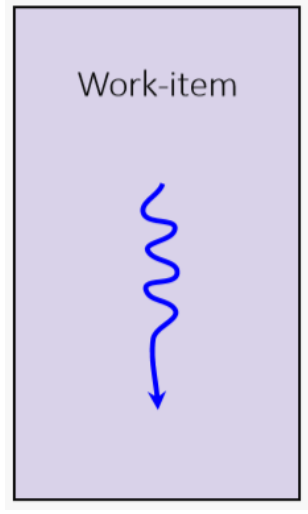
ND RANGE KERNELS

LEARNING OBJECTIVES

- Learn about the SYCL execution and memory model
- Learn how to enqueue an nd-range kernel functions
- Learn how to use local memory.

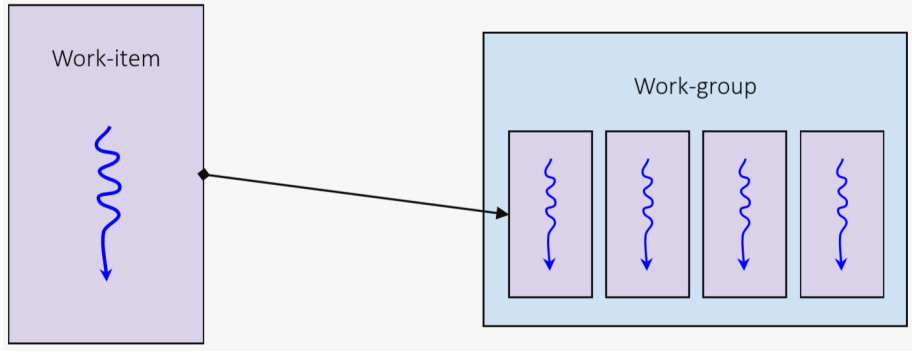
SYCL EXECUTION MODEL

- SYCL kernel functions are executed by **work-items**
- You can think of a work-item as a thread of execution
- Each work-item will execute a SYCL kernel function from start to end
- A work-item can run on CPU threads, SIMD lanes, GPU threads, or any other kind of processing element



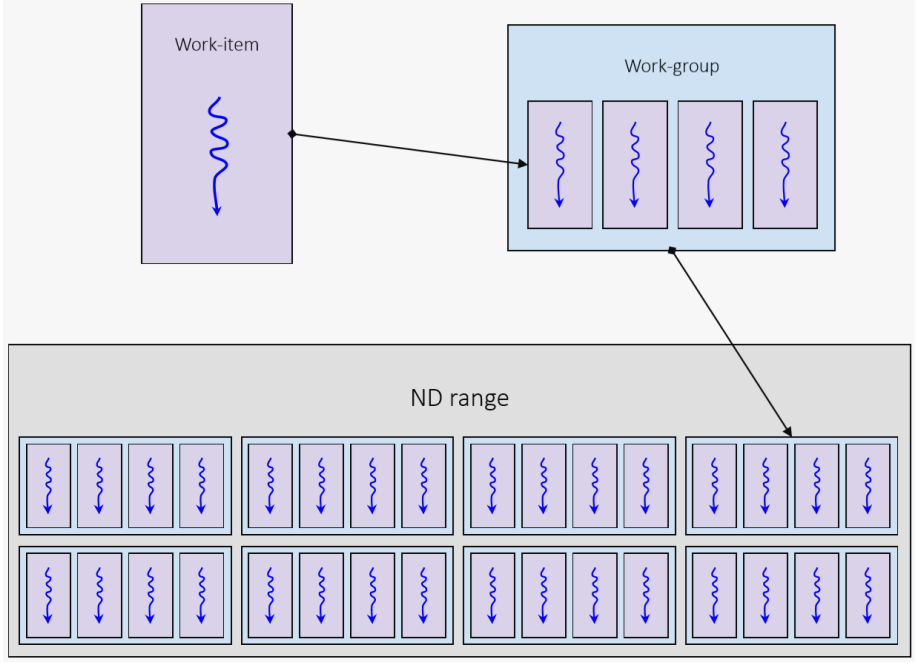
SYCL EXECUTION MODEL

- Work-items are collected together into **work-groups**
- The size of work-groups is generally relative to what is optimal on the device being targeted
- It can also be affected by the resources used by each work-item



