3rd party code
- PR #1808⁵¹⁹³ - Fixing #1723
- PR #1807⁵¹⁹⁴ - Making sure resolve_localities does not hang during normal operation
- Issue #1806⁵¹⁹⁵ - Spinlock no longer movable and deletes operator '=', breaks MiniGhost

⁵¹⁷³ <https://github.com/STELLAR-GROUP/hpx/pull/1831>

⁵¹⁷⁴ <https://github.com/STELLAR-GROUP/hpx/pull/1830>

⁵¹⁷⁵ <https://github.com/STELLAR-GROUP/hpx/pull/1829>

⁵¹⁷⁶ <https://github.com/STELLAR-GROUP/hpx/pull/1828>

⁵¹⁷⁷ <https://github.com/STELLAR-GROUP/hpx/pull/1827>

⁵¹⁷⁸ <https://github.com/STELLAR-GROUP/hpx/issues/1826>

⁵¹⁷⁹ <https://github.com/STELLAR-GROUP/hpx/pull/1825>

⁵¹⁸⁰ <https://github.com/STELLAR-GROUP/hpx/pull/1823>

⁵¹⁸¹ <https://github.com/STELLAR-GROUP/hpx/pull/1822>

⁵¹⁸² <https://github.com/STELLAR-GROUP/hpx/pull/1821>

⁵¹⁸³ <https://github.com/STELLAR-GROUP/hpx/pull/1820>

⁵¹⁸⁴ <https://github.com/STELLAR-GROUP/hpx/pull/1819>

⁵¹⁸⁵ <https://github.com/STELLAR-GROUP/hpx/issues/1817>

⁵¹⁸⁶ <https://github.com/STELLAR-GROUP/hpx/pull/1816>

⁵¹⁸⁷ <https://github.com/STELLAR-GROUP/hpx/pull/1814>

⁵¹⁸⁸ <https://github.com/STELLAR-GROUP/hpx/issues/1813>

⁵¹⁸⁹ <https://github.com/STELLAR-GROUP/hpx/pull/1812>

⁵¹⁹⁰ <https://github.com/STELLAR-GROUP/hpx/pull/1811>

⁵¹⁹¹ <https://github.com/STELLAR-GROUP/hpx/pull/1810>

⁵¹⁹² <https://github.com/STELLAR-GROUP/hpx/pull/1809>

⁵¹⁹³ <https://github.com/STELLAR-GROUP/hpx/pull/1808>

⁵¹⁹⁴ <https://github.com/STELLAR-GROUP/hpx/pull/1807>

⁵¹⁹⁵ <https://github.com/STELLAR-GROUP/hpx/issues/1806>

- Issue #1804⁵¹⁹⁶ - register_with_basename causes hangs
- PR #1801⁵¹⁹⁷ - Enhanced the inspect tool to take user directly to the problem with hyperlinks
- Issue #1800⁵¹⁹⁸ - Problems compiling application on smic
- PR #1799⁵¹⁹⁹ - Fixing cv exceptions
- PR #1798⁵²⁰⁰ - Documentation refactoring & updating
- PR #1797⁵²⁰¹ - Updating the activeharmony CMake module
- PR #1795⁵²⁰² - Fixing cv
- PR #1794⁵²⁰³ - Fix connect with hpx::runtime_mode_connect
- PR #1793⁵²⁰⁴ - fix a wrong use of HPX_MAX_CPU_COUNT instead of HPX_HAVE_MAX_CPU_COUNT
- PR #1792⁵²⁰⁵ - Allow for default constructed parcel instances to be moved
- PR #1791⁵²⁰⁶ - Fix connect with hpx::runtime_mode_connect
- Issue #1790⁵²⁰⁷ - assertion action_.get() failed: HPX(assertion_failure) when running Octotiger with pull request 1786
- PR #1789⁵²⁰⁸ - Fixing discover_counter_types API function
- Issue #1788⁵²⁰⁹ - connect with hpx::runtime_mode_connect
- Issue #1787⁵²¹⁰ - discover_counter_types not working
- PR #1786⁵²¹¹ - Changing addressing_service to use std::unordered_map instead of std::map
- PR #1785⁵²¹² - Fix is_iterator for container algorithms
- PR #1784⁵²¹³ - Adding new command line options:
- PR #1783⁵²¹⁴ - Minor changes for APEX support
- PR #1782⁵²¹⁵ - Drop legacy forwarding action traits
- PR #1781⁵²¹⁶ - Attempt to resolve the race between cv::wait_xxx and cv::notify_all
- PR #1780⁵²¹⁷ - Removing serialize_sequence
- PR #1779⁵²¹⁸ - Fixed #1501: hwloc configuration options are wrong for MIC

⁵¹⁹⁶ <https://github.com/STELLAR-GROUP/hpx/issues/1804>

⁵¹⁹⁷ <https://github.com/STELLAR-GROUP/hpx/pull/1801>

⁵¹⁹⁸ <https://github.com/STELLAR-GROUP/hpx/issues/1800>

⁵¹⁹⁹ <https://github.com/STELLAR-GROUP/hpx/pull/1799>

⁵²⁰⁰ <https://github.com/STELLAR-GROUP/hpx/pull/1798>

⁵²⁰¹ <https://github.com/STELLAR-GROUP/hpx/pull/1797>

⁵²⁰² <https://github.com/STELLAR-GROUP/hpx/pull/1795>

⁵²⁰³ <https://github.com/STELLAR-GROUP/hpx/pull/1794>

⁵²⁰⁴ <https://github.com/STELLAR-GROUP/hpx/pull/1793>

⁵²⁰⁵ <https://github.com/STELLAR-GROUP/hpx/pull/1792>

⁵²⁰⁶ <https://github.com/STELLAR-GROUP/hpx/pull/1791>

⁵²⁰⁷ <https://github.com/STELLAR-GROUP/hpx/issues/1790>

⁵²⁰⁸ <https://github.com/STELLAR-GROUP/hpx/pull/1789>

⁵²⁰⁹ <https://github.com/STELLAR-GROUP/hpx/issues/1788>

⁵²¹⁰ <https://github.com/STELLAR-GROUP/hpx/issues/1787>

⁵²¹¹ <https://github.com/STELLAR-GROUP/hpx/pull/1786>

⁵²¹² <https://github.com/STELLAR-GROUP/hpx/pull/1785>

⁵²¹³ <https://github.com/STELLAR-GROUP/hpx/pull/1784>

⁵²¹⁴ <https://github.com/STELLAR-GROUP/hpx/pull/1783>

⁵²¹⁵ <https://github.com/STELLAR-GROUP/hpx/pull/1782>

⁵²¹⁶ <https://github.com/STELLAR-GROUP/hpx/pull/1781>

⁵²¹⁷ <https://github.com/STELLAR-GROUP/hpx/pull/1780>

⁵²¹⁸ <https://github.com/STELLAR-GROUP/hpx/pull/1779>

- [PR #1778⁵²¹⁹](#) - Removing ability to enable/disable parcel handling
- [PR #1777⁵²²⁰](#) - Completely removing stackless threads
- [PR #1776⁵²²¹](#) - Cleaning up util/plugin
- [PR #1775⁵²²²](#) - Agas fixes
- [PR #1774⁵²²³](#) - Action invocation count
- [PR #1773⁵²²⁴](#) - replaced MSVC variable with WIN32
- [PR #1772⁵²²⁵](#) - Fixing Problems in MPI parcelport and future serialization.
- [PR #1771⁵²²⁶](#) - Fixing intel 13 compiler errors related to variadic template template parameters for `lcos::when_` tests
- [PR #1770⁵²²⁷](#) - Forwarding decay to `std::`
- [PR #1769⁵²²⁸](#) - Add more characters with special regex meaning to the existing patch
- [PR #1768⁵²²⁹](#) - Adding test for `receive_buffer`
- [PR #1767⁵²³⁰](#) - Making sure that uptime counter throws exception on any attempt to be reset
- [PR #1766⁵²³¹](#) - Cleaning up code related to throttling scheduler
- [PR #1765⁵²³²](#) - Restricting `thread_data` to creating only with `intrusive_pointers`
- [PR #1764⁵²³³](#) - Fixing 1763
- [Issue #1763⁵²³⁴](#) - UB in `thread_data::operator delete`
- [PR #1762⁵²³⁵](#) - Making sure all serialization registries/factories are unique
- [PR #1761⁵²³⁶](#) - Fixed #1751: `hpx::future::wait_for` fails a simple test
- [PR #1758⁵²³⁷](#) - Fixing #1757
- [Issue #1757⁵²³⁸](#) - pinning not correct using `-hpx:bind`
- [Issue #1756⁵²³⁹](#) - compilation error with MinGW
- [PR #1755⁵²⁴⁰](#) - Making output serialization const-correct
- [Issue #1753⁵²⁴¹](#) - HPX performance degrades with time since execution begins

⁵²¹⁹ <https://github.com/STELLAR-GROUP/hpx/pull/1778>

⁵²²⁰ <https://github.com/STELLAR-GROUP/hpx/pull/1777>

⁵²²¹ <https://github.com/STELLAR-GROUP/hpx/pull/1776>

⁵²²² <https://github.com/STELLAR-GROUP/hpx/pull/1775>

⁵²²³ <https://github.com/STELLAR-GROUP/hpx/pull/1774>

⁵²²⁴ <https://github.com/STELLAR-GROUP/hpx/pull/1773>

⁵²²⁵ <https://github.com/STELLAR-GROUP/hpx/pull/1772>

⁵²²⁶ <https://github.com/STELLAR-GROUP/hpx/pull/1771>

⁵²²⁷ <https://github.com/STELLAR-GROUP/hpx/pull/1770>

⁵²²⁸ <https://github.com/STELLAR-GROUP/hpx/pull/1769>

⁵²²⁹ <https://github.com/STELLAR-GROUP/hpx/pull/1768>

⁵²³⁰ <https://github.com/STELLAR-GROUP/hpx/pull/1767>

⁵²³¹ <https://github.com/STELLAR-GROUP/hpx/pull/1766>

⁵²³² <https://github.com/STELLAR-GROUP/hpx/pull/1765>

⁵²³³ <https://github.com/STELLAR-GROUP/hpx/pull/1764>

⁵²³⁴ <https://github.com/STELLAR-GROUP/hpx/issues/1763>

⁵²³⁵ <https://github.com/STELLAR-GROUP/hpx/pull/1762>

⁵²³⁶ <https://github.com/STELLAR-GROUP/hpx/pull/1761>

⁵²³⁷ <https://github.com/STELLAR-GROUP/hpx/pull/1758>

⁵²³⁸ <https://github.com/STELLAR-GROUP/hpx/issues/1757>

⁵²³⁹ <https://github.com/STELLAR-GROUP/hpx/issues/1756>

⁵²⁴⁰ <https://github.com/STELLAR-GROUP/hpx/pull/1755>

⁵²⁴¹ <https://github.com/STELLAR-GROUP/hpx/issues/1753>

- [Issue #1752⁵²⁴²](#) - Error in AGAS
- [Issue #1751⁵²⁴³](#) - `hpx::future::wait_for` fails a simple test
- [PR #1750⁵²⁴⁴](#) - Removing `hpx_fwd.hpp` includes
- [PR #1749⁵²⁴⁵](#) - Simplify `result_of` and friends
- [PR #1747⁵²⁴⁶](#) - Removed superfluous code from `message_buffer.hpp`
- [PR #1746⁵²⁴⁷](#) - Tuple dependencies
- [Issue #1745⁵²⁴⁸](#) - Broken when `_some` which takes iterators
- [PR #1744⁵²⁴⁹](#) - Refining archive interface
- [PR #1743⁵²⁵⁰](#) - Fixing when `_all` when only a single future is passed
- [PR #1742⁵²⁵¹](#) - Config includes
- [PR #1741⁵²⁵²](#) - Os executors
- [Issue #1740⁵²⁵³](#) - `hpx::promise` has some problems
- [PR #1739⁵²⁵⁴](#) - Parallel composition with generic containers
- [Issue #1738⁵²⁵⁵](#) - After building program and successfully linking to a version of `hpx` `DHPX_DIR` seems to be ignored
- [Issue #1737⁵²⁵⁶](#) - Uptime problems
- [PR #1736⁵²⁵⁷](#) - added convenience `c-tor` and `begin()/end()` to `serialize_buffer`
- [PR #1735⁵²⁵⁸](#) - Config includes
- [PR #1734⁵²⁵⁹](#) - Fixed #1688: Add timer counters for `tfunc_total` and `exec_total`
- [Issue #1733⁵²⁶⁰](#) - Add unit test for `hpx/lcos/local/receive_buffer.hpp`
- [PR #1732⁵²⁶¹](#) - Renaming `get_os_thread_count`
- [PR #1731⁵²⁶²](#) - Basename registration
- [Issue #1730⁵²⁶³](#) - Use after move of `thread_init_data`
- [PR #1729⁵²⁶⁴](#) - Rewriting channel based on new gate component

⁵²⁴² <https://github.com/STELLAR-GROUP/hpx/issues/1752>

⁵²⁴³ <https://github.com/STELLAR-GROUP/hpx/issues/1751>

⁵²⁴⁴ <https://github.com/STELLAR-GROUP/hpx/pull/1750>

⁵²⁴⁵ <https://github.com/STELLAR-GROUP/hpx/pull/1749>

⁵²⁴⁶ <https://github.com/STELLAR-GROUP/hpx/pull/1747>

⁵²⁴⁷ <https://github.com/STELLAR-GROUP/hpx/pull/1746>

⁵²⁴⁸ <https://github.com/STELLAR-GROUP/hpx/issues/1745>

⁵²⁴⁹ <https://github.com/STELLAR-GROUP/hpx/pull/1744>

⁵²⁵⁰ <https://github.com/STELLAR-GROUP/hpx/pull/1743>

⁵²⁵¹ <https://github.com/STELLAR-GROUP/hpx/pull/1742>

⁵²⁵² <https://github.com/STELLAR-GROUP/hpx/pull/1741>

⁵²⁵³ <https://github.com/STELLAR-GROUP/hpx/issues/1740>

⁵²⁵⁴ <https://github.com/STELLAR-GROUP/hpx/pull/1739>

⁵²⁵⁵ <https://github.com/STELLAR-GROUP/hpx/issues/1738>

⁵²⁵⁶ <https://github.com/STELLAR-GROUP/hpx/issues/1737>

⁵²⁵⁷ <https://github.com/STELLAR-GROUP/hpx/pull/1736>

⁵²⁵⁸ <https://github.com/STELLAR-GROUP/hpx/pull/1735>

⁵²⁵⁹ <https://github.com/STELLAR-GROUP/hpx/pull/1734>

⁵²⁶⁰ <https://github.com/STELLAR-GROUP/hpx/issues/1733>

⁵²⁶¹ <https://github.com/STELLAR-GROUP/hpx/pull/1732>

⁵²⁶² <https://github.com/STELLAR-GROUP/hpx/pull/1731>

⁵²⁶³ <https://github.com/STELLAR-GROUP/hpx/issues/1730>

⁵²⁶⁴ <https://github.com/STELLAR-GROUP/hpx/pull/1729>

- PR #1728⁵²⁶⁵ - Fixing #1722
- PR #1727⁵²⁶⁶ - Fixing compile problems with apply_colocated
- PR #1726⁵²⁶⁷ - Apex integration
- PR #1725⁵²⁶⁸ - fixed test timeouts
- PR #1724⁵²⁶⁹ - Renaming vector
- Issue #1723⁵²⁷⁰ - Drop support for intel compilers and gcc 4.4. based standard libs
- Issue #1722⁵²⁷¹ - Add support for detecting non-ready futures before serialization
- PR #1721⁵²⁷² - Unifying parallel executors, initializing from launch policy
- PR #1720⁵²⁷³ - dropped superfluous typedef
- Issue #1718⁵²⁷⁴ - Windows 10 x64, VS 2015 - Unknown CMake command “add_hpx_pseudo_target”.
- PR #1717⁵²⁷⁵ - Timed executor traits for thread-executors
- PR #1716⁵²⁷⁶ - serialization of arrays didn’t work with non-pod types. fixed
- PR #1715⁵²⁷⁷ - List serialization
- PR #1714⁵²⁷⁸ - changing misspellings
- PR #1713⁵²⁷⁹ - Fixed distribution policy executors
- PR #1712⁵²⁸⁰ - Moving library detection to be executed after feature tests
- PR #1711⁵²⁸¹ - Simplify parcel
- PR #1710⁵²⁸² - Compile only tests
- PR #1709⁵²⁸³ - Implemented timed executors
- PR #1708⁵²⁸⁴ - Implement parallel::executor_traits for thread-executors
- PR #1707⁵²⁸⁵ - Various fixes to threads::executors to make custom schedulers work
- PR #1706⁵²⁸⁶ - Command line option –hpx:cores does not work as expected
- Issue #1705⁵²⁸⁷ - command line option –hpx:cores does not work as expected

5265 <https://github.com/STELLAR-GROUP/hpx/pull/1728>
5266 <https://github.com/STELLAR-GROUP/hpx/pull/1727>
5267 <https://github.com/STELLAR-GROUP/hpx/pull/1726>
5268 <https://github.com/STELLAR-GROUP/hpx/pull/1725>
5269 <https://github.com/STELLAR-GROUP/hpx/pull/1724>
5270 <https://github.com/STELLAR-GROUP/hpx/issues/1723>
5271 <https://github.com/STELLAR-GROUP/hpx/issues/1722>
5272 <https://github.com/STELLAR-GROUP/hpx/pull/1721>
5273 <https://github.com/STELLAR-GROUP/hpx/pull/1720>
5274 <https://github.com/STELLAR-GROUP/hpx/issues/1718>
5275 <https://github.com/STELLAR-GROUP/hpx/pull/1717>
5276 <https://github.com/STELLAR-GROUP/hpx/pull/1716>
5277 <https://github.com/STELLAR-GROUP/hpx/pull/1715>
5278 <https://github.com/STELLAR-GROUP/hpx/pull/1714>
5279 <https://github.com/STELLAR-GROUP/hpx/pull/1713>
5280 <https://github.com/STELLAR-GROUP/hpx/pull/1712>
5281 <https://github.com/STELLAR-GROUP/hpx/pull/1711>
5282 <https://github.com/STELLAR-GROUP/hpx/pull/1710>
5283 <https://github.com/STELLAR-GROUP/hpx/pull/1709>
5284 <https://github.com/STELLAR-GROUP/hpx/pull/1708>
5285 <https://github.com/STELLAR-GROUP/hpx/pull/1707>
5286 <https://github.com/STELLAR-GROUP/hpx/pull/1706>
5287 <https://github.com/STELLAR-GROUP/hpx/issues/1705>

- PR #1704⁵²⁸⁸ - vector deserialization is speeded up a little
- PR #1703⁵²⁸⁹ - Fixing shared_mutes
- Issue #1702⁵²⁹⁰ - Shared_mutex does not compile with no_mutex cond_var
- PR #1701⁵²⁹¹ - Add distribution_policy_executor
- PR #1700⁵²⁹² - Executor parameters
- PR #1699⁵²⁹³ - Readers writer lock
- PR #1698⁵²⁹⁴ - Remove leftovers
- PR #1697⁵²⁹⁵ - Fixing held locks
- PR #1696⁵²⁹⁶ - Modified Scan Partitioner for Algorithms
- PR #1695⁵²⁹⁷ - This thread executors
- PR #1694⁵²⁹⁸ - Fixed #1688: Add timer counters for tfunc_total and exec_total
- PR #1693⁵²⁹⁹ - Fix #1691: is_executor template specification fails for inherited executors
- PR #1692⁵³⁰⁰ - Fixed #1662: Possible exception source in coalescing_message_handler
- Issue #1691⁵³⁰¹ - is_executor template specification fails for inherited executors
- PR #1690⁵³⁰² - added macro for non-intrusive serialization of classes without a default c-tor
- PR #1689⁵³⁰³ - Replace value_or_error with custom storage, unify future_data state
- Issue #1688⁵³⁰⁴ - Add timer counters for tfunc_total and exec_total
- PR #1687⁵³⁰⁵ - Fixed interval timer
- PR #1686⁵³⁰⁶ - Fixing cmake warnings about not existing pseudo target dependencies
- PR #1685⁵³⁰⁷ - Converting partitioners to use bulk async execute
- PR #1683⁵³⁰⁸ - Adds a tool for inspect that checks for character limits
- PR #1682⁵³⁰⁹ - Change project name to (uppercase) HPX
- PR #1681⁵³¹⁰ - Counter shortnames

⁵²⁸⁸ <https://github.com/STELLAR-GROUP/hpx/pull/1704>
⁵²⁸⁹ <https://github.com/STELLAR-GROUP/hpx/pull/1703>
⁵²⁹⁰ <https://github.com/STELLAR-GROUP/hpx/issues/1702>
⁵²⁹¹ <https://github.com/STELLAR-GROUP/hpx/pull/1701>
⁵²⁹² <https://github.com/STELLAR-GROUP/hpx/pull/1700>
⁵²⁹³ <https://github.com/STELLAR-GROUP/hpx/pull/1699>
⁵²⁹⁴ <https://github.com/STELLAR-GROUP/hpx/pull/1698>
⁵²⁹⁵ <https://github.com/STELLAR-GROUP/hpx/pull/1697>
⁵²⁹⁶ <https://github.com/STELLAR-GROUP/hpx/pull/1696>
⁵²⁹⁷ <https://github.com/STELLAR-GROUP/hpx/pull/1695>
⁵²⁹⁸ <https://github.com/STELLAR-GROUP/hpx/pull/1694>
⁵²⁹⁹ <https://github.com/STELLAR-GROUP/hpx/pull/1693>
⁵³⁰⁰ <https://github.com/STELLAR-GROUP/hpx/pull/1692>
⁵³⁰¹ <https://github.com/STELLAR-GROUP/hpx/issues/1691>
⁵³⁰² <https://github.com/STELLAR-GROUP/hpx/pull/1690>
⁵³⁰³ <https://github.com/STELLAR-GROUP/hpx/pull/1689>
⁵³⁰⁴ <https://github.com/STELLAR-GROUP/hpx/issues/1688>
⁵³⁰⁵ <https://github.com/STELLAR-GROUP/hpx/pull/1687>
⁵³⁰⁶ <https://github.com/STELLAR-GROUP/hpx/pull/1686>
⁵³⁰⁷ <https://github.com/STELLAR-GROUP/hpx/pull/1685>
⁵³⁰⁸ <https://github.com/STELLAR-GROUP/hpx/pull/1683>
⁵³⁰⁹ <https://github.com/STELLAR-GROUP/hpx/pull/1682>
⁵³¹⁰ <https://github.com/STELLAR-GROUP/hpx/pull/1681>

- PR #1680⁵³¹¹ - Extended Non-intrusive Serialization to Ease Usage for Library Developers
- PR #1679⁵³¹² - Working on 1544: More executor changes
- PR #1678⁵³¹³ - Transpose fixes
- PR #1677⁵³¹⁴ - Improve Boost compatibility check
- PR #1676⁵³¹⁵ - 1d stencil fix
- Issue #1675⁵³¹⁶ - hpx project name is not HPX
- PR #1674⁵³¹⁷ - Fixing the MPI parcelport
- PR #1673⁵³¹⁸ - added move semantics to map/vector deserialization
- PR #1672⁵³¹⁹ - Vs2015 await
- PR #1671⁵³²⁰ - Adapt transform for #1668
- PR #1670⁵³²¹ - Started to work on #1668
- PR #1669⁵³²² - Add this_thread_executors
- Issue #1667⁵³²³ - Apple build instructions in docs are out of date
- PR #1666⁵³²⁴ - Apex integration
- PR #1665⁵³²⁵ - Fixes an error with the whitespace check that showed the incorrect location of the error
- Issue #1664⁵³²⁶ - Inspect tool found incorrect endline whitespace
- PR #1663⁵³²⁷ - Improve use of locks
- Issue #1662⁵³²⁸ - Possible exception source in coalescing_message_handler
- PR #1661⁵³²⁹ - Added support for 128bit number serialization
- PR #1660⁵³³⁰ - Serialization 128bits
- PR #1659⁵³³¹ - Implemented inner_product and adjacent_diff algos
- PR #1658⁵³³² - Add serialization for std::set (as there is for std::vector and std::map)
- PR #1657⁵³³³ - Use of shared_ptr in io_service_pool changed to unique_ptr

⁵³¹¹ <https://github.com/STELLAR-GROUP/hpx/pull/1680>

⁵³¹² <https://github.com/STELLAR-GROUP/hpx/pull/1679>

⁵³¹³ <https://github.com/STELLAR-GROUP/hpx/pull/1678>

⁵³¹⁴ <https://github.com/STELLAR-GROUP/hpx/pull/1677>

⁵³¹⁵ <https://github.com/STELLAR-GROUP/hpx/pull/1676>

⁵³¹⁶ <https://github.com/STELLAR-GROUP/hpx/issues/1675>

⁵³¹⁷ <https://github.com/STELLAR-GROUP/hpx/pull/1674>

⁵³¹⁸ <https://github.com/STELLAR-GROUP/hpx/pull/1673>

⁵³¹⁹ <https://github.com/STELLAR-GROUP/hpx/pull/1672>

⁵³²⁰ <https://github.com/STELLAR-GROUP/hpx/pull/1671>

⁵³²¹ <https://github.com/STELLAR-GROUP/hpx/pull/1670>

⁵³²² <https://github.com/STELLAR-GROUP/hpx/pull/1669>

⁵³²³ <https://github.com/STELLAR-GROUP/hpx/issues/1667>

⁵³²⁴ <https://github.com/STELLAR-GROUP/hpx/pull/1666>

⁵³²⁵ <https://github.com/STELLAR-GROUP/hpx/pull/1665>

⁵³²⁶ <https://github.com/STELLAR-GROUP/hpx/issues/1664>

⁵³²⁷ <https://github.com/STELLAR-GROUP/hpx/pull/1663>

⁵³²⁸ <https://github.com/STELLAR-GROUP/hpx/issues/1662>

⁵³²⁹ <https://github.com/STELLAR-GROUP/hpx/pull/1661>

⁵³³⁰ <https://github.com/STELLAR-GROUP/hpx/pull/1660>

⁵³³¹ <https://github.com/STELLAR-GROUP/hpx/pull/1659>

⁵³³² <https://github.com/STELLAR-GROUP/hpx/pull/1658>

⁵³³³ <https://github.com/STELLAR-GROUP/hpx/pull/1657>

- Issue #1656⁵³³⁴ - 1d_stencil codes all have wrong factor
- PR #1654⁵³³⁵ - When using runtime_mode_connect, find the correct localhost public ip address
- PR #1653⁵³³⁶ - Fixing 1617
- PR #1652⁵³³⁷ - Remove traits::action_may_require_id_splitting
- PR #1651⁵³³⁸ - Fixed performance counters related to AGAS cache timings
- PR #1650⁵³³⁹ - Remove leftovers of traits::type_size
- PR #1649⁵³⁴⁰ - Shorten target names on Windows to shorten used path names
- PR #1648⁵³⁴¹ - Fixing problems introduced by merging #1623 for older compilers
- PR #1647⁵³⁴² - Simplify running automatic builds on Windows
- Issue #1646⁵³⁴³ - Cache insert and update performance counters are broken
- Issue #1644⁵³⁴⁴ - Remove leftovers of traits::type_size
- Issue #1643⁵³⁴⁵ - Remove traits::action_may_require_id_splitting
- PR #1642⁵³⁴⁶ - Adds spell checker to the inspect tool for qbk and doxygen comments
- PR #1640⁵³⁴⁷ - First step towards fixing 688
- PR #1639⁵³⁴⁸ - Re-apply remaining changes from limit_dataflow_recursion branch
- PR #1638⁵³⁴⁹ - This fixes possible deadlock in the test ignore_while_locked_1485
- PR #1637⁵³⁵⁰ - Fixing hpx::wait_all() invoked with two vector<future<T>>
- PR #1636⁵³⁵¹ - Partially re-apply changes from limit_dataflow_recursion branch
- PR #1635⁵³⁵² - Adding missing test for #1572
- PR #1634⁵³⁵³ - Revert “Limit recursion-depth in dataflow to a configurable constant”
- PR #1633⁵³⁵⁴ - Add command line option to ignore batch environment
- PR #1631⁵³⁵⁵ - hpx::lcos::queue exhibits strange behavior
- PR #1630⁵³⁵⁶ - Fixed endlines_whitespace_check.cpp to detect lines with only whitespace

⁵³³⁴ <https://github.com/STELLAR-GROUP/hpx/issues/1656>

⁵³³⁵ <https://github.com/STELLAR-GROUP/hpx/pull/1654>

⁵³³⁶ <https://github.com/STELLAR-GROUP/hpx/pull/1653>

⁵³³⁷ <https://github.com/STELLAR-GROUP/hpx/pull/1652>

⁵³³⁸ <https://github.com/STELLAR-GROUP/hpx/pull/1651>

⁵³³⁹ <https://github.com/STELLAR-GROUP/hpx/pull/1650>

⁵³⁴⁰ <https://github.com/STELLAR-GROUP/hpx/pull/1649>

⁵³⁴¹ <https://github.com/STELLAR-GROUP/hpx/pull/1648>

⁵³⁴² <https://github.com/STELLAR-GROUP/hpx/pull/1647>

⁵³⁴³ <https://github.com/STELLAR-GROUP/hpx/issues/1646>

⁵³⁴⁴ <https://github.com/STELLAR-GROUP/hpx/issues/1644>

⁵³⁴⁵ <https://github.com/STELLAR-GROUP/hpx/issues/1643>

⁵³⁴⁶ <https://github.com/STELLAR-GROUP/hpx/pull/1642>

⁵³⁴⁷ <https://github.com/STELLAR-GROUP/hpx/pull/1640>

⁵³⁴⁸ <https://github.com/STELLAR-GROUP/hpx/pull/1639>

⁵³⁴⁹ <https://github.com/STELLAR-GROUP/hpx/pull/1638>

⁵³⁵⁰ <https://github.com/STELLAR-GROUP/hpx/pull/1637>

⁵³⁵¹ <https://github.com/STELLAR-GROUP/hpx/pull/1636>

⁵³⁵² <https://github.com/STELLAR-GROUP/hpx/pull/1635>

⁵³⁵³ <https://github.com/STELLAR-GROUP/hpx/pull/1634>

⁵³⁵⁴ <https://github.com/STELLAR-GROUP/hpx/pull/1633>

⁵³⁵⁵ <https://github.com/STELLAR-GROUP/hpx/pull/1631>

⁵³⁵⁶ <https://github.com/STELLAR-GROUP/hpx/pull/1630>

- Issue #1629⁵³⁵⁷ - Inspect trailing whitespace checker problem
- PR #1628⁵³⁵⁸ - Removed meaningless const qualifiers. Minor icpc fix.
- PR #1627⁵³⁵⁹ - Fixing the queue LCO and add example demonstrating its use
- PR #1626⁵³⁶⁰ - Deprecating get_gid(), add get_id() and get_unmanaged_id()
- PR #1625⁵³⁶¹ - Allowing to specify whether to send credits along with message
- Issue #1624⁵³⁶² - Lifetime issue
- Issue #1623⁵³⁶³ - hpx::wait_all() invoked with two vector<future<T>> fails
- PR #1622⁵³⁶⁴ - Executor partitioners
- PR #1621⁵³⁶⁵ - Clean up coroutines implementation
- Issue #1620⁵³⁶⁶ - Revert #1535
- PR #1619⁵³⁶⁷ - Fix result type calculation for hpx::make_continuation
- PR #1618⁵³⁶⁸ - Fixing RDTSC on Xeon/Phi
- Issue #1617⁵³⁶⁹ - hpx cmake not working when run as a subproject
- Issue #1616⁵³⁷⁰ - cmake problem resulting in RDTSC not working correctly for Xeon Phi creates very strange results for duration counters
- Issue #1615⁵³⁷¹ - hpx::make_continuation requires input and output to be the same
- PR #1614⁵³⁷² - Fixed remove copy test
- Issue #1613⁵³⁷³ - Dataflow causes stack overflow
- PR #1612⁵³⁷⁴ - Modified foreach partitioner to use bulk execute
- PR #1611⁵³⁷⁵ - Limit recursion-depth in dataflow to a configurable constant
- PR #1610⁵³⁷⁶ - Increase timeout for CircleCI
- PR #1609⁵³⁷⁷ - Refactoring thread manager, mainly extracting thread pool
- PR #1608⁵³⁷⁸ - Fixed running multiple localities without localities parameter
- PR #1607⁵³⁷⁹ - More algorithm fixes to adjacentfind

⁵³⁵⁷ <https://github.com/STELLAR-GROUP/hpx/issues/1629>

⁵³⁵⁸ <https://github.com/STELLAR-GROUP/hpx/pull/1628>

⁵³⁵⁹ <https://github.com/STELLAR-GROUP/hpx/pull/1627>

⁵³⁶⁰ <https://github.com/STELLAR-GROUP/hpx/pull/1626>

⁵³⁶¹ <https://github.com/STELLAR-GROUP/hpx/pull/1625>

⁵³⁶² <https://github.com/STELLAR-GROUP/hpx/issues/1624>

⁵³⁶³ <https://github.com/STELLAR-GROUP/hpx/issues/1623>

⁵³⁶⁴ <https://github.com/STELLAR-GROUP/hpx/pull/1622>

⁵³⁶⁵ <https://github.com/STELLAR-GROUP/hpx/pull/1621>

⁵³⁶⁶ <https://github.com/STELLAR-GROUP/hpx/issues/1620>

⁵³⁶⁷ <https://github.com/STELLAR-GROUP/hpx/pull/1619>

⁵³⁶⁸ <https://github.com/STELLAR-GROUP/hpx/pull/1618>

⁵³⁶⁹ <https://github.com/STELLAR-GROUP/hpx/issues/1617>

⁵³⁷⁰ <https://github.com/STELLAR-GROUP/hpx/issues/1616>

⁵³⁷¹ <https://github.com/STELLAR-GROUP/hpx/issues/1615>

⁵³⁷² <https://github.com/STELLAR-GROUP/hpx/pull/1614>

⁵³⁷³ <https://github.com/STELLAR-GROUP/hpx/issues/1613>

⁵³⁷⁴ <https://github.com/STELLAR-GROUP/hpx/pull/1612>

⁵³⁷⁵ <https://github.com/STELLAR-GROUP/hpx/pull/1611>

⁵³⁷⁶ <https://github.com/STELLAR-GROUP/hpx/pull/1610>

⁵³⁷⁷ <https://github.com/STELLAR-GROUP/hpx/pull/1609>

⁵³⁷⁸ <https://github.com/STELLAR-GROUP/hpx/pull/1608>

⁵³⁷⁹ <https://github.com/STELLAR-GROUP/hpx/pull/1607>

- Issue #1606⁵³⁸⁰ - Running without localities parameter binds to bogus port range
- Issue #1605⁵³⁸¹ - Too many serializations
- PR #1604⁵³⁸² - Changes the HPX image into a hyperlink
- PR #1601⁵³⁸³ - Fixing problems with remove_copy algorithm tests
- PR #1600⁵³⁸⁴ - Actions with ids cleanup
- PR #1599⁵³⁸⁵ - Duplicate binding of global ids should fail
- PR #1598⁵³⁸⁶ - Fixing array access
- PR #1597⁵³⁸⁷ - Improved the reliability of connecting/disconnecting localities
- Issue #1596⁵³⁸⁸ - Duplicate id binding should fail
- PR #1595⁵³⁸⁹ - Fixing more cmake config constants
- PR #1594⁵³⁹⁰ - Fixing preprocessor constant used to enable C++11 chrono
- PR #1593⁵³⁹¹ - Adding operator|() for hpx::launch
- Issue #1592⁵³⁹² - Error (typo) in the docs
- Issue #1590⁵³⁹³ - CMake fails when CMAKE_BINARY_DIR contains '+'
- Issue #1589⁵³⁹⁴ - Disconnecting a locality results in segfault using heartbeat example
- PR #1588⁵³⁹⁵ - Fix doc string for config option HPX_WITH_EXAMPLES
- PR #1586⁵³⁹⁶ - Fixing 1493
- PR #1585⁵³⁹⁷ - Additional Check for Inspect Tool to detect Endline Whitespace
- Issue #1584⁵³⁹⁸ - Clean up coroutines implementation
- PR #1583⁵³⁹⁹ - Adding a check for end line whitespace
- PR #1582⁵⁴⁰⁰ - Attempt to fix assert firing after scheduling loop was exited
- PR #1581⁵⁴⁰¹ - Fixed adjacentfind_binary test
- PR #1580⁵⁴⁰² - Prevent some of the internal cmake lists from growing indefinitely

5380 <https://github.com/STELLAR-GROUP/hpx/issues/1606>
5381 <https://github.com/STELLAR-GROUP/hpx/issues/1605>
5382 <https://github.com/STELLAR-GROUP/hpx/pull/1604>
5383 <https://github.com/STELLAR-GROUP/hpx/pull/1601>
5384 <https://github.com/STELLAR-GROUP/hpx/pull/1600>
5385 <https://github.com/STELLAR-GROUP/hpx/pull/1599>
5386 <https://github.com/STELLAR-GROUP/hpx/pull/1598>
5387 <https://github.com/STELLAR-GROUP/hpx/pull/1597>
5388 <https://github.com/STELLAR-GROUP/hpx/issues/1596>
5389 <https://github.com/STELLAR-GROUP/hpx/pull/1595>
5390 <https://github.com/STELLAR-GROUP/hpx/pull/1594>
5391 <https://github.com/STELLAR-GROUP/hpx/pull/1593>
5392 <https://github.com/STELLAR-GROUP/hpx/issues/1592>
5393 <https://github.com/STELLAR-GROUP/hpx/issues/1590>
5394 <https://github.com/STELLAR-GROUP/hpx/issues/1589>
5395 <https://github.com/STELLAR-GROUP/hpx/pull/1588>
5396 <https://github.com/STELLAR-GROUP/hpx/pull/1586>
5397 <https://github.com/STELLAR-GROUP/hpx/pull/1585>
5398 <https://github.com/STELLAR-GROUP/hpx/issues/1584>
5399 <https://github.com/STELLAR-GROUP/hpx/pull/1583>
5400 <https://github.com/STELLAR-GROUP/hpx/pull/1582>
5401 <https://github.com/STELLAR-GROUP/hpx/pull/1581>
5402 <https://github.com/STELLAR-GROUP/hpx/pull/1580>

