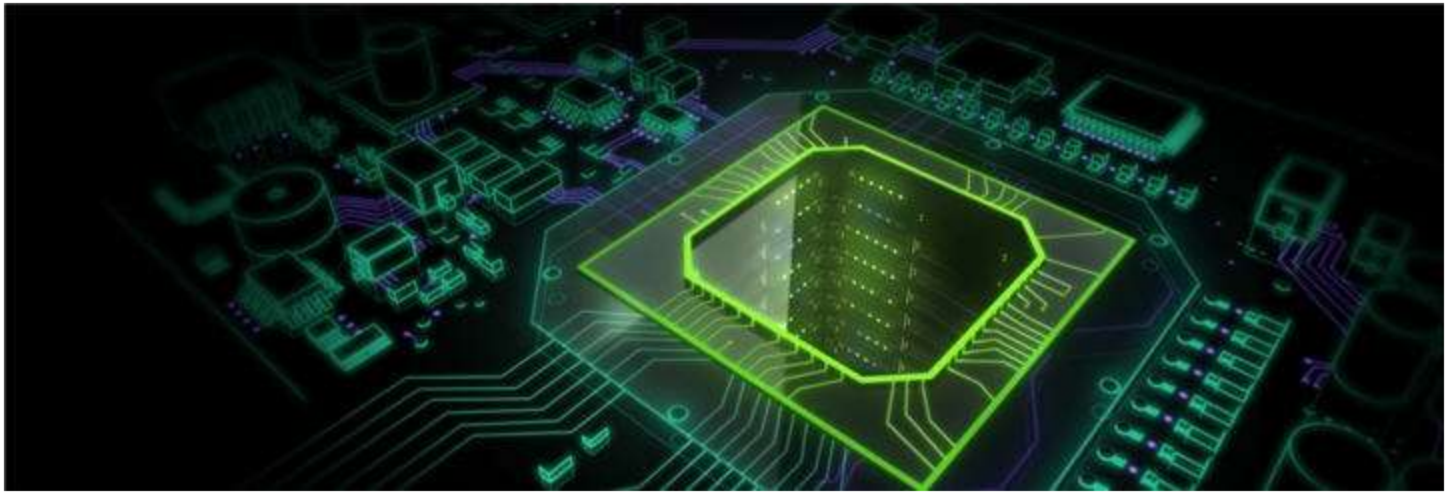
CSCI-GA.3033-012

Graphics Processing Units (GPUs): Architecture and Programming

Lecture 11: OpenCL

Mohamed Zahran (aka Z)
mzahran@cs.nyu.edu
http://www.mzahran.com

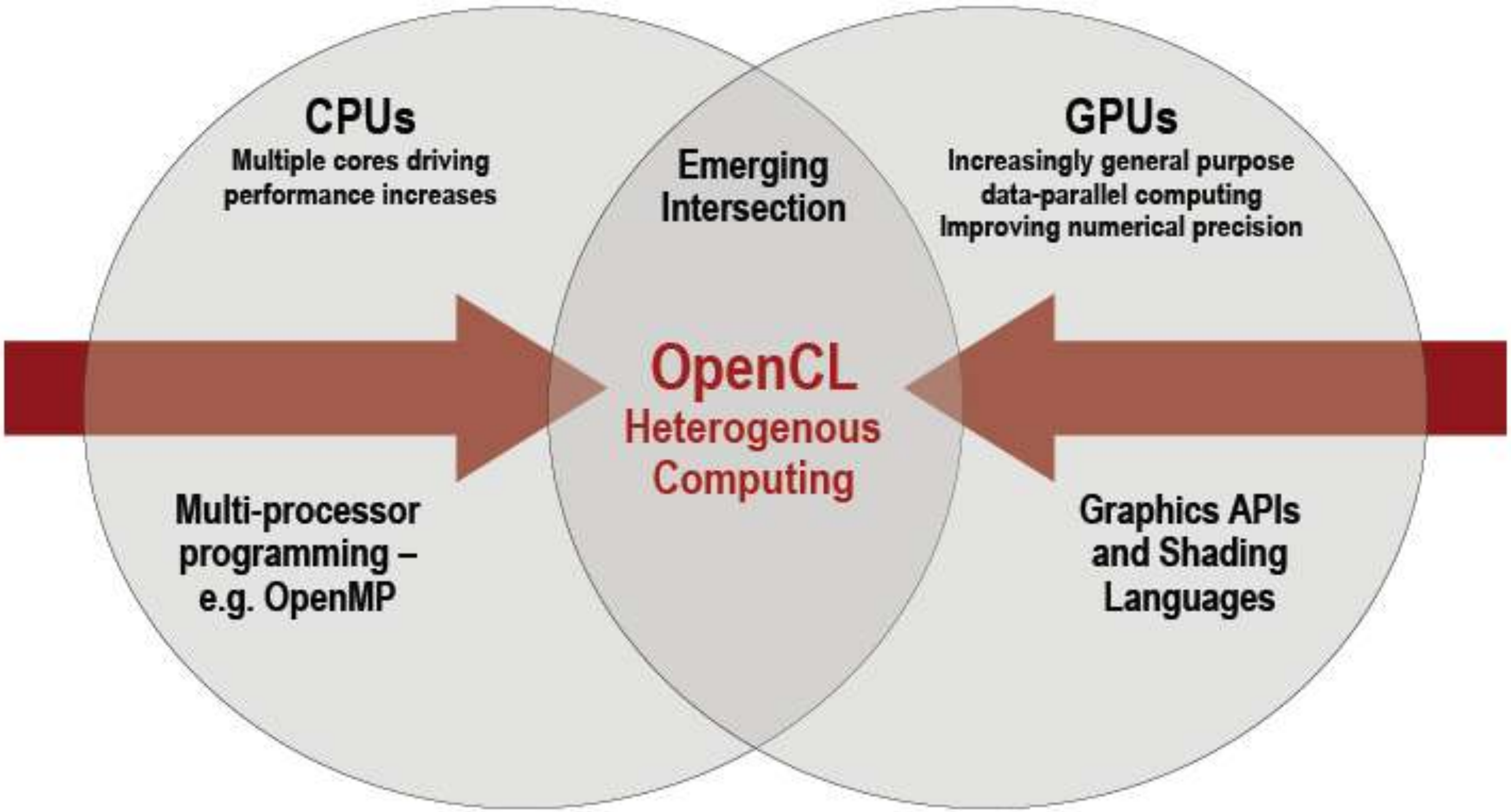


Open Computing Language

OpenCL Working Group

- Diverse industry participation
  - Processor vendors, system OEMs, middleware vendors, application developers
- Many industry-leading experts involved in OpenCL's design
  - A healthy diversity of industry perspectives
