MANAGING DATA

LEARNING OBJECTIVES

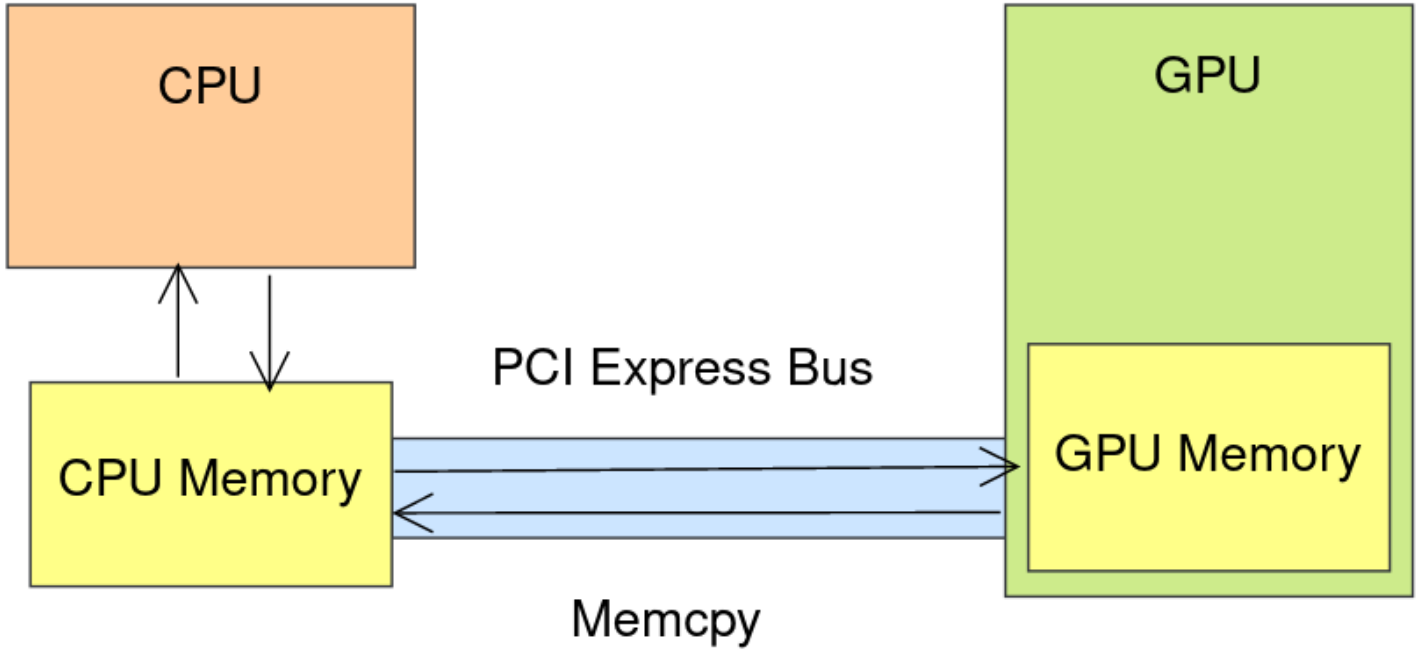
- Learn about the USM and buffer/accessor models for managing data
- Learn how to allocate, transfer and free memory using USM.
- Learn how a buffer synchronizes data
- Learn how to access data in a kernel function

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.

