INTRODUCTION TO PROGRAMMING IN CUDA C

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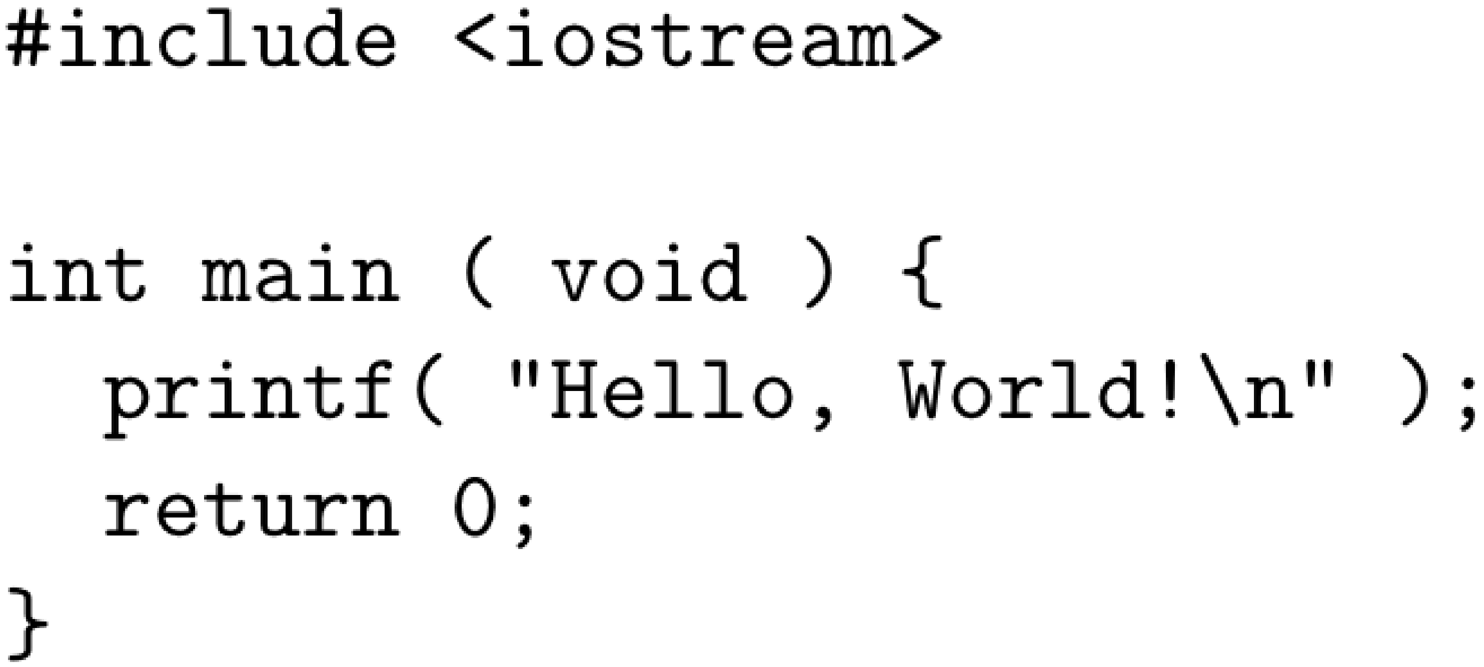
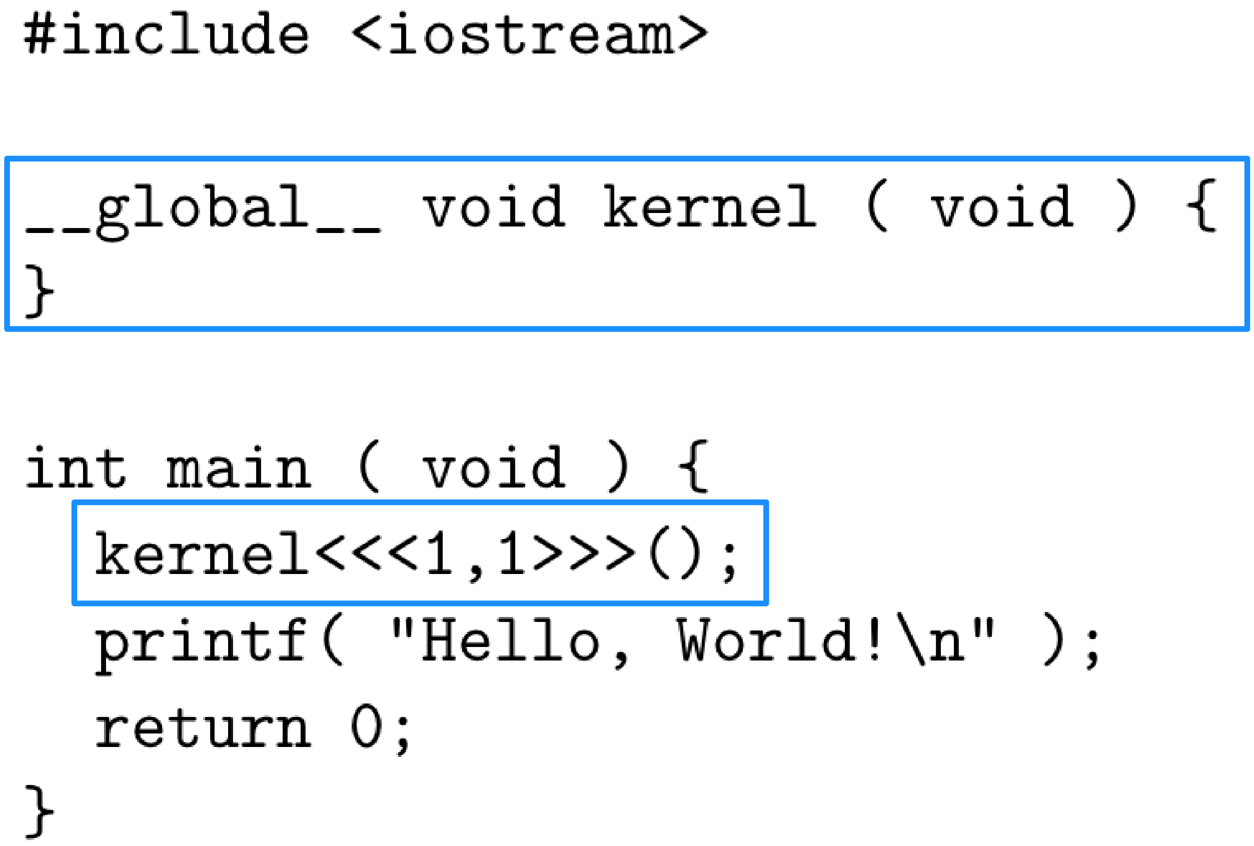
BASIC C PROGRAM



```
#include <iostream>

int main ( void ) {
  printf( "Hello, World!\n" );
  return 0;
}
```

BASIC CUDA C PROGRAM



```
#include <iostream>

__global__ void kernel ( void ) {
}

int main ( void ) {
  kernel<<<1,1>>>();
  printf( "Hello, World!\n" );
  return 0;
}
```

```
#include <iostream>

__global__ void kernel ( void ) {
}

int main ( void ) {
  kernel<<<1,1>>>();
  printf( "Hello, World!\n" );
  return 0;
}
```

Prefix that says: "only run this function on the GPU"

