An introduction to CUDA

Einstein Morales

University of Puerto Rico at Mayagüez

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Introduction

CPU optimized for fast single-thread execution

- Cores designed to execute 1 thread or 2 threads concurrently
- Large caches attempt to hide DRAM access times
- Cores optimized for low-latency cache accesses

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GPU optimized for high multi-thread throughput

- Cores designed to execute many parallel threads concurrently
- Cores optimized for data-parallel, throughput computation
- Chips use extensive multithreading to tolerate DRAM access times

CUDA: Support

CUDA is a parallel computing platform and application programming interface (API) model created by NVIDIA
The CUDA platform is designed to work with programming languages such as C, C++ and Fortran.
CUDA: Compute Unified Device Architecture

- Fortran, Java, Python, C++ and others.
- MATLAB, Mathematica, R, LabView.

CUDA: Terminology

- Host: The CPU and its memory (host memory)
- Device: The GPU and its memory (device memory)

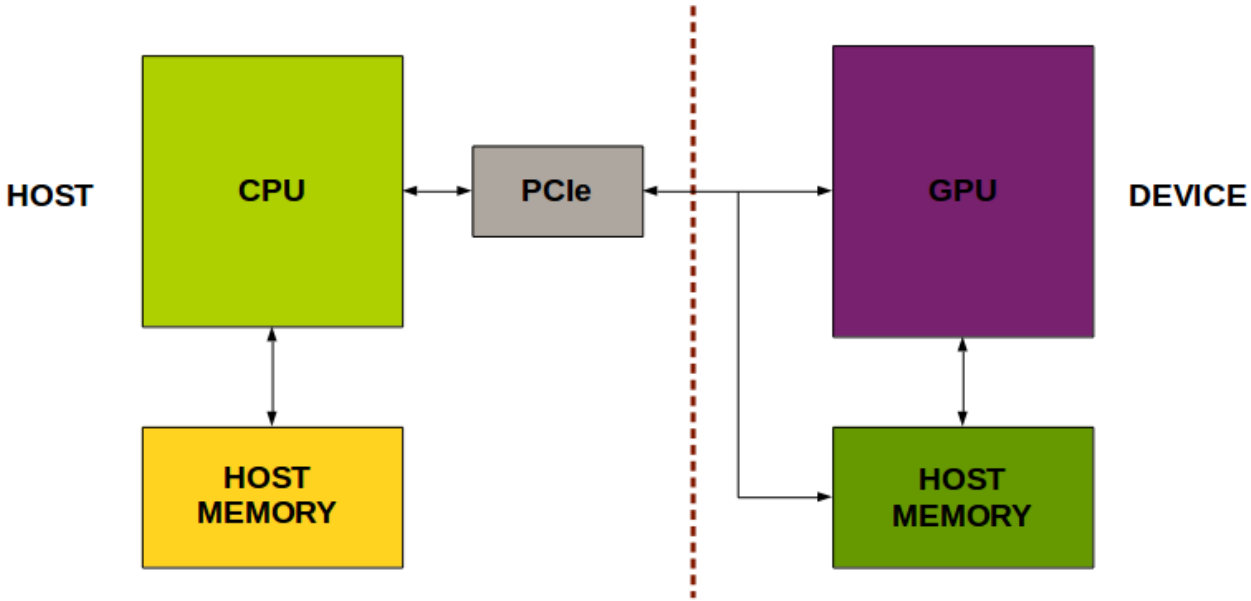


Fig. : CUDA execution flow

CUDA execution model

- Serial code executes in a Host (CPU) thread
- Parallel code executes in many concurrent Device (GPU) threads across multiple parallel processing elements.