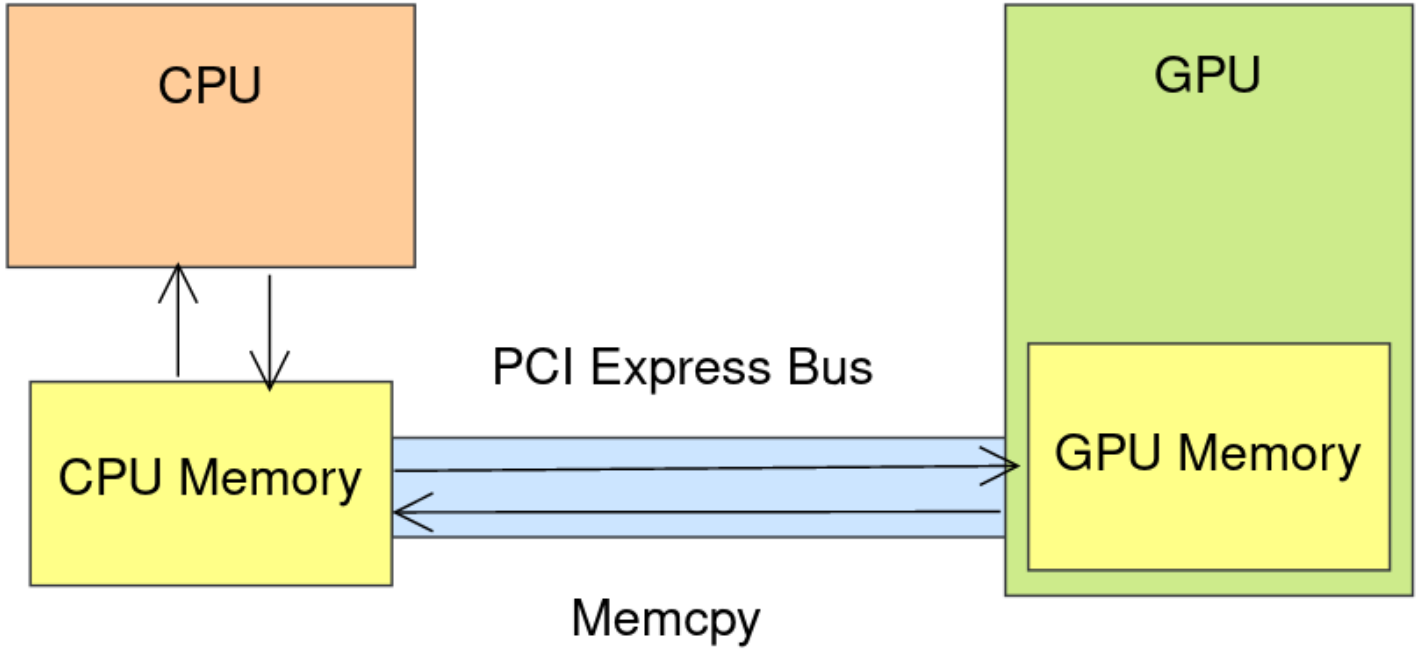
CPU AND GPU MEMORY

- 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 AND GPU MEMORY

- Memory transfers between CPU and GPU are a bottleneck.
- We want to minimize these transfers, when possible.



USM ALLOCATION TYPES

- There are different ways USM memory can be allocated: host, device and shared.

Type	Description	Accessible on host?	Accessible on device?	Located on
device	Allocations in device memory	✗	✓	device
host	Allocations in host memory	✓	✓	host
shared	Allocations shared between host and device	✓	✓	Can migrate between host and device

Figure 6-1. *USM allocation types*

(from book)

USING USM - MALLOC DEVICE

```
// Allocate memory on device
T *device_ptr = sycl::malloc_device<T>(n, myQueue);

// Copy data to device
myQueue.memcpy(device_ptr, cpu_ptr, n * sizeof(T));

// ...
// Do some computation on device
// ...

// Copy data back to CPU
myQueue.memcpy(result_ptr, device_ptr, n * sizeof(T)).wait();

// Free allocated data
sycl::free(device_ptr, myQueue);
```

- It is important to free memory after it has been used to avoid memory leaks.

USING USM - MALLOC SHARED

```
// Allocate shared memory
T *shared_ptr = sycl::malloc_shared<T>(n, myQueue);

// Shared memory can be accessed on host as well as device
for (auto i = 0; i < n; ++i)
  shared_ptr[i] = i;

// ...
// Do some computation on device
// ...

// Free allocated data
sycl::free(shared_ptr, myQueue);
```

- Shared memory is accessible on host and device.
- Performance of shared memory accesses may be poor depending on platform.

SYCL BUFFERS & ACCESSORS

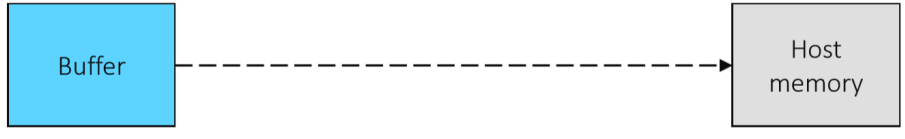
- SYCL provides an API which takes care of allocations and `memcpy`s, as well as some other things.