- Apple initially proposed and is very active in the working group
  - Serving as specification editor
- Here are some of the other companies in the OpenCL working group

Processor Parallelism



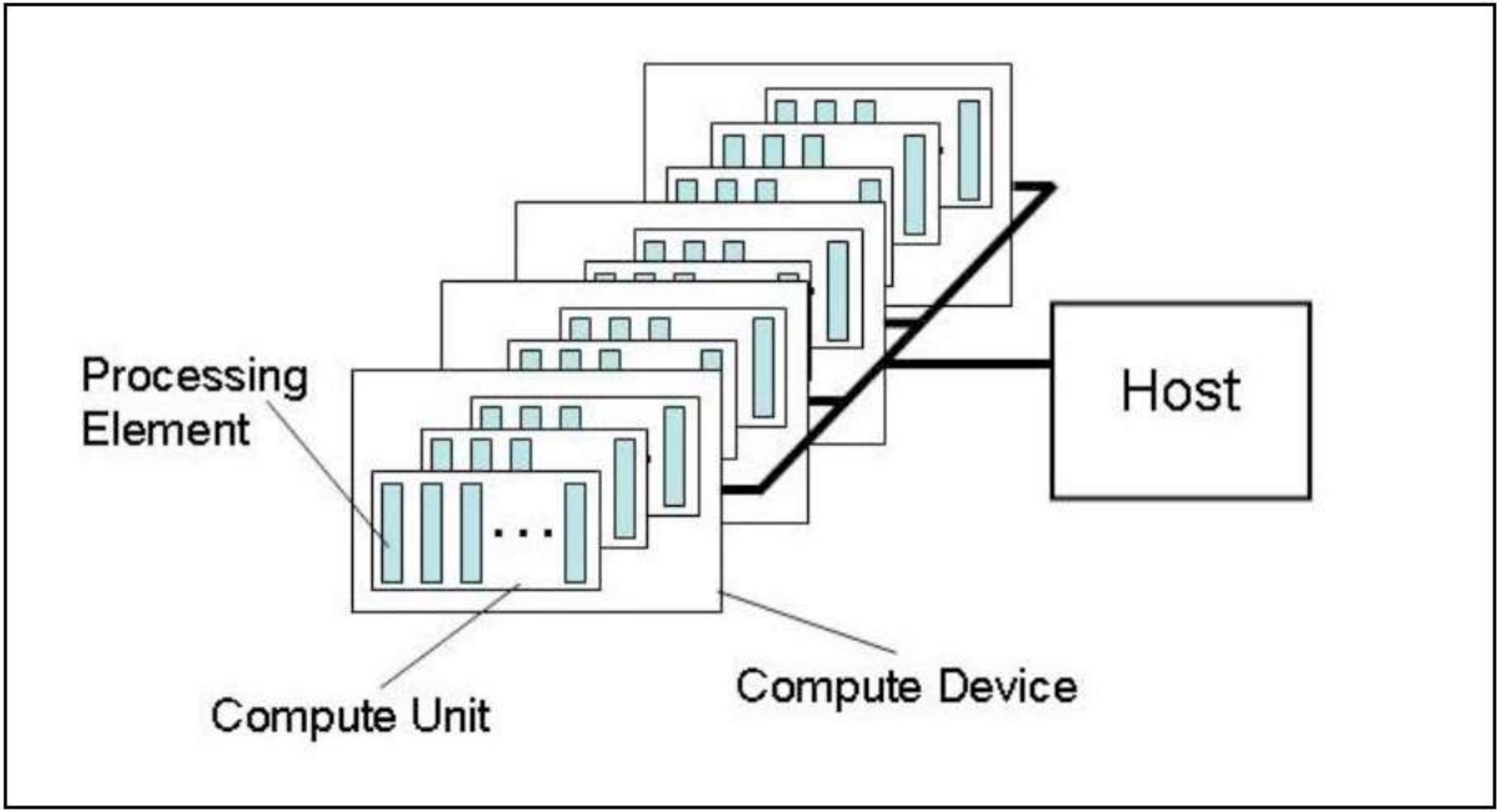
Design Goals

- Use all computation resources in the system (GPUs and CPUs as peers)
- Data parallel model (SIMD) and task parallel model
  - Efficient programming
  - Extension to C
- Abstract underlying parallelism
- Drive future hardware requirements

