# Multi-dimensional mapping of dataspace; Synchronization

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# Course Organization

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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

- **gridDim.x/y/z** $\in [1, 2^{16}]$
- (**blockIdx.x, blockIdx.y, blockIdx.z**) is one block
- All threads in the block sees the same value of system vars **blockIdx.x, blockIdx.y, blockIdx.z**
- **blockIdx.x/y/z** $\in$ [0, **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) - $\surd$
- (8, 16, 4) - $\surd$
- (32, 16, 2) - $\surd$
- (32, 32, 32) - $\times$

# 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

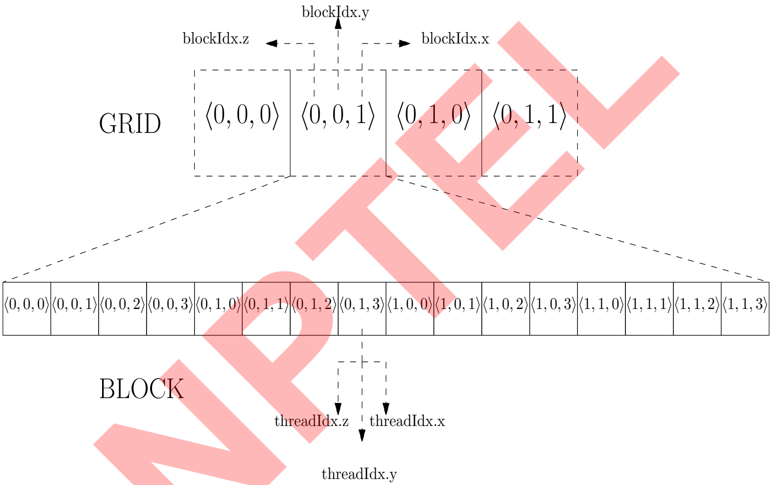
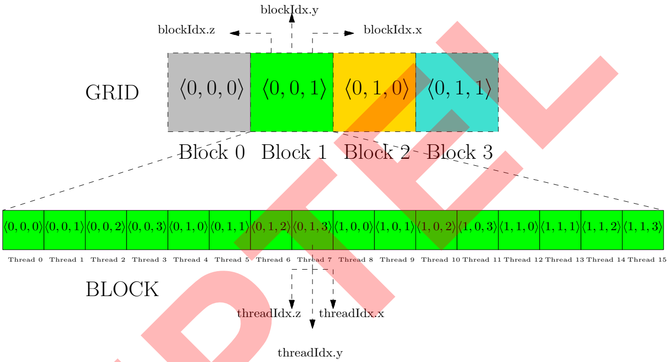



Figure: Grids and Blocks

| | 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




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

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 = globalThreadId / NumCols  j = globalThreadId % NumCols

NumRows * NumCols = gridDim.x * gridDim.y * gridDim.z * blockDim.x * blockDim.y * 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

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

$gridDim = \langle 3, 2 \rangle$ $\qquad$ $blockDim = \langle 5, 4 \rangle$

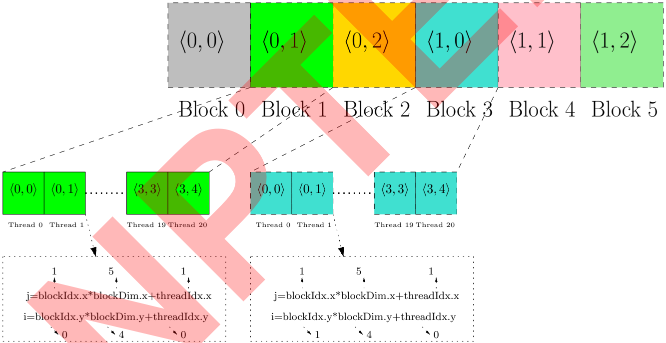



Figure: Two Dimensional Kernel

# 8 X 15 Matrix

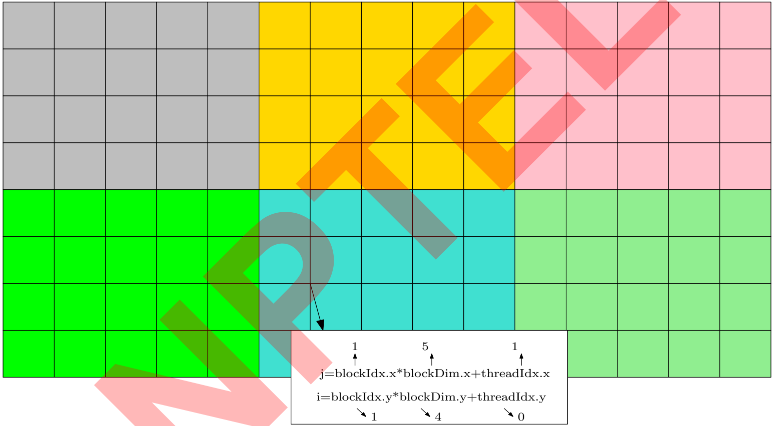



Figure: Two Dimensional Kernel-Data Mapping

$$nX = blockDim.x * gridDim.x$$
$$nY = blockDim.y * gridDim.y$$
$$nZ = blockDim.z * gridDim.z$$

