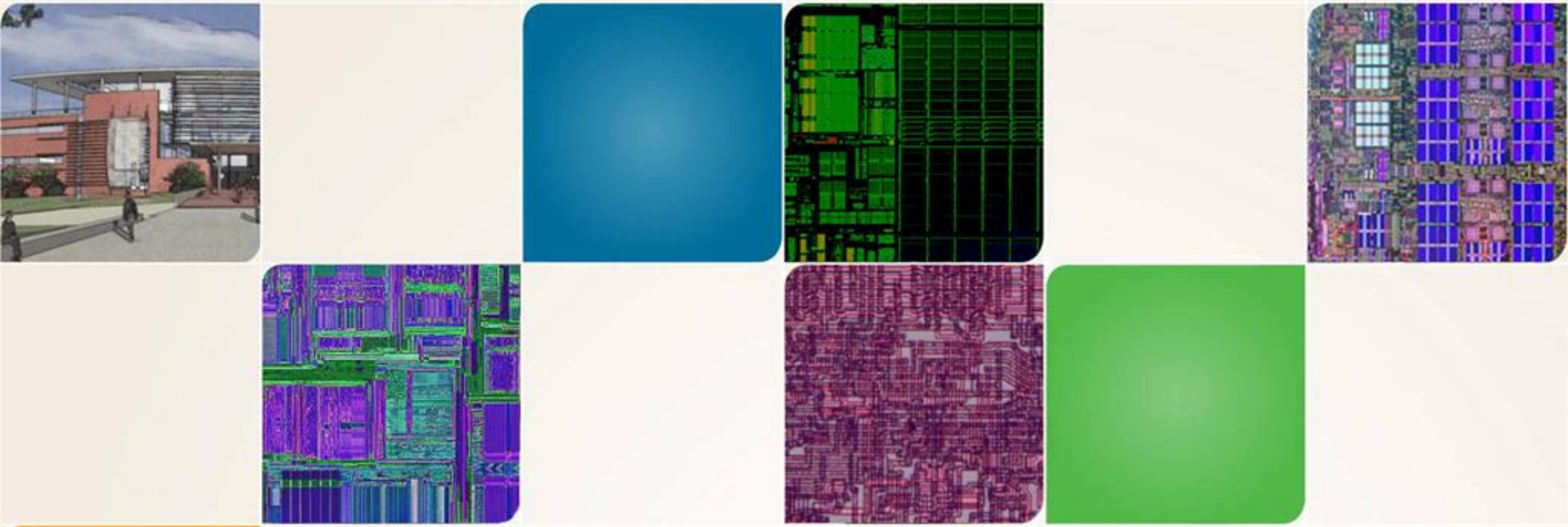

CS4803DGC Design Game Consoles

Spring 2010

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Georgia Tech College of Computing

OpenCL Spec

http://www.khronos.org/registry/cl/specs/opencl-1.0.48.pdf

OpenCL

- OpenCL (open computing Language): a framework for writing programs that execute across heterogeneous platforms considering CPUs, GPUs, and other processors.
- Initiated by Apple Inc. Now AMD, Intel, NVIDIA, etc.
- AMD gave up CTM (close to Metal) and decided to support OpenCL
- Nvidia will full support openCL1.0

Participating companies.