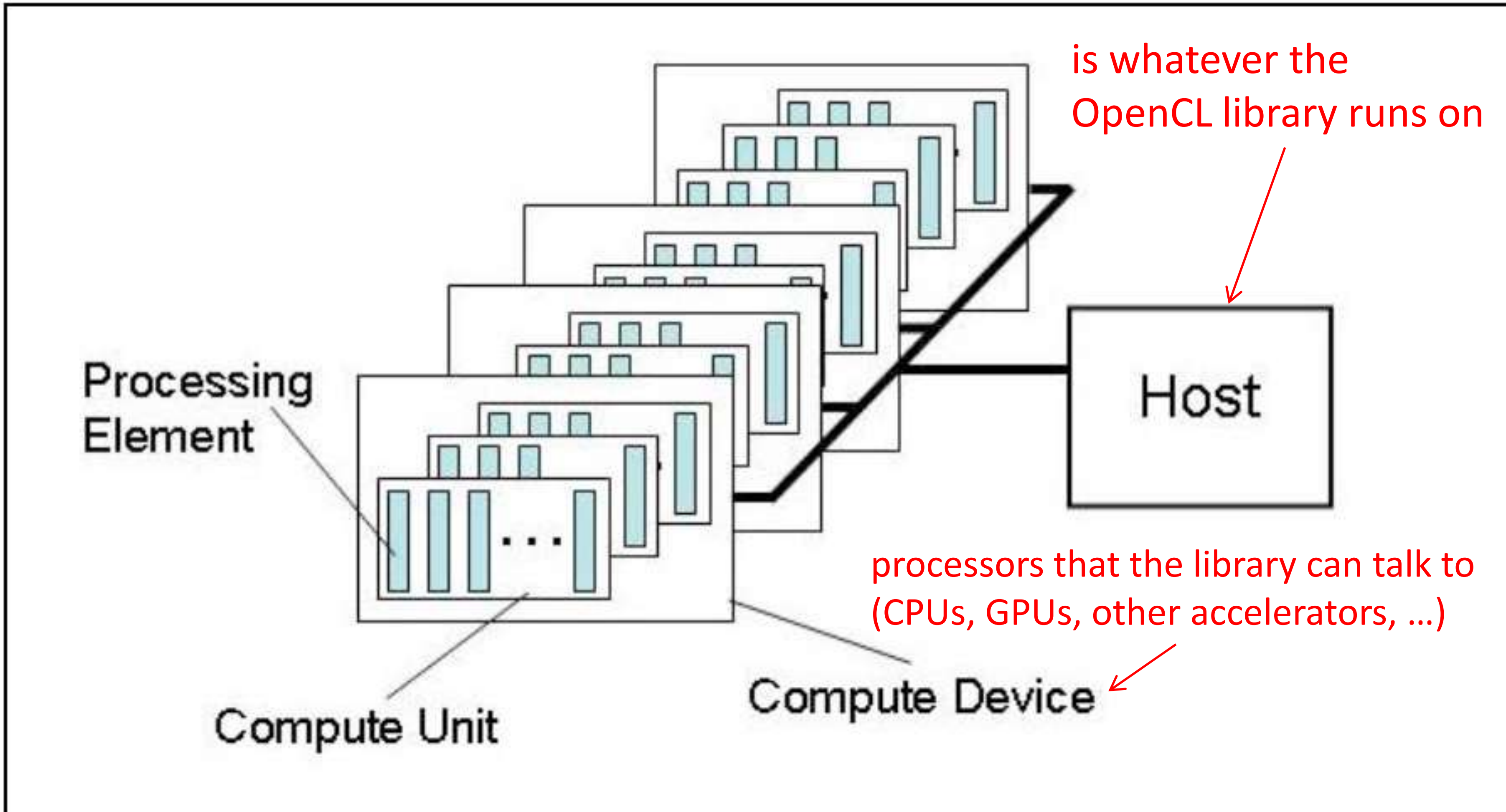
Implementation

- Each OpenCL implementation (OpenCL library from AMD, NVIDIA, etc.) defines *platforms* which enable the host system to interact with OpenCL-capable devices

OpenCL Platform Model



OpenCL Platform Model



Each processing element maintains its own program counter.

A Platform Is:

- "The host plus a collection of devices managed by the OpenCL framework that allow an application to share resources and execute kernels on devices in the platform."
- Platforms represented by a *cl_platform* object, initialized with clGetPlatformID()

Simple code for identifying platform

```
//Platform
cl_platform_id   platform;
clGetPlatformIDs (1, &platform, NULL);
```