- PR #1579⁵⁴⁰³ - Removing type_size trait, replacing it with special archive type
- Issue #1578⁵⁴⁰⁴ - Remove demangle_helper
- PR #1577⁵⁴⁰⁵ - Get ptr problems
- Issue #1576⁵⁴⁰⁶ - Refactor async, dataflow, and future::then
- PR #1575⁵⁴⁰⁷ - Fixing tests for parallel rotate
- PR #1574⁵⁴⁰⁸ - Cleaning up schedulers
- PR #1573⁵⁴⁰⁹ - Fixing thread pool executor
- PR #1572⁵⁴¹⁰ - Fixing number of configured localities
- PR #1571⁵⁴¹¹ - Reimplement decay
- PR #1570⁵⁴¹² - Refactoring async, apply, and dataflow APIs
- PR #1569⁵⁴¹³ - Changed range for mach-o library lookup
- PR #1568⁵⁴¹⁴ - Mark decltype support as required
- PR #1567⁵⁴¹⁵ - Removed const from algorithms
- Issue #1566⁵⁴¹⁶ - CMAKE Configuration Test Failures for clang 3.5 on debian
- PR #1565⁵⁴¹⁷ - Dylib support
- PR #1564⁵⁴¹⁸ - Converted partitioners and some algorithms to use executors
- PR #1563⁵⁴¹⁹ - Fix several #includes for Boost.Preprocessor
- PR #1562⁵⁴²⁰ - Adding configuration option disabling/enabling all message handlers
- PR #1561⁵⁴²¹ - Removed all occurrences of boost::move replacing it with std::move
- Issue #1560⁵⁴²² - Leftover HPX_REGISTER_ACTION_DECLARATION_2
- PR #1558⁵⁴²³ - Revisit async/apply SFINAE conditions
- PR #1557⁵⁴²⁴ - Removing type_size trait, replacing it with special archive type
- PR #1556⁵⁴²⁵ - Executor algorithms

⁵⁴⁰³ <https://github.com/STELLAR-GROUP/hpx/pull/1579>

⁵⁴⁰⁴ <https://github.com/STELLAR-GROUP/hpx/issues/1578>

⁵⁴⁰⁵ <https://github.com/STELLAR-GROUP/hpx/pull/1577>

⁵⁴⁰⁶ <https://github.com/STELLAR-GROUP/hpx/issues/1576>

⁵⁴⁰⁷ <https://github.com/STELLAR-GROUP/hpx/pull/1575>

⁵⁴⁰⁸ <https://github.com/STELLAR-GROUP/hpx/pull/1574>

⁵⁴⁰⁹ <https://github.com/STELLAR-GROUP/hpx/pull/1573>

⁵⁴¹⁰ <https://github.com/STELLAR-GROUP/hpx/pull/1572>

⁵⁴¹¹ <https://github.com/STELLAR-GROUP/hpx/pull/1571>

⁵⁴¹² <https://github.com/STELLAR-GROUP/hpx/pull/1570>

⁵⁴¹³ <https://github.com/STELLAR-GROUP/hpx/pull/1569>

⁵⁴¹⁴ <https://github.com/STELLAR-GROUP/hpx/pull/1568>

⁵⁴¹⁵ <https://github.com/STELLAR-GROUP/hpx/pull/1567>

⁵⁴¹⁶ <https://github.com/STELLAR-GROUP/hpx/issues/1566>

⁵⁴¹⁷ <https://github.com/STELLAR-GROUP/hpx/pull/1565>

⁵⁴¹⁸ <https://github.com/STELLAR-GROUP/hpx/pull/1564>

⁵⁴¹⁹ <https://github.com/STELLAR-GROUP/hpx/pull/1563>

⁵⁴²⁰ <https://github.com/STELLAR-GROUP/hpx/pull/1562>

⁵⁴²¹ <https://github.com/STELLAR-GROUP/hpx/pull/1561>

⁵⁴²² <https://github.com/STELLAR-GROUP/hpx/issues/1560>

⁵⁴²³ <https://github.com/STELLAR-GROUP/hpx/pull/1558>

⁵⁴²⁴ <https://github.com/STELLAR-GROUP/hpx/pull/1557>

⁵⁴²⁵ <https://github.com/STELLAR-GROUP/hpx/pull/1556>

- PR #1555⁵⁴²⁶ - Remove the necessity to specify archive flags on the receiving end
- PR #1554⁵⁴²⁷ - Removing obsolete Boost.Serialization macros
- PR #1553⁵⁴²⁸ - Properly fix HPX_DEFINE_*_ACTION macros
- PR #1552⁵⁴²⁹ - Fixed algorithms relying on copy_if implementation
- PR #1551⁵⁴³⁰ - PxfS - Modifying FindOrangeFS.cmake based on OrangeFS 2.9.X
- Issue #1550⁵⁴³¹ - Passing plain identifier inside HPX_DEFINE_PLAIN_ACTION_1
- PR #1549⁵⁴³² - Fixing intel14/libstdc++4.4
- PR #1548⁵⁴³³ - Moving raw_ptr to detail namespace
- PR #1547⁵⁴³⁴ - Adding support for executors to future.then
- PR #1546⁵⁴³⁵ - Executor traits result types
- PR #1545⁵⁴³⁶ - Integrate executors with dataflow
- PR #1543⁵⁴³⁷ - Fix potential zero-copy for primarynamespace::bulk_service_async et.al.
- PR #1542⁵⁴³⁸ - Merging HPX0.9.10 into pxfs branch
- PR #1541⁵⁴³⁹ - Removed stale cmake tests, unused since the great cmake refactoring
- PR #1540⁵⁴⁴⁰ - Fix idle-rate on platforms without TSC
- PR #1539⁵⁴⁴¹ - Reporting situation if zero-copy-serialization was performed by a parcel generated from a plain apply/async
- PR #1538⁵⁴⁴² - Changed return type of bulk executors and added test
- Issue #1537⁵⁴⁴³ - Incorrect cpuid config tests
- PR #1536⁵⁴⁴⁴ - Changed return type of bulk executors and added test
- PR #1535⁵⁴⁴⁵ - Make sure promise::get_gid() can be called more than once
- PR #1534⁵⁴⁴⁶ - Fixed async_callback with bound callback
- PR #1533⁵⁴⁴⁷ - Updated the link in the documentation to a publically- accessible URL
- PR #1532⁵⁴⁴⁸ - Make sure sync primitives are not copyable nor movable

5426 <https://github.com/STELLAR-GROUP/hpx/pull/1555>

5427 <https://github.com/STELLAR-GROUP/hpx/pull/1554>

5428 <https://github.com/STELLAR-GROUP/hpx/pull/1553>

5429 <https://github.com/STELLAR-GROUP/hpx/pull/1552>

5430 <https://github.com/STELLAR-GROUP/hpx/pull/1551>

5431 <https://github.com/STELLAR-GROUP/hpx/issues/1550>

5432 <https://github.com/STELLAR-GROUP/hpx/pull/1549>

5433 <https://github.com/STELLAR-GROUP/hpx/pull/1548>

5434 <https://github.com/STELLAR-GROUP/hpx/pull/1547>

5435 <https://github.com/STELLAR-GROUP/hpx/pull/1546>

5436 <https://github.com/STELLAR-GROUP/hpx/pull/1545>

5437 <https://github.com/STELLAR-GROUP/hpx/pull/1543>

5438 <https://github.com/STELLAR-GROUP/hpx/pull/1542>

5439 <https://github.com/STELLAR-GROUP/hpx/pull/1541>

5440 <https://github.com/STELLAR-GROUP/hpx/pull/1540>

5441 <https://github.com/STELLAR-GROUP/hpx/pull/1539>

5442 <https://github.com/STELLAR-GROUP/hpx/pull/1538>

5443 <https://github.com/STELLAR-GROUP/hpx/issues/1537>

5444 <https://github.com/STELLAR-GROUP/hpx/pull/1536>

5445 <https://github.com/STELLAR-GROUP/hpx/pull/1535>

5446 <https://github.com/STELLAR-GROUP/hpx/pull/1534>

5447 <https://github.com/STELLAR-GROUP/hpx/pull/1533>

5448 <https://github.com/STELLAR-GROUP/hpx/pull/1532>

- PR #1531⁵⁴⁴⁹ - Fix unwrapped issue with future ranges of void type
- PR #1530⁵⁴⁵⁰ - Serialization complex
- Issue #1528⁵⁴⁵¹ - Unwrapped issue with future<void>
- Issue #1527⁵⁴⁵² - HPX does not build with Boost 1.58.0
- PR #1526⁵⁴⁵³ - Added support for boost.multi_array serialization
- PR #1525⁵⁴⁵⁴ - Properly handle deferred futures, fixes #1506
- PR #1524⁵⁴⁵⁵ - Making sure invalid action argument types generate clear error message
- Issue #1522⁵⁴⁵⁶ - Need serialization support for boost multi array
- Issue #1521⁵⁴⁵⁷ - Remote async and zero-copy serialization optimizations don't play well together
- PR #1520⁵⁴⁵⁸ - Fixing UB while registering polymorphic classes for serialization
- PR #1519⁵⁴⁵⁹ - Making detail::condition_variable safe to use
- PR #1518⁵⁴⁶⁰ - Fix when_some bug missing indices in its result
- Issue #1517⁵⁴⁶¹ - Typo may affect CMake build system tests
- PR #1516⁵⁴⁶² - Fixing Posix context
- PR #1515⁵⁴⁶³ - Fixing Posix context
- PR #1514⁵⁴⁶⁴ - Correct problems with loading dynamic components
- PR #1513⁵⁴⁶⁵ - Fixing intel glibc4 4
- Issue #1508⁵⁴⁶⁶ - memory and papi counters do not work
- Issue #1507⁵⁴⁶⁷ - Unrecognized Command Line Option Error causing exit status 0
- Issue #1506⁵⁴⁶⁸ - Properly handle deferred futures
- PR #1505⁵⁴⁶⁹ - Adding #include - would not compile without this
- Issue #1502⁵⁴⁷⁰ - boost::filesystem::exists throws unexpected exception
- Issue #1501⁵⁴⁷¹ - hwloc configuration options are wrong for MIC

5449 <https://github.com/STELLAR-GROUP/hpx/pull/1531>
5450 <https://github.com/STELLAR-GROUP/hpx/pull/1530>
5451 <https://github.com/STELLAR-GROUP/hpx/issues/1528>
5452 <https://github.com/STELLAR-GROUP/hpx/issues/1527>
5453 <https://github.com/STELLAR-GROUP/hpx/pull/1526>
5454 <https://github.com/STELLAR-GROUP/hpx/pull/1525>
5455 <https://github.com/STELLAR-GROUP/hpx/pull/1524>
5456 <https://github.com/STELLAR-GROUP/hpx/issues/1522>
5457 <https://github.com/STELLAR-GROUP/hpx/issues/1521>
5458 <https://github.com/STELLAR-GROUP/hpx/pull/1520>
5459 <https://github.com/STELLAR-GROUP/hpx/pull/1519>
5460 <https://github.com/STELLAR-GROUP/hpx/pull/1518>
5461 <https://github.com/STELLAR-GROUP/hpx/issues/1517>
5462 <https://github.com/STELLAR-GROUP/hpx/pull/1516>
5463 <https://github.com/STELLAR-GROUP/hpx/pull/1515>
5464 <https://github.com/STELLAR-GROUP/hpx/pull/1514>
5465 <https://github.com/STELLAR-GROUP/hpx/pull/1513>
5466 <https://github.com/STELLAR-GROUP/hpx/issues/1508>
5467 <https://github.com/STELLAR-GROUP/hpx/issues/1507>
5468 <https://github.com/STELLAR-GROUP/hpx/issues/1506>
5469 <https://github.com/STELLAR-GROUP/hpx/pull/1505>
5470 <https://github.com/STELLAR-GROUP/hpx/issues/1502>
5471 <https://github.com/STELLAR-GROUP/hpx/issues/1501>

- PR #1504⁵⁴⁷² - Making sure boost::filesystem::exists() does not throw
- PR #1500⁵⁴⁷³ - Exit application on --hpx:version/-v and --hpx:info
- PR #1498⁵⁴⁷⁴ - Extended task block
- PR #1497⁵⁴⁷⁵ - Unique ptr serialization
- PR #1496⁵⁴⁷⁶ - Unique ptr serialization (closed)
- PR #1495⁵⁴⁷⁷ - Switching circledi build type to debug
- Issue #1494⁵⁴⁷⁸ - --hpx:version/-v does not exit after printing version information
- Issue #1493⁵⁴⁷⁹ - add an hpx_ prefix to libraries and components to avoid name conflicts
- Issue #1492⁵⁴⁸⁰ - Define and ensure limitations for arguments to async/apply
- PR #1489⁵⁴⁸¹ - Enable idle rate counter on demand
- PR #1488⁵⁴⁸² - Made sure detail::condition_variable can be safely destroyed
- PR #1487⁵⁴⁸³ - Introduced default (main) template implementation for ignore_while_checking
- PR #1486⁵⁴⁸⁴ - Add HPX inspect tool
- Issue #1485⁵⁴⁸⁵ - ignore_while_locked doesn't support all Lockable types
- PR #1484⁵⁴⁸⁶ - Docker image generation
- PR #1483⁵⁴⁸⁷ - Move external endian library into HPX
- PR #1482⁵⁴⁸⁸ - Actions with integer type ids
- Issue #1481⁵⁴⁸⁹ - Sync primitives safe destruction
- Issue #1480⁵⁴⁹⁰ - Move external/boost/endian into hpx/util
- Issue #1478⁵⁴⁹¹ - Boost inspect violations
- PR #1479⁵⁴⁹² - Adds serialization for arrays; some further/minor fixes
- PR #1477⁵⁴⁹³ - Fixing problems with the Intel compiler using a GCC 4.4 std library
- PR #1476⁵⁴⁹⁴ - Adding hpx::lcos::latch and hpx::lcos::local::latch

⁵⁴⁷² <https://github.com/STELLAR-GROUP/hpx/pull/1504>

⁵⁴⁷³ <https://github.com/STELLAR-GROUP/hpx/pull/1500>

⁵⁴⁷⁴ <https://github.com/STELLAR-GROUP/hpx/pull/1498>

⁵⁴⁷⁵ <https://github.com/STELLAR-GROUP/hpx/pull/1497>

⁵⁴⁷⁶ <https://github.com/STELLAR-GROUP/hpx/pull/1496>

⁵⁴⁷⁷ <https://github.com/STELLAR-GROUP/hpx/pull/1495>

⁵⁴⁷⁸ <https://github.com/STELLAR-GROUP/hpx/issues/1494>

⁵⁴⁷⁹ <https://github.com/STELLAR-GROUP/hpx/issues/1493>

⁵⁴⁸⁰ <https://github.com/STELLAR-GROUP/hpx/issues/1492>

⁵⁴⁸¹ <https://github.com/STELLAR-GROUP/hpx/pull/1489>

⁵⁴⁸² <https://github.com/STELLAR-GROUP/hpx/pull/1488>

⁵⁴⁸³ <https://github.com/STELLAR-GROUP/hpx/pull/1487>

⁵⁴⁸⁴ <https://github.com/STELLAR-GROUP/hpx/pull/1486>

⁵⁴⁸⁵ <https://github.com/STELLAR-GROUP/hpx/issues/1485>

⁵⁴⁸⁶ <https://github.com/STELLAR-GROUP/hpx/pull/1484>

⁵⁴⁸⁷ <https://github.com/STELLAR-GROUP/hpx/pull/1483>

⁵⁴⁸⁸ <https://github.com/STELLAR-GROUP/hpx/pull/1482>

⁵⁴⁸⁹ <https://github.com/STELLAR-GROUP/hpx/issues/1481>

⁵⁴⁹⁰ <https://github.com/STELLAR-GROUP/hpx/issues/1480>

⁵⁴⁹¹ <https://github.com/STELLAR-GROUP/hpx/issues/1478>

⁵⁴⁹² <https://github.com/STELLAR-GROUP/hpx/pull/1479>

⁵⁴⁹³ <https://github.com/STELLAR-GROUP/hpx/pull/1477>

⁵⁴⁹⁴ <https://github.com/STELLAR-GROUP/hpx/pull/1476>

- Issue #1475⁵⁴⁹⁵ - Boost inspect violations
- PR #1473⁵⁴⁹⁶ - Fixing action move tests
- Issue #1471⁵⁴⁹⁷ - Sync primitives should not be movable
- PR #1470⁵⁴⁹⁸ - Removing `hpx::util::polymorphic_factory`
- PR #1468⁵⁴⁹⁹ - Fixed container creation
- Issue #1467⁵⁵⁰⁰ - HPX application fail during finalization
- Issue #1466⁵⁵⁰¹ - HPX doesn't pick up Torque's nodefile on SuperMIC
- Issue #1464⁵⁵⁰² - HPX option for pre and post bootstrap performance counters
- PR #1463⁵⁵⁰³ - Replacing `async_colocated(id, ...)` with `async(colocated(id), ...)`
- PR #1462⁵⁵⁰⁴ - Consolidated `task_region` with N4411
- PR #1461⁵⁵⁰⁵ - Consolidate inconsistent CMake option names
- Issue #1460⁵⁵⁰⁶ - Which `malloc` is actually used? or at least which one is HPX built with
- Issue #1459⁵⁵⁰⁷ - Make `cmake` configure step fail explicitly if compiler version is not supported
- Issue #1458⁵⁵⁰⁸ - Update `parallel::task_region` with N4411
- PR #1456⁵⁵⁰⁹ - Consolidating `new_<>()`
- Issue #1455⁵⁵¹⁰ - Replace `async_colocated(id, ...)` with `async(colocated(id), ...)`
- PR #1454⁵⁵¹¹ - Removed harmful `std::moves` from return statements
- PR #1453⁵⁵¹² - Use range-based for-loop instead of `Boost.Foreach`
- PR #1452⁵⁵¹³ - C++ feature tests
- PR #1451⁵⁵¹⁴ - When serializing, pass archive flags to `traits::get_type_size`
- Issue #1450⁵⁵¹⁵ - `traits::get_type_size` needs archive flags to enable `zero_copy` optimizations
- Issue #1449⁵⁵¹⁶ - "couldn't create performance counter" - AGAS
- Issue #1448⁵⁵¹⁷ - Replace distributing factories with `new_<T[]>(...)`

⁵⁴⁹⁵ <https://github.com/STELLAR-GROUP/hpx/issues/1475>

⁵⁴⁹⁶ <https://github.com/STELLAR-GROUP/hpx/pull/1473>

⁵⁴⁹⁷ <https://github.com/STELLAR-GROUP/hpx/issues/1471>

⁵⁴⁹⁸ <https://github.com/STELLAR-GROUP/hpx/pull/1470>

⁵⁴⁹⁹ <https://github.com/STELLAR-GROUP/hpx/pull/1468>

⁵⁵⁰⁰ <https://github.com/STELLAR-GROUP/hpx/issues/1467>

⁵⁵⁰¹ <https://github.com/STELLAR-GROUP/hpx/issues/1466>

⁵⁵⁰² <https://github.com/STELLAR-GROUP/hpx/issues/1464>

⁵⁵⁰³ <https://github.com/STELLAR-GROUP/hpx/pull/1463>

⁵⁵⁰⁴ <https://github.com/STELLAR-GROUP/hpx/pull/1462>

⁵⁵⁰⁵ <https://github.com/STELLAR-GROUP/hpx/pull/1461>

⁵⁵⁰⁶ <https://github.com/STELLAR-GROUP/hpx/issues/1460>

⁵⁵⁰⁷ <https://github.com/STELLAR-GROUP/hpx/issues/1459>

⁵⁵⁰⁸ <https://github.com/STELLAR-GROUP/hpx/issues/1458>

⁵⁵⁰⁹ <https://github.com/STELLAR-GROUP/hpx/pull/1456>

⁵⁵¹⁰ <https://github.com/STELLAR-GROUP/hpx/issues/1455>

⁵⁵¹¹ <https://github.com/STELLAR-GROUP/hpx/pull/1454>

⁵⁵¹² <https://github.com/STELLAR-GROUP/hpx/pull/1453>

⁵⁵¹³ <https://github.com/STELLAR-GROUP/hpx/pull/1452>

⁵⁵¹⁴ <https://github.com/STELLAR-GROUP/hpx/pull/1451>

⁵⁵¹⁵ <https://github.com/STELLAR-GROUP/hpx/issues/1450>

⁵⁵¹⁶ <https://github.com/STELLAR-GROUP/hpx/issues/1449>

⁵⁵¹⁷ <https://github.com/STELLAR-GROUP/hpx/issues/1448>

- [PR #1447⁵⁵¹⁸](#) - Removing obsolete `remote_object` component
- [PR #1446⁵⁵¹⁹](#) - Hpx serialization
- [PR #1445⁵⁵²⁰](#) - Replacing `travis` with `circleci`
- [PR #1443⁵⁵²¹](#) - Always stripping HPX command line arguments before executing `start` function
- [PR #1442⁵⁵²²](#) - Adding `-hpx:bind=none` to disable thread affinities
- [Issue #1439⁵⁵²³](#) - Libraries get linked in multiple times, `RPATH` is not properly set
- [PR #1438⁵⁵²⁴](#) - Removed superfluous typedefs
- [Issue #1437⁵⁵²⁵](#) - `hpx::init()` should strip HPX-related flags from `argv`
- [Issue #1436⁵⁵²⁶](#) - Add strong scaling option to `htts`
- [PR #1435⁵⁵²⁷](#) - Adding `async_cb`, `async_continue_cb`, and `async_colocated_cb`
- [PR #1434⁵⁵²⁸](#) - Added missing install rule, removed some dead CMake code
- [PR #1433⁵⁵²⁹](#) - Add `GitExternal` and `SubProject` cmake scripts from `eyescale/cmake` repo
- [Issue #1432⁵⁵³⁰](#) - Add command line flag to disable thread pinning
- [PR #1431⁵⁵³¹](#) - Fix #1423
- [Issue #1430⁵⁵³²](#) - Inconsistent CMake option names
- [Issue #1429⁵⁵³³](#) - Configure setting `HPX_HAVE_PARCELPORTR_MPI` is ignored
- [PR #1428⁵⁵³⁴](#) - Fixes #1419 (closed)
- [PR #1427⁵⁵³⁵](#) - Adding `stencil_iterator` and `transform_iterator`
- [PR #1426⁵⁵³⁶](#) - Fixes #1419
- [PR #1425⁵⁵³⁷](#) - During serialization memory allocation should honour allocator chunk size
- [Issue #1424⁵⁵³⁸](#) - chunk allocation during serialization does not use memory pool/allocator chunk size
- [Issue #1423⁵⁵³⁹](#) - Remove `HPX_STD_UNIQUE_PTR`
- [Issue #1422⁵⁵⁴⁰](#) - `hpx:threads=all` allocates too many os threads

⁵⁵¹⁸ <https://github.com/STELLAR-GROUP/hpx/pull/1447>
⁵⁵¹⁹ <https://github.com/STELLAR-GROUP/hpx/pull/1446>
⁵⁵²⁰ <https://github.com/STELLAR-GROUP/hpx/pull/1445>
⁵⁵²¹ <https://github.com/STELLAR-GROUP/hpx/pull/1443>
⁵⁵²² <https://github.com/STELLAR-GROUP/hpx/pull/1442>
⁵⁵²³ <https://github.com/STELLAR-GROUP/hpx/issues/1439>
⁵⁵²⁴ <https://github.com/STELLAR-GROUP/hpx/pull/1438>
⁵⁵²⁵ <https://github.com/STELLAR-GROUP/hpx/issues/1437>
⁵⁵²⁶ <https://github.com/STELLAR-GROUP/hpx/issues/1436>
⁵⁵²⁷ <https://github.com/STELLAR-GROUP/hpx/pull/1435>
⁵⁵²⁸ <https://github.com/STELLAR-GROUP/hpx/pull/1434>
⁵⁵²⁹ <https://github.com/STELLAR-GROUP/hpx/pull/1433>
⁵⁵³⁰ <https://github.com/STELLAR-GROUP/hpx/issues/1432>
⁵⁵³¹ <https://github.com/STELLAR-GROUP/hpx/pull/1431>
⁵⁵³² <https://github.com/STELLAR-GROUP/hpx/issues/1430>
⁵⁵³³ <https://github.com/STELLAR-GROUP/hpx/issues/1429>
⁵⁵³⁴ <https://github.com/STELLAR-GROUP/hpx/pull/1428>
⁵⁵³⁵ <https://github.com/STELLAR-GROUP/hpx/pull/1427>
⁵⁵³⁶ <https://github.com/STELLAR-GROUP/hpx/pull/1426>
⁵⁵³⁷ <https://github.com/STELLAR-GROUP/hpx/pull/1425>
⁵⁵³⁸ <https://github.com/STELLAR-GROUP/hpx/issues/1424>
⁵⁵³⁹ <https://github.com/STELLAR-GROUP/hpx/issues/1423>
⁵⁵⁴⁰ <https://github.com/STELLAR-GROUP/hpx/issues/1422>

- PR #1420⁵⁵⁴¹ - added .travis.yml
- Issue #1419⁵⁵⁴² - Unify enums: `hpx::runtime::state` and `hpx::state`
- PR #1416⁵⁵⁴³ - Adding travis builder
- Issue #1414⁵⁵⁴⁴ - Correct directory for `dispatch_gcc46.hpp` iteration
- Issue #1410⁵⁵⁴⁵ - Set operation algorithms
- Issue #1389⁵⁵⁴⁶ - Parallel algorithms relying on scan partitioner break for small number of elements
- Issue #1325⁵⁵⁴⁷ - Exceptions thrown during parcel handling are not handled correctly
- Issue #1315⁵⁵⁴⁸ - Errors while running performance tests
- Issue #1309⁵⁵⁴⁹ - `hpx::vector` partitions are not easily extendable by applications
- PR #1300⁵⁵⁵⁰ - Added serialization/de-serialization to `examples.tuplespace`
- Issue #1251⁵⁵⁵¹ - `hpx::threads::get_thread_count` doesn't consider pending threads
- Issue #1008⁵⁵⁵² - Decrease in application performance overtime; occasional spikes of major slowdown
- Issue #1001⁵⁵⁵³ - Zero copy serialization raises assert
- Issue #721⁵⁵⁵⁴ - Make HPX usable for Xeon Phi
- Issue #524⁵⁵⁵⁵ - Extend scheduler to support threads which can't be stolen

HPX V0.9.10 (Mar 24, 2015)

General changes

This is the 12th official release of *HPX*. It coincides with the 7th anniversary of the first commit to our source code repository. Since then, we have seen over 12300 commits amounting to more than 220000 lines of C++ code.

The major focus of this release was to improve the reliability of large scale runs. We believe to have achieved this goal as we now can reliably run *HPX* applications on up to ~24k cores. We have also shown that HPX can be used with success for symmetric runs (applications using both, host cores and Intel Xeon/Phi coprocessors). This is a huge step forward in terms of the usability of *HPX*. The main focus of this work involved isolating the causes of the segmentation faults at start up and shut down. Many of these issues were discovered to be the result of the suspension of threads which hold locks.

A very important improvement introduced with this release is the refactoring of the code representing our parcel-port implementation. Parcel- ports can now be implemented by 3rd parties as independent plugins which are dynamically loaded at runtime (static linking of parcel-ports is also supported). This refactoring also includes a massive improvement of the performance of our existing parcel-ports. We were able to significantly reduce the networking latencies

⁵⁵⁴¹ <https://github.com/STELLAR-GROUP/hpx/pull/1420>
⁵⁵⁴² <https://github.com/STELLAR-GROUP/hpx/issues/1419>
⁵⁵⁴³ <https://github.com/STELLAR-GROUP/hpx/pull/1416>
⁵⁵⁴⁴ <https://github.com/STELLAR-GROUP/hpx/issues/1414>
⁵⁵⁴⁵ <https://github.com/STELLAR-GROUP/hpx/issues/1410>
⁵⁵⁴⁶ <https://github.com/STELLAR-GROUP/hpx/issues/1389>
⁵⁵⁴⁷ <https://github.com/STELLAR-GROUP/hpx/issues/1325>
⁵⁵⁴⁸ <https://github.com/STELLAR-GROUP/hpx/issues/1315>
⁵⁵⁴⁹ <https://github.com/STELLAR-GROUP/hpx/issues/1309>
⁵⁵⁵⁰ <https://github.com/STELLAR-GROUP/hpx/pull/1300>
⁵⁵⁵¹ <https://github.com/STELLAR-GROUP/hpx/issues/1251>
⁵⁵⁵² <https://github.com/STELLAR-GROUP/hpx/issues/1008>
⁵⁵⁵³ <https://github.com/STELLAR-GROUP/hpx/issues/1001>
⁵⁵⁵⁴ <https://github.com/STELLAR-GROUP/hpx/issues/721>
⁵⁵⁵⁵ <https://github.com/STELLAR-GROUP/hpx/issues/524>

and to improve the available networking bandwidth. Please note that in this release we disabled the `ibverbs` and `ipc` parcel ports as those have not been ported to the new plugin system yet (see [Issue #839](#)⁵⁵⁵⁶).

Another corner stone of this release is our work towards a complete implementation of `__cpp11_n4104__` (Working Draft, Technical Specification for C++ Extensions for Parallelism). This document defines a set of parallel algorithms to be added to the C++ standard library. We now have implemented about 75% of all specified parallel algorithms (see [[link hpx.manual.parallel.parallel_algorithms](#) Parallel Algorithms] for more details). We also implemented some extensions to `__cpp11_n4104__` allowing to invoke all of the algorithms asynchronously.

This release adds a first implementation of `hpx::vector` which is a distributed data structure closely aligned to the functionality of `std::vector`. The difference is that `hpx::vector` stores the data in partitions where the partitions can be distributed over different localities. We started to work on allowing to use the parallel algorithms with `hpx::vector`. At this point we have implemented only a few of the parallel algorithms to support distributed data structures (like `hpx::vector`) for testing purposes (see [Issue #1338](#)⁵⁵⁵⁷ for a documentation of our progress).

Breaking changes

With this release we put a lot of effort into changing the code base to be more compatible to C++11. These changes have caused the following issues for backward compatibility:

- Move to Variadics- All of the API now uses variadic templates. However, this change required to modify the argument sequence for some of the exiting API functions (`hpx::async_continue`, `hpx::apply_continue`, `hpx::when_each`, `hpx::wait_each`, synchronous invocation of actions).
- Changes to Macros- We also removed the macros `HPX_STD_FUNCTION` and `HPX_STD_TUPLE`. This shouldn't affect any user code as we replaced `HPX_STD_FUNCTION` with `hpx::util::function_nonser` which was the default expansion used for this macro. All *HPX* API functions which expect a `hpx::util::function_nonser` (or a `hpx::util::unique_function_nonser`) can now be transparently called with a compatible `std::function` instead. Similarly, `HPX_STD_TUPLE` was replaced by its default expansion as well: `hpx::util::tuple`.
- Changes to `hpx::unique_future`- `hpx::unique_future`, which was deprecated in the previous release for `hpx::future` is now completely removed from *HPX*. This completes the transition to a completely standards conforming implementation of `hpx::future`.
- Changes to Supported Compilers. Finally, in order to utilize more C++11 semantics, we have officially dropped support for GCC 4.4 and MSVC 2012. Please see our [Prerequisites](#) page for more details.

Bug fixes (closed tickets)

Here is a list of the important tickets we closed for this release.

- [Issue #1402](#)⁵⁵⁵⁸ - Internal `shared_future` serialization copies
- [Issue #1399](#)⁵⁵⁵⁹ - Build takes unusually long time...
- [Issue #1398](#)⁵⁵⁶⁰ - Tests using the scan partitioner are broken on at least gcc 4.7 and intel compiler
- [Issue #1397](#)⁵⁵⁶¹ - Completely remove `hpx::unique_future`
- [Issue #1396](#)⁵⁵⁶² - Parallel scan algorithms with different initial values

⁵⁵⁵⁶ <https://github.com/STELLAR-GROUP/hpx/issues/839>

⁵⁵⁵⁷ <https://github.com/STELLAR-GROUP/hpx/issues/1338>

⁵⁵⁵⁸ <https://github.com/STELLAR-GROUP/hpx/issues/1402>

⁵⁵⁵⁹ <https://github.com/STELLAR-GROUP/hpx/issues/1399>

⁵⁵⁶⁰ <https://github.com/STELLAR-GROUP/hpx/issues/1398>

⁵⁵⁶¹ <https://github.com/STELLAR-GROUP/hpx/issues/1397>

⁵⁵⁶² <https://github.com/STELLAR-GROUP/hpx/issues/1396>

- [Issue #1395⁵⁵⁶³](#) - Race Condition - 1d_stencil_8 - SuperMIC
- [Issue #1394⁵⁵⁶⁴](#) - “suspending thread while at least one lock is being held” - 1d_stencil_8 - SuperMIC
- [Issue #1393⁵⁵⁶⁵](#) - SEGFault in 1d_stencil_8 on SuperMIC
- [Issue #1392⁵⁵⁶⁶](#) - Fixing #1168
- [Issue #1391⁵⁵⁶⁷](#) - Parallel Algorithms for scan partitioner for small number of elements
- [Issue #1387⁵⁵⁶⁸](#) - Failure with more than 4 localities
- [Issue #1386⁵⁵⁶⁹](#) - Dispatching unhandled exceptions to outer user code
- [Issue #1385⁵⁵⁷⁰](#) - Adding Copy algorithms, fixing `parallel::copy_if`
- [Issue #1384⁵⁵⁷¹](#) - Fixing 1325
- [Issue #1383⁵⁵⁷²](#) - Fixed #504: Refactor Dataflow LCO to work with futures, this removes the dataflow component as it is obsolete
- [Issue #1382⁵⁵⁷³](#) - `is_sorted`, `is_sorted_until` and `is_partitioned` algorithms
- [Issue #1381⁵⁵⁷⁴](#) - fix for CMake versions prior to 3.1
- [Issue #1380⁵⁵⁷⁵](#) - resolved warning in CMake 3.1 and newer
- [Issue #1379⁵⁵⁷⁶](#) - Compilation error with papi
- [Issue #1378⁵⁵⁷⁷](#) - Towards safer migration
- [Issue #1377⁵⁵⁷⁸](#) - HPXConfig.cmake should include `TCMALLOC_LIBRARY` and `TCMALLOC_INCLUDE_DIR`
- [Issue #1376⁵⁵⁷⁹](#) - Warning on uninitialized member
- [Issue #1375⁵⁵⁸⁰](#) - Fixing 1163
- [Issue #1374⁵⁵⁸¹](#) - Fixing the MSVC 12 release builder
- [Issue #1373⁵⁵⁸²](#) - Modifying parallel search algorithm for zero length searches
- [Issue #1372⁵⁵⁸³](#) - Modifying parallel search algorithm for zero length searches
- [Issue #1371⁵⁵⁸⁴](#) - Avoid holding a lock during `agas::incf` while doing a credit split
- [Issue #1370⁵⁵⁸⁵](#) - `--hpx:bind` throws unexpected error

⁵⁵⁶³ <https://github.com/STELLAR-GROUP/hpx/issues/1395>

⁵⁵⁶⁴ <https://github.com/STELLAR-GROUP/hpx/issues/1394>

⁵⁵⁶⁵ <https://github.com/STELLAR-GROUP/hpx/issues/1393>

⁵⁵⁶⁶ <https://github.com/STELLAR-GROUP/hpx/issues/1392>

⁵⁵⁶⁷ <https://github.com/STELLAR-GROUP/hpx/issues/1391>

⁵⁵⁶⁸ <https://github.com/STELLAR-GROUP/hpx/issues/1387>

⁵⁵⁶⁹ <https://github.com/STELLAR-GROUP/hpx/issues/1386>

⁵⁵⁷⁰ <https://github.com/STELLAR-GROUP/hpx/issues/1385>

⁵⁵⁷¹ <https://github.com/STELLAR-GROUP/hpx/issues/1384>

⁵⁵⁷² <https://github.com/STELLAR-GROUP/hpx/issues/1383>

⁵⁵⁷³ <https://github.com/STELLAR-GROUP/hpx/issues/1382>

⁵⁵⁷⁴ <https://github.com/STELLAR-GROUP/hpx/issues/1381>

⁵⁵⁷⁵ <https://github.com/STELLAR-GROUP/hpx/issues/1380>

⁵⁵⁷⁶ <https://github.com/STELLAR-GROUP/hpx/issues/1379>

⁵⁵⁷⁷ <https://github.com/STELLAR-GROUP/hpx/issues/1378>

⁵⁵⁷⁸ <https://github.com/STELLAR-GROUP/hpx/issues/1377>

⁵⁵⁷⁹ <https://github.com/STELLAR-GROUP/hpx/issues/1376>

⁵⁵⁸⁰ <https://github.com/STELLAR-GROUP/hpx/issues/1375>

⁵⁵⁸¹ <https://github.com/STELLAR-GROUP/hpx/issues/1374>

⁵⁵⁸² <https://github.com/STELLAR-GROUP/hpx/issues/1373>

⁵⁵⁸³ <https://github.com/STELLAR-GROUP/hpx/issues/1372>

⁵⁵⁸⁴ <https://github.com/STELLAR-GROUP/hpx/issues/1371>

⁵⁵⁸⁵ <https://github.com/STELLAR-GROUP/hpx/issues/1370>

- [Issue #1369⁵⁵⁸⁶](#) - Getting rid of (void) in loops
- [Issue #1368⁵⁵⁸⁷](#) - Variadic templates support for tuple
- [Issue #1367⁵⁵⁸⁸](#) - One last batch of variadic templates support
- [Issue #1366⁵⁵⁸⁹](#) - Fixing symbolic namespace hang
- [Issue #1365⁵⁵⁹⁰](#) - More held locks
- [Issue #1364⁵⁵⁹¹](#) - Add counters 1363
- [Issue #1363⁵⁵⁹²](#) - Add thread overhead counters
- [Issue #1362⁵⁵⁹³](#) - Std config removal
- [Issue #1361⁵⁵⁹⁴](#) - Parcelport plugins
- [Issue #1360⁵⁵⁹⁵](#) - Detuplify transfer_action
- [Issue #1359⁵⁵⁹⁶](#) - Removed obsolete checks
- [Issue #1358⁵⁵⁹⁷](#) - Fixing 1352
- [Issue #1357⁵⁵⁹⁸](#) - Variadic templates support for runtime_support and components
- [Issue #1356⁵⁵⁹⁹](#) - fixed coordinate test for intel13
- [Issue #1355⁵⁶⁰⁰](#) - fixed coordinate.hpp
- [Issue #1354⁵⁶⁰¹](#) - Lexicographical Compare completed
- [Issue #1353⁵⁶⁰²](#) - HPX should set Boost_ADDITIONAL_VERSIONS flags
- [Issue #1352⁵⁶⁰³](#) - Error: Cannot find action ‘’ in type registry: HPX(bad_action_code)
- [Issue #1351⁵⁶⁰⁴](#) - Variadic templates support for appliers
- [Issue #1350⁵⁶⁰⁵](#) - Actions simplification
- [Issue #1349⁵⁶⁰⁶](#) - Variadic when and wait functions
- [Issue #1348⁵⁶⁰⁷](#) - Added hpx_init header to test files
- [Issue #1347⁵⁶⁰⁸](#) - Another batch of variadic templates support

