



Hands-On HPC Application Development Using C++ and SYCL

James Reinders, Phuong Nguyen, Thomas Applencourt, Rod Burns, Alastair Murray



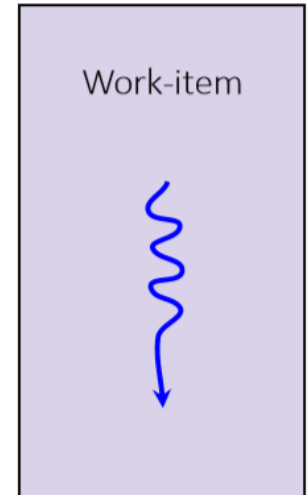
ND RANGE KERNELS

LEARNING OBJECTIVES

- Learn about the SYCL execution and memory model
- Learn how to enqueue an nd-range kernel function

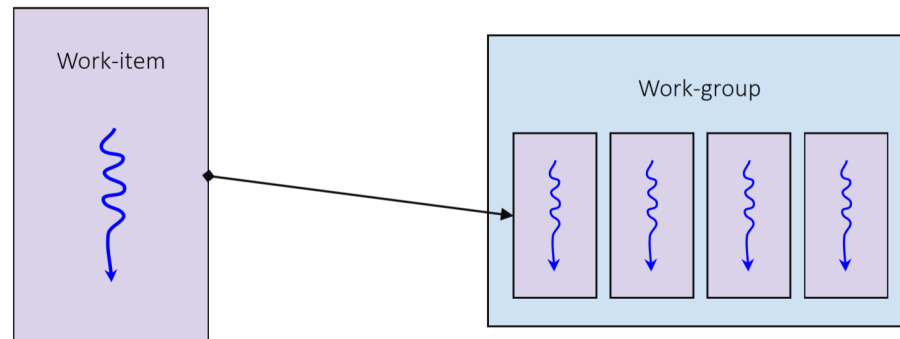
SYCL EXECUTION MODEL

- 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



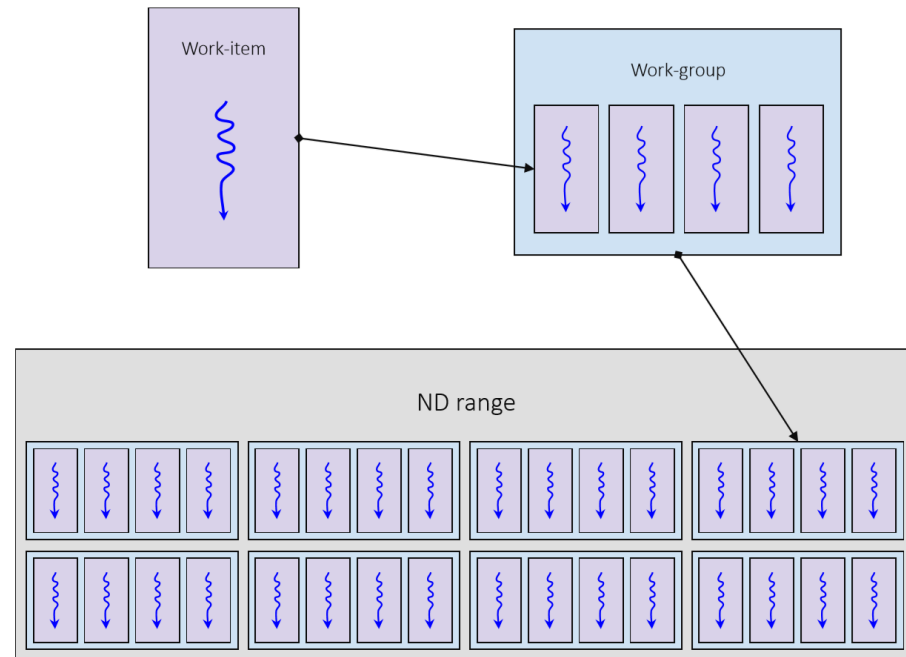
SYCL EXECUTION MODEL

- 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

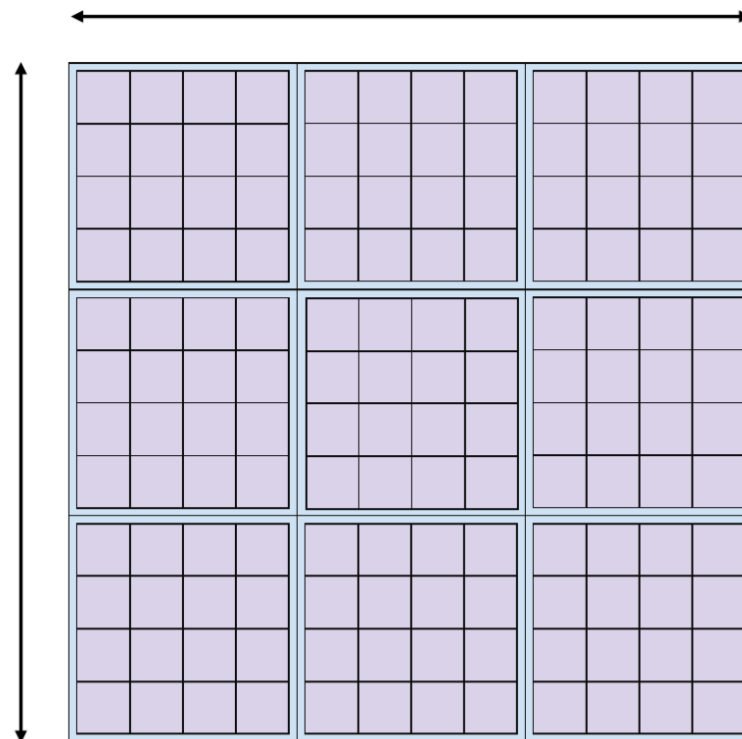
- SYCL kernel functions are invoked within an **nd-range**
- An nd-range has a number of work-groups and subsequently a number of work-items
- Work-groups always have the same number of work-items



SYCL EXECUTION MODEL

- The nd-range describes an **iteration space**: how it is composed in terms of work-groups and work-items
- An nd-range can be 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

