SYCL Academy

DATA PARALLELISM

LEARNING OBJECTIVES

- Learn about task parallelism and data parallelism
- Learn about the SPMD model for describing data parallelism
- Learn about SYCL execution and memory models
- Learn about enqueuing kernel functions with `parallel_for`

TASK VS DATA PARALLELISM

- **Task parallelism** is where you have several, possibly distinct tasks executing in parallel.
  - In task parallelism you generally optimize for latency.
- **Data parallelism** is where you have the same task being performed on multiple elements of data.
  - In data parallelism you generally optimize for throughput.

VECTOR PROCESSORS

- Many processors are vector processors, which means they can naturally perform data parallelism.
  - GPUs are designed to be parallel.
  - CPUs have SIMD instructions which perform the same instruction on a number elements of data.

SPMD MODEL FOR DESCRIBING DATA PARALLELISM

Sequential CPU code

```
void calc(const int in[], int out[]) {
  // all iterations are run in the same
  // thread in a loop
  for (int i = 0; i < 1024; i++){
    out[i] = in[i] * in[i];
  }
}

// calc(...) is invoked just once and all
// iterations are performed inline
calc(in, out);
```

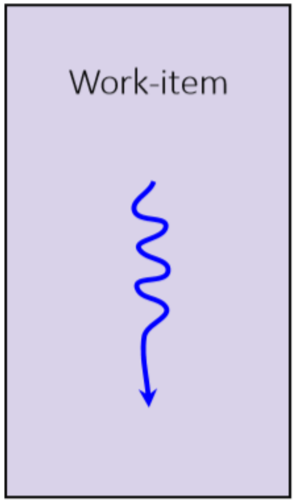
Parallel SPMD code

```
void calc(const int in[], int out[], int id) {
  // function is described in terms of
  // a single iteration
  out[id] = in[id] * in[id];
}

// parallel_for invokes calc(...) multiple
// times in parallel
parallel_for(calc, in, out, 1024);
```

