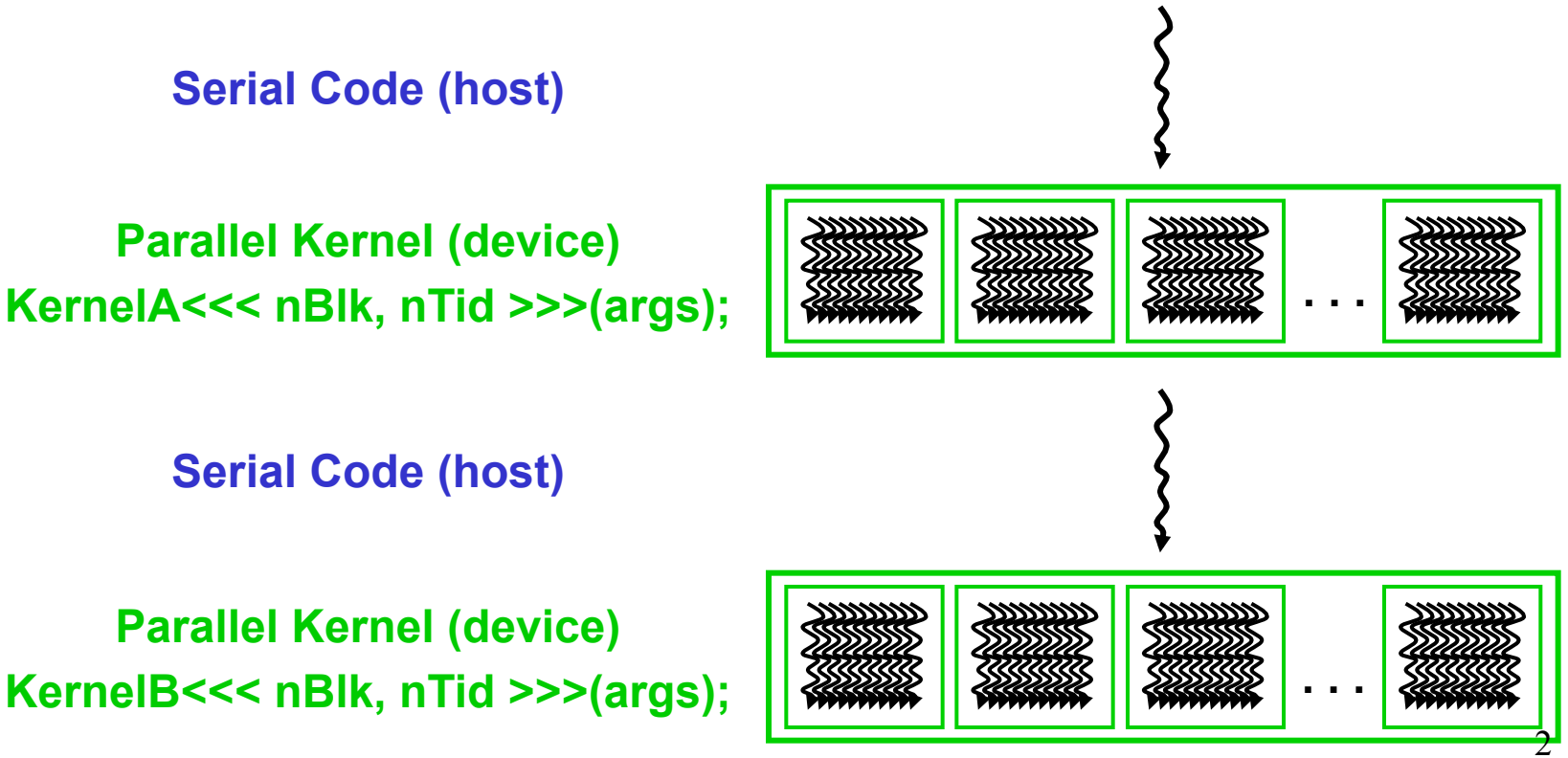
CS/EE 217
GPU Architecture and Programming