Number of platform entries

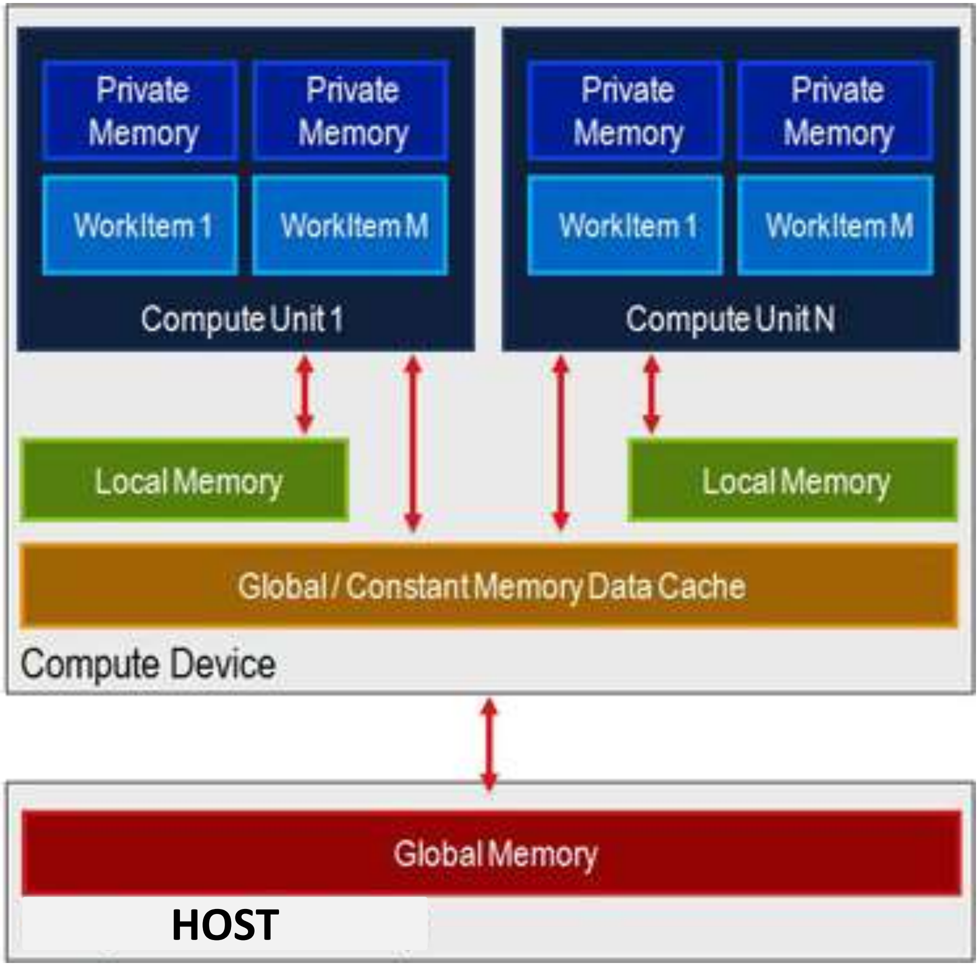
List of OpenCL platforms found. (Platform IDs)
In our case just one platform, identified by &platform

Returns number of OpenCL platforms available. If NULL, ignored.

A Bit of Vocabulary

- Kernel: Smallest unit of execution, like a C function
- Host program: A collection of kernels
- Work group: a collection of work items
  - Has a unique work-group ID
- Work item: an instance of kernel at run time
  - Has a unique ID within the work-group

OpenCL Memory Model



- Relaxed consistency model
- Implementations map this hierarchy to available memories

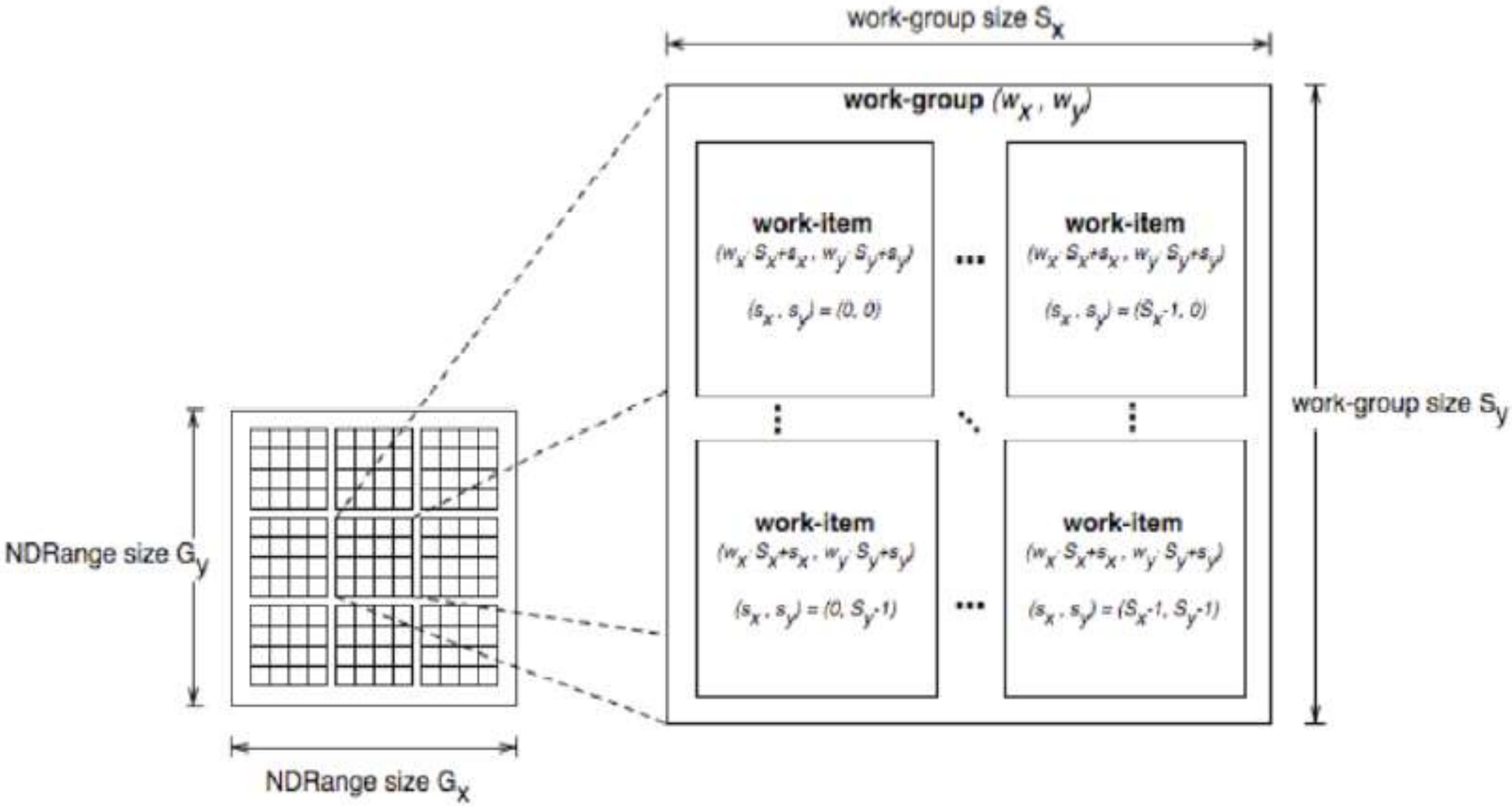
OpenCL Memory Model

- Memory management is explicit
  - Must move data from host memory to device global memory, from global memory to local memory, and back
- Work-groups are assigned to execute on compute-units
  - No guaranteed coherency between different work-groups

NDRange

- N-Dimensional Range
- N = 1D, 2D, or 3D
- An index space in which kernels are executed
- A work-item is a single kernel instance at a point in the index space
- Does this remind you of something? (GRID?)