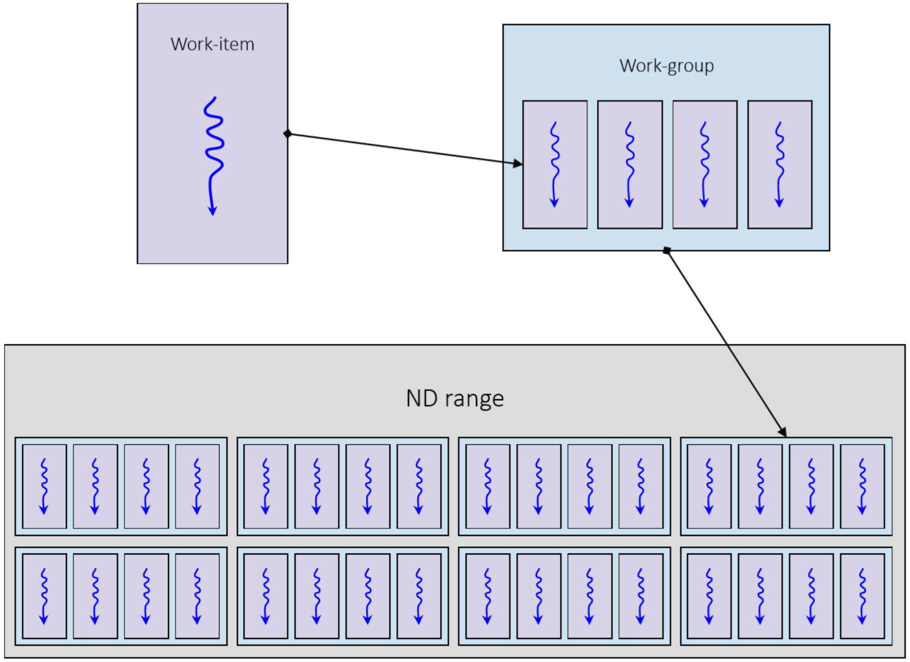
SYCL EXECUTION MODEL

- In 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

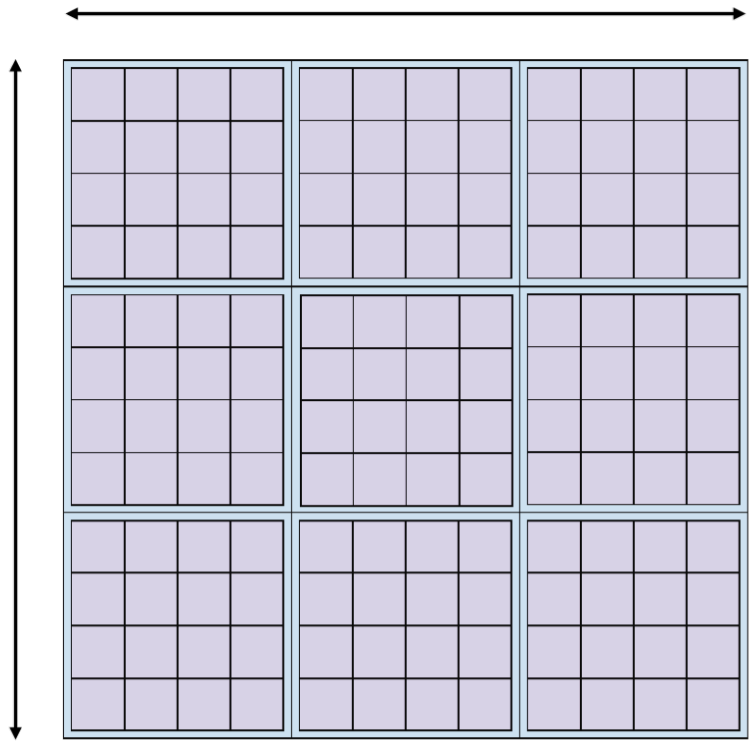
- SYCL kernel functions are invoked within an **nd-range**
- An nd-range has a number of work-groups and subsequently a number of work-items
- Work-groups always have the same number of work-items



SYCL EXECUTION MODEL

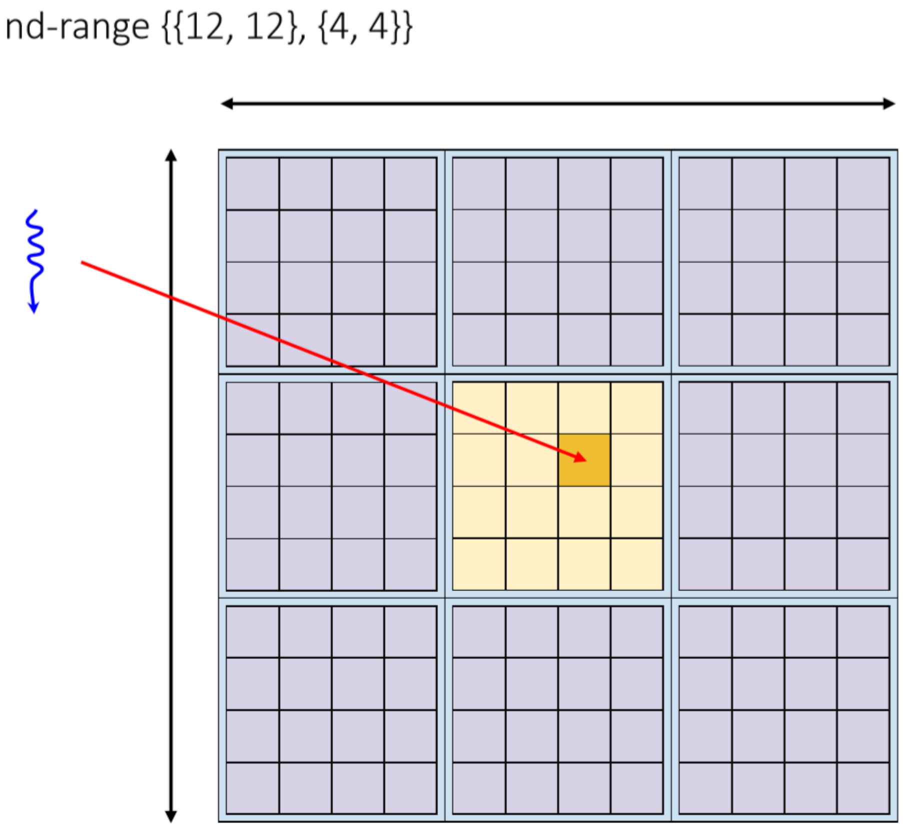
- The nd-range describes an **iteration space**: how it is composed in terms of work-groups and work-items
- An nd-range can have 1, 2 or 3 dimensions
- An nd-range has two components
  - The **global-range** describes the total number of work-items in each dimension
  - The **local-range** describes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