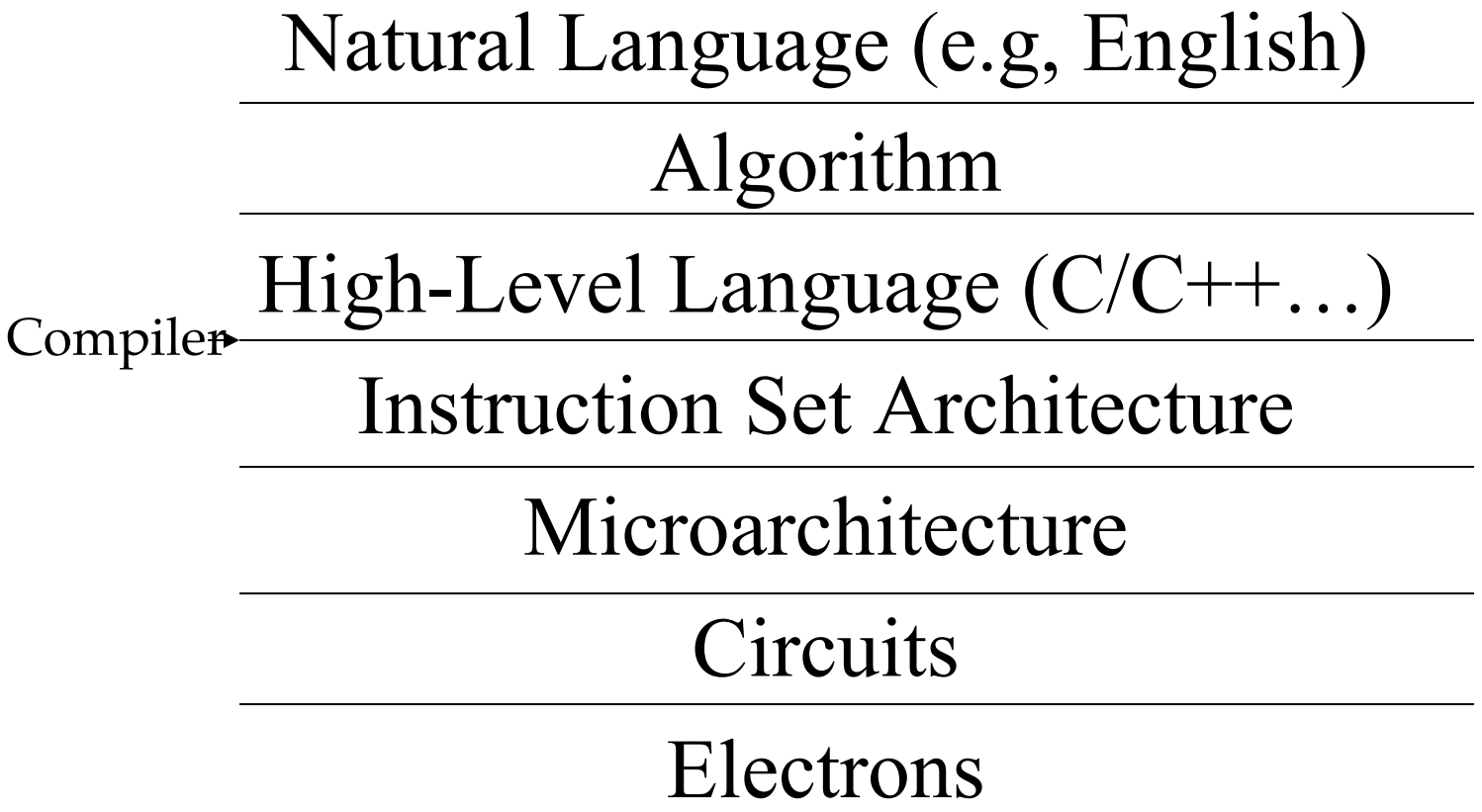
Lecture 2:
Introduction to CUDA C

CUDA /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



From Natural Language to Electrons



The ISA

- An Instruction Set Architecture (ISA) is a contract between the hardware and the software.

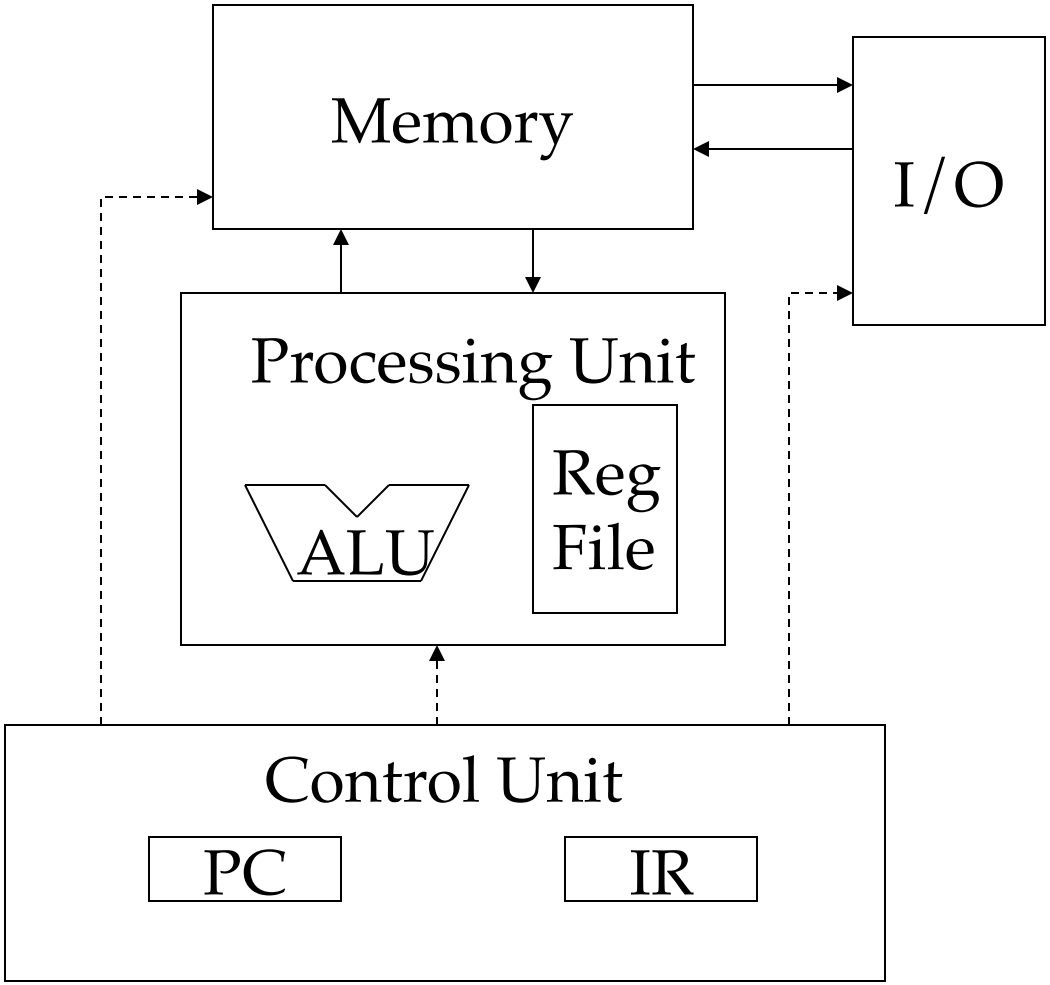
- As the name suggests, it is a set of instructions that the architecture (hardware) can execute.

