A QUICK INTRODUCTION TO SYCL

LEARNING OBJECTIVES

- Quick SYCL introduction
- Writing a one-page application

WHAT IS SYCL?

SYCL is a single source, high-level, standard C++ programming model, that can target a range of heterogeneous platforms

WHAT IS SYCL?

A first example of SYCL code.

```
#include <sycl/sycl.hpp>
#include <vector>

int main() {
    constexpr static size_t N{10000};
    std::vector<float> a(N, 1.0f);
    std::vector<float> b(N, 2.0f);
    std::vector<float> c(N, 0.0f);

    sycl::queue q{};

    {
        sycl::buffer buf_a{a};
        sycl::buffer buf_b{b};
        sycl::buffer buf_c{c};
        q.submit([&](sycl::handler& h){
            sycl::accessor acc_a{buf_a, h, sycl::read_write};
            sycl::accessor acc_b{buf_b, h, sycl::read_only};
            sycl::accessor acc_c{buf_c, h, sycl::write_only, sycl::no_init};
            h.parallel_for<class my_kernel>(N, [=](sycl::id<1> id){
                acc_a[id] += acc_b[id];
                acc_c[id] = 2.0f * acc_a[id];
            });
        }).wait();
    }

    for (float x : c) {std::cout << x << " ";}
    std::cout << std::endl;

    return 0;
}
```

Device management with queues

Memory management with buffers

Submit a work unit to a queue

Execute code on a device

SYCL KEY CONCEPTS

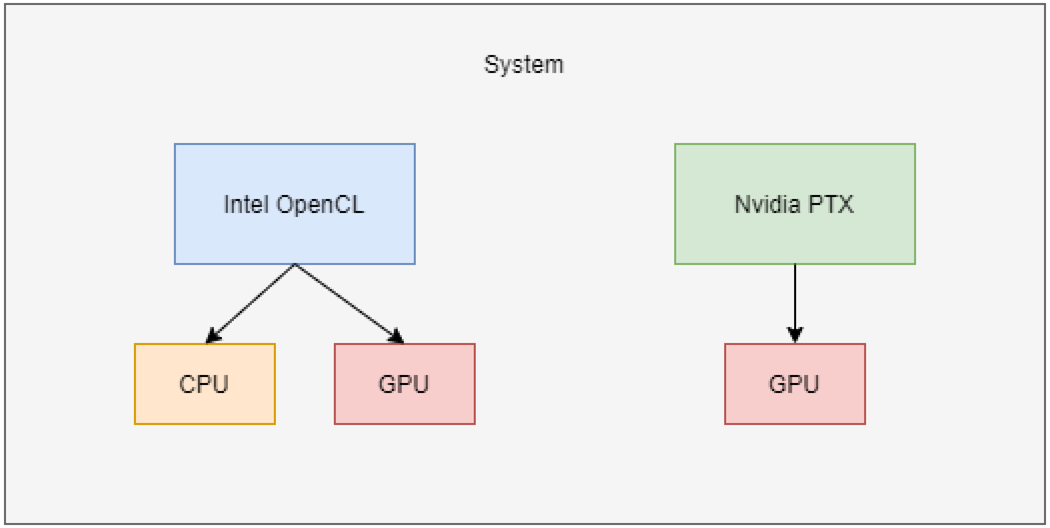
- SYCL is a C++-based programming model:
    - Device code and host code exist in the same file
    - Device code can use templates and other C++ features
    - Designed with "modern" C++ in mind
- SYCL provides high-level abstractions over common boilerplate code
    - Platform/device selection
    - Buffer creation and data movement
    - Kernel function compilation
    - Dependency management and scheduling