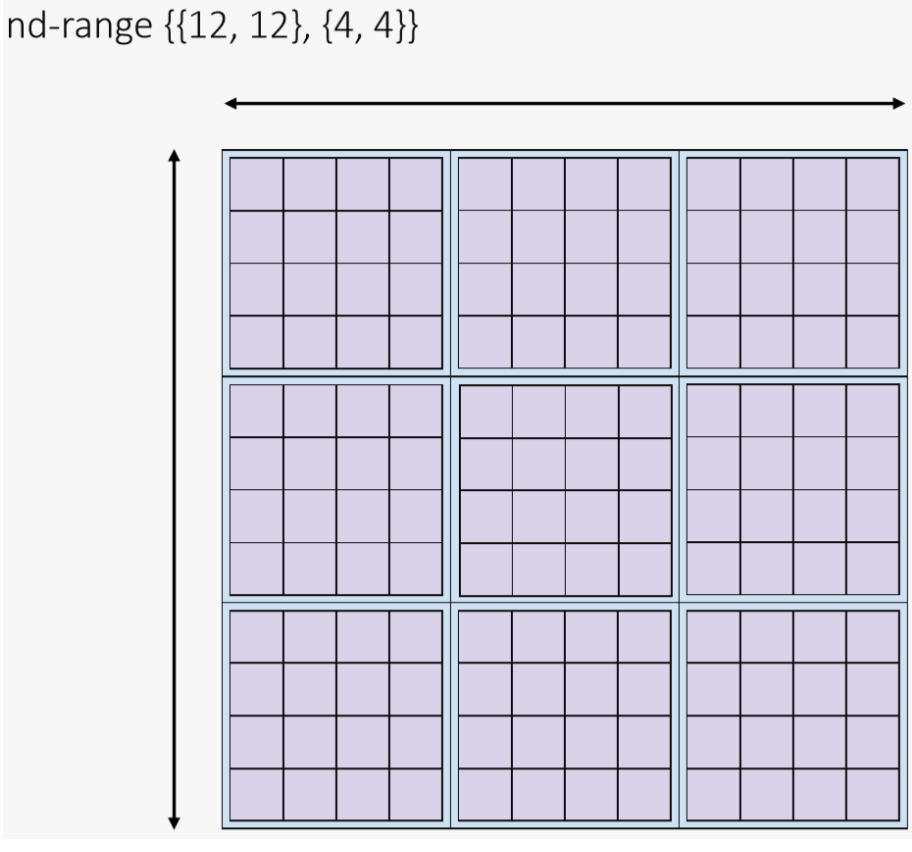
SYCL EXECUTION MODEL

- SYCL kernel functions are invoked within an **nd-range**
- An nd-range has a number of work-groups and subsequently a number of work-items
- Work-groups always have the same number of work-items