A program at the ISA level

- A program is a set of instructions stored in memory that can be read, interpreted, and executed by the hardware.

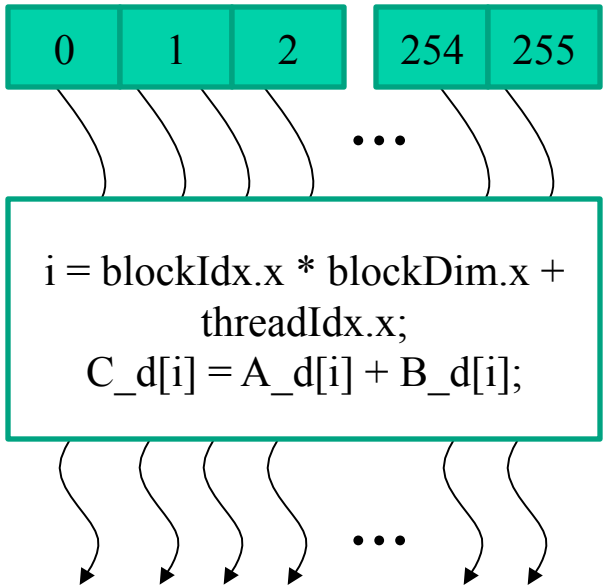
- Program instructions operate on data stored in memory or provided by Input/Output (I/O) device.

The Von-Neumann Model



Arrays of Parallel Threads

- A CUDA kernel is executed by a grid (array) of threads
  - All threads in a grid run the same kernel code (SPMD)
  - Each thread has an index that it uses to compute memory addresses and make control decisions



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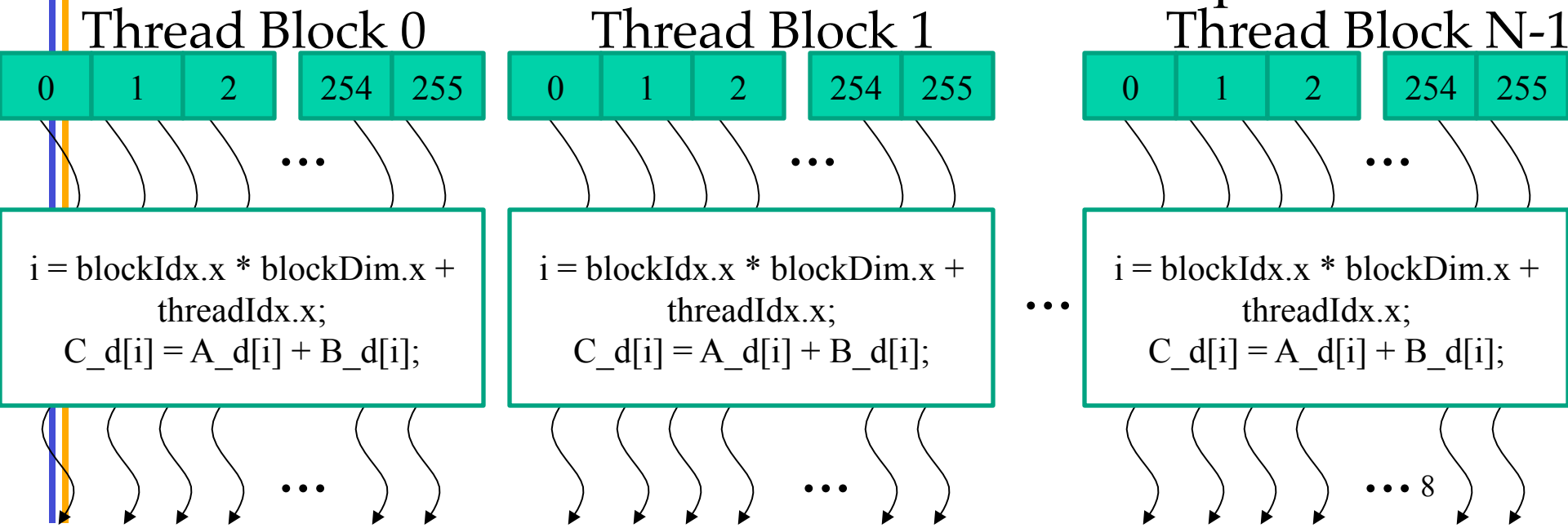
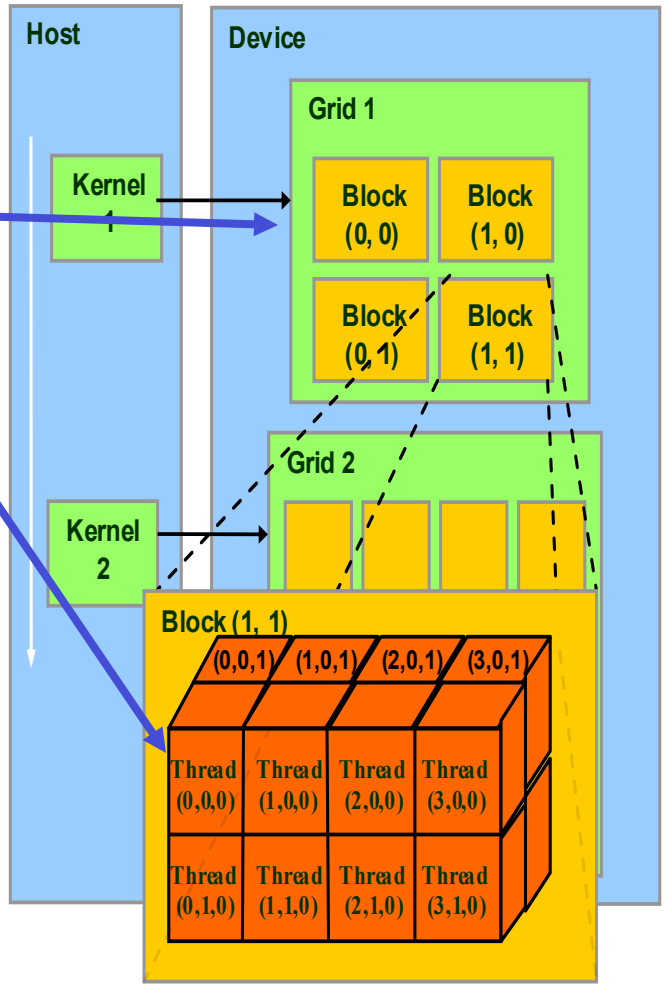
Thread Blocks: Scalable Cooperation