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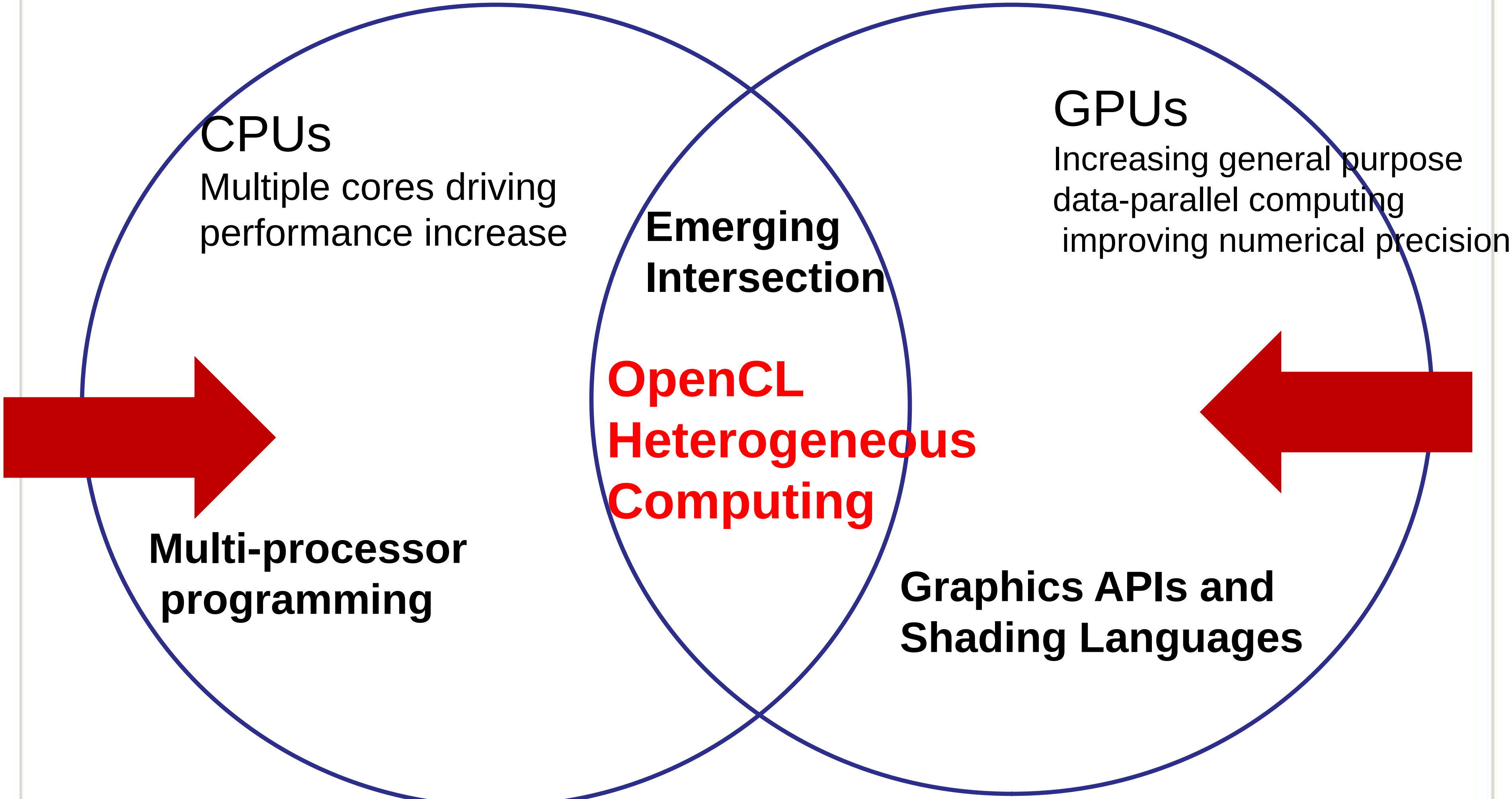
Processor Parallelism



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OpenCL standard …

- Supports both data- and task-based parallel programming models (CPU: task, GPU: data)
- Utilizes a subset of ISO C99 with extensions for parallelism
- Defines consistent numerical requirements based on IEEE 754
- Defines a configuration profile for handheld and embedded devices
- Efficiently interoperates with OpenGL, OpenGL ES and other graphics APIs

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Impacts of openCL

- Software developers write parallel programs that will run on many devices
- Hardware developers target openCL
- Enables OpenCL on mobile and embedded silicon

