CS/EE 217 GPU Architecture and Parallel Programming

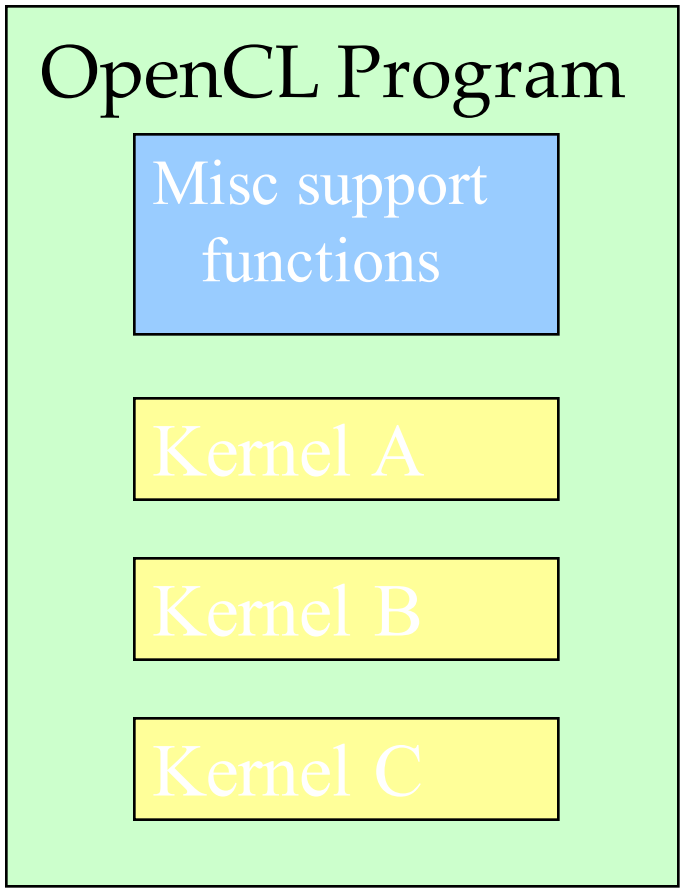
Lecture 22: Introduction to OpenCL

Objective

- To Understand the OpenCL programming model
  - basic concepts and data types
  - OpenCL application programming interface - basic
  - Simple examples to illustrate basic concepts and functionalities

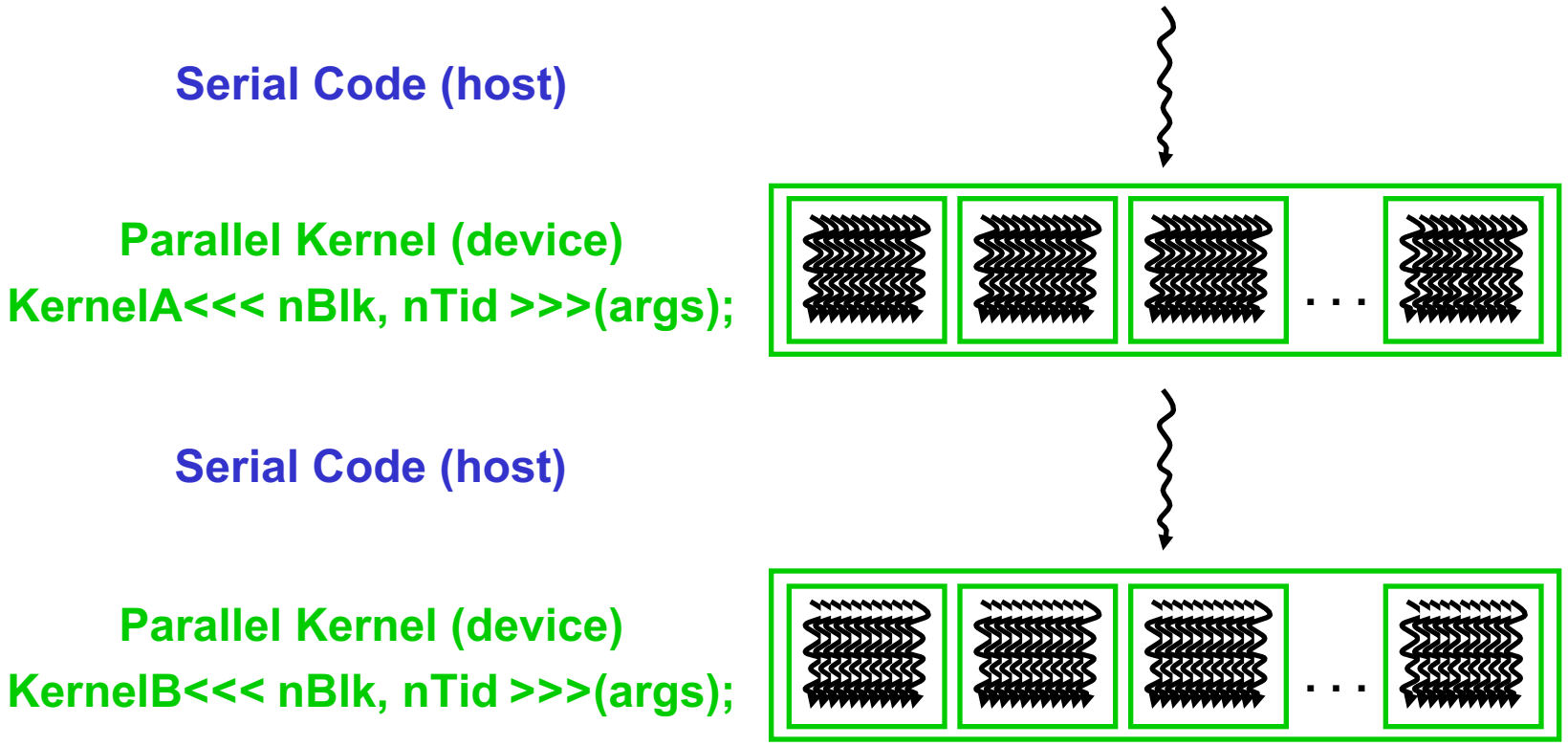
OpenCL Programs

- An OpenCL "program" contains one or more "kernels" and any supporting routines that run on a target device
- An OpenCL kernel is the basic unit of parallel code that can be executed on a target device



OpenCL Execution Model

- Integrated host+device app C program
  - Serial or modestly parallel parts in **host** C code
  - Highly parallel parts in **device** SPMD kernel C code