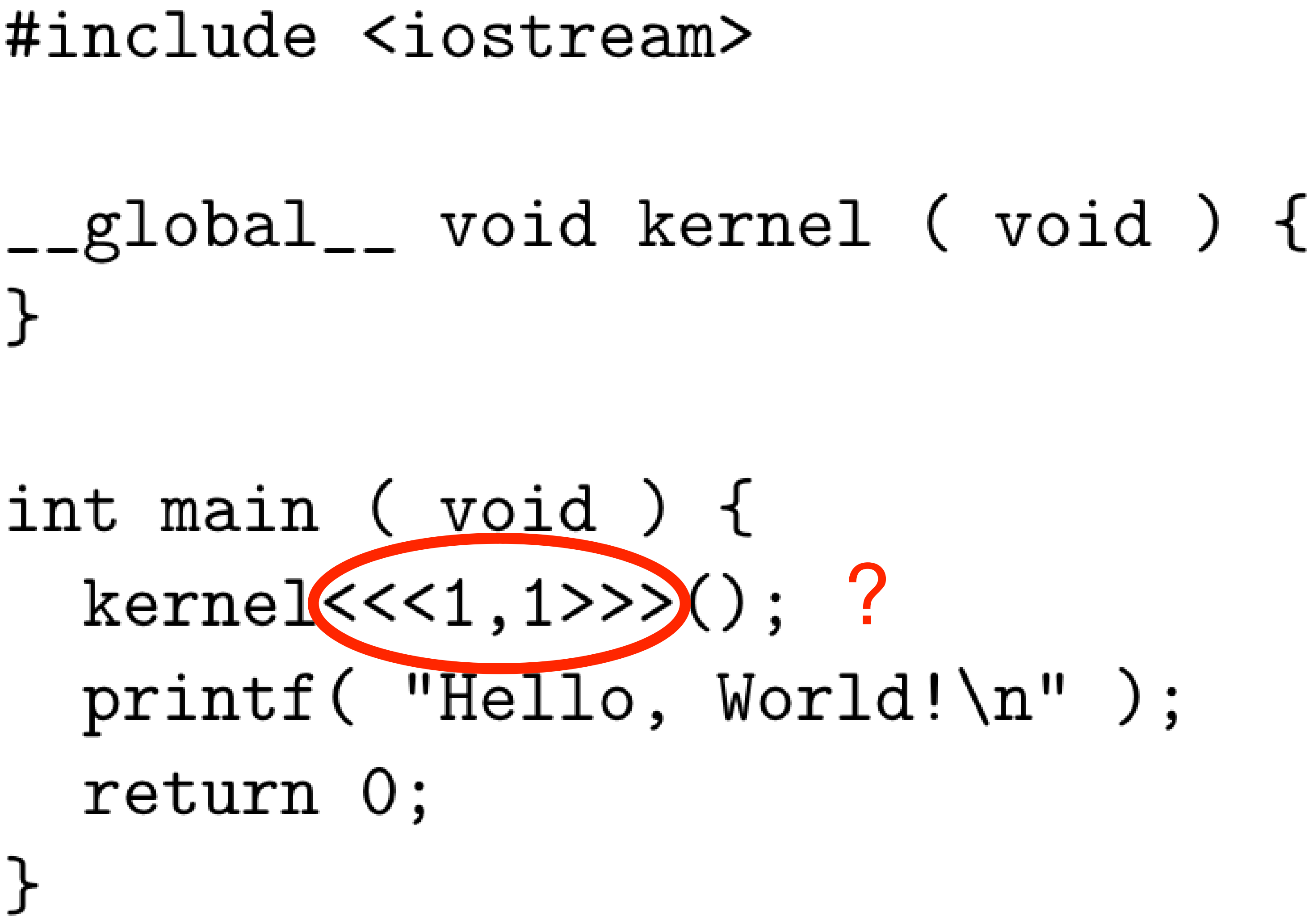
```
#include <iostream>

__global__ void kernel ( void ) {
}

int main ( void ) {
   kernel<<<1,1>>>();
   printf( "Hello, World!\n" );
   return 0;
}
```

Started on CPU

Sent to GPU

Done on CPU

Done on CPU



```
#include <iostream>

__global__ void kernel ( void ) {
}

int main ( void ) {
  kernel<<<1,1>>>();
  printf( "Hello, World!\n" );
  return 0;
}
```

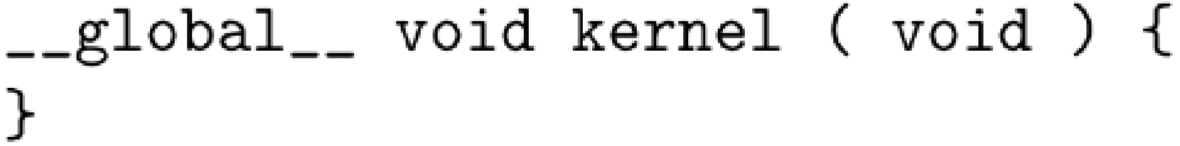
?

REVIEW OF PARALLELIZATION

Parallelization: Running different calculations simultaneously.

Kernel: An instruction set executed on the GPU. (All others are executed on the CPU.)

In CUDA C, a kernel is any function prefixed with the keyword, `__global__`. For example:



```
__global__ void kernel ( void ) {
}
```

PARALLELIZATION AND THE SIMD PARADIGM

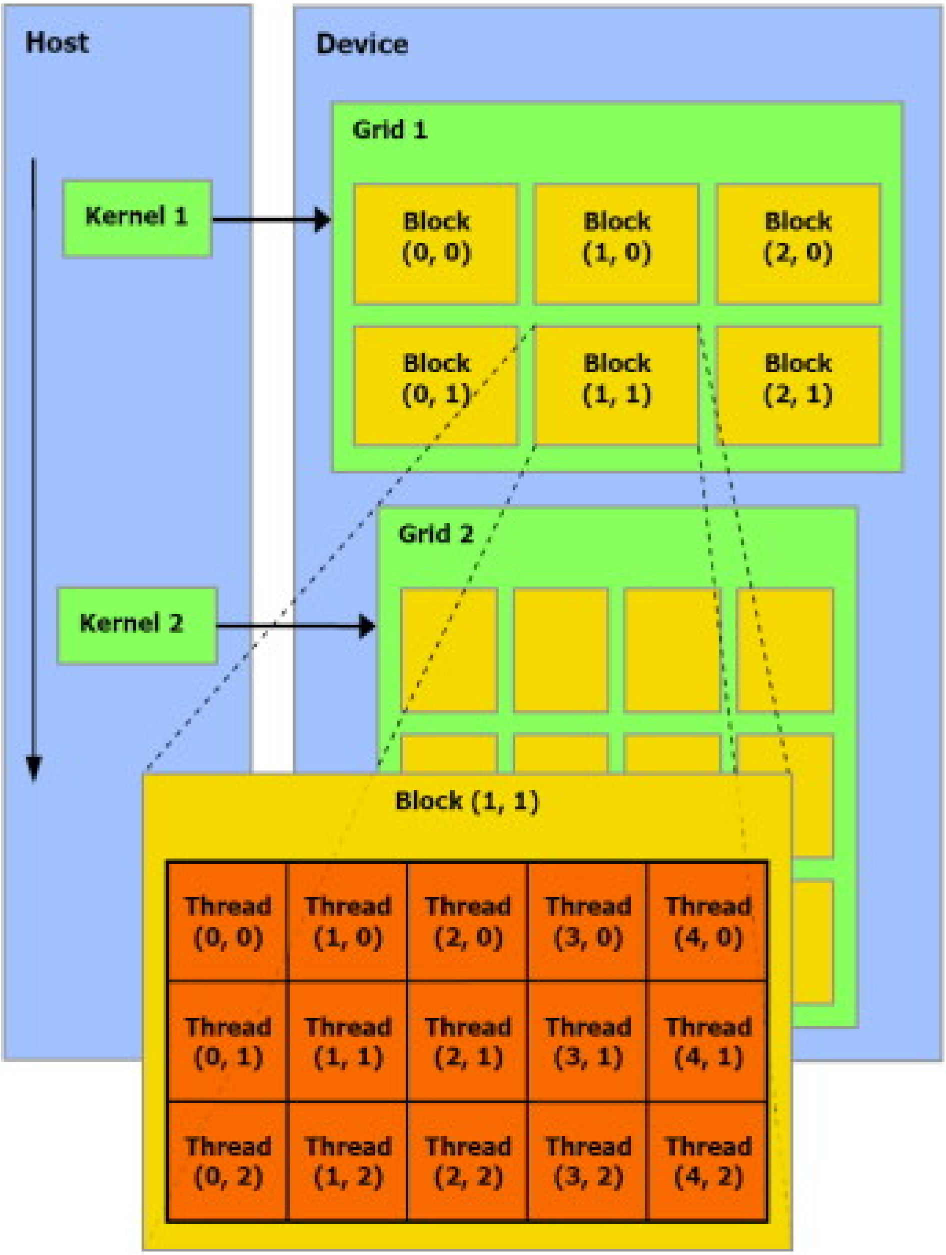
SIMD: Single Instruction Multiple Data. The paradigm works like this:

