Basic Example: Matrix Multiplication using CUDA

General-purpose Programming of Massively Parallel Graphics Processors

Shiraz University, Spring 2010
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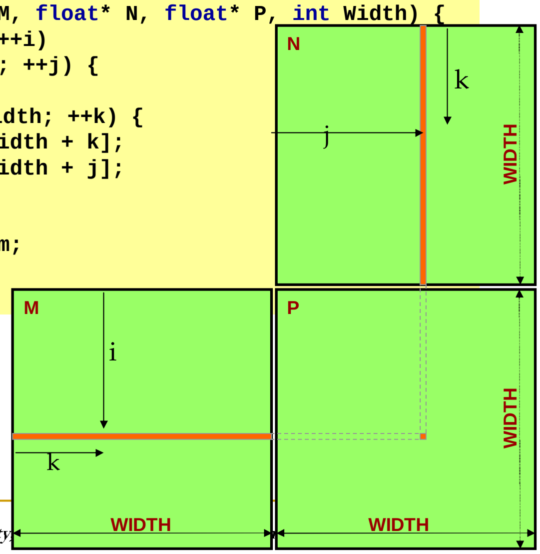
Some materials/slides are adapted from:
Andreas Moshovos' Course at the University of Toronto
UIUC course by Wen-Mei Hwu and David Kirk

A Simple Host Version in C

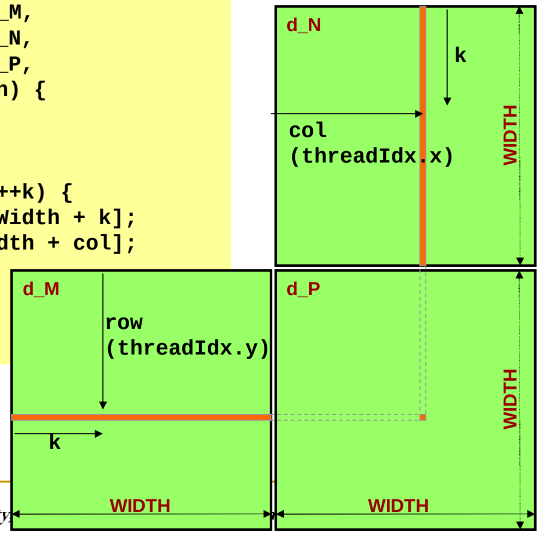
```
void MatrixMulOnHost( float* M, float* N, float* P, int Width) {
  for (int i = 0; i < Width; ++i)
    for (int j = 0; j < Width; ++j) {
        float sum = 0;
        for (int k = 0; k < Width; ++k) {
             float a = M[i * Width + k];
             float b = N[k * Width + j];
             sum += a * b;
        }
        P[i * Width + j] = sum;
    }
}
```



Adapted From:
David Kirk/NVIDIA and Wen-mei W. Hwu, UIUC

GPU Kernel Function

```
__global__
void MatrixMulKernel(float* d_M,
                     float* d_N,
                     float* d_P,
                     int Width) {
  int row = threadIdx.y;
  int col = threadIdx.x;
  float P_val = 0;
  for (int k = 0; k < Width; ++k) {
    float M_elem = d_M[row * Width + k];
    float N_elem = d_N[k * Width + col];
    P_val += M_elem * N_elem;
  }
  d_p[row*Width+col] = P_val;
}
```



Input Data Allocation and Transfer

```
void MatrixMulOnDevice(float* M,
                       float* N,
                       float* P,
                       int Width)
{
   int matrix_size = Width * Width * sizeof(float);
   float *d_M, *d_N, *d_P;

   // Allocate and Load M and N to device memory
   cudaMalloc(&d_M, matrix_size);
   cudaMemcpy(d_M, M, matrix_size, cudaMemcpyHostToDevice);

   cudaMalloc(&d_N, matrix_size);
   cudaMemcpy(d_N, N, matrix_size, cudaMemcpyHostToDevice);

   // Allocate P on the device
   cudaMalloc(&d_P, matrix_size);
```

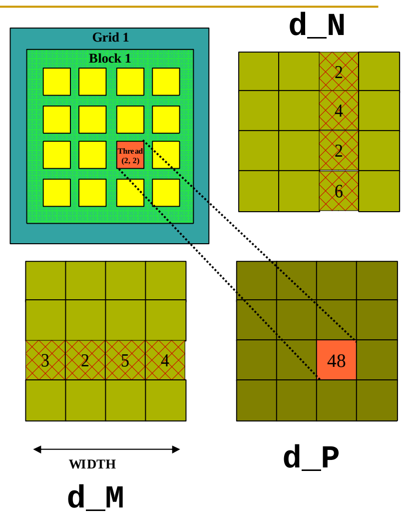
Kernel Invocation and Copy Results

```
   // Setup the execution configuration
   dim3 dimGrid(1, 1);
   dim3 dimBlock(Width, Width);


   // Launch the device computation threads!
   MatrixMulKernel<<<dimGrid, dimBlock>>>(d_M, d_N, d_P,
Width);

   // Copy back the results from device to host
   cudaMemcpy(P, d_P, matrix_size, cudaMemcpyDeviceToHost);

   // Free up the device memory matrices
   cudaFree(d_P);
   cudaFree(d_M);
   cudaFree(d_N);
```