- Divide thread array into multiple blocks
  - Threads within a block cooperate via **shared memory, atomic operations** and **barrier synchronization**
  - Threads in different blocks cannot cooperate

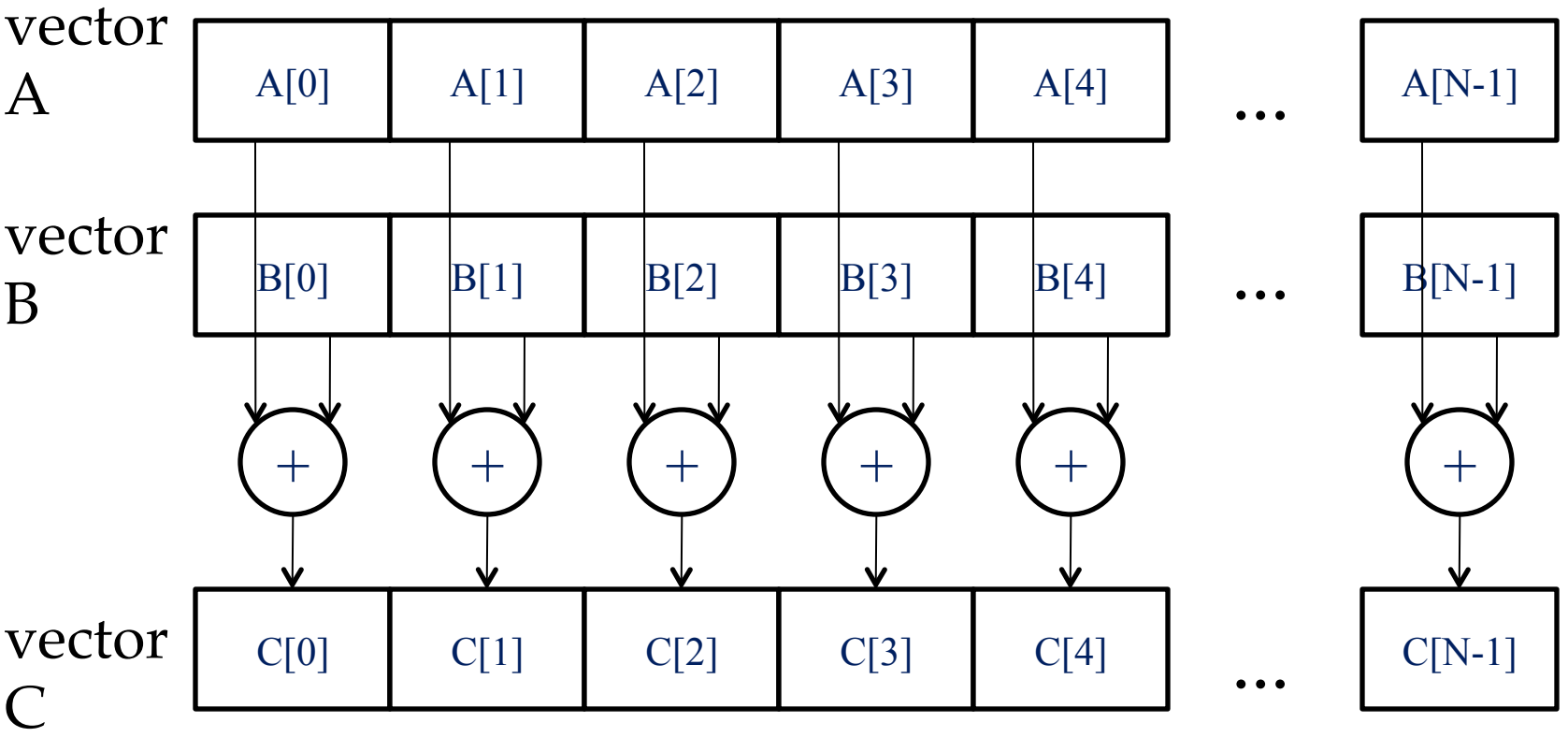


blockIdx and threadIdx

- Each thread uses indices to decide what data to work on
  - blockIdx: 1D, 2D, or 3D (CUDA 4.0)
  - threadIdx: 1D, 2D, or 3D
- Simplifies memory addressing when processing multidimensional data
  - Image processing
  - Solving PDEs on volumes
  - …



