Massively Parallel Task-Based Programming with HPX

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Parallelism in C++
- State of the Art
- The HPX Parallel Runtime System
- The Future, async and dataflow
- Concepts of Parallelism
- Parallel Algorithms

Parallel Programming with HPX
- The HPX Programming Model
- Examples:
  - Fibonacci
  - Simple Loop Parallelization
  - SAXPY routine with data locality
  - Hello Distributed World!
  - Matrix Transpose

Acknowledgements

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- And many others...

Parallelism in C++

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State of the Art

- Modern architectures impose massive challenges on programmability in the context of performance portability
  - Massive increase in on-node parallelism
  - Deep memory hierarchies
- Only portable parallelization solution for C++ programmers (today): OpenMP and MPI
  - Hugely successful for years
  - Widely used and supported
  - Simple use for simple use cases
  - Very portable
  - Highly optimized

The C++ Standard

- C++11 introduced lower level abstractions
  - std::thread, std::mutex, std::future, etc.
  - Fairly limited (low level), more is needed
  - C++ needs stronger support for higher-level parallelism
- New standard: C++17:
  - Parallel versions of STL algorithms (P0024R2)
- Several proposals to the Standardization Committee are accepted or under consideration
  - Technical Specification: Concurrency (N4577)
  - Other proposals: Coroutines (P0057R2), task blocks (N4411), executors (P0058R1)

The C++ Standard – Our Vision

Currently there is no overarching vision related to higher-level parallelism

- Goal is to standardize a ‘big story’ by 2020
- No need for OpenMP, OpenACC, OpenCL, etc.
- This tutorial tries to show results of our take on this

HPX – A general purpose parallel Runtime System

- Solidly based on a theoretical foundation – a well defined, new execution model (ParalleX)
- Exposes a coherent and uniform, standards-oriented API for ease of programming parallel and distributed applications.
  - Enables to write fully asynchronous code using hundreds of millions of threads.
  - Provides unified syntax and semantics for local and remote operations.
- Developed to run at any scale
- Compliant C++ Standard implementation (and more)
- Open Source: Published under the Boost Software License

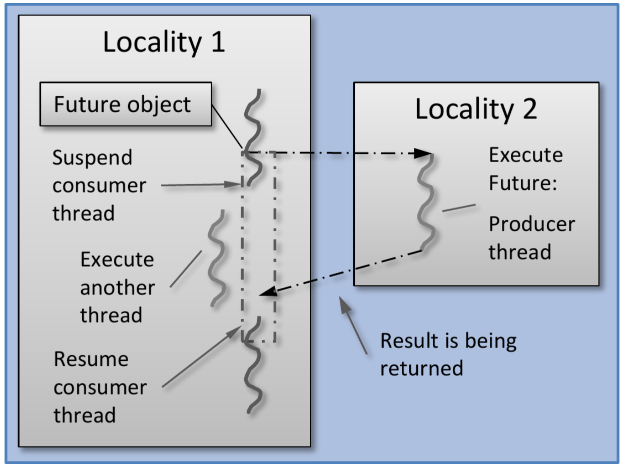
HPX – A general purpose parallel Runtime System

HPX represents an innovative mixture of

- A global system-wide address space (AGAS - Active Global Address Space)
- Fine grain parallelism and lightweight synchronization
- Combined with implicit, work queue based, message driven computation
- Full semantic equivalence of local and remote execution, and
- Explicit support for hardware accelerators (through percolation)

What is a (the) future

A future is an object representing a result which has not been calculated yet



- Enables transparent synchronization with producer
- Hides notion of dealing with threads
- Makes asynchrony manageable
- Allows for composition of several asynchronous operations
- Turns concurrency into parallelism

What is a (the) future

Many ways to get hold of a future, simplest way is to use (std) async:

```
int universal_answer() { return 42; }
void deep_thought() {
    future<int> promised_answer
        = async(&universal_answer);
    // do other things for 7.5 million years
    cout << promised_answer.get() << endl;
    // prints 42, eventually
}
```

Compositional facilities

Sequential composition of futures:

```
future<string> make_string() {
  future<int> f1 =
    async([]() -> int { return 123; });
  future<string> f2 = f1.then(
    [](future<int> f) -> string
    {
      // here .get() won't block
      return to_string(f.get());
    });
  return f2;
}
```

Compositional facilities

Parallel composition of futures

```
future<int> test_when_all() {
  future<int> future1 =
    async([]() -> int { return 125; });
  future<string> future2 =
    async([]() -> string { return string("hi"); });
  auto all_f = when_all(future1, future2);
  future<int> result = all_f.then(
    [](auto f) -> int {
      return do_work(f.get());
    });
  return result;
}
```

Dataflow – The new 'async' (HPX)

- What if one or more arguments to 'async' are futures themselves?
- Normal behavior: pass futures through to function
- Extended behavior: wait for futures to become ready before invoking the function:

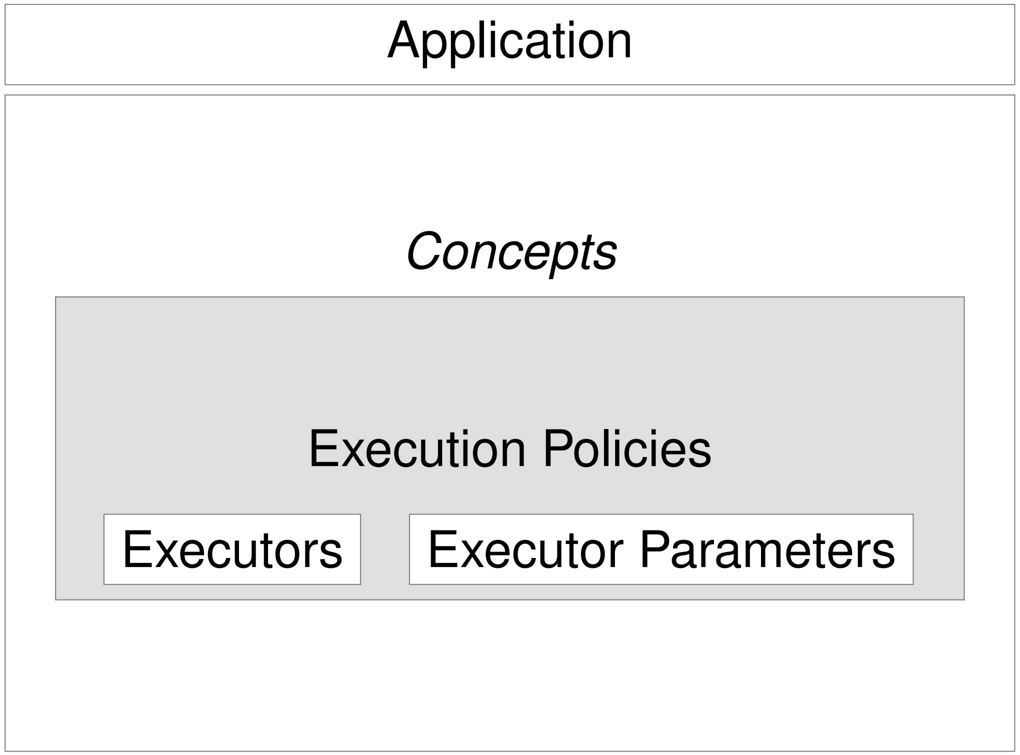
```
template <typename F, typename... Arg>
future<result_of_t<F(Args...)>>
// requires(is_callable<F(Arg...)>)
dataflow(F && f, Arg &&... arg);
```

- If ArgN is a future, then the invocation of F will be delayed
- Non-future arguments are passed through

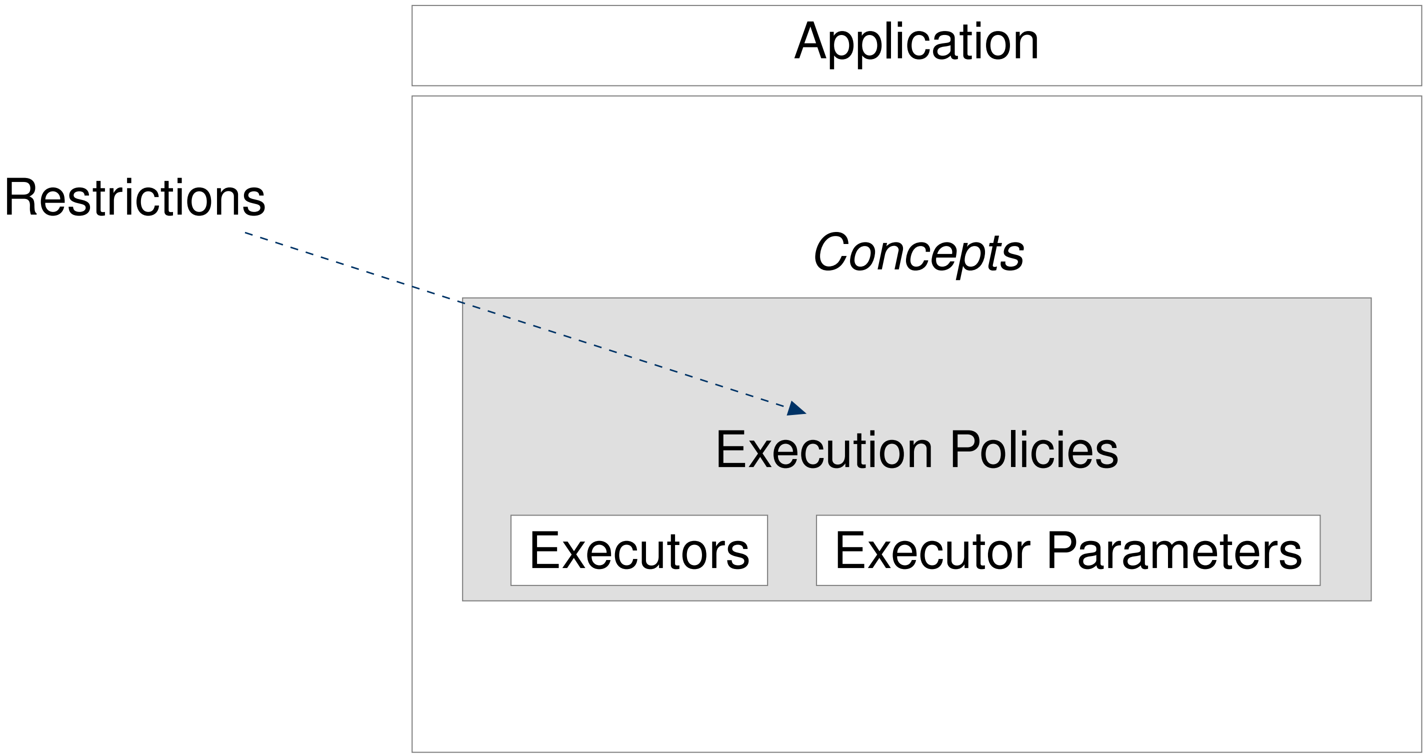
Concepts of Parallelism – Parallel Execution Properties

