CPSC/ECE 4780/6780

General-Purpose Computation on Graphical Processing Units (GPGPU)

Lecture 3: Introduction to CUDA

Recaps from Last Lecture

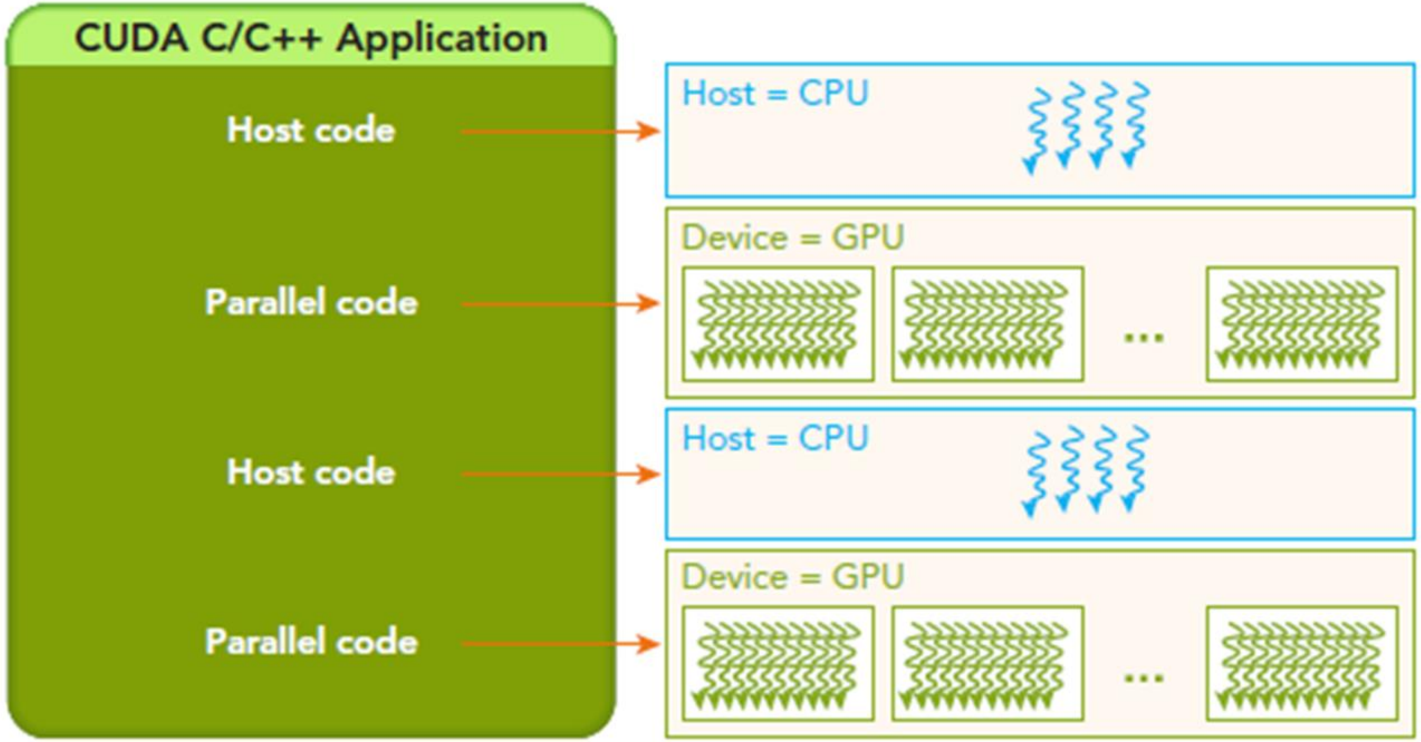
- What is GPU?
- History of GPUs
- Architecture of GPU
- CPU/GPU comparisons
- Why should we use GPUs?
- CPU+GPU acceleration
- GPGPU programming

What is CUDA?

- CUDA – “Compute Unified Device Architecture”
- General-purpose parallel computing platform and programming model
- Created by NVIDIA first in 2007
- Written mostly like C