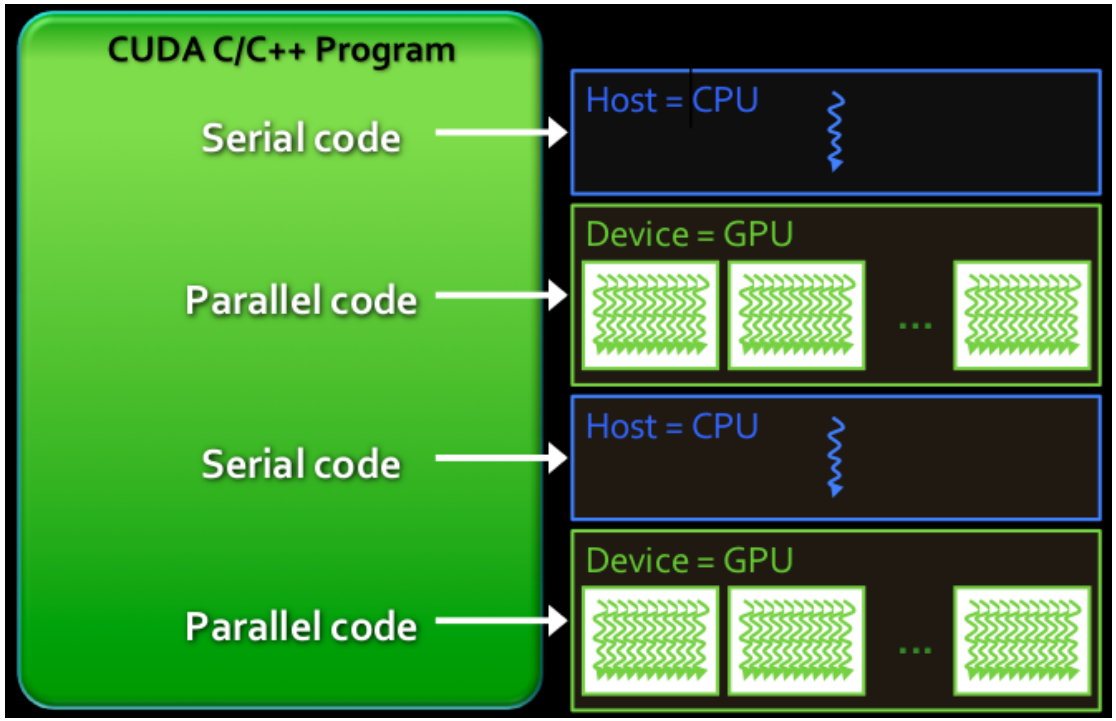


Fig. : CUDA execution model

CUDA Threads

- Difference between the threads of the CPU and GPU
  - GPU threads are very light
  - Thousands of threads are necessary for good performance, the CPU uses only a few.

CUDA Threads

- GPUs can handle thousands of concurrent threads.