5586 <https://github.com/STELLAR-GROUP/hpx/issues/1369>
5587 <https://github.com/STELLAR-GROUP/hpx/issues/1368>
5588 <https://github.com/STELLAR-GROUP/hpx/issues/1367>
5589 <https://github.com/STELLAR-GROUP/hpx/issues/1366>
5590 <https://github.com/STELLAR-GROUP/hpx/issues/1365>
5591 <https://github.com/STELLAR-GROUP/hpx/issues/1364>
5592 <https://github.com/STELLAR-GROUP/hpx/issues/1363>
5593 <https://github.com/STELLAR-GROUP/hpx/issues/1362>
5594 <https://github.com/STELLAR-GROUP/hpx/issues/1361>
5595 <https://github.com/STELLAR-GROUP/hpx/issues/1360>
5596 <https://github.com/STELLAR-GROUP/hpx/issues/1359>
5597 <https://github.com/STELLAR-GROUP/hpx/issues/1358>
5598 <https://github.com/STELLAR-GROUP/hpx/issues/1357>
5599 <https://github.com/STELLAR-GROUP/hpx/issues/1356>
5600 <https://github.com/STELLAR-GROUP/hpx/issues/1355>
5601 <https://github.com/STELLAR-GROUP/hpx/issues/1354>
5602 <https://github.com/STELLAR-GROUP/hpx/issues/1353>
5603 <https://github.com/STELLAR-GROUP/hpx/issues/1352>
5604 <https://github.com/STELLAR-GROUP/hpx/issues/1351>
5605 <https://github.com/STELLAR-GROUP/hpx/issues/1350>
5606 <https://github.com/STELLAR-GROUP/hpx/issues/1349>
5607 <https://github.com/STELLAR-GROUP/hpx/issues/1348>
5608 <https://github.com/STELLAR-GROUP/hpx/issues/1347>

- Issue #1346⁵⁶⁰⁹ - Segmented copy
- Issue #1345⁵⁶¹⁰ - Attempting to fix hangs during shutdown
- Issue #1344⁵⁶¹¹ - Std config removal
- Issue #1343⁵⁶¹² - Removing various distribution policies for `hpx::vector`
- Issue #1342⁵⁶¹³ - Inclusive scan
- Issue #1341⁵⁶¹⁴ - Exclusive scan
- Issue #1340⁵⁶¹⁵ - Adding `parallel::count` for distributed data structures, adding tests
- Issue #1339⁵⁶¹⁶ - Update argument order for `transform_reduce`
- Issue #1337⁵⁶¹⁷ - Fix dataflow to handle properly ranges of futures
- Issue #1336⁵⁶¹⁸ - dataflow needs to hold onto futures passed to it
- Issue #1335⁵⁶¹⁹ - Fails to compile with `msvc14`
- Issue #1334⁵⁶²⁰ - Examples build problem
- Issue #1333⁵⁶²¹ - Distributed transform reduce
- Issue #1332⁵⁶²² - Variadic templates support for actions
- Issue #1331⁵⁶²³ - Some ambiguous calls of `map::erase` have been prevented by adding additional check in locality constructor.
- Issue #1330⁵⁶²⁴ - Defining Plain Actions does not work as described in the documentation
- Issue #1329⁵⁶²⁵ - Distributed vector cleanup
- Issue #1328⁵⁶²⁶ - Sync docs and comments with code in `hello_world` example
- Issue #1327⁵⁶²⁷ - Typos in docs
- Issue #1326⁵⁶²⁸ - Documentation and code diverged in Fibonacci tutorial
- Issue #1325⁵⁶²⁹ - Exceptions thrown during parcel handling are not handled correctly
- Issue #1324⁵⁶³⁰ - fixed bandwidth calculation
- Issue #1323⁵⁶³¹ - `mmap()` failed to allocate thread stack due to insufficient resources

⁵⁶⁰⁹ <https://github.com/STELLAR-GROUP/hpx/issues/1346>

⁵⁶¹⁰ <https://github.com/STELLAR-GROUP/hpx/issues/1345>

⁵⁶¹¹ <https://github.com/STELLAR-GROUP/hpx/issues/1344>

⁵⁶¹² <https://github.com/STELLAR-GROUP/hpx/issues/1343>

⁵⁶¹³ <https://github.com/STELLAR-GROUP/hpx/issues/1342>

⁵⁶¹⁴ <https://github.com/STELLAR-GROUP/hpx/issues/1341>

⁵⁶¹⁵ <https://github.com/STELLAR-GROUP/hpx/issues/1340>

⁵⁶¹⁶ <https://github.com/STELLAR-GROUP/hpx/issues/1339>

⁵⁶¹⁷ <https://github.com/STELLAR-GROUP/hpx/issues/1337>

⁵⁶¹⁸ <https://github.com/STELLAR-GROUP/hpx/issues/1336>

⁵⁶¹⁹ <https://github.com/STELLAR-GROUP/hpx/issues/1335>

⁵⁶²⁰ <https://github.com/STELLAR-GROUP/hpx/issues/1334>

⁵⁶²¹ <https://github.com/STELLAR-GROUP/hpx/issues/1333>

⁵⁶²² <https://github.com/STELLAR-GROUP/hpx/issues/1332>

⁵⁶²³ <https://github.com/STELLAR-GROUP/hpx/issues/1331>

⁵⁶²⁴ <https://github.com/STELLAR-GROUP/hpx/issues/1330>

⁵⁶²⁵ <https://github.com/STELLAR-GROUP/hpx/issues/1329>

⁵⁶²⁶ <https://github.com/STELLAR-GROUP/hpx/issues/1328>

⁵⁶²⁷ <https://github.com/STELLAR-GROUP/hpx/issues/1327>

⁵⁶²⁸ <https://github.com/STELLAR-GROUP/hpx/issues/1326>

⁵⁶²⁹ <https://github.com/STELLAR-GROUP/hpx/issues/1325>

⁵⁶³⁰ <https://github.com/STELLAR-GROUP/hpx/issues/1324>

⁵⁶³¹ <https://github.com/STELLAR-GROUP/hpx/issues/1323>

- [Issue #1322](#)⁵⁶³² - HPX fails to build aa182cf
- [Issue #1321](#)⁵⁶³³ - Limiting size of outgoing messages while coalescing parcels
- [Issue #1320](#)⁵⁶³⁴ - passing a future with launch::deferred in remote function call causes hang
- [Issue #1319](#)⁵⁶³⁵ - An exception when tries to specify number high priority threads with abp-priority
- [Issue #1318](#)⁵⁶³⁶ - Unable to run program with abp-priority and numa-sensitivity enabled
- [Issue #1317](#)⁵⁶³⁷ - N4071 Search/Search_n finished, minor changes
- [Issue #1316](#)⁵⁶³⁸ - Add config option to make -lhp.run_hpx_main!=1 the default
- [Issue #1314](#)⁵⁶³⁹ - Variadic support for async and apply
- [Issue #1313](#)⁵⁶⁴⁰ - Adjust when_any/some to the latest proposed interfaces
- [Issue #1312](#)⁵⁶⁴¹ - Fixing #857: hpx::naming::locality leaks parcelport specific information into the public interface
- [Issue #1311](#)⁵⁶⁴² - Distributed get'er/set'er_values for distributed vector
- [Issue #1310](#)⁵⁶⁴³ - Crashing in hpx::parcelset::policies::mpi::connection_handler::handle_messages() on SuperMIC
- [Issue #1308](#)⁵⁶⁴⁴ - Unable to execute an application with -hpx:threads
- [Issue #1307](#)⁵⁶⁴⁵ - merge_graph linking issue
- [Issue #1306](#)⁵⁶⁴⁶ - First batch of variadic templates support
- [Issue #1305](#)⁵⁶⁴⁷ - Create a compiler wrapper
- [Issue #1304](#)⁵⁶⁴⁸ - Provide a compiler wrapper for hpx
- [Issue #1303](#)⁵⁶⁴⁹ - Drop support for GCC44
- [Issue #1302](#)⁵⁶⁵⁰ - Fixing #1297
- [Issue #1301](#)⁵⁶⁵¹ - Compilation error when tried to use boost range iterators with wait_all
- [Issue #1298](#)⁵⁶⁵² - Distributed vector
- [Issue #1297](#)⁵⁶⁵³ - Unable to invoke component actions recursively

⁵⁶³² <https://github.com/STELLAR-GROUP/hpx/issues/1322>

⁵⁶³³ <https://github.com/STELLAR-GROUP/hpx/issues/1321>

⁵⁶³⁴ <https://github.com/STELLAR-GROUP/hpx/issues/1320>

⁵⁶³⁵ <https://github.com/STELLAR-GROUP/hpx/issues/1319>

⁵⁶³⁶ <https://github.com/STELLAR-GROUP/hpx/issues/1318>

⁵⁶³⁷ <https://github.com/STELLAR-GROUP/hpx/issues/1317>

⁵⁶³⁸ <https://github.com/STELLAR-GROUP/hpx/issues/1316>

⁵⁶³⁹ <https://github.com/STELLAR-GROUP/hpx/issues/1314>

⁵⁶⁴⁰ <https://github.com/STELLAR-GROUP/hpx/issues/1313>

⁵⁶⁴¹ <https://github.com/STELLAR-GROUP/hpx/issues/1312>

⁵⁶⁴² <https://github.com/STELLAR-GROUP/hpx/issues/1311>

⁵⁶⁴³ <https://github.com/STELLAR-GROUP/hpx/issues/1310>

⁵⁶⁴⁴ <https://github.com/STELLAR-GROUP/hpx/issues/1308>

⁵⁶⁴⁵ <https://github.com/STELLAR-GROUP/hpx/issues/1307>

⁵⁶⁴⁶ <https://github.com/STELLAR-GROUP/hpx/issues/1306>

⁵⁶⁴⁷ <https://github.com/STELLAR-GROUP/hpx/issues/1305>

⁵⁶⁴⁸ <https://github.com/STELLAR-GROUP/hpx/issues/1304>

⁵⁶⁴⁹ <https://github.com/STELLAR-GROUP/hpx/issues/1303>

⁵⁶⁵⁰ <https://github.com/STELLAR-GROUP/hpx/issues/1302>

⁵⁶⁵¹ <https://github.com/STELLAR-GROUP/hpx/issues/1301>

⁵⁶⁵² <https://github.com/STELLAR-GROUP/hpx/issues/1298>

⁵⁶⁵³ <https://github.com/STELLAR-GROUP/hpx/issues/1297>

- Issue #1294⁵⁶⁵⁴ - HDF5 build error
- Issue #1275⁵⁶⁵⁵ - The parcelport implementation is non-optimal
- Issue #1267⁵⁶⁵⁶ - Added classes and unit tests for local_file, orangefs_file and pxfs_file
- Issue #1264⁵⁶⁵⁷ - Error “assertion ‘!m_fun’ failed” randomly occurs when using TCP
- Issue #1254⁵⁶⁵⁸ - thread binding seems to not work properly
- Issue #1220⁵⁶⁵⁹ - parallel::copy_if is broken
- Issue #1217⁵⁶⁶⁰ - Find a better way of fixing the issue patched by #1216
- Issue #1168⁵⁶⁶¹ - Starting HPX on Cray machines using aprun isn’t working correctly
- Issue #1085⁵⁶⁶² - Replace startup and shutdown barriers with broadcasts
- Issue #981⁵⁶⁶³ - With SLURM, -hpx:threads=8 should not be necessary
- Issue #857⁵⁶⁶⁴ - hpx::naming::locality leaks parcelport specific information into the public interface
- Issue #850⁵⁶⁶⁵ - “flush” not documented
- Issue #763⁵⁶⁶⁶ - Create buildbot instance that uses std::bind as HPX_STD_BIND
- Issue #680⁵⁶⁶⁷ - Convert parcel ports into a plugin system
- Issue #582⁵⁶⁶⁸ - Make exception thrown from HPX threads available from hpx::init
- Issue #504⁵⁶⁶⁹ - Refactor Dataflow LCO to work with futures
- Issue #196⁵⁶⁷⁰ - Don’t store copies of the locality network metadata in the gva table

HPX V0.9.9 (Oct 31, 2014, codename Spooky)

General changes

We have had over 1500 commits since the last release and we have closed over 200 tickets (bugs, feature requests, pull requests, etc.). These are by far the largest numbers of commits and resolved issues for any of the *HPX* releases so far. We are especially happy about the large number of people who contributed for the first time to *HPX*.

- We completed the transition from the older (non-conforming) implementation of `hpx::future` to the new and fully conforming version by removing the old code and by renaming the type `hpx::unique_future` to `hpx::future`. In order to maintain backwards compatibility with existing code which uses the type `hpx::unique_future` we support the configuration variable `HPX_UNIQUE_FUTURE_ALIAS`. If this variable is set to `ON` while running `cmake` it will additionally define a template alias for this type.

⁵⁶⁵⁴ <https://github.com/STELLAR-GROUP/hpx/issues/1294>

⁵⁶⁵⁵ <https://github.com/STELLAR-GROUP/hpx/issues/1275>

⁵⁶⁵⁶ <https://github.com/STELLAR-GROUP/hpx/issues/1267>

⁵⁶⁵⁷ <https://github.com/STELLAR-GROUP/hpx/issues/1264>

⁵⁶⁵⁸ <https://github.com/STELLAR-GROUP/hpx/issues/1254>

⁵⁶⁵⁹ <https://github.com/STELLAR-GROUP/hpx/issues/1220>

⁵⁶⁶⁰ <https://github.com/STELLAR-GROUP/hpx/issues/1217>

⁵⁶⁶¹ <https://github.com/STELLAR-GROUP/hpx/issues/1168>

⁵⁶⁶² <https://github.com/STELLAR-GROUP/hpx/issues/1085>

⁵⁶⁶³ <https://github.com/STELLAR-GROUP/hpx/issues/981>

⁵⁶⁶⁴ <https://github.com/STELLAR-GROUP/hpx/issues/857>

⁵⁶⁶⁵ <https://github.com/STELLAR-GROUP/hpx/issues/850>

⁵⁶⁶⁶ <https://github.com/STELLAR-GROUP/hpx/issues/763>

⁵⁶⁶⁷ <https://github.com/STELLAR-GROUP/hpx/issues/680>

⁵⁶⁶⁸ <https://github.com/STELLAR-GROUP/hpx/issues/582>

⁵⁶⁶⁹ <https://github.com/STELLAR-GROUP/hpx/issues/504>

⁵⁶⁷⁰ <https://github.com/STELLAR-GROUP/hpx/issues/196>

- We rewrote and significantly changed our build system. Please have a look at the new (now generated) documentation here: *Building HPX*. Please revisit your build scripts to adapt to the changes. The most notable changes are:
 - HPX_NO_INSTALL is no longer necessary.
 - For external builds, you need to set HPX_DIR instead of HPX_ROOT as described here: *Using HPX with CMake-based projects*.
 - IDEs that support multiple configurations (Visual Studio and XCode) can now be used as intended. that means no build dir.
 - Building HPX statically (without dynamic libraries) is now supported (-DHPX_STATIC_LINKING=On).
 - Please note that many variables used to configure the build process have been renamed to unify the naming conventions (see the section *CMake options* for more information).
 - This also fixes a long list of issues, for more information see [Issue #1204](#)⁵⁶⁷¹.
- We started to implement various proposals to the C++ Standardization committee related to parallelism and concurrency, most notably [N4409](#)⁵⁶⁷² (Working Draft, Technical Specification for C++ Extensions for Parallelism), [N4411](#)⁵⁶⁷³ (Task Region Rev. 3), and [N4313](#)⁵⁶⁷⁴ (Working Draft, Technical Specification for C++ Extensions for Concurrency).
- We completely remodeled our automatic build system to run builds and unit tests on various systems and compilers. This allows us to find most bugs right as they were introduced and helps to maintain a high level of quality and compatibility. The newest build logs can be found at [HPX Buildbot Website](#)⁵⁶⁷⁵.

Bug fixes (closed tickets)

Here is a list of the important tickets we closed for this release.

- [Issue #1296](#)⁵⁶⁷⁶ - Rename make_error_future to make_exceptional_future, adjust to N4123
- [Issue #1295](#)⁵⁶⁷⁷ - building issue
- [Issue #1293](#)⁵⁶⁷⁸ - Transpose example
- [Issue #1292](#)⁵⁶⁷⁹ - Wrong abs() function used in example
- [Issue #1291](#)⁵⁶⁸⁰ - non-synchronized shift operators have been removed
- [Issue #1290](#)⁵⁶⁸¹ - RDTSCP is defined as true for Xeon Phi build
- [Issue #1289](#)⁵⁶⁸² - Fixing 1288
- [Issue #1288](#)⁵⁶⁸³ - Add new performance counters
- [Issue #1287](#)⁵⁶⁸⁴ - Hierarchy scheduler broken performance counters

⁵⁶⁷¹ <https://github.com/STELLAR-GROUP/hpx/issues/1204>

⁵⁶⁷² <http://wg21.link/n4409>

⁵⁶⁷³ <http://wg21.link/n4411>

⁵⁶⁷⁴ <http://wg21.link/n4313>

⁵⁶⁷⁵ <http://rostam.cct.lsu.edu/>

⁵⁶⁷⁶ <https://github.com/STELLAR-GROUP/hpx/issues/1296>

⁵⁶⁷⁷ <https://github.com/STELLAR-GROUP/hpx/issues/1295>

⁵⁶⁷⁸ <https://github.com/STELLAR-GROUP/hpx/issues/1293>

⁵⁶⁷⁹ <https://github.com/STELLAR-GROUP/hpx/issues/1292>

⁵⁶⁸⁰ <https://github.com/STELLAR-GROUP/hpx/issues/1291>

⁵⁶⁸¹ <https://github.com/STELLAR-GROUP/hpx/issues/1290>

⁵⁶⁸² <https://github.com/STELLAR-GROUP/hpx/issues/1289>

⁵⁶⁸³ <https://github.com/STELLAR-GROUP/hpx/issues/1288>

⁵⁶⁸⁴ <https://github.com/STELLAR-GROUP/hpx/issues/1287>

- [Issue #1286⁵⁶⁸⁵](#) - Algorithm cleanup
- [Issue #1285⁵⁶⁸⁶](#) - Broken Links in Documentation
- [Issue #1284⁵⁶⁸⁷](#) - Uninitialized copy
- [Issue #1283⁵⁶⁸⁸](#) - missing boost::scoped_ptr includes
- [Issue #1282⁵⁶⁸⁹](#) - Update documentation of build options for schedulers
- [Issue #1281⁵⁶⁹⁰](#) - reset idle rate counter
- [Issue #1280⁵⁶⁹¹](#) - Bug when executing on Intel MIC
- [Issue #1279⁵⁶⁹²](#) - Add improved when_all/wait_all
- [Issue #1278⁵⁶⁹³](#) - Implement improved when_all/wait_all
- [Issue #1277⁵⁶⁹⁴](#) - feature request: get access to argc argv and variables_map
- [Issue #1276⁵⁶⁹⁵](#) - Remove merging map
- [Issue #1274⁵⁶⁹⁶](#) - Weird (wrong) string code in papi.cpp
- [Issue #1273⁵⁶⁹⁷](#) - Sequential task execution policy
- [Issue #1272⁵⁶⁹⁸](#) - Avoid CMake name clash for Boost.Thread library
- [Issue #1271⁵⁶⁹⁹](#) - Updates on HPX Test Units
- [Issue #1270⁵⁷⁰⁰](#) - hpx/util/safe_lexical_cast.hpp is added
- [Issue #1269⁵⁷⁰¹](#) - Added default value for “LIB” cmake variable
- [Issue #1268⁵⁷⁰²](#) - Memory Counters not working
- [Issue #1266⁵⁷⁰³](#) - FindHPX.cmake is not installed
- [Issue #1263⁵⁷⁰⁴](#) - apply_remote test takes too long
- [Issue #1262⁵⁷⁰⁵](#) - Chrono cleanup
- [Issue #1261⁵⁷⁰⁶](#) - Need make install for papi counters and this builds all the examples
- [Issue #1260⁵⁷⁰⁷](#) - Documentation of Stencil example claims

⁵⁶⁸⁵ <https://github.com/STELLAR-GROUP/hpx/issues/1286>

⁵⁶⁸⁶ <https://github.com/STELLAR-GROUP/hpx/issues/1285>

⁵⁶⁸⁷ <https://github.com/STELLAR-GROUP/hpx/issues/1284>

⁵⁶⁸⁸ <https://github.com/STELLAR-GROUP/hpx/issues/1283>

⁵⁶⁸⁹ <https://github.com/STELLAR-GROUP/hpx/issues/1282>

⁵⁶⁹⁰ <https://github.com/STELLAR-GROUP/hpx/issues/1281>

⁵⁶⁹¹ <https://github.com/STELLAR-GROUP/hpx/issues/1280>

⁵⁶⁹² <https://github.com/STELLAR-GROUP/hpx/issues/1279>

⁵⁶⁹³ <https://github.com/STELLAR-GROUP/hpx/issues/1278>

⁵⁶⁹⁴ <https://github.com/STELLAR-GROUP/hpx/issues/1277>

⁵⁶⁹⁵ <https://github.com/STELLAR-GROUP/hpx/issues/1276>

⁵⁶⁹⁶ <https://github.com/STELLAR-GROUP/hpx/issues/1274>

⁵⁶⁹⁷ <https://github.com/STELLAR-GROUP/hpx/issues/1273>

⁵⁶⁹⁸ <https://github.com/STELLAR-GROUP/hpx/issues/1272>

⁵⁶⁹⁹ <https://github.com/STELLAR-GROUP/hpx/issues/1271>

⁵⁷⁰⁰ <https://github.com/STELLAR-GROUP/hpx/issues/1270>

⁵⁷⁰¹ <https://github.com/STELLAR-GROUP/hpx/issues/1269>

⁵⁷⁰² <https://github.com/STELLAR-GROUP/hpx/issues/1268>

⁵⁷⁰³ <https://github.com/STELLAR-GROUP/hpx/issues/1266>

⁵⁷⁰⁴ <https://github.com/STELLAR-GROUP/hpx/issues/1263>

⁵⁷⁰⁵ <https://github.com/STELLAR-GROUP/hpx/issues/1262>

⁵⁷⁰⁶ <https://github.com/STELLAR-GROUP/hpx/issues/1261>

⁵⁷⁰⁷ <https://github.com/STELLAR-GROUP/hpx/issues/1260>

- [Issue #1259⁵⁷⁰⁸](https://github.com/STELLAR-GROUP/hpx/issues/1259) - Avoid double-linking Boost on Windows
- [Issue #1257⁵⁷⁰⁹](https://github.com/STELLAR-GROUP/hpx/issues/1257) - Adding additional parameter to create_thread
- [Issue #1256⁵⁷¹⁰](https://github.com/STELLAR-GROUP/hpx/issues/1256) - added buildbot changes to release notes
- [Issue #1255⁵⁷¹¹](https://github.com/STELLAR-GROUP/hpx/issues/1255) - Cannot build MiniGhost
- [Issue #1253⁵⁷¹²](https://github.com/STELLAR-GROUP/hpx/issues/1253) - hpx::thread defects
- [Issue #1252⁵⁷¹³](https://github.com/STELLAR-GROUP/hpx/issues/1252) - HPX_PREFIX is too fragile
- [Issue #1250⁵⁷¹⁴](https://github.com/STELLAR-GROUP/hpx/issues/1250) - switch_to_fiber_emulation does not work properly
- [Issue #1249⁵⁷¹⁵](https://github.com/STELLAR-GROUP/hpx/issues/1249) - Documentation is generated under Release folder
- [Issue #1248⁵⁷¹⁶](https://github.com/STELLAR-GROUP/hpx/issues/1248) - Fix usage of hpx_generic_coroutine_context and get tests passing on powerpc
- [Issue #1247⁵⁷¹⁷](https://github.com/STELLAR-GROUP/hpx/issues/1247) - Dynamic linking error
- [Issue #1246⁵⁷¹⁸](https://github.com/STELLAR-GROUP/hpx/issues/1246) - Make cpuid.cpp C++11 compliant
- [Issue #1245⁵⁷¹⁹](https://github.com/STELLAR-GROUP/hpx/issues/1245) - HPX fails on startup (setting thread affinity mask)
- [Issue #1244⁵⁷²⁰](https://github.com/STELLAR-GROUP/hpx/issues/1244) - HPX_WITH_RDTSC configure test fails, but should succeed
- [Issue #1243⁵⁷²¹](https://github.com/STELLAR-GROUP/hpx/issues/1243) - CTest dashboard info for CSCS CDash drop location
- [Issue #1242⁵⁷²²](https://github.com/STELLAR-GROUP/hpx/issues/1242) - Mac fixes
- [Issue #1241⁵⁷²³](https://github.com/STELLAR-GROUP/hpx/issues/1241) - Failure in Distributed with Boost 1.56
- [Issue #1240⁵⁷²⁴](https://github.com/STELLAR-GROUP/hpx/issues/1240) - fix a race condition in examples.diskperf
- [Issue #1239⁵⁷²⁵](https://github.com/STELLAR-GROUP/hpx/issues/1239) - fix wait_each in examples.diskperf
- [Issue #1238⁵⁷²⁶](https://github.com/STELLAR-GROUP/hpx/issues/1238) - Fixed #1237: hpx::util::portable_binary_iarchive failed
- [Issue #1237⁵⁷²⁷](https://github.com/STELLAR-GROUP/hpx/issues/1237) - hpx::util::portable_binary_iarchive failed
- [Issue #1235⁵⁷²⁸](https://github.com/STELLAR-GROUP/hpx/issues/1235) - Fixing clang warnings and errors
- [Issue #1234⁵⁷²⁹](https://github.com/STELLAR-GROUP/hpx/issues/1234) - TCP runs fail: Transport endpoint is not connected
- [Issue #1233⁵⁷³⁰](https://github.com/STELLAR-GROUP/hpx/issues/1233) - Making sure the correct number of threads is registered with AGAS

⁵⁷⁰⁸ <https://github.com/STELLAR-GROUP/hpx/issues/1259>

⁵⁷⁰⁹ <https://github.com/STELLAR-GROUP/hpx/issues/1257>

⁵⁷¹⁰ <https://github.com/STELLAR-GROUP/hpx/issues/1256>

⁵⁷¹¹ <https://github.com/STELLAR-GROUP/hpx/issues/1255>

⁵⁷¹² <https://github.com/STELLAR-GROUP/hpx/issues/1253>

⁵⁷¹³ <https://github.com/STELLAR-GROUP/hpx/issues/1252>

⁵⁷¹⁴ <https://github.com/STELLAR-GROUP/hpx/issues/1250>

⁵⁷¹⁵ <https://github.com/STELLAR-GROUP/hpx/issues/1249>

⁵⁷¹⁶ <https://github.com/STELLAR-GROUP/hpx/issues/1248>

⁵⁷¹⁷ <https://github.com/STELLAR-GROUP/hpx/issues/1247>

⁵⁷¹⁸ <https://github.com/STELLAR-GROUP/hpx/issues/1246>

⁵⁷¹⁹ <https://github.com/STELLAR-GROUP/hpx/issues/1245>

⁵⁷²⁰ <https://github.com/STELLAR-GROUP/hpx/issues/1244>

⁵⁷²¹ <https://github.com/STELLAR-GROUP/hpx/issues/1243>

⁵⁷²² <https://github.com/STELLAR-GROUP/hpx/issues/1242>

⁵⁷²³ <https://github.com/STELLAR-GROUP/hpx/issues/1241>

⁵⁷²⁴ <https://github.com/STELLAR-GROUP/hpx/issues/1240>

⁵⁷²⁵ <https://github.com/STELLAR-GROUP/hpx/issues/1239>

⁵⁷²⁶ <https://github.com/STELLAR-GROUP/hpx/issues/1238>

⁵⁷²⁷ <https://github.com/STELLAR-GROUP/hpx/issues/1237>

⁵⁷²⁸ <https://github.com/STELLAR-GROUP/hpx/issues/1235>

⁵⁷²⁹ <https://github.com/STELLAR-GROUP/hpx/issues/1234>

⁵⁷³⁰ <https://github.com/STELLAR-GROUP/hpx/issues/1233>

- Issue #1232⁵⁷³¹ - Fixing race in wait_XXX
- Issue #1231⁵⁷³² - Parallel minmax
- Issue #1230⁵⁷³³ - Distributed run of 1d_stencil_8 uses less threads than spec. & sometimes gives errors
- Issue #1229⁵⁷³⁴ - Unstable number of threads
- Issue #1228⁵⁷³⁵ - HPX link error (cmake / MPI)
- Issue #1226⁵⁷³⁶ - Warning about struct/class thread_counters
- Issue #1225⁵⁷³⁷ - Adding parallel::replace etc
- Issue #1224⁵⁷³⁸ - Extending dataflow to pass through non-future arguments
- Issue #1223⁵⁷³⁹ - Remaining find algorithms implemented, N4071
- Issue #1222⁵⁷⁴⁰ - Merging all the changes
- Issue #1221⁵⁷⁴¹ - No error output when using mpirun with hpx
- Issue #1219⁵⁷⁴² - Adding new AGAS cache performance counters
- Issue #1216⁵⁷⁴³ - Fixing using futures (clients) as arguments to actions
- Issue #1215⁵⁷⁴⁴ - Error compiling simple component
- Issue #1214⁵⁷⁴⁵ - Stencil docs
- Issue #1213⁵⁷⁴⁶ - Using more than a few dozen MPI processes on SuperMike results in a seg fault before getting to hpx_main
- Issue #1212⁵⁷⁴⁷ - Parallel rotate
- Issue #1211⁵⁷⁴⁸ - Direct actions cause the future's shared_state to be leaked
- Issue #1210⁵⁷⁴⁹ - Refactored local::promise to be standard conformant
- Issue #1209⁵⁷⁵⁰ - Improve command line handling
- Issue #1208⁵⁷⁵¹ - Adding parallel::reverse and parallel::reverse_copy
- Issue #1207⁵⁷⁵² - Add copy_backward and move_backward
- Issue #1206⁵⁷⁵³ - N4071 additional algorithms implemented

⁵⁷³¹ <https://github.com/STELLAR-GROUP/hpx/issues/1232>

⁵⁷³² <https://github.com/STELLAR-GROUP/hpx/issues/1231>

⁵⁷³³ <https://github.com/STELLAR-GROUP/hpx/issues/1230>

⁵⁷³⁴ <https://github.com/STELLAR-GROUP/hpx/issues/1229>

⁵⁷³⁵ <https://github.com/STELLAR-GROUP/hpx/issues/1228>

⁵⁷³⁶ <https://github.com/STELLAR-GROUP/hpx/issues/1226>

⁵⁷³⁷ <https://github.com/STELLAR-GROUP/hpx/issues/1225>

⁵⁷³⁸ <https://github.com/STELLAR-GROUP/hpx/issues/1224>

⁵⁷³⁹ <https://github.com/STELLAR-GROUP/hpx/issues/1223>

⁵⁷⁴⁰ <https://github.com/STELLAR-GROUP/hpx/issues/1222>

⁵⁷⁴¹ <https://github.com/STELLAR-GROUP/hpx/issues/1221>

⁵⁷⁴² <https://github.com/STELLAR-GROUP/hpx/issues/1219>

⁵⁷⁴³ <https://github.com/STELLAR-GROUP/hpx/issues/1216>

⁵⁷⁴⁴ <https://github.com/STELLAR-GROUP/hpx/issues/1215>

⁵⁷⁴⁵ <https://github.com/STELLAR-GROUP/hpx/issues/1214>

⁵⁷⁴⁶ <https://github.com/STELLAR-GROUP/hpx/issues/1213>

⁵⁷⁴⁷ <https://github.com/STELLAR-GROUP/hpx/issues/1212>

⁵⁷⁴⁸ <https://github.com/STELLAR-GROUP/hpx/issues/1211>

⁵⁷⁴⁹ <https://github.com/STELLAR-GROUP/hpx/issues/1210>

⁵⁷⁵⁰ <https://github.com/STELLAR-GROUP/hpx/issues/1209>

⁵⁷⁵¹ <https://github.com/STELLAR-GROUP/hpx/issues/1208>

⁵⁷⁵² <https://github.com/STELLAR-GROUP/hpx/issues/1207>

⁵⁷⁵³ <https://github.com/STELLAR-GROUP/hpx/issues/1206>

- Issue #1204⁵⁷⁵⁴ - Cmake simplification and various other minor changes
- Issue #1203⁵⁷⁵⁵ - Implementing new launch policy for (local) `async: hpx::launch::fork`.
- Issue #1202⁵⁷⁵⁶ - Failed assertion in `connection_cache.hpp`
- Issue #1201⁵⁷⁵⁷ - `pkg-config` doesn't add `mpi` link directories
- Issue #1200⁵⁷⁵⁸ - Error when querying time performance counters
- Issue #1199⁵⁷⁵⁹ - library path is now configurable (again)
- Issue #1198⁵⁷⁶⁰ - Error when querying performance counters
- Issue #1197⁵⁷⁶¹ - tests fail with intel compiler
- Issue #1196⁵⁷⁶² - Silence several warnings
- Issue #1195⁵⁷⁶³ - Rephrase initializers to work with VC++ 2012
- Issue #1194⁵⁷⁶⁴ - Simplify parallel algorithms
- Issue #1193⁵⁷⁶⁵ - Adding `parallel::equal`
- Issue #1192⁵⁷⁶⁶ - HPX(`out_of_memory`) on including `<hpx/hpx.hpp>`
- Issue #1191⁵⁷⁶⁷ - Fixing #1189
- Issue #1190⁵⁷⁶⁸ - Chrono cleanup
- Issue #1189⁵⁷⁶⁹ - Deadlock .. somewhere? (probably serialization)
- Issue #1188⁵⁷⁷⁰ - Removed `future::get_status()`
- Issue #1186⁵⁷⁷¹ - Fixed `FindOpenCL` to find current AMD APP SDK
- Issue #1184⁵⁷⁷² - Tweaking future unwrapping
- Issue #1183⁵⁷⁷³ - Extended `parallel::reduce`
- Issue #1182⁵⁷⁷⁴ - `future::unwrap` hangs for `launch::deferred`
- Issue #1181⁵⁷⁷⁵ - Adding `all_of`, `any_of`, and `none_of` and corresponding documentation
- Issue #1180⁵⁷⁷⁶ - `hpx::cout` defect

⁵⁷⁵⁴ <https://github.com/STELLAR-GROUP/hpx/issues/1204>

⁵⁷⁵⁵ <https://github.com/STELLAR-GROUP/hpx/issues/1203>

⁵⁷⁵⁶ <https://github.com/STELLAR-GROUP/hpx/issues/1202>

⁵⁷⁵⁷ <https://github.com/STELLAR-GROUP/hpx/issues/1201>

⁵⁷⁵⁸ <https://github.com/STELLAR-GROUP/hpx/issues/1200>

⁵⁷⁵⁹ <https://github.com/STELLAR-GROUP/hpx/issues/1199>

⁵⁷⁶⁰ <https://github.com/STELLAR-GROUP/hpx/issues/1198>

⁵⁷⁶¹ <https://github.com/STELLAR-GROUP/hpx/issues/1197>

⁵⁷⁶² <https://github.com/STELLAR-GROUP/hpx/issues/1196>

⁵⁷⁶³ <https://github.com/STELLAR-GROUP/hpx/issues/1195>

⁵⁷⁶⁴ <https://github.com/STELLAR-GROUP/hpx/issues/1194>

⁵⁷⁶⁵ <https://github.com/STELLAR-GROUP/hpx/issues/1193>

⁵⁷⁶⁶ <https://github.com/STELLAR-GROUP/hpx/issues/1192>

⁵⁷⁶⁷ <https://github.com/STELLAR-GROUP/hpx/issues/1191>

⁵⁷⁶⁸ <https://github.com/STELLAR-GROUP/hpx/issues/1190>

⁵⁷⁶⁹ <https://github.com/STELLAR-GROUP/hpx/issues/1189>

⁵⁷⁷⁰ <https://github.com/STELLAR-GROUP/hpx/issues/1188>

⁵⁷⁷¹ <https://github.com/STELLAR-GROUP/hpx/issues/1186>

⁵⁷⁷² <https://github.com/STELLAR-GROUP/hpx/issues/1184>

⁵⁷⁷³ <https://github.com/STELLAR-GROUP/hpx/issues/1183>

⁵⁷⁷⁴ <https://github.com/STELLAR-GROUP/hpx/issues/1182>

⁵⁷⁷⁵ <https://github.com/STELLAR-GROUP/hpx/issues/1181>

⁵⁷⁷⁶ <https://github.com/STELLAR-GROUP/hpx/issues/1180>

- Issue #1179⁵⁷⁷⁷ - `hpx::async` does not work for member function pointers when called on types with self-defined unary operator*
- Issue #1178⁵⁷⁷⁸ - Implemented variadic `hpx::util::zip_iterator`
- Issue #1177⁵⁷⁷⁹ - MPI parcelport defect
- Issue #1176⁵⁷⁸⁰ - `HPX_DEFINE_COMPONENT_CONST_ACTION_TPL` does not have a 2-argument version
- Issue #1175⁵⁷⁸¹ - Create `util::zip_iterator` working with `util::tuple<>`
- Issue #1174⁵⁷⁸² - Error Building HPX on linux, `root_certificate_authority.cpp`
- Issue #1173⁵⁷⁸³ - `hpx::cout` output lost
- Issue #1172⁵⁷⁸⁴ - HPX build error with Clang 3.4.2
- Issue #1171⁵⁷⁸⁵ - `CMAKE_INSTALL_PREFIX` ignored
- Issue #1170⁵⁷⁸⁶ - Close `hpx_benchmarks` repository on Github
- Issue #1169⁵⁷⁸⁷ - Buildbot emails have syntax error in url
- Issue #1167⁵⁷⁸⁸ - Merge partial implementation of standards proposal N3960
- Issue #1166⁵⁷⁸⁹ - Fixed several compiler warnings
- Issue #1165⁵⁷⁹⁰ - `cmake` warns: “`tests.regressions.actions`” does not exist
- Issue #1164⁵⁷⁹¹ - Want my own serialization of `hpx::future`
- Issue #1162⁵⁷⁹² - Segfault in `hello_world` example
- Issue #1161⁵⁷⁹³ - Use `HPX_ASSERT` to aid the compiler
- Issue #1160⁵⁷⁹⁴ - Do not put `-DNDEBUG` into `hpx_application.pc`
- Issue #1159⁵⁷⁹⁵ - Support Clang 3.4.2
- Issue #1158⁵⁷⁹⁶ - Fixed #1157: Rename `when_n/wait_n`, add `when_xxx_n/wait_xxx_n`
- Issue #1157⁵⁷⁹⁷ - Rename `when_n/wait_n`, add `when_xxx_n/wait_xxx_n`
- Issue #1156⁵⁷⁹⁸ - Force inlining fails
- Issue #1155⁵⁷⁹⁹ - changed header of `printout` to be compatible with python csv module