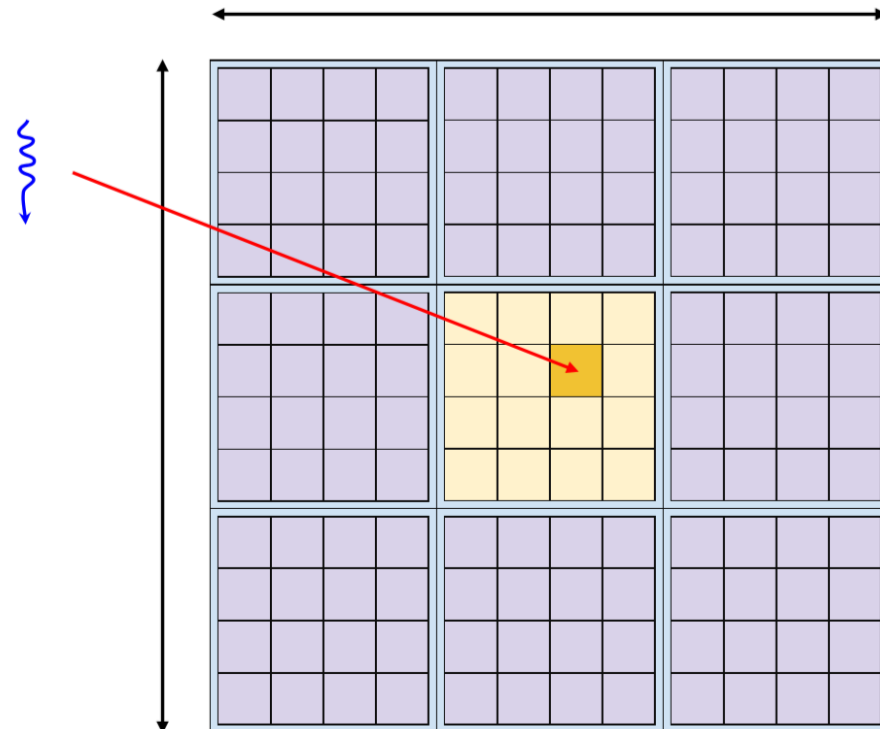
nd-range $\{\{12, 12\}, \{4, 4\}\}$



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:** $\{1, 2\}$

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



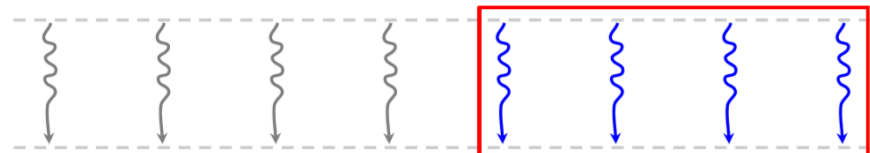
SYCL EXECUTION MODEL

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



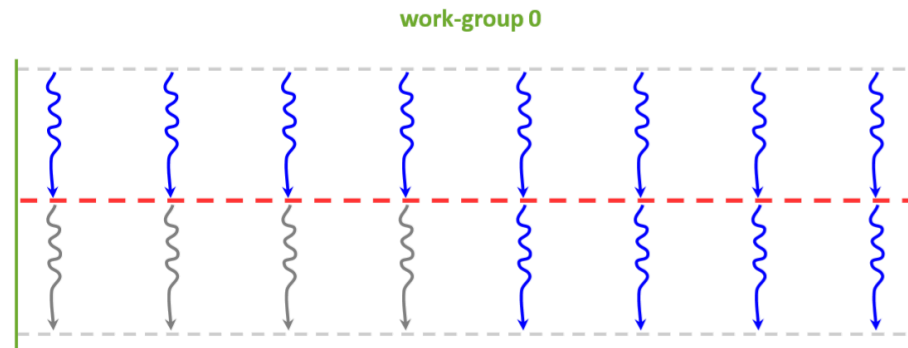
SYCL EXECUTION MODEL

- 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 work-groups are executed in is implementation defined