- The ***execution restrictions*** applicable for the work items
- In what ***sequence*** the work items have to be executed
- ***Where*** the work items should be executed
- The ***parameters*** of the execution environment

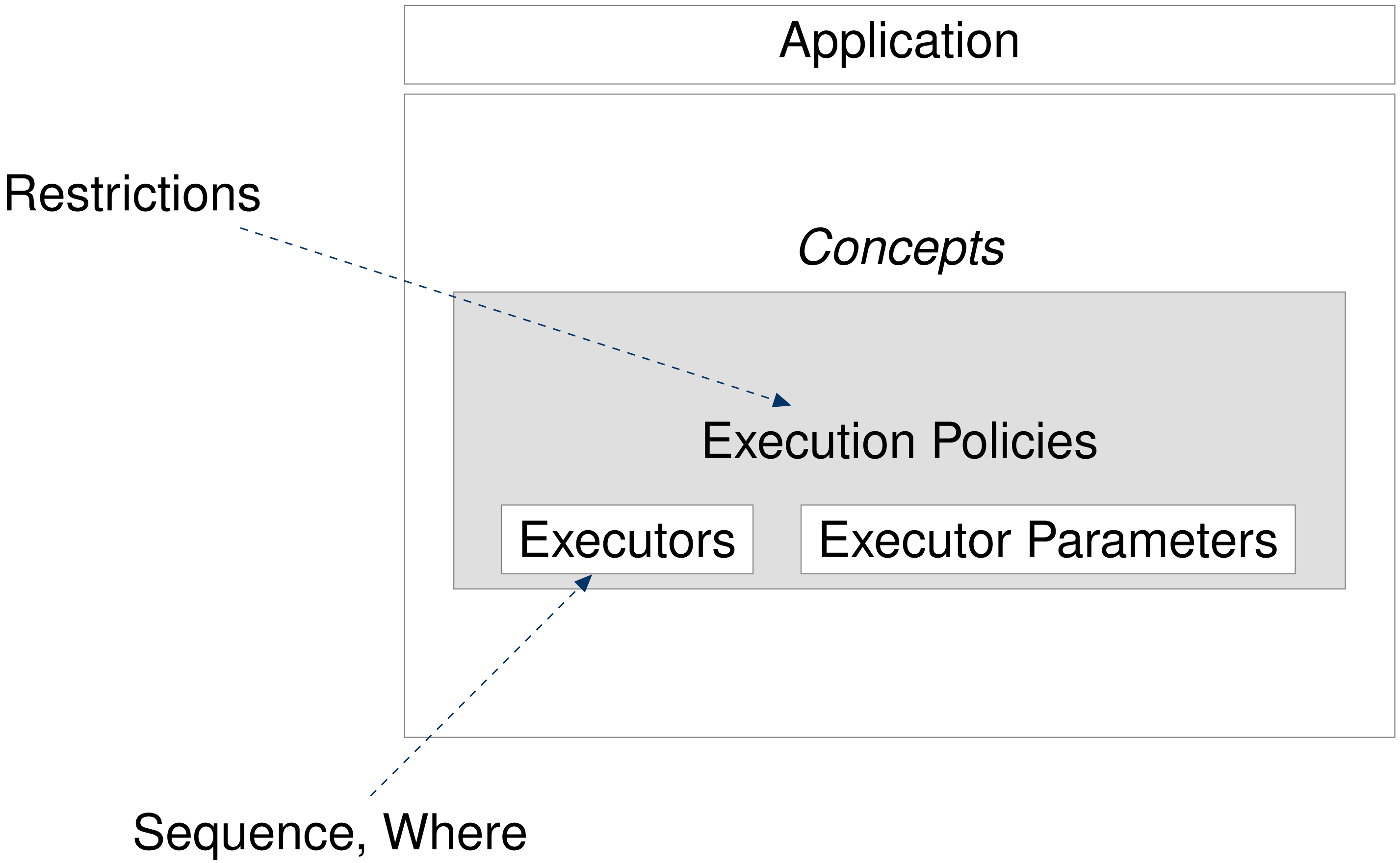
Concepts and Types of Parallelism



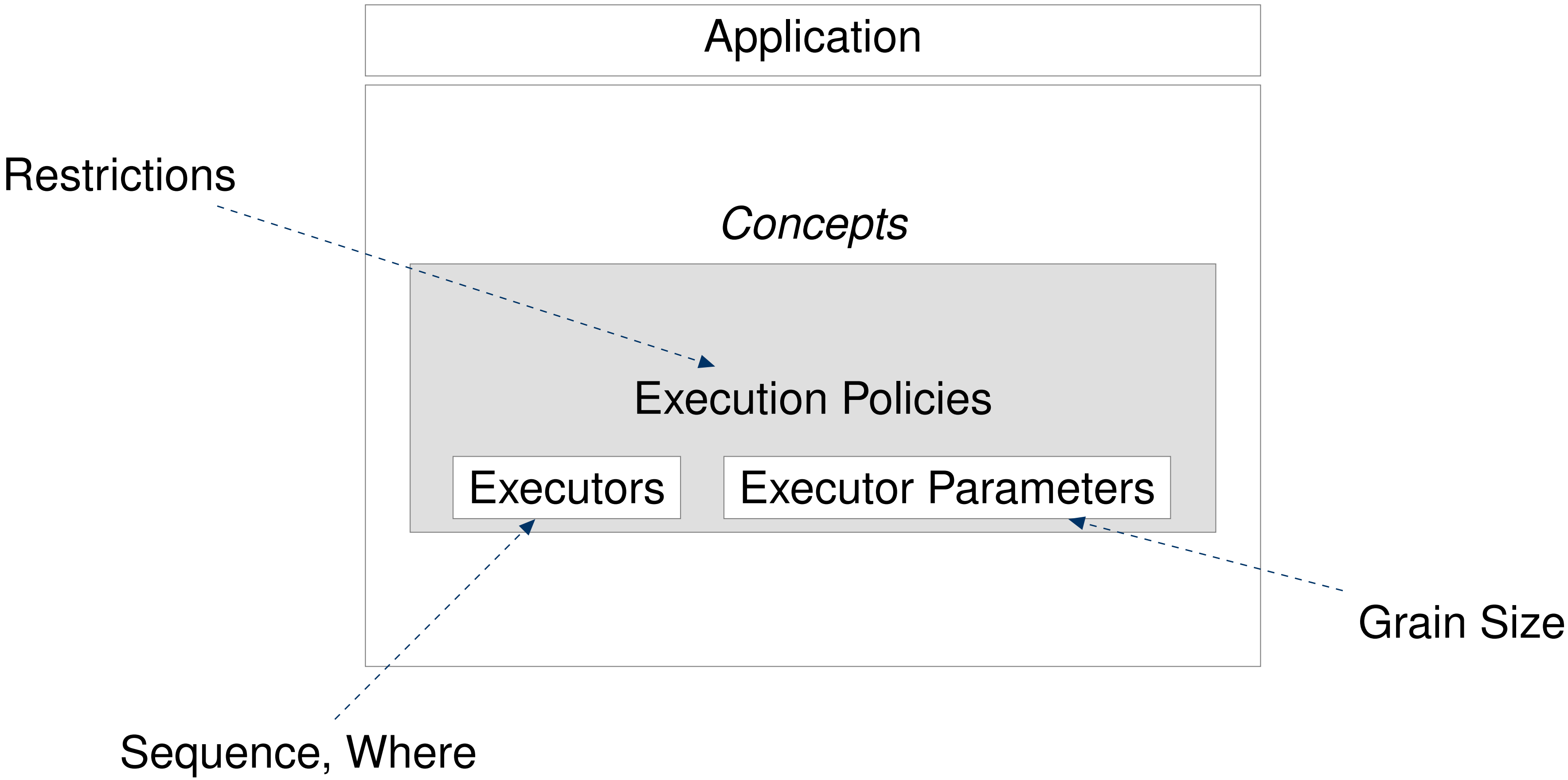
Concepts and Types of Parallelism



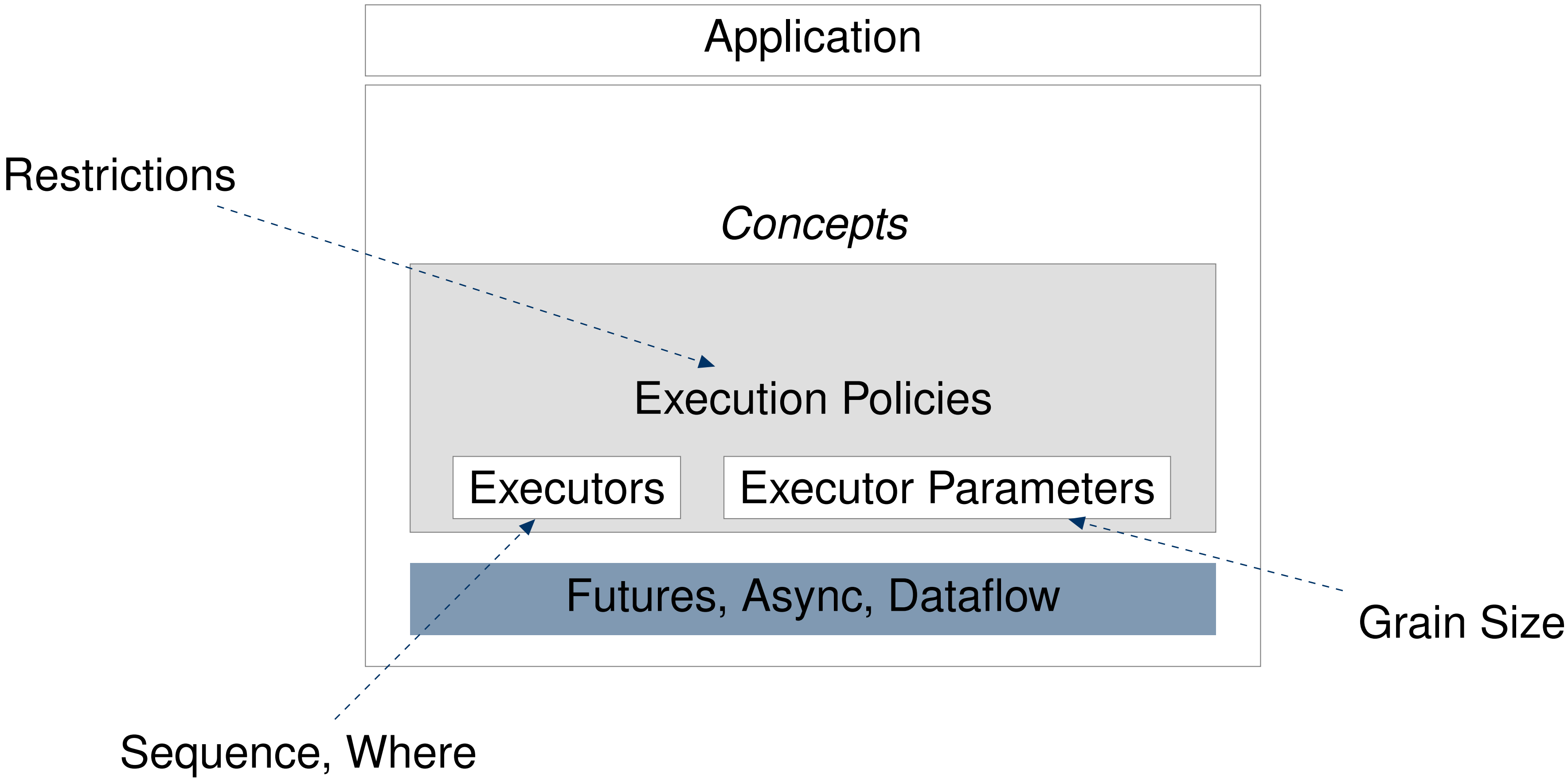
Concepts and Types of Parallelism



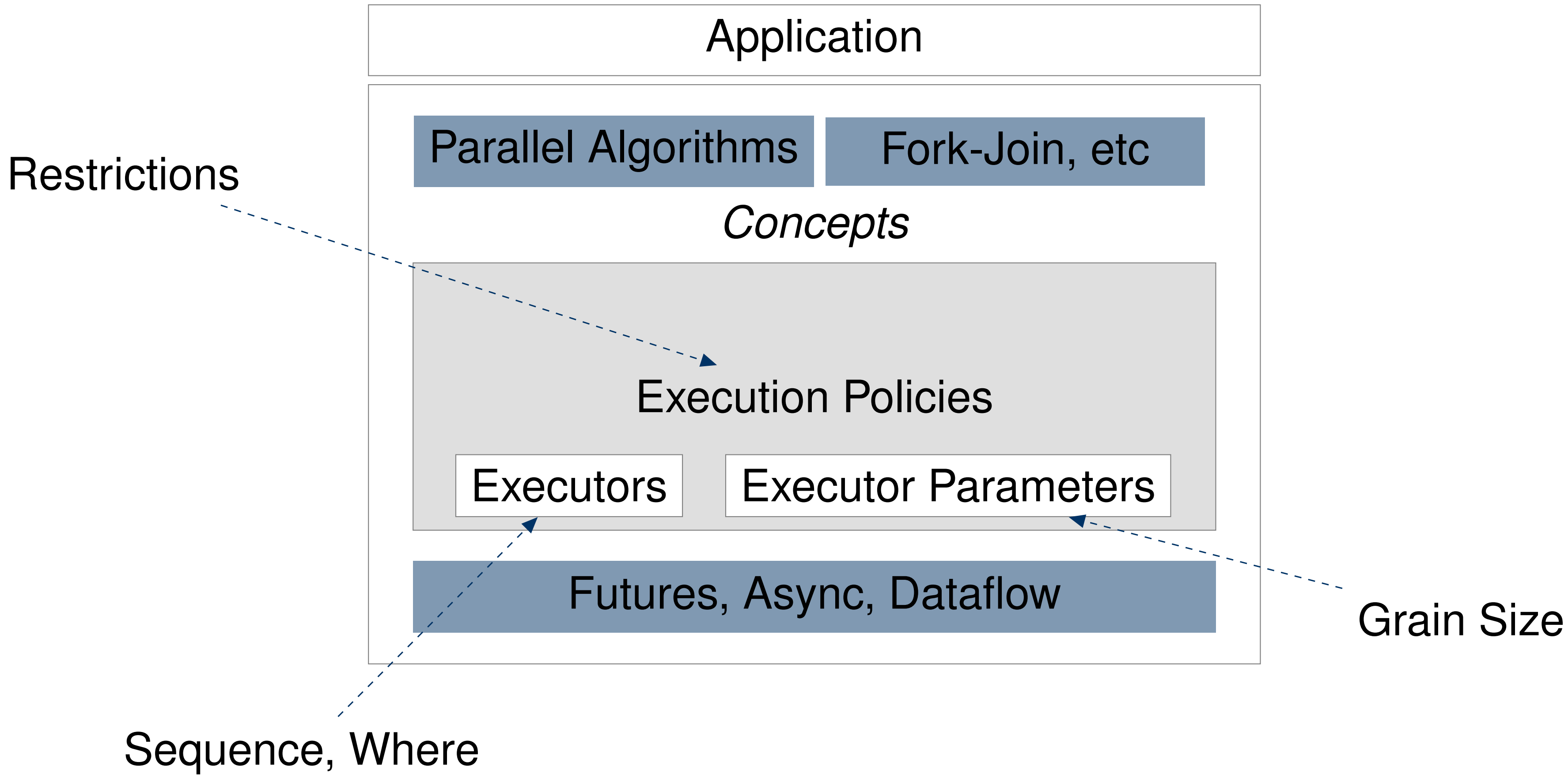
Concepts and Types of Parallelism



Concepts and Types of Parallelism



Concepts and Types of Parallelism



Execution Policies (std)

- Specify execution guarantees (in terms of thread-safety) for executed parallel tasks:
  - `sequential_execution_policy: seq`
  - `parallel_execution_policy: par`
  - `parallel_vector_execution_policy: par_vec`
- In parallelism TS used for parallel algorithms only

Execution Policies (Extensions)

- Asynchronous Execution Policies:
  - `sequential_task_execution_policy: seq(task)`
  - `parallel_task_execution_policy: par(task)`
- In both cases the formerly synchronous functions return a future<R>
- Instruct the parallel construct to be executed asynchronously
- Allows integration with asynchronous control flow

Executors

- Executor are objects responsible for
  - Creating execution agents on which work is performed (N4466)
  - In N4466 this is limited to parallel algorithms, here much broader use
- Abstraction of the (potentially platform-specific) mechanisms for launching work
- Responsible for defining the ***Where*** and ***How*** of the execution of tasks

Executors

- Executors must implement one function:
  `async_execute(F&& f, Args&&... args)`
- Invocation of executors happens through `executor_traits` which exposes (emulates) additional functionality:

```
executor_traits<my_executor_type>::
  execute(
my_executor,
[](size_t i){ // perform task i }, n)
  ;
```

- Four modes of invocation: single async, single sync, bulk async and bulk sync
- The async calls return a future

