CUDA ON ARM PLATFORM—矩阵乘 & 矩阵转置

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CUDA并行计算基础

- GPU的存储单元
- 矩阵相乘
- 矩阵转置

GPU的存储单元

Each thread can:

R/W per-thread registers

R/W per-thread local memory

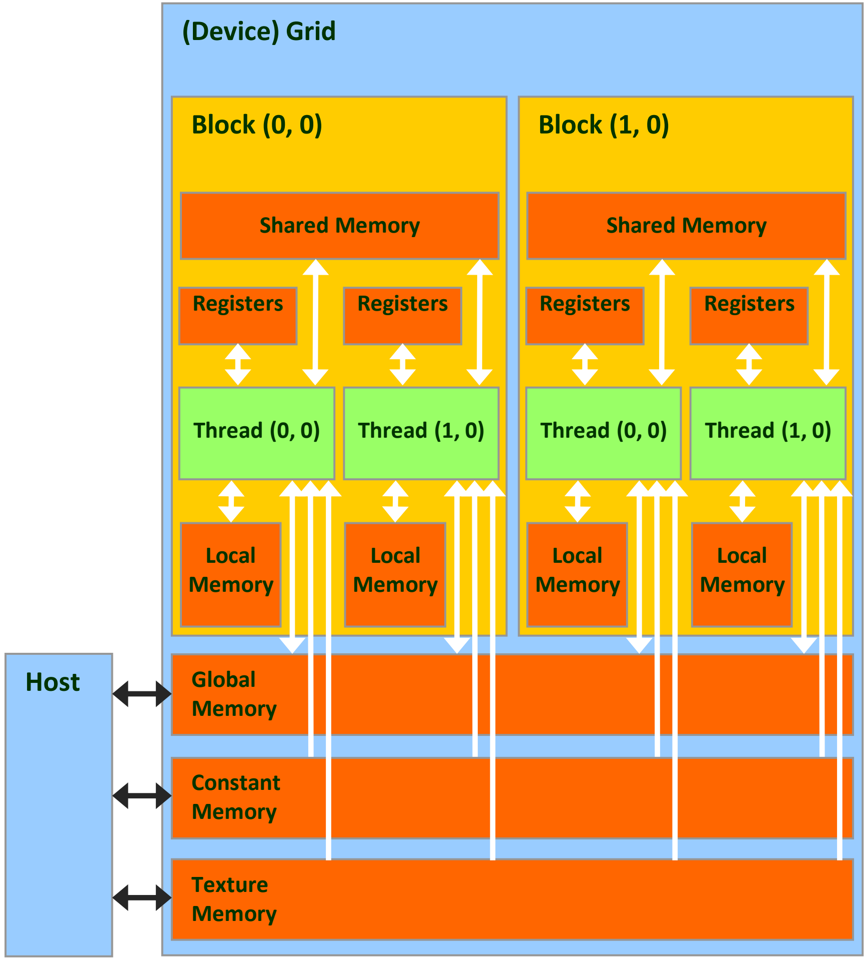
R/W per-block shared memory

R/W per-grid global memory

Read only per-grid constant memory

Read only per-grid texture memory

- The host global
  constant texture



MEMORY ALLOCATION / RELEASE

CPU memory:

- malloc()
- memset()
- free()

GPU memory:

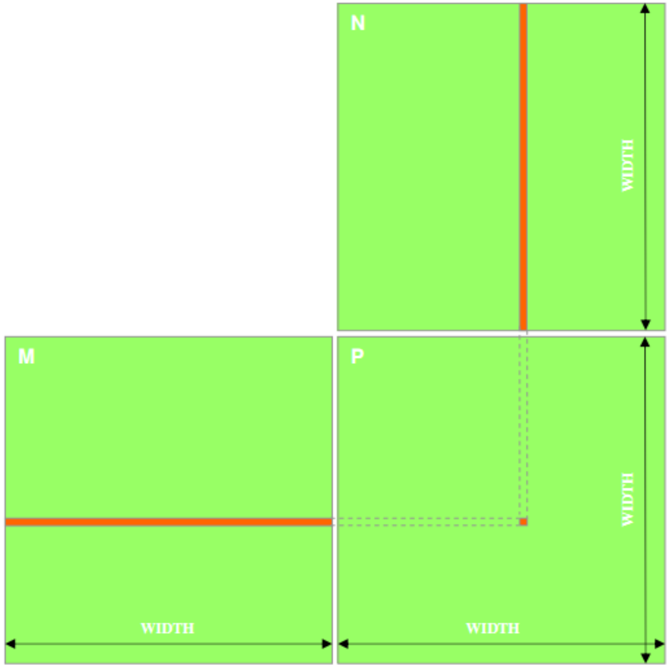
- cudaMalloc()
- cudaMemset()
- cudaFree()

矩阵相乘样例

```
void cpu_matrix_mult(int *h_m, int *h_n, int *h_result, int m,
int n, int k) {
    for (int i = 0; i < m; ++i)
    {
        for (int j = 0; j < k; ++j)
        {
            int tmp = 0.0;
            for (int h = 0; h < n; ++h)
            {
                tmp += h_m[i * n + h] * h_n[h * k + j];
            }
            h_result[i * k + j] = tmp;
        }
    }
}
```