nd-range {{12, 12}, {4, 4}}



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**: {5, 6}
    - **Group range**: {3, 3}
    - **Group id**: {1, 1}
    - **Local range**: {4, 4}
    - **Local id**: {1, 2}

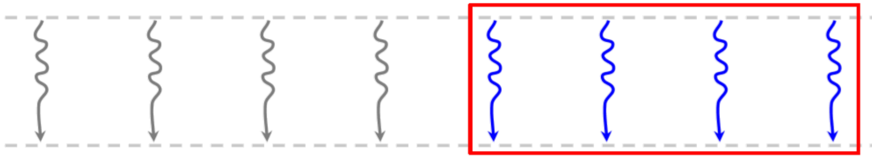


SYCL EXECUTION MODEL

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

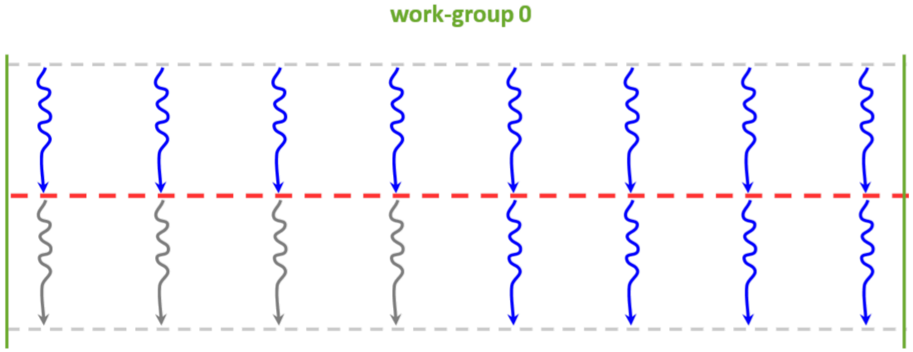
SYCL EXECUTION MODEL

- Multiple work-items will generally execute concurrently
- On vector hardware this is often done in lock-step, with neighboring work-items executing the same instruction at all times
- 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 work-groups are executed in is implementation defined