Executor Examples

- `sequential_executor`, `parallel_executor`:
  - Default executors corresponding to par, seq
- `this_thread_executor`
- `thread_pool_executor`
  - Specify core(s) to run on (NUMA aware)
- `distribution_policy_executor`
  - Use one of HPX's (distributed) distribution policies, specify node(s) to run on
- `cuda::default_executor`
  - Use for running things on GPU
- Etc.

Execution Parameters

Allows to control the grain size of work

- i.e. amount of iterations of a parallel `for_each` run on the same thread
- Similar to OpenMP scheduling policies: `static`, `guided`, `dynamic`
- Much more fine control

Rebind Execution Policies

Execution policies have associated default executor and default executor parameters

- `par`: parallel executor, static chunk size
- `seq`: sequential executor, no chunking
- Rebind executor and executor parameters

```
numa_executor exec;
// rebind only executor
auto policy1 = par.on(exec);
static_chunk_size param;

// rebind only executor parameter
auto policy2 = par.with(param);
// rebind both
auto policy3 = par.on(exec).with(param);
```

Parallel Algorithms

adjacent_difference	adjacent_find	all_of	any_of
copy	copy_if	copy_n	count
count_if	equal	exclusive_scan	fill
fill_n	find	find_end	find_first_of
find_if	find_if_not	for_each	for_each_n
generate	generate_n	includes	inclusive_scan
inner_product	inplace_merge	is_heap	is_heap_until
is_partitioned	is_sorted	is_sorted_until	lexicographical_compare
max_element	merge	min_element	minmax_element
mismatch	move	none_of	nth_element
partial_sort	partial_sort_copy	partition	partition_copy
reduce	remove	remove_copy	remove_copy_if
remove_if	replace	replace_copy	replace_copy_if
replace_if	reverse	reverse_copy	rotate
rotate_copy	search	search_n	set_difference
set_intersection	set_symmetric_difference	set_union	sort
stable_partition	stable_sort	swap_ranges	transform
transform_exclusive_scan	transform_inclusive_scan	transform_reduce	uninitialized_copy
uninitialized_copy_n	uninitialized_fill	uninitialized_fill_n	unique
unique_copy			

