The 11th International workshop on OpenCL and SYCL

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Towards Alignment of Parallelism in SYCL and ISO C++

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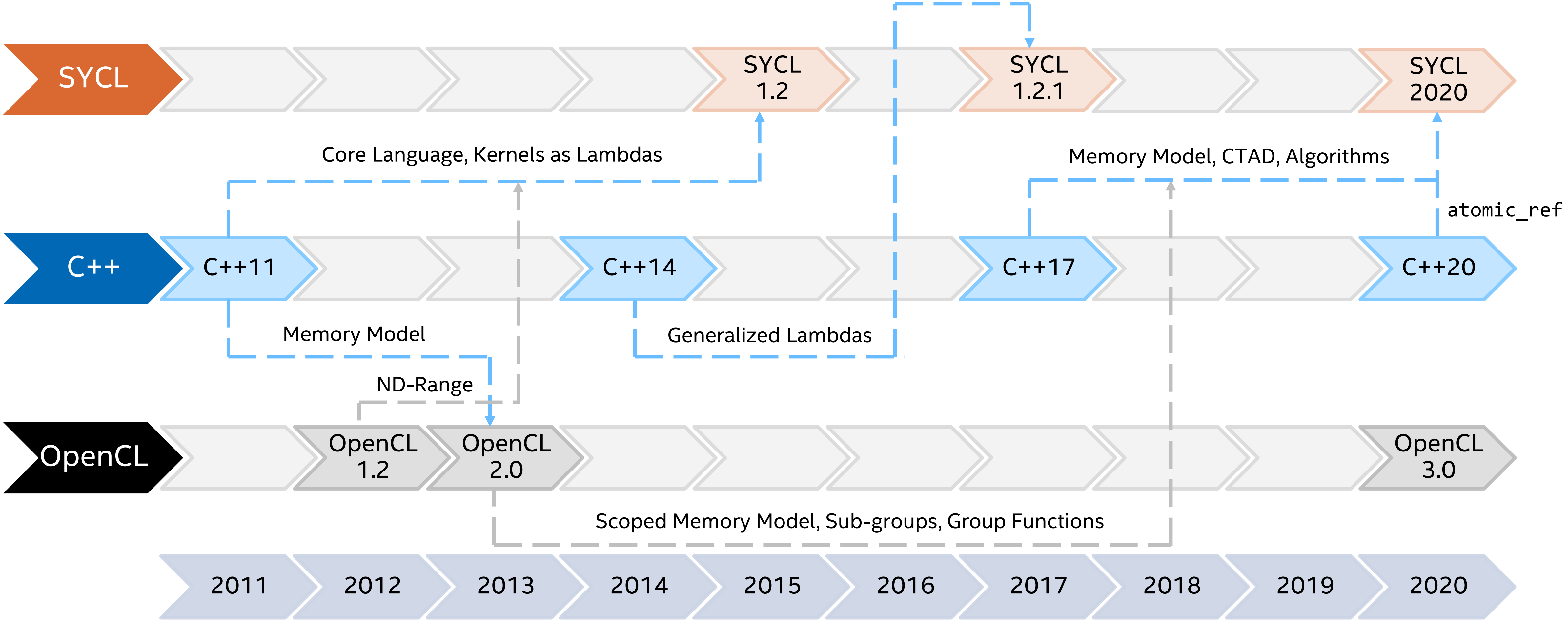
Parallel Evolution of SYCL, ISO C++ and OpenCL



Maintaining alignment between these specifications requires constant, ongoing effort!

Motivating Use-Case: Global Synchronization

Should this code work? Does it?

```
template <size_t Dimensions>
void arrive_and_wait(size_t expected, sycl::group<Dimensions> wg, ...)
{
  // Wait for all work-items in the group before signaling arrival
  sycl::group_barrier(wg);

  // Elect one work-item to synchronize with other groups
  if (wg.leader()) {

    // Signal that this group has arrived at the barrier
    atomic_counter++;

    // Spin while waiting for all groups to arrive
    while (atomic_counter.load() != expected) {}
  }

  // Wait for the leader to finish synchronizing with other groups
  sycl::group_barrier(wg);
}
```

Assumption 1:
Leader of the work-group makes progress while other work-items wait at second barrier.