1. The CPU sends a kernel (a SINGLE INSTRUCTION set) to the GPU.
2. The GPU executes the kernel MULTIPLE times simultaneously in **PARALLEL**. Each such execution of the kernel is called a **thread**, and each thread is executed on different parts of a giant data set.

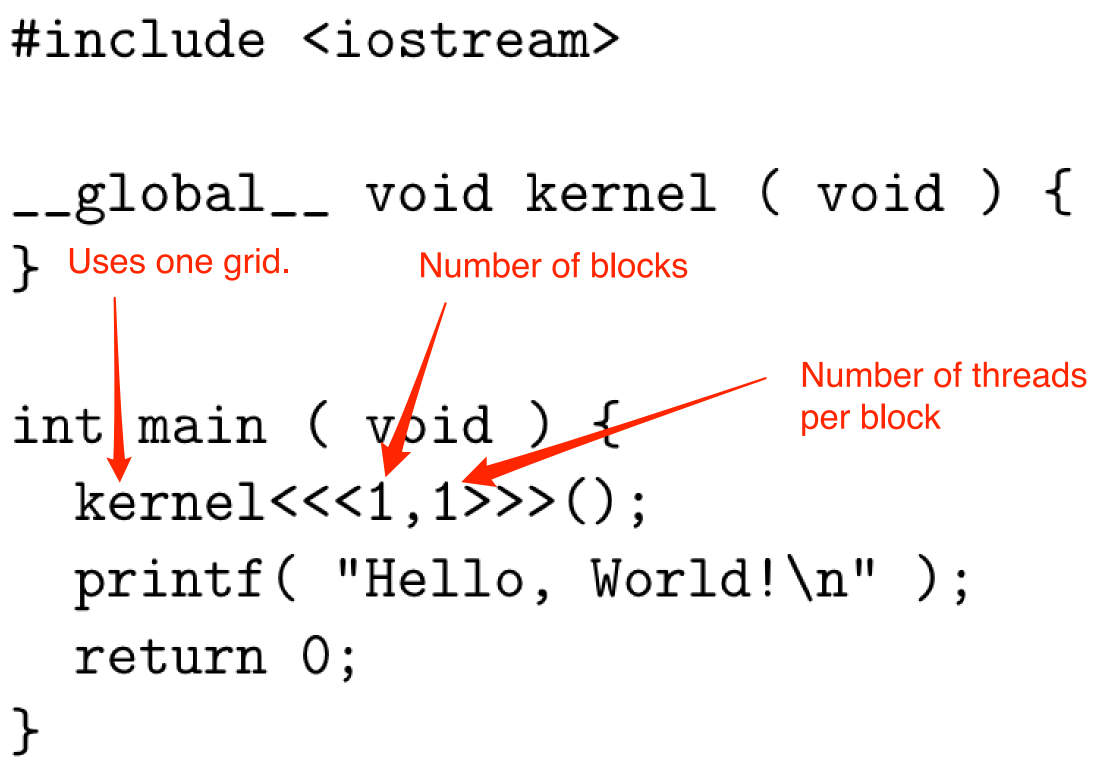
ORGANIZATION OF THREADS

Grid; The collection of all the threads that are spawned when the CPU sends a kernel to the GPU.

Block: A collection of threads within a grid that share memory quickly and easily.


Host
Device
Grid 1
Kernel 1
Block (0, 0)
Block (1, 0)
Block (2, 0)
Block (0, 1)
Block (1, 1)
Block (2, 1)
Grid 2
Kernel 2
Block (1, 1)
Thread (0, 0)
Thread (1, 0)
Thread (2, 0)
Thread (3, 0)
Thread (4, 0)
Thread (0, 1)
Thread (1, 1)
Thread (2, 1)
Thread (3, 1)
Thread (4, 1)
Thread (0, 2)
Thread (1, 2)
Thread (2, 2)
Thread (3, 2)
Thread (4, 2)

NOW BACK TO THE STUFF IN ANGLE BRACKTES...



```
#include <iostream>

__global__ void kernel ( void ) {
}

int main ( void ) {
  kernel<<<1,1>>>();
  printf( "Hello, World!\n" );
  return 0;
}
```

Uses one grid.

Number of blocks

Number of threads per block

Here, the GPU runs kernel() one time:

```
#include <iostream>

__global__ void kernel ( void ) {
}

int main ( void ) {
  kernel<<<1,1>>>();
  printf( "Hello, World!" \n" )
  return 0;
}
```

Here, the GPU runs kernel() 5 times:

```
#include <iostream>

__global__ void kernel ( void ) {
}

int main ( void ) {
  kernel<<<5,1>>>();
  printf( "Hello, World!" \n" )
  return 0;
}
```

Here, the GPU runs kernel() 5 times:

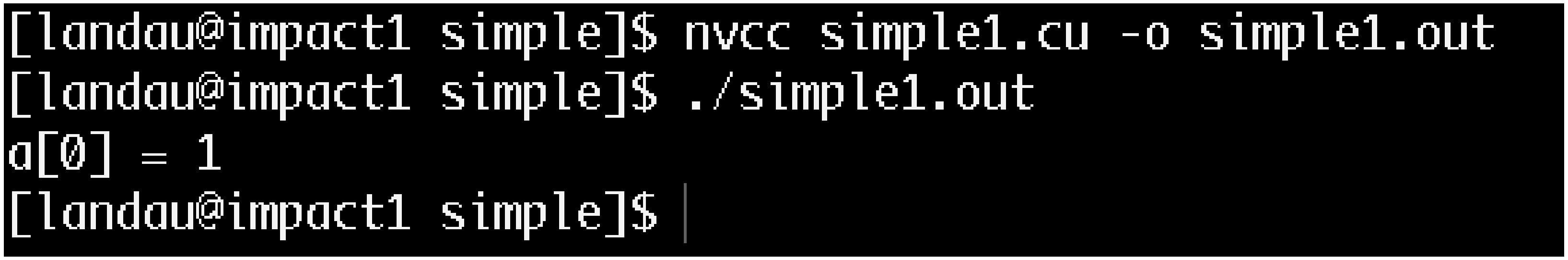
```
#include <iostream>

__global__ void kernel ( void ) {
}

int main ( void ) {
  kernel<<<1,5>>>();
  printf( "Hello, World!" \n" )
  return 0;
}
```

Here, the GPU runs kernel() 20 times:

```
#include <iostream>

__global__ void kernel ( void ) {
}

int main ( void ) {
  kernel<<<4,5>>>();
  printf( "Hello, World!" \n" )
  return 0;
}
```

PASSING DATA TO AND FROM THE GPU: simple1.cu

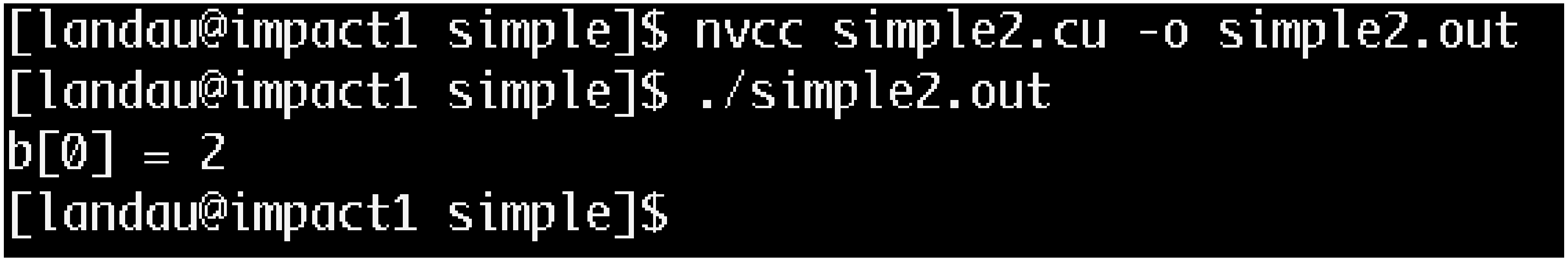
```
#include <stdio.h>
#include <stdlib.h>

__global__ void colonel(int *dev_a){
  *dev_a = 1;
}

int main(){

  // Declare variables and allocate memory on the GPU.
  int a[1], *dev_a;
  cudaMalloc((void**) &dev_a, sizeof(int));

  // Execute kernel and copy the result to CPU memory.
  colonel<<<1,1>>>(dev_a);
  cudaMemcpy(a, dev_a, sizeof(int), cudaMemcpyDeviceToHost);

  // Print result and free dynamically allocated memory.
  printf("a[0] = %d\n", a[0]); // REMEMBER: INDEXING IN C STARTS FROM 0.
  cudaFree(dev_a);

}
```



```
[landau@impact1 simple]$ nvcc simple1.cu -o simple1.out
[landau@impact1 simple]$ ./simple1.out
a[0] = 1
[landau@impact1 simple]$
```

PASSING DATA TO AND FROM THE GPU: simple2.cu

```
#include <stdio.h>
#include <stdlib.h>

__global__ void colonel(int *dev_a){
  *dev_a = *dev_a + 1;
}

int main(){
  // Declare variables and allocate memory on the GPU.
  int a[1], *dev_a;
  cudaMalloc((void**) &dev_a, sizeof(int));

  // Intitialize argument a, executed kernel, and store result back in a.
  a[0] = 1; // REMEMBER: INDEXING IN C STARTS FROM 0.
  cudaMemcpy(dev_a, a, sizeof(int), cudaMemcpyHostToDevice);
  colonel<<<1,1>>>(dev_a);
  cudaMemcpy(a, dev_a, sizeof(int), cudaMemcpyDeviceToHost);

  // Print result and free dynamically allocated memory.
  printf("a[0] = %d\n", a[0]); // REMEMBER: INDEXING IN C STARTS FROM 0.
  cudaFree(dev_a);
}
```



```
[landau@impact1 simple]$ nvcc simple2.cu -o simple2.out
[landau@impact1 simple]$ ./simple2.out
b[0] = 2
[landau@impact1 simple]$
```

threadIdx.x AND blockIdx.x

Say the CPU sends a kernel to the GPU with B blocks and T threads per block.

The following CUDA C variables are available for use in the kernel:

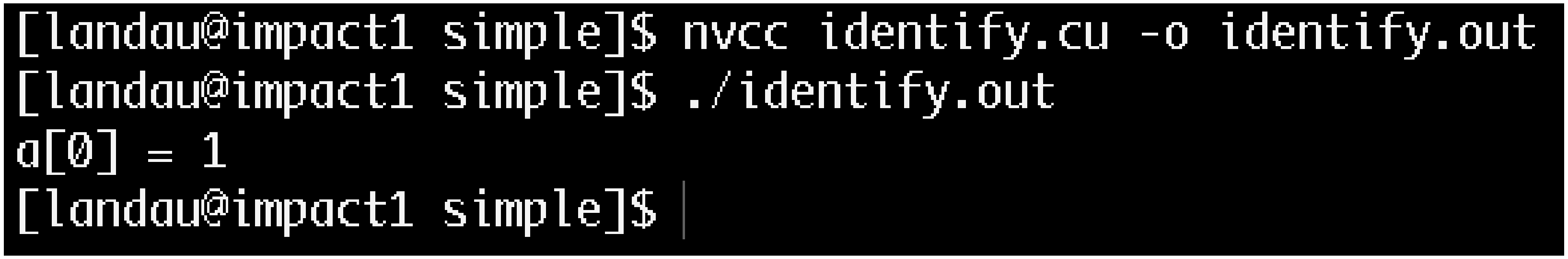
blockIdx.x: the block ID corresponding to the current thread, an integer from 0 to $B - 1$ inclusive.

threadIdx.x: the thread ID of the current thread within its block, an integer from 0 to $T - 1$ inclusive.