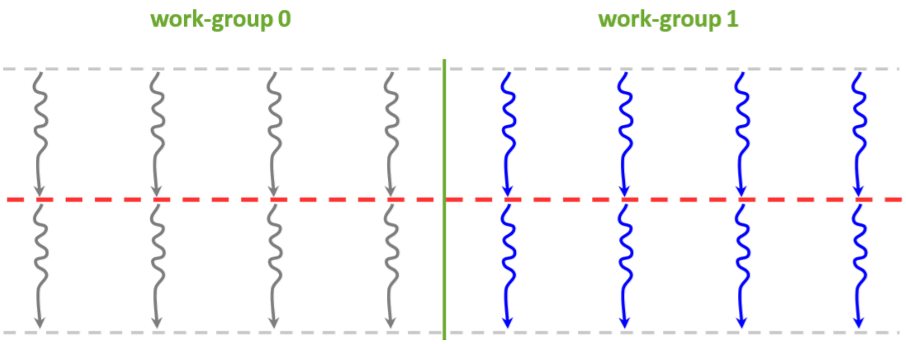
SYCL EXECUTION MODEL

- 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



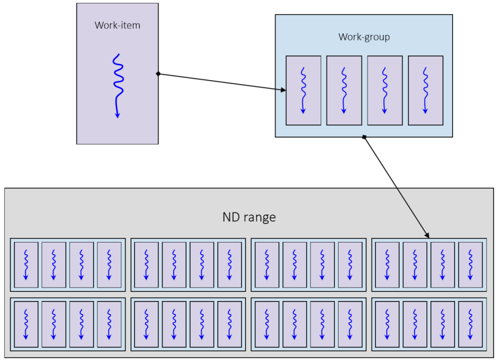
SYCL EXECUTION MODEL

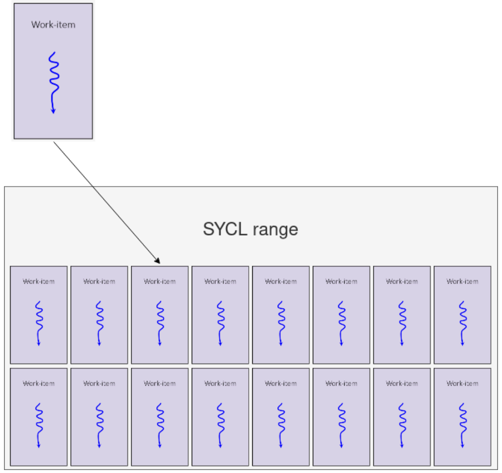
- SYCL does not support synchronizing across all work-items in the nd-range
- The only way to do this is to split the computation into separate SYCL kernel functions



SYCL EXECUTION MODEL

- SYCL also provides a simplified execution model with `sycl::range` in place of `sycl::nd_range`
- Caller only provides the global range
- Local range is decided by the runtime and cannot be inspected
- No synchronization is possible between work items
- Useful for simple problems which don't require synchronization, local memory and ultimate performance
    - Runtime may not always have enough information to choose the best-performing size





PARALLEL_FOR

```
cgh.parallel_for<my_kernel>(sycl::nd_range{{1024, 16}, {32, 4}},
                            [=](sycl::nd_item<2> item){
  // SYCL kernel function is executed
  // on a range of work-items
});
```

- In SYCL, kernel functions can be enqueued to execute over a range of work-items using `sycl::handler::parallel_for`
- The first argument to `parallel_for` is an `nd_range` or a `range` which describes the iteration space over which the kernel is to be executed
- The kernel function has to take an `nd_item` or `item`, respectively, as the parameter (or any type they can be implicitly converted to, commonly from `item` to `id`)

EXPRESSING PARALLELISM

```
cgh.parallel_for<kernel>((sycl::nd_range<1>{1024,
  [=](sycl::nd_item<1> ndItem){
    /* kernel function code */
    id globalId = ndItem.get_global_id();
    id localId = ndItem.get_local_id();
});
```

- Overload taking an `nd_range` object specifies the global and local range
- An `nd_item` parameter represents the global and local range and index

```
cgh.parallel_for<kernel>(sycl::range<1>{1024},
  [=](sycl::item<1> item){
    /* kernel function code */
    id globalId = item.get_id();
});
```