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OpenCL Architecture

- Platform Model
- Memory Model
- Execution Model
- Programming Model

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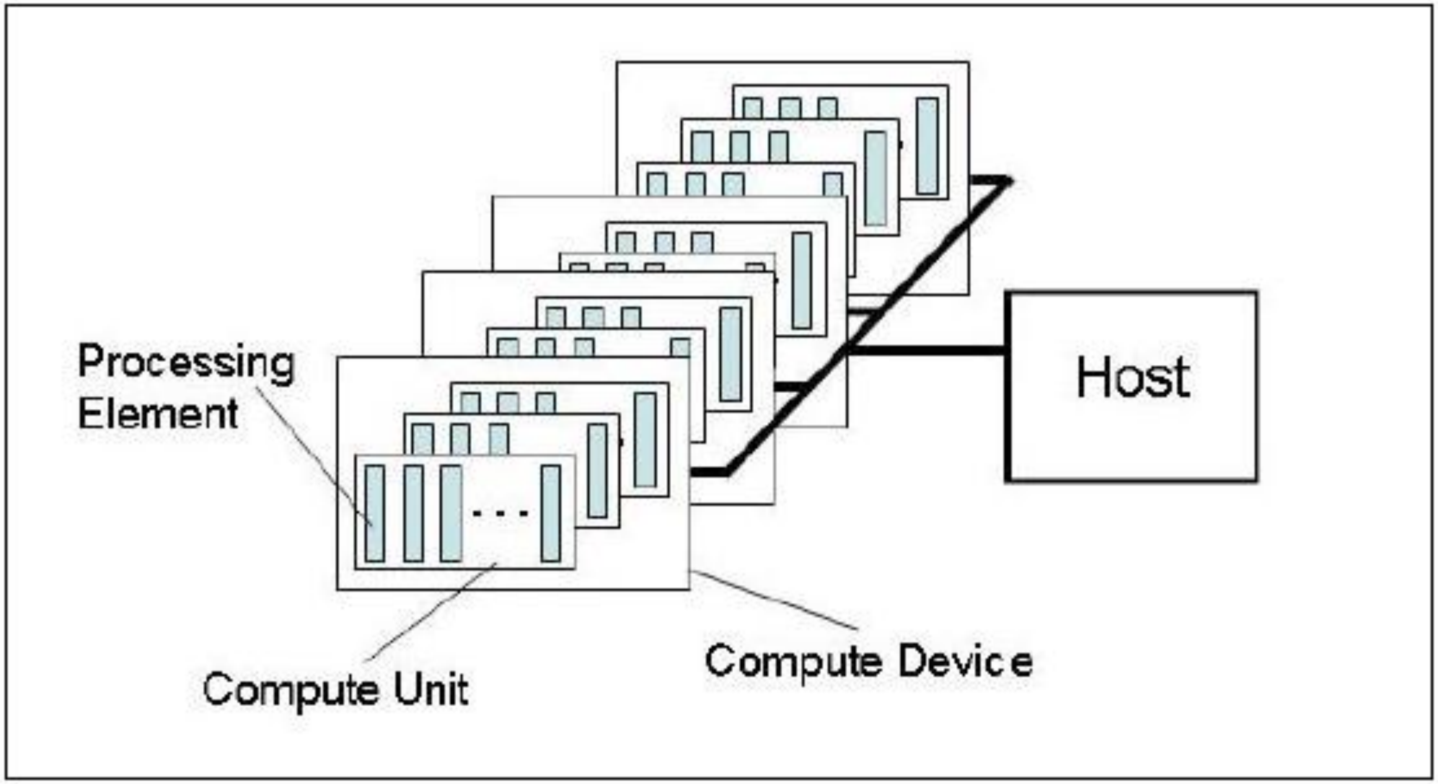
Platform Model



One Host+ one ore more compute devices

-Each compute device is composed of one or more compute units

-Each compute unit is further divided into one or more processing units

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Execution Model

- OpenCL Program:
  - Kernels
    - Basic unit of executable code – similar to C function
    - Data-parallel or task-parallel
  - Host Program
    - Collection of compute kernels and internal functions
    - Analogous to a dynamic library