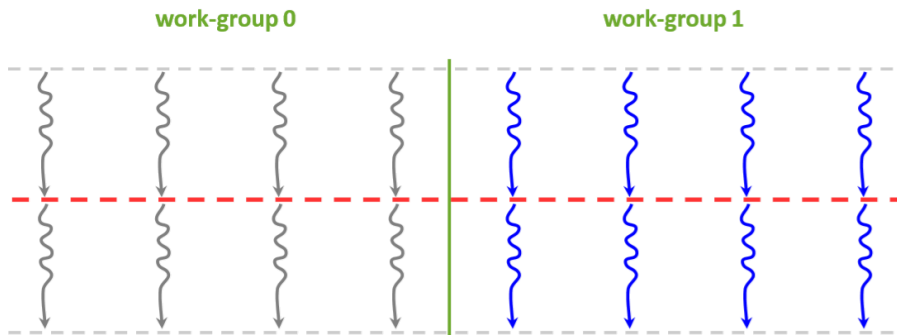
SYCL EXECUTION MODEL

- 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



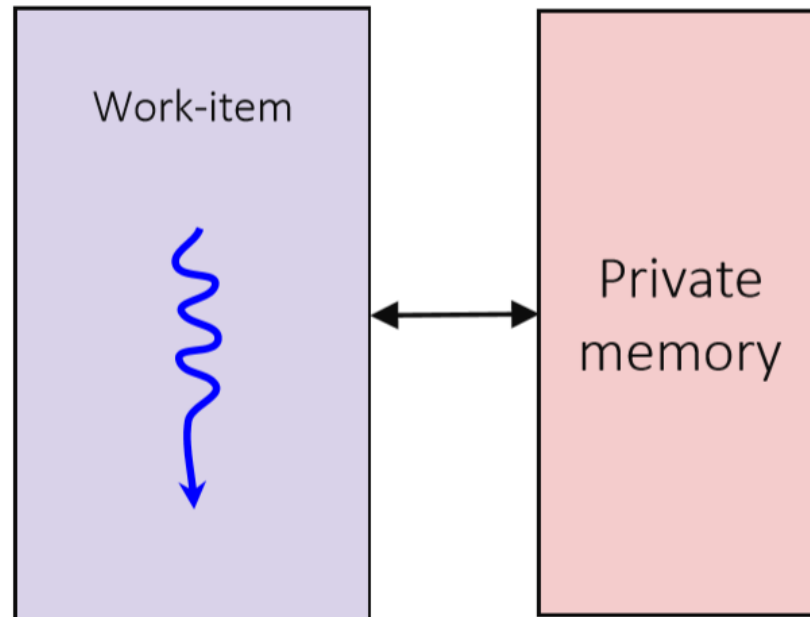
SYCL EXECUTION MODEL

- 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

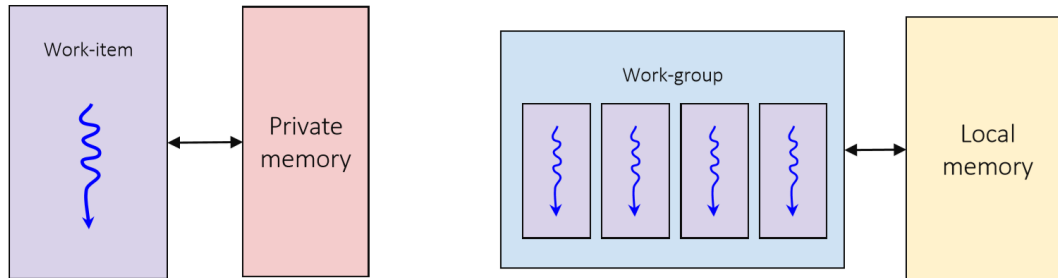


SYCL MEMORY MODEL

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

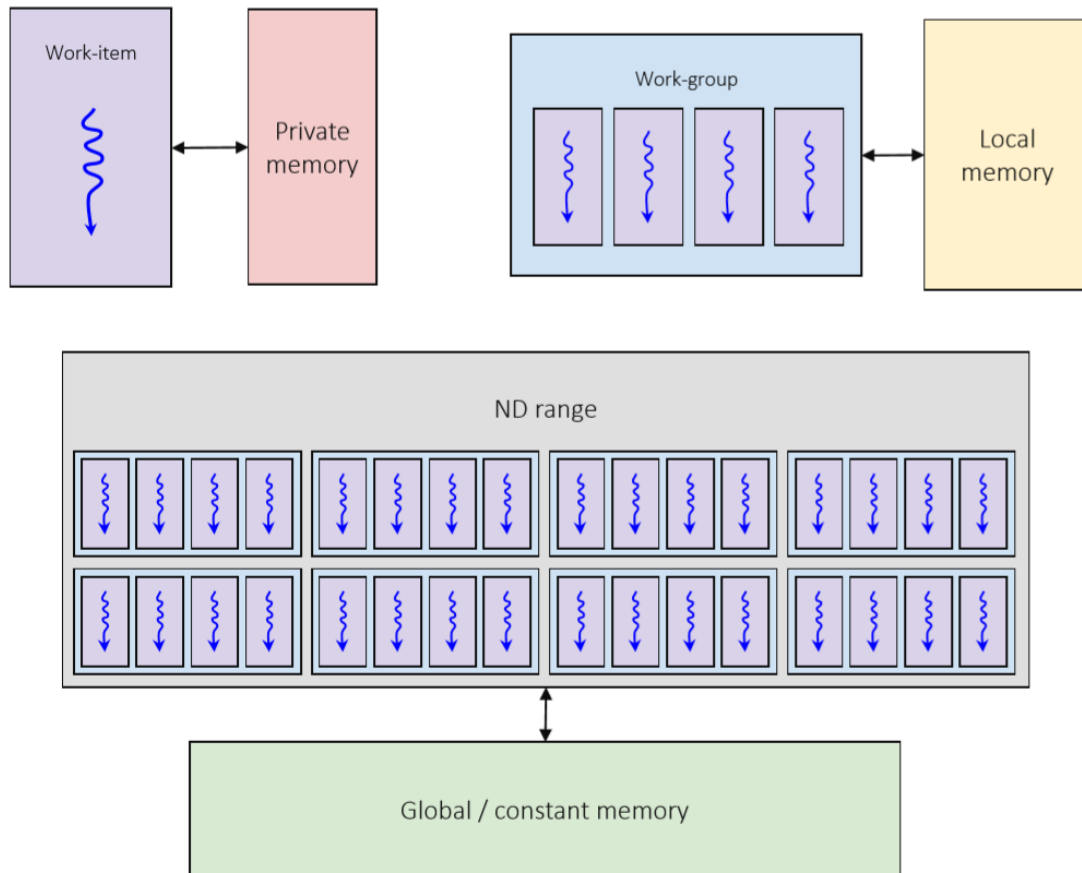


SYCL MEMORY MODEL



- 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

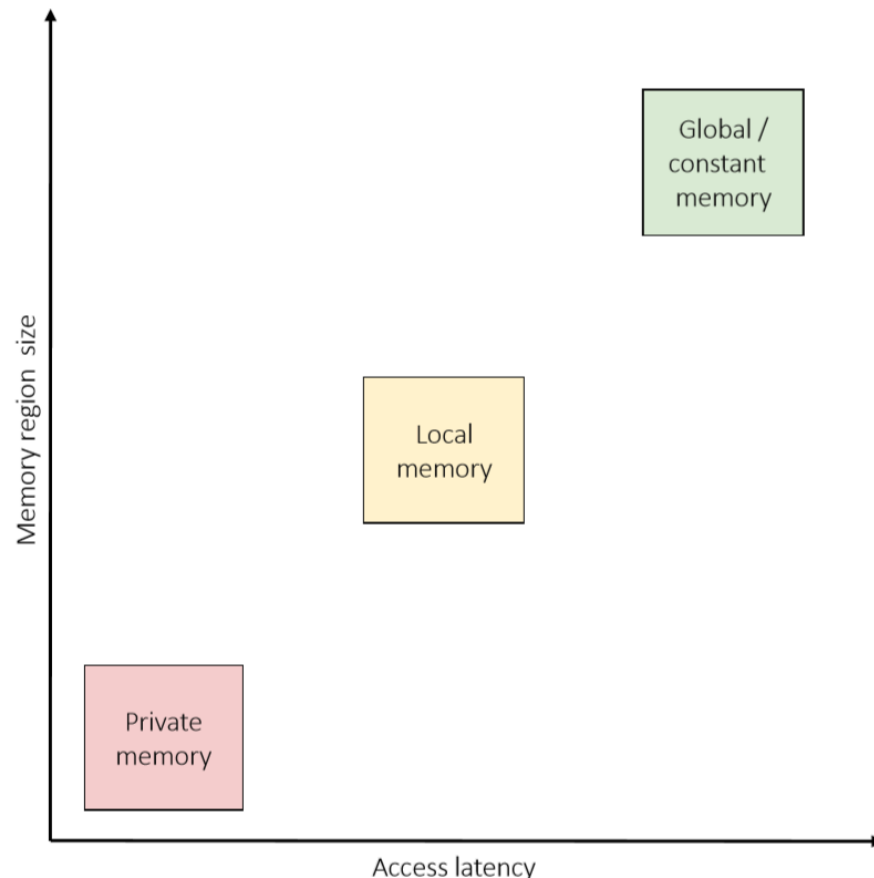
SYCL MEMORY MODEL



- Each work-item can access 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

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

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

```
cgh.parallel_for<kernel>(nd_range<1>(range<1>(1024),  
    range<1>(32)), [=](nd_item<1> ndItem){  
        /* 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
-
- 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
-
- Overload taking an **nd_range** object specifies the global and local range
 - An **nd_item** parameter represents the global and local range and

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

```
buffer<float, 1> bufA(dA.data(), range<1>(dA.size()));
buffer<float, 1> bufB(dB.data(), range<1>(dB.size()));
buffer<float, 1> bufO(dO.data(), 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>(range<1>(dA.size()),
        [=](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

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gpuQueue.submit([&](handler &cgh){
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    sycl::accessor inB{bufB, cgh, sycl::read_only};
    sycl::accessor out{bufO, cgh, sycl::write_only};
    cgh.parallel_for<add>(rng, [=](id<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/Exercise_14_ND_Range_Kernel/source

Implement a SYCL application that will perform a vector add using `parallel_for`, adding multiple elements in parallel.