Kernel Execution



- Total number of work-items = G_x * G_y
- Size of each work-group = S_x * S_y
- Global ID can be computed from work-group ID and local ID

Programming Model

- Data Parallel
  - Work-groups can be defined explicitly (like CUDA) or implicitly (specify the number of work-items and OpenCL creates the work-groups)
- Task Parallel
  - Kernel is executed independent of an index space
  - Can be written in OpenCL C or native compiled from C/C++

Once a platform is selected, we can then query for the devices that it knows how to interact with

```
clGetDeviceIDs⁴ (cl_platform_id platform,
                 cl_device_type device_type,
                 cl_uint num_entries,
                 cl_device_id *devices,
                 cl_uint *num_devices)
```

- We can specify which types of devices we are interested in (e.g. all devices, CPUs only, GPUs only)

A Context

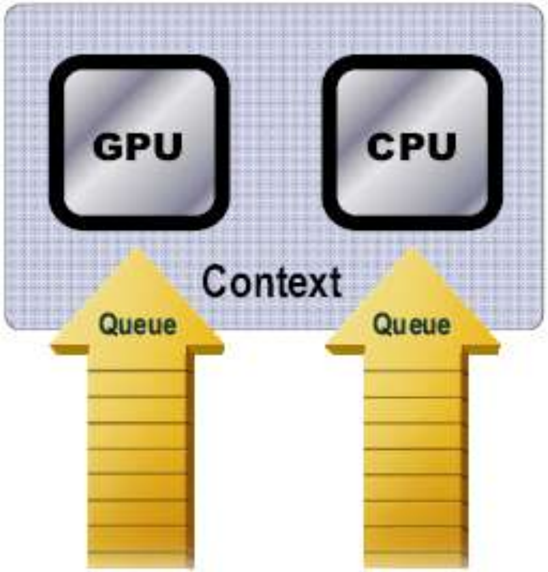
- A context refers to the environment for managing OpenCL objects and resources
- To manage OpenCL programs, the following are associated with a context
  - Devices: the things doing the execution
  - Program objects: the program source that implements the kernels
  - Kernels: functions that run on OpenCL devices
  - Memory objects: data that are operated on by the device
  - Command queues: mechanisms for interaction with the devices

Command Queues

- A *command queue* is the mechanism for the host to request that an action be performed by the device
  - Perform a memory transfer, begin executing, etc.
- A separate command queue is required for each device
- Commands within the queue can be synchronous or asynchronous
- Commands can execute in-order or out-of-order

Setup

1. Get the device(s)
2. Create a context
3. Create command queue(s)




```
cl_uint num_devices_returned;
cl_device_id devices[2];
err = clGetDeviceIDs(NULL, CL_DEVICE_TYPE_GPU, 1,
                     &devices[0], num_devices_returned);
err = clGetDeviceIDs(NULL, CL_DEVICE_TYPE_CPU, 1,
                     &devices[1], &num_devices_returned);

cl_context context;
context = clCreateContext(0, 2, devices, NULL, NULL, &err);

cl_command_queue queue_gpu, queue_cpu;
queue_gpu = clCreateCommandQueue(context, devices[0], 0, &err);
queue_cpu = clCreateCommandQueue(context, devices[1], 0, &err);
```

Memory Objects

- Memory objects are OpenCL data that can be moved on and off devices
  - Objects are classified as either buffers or images
- Buffers
  - Contiguous chunks of memory – stored sequentially and can be accessed directly (arrays, pointers, structs)
  - Read/write capable
- Images
  - Opaque objects (2D or 3D)
  - Can only be accessed via read_image() and write_image()
  - Can either be read or written in a kernel, but not both

Allocating Memory on Device

Use clCreatBuffer:

```
cl_mem clCreateBuffer(cl_context context,
                      cl_mem_flags flags,
                      size_t size,
                      void *host_ptr,
                      cl_int *errcode_ret)
```

OpenCL context

Bit field to specify type of allocation/usage (CL_MEM_READ_WRITE ,…)

Ptr to buffer data (May be previously allocated.)

Returns error code if an error

Returns memory object

Example: Allocating Two Vectors on Device

```
// source data on host, two vectors

int *A, *B;
A = new int[N];
B = new int[N];
for(int i = 0; i < N; i++) {
        A[i] = rand()%1000;
        B[i] = rand()%1000;
}
…

// Allocate GPU memory for source vectors

cl_mem GPUVector1 =
clCreateBuffer(GPUContext,CL_MEM_READ_ONLY |
CL_MEM_COPY_HOST_PTR,sizeof(int)*N, A, NULL);

cl_mem GPUVector2 =
clCreateBuffer(GPUContext,CL_MEM_READ_ONLY |
CL_MEM_COPY_HOST_PTR,sizeof(int)*N, B, NULL);
```

Example: Allocating A Vector on Device for Results

```
// Allocate GPU memory for output vector

cl_mem GPUOutputVector =
clCreateBuffer(GPUContext,CL_MEM_WRITE_ONLY,sizeof(int)*N,
NULL,NULL);
```