SYCL SYSTEM TOPOLOGY

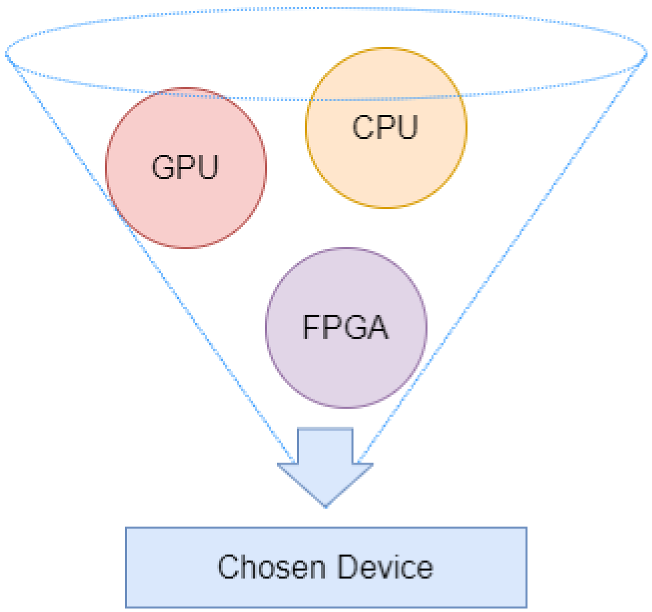
- A SYCL application can execute work across a range of different heterogeneous devices.
- The devices that are available in any given system are determined at runtime through topology discovery.

PLATFORMS AND DEVICES

- The SYCL runtime will discover a set of platforms that are available in the system.
  - Each platform represents a backend implementation such as Intel OpenCL or Nvidia CUDA.
- The SYCL runtime will also discover all the devices available for each of those platforms.
  - CPU, GPU, FPGA, and other kinds of accelerators.



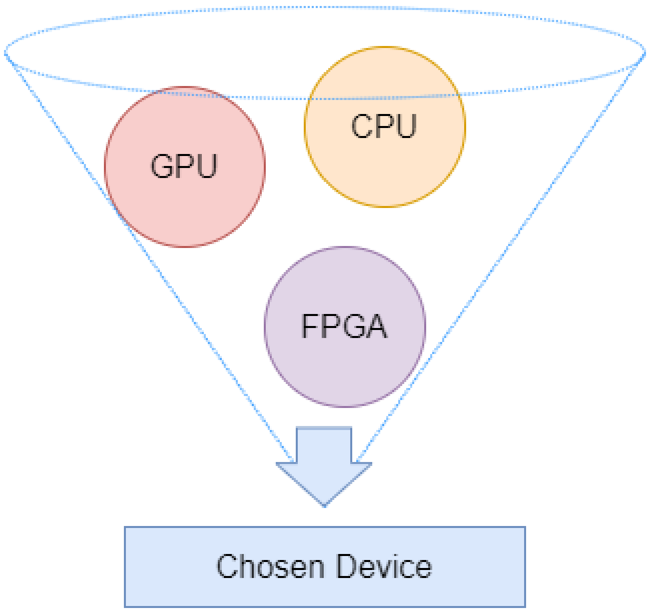
QUERYING WITH A DEVICE SELECTOR



- To simplify the process of traversing the system topology SYCL provides device selectors.
- A device selector is is a callable C++ object which defines a heuristic for scoring devices.
- SYCL provides a number of standard device selectors, e.g. `default_selector_v`, `gpu_selector_v`, etc.
- Users can also create their own device selectors.

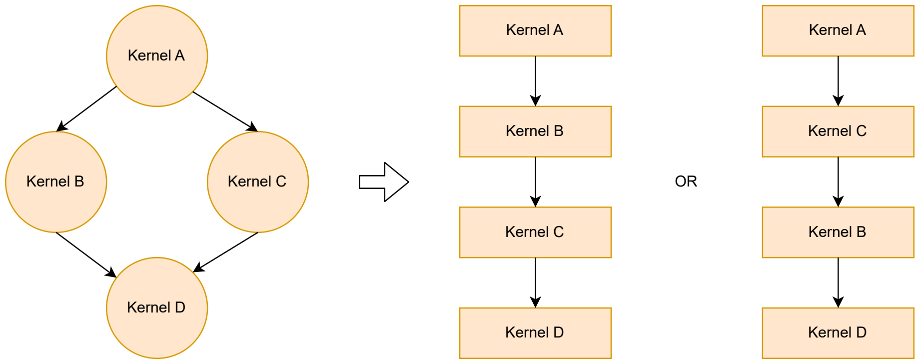
QUERYING WITH A DEVICE SELECTOR

```
auto gpuDevice = device(gpu_selector_v);
```