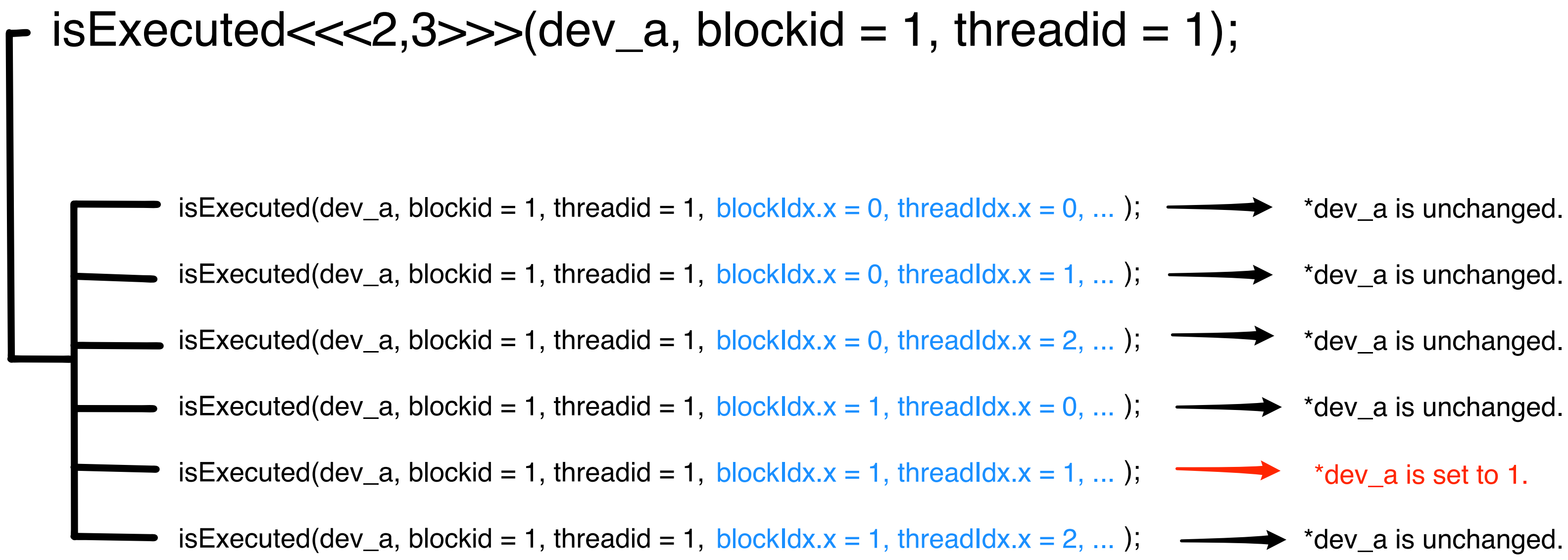
NOTE: there are also variables like blockIdx.y and threadIdx.y, but those are only useful if you deliberately organize your blocks and threads in two-dimensional arrays (which can be done).

USING blockIdx.x AND threadIdx.x: identify.cu

```
#include <stdio.h>
#include <stdlib.h>

__global__ void isExecuted(int *dev_a, int blockid, int threadid){

  if(blockIdx.x == blockid && threadIdx.x == threadid)
    *dev_a = 1;

}

int main(){

  // Declare variables and allocate memory on the GPU.
  int init[1], a[1], *dev_a;
  cudaMalloc((void**) &dev_a, sizeof(int));

  // Initialize dev_a, execute kernel, and copy the result to CPU memory.
  init[1] = 0;
  cudaMemcpy(dev_a, init, sizeof(int), cudaMemcpyHostToDevice);
  isExecuted<<<100,100>>>(dev_a, 2, 4);
        // NOTE: INDEXING OF THREADS AND BLOCKS STARTS FROM 0.
  cudaMemcpy(a, dev_a, sizeof(int), cudaMemcpyDeviceToHost);

  // Print result and free dynamically allocated memory.
  printf("a[0] = %d\n", a[0]); // REMEMBER: INDEXING IN C STARTS FROM 0.
  cudaFree(dev_a);

}
```



```
[landau@impact1 simple]$ nvcc identify.cu -o identify.out
[landau@impact1 simple]$ ./identify.out
a[0] = 1
[landau@impact1 simple]$ 
```



isExecuted<<<2,3>>>(dev_a, blockid = 1, threadid = 1);

isExecuted(dev_a, blockid = 1, threadid = 1, blockIdx.x = 0, threadIdx.x = 0, ...); → *dev_a is unchanged.

isExecuted(dev_a, blockid = 1, threadid = 1, blockIdx.x = 0, threadIdx.x = 1, ...); → *dev_a is unchanged.

isExecuted(dev_a, blockid = 1, threadid = 1, blockIdx.x = 0, threadIdx.x = 2, ...); → *dev_a is unchanged.

isExecuted(dev_a, blockid = 1, threadid = 1, blockIdx.x = 1, threadIdx.x = 0, ...); → *dev_a is unchanged.

isExecuted(dev_a, blockid = 1, threadid = 1, blockIdx.x = 1, threadIdx.x = 1, ...); → *dev_a is set to 1.

isExecuted(dev_a, blockid = 1, threadid = 1, blockIdx.x = 1, threadIdx.x = 2, ...); → *dev_a is unchanged.

You can verify that when the line,

```
isExecuted<<<1,1>>>(dev_a, 0, 0);
```

is changed to:

```
isExecuted<<<1,1>>>(dev_a, 2, 4);
```

the output of the program:

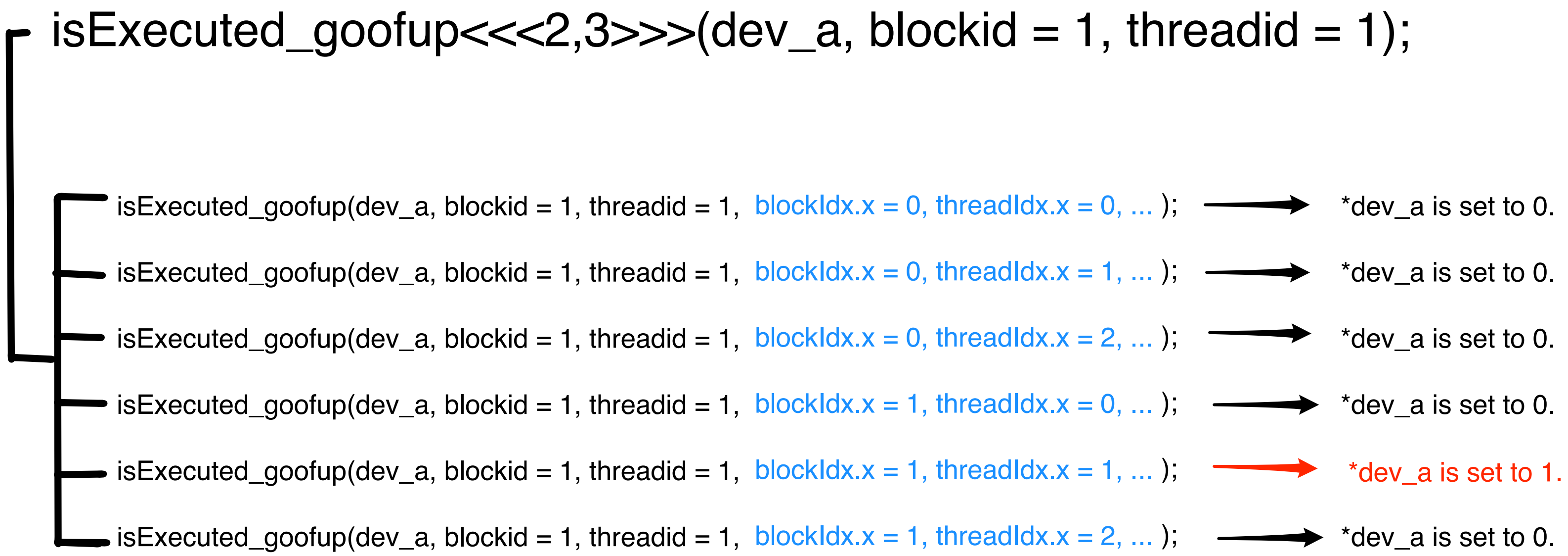
```
a[0] = 0
```

which makes sense because there was no block number 2 or thread number 4.