Transferring Data

- OpenCL provides commands to transfer data to and from devices
  - clEnqueue{Read|Write}{Buffer|Image}
  - Copying from the host to a device is considered *writing*
  - Copying from a device to the host is *reading*

Transferring Data

```
cl_int  clEnqueueWriteBuffer (cl_command_queue command_queue,
                              cl_mem buffer,
                              cl_bool blocking_write,
                              size_t offset,
                              size_t cb,
                              const void *ptr,
                              cl_uint num_events_in_wait_list,
                              const cl_event *event_wait_list,
                              cl_event *event)
```

- This command initializes the OpenCL memory object and writes data to the device associated with the command queue
  - The command will write data from a host pointer (*ptr*) to the device
- The *blocking_write* parameter specifies whether or not the command should return before the data transfer is complete
- Events can specify which commands should be completed before this one runs

Compilation Model

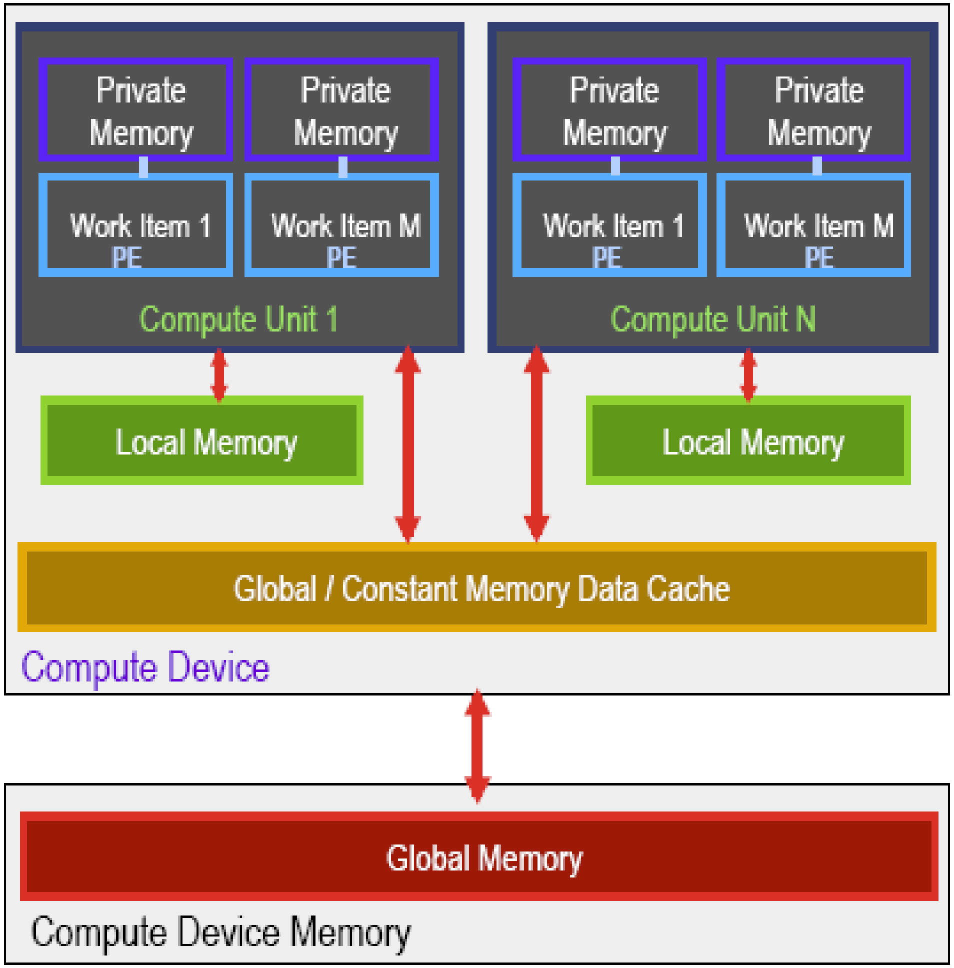
- More complicated than CUDA
- uses Dynamic/Runtime compilation model
  1. The code is complied to an Intermediate Representation (IR)
     - Usually an assembler or a virtual machine
     - Known as offline compilation
  2. The IR is compiled to a machine code for execution.
     - This step is much shorter.
     - It is known as online compilation.
- Starting a kernel can be expensive, so try to make individual kernels do a large amount of work.