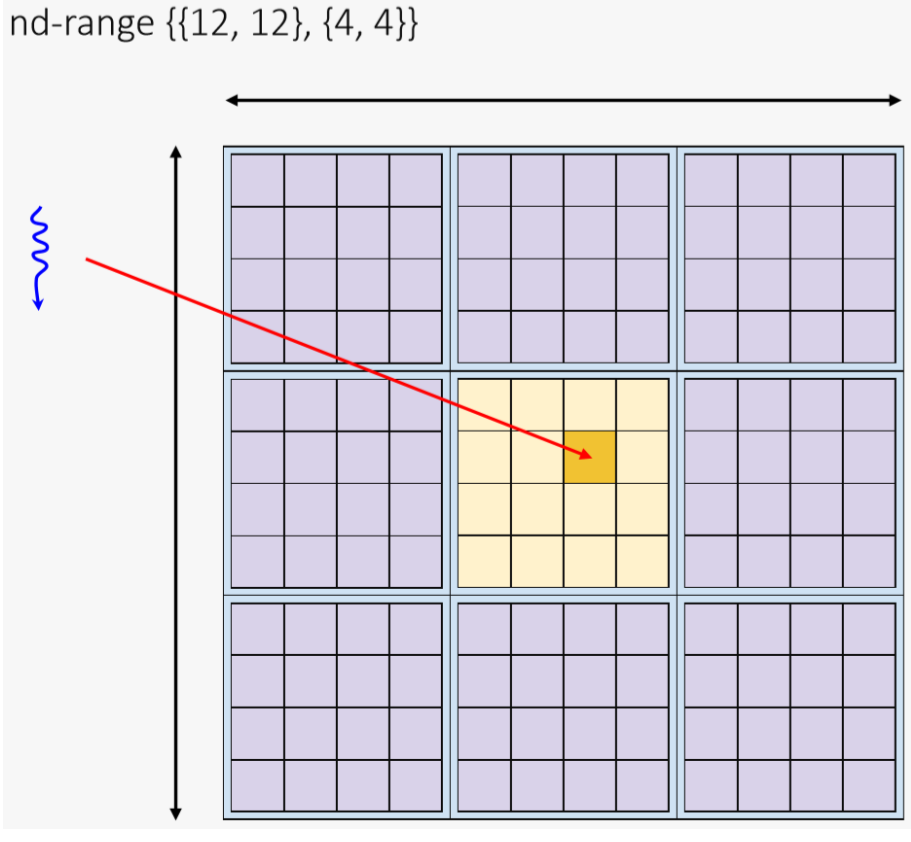
SYCL EXECUTION MODEL

- The nd-range describes an **iteration space**; how the work-items and work-groups are composed
- An nd-range can be 1, 2 or 3 dimensions
- An nd-range has two components
  - The **global-range** describes the total number of workitems in each dimension
  - The **local-range** describes the number of work-items in a work-group in each dimension



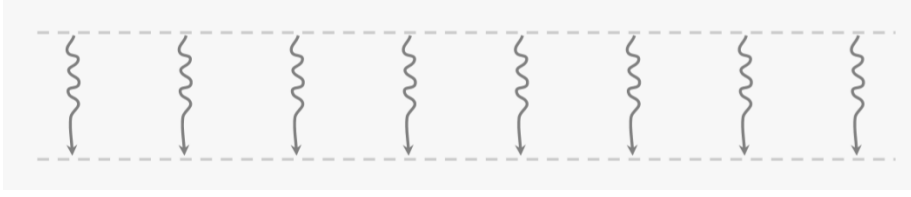
SYCL EXECUTION MODEL

- Each invocation in the iteration space of an nd-range is a work-item
- Each invocation knows which work-item it is on and can query certain information about its position in the nd-range
- Each work-item has the following:
  - **Global range**: {12, 12}
  - **Global id**: {6, 5}
  - **Group range**: {3, 3}
  - **Group id**: {1, 1}
  - **Local range**: {4, 4}
  - **Local id**: {2, 1}



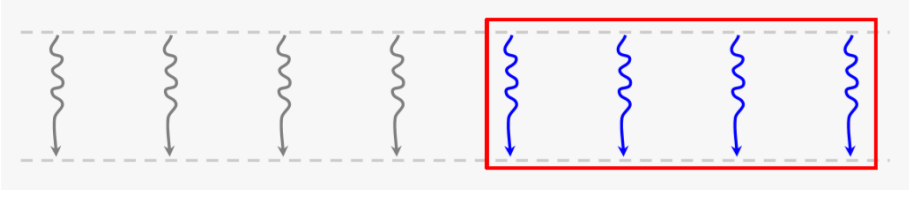
SYCL EXECUTION MODEL

Typically an nd-range invocation SYCL will execute the SYCL kernel function on a very large number of work-items, often in the thousands