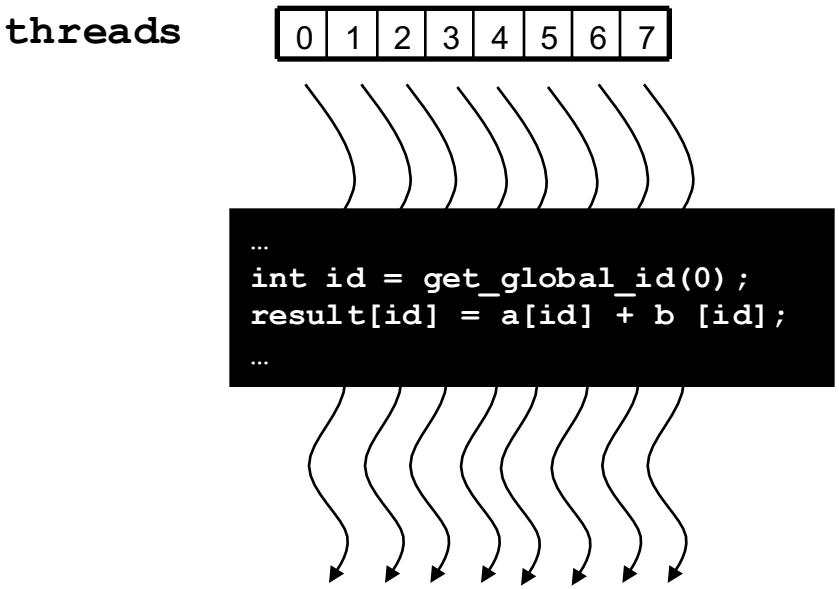
OpenCL Kernels

- Code that actually executes on target devices
- Kernel body is instantiated once for each work item
  - An OpenCL work item is equivalent to a CUDA thread
- Each OpenCL work item gets a unique index

```
__kernel void
vadd(__global const float *a,
     __global const float *b,
     __global float *result)
{
  int id = get_global_id(0);
  result[id] = a[id] + b[id];
}
```

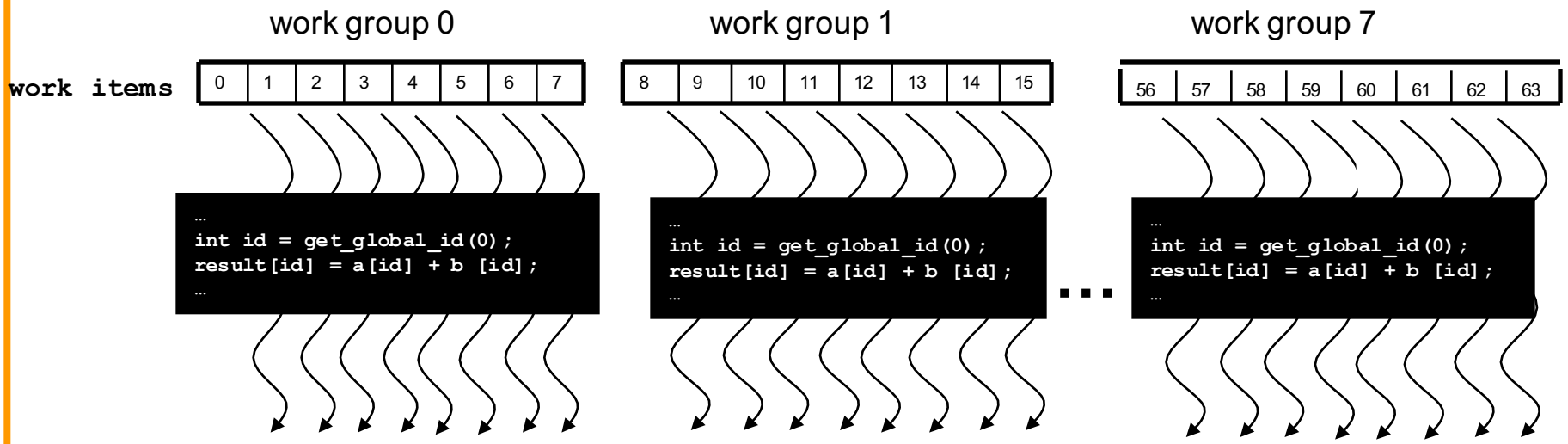
Array of Parallel Work Items

- An OpenCL kernel is executed by an array of work items
  - All work items run the same code (SPMD)
  - Each work item has an index that it uses to compute memory addresses and make control decisions



Work Groups: Scalable Cooperation

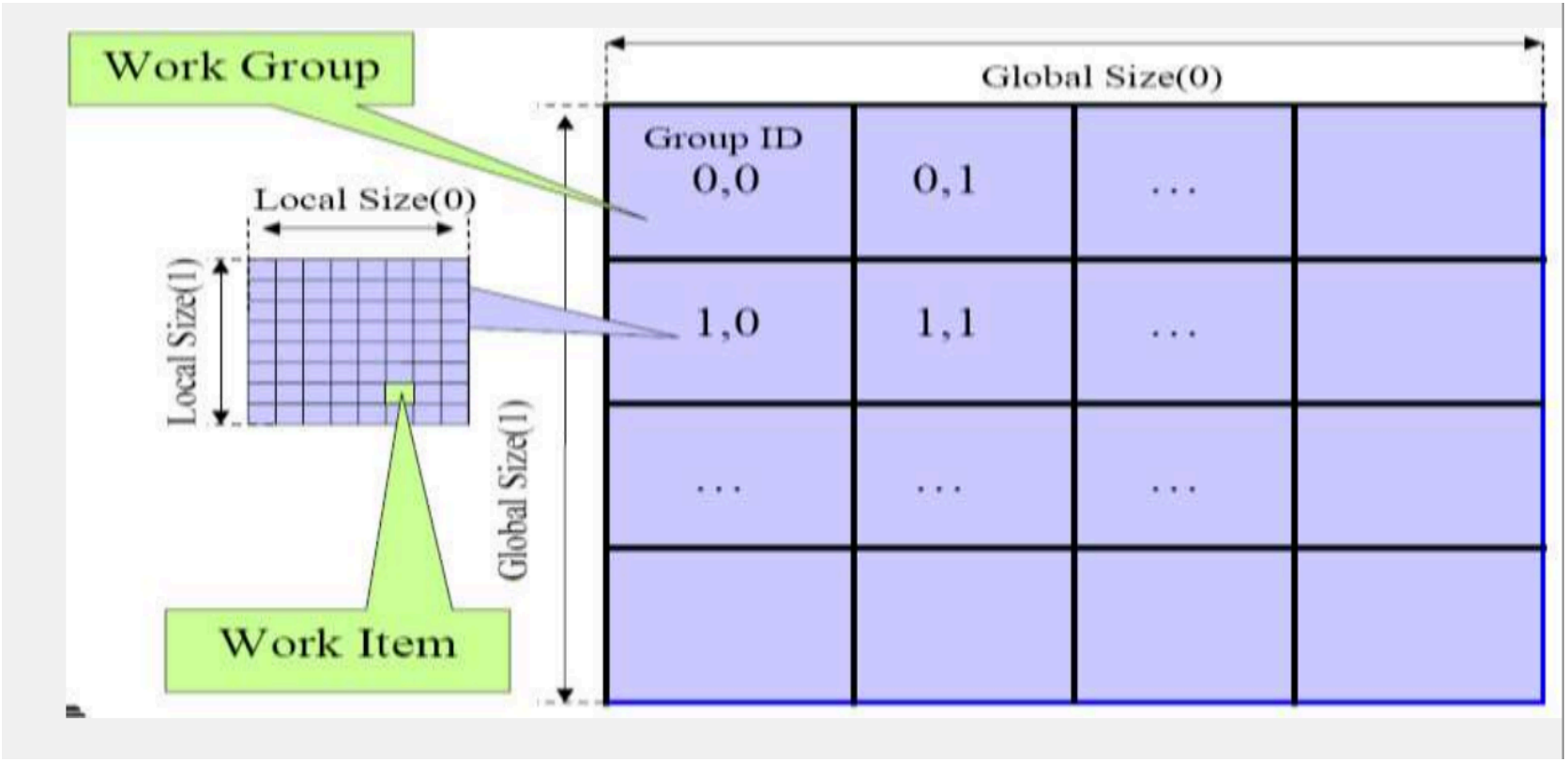
- Divide monolithic work item array into work groups
  - Work items within a work group cooperate via **shared memory, atomic operations** and **barrier synchronization**
  - Work items in different work groups cannot cooperate