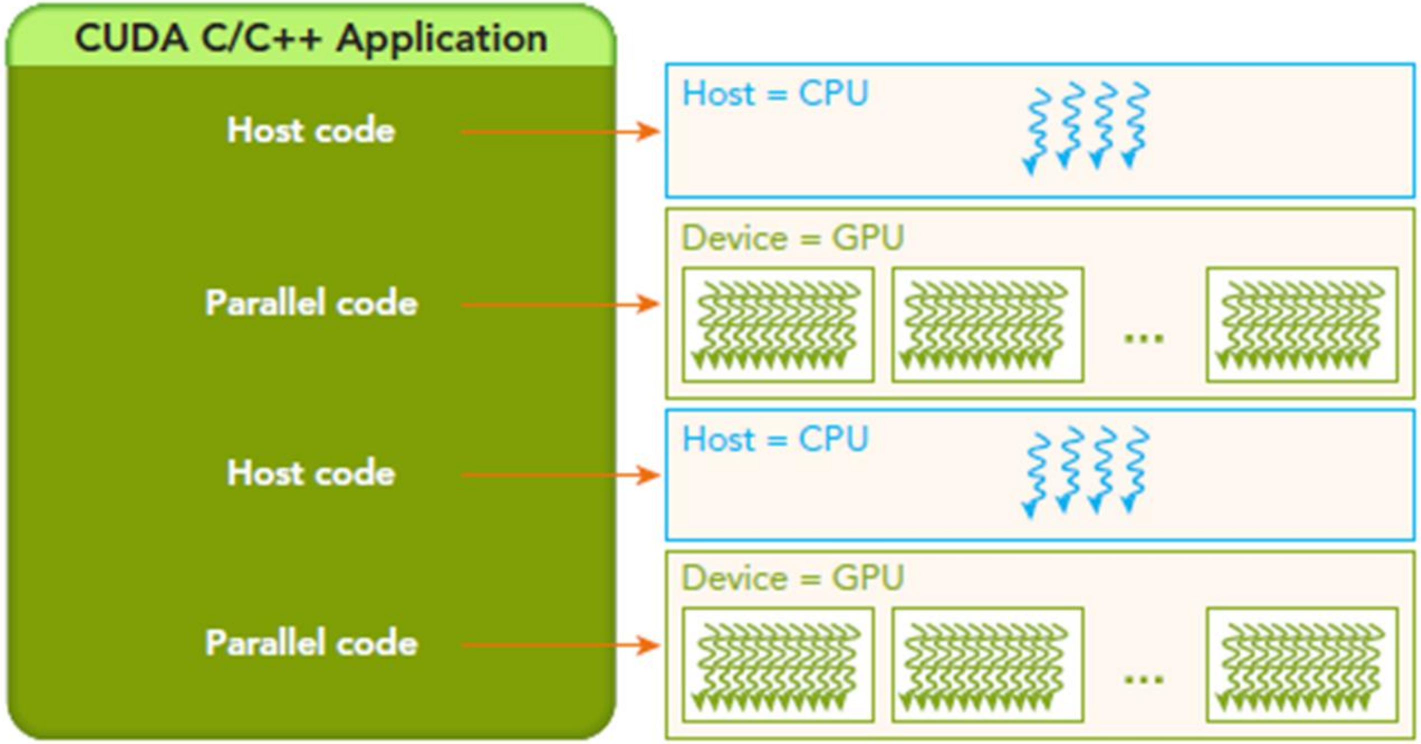
CUDA Programming Structure

- Integrated host + device application C program
  - Host – CPU and its memory
    - Serial or modestly parallel parts
    - Written in ANSI C
  - Device – GPU and its memory
    - Highly parallel parts
    - Written in CUDA C
    - “Kernel”



Processing Flow of a CUDA Program

- Copy input data from CPU memory to GPU memory
- Invoke kernels to operate on the data stored in GPU memory
- Copy data back from GPU memory to CPU memory



Memory Management and Data Transfer

- Host and device memory are separate entities
  - Host pointers point to CPU memory
    - May be passed to/from device code
    - May not be dereferenced in device code
  - Device pointers point to GPU memory
    - May be passed to/from host code
    - May not be dereferenced in host code

STANDARD C FUNCTIONS	CUDA C FUNCTIONS
`malloc`	`cudaMalloc`
`memcpy`	`cudaMemcpy`
`memset`	`cudaMemset`
`free`	`cudaFree`