Assumption 2:
Every work-group leader makes progress.

Empirical evidence for support under “occupancy-bound execution” by Sorensen et al. on multiple GPUs

Motivating Use-Case: Sub-group Specialization

Should this code work? Does it?

```
void produce(sycl::local_ptr<example::concurrent_queue> tasks)
{
  if (sg.leader())
  {
    tasks->push(...);
  }
  ...
}

void consume(sycl::local_ptr<example::concurrent_queue> tasks)
{
  if (sg.leader())
  {
    work = tasks->pop();
  }
  foo(work);
  ...
}
```

Assumptions:
Leader of every sub-group makes progress, while other work-items wait at a barrier (not shown).

NB: Assumptions only relevant for sub-groups in the same work-group

Empirical evidence for support of "warp specialization" by Bauer et al. on NVIDIA GPUs

Forward Progress Guarantees in ISO C++

Guarantee	Concurrent	Parallel	Weakly Parallel
Eventually executes its first step	✓	✗	✗
Makes progress after executing its first step	✓	✓	✗

	Concurrent	Parallel	Weakly Parallel
Mental Model	OS threads	Tasks	≈Fibers?
Provided By	`std::thread`	`par`	`par_unseq`

Forward Progress Guarantees in SYCL?

Guarantee	Work-item in `parallel_for`	Work-item in ND-Range `parallel_for`
Eventually executes its first step	✘	✘
Makes progress after executing its first step	✘	✘
Makes progress when other work-items hit a barrier	*N/A*	?

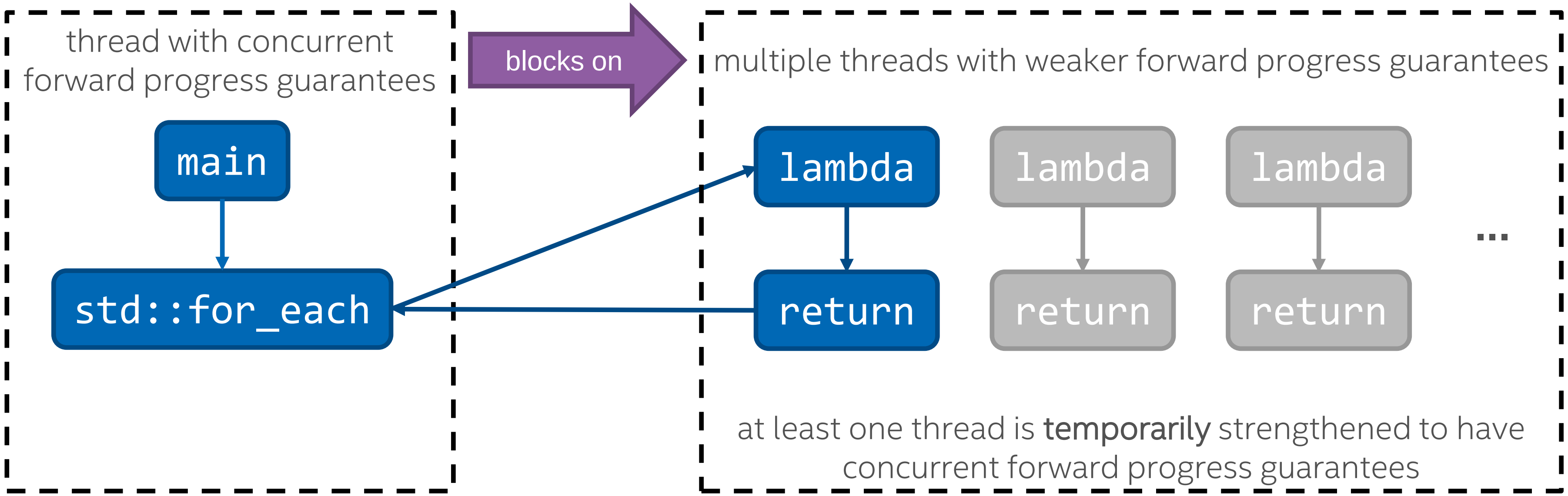
SYCL 2020, Revision 6, Section 3.8.3.4:

"A SYCL implementation must execute work-items concurrently† and must ensure that the work-items in a group obey the semantics of group barriers, but are not required to provide any additional forward progress guarantees"

† Not "concurrent forward progress guarantees"!