OpenCL

OpenCL API Call	Explanation	CUDA Equivalent
get_global_id(0);	global index of the work item in the x dimension	blockIdx.x*blockDim.x+ threadIdx.x
get_local_id(0)	local index of the work item within the work group in the x dimension	threadIdx.x
get_global_size(0);	size of NDRange in the x dimension	gridDim.x*blockDim.x
get_local_size(0);	Size of each work group in the x dimension	blockDim.x

Multidimensional Work indexing



OpenCL Data Parallel Model Summary

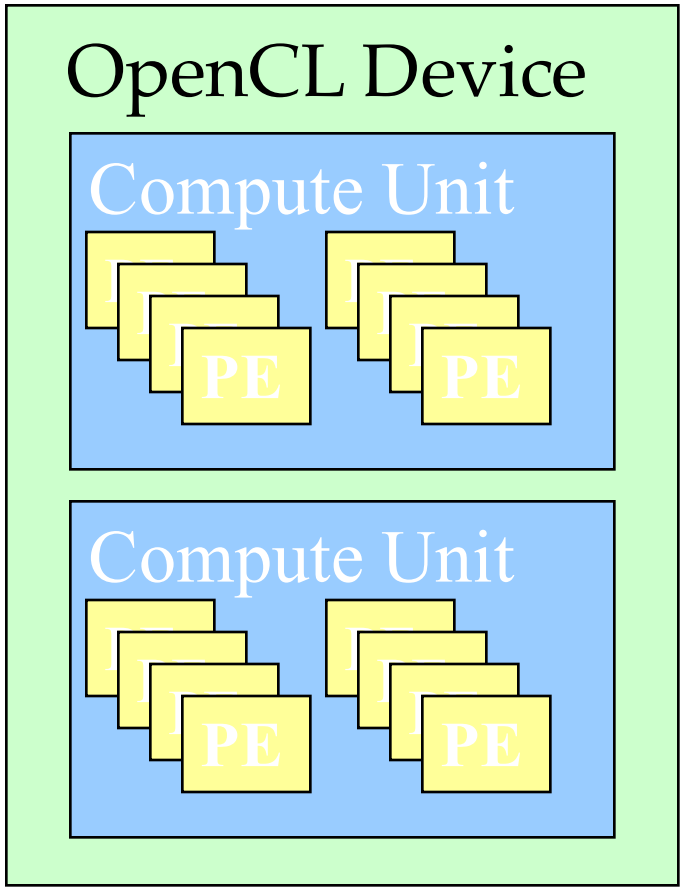
- Parallel work is submitted to devices by launching kernels
- Kernels run over global dimension index ranges (NDRange), broken up into “work groups”, and “work items”
- Work items executing within the same work group can synchronize with each other with barriers or memory fences
- Work items in different work groups can’t sync with each other, except by launching a new kernel