ASIDE: AVOIDING PITFALLS IN PARALLELIZATION

What problem would arise if I used the function, isExectued_goofup(), instead of Executed():

```
__global__ void isExecuted_goofup(int *dev_a, int blockid,
               int threadid){

  if(blockIdx.x == blockid && threadIdx.x == threadid)
    *dev_a = 1;
  else
    *dev_a = 0;

}
```



isExecuted_goofup<<<2,3>>>(dev_a, blockid = 1, threadid = 1);

isExecuted_goofup(dev_a, blockid = 1, threadid = 1, blockIdx.x = 0, threadIdx.x = 0, ...); → *dev_a is set to 0.

isExecuted_goofup(dev_a, blockid = 1, threadid = 1, blockIdx.x = 0, threadIdx.x = 1, ...); → *dev_a is set to 0.

isExecuted_goofup(dev_a, blockid = 1, threadid = 1, blockIdx.x = 0, threadIdx.x = 2, ...); → *dev_a is set to 0.

isExecuted_goofup(dev_a, blockid = 1, threadid = 1, blockIdx.x = 1, threadIdx.x = 0, ...); → *dev_a is set to 0.

isExecuted_goofup(dev_a, blockid = 1, threadid = 1, blockIdx.x = 1, threadIdx.x = 1, ...); → *dev_a is set to 1.

isExecuted_goofup(dev_a, blockid = 1, threadid = 1, blockIdx.x = 1, threadIdx.x = 2, ...); → *dev_a is set to 0.

If block 1 thread 1 finishes last, then *dev_a = 1.
If block 1 thread 1 does not finish last, *dev_a = 0.

We can't know or control which thread finishes last!

EXAMPLE: VECTOR SUMMATION (Sanders, et. al.)

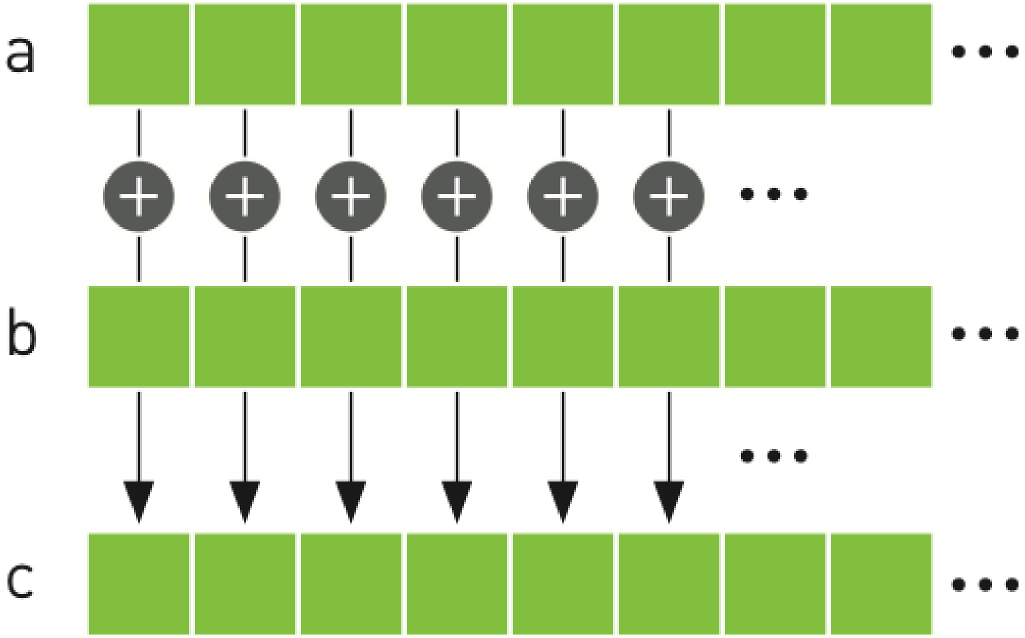
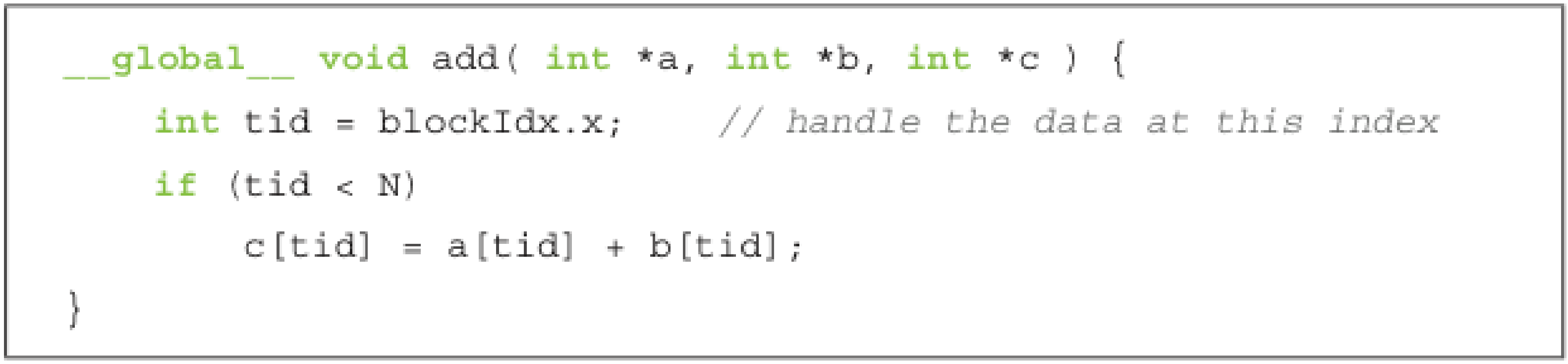
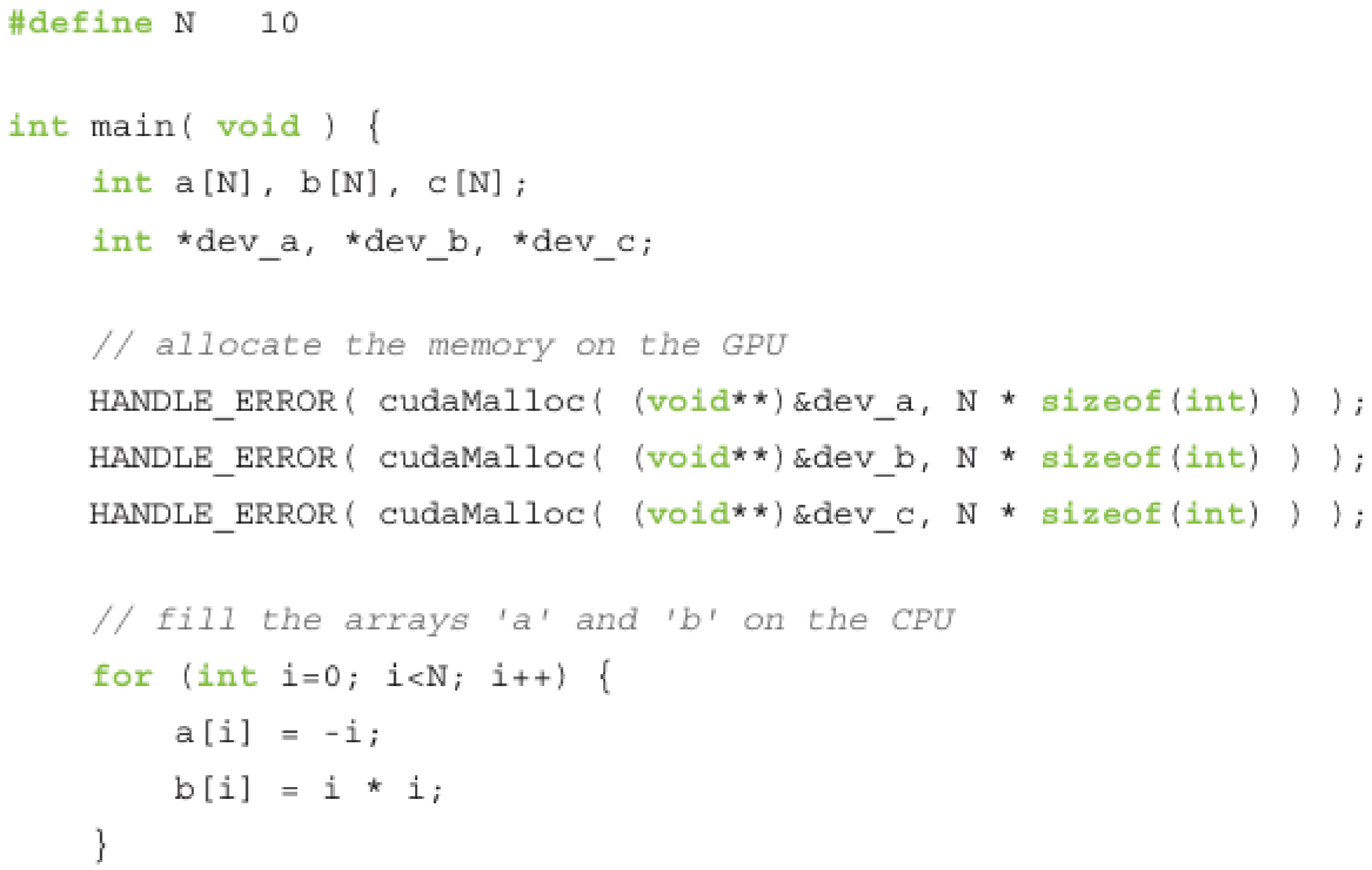