- The pieces of code running on the gpu are called kernels
- A *kernel* is executed by a set of threads.
- All threads execute the same code (SPMD)
- Each thread has an index that is used to calculate memory addresses that this will access.

Example

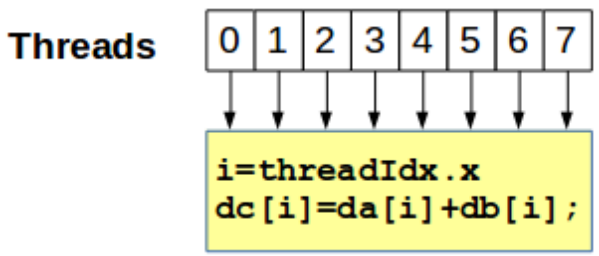
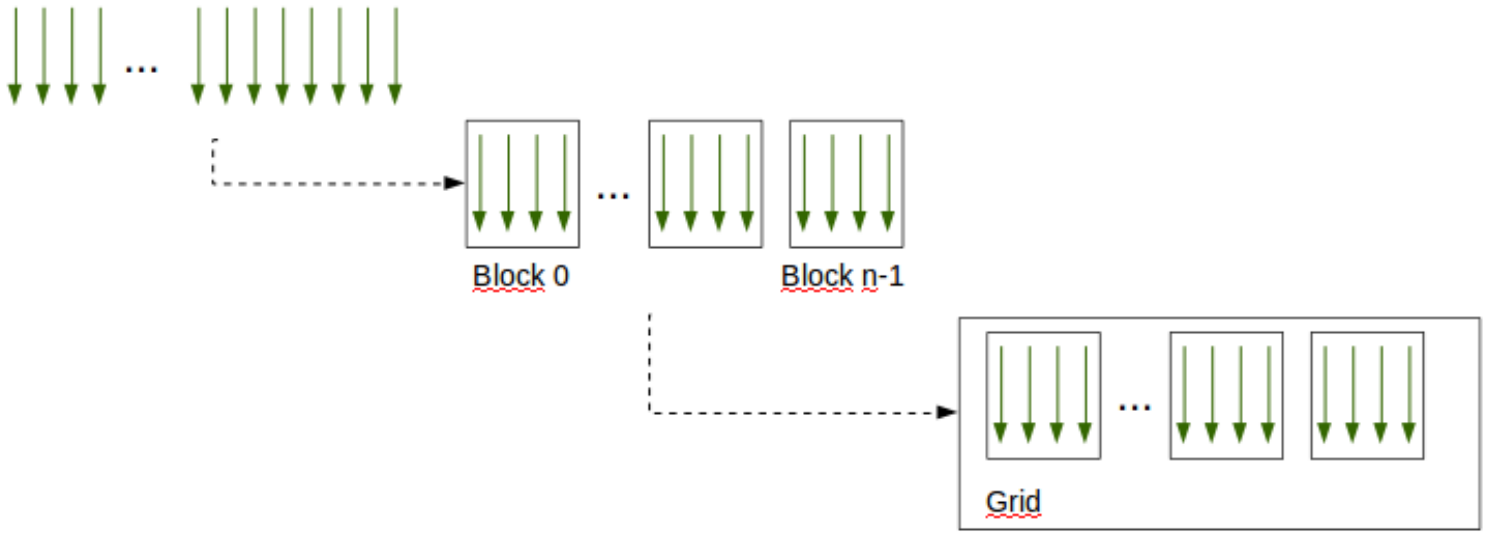