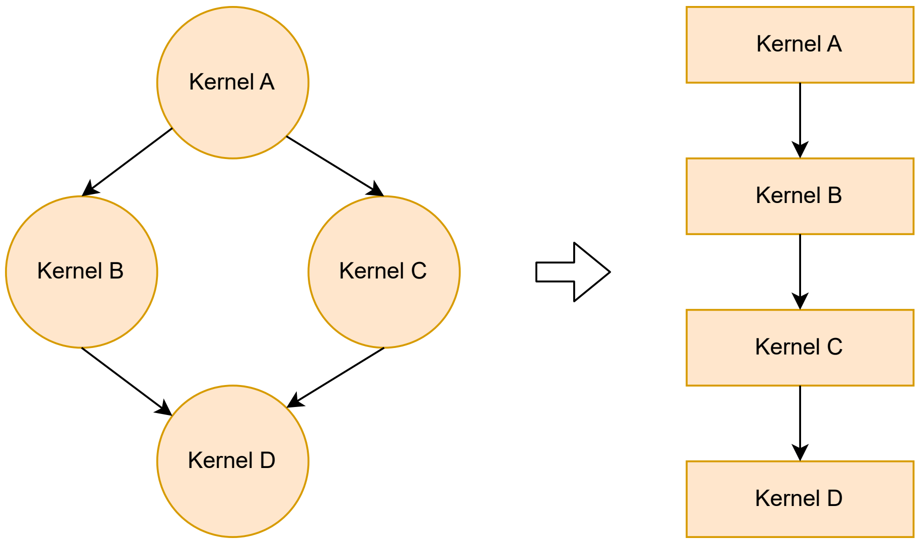
- A device selector takes a parameter of type `const device &` and gives it a "score".
- Used to query all devices and return the one with the highest "score".
- A device with a negative score will never be chosen.

SYCL QUEUES



- Commands are submitted to devices in SYCL by means of a Queue
- SYCL queues are by default out-of-order.
- This means commands are allowed to be overlapped, re-ordered, and executed concurrently, providing dependencies are honoured to ensure consistency.

IN-ORDER EXECUTION



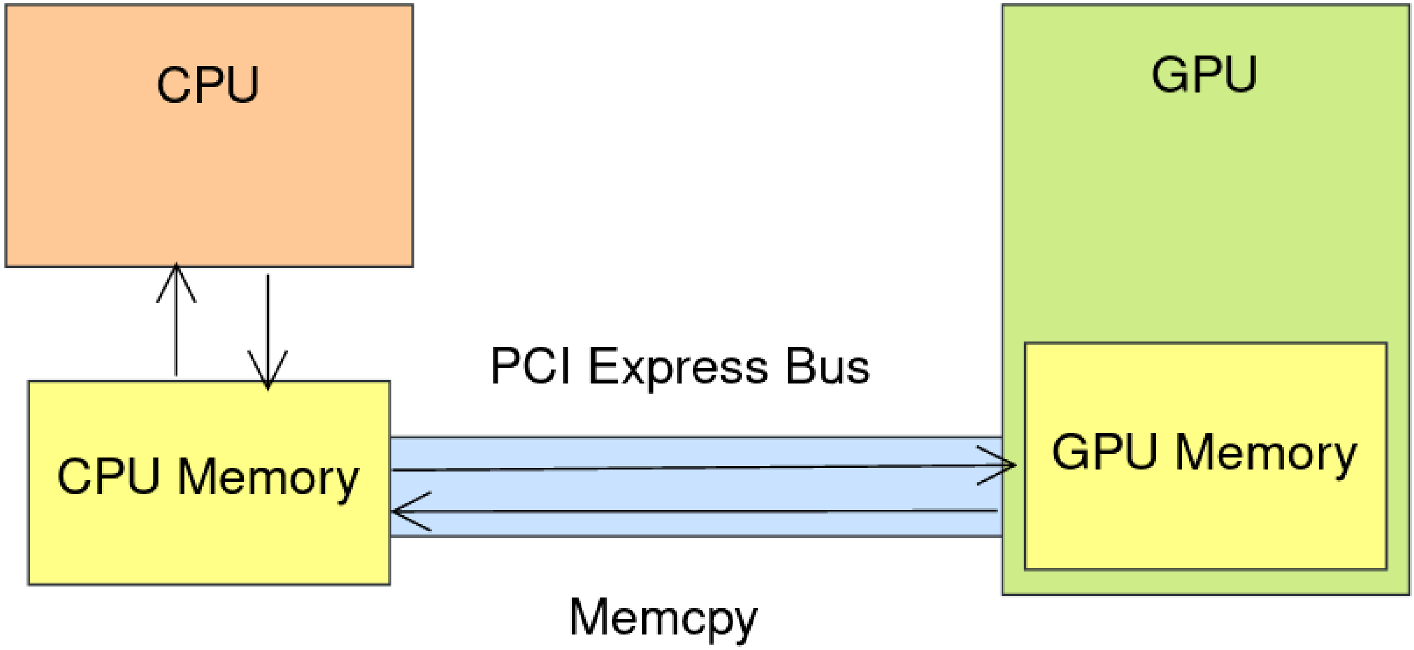
- SYCL queues can be configured to be in-order.
- This mean commands must execute strictly in the order they were enqueued.