⁵⁷⁷⁷ <https://github.com/STELLAR-GROUP/hpx/issues/1179>

⁵⁷⁷⁸ <https://github.com/STELLAR-GROUP/hpx/issues/1178>

⁵⁷⁷⁹ <https://github.com/STELLAR-GROUP/hpx/issues/1177>

⁵⁷⁸⁰ <https://github.com/STELLAR-GROUP/hpx/issues/1176>

⁵⁷⁸¹ <https://github.com/STELLAR-GROUP/hpx/issues/1175>

⁵⁷⁸² <https://github.com/STELLAR-GROUP/hpx/issues/1174>

⁵⁷⁸³ <https://github.com/STELLAR-GROUP/hpx/issues/1173>

⁵⁷⁸⁴ <https://github.com/STELLAR-GROUP/hpx/issues/1172>

⁵⁷⁸⁵ <https://github.com/STELLAR-GROUP/hpx/issues/1171>

⁵⁷⁸⁶ <https://github.com/STELLAR-GROUP/hpx/issues/1170>

⁵⁷⁸⁷ <https://github.com/STELLAR-GROUP/hpx/issues/1169>

⁵⁷⁸⁸ <https://github.com/STELLAR-GROUP/hpx/issues/1167>

⁵⁷⁸⁹ <https://github.com/STELLAR-GROUP/hpx/issues/1166>

⁵⁷⁹⁰ <https://github.com/STELLAR-GROUP/hpx/issues/1165>

⁵⁷⁹¹ <https://github.com/STELLAR-GROUP/hpx/issues/1164>

⁵⁷⁹² <https://github.com/STELLAR-GROUP/hpx/issues/1162>

⁵⁷⁹³ <https://github.com/STELLAR-GROUP/hpx/issues/1161>

⁵⁷⁹⁴ <https://github.com/STELLAR-GROUP/hpx/issues/1160>

⁵⁷⁹⁵ <https://github.com/STELLAR-GROUP/hpx/issues/1159>

⁵⁷⁹⁶ <https://github.com/STELLAR-GROUP/hpx/issues/1158>

⁵⁷⁹⁷ <https://github.com/STELLAR-GROUP/hpx/issues/1157>

⁵⁷⁹⁸ <https://github.com/STELLAR-GROUP/hpx/issues/1156>

⁵⁷⁹⁹ <https://github.com/STELLAR-GROUP/hpx/issues/1155>

- [Issue #1154⁵⁸⁰⁰](#) - Fixing iostreams
- [Issue #1153⁵⁸⁰¹](#) - Standard manipulators (like `std::endl`) do not work with `hpx::ostream`
- [Issue #1152⁵⁸⁰²](#) - Functions revamp
- [Issue #1151⁵⁸⁰³](#) - Suppressing `cmake 3.0` policy warning for `CMP0026`
- [Issue #1150⁵⁸⁰⁴](#) - Client Serialization error
- [Issue #1149⁵⁸⁰⁵](#) - Segfault on Stampede
- [Issue #1148⁵⁸⁰⁶](#) - Refactoring mini-ghost
- [Issue #1147⁵⁸⁰⁷](#) - `N3960 copy_if` and `copy_n` implemented and tested
- [Issue #1146⁵⁸⁰⁸](#) - Stencil print
- [Issue #1145⁵⁸⁰⁹](#) - `N3960 hpx::parallel::copy` implemented and tested
- [Issue #1144⁵⁸¹⁰](#) - OpenMP examples `1d_stencil` do not build
- [Issue #1143⁵⁸¹¹](#) - `1d_stencil` OpenMP examples do not build
- [Issue #1142⁵⁸¹²](#) - Cannot build HPX with `gcc 4.6` on OS X
- [Issue #1140⁵⁸¹³](#) - Fix OpenMP lookup, enable usage of config tests in external CMake projects.
- [Issue #1139⁵⁸¹⁴](#) - `hpx/hpx/config/compiler_specific.hpp`
- [Issue #1138⁵⁸¹⁵](#) - clean up `pkg-config` files
- [Issue #1137⁵⁸¹⁶](#) - Improvements to create binary packages
- [Issue #1136⁵⁸¹⁷](#) - `HPX_GCC_VERSION` not defined on all compilers
- [Issue #1135⁵⁸¹⁸](#) - Avoiding collision between `winsock2.h` and `windows.h`
- [Issue #1134⁵⁸¹⁹](#) - Making sure, that `hpx::finalize` can be called from any locality
- [Issue #1133⁵⁸²⁰](#) - `1d stencil` examples
- [Issue #1131⁵⁸²¹](#) - Refactor `unique_function` implementation
- [Issue #1130⁵⁸²²](#) - Unique function

⁵⁸⁰⁰ <https://github.com/STELLAR-GROUP/hpx/issues/1154>

⁵⁸⁰¹ <https://github.com/STELLAR-GROUP/hpx/issues/1153>

⁵⁸⁰² <https://github.com/STELLAR-GROUP/hpx/issues/1152>

⁵⁸⁰³ <https://github.com/STELLAR-GROUP/hpx/issues/1151>

⁵⁸⁰⁴ <https://github.com/STELLAR-GROUP/hpx/issues/1150>

⁵⁸⁰⁵ <https://github.com/STELLAR-GROUP/hpx/issues/1149>

⁵⁸⁰⁶ <https://github.com/STELLAR-GROUP/hpx/issues/1148>

⁵⁸⁰⁷ <https://github.com/STELLAR-GROUP/hpx/issues/1147>

⁵⁸⁰⁸ <https://github.com/STELLAR-GROUP/hpx/issues/1146>

⁵⁸⁰⁹ <https://github.com/STELLAR-GROUP/hpx/issues/1145>

⁵⁸¹⁰ <https://github.com/STELLAR-GROUP/hpx/issues/1144>

⁵⁸¹¹ <https://github.com/STELLAR-GROUP/hpx/issues/1143>

⁵⁸¹² <https://github.com/STELLAR-GROUP/hpx/issues/1142>

⁵⁸¹³ <https://github.com/STELLAR-GROUP/hpx/issues/1140>

⁵⁸¹⁴ <https://github.com/STELLAR-GROUP/hpx/issues/1139>

⁵⁸¹⁵ <https://github.com/STELLAR-GROUP/hpx/issues/1138>

⁵⁸¹⁶ <https://github.com/STELLAR-GROUP/hpx/issues/1137>

⁵⁸¹⁷ <https://github.com/STELLAR-GROUP/hpx/issues/1136>

⁵⁸¹⁸ <https://github.com/STELLAR-GROUP/hpx/issues/1135>

⁵⁸¹⁹ <https://github.com/STELLAR-GROUP/hpx/issues/1134>

⁵⁸²⁰ <https://github.com/STELLAR-GROUP/hpx/issues/1133>

⁵⁸²¹ <https://github.com/STELLAR-GROUP/hpx/issues/1131>

⁵⁸²² <https://github.com/STELLAR-GROUP/hpx/issues/1130>

- Issue #1129⁵⁸²³ - Some fixes to the Build system on OS X
- Issue #1128⁵⁸²⁴ - Action future args
- Issue #1127⁵⁸²⁵ - Executor causes segmentation fault
- Issue #1124⁵⁸²⁶ - Adding new API functions: `register_id_with_basename`, `unregister_id_with_basename`, `find_ids_from_basename`; adding test
- Issue #1123⁵⁸²⁷ - Reduce nesting of try-catch construct in `encode_parcels?`
- Issue #1122⁵⁸²⁸ - Client base fixes
- Issue #1121⁵⁸²⁹ - Update `hpxrun.py.in`
- Issue #1120⁵⁸³⁰ - HTTPS2 tests compile errors on v110 (VS2012)
- Issue #1119⁵⁸³¹ - Remove references to `boost::atomic` in accumulator example
- Issue #1118⁵⁸³² - Only build test `thread_pool_executor_1114_test` if `HPX_SCHEDULER` is set
- Issue #1117⁵⁸³³ - `local_queue_executor` linker error on vc110
- Issue #1116⁵⁸³⁴ - Disabled performance counter should give runtime errors, not invalid data
- Issue #1115⁵⁸³⁵ - Compile error with Intel C++ 13.1
- Issue #1114⁵⁸³⁶ - Default constructed executor is not usable
- Issue #1113⁵⁸³⁷ - Fast compilation of logging causes ABI incompatibilities between different `NDEBUG` values
- Issue #1112⁵⁸³⁸ - Using `thread_pool_executors` causes segfault
- Issue #1111⁵⁸³⁹ - `hpx::threads::get_thread_data` always returns zero
- Issue #1110⁵⁸⁴⁰ - Remove unnecessary null pointer checks
- Issue #1109⁵⁸⁴¹ - More tests adjustments
- Issue #1108⁵⁸⁴² - Clarify build rules for “`libboost_atomic-mt.so`”?
- Issue #1107⁵⁸⁴³ - Remove unnecessary null pointer checks
- Issue #1106⁵⁸⁴⁴ - `network_storage` benchmark improvements, adding legends to plots and tidying layout
- Issue #1105⁵⁸⁴⁵ - Add more plot outputs and improve instructions doc

5823 <https://github.com/STELLAR-GROUP/hpx/issues/1129>

5824 <https://github.com/STELLAR-GROUP/hpx/issues/1128>

5825 <https://github.com/STELLAR-GROUP/hpx/issues/1127>

5826 <https://github.com/STELLAR-GROUP/hpx/issues/1124>

5827 <https://github.com/STELLAR-GROUP/hpx/issues/1123>

5828 <https://github.com/STELLAR-GROUP/hpx/issues/1122>

5829 <https://github.com/STELLAR-GROUP/hpx/issues/1121>

5830 <https://github.com/STELLAR-GROUP/hpx/issues/1120>

5831 <https://github.com/STELLAR-GROUP/hpx/issues/1119>

5832 <https://github.com/STELLAR-GROUP/hpx/issues/1118>

5833 <https://github.com/STELLAR-GROUP/hpx/issues/1117>

5834 <https://github.com/STELLAR-GROUP/hpx/issues/1116>

5835 <https://github.com/STELLAR-GROUP/hpx/issues/1115>

5836 <https://github.com/STELLAR-GROUP/hpx/issues/1114>

5837 <https://github.com/STELLAR-GROUP/hpx/issues/1113>

5838 <https://github.com/STELLAR-GROUP/hpx/issues/1112>

5839 <https://github.com/STELLAR-GROUP/hpx/issues/1111>

5840 <https://github.com/STELLAR-GROUP/hpx/issues/1110>

5841 <https://github.com/STELLAR-GROUP/hpx/issues/1109>

5842 <https://github.com/STELLAR-GROUP/hpx/issues/1108>

5843 <https://github.com/STELLAR-GROUP/hpx/issues/1107>

5844 <https://github.com/STELLAR-GROUP/hpx/issues/1106>

5845 <https://github.com/STELLAR-GROUP/hpx/issues/1105>

- [Issue #1104⁵⁸⁴⁶](#) - Complete quoting for parameters of some CMake commands
- [Issue #1103⁵⁸⁴⁷](#) - Work on test/scripts
- [Issue #1102⁵⁸⁴⁸](#) - Changed minimum requirement of window install to 2012
- [Issue #1101⁵⁸⁴⁹](#) - Changed minimum requirement of window install to 2012
- [Issue #1100⁵⁸⁵⁰](#) - Changed readme to no longer specify using MSVC 2010 compiler
- [Issue #1099⁵⁸⁵¹](#) - Error returning futures from component actions
- [Issue #1098⁵⁸⁵²](#) - Improve storage test
- [Issue #1097⁵⁸⁵³](#) - data_actions quickstart example calls missing function decorate_action of data_get_action
- [Issue #1096⁵⁸⁵⁴](#) - MPI parcelport broken with new zero copy optimization
- [Issue #1095⁵⁸⁵⁵](#) - Warning C4005: _WIN32_WINNT: Macro redefinition
- [Issue #1094⁵⁸⁵⁶](#) - Syntax error for -DHPX_UNIQUE_FUTURE_ALIAS in master
- [Issue #1093⁵⁸⁵⁷](#) - Syntax error for -DHPX_UNIQUE_FUTURE_ALIAS
- [Issue #1092⁵⁸⁵⁸](#) - Rename unique_future<> back to future<>
- [Issue #1091⁵⁸⁵⁹](#) - Inconsistent error message
- [Issue #1090⁵⁸⁶⁰](#) - On windows 8.1 the examples crashed if using more than one os thread
- [Issue #1089⁵⁸⁶¹](#) - Components should be allowed to have their own executor
- [Issue #1088⁵⁸⁶²](#) - Add possibility to select a network interface for the ibverbs parcelport
- [Issue #1087⁵⁸⁶³](#) - ibverbs and ipc parcelport uses zero copy optimization
- [Issue #1083⁵⁸⁶⁴](#) - Make shell examples copyable in docs
- [Issue #1082⁵⁸⁶⁵](#) - Implement proper termination detection during shutdown
- [Issue #1081⁵⁸⁶⁶](#) - Implement thread_specific_ptr for hpx::threads
- [Issue #1072⁵⁸⁶⁷](#) - make install not working properly
- [Issue #1070⁵⁸⁶⁸](#) - Complete quoting for parameters of some CMake commands

⁵⁸⁴⁶ <https://github.com/STELLAR-GROUP/hpx/issues/1104>

⁵⁸⁴⁷ <https://github.com/STELLAR-GROUP/hpx/issues/1103>

⁵⁸⁴⁸ <https://github.com/STELLAR-GROUP/hpx/issues/1102>

⁵⁸⁴⁹ <https://github.com/STELLAR-GROUP/hpx/issues/1101>

⁵⁸⁵⁰ <https://github.com/STELLAR-GROUP/hpx/issues/1100>

⁵⁸⁵¹ <https://github.com/STELLAR-GROUP/hpx/issues/1099>

⁵⁸⁵² <https://github.com/STELLAR-GROUP/hpx/issues/1098>

⁵⁸⁵³ <https://github.com/STELLAR-GROUP/hpx/issues/1097>

⁵⁸⁵⁴ <https://github.com/STELLAR-GROUP/hpx/issues/1096>

⁵⁸⁵⁵ <https://github.com/STELLAR-GROUP/hpx/issues/1095>

⁵⁸⁵⁶ <https://github.com/STELLAR-GROUP/hpx/issues/1094>

⁵⁸⁵⁷ <https://github.com/STELLAR-GROUP/hpx/issues/1093>

⁵⁸⁵⁸ <https://github.com/STELLAR-GROUP/hpx/issues/1092>

⁵⁸⁵⁹ <https://github.com/STELLAR-GROUP/hpx/issues/1091>

⁵⁸⁶⁰ <https://github.com/STELLAR-GROUP/hpx/issues/1090>

⁵⁸⁶¹ <https://github.com/STELLAR-GROUP/hpx/issues/1089>

⁵⁸⁶² <https://github.com/STELLAR-GROUP/hpx/issues/1088>

⁵⁸⁶³ <https://github.com/STELLAR-GROUP/hpx/issues/1087>

⁵⁸⁶⁴ <https://github.com/STELLAR-GROUP/hpx/issues/1083>

⁵⁸⁶⁵ <https://github.com/STELLAR-GROUP/hpx/issues/1082>

⁵⁸⁶⁶ <https://github.com/STELLAR-GROUP/hpx/issues/1081>

⁵⁸⁶⁷ <https://github.com/STELLAR-GROUP/hpx/issues/1072>

⁵⁸⁶⁸ <https://github.com/STELLAR-GROUP/hpx/issues/1070>

- Issue #1059⁵⁸⁶⁹ - Fix more unused variable warnings
- Issue #1051⁵⁸⁷⁰ - Implement when_each
- Issue #973⁵⁸⁷¹ - Would like option to report hwloc bindings
- Issue #970⁵⁸⁷² - Bad flags for Fortran compiler
- Issue #941⁵⁸⁷³ - Create a proper user level context switching class for BG/Q
- Issue #935⁵⁸⁷⁴ - Build error with gcc 4.6 and Boost 1.54.0 on hpx trunk and 0.9.6
- Issue #934⁵⁸⁷⁵ - Want to build HPX without dynamic libraries
- Issue #927⁵⁸⁷⁶ - Make hpx/lcos/reduce.hpp accept futures of id_type
- Issue #926⁵⁸⁷⁷ - All unit tests that are run with more than one thread with CTest/hpx_run_test should configure hpx.os_threads
- Issue #925⁵⁸⁷⁸ - regression_dataflow_791 needs to be brought in line with HPX standards
- Issue #899⁵⁸⁷⁹ - Fix race conditions in regression tests
- Issue #879⁵⁸⁸⁰ - Hung test leads to cascading test failure; make tests should support the MPI parcelport
- Issue #865⁵⁸⁸¹ - future<T> and friends shall work for movable only Ts
- Issue #847⁵⁸⁸² - Dynamic libraries are not installed on OS X
- Issue #816⁵⁸⁸³ - First Program tutorial pull request
- Issue #799⁵⁸⁸⁴ - Wrap lexical_cast to avoid exceptions
- Issue #720⁵⁸⁸⁵ - broken configuration when using cmake on Ubuntu
- Issue #622⁵⁸⁸⁶ - --hpx:hpx and --hpx:debug-hpx-log is nonsensical
- Issue #525⁵⁸⁸⁷ - Extend barrier LCO test to run in distributed
- Issue #515⁵⁸⁸⁸ - Multi-destination version of hpx::apply is broken
- Issue #509⁵⁸⁸⁹ - Push Boost.Atomic changes upstream
- Issue #503⁵⁸⁹⁰ - Running HPX applications on Windows should not require setting %PATH%
- Issue #461⁵⁸⁹¹ - Add a compilation sanity test

5869 <https://github.com/STELLAR-GROUP/hpx/issues/1059>

5870 <https://github.com/STELLAR-GROUP/hpx/issues/1051>

5871 <https://github.com/STELLAR-GROUP/hpx/issues/973>

5872 <https://github.com/STELLAR-GROUP/hpx/issues/970>

5873 <https://github.com/STELLAR-GROUP/hpx/issues/941>

5874 <https://github.com/STELLAR-GROUP/hpx/issues/935>

5875 <https://github.com/STELLAR-GROUP/hpx/issues/934>

5876 <https://github.com/STELLAR-GROUP/hpx/issues/927>

5877 <https://github.com/STELLAR-GROUP/hpx/issues/926>

5878 <https://github.com/STELLAR-GROUP/hpx/issues/925>

5879 <https://github.com/STELLAR-GROUP/hpx/issues/899>

5880 <https://github.com/STELLAR-GROUP/hpx/issues/879>

5881 <https://github.com/STELLAR-GROUP/hpx/issues/865>

5882 <https://github.com/STELLAR-GROUP/hpx/issues/847>

5883 <https://github.com/STELLAR-GROUP/hpx/issues/816>

5884 <https://github.com/STELLAR-GROUP/hpx/issues/799>

5885 <https://github.com/STELLAR-GROUP/hpx/issues/720>

5886 <https://github.com/STELLAR-GROUP/hpx/issues/622>

5887 <https://github.com/STELLAR-GROUP/hpx/issues/525>

5888 <https://github.com/STELLAR-GROUP/hpx/issues/515>

5889 <https://github.com/STELLAR-GROUP/hpx/issues/509>

5890 <https://github.com/STELLAR-GROUP/hpx/issues/503>

5891 <https://github.com/STELLAR-GROUP/hpx/issues/461>

- Issue #456⁵⁸⁹² - hpx_run_tests.py should log output from tests that timeout
- Issue #454⁵⁸⁹³ - Investigate threadmanager performance
- Issue #345⁵⁸⁹⁴ - Add more versatile environmental/cmake variable support to hpx_find_* CMake macros
- Issue #209⁵⁸⁹⁵ - Support multiple configurations in generated build files
- Issue #190⁵⁸⁹⁶ - hpx::cout should be a std::ostream
- Issue #189⁵⁸⁹⁷ - iostreams component should use startup/shutdown functions
- Issue #183⁵⁸⁹⁸ - Use Boost.ICL for correctness in AGAS
- Issue #44⁵⁸⁹⁹ - Implement real futures

HPX V0.9.8 (Mar 24, 2014)

We have had over 800 commits since the last release and we have closed over 65 tickets (bugs, feature requests, etc.).

With the changes below, *HPX* is once again leading the charge of a whole new era of computation. By intrinsically breaking down and synchronizing the work to be done, *HPX* insures that application developers will no longer have to fret about where a segment of code executes. That allows coders to focus their time and energy to understanding the data dependencies of their algorithms and thereby the core obstacles to an efficient code. Here are some of the advantages of using *HPX*:

- *HPX* is solidly rooted in a sophisticated theoretical execution model – ParalleX
- *HPX* exposes an API fully conforming to the C++11 and the draft C++14 standards, extended and applied to distributed computing. Everything programmers know about the concurrency primitives of the standard C++ library is still valid in the context of *HPX*.
- It provides a competitive, high performance implementation of modern, future-proof ideas which gives an smooth migration path from today’s mainstream techniques
- There is no need for the programmer to worry about lower level parallelization paradigms like threads or message passing; no need to understand pthreads, MPI, OpenMP, or Windows threads, etc.
- There is no need to think about different types of parallelism such as tasks, pipelines, or fork-join, task or data parallelism.
- The same source of your program compiles and runs on Linux, BlueGene/Q, Mac OS X, Windows, and Android.
- The same code runs on shared memory multi-core systems and supercomputers, on handheld devices and Intel® Xeon Phi™ accelerators, or a heterogeneous mix of those.

⁵⁸⁹² <https://github.com/STELLAR-GROUP/hpx/issues/456>

⁵⁸⁹³ <https://github.com/STELLAR-GROUP/hpx/issues/454>

⁵⁸⁹⁴ <https://github.com/STELLAR-GROUP/hpx/issues/345>

⁵⁸⁹⁵ <https://github.com/STELLAR-GROUP/hpx/issues/209>

⁵⁸⁹⁶ <https://github.com/STELLAR-GROUP/hpx/issues/190>

⁵⁸⁹⁷ <https://github.com/STELLAR-GROUP/hpx/issues/189>

⁵⁸⁹⁸ <https://github.com/STELLAR-GROUP/hpx/issues/183>

⁵⁸⁹⁹ <https://github.com/STELLAR-GROUP/hpx/issues/44>

General changes

- A major API breaking change for this release was introduced by implementing `hpx::future` and `hpx::shared_future` fully in conformance with the C++11 Standard⁵⁹⁰⁰. While `hpx::shared_future` is new and will not create any compatibility problems, we revised the interface and implementation of the existing `hpx::future`. For more details please see the [mailing list archive](#)⁵⁹⁰¹. To avoid any incompatibilities for existing code we named the type which implements the `std::future` interface as `hpx::unique_future`. For the next release this will be renamed to `hpx::future`, making it full conforming to C++11 Standard⁵⁹⁰².
- A large part of the code base of *HPX* has been refactored and partially re-implemented. The main changes were related to
 - The threading subsystem: these changes significantly reduce the amount of overheads caused by the schedulers, improve the modularity of the code base, and extend the variety of available scheduling algorithms.
 - The parcel subsystem: these changes improve the performance of the *HPX* networking layer, modularize the structure of the parcelports, and simplify the creation of new parcelports for other underlying networking libraries.
 - The API subsystem: these changes improved the conformance of the API to C++11 Standard, extend and unify the available API functionality, and decrease the overheads created by various elements of the API.
 - The robustness of the component loading subsystem has been improved significantly, allowing to more portably and more reliably register the components needed by an application as startup. This additionally speeds up general application initialization.
- We added new API functionality like `hpx::migrate` and `hpx::copy_component` which are the basic building blocks necessary for implementing higher level abstractions for system-wide load balancing, runtime-adaptive resource management, and object-oriented checkpointing and state-management.
- We removed the use of C++11 move emulation (using `Boost.Move`), replacing it with C++11 rvalue references. This is the first step towards using more and more native C++11 facilities which we plan to introduce in the future.
- We improved the reference counting scheme used by *HPX* which helps managing distributed objects and memory. This improves the overall stability of *HPX* and further simplifies writing real world applications.
- The minimal Boost version required to use *HPX* is now V1.49.0.
- This release coincides with the first release of HPXPI (V0.1.0), the first implementation of the *XPI specification*⁵⁹⁰³.

Bug fixes (closed tickets)

Here is a list of the important tickets we closed for this release.

- [Issue #1086](#)⁵⁹⁰⁴ - Expose internal `boost::shared_array` to allow user management of array lifetime
- [Issue #1083](#)⁵⁹⁰⁵ - Make shell examples copyable in docs
- [Issue #1080](#)⁵⁹⁰⁶ - `/threads{locality#*/total}/count/cumulative` broken
- [Issue #1079](#)⁵⁹⁰⁷ - Build problems on OS X

⁵⁹⁰⁰ <http://www.open-std.org/jtc1/sc22/wg21>

⁵⁹⁰¹ <http://mail.cct.lsu.edu/pipermail/hpx-users/2014-January/000141.html>

⁵⁹⁰² <http://www.open-std.org/jtc1/sc22/wg21>

⁵⁹⁰³ <https://github.com/STELLAR-GROUP/hpxpi/blob/master/spec.pdf?raw=true>

⁵⁹⁰⁴ <https://github.com/STELLAR-GROUP/hpx/issues/1086>

⁵⁹⁰⁵ <https://github.com/STELLAR-GROUP/hpx/issues/1083>

⁵⁹⁰⁶ <https://github.com/STELLAR-GROUP/hpx/issues/1080>

⁵⁹⁰⁷ <https://github.com/STELLAR-GROUP/hpx/issues/1079>

- [Issue #1078⁵⁹⁰⁸](#) - Improve robustness of component loading
- [Issue #1077⁵⁹⁰⁹](#) - Fix a missing enum definition for ‘take’ mode
- [Issue #1076⁵⁹¹⁰](#) - Merge Jb master
- [Issue #1075⁵⁹¹¹](#) - Unknown CMake command “add_hpx_pseudo_target”
- [Issue #1074⁵⁹¹²](#) - Implement `apply_continue_callback` and `apply_colocated_callback`
- [Issue #1073⁵⁹¹³](#) - The new `apply_colocated` and `async_colocated` functions lead to automatic registered functions
- [Issue #1071⁵⁹¹⁴](#) - Remove `deferred_packaged_task`
- [Issue #1069⁵⁹¹⁵](#) - `serialize_buffer` with allocator fails at destruction
- [Issue #1068⁵⁹¹⁶](#) - Coroutine include and forward declarations missing
- [Issue #1067⁵⁹¹⁷](#) - Add allocator support to `util::serialize_buffer`
- [Issue #1066⁵⁹¹⁸](#) - Allow for `MPI_Init` being called before HPX launches
- [Issue #1065⁵⁹¹⁹](#) - AGAS cache isn’t used/populated on worker localities
- [Issue #1064⁵⁹²⁰](#) - Reorder includes to ensure `ws2` includes early
- [Issue #1063⁵⁹²¹](#) - Add `hpx::runtime::suspend` and `hpx::runtime::resume`
- [Issue #1062⁵⁹²²](#) - Fix `async_continue` to properly handle return types
- [Issue #1061⁵⁹²³](#) - Implement `async_colocated` and `apply_colocated`
- [Issue #1060⁵⁹²⁴](#) - Implement minimal component migration
- [Issue #1058⁵⁹²⁵](#) - Remove `HPX_UTIL_TUPLE` from code base
- [Issue #1057⁵⁹²⁶](#) - Add performance counters for threading subsystem
- [Issue #1055⁵⁹²⁷](#) - Thread allocation uses two memory pools
- [Issue #1053⁵⁹²⁸](#) - Work stealing flawed
- [Issue #1052⁵⁹²⁹](#) - Fix a number of warnings
- [Issue #1049⁵⁹³⁰](#) - Fixes for TLS on OSX and more reliable test running

⁵⁹⁰⁸ <https://github.com/STELLAR-GROUP/hpx/issues/1078>

⁵⁹⁰⁹ <https://github.com/STELLAR-GROUP/hpx/issues/1077>

⁵⁹¹⁰ <https://github.com/STELLAR-GROUP/hpx/issues/1076>

⁵⁹¹¹ <https://github.com/STELLAR-GROUP/hpx/issues/1075>

⁵⁹¹² <https://github.com/STELLAR-GROUP/hpx/issues/1074>

⁵⁹¹³ <https://github.com/STELLAR-GROUP/hpx/issues/1073>

⁵⁹¹⁴ <https://github.com/STELLAR-GROUP/hpx/issues/1071>

⁵⁹¹⁵ <https://github.com/STELLAR-GROUP/hpx/issues/1069>

⁵⁹¹⁶ <https://github.com/STELLAR-GROUP/hpx/issues/1068>

⁵⁹¹⁷ <https://github.com/STELLAR-GROUP/hpx/issues/1067>

⁵⁹¹⁸ <https://github.com/STELLAR-GROUP/hpx/issues/1066>

⁵⁹¹⁹ <https://github.com/STELLAR-GROUP/hpx/issues/1065>

⁵⁹²⁰ <https://github.com/STELLAR-GROUP/hpx/issues/1064>

⁵⁹²¹ <https://github.com/STELLAR-GROUP/hpx/issues/1063>

⁵⁹²² <https://github.com/STELLAR-GROUP/hpx/issues/1062>

⁵⁹²³ <https://github.com/STELLAR-GROUP/hpx/issues/1061>

⁵⁹²⁴ <https://github.com/STELLAR-GROUP/hpx/issues/1060>

⁵⁹²⁵ <https://github.com/STELLAR-GROUP/hpx/issues/1058>

⁵⁹²⁶ <https://github.com/STELLAR-GROUP/hpx/issues/1057>

⁵⁹²⁷ <https://github.com/STELLAR-GROUP/hpx/issues/1055>

⁵⁹²⁸ <https://github.com/STELLAR-GROUP/hpx/issues/1053>

⁵⁹²⁹ <https://github.com/STELLAR-GROUP/hpx/issues/1052>

⁵⁹³⁰ <https://github.com/STELLAR-GROUP/hpx/issues/1049>

- Issue #1048⁵⁹³¹ - Fixing after 588 hang
- Issue #1047⁵⁹³² - Use port '0' for networking when using one locality
- Issue #1046⁵⁹³³ - `composable_guard` test is broken when having more than one thread
- Issue #1045⁵⁹³⁴ - Security missing headers
- Issue #1044⁵⁹³⁵ - Native TLS on FreeBSD via `__thread`
- Issue #1043⁵⁹³⁶ - `async` et.al. compute the wrong result type
- Issue #1042⁵⁹³⁷ - `async` et.al. implicitly unwrap `reference_wrappers`
- Issue #1041⁵⁹³⁸ - Remove redundant costly Kleene stars from regex searches
- Issue #1040⁵⁹³⁹ - CMake script regex match patterns has unnecessary kleenes
- Issue #1039⁵⁹⁴⁰ - Remove use of `Boost.Move` and replace with `std::move` and real rvalue refs
- Issue #1038⁵⁹⁴¹ - Bump minimal required Boost to 1.49.0
- Issue #1037⁵⁹⁴² - Implicit unwrapping of futures in `async` broken
- Issue #1036⁵⁹⁴³ - Scheduler hangs when user code attempts to “block” OS-threads
- Issue #1035⁵⁹⁴⁴ - Idle-rate counter always reports 100% idle rate
- Issue #1034⁵⁹⁴⁵ - Symbolic name registration causes application hangs
- Issue #1033⁵⁹⁴⁶ - Application options read in from an options file generate an error message
- Issue #1032⁵⁹⁴⁷ - `hpx::id_type` local reference counting is wrong
- Issue #1031⁵⁹⁴⁸ - Negative entry in reference count table
- Issue #1030⁵⁹⁴⁹ - Implement `condition_variable`
- Issue #1029⁵⁹⁵⁰ - Deadlock in thread scheduling subsystem
- Issue #1028⁵⁹⁵¹ - HPX-thread cumulative count performance counters report incorrect value
- Issue #1027⁵⁹⁵² - Expose `hpx::thread_interrupted` error code as a separate exception type
- Issue #1026⁵⁹⁵³ - Exceptions thrown in asynchronous calls can be lost if the value of the future is never queried

⁵⁹³¹ <https://github.com/STELLAR-GROUP/hpx/issues/1048>

⁵⁹³² <https://github.com/STELLAR-GROUP/hpx/issues/1047>

⁵⁹³³ <https://github.com/STELLAR-GROUP/hpx/issues/1046>

⁵⁹³⁴ <https://github.com/STELLAR-GROUP/hpx/issues/1045>

⁵⁹³⁵ <https://github.com/STELLAR-GROUP/hpx/issues/1044>

⁵⁹³⁶ <https://github.com/STELLAR-GROUP/hpx/issues/1043>

⁵⁹³⁷ <https://github.com/STELLAR-GROUP/hpx/issues/1042>

⁵⁹³⁸ <https://github.com/STELLAR-GROUP/hpx/issues/1041>

⁵⁹³⁹ <https://github.com/STELLAR-GROUP/hpx/issues/1040>

⁵⁹⁴⁰ <https://github.com/STELLAR-GROUP/hpx/issues/1039>

⁵⁹⁴¹ <https://github.com/STELLAR-GROUP/hpx/issues/1038>

⁵⁹⁴² <https://github.com/STELLAR-GROUP/hpx/issues/1037>

⁵⁹⁴³ <https://github.com/STELLAR-GROUP/hpx/issues/1036>

⁵⁹⁴⁴ <https://github.com/STELLAR-GROUP/hpx/issues/1035>

⁵⁹⁴⁵ <https://github.com/STELLAR-GROUP/hpx/issues/1034>

⁵⁹⁴⁶ <https://github.com/STELLAR-GROUP/hpx/issues/1033>

⁵⁹⁴⁷ <https://github.com/STELLAR-GROUP/hpx/issues/1032>

⁵⁹⁴⁸ <https://github.com/STELLAR-GROUP/hpx/issues/1031>

⁵⁹⁴⁹ <https://github.com/STELLAR-GROUP/hpx/issues/1030>

⁵⁹⁵⁰ <https://github.com/STELLAR-GROUP/hpx/issues/1029>

⁵⁹⁵¹ <https://github.com/STELLAR-GROUP/hpx/issues/1028>

⁵⁹⁵² <https://github.com/STELLAR-GROUP/hpx/issues/1027>

⁵⁹⁵³ <https://github.com/STELLAR-GROUP/hpx/issues/1026>

- [Issue #1025⁵⁹⁵⁴](#) - `future::wait_for/wait_until` do not remove callback
- [Issue #1024⁵⁹⁵⁵](#) - Remove dependence to boost assert and create hpx assert
- [Issue #1023⁵⁹⁵⁶](#) - Segfaults with `tcmalloc`
- [Issue #1022⁵⁹⁵⁷](#) - prerequisites link in readme is broken
- [Issue #1020⁵⁹⁵⁸](#) - HPX Deadlock on external synchronization
- [Issue #1019⁵⁹⁵⁹](#) - Convert using `BOOST_ASSERT` to `HPX_ASSERT`
- [Issue #1018⁵⁹⁶⁰](#) - compiling bug with gcc 4.8.1
- [Issue #1017⁵⁹⁶¹](#) - Possible crash in `io_pool` executor
- [Issue #1016⁵⁹⁶²](#) - Crash at startup
- [Issue #1014⁵⁹⁶³](#) - Implement Increment/Decrement Merging
- [Issue #1013⁵⁹⁶⁴](#) - Add more logging channels to enable greater control over logging granularity
- [Issue #1012⁵⁹⁶⁵](#) - `--hpx:debug-hpx-log` and `--hpx:debug-agas-log` lead to non-thread safe writes
- [Issue #1011⁵⁹⁶⁶](#) - After installation, running applications from the build/staging directory no longer works
- [Issue #1010⁵⁹⁶⁷](#) - Mergeable decrement requests are not being merged
- [Issue #1009⁵⁹⁶⁸](#) - `--hpx:list-symbolic-names` crashes
- [Issue #1007⁵⁹⁶⁹](#) - Components are not properly destroyed
- [Issue #1006⁵⁹⁷⁰](#) - Segfault/hang in `set_data`
- [Issue #1003⁵⁹⁷¹](#) - Performance counter naming issue
- [Issue #982⁵⁹⁷²](#) - Race condition during startup
- [Issue #912⁵⁹⁷³](#) - OS X: component type not found in map
- [Issue #663⁵⁹⁷⁴](#) - Create a buildbot slave based on Clang 3.2/OSX
- [Issue #636⁵⁹⁷⁵](#) - Expose `this_locality::apply<act>(p1, p2)`; for local execution
- [Issue #197⁵⁹⁷⁶](#) - Add `--console=address` option for PBS runs

⁵⁹⁵⁴ <https://github.com/STELLAR-GROUP/hpx/issues/1025>

⁵⁹⁵⁵ <https://github.com/STELLAR-GROUP/hpx/issues/1024>

⁵⁹⁵⁶ <https://github.com/STELLAR-GROUP/hpx/issues/1023>

⁵⁹⁵⁷ <https://github.com/STELLAR-GROUP/hpx/issues/1022>

⁵⁹⁵⁸ <https://github.com/STELLAR-GROUP/hpx/issues/1020>

⁵⁹⁵⁹ <https://github.com/STELLAR-GROUP/hpx/issues/1019>

⁵⁹⁶⁰ <https://github.com/STELLAR-GROUP/hpx/issues/1018>

⁵⁹⁶¹ <https://github.com/STELLAR-GROUP/hpx/issues/1017>

⁵⁹⁶² <https://github.com/STELLAR-GROUP/hpx/issues/1016>

⁵⁹⁶³ <https://github.com/STELLAR-GROUP/hpx/issues/1014>

⁵⁹⁶⁴ <https://github.com/STELLAR-GROUP/hpx/issues/1013>

⁵⁹⁶⁵ <https://github.com/STELLAR-GROUP/hpx/issues/1012>

⁵⁹⁶⁶ <https://github.com/STELLAR-GROUP/hpx/issues/1011>

⁵⁹⁶⁷ <https://github.com/STELLAR-GROUP/hpx/issues/1010>

⁵⁹⁶⁸ <https://github.com/STELLAR-GROUP/hpx/issues/1009>

⁵⁹⁶⁹ <https://github.com/STELLAR-GROUP/hpx/issues/1007>

⁵⁹⁷⁰ <https://github.com/STELLAR-GROUP/hpx/issues/1006>

⁵⁹⁷¹ <https://github.com/STELLAR-GROUP/hpx/issues/1003>

⁵⁹⁷² <https://github.com/STELLAR-GROUP/hpx/issues/982>

⁵⁹⁷³ <https://github.com/STELLAR-GROUP/hpx/issues/912>

⁵⁹⁷⁴ <https://github.com/STELLAR-GROUP/hpx/issues/663>

⁵⁹⁷⁵ <https://github.com/STELLAR-GROUP/hpx/issues/636>

⁵⁹⁷⁶ <https://github.com/STELLAR-GROUP/hpx/issues/197>

- [Issue #175⁵⁹⁷⁷](#) - Asynchronous AGAS API

HPX V0.9.7 (Nov 13, 2013)

We have had over 1000 commits since the last release and we have closed over 180 tickets (bugs, feature requests, etc.).

General changes

- Ported HPX to BlueGene/Q
- Improved HPX support for Xeon/Phi accelerators
- Reimplemented `hpx::bind`, `hpx::tuple`, and `hpx::function` for better performance and better compliance with the C++11 Standard. Added `hpx::mem_fn`.
- Reworked `hpx::when_all` and `hpx::when_any` for better compliance with the ongoing C++ standardization effort, added heterogeneous version for those functions. Added `hpx::when_any_swapped`.
- Added `hpx::copy` as a precursor for a migrate functionality
- Added `hpx::get_ptr` allowing to directly access the memory underlying a given component
- Added the `hpx::lcos::broadcast`, `hpx::lcos::reduce`, and `hpx::lcos::fold` collective operations
- Added `hpx::get_locality_name` allowing to retrieve the name of any of the localities for the application.
- Added support for more flexible thread affinity control from the HPX command line, such as new modes for `--hpx:bind` (`balanced`, `scattered`, `compact`), improved default settings when running multiple localities on the same node.
- Added experimental executors for simpler thread pooling and scheduling. This API may change in the future as it will stay aligned with the ongoing C++ standardization efforts.
- Massively improved the performance of the HPX serialization code. Added partial support for zero copy serialization of array and bitwise-copyable types.
- General performance improvements of the code related to threads and futures.