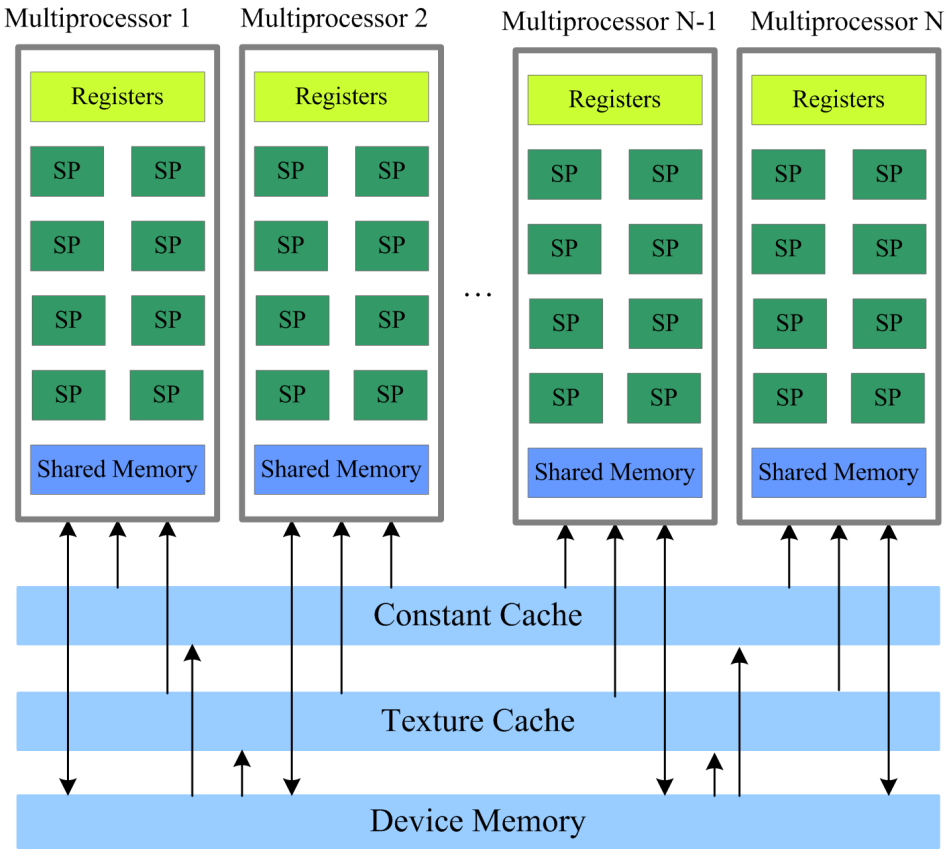
Fig. : thread identifier

CUDA threads organizations

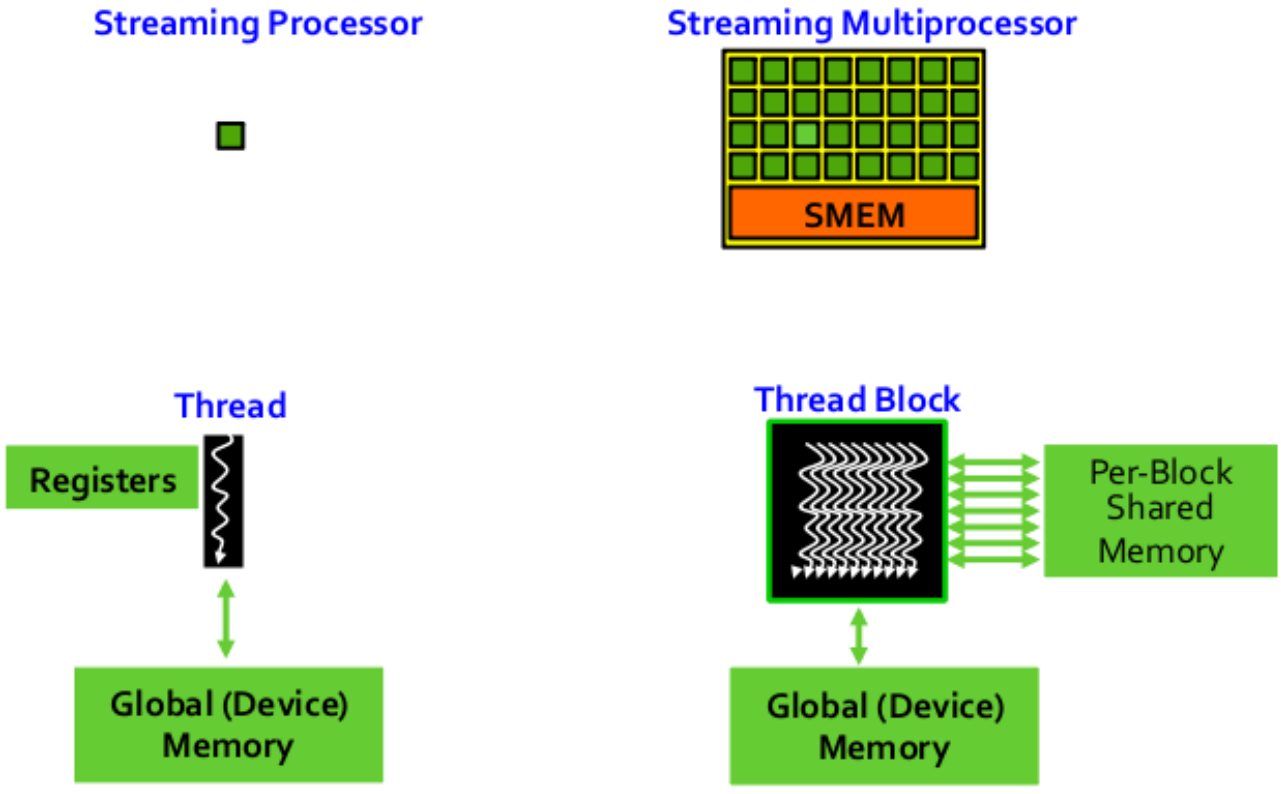


- Threads are grouped into blocks
- Blocks are grouped into a grid
- A *kernel* is executed as a grid of blocks of threads