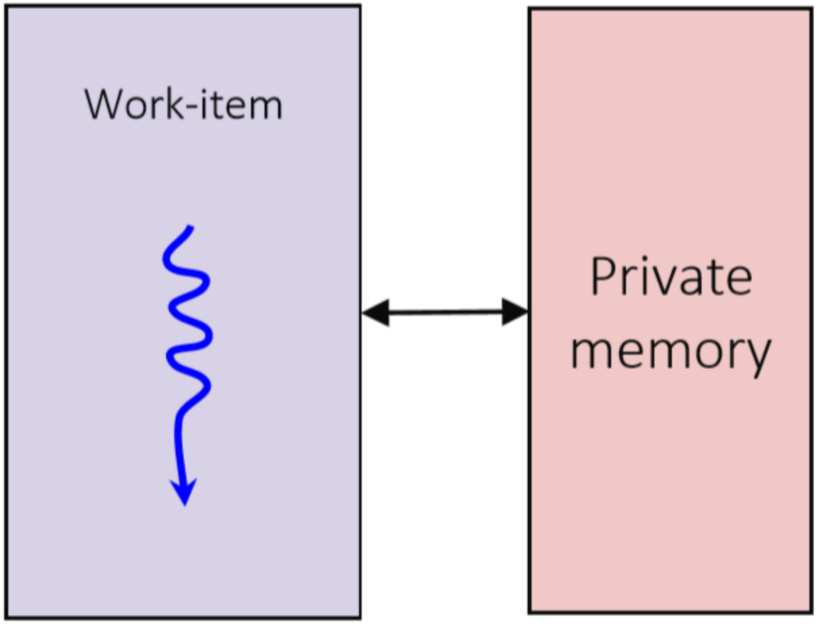
- Overload taking a `range` object specifies the global range, runtime decides local range
- An `item` parameter represents the global range and the index within the global range

```
cgh.parallel_for<kernel>(sycl::range<1>{1024},
  [=](sycl::id<1> globalId){
    /* kernel function code */
});
```

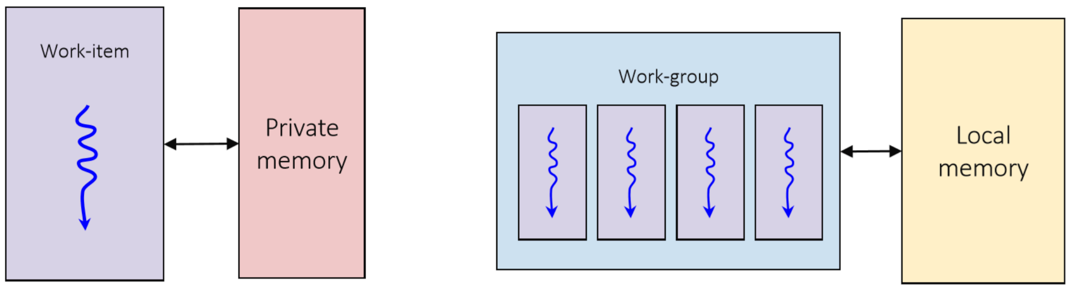
- Overload taking a `range` object specifies the global range, runtime decides local range
- An `id` parameter represents the index within the global range