Bug fixes (closed tickets)

Here is a list of the important tickets we closed for this release.

- [Issue #1005⁵⁹⁷⁸](#) - Allow one to disable array optimizations and zero copy optimizations for each parcelport
- [Issue #1004⁵⁹⁷⁹](#) - Generate new HPX logo image for the docs
- [Issue #1002⁵⁹⁸⁰](#) - If MPI parcelport is not available, running HPX under mpirun should fail
- [Issue #1001⁵⁹⁸¹](#) - Zero copy serialization raises assert
- [Issue #1000⁵⁹⁸²](#) - Can't connect to a HPX application running with the MPI parcelport from a non MPI parcelport locality
- [Issue #999⁵⁹⁸³](#) - Optimize `hpx::when_n`

⁵⁹⁷⁷ <https://github.com/STELLAR-GROUP/hpx/issues/175>

⁵⁹⁷⁸ <https://github.com/STELLAR-GROUP/hpx/issues/1005>

⁵⁹⁷⁹ <https://github.com/STELLAR-GROUP/hpx/issues/1004>

⁵⁹⁸⁰ <https://github.com/STELLAR-GROUP/hpx/issues/1002>

⁵⁹⁸¹ <https://github.com/STELLAR-GROUP/hpx/issues/1001>

⁵⁹⁸² <https://github.com/STELLAR-GROUP/hpx/issues/1000>

⁵⁹⁸³ <https://github.com/STELLAR-GROUP/hpx/issues/999>

- [Issue #998⁵⁹⁸⁴](#) - Fixed const-correctness
- [Issue #997⁵⁹⁸⁵](#) - Making `serialize_buffer::data()` type save
- [Issue #996⁵⁹⁸⁶](#) - Memory leak in `hpx::lcos::promise`
- [Issue #995⁵⁹⁸⁷](#) - Race while registering pre-shutdown functions
- [Issue #994⁵⁹⁸⁸](#) - `thread_rescheduling` regression test does not compile
- [Issue #992⁵⁹⁸⁹](#) - Correct comments and messages
- [Issue #991⁵⁹⁹⁰](#) - `setcap cap_sys_rawio=ep` for power profiling causes an HPX application to abort
- [Issue #989⁵⁹⁹¹](#) - Jacobi hangs during execution
- [Issue #988⁵⁹⁹²](#) - `multiple_init` test is failing
- [Issue #986⁵⁹⁹³](#) - Can't call a function called "init" from "main" when using `<hpx/hpx_main.hpp>`
- [Issue #984⁵⁹⁹⁴](#) - Reference counting tests are failing
- [Issue #983⁵⁹⁹⁵](#) - `thread_suspension_executor` test fails
- [Issue #980⁵⁹⁹⁶](#) - Terminating HPX threads don't leave stack in virgin state
- [Issue #979⁵⁹⁹⁷](#) - Static scheduler not in documents
- [Issue #978⁵⁹⁹⁸](#) - Preprocessing limits are broken
- [Issue #977⁵⁹⁹⁹](#) - Make `tests.regressions.lcos.future_hang_on_get` shorter
- [Issue #976⁶⁰⁰⁰](#) - Wrong library order in `pkgconfig`
- [Issue #975⁶⁰⁰¹](#) - Please reopen #963
- [Issue #974⁶⁰⁰²](#) - Option `pu-offset` ignored in `fixing_588` branch
- [Issue #972⁶⁰⁰³](#) - Cannot use MKL with HPX
- [Issue #969⁶⁰⁰⁴](#) - Non-existent INI files requested on the command line via `--hpx:config` do not cause warnings or errors.
- [Issue #968⁶⁰⁰⁵](#) - Cannot build examples in `fixing_588` branch
- [Issue #967⁶⁰⁰⁶](#) - Command line description of `--hpx:queuing` seems wrong

⁵⁹⁸⁴ <https://github.com/STELLAR-GROUP/hpx/issues/998>

⁵⁹⁸⁵ <https://github.com/STELLAR-GROUP/hpx/issues/997>

⁵⁹⁸⁶ <https://github.com/STELLAR-GROUP/hpx/issues/996>

⁵⁹⁸⁷ <https://github.com/STELLAR-GROUP/hpx/issues/995>

⁵⁹⁸⁸ <https://github.com/STELLAR-GROUP/hpx/issues/994>

⁵⁹⁸⁹ <https://github.com/STELLAR-GROUP/hpx/issues/992>

⁵⁹⁹⁰ <https://github.com/STELLAR-GROUP/hpx/issues/991>

⁵⁹⁹¹ <https://github.com/STELLAR-GROUP/hpx/issues/989>

⁵⁹⁹² <https://github.com/STELLAR-GROUP/hpx/issues/988>

⁵⁹⁹³ <https://github.com/STELLAR-GROUP/hpx/issues/986>

⁵⁹⁹⁴ <https://github.com/STELLAR-GROUP/hpx/issues/984>

⁵⁹⁹⁵ <https://github.com/STELLAR-GROUP/hpx/issues/983>

⁵⁹⁹⁶ <https://github.com/STELLAR-GROUP/hpx/issues/980>

⁵⁹⁹⁷ <https://github.com/STELLAR-GROUP/hpx/issues/979>

⁵⁹⁹⁸ <https://github.com/STELLAR-GROUP/hpx/issues/978>

⁵⁹⁹⁹ <https://github.com/STELLAR-GROUP/hpx/issues/977>

⁶⁰⁰⁰ <https://github.com/STELLAR-GROUP/hpx/issues/976>

⁶⁰⁰¹ <https://github.com/STELLAR-GROUP/hpx/issues/975>

⁶⁰⁰² <https://github.com/STELLAR-GROUP/hpx/issues/974>

⁶⁰⁰³ <https://github.com/STELLAR-GROUP/hpx/issues/972>

⁶⁰⁰⁴ <https://github.com/STELLAR-GROUP/hpx/issues/969>

⁶⁰⁰⁵ <https://github.com/STELLAR-GROUP/hpx/issues/968>

⁶⁰⁰⁶ <https://github.com/STELLAR-GROUP/hpx/issues/967>

- Issue #966⁶⁰⁰⁷ - `--hpx:print-bind` physical core numbers are wrong
- Issue #965⁶⁰⁰⁸ - Deadlock when building in Release mode
- Issue #963⁶⁰⁰⁹ - Not all worker threads are working
- Issue #962⁶⁰¹⁰ - Problem with SLURM integration
- Issue #961⁶⁰¹¹ - `--hpx:print-bind` outputs incorrect information
- Issue #960⁶⁰¹² - Fix cut and paste error in documentation of `get_thread_priority`
- Issue #959⁶⁰¹³ - Change link to `boost.atomic` in documentation to point to `boost.org`
- Issue #958⁶⁰¹⁴ - Undefined reference to `intrusive_ptr_release`
- Issue #957⁶⁰¹⁵ - Make tuple standard compliant
- Issue #956⁶⁰¹⁶ - Segfault with `a3382fb`
- Issue #955⁶⁰¹⁷ - `--hpx:nodes` and `--hpx:nodefiles` do not work with foreign nodes
- Issue #954⁶⁰¹⁸ - Make order of arguments for `hpx::async` and `hpx::broadcast` consistent
- Issue #953⁶⁰¹⁹ - Cannot use MKL with HPX
- Issue #952⁶⁰²⁰ - `register_[pre_]shutdown_function` never throw
- Issue #951⁶⁰²¹ - Assert when number of threads is greater than hardware concurrency
- Issue #948⁶⁰²² - `HPX_HAVE_GENERIC_CONTEXT_COROUTINES` conflicts with `HPX_HAVE_FIBER_BASED_COROUTINES`
- Issue #947⁶⁰²³ - Need `MPI_THREAD_MULTIPLE` for backward compatibility
- Issue #946⁶⁰²⁴ - HPX does not call `MPI_Finalize`
- Issue #945⁶⁰²⁵ - Segfault with `hpx::lcos::broadcast`
- Issue #944⁶⁰²⁶ - OS X: assertion `pu_offset_ < hardware_concurrency` failed
- Issue #943⁶⁰²⁷ - `#include <hpx/hpx_main.hpp>` does not work
- Issue #942⁶⁰²⁸ - Make the BG/Q work with `-O3`
- Issue #940⁶⁰²⁹ - Use separator when concatenating locality name

⁶⁰⁰⁷ <https://github.com/STELLAR-GROUP/hpx/issues/966>

⁶⁰⁰⁸ <https://github.com/STELLAR-GROUP/hpx/issues/965>

⁶⁰⁰⁹ <https://github.com/STELLAR-GROUP/hpx/issues/963>

⁶⁰¹⁰ <https://github.com/STELLAR-GROUP/hpx/issues/962>

⁶⁰¹¹ <https://github.com/STELLAR-GROUP/hpx/issues/961>

⁶⁰¹² <https://github.com/STELLAR-GROUP/hpx/issues/960>

⁶⁰¹³ <https://github.com/STELLAR-GROUP/hpx/issues/959>

⁶⁰¹⁴ <https://github.com/STELLAR-GROUP/hpx/issues/958>

⁶⁰¹⁵ <https://github.com/STELLAR-GROUP/hpx/issues/957>

⁶⁰¹⁶ <https://github.com/STELLAR-GROUP/hpx/issues/956>

⁶⁰¹⁷ <https://github.com/STELLAR-GROUP/hpx/issues/955>

⁶⁰¹⁸ <https://github.com/STELLAR-GROUP/hpx/issues/954>

⁶⁰¹⁹ <https://github.com/STELLAR-GROUP/hpx/issues/953>

⁶⁰²⁰ <https://github.com/STELLAR-GROUP/hpx/issues/952>

⁶⁰²¹ <https://github.com/STELLAR-GROUP/hpx/issues/951>

⁶⁰²² <https://github.com/STELLAR-GROUP/hpx/issues/948>

⁶⁰²³ <https://github.com/STELLAR-GROUP/hpx/issues/947>

⁶⁰²⁴ <https://github.com/STELLAR-GROUP/hpx/issues/946>

⁶⁰²⁵ <https://github.com/STELLAR-GROUP/hpx/issues/945>

⁶⁰²⁶ <https://github.com/STELLAR-GROUP/hpx/issues/944>

⁶⁰²⁷ <https://github.com/STELLAR-GROUP/hpx/issues/943>

⁶⁰²⁸ <https://github.com/STELLAR-GROUP/hpx/issues/942>

⁶⁰²⁹ <https://github.com/STELLAR-GROUP/hpx/issues/940>

- [Issue #939](#)⁶⁰³⁰ - Refactor MPI parcelport to use MPI_Wait instead of multiple MPI_Test calls
- [Issue #938](#)⁶⁰³¹ - Want to officially access client_base::gid_
- [Issue #937](#)⁶⁰³² - client_base::gid_ should be private`
- [Issue #936](#)⁶⁰³³ - Want doxygen-like source code index
- [Issue #935](#)⁶⁰³⁴ - Build error with gcc 4.6 and Boost 1.54.0 on hpx trunk and 0.9.6
- [Issue #933](#)⁶⁰³⁵ - Cannot build HPX with Boost 1.54.0
- [Issue #932](#)⁶⁰³⁶ - Components are destructed too early
- [Issue #931](#)⁶⁰³⁷ - Make HPX work on BG/Q
- [Issue #930](#)⁶⁰³⁸ - make git-docs is broken
- [Issue #929](#)⁶⁰³⁹ - Generating index in docs broken
- [Issue #928](#)⁶⁰⁴⁰ - Optimize hpx::util::static_ for C++11 compilers supporting magic statics
- [Issue #924](#)⁶⁰⁴¹ - Make kill_process_tree (in process.py) more robust on Mac OSX
- [Issue #923](#)⁶⁰⁴² - Correct BLAS and RNPL cmake tests
- [Issue #922](#)⁶⁰⁴³ - Cannot link against BLAS
- [Issue #921](#)⁶⁰⁴⁴ - Implement hpx::mem_fn
- [Issue #920](#)⁶⁰⁴⁵ - Output locality with --hpx:print-bind
- [Issue #919](#)⁶⁰⁴⁶ - Correct grammar; simplify boolean expressions
- [Issue #918](#)⁶⁰⁴⁷ - Link to hello_world.cpp is broken
- [Issue #917](#)⁶⁰⁴⁸ - adapt cmake file to new boostbook version
- [Issue #916](#)⁶⁰⁴⁹ - fix problem building documentation with xsltproc >= 1.1.27
- [Issue #915](#)⁶⁰⁵⁰ - Add another TBBMalloc library search path
- [Issue #914](#)⁶⁰⁵¹ - Build problem with Intel compiler on Stampede (TACC)
- [Issue #913](#)⁶⁰⁵² - fix error messages in fibonacci examples

⁶⁰³⁰ <https://github.com/STELLAR-GROUP/hpx/issues/939>

⁶⁰³¹ <https://github.com/STELLAR-GROUP/hpx/issues/938>

⁶⁰³² <https://github.com/STELLAR-GROUP/hpx/issues/937>

⁶⁰³³ <https://github.com/STELLAR-GROUP/hpx/issues/936>

⁶⁰³⁴ <https://github.com/STELLAR-GROUP/hpx/issues/935>

⁶⁰³⁵ <https://github.com/STELLAR-GROUP/hpx/issues/933>

⁶⁰³⁶ <https://github.com/STELLAR-GROUP/hpx/issues/932>

⁶⁰³⁷ <https://github.com/STELLAR-GROUP/hpx/issues/931>

⁶⁰³⁸ <https://github.com/STELLAR-GROUP/hpx/issues/930>

⁶⁰³⁹ <https://github.com/STELLAR-GROUP/hpx/issues/929>

⁶⁰⁴⁰ <https://github.com/STELLAR-GROUP/hpx/issues/928>

⁶⁰⁴¹ <https://github.com/STELLAR-GROUP/hpx/issues/924>

⁶⁰⁴² <https://github.com/STELLAR-GROUP/hpx/issues/923>

⁶⁰⁴³ <https://github.com/STELLAR-GROUP/hpx/issues/922>

⁶⁰⁴⁴ <https://github.com/STELLAR-GROUP/hpx/issues/921>

⁶⁰⁴⁵ <https://github.com/STELLAR-GROUP/hpx/issues/920>

⁶⁰⁴⁶ <https://github.com/STELLAR-GROUP/hpx/issues/919>

⁶⁰⁴⁷ <https://github.com/STELLAR-GROUP/hpx/issues/918>

⁶⁰⁴⁸ <https://github.com/STELLAR-GROUP/hpx/issues/917>

⁶⁰⁴⁹ <https://github.com/STELLAR-GROUP/hpx/issues/916>

⁶⁰⁵⁰ <https://github.com/STELLAR-GROUP/hpx/issues/915>

⁶⁰⁵¹ <https://github.com/STELLAR-GROUP/hpx/issues/914>

⁶⁰⁵² <https://github.com/STELLAR-GROUP/hpx/issues/913>

- [Issue #911](#)⁶⁰⁵³ - Update OS X build instructions
- [Issue #910](#)⁶⁰⁵⁴ - Want like to specify MPI_ROOT instead of compiler wrapper script
- [Issue #909](#)⁶⁰⁵⁵ - Warning about void* arithmetic
- [Issue #908](#)⁶⁰⁵⁶ - Buildbot for MIC is broken
- [Issue #906](#)⁶⁰⁵⁷ - Can't use --hpx:bind=balanced with multiple MPI processes
- [Issue #905](#)⁶⁰⁵⁸ - --hpx:bind documentation should describe full grammar
- [Issue #904](#)⁶⁰⁵⁹ - Add hpx::lcos::fold and hpx::lcos::inverse_fold collective operation
- [Issue #903](#)⁶⁰⁶⁰ - Add hpx::when_any_swapped()
- [Issue #902](#)⁶⁰⁶¹ - Add hpx::lcos::reduce collective operation
- [Issue #901](#)⁶⁰⁶² - Web documentation is not searchable
- [Issue #900](#)⁶⁰⁶³ - Web documentation for trunk has no index
- [Issue #898](#)⁶⁰⁶⁴ - Some tests fail with GCC 4.8.1 and MPI parcel port
- [Issue #897](#)⁶⁰⁶⁵ - HWLOC causes failures on Mac
- [Issue #896](#)⁶⁰⁶⁶ - pu-offset leads to startup error
- [Issue #895](#)⁶⁰⁶⁷ - hpx::get_locality_name not defined
- [Issue #894](#)⁶⁰⁶⁸ - Race condition at shutdown
- [Issue #893](#)⁶⁰⁶⁹ - --hpx:print-bind switches std::cout to hexadecimal mode
- [Issue #892](#)⁶⁰⁷⁰ - hwloc_topology_load can be expensive – don't call multiple times
- [Issue #891](#)⁶⁰⁷¹ - The documentation for get_locality_name is wrong
- [Issue #890](#)⁶⁰⁷² - --hpx:print-bind should not exit
- [Issue #889](#)⁶⁰⁷³ - --hpx:debug-hpx-log=FILE does not work
- [Issue #888](#)⁶⁰⁷⁴ - MPI parcelport does not exit cleanly for --hpx:print-bind
- [Issue #887](#)⁶⁰⁷⁵ - Choose thread affinities more cleverly

⁶⁰⁵³ <https://github.com/STELLAR-GROUP/hpx/issues/911>

⁶⁰⁵⁴ <https://github.com/STELLAR-GROUP/hpx/issues/910>

⁶⁰⁵⁵ <https://github.com/STELLAR-GROUP/hpx/issues/909>

⁶⁰⁵⁶ <https://github.com/STELLAR-GROUP/hpx/issues/908>

⁶⁰⁵⁷ <https://github.com/STELLAR-GROUP/hpx/issues/906>

⁶⁰⁵⁸ <https://github.com/STELLAR-GROUP/hpx/issues/905>

⁶⁰⁵⁹ <https://github.com/STELLAR-GROUP/hpx/issues/904>

⁶⁰⁶⁰ <https://github.com/STELLAR-GROUP/hpx/issues/903>

⁶⁰⁶¹ <https://github.com/STELLAR-GROUP/hpx/issues/902>

⁶⁰⁶² <https://github.com/STELLAR-GROUP/hpx/issues/901>

⁶⁰⁶³ <https://github.com/STELLAR-GROUP/hpx/issues/900>

⁶⁰⁶⁴ <https://github.com/STELLAR-GROUP/hpx/issues/898>

⁶⁰⁶⁵ <https://github.com/STELLAR-GROUP/hpx/issues/897>

⁶⁰⁶⁶ <https://github.com/STELLAR-GROUP/hpx/issues/896>

⁶⁰⁶⁷ <https://github.com/STELLAR-GROUP/hpx/issues/895>

⁶⁰⁶⁸ <https://github.com/STELLAR-GROUP/hpx/issues/894>

⁶⁰⁶⁹ <https://github.com/STELLAR-GROUP/hpx/issues/893>

⁶⁰⁷⁰ <https://github.com/STELLAR-GROUP/hpx/issues/892>

⁶⁰⁷¹ <https://github.com/STELLAR-GROUP/hpx/issues/891>

⁶⁰⁷² <https://github.com/STELLAR-GROUP/hpx/issues/890>

⁶⁰⁷³ <https://github.com/STELLAR-GROUP/hpx/issues/889>

⁶⁰⁷⁴ <https://github.com/STELLAR-GROUP/hpx/issues/888>

⁶⁰⁷⁵ <https://github.com/STELLAR-GROUP/hpx/issues/887>

- [Issue #886⁶⁰⁷⁶](#) - Logging documentation is confusing
- [Issue #885⁶⁰⁷⁷](#) - Two threads are slower than one
- [Issue #884⁶⁰⁷⁸](#) - `is_callable` failing with member pointers in C++11
- [Issue #883⁶⁰⁷⁹](#) - Need help with `is_callable_test`
- [Issue #882⁶⁰⁸⁰](#) - `tests.regressions.lcos.future_hang_on_get` does not terminate
- [Issue #881⁶⁰⁸¹](#) - `tests/regressions/block_matrix/matrix.hh` won't compile with GCC 4.8.1
- [Issue #880⁶⁰⁸²](#) - HPX does not work on OS X
- [Issue #878⁶⁰⁸³](#) - `future::unwrap` triggers assertion
- [Issue #877⁶⁰⁸⁴](#) - “make tests” has build errors on Ubuntu 12.10
- [Issue #876⁶⁰⁸⁵](#) - `tcmalloc` is used by default, even if it is not present
- [Issue #875⁶⁰⁸⁶](#) - `global_fixture` is defined in a header file
- [Issue #874⁶⁰⁸⁷](#) - Some tests take very long
- [Issue #873⁶⁰⁸⁸](#) - Add block-matrix code as regression test
- [Issue #872⁶⁰⁸⁹](#) - HPX documentation does not say how to run tests with detailed output
- [Issue #871⁶⁰⁹⁰](#) - All tests fail with “make test”
- [Issue #870⁶⁰⁹¹](#) - Please explicitly disable serialization in classes that don't support it
- [Issue #868⁶⁰⁹²](#) - `boost_any` test failing
- [Issue #867⁶⁰⁹³](#) - Reduce the number of copies of `hpx::function` arguments
- [Issue #863⁶⁰⁹⁴](#) - Futures should not require a default constructor
- [Issue #862⁶⁰⁹⁵](#) - `value_or_error` shall not default construct its result
- [Issue #861⁶⁰⁹⁶](#) - `HPX_UNUSED` macro
- [Issue #860⁶⁰⁹⁷](#) - Add functionality to copy construct a component
- [Issue #859⁶⁰⁹⁸](#) - `hpx::endl` should flush

⁶⁰⁷⁶ <https://github.com/STELLAR-GROUP/hpx/issues/886>

⁶⁰⁷⁷ <https://github.com/STELLAR-GROUP/hpx/issues/885>

⁶⁰⁷⁸ <https://github.com/STELLAR-GROUP/hpx/issues/884>

⁶⁰⁷⁹ <https://github.com/STELLAR-GROUP/hpx/issues/883>

⁶⁰⁸⁰ <https://github.com/STELLAR-GROUP/hpx/issues/882>

⁶⁰⁸¹ <https://github.com/STELLAR-GROUP/hpx/issues/881>

⁶⁰⁸² <https://github.com/STELLAR-GROUP/hpx/issues/880>

⁶⁰⁸³ <https://github.com/STELLAR-GROUP/hpx/issues/878>

⁶⁰⁸⁴ <https://github.com/STELLAR-GROUP/hpx/issues/877>

⁶⁰⁸⁵ <https://github.com/STELLAR-GROUP/hpx/issues/876>

⁶⁰⁸⁶ <https://github.com/STELLAR-GROUP/hpx/issues/875>

⁶⁰⁸⁷ <https://github.com/STELLAR-GROUP/hpx/issues/874>

⁶⁰⁸⁸ <https://github.com/STELLAR-GROUP/hpx/issues/873>

⁶⁰⁸⁹ <https://github.com/STELLAR-GROUP/hpx/issues/872>

⁶⁰⁹⁰ <https://github.com/STELLAR-GROUP/hpx/issues/871>

⁶⁰⁹¹ <https://github.com/STELLAR-GROUP/hpx/issues/870>

⁶⁰⁹² <https://github.com/STELLAR-GROUP/hpx/issues/868>

⁶⁰⁹³ <https://github.com/STELLAR-GROUP/hpx/issues/867>

⁶⁰⁹⁴ <https://github.com/STELLAR-GROUP/hpx/issues/863>

⁶⁰⁹⁵ <https://github.com/STELLAR-GROUP/hpx/issues/862>

⁶⁰⁹⁶ <https://github.com/STELLAR-GROUP/hpx/issues/861>

⁶⁰⁹⁷ <https://github.com/STELLAR-GROUP/hpx/issues/860>

⁶⁰⁹⁸ <https://github.com/STELLAR-GROUP/hpx/issues/859>

- [Issue #858](#)⁶⁰⁹⁹ - Create `hpx::get_ptr<>` allowing to access component implementation
- [Issue #855](#)⁶¹⁰⁰ - Implement `hpx::INVOKE`
- [Issue #854](#)⁶¹⁰¹ - `hpx/hpx.hpp` does not include `hpx/include/iostreams.hpp`
- [Issue #853](#)⁶¹⁰² - Feature request: null future
- [Issue #852](#)⁶¹⁰³ - Feature request: Locality names
- [Issue #851](#)⁶¹⁰⁴ - `hpx::cout` output does not appear on screen
- [Issue #849](#)⁶¹⁰⁵ - All tests fail on OS X after installing
- [Issue #848](#)⁶¹⁰⁶ - Update OS X build instructions
- [Issue #846](#)⁶¹⁰⁷ - Update `hpx_external_example`
- [Issue #845](#)⁶¹⁰⁸ - Issues with having both debug and release modules in the same directory
- [Issue #844](#)⁶¹⁰⁹ - Create configuration header
- [Issue #843](#)⁶¹¹⁰ - Tests should use CTest
- [Issue #842](#)⁶¹¹¹ - Remove `buffer_pool` from MPI parcelport
- [Issue #841](#)⁶¹¹² - Add possibility to broadcast an index with `hpx::lcos::broadcast`
- [Issue #838](#)⁶¹¹³ - Simplify `util::tuple`
- [Issue #837](#)⁶¹¹⁴ - Adopt `boost::tuple` tests for `util::tuple`
- [Issue #836](#)⁶¹¹⁵ - Adopt `boost::function` tests for `util::function`
- [Issue #835](#)⁶¹¹⁶ - Tuple interface missing pieces
- [Issue #833](#)⁶¹¹⁷ - Partially preprocessing files not working
- [Issue #832](#)⁶¹¹⁸ - Native papi counters do not work with wild cards
- [Issue #831](#)⁶¹¹⁹ - Arithmetics counter fails if only one parameter is given
- [Issue #830](#)⁶¹²⁰ - Convert `hpx::util::function` to use new scheme for serializing its base pointer
- [Issue #829](#)⁶¹²¹ - Consistently use `decay<T>` instead of `remove_const< remove_reference<T>>`

⁶⁰⁹⁹ <https://github.com/STELLAR-GROUP/hpx/issues/858>

⁶¹⁰⁰ <https://github.com/STELLAR-GROUP/hpx/issues/855>

⁶¹⁰¹ <https://github.com/STELLAR-GROUP/hpx/issues/854>

⁶¹⁰² <https://github.com/STELLAR-GROUP/hpx/issues/853>

⁶¹⁰³ <https://github.com/STELLAR-GROUP/hpx/issues/852>

⁶¹⁰⁴ <https://github.com/STELLAR-GROUP/hpx/issues/851>

⁶¹⁰⁵ <https://github.com/STELLAR-GROUP/hpx/issues/849>

⁶¹⁰⁶ <https://github.com/STELLAR-GROUP/hpx/issues/848>

⁶¹⁰⁷ <https://github.com/STELLAR-GROUP/hpx/issues/846>

⁶¹⁰⁸ <https://github.com/STELLAR-GROUP/hpx/issues/845>

⁶¹⁰⁹ <https://github.com/STELLAR-GROUP/hpx/issues/844>

⁶¹¹⁰ <https://github.com/STELLAR-GROUP/hpx/issues/843>

⁶¹¹¹ <https://github.com/STELLAR-GROUP/hpx/issues/842>

⁶¹¹² <https://github.com/STELLAR-GROUP/hpx/issues/841>

⁶¹¹³ <https://github.com/STELLAR-GROUP/hpx/issues/838>

⁶¹¹⁴ <https://github.com/STELLAR-GROUP/hpx/issues/837>

⁶¹¹⁵ <https://github.com/STELLAR-GROUP/hpx/issues/836>

⁶¹¹⁶ <https://github.com/STELLAR-GROUP/hpx/issues/835>

⁶¹¹⁷ <https://github.com/STELLAR-GROUP/hpx/issues/833>

⁶¹¹⁸ <https://github.com/STELLAR-GROUP/hpx/issues/832>

⁶¹¹⁹ <https://github.com/STELLAR-GROUP/hpx/issues/831>

⁶¹²⁰ <https://github.com/STELLAR-GROUP/hpx/issues/830>

⁶¹²¹ <https://github.com/STELLAR-GROUP/hpx/issues/829>

- [Issue #828](#)⁶¹²² - Update future implementation to N3721 and N3722
- [Issue #827](#)⁶¹²³ - Enable MPI parcelport for bootstrapping whenever application was started using mpirun
- [Issue #826](#)⁶¹²⁴ - Support command line option `--hpx:print-bind` even if `--hpx::bind` was not used
- [Issue #825](#)⁶¹²⁵ - Memory counters give segfault when attempting to use thread wild cards or numbers only total works
- [Issue #824](#)⁶¹²⁶ - Enable lambda functions to be used with `hpx::async/hpx::apply`
- [Issue #823](#)⁶¹²⁷ - Using a hashing filter
- [Issue #822](#)⁶¹²⁸ - Silence unused variable warning
- [Issue #821](#)⁶¹²⁹ - Detect if a function object is callable with given arguments
- [Issue #820](#)⁶¹³⁰ - Allow wildcards to be used for performance counter names
- [Issue #819](#)⁶¹³¹ - Make the AGAS symbolic name registry distributed
- [Issue #818](#)⁶¹³² - Add `future::then()` overload taking an executor
- [Issue #817](#)⁶¹³³ - Fixed typo
- [Issue #815](#)⁶¹³⁴ - Create an lco that is performing an efficient broadcast of actions
- [Issue #814](#)⁶¹³⁵ - Papi counters cannot specify `thread#*` to get the counts for all threads
- [Issue #813](#)⁶¹³⁶ - Scoped unlock
- [Issue #811](#)⁶¹³⁷ - `simple_central_tuplespace_client` run error
- [Issue #810](#)⁶¹³⁸ - ostream error when `<<` any objects
- [Issue #809](#)⁶¹³⁹ - Optimize parcel serialization
- [Issue #808](#)⁶¹⁴⁰ - HPX applications throw exception when executed from the build directory
- [Issue #807](#)⁶¹⁴¹ - Create performance counters exposing overall AGAS statistics
- [Issue #795](#)⁶¹⁴² - Create timed `make_ready_future`
- [Issue #794](#)⁶¹⁴³ - Create heterogeneous `when_all/when_any/etc.`
- [Issue #721](#)⁶¹⁴⁴ - Make HPX usable for Xeon Phi

⁶¹²² <https://github.com/STELLAR-GROUP/hpx/issues/828>

⁶¹²³ <https://github.com/STELLAR-GROUP/hpx/issues/827>

⁶¹²⁴ <https://github.com/STELLAR-GROUP/hpx/issues/826>

⁶¹²⁵ <https://github.com/STELLAR-GROUP/hpx/issues/825>

⁶¹²⁶ <https://github.com/STELLAR-GROUP/hpx/issues/824>

⁶¹²⁷ <https://github.com/STELLAR-GROUP/hpx/issues/823>

⁶¹²⁸ <https://github.com/STELLAR-GROUP/hpx/issues/822>

⁶¹²⁹ <https://github.com/STELLAR-GROUP/hpx/issues/821>

⁶¹³⁰ <https://github.com/STELLAR-GROUP/hpx/issues/820>

⁶¹³¹ <https://github.com/STELLAR-GROUP/hpx/issues/819>

⁶¹³² <https://github.com/STELLAR-GROUP/hpx/issues/818>

⁶¹³³ <https://github.com/STELLAR-GROUP/hpx/issues/817>

⁶¹³⁴ <https://github.com/STELLAR-GROUP/hpx/issues/815>

⁶¹³⁵ <https://github.com/STELLAR-GROUP/hpx/issues/814>

⁶¹³⁶ <https://github.com/STELLAR-GROUP/hpx/issues/813>

⁶¹³⁷ <https://github.com/STELLAR-GROUP/hpx/issues/811>

⁶¹³⁸ <https://github.com/STELLAR-GROUP/hpx/issues/810>

⁶¹³⁹ <https://github.com/STELLAR-GROUP/hpx/issues/809>

⁶¹⁴⁰ <https://github.com/STELLAR-GROUP/hpx/issues/808>

⁶¹⁴¹ <https://github.com/STELLAR-GROUP/hpx/issues/807>

⁶¹⁴² <https://github.com/STELLAR-GROUP/hpx/issues/795>

⁶¹⁴³ <https://github.com/STELLAR-GROUP/hpx/issues/794>

⁶¹⁴⁴ <https://github.com/STELLAR-GROUP/hpx/issues/721>

- Issue #694⁶¹⁴⁵ - CMake should complain if you attempt to build an example without its dependencies
- Issue #692⁶¹⁴⁶ - SLURM support broken
- Issue #683⁶¹⁴⁷ - python/hpx/process.py imports epoll on all platforms
- Issue #619⁶¹⁴⁸ - Automate the doc building process
- Issue #600⁶¹⁴⁹ - GTC performance broken
- Issue #577⁶¹⁵⁰ - Allow for zero copy serialization/networking
- Issue #551⁶¹⁵¹ - Change executable names to have debug postfix in Debug builds
- Issue #544⁶¹⁵² - Write a custom .lib file on Windows pulling in hpx_init and hpx.dll, phase out hpx_init
- Issue #534⁶¹⁵³ - hpx::init should take functions by std::function and should accept all forms of hpx_main
- Issue #508⁶¹⁵⁴ - FindPackage fails to set FOO_LIBRARY_DIR
- Issue #506⁶¹⁵⁵ - Add cmake support to generate ini files for external applications
- Issue #470⁶¹⁵⁶ - Changing build-type after configure does not update boost library names
- Issue #453⁶¹⁵⁷ - Document hpx_run_tests.py
- Issue #445⁶¹⁵⁸ - Significant performance mismatch between MPI and HPX in SMP for allgather example
- Issue #443⁶¹⁵⁹ - Make docs viewable from build directory
- Issue #421⁶¹⁶⁰ - Support multiple HPX instances per node in a batch environment like PBS or SLURM
- Issue #316⁶¹⁶¹ - Add message size limitation
- Issue #249⁶¹⁶² - Clean up locking code in big boot barrier
- Issue #136⁶¹⁶³ - Persistent CMake variables need to be marked as cache variables

⁶¹⁴⁵ <https://github.com/STELLAR-GROUP/hpx/issues/694>

⁶¹⁴⁶ <https://github.com/STELLAR-GROUP/hpx/issues/692>

⁶¹⁴⁷ <https://github.com/STELLAR-GROUP/hpx/issues/683>

⁶¹⁴⁸ <https://github.com/STELLAR-GROUP/hpx/issues/619>

⁶¹⁴⁹ <https://github.com/STELLAR-GROUP/hpx/issues/600>

⁶¹⁵⁰ <https://github.com/STELLAR-GROUP/hpx/issues/577>

⁶¹⁵¹ <https://github.com/STELLAR-GROUP/hpx/issues/551>

⁶¹⁵² <https://github.com/STELLAR-GROUP/hpx/issues/544>

⁶¹⁵³ <https://github.com/STELLAR-GROUP/hpx/issues/534>

⁶¹⁵⁴ <https://github.com/STELLAR-GROUP/hpx/issues/508>

⁶¹⁵⁵ <https://github.com/STELLAR-GROUP/hpx/issues/506>

⁶¹⁵⁶ <https://github.com/STELLAR-GROUP/hpx/issues/470>

⁶¹⁵⁷ <https://github.com/STELLAR-GROUP/hpx/issues/453>

⁶¹⁵⁸ <https://github.com/STELLAR-GROUP/hpx/issues/445>

⁶¹⁵⁹ <https://github.com/STELLAR-GROUP/hpx/issues/443>

⁶¹⁶⁰ <https://github.com/STELLAR-GROUP/hpx/issues/421>

⁶¹⁶¹ <https://github.com/STELLAR-GROUP/hpx/issues/316>

⁶¹⁶² <https://github.com/STELLAR-GROUP/hpx/issues/249>

⁶¹⁶³ <https://github.com/STELLAR-GROUP/hpx/issues/136>

HPX V0.9.6 (Jul 30, 2013)

We have had over 1200 commits since the last release and we have closed roughly 140 tickets (bugs, feature requests, etc.).

General changes

The major new features in this release are:

- We further consolidated the API exposed by *HPX*. We aligned our APIs as much as possible with the existing [C++11 Standard](http://www.open-std.org/jtc1/sc22/wg21)⁶¹⁶⁴ and related proposals to the C++ standardization committee (such as [N3632](http://wg21.link/n3632)⁶¹⁶⁵ and [N3857](http://wg21.link/n3857)⁶¹⁶⁶).
- We implemented a first version of a distributed AGAS service which essentially eliminates all explicit AGAS network traffic.
- We created a native *ibverbs* parcelport allowing to take advantage of the superior latency and bandwidth characteristics of Infiniband networks.
- We successfully ported *HPX* to the Xeon Phi platform.
- Support for the SLURM scheduling system was implemented.
- Major efforts have been dedicated to improving the performance counter framework, numerous new counters were implemented and new APIs were added.
- We added a modular parcel compression system allowing to improve bandwidth utilization (by reducing the overall size of the transferred data).
- We added a modular parcel coalescing system allowing to combine several parcels into larger messages. This reduces latencies introduced by the communication layer.
- Added an experimental executors API allowing to use different scheduling policies for different parts of the code. This API has been modelled after the Standards proposal [N3562](http://wg21.link/n3562)⁶¹⁶⁷. This API is bound to change in the future, though.
- Added minimal security support for localities which is enforced on the parcelport level. This support is preliminary and experimental and might change in the future.
- We created a parcelport using low level MPI functions. This is in support of legacy applications which are to be gradually ported and to support platforms where MPI is the only available portable networking layer.
- We added a preliminary and experimental implementation of a tuple-space object which exposes an interface similar to such systems described in the literature (see for instance [The Linda Coordination Language](https://en.wikipedia.org/wiki/Linda_(coordination_language))⁶¹⁶⁸).

⁶¹⁶⁴ <http://www.open-std.org/jtc1/sc22/wg21>

⁶¹⁶⁵ <http://wg21.link/n3632>

⁶¹⁶⁶ <http://wg21.link/n3857>

⁶¹⁶⁷ <http://wg21.link/n3562>

⁶¹⁶⁸ [https://en.wikipedia.org/wiki/Linda_\(coordination_language\)](https://en.wikipedia.org/wiki/Linda_(coordination_language))

Bug fixes (closed tickets)

Here is a list of the important tickets we closed for this release. This is again a very long list of newly implemented features and fixed issues.