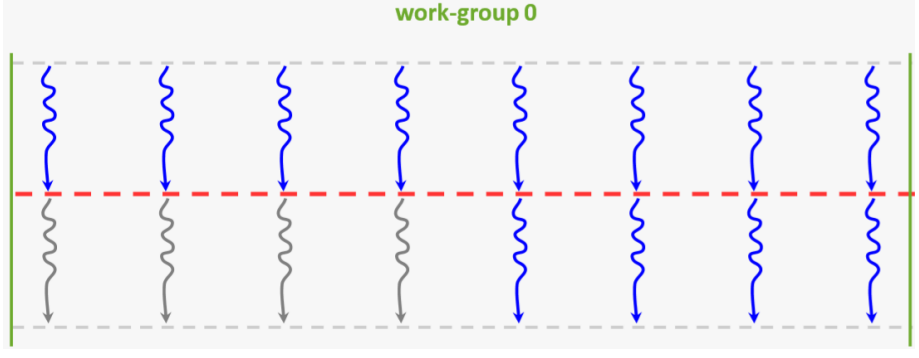
SYCL EXECUTION MODEL

- Multiple work-items will generally execute concurrently
- On vector hardware this is often done in lock-step, which means the same hardware instructions
- The number of work-items that will execute concurrently can vary from one device to another
- Work-items will be batched along with other work-items in the same work-group
- The order work-items and workgroups are executed in is implementation defined



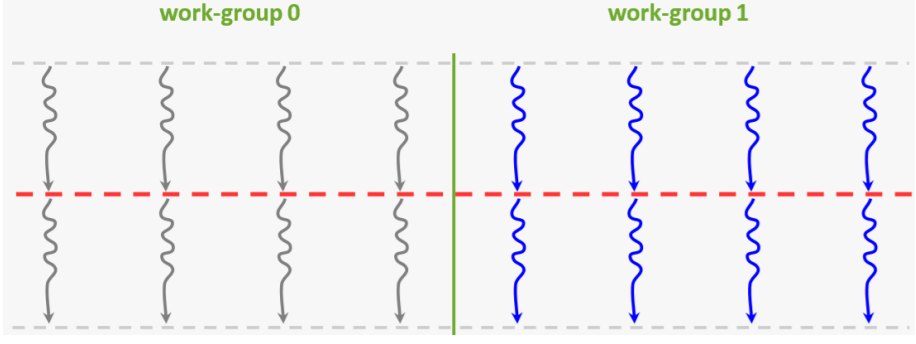
SYCL EXECUTION MODEL

- Work-items in a work-group can be synchronized using a work-group barrier
    - All work-items within a work-group must reach the barrier before any can continue on