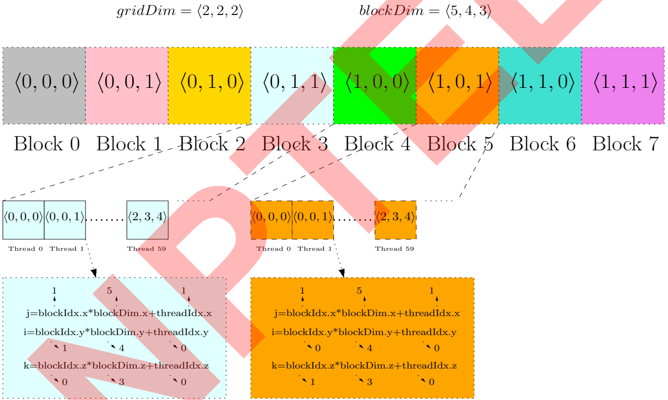



Figure: Three Dimensional Kernel

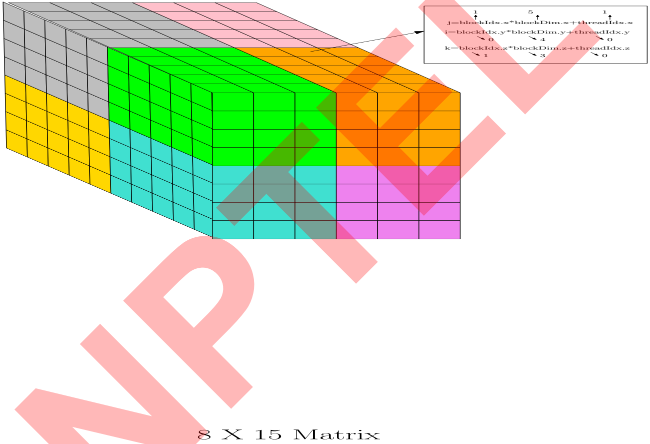



Figure: Three Dimensional Kernel-Data Mapping

# Synchronization

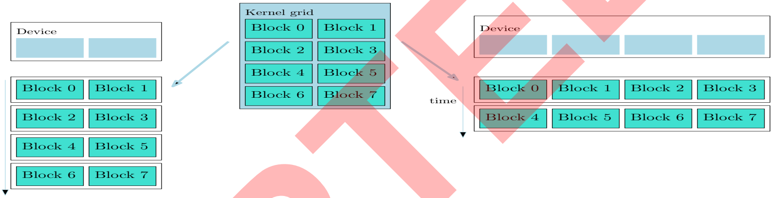



Figure: Mapping Blocks to Hardware

- 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 __synchthreads() is used for enforcing synchronization.

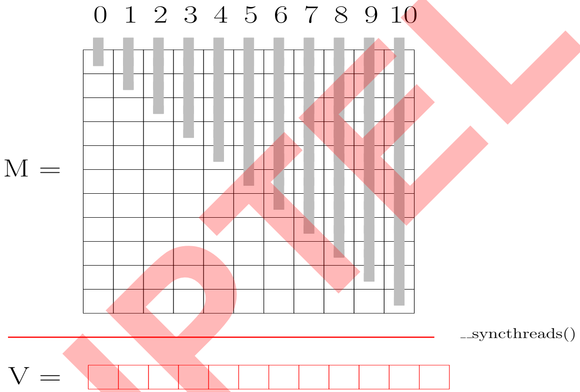



Figure: Input: A 11 X 11 matrix, Output: A vector of size 12 where each element represents the column sums and the last element represents the sum of the column sums.

# 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

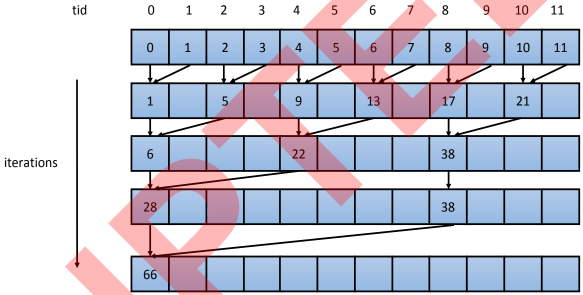



Figure: Reducing an array of 12 elements