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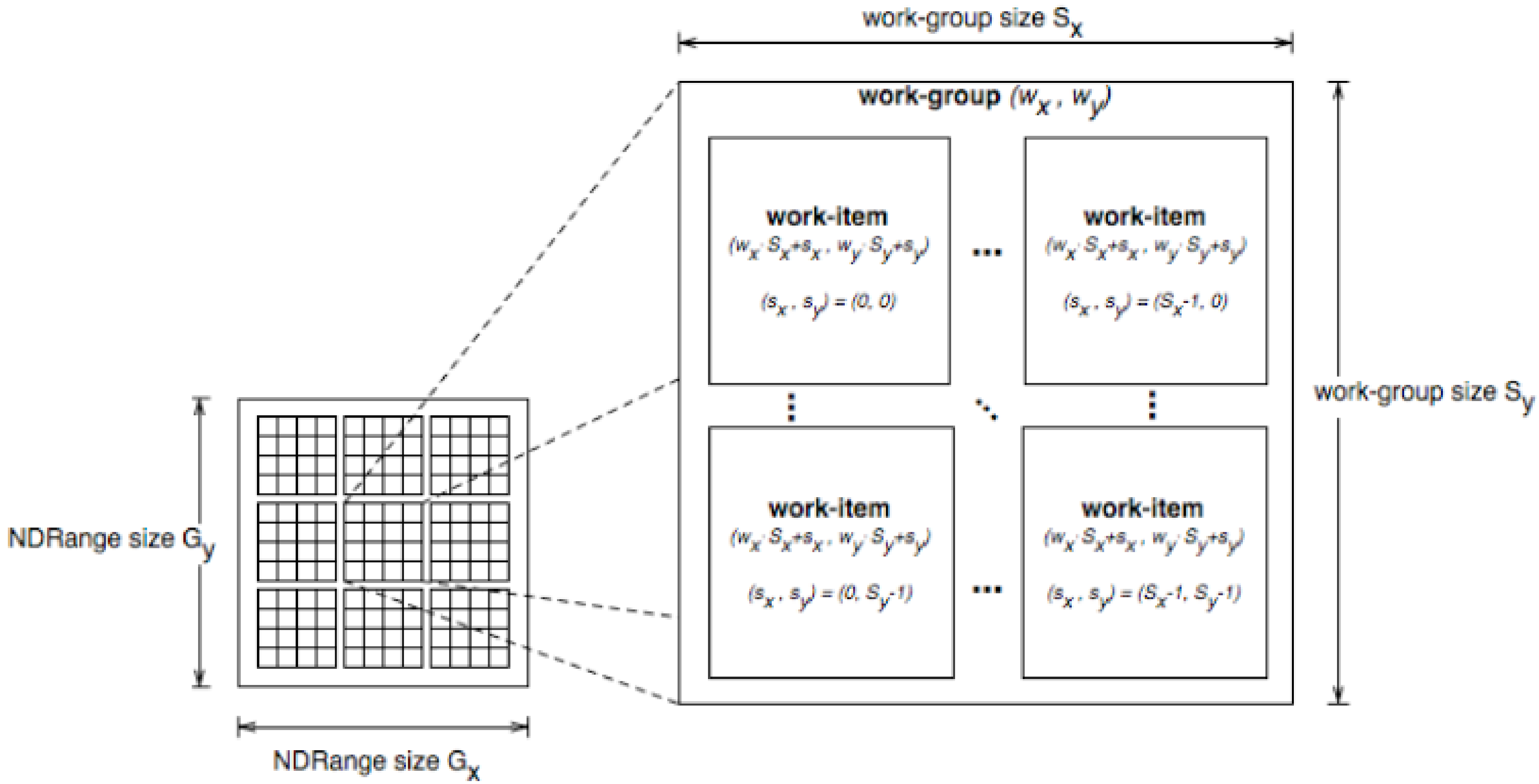
Execution Model