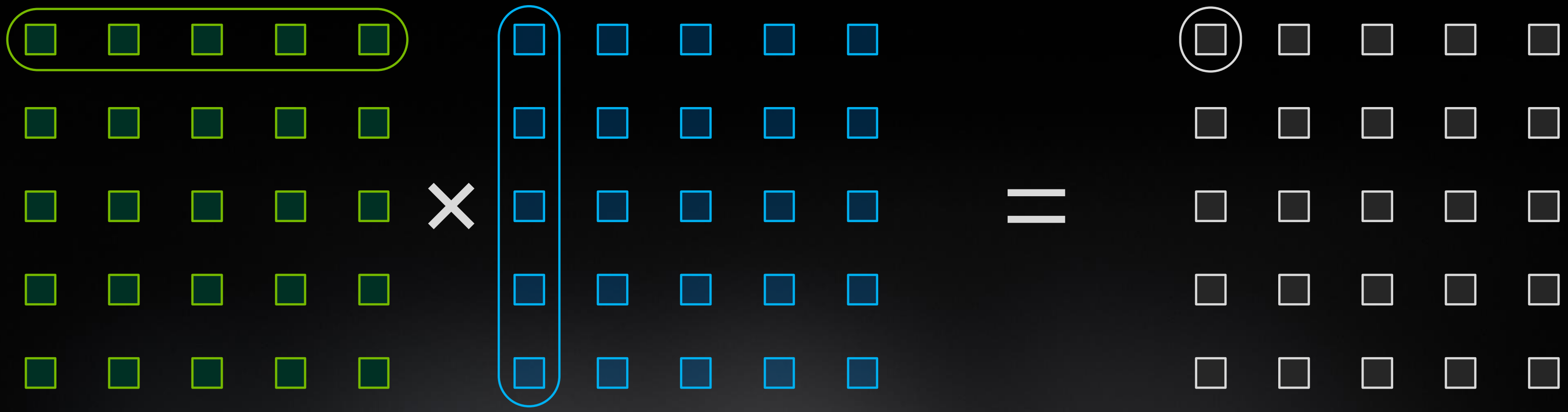
P = M * N

假定 M and N 是方阵

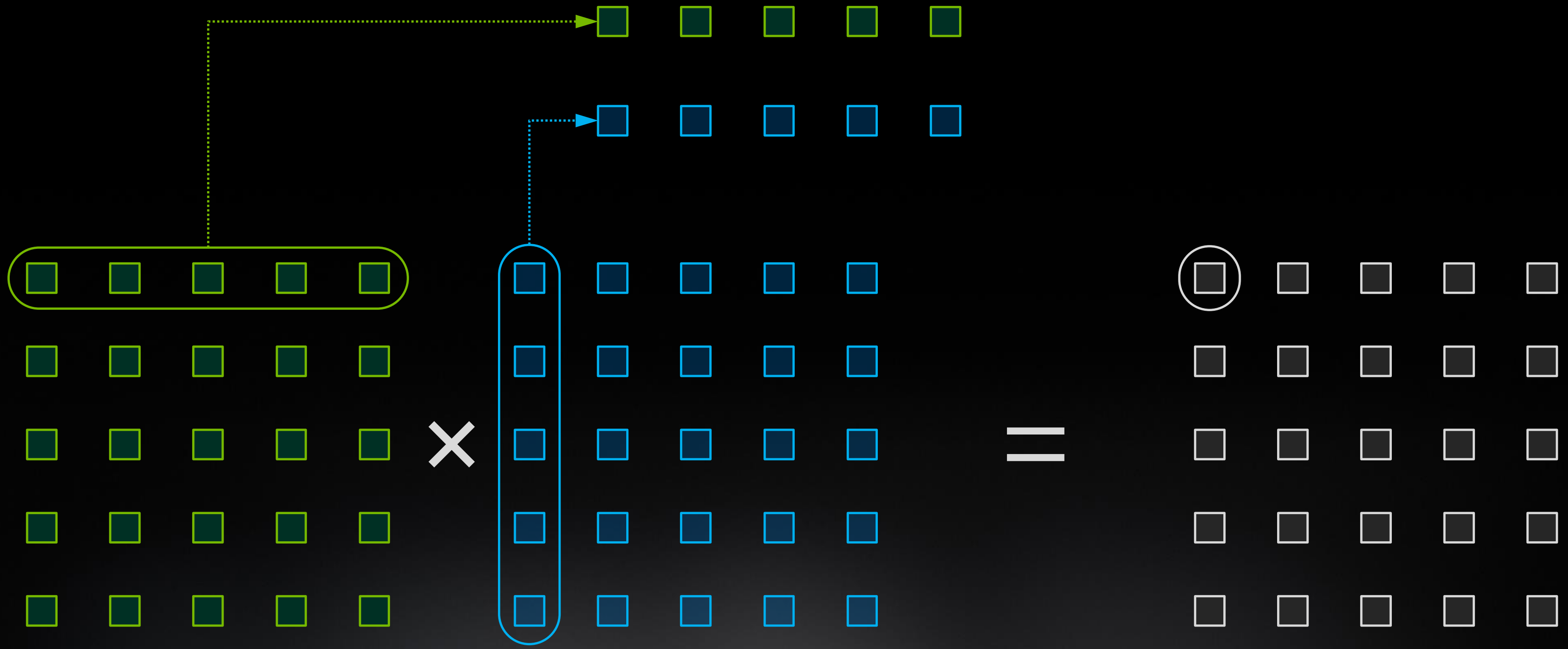


$$\begin{bmatrix} a_{11} & a_{12} & a_{13} \\ a_{21} & a_{22} & a_{23} \\ a_{31} & a_{32} & a_{33} \end{bmatrix} \times \begin{bmatrix} b_{11} & b_{12} & b_{13} \\ b_{21} & b_{22} & b_{23} \\ b_{31} & b_{32} & b_{33} \end{bmatrix} = \begin{bmatrix} a_{11}\times b_{11}+a_{12}\times b_{21}+a_{13}\times b_{31} & a_{11}\times b_{12}+a_{12}\times b_{22}+a_{13}\times b_{32} & a_{11}\times b_{13}+a_{12}\times b_{23}+a_{13}\times b_{33} \\ a_{21}\times b_{11}+a_{22}\times b_{21}+a_{23}\times b_{31} & a_{21}\times b_{12}+a_{22}\times b_{22}+a_{23}\times b_{32} & a_{21}\times b_{13}+a_{22}\times b_{23}+a_{23}\times b_{33} \\ a_{31}\times b_{11}+a_{32}\times b_{21}+a_{33}\times b_{31} & a_{31}\times b_{12}+a_{32}\times b_{22}+a_{33}\times b_{32} & a_{31}\times b_{13}+a_{32}\times b_{23}+a_{33}\times b_{33} \end{bmatrix}$$