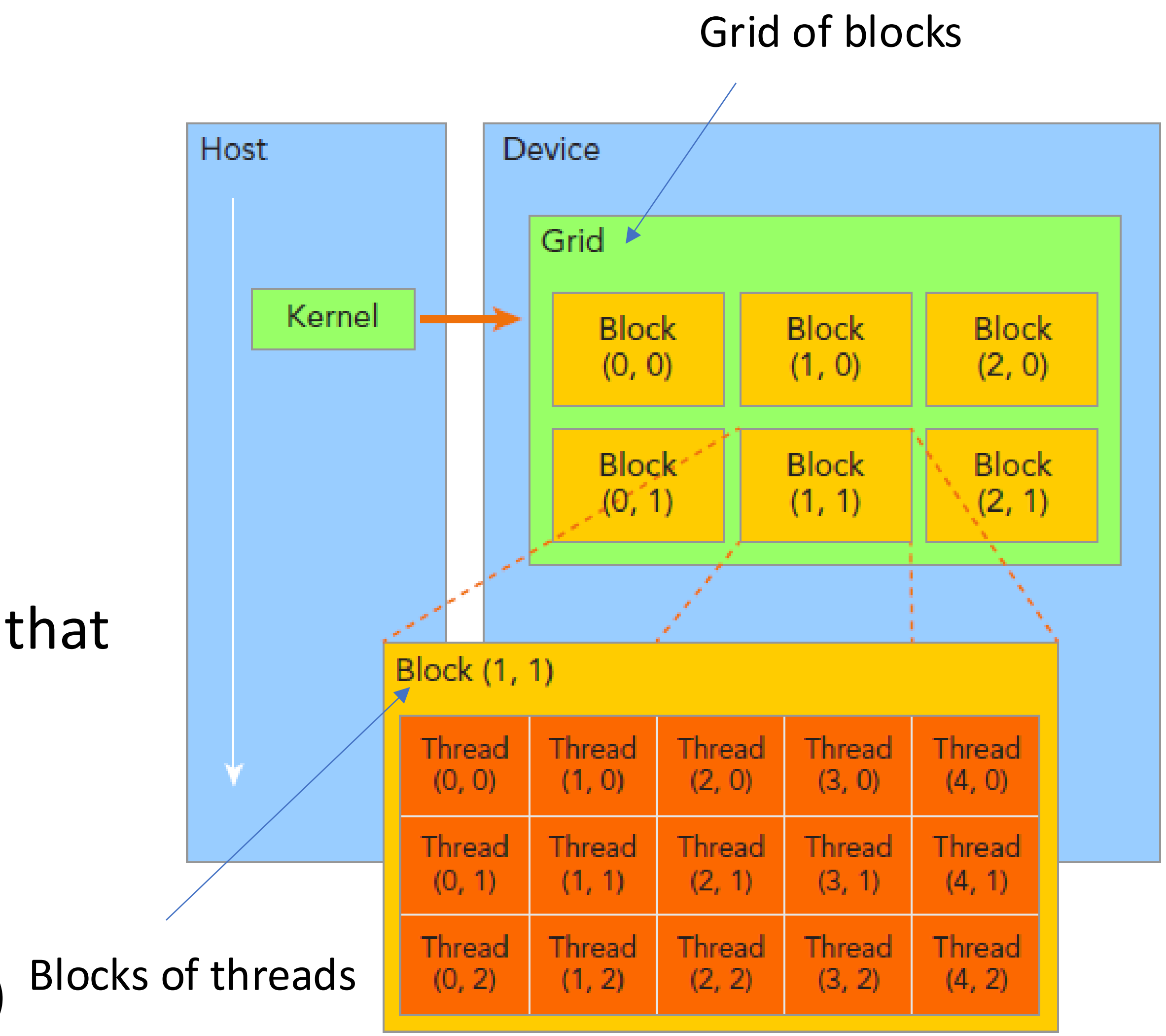
Host and device memory functions

CUDA Function Declaration

- CUDA extensions to C functional declaration
  - __global__: indicates a CUDA kernel function
    - executed on the device
    - Only callable from the host
    - Must have a void return type
  - __device__: indicates a CUDA device function
    - Executed on the device
    - Only callable from the device
  - __host__: indicates a CUDA host function
    - Executed on the host
    - Only callable from the host

Organizing Threads

- Two-level thread hierarchy
  - Grids of blocks
  - Blocks of threads
- All threads in a grid share the same global memory space
- A thread block is a group of threads that can cooperate with each other by:
  - Block-local synchronization
  - Block-local shared memory
- Threads coordinates:
  - blockIdx (block index within a grid)
  - threadIdx (thread index within a block)
  - Type: unit3 (.x, .y, .z)