- **Kernel Execution**
  - The host program invokes a kernel over an index space called an ***NDRange***
    - NDRange = “N-Dimensional Range”
    - NDRange can be a 1, 2, or 3-dimensional space
  - A single kernel instance at a point in the index space is called a ***work-item***
    - Work-items have unique global IDs from the index space
    - **CUDA thread Ids**
  - Work-items are further grouped into ***work-groups***
    - Work-groups have a unique work-group ID
    - Work-items have a unique local ID within a work-group
    - CUDA Block IDs

An Example of NDR



Total number of work-items = G_x x G_y
Size of each work-group = S_x x S_y

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Context and Command Queues

- **Contexts are used to contain and manage the state of the "world"**
- **Kernels are executed in contexts defined and manipulated by the host**
  - Devices
  - Kernels - OpenCL functions
  - Program objects - kernel source and executable
  - Memory objects
- **Command-queue - coordinates execution of kernels**
  - Kernel execution commands
  - Memory commands - transfer or mapping of memory object data
  - Synchronization commands - constrains the order of commands
- **Applications queue compute kernel execution instances**
  - Queued in-order
  - Executed in-order or out-of-order
  - Events are used to implement appropriate synchronization of execution instances

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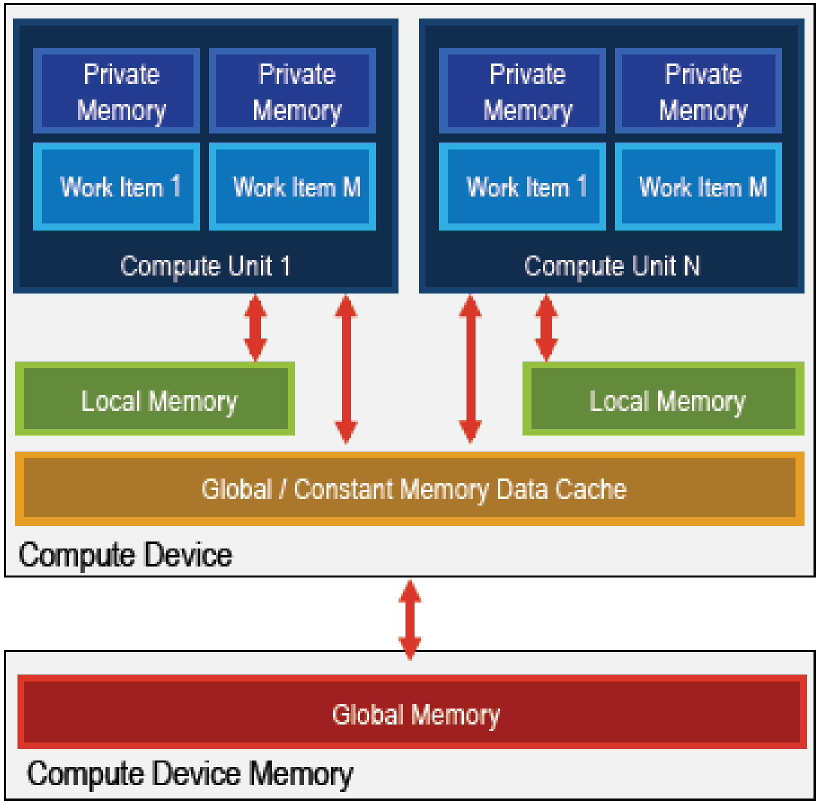
Memory Model

- Shared memory
  - Relaxed consistency
  - (similar to CUDA)
- Global memory
  - Global memory in CUDA
- Constant memory
  - Constant memory in CUDA
- Local memory (local memory to work group)
  - Shared memory in CUDA
- Private memory (private to a work item)
  - local memory in CUDA



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Memory Region

	Global	Constant	Local	Private
Host	Dynamic allocation Read/write access	Dynamic allocation Read/write access	Dynamic allocation No access	Dynamic allocation No access
Kernel	No allocation Read/Write access	Static allocation Read-only access	Static allocation Read/write access	Static allocation Read/write access