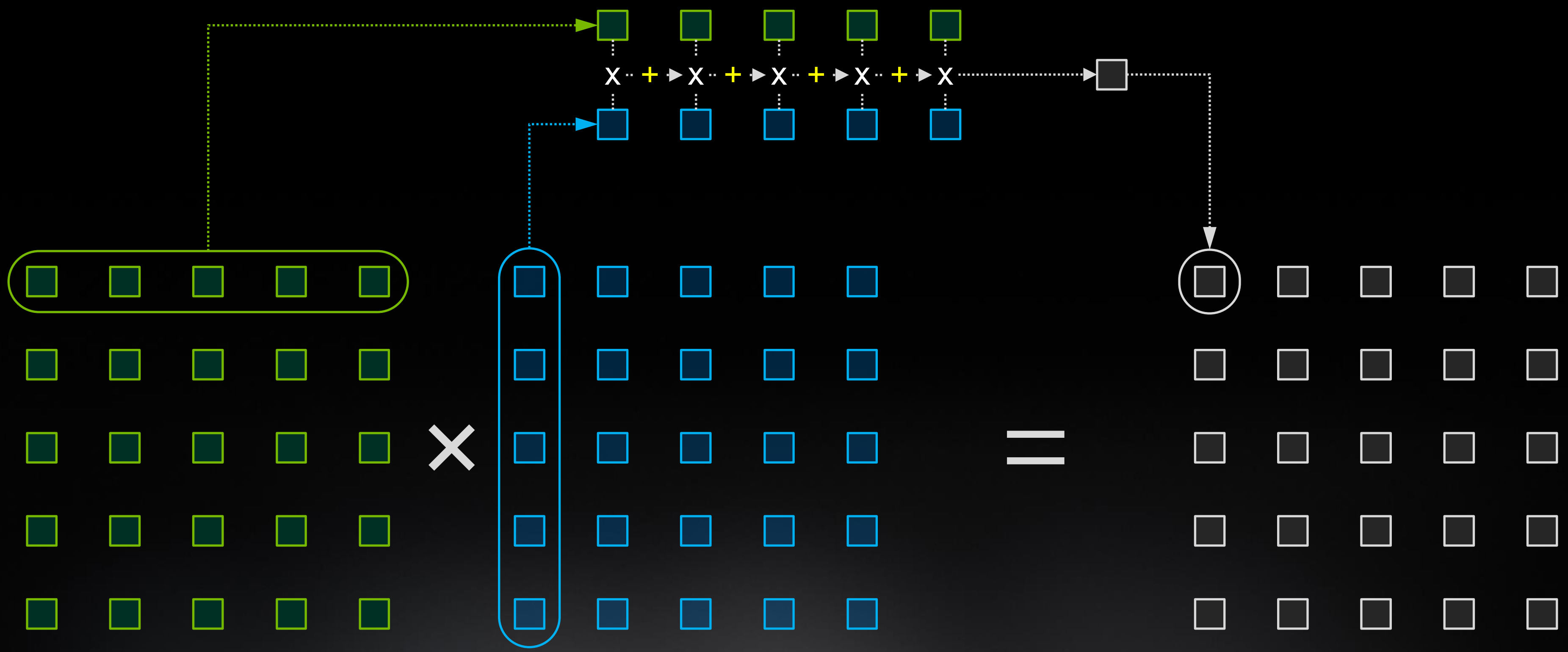
矩阵乘示例



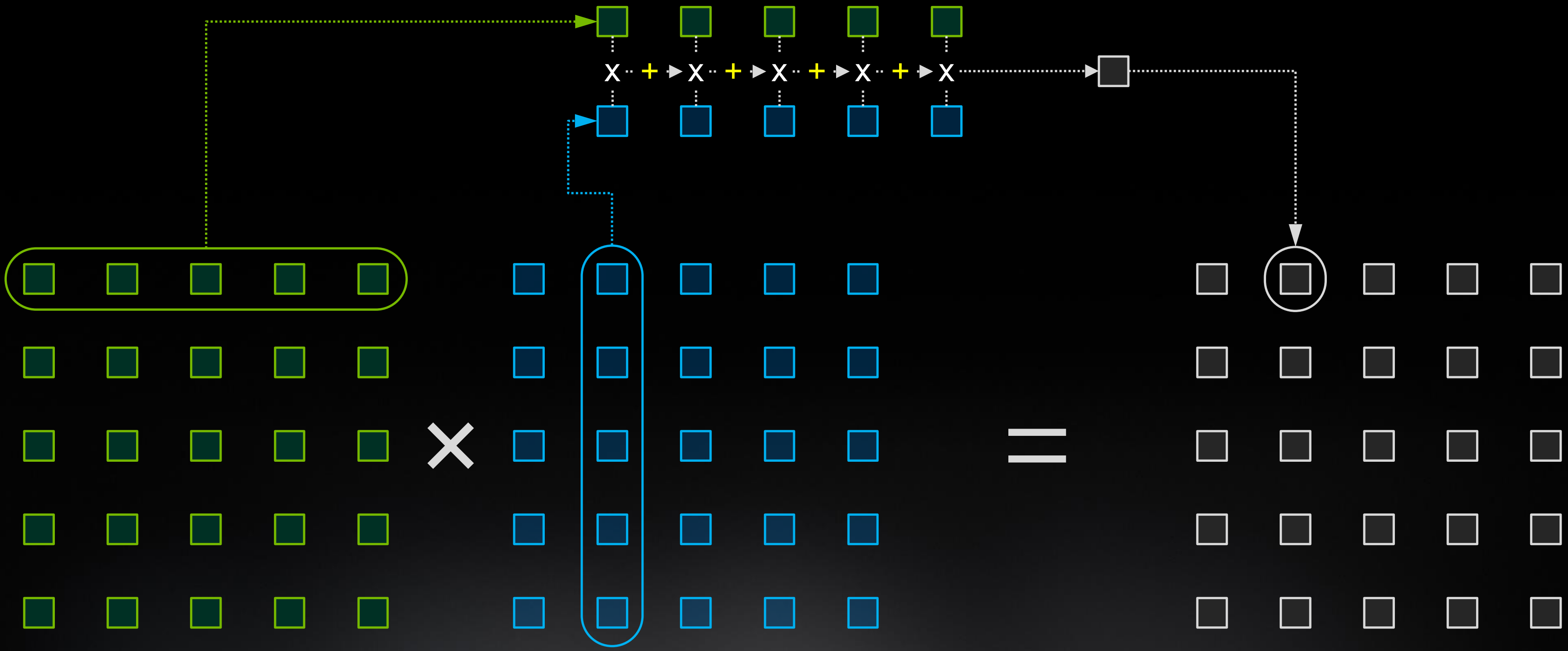
矩阵乘示例



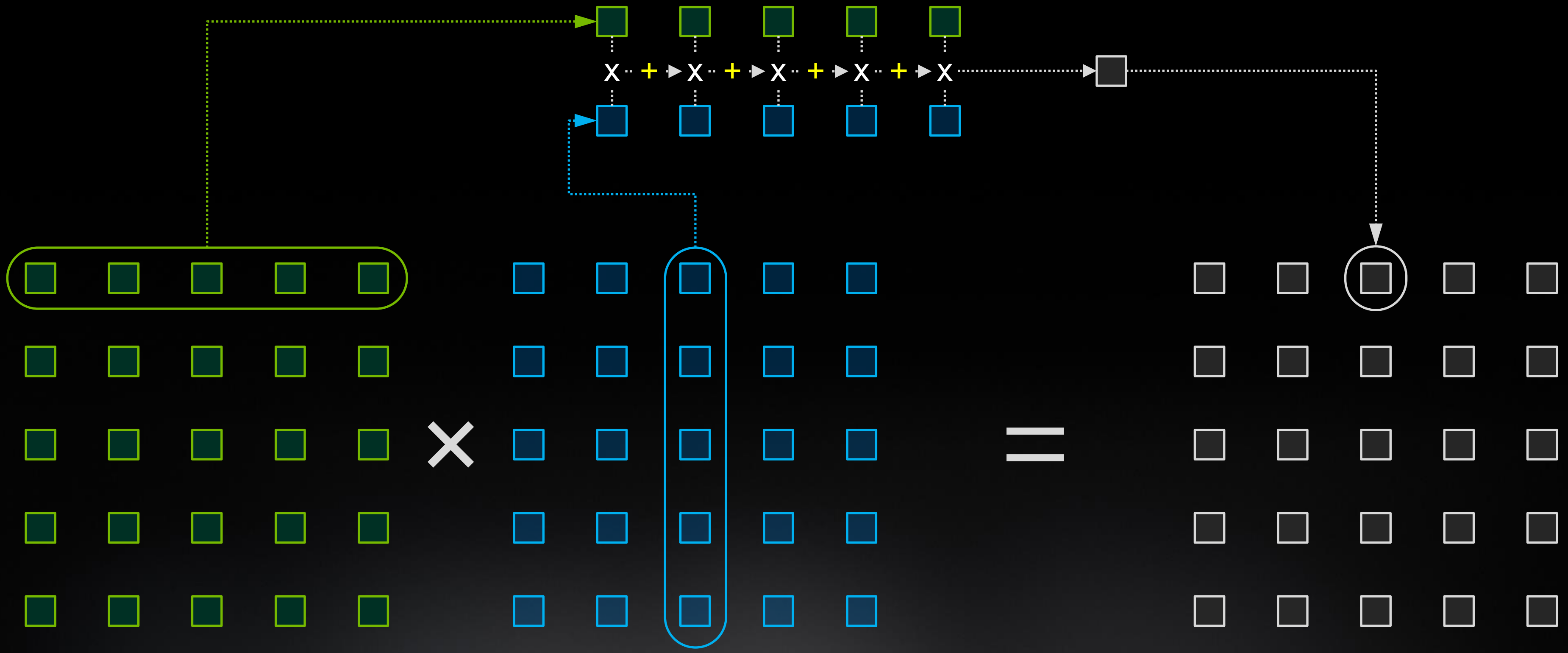
矩阵乘示例



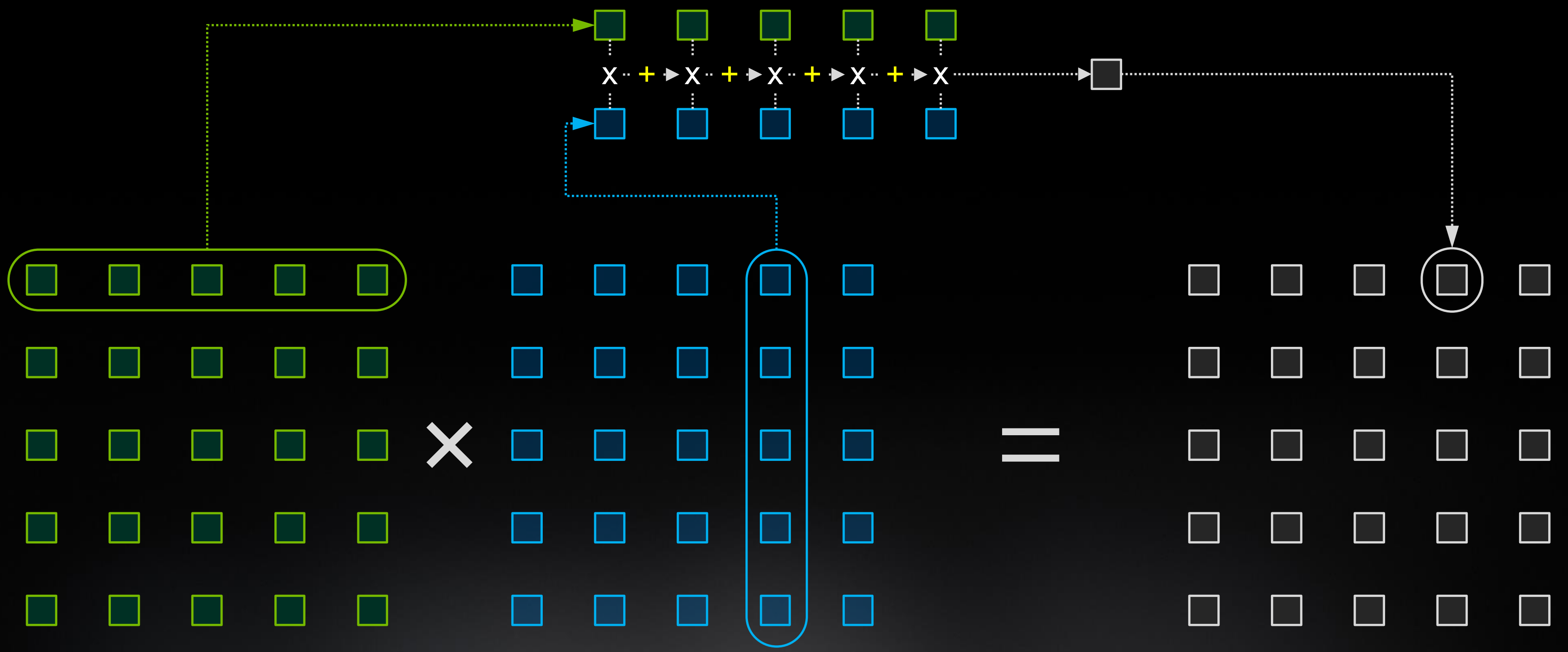
矩阵乘示例



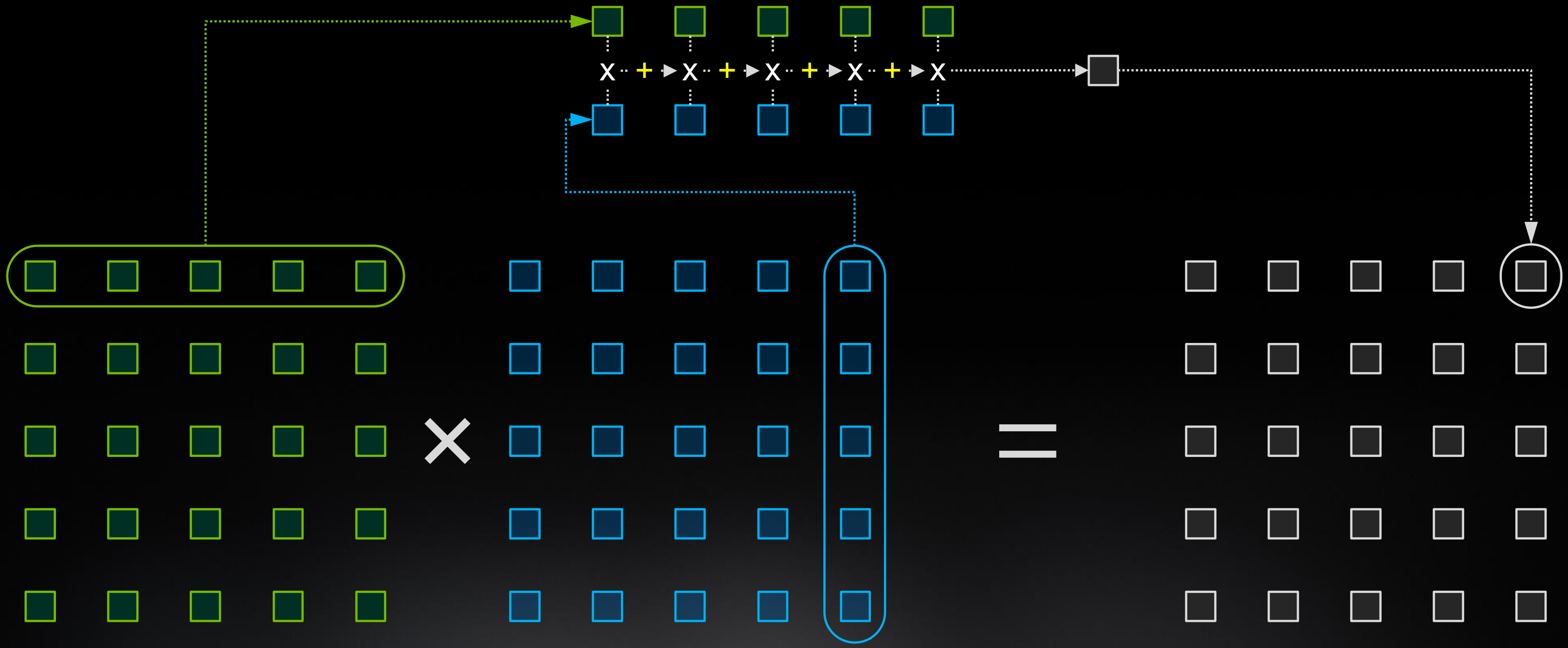
矩阵乘示例



矩阵乘示例

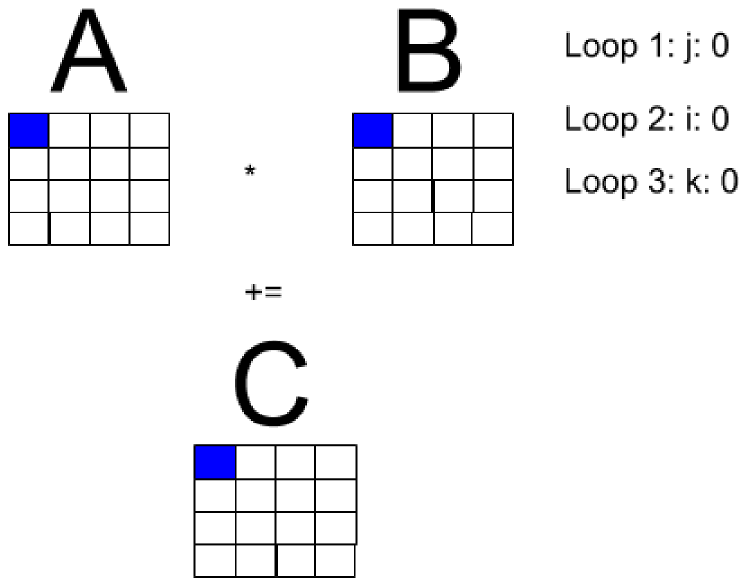


矩阵乘示例



矩阵相乘样例

```
void cpu_matrix_mult(int *h_m, int *h_n, int *h_result, int m,
int n, int k) {