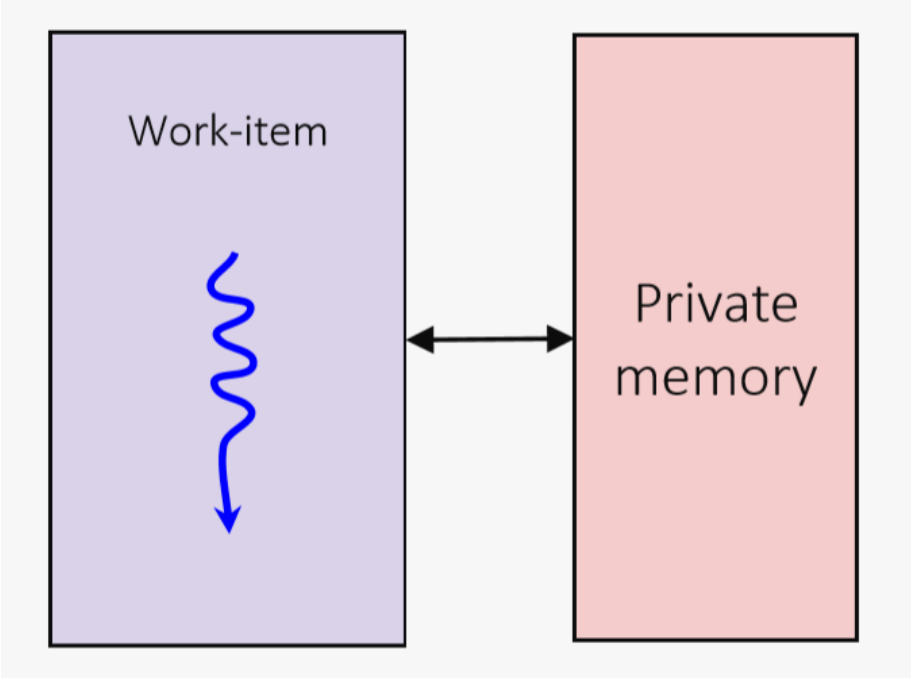
SYCL EXECUTION MODEL

- SYCL does not support synchronizing across all work-items in the nd-range
- The only way to do this is to split the computation into separate SYCL kernel functions

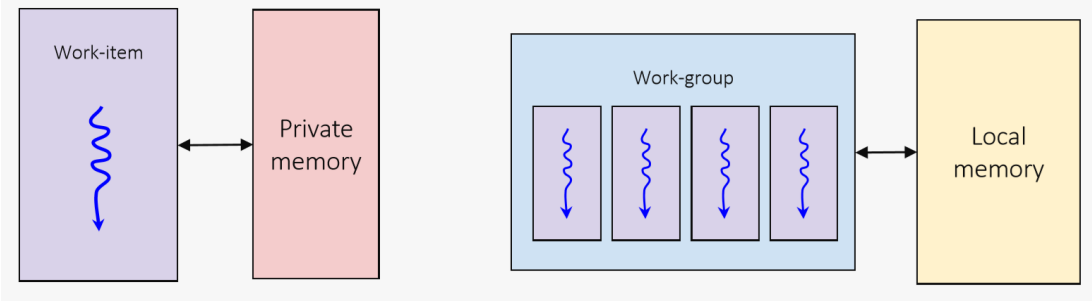


SYCL MEMORY MODEL

- Each work-item can access a dedicated region of **private memory**
- A work-item cannot access the private memory of another work-item