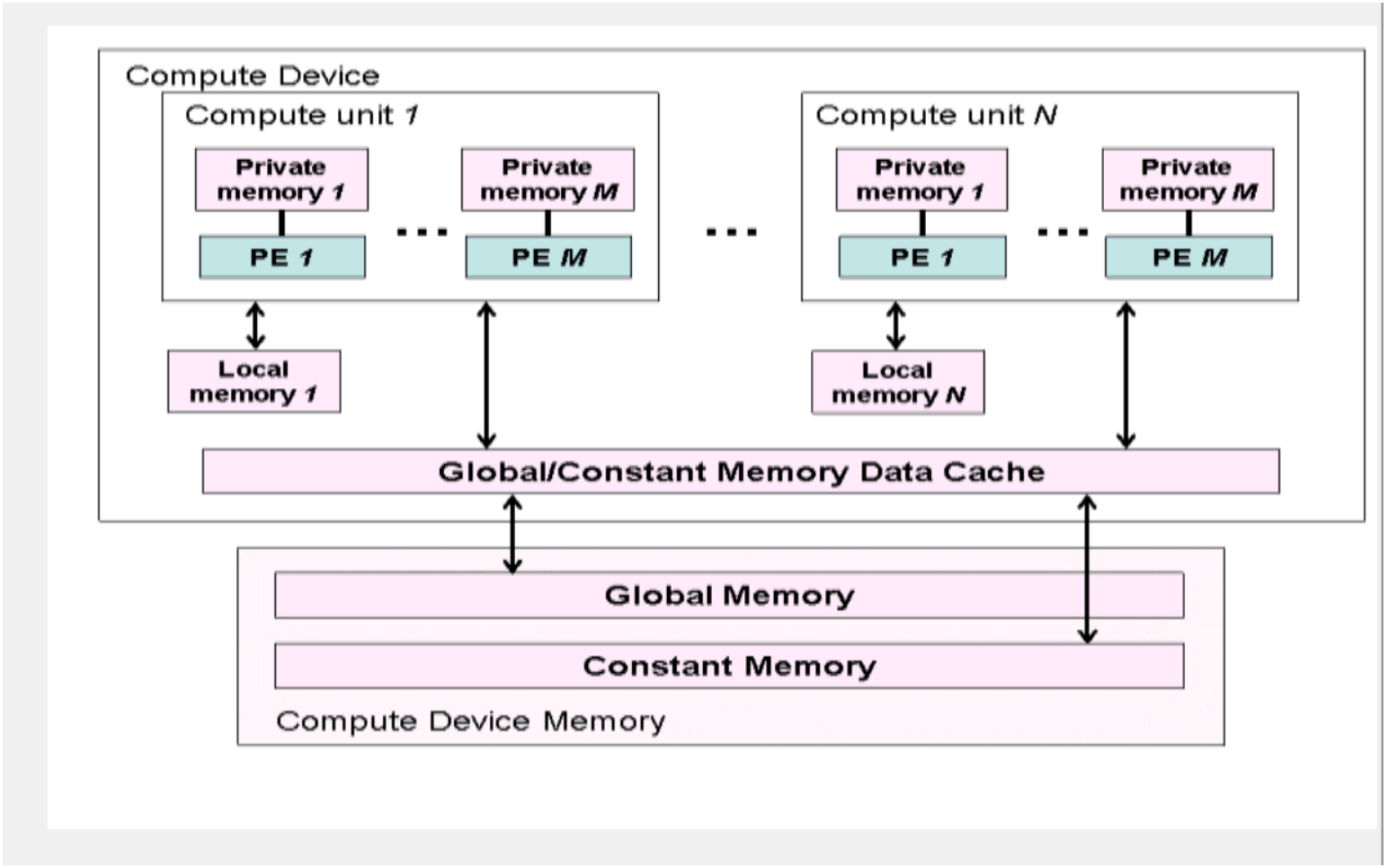
OpenCL Host Code

- Prepare and trigger device code execution
  - Create and manage device context(s) and associate work queue(s), etc…
  - Memory allocations, memory copies, etc
  - Kernel launch
- OpenCL programs are normally compiled entirely at runtime, which must be managed by host code

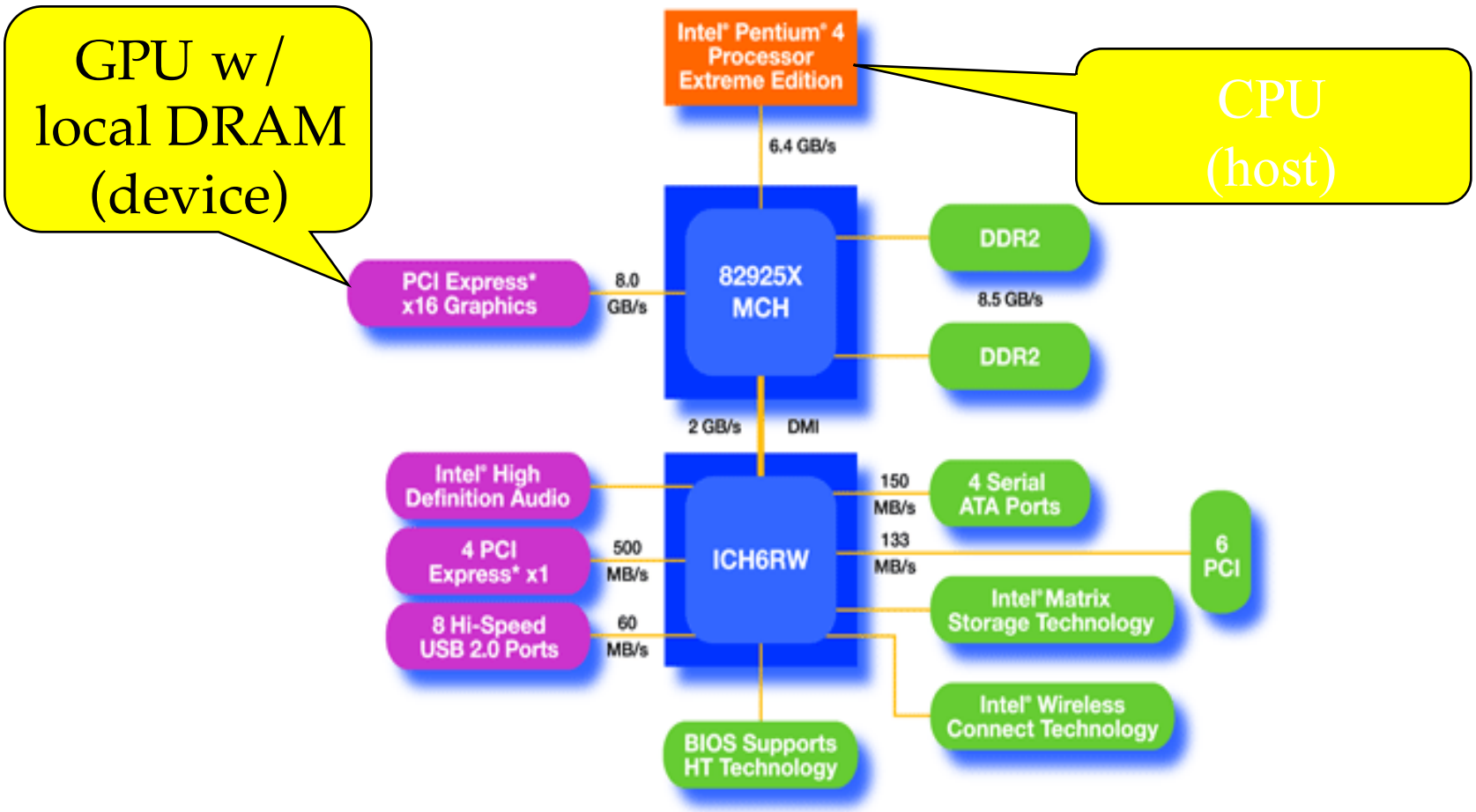
OpenCL Hardware Abstraction

- OpenCL exposes CPUs, GPUs, and other Accelerators as “devices”
- Each “device” contains one or more “compute units”, i.e. cores, SMs, etc...
- Each “compute unit” contains one or more SIMD “processing elements”