- [Issue #806](#)⁶¹⁶⁹ - make (all) in examples folder does nothing
- [Issue #805](#)⁶¹⁷⁰ - Adding the introduction and fixing DOCBOOK dependencies for Windows use
- [Issue #804](#)⁶¹⁷¹ - Add stackless (non-suspendable) thread type
- [Issue #803](#)⁶¹⁷² - Create proper serialization support functions for util::tuple
- [Issue #800](#)⁶¹⁷³ - Add possibility to disable array optimizations during serialization
- [Issue #798](#)⁶¹⁷⁴ - HPX_LIMIT does not work for local dataflow
- [Issue #797](#)⁶¹⁷⁵ - Create a parcelport which uses MPI
- [Issue #796](#)⁶¹⁷⁶ - Problem with Large Numbers of Threads
- [Issue #793](#)⁶¹⁷⁷ - Changing dataflow test case to hang consistently
- [Issue #792](#)⁶¹⁷⁸ - CMake Error
- [Issue #791](#)⁶¹⁷⁹ - Problems with local::dataflow
- [Issue #790](#)⁶¹⁸⁰ - wait_for() doesn't compile
- [Issue #789](#)⁶¹⁸¹ - HPX with Intel compiler segfaults
- [Issue #788](#)⁶¹⁸² - Intel compiler support
- [Issue #787](#)⁶¹⁸³ - Fixed SFINAEd specializations
- [Issue #786](#)⁶¹⁸⁴ - Memory issues during benchmarking.
- [Issue #785](#)⁶¹⁸⁵ - Create an API allowing to register external threads with HPX
- [Issue #784](#)⁶¹⁸⁶ - util::plugin is throwing an error when a symbol is not found
- [Issue #783](#)⁶¹⁸⁷ - How does hpx::bind work?
- [Issue #782](#)⁶¹⁸⁸ - Added quotes around STRING REPLACE potentially empty arguments
- [Issue #781](#)⁶¹⁸⁹ - Make sure no exceptions propagate into the thread manager

⁶¹⁶⁹ <https://github.com/STELLAR-GROUP/hpx/issues/806>

⁶¹⁷⁰ <https://github.com/STELLAR-GROUP/hpx/issues/805>

⁶¹⁷¹ <https://github.com/STELLAR-GROUP/hpx/issues/804>

⁶¹⁷² <https://github.com/STELLAR-GROUP/hpx/issues/803>

⁶¹⁷³ <https://github.com/STELLAR-GROUP/hpx/issues/800>

⁶¹⁷⁴ <https://github.com/STELLAR-GROUP/hpx/issues/798>

⁶¹⁷⁵ <https://github.com/STELLAR-GROUP/hpx/issues/797>

⁶¹⁷⁶ <https://github.com/STELLAR-GROUP/hpx/issues/796>

⁶¹⁷⁷ <https://github.com/STELLAR-GROUP/hpx/issues/793>

⁶¹⁷⁸ <https://github.com/STELLAR-GROUP/hpx/issues/792>

⁶¹⁷⁹ <https://github.com/STELLAR-GROUP/hpx/issues/791>

⁶¹⁸⁰ <https://github.com/STELLAR-GROUP/hpx/issues/790>

⁶¹⁸¹ <https://github.com/STELLAR-GROUP/hpx/issues/789>

⁶¹⁸² <https://github.com/STELLAR-GROUP/hpx/issues/788>

⁶¹⁸³ <https://github.com/STELLAR-GROUP/hpx/issues/787>

⁶¹⁸⁴ <https://github.com/STELLAR-GROUP/hpx/issues/786>

⁶¹⁸⁵ <https://github.com/STELLAR-GROUP/hpx/issues/785>

⁶¹⁸⁶ <https://github.com/STELLAR-GROUP/hpx/issues/784>

⁶¹⁸⁷ <https://github.com/STELLAR-GROUP/hpx/issues/783>

⁶¹⁸⁸ <https://github.com/STELLAR-GROUP/hpx/issues/782>

⁶¹⁸⁹ <https://github.com/STELLAR-GROUP/hpx/issues/781>

- [Issue #780⁶¹⁹⁰](#) - Allow arithmetics performance counters to expand its parameters
- [Issue #779⁶¹⁹¹](#) - Test case for 778
- [Issue #778⁶¹⁹²](#) - Swapping futures segfaults
- [Issue #777⁶¹⁹³](#) - `hpx::lcos::details::when_xxx` don't restore completion handlers
- [Issue #776⁶¹⁹⁴](#) - Compiler chokes on dataflow overload with launch policy
- [Issue #775⁶¹⁹⁵](#) - Runtime error with local dataflow (copying futures?)
- [Issue #774⁶¹⁹⁶](#) - Using local dataflow without explicit namespace
- [Issue #773⁶¹⁹⁷](#) - Local dataflow with `unwrap`: functor operators need to be `const`
- [Issue #772⁶¹⁹⁸](#) - Allow (remote) actions to return a future
- [Issue #771⁶¹⁹⁹](#) - Setting `HPX_LIMIT` gives huge boost MPL errors
- [Issue #770⁶²⁰⁰](#) - Add launch policy to (local) dataflow
- [Issue #769⁶²⁰¹](#) - Make compile time configuration information available
- [Issue #768⁶²⁰²](#) - Const correctness problem in local dataflow
- [Issue #767⁶²⁰³](#) - Add launch policies to `async`
- [Issue #766⁶²⁰⁴](#) - Mark data structures for optimized (array based) serialization
- [Issue #765⁶²⁰⁵](#) - Align `hpx::any` with N3508: Any Library Proposal (Revision 2)
- [Issue #764⁶²⁰⁶](#) - Align `hpx::future` with newest N3558: A Standardized Representation of Asynchronous Operations
- [Issue #762⁶²⁰⁷](#) - added a human readable output for the ping pong example
- [Issue #761⁶²⁰⁸](#) - Ambiguous typename when constructing derived component
- [Issue #760⁶²⁰⁹](#) - Simple components can not be derived
- [Issue #759⁶²¹⁰](#) - make install doesn't give a complete install
- [Issue #758⁶²¹¹](#) - Stack overflow when using `locking_hook<>`
- [Issue #757⁶²¹²](#) - copy paste error; unsupported function overloading

⁶¹⁹⁰ <https://github.com/STELLAR-GROUP/hpx/issues/780>

⁶¹⁹¹ <https://github.com/STELLAR-GROUP/hpx/issues/779>

⁶¹⁹² <https://github.com/STELLAR-GROUP/hpx/issues/778>

⁶¹⁹³ <https://github.com/STELLAR-GROUP/hpx/issues/777>

⁶¹⁹⁴ <https://github.com/STELLAR-GROUP/hpx/issues/776>

⁶¹⁹⁵ <https://github.com/STELLAR-GROUP/hpx/issues/775>

⁶¹⁹⁶ <https://github.com/STELLAR-GROUP/hpx/issues/774>

⁶¹⁹⁷ <https://github.com/STELLAR-GROUP/hpx/issues/773>

⁶¹⁹⁸ <https://github.com/STELLAR-GROUP/hpx/issues/772>

⁶¹⁹⁹ <https://github.com/STELLAR-GROUP/hpx/issues/771>

⁶²⁰⁰ <https://github.com/STELLAR-GROUP/hpx/issues/770>

⁶²⁰¹ <https://github.com/STELLAR-GROUP/hpx/issues/769>

⁶²⁰² <https://github.com/STELLAR-GROUP/hpx/issues/768>

⁶²⁰³ <https://github.com/STELLAR-GROUP/hpx/issues/767>

⁶²⁰⁴ <https://github.com/STELLAR-GROUP/hpx/issues/766>

⁶²⁰⁵ <https://github.com/STELLAR-GROUP/hpx/issues/765>

⁶²⁰⁶ <https://github.com/STELLAR-GROUP/hpx/issues/764>

⁶²⁰⁷ <https://github.com/STELLAR-GROUP/hpx/issues/762>

⁶²⁰⁸ <https://github.com/STELLAR-GROUP/hpx/issues/761>

⁶²⁰⁹ <https://github.com/STELLAR-GROUP/hpx/issues/760>

⁶²¹⁰ <https://github.com/STELLAR-GROUP/hpx/issues/759>

⁶²¹¹ <https://github.com/STELLAR-GROUP/hpx/issues/758>

⁶²¹² <https://github.com/STELLAR-GROUP/hpx/issues/757>

- Issue #756⁶²¹³ - GTCX runtime issue in Gordon
- Issue #755⁶²¹⁴ - Papi counters don't work with reset and evaluate API's
- Issue #753⁶²¹⁵ - cmake bugfix and improved component action docs
- Issue #752⁶²¹⁶ - hpx simple component docs
- Issue #750⁶²¹⁷ - Add hpx::util::any
- Issue #749⁶²¹⁸ - Thread phase counter is not reset
- Issue #748⁶²¹⁹ - Memory performance counter are not registered
- Issue #747⁶²²⁰ - Create performance counters exposing arithmetic operations
- Issue #745⁶²²¹ - apply_callback needs to invoke callback when applied locally
- Issue #744⁶²²² - CMake fixes
- Issue #743⁶²²³ - Problem Building github version of HPX
- Issue #742⁶²²⁴ - Remove HPX_STD_BIND
- Issue #741⁶²²⁵ - assertion 'px != 0' failed: HPX(assertion_failure) for low numbers of OS threads
- Issue #739⁶²²⁶ - Performance counters do not count to the end of the program or evaluation
- Issue #738⁶²²⁷ - Dedicated AGAS server runs don't work; console ignores -a option.
- Issue #737⁶²²⁸ - Missing bind overloads
- Issue #736⁶²²⁹ - Performance counter wildcards do not always work
- Issue #735⁶²³⁰ - Create native ibverbs parcelport based on rdma operations
- Issue #734⁶²³¹ - Threads stolen performance counter total is incorrect
- Issue #733⁶²³² - Test benchmarks need to be checked and fixed
- Issue #732⁶²³³ - Build fails with Mac, using mac ports clang-3.3 on latest git branch
- Issue #731⁶²³⁴ - Add global start/stop API for performance counters
- Issue #730⁶²³⁵ - Performance counter values are apparently incorrect

⁶²¹³ <https://github.com/STELLAR-GROUP/hpx/issues/756>

⁶²¹⁴ <https://github.com/STELLAR-GROUP/hpx/issues/755>

⁶²¹⁵ <https://github.com/STELLAR-GROUP/hpx/issues/753>

⁶²¹⁶ <https://github.com/STELLAR-GROUP/hpx/issues/752>

⁶²¹⁷ <https://github.com/STELLAR-GROUP/hpx/issues/750>

⁶²¹⁸ <https://github.com/STELLAR-GROUP/hpx/issues/749>

⁶²¹⁹ <https://github.com/STELLAR-GROUP/hpx/issues/748>

⁶²²⁰ <https://github.com/STELLAR-GROUP/hpx/issues/747>

⁶²²¹ <https://github.com/STELLAR-GROUP/hpx/issues/745>

⁶²²² <https://github.com/STELLAR-GROUP/hpx/issues/744>

⁶²²³ <https://github.com/STELLAR-GROUP/hpx/issues/743>

⁶²²⁴ <https://github.com/STELLAR-GROUP/hpx/issues/742>

⁶²²⁵ <https://github.com/STELLAR-GROUP/hpx/issues/741>

⁶²²⁶ <https://github.com/STELLAR-GROUP/hpx/issues/739>

⁶²²⁷ <https://github.com/STELLAR-GROUP/hpx/issues/738>

⁶²²⁸ <https://github.com/STELLAR-GROUP/hpx/issues/737>

⁶²²⁹ <https://github.com/STELLAR-GROUP/hpx/issues/736>

⁶²³⁰ <https://github.com/STELLAR-GROUP/hpx/issues/735>

⁶²³¹ <https://github.com/STELLAR-GROUP/hpx/issues/734>

⁶²³² <https://github.com/STELLAR-GROUP/hpx/issues/733>

⁶²³³ <https://github.com/STELLAR-GROUP/hpx/issues/732>

⁶²³⁴ <https://github.com/STELLAR-GROUP/hpx/issues/731>

⁶²³⁵ <https://github.com/STELLAR-GROUP/hpx/issues/730>

- [Issue #729](#)⁶²³⁶ - Unhandled switch
- [Issue #728](#)⁶²³⁷ - Serialization of `hpx::util::function` between two localities causes seg faults
- [Issue #727](#)⁶²³⁸ - Memory counters on Mac OS X
- [Issue #725](#)⁶²³⁹ - Restore original thread priority on resume
- [Issue #724](#)⁶²⁴⁰ - Performance benchmarks do not depend on main HPX libraries
- [Issue #723](#)⁶²⁴¹ - `[teletype]-hpx:nodes=`cat $PBS_NODEFILE` works; -hpx:nodefile=$PBS_NODEFILE does not.[c++]`
- [Issue #722](#)⁶²⁴² - Fix binding `const` member functions as actions
- [Issue #719](#)⁶²⁴³ - Create performance counter exposing compression ratio
- [Issue #718](#)⁶²⁴⁴ - Add possibility to compress parcel data
- [Issue #717](#)⁶²⁴⁵ - `strip_credit_from_gid` has misleading semantics
- [Issue #716](#)⁶²⁴⁶ - Non-option arguments to programs run using `pbsdsh` must be before `--hpx:nodes`, contrary to directions
- [Issue #715](#)⁶²⁴⁷ - Re-thrown exceptions should retain the original call site
- [Issue #714](#)⁶²⁴⁸ - failed assertion in debug mode
- [Issue #713](#)⁶²⁴⁹ - Add performance counters monitoring connection caches
- [Issue #712](#)⁶²⁵⁰ - Adjust parcel related performance counters to be connection type specific
- [Issue #711](#)⁶²⁵¹ - configuration failure
- [Issue #710](#)⁶²⁵² - Error “timed out while trying to find room in the connection cache” when trying to start multiple localities on a single computer
- [Issue #709](#)⁶²⁵³ - Add new thread state ‘staged’ referring to task descriptions
- [Issue #708](#)⁶²⁵⁴ - Detect/mitigate bad non-system installs of GCC on Redhat systems
- [Issue #707](#)⁶²⁵⁵ - Many examples do not link with Git HEAD version
- [Issue #706](#)⁶²⁵⁶ - `hpx::init` removes portions of non-option command line arguments before last = sign
- [Issue #705](#)⁶²⁵⁷ - Create rolling average and median aggregating performance counters

⁶²³⁶ <https://github.com/STELLAR-GROUP/hpx/issues/729>
⁶²³⁷ <https://github.com/STELLAR-GROUP/hpx/issues/728>
⁶²³⁸ <https://github.com/STELLAR-GROUP/hpx/issues/727>
⁶²³⁹ <https://github.com/STELLAR-GROUP/hpx/issues/725>
⁶²⁴⁰ <https://github.com/STELLAR-GROUP/hpx/issues/724>
⁶²⁴¹ <https://github.com/STELLAR-GROUP/hpx/issues/723>
⁶²⁴² <https://github.com/STELLAR-GROUP/hpx/issues/722>
⁶²⁴³ <https://github.com/STELLAR-GROUP/hpx/issues/719>
⁶²⁴⁴ <https://github.com/STELLAR-GROUP/hpx/issues/718>
⁶²⁴⁵ <https://github.com/STELLAR-GROUP/hpx/issues/717>
⁶²⁴⁶ <https://github.com/STELLAR-GROUP/hpx/issues/716>
⁶²⁴⁷ <https://github.com/STELLAR-GROUP/hpx/issues/715>
⁶²⁴⁸ <https://github.com/STELLAR-GROUP/hpx/issues/714>
⁶²⁴⁹ <https://github.com/STELLAR-GROUP/hpx/issues/713>
⁶²⁵⁰ <https://github.com/STELLAR-GROUP/hpx/issues/712>
⁶²⁵¹ <https://github.com/STELLAR-GROUP/hpx/issues/711>
⁶²⁵² <https://github.com/STELLAR-GROUP/hpx/issues/710>
⁶²⁵³ <https://github.com/STELLAR-GROUP/hpx/issues/709>
⁶²⁵⁴ <https://github.com/STELLAR-GROUP/hpx/issues/708>
⁶²⁵⁵ <https://github.com/STELLAR-GROUP/hpx/issues/707>
⁶²⁵⁶ <https://github.com/STELLAR-GROUP/hpx/issues/706>
⁶²⁵⁷ <https://github.com/STELLAR-GROUP/hpx/issues/705>

- Issue #704⁶²⁵⁸ - Create performance counter to expose thread queue waiting time
- Issue #703⁶²⁵⁹ - Add support to HPX build system to find libcrtool.a and related headers
- Issue #699⁶²⁶⁰ - Generalize instrumentation support
- Issue #698⁶²⁶¹ - compilation failure with hwloc absent
- Issue #697⁶²⁶² - Performance counter counts should be zero indexed
- Issue #696⁶²⁶³ - Distributed problem
- Issue #695⁶²⁶⁴ - Bad perf counter time printed
- Issue #693⁶²⁶⁵ - --help doesn't print component specific command line options
- Issue #692⁶²⁶⁶ - SLURM support broken
- Issue #691⁶²⁶⁷ - exception while executing any application linked with hwloc
- Issue #690⁶²⁶⁸ - thread_id_test and thread_launcher_test failing
- Issue #689⁶²⁶⁹ - Make the buildbots use hwloc
- Issue #687⁶²⁷⁰ - compilation error fix (hwloc_topology)
- Issue #686⁶²⁷¹ - Linker Error for Applications
- Issue #684⁶²⁷² - Pinning of service thread fails when number of worker threads equals the number of cores
- Issue #682⁶²⁷³ - Add performance counters exposing number of stolen threads
- Issue #681⁶²⁷⁴ - Add apply_continue for asynchronous chaining of actions
- Issue #679⁶²⁷⁵ - Remove obsolete async_callback API functions
- Issue #678⁶²⁷⁶ - Add new API for setting/triggering LCOs
- Issue #677⁶²⁷⁷ - Add async_continue for true continuation style actions
- Issue #676⁶²⁷⁸ - Buildbot for gcc 4.4 broken
- Issue #675⁶²⁷⁹ - Partial preprocessing broken
- Issue #674⁶²⁸⁰ - HPX segfaults when built with gcc 4.7

⁶²⁵⁸ <https://github.com/STELLAR-GROUP/hpx/issues/704>

⁶²⁵⁹ <https://github.com/STELLAR-GROUP/hpx/issues/703>

⁶²⁶⁰ <https://github.com/STELLAR-GROUP/hpx/issues/699>

⁶²⁶¹ <https://github.com/STELLAR-GROUP/hpx/issues/698>

⁶²⁶² <https://github.com/STELLAR-GROUP/hpx/issues/697>

⁶²⁶³ <https://github.com/STELLAR-GROUP/hpx/issues/696>

⁶²⁶⁴ <https://github.com/STELLAR-GROUP/hpx/issues/695>

⁶²⁶⁵ <https://github.com/STELLAR-GROUP/hpx/issues/693>

⁶²⁶⁶ <https://github.com/STELLAR-GROUP/hpx/issues/692>

⁶²⁶⁷ <https://github.com/STELLAR-GROUP/hpx/issues/691>

⁶²⁶⁸ <https://github.com/STELLAR-GROUP/hpx/issues/690>

⁶²⁶⁹ <https://github.com/STELLAR-GROUP/hpx/issues/689>

⁶²⁷⁰ <https://github.com/STELLAR-GROUP/hpx/issues/687>

⁶²⁷¹ <https://github.com/STELLAR-GROUP/hpx/issues/686>

⁶²⁷² <https://github.com/STELLAR-GROUP/hpx/issues/684>

⁶²⁷³ <https://github.com/STELLAR-GROUP/hpx/issues/682>

⁶²⁷⁴ <https://github.com/STELLAR-GROUP/hpx/issues/681>

⁶²⁷⁵ <https://github.com/STELLAR-GROUP/hpx/issues/679>

⁶²⁷⁶ <https://github.com/STELLAR-GROUP/hpx/issues/678>

⁶²⁷⁷ <https://github.com/STELLAR-GROUP/hpx/issues/677>

⁶²⁷⁸ <https://github.com/STELLAR-GROUP/hpx/issues/676>

⁶²⁷⁹ <https://github.com/STELLAR-GROUP/hpx/issues/675>

⁶²⁸⁰ <https://github.com/STELLAR-GROUP/hpx/issues/674>

- Issue #673⁶²⁸¹ - `use_guard_pages` has inconsistent preprocessor guards
- Issue #672⁶²⁸² - External build breaks if library path has spaces
- Issue #671⁶²⁸³ - release tarballs are tarbombs
- Issue #670⁶²⁸⁴ - CMake won't find Boost headers in layout=versioned install
- Issue #669⁶²⁸⁵ - Links in docs to source files broken if not installed
- Issue #667⁶²⁸⁶ - Not reading ini file properly
- Issue #664⁶²⁸⁷ - Adapt new meanings of 'const' and 'mutable'
- Issue #661⁶²⁸⁸ - Implement BTL Parcel port
- Issue #655⁶²⁸⁹ - Make HPX work with the "decltype" result_of
- Issue #647⁶²⁹⁰ - documentation for specifying the number of high priority threads
--`hpx:high-priority-threads`
- Issue #643⁶²⁹¹ - Error parsing host file
- Issue #642⁶²⁹² - HWLoc issue with TAU
- Issue #639⁶²⁹³ - Logging potentially suspends a running thread
- Issue #634⁶²⁹⁴ - Improve error reporting from parcel layer
- Issue #627⁶²⁹⁵ - Add tests for async and apply overloads that accept regular C++ functions
- Issue #626⁶²⁹⁶ - `hpx/future.hpp` header
- Issue #601⁶²⁹⁷ - Intel support
- Issue #557⁶²⁹⁸ - Remove action codes
- Issue #531⁶²⁹⁹ - AGAS request and response classes should use switch statements
- Issue #529⁶³⁰⁰ - Investigate the state of hwloc support
- Issue #526⁶³⁰¹ - Make HPX aware of hyper-threading
- Issue #518⁶³⁰² - Create facilities allowing to use plain arrays as action arguments
- Issue #473⁶³⁰³ - hwloc thread binding is broken on CPUs with hyperthreading

⁶²⁸¹ <https://github.com/STELLAR-GROUP/hpx/issues/673>

⁶²⁸² <https://github.com/STELLAR-GROUP/hpx/issues/672>

⁶²⁸³ <https://github.com/STELLAR-GROUP/hpx/issues/671>

⁶²⁸⁴ <https://github.com/STELLAR-GROUP/hpx/issues/670>

⁶²⁸⁵ <https://github.com/STELLAR-GROUP/hpx/issues/669>

⁶²⁸⁶ <https://github.com/STELLAR-GROUP/hpx/issues/667>

⁶²⁸⁷ <https://github.com/STELLAR-GROUP/hpx/issues/664>

⁶²⁸⁸ <https://github.com/STELLAR-GROUP/hpx/issues/661>

⁶²⁸⁹ <https://github.com/STELLAR-GROUP/hpx/issues/655>

⁶²⁹⁰ <https://github.com/STELLAR-GROUP/hpx/issues/647>

⁶²⁹¹ <https://github.com/STELLAR-GROUP/hpx/issues/643>

⁶²⁹² <https://github.com/STELLAR-GROUP/hpx/issues/642>

⁶²⁹³ <https://github.com/STELLAR-GROUP/hpx/issues/639>

⁶²⁹⁴ <https://github.com/STELLAR-GROUP/hpx/issues/634>

⁶²⁹⁵ <https://github.com/STELLAR-GROUP/hpx/issues/627>

⁶²⁹⁶ <https://github.com/STELLAR-GROUP/hpx/issues/626>

⁶²⁹⁷ <https://github.com/STELLAR-GROUP/hpx/issues/601>

⁶²⁹⁸ <https://github.com/STELLAR-GROUP/hpx/issues/557>

⁶²⁹⁹ <https://github.com/STELLAR-GROUP/hpx/issues/531>

⁶³⁰⁰ <https://github.com/STELLAR-GROUP/hpx/issues/529>

⁶³⁰¹ <https://github.com/STELLAR-GROUP/hpx/issues/526>

⁶³⁰² <https://github.com/STELLAR-GROUP/hpx/issues/518>

⁶³⁰³ <https://github.com/STELLAR-GROUP/hpx/issues/473>

- [Issue #383](#)⁶³⁰⁴ - Change result type detection for `hpx::util::bind` to use `result_of` protocol
- [Issue #341](#)⁶³⁰⁵ - Consolidate route code
- [Issue #219](#)⁶³⁰⁶ - Only copy arguments into actions once
- [Issue #177](#)⁶³⁰⁷ - Implement distributed AGAS
- [Issue #43](#)⁶³⁰⁸ - Support for Darwin (Xcode + Clang)

HPX V0.9.5 (Jan 16, 2013)

We have had over 1000 commits since the last release and we have closed roughly 150 tickets (bugs, feature requests, etc.).

General changes

This release is continuing along the lines of code and API consolidation, and overall usability improvements. We dedicated much attention to performance and we were able to significantly improve the threading and networking subsystems.

We successfully ported *HPX* to the Android platform. *HPX* applications now not only can run on mobile devices, but we support heterogeneous applications running across architecture boundaries. At the Supercomputing Conference 2012 we demonstrated connecting Android tablets to simulations running on a Linux cluster. The Android tablet was used to query performance counters from the Linux simulation and to steer its parameters.

We successfully ported *HPX* to Mac OSX (using the Clang compiler). Thanks to Pyry Jähkölä for contributing the corresponding patches. Please see the section `macos_installation` for more details.

We made a special effort to make *HPX* usable in highly concurrent use cases. Many of the *HPX* API functions which possibly take longer than 100 microseconds to execute now can be invoked asynchronously. We added uniform support for composing futures which simplifies to write asynchronous code. *HPX* actions (function objects encapsulating possibly concurrent remote function invocations) are now well integrated with all other API facilities such like `hpx::bind`.

All of the API has been aligned as much as possible with established paradigms. *HPX* now mirrors many of the facilities as defined in the C++11 Standard, such as `hpx::thread`, `hpx::function`, `hpx::future`, etc.

A lot of work has been put into improving the documentation. Many of the API functions are documented now, concepts are explained in detail, and examples are better described than before. The new documentation index enables finding information with lesser effort.

This is the first release of *HPX* we perform after the move to [Github](#)⁶³⁰⁹. This step has enabled a wider participation from the community and further encourages us in our decision to release *HPX* as a true open source library (*HPX* is licensed under the very liberal [Boost Software License](#)⁶³¹⁰).

⁶³⁰⁴ <https://github.com/STELLAR-GROUP/hpx/issues/383>

⁶³⁰⁵ <https://github.com/STELLAR-GROUP/hpx/issues/341>

⁶³⁰⁶ <https://github.com/STELLAR-GROUP/hpx/issues/219>

⁶³⁰⁷ <https://github.com/STELLAR-GROUP/hpx/issues/177>

⁶³⁰⁸ <https://github.com/STELLAR-GROUP/hpx/issues/43>

⁶³⁰⁹ <https://github.com/STELLAR-GROUP/hpx/>

⁶³¹⁰ https://www.boost.org/LICENSE_1_0.txt

Bug fixes (closed tickets)

Here is a list of the important tickets we closed for this release. This is by far the longest list of newly implemented features and fixed issues for any of HPX' releases so far.

- [Issue #666⁶³¹¹](#) - Segfault on calling `hpx::finalize` twice
- [Issue #665⁶³¹²](#) - Adding declaration `num_of_cores`
- [Issue #662⁶³¹³](#) - `pkgconfig` is building wrong
- [Issue #660⁶³¹⁴](#) - Need `uninterrupt` function
- [Issue #659⁶³¹⁵](#) - Move our logging library into a different namespace
- [Issue #658⁶³¹⁶](#) - Dynamic performance counter types are broken
- [Issue #657⁶³¹⁷](#) - HPX v0.9.5 (RC1) `hello_world` example segfaulting
- [Issue #656⁶³¹⁸](#) - Define the affinity of `parcel-pool`, `io-pool`, and `timer-pool` threads
- [Issue #654⁶³¹⁹](#) - Integrate the Boost `auto_index` tool with documentation
- [Issue #653⁶³²⁰](#) - Make HPX build on OS X + Clang + `libc++`
- [Issue #651⁶³²¹](#) - Add fine-grained control for thread pinning
- [Issue #650⁶³²²](#) - Command line no error message when using `-hpx:(anything)`
- [Issue #645⁶³²³](#) - Command line aliases don't work in `[teletype]`@file`[c++]`
- [Issue #644⁶³²⁴](#) - Terminated threads are not always properly cleaned up
- [Issue #640⁶³²⁵](#) - `future_data<T>::set_on_completed_` used without locks
- [Issue #638⁶³²⁶](#) - `hpx` build with intel compilers fails on linux
- [Issue #637⁶³²⁷](#) - `--copy-dt-needed-entries` breaks with gold
- [Issue #635⁶³²⁸](#) - Boost V1.53 will add `Boost.Lockfree` and `Boost.Atomic`
- [Issue #633⁶³²⁹](#) - Re-add examples to final 0.9.5 release
- [Issue #632⁶³³⁰](#) - Example `thread_aware_timer` is broken
- [Issue #631⁶³³¹](#) - FFT application throws error in `parcellayer`

⁶³¹¹ <https://github.com/STELLAR-GROUP/hpx/issues/666>

⁶³¹² <https://github.com/STELLAR-GROUP/hpx/issues/665>

⁶³¹³ <https://github.com/STELLAR-GROUP/hpx/issues/662>

⁶³¹⁴ <https://github.com/STELLAR-GROUP/hpx/issues/660>

⁶³¹⁵ <https://github.com/STELLAR-GROUP/hpx/issues/659>

⁶³¹⁶ <https://github.com/STELLAR-GROUP/hpx/issues/658>

⁶³¹⁷ <https://github.com/STELLAR-GROUP/hpx/issues/657>

⁶³¹⁸ <https://github.com/STELLAR-GROUP/hpx/issues/656>

⁶³¹⁹ <https://github.com/STELLAR-GROUP/hpx/issues/654>

⁶³²⁰ <https://github.com/STELLAR-GROUP/hpx/issues/653>

⁶³²¹ <https://github.com/STELLAR-GROUP/hpx/issues/651>

⁶³²² <https://github.com/STELLAR-GROUP/hpx/issues/650>

⁶³²³ <https://github.com/STELLAR-GROUP/hpx/issues/645>

⁶³²⁴ <https://github.com/STELLAR-GROUP/hpx/issues/644>

⁶³²⁵ <https://github.com/STELLAR-GROUP/hpx/issues/640>

⁶³²⁶ <https://github.com/STELLAR-GROUP/hpx/issues/638>

⁶³²⁷ <https://github.com/STELLAR-GROUP/hpx/issues/637>

⁶³²⁸ <https://github.com/STELLAR-GROUP/hpx/issues/635>

⁶³²⁹ <https://github.com/STELLAR-GROUP/hpx/issues/633>

⁶³³⁰ <https://github.com/STELLAR-GROUP/hpx/issues/632>

⁶³³¹ <https://github.com/STELLAR-GROUP/hpx/issues/631>

- [Issue #630](#)⁶³³² - Event synchronization example is broken
- [Issue #629](#)⁶³³³ - Waiting on futures hangs
- [Issue #628](#)⁶³³⁴ - Add an HPX_ALWAYS_ASSERT macro
- [Issue #625](#)⁶³³⁵ - Port coroutines context switch benchmark
- [Issue #621](#)⁶³³⁶ - New INI section for stack sizes
- [Issue #618](#)⁶³³⁷ - pkg_config support does not work with a HPX debug build
- [Issue #617](#)⁶³³⁸ - hpx/external/logging/boost/logging/detail/cache_before_init.hpp:139:67: error: 'get_thread_id' was not declared in this scope
- [Issue #616](#)⁶³³⁹ - Change wait_xxx not to use locking
- [Issue #615](#)⁶³⁴⁰ - Revert visibility 'fix' (fb0b6b8245dad1127b0c25ebafd9386b3945cca9)
- [Issue #614](#)⁶³⁴¹ - Fix Dataflow linker error
- [Issue #613](#)⁶³⁴² - find_here should throw an exception on failure
- [Issue #612](#)⁶³⁴³ - Thread phase doesn't show up in debug mode
- [Issue #611](#)⁶³⁴⁴ - Make stack guard pages configurable at runtime (initialization time)
- [Issue #610](#)⁶³⁴⁵ - Co-Locate Components
- [Issue #609](#)⁶³⁴⁶ - future_overhead
- [Issue #608](#)⁶³⁴⁷ - --hpx:list-counter-infos problem
- [Issue #607](#)⁶³⁴⁸ - Update Boost.Context based backend for coroutines
- [Issue #606](#)⁶³⁴⁹ - 1d_wave_equation is not working
- [Issue #605](#)⁶³⁵⁰ - Any C++ function that has serializable arguments and a serializable return type should be re-motable
- [Issue #604](#)⁶³⁵¹ - Connecting localities isn't working anymore
- [Issue #603](#)⁶³⁵² - Do not verify any ini entries read from a file
- [Issue #602](#)⁶³⁵³ - Rename argument_size to type_size/ added implementation to get parcel size

⁶³³² <https://github.com/STELLAR-GROUP/hpx/issues/630>

⁶³³³ <https://github.com/STELLAR-GROUP/hpx/issues/629>

⁶³³⁴ <https://github.com/STELLAR-GROUP/hpx/issues/628>

⁶³³⁵ <https://github.com/STELLAR-GROUP/hpx/issues/625>

⁶³³⁶ <https://github.com/STELLAR-GROUP/hpx/issues/621>

⁶³³⁷ <https://github.com/STELLAR-GROUP/hpx/issues/618>

⁶³³⁸ <https://github.com/STELLAR-GROUP/hpx/issues/617>

⁶³³⁹ <https://github.com/STELLAR-GROUP/hpx/issues/616>

⁶³⁴⁰ <https://github.com/STELLAR-GROUP/hpx/issues/615>

⁶³⁴¹ <https://github.com/STELLAR-GROUP/hpx/issues/614>

⁶³⁴² <https://github.com/STELLAR-GROUP/hpx/issues/613>

⁶³⁴³ <https://github.com/STELLAR-GROUP/hpx/issues/612>

⁶³⁴⁴ <https://github.com/STELLAR-GROUP/hpx/issues/611>

⁶³⁴⁵ <https://github.com/STELLAR-GROUP/hpx/issues/610>

⁶³⁴⁶ <https://github.com/STELLAR-GROUP/hpx/issues/609>

⁶³⁴⁷ <https://github.com/STELLAR-GROUP/hpx/issues/608>

⁶³⁴⁸ <https://github.com/STELLAR-GROUP/hpx/issues/607>

⁶³⁴⁹ <https://github.com/STELLAR-GROUP/hpx/issues/606>

⁶³⁵⁰ <https://github.com/STELLAR-GROUP/hpx/issues/605>

⁶³⁵¹ <https://github.com/STELLAR-GROUP/hpx/issues/604>

⁶³⁵² <https://github.com/STELLAR-GROUP/hpx/issues/603>

⁶³⁵³ <https://github.com/STELLAR-GROUP/hpx/issues/602>

- Issue #599⁶³⁵⁴ - Enable locality specific command line options
- Issue #598⁶³⁵⁵ - Need an API that accesses the performance counter reporting the system uptime
- Issue #597⁶³⁵⁶ - compiling on ranger
- Issue #595⁶³⁵⁷ - I need a place to store data in a thread self pointer
- Issue #594⁶³⁵⁸ - 32/64 interoperability
- Issue #593⁶³⁵⁹ - Warn if logging is disabled at compile time but requested at runtime
- Issue #592⁶³⁶⁰ - Add optional argument value to `--hpx:list-counters` and `--hpx:list-counter-infos`
- Issue #591⁶³⁶¹ - Allow for wildcards in performance counter names specified with `--hpx:print-counter`
- Issue #590⁶³⁶² - Local promise semantic differences
- Issue #589⁶³⁶³ - Create API to query performance counter names
- Issue #587⁶³⁶⁴ - Add `get_num_localities` and `get_num_threads` to AGAS API
- Issue #586⁶³⁶⁵ - Adjust local AGAS cache size based on number of localities
- Issue #585⁶³⁶⁶ - Error while using counters in HPX
- Issue #584⁶³⁶⁷ - counting argument size of actions, initial pass.
- Issue #581⁶³⁶⁸ - Remove `RemoteResult` template parameter for `future<>`
- Issue #580⁶³⁶⁹ - Add possibility to hook into actions
- Issue #578⁶³⁷⁰ - Use angle brackets in HPX error dumps
- Issue #576⁶³⁷¹ - Exception incorrectly thrown when `--help` is used
- Issue #575⁶³⁷² - HPX(`bad_component_type`) with gcc 4.7.2 and boost 1.51
- Issue #574⁶³⁷³ - `--hpx:connect` command line parameter not working correctly
- Issue #571⁶³⁷⁴ - `hpx::wait()` (callback version) should pass the future to the callback function
- Issue #570⁶³⁷⁵ - `hpx::wait` should operate on `boost::arrays` and `std::lists`
- Issue #569⁶³⁷⁶ - Add a logging sink for Android

⁶³⁵⁴ <https://github.com/STELLAR-GROUP/hpx/issues/599>
⁶³⁵⁵ <https://github.com/STELLAR-GROUP/hpx/issues/598>
⁶³⁵⁶ <https://github.com/STELLAR-GROUP/hpx/issues/597>
⁶³⁵⁷ <https://github.com/STELLAR-GROUP/hpx/issues/595>
⁶³⁵⁸ <https://github.com/STELLAR-GROUP/hpx/issues/594>
⁶³⁵⁹ <https://github.com/STELLAR-GROUP/hpx/issues/593>
⁶³⁶⁰ <https://github.com/STELLAR-GROUP/hpx/issues/592>
⁶³⁶¹ <https://github.com/STELLAR-GROUP/hpx/issues/591>
⁶³⁶² <https://github.com/STELLAR-GROUP/hpx/issues/590>
⁶³⁶³ <https://github.com/STELLAR-GROUP/hpx/issues/589>
⁶³⁶⁴ <https://github.com/STELLAR-GROUP/hpx/issues/587>
⁶³⁶⁵ <https://github.com/STELLAR-GROUP/hpx/issues/586>
⁶³⁶⁶ <https://github.com/STELLAR-GROUP/hpx/issues/585>
⁶³⁶⁷ <https://github.com/STELLAR-GROUP/hpx/issues/584>
⁶³⁶⁸ <https://github.com/STELLAR-GROUP/hpx/issues/581>
⁶³⁶⁹ <https://github.com/STELLAR-GROUP/hpx/issues/580>
⁶³⁷⁰ <https://github.com/STELLAR-GROUP/hpx/issues/578>
⁶³⁷¹ <https://github.com/STELLAR-GROUP/hpx/issues/576>
⁶³⁷² <https://github.com/STELLAR-GROUP/hpx/issues/575>
⁶³⁷³ <https://github.com/STELLAR-GROUP/hpx/issues/574>
⁶³⁷⁴ <https://github.com/STELLAR-GROUP/hpx/issues/571>
⁶³⁷⁵ <https://github.com/STELLAR-GROUP/hpx/issues/570>
⁶³⁷⁶ <https://github.com/STELLAR-GROUP/hpx/issues/569>