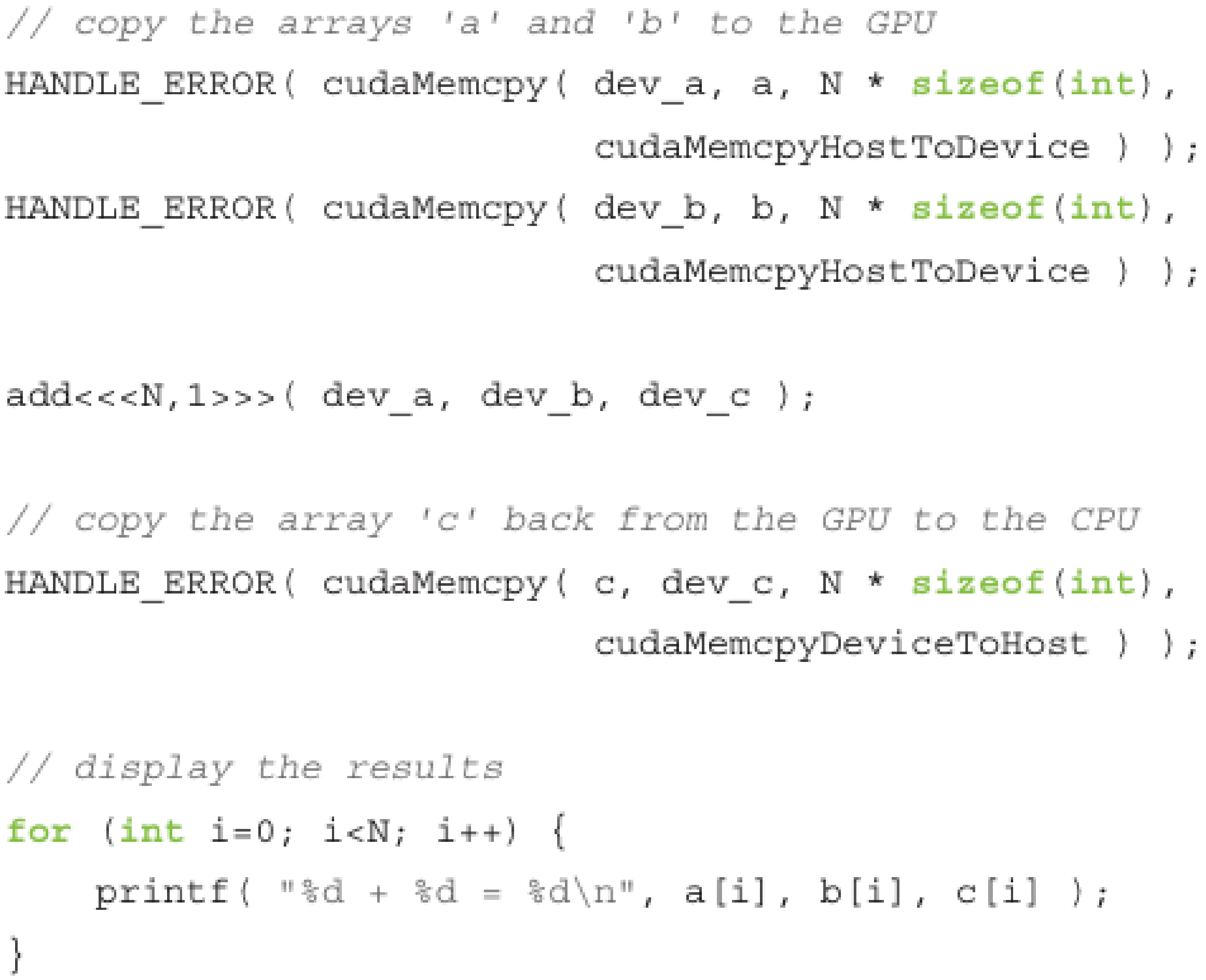
Figure 4.1 Summing two vectors



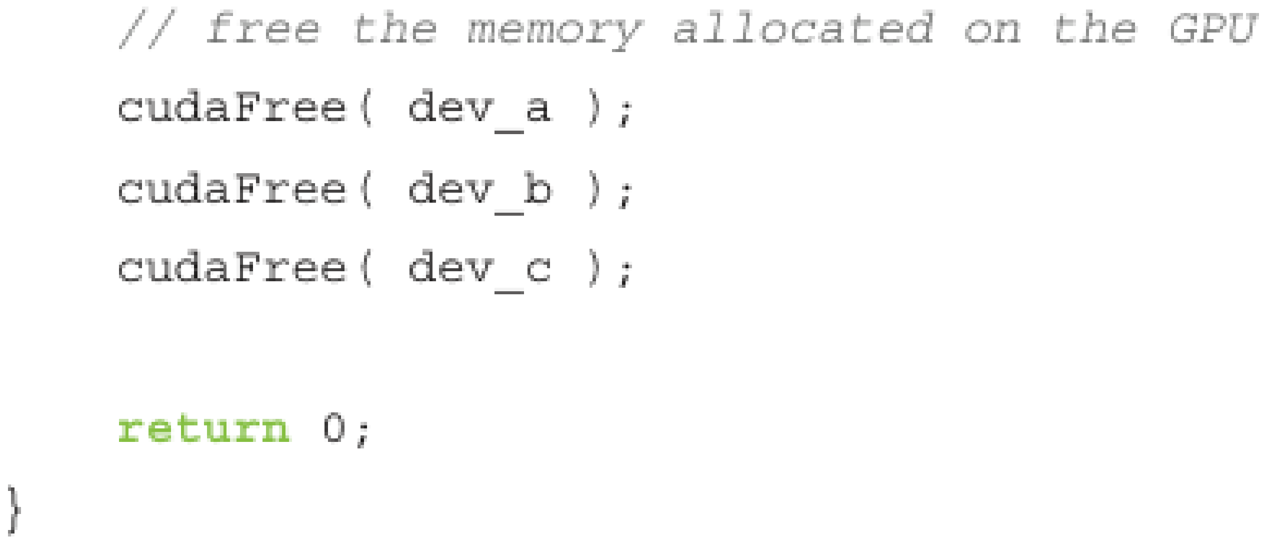
```
__global__ void add( int *a, int *b, int *c ) {
    int tid = blockIdx.x;    // handle the data at this index
    if (tid < N)
        c[tid] = a[tid] + b[tid];
}
```



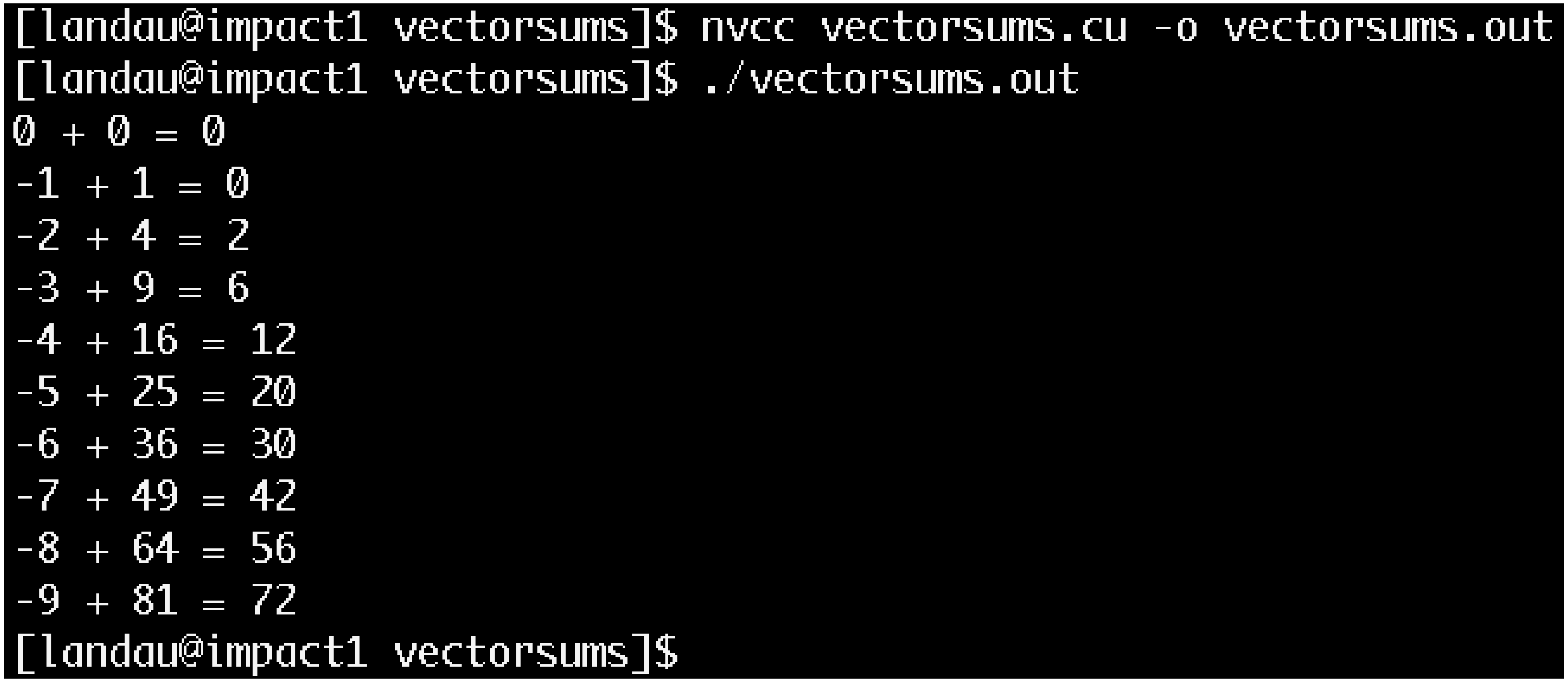
```
#define N   10

int main( void ) {
    int a[N], b[N], c[N];
    int *dev_a, *dev_b, *dev_c;

    // allocate the memory on the GPU
    HANDLE_ERROR( cudaMalloc( (void**)&dev_a, N * sizeof(int) ) );
    HANDLE_ERROR( cudaMalloc( (void**)&dev_b, N * sizeof(int) ) );
    HANDLE_ERROR( cudaMalloc( (void**)&dev_c, N * sizeof(int) ) );

    // fill the arrays 'a' and 'b' on the CPU
    for (int i=0; i<N; i++) {
        a[i] = -i;
        b[i] = i * i;
    }
```



```
// copy the arrays 'a' and 'b' to the GPU
HANDLE_ERROR( cudaMemcpy( dev_a, a, N * sizeof(int),
                          cudaMemcpyHostToDevice ) );
HANDLE_ERROR( cudaMemcpy( dev_b, b, N * sizeof(int),