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

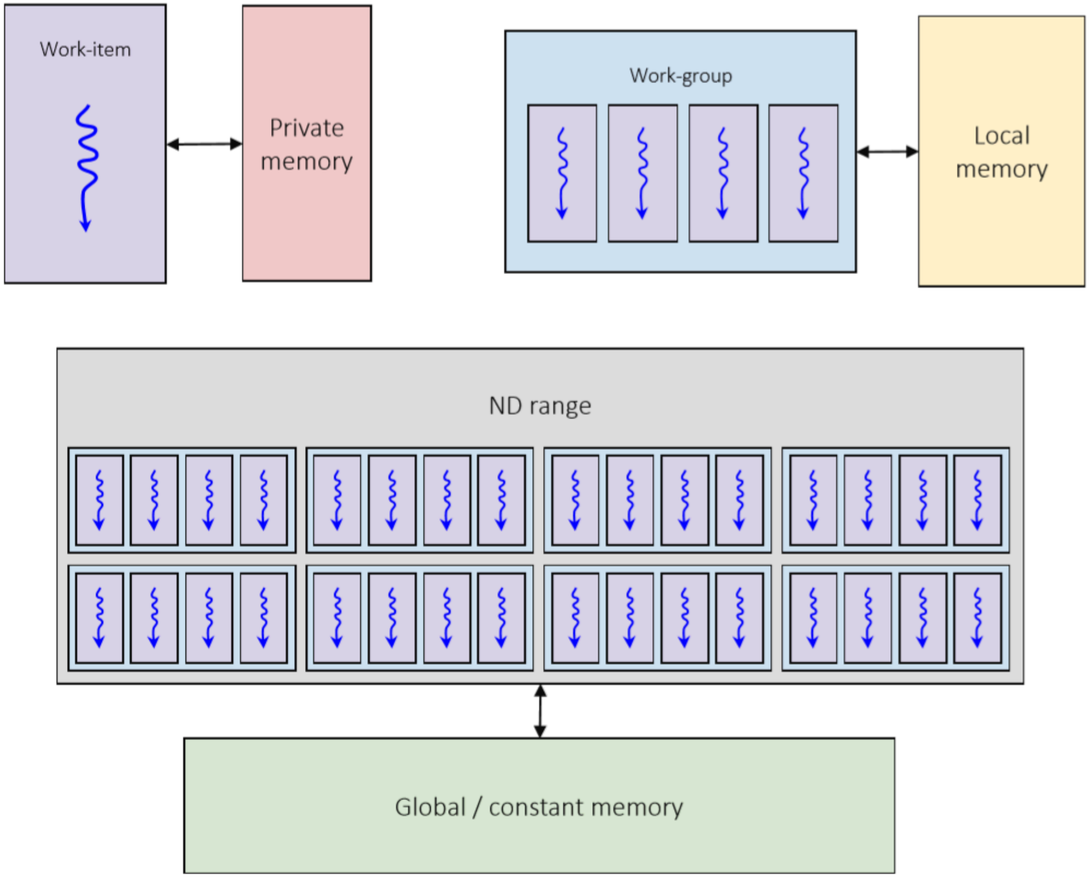


SYCL MEMORY MODEL



- 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 work-group

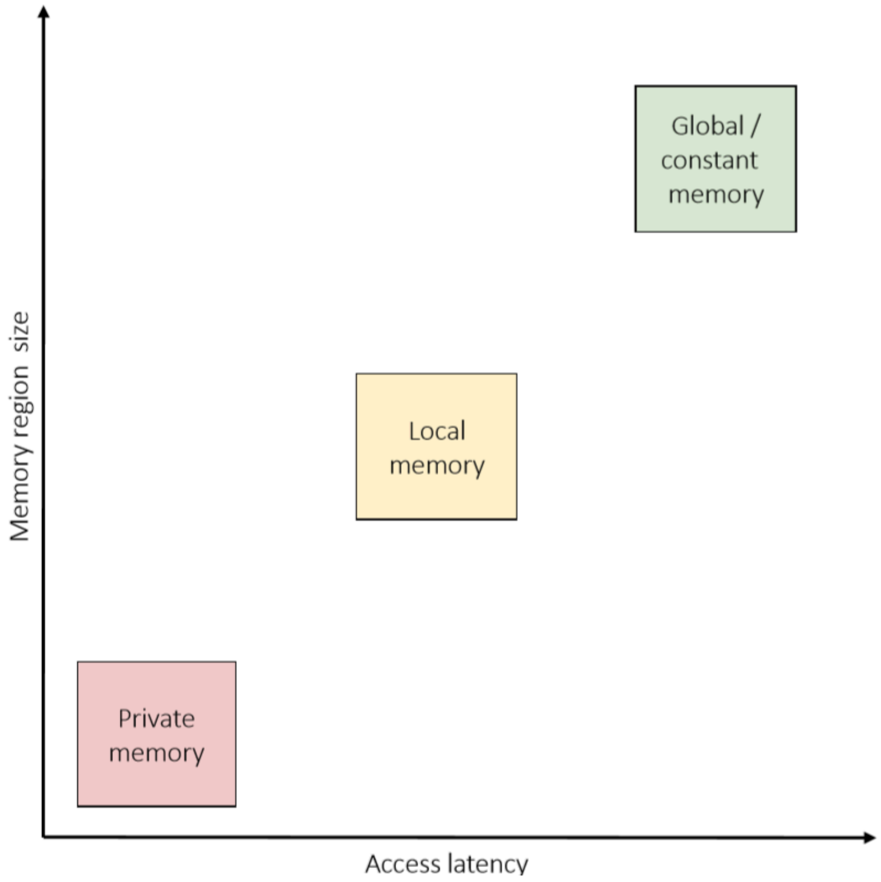
SYCL MEMORY MODEL



- Each work-item can access all of the **global memory**

SYCL MEMORY MODEL

- Each memory region has a different size and access latency
- Global 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 memory



ACCESSING DATA WITH ACCESSORS

- There are a few different ways to access the data represented by an accessor
  - The subscript operator can take an **id**
    - Must be the same dimensionality of the accessor
    - For dimensions > 1, linear address is calculated in row major
- Nested subscript operators can be called for each dimension taking a **size_t**
  - E.g. a 3-dimensional accessor: acc[x][y][z] = …
- A pointer to memory can be retrieved by calling **get_pointer**
  - This returns a raw pointer to the data

ACCESSING DATA WITH ACCESSORS

```
sycl::buffer<float, 1> bufA(dA.data(), sycl::range<1>(dA.size
sycl::buffer<float, 1> bufB(dB.data(), sycl::range<1>(dB.size
sycl::buffer<float, 1> bufO(dO.data(), sycl::range<1>(dO.size

gpuQueue.submit([&](sycl::handler &cgh){
  sycl::accessor inA{bufA, cgh, sycl::read_only};
  sycl::accessor inB{bufB, cgh, sycl::read_only};
  sycl::accessor out{bufO, cgh, sycl::write_only};