Parallel Algorithms

```
std::vector<int> v = { 1, 2, 3, 4, 5, 6 };
parallel::transform(
  parallel::par, begin(v), end(v),
  [](int i) -> int {
    return i + 1;
  });
// prints: 2,3,4,5,6,7,
for (int i : v) std::cout << i << ",";
```

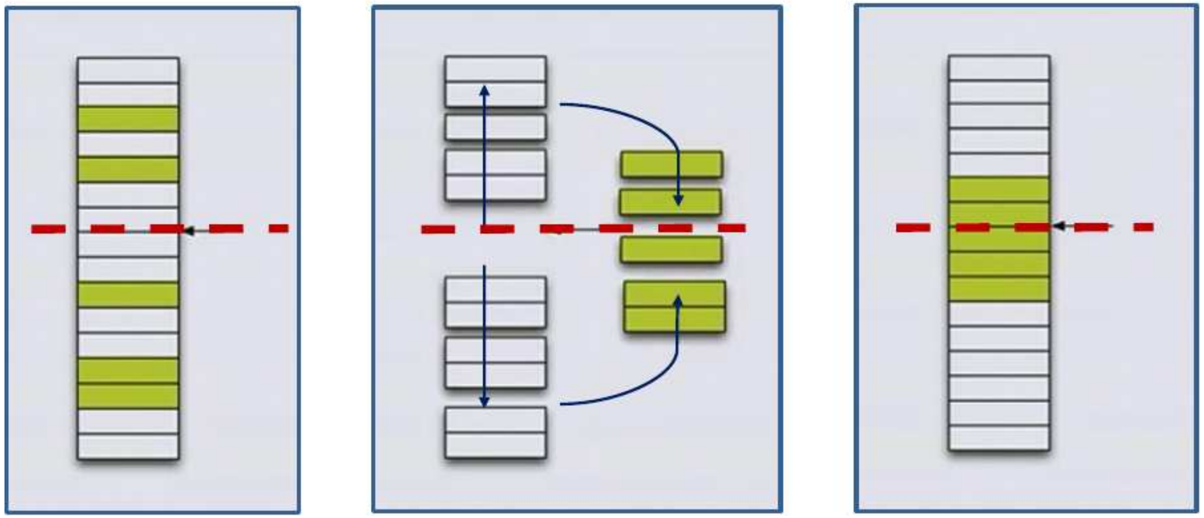
Parallel Algorithms

```
// uses default executor: par
std::vector<double> d = { ... };
parallel::fill(par, begin(d), end(d), 0.0);
// rebind par to user-defined executor
my_executor my_exec = ...;

parallel::fill(par.on(my_exec),
  begin(d), end(d), 0.0);

// rebind par to user-defined executor and user
// defined executor parameters
my_params my_par = ...
parallel::fill(par.on(my_exec).with(my_par),
  begin(d), end(d), 0.0);
```

Extending Parallel Algorithms



Sean Parent: C++ Seasoning, Going Native 2013

Extending Parallel Algorithms

```
template <typename BiIter, typename Pred>
pair<BiIter, BiIter> gather(BiIter f, BiIter l,
    BiIter p, Pred pred)
{
    BiIter it1 = stable_partition(f, p, not1(pred));
    BiIter it2 = stable_partition(p, l, pred);
    return make_pair(it1, it2);
}
```

Extending Parallel Algorithms

```
template <typename BiIter, typename Pred>
future<pair<BiIter, BiIter>> gather_async(BiIter f,
   BiIter l, BiIter p, Pred pred)
{
  future<BiIter> f1 =
    parallel::stable_partition(par(task), f, p,
      not1(pred));
  future<BiIter> f2 =
    parallel::stable_partition(par(task), p, l,
      pred);
  return dataflow(
    unwrapped([](BiIter r1, BiIter r2) { return
      make_pair(r1, r2); }),
      f1, f2);
}
```

Extending Parallel Algorithms (await: P0057R2)

```
template <typename BiIter, typename Pred>
future<pair<BiIter, BiIter>> gather_async(BiIter
  f, BiIter l, BiIter p, Pred pred)
{
  future<BiIter> f1 =
    parallel::stable_partition(par(task), f, p,
      not1(pred));
  future<BiIter> f2 =
    parallel::stable_partition(par(task), p, l,
      pred);
  return make_pair(await f1, await f2);
}
```

More Information

- `https://github.com/STEllAR-GROUP/hpx`
- `http://stellar-group.org`
- `http://www.open-std.org/jtc1/sc22/wg21/docs/papers`
- `https://isocpp.org/std/the-standard`
- hpx-users@stellar.cct.lsu.edu
- #STE||AR @ irc.freenode.org

Collaborations:

- FET-HPC (H2020): AllScale (`https://allscale.eu`)
- NSF: STORM (`http://storm.stellar-group.org`)
- DOE: Part of X-Stack