    for (int i = 0; i < m; ++i)
    {
        for (int j = 0; j < k; ++j)
        {
            int tmp = 0.0;
            for (int h = 0; h < n; ++h)
            {
                tmp += h_m[i * n + h] * h_n[h * k + j];
            }
            h_result[i * k + j] = tmp;
        }
    }
}
```



P = M * N

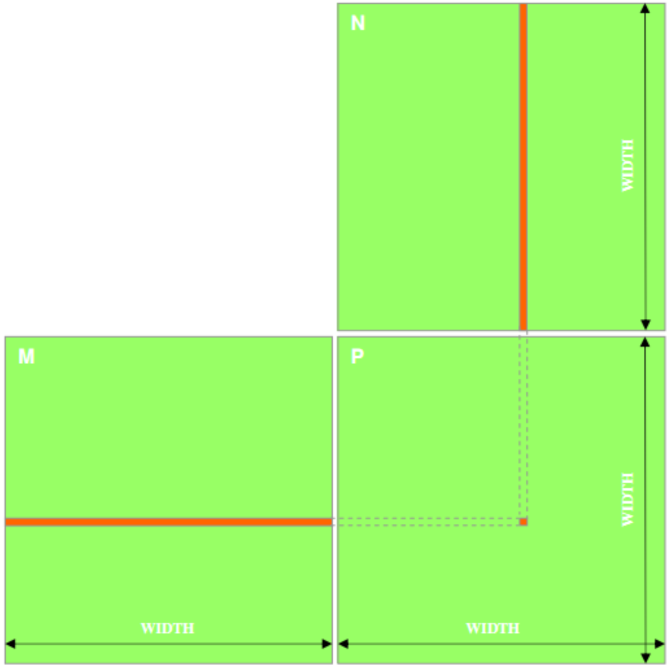
假定 M and N 是方阵

如果，M=N=1000

那么，我们要做1000*1000*1000次： tmp += h_m[i * n + h] * h_n[h * k + j];

矩阵相乘样例

```
void cpu_matrix_mult(int *h_m, int *h_n, int *h_result, int m,
int n, int k) {
    for (int i = 0; i < m; ++i)
    {
        for (int j = 0; j < k; ++j)
        {
            int tmp = 0.0;
            for (int h = 0; h < n; ++h)
            {
                tmp += h_m[i * n + h] * h_n[h * k + j];
            }
            h_result[i * k + j] = tmp;
        }
    }
}
```