Typical OpenCL Program Flow

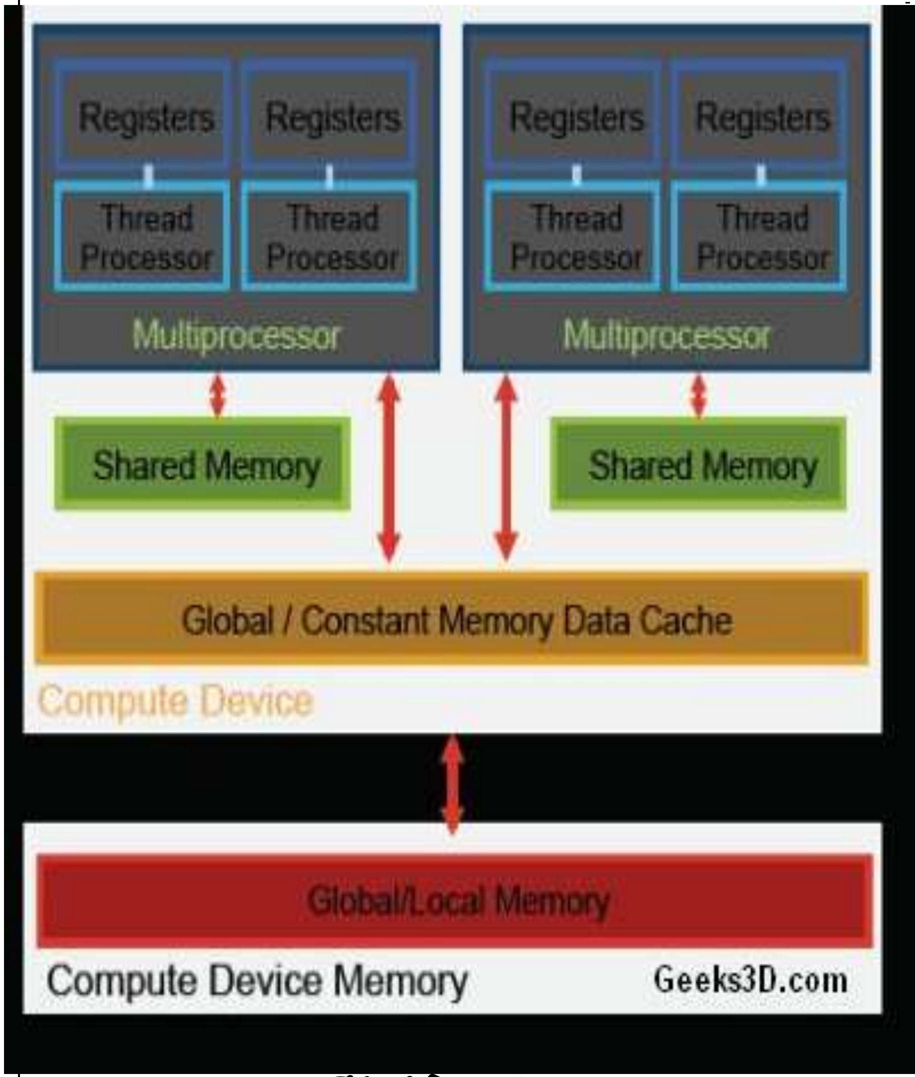
- Select the desired devices (ex: all GPUs)
- Create a context
- Create command queues (per device)
- Compile programs
- Create kernels
- Allocate memory on devices
- Transfer data to devices
- Execute
- Transfer results back
- Free memory on devices

OpenCL vs CUDA

Memory Model Comparison



OpenCL



CUDA

CUDA vs OpenCL

CUDA

- Global mem
- Shared (per-block) mem
- Local mem
- Kernel
- block
- Thread
- Easier compilation
- A bit restricted

OpenCL

- Global mem
- Local memory
- Private memory
- Program
- Work-group
- Work-item
- Complicated compilation
- More versatile (GPU, CPU, Cell, DSP, ..)