"Blocking with Forward Progress Guarantee Delegation" in ISO C++

```
// Assume calling thread has concurrent forward progress guarantees
std::for_each(std::par_unseq, c.begin(), c.end(), [&](auto x)
{
  ... // Each invocation has weakly parallel forward progress guarantees
}); // Calling thread blocks with forward progress delegation
```



Forward Progress Guarantees in SYCL (Revisited)

Guarantee	Work-item in `parallel_for`	Work-item in ND-Range `parallel_for`
Eventually executes its first step	✗	✗
Makes progress after executing its first step	✗	✗
Makes progress when other work-items hit a barrier	*N/A*	✓

Proposed Fixes to Section 3.8.3.4:

1. "Each work-item … is a separate thread of execution, providing at least weakly parallel forward progress guarantees."
2. "When a work-item arrives at a group barrier acting on group *G*, implementations must eventually select and potentially strengthen another work-item in group *G* that has not yet arrived at the barrier."

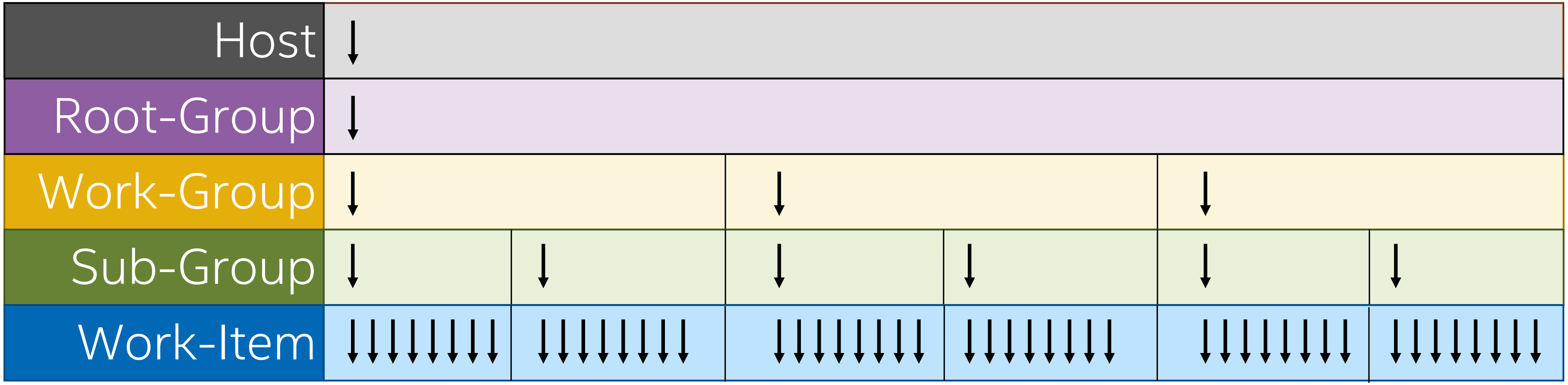
Hypothetical: SYCL Implemented with ISO C++

```
template <typename Kernel>
void handler::parallel_for(sycl::nd_range<1> ndr, Kernel f) {

  std::vector<size_t> groups = { 1, 2, ..., ndr.get_group_range()[0] };
  std::vector<size_t> items = { 1, 2, ..., ndr.get_local_range()[0] };

  // Create a thread of execution providing parallel forward progress guarantees per work-group
  std::for_each(std::execution::par, std::begin(groups), std::end(groups), [&](size_t group_id) {

    // Create a thread of execution providing weakly parallel forward progress guarantees per work-item
    std::for_each(std::execution::par_unseq, std::begin(items), std::end(items), [&](size_t item_id) {

      // Invoke the user supplied kernel function object
      sycl::nd_item<1> item = sycl::detail::make_nd_item<1>(group_id, item_id);
      f(item);

    });

  });

}
```

NB: Not all threads of execution are *created* at the same time.