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  - Enables to write fully asynchronous code using hundreds of millions of threads.
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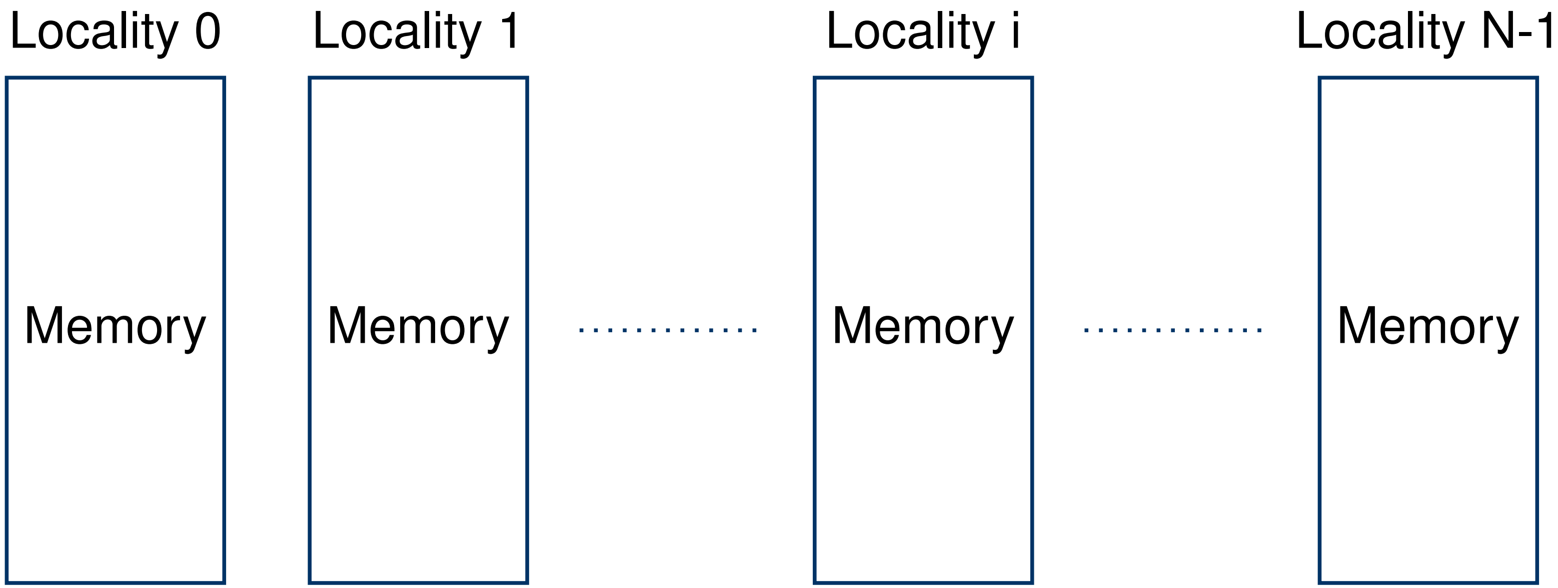
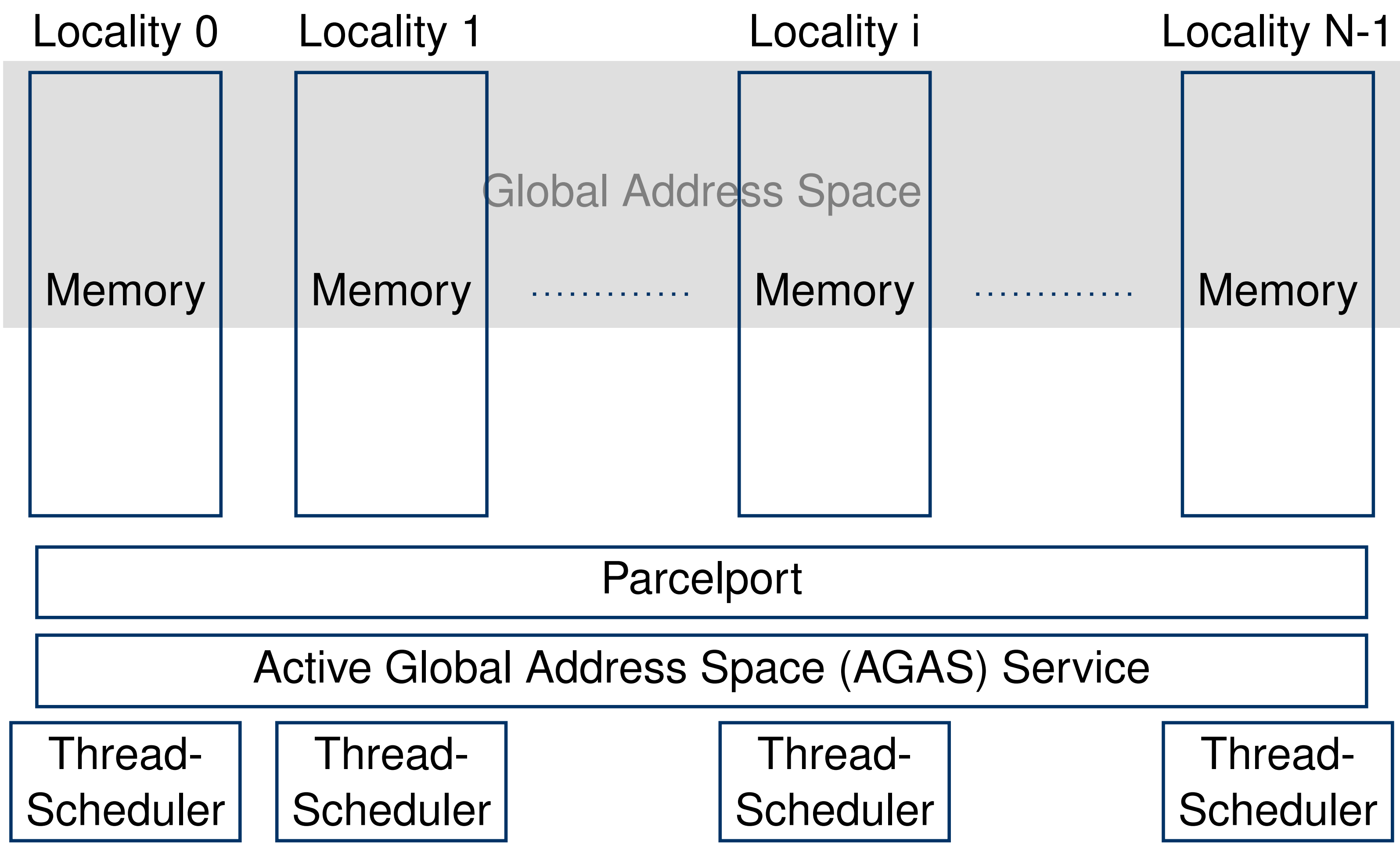
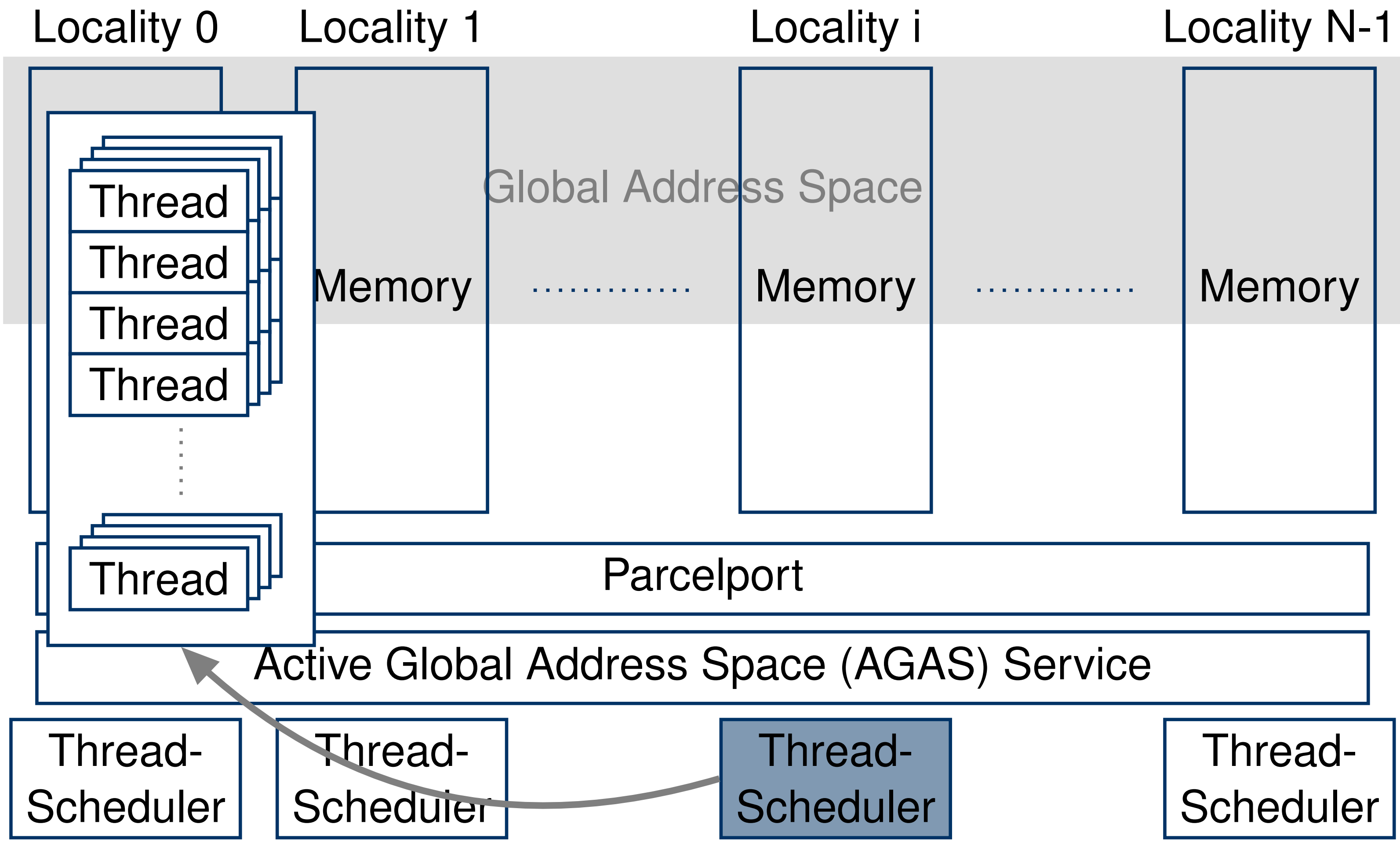
HPX – The programming model