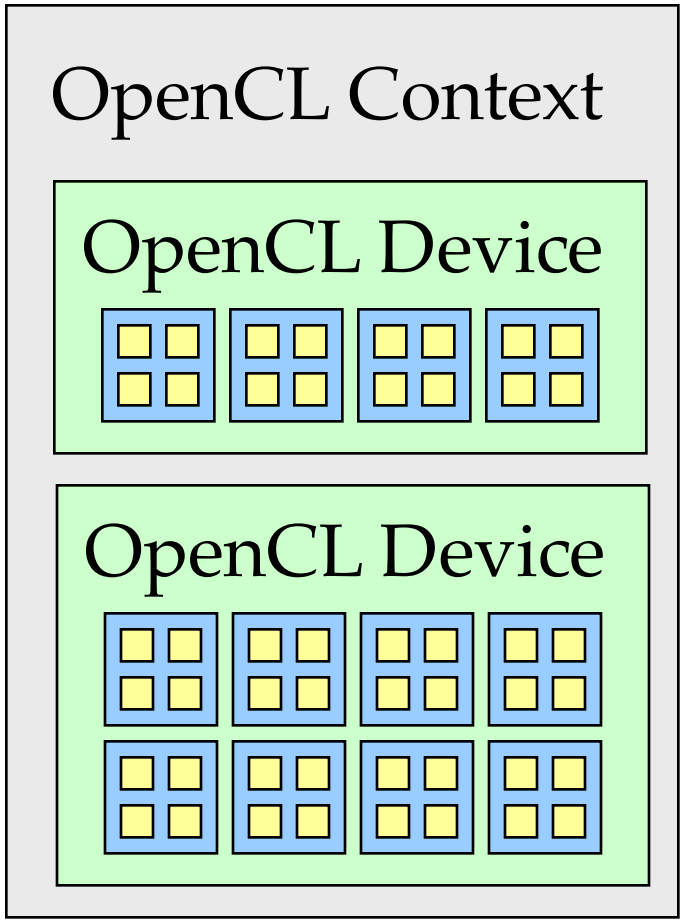

Compute Device
Compute unit 1
Private memory 1
Private memory M
PE 1
PE M
Compute unit N
Private memory 1
Private memory M
PE 1
PE M
Local memory 1
Local memory N
Global/Constant Memory Data Cache
Global Memory
Constant Memory
Compute Device Memory

An Example of Physical Reality Behind OpenCL Abstraction



OpenCL Context

- Contains one or more devices
- OpenCL memory objects are associated with a context, not a specific device
- clCreateBuffer() is the main data object allocation function
  - error if an allocation is too large for any device in the context
- Each device needs its own work queue(s)
- Memory transfers are associated with a command queue (thus a specific device)

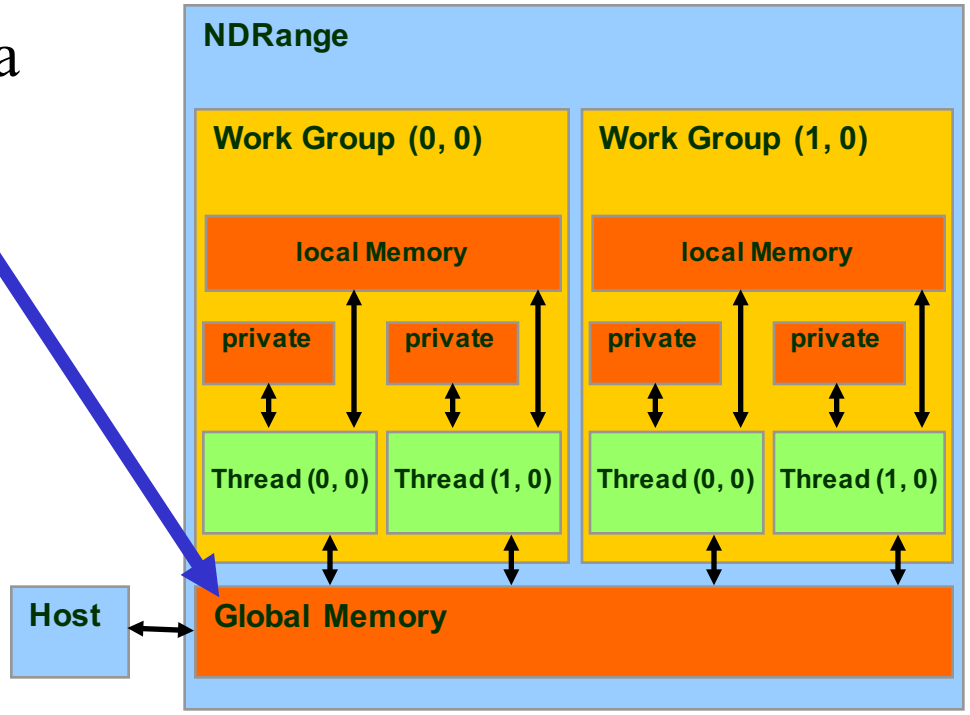


OpenCL Context Setup Code (simple)

```
cl_int clerr = CL_SUCCESS;
cl_context clctx = clCreateContextFromType(0, CL_DEVICE_TYPE_ALL, NULL,
    NULL, &clerr);

size_t parmsz;
clerr = clGetContextInfo(clctx, CL_CONTEXT_DEVICES, 0, NULL, &parmsz);

cl_device_id* cldevs = (cl_device_id *) malloc(parmsz);
clerr = clGetContextInfo(clctx, CL_CONTEXT_DEVICES, parmsz, cldevs, NULL);

cl_command_queue clcmdq = clCreateCommandQueue(clctx, cldevs[0], 0, &clerr);
```