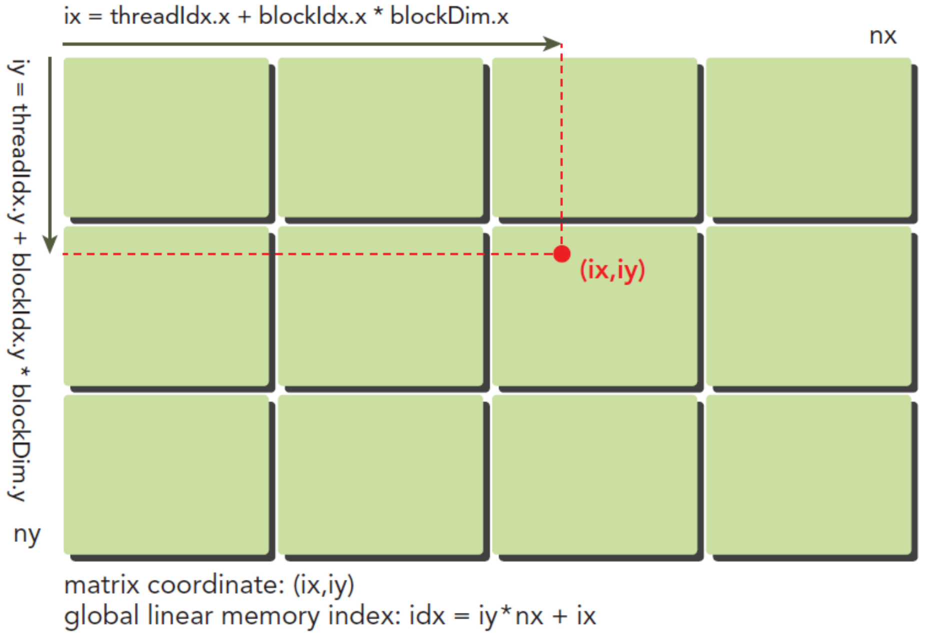
P = M * N

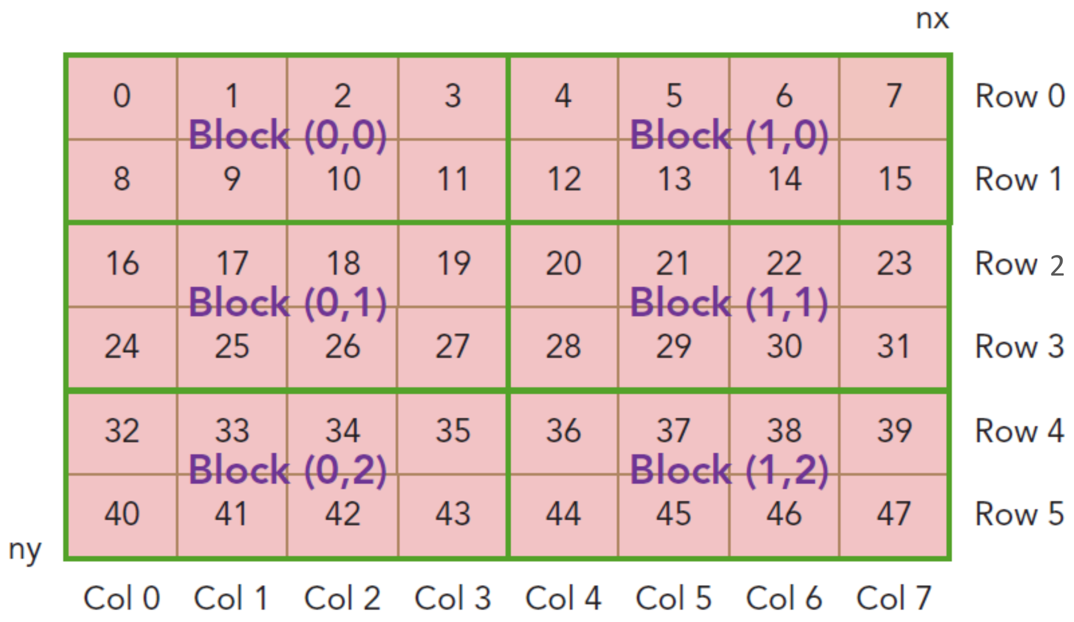
假定 M and N 是方阵

那么，利用CUDA该怎么解决这个问题呢?

空间换时间!

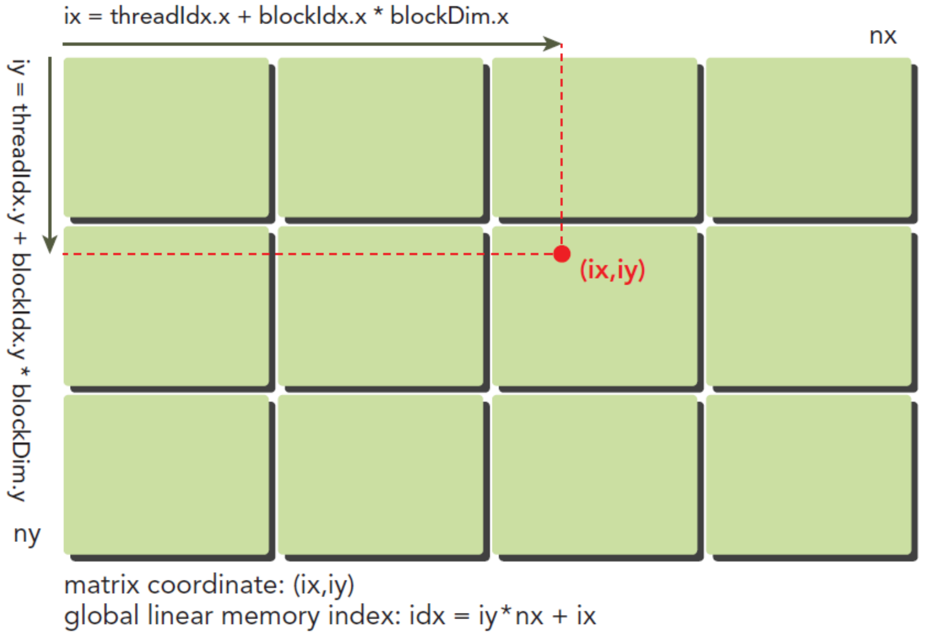
2D GRID AND 2D BLOCKS

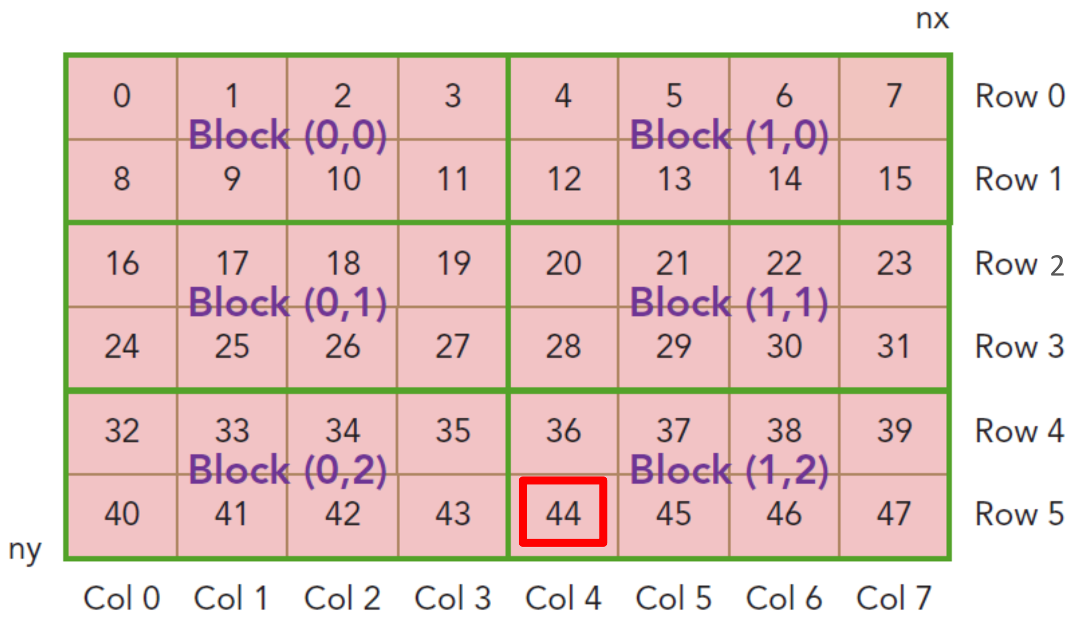





```
__global__ void printThreadIndex(const int nx, const int ny) {
    int ix = threadIdx.x + blockIdx.x * blockDim.x;
    int iy = threadIdx.y + blockIdx.y * blockDim.y;
    unsigned int idx = iy*nx + ix;
    printf("thread_id (%d,%d) block_id (%d,%d) coordinate (%d, %d) "
        "global index %2d \n", threadIdx.x, threadIdx.y, blockIdx.x, blockIdx.y, ix, iy, idx);
}
```