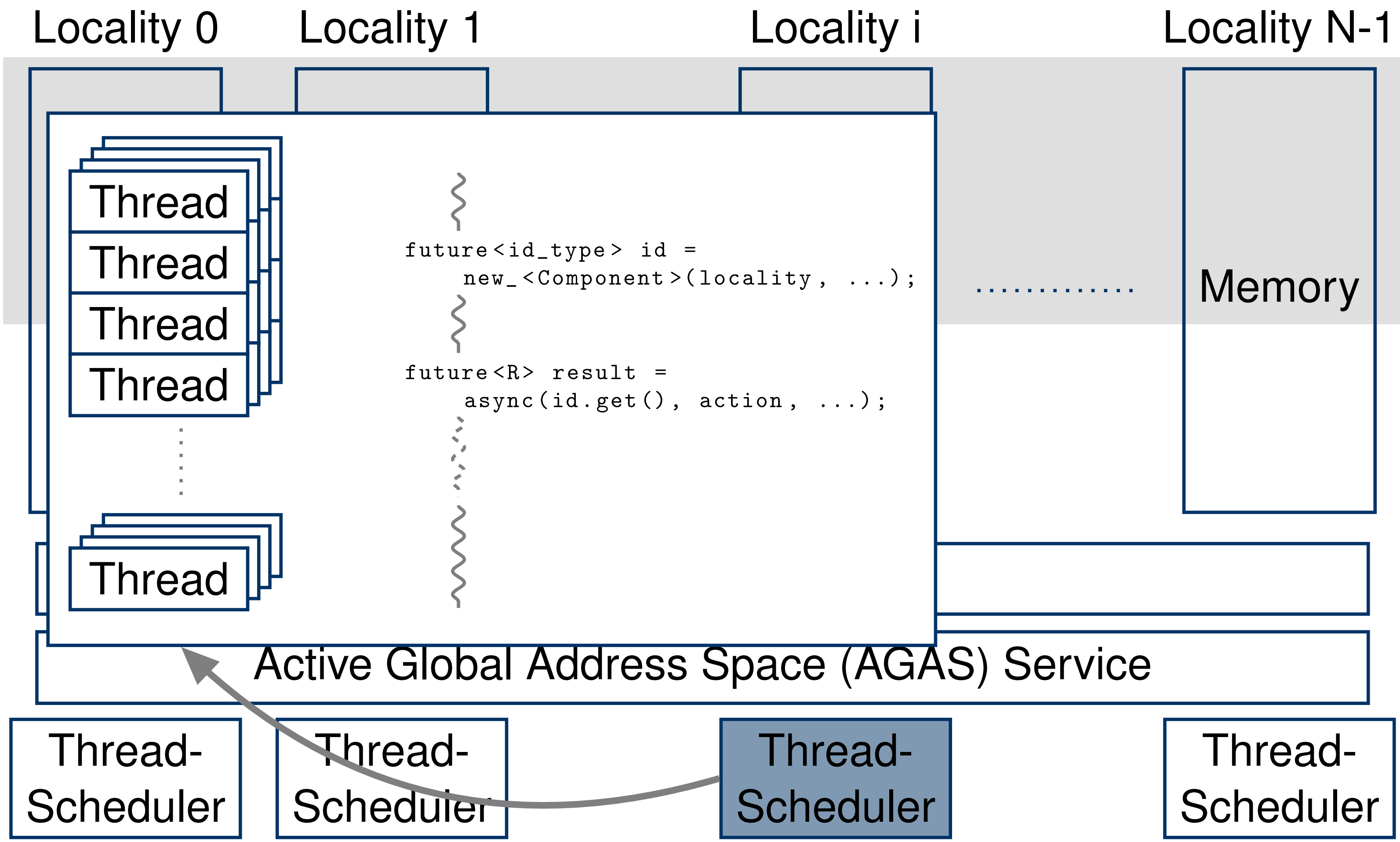
HPX – The programming model



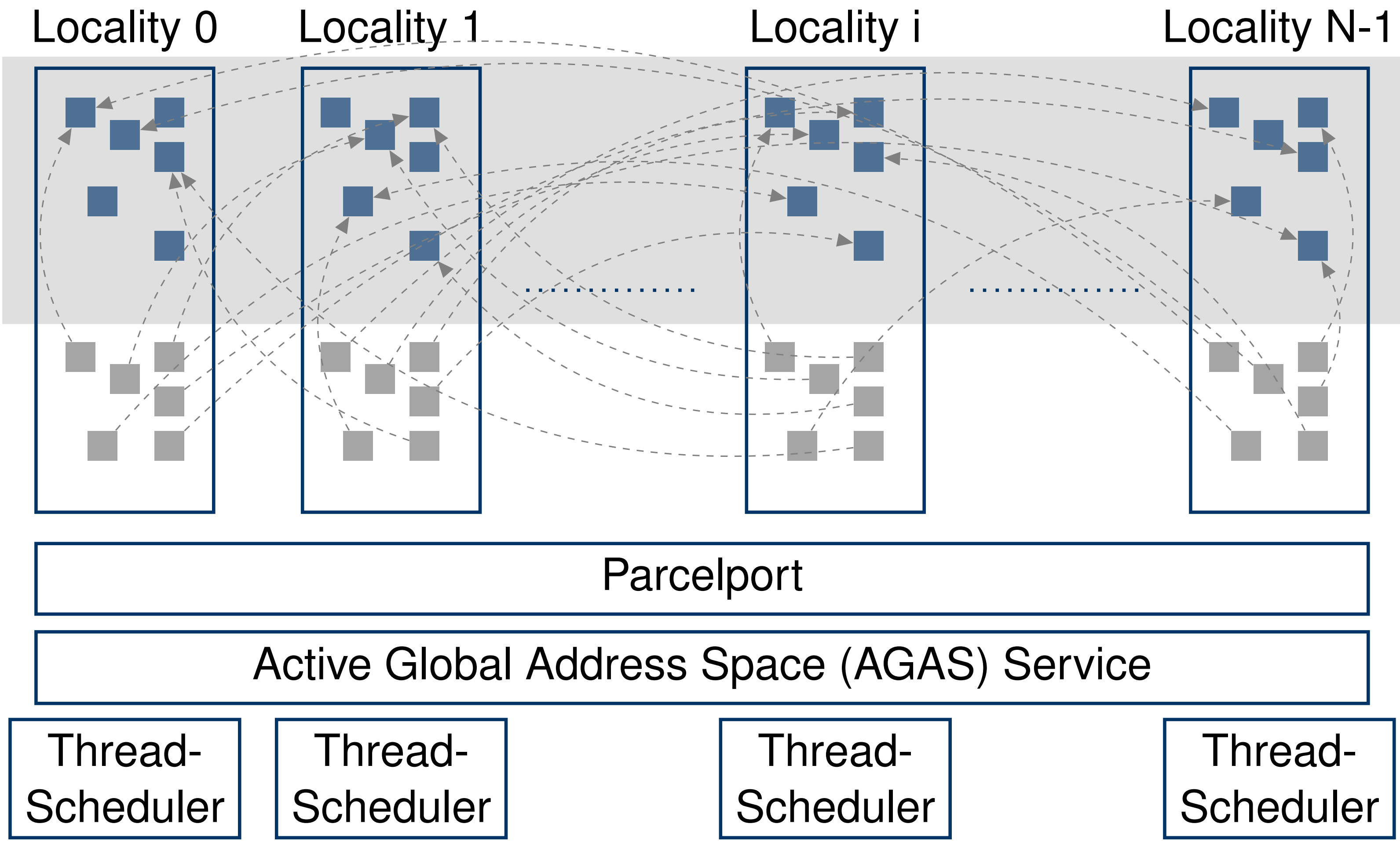
HPX – The programming model



HPX – The programming model



HPX – The programming model



HPX 101 – API Overview

`R f(p...)`	Synchronous (returns `R`)	Asynchronous (returns `future<R>`)	Fire & Forget (returns `void`)
Functions (direct)	`f(p...)` C++	`async(f, p...)`	`apply(f, p...)`
Functions (lazy)	`bind(f, p...)(...)`	`async(bind(f, p...), ...)` C++ Standard Library	`apply(bind(f, p...), ...)`
Actions (direct)	`HPX_ACTION(f, a)` `a()(id, p...)`	`HPX_ACTION(f, a)` `async(a(), id, p...)`	`HPX_ACTION(f, a)` `apply(a(), id, p...)`
Actions (lazy)	`HPX_ACTION(f, a)` `bind(a(), id, p...)(...)`	`HPX_ACTION(f, a)` `async(bind(a(), id, p...), ...)`	`HPX_ACTION(f, a)` `apply(bind(a(), id, p...), ...)` HPX

In Addition: `dataflow(func, f1, f2);`

HPX 101 – Example

```
void hello_world(std::string msg)
{ std::cout << msg << '\n'; }
```

HPX 101 – Example

```
void hello_world(std::string msg)
{ std::cout << msg << '\n'; }

// Asynchronously call hello_world: Returns a
  future
hpx::future<void> f1
  = hpx::async(hello_world, "Hello HPX!");

// Asynchronously call hello_world: Fire &
  forget
hpx::apply(hello_world, "Forget me not!");
```

HPX 101 – Example

```
void hello_world(std::string msg)
{ std::cout << msg << '\n'; }

// Register hello_world as an action
HPX_PLAIN_ACTION(hello_world);

// Asynchronously call hello_world_action
hpx::future<void> f2
  = hpx::async(hello_world_action, hpx::
    find_here(), "Hello HPX!");
```

HPX 101 – Future Composition

```
// Attach a Continuation to a future
future<R> ff = ...;
ff.then([](future<R> f){ do_work(f.get()) });

// All input futures become ready
hpx::when_all(...);

// N of the input futures become ready
hpx::when_some(...);

// One of the input futures become ready
hpx::when_any(...);

// Asynchronously call f after inputs are ready
hpx::future<void> f3
  = dataflow(f, ...);
```

Fibonacci – serial

```
int fib(int n)
{
  if (n < 2) return n;
  return fib(n-1) + fib(n-2);
}
```

Fibonacci – parallel

```
int fib(int n)
{
  if (n < 2) return n;

  future<int> fib1 = hpx::async(fib, n-1);
  future<int> fib2 = hpx::async(fib, n-2);
  return fib1.get() + fib2.get();
}
```

Fibonacci – parallel, take 2

```
future<int> fib(int n)
{
  if(n < 2)
    return hpx::make_ready_future(n);

  if(n < 10)
    return hpx::make_ready_future(fib_serial(n));

  future<int> fib1 = hpx::async(fib, n-1);
  future<int> fib2 = hpx::async(fib, n-2);
  return
    dataflow(unwrapped([](int f1, int f2){
        return f1 + f2;
    }), fib1, fib2);
}
```

Fibonacci – parallel, take 3

```
future<int> fib(int n)
{
  if(n < 2)
    return hpx::make_ready_future(n);

  if(n < 10)
    return hpx::make_ready_future(fib_serial(n)
      );

  future<int> fib1 = hpx::async(fib, n-1);
  future<int> fib2 = hpx::async(fib, n-2);
  return await fib1 + await fib2;
}
```

Loop parallelization

```
// Serial version

int lo = 1;
int hi = 1000;
auto range
  = boost::irange(lo, hi);
for(int i : range)
{
  do_work(i);
}
```

Loop parallelization

```
// Serial version

int lo = 1;
int hi = 1000;
auto range
  = boost::irange(lo
    , hi);
for(int i : range)
{
  do_work(i);
}
```

```
// Parallel version

int lo = 1;
int hi = 1000;
auto range
  = boost::irange(lo, hi)
    ;
for_each(
  par, begin(range), end(
    range),
  [](int i) {
    do_work(i);
  });
```

Loop parallelization

```
// Serial version

int lo = 1;
int hi = 1000;
auto range
  = boost::irange(lo
    , hi);
for(int i : range)
{
  do_work(i);
}
```

```
// Task parallel version

int lo = 1;
int hi = 1000;
auto range
  = boost::irange(lo, hi);
future<void> f = for_each(
  par(task), begin(range), end
    (range),
  [](int i) {
    do_work(i);
  });
other_expensive_work();
// Wait for loop to finish:
f.wait();
```

SAXPY routine with data locality

- $a[i] = b[i] * x + c[i]$, for i from 0 to $N - 1$
- Using parallel algorithms
- Explicit Control over data locality
- No raw Loops

SAXPY routine with data locality

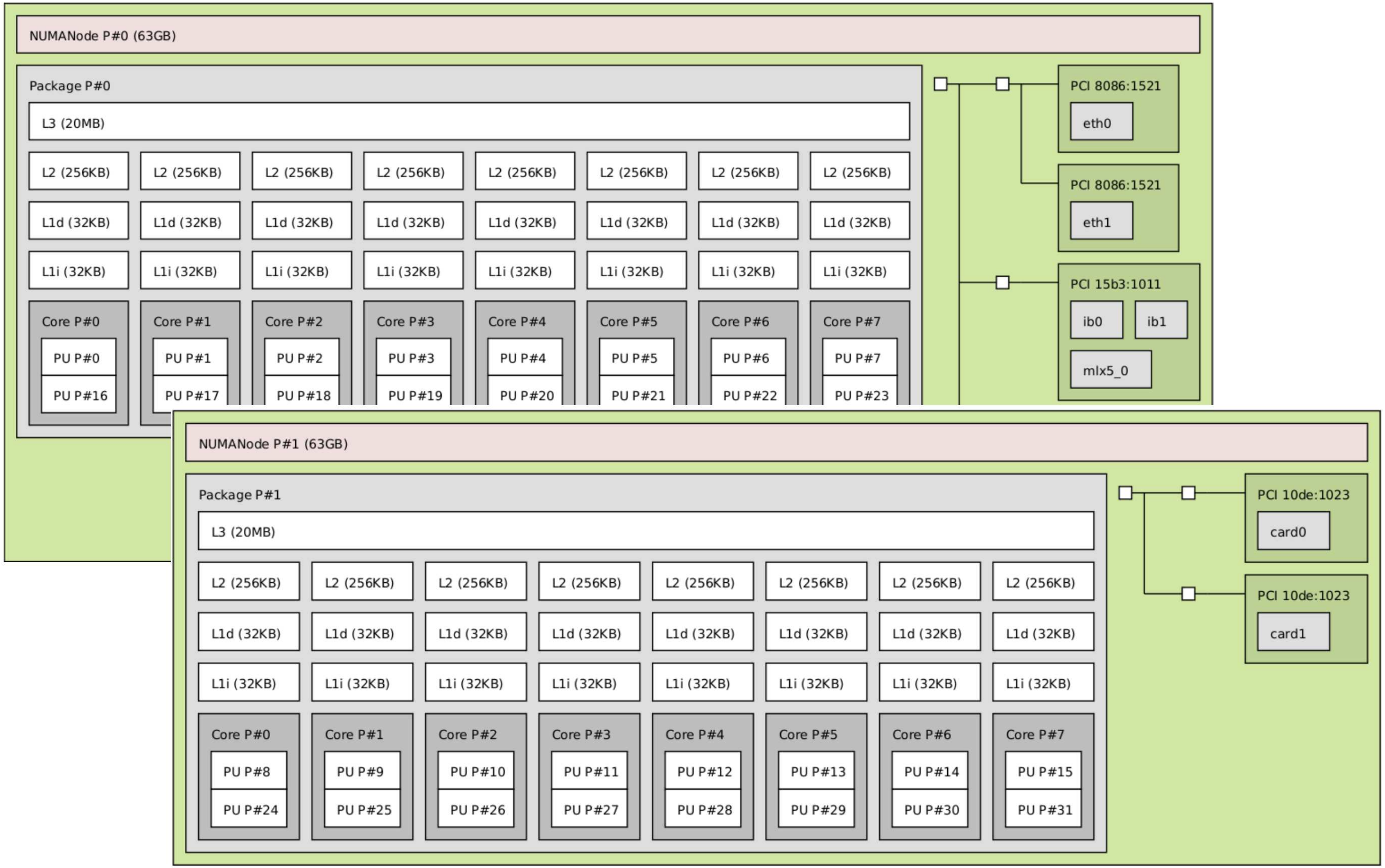
Complete serial version:

```
std::vector<double> a = ...;
std::vector<double> b = ...;
std::vector<double> c = ...;
double x = ...;

std::transform(b.begin(), b.end(),
  c.begin(), c.end(), a.begin(),
  [x](double bb, double cc)
  {
      return bb * x + cc;
  });
```