Vector Addition – Conceptual View

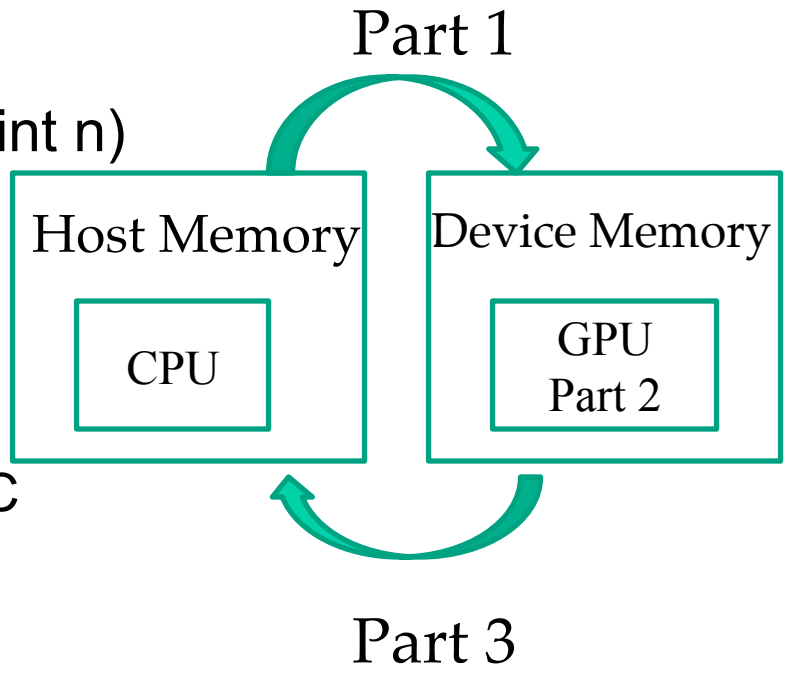


Vector Addition – Traditional C Code

```
// Compute vector sum C = A+B
void vecAdd(float* A, float* B, float* C, int n)
{
  for (i = 0, i < n, i++)
    C[i] = A[i] + B[i];
}

int main()
{
    // Memory allocation for A_h, B_h, and C_h
    // I/O to read A_h and B_h, N elements
    …
    vecAdd(A_h, B_h, C_h, N);
}
```

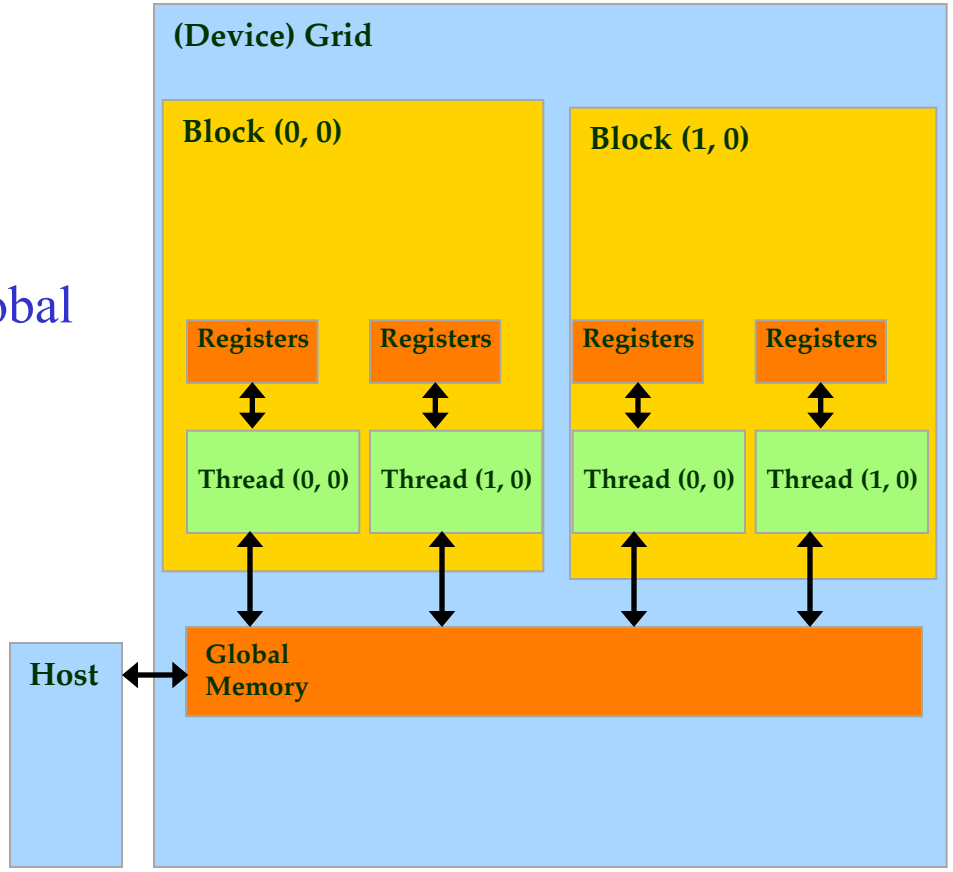
Heterogeneous Computing vecAdd Host Code

```
#include <cuda.h>
void vecAdd(float* A, float* B, float* C, int n)
{
    int size = n* sizeof(float);
   float* A_d, B_d, C_d;
    …
1. // Allocate device memory for A, B, and C
    // copy A and B to device memory

2. // Kernel launch code – to have the device
    // to perform the actual vector addition

3. // copy C from the device memory
    // Free device vectors
}
```