  cgh.parallel_for<add>(sycl::range<1>(dA.size()),
    [=](sycl::id<1> i){
    out[i] = inA[i] + inB[i];
  });
});
```

- Here we access the data of the `accessor` by passing in the `id` passed to the SYCL kernel function.

ACCESSING DATA WITH ACCESSORS

```
sycl::buffer<float, 1> bufA(dA.data(), sycl::range<1>(dA.size
sycl::buffer<float, 1> bufB(dB.data(), sycl::range<1>(dB.size
sycl::buffer<float, 1> bufO(dO.data(), sycl::range<1>(dO.size

gpuQueue.submit([&](handler &cgh){
  sycl::accessor inA{bufA, cgh, sycl::read_only};
  sycl::accessor inB{bufB, cgh, sycl::read_only};
  sycl::accessor out{bufO, cgh, sycl::write_only};
  cgh.parallel_for<add>(rng, [=](sycl::item<3> i){
    auto ptrA = inA.get_pointer();
    auto ptrB = inB.get_pointer();
    auto ptrO = out.get_pointer();
    auto linearId = i.get_linear_id();

    ptrA[linearId] = ptrB[linearId] + ptrO[linearId];
  });
});
```

- Here we retrieve the underlying pointer for each of the `accessors`.
- We then access the pointer using the linearized `id` by calling the `get_linear_id` member function on the `item`.
- Again this linearization is calculated in row-major order.

QUESTIONS

EXERCISE

Code_Exercises/Data_Parallelism/source.cpp

Implement a SYCL application using `parallel_for` to add two arrays of values

- Use buffers and accessors to manage data
- Try the `sycl::range` and `sycl::nd_range` variants