Pseudocode of a hypothetical implementation for illustrative purposes only.

New Mental Model: A Hierarchy of Threads



- The **host** has at least one thread and creates one thread per root-group.
- The root-group creates one thread per work-group.
- Each work-group creates one thread per sub-group.
- Each sub-group creates one thread per work-item.

Each thread <u>blocks with forward progress guarantee delegation</u> on its children.

New Mental Model: Mapping to OpenCL 1.x

Host	Concurrent
Root-Group	Weakly Parallel
Work-Group	Weakly Parallel
Sub-Group	Weakly Parallel
Work-Item	Weakly Parallel

- At least one {root-group, work-group, sub-group, work-item} makes progress.
- Individual {root-group, work-group, sub-group, work-item}s have no guarantees.

Each thread blocks with forward progress guarantee delegation on its children.

New Mental Model: Mapping to OpenCL 2.x†

Host	Concurrent
Root-Group	Weakly Parallel
Work-Group	Weakly Parallel
Sub-Group	**Concurrent**
Work-Item	Weakly Parallel

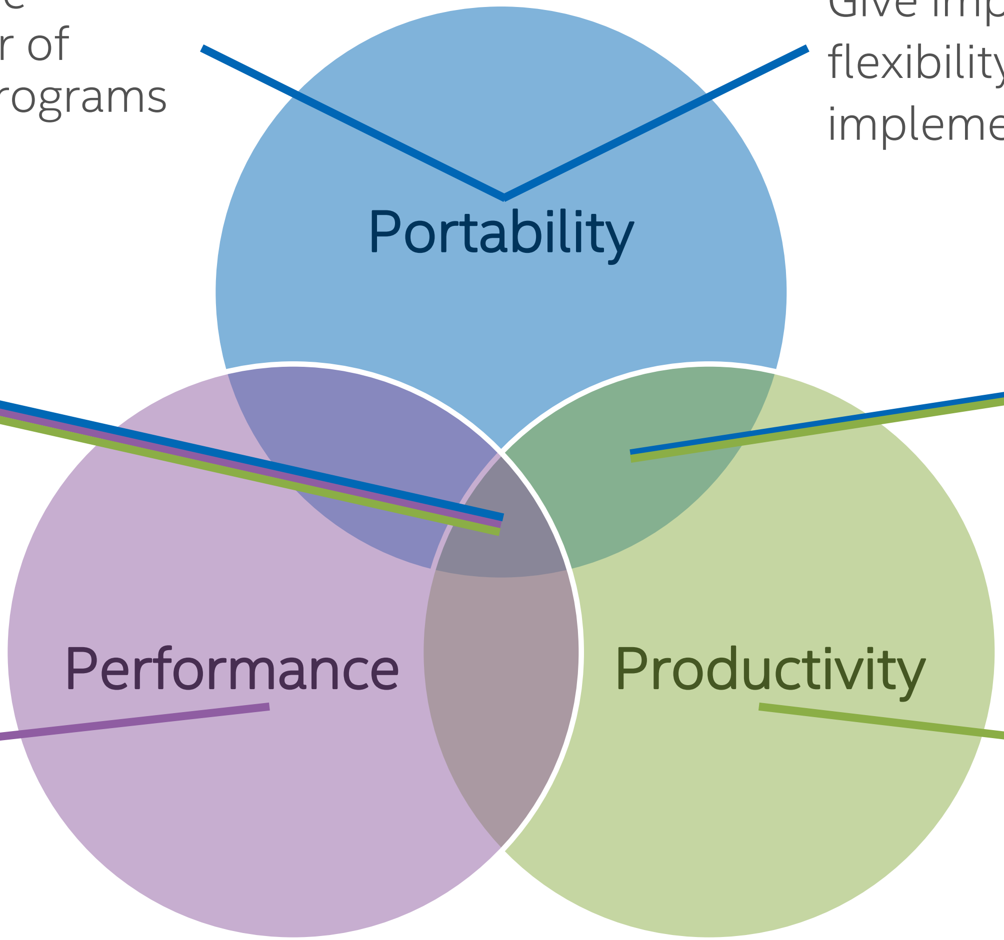
- At least one {root-group, work-group} makes progress.
- Every sub-group in an executing work-group makes progress.
- At least one work-item per sub-group makes progress.
- Individual {root-group, work-group, work-item}s have no guarantees.