MEMORY MODELS

- In SYCL there are two models for managing data:
  - The buffer/accessor model.
  - The USM (unified shared memory) model.
- Which model you choose can have an effect on how you enqueue kernel functions.

CPU AND GPU MEMORY

- A GPU has its own memory, separate to CPU memory.
- In order for the GPU to use memory from the CPU, the following actions must take place (either explicitly or implicitly):
  - Memory allocation on the GPU.
  - Data migration from the CPU to the allocation on the GPU.
  - Some computation on the GPU.
  - Migration of the result back to the CPU.

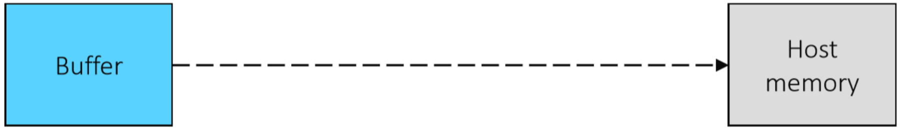

CPU
GPU
PCI Express Bus
CPU Memory
GPU Memory
Memcpy

SYCL BUFFERS & ACCESSORS

- The buffer/accessor model separates the storage and access of data
  - A SYCL buffer manages data across the host and any number of devices
  - A SYCL accessor requests access to data on the host or on a device for a specific SYCL kernel function
- Accessors are also used to access data within a SYCL kernel function
  - This means they are declared in the host code but captured by and then accessed within a SYCL kernel function

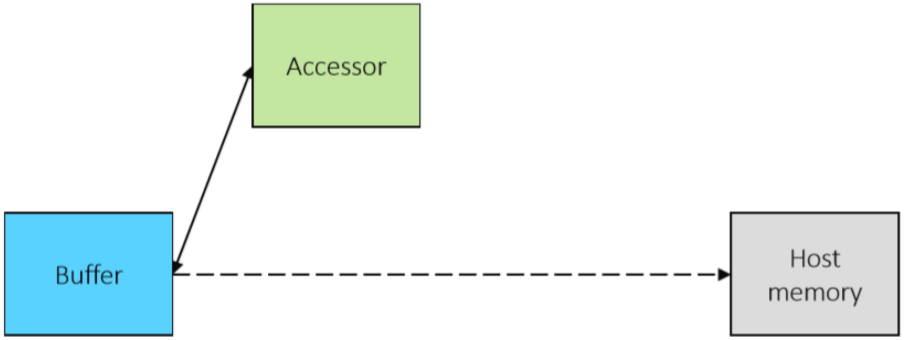
SYCL BUFFERS & ACCESSORS

- When a buffer object is constructed it will not allocate or copy to device memory at first
- This will only happen once the SYCL runtime knows the data needs to be accessed and where it needs to be accessed



SYCL BUFFERS & ACCESSORS

- Constructing an accessor specifies a request to access the data managed by the buffer
- There are a range of different types of accessor which provide different ways to access 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.

USM: MALLOC_DEVICE

```
void* malloc_device(size_t numBytes, const queue& syclQueue, const property_list &propList = {});

template <typename T>
T* malloc_device(size_t count, const queue& syclQueue,  const property_list &propList = {});
```

- A USM device allocation is performed by calling one of the `malloc_device` functions.
- Both of these functions allocate the specified region of memory on the `device` associated with the specified queue.
- The pointer returned is only accessible in a kernel function running on that `device`.
- Synchronous exception if the device does not have aspect::usm_device_allocations
- This is a blocking operation.