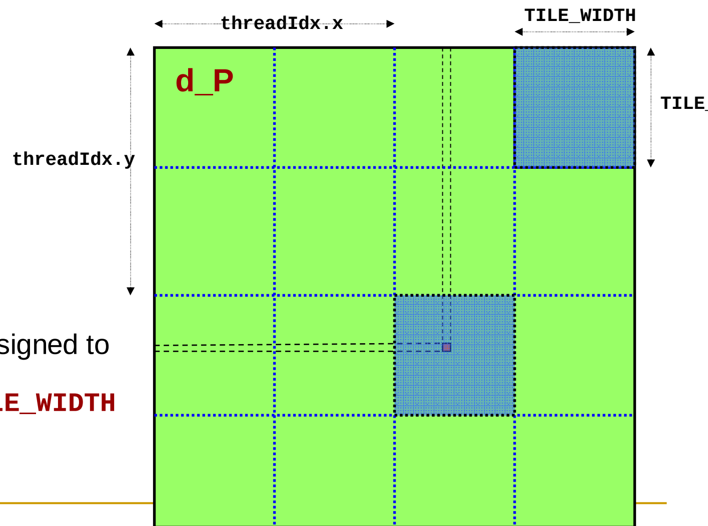
Only One Thread Block Used

- One Block of threads compute matrix **d_P**
- Each thread
  - Loads a row of matrix **d_M**
  - Loads a column of matrix **d_N**
  - Perform one multiply and addition for each pair of **d_M** and **d_N** elements
  - Computes one element of **d_P**

Size of matrix limited by the number of threads allowed in a thread block



Solution 1: Give Each Thread More Work



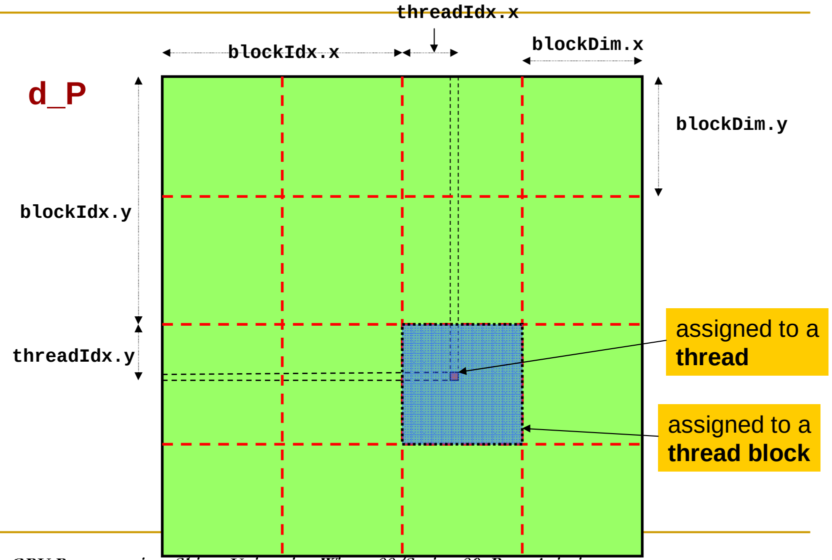
Each thread is assigned to a ***Tile*** of **TILE_WIDTHxTILE_WIDTH** entries

Solution 1: Give Each Thread More Work

```
__global__ void MatrixMulKernel(float* d_M,
                                float* d_N,
                                float* d_P,
                                int Width) {
  int start_row = threadIdx.y * TILE_WIDTH;
  int end_row = start_row + TILE_WIDTH;
  int start_col = threadIdx.x * TILE_WIDTH;
  int end_col = start_col + TILE_WIDTH;

  for (int row = start_row; row < end_row; row++) {
     for(int col = start_col; col < end_col; col++) {
        float P_val = 0;
        for (int k = 0; k < Width; ++k) {
           float M_elem = d_M[row * Width + k];
           float N_elem = d_N[k * Width + col];
           P_val += M_elem * N_elem;
        }
        d_p[row*Width+col] = P_val;
     }
  }
```

With one block we utilize only one multiprocessor!

Solution 2: Use Multiple Thread Blocks



Solution 2: Use Multiple Thread Blocks

```
__global__
void MatrixMulKernel(float* d_M,
                     float* d_