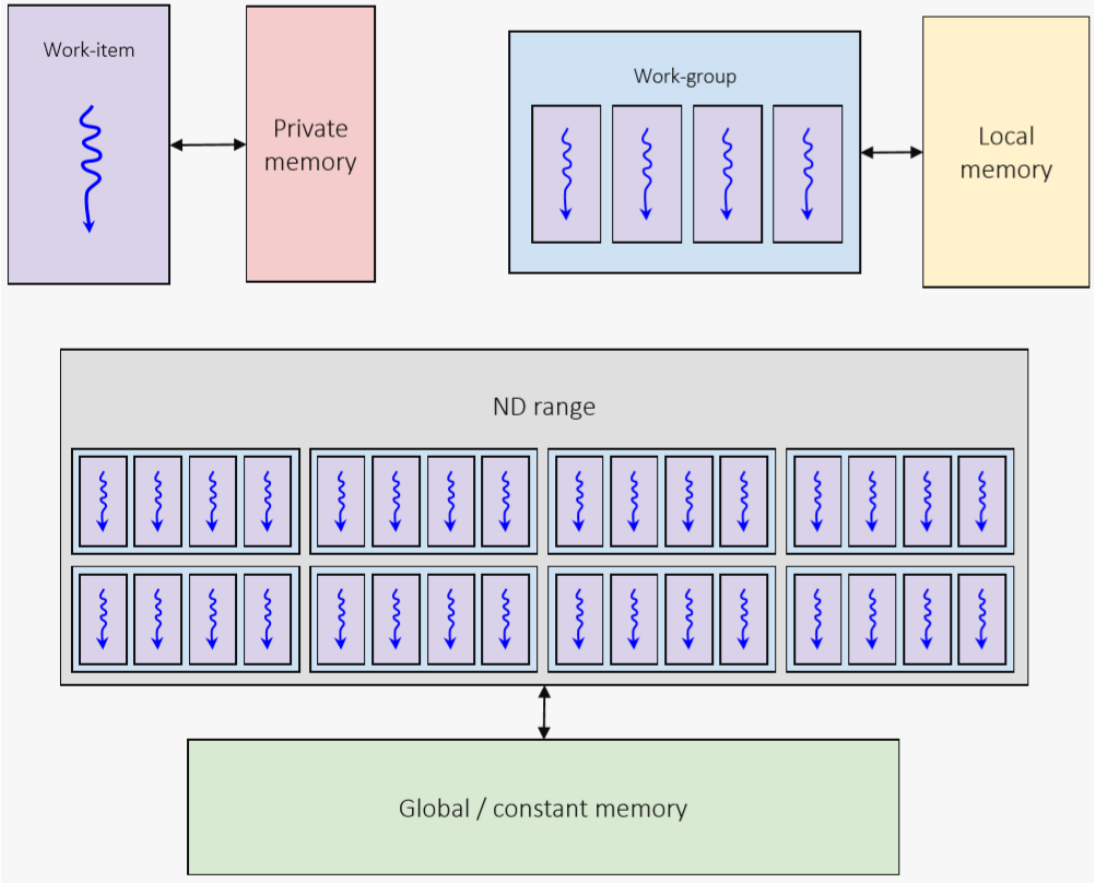


SYCL MEMORY MODEL



- Each work-item can access a dedicated region of **local memory** accessible to all work-items in a work-group
- A work-item cannot access the local memory of another workgroup

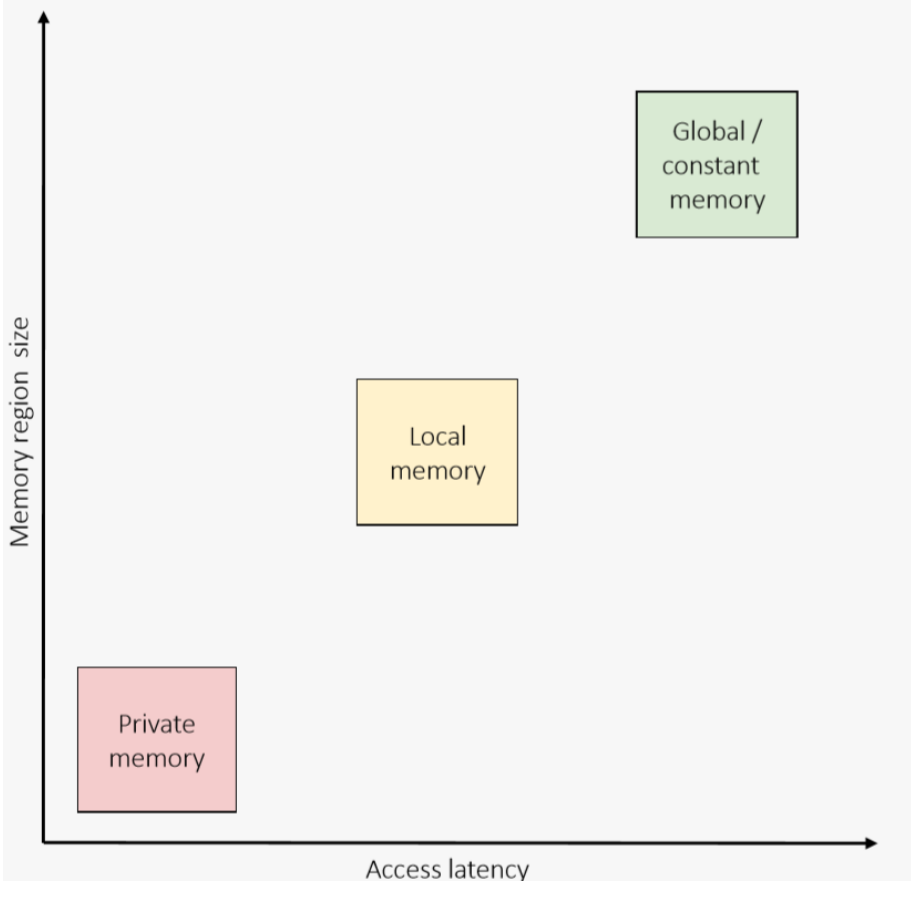
SYCL MEMORY MODEL



- Each work-item can access a single region of **global memory** that's accessible to all work-items in a ND-range
- Each work-item can also access a region of global memory reserved as **constant memory**, which is read-only