Streaming multiprocesors



Blocks execute on Streaming Multiprocessors

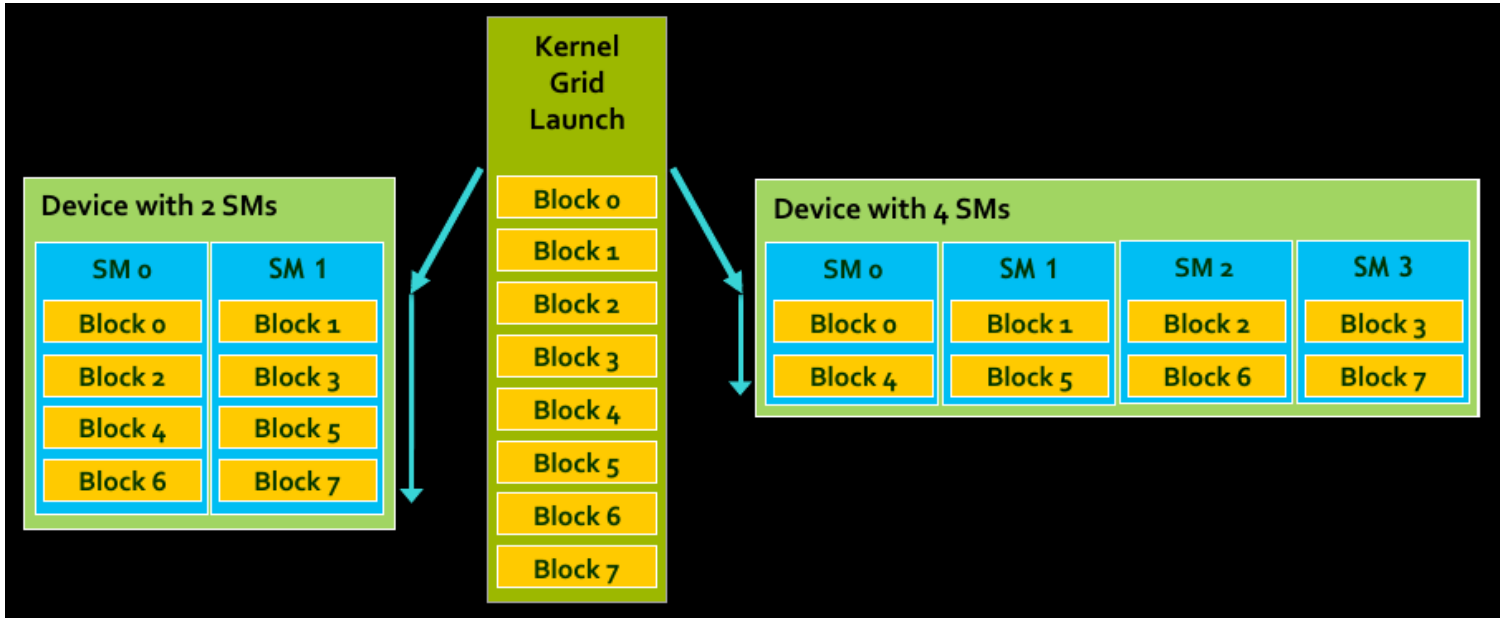


Kernel execution

1. A thread executes on a single SP.
2. A block executes on a single SM.
   - Threads and blocks do not migrate to different SMs.
   - All threads within block execute in concurrently, in parallel.
3. A SM may execute multiple blocks.
   - Must be able to satisfy aggregate register and memory demands.
4. A grid executes on a single device (GPU).

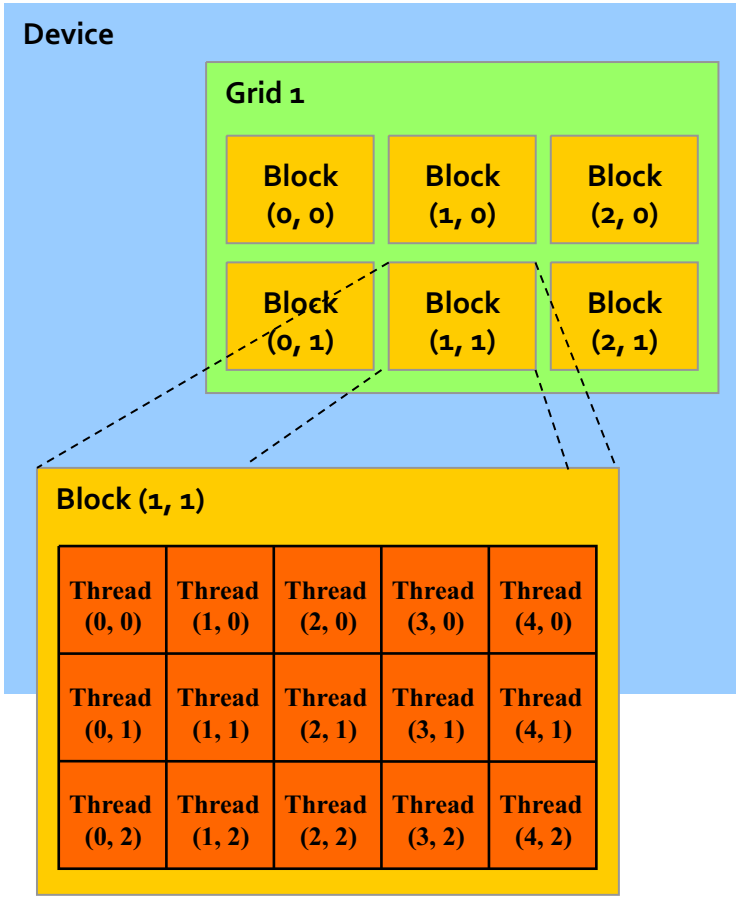
Independent execution of blocks provides scalability