SAXPY routine with data locality

Parallel version, no data locality:

```
std::vector<double> a = ...;
std::vector<double> b = ...;
std::vector<double> c = ...;
double x = ...;

parallel::transform(parallel::par,
  b.begin(), b.end(),
  c.begin(), c.end(), a.begin(),
  [x](double bb, double cc)
  {
      return bb * x + cc;
  });
```


NUMANode P#0 (63GB)
Package P#0
L3 (20MB)
L2 (256KB)
L1d (32KB)
L1i (32KB)
Core P#0
Core P#1
Core P#2
Core P#3
Core P#4
Core P#5
Core P#6
Core P#7
PU P#0
PU P#1
PU P#2
PU P#3
PU P#4
PU P#5
PU P#6
PU P#7
PU P#16
PU P#17
PU P#18
PU P#19
PU P#20
PU P#21
PU P#22
PU P#23
PCI 8086:1521
eth0
PCI 8086:1521
eth1
PCI 15b3:1011
ib0
ib1
mlx5_0
NUMANode P#1 (63GB)
Package P#1
L3 (20MB)
L2 (256KB)
L1d (32KB)
L1i (32KB)
Core P#0
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PU P#26
PU P#27
PU P#28
PU P#29
PU P#30
PU P#31
PCI 10de:1023
card0
PCI 10de:1023
card1

SAXPY routine

Parallel version, no data locality:

```
std::vector<hpx::compute::host::target> target =
  hpx::compute::host::get_numa_domains();

hpx::compute::host::block_allocator<double> alloc(
  targets);

hpx::compute::vector<double, block_allocator<double
  >> a(..., alloc);
hpx::compute::vector<double, block_allocator<double
  >> b(..., alloc);
hpx::compute::vector<double, block_allocator<double
  >> c(..., alloc);
double x = ...;

hpx::compute::host::block_executor<> numa_executor(
```

SAXPY routine

Parallel version, running on the GPU:

```
hpx::compute::cuda::target target = hpx::compute::
  cuda::get_default_device();

hpx::compute::host::cuda_allocator<double> alloc(
  target);

hpx::compute::vector<double, block_allocator<double
  >> a(..., alloc);
hpx::compute::vector<double, block_allocator<double
  >> b(..., alloc);
hpx::compute::vector<double, block_allocator<double
  >> c(..., alloc);
double x = ...;

hpx::compute::host::cuda_executor executor(target);
```

More on HPX GPU support

- Executors to modify behavior of how the warps are scheduled
- Executor Parameters to modify chunking (partitioning) of parallel work
- Dynamic parallelism: `hpx::parallel::sort(....);`
  `hpx::async(cuda_exec, [&]()`

More on HPX data locality

- The goal is to be able to expose high level support for all kinds of memory:
  - Scratch Pads
  - High Bandwidth Memory (KNL)
  - Remote Targets (memory locations)
- Targets are the missing link between where data is executed, and where it is located

Hello Distributed World!

```
struct hello_world_component;
struct hello_world;

int main()
{
  hello_world hw(hpx::find_here());

  hw.print();
}
```

Components Interface: Writing a component

```
// Component implementation
struct hello_world_component
  : hpx::components::component_base<
        hello_world_component
    >
{
    // ...
};
```

Components Interface: Writing a component

```
// Component implementation
struct hello_world_component
  : hpx::components::component_base<
        hello_world_component
    >
{
    void print() { std::cout << "Hello World!\n
      "; }
    // define print_action
    HPX_DEFINE_COMPONENT_ACTION(
      hello_world_component, print);
};
```

Components Interface: Writing a component

```
// Component implementation
struct hello_world_component
  : hpx::components::component_base<
        hello_world_component
    >
{
    // ...
};

// Register component
typedef hpx::components::component<
    hello_world_component
> hello_world_type;

HPX_REGISTER_MINIMAL_COMPONENT_FACTORY(
  hello_world_type, hello_world);
```

Components Interface: Writing a component

```
// Component implementation
struct hello_world_component
  : hpx::components::component_base<
        hello_world_component
    >
{
    // ...
};

// Register component ...

// Register action
HPX_REGISTER_ACTION(print_action);
```

Components Interface: Writing a component

```
struct hello_world_component;

// Client implementation
struct hello_world
  : hpx::components::client_base<hello_world,
    hello_world_component>
{
    // ...
};

int main()
{
    // ...
}
```

Components Interface: Writing a component

```
struct hello_world_component;

// Client implementation
struct hello_world
  : hpx::components::client_base<hello_world,
    hello_world_component>
{
    typedef
        hpx::components::client_base<
          hello_world, hello_world_component>
        base_type;

    hello_world(hpx::id_type where)
      : base_type(
          hpx::new_<hello_world_component>(
            where)
```

Components Interface: Writing a component

```
struct hello_world_component;

// Client implementation
struct hello_world
  : hpx::components::client_base<hello_world,
    hello_world_component>
{
    // base_type

    hello_world(hpx::id_type where);

    hpx::future<void> print()
    {
        hello_world_component::print_action act
        ;
        return hpx::async(act, get_gid());
```

Components Interface: Writing a component

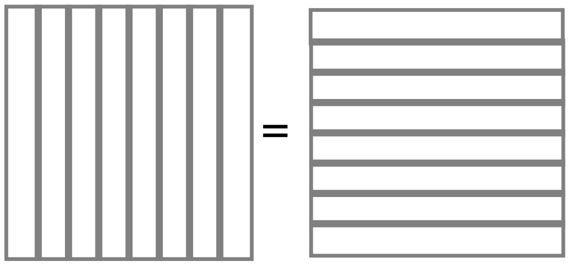
```
struct hello_world_component;

// Client implementation
struct hello_world
  : hpx::components::client_base<hello_world,
    hello_world_component>
{
    hello_world(hpx::id_type where);
    hpx::future<void> print();
};

int main()
{
    hello_world hw(hpx::find_here());
    hw.print();
}
```

Matrix Transpose

$B = A^T \Rightarrow$



Inspired by the Intel Parallel Research Kernels
(https://github.com/ParRes/Kernels)

Matrix Transpose

```
std::vector<double> A(order * order);
std::vector<double> B(order * order);

for(std::size_t i = 0; i < order; ++i)
{
  for(std::size_t j = 0; j < order; ++j)
  {
    B[i + order * j] = A[j + order * i];
  }
}
```

Example: Matrix Transpose

```
std::vector<double> A(order * order);
std::vector<double> B(order * order);

auto range = irange(0, order);
// parallel for
for_each(par, begin(range), end(range),
  [&](std::size_t i)
  {
    for(std::size_t j = 0; j < order; ++j)
    {
        B[i + order * j] = A[j + order * i];
    }
  }
);
```

Example: Matrix Transpose

```
std::size_t my_id = hpx::get_locality_id();
std::size_t num_blocks = hpx::
  get_num_localities().get();
std::size_t block_order = order / num_blocks;
std::vector<block> A(num_blocks);
std::vector<block> B(num_blocks);
```

Example: Matrix Transpose

```
for(std::size_t b = 0; b < num_blocks; ++b) {
  if(b == my_id) {
    A[b] = block(block_order * order);
    hpx::register_id_with_basename("A", get_gid
      (), b);
    B[b] = block(block_order * order);
    hpx::register_id_with_basename("B", get_gid
      (), b);
  }
  else {
    A[b] = hpx::find_id_from_basename("A", b);
    B[b] = hpx::find_id_from_basename("B", b);
  }
}
```

Example: Matrix Transpose

```
std::vector<hpx::future<void>> phases(
  num_blocks);
auto range = irange(0, num_blocks);
for_each(par, begin(range), end(range),
   [&](std::size_t phase)
   {
     std::size_t block_size = block_order *
       block_order;
     phases[b] = hpx::lcos::dataflow(
       transpose,
       A[phase].get_sub_block(my_id * block_size
         , block_size),
       B[my_id].get_sub_block(phase * block_size
         , block_size)
     );
   });
```