Partial Overview of CUDA Memories

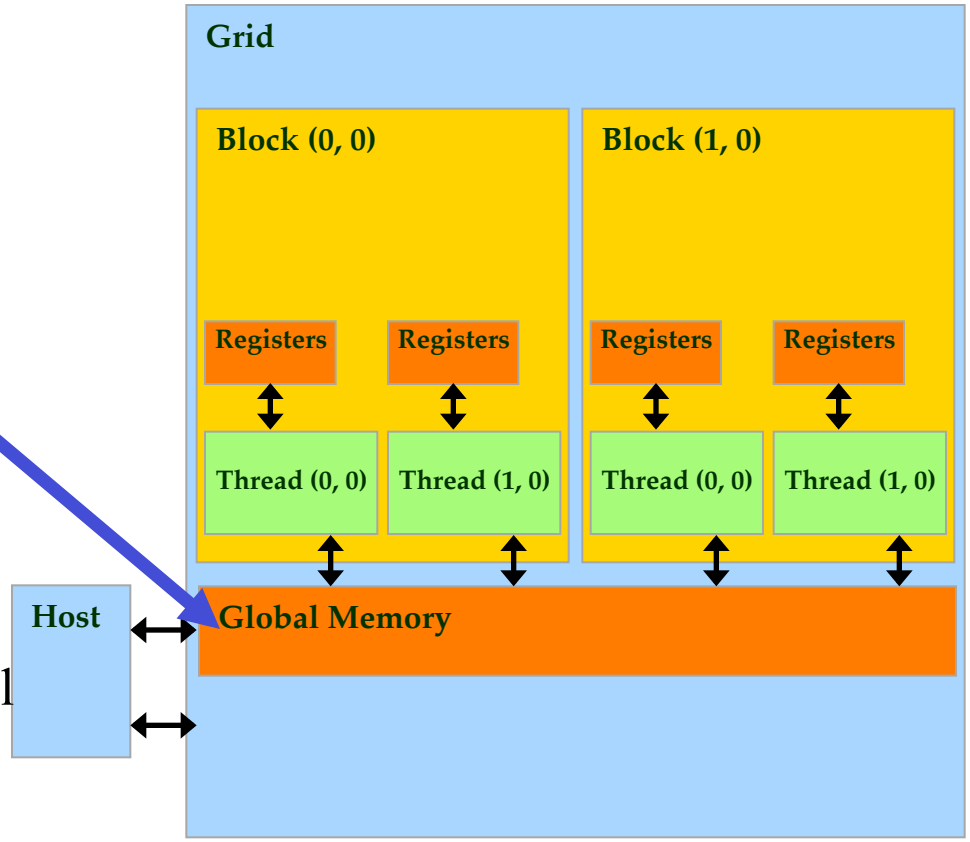
- Device code can:
  - R/W per-thread registers
  - R/W per-grid global memory
- Host code can
  - Transfer data to/from per grid global memory



We will cover more later.

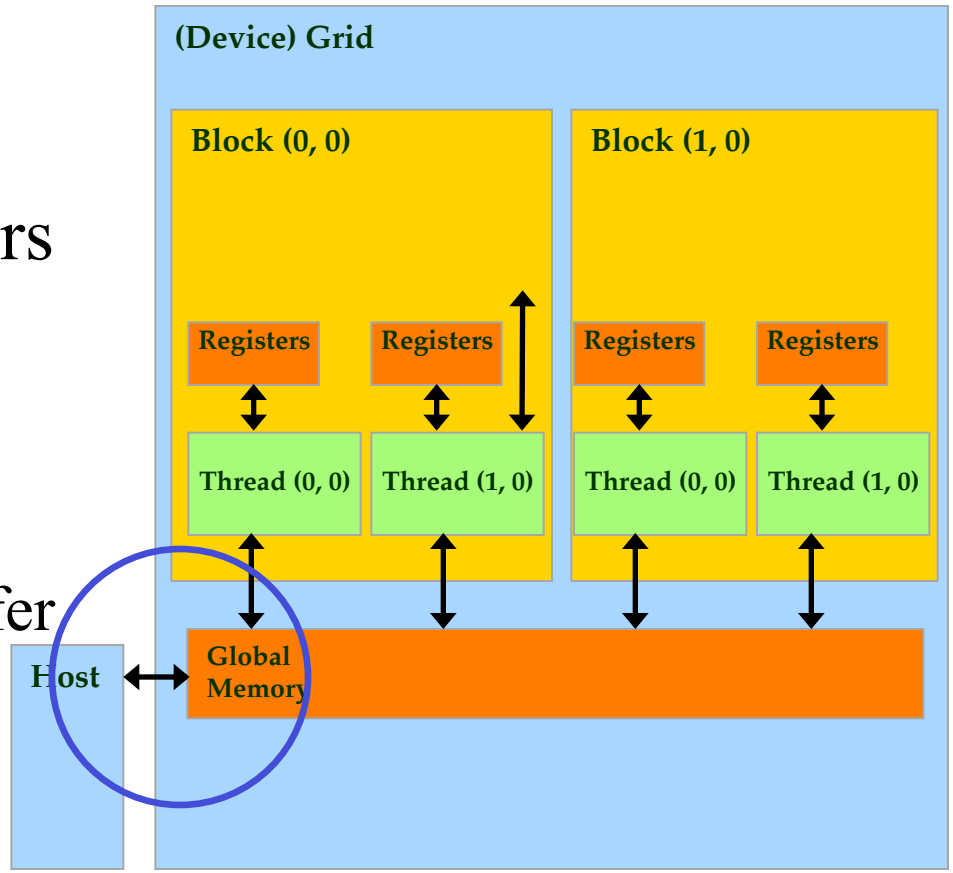
CUDA Device Memory Management API functions