Blocks can be distributed across any number of SMs



Thread and Block ID and Dimensions

- Built-in variables
  - `threadIdx`, `blockIdx`
  - `blockDim`, `gridDim`



Examples of Indexes and Indexing

```
__global__ void kernel( int *a )
{
    int idx = blockIdx.x*blockDim.x + threadIdx.x;
    a[idx] = 7;
}
```

Output: 7 7 7 7 7 7 7 7 7 7 7 7 7 7 7 7

```
__global__ void kernel( int *a )
{
    int idx = blockIdx.x*blockDim.x + threadIdx.x;
    a[idx] = blockIdx.x;
}
```

Output: 0 0 0 0 1 1 1 1 2 2 2 2 3 3 3 3

```
__global__ void kernel( int *a )
{
    int idx = blockIdx.x*blockDim.x + threadIdx.x
    a[idx] = threadIdx.x;
}
```

Output: 0 1 2 3 0 1 2 3 0 1 2 3 0 1 2 3

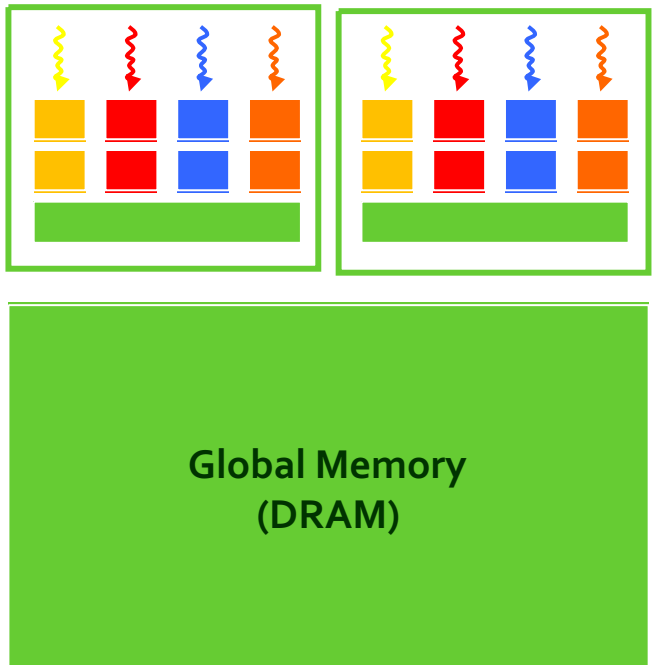
Example of 2D indexing

```
__global__ void kernel(int *a, int dimx, int
{
  int ix  = blockIdx.x*blockDim.x + threadIdx.x;
  int iy  = blockIdx.y*blockDim.y + threadIdx.y;
  int idx = iy * dimx + ix;

  a[idx]  = a[idx]+1;
}
```

CUDA Memory Hierarchy

- Thread
  - Registers
  - Local memory
- Thread Block
  - Shared memory
- All Thread Blocks
  - Global Memory



Example: SAXPY Kernel [1/4]

```
// [compute] for (i=0; i < n; i++) y[i] = a * x[i] + y[i];
//   Each thread processes one element
__global__ void saxpy(int n, float a, float* x, float* y)
{
  int i = threadIdx.x + blockDim.x * blockIdx.x;
  if (i < n) y[i] = a*x[i] + y[i];
}

int main()
{
  ...
  // invoke parallel SAXPY kernel with 256 threads / block
  int nblocks = (n + 255)/256;
  saxpy<<<nblocks, 256>>>(n, 2.0, d_x, d_y);
  ...
}
```