                          cudaMemcpyHostToDevice ) );

add<<<N,1>>>( dev_a, dev_b, dev_c );

// copy the array 'c' back from the GPU to the CPU
HANDLE_ERROR( cudaMemcpy( c, dev_c, N * sizeof(int),
                          cudaMemcpyDeviceToHost ) );

// display the results
for (int i=0; i<N; i++) {
    printf( "%d + %d = %d\n", a[i], b[i], c[i] );
}
```



```
    // free the memory allocated on the GPU
    cudaFree( dev_a );
    cudaFree( dev_b );
    cudaFree( dev_c );

    return 0;
}
```



```
[landau@impact1 vectorsums]$ nvcc vectorsums.cu -o vectorsums.out
[landau@impact1 vectorsums]$ ./vectorsums.out
0 + 0 = 0
-1 + 1 = 0
-2 + 4 = 2
-3 + 9 = 6
-4 + 16 = 12
-5 + 25 = 20
-6 + 36 = 30
-7 + 49 = 42
-8 + 64 = 56
-9 + 81 = 72
[landau@impact1 vectorsums]$
```

You can download the code, along with other simple CUDA C examples, at https://github.com/jarad/gpuIntroduction/tree/master/CUDA_C_sandbox.

REFERENCES

J. Sanders and E. Kandrot. *CUDA by Example*. Addison-Wesley, 2010.