- Issue #568⁶³⁷⁷ - 2-argument version of HPX_DEFINE_COMPONENT_ACTION
- Issue #567⁶³⁷⁸ - Connecting to a running HPX application works only once
- Issue #565⁶³⁷⁹ - HPX doesn't shutdown properly
- Issue #564⁶³⁸⁰ - Partial preprocessing of new component creation interface
- Issue #563⁶³⁸¹ - Add `hpx::start/hpx::stop` to avoid blocking main thread
- Issue #562⁶³⁸² - All command line arguments swallowed by `hpx`
- Issue #561⁶³⁸³ - `Boost.Tuple` is not move aware
- Issue #558⁶³⁸⁴ - `boost::shared_ptr<>` style semantics/syntax for client classes
- Issue #556⁶³⁸⁵ - Creation of partially preprocessed headers should be enabled for Boost newer than V1.50
- Issue #555⁶³⁸⁶ - `BOOST_FORCEINLINE` does not name a type
- Issue #554⁶³⁸⁷ - Possible race condition in `thread get_id()`
- Issue #552⁶³⁸⁸ - Move enable `client_base`
- Issue #550⁶³⁸⁹ - Add stack size category 'huge'
- Issue #549⁶³⁹⁰ - ShenEOS run seg-faults on single or distributed runs
- Issue #545⁶³⁹¹ - `AUTOGLOB` broken for `add_hpx_component`
- Issue #542⁶³⁹² - `FindHPX_HDF5` still searches multiple times
- Issue #541⁶³⁹³ - Quotes around application name in `hpx::init`
- Issue #539⁶³⁹⁴ - Race condition occurring with new lightweight threads
- Issue #535⁶³⁹⁵ - `hpx_run_tests.py` exits with no error code when tests are missing
- Issue #530⁶³⁹⁶ - Thread description(<unknown>) in logs
- Issue #523⁶³⁹⁷ - Make thread objects more lightweight
- Issue #521⁶³⁹⁸ - `hpx::error_code` is not usable for lightweight error handling
- Issue #520⁶³⁹⁹ - Add full user environment to HPX logs

⁶³⁷⁷ <https://github.com/STELLAR-GROUP/hpx/issues/568>

⁶³⁷⁸ <https://github.com/STELLAR-GROUP/hpx/issues/567>

⁶³⁷⁹ <https://github.com/STELLAR-GROUP/hpx/issues/565>

⁶³⁸⁰ <https://github.com/STELLAR-GROUP/hpx/issues/564>

⁶³⁸¹ <https://github.com/STELLAR-GROUP/hpx/issues/563>

⁶³⁸² <https://github.com/STELLAR-GROUP/hpx/issues/562>

⁶³⁸³ <https://github.com/STELLAR-GROUP/hpx/issues/561>

⁶³⁸⁴ <https://github.com/STELLAR-GROUP/hpx/issues/558>

⁶³⁸⁵ <https://github.com/STELLAR-GROUP/hpx/issues/556>

⁶³⁸⁶ <https://github.com/STELLAR-GROUP/hpx/issues/555>

⁶³⁸⁷ <https://github.com/STELLAR-GROUP/hpx/issues/554>

⁶³⁸⁸ <https://github.com/STELLAR-GROUP/hpx/issues/552>

⁶³⁸⁹ <https://github.com/STELLAR-GROUP/hpx/issues/550>

⁶³⁹⁰ <https://github.com/STELLAR-GROUP/hpx/issues/549>

⁶³⁹¹ <https://github.com/STELLAR-GROUP/hpx/issues/545>

⁶³⁹² <https://github.com/STELLAR-GROUP/hpx/issues/542>

⁶³⁹³ <https://github.com/STELLAR-GROUP/hpx/issues/541>

⁶³⁹⁴ <https://github.com/STELLAR-GROUP/hpx/issues/539>

⁶³⁹⁵ <https://github.com/STELLAR-GROUP/hpx/issues/535>

⁶³⁹⁶ <https://github.com/STELLAR-GROUP/hpx/issues/530>

⁶³⁹⁷ <https://github.com/STELLAR-GROUP/hpx/issues/523>

⁶³⁹⁸ <https://github.com/STELLAR-GROUP/hpx/issues/521>

⁶³⁹⁹ <https://github.com/STELLAR-GROUP/hpx/issues/520>

- [Issue #519](#)⁶⁴⁰⁰ - Build succeeds, running fails
- [Issue #517](#)⁶⁴⁰¹ - Add a guard page to linux coroutine stacks
- [Issue #516](#)⁶⁴⁰² - `hpx::thread::detach` suspends while holding locks, leads to hang in debug
- [Issue #514](#)⁶⁴⁰³ - Preprocessed headers for `<hpx/apply.hpp>` don't compile
- [Issue #513](#)⁶⁴⁰⁴ - Buildbot configuration problem
- [Issue #512](#)⁶⁴⁰⁵ - Implement action based stack size customization
- [Issue #511](#)⁶⁴⁰⁶ - Move action priority into a separate type trait
- [Issue #510](#)⁶⁴⁰⁷ - trunk broken
- [Issue #507](#)⁶⁴⁰⁸ - no matching function for call to `boost::scoped_ptr<hpx::threads::topology>::scoped_ptr(hpx::thre`
- [Issue #505](#)⁶⁴⁰⁹ - `undefined_symbol` regression test currently failing
- [Issue #502](#)⁶⁴¹⁰ - Adding OpenCL and OCLM support to HPX for Windows and Linux
- [Issue #501](#)⁶⁴¹¹ - `find_package(HPX)` sets cmake output variables
- [Issue #500](#)⁶⁴¹² - `wait_any/wait_all` are badly named
- [Issue #499](#)⁶⁴¹³ - Add support for disabling pbs support in pbs runs
- [Issue #498](#)⁶⁴¹⁴ - Error during no-cache runs
- [Issue #496](#)⁶⁴¹⁵ - Add partial preprocessing support to cmake
- [Issue #495](#)⁶⁴¹⁶ - Support HPX modules exporting startup/shutdown functions only
- [Issue #494](#)⁶⁴¹⁷ - Allow modules to specify when to run startup/shutdown functions
- [Issue #493](#)⁶⁴¹⁸ - Avoid constructing a string in `make_success_code`
- [Issue #492](#)⁶⁴¹⁹ - Performance counter creation is no longer synchronized at startup
- [Issue #491](#)⁶⁴²⁰ - Performance counter creation is no longer synchronized at startup
- [Issue #490](#)⁶⁴²¹ - Sheneos on `_completed_bulk` seg fault in distributed
- [Issue #489](#)⁶⁴²² - compiling issue with `g++44`

⁶⁴⁰⁰ <https://github.com/STELLAR-GROUP/hpx/issues/519>

⁶⁴⁰¹ <https://github.com/STELLAR-GROUP/hpx/issues/517>

⁶⁴⁰² <https://github.com/STELLAR-GROUP/hpx/issues/516>

⁶⁴⁰³ <https://github.com/STELLAR-GROUP/hpx/issues/514>

⁶⁴⁰⁴ <https://github.com/STELLAR-GROUP/hpx/issues/513>

⁶⁴⁰⁵ <https://github.com/STELLAR-GROUP/hpx/issues/512>

⁶⁴⁰⁶ <https://github.com/STELLAR-GROUP/hpx/issues/511>

⁶⁴⁰⁷ <https://github.com/STELLAR-GROUP/hpx/issues/510>

⁶⁴⁰⁸ <https://github.com/STELLAR-GROUP/hpx/issues/507>

⁶⁴⁰⁹ <https://github.com/STELLAR-GROUP/hpx/issues/505>

⁶⁴¹⁰ <https://github.com/STELLAR-GROUP/hpx/issues/502>

⁶⁴¹¹ <https://github.com/STELLAR-GROUP/hpx/issues/501>

⁶⁴¹² <https://github.com/STELLAR-GROUP/hpx/issues/500>

⁶⁴¹³ <https://github.com/STELLAR-GROUP/hpx/issues/499>

⁶⁴¹⁴ <https://github.com/STELLAR-GROUP/hpx/issues/498>

⁶⁴¹⁵ <https://github.com/STELLAR-GROUP/hpx/issues/496>

⁶⁴¹⁶ <https://github.com/STELLAR-GROUP/hpx/issues/495>

⁶⁴¹⁷ <https://github.com/STELLAR-GROUP/hpx/issues/494>

⁶⁴¹⁸ <https://github.com/STELLAR-GROUP/hpx/issues/493>

⁶⁴¹⁹ <https://github.com/STELLAR-GROUP/hpx/issues/492>

⁶⁴²⁰ <https://github.com/STELLAR-GROUP/hpx/issues/491>

⁶⁴²¹ <https://github.com/STELLAR-GROUP/hpx/issues/490>

⁶⁴²² <https://github.com/STELLAR-GROUP/hpx/issues/489>

- Issue #488⁶⁴²³ - Adding OpenCL and OCLM support to HPX for the MSVC platform
- Issue #487⁶⁴²⁴ - FindHPX.cmake problems
- Issue #485⁶⁴²⁵ - Change distributing_factory and binpacking_factory to use bulk creation
- Issue #484⁶⁴²⁶ - Change HPX_DONT_USE_PREPROCESSED_FILES to HPX_USE_PREPROCESSED_FILES
- Issue #483⁶⁴²⁷ - Memory counter for Windows
- Issue #479⁶⁴²⁸ - strange errors appear when requesting performance counters on multiple nodes
- Issue #477⁶⁴²⁹ - Create (global) timer for multi-threaded measurements
- Issue #472⁶⁴³⁰ - Add partial preprocessing using Wave
- Issue #471⁶⁴³¹ - Segfault stack traces don't show up in release
- Issue #468⁶⁴³² - External projects need to link with internal components
- Issue #462⁶⁴³³ - Startup/shutdown functions are called more than once
- Issue #458⁶⁴³⁴ - Consolidate hpx::util::high_resolution_timer and hpx::util::high_resolution_clock
- Issue #457⁶⁴³⁵ - index out of bounds in allgather_and_gate on 4 cores or more
- Issue #448⁶⁴³⁶ - Make HPX compile with clang
- Issue #447⁶⁴³⁷ - 'make tests' should execute tests on local installation
- Issue #446⁶⁴³⁸ - Remove SVN-related code from the codebase
- Issue #444⁶⁴³⁹ - race condition in smp
- Issue #441⁶⁴⁴⁰ - Patched Boost.Serialization headers should only be installed if needed
- Issue #439⁶⁴⁴¹ - Components using HPX_REGISTER_STARTUP_MODULE fail to compile with MSVC
- Issue #436⁶⁴⁴² - Verify that no locks are being held while threads are suspended
- Issue #435⁶⁴⁴³ - Installing HPX should not clobber existing Boost installation
- Issue #434⁶⁴⁴⁴ - Logging external component failed (Boost 1.50)
- Issue #433⁶⁴⁴⁵ - Runtime crash when building all examples

⁶⁴²³ <https://github.com/STELLAR-GROUP/hpx/issues/488>

⁶⁴²⁴ <https://github.com/STELLAR-GROUP/hpx/issues/487>

⁶⁴²⁵ <https://github.com/STELLAR-GROUP/hpx/issues/485>

⁶⁴²⁶ <https://github.com/STELLAR-GROUP/hpx/issues/484>

⁶⁴²⁷ <https://github.com/STELLAR-GROUP/hpx/issues/483>

⁶⁴²⁸ <https://github.com/STELLAR-GROUP/hpx/issues/479>

⁶⁴²⁹ <https://github.com/STELLAR-GROUP/hpx/issues/477>

⁶⁴³⁰ <https://github.com/STELLAR-GROUP/hpx/issues/472>

⁶⁴³¹ <https://github.com/STELLAR-GROUP/hpx/issues/471>

⁶⁴³² <https://github.com/STELLAR-GROUP/hpx/issues/468>

⁶⁴³³ <https://github.com/STELLAR-GROUP/hpx/issues/462>

⁶⁴³⁴ <https://github.com/STELLAR-GROUP/hpx/issues/458>

⁶⁴³⁵ <https://github.com/STELLAR-GROUP/hpx/issues/457>

⁶⁴³⁶ <https://github.com/STELLAR-GROUP/hpx/issues/448>

⁶⁴³⁷ <https://github.com/STELLAR-GROUP/hpx/issues/447>

⁶⁴³⁸ <https://github.com/STELLAR-GROUP/hpx/issues/446>

⁶⁴³⁹ <https://github.com/STELLAR-GROUP/hpx/issues/444>

⁶⁴⁴⁰ <https://github.com/STELLAR-GROUP/hpx/issues/441>

⁶⁴⁴¹ <https://github.com/STELLAR-GROUP/hpx/issues/439>

⁶⁴⁴² <https://github.com/STELLAR-GROUP/hpx/issues/436>

⁶⁴⁴³ <https://github.com/STELLAR-GROUP/hpx/issues/435>

⁶⁴⁴⁴ <https://github.com/STELLAR-GROUP/hpx/issues/434>

⁶⁴⁴⁵ <https://github.com/STELLAR-GROUP/hpx/issues/433>

- [Issue #432](#)⁶⁴⁴⁶ - Dataflow hangs on 512 cores/64 nodes
- [Issue #430](#)⁶⁴⁴⁷ - Problem with distributing factory
- [Issue #424](#)⁶⁴⁴⁸ - File paths referring to XSL-files need to be properly escaped
- [Issue #417](#)⁶⁴⁴⁹ - Make dataflow LCOs work out of the box by using partial preprocessing
- [Issue #413](#)⁶⁴⁵⁰ - `hpx_svnversion.py` fails on Windows
- [Issue #412](#)⁶⁴⁵¹ - Make `hpx::error_code` equivalent to `hpx::exception`
- [Issue #398](#)⁶⁴⁵² - HPX clobbers out-of-tree application specific CMake variables (specifically `CMAKE_BUILD_TYPE`)
- [Issue #394](#)⁶⁴⁵³ - Remove code generating random port numbers for network
- [Issue #378](#)⁶⁴⁵⁴ - ShenEOS scaling issues
- [Issue #354](#)⁶⁴⁵⁵ - Create a coroutines wrapper for `Boost.Context`
- [Issue #349](#)⁶⁴⁵⁶ - Commandline option `--localities=N/-lN` should be necessary only on AGAS locality
- [Issue #334](#)⁶⁴⁵⁷ - Add `auto_index` support to cmake based documentation toolchain
- [Issue #318](#)⁶⁴⁵⁸ - Network benchmarks
- [Issue #317](#)⁶⁴⁵⁹ - Implement network performance counters
- [Issue #310](#)⁶⁴⁶⁰ - Duplicate logging entries
- [Issue #230](#)⁶⁴⁶¹ - Add compile time option to disable thread debugging info
- [Issue #171](#)⁶⁴⁶² - Add an INI option to turn off deadlock detection independently of logging
- [Issue #170](#)⁶⁴⁶³ - OSHL internal counters are incorrect
- [Issue #103](#)⁶⁴⁶⁴ - Better diagnostics for multiple component/action registrations under the same name
- [Issue #48](#)⁶⁴⁶⁵ - Support for Darwin (Xcode + Clang)
- [Issue #21](#)⁶⁴⁶⁶ - Build fails with GCC 4.6

⁶⁴⁴⁶ <https://github.com/STELLAR-GROUP/hpx/issues/432>

⁶⁴⁴⁷ <https://github.com/STELLAR-GROUP/hpx/issues/430>

⁶⁴⁴⁸ <https://github.com/STELLAR-GROUP/hpx/issues/424>

⁶⁴⁴⁹ <https://github.com/STELLAR-GROUP/hpx/issues/417>

⁶⁴⁵⁰ <https://github.com/STELLAR-GROUP/hpx/issues/413>

⁶⁴⁵¹ <https://github.com/STELLAR-GROUP/hpx/issues/412>

⁶⁴⁵² <https://github.com/STELLAR-GROUP/hpx/issues/398>

⁶⁴⁵³ <https://github.com/STELLAR-GROUP/hpx/issues/394>

⁶⁴⁵⁴ <https://github.com/STELLAR-GROUP/hpx/issues/378>

⁶⁴⁵⁵ <https://github.com/STELLAR-GROUP/hpx/issues/354>

⁶⁴⁵⁶ <https://github.com/STELLAR-GROUP/hpx/issues/349>

⁶⁴⁵⁷ <https://github.com/STELLAR-GROUP/hpx/issues/334>

⁶⁴⁵⁸ <https://github.com/STELLAR-GROUP/hpx/issues/318>

⁶⁴⁵⁹ <https://github.com/STELLAR-GROUP/hpx/issues/317>

⁶⁴⁶⁰ <https://github.com/STELLAR-GROUP/hpx/issues/310>

⁶⁴⁶¹ <https://github.com/STELLAR-GROUP/hpx/issues/230>

⁶⁴⁶² <https://github.com/STELLAR-GROUP/hpx/issues/171>

⁶⁴⁶³ <https://github.com/STELLAR-GROUP/hpx/issues/170>

⁶⁴⁶⁴ <https://github.com/STELLAR-GROUP/hpx/issues/103>

⁶⁴⁶⁵ <https://github.com/STELLAR-GROUP/hpx/issues/48>

⁶⁴⁶⁶ <https://github.com/STELLAR-GROUP/hpx/issues/21>

HPX V0.9.0 (Jul 5, 2012)

We have had roughly 800 commits since the last release and we have closed approximately 80 tickets (bugs, feature requests, etc.).

General changes

- Significant improvements made to the usability of *HPX* in large-scale, distributed environments.
- Renamed `hpx::lcos::packaged_task` to `hpx::lcos::packaged_action` to reflect the semantic differences to a `packaged_task` as defined by the C++11 Standard⁶⁴⁶⁷.
- *HPX* now exposes `hpx::thread` which is compliant to the C++11 `std::thread` type except that it (purely locally) represents an *HPX* thread. This new type does not expose any of the remote capabilities of the underlying *HPX*-thread implementation.
- The type `hpx::lcos::future` is now compliant to the C++11 `std::future<>` type. This type can be used to synchronize both, local and remote operations. In both cases the control flow will ‘return’ to the future in order to trigger any continuation.
- The types `hpx::lcos::local::promise` and `hpx::lcos::local::packaged_task` are now compliant to the C++11 `std::promise<>` and `std::packaged_task<>` types. These can be used to create a future representing local work only. Use the types `hpx::lcos::promise` and `hpx::lcos::packaged_action` to wrap any (possibly remote) action into a future.
- `hpx::thread` and `hpx::lcos::future` are now cancelable.
- Added support for sequential and logic composition of `hpx::lcos::futures`. The member function `hpx::lcos::future::when` permits futures to be sequentially composed. The helper functions `hpx::wait_all`, `hpx::wait_any`, and `hpx::wait_n` can be used to wait for more than one future at a time.
- *HPX* now exposes `hpx::apply` and `hpx::async` as the preferred way of creating (or invoking) any deferred work. These functions are usable with various types of functions, function objects, and actions and provide a uniform way to spawn deferred tasks.
- *HPX* now utilizes `hpx::util::bind` to (partially) bind local functions and function objects, and also actions. Remote bound actions can have placeholders as well.
- *HPX* continuations are now fully polymorphic. The class `hpx::actions::forwarding_continuation` is an example of how the user can write its own types of continuations. It can be used to execute any function as an continuation of a particular action.
- Reworked the action invocation API to be fully conformant to normal functions. Actions can now be invoked using `hpx::apply`, `hpx::async`, or using the `operator()` implemented on actions. Actions themselves can now be cheaply instantiated as they do not have any members anymore.
- Reworked the lazy action invocation API. Actions can now be directly bound using `hpx::util::bind` by passing an action instance as the first argument.
- A minimal *HPX* program now looks like this:

```
#include <hpx/hpx_init.hpp>

int hpx_main()
{
    return hpx::finalize();
}
```

(continues on next page)

⁶⁴⁶⁷ <http://www.open-std.org/jtc1/sc22/wg21>

(continued from previous page)

```
int main()
{
    return hpx::init();
}
```

This removes the immediate dependency on the `Boost.Program_options`⁶⁴⁶⁸ library.

Note: This minimal version of an *HPX* program does not support any of the default command line arguments (such as `-help`, or command line options related to PBS). It is suggested to always pass `argc` and `argv` to *HPX* as shown in the example below.

- In order to support those, but still not to depend on `Boost.Program_options`⁶⁴⁶⁹, the minimal program can be written as:

```
#include <hpx/hpx_init.hpp>

// The arguments for hpx_main can be left off, which very similar to the
// behavior of ``main()`` as defined by C++.
int hpx_main(int argc, char* argv[])
{
    return hpx::finalize();
}

int main(int argc, char* argv[])
{
    return hpx::init(argc, argv);
}
```

- Added performance counters exposing the number of component instances which are alive on a given locality.
- Added performance counters exposing then number of messages sent and received, the number of parcels sent and received, the number of bytes sent and received, the overall time required to send and receive data, and the overall time required to serialize and deserialize the data.
- Added a new component: `hpx::components::binpacking_factory` which is equivalent to the existing `hpx::components::distributing_factory` component, except that it equalizes the overall population of the components to create. It exposes two factory methods, one based on the number of existing instances of the component type to create, and one based on an arbitrary performance counter which will be queried for all relevant localities.
- Added API functions allowing to access elements of the diagnostic information embedded in the given exception: `hpx::get_locality_id`, `hpx::get_host_name`, `hpx::get_process_id`, `hpx::get_function_name`, `hpx::get_file_name`, `hpx::get_line_number`, `hpx::get_os_thread`, `hpx::get_thread_id`, and `hpx::get_thread_description`.

⁶⁴⁶⁸ https://www.boost.org/doc/html/program_options.html

⁶⁴⁶⁹ https://www.boost.org/doc/html/program_options.html

Bug fixes (closed tickets)

Here is a list of the important tickets we closed for this release:

- [Issue #71](#)⁶⁴⁷⁰ - GIDs that are not serialized via `handle_gid<>` should raise an exception
- [Issue #105](#)⁶⁴⁷¹ - Allow for `hpx::util::functions` to be registered in the AGAS symbolic namespace
- [Issue #107](#)⁶⁴⁷² - Nasty threadmanger race condition (reproducible in `sheneos_test`)
- [Issue #108](#)⁶⁴⁷³ - Add millisecond resolution to *HPX* logs on Linux
- [Issue #110](#)⁶⁴⁷⁴ - Shutdown hang in distributed with release build
- [Issue #116](#)⁶⁴⁷⁵ - Don't use TSS for the applier and runtime pointers
- [Issue #162](#)⁶⁴⁷⁶ - Move local synchronous execution shortcut from `hpx::function` to the applier
- [Issue #172](#)⁶⁴⁷⁷ - Cache sources in CMake and check if they change manually
- [Issue #178](#)⁶⁴⁷⁸ - Add an INI option to turn off ranged-based AGAS caching
- [Issue #187](#)⁶⁴⁷⁹ - Support for disabling performance counter deployment
- [Issue #202](#)⁶⁴⁸⁰ - Support for sending performance counter data to a specific file
- [Issue #218](#)⁶⁴⁸¹ - `boost.coroutines` allows different stack sizes, but stack pool is unaware of this
- [Issue #231](#)⁶⁴⁸² - Implement movable `boost::bind`
- [Issue #232](#)⁶⁴⁸³ - Implement movable `boost::function`
- [Issue #236](#)⁶⁴⁸⁴ - Allow binding `hpx::util::function` to actions
- [Issue #239](#)⁶⁴⁸⁵ - Replace `hpx::function` with `hpx::util::function`
- [Issue #240](#)⁶⁴⁸⁶ - Can't specify `RemoteResult` with `lcos::async`
- [Issue #242](#)⁶⁴⁸⁷ - `REGISTER_TEMPLATE` support for plain actions
- [Issue #243](#)⁶⁴⁸⁸ - `handle_gid<>` support for `hpx::util::function`
- [Issue #245](#)⁶⁴⁸⁹ - `*_c_cache` code throws an exception if the queried GID is not in the local cache
- [Issue #246](#)⁶⁴⁹⁰ - Undefined references in `dataflow/adaptiveId` example

⁶⁴⁷⁰ <https://github.com/STELLAR-GROUP/hpx/issues/71>
⁶⁴⁷¹ <https://github.com/STELLAR-GROUP/hpx/issues/105>
⁶⁴⁷² <https://github.com/STELLAR-GROUP/hpx/issues/107>
⁶⁴⁷³ <https://github.com/STELLAR-GROUP/hpx/issues/108>
⁶⁴⁷⁴ <https://github.com/STELLAR-GROUP/hpx/issues/110>
⁶⁴⁷⁵ <https://github.com/STELLAR-GROUP/hpx/issues/116>
⁶⁴⁷⁶ <https://github.com/STELLAR-GROUP/hpx/issues/162>
⁶⁴⁷⁷ <https://github.com/STELLAR-GROUP/hpx/issues/172>
⁶⁴⁷⁸ <https://github.com/STELLAR-GROUP/hpx/issues/178>
⁶⁴⁷⁹ <https://github.com/STELLAR-GROUP/hpx/issues/187>
⁶⁴⁸⁰ <https://github.com/STELLAR-GROUP/hpx/issues/202>
⁶⁴⁸¹ <https://github.com/STELLAR-GROUP/hpx/issues/218>
⁶⁴⁸² <https://github.com/STELLAR-GROUP/hpx/issues/231>
⁶⁴⁸³ <https://github.com/STELLAR-GROUP/hpx/issues/232>
⁶⁴⁸⁴ <https://github.com/STELLAR-GROUP/hpx/issues/236>
⁶⁴⁸⁵ <https://github.com/STELLAR-GROUP/hpx/issues/239>
⁶⁴⁸⁶ <https://github.com/STELLAR-GROUP/hpx/issues/240>
⁶⁴⁸⁷ <https://github.com/STELLAR-GROUP/hpx/issues/242>
⁶⁴⁸⁸ <https://github.com/STELLAR-GROUP/hpx/issues/243>
⁶⁴⁸⁹ <https://github.com/STELLAR-GROUP/hpx/issues/245>
⁶⁴⁹⁰ <https://github.com/STELLAR-GROUP/hpx/issues/246>

- Issue #252⁶⁴⁹¹ - Problems configuring sheneos with CMake
- Issue #254⁶⁴⁹² - Lifetime of components doesn't end when client goes out of scope
- Issue #259⁶⁴⁹³ - CMake does not detect that MSVC10 has lambdas
- Issue #260⁶⁴⁹⁴ - io_service_pool segfault
- Issue #261⁶⁴⁹⁵ - Late parcel executed outside of pxtread
- Issue #263⁶⁴⁹⁶ - Cannot select allocator with CMake
- Issue #264⁶⁴⁹⁷ - Fix allocator select
- Issue #267⁶⁴⁹⁸ - Runtime error for hello_world
- Issue #269⁶⁴⁹⁹ - pthread_affinity_np test fails to compile
- Issue #270⁶⁵⁰⁰ - Compiler noise due to -Wcast-qual
- Issue #275⁶⁵⁰¹ - Problem with configuration tests/include paths on Gentoo
- Issue #325⁶⁵⁰² - Sheneos is 200-400 times slower than the fortran equivalent
- Issue #331⁶⁵⁰³ - `hpx::init` and `hpx::main()` should not depend on `program_options`
- Issue #333⁶⁵⁰⁴ - Add doxygen support to CMake for doc toolchain
- Issue #340⁶⁵⁰⁵ - Performance counters for parcels
- Issue #346⁶⁵⁰⁶ - Component loading error when running hello_world in distributed on MSVC2010
- Issue #362⁶⁵⁰⁷ - Missing initializer error
- Issue #363⁶⁵⁰⁸ - Parcel port serialization error
- Issue #366⁶⁵⁰⁹ - Parcel buffering leads to types incompatible exception
- Issue #368⁶⁵¹⁰ - Scalable alternative to `rand()` needed for *HPX*
- Issue #369⁶⁵¹¹ - IB over IP is substantially slower than just using standard TCP/IP
- Issue #374⁶⁵¹² - `hpx::lcos::wait` should work with dataflows and arbitrary classes meeting the future interface
- Issue #375⁶⁵¹³ - Conflicting/ambiguous overloads of `hpx::lcos::wait`

⁶⁴⁹¹ <https://github.com/STELLAR-GROUP/hpx/issues/252>

⁶⁴⁹² <https://github.com/STELLAR-GROUP/hpx/issues/254>

⁶⁴⁹³ <https://github.com/STELLAR-GROUP/hpx/issues/259>

⁶⁴⁹⁴ <https://github.com/STELLAR-GROUP/hpx/issues/260>

⁶⁴⁹⁵ <https://github.com/STELLAR-GROUP/hpx/issues/261>

⁶⁴⁹⁶ <https://github.com/STELLAR-GROUP/hpx/issues/263>

⁶⁴⁹⁷ <https://github.com/STELLAR-GROUP/hpx/issues/264>

⁶⁴⁹⁸ <https://github.com/STELLAR-GROUP/hpx/issues/267>

⁶⁴⁹⁹ <https://github.com/STELLAR-GROUP/hpx/issues/269>

⁶⁵⁰⁰ <https://github.com/STELLAR-GROUP/hpx/issues/270>

⁶⁵⁰¹ <https://github.com/STELLAR-GROUP/hpx/issues/275>

⁶⁵⁰² <https://github.com/STELLAR-GROUP/hpx/issues/325>

⁶⁵⁰³ <https://github.com/STELLAR-GROUP/hpx/issues/331>

⁶⁵⁰⁴ <https://github.com/STELLAR-GROUP/hpx/issues/333>

⁶⁵⁰⁵ <https://github.com/STELLAR-GROUP/hpx/issues/340>

⁶⁵⁰⁶ <https://github.com/STELLAR-GROUP/hpx/issues/346>

⁶⁵⁰⁷ <https://github.com/STELLAR-GROUP/hpx/issues/362>

⁶⁵⁰⁸ <https://github.com/STELLAR-GROUP/hpx/issues/363>

⁶⁵⁰⁹ <https://github.com/STELLAR-GROUP/hpx/issues/366>

⁶⁵¹⁰ <https://github.com/STELLAR-GROUP/hpx/issues/368>

⁶⁵¹¹ <https://github.com/STELLAR-GROUP/hpx/issues/369>

⁶⁵¹² <https://github.com/STELLAR-GROUP/hpx/issues/374>

⁶⁵¹³ <https://github.com/STELLAR-GROUP/hpx/issues/375>

- Issue #376⁶⁵¹⁴ - Find_HPX.cmake should set CMake variable HPX_FOUND for out of tree builds
- Issue #377⁶⁵¹⁵ - ShenEOS interpolate bulk and interpolate_one_bulk are broken
- Issue #379⁶⁵¹⁶ - Add support for distributed runs under SLURM
- Issue #382⁶⁵¹⁷ - _Unwind_Word not declared in boost.backtrace
- Issue #387⁶⁵¹⁸ - Doxygen should look only at list of specified files
- Issue #388⁶⁵¹⁹ - Running make install on an out-of-tree application is broken
- Issue #391⁶⁵²⁰ - Out-of-tree application segfaults when running in qsub
- Issue #392⁶⁵²¹ - Remove HPX_NO_INSTALL option from cmake build system
- Issue #396⁶⁵²² - Pragma related warnings when compiling with older gcc versions
- Issue #399⁶⁵²³ - Out of tree component build problems
- Issue #400⁶⁵²⁴ - Out of source builds on Windows: linker should not receive compiler flags
- Issue #401⁶⁵²⁵ - Out of source builds on Windows: components need to be linked with hpx_serialization
- Issue #404⁶⁵²⁶ - gfortran fails to link automatically when fortran files are present
- Issue #405⁶⁵²⁷ - Inability to specify linking order for external libraries
- Issue #406⁶⁵²⁸ - Adapt action limits such that dataflow applications work without additional defines
- Issue #415⁶⁵²⁹ - locality_results is not a member of hpx::components::server
- Issue #425⁶⁵³⁰ - Breaking changes to traits::*result wrt std::vector<id_type>
- Issue #426⁶⁵³¹ - AUTOGLOB needs to be updated to support fortran

HPX V0.8.1 (Apr 21, 2012)

This is a point release including important bug fixes for *HPX V0.8.0 (Mar 23, 2012)*.

- ⁶⁵¹⁴ <https://github.com/STELLAR-GROUP/hpx/issues/376>
- ⁶⁵¹⁵ <https://github.com/STELLAR-GROUP/hpx/issues/377>
- ⁶⁵¹⁶ <https://github.com/STELLAR-GROUP/hpx/issues/379>
- ⁶⁵¹⁷ <https://github.com/STELLAR-GROUP/hpx/issues/382>
- ⁶⁵¹⁸ <https://github.com/STELLAR-GROUP/hpx/issues/387>
- ⁶⁵¹⁹ <https://github.com/STELLAR-GROUP/hpx/issues/388>
- ⁶⁵²⁰ <https://github.com/STELLAR-GROUP/hpx/issues/391>
- ⁶⁵²¹ <https://github.com/STELLAR-GROUP/hpx/issues/392>
- ⁶⁵²² <https://github.com/STELLAR-GROUP/hpx/issues/396>
- ⁶⁵²³ <https://github.com/STELLAR-GROUP/hpx/issues/399>
- ⁶⁵²⁴ <https://github.com/STELLAR-GROUP/hpx/issues/400>
- ⁶⁵²⁵ <https://github.com/STELLAR-GROUP/hpx/issues/401>
- ⁶⁵²⁶ <https://github.com/STELLAR-GROUP/hpx/issues/404>
- ⁶⁵²⁷ <https://github.com/STELLAR-GROUP/hpx/issues/405>
- ⁶⁵²⁸ <https://github.com/STELLAR-GROUP/hpx/issues/406>
- ⁶⁵²⁹ <https://github.com/STELLAR-GROUP/hpx/issues/415>
- ⁶⁵³⁰ <https://github.com/STELLAR-GROUP/hpx/issues/425>
- ⁶⁵³¹ <https://github.com/STELLAR-GROUP/hpx/issues/426>

General changes

- *HPX* does not need to be installed anymore to be functional.

Bug fixes (closed tickets)

Here is a list of the important tickets we closed for this point release:

- [Issue #295](https://github.com/STELLAR-GROUP/hpx/issues/295)⁶⁵³² - Don't require install path to be known at compile time.
- [Issue #371](https://github.com/STELLAR-GROUP/hpx/issues/371)⁶⁵³³ - Add `hpx::iostreams` to standard build.
- [Issue #384](https://github.com/STELLAR-GROUP/hpx/issues/384)⁶⁵³⁴ - Fix compilation with GCC 4.7.
- [Issue #390](https://github.com/STELLAR-GROUP/hpx/issues/390)⁶⁵³⁵ - Remove `keep_factory_alive` startup call from ShenEOS; add shutdown call to `H5close`.
- [Issue #393](https://github.com/STELLAR-GROUP/hpx/issues/393)⁶⁵³⁶ - Thread affinity control is broken.

Bug fixes (commits)

Here is a list of the important commits included in this point release:

- `r7642` - External: Fix backtrace memory violation.
- **`r7775` - Components: Fix symbol visibility bug with component startup** providers. This prevents one components providers from overriding another components.
- `r7778` - Components: Fix startup/shutdown provider shadowing issues.

HPX V0.8.0 (Mar 23, 2012)

We have had roughly 1000 commits since the last release and we have closed approximately 70 tickets (bugs, feature requests, etc.).

General changes

- Improved PBS support, allowing for arbitrary naming schemes of node-hostnames.
- Finished verification of the reference counting framework.
- Implemented decrement merging logic to optimize the distributed reference counting system.
- Restructured the LCO framework. Renamed `hpx::lcos::eager_future<>` and `hpx::lcos::lazy_future<>` into `hpx::lcos::packaged_task` and `hpx::lcos::deferred_packaged_task`. Split `hpx::lcos::promise` into `hpx::lcos::packaged_task` and `hpx::lcos::future`. Added 'local' futures (in namespace `hpx::lcos::local`).
- Improved the general performance of local and remote action invocations. This (under certain circumstances) drastically reduces the number of copies created for each of the parameters and return values.

⁶⁵³² <https://github.com/STELLAR-GROUP/hpx/issues/295>

⁶⁵³³ <https://github.com/STELLAR-GROUP/hpx/issues/371>

⁶⁵³⁴ <https://github.com/STELLAR-GROUP/hpx/issues/384>

⁶⁵³⁵ <https://github.com/STELLAR-GROUP/hpx/issues/390>

⁶⁵³⁶ <https://github.com/STELLAR-GROUP/hpx/issues/393>

- Reworked the performance counter framework. Performance counters are now created only when needed, which reduces the overall resource requirements. The new framework allows for much more flexible creation and management of performance counters. The new sine example application demonstrates some of the capabilities of the new infrastructure.
- Added a buildbot-based continuous build system which gives instant, automated feedback on each commit to SVN.
- Added more automated tests to verify proper functioning of *HPX*.
- Started to create documentation for *HPX* and its API.
- Added documentation toolchain to the build system.
- Added dataflow LCO.
- Changed default *HPX* command line options to have `hpx:` prefix. For instance, the former option `--threads` is now `--hpx:threads`. This has been done to make ambiguities with possible application specific command line options as unlikely as possible. See the section *HPX Command Line Options* for a full list of available options.
- Added the possibility to define command line aliases. The former short (one-letter) command line options have been predefined as aliases for backwards compatibility. See the section *HPX Command Line Options* for a detailed description of command line option aliasing.
- Network connections are now cached based on the connected host. The number of simultaneous connections to a particular host is now limited. Parcels are buffered and bundled if all connections are in use.
- Added more refined thread affinity control. This is based on the external library Portable Hardware Locality (HWLOC).
- Improved support for Windows builds with CMake.
- Added support for components to register their own command line options.
- Added the possibility to register custom startup/shutdown functions for any component. These functions are guaranteed to be executed by an *HPX* thread.
- Added two new experimental thread schedulers: `hierarchy_scheduler` and `periodic_priority_scheduler`. These can be activated by using the command line options `--hpx:queuing=hierarchy` or `--hpx:queuing=periodic`.

Example applications

- Graph500 performance benchmark⁶⁵³⁷ (thanks to Matthew Anderson for contributing this application).
- GTC (Gyrokinetic Toroidal Code)⁶⁵³⁸: a skeleton for particle in cell type codes.
- Random Memory Access: an example demonstrating random memory accesses in a large array
- ShenEOS example⁶⁵³⁹, demonstrating partitioning of large read-only data structures and exposing an interpolation API.
- Sine performance counter demo.
- Accumulator examples demonstrating how to write and use *HPX* components.
- Quickstart examples (like `hello_world`, `fibonacci`, `quicksort`, `factorial`, etc.) demonstrating simple *HPX* concepts which introduce some of the concepts in *HPX*.
- Load balancing and work stealing demos.