Memory Consistency

- a relaxed consistency memory model
  - Across work-items (threads) no consistency
  - Within a work-item (thread) load/store consistency → in order execution
  - Consistency of memory shared between commands are enforced through synchronization

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Data Parallel Programming Model

- **Define N-Dimensional computation domain**
  - Each independent element of execution in an N-Dimensional domain is called a *work-item*
  - N-Dimensional domain defines the total number of work-items that execute in parallel = *global work size*
- **Work-items can be grouped together — *work-group***
  - Work-items in group can communicate with each other
  - Can synchronize execution among work-items in group to coordinate memory access
- **Execute multiple work-groups in parallel**
  - Mapping of global work size to work-group can be implicit or explicit

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Task Parallel Programming Model

- Data-parallel execution model must be implemented by all OpenCL compute devices
- Users express parallelism by
  – using vector data types implemented by the device,
  – enqueuing multiple tasks, and/or
  – enqueuing native kernels developed using a programming model orthogonal to OpenCL.

Synchronization

- Work-items in a single-work group
  - Similar to _synchthreads ();
- Synchronization points between commands and command-queues
  - Similar to multiple kernels in CUDA but more generalized.
  - Command-queue barrier
    - Ensure all previously queued commands are executed and memory are reflected.
  - Waiting on an event.

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OpenCL Framework

- **OpenCL Platform layer**: The platform layer allows the host program to discover openCL devices and their capabilities and to create contexts.
- **OpenCL Runtime:** The runtime allows the host program to manipulate contexts once they have been created.
- **OpenCL Compiler:** The OpenCL compiler creates program executables that contain OpenCL kernels

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Platform Layer

- **Platform layer allows applications to query for platform specific features**
- **Querying platform info (i.e., OpenCL profile)**
- **Querying devices**
  - *clGetDeviceIDs()*
    - Find out what compute devices are on the system
    - Device types include CPUs, GPUs, or Accelerators
  - *clGetDeviceInfo()*
  - Queries the capabilities of the discovered compute devices such as:
    - Number of compute cores
    - NDRange limits
    - Maximum work-group size
    - Sizes of the different memory spaces (constant, local, global)
    - Maximum memory object size

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Platform Layer

- **Creating contexts**

```
cl_context    clCreateContext (cl_context_properties properties,
                               cl_uint num_devices,
                               const cl_device_id *devices,
                               void (*pfn_notify)(const char *errinfo,
                                                  const void *private_info, size_t cb,
                                                  void *user_data),
                               void *user_data,
                               cl_int *errcode_ret)
```

  - Contexts are used by the OpenCL runtime to manage objects and execute kernels on one or more devices
  - Contexts are associated to one or more devices
  - Multiple contexts could be associated to the same device
  - *clCreateContext() and clCreateContextFromType() returns a handle to the created contexts*

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Command-Queues

- Command-queues store a set of operations to perform
- Command-queues are associated to a context
- Multiple command-queues can be created to handle independent commands that don't require synchronization
- Execution of the command-queue is guaranteed to be completed at sync points

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Memory Objects

- **Buffer objects**
  - One-dimensional collection of objects (like C arrays)
  - Valid elements include scalar and vector types as well as user defined structures
  - Buffer objects can be accessed via pointers in the kernel
- **Image objects**
  - Two- or three-dimensional **texture, frame-buffer, or images**
  - Must be addressed through built-in functions
- **Sampler objects**
  - Describes how to sample an image in the kernel
  - Addressing modes
  - Filtering modes

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OpenCL C for Compute Kernels

- **Derived from ISO C99**
  - A few restrictions: recursion, function pointers, functions in C99 standard headers ...
  - Preprocessing directives defined by C99 are supported
- **Built-in Data Types**
  - Scalar and vector data types, Pointers
  - Data-type conversion functions: convert_type<_sat><_roundingmode>
  - Image types: image2d_t, image3d_t and sampler_t
- **Built-in Functions — Required**
  - work-item functions, math.h, read and write image
  - Relational, geometric functions, synchronization functions
- **Built-in Functions — Optional**
  - double precision, atomics to global and local memory
  - selection of rounding mode, writes to image3d_t surface

