CUDA – Beyond Basics

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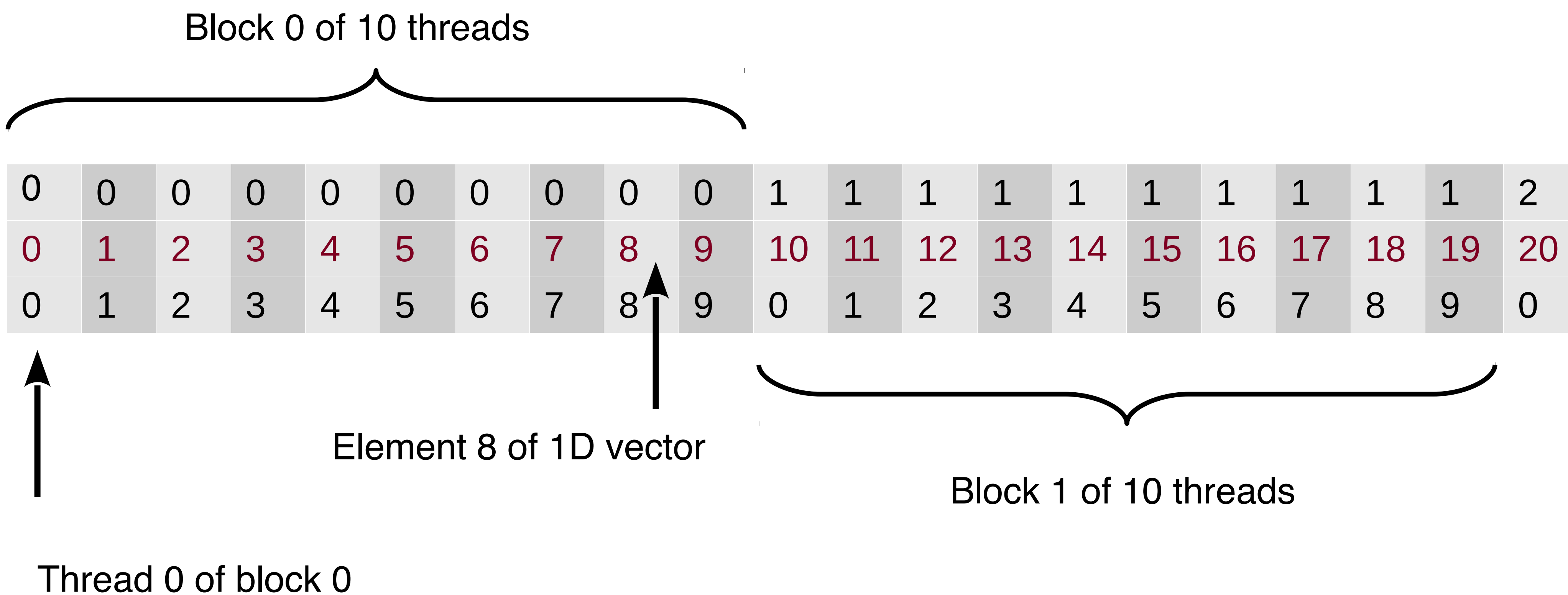
Mixing Blocks and Threads

```
int N = 100, SN = N * sizeof(double);

__global__ void sum(double *a, double *b, double *c) {
  int idx = threadIdx.x + blockIdx.x * blockDim.x;
  c[idx] = a[idx] + b[idx]; // no loop!
}

int main(void) {
  double *dev_a, *dev_b, *dev_c, *hst_a, *hst_b, *hst_c;

  cudaMalloc( &dev_a, SN ); hst_a = calloc(N, sizeof(double));
  cudaMalloc( &dev_b, SN ); hst_b = calloc(N, sizeof(double));
  cudaMalloc( &dev_c, SN ); hst_c = malloc(N, sizeof(double));

  cudaMemcpy( dev_a, hst_a, SN, cudaMemcpyHostToDevice );
  cudaMemcpy( dev_b, hst_b, SN, cudaMemcpyHostToDevice );

  sum<<<10,10>>>(dev_a, dev_b, dev_c); // all 100 elements will be used

  cudaMemcpy( &hst_c, dev_c, SN, cudaMemcpyDeviceToHost );

  for (int i=0; i<10; ++i) printf("%g\n", hst_c[i]);

  cudaFree(dev_a); free(hst_a);
  cudaFree(dev_b); free(hst_b);
  cudaFree(dev_c); free(hst_c);

  return 0;
}
```

Block and Thread Indexing with <<<10,10>>>



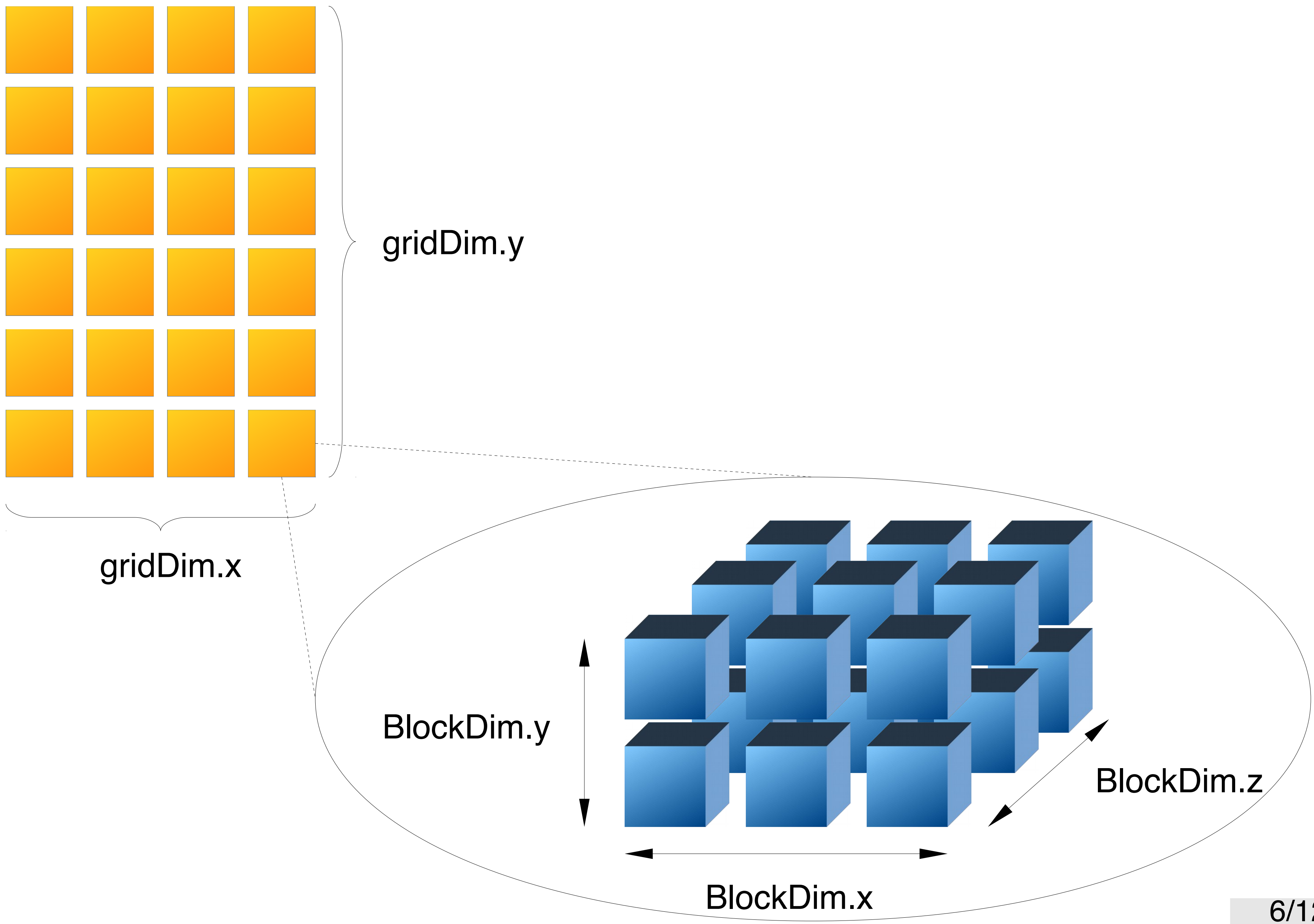
Mixing Blocks and Threads and Loop

```
int N = 1000, SN = N * sizeof(double);

__global__ void sum(double *a, double *b, double *c) {
  int idx = (threadIdx.x + blockIdx.x * blockDim.x) * 10;
  for (int i=0; i<10; ++i) c[idx+i] = a[idx+i] + b[idx+i]; // use loop
}

int main(void) {
  double *dev_a, *dev_b, *dev_c, *hst_a, *hst_b, *hst_c;

  cudaMalloc( &dev_a, SN ); hst_a = calloc(N, sizeof(double));
  cudaMalloc( &dev_b, SN ); hst_b = calloc(N, sizeof(double));
  cudaMalloc( &dev_c, SN ); hst_c = malloc(N, sizeof(double));

  cudaMemcpy( dev_a, hst_a, SN, cudaMemcpyHostToDevice );
  cudaMemcpy( dev_b, hst_b, SN, cudaMemcpyHostToDevice );

  Sum<<<10,10>>>(dev_a, dev_b, dev_c);

  cudaMemcpy( &hst_c, dev_c, SN, cudaMemcpyDeviceToHost );

  for (int i=0; i<10; ++i) printf(“%g\n”, hst_c[i]);

  cudaFree(dev_a); free(hst_a);
  cudaFree(dev_b); free(hst_b);
  cudaFree(dev_c); free(hst_c);

  return 0;
}
```