SYCL MEMORY MODEL

- Each memory region has a different size and access latency
- Global / constant memory is larger than local memory and local memory is larger than private memory
- Private memory is faster than local memory and local memory is faster than global / constant memory



EXPRESSING PARALLELISM

```
q.parallel_for<kernel>(range<1>(1024),
  [=](id<1> idx){
    /* kernel function code */
});
```

- Overload taking a **range** object specifies the global range, runtime decides local range
- An **id** parameter represents the index within the global range

---

```
q.parallel_for<kernel>(range<1>(1024),
  [=](item<1> item){
    /* kernel function code */
});
```

- Overload taking a **range** object specifies the global range, runtime decides local range
- An **item** parameter represents the global range and the index within the global range

---

```
q.parallel_for<kernel>(nd_range<1>(range<1>(1024),
  range<1>(32)),[=](nd_item<1> ndItem){
    /* kernel function code */
```

EXPRESSING PARALLELISM

```
auto global_range=sycl::range<2>(1024, 64);
auto wkgroup_sz=sycl::range<2>(64, 64);

// OK - local range divides global range
// component wise
auto my_nd = sycl::ndrange(global_range, wkgroup_sz);

q.parallel_for<kernel>(my_nd,[=](nd_item<1> ndItem){
    /* kernel function code */
});
```

```
auto global_range=sycl::range<2>(1000);
auto wkgroup_sz=sycl::range<2>(64);

// Not OK - local range doesn't divide divide
// global range component-wise
auto my_nd = sycl::ndrange(global_range, wkgroup_sz);

q.parallel_for<kernel>(my_nd,[=](nd_item<1> ndItem){
    /* kernel function code */
});
```

- On most hardware, `global_range[i]` must be a multiple of `local_range[i]`.
- For Nvidia hardware, workgroup sizes are best chosen from 8, 16, 32, 64, 128, 256, 512, 1024.

USING LOCAL MEMORY

```
q.submit([&](sycl::handler &cgh) {

  // Local memory is declared using accessors
  // template parameter
  // sycl::target::local
```

USING LOCAL MEMORY

```
q.submit([&](sycl::handler &cgh) {

  // Local memory is declared using accessors
  // with the template parameter
  // sycl::access::target::local
  sycl::accessor<T, 1,
    sycl::access::mode::read_write,
    sycl::access::target::local>
    local_mem(sycl::range<1>(local_mem_sz),
        cgh);

  cgh.parallel_for(my_ndrange, my_depEvs, [=](sycl::nd_item

          local_mem[5] = /* */

  }
  });
});
```

- You can treat accessors like pointers from within kernels. Use the [ ] operator.

ND_ITEM MEMBER FUNCTIONS

```
q.submit([&](sycl::handler &cgh) {

  // Local memory is declared using accessors
  // with the template parameter
  // sycl::access::target::local
  sycl::accessor<T, 1,
    sycl::access::mode::read_write,
    sycl::access::target::local>
    local_mem(sycl::range<1>(local_mem_sz),
        cgh);

  cgh.parallel_for(my_ndrange, my_depEvs, [=](sycl::nd_item

          // ND item member functions
          auto globalIdx = i.get_global_linear_id();
          auto localIdx = i.get_local_linear_id();
          auto groupIdx = i.get_local_linear_id();

          local_mem[localIdx] = /* */

          i.barrier();

  }
  });
});
```

- Some useful member functions of `nd_item` include:
  - `get_global_linear_id(`
  - `get_local_linear_id()`
  - `get_group_linear_id()`
  - `barrier()`

QUESTIONS

EXERCISE

Code_Exercises/Exercise_04_ND_Range_Kernel/source.cpp

Implement a SYCL application that will reverse the order of an array using `parallel_for`, with an ND range and local memory.