Very Quick Introduction to CUDA

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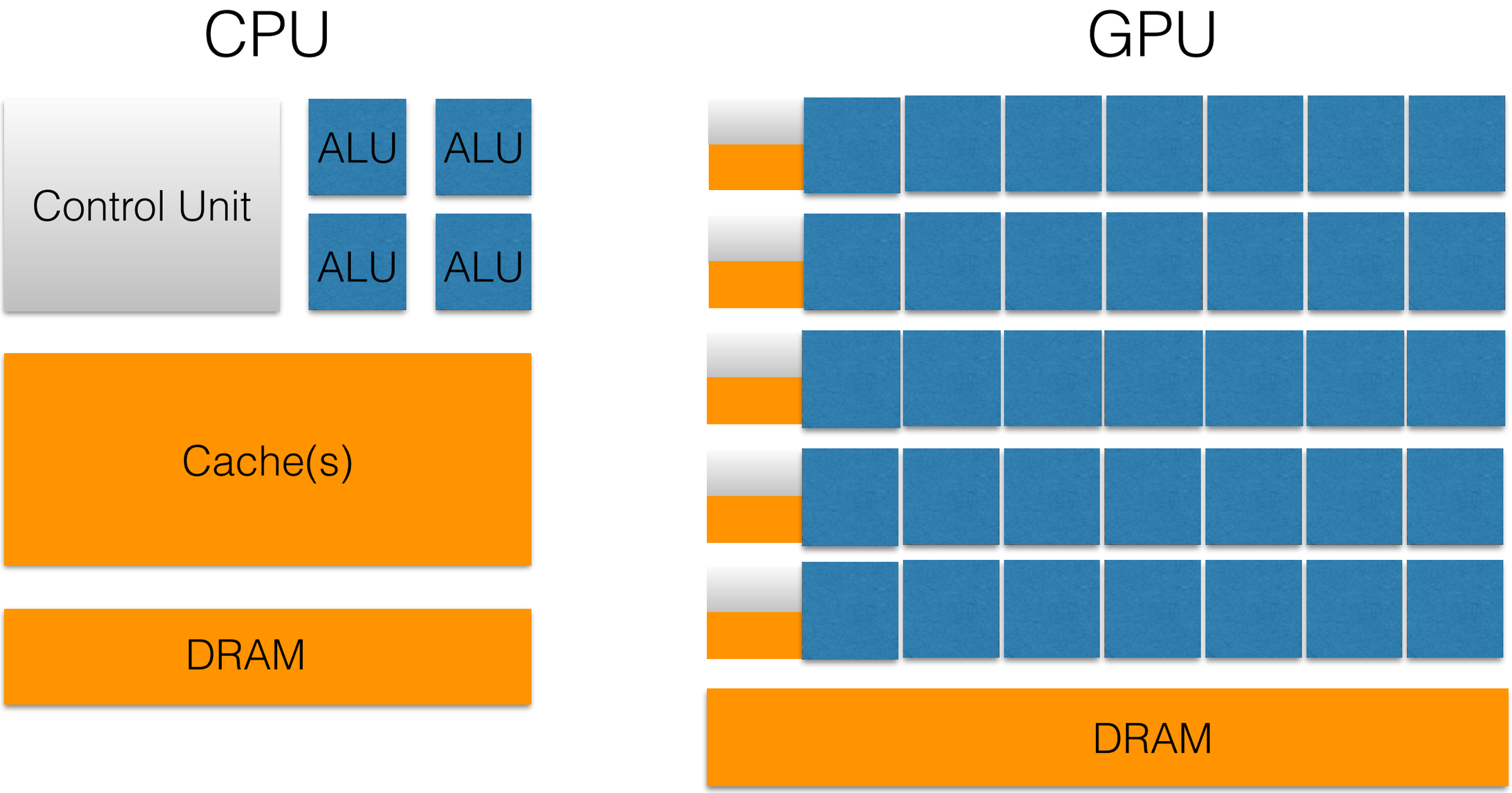
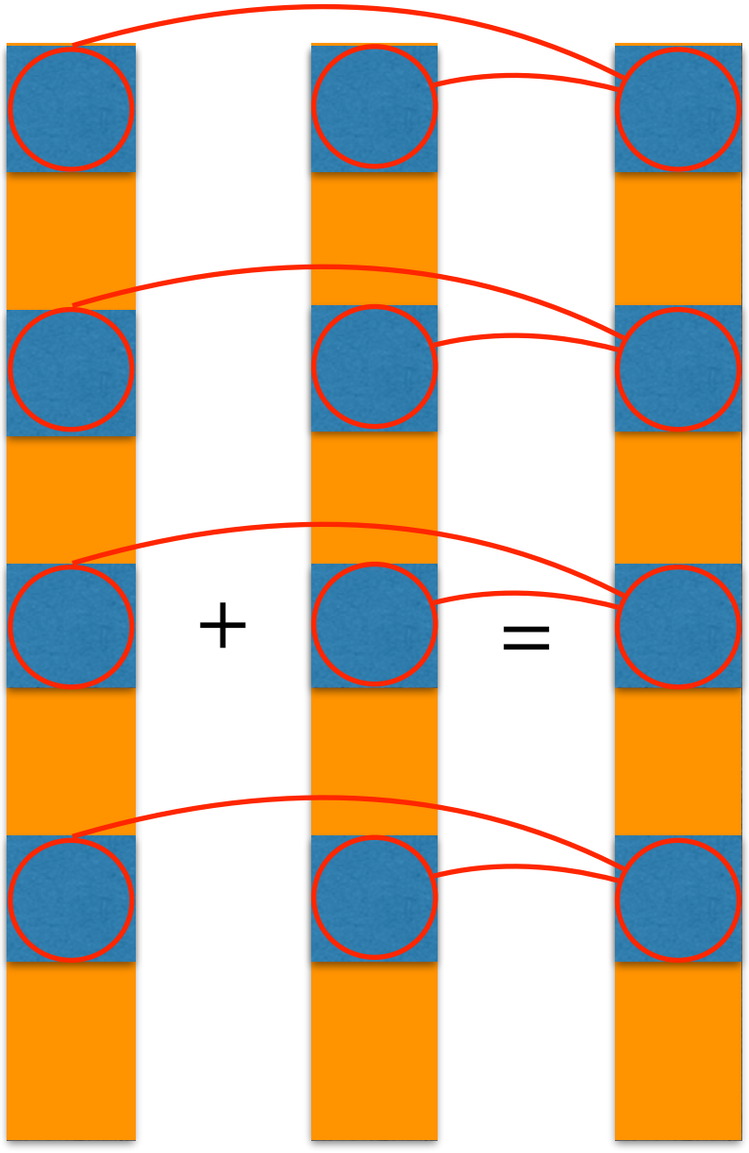
Hardware Basics

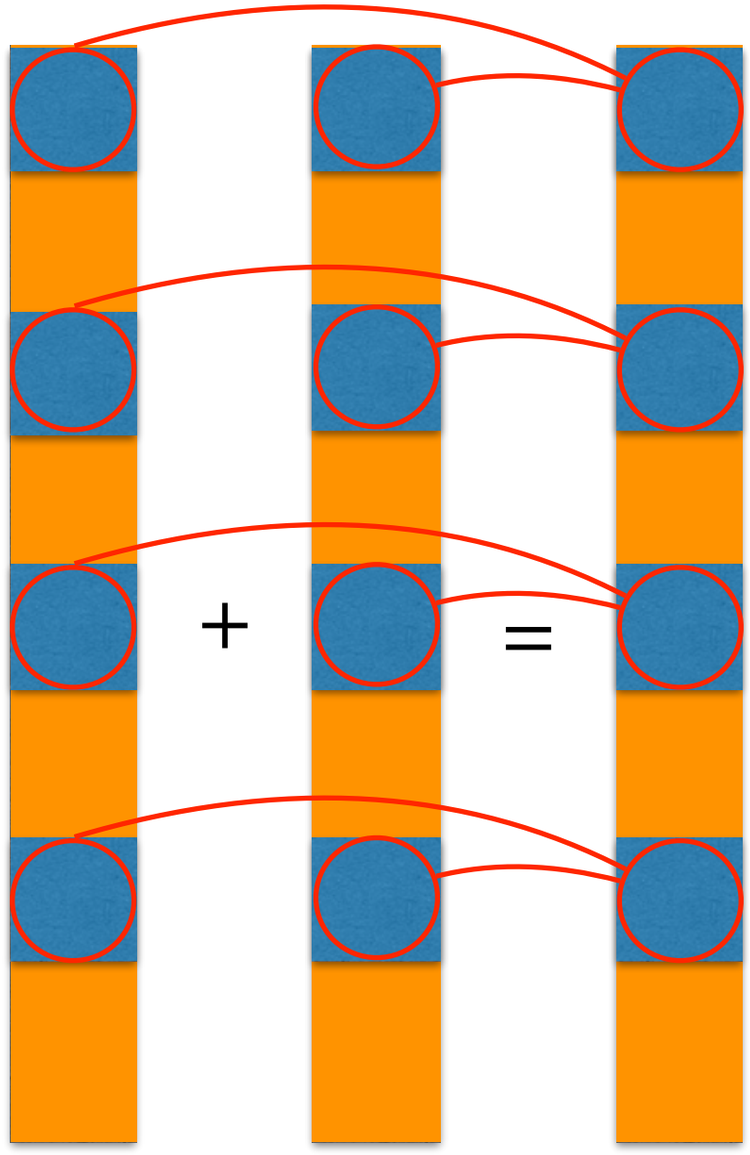


- CPUs are **latency** oriented (minimize execution of serial code)
- GPUs are **throughput** oriented (maximize number of floating point operations)

Data Parallelism

Eg. vector addition, serial vs. parallel



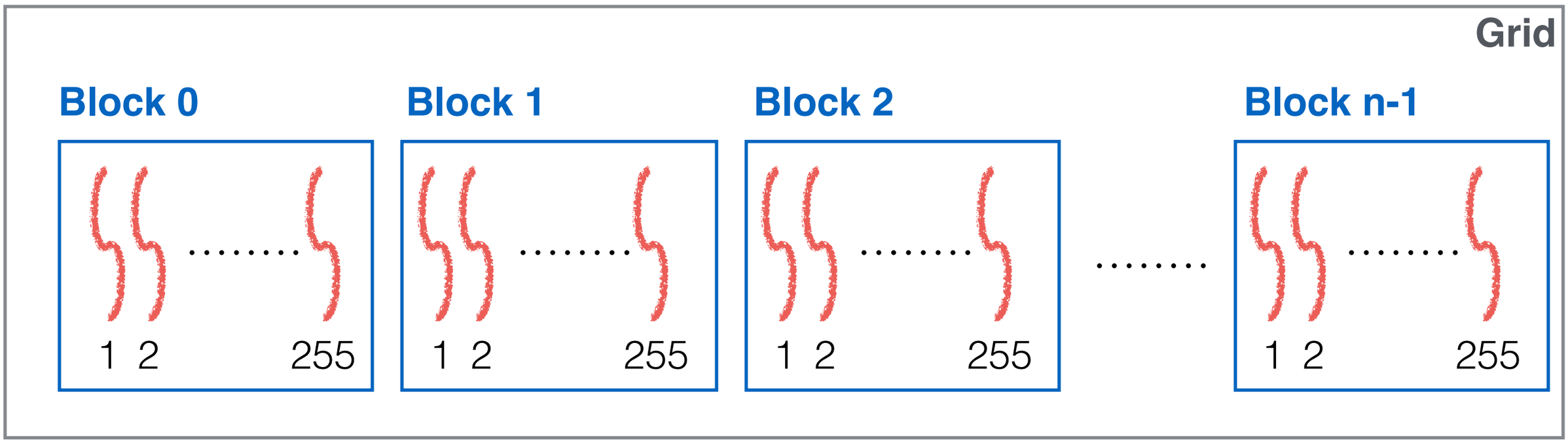


CUDA C

- **C**ompute **U**nified **D**evice **A**rchitecture
- NVIDIA GPUs can be programmed by CUDA, extension of C language (CUDA Fortran is also available)
- CUDA C is compiled with **nvcc**

- Host —> CPU; Device —> GPU (They do not share memory!)
- The **HOST** launches a kernel that execute on the **DEVICE**
- A kernel is a data-parallel computation, executed by many **threads**.
- The number of threads are very large (~ 1000 or more)

Thread Organization



CUDA C

- Threads are grouped into blocks.
- Each block shares memory.

Eg. Vector addition:

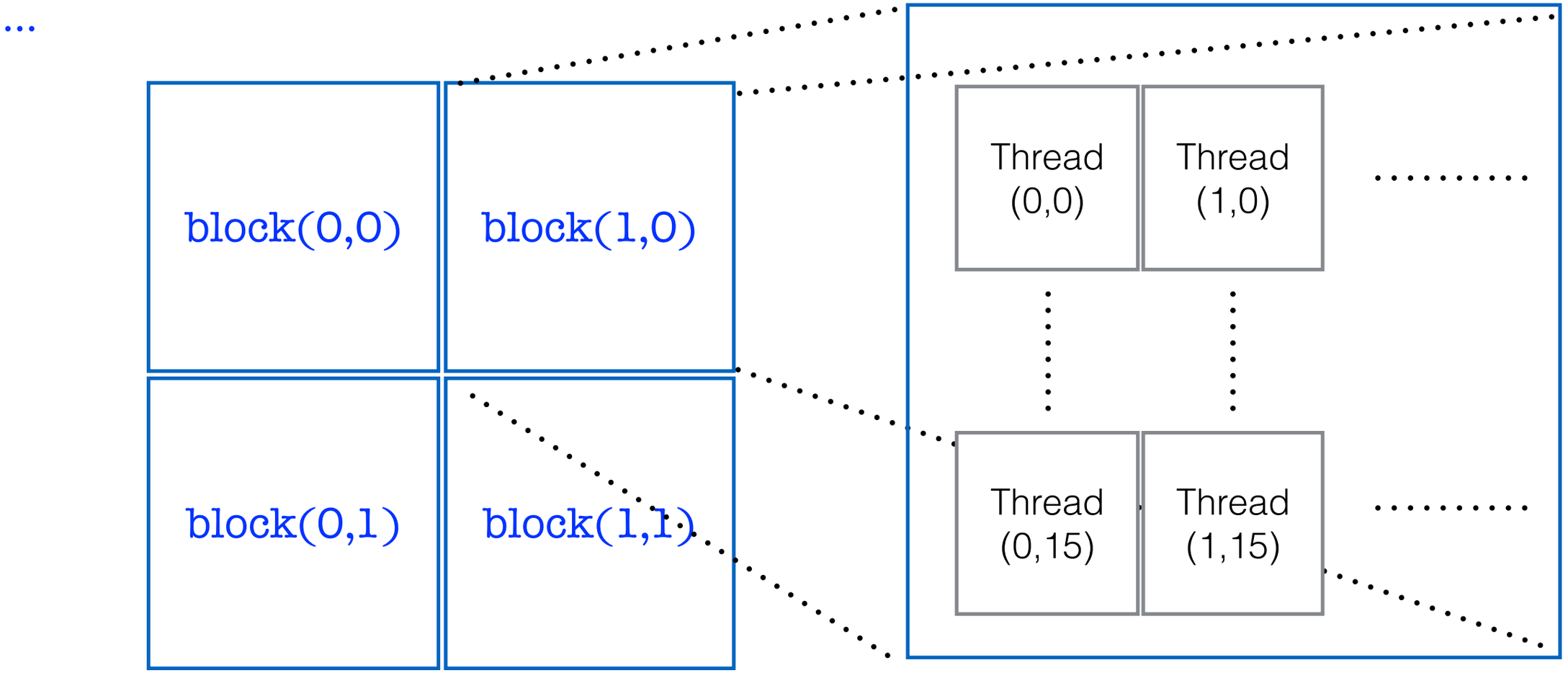
```
int main(void) {
  ...
  vecAdd<<< blocksPerGrid, THREADS_PER_BLOCK >>> (d_A, d_B, d_C);
  ...
}

__global__ static void vecAdd (float *a, float *b, float *c){
  .....
}
```

The __global__ qualifer alerts the compiler that the code block will run on the **DEVICE**, but can be called from the **HOST**.

CUDA C

- Grids and threads can also be arranged in 2d arrays (useful for image processing)

```
dim3 blocks(2,2)
dim3 threads(16,16)
....
kernel <<< blocks, threads >>>( );
```



Code Example - 1

Hello World!

```
#include <stdio.h>

__device__ const char *STR = "HELLO WORLD!";
const char STR_LENGTH = 12;

__global__ void hello(){
    printf("%c\n", STR[threadId.x % STR_LENGTH]);
}

int main(void){
    int threads_per_block = STR_LENGHT;
    int blocks_per_grid = 1;

    hello <<< blocks_per_grid, threads_per_block >>> ();

    cudaDeviceSynchronize();

    return 0;
}
```

Output:

```
H
E
L
L
O

W
O
R
L
D
!
```

Halt host thread execution on CPU until the device has finished processing all previously requested tasks.

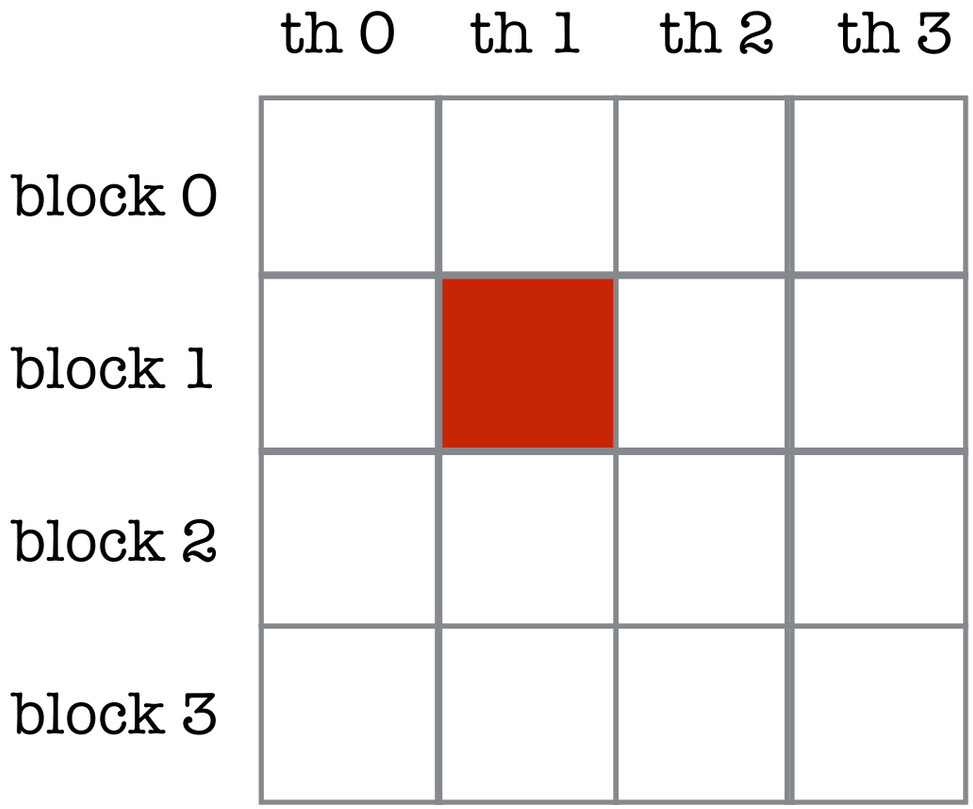
Code Example - 2

Vector Addition (Very large vectors)

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

e.g.: **blockDim** = 4, **gridDim** = 4

tid = th.id + blk.id * blk.dim
= 1 + 1 * 4
= 5

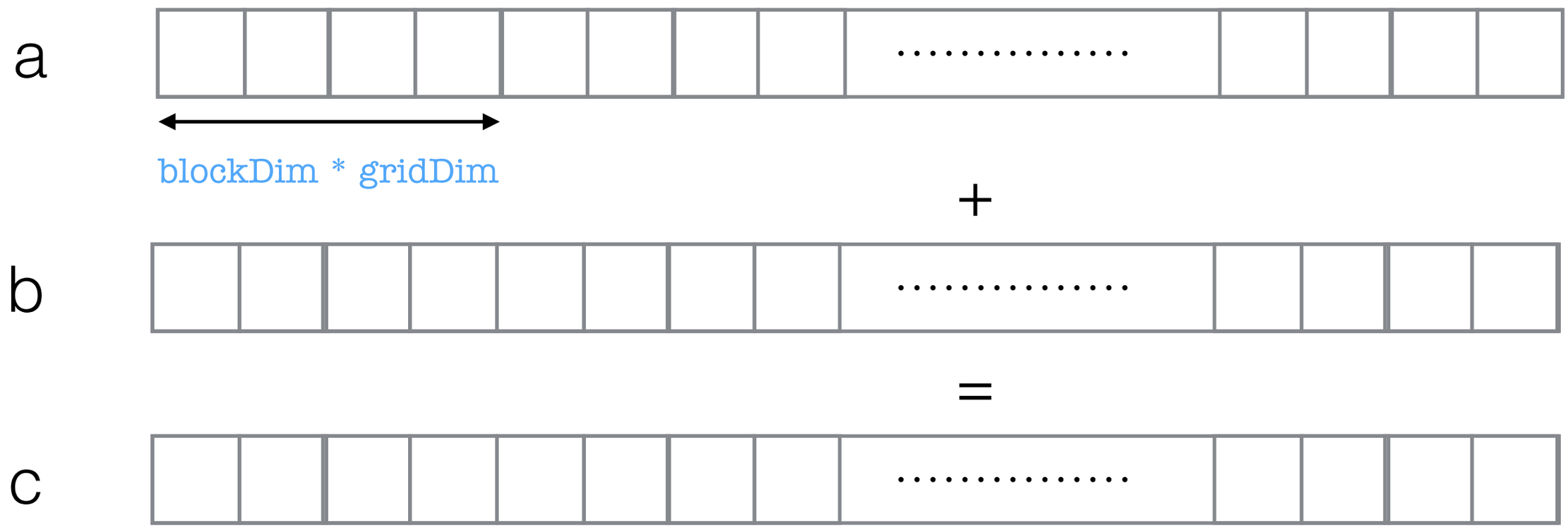


Code Example - 2

Vector Addition (Very large vectors)

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

e.g.: **N** = 256, **blockDim** = 2, **gridDim** = 2 —> **offset = blockDim * gridDim**



Code Example - 2

- Define arrays to be used on the HOST, and allocate memory.

```
int a[N], b[N], c[N];
int *dev_a, *dev_b, *dev_c;

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

- Copy arrays to the DEVICE

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

- Launch the kernel, then copy result from DEVICE to HOST

```
add<<<128,128>>>( dev_a, dev_b, dev_c) ; // Launch N=128 blocks each containing M=128 threads

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

- Free memory

```
//Free memory
cudaFree(dev_a);
cudaFree(dev_b);
cudaFree(dev_c);
```

Code Example - 3

Dot product

```
__global__ void dot (float *a, float *b, float *c) {
  __shared__ float cache[threadsPerBlock];
  int tid = threadIdx.x + blockIdx.x * blockDim.x;
  int cacheIndex = threadIdx.x;

  float temp = 0;
  while (tid<N){
    temp += a[tid] * b[tid];
    tid += blockDim.x * gridDim.x;
  }

  // Set cache values
  cache[cacheIndex] = temp;

  // Synchronize threads
  __syncthreads();
```

vector for storing each block's result

index used for storing

temp has the result within each block

For each block, there is a **different** cache vector.

Wait until all threads finish!

- Recall, each Block shares memory!
- Each block will have a its own copy of **`cahce[]`**, i.e. a partial result.
- Final step is reduction, i.e. summing all the partial results in **`cahce[]`** to obtain a final answer.

Code Example - 3

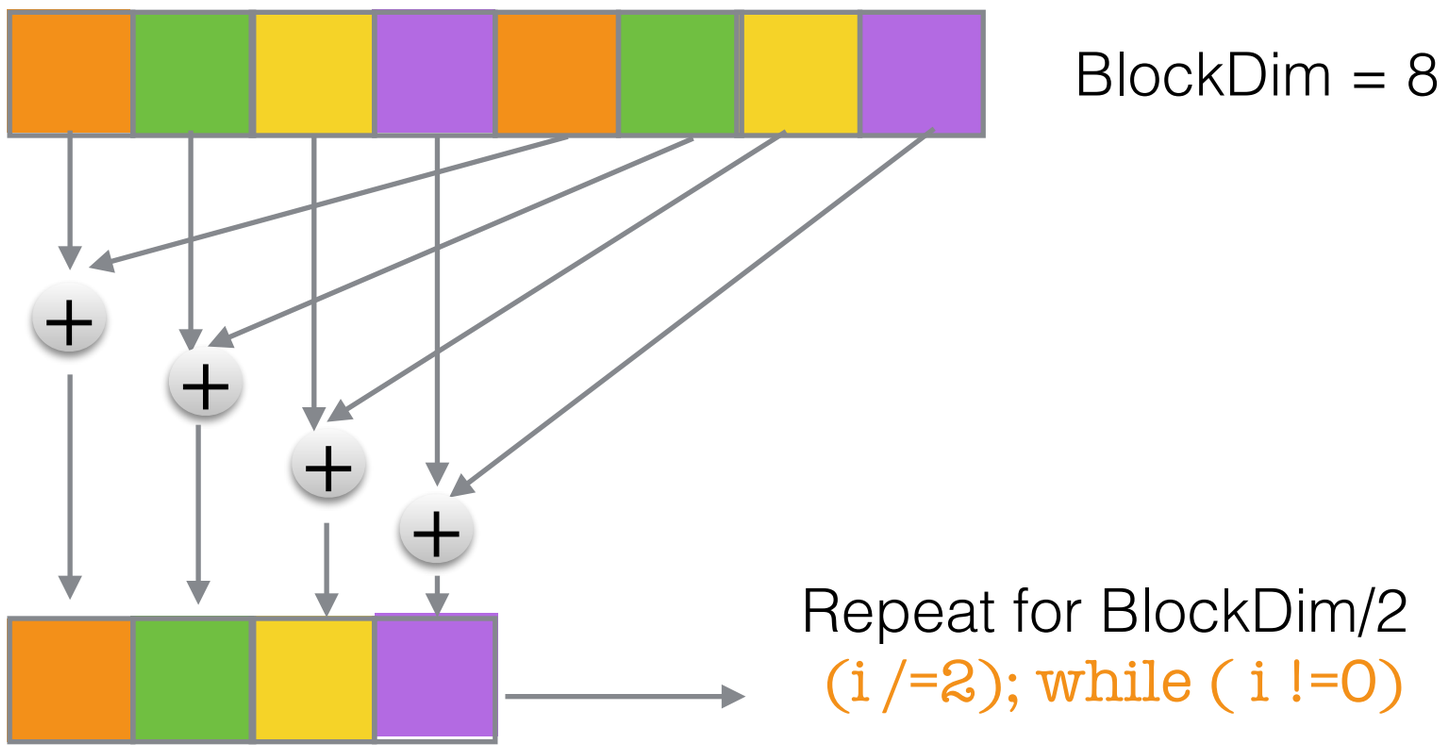
```
// Reduction (even number of threads assumed)
int i = blockDim.x/2;
while ( i != 0 ){
  if (cacheIndex < i)
    cache[cacheIndex] += cache[cacheIndex + i];

  __syncthreads();
  i /= 2;
}
```

Parallel reduction

```
// Write to c using the threadId 0
if (cacheIndex == 0)
  c[blockIdx.x] = cache[0];
```

Finally, write the final answer, with one thread (serial).

Parallel reduction:
(Not the best one!)



BlockDim = 8

Repeat for BlockDim/2
(i /=2); while (i !=0)