Grid, Blocks, Threads

- Complete syntax (almost):
  - kernel<<<gridDim, blockDim>>>
- CUDA API provides a data type: dim3
  - Grid of blocks: dim3 gridDim(grid_X_dimension, grid_Y_dimension)
  - Block of threads: dim3 blockDim(blk_X_d, blk_Y_d, blk_Z_d)

CUDA Grid of Blocks and Blocks of Threads



Sample Limitations for and Early NVIDIA GPU

- GT200 was an early programmable GPU
- It had the following limits
  - 512 threads / block
  - 1024 threads / SM
  - 8 blocks / SM
  - 32 threads / warp

Comparison of Early NVIDIA GPUs

GPU	G80	GT200	GF100
Transistors (billions)	.681	1.4	3.0
CUDA Cores	128	240	512
Double precision FP	None	30 FMA ops / clock	256 FMA ops / clock
Single precision FP	128 MAD ops / clock	240 ops / clock	512 FMA ops / clock
Special Function Units / SM	2	2	4
Warp schedulers / SM	1	1	2
Shared memory / SM (KiB)	16	16	16 or 48
L1 Cache / SM (KiB)	None	None	16 or 48
L2 Cache (KiB)	None	None	768
ECC Memory Support	No	No	Yes
Concurrent kernels	No	No	1..16
Load/Store Address Bits	32	32	64

Calling Functions Inside Kernels

```
__device__ int fib(int n) { // don't do this!!!
  if (n > 2)
    return fib(n-2) + fib(n-1);
  return n;
}

__device__ int gpu_function(int ix) {
  return ix + 1;
}

__global__ void kernel(int *a, int *b, int *c) {
  c[0] = a[0] + gpu_function(b[0]);
}

int main(void) {
  kernel<<<10,10>>>(dev_a, dev_b, dev_c);

  return 0;
}
```

Synchronization Between Threads

- Threads within a block execute together and share:
  - L1 Cache
  - Shared memory
- Threads often do not execute all at the same time
  - But most of the time there are multiple threads executing
- They must synchronize
  - Synchronization is for all threads inside a single block
  - Blocks of threads are executed in arbitrary order
    - Gives CUDA runtime scheduling flexibility
- The most often used synchronization method
  - __syncthreads()

Sample Usage of Thread Synchronization

- Synchronization is invoked in kernel functions
  - ```
    __global__ kernel() {
      // parallel code section 0

      // wait for all threads to finish section 0
      __syncthreads();

      // parallel code section 1
    }
    ```
- Common mistake: not all threads reach synchronzation
  - ```
    __global__ error_kernel() {
      if (threadIdx.x == 13) {
        // only some threads synchronize
        __syncthreads();
    }  else
        /*empty*/;
    }
    ```

Asynchronous CUDA Calls

- Recall the following
  - The speed of the PCIexpress bus is slow
  - Overlapping computation and communication
  - CPUs and GPUs are independent and work in parallel
  - There may be more than one CPU/GPU installed
- There are asynchronous equivalents of many CUDA calls
  - cudaMemcpy() has asynchronous equivalent cudaMemcpyAsync()
    - cudaMemcpy() will block CPU until the copy finishes
    - cudaMemcpyAsync() returns immediately and proceeds in the background
      - Keep in mind that CPU resources are needed to make progress
  - cudaDeviceSynchronize() blocks CPU until all past asynchronous calls complete