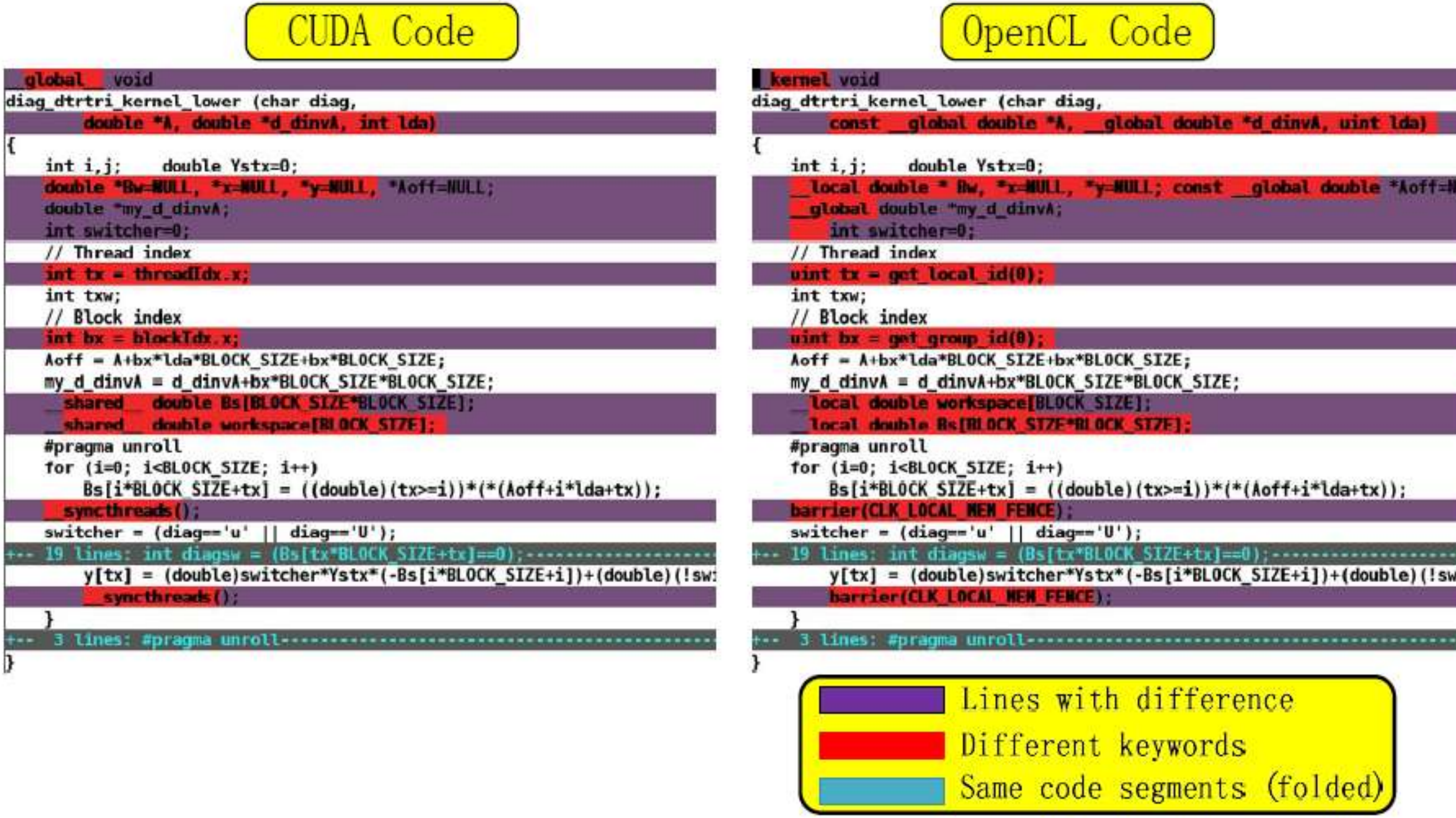
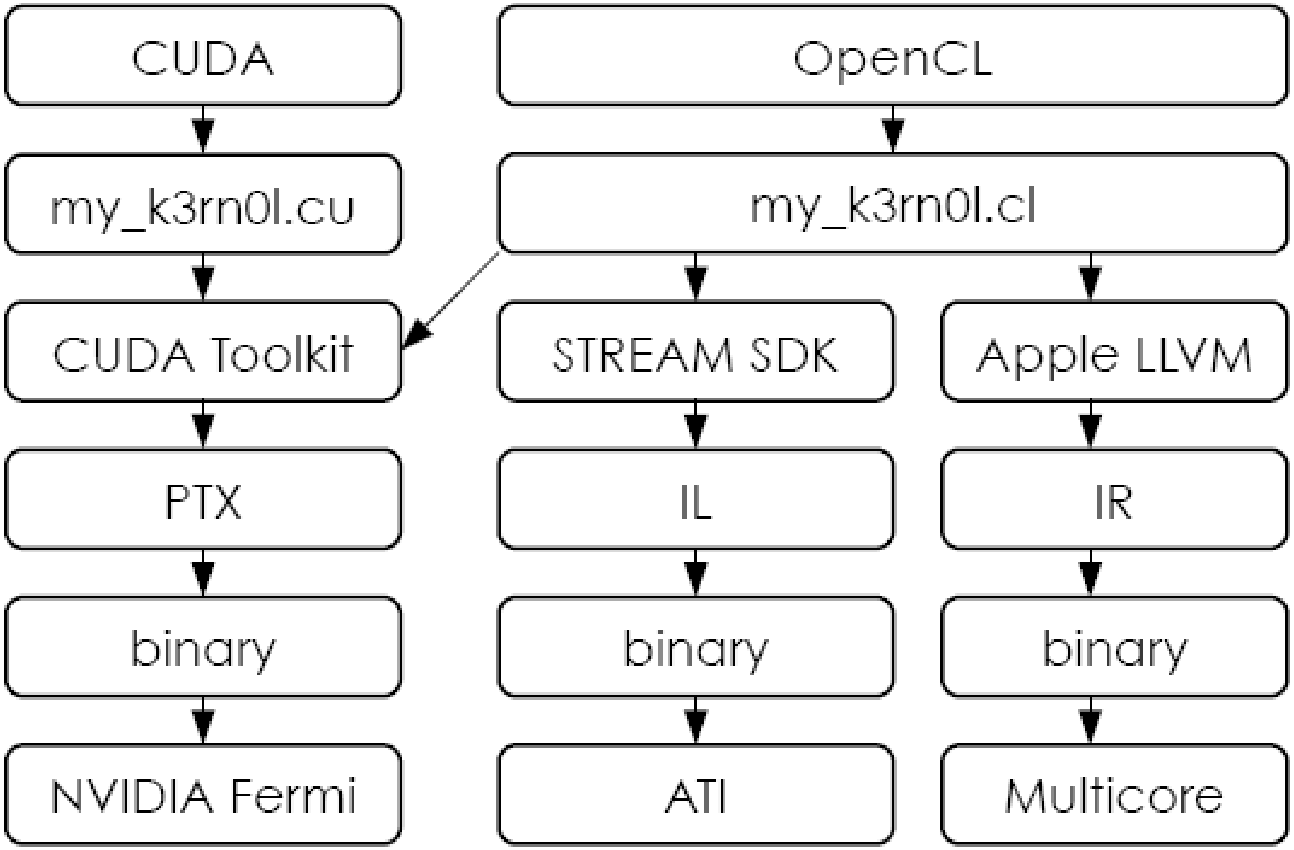


Figure from: *From CUDA to OpenCL: Towards a performance-portable solution for multi-platform GPU programming*, Pend Du et. al. Elsevier Parallel Computing Journal, Volume 38, Issue 8, August 2012, Pages 391–407



Software Stack for CUDA and OpenCL

Figure from: *From CUDA to OpenCL: Towards a performance-portable solution for multi-platform GPU programming*, Pend Du et. al. Elsevier Parallel Computing Journal, Volume 38, Issue 8, August 2012, Pages 391–407

OpenCL on NVIDIA Hardware

- Vector types in OpenCL
  - Use it for convenience not performance
  - NVIDIA is a scalar architecture
  - Better have more work items than large vector per work item
- Many concurrent work-items is a good way to overlap computation and memory access for high-intensity arithmetic programs

OpenCL on NVIDIA Hardware

- Take advantage of __local memory
- Work-items can cooperate via this __local memory using barrier() which has low overhead
- Use __local memory to manage locality and reduce global memory access

For Fun!

http://www.simplyhired.com/a/jobtrends/trend/q-opencl%2Ccuda%2Copenmp

Conclusions

- CUDA has been around for longer -> more libraries and OpenCL is playing catch-up
- OpenCL is more versatile (CUDA on Radeon?)