- cudaMalloc()
  - Allocates object in the device global memory
  - Two parameters
    - **Address of a pointer** to the allocated object
    - **Size of** of allocated object in terms of bytes
- cudaFree()
  - Frees object from device global memory
    - **Pointer** to freed object



Host-Device Data Transfer API functions

- cudaMemcpy()
  - memory data transfer
  - Requires four parameters
    - Pointer to destination
    - Pointer to source
    - Number of bytes copied
    - Type/Direction of transfer
  - Transfer to device is asynchronous



```
void vecAdd(float* A, float* B, float* C, int n)
{
    int size = n * sizeof(float);
    float* A_d, B_d, C_d;

1. // Transfer A and B to device memory
     cudaMalloc((void **) &A_d, size);
     cudaMemcpy(A_d, A, size, cudaMemcpyHostToDevice);
     cudaMalloc((void **) &B_d, size);
     cudaMemcpy(B_d, B, size, cudaMemcpyHostToDevice);

      // Allocate device memory for
      cudaMalloc((void **) &C_d, size);

2.   // Kernel invocation code – to be shown later
   …
3.     // Transfer C from device to host
      cudaMemcpy(C, C_d, size,
cudaMemcpyDeviceToHost);
        // Free device memory for A, B, C
      cudaFree(A_d); cudaFree(B_d); cudaFree (C_d);
}
```

Check for API Errors in Host Code

```
cudaError_t err = cudaMalloc((void**)&d_A,size);

if (err!=cudaSuccess) {
      printf("%s in %s at line %d\n",
cudaGetErrorString(err), __FILE__, __LINE__);
      exit(EXIT_FAILURE);
}
```

Example: Vector Addition Kernel

Device Code

```
// Compute vector sum C = A+B
// Each thread performs one pair-wise addition
__global__
void vecAddKernel(float* A_d, float* B_d, float* C_d, int n)
{
    int i = threadIdx.x + blockDim.x * blockIdx.x;
    if(i<n) C_d[i] = A_d[i] + B_d[i];
}

int vectAdd(float* A, float* B, float* C, int n)
{
    // A_d, B_d, C_d allocations and copies omitted
    // Run ceil(n/256) blocks of 256 threads each
    vecAddKernel<<<ceil(n/256), 256>>>(A_d, B_d, C_d, n);
}
```

Example: Vector Addition Kernel

```
// Compute vector sum C = A+B
// Each thread performs one pair-wise addition
__global__
void vecAddkernel(float* A_d, float* B_d, float* C_d, int n)
{
    int i = threadIdx.x + blockDim.x * blockIdx.x;
    if(i<n) C_d[i] = A_d[i] + B_d[i];
}
```

Host Code

```
int vecAdd(float* A, float* B, float* C, int n)
{
 // A_d, B_d, C_d allocations and copies omitted
 // Run ceil(n/256) blocks of 256 threads each
  vecAddKernnel<<<ceil(n/256),256>>>(A_d, B_d, C_d, n);
}
```

More on Kernel Launch

Host Code

```
int vecAdd(float* A, float* B, float* C, int n)
{
 // A_d, B_d, C_d allocations and copies omitted
 // Run ceil(n/256) blocks of 256 threads each
  dim3 DimGrid(n/256, 1, 1);
  if (n%256) DimGrid.x++;
  dim3 DimBlock(256, 1, 1);

  vecAddKernnel<<<DimGrid,DimBlock>>>(A_d, B_d, C_d, n);
}
```

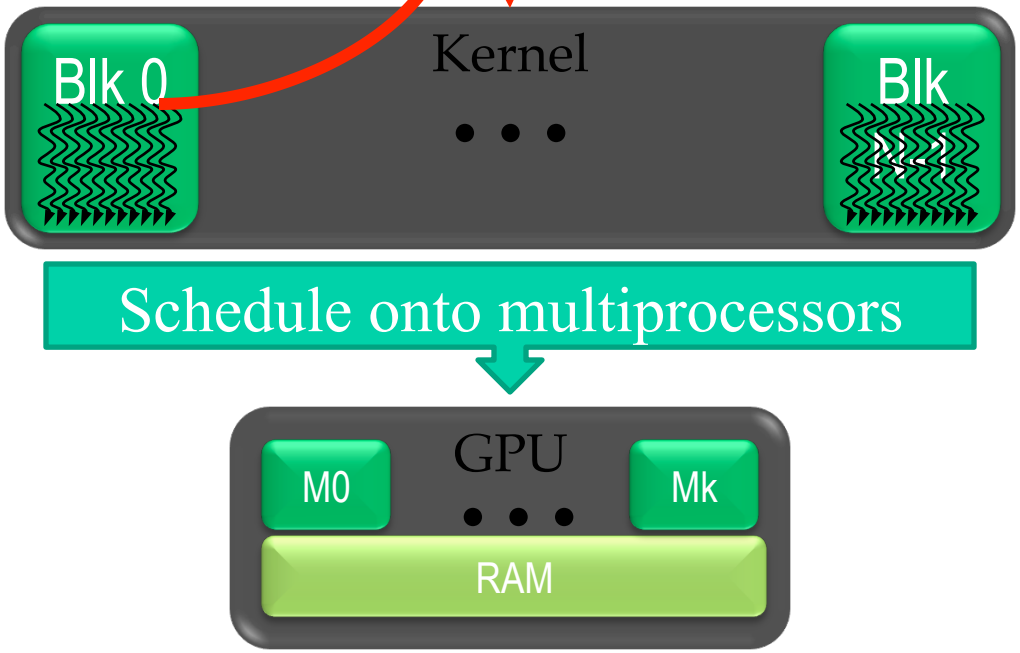
```
dim3 DimGrid((n-1)/256 + 1, 1, 1);
```