† Assuming support for CL_DEVICE_SUB_GROUP_INDEPENDENT_FORWARD_PROGRESS.

Designing an Extension: High-Level Goals

Don't change the default behavior of existing SYCL programs

Give implementations flexibility, not additional implementation burden



Let developers decide how to balance P3 trade-offs

Allow developers to reason about where code will run correctly

Enable opt-in to strong guarantees to enable new algorithms

Re-use existing mechanisms for querying device capabilities

Using the Extension: Declaring Requirements

```
struct MyKernel
{
  // Kernel function calls arrive_and_wait
  // (Other functionality omitted)
  void operator()(sycl::nd_item<1> it) {
    ...
    arrive_and_wait(num_work_groups, it.get_group());
    ...
  }

  // Kernel Properties: Declare requirements
  auto get(sycl::properties_tag)
  {
    return sycl::properties {
      sycl::work_group_progress
      <sycl::forward_progress_guarantee::concurrent,
       sycl::execution_scope::root_group>
    };
  }

  size_t num_work_groups;
};
```

Requirements are embedded in the kernel.

"At least one work-item in each work-group created by the same root-group must provide concurrent forward progress guarantees."

Using the Extension: Submitting the Kernel

```
try {
  // Kernel Launch: Attempt to use a fixed ND-range
  auto range = sycl::nd_range<1>{num_wg * wg_size, wg_size};
  q.parallel_for(range, MyKernel(num_wg));
}
catch (...)
{
  // Fall back to an alternative kernel implementation
  // or exit with an error
}
```

Requirements are extracted automatically from the kernel definition.

Implementation throws an exception if the requirements cannot be satisfied.

Using the Extension: Querying Support

```
// Device Queries: Check support for requirements
using query = sycl::info::device::forward_progress_guarantee
              <sycl::forward_progress_guarantee::concurrent,
               sycl::execution_scope::root_group>;
sycl::device dev = q.get_device();
auto capability = dev.get_info<query>();
if (capability >= sycl::forward_progress_guarantee::concurrent)
{
  // Kernel Launch Queries: Determine valid ND-range size
  using size_query = sycl::info::kernel::max_work_group_size;
  using num_query = sycl::info::kernel::max_num_work_groups;
  auto bundle = sycl::get_kernel_bundle(q.get_context());
  auto kernel = bundle.get_kernel<class MyKernel>();
  auto wg_size = kernel.get_info<size_query>(q);
  auto num_wg = kernel.get_info<num_query>(q, wg_size);

  // Kernel Launch: Use results from queries
  auto range = sycl::nd_range<1>{num_wg * wg_size, wg_size};
  q.parallel_for(range, MyKernel(num_wg));

}
else { ... } // Fallback path as before (see previous slides)
```

← Check whether the device can satisfy the requirements at all.

← Check for implementation-specific limits on the maximum work-group size and number of work-groups.

Summary

- We've bridged the gap between SYCL and C++17 parallelism
  - Fixed underdefined aspects of SYCL by reusing proven terminology/concepts
  - Defined a way to reason about hierarchical forward progress guarantees
  - Proposed new features to state assumptions/requirements and query support

- Ongoing effort to maintain alignment and influence other standards
  - Explore interaction between ND-range kernels and `std::execution`
  - Apply our learnings to OpenCL, SPIR-V, Vulkan
  - Feedback welcome at https://github.com/intel/llvm/pull/7598

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