2D GRID AND 2D BLOCKS





int index = (blockIdx.y*blockDim.y+threadIdx.y)*nx+ (blockIdx.x * blockDim.x + threadIdx.x);

Index == (2*2+1)*8+(1*4+0)

矩阵相乘样例

Grid

0,0	1,0	2,0	3,0	0,0	1,0	2,0	3,0	0,0	1,0	2,0	3,0
0,1	1,1	2,1	3,1	0,0	1,1	2,1	3,1	0,1	1,1	2,1	3,1
0,2	1,2	2,2	3,2	0,2	1,2	2,2	3,2	0,2	1,2	2,2	3,2
0,0	1,1	2,0	3,0	0,0	1,0	2,0	3,0	0,0	1,0	2,0	3,0
0,0	1,1	2,1	3,1	0,0	1,1	2,1	3,1	0,1	1,1	2,1	3,1
0,0	1,2	2,2	3,2	0,0	1,2	2,2	3,2	0,2	1,2	2,2	3,2

threadIdx.x = 2
threadIdx.y = 0
blockIdx.x = 1
blockIdx.y = 1
blockDim.x = 4
blockDim.y = 3

每个颜色对应一个block
该线程在grid中所有线程的索引为：

Thread_x = blockIdx.x*blockDim.x+threadIdx.x = 6
Thread_y = blockIdx.y*blockDim.y+threadIdx.y = 3

矩阵相乘样例

当把整个grid对应到一个矩阵的时候，它就像下面的样子：

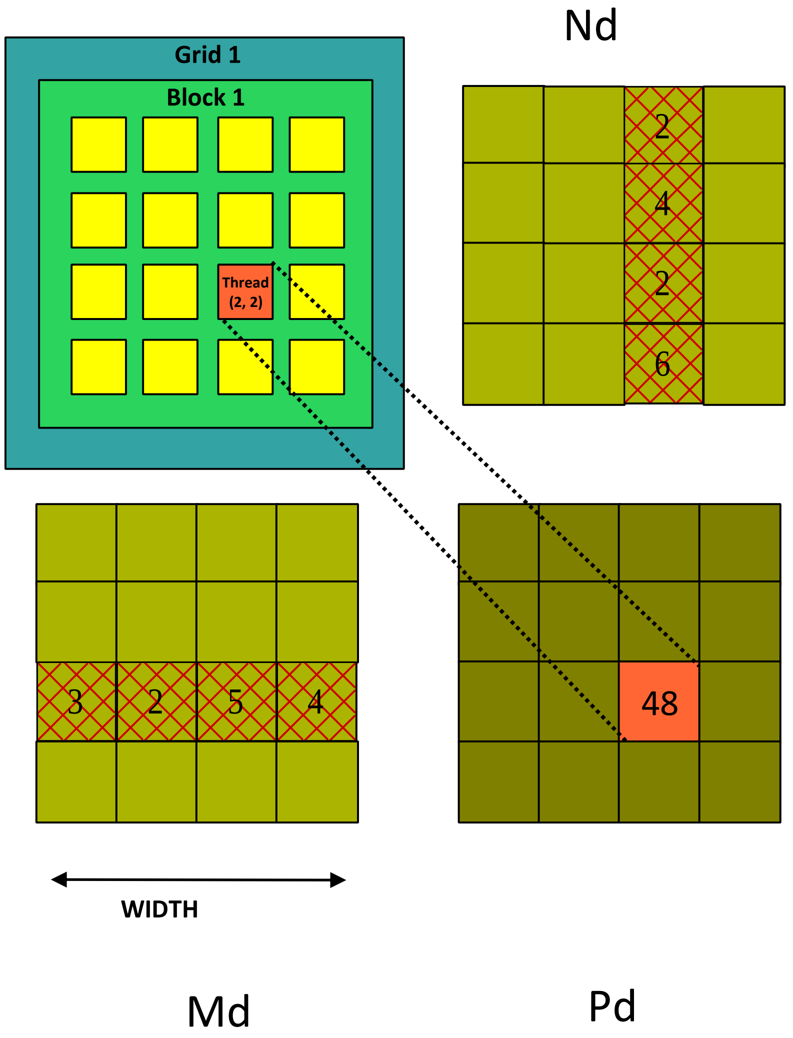
0,0	**1,0**	**2,0**	**3,0**	**4,0**	**5,0**	**6,0**	**7,0**	**8,0**	**9,0**	**10,0**	**11,0**
0,1	1,1	2,1	3,1	4,1	5,1	6,1	7,1	8,1	9,1	10,1	11,1
0,2	1,2	2,2	3,2	4,2	5,2	6,2	7,2	8,2	9,2	10,2	11,2
0,3	1,3	2,3	3,3	4,3	5,3	6,3	7,3	8,3	9,3	10,3	11,3
0,4	1,4	2,4	3,4	4,4	5,4	6,4	7,4	8,4	9,4	10,4	11,4
0,5	1,5	2,5	3,5	4,5	5,5	6,5	7,5	8,5	9,5	10,5	11,5

而该线程在grid中所有线程的索引正好对应到矩阵的坐标。
该线程在grid中所有线程的索引为：

Thread_x = blockIdx.x*blockDim.x+threadIdx.x = 6
Thread_y = blockIdx.y*blockDim.y+threadIdx.y = 3

矩阵相乘样例

- 一个线程grid计算Pd
  - 每个线程计算Pd的一个元素
- 每个线程
  - 读入矩阵Md的一行
  - 读入矩阵Nd的一列
  - 为每对Md和Nd元素执行一次乘法和加法