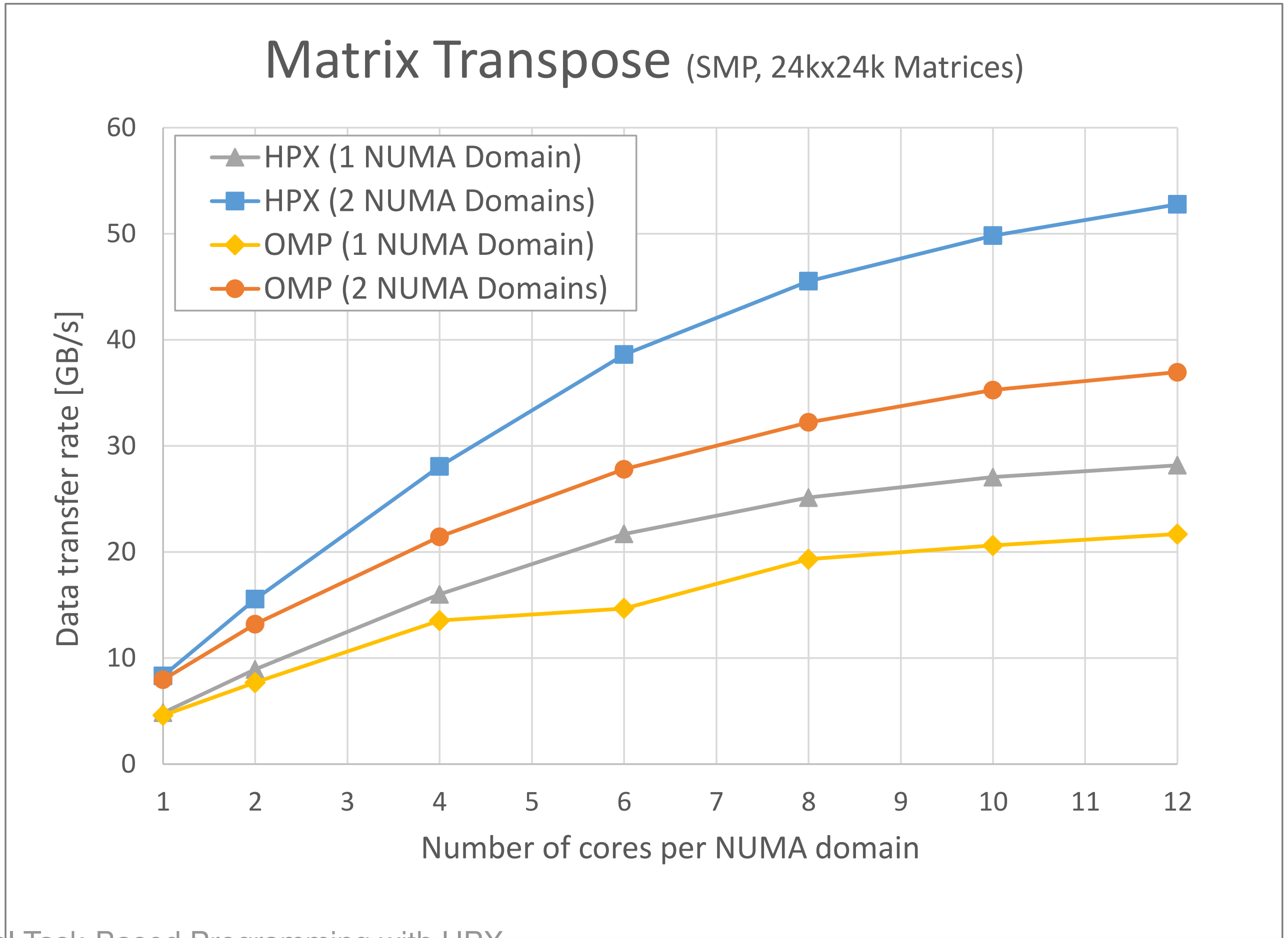
Example: Matrix Transpose

```
void transpose(hpx::future<sub_block> Af, hpx::
  future<sub_block> Bf)
{
  sub_block A = Af.get();
  sub_block B = Bf.get();
  for(std::size_t i = 0; i < block_order; ++i)
  {
    for(std::size_t j = 0; j < block_order; ++j
      )
    {
        B[i + block_order * j] = A[j +
          block_order * i];
    }
  }
}
```

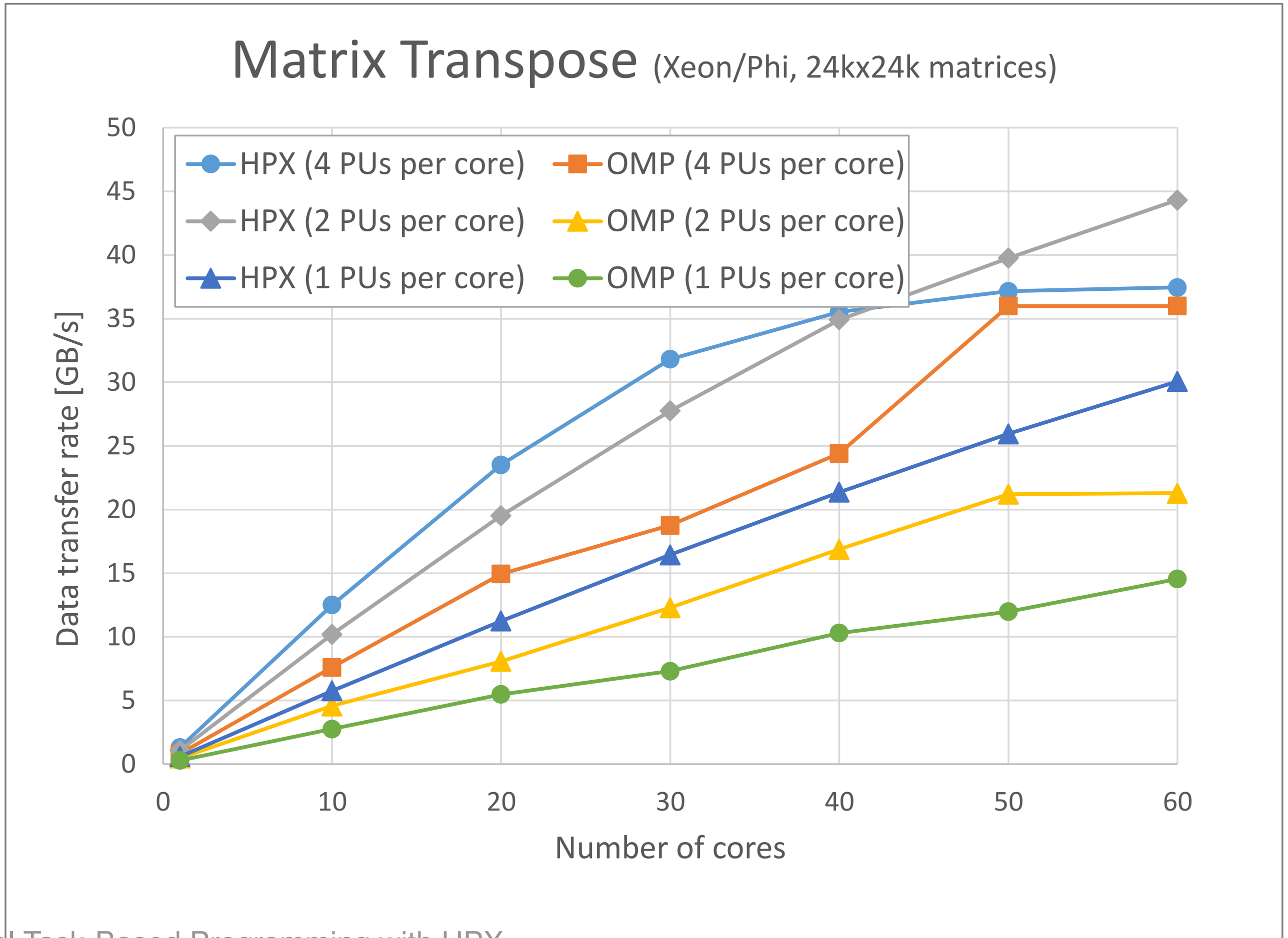
Example: Matrix Transpose

```
struct block_component
  : hpx::components::component_base<
    block_component>
{
  block_component() {}
  block_component(std::size_t size)
    : data_(size) {}
  sub_block get_sub_block(std::size_t offset,
    std::size_t size)
  {
      return sub_block(&data_[offset], size);
  }
  HPX_DEFINE_COMPONENT_ACTION(block_component,
    get_sub_block);
  std::vector<double> data_;
};
```

Matrix Transpose



Matrix Transpose



Hands-On Examples

- quicksort
- Matrix Multiplication
- Heat diffusion
- Numerical integrator
- To be found at `git@github.com:sithhell/LoOPS_Examples.git`

Conclusions

- Higher-level parallelization abstractions in C++:
  - uniform, versatile, and generic
  - All of this is enabled by use of modern C++ facilities
  - Runtime system (fine-grain, task-based schedulers)
  - Performant, portable implementation
- Asynchronous task based programming to efficiently express parallelism
- Seamless extensions for distributed computing

Parallelism is here to stay!

- Massive Parallel Hardware is already part of our daily lives!
- Parallelism is observable everywhere:
  - $\Rightarrow$ IoT: Massive amount devices existing in parallel
  - $\Rightarrow$ Embedded: Meet massively parallel energy-aware systems (Embedded GPUs, Epiphany, DSPs, FPGAs)
  - $\Rightarrow$ Automotive: Massive amount of parallel sensor data to process
- We all need solutions on how to deal with this, efficiently and pragmatically

More Information

- https://github.com/STEllAR-GROUP/hpx
- http://stellar-group.org
- http://www.open-std.org/jtc1/sc22/wg21/docs/papers
- https://isocpp.org/std/the-standard
- hpx-users@stellar.cct.lsu.edu
- #STE||AR @ irc.freenode.org

Collaborations:

- FET-HPC (H2020): AllScale (https://allscale.eu)
- NSF: STORM (http://storm.stellar-group.org)
- DOE: Part of X-Stack