- Any call to a kernel function is asynchronous from CUDA 1.0 on, explicit synch needed for blocking

Kernel execution in a nutshell

```
__host__
Void vecAdd()
{
  dim3 DimGrid = (ceil(n/256,1,1);
  dim3 DimBlock = (256,1,1);

vecAddKernel<<<DimGrid,DimBlock>>>
(A_d,B_d,C_d,n);
}
```

```
__global__
void vecAddKernel(float *A_d,
     float *B_d, float *C_d, int n)
{
    int i = blockIdx.x * blockDim.x
      + threadIdx.x;

    if( i<n ) C_d[i] = A_d[i]+B_d[i];
}
```

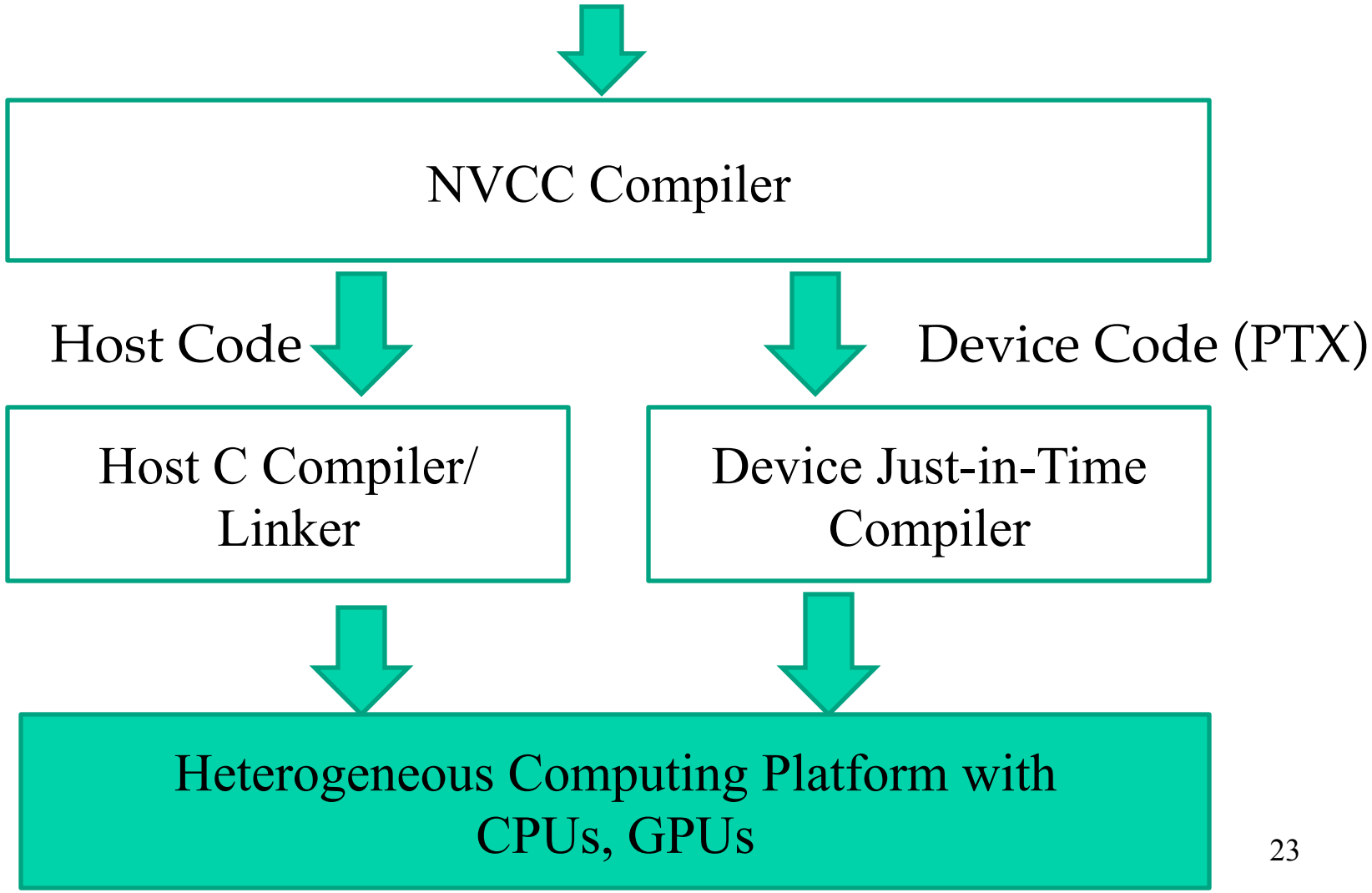


More on CUDA Function Declarations

	Executed on the:	Only callable from the:
`__device__ float DeviceFunc()`	device	device
`__global__ void KernelFunc()`	device	host
`__host__ float HostFunc()`	host	host

- **`__global__`** defines a kernel function
  - Each "__" consists of two underscore characters
  - A kernel function must return **`void`**
- **`__device__`** and **`__host__`** can be used together

Compiling A CUDA Program



QUESTIONS?