矩阵相乘样例

计算出当前执行的线程在所有线程中的坐标

读取M矩阵的一行，N矩阵的一列，并做乘积累加

```
__global__ void gpu_matrix_mult(int *M,int *N, int *P, int m_size, int n_size, int k_size)
{
    int row = blockIdx.y * blockDim.y + threadIdx.y;
    int col = blockIdx.x * blockDim.x + threadIdx.x;
    int sum = 0;
    if( col < k_size && row < m_size)
    {
        for(int i = 0; i < n; i++)
        {
            sum += M[row * n_size + i] * N[i *  k_size + col];
        }
        P[row * k_size + col] = sum;
    }
}
```

矩阵相乘样例

```
int main(int argc, char const *argv[])
{
    int m=100;
    int n=100;
    int k=100;

    int *h_a, *h_b, *h_c, *h_cc;
    cudaMallocHost((void **) &h_a, sizeof(int)*m*n);
    cudaMallocHost((void **) &h_b, sizeof(int)*n*k);
    cudaMallocHost((void **) &h_c, sizeof(int)*m*k);
    cudaMallocHost((void **) &h_cc, sizeof(int)*m*k);

    for (int i = 0; i < m; ++i) {
        for (int j = 0; j < n; ++j) {
            h_a[i * n + j] = rand() % 1024;
        }
    }

    for (int i = 0; i < n; ++i) {
        for (int j = 0; j < k; ++j) {
            h_b[i * k + j] = rand() % 1024;
        }
    }

    int *d_a, *d_b, *d_c;
    cudaMalloc((void **) &d_a, sizeof(int)*m*n);
    cudaMalloc((void **) &d_b, sizeof(int)*n*k);
    cudaMalloc((void **) &d_c, sizeof(int)*m*k);

    // copy matrix A and B from host to device memory
    cudaMemcpy(d_a, h_a, sizeof(int)*m*n, cudaMemcpyHostToDevice);
    cudaMemcpy(d_b, h_b, sizeof(int)*n*k, cudaMemcpyHostToDevice);

    unsigned int grid_rows = (m + BLOCK_SIZE - 1) / BLOCK_SIZE;
    unsigned int grid_cols = (k + BLOCK_SIZE - 1) / BLOCK_SIZE;
    dim3 dimGrid(grid_cols, grid_rows);
    dim3 dimBlock(BLOCK_SIZE, BLOCK_SIZE);

    gpu_matrix_mult<<<dimGrid, dimBlock>>>(d_a, d_b, d_c, m, n, k);

    cudaMemcpy(h_c, d_c, sizeof(int)*m*k, cudaMemcpyDeviceToHost);
    //cudaThreadSynchronize();
```

```
__global__ void gpu_matrix_mult(int *a,int *b, int *c, int m, int n, int k)
{
    int row = blockIdx.y * blockDim.y + threadIdx.y;
    int col = blockIdx.x * blockDim.x + threadIdx.x;
    int sum = 0;
    if( col < k && row < m)
    {
        for(int i = 0; i < n; i++)
        {
            sum += a[row * n + i] * b[i * k + col];
        }
        c[row * k + col] = sum;
    }
}
```

矩阵相乘样例

- 在算法实现中最主要的性能问题是什么?
- 主要的限制是什么?

矩阵转置示例

blockDim.x* blockIdx.x

threadIdx.x

0, 0	0, 1	0, 2	0, 3	0, 4	0, 5	0, 6	0, 7	0, 8	0, 9	0, 10	0, 11	0, 12	0, 13	0, 14	0, 15
1, 0	1, 1	1, 2	1, 3	1, 4	1, 5	1, 6	1, 7	1, 8	1, 9	1, 10	1, 11	1, 12	1, 13	1, 14	1, 15
2, 0	2, 1	2, 2	2, 3	2, 4	2, 5	2, 6	2, 7	2, 8	2, 9	2, 10	2, 11	2, 12	2, 13	2, 14	2, 15
3, 0	3, 1	3, 2	3, 3	3, 4	3, 5	3, 6	3, 7	3, 8	3, 9	3, 10	3, 11	3, 12	3, 13	3, 14	3, 15
4, 0	4, 1	4, 2	4, 3	4, 4	4, 5	4, 6	4, 7	4, 8	4, 9	4, 10	4, 11	4, 12	4, 13	4, 14	4, 15
5, 0	5, 1	5, 2	5, 3	5, 4	5, 5	5, 6	5, 7	5, 8	5, 9	5, 10	5, 11	5, 12	5, 13	5, 14	5, 15
6, 0	6, 1	6, 2	6, 3	6, 4	6, 5	6, 6	6, 7	6, 8	6, 9	6, 10	6, 11	6, 12	6, 13	6, 14	6, 15
7, 0	7, 1	7, 2	7, 3	7, 4	7, 5	7, 6	7, 7	7, 8	7, 9	7, 10	7, 11	7, 12	7, 13	7, 14	7, 15
8, 0	8, 1	8, 2	8, 3	8, 4	8, 5	8, 6	8, 7	8, 8	8, 9	8, 10	8, 11	8, 12	8, 13	8, 14	8, 15
9, 0	9, 1	9, 2	9, 3	9, 4	9, 5	9, 6	9, 7	9, 8	9, 9	9, 10	9, 11	9, 12	9, 13	9, 14	9, 15
10, 0	10, 1	10, 2	10, 3	10, 4	10, 5	10, 6	10, 7	10, 8	10, 9	10, 10	10, 11	10, 12	10, 13	10, 14	10, 15
11, 0	11, 1	11, 2	11, 3	11, 4	11, 5	11, 6	11, 7	11, 8	11, 9	11, 10	11, 11	11, 12	11, 13	11, 14	11, 15
12, 0	12, 1	12, 2	12, 3	12, 4	12, 5	12, 6	12, 7	12, 8	12, 9	12, 10	12, 11	12, 12	12, 13	12, 14	12, 15
13, 0	13, 1	13, 2	13, 3	13, 4	13, 5	13, 6	13, 7	13, 8	13, 9	13, 10	13, 11	13, 12	13, 13	13, 14	13, 15
14, 0	14, 1	14, 2	14, 3	14, 4	14, 5	14, 6	14, 7	14, 8	14, 9	14, 10	14, 11	14, 12	14, 13	14, 14	14, 15
15, 0	15, 1	15, 2	15, 3	15, 4	15, 5	15, 6	15, 7	15, 8	15, 9	15, 10	15, 11	15, 12	15, 13	15, 14	15, 15

```
__global__ void gpu_transpose(int *in,int *out, int width)
{
    int y = blockIdx.y * blockDim.y + threadIdx.y;
    int x = blockIdx.x * blockDim.x + threadIdx.x;

    if( y < width && x < width)
    {
        out[x * width + y] = in[y * width + x];
    }
}
```

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https://developer.nvidia-china.com

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