Example: SAXPY Kernel [1/4]

```
// [computes] for (i=0; i < n; i++) y[i] = a * x[i] + y[i];
//   Each thread processes one element
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  int nblocks = (n + 255)/256;
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  ...
}
```

Device Code

Example: SAXPY Kernel [1/4]

```
// [computes] for (i=0; i < n; i++) y[i] = a * x[i] + y[i];
//   Each thread processes one element
__global__ void saxpy(int n, float a, float* x, float* y)
{
  int i = threadIdx.x + blockDim.x * blockIdx.x;
  if (i < n) y[i] = a*x[i] + y[i];
}
```

Host Code

```
int main()
{
  ...
  // invoke parallel SAXPY kernel with 256 threads / block
  int nblocks = (n + 255)/256;
  saxpy<<<nblocks, 256>>>(n, 2.0, d_x, d_y);
  ...
}
```

Example: SAXPY Kernel [2/4]

```
int main()
{
  // allocate and initialize host (CPU) memory
  float* x = ...;
  float* y = ...;

  // allocate device (GPU) memory
  float *d_x, *d_y;
  cudaMalloc((void**) &d_x, n * sizeof(float));
  cudaMalloc((void**) &d_y, n * sizeof(float));

  // copy x and y from host memory to device memory
  cudaMemcpy(d_x, x, n*sizeof(float), cudaMemcpyHostToDevice);
  cudaMemcpy(d_y, y, n*sizeof(float), cudaMemcpyHostToDevice);

  // invoke parallel SAXPY kernel with 256 threads / block
  int nblocks = (n + 255)/256;
  saxpy<<<nblocks, 256>>>(n, 2.0, d_x, d_y);
```

Example: SAXPY Kernel [2/4]

```
int main()
{
  // allocate and initialize host (CPU) memory
  float* x = ...;
  float* y = ...;

  // allocate device (GPU) memory
  float *d_x, *d_y;
  cudaMalloc((void**) &d_x, n * sizeof(float));
  cudaMalloc((void**) &d_y, n * sizeof(float));

  // copy x and y from host memory to device memory
  cudaMemcpy(d_x, x, n*sizeof(float), cudaMemcpyHostToDevice);
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  // invoke parallel SAXPY kernel with 256 threads / block
  int nblocks = (n + 255)/256;
  saxpy<<<nblocks, 256>>>(n, 2.0, d_x, d_y);
```

Example: SAXPY Kernel [3/4]

```
  // invoke parallel SAXPY kernel with 256 threads / block
  int nblocks = (n + 255)/256;
  saxpy<<<nblocks, 256>>>(n, 2.0, d_x, d_y);

  // copy y from device (GPU) memory to host (CPU) memory
  cudaMemcpy(y, d_y, n*sizeof(float), cudaMemcpyDeviceToHost);

  // do something with the result…


  // free device (GPU) memory
  cudaFree(d_x);
  cudaFree(d_y;

  return 0;
}
```

Example: SAXPY Kernel [3/4]

```
  // invoke parallel SAXPY kernel with 256 threads / block
  int nblocks = (n + 255)/256;
  saxpy<<<nblocks, 256>>>(n, 2.0, d_x, d_y);

  // copy y from device (GPU) memory to host (CPU) memory
  cudaMemcpy(y, d_y, n*sizeof(float), cudaMemcpyDeviceToHost);

  // do something with the result…

  // free device (GPU) memory
  cudaFree(d_x);
  cudaFree(d_y;

  return 0;
}
```

Example: SAXPY Kernel [4/4]

```
void saxpy_serial(int n, float a, float* x, float* y)
{
  for (int i = 0; i < n; ++i)
    y[i] = a*x[i] + y[i];
}
// invoke host SAXPY function
saxpy_serial(n, 2.0, x, y);
```

Standard C Code

```
__global__ void saxpy(int n, float a, float* x, float* y)
{
  int i = blockIdx.x*blockDim.x + threadIdx.x;
  if (i < n)  y[i] = a*x[i] + y[i];
}
// invoke parallel SAXPY kernel with 256 threads/block
int nblocks = (n + 255) / 256;
saxpy<<<nblocks, 256>>>(n, 2.0, x, y);
```

CUDA C Code

questions so far