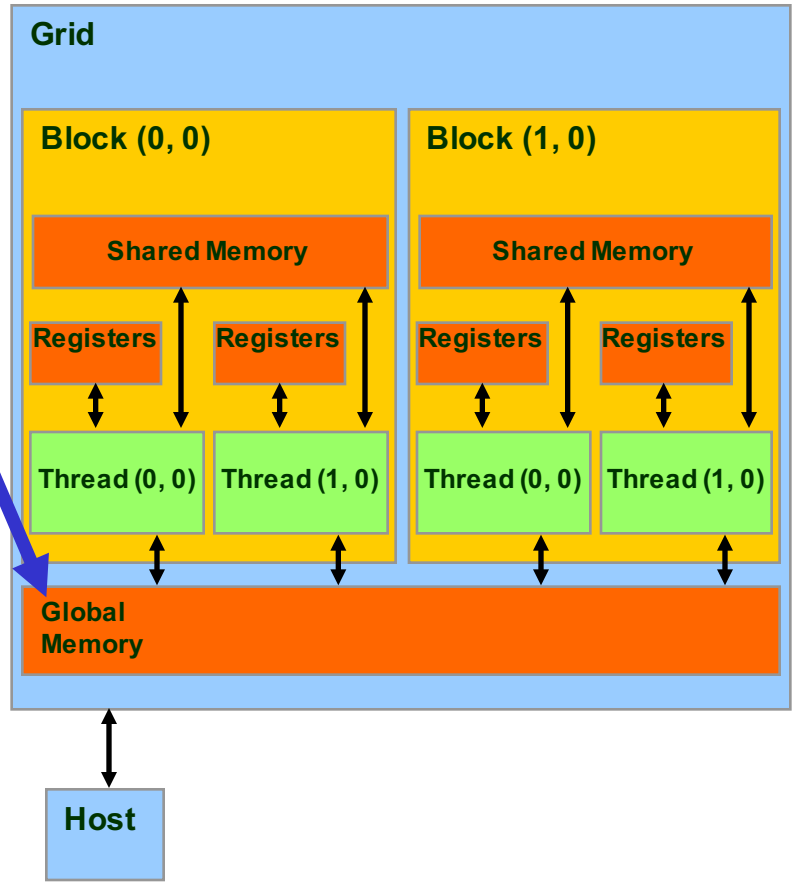
OpenCL Memory Model Overview

- Global memory
  - Main means of communicating R/W Data between host and device
  - Contents visible to all threads
  - Long latency access
- We will focus on global memory for now



OpenCL Device Memory Allocation

- **clCreateBuffer();**
  - Allocates object in the device Global Memory
  - Returns a pointer to the object
  - Requires five parameters
    - OpenCL context pointer
    - Flags for access type by device
    - Size of allocated object
    - Host memory pointer, if used in copy-from-host mode
    - Error code
- **clReleaseMemObject()**
  - Frees object
    - Pointer to freed object

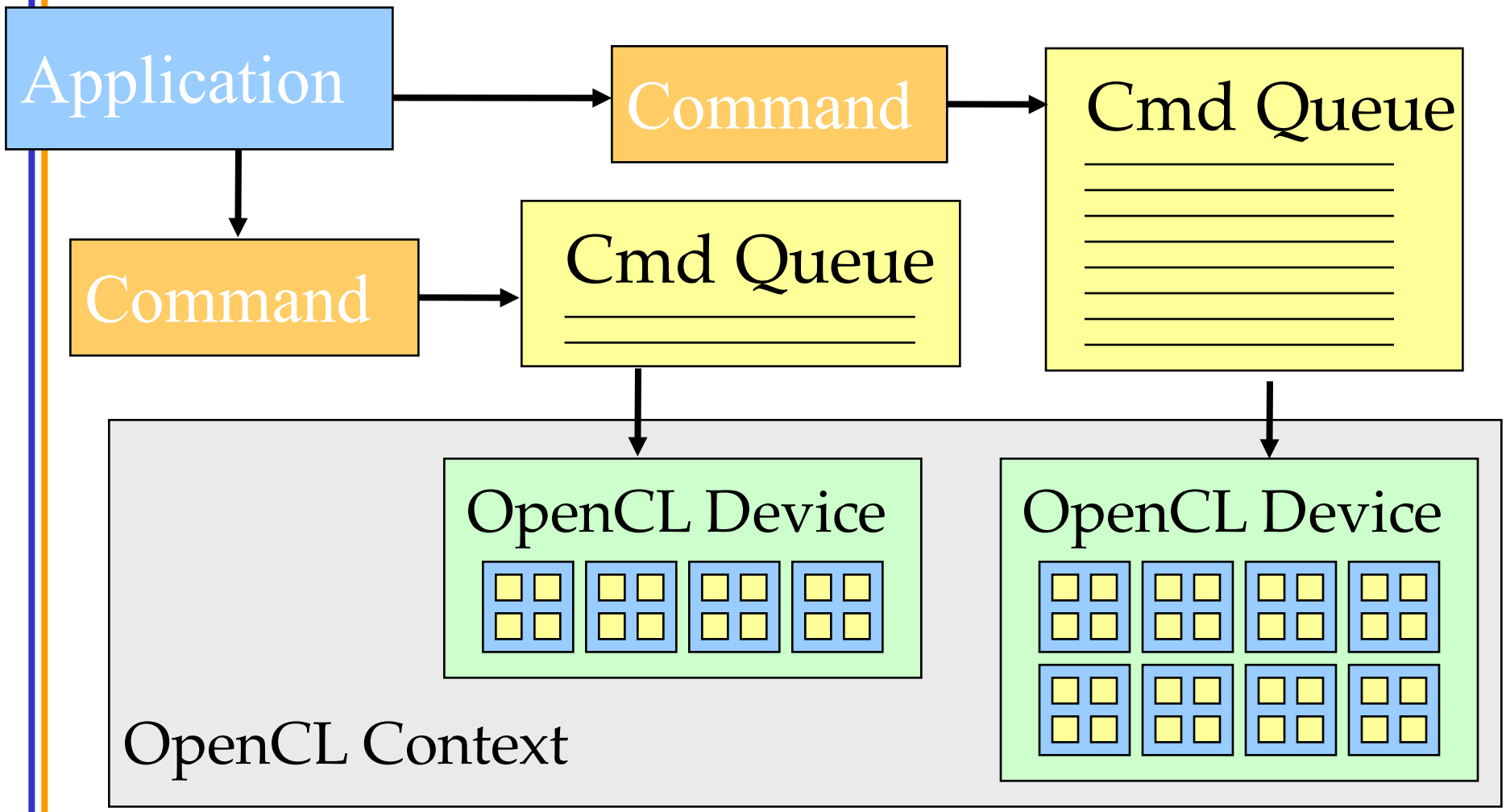


OpenCL Device Memory Allocation (cont.)