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OpenCL C language Restrictions

- Pointers to functions are not allowed
- Pointers to pointers allowed within a kernel, but not as an argument
- Bit-fields are not supported
- Variable length arrays and structures are not supported
- Recursion is not supported
- Writes to a pointer of types less than 32-bit are not supported
- Double types are not supported, but reserved
  - (Newer CUDA support this)
- 3D Image writes are not supported
- Some restrictions are addressed through extensions

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OpenCL vs. CUDA

	OpenCL	CUDA
Execution Model	Work-groups/work-items	Block/Thread
Memory model	Global/constant/local/priv ate	Global/constant/shared/lo cal + Texture
Memory consistency	Weak consistency	Weak consistency
Synchronization	Synchronization using a work-group barrier (between work-items)	Using synch_threads Between threads
Compilation	Dynamic compilation	Static compilation

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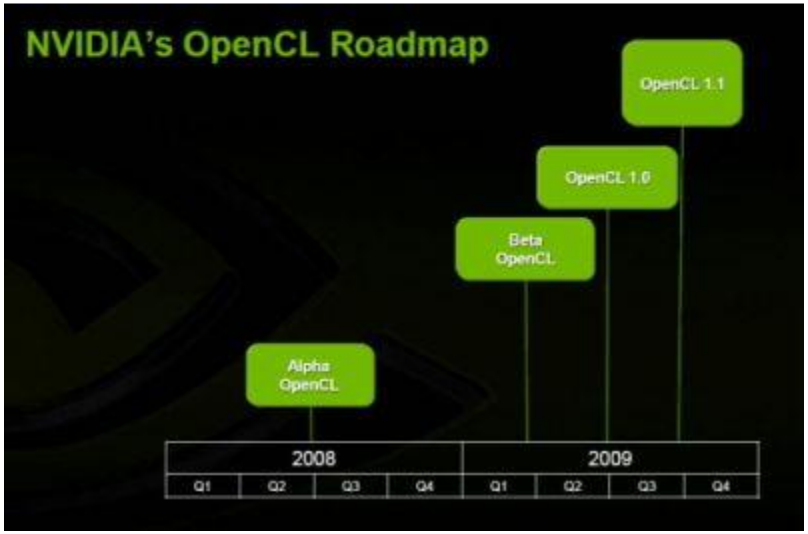
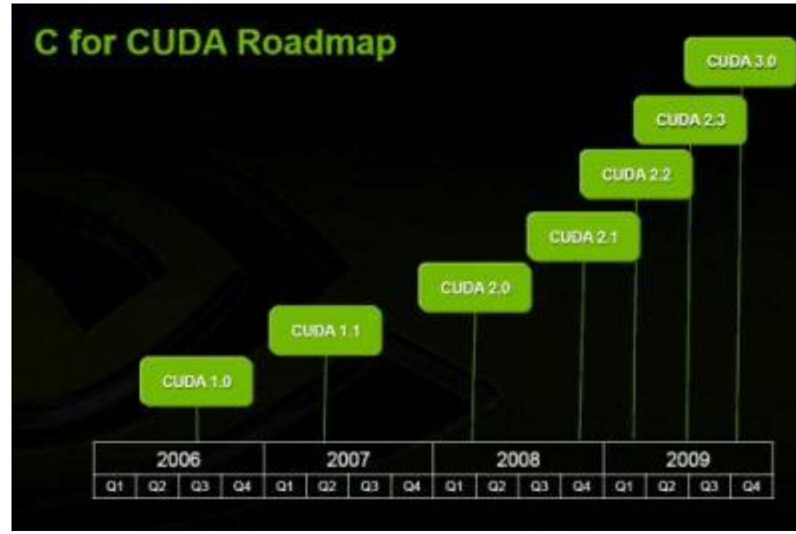
CUDA ? OpenCL?