USM: FREE

```
void free(void* ptr, queue& syclQueue);
```

* In order to prevent memory leaks USM device allocations must be free by calling the `free` function.
* The queue must be the same as was used to allocate the memory.
* This is a blocking operation.

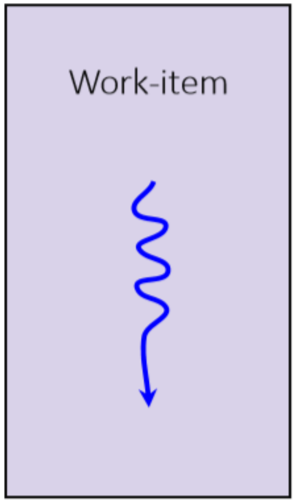
USM: MEMCPY

```
event queue::memcpy(void* dest, const void* src, size_t numBytes, const std::vector &depEvents);
```

- Data can be copied to and from a USM device allocation by calling the queue's `memcpy` member function.
- The source and destination can be either a host application pointer or a USM device allocation.
- This is an asynchronous operation enqueued to the queue.
- An `event` is returned which can be used to synchronize with the completion of copy operation.
- May depend on other events via `depEvents`

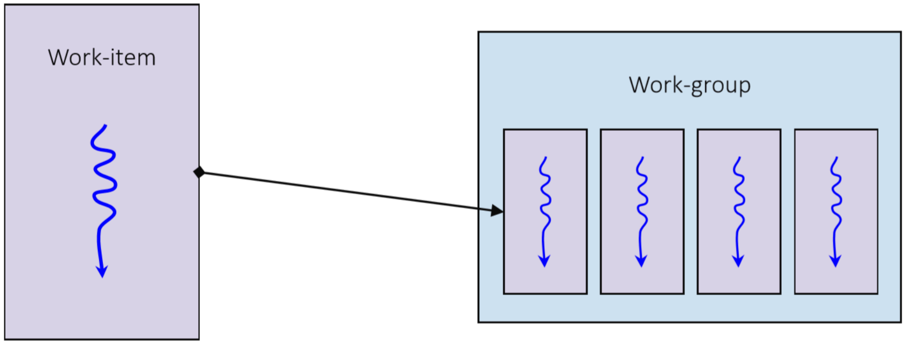
SYCL EXECUTION MODEL

- 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



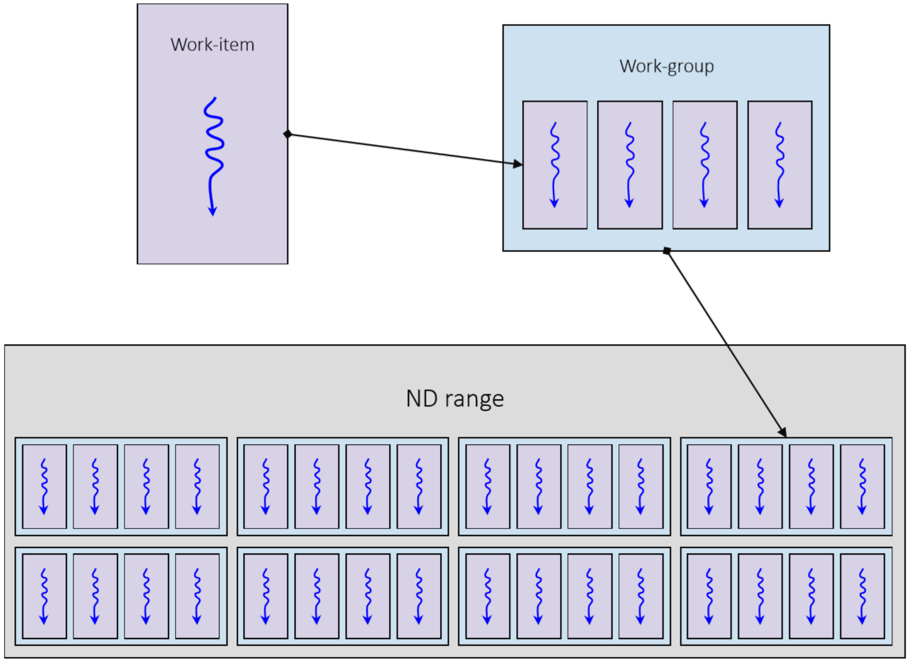
SYCL EXECUTION MODEL

- 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

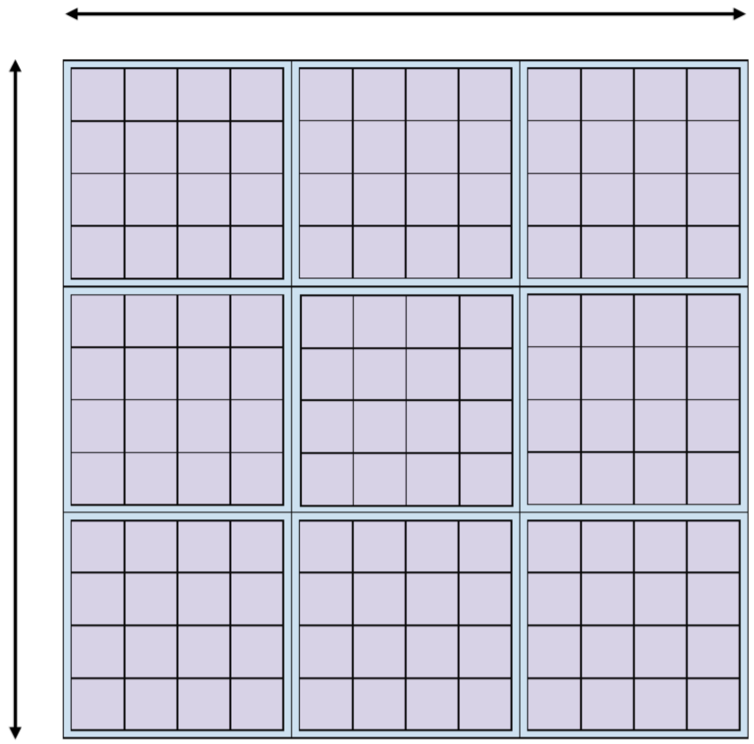
- SYCL kernel functions are invoked within an **nd-range**
- An nd-range has a number of work-groups and subsequently a number of work-items
- Work-groups always have the same number of work-items



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}}



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

SYCL KERNELS

- SYCL kernels (i.e. the device function the programmer wants executed) are expressed either as C++ function objects or lambdas.
- Comparing with other GPU paradigms, kernel arguments are either data members or lambda captures, respectively
- For function objects, the member function `operator()(sycl::id)` is the compute function, which is equivalent to the lambda style

```
// then add slides explaining the practical work and how to
// glue it all together from scratch
```

FUNCTION OBJECT

```
class MyKernel {
  sycl::accessor input_;
  float* output_;

  MyKernel(sycl::buffer buf, float* output, sycl::handler& h)
    : input{buf.get_access(h)}, output_{output} {}

  // const is required
  void operator()(sycl::item<1> i) const {
    ; // computation here
  }
};
```

The members are accessible on the device inside the function call operator.

LAMBDA FUNCTION

```
sycl::buffer buf = /* normal init */;
float * output = sycl::malloc_device(/* params */);

... queue submit as normal ...

auto acc = buf.get_access(h);
auto func = [=](sycl::item<1> i) {
  acc[i] = someVal;
  output[i.get_global_linear_id()] = someOtherVal;
});
handler.parallel_for(range, func);
```

The variables used implicitly are captured by value and are usable in the kernel.

SYCL KERNELS

- These forms are equivalent (as in normal C++) and which one to use depends on preference and use case
- Each instance of the kernel has a uniquely valued `sycl::item` describing its position in the iteration space as covered in "SYCL execution model"
- Can be used to index into accessors, pointers etc.

FIRST EXERCISE

- Goal: Learn to use different techniques for synchronizing commands and data
- The exercise README is in the "Code_Exercises/Asynchronous_Execution" folder

```
* In the "syclacademy/tree/isc25" page you can find links to the Compiler Explorer code
```

- Follow the guidelines in the README and comments in the source.cpp file or equivalent CE code

```
* There is a solution file in the repo and CE link, but only use it if you need to
```