- Code example:
  - Allocate a 1024 single precision float array
  - Attach the allocated storage to d_a
  - "d_" is often used to indicate a device data structure

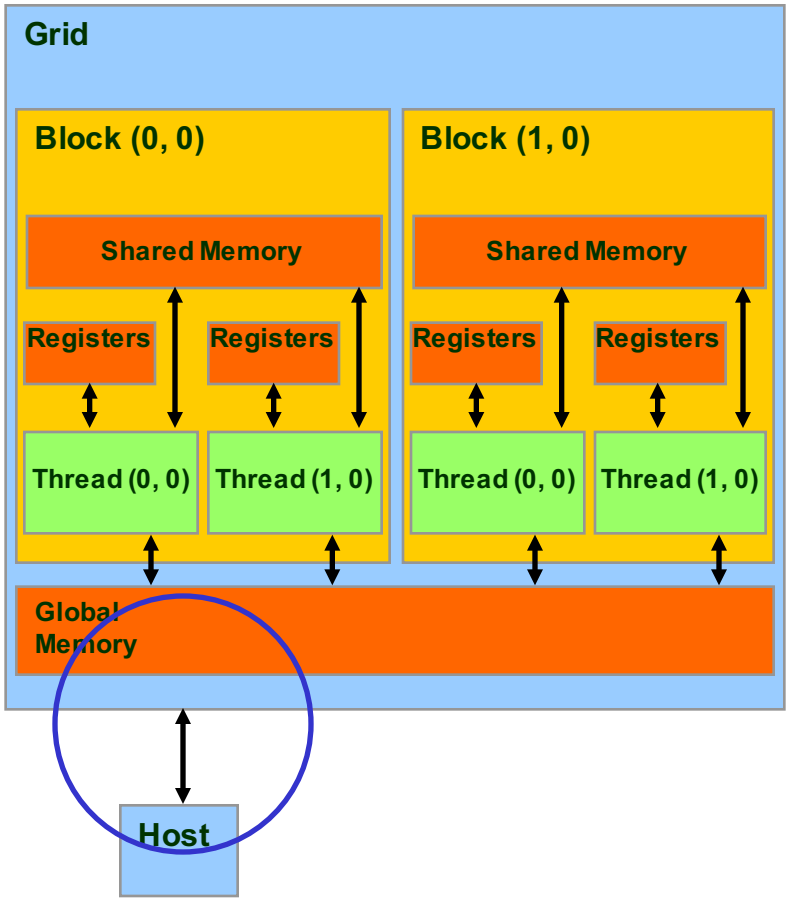
```
VECTOR_SIZE = 1024;
cl_mem d_a;
int size = VECTOR_SIZE* sizeof(float);

d_a = clCreateBuffe(clctx, CL_MEM_READ_ONLY, size, NULL, NULL);
clReleaseMemObject(d_a);
```

OpenCL Device Command Execution



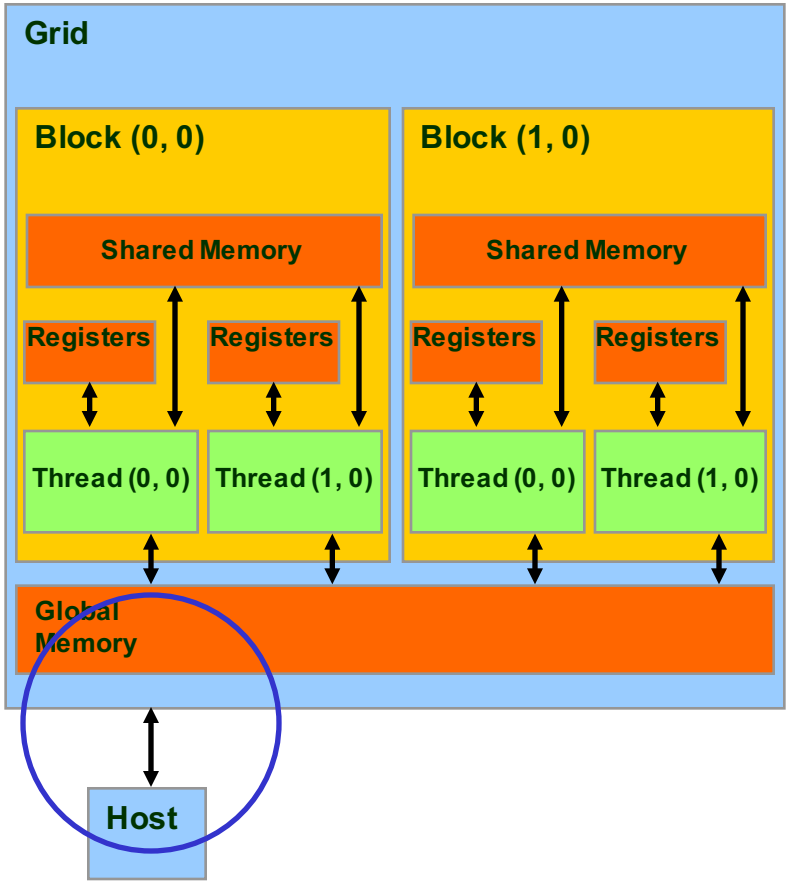
OpenCL Host-to-Device Data Transfer

- clEnqueueWriteBuffer();
  - memory data transfer to device
  - Requires nine parameters
    - OpenCL command queue pointer
    - Destination OpenCL memory buffer
    - Blocking flag
    - Offset in bytes
    - Size (in bytes) of written data
    - Host memory pointer
    - List of events to be completed before execution of this command
    - Event object tied to this command
- Asynchronous transfer later



OpenCL Device-to-Host Data Transfer

- clEnqueueReadBuffer();
  - memory data transfer to host
  - requires nine parameters
    - OpenCL command queue pointer
    - Source OpenCL memory buffer
    - Blocking flag
    - Offset in bytes
    - Size of bytes of read data
    - Destination host memory pointer
    - List of events to be completed before execution of this command
    - Event object tied to this command
- Asynchronous transfer later



OpenCL Host-Device Data Transfer (cont.)

- Code example:
  - Transfer a 64 * 64 single precision float array
  - a is in host memory and d_a is in device memory

```
int mem_size = 64*64*sizeof(float);
clEnqueueWriteBuffer(clcmdq, d_a, CL_FALSE, 0,
    mem_size, (const void * )a, 0, 0, NULL);

clEnqueueReadBuffer(clcmdq, d_result, CL_FALSE, 0,
    mem_size, (void * ) host_result, 0, 0, NULL);
```

OpenCL Host-Device Data Transfer (cont.)