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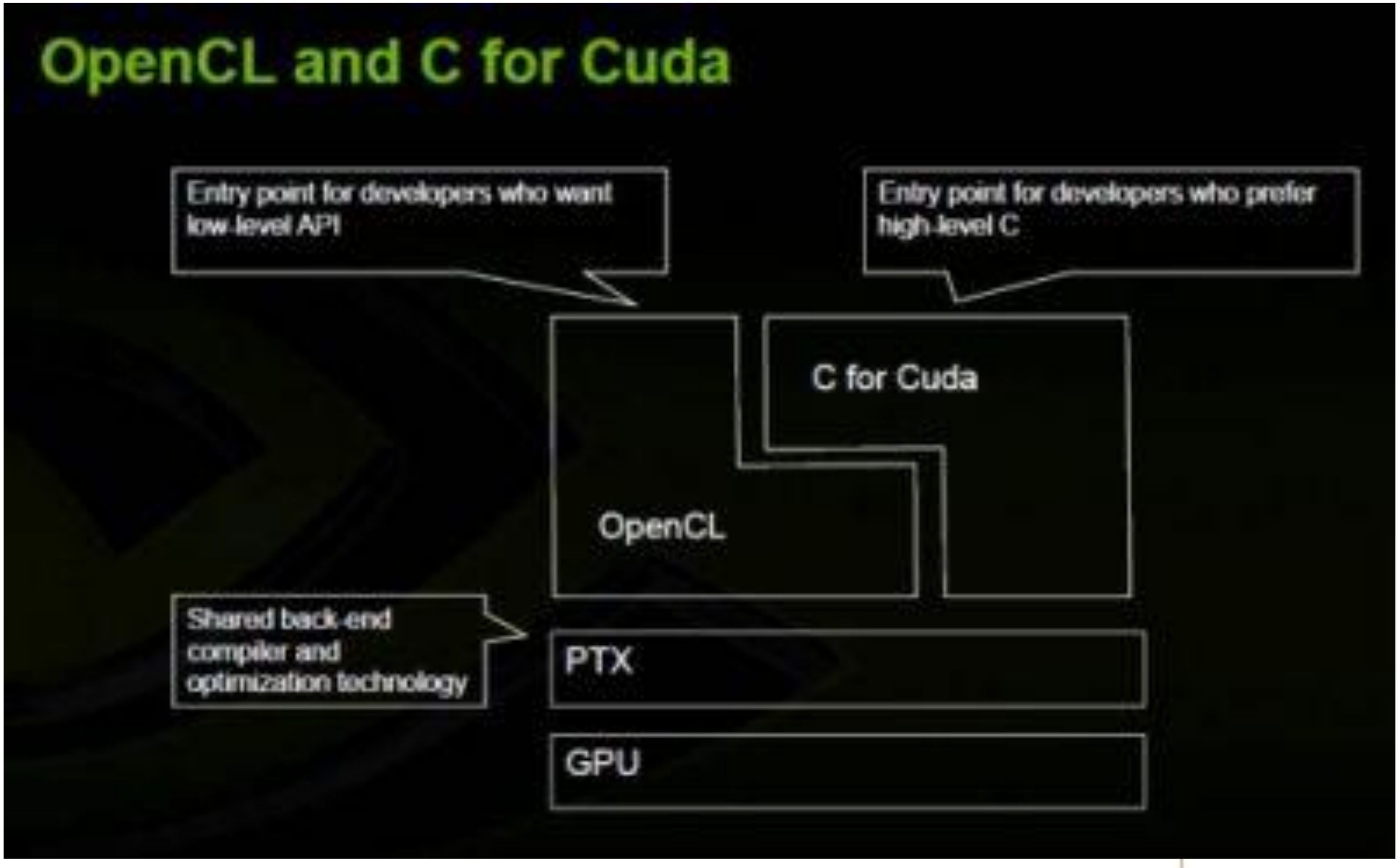
OpenCL and C for CUDA



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