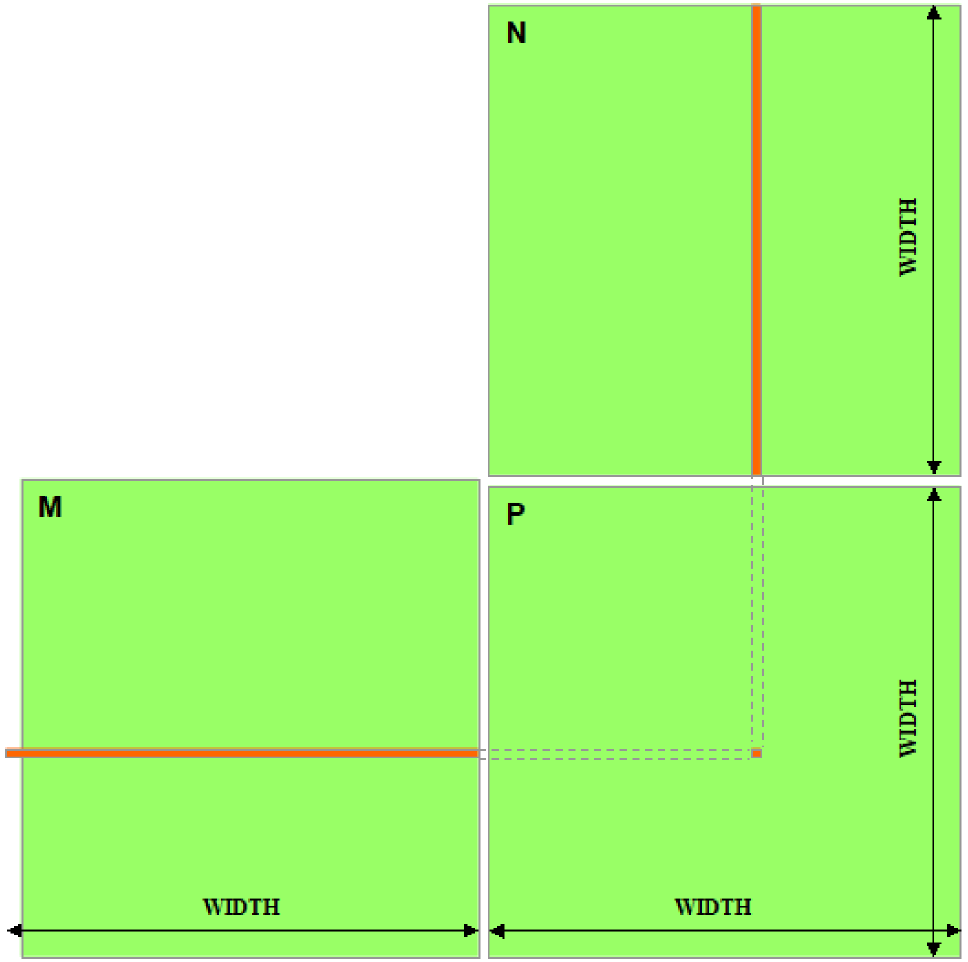


A thread hierarchy structure with a 2D grid containing 2D blocks

Matrix Multiplication on CPU

- M * N => P

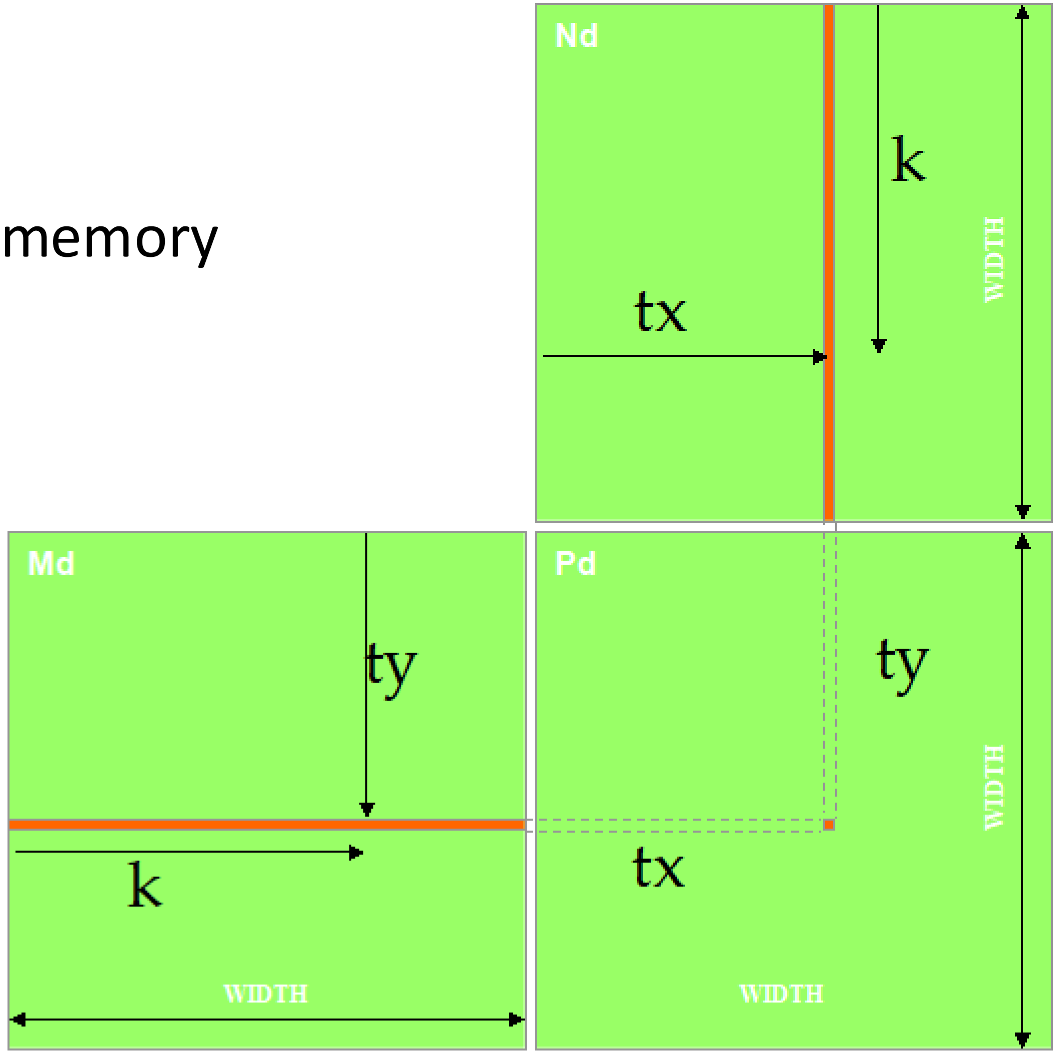
```
void MatrixMulOnHost(float* M, float* N, float* P, int Width)
{
    for (int i = 0; i < Width; ++i)
        for (int j = 0; j < Width; ++j) {
            double sum = 0;
            for (int k = 0; k < Width; ++k) {
                double a = M[i * width + k];
                double b = N[k * width + j];
                sum += a * b;
            }
            P[i * Width + j] = sum;
        }
```



Matrix Multiplication on GPU

- One thread calculates one element of P
- M and N are loaded width times from global memory

```
__global__ void MatrixMulKernel(float* Md, float* Nd, float* Pd, int Width)
{
   int tx = threadIdx.x;
   int ty = threadIdx.y;
   float Pvalue = 0;
   for (int k = 0; k < Width; ++k) {
      float Melement = Md[threadIdx.y*Width+k];
      float Nelement = Nd[k*Width+threadIdx.x];
      Pvalue += Melement * Nelement;
   }
  Pd[threadIdx.y*Width+threadIdx.x] = Pvalue;
}
```



CUDA Device Properties

- Get the count of CUDA devices
  - int count;
  - cudaGetDeviceCount(&count);
- Query relevant information of a device
  - cudaDeviceProp prop;
  - cudaGetDeviceProperties(&prop, i);