- clCreateBuffer and clEnqueueWriteBuffer can be combined into a single command using special flags.
- Eg:

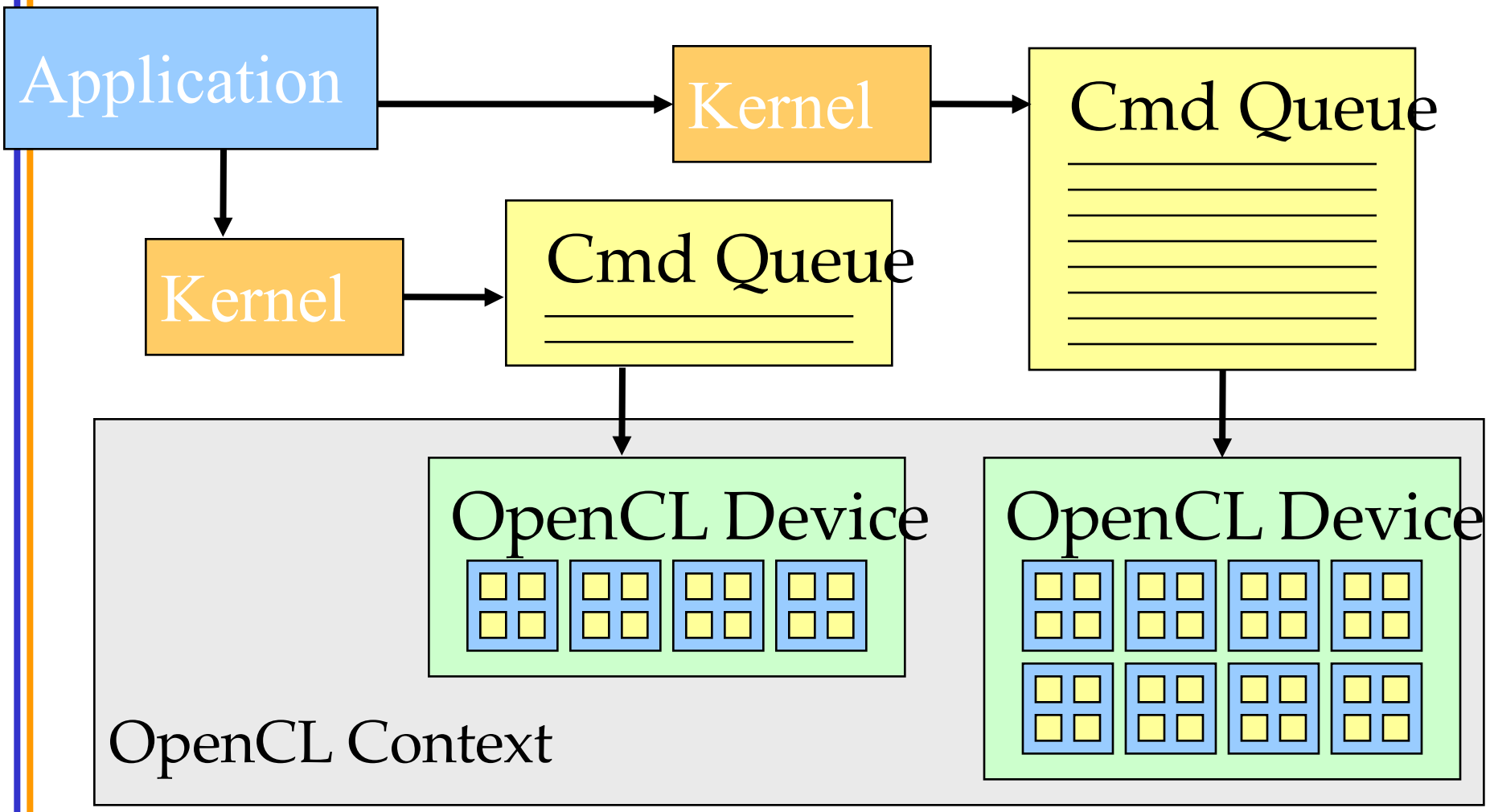
```
d_A=clCreateBuffer(clctxt, CL_MEM_READ_ONLY |
  CL_MEM_COPY_HOST_PTR, mem_size, h_A, NULL);
```

  - Combination of 2 flags here. CL_MEM_COPY_HOST_PTR to be used only if a valid host pointer is specified.
  - This creates a memory buffer on the device, and copies data from h_A into d_A.
  - Includes an implicit clEnqueueWriteBuffer operation, for all devices/command queues tied to the context clctxt.

OpenCL Memories

- __global – large, long latency
- __private – on-chip device registers
- __local – memory accessible from multiple PEs or work items. May be SRAM or DRAM, must query…
- __constant – read-only constant cache
- Device memory is managed explicitly by the programmer, as with CUDA

OpenCL Kernel Execution Launch



OpenCL Kernel Compilation Example

```
const char* vaddsrc =
  "__kernel void vadd(__global float *d_A, __global float *d_B, __global float *d_C, int N) { \n"
   […etc and so forth…]
cl_program clpgm;
clpgm = clCreateProgramWithSource(clctx, 1, &vaddsrc, NULL, &clerr);
char clcompileflags[4096];
sprintf(clcompileflags, "-cl-mad-enable");
clerr = clBuildProgram(clpgm, 0, NULL, clcompileflags, NULL, NULL);
cl_kernel clkern = clCreateKernel(clpgm, "vadd", &clerr);
```

OpenCL kernel source code as a big string

Gives raw source code string(s) to OpenCL

Set compiler flags, compile source, and retreive a handle to the "vadd" kernel

Summary: Host code for `vadd`

```
int main()
{   // allocate and initialize host (CPU) memory
    float *h_A = …,   *h_B = …;
    // allocate device (GPU) memory
  cl_mem d_A, d_B, d_C;
  d_A = clCreateBuffer(clctx, CL_MEM_READ_ONLY |
        CL_MEM_COPY_HOST_PTR, N *sizeof(float), h_A, NULL);
  d_B = clCreateBuffer(clctx, CL_MEM_READ_ONLY |
        CL_MEM_COPY_HOST_PTR, N *sizeof(float), h_B, NULL);
  d_C = clCreateBuffer(clctx, CL_MEM_WRITE_ONLY, N
   *sizeof(float), NULL, NULL);
  clkern=clCreateKernel(clpgm, “vadd", NULL);
  clerr= clSetKernelArg(clkern, 0, sizeof(cl_mem), (void *)&d_A);
  clerr= clSetKernelArg(clkern, 1, sizeof(cl_mem), (void *)&d_B);
  clerr= clSetKernelArg(clkern, 2, sizeof(cl_mem), (void *)&d_C);
  clerr= clSetKernelArg(clkern, 3, sizeof(int), &N);
```

Summary of Host Code (cont.)

```
cl_event event=NULL;
clerr= clEnqueueNDRangeKernel(clcmdq, clkern, 2, NULL, Gsz,Bsz, 0, NULL,
        &event);
clerr= clWaitForEvents(1, &event);
clEnqueueReadBuffer(clcmdq, d_C, CL_TRUE, 0, N*sizeof(float), h_C, 0, NULL,
        NULL);
clReleaseMemObject(d_A);
clReleaseMemObject(d_B);
clReleaseMemObject(d_C);
}
```

ANY MORE QUESTIONS?
READ CHAPTER 14