⁶⁵³⁷ <http://www.graph500.org/>

⁶⁵³⁸ <http://www.nersc.gov/research-and-development/benchmarking-and-workload-characterization/nersc-6-benchmarks/gtc/>

⁶⁵³⁹ <http://stellarcollapse.org/equationofstate>

API changes

- Moved all local LCOs into a separate namespace `hpx::lcos::local` (for instance, `hpx::lcos::local_mutex` is now `hpx::lcos::local::mutex`).
- Replaced `hpx::actions::function` with `hpx::util::function`. Cleaned up related code.
- Removed `hpx::traits::handle_gid` and moved handling of global reference counts into the corresponding serialization code.
- Changed terminology: `prefix` is now called `locality_id`, renamed the corresponding API functions (such as `hpx::get_prefix`, which is now called `hpx::get_locality_id`).
- Adding `hpx::find_remote_localities`, and `hpx::get_num_localities`.
- Changed performance counter naming scheme to make it more bash friendly. The new performance counter naming scheme is now

```
/object{parentname#parentindex/instance#index}/counter#parameters
```

- Added `hpx::get_worker_thread_num` replacing `hpx::threadmanager_base::get_thread_num`.
- Renamed `hpx::get_num_os_threads` to `hpx::get_os_threads_count`.
- Added `hpx::threads::get_thread_count`.
- Restructured the Futures sub-system, renaming types in accordance with the terminology used by the C++11 ISO standard.

Bug fixes (closed tickets)

Here is a list of the important tickets we closed for this release:

- [Issue #31](#)⁶⁵⁴⁰ - Specialize `handle_gid<>` for examples and tests
- [Issue #72](#)⁶⁵⁴¹ - Fix AGAS reference counting
- [Issue #104](#)⁶⁵⁴² - heartbeat throws an exception when decrefing the performance counter it's watching
- [Issue #111](#)⁶⁵⁴³ - throttle causes an exception on the target application
- [Issue #142](#)⁶⁵⁴⁴ - One failed component loading causes an unrelated component to fail
- [Issue #165](#)⁶⁵⁴⁵ - Remote exception propagation bug in AGAS reference counting test
- [Issue #186](#)⁶⁵⁴⁶ - Test credit exhaustion/splitting (e.g. `prepare_gid` and symbol NS)
- [Issue #188](#)⁶⁵⁴⁷ - Implement remaining AGAS reference counting test cases
- [Issue #258](#)⁶⁵⁴⁸ - No type checking of GIDs in stubs classes
- [Issue #271](#)⁶⁵⁴⁹ - Seg fault/shared pointer assertion in distributed code

⁶⁵⁴⁰ <https://github.com/STELLAR-GROUP/hpx/issues/31>

⁶⁵⁴¹ <https://github.com/STELLAR-GROUP/hpx/issues/72>

⁶⁵⁴² <https://github.com/STELLAR-GROUP/hpx/issues/104>

⁶⁵⁴³ <https://github.com/STELLAR-GROUP/hpx/issues/111>

⁶⁵⁴⁴ <https://github.com/STELLAR-GROUP/hpx/issues/142>

⁶⁵⁴⁵ <https://github.com/STELLAR-GROUP/hpx/issues/165>

⁶⁵⁴⁶ <https://github.com/STELLAR-GROUP/hpx/issues/186>

⁶⁵⁴⁷ <https://github.com/STELLAR-GROUP/hpx/issues/188>

⁶⁵⁴⁸ <https://github.com/STELLAR-GROUP/hpx/issues/258>

⁶⁵⁴⁹ <https://github.com/STELLAR-GROUP/hpx/issues/271>

- Issue #281⁶⁵⁵⁰ - CMake options need descriptive text
- Issue #283⁶⁵⁵¹ - AGAS caching broken (gva_cache needs to be rewritten with ICL)
- Issue #285⁶⁵⁵² - HPX_INSTALL root directory not the same as CMAKE_INSTALL_PREFIX
- Issue #286⁶⁵⁵³ - New segfault in dataflow applications
- Issue #289⁶⁵⁵⁴ - Exceptions should only be logged if not handled
- Issue #290⁶⁵⁵⁵ - c++11 tests failure
- Issue #293⁶⁵⁵⁶ - Build target for component libraries
- Issue #296⁶⁵⁵⁷ - Compilation error with Boost V1.49rc1
- Issue #298⁶⁵⁵⁸ - Illegal instructions on termination
- Issue #299⁶⁵⁵⁹ - gravity aborts with multiple threads
- Issue #301⁶⁵⁶⁰ - Build error with Boost trunk
- Issue #303⁶⁵⁶¹ - Logging assertion failure in distributed runs
- Issue #304⁶⁵⁶² - Exception 'what' strings are lost when exceptions from decode_parcel are reported
- Issue #306⁶⁵⁶³ - Performance counter user interface issues
- Issue #307⁶⁵⁶⁴ - Logging exception in distributed runs
- Issue #308⁶⁵⁶⁵ - Logging deadlocks in distributed
- Issue #309⁶⁵⁶⁶ - Reference counting test failures and exceptions
- Issue #311⁶⁵⁶⁷ - Merge AGAS remote_interface with the runtime_support object
- Issue #314⁶⁵⁶⁸ - Object tracking for id_types
- Issue #315⁶⁵⁶⁹ - Remove handle_gid and handle credit splitting in id_type serialization
- Issue #320⁶⁵⁷⁰ - applier::get_locality_id() should return an error value (or throw an exception)
- Issue #321⁶⁵⁷¹ - Optimization for id_types which are never split should be restored
- Issue #322⁶⁵⁷² - Command line processing ignored with Boost 1.47.0

⁶⁵⁵⁰ <https://github.com/STELLAR-GROUP/hpx/issues/281>

⁶⁵⁵¹ <https://github.com/STELLAR-GROUP/hpx/issues/283>

⁶⁵⁵² <https://github.com/STELLAR-GROUP/hpx/issues/285>

⁶⁵⁵³ <https://github.com/STELLAR-GROUP/hpx/issues/286>

⁶⁵⁵⁴ <https://github.com/STELLAR-GROUP/hpx/issues/289>

⁶⁵⁵⁵ <https://github.com/STELLAR-GROUP/hpx/issues/290>

⁶⁵⁵⁶ <https://github.com/STELLAR-GROUP/hpx/issues/293>

⁶⁵⁵⁷ <https://github.com/STELLAR-GROUP/hpx/issues/296>

⁶⁵⁵⁸ <https://github.com/STELLAR-GROUP/hpx/issues/298>

⁶⁵⁵⁹ <https://github.com/STELLAR-GROUP/hpx/issues/299>

⁶⁵⁶⁰ <https://github.com/STELLAR-GROUP/hpx/issues/301>

⁶⁵⁶¹ <https://github.com/STELLAR-GROUP/hpx/issues/303>

⁶⁵⁶² <https://github.com/STELLAR-GROUP/hpx/issues/304>

⁶⁵⁶³ <https://github.com/STELLAR-GROUP/hpx/issues/306>

⁶⁵⁶⁴ <https://github.com/STELLAR-GROUP/hpx/issues/307>

⁶⁵⁶⁵ <https://github.com/STELLAR-GROUP/hpx/issues/308>

⁶⁵⁶⁶ <https://github.com/STELLAR-GROUP/hpx/issues/309>

⁶⁵⁶⁷ <https://github.com/STELLAR-GROUP/hpx/issues/311>

⁶⁵⁶⁸ <https://github.com/STELLAR-GROUP/hpx/issues/314>

⁶⁵⁶⁹ <https://github.com/STELLAR-GROUP/hpx/issues/315>

⁶⁵⁷⁰ <https://github.com/STELLAR-GROUP/hpx/issues/320>

⁶⁵⁷¹ <https://github.com/STELLAR-GROUP/hpx/issues/321>

⁶⁵⁷² <https://github.com/STELLAR-GROUP/hpx/issues/322>

- Issue #323⁶⁵⁷³ - Credit exhaustion causes object to stay alive
- Issue #324⁶⁵⁷⁴ - Duplicate exception messages
- Issue #326⁶⁵⁷⁵ - Integrate Quickbook with CMake
- Issue #329⁶⁵⁷⁶ - --help and --version should still work
- Issue #330⁶⁵⁷⁷ - Create pkg-config files
- Issue #337⁶⁵⁷⁸ - Improve usability of performance counter timestamps
- Issue #338⁶⁵⁷⁹ - Non-std exceptions deriving from std::exceptions in tfunc may be sliced
- Issue #339⁶⁵⁸⁰ - Decrease the number of send_pending_parcel threads
- Issue #343⁶⁵⁸¹ - Dynamically setting the stack size doesn't work
- Issue #351⁶⁵⁸² - 'make install' does not update documents
- Issue #353⁶⁵⁸³ - Disable FIXMEs in the docs by default; add a doc developer CMake option to enable FIXMEs
- Issue #355⁶⁵⁸⁴ - 'make' doesn't do anything after correct configuration
- Issue #356⁶⁵⁸⁵ - Don't use hpx::util::static_ in topology code
- Issue #359⁶⁵⁸⁶ - Infinite recursion in hpx::tuple serialization
- Issue #361⁶⁵⁸⁷ - Add compile time option to disable logging completely
- Issue #364⁶⁵⁸⁸ - Installation seriously broken in r7443

HPX V0.7.0 (Dec 12, 2011)

We have had roughly 1000 commits since the last release and we have closed approximately 120 tickets (bugs, feature requests, etc.).

⁶⁵⁷³ <https://github.com/STELLAR-GROUP/hpx/issues/323>
⁶⁵⁷⁴ <https://github.com/STELLAR-GROUP/hpx/issues/324>
⁶⁵⁷⁵ <https://github.com/STELLAR-GROUP/hpx/issues/326>
⁶⁵⁷⁶ <https://github.com/STELLAR-GROUP/hpx/issues/329>
⁶⁵⁷⁷ <https://github.com/STELLAR-GROUP/hpx/issues/330>
⁶⁵⁷⁸ <https://github.com/STELLAR-GROUP/hpx/issues/337>
⁶⁵⁷⁹ <https://github.com/STELLAR-GROUP/hpx/issues/338>
⁶⁵⁸⁰ <https://github.com/STELLAR-GROUP/hpx/issues/339>
⁶⁵⁸¹ <https://github.com/STELLAR-GROUP/hpx/issues/343>
⁶⁵⁸² <https://github.com/STELLAR-GROUP/hpx/issues/351>
⁶⁵⁸³ <https://github.com/STELLAR-GROUP/hpx/issues/353>
⁶⁵⁸⁴ <https://github.com/STELLAR-GROUP/hpx/issues/355>
⁶⁵⁸⁵ <https://github.com/STELLAR-GROUP/hpx/issues/356>
⁶⁵⁸⁶ <https://github.com/STELLAR-GROUP/hpx/issues/359>
⁶⁵⁸⁷ <https://github.com/STELLAR-GROUP/hpx/issues/361>
⁶⁵⁸⁸ <https://github.com/STELLAR-GROUP/hpx/issues/364>

General changes

- Completely removed code related to deprecated AGAS V1, started to work on AGAS V2.1.
- Started to clean up and streamline the exposed APIs (see ‘API changes’ below for more details).
- Revamped and unified performance counter framework, added a lot of new performance counter instances for monitoring of a diverse set of internal *HPX* parameters (queue lengths, access statistics, etc.).
- Improved general error handling and logging support.
- Fixed several race conditions, improved overall stability, decreased memory footprint, improved overall performance (major optimizations include native TLS support and ranged-based AGAS caching).
- Added support for running *HPX* applications with PBS.
- Many updates to the build system, added support for gcc 4.5.x and 4.6.x, added C++11 support.
- Many updates to default command line options.
- Added many tests, set up buildbot for continuous integration testing.
- Better shutdown handling of distributed applications.

Example applications

- quickstart/factorial and quickstart/fibonacci, future-recursive parallel algorithms.
- quickstart/hello_world, distributed hello world example.
- quickstart/rma, simple remote memory access example
- quickstart/quicksort, parallel quicksort implementation.
- gtc, gyrokinetic torodial code.
- bfs, breadth-first-search, example code for a graph application.
- sheneos, partitioning of large data sets.
- accumulator, simple component example.
- balancing/os_thread_num, balancing/px_thread_phase, examples demonstrating load balancing and work stealing.

API changes

- Added `hpx::find_all_localities`.
- Added `hpx::terminate` for non-graceful termination of applications.
- Added `hpx::lcos::async` functions for simpler asynchronous programming.
- Added new AGAS interface for handling of symbolic namespace (`hpx::agas::*`).
- Renamed `hpx::components::wait` to `hpx::lcos::wait`.
- Renamed `hpx::lcos::future_value` to `hpx::lcos::promise`.
- Renamed `hpx::lcos::recursive_mutex` to `hpx::lcos::local_recursive_mutex`, `hpx::lcos::mutex` to `hpx::lcos::local_mutex`
- Removed support for Boost versions older than V1.38, recommended Boost version is now V1.47 and newer.

- Removed `hpx::process` (this will be replaced by a real process implementation in the future).
- Removed non-functional LCO code (`hpx::lcos::dataflow`, `hpx::lcos::thunk`, `hpx::lcos::dataflow_variable`).
- Removed deprecated `hpx::naming::full_address`.

Bug fixes (closed tickets)

Here is a list of the important tickets we closed for this release:

- [Issue #28⁶⁵⁸⁹](#) - Integrate Windows/Linux CMake code for *HPX* core
- [Issue #32⁶⁵⁹⁰](#) - `hpx::cout()` should be `hpx::cout`
- [Issue #33⁶⁵⁹¹](#) - AGAS V2 legacy client does not properly handle `error_code`
- [Issue #60⁶⁵⁹²](#) - AGAS: allow for `registerid` to optionally take ownership of the `gid`
- [Issue #62⁶⁵⁹³](#) - `adaptive1d` compilation failure in Fusion
- [Issue #64⁶⁵⁹⁴](#) - Parcel subsystem doesn't resolve domain names
- [Issue #83⁶⁵⁹⁵](#) - No error handling if no console is available
- [Issue #84⁶⁵⁹⁶](#) - No error handling if a hosted locality is treated as the bootstrap server
- [Issue #90⁶⁵⁹⁷](#) - Add general commandline option `-N`
- [Issue #91⁶⁵⁹⁸](#) - Add possibility to read command line arguments from file
- [Issue #92⁶⁵⁹⁹](#) - Always log exceptions/errors to the log file
- [Issue #93⁶⁶⁰⁰](#) - Log the command line/program name
- [Issue #95⁶⁶⁰¹](#) - Support for distributed launches
- [Issue #97⁶⁶⁰²](#) - Attempt to create a bad component type in AMR examples
- [Issue #100⁶⁶⁰³](#) - `factorial` and `factorial_get` examples trigger AGAS component type assertions
- [Issue #101⁶⁶⁰⁴](#) - Segfault when `hpx::process::here()` is called in `fibonacci2`
- [Issue #102⁶⁶⁰⁵](#) - `unknown_component_address` in `int_object_semaphore_client`
- [Issue #114⁶⁶⁰⁶](#) - `marduk` raises assertion with default parameters

⁶⁵⁸⁹ <https://github.com/STELLAR-GROUP/hpx/issues/28>

⁶⁵⁹⁰ <https://github.com/STELLAR-GROUP/hpx/issues/32>

⁶⁵⁹¹ <https://github.com/STELLAR-GROUP/hpx/issues/33>

⁶⁵⁹² <https://github.com/STELLAR-GROUP/hpx/issues/60>

⁶⁵⁹³ <https://github.com/STELLAR-GROUP/hpx/issues/62>

⁶⁵⁹⁴ <https://github.com/STELLAR-GROUP/hpx/issues/64>

⁶⁵⁹⁵ <https://github.com/STELLAR-GROUP/hpx/issues/83>

⁶⁵⁹⁶ <https://github.com/STELLAR-GROUP/hpx/issues/84>

⁶⁵⁹⁷ <https://github.com/STELLAR-GROUP/hpx/issues/90>

⁶⁵⁹⁸ <https://github.com/STELLAR-GROUP/hpx/issues/91>

⁶⁵⁹⁹ <https://github.com/STELLAR-GROUP/hpx/issues/92>

⁶⁶⁰⁰ <https://github.com/STELLAR-GROUP/hpx/issues/93>

⁶⁶⁰¹ <https://github.com/STELLAR-GROUP/hpx/issues/95>

⁶⁶⁰² <https://github.com/STELLAR-GROUP/hpx/issues/97>

⁶⁶⁰³ <https://github.com/STELLAR-GROUP/hpx/issues/100>

⁶⁶⁰⁴ <https://github.com/STELLAR-GROUP/hpx/issues/101>

⁶⁶⁰⁵ <https://github.com/STELLAR-GROUP/hpx/issues/102>

⁶⁶⁰⁶ <https://github.com/STELLAR-GROUP/hpx/issues/114>

- [Issue #115⁶⁶⁰⁷](https://github.com/STELLAR-GROUP/hpx/issues/115) - Logging messages for SMP runs (on the console) shouldn't be buffered
- [Issue #119⁶⁶⁰⁸](https://github.com/STELLAR-GROUP/hpx/issues/119) - marduk linking strategy breaks other applications
- [Issue #121⁶⁶⁰⁹](https://github.com/STELLAR-GROUP/hpx/issues/121) - pbsdsh problem
- [Issue #123⁶⁶¹⁰](https://github.com/STELLAR-GROUP/hpx/issues/123) - marduk, dataflow and adaptive1d fail to build
- [Issue #124⁶⁶¹¹](https://github.com/STELLAR-GROUP/hpx/issues/124) - Lower default preprocessing arity
- [Issue #125⁶⁶¹²](https://github.com/STELLAR-GROUP/hpx/issues/125) - Move hpx::detail::diagnostic_information out of the detail namespace
- [Issue #126⁶⁶¹³](https://github.com/STELLAR-GROUP/hpx/issues/126) - Test definitions for AGAS reference counting
- [Issue #128⁶⁶¹⁴](https://github.com/STELLAR-GROUP/hpx/issues/128) - Add averaging performance counter
- [Issue #129⁶⁶¹⁵](https://github.com/STELLAR-GROUP/hpx/issues/129) - Error with endian.hpp while building adaptive1d
- [Issue #130⁶⁶¹⁶](https://github.com/STELLAR-GROUP/hpx/issues/130) - Bad initialization of performance counters
- [Issue #131⁶⁶¹⁷](https://github.com/STELLAR-GROUP/hpx/issues/131) - Add global startup/shutdown functions to component modules
- [Issue #132⁶⁶¹⁸](https://github.com/STELLAR-GROUP/hpx/issues/132) - Avoid using auto_ptr
- [Issue #133⁶⁶¹⁹](https://github.com/STELLAR-GROUP/hpx/issues/133) - On Windows hpx.dll doesn't get installed
- [Issue #134⁶⁶²⁰](https://github.com/STELLAR-GROUP/hpx/issues/134) - HPX_LIBRARY does not reflect real library name (on Windows)
- [Issue #135⁶⁶²¹](https://github.com/STELLAR-GROUP/hpx/issues/135) - Add detection of unique_ptr to build system
- [Issue #137⁶⁶²²](https://github.com/STELLAR-GROUP/hpx/issues/137) - Add command line option allowing to repeatedly evaluate performance counters
- [Issue #139⁶⁶²³](https://github.com/STELLAR-GROUP/hpx/issues/139) - Logging is broken
- [Issue #140⁶⁶²⁴](https://github.com/STELLAR-GROUP/hpx/issues/140) - CMake problem on windows
- [Issue #141⁶⁶²⁵](https://github.com/STELLAR-GROUP/hpx/issues/141) - Move all non-component libraries into \$PREFIX/lib/hpx
- [Issue #143⁶⁶²⁶](https://github.com/STELLAR-GROUP/hpx/issues/143) - adaptive1d throws an exception with the default command line options
- [Issue #146⁶⁶²⁷](https://github.com/STELLAR-GROUP/hpx/issues/146) - Early exception handling is broken
- [Issue #147⁶⁶²⁸](https://github.com/STELLAR-GROUP/hpx/issues/147) - Sheneos doesn't link on Linux
- [Issue #149⁶⁶²⁹](https://github.com/STELLAR-GROUP/hpx/issues/149) - sheneos_test hangs

⁶⁶⁰⁷ <https://github.com/STELLAR-GROUP/hpx/issues/115>

⁶⁶⁰⁸ <https://github.com/STELLAR-GROUP/hpx/issues/119>

⁶⁶⁰⁹ <https://github.com/STELLAR-GROUP/hpx/issues/121>

⁶⁶¹⁰ <https://github.com/STELLAR-GROUP/hpx/issues/123>

⁶⁶¹¹ <https://github.com/STELLAR-GROUP/hpx/issues/124>

⁶⁶¹² <https://github.com/STELLAR-GROUP/hpx/issues/125>

⁶⁶¹³ <https://github.com/STELLAR-GROUP/hpx/issues/126>

⁶⁶¹⁴ <https://github.com/STELLAR-GROUP/hpx/issues/128>

⁶⁶¹⁵ <https://github.com/STELLAR-GROUP/hpx/issues/129>

⁶⁶¹⁶ <https://github.com/STELLAR-GROUP/hpx/issues/130>

⁶⁶¹⁷ <https://github.com/STELLAR-GROUP/hpx/issues/131>

⁶⁶¹⁸ <https://github.com/STELLAR-GROUP/hpx/issues/132>

⁶⁶¹⁹ <https://github.com/STELLAR-GROUP/hpx/issues/133>

⁶⁶²⁰ <https://github.com/STELLAR-GROUP/hpx/issues/134>

⁶⁶²¹ <https://github.com/STELLAR-GROUP/hpx/issues/135>

⁶⁶²² <https://github.com/STELLAR-GROUP/hpx/issues/137>

⁶⁶²³ <https://github.com/STELLAR-GROUP/hpx/issues/139>

⁶⁶²⁴ <https://github.com/STELLAR-GROUP/hpx/issues/140>

⁶⁶²⁵ <https://github.com/STELLAR-GROUP/hpx/issues/141>

⁶⁶²⁶ <https://github.com/STELLAR-GROUP/hpx/issues/143>

⁶⁶²⁷ <https://github.com/STELLAR-GROUP/hpx/issues/146>

⁶⁶²⁸ <https://github.com/STELLAR-GROUP/hpx/issues/147>

⁶⁶²⁹ <https://github.com/STELLAR-GROUP/hpx/issues/149>

- [Issue #154⁶⁶³⁰](#) - Compilation fails for r5661
- [Issue #155⁶⁶³¹](#) - Sine performance counters example chokes on chrono headers
- [Issue #156⁶⁶³²](#) - Add build type to `--version`
- [Issue #157⁶⁶³³](#) - Extend AGAS caching to store gid ranges
- [Issue #158⁶⁶³⁴](#) - r5691 doesn't compile
- [Issue #160⁶⁶³⁵](#) - Re-add AGAS function for resolving a locality to its prefix
- [Issue #168⁶⁶³⁶](#) - Managed components should be able to access their own GID
- [Issue #169⁶⁶³⁷](#) - Rewrite AGAS future pool
- [Issue #179⁶⁶³⁸](#) - Complete switch to request class for AGAS server interface
- [Issue #182⁶⁶³⁹](#) - Sine performance counter is loaded by other examples
- [Issue #185⁶⁶⁴⁰](#) - Write tests for symbol namespace reference counting
- [Issue #191⁶⁶⁴¹](#) - Assignment of read-only variable in `point_geometry`
- [Issue #200⁶⁶⁴²](#) - Seg faults when querying performance counters
- [Issue #204⁶⁶⁴³](#) - `--ifnames` and suffix stripping needs to be more generic
- [Issue #205⁶⁶⁴⁴](#) - `--list-*` and `--print-counter-*` options do not work together and produce no warning
- [Issue #207⁶⁶⁴⁵](#) - Implement decrement entry merging
- [Issue #208⁶⁶⁴⁶](#) - Replace the spinlocks in AGAS with `hpx::lcos::local_mutexes`
- [Issue #210⁶⁶⁴⁷](#) - Add an `--ifprefix` option
- [Issue #214⁶⁶⁴⁸](#) - Performance test for PX-thread creation
- [Issue #216⁶⁶⁴⁹](#) - VS2010 compilation
- [Issue #222⁶⁶⁵⁰](#) - r6045 `context_linux_x86.hpp`
- [Issue #223⁶⁶⁵¹](#) - fibonacci hangs when changing the state of an active thread
- [Issue #225⁶⁶⁵²](#) - Active threads end up in the FEB wait queue

⁶⁶³⁰ <https://github.com/STELLAR-GROUP/hpx/issues/154>

⁶⁶³¹ <https://github.com/STELLAR-GROUP/hpx/issues/155>

⁶⁶³² <https://github.com/STELLAR-GROUP/hpx/issues/156>

⁶⁶³³ <https://github.com/STELLAR-GROUP/hpx/issues/157>

⁶⁶³⁴ <https://github.com/STELLAR-GROUP/hpx/issues/158>

⁶⁶³⁵ <https://github.com/STELLAR-GROUP/hpx/issues/160>

⁶⁶³⁶ <https://github.com/STELLAR-GROUP/hpx/issues/168>

⁶⁶³⁷ <https://github.com/STELLAR-GROUP/hpx/issues/169>

⁶⁶³⁸ <https://github.com/STELLAR-GROUP/hpx/issues/179>

⁶⁶³⁹ <https://github.com/STELLAR-GROUP/hpx/issues/182>

⁶⁶⁴⁰ <https://github.com/STELLAR-GROUP/hpx/issues/185>

⁶⁶⁴¹ <https://github.com/STELLAR-GROUP/hpx/issues/191>

⁶⁶⁴² <https://github.com/STELLAR-GROUP/hpx/issues/200>

⁶⁶⁴³ <https://github.com/STELLAR-GROUP/hpx/issues/204>

⁶⁶⁴⁴ <https://github.com/STELLAR-GROUP/hpx/issues/205>

⁶⁶⁴⁵ <https://github.com/STELLAR-GROUP/hpx/issues/207>

⁶⁶⁴⁶ <https://github.com/STELLAR-GROUP/hpx/issues/208>

⁶⁶⁴⁷ <https://github.com/STELLAR-GROUP/hpx/issues/210>

⁶⁶⁴⁸ <https://github.com/STELLAR-GROUP/hpx/issues/214>

⁶⁶⁴⁹ <https://github.com/STELLAR-GROUP/hpx/issues/216>

⁶⁶⁵⁰ <https://github.com/STELLAR-GROUP/hpx/issues/222>

⁶⁶⁵¹ <https://github.com/STELLAR-GROUP/hpx/issues/223>

⁶⁶⁵² <https://github.com/STELLAR-GROUP/hpx/issues/225>

- Issue #226⁶⁶⁵³ - VS Build Error for Accumulator Client
- Issue #228⁶⁶⁵⁴ - Move all traits into namespace `hpx::traits`
- Issue #229⁶⁶⁵⁵ - Invalid initialization of reference in `thread_init_data`
- Issue #235⁶⁶⁵⁶ - Invalid GID in `iostreams`
- Issue #238⁶⁶⁵⁷ - Demangle type names for the default implementation of `get_action_name`
- Issue #241⁶⁶⁵⁸ - C++11 support breaks GCC 4.5
- Issue #247⁶⁶⁵⁹ - Reference to temporary with GCC 4.4
- Issue #248⁶⁶⁶⁰ - Seg fault at shutdown with GCC 4.4
- Issue #253⁶⁶⁶¹ - Default component action registration kills compiler
- Issue #272⁶⁶⁶² - G++ unrecognized command line option
- Issue #273⁶⁶⁶³ - quicksort example doesn't compile
- Issue #277⁶⁶⁶⁴ - Invalid CMake logic for Windows

2.10.2 Namespace changes

HPX V1.9.0 Namespace changes

The latest release includes amongst others changes in the namespaces so that *HPX* facilities correspond to the C++ Standard Library. The old namespaces are deprecated. Below is a comprehensive list of the namespace changes.

Table 2.187: Namespace changes in V1.9.0

Old namespace	New namespace
<code>hpx::util::mem_fn</code>	<code>hpx::mem_fn</code>
<code>hpx::util::invoke</code>	<code>hpx::invoke</code>
<code>hpx::util::invoke_r</code>	<code>hpx::invoke_r</code>
<code>hpx::util::invoke_fused</code>	<code>hpx::invoke_fused</code>
<code>hpx::util::invoke_fused_r</code>	<code>hpx::invoke_fused_r</code>
<code>hpx::util::unlock_guard</code>	<code>hpx::unlock_guard</code>
<code>hpx::parallel::v1::reduce_by_key</code>	<code>hpx::experimental::reduce_by_key</code>
<code>hpx::parallel::v1::sort_by_key</code>	<code>hpx::experimental::sort_by_key</code>
<code>hpx::parallel::task_canceled_exception</code>	<code>hpx::experimental::task_canceled_exception</code>
<code>hpx::parallel::task_block</code>	<code>hpx::experimental::task_block</code>
<code>hpx::parallel::define_task_block</code>	<code>hpx::experimental::define_task_block</code>
<code>hpx::parallel::define_task_block_restore_thread</code>	<code>hpx::experimental::define_task_block_restore_thread</code>
<code>hpx::execution::experimental::task_group</code>	<code>hpx::experimental::task_group</code>

⁶⁶⁵³ <https://github.com/STELLAR-GROUP/hpx/issues/226>

⁶⁶⁵⁴ <https://github.com/STELLAR-GROUP/hpx/issues/228>

⁶⁶⁵⁵ <https://github.com/STELLAR-GROUP/hpx/issues/229>

⁶⁶⁵⁶ <https://github.com/STELLAR-GROUP/hpx/issues/235>

⁶⁶⁵⁷ <https://github.com/STELLAR-GROUP/hpx/issues/238>

⁶⁶⁵⁸ <https://github.com/STELLAR-GROUP/hpx/issues/241>

⁶⁶⁵⁹ <https://github.com/STELLAR-GROUP/hpx/issues/247>

⁶⁶⁶⁰ <https://github.com/STELLAR-GROUP/hpx/issues/248>

⁶⁶⁶¹ <https://github.com/STELLAR-GROUP/hpx/issues/253>

⁶⁶⁶² <https://github.com/STELLAR-GROUP/hpx/issues/272>

⁶⁶⁶³ <https://github.com/STELLAR-GROUP/hpx/issues/273>

⁶⁶⁶⁴ <https://github.com/STELLAR-GROUP/hpx/issues/277>

2.11 Citing *HPX*

Please cite *HPX* whenever you use it for publications. Use our paper in The Journal of Open Source Software as the main citation for *HPX*: ⁶⁶⁶⁵. Use the Zenodo entry for referring to the latest version of *HPX*: ⁶⁶⁶⁶. Entries for citing specific versions of *HPX* can also be found at ⁶⁶⁶⁷.

2.12 *HPX* users

A list of institutions and projects using *HPX* can be found on the *HPX Users*⁶⁶⁶⁸ page.

2.13 About *HPX*

2.13.1 History

The development of High Performance ParalleX (*HPX*) began in 2007. At that time, Hartmut Kaiser became interested in the work done by the ParalleX group at the [Center for Computation and Technology \(CCT\)](#)⁶⁶⁶⁹, a multi-disciplinary research institute at [Louisiana State University \(LSU\)](#)⁶⁶⁷⁰. The ParalleX group was working to develop a new and experimental execution model for future high performance computing architectures. This model was christened ParalleX. The first implementations of ParalleX were crude, and many of those designs had to be discarded entirely. However, over time the team learned quite a bit about how to design a parallel, distributed runtime system which implements the concepts of ParalleX.

From the very beginning, this endeavour has been a group effort. In addition to a handful of interested researchers, there have always been graduate and undergraduate students participating in the discussions, design, and implementation of *HPX*. In 2011 we decided to formalize our collective research efforts by creating the [STE||AR](#)⁶⁶⁷¹ group (Systems Technology, Emergent Parallelism, and Algorithm Research). Over time, the team grew to include researchers around the country and the world. In 2014, the [STE||AR](#)⁶⁶⁷² Group was reorganized to become the international community it is today. This consortium of researchers aims to develop stable, sustainable, and scalable tools which will enable application developers to exploit the parallelism latent in the machines of today and tomorrow. Our goal of the *HPX* project is to create a high quality, freely available, open source implementation of ParalleX concepts for conventional and future systems by building a modular and standards conforming runtime system for SMP and distributed application environments. The API exposed by *HPX* is conformant to the interfaces defined by the C++ ISO Standard and adheres to the programming guidelines used by the [Boost](#)⁶⁶⁷³ collection of C++ libraries. We steer the development of *HPX* with real world applications and aim to provide a smooth migration path for domain scientists.

To learn more about [STE||AR](#)⁶⁶⁷⁴ and ParalleX, see *People* and *Why HPX?*.

⁶⁶⁶⁵ <https://joss.theoj.org/papers/022e5917b95517dff20cd3742ab95eca>

⁶⁶⁶⁶ <https://doi.org/10.5281/zenodo.598202>

⁶⁶⁶⁷ <https://doi.org/10.5281/zenodo.598202>

⁶⁶⁶⁸ <https://hpx.stellar-group.org/hpx-users/>

⁶⁶⁶⁹ <https://www.cct.lsu.edu>

⁶⁶⁷⁰ <https://www.lsu.edu>

⁶⁶⁷¹ <https://stellar-group.org>

⁶⁶⁷² <https://stellar-group.org>

⁶⁶⁷³ <https://www.boost.org/>

⁶⁶⁷⁴ <https://stellar-group.org>

2.13.2 People

The STE||AR⁶⁶⁷⁵ Group (pronounced as stellar) stands for “Systems Technology, Emergent Parallelism, and Algorithm Research”. We are an international group of faculty, researchers, and students working at various institutions around the world. The goal of the STE||AR⁶⁶⁷⁶ Group is to promote the development of scalable parallel applications by providing a community for ideas, a framework for collaboration, and a platform for communicating these concepts to the broader community.

Our work is focused on building technologies for scalable parallel applications. *HPX*, our general purpose C++ runtime system for parallel and distributed applications, is no exception. We use *HPX* for a broad range of scientific applications, helping scientists and developers to write code which scales better and shows better performance compared to more conventional programming models such as MPI.

HPX is based on *ParalleX* which is a new (and still experimental) parallel execution model aiming to overcome the limitations imposed by the current hardware and the techniques we use to write applications today. Our group focuses on two types of applications - those requiring excellent strong scaling, allowing for a dramatic reduction of execution time for fixed workloads and those needing highest level of sustained performance through massive parallelism. These applications are presently unable (through conventional practices) to effectively exploit a relatively small number of cores in a multi-core system. By extension, these application will not be able to exploit high-end exascale computing systems which are likely to employ hundreds of millions of such cores by the end of this decade.

Critical bottlenecks to the effective use of new generation high performance computing (HPC) systems include:

- *Starvation*: due to lack of usable application parallelism and means of managing it,
- *Overhead*: reduction to permit strong scalability, improve efficiency, and enable dynamic resource management,
- *Latency*: from remote access across system or to local memories,
- *Contention*: due to multicore chip I/O pins, memory banks, and system interconnects.

The *ParalleX* model has been devised to address these challenges by enabling a new computing dynamic through the application of message-driven computation in a global address space context with lightweight synchronization. The work on *HPX* is centered around implementing the concepts as defined by the *ParalleX* model. *HPX* is currently targeted at conventional machines, such as classical Linux based Beowulf clusters and SMP nodes.

We fully understand that the success of *HPX* (and *ParalleX*) is very much the result of the work of many people. To see a list of who is contributing see our tables below.

⁶⁶⁷⁵ <https://stellar-group.org>

⁶⁶⁷⁶ <https://stellar-group.org>

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Table 2.188: Contributors

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⁶⁶⁷⁷ <https://www.cct.lsu.edu>

⁶⁶⁷⁸ <https://www.lsu.edu>

⁶⁶⁷⁹ <https://www3.cs.fau.de>

⁶⁶⁸⁰ <https://www.fau.de>

⁶⁶⁸¹ <https://www.cscs.ch>

⁶⁶⁸² <https://www.cscs.ch>

⁶⁶⁸³ <https://www.cct.lsu.edu>

⁶⁶⁸⁴ <https://www.lsu.edu>

⁶⁶⁸⁵ <https://www3.cs.fau.de>

⁶⁶⁸⁶ <https://www.fau.de>

⁶⁶⁸⁷ <https://www.cct.lsu.edu>

⁶⁶⁸⁸ <https://www.lsu.edu>

⁶⁶⁸⁹ <https://www.cct.lsu.edu>

⁶⁶⁹⁰ <https://www.lsu.edu>

⁶⁶⁹¹ <https://www.universite-paris-saclay.fr/en>

⁶⁶⁹² <https://www.amd.com/en>

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⁶⁶⁹⁵ <https://www.cct.lsu.edu>

⁶⁶⁹⁶ <https://www.lsu.edu>

⁶⁶⁹⁷ <https://www3.cs.fau.de>

⁶⁶⁹⁸ <https://www.fau.de>

⁶⁶⁹⁹ <https://www.cct.lsu.edu>

⁶⁷⁰⁰ <https://www.lsu.edu>

⁶⁷⁰¹ <https://www.cct.lsu.edu>

⁶⁷⁰² <https://www.lsu.edu>

⁶⁷⁰³ <https://www.amd.com/en>

⁶⁷⁰⁴ <https://www.tudelft.nl/en/eemcs>

⁶⁷⁰⁵ <https://www.tudelft.nl/en/>

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⁶⁷⁰⁶ <https://www.cscs.ch>

⁶⁷⁰⁷ <https://www.cscs.ch>

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⁶⁷⁰⁸ <https://www.lsu.edu>

⁶⁷⁰⁹ <https://www.lsu.edu>

⁶⁷¹⁰ <https://www.lsu.edu>

⁶⁷¹¹ <https://www.lsu.edu>

⁶⁷¹² <https://www.libgeodecomp.org/>

⁶⁷¹³ <https://www.libgeodecomp.org/>

⁶⁷¹⁴ <https://www.lsu.edu>

⁶⁷¹⁵ <https://www.conan.io/>

⁶⁷¹⁶ <https://www.lsu.edu>

⁶⁷¹⁷ <https://uoregon.edu/>

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⁶⁷¹⁸ <https://github.com/STELLAR-GROUP/hpxcl/>

⁶⁷¹⁹ <https://www.cct.lsu.edu>

⁶⁷²⁰ <http://wg21.link/n4313>

⁶⁷²¹ <https://www3.cs.fau.de>

⁶⁷²² <https://developers.google.com/open-source/soc/>

⁶⁷²³ <https://www3.cs.fau.de>

⁶⁷²⁴ <http://rosta.cct.lsu.edu/>

⁶⁷²⁵ <https://github.com/STELLAR-GROUP/hpxcl/>

⁶⁷²⁶ <https://www.khronos.org/opencv/>

⁶⁷²⁷ <https://portablecl.org/>

⁶⁷²⁸ <https://www.khronos.org/opencv/>

⁶⁷²⁹ <https://www.unlv.edu>

⁶⁷³⁰ <http://wg21.link/n4313>

⁶⁷³¹ <https://www.lsu.edu>

⁶⁷³² <https://github.com/STELLAR-GROUP/hpxcl/>

⁶⁷³³ https://www.nvidia.com/object/cuda_home_new.html

⁶⁷³⁴ <https://www.numscale.com/nt2/>

⁶⁷³⁵ <https://www.cscs.ch>

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⁶⁷³⁶ <https://www.nmsu.edu>

⁶⁷³⁷ <https://hpx.stellar-group.org/funding-acknowledgements/>

⁶⁷³⁸ <https://developers.google.com/open-source/soc/>

⁶⁷³⁹ <https://developers.google.com/season-of-docs/>

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