- Set device property and choose a proper device
  - int dev;
  - cudaDeviceProp prop;
  - prop.major = 1;
  - prop.minor = 3
  - cudaChooseDevice(&dev, &prop);
  - cudaSetDevice(dev);

Coding Examples

- Coding
  - First CUDA program: Hello World
  - Add two numbers
  - Add two vectors
    - By blockIdx
    - By threadIdx
    - Combined
  - Query device property
- Compilation: use nvcc

Option 1: Running your code on Palmetto Cluster

Palmetto is comprised of 1786 compute nodes (totaling 34916 CPU cores), and features:

- 1786 compute nodes, totaling 34916 cores
- Over 850 nodes are equipped with 2x NVIDIA Tesla GPUs (K20, K40, P100, V100 and A100)

Connecting via SSH

- ssh username@slogin.palmetto.clemson.edu

Or via Open OnDemand (a browser-based GUI)

- ondemand.rcd.clemson.edu

Load CUDA module:

cat /etc/hardware-table

- module load cuda gcc

Compile .cu code with "nvcc", e.g.,

- nvcc helloworld.cu
- nvcc –o helloworld helloworld.cu

https://docs.rcd.clemson.edu/palmetto/connect/ssh/

Or Option 2: Running your code on School of Computing machines

ssh username@titan[1..6].computing.clemson.edu
Or through Virtual Desktop (recommended for programs with graphical output):
https://virtual.computing.clemson.edu

https://computing.clemson.edu/help/virtual.html

Open OnDemand Screenshot