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

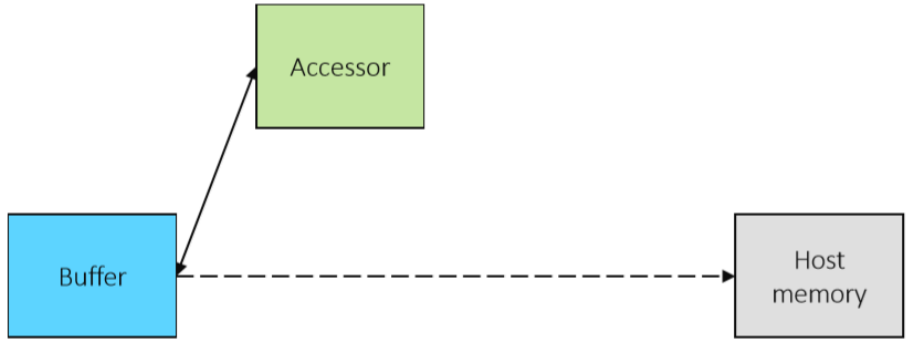
SYCL BUFFERS & ACCESSORS

- A SYCL buffer can be constructed with a pointer to host memory
- For the lifetime of the buffer this memory is owned by the SYCL runtime
- 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



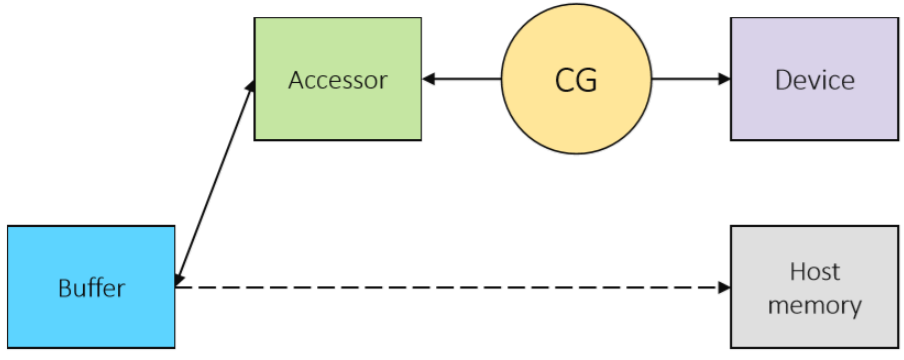
SYCL BUFFERS & ACCESSORS

- 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



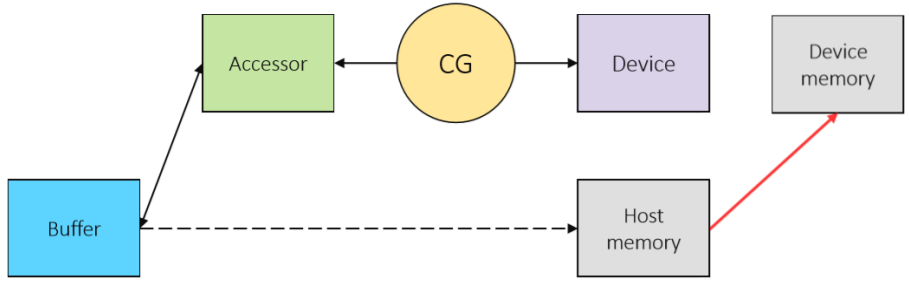
SYCL BUFFERS & ACCESSORS

- When an accessor is constructed it is associated with a command group via the handler object
- This connects the buffer that is being accessed, the way in which it's being accessed and the device that the command group is being submitted to



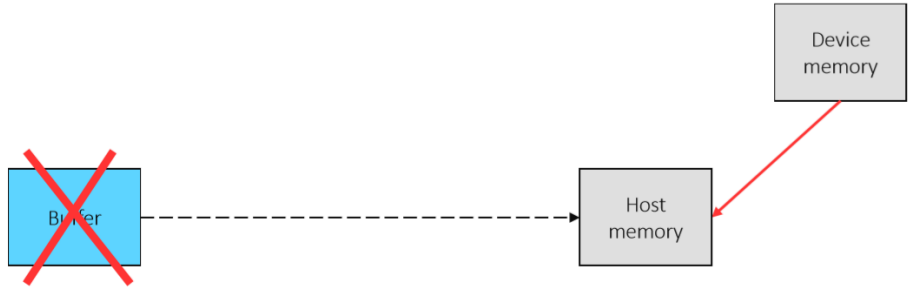
SYCL BUFFERS & ACCESSORS

- Once the SYCL scheduler selects the command group to be executed it must first satisfy its data dependencies
- If necessary, this includes allocating and copying the data to the device accessing that data
- If the most recent copy of the data is already on the device then the runtime will not copy again



SYCL BUFFERS & ACCESSORS

- Data will remain in device memory after kernels finish executing until another accessor requests access in a different device or on the host
- When the buffer object is destroyed it will wait for any outstanding work that is accessing the data to complete and then copy back to the original host memory



SYCL BUFFERS & ACCESSORS

```
T var = 42;

{
  // Create buffer pointing to var.
  auto buf = sycl::buffer{&var, sycl::range<1>{1}};

  // ...
  // Do some computation on device. Use accessors to access buffer
  // ...

} // var updated here

assert(var != 42);
```

- A buffer is associated with a type, range and dimensionality. Dimensionality must be either 1, 2 or 3.
- Usually type and dimensionality can be inferred using CTAD.
- If a buffer is associated with some allocation in host memory, the host memory will be updated only once the buffer goes out of scope.

ACCESSOR CLASS

```
template <typename DataT, int Dimensions, access_mode AccessMode,
          target AccessTarget, access::placeholder isPlaceholder>
sycl::accessor;
```

- Access to the data managed by a buffer
- DataT specifies the type of each element that the accessor accesses.
- Zero, one, two, or three Dimensions matching the underlying buffer
- AccessMode specifies whether the accessor can read or write the underlying data (read, write or read_write)
- AccessTarget can be target::device or target::host_task
- An accessor can optionally be a placeholder accessor, which allows it to be constructed in advance outside of a command group

ACCESSOR CLASS

- There are many different ways to use the `accessor` class.
  - Accessing data on a device.
  - Accessing data immediately in the host application.
  - Allocating local memory.
- For now we are going to focus on accessing data on a device.

CONSTRUCTING AN ACCESSOR

```
auto acc = sycl::accessor{bufA, cgh};
```

- There are many ways to construct an `accessor`.
- The `accessor` class supports CTAD so it's not necessary to specify all of the template arguments.
- The most common way to construct an `accessor` is from a `buffer` and a `handler` associated with the command group function you are within.
    - The element type and dimensionality are inferred from the `buffer`.
    - The `access_mode` is defaulted to `access_mode::read_write`.

SPECIFYING THE ACCESS MODE

```
auto readAcc = sycl::accessor{bufA, cgh, sycl::read_only};
auto writeAcc = sycl::accessor{bufB, cgh, sycl::write_only};
```

- When constructing an `accessor` you will likely also want to specify the `access_mode`
- You can do this by passing one of the CTAD tags:
  - `read_only` will result in `access_mode::read`.
  - `write_only` will result in `access_mode::write`.

SPECIFYING NO INITIALIZATION

```
auto acc = sycl::accessor{buf, cgh, sycl::no_init};
```

- When constructing an `accessor` you may also want to discard the original data of a `buffer`.
- You can do this by passing the `no_init` property.

USING ACCESSORS

```
T var = 42;

{
  // Create buffer pointing to var.
  auto bufA = sycl::buffer{&var, sycl::range<1>{1}};
  auto bufB = sycl::buffer{&var, sycl::range<1>{1}};

  q.submit([&](sycl::handler &cgh) {
        auto accA = sycl::accessor{bufA, cgh, sycl::read_only};
        auto accB = sycl::accessor{bufA, cgh, sycl::no_init};

  cgh.single_task<mykernel>(...); // Do some work
  });

} // var updated here

assert(var != 42);
```

- Buffers and accessors take care of memory migration, as well as dependency analysis.

OPERATOR[]

```
gpuQueue.submit([&](handler &cgh){
  auto inA = sycl::accessor{bufA, cgh, sycl::read_only};
  auto inB = sycl::accessor{bufB, cgh, sycl::read_only};
  auto out = sycl::accessor{bufO, cgh, sycl::write_only};
  cgh.single_task<mykernel>([=]{
    out[0] = inA[0] + inB[0];
  });
});
```

- As well as specifying data dependencies an `accessor` can also be used to access the data from within a kernel function.
- You can do this by calling `operator[]` on the `accessor`.
  - `operator[]` for USM pointers must take a `size_t`, whereas `operator[]` for accessors can take a multi-dimensional `sycl::id` or a `size_t`.

QUESTIONS

EXERCISE

Code_Exercises/Exercise_3_Scalar_Add/source

Implement a SYCL application that adds two variables and returns the result using:

1. The USM memory model
2. The buffer/accessor memory model.