

Multi-dimensional mapping of dataspace; Synchronization

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Course Organization

Topic	Week	Hours
Review of basic COA w.r.t. performance	1	2
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Multi dimensional block

In general

- ▶ a grid is a 3-D array of blocks
- ▶ a block is a 3-D array of threads
- ▶ specified by C struct type `dim3`
- ▶ unused dimensions are set to 1



Multi dimensional grid, block

```
dim3 X(ceil(n/256.0), 1, 1);  
dim3 Y(256, 1, 1);  
vecAddKernel<<<X, Y>>>(..);  
vecAddKernel<<<ceil(n/256), 256>>>(..);  
//CUDA compiler is smart enough to realise both as equivalent
```



Multi dimensional grid, block

- ▶ $\text{gridDim.x/y/z} \in [1, 2^{16}]$
- ▶ $(\text{blockIdx.x}, \text{blockIdx.y}, \text{blockIdx.z})$ is one block
- ▶ All threads in the block sees the same value of system vars **blockIdx.x**, **blockIdx.y**, **blockIdx.z**
- ▶ $\text{blockIdx.x/y/z} \in [0, \text{gridDim.x/y/z} - 1]$



Multi dimensional grid, block

block dimension is limited by total number of threads possible in a block – 1024.

- ▶ (512, 1, 1) - ✓
- ▶ (8, 16, 4) - ✓
- ▶ (32, 16, 2) - ✓
- ▶ (32, 32, 32) - ✗



Multi dimensional grid, block declaration

Consider the following host side code

```
dim3 X(2, 2, 1);  
dim3 Y(4, 2, 2);  
vecAddKernel<<<X, Y>>>(...);
```

The memory layout thus created in device when the kernel is launched is shown next



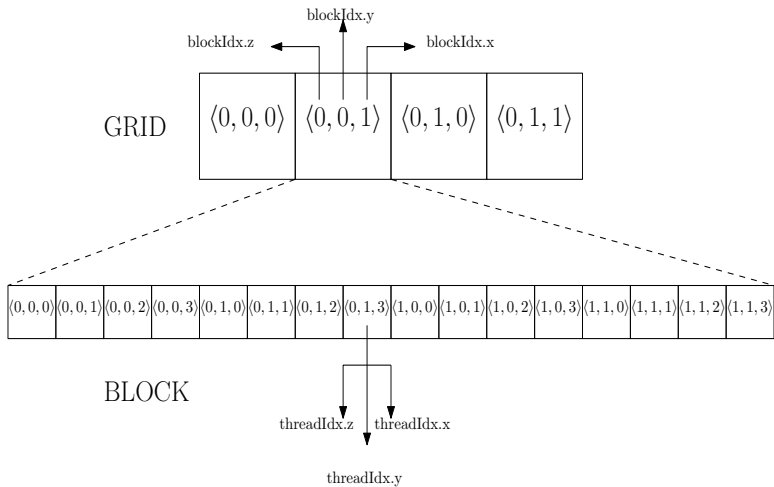


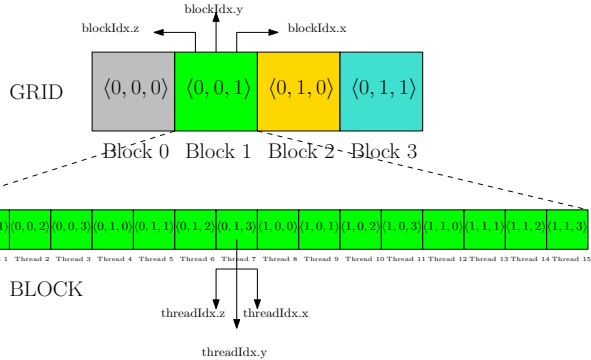
Figure: Grids and Blocks



	Col 0	Col 1	Col 2	Col 3	Col 4	Col 5	Col 6	Col 7
Row 0								
Row 1								
Row 2								
Row 3								
Row 4								
Row 5								
Row 6								
Row 7								

Figure: 2D Matrix





$$\text{blockNum} = \text{blockIdx.z} * (\text{gridDim.x} * \text{gridDim.y}) + \text{blockIdx.y} * \text{gridDim.x} + \text{blockIdx.x}$$

$$\text{threadNum} = \text{threadIdx.z} * (\text{blockDim.x} * \text{blockDim.y}) + \text{threadIdx.y} * (\text{blockDim.x}) + \text{threadIdx.x}$$

$$\text{globalThreadId} = \text{blockNum} * (\text{blockDim.x} * \text{blockDim.y} * \text{blockDim.z}) + \text{threadNum}$$

Figure: Global Thread IDs



Relations among variables

```
blockNum = blockIdx.z * (gridDim.x * gridDim.y) + blockIdx.y * gridDim.x +  
    blockIdx.x;  
threadNum = threadIdx.z * (blockDim.x * blockDim.y) + threadIdx.y * (blockDim.  
    x) + threadIdx.x;  
globalThreadId = blockNum * (blockDim.x * blockDim.y * blockDim.z) + threadNum  
    ;
```



	Col 0	Col 1	Col 2	Col 3	Col 4	Col 5	Col 6	Col 7
Row 0	0	1	2	3	4	5	6	7
Row 1	8	9	10	11	12	13	14	15
Row 2	16	17	18	19	20	21	22	23
Row 3	24	25	26	27	28	29	30	31
Row 4	32	33	34	35	36	37	38	39
Row 5	40	41	42	43	44	45	46	47
Row 6	48	49	50	51	52	53	54	55
Row 7	56	57	58	59	60	61	62	63

$i = \text{globalThreadId} / \text{NumCols}$ $j = \text{globalThreadId} \% \text{NumCols}$
 $\text{NumRows} * \text{NumCols} = \text{gridDim.x} * \text{gridDim.y} * \text{gridDim.z} * \text{blockDim.x} * \text{blockDim.y} * \text{blockDim.z}$

Figure: Mapping Threads to Matrix



Mapping between kernels and data

The CUDA programming interface provides support for mapping kernels of any dimension (upto 3) to data of any dimension

- ▶ Mapping a 3D kernel to 2D kernel results in complex memory access expressions.
- ▶ Makes sense to map 2D kernel to 2D data and 3D kernel to 3D data



$$\text{NumCols} = \text{blockDim.x} * \text{gridDim.x}$$

$$\text{NumRows} = \text{blockDim.y} * \text{gridDim.y}$$

$$\text{gridDim} = \langle 3, 2 \rangle$$

$$\text{blockDim} = \langle 5, 4 \rangle$$

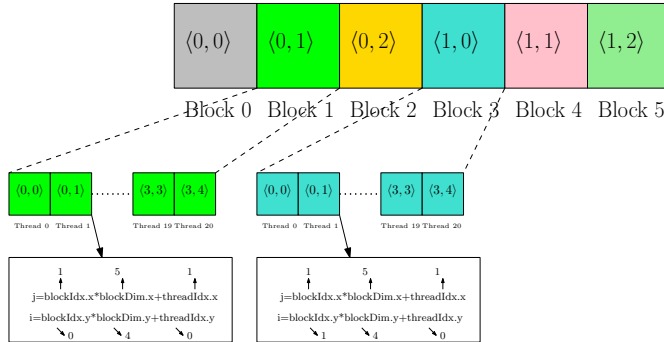


Figure: Two Dimensional Kernel



8 X 15 Matrix

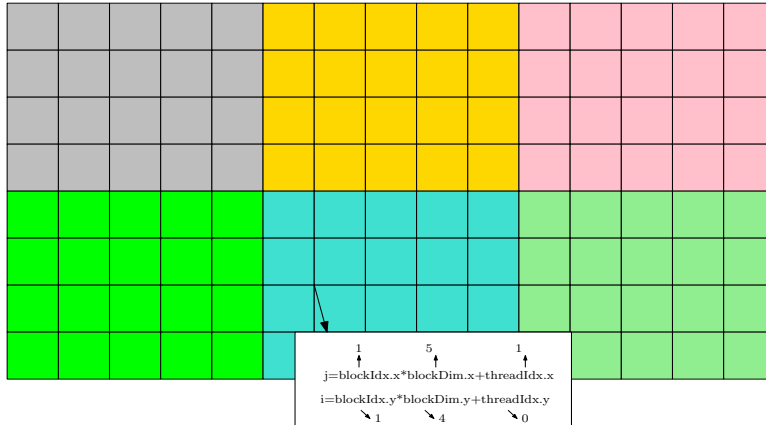


Figure: Two Dimensional Kernel-Data Mapping



$$nX = \text{blockDim.x} * \text{gridDim.x}$$

$$nY = \text{blockDim.y} * \text{gridDim.y}$$

$$nZ = \text{blockDim.z} * \text{gridDim.z}$$

$$\text{gridDim} = \langle 2, 2, 2 \rangle$$

$$\text{blockDim} = \langle 5, 4, 3 \rangle$$

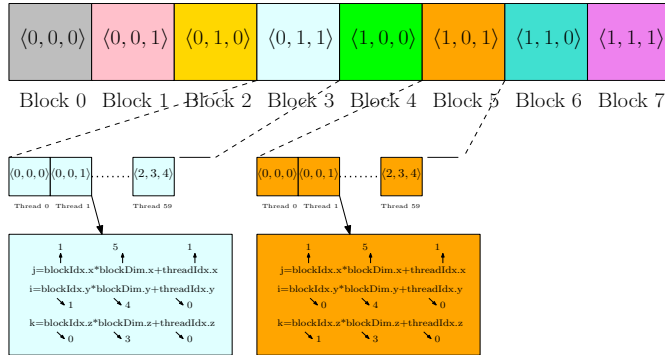
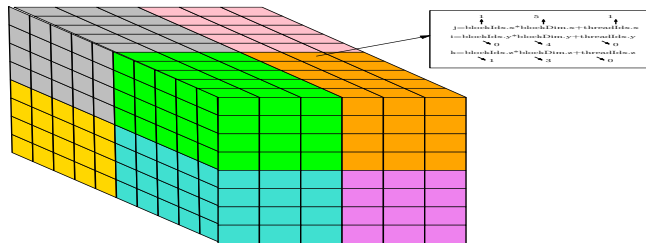


Figure: Three Dimensional Kernel





8 X 15 Matrix

Figure: Three Dimensional Kernel-Data Mapping



Synchronization

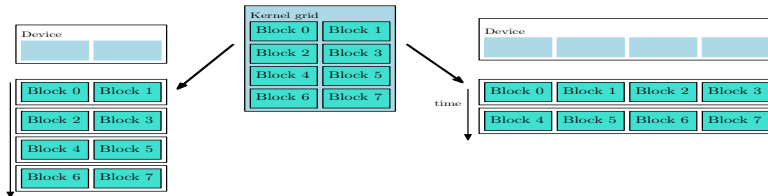


Figure: Mapping Blocks to Hardware

- ▶ Each block can execute in any order relative to other blocks.
- ▶ Lack of synchronization constraints between blocks enables scalability.



Synchronization

- ▶ Synchronization constraints can be enforced to threads inside a thread block.
- ▶ Threads may co-operate with each other and share data with the help of local memory (more on this later)
- ▶ CUDA construct `__syncthreads()` is used for enforcing synchronization.



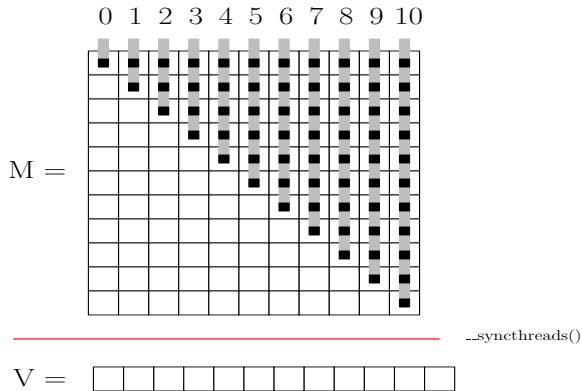


Figure: Input: A 11 X 11 matrix, Output: A vector of size 12 where each element represents the column sums and the last element represents the sum of the column sums.



Synchronization Host Program

```
int main()
{
    int N=1024;
    int size_M=N*N;
    int size_V=N+1;

    cudaMemcpy(d_M,M,size_M*sizeof(float),
    cudaMemcpyHostToDevice);
    cudaMemcpy(d_V, V, size_V*sizeof(float),
    cudaMemcpyHostToDevice);
    dim3 grid(1,1,1);
    dim3 block(N,1,1);
    sumTriangle<<<grid,block>>>(d_M,d_V,N);
    cudaMemcpy(V,d_V,size_V*sizeof(float),
    cudaMemcpyDeviceToHost);
}
```



Kernel

```
__global__  
void sumTriangle(float* M, float* V, int N){  
  
    int j=threadIdx.x;  
    float sum=0.0;  
    for (int i=0;i<j;i++)  
        sum+=M[i*N+j];  
  
    V[j]=sum;  
    __syncthreads();  
}
```



Kernel

```
if(j == N-1)
{
    sum = 0.0;
    for(i=0;i<N;i++)
        sum =sum + V[i];
    V[N] = sum;
}
```

Once each thread finishes computing sum across columns, the total sum is computed by the last thread.



Synchronization Program Variant I

Modification: Only elements at odd indices are summed.

```
__global__  
void sumTriangle(float* M, float* V, int N){  
  
    int j=threadIdx.x;  
    float sum=0.0;  
    for (int i=0;i<j;i++)  
        if(i%2) // Check for odd indices  
            sum+=M[i*N+j];  
  
    V[j]=sum;  
    __syncthreads();  
}
```



Synchronization Program Variant I

Addition still carried out by the last thread.

```
if(j == N)
{
    sum = 0.0;
    for(i=0;i<N;i++)
        sum =sum + V[i];
    V[N+1] = sum;
}
```



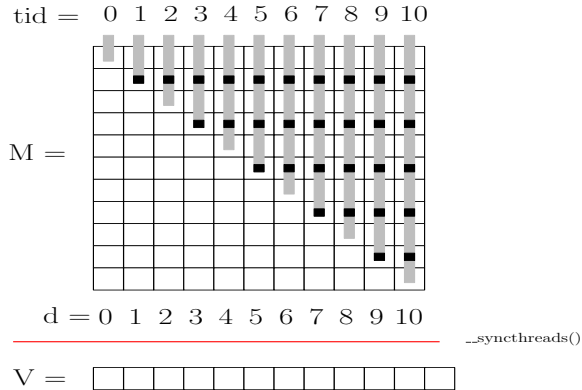


Figure: A variant of SumTriangle where only the elements at odd indices of a column are added



Synchronization Program Variant II

Modification: Consider summing all indices again. But use all threads for final reduction.

```
__global__  
void sumTriangle(float* M, float* V, int N){  
  
    int j=threadIdx.x;  
    float sum=0.0;  
    for (int i=0;i<j;i++)  
        sum+=M[i*N+j];  
  
    V[j]=sum;  
    __syncthreads();  
}
```



Synchronization Program Variant II

Reduction possible since addition is an associative operation.

```
for(unsigned int s=1; s<N; s*= 2)
{
    if (j %(2*s)==0 && j+s < N)
        V[j]+=V[j+s];
    __syncthreads();
}
```

Once each thread finishes computing sum across columns, the total sum is computed by all the threads.



Reduction

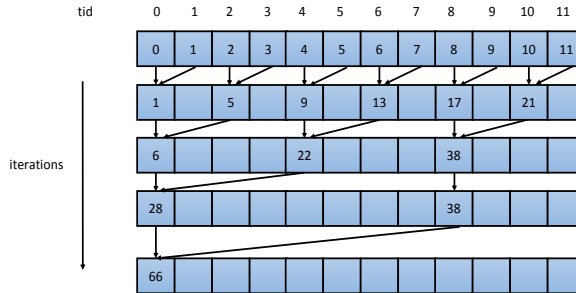


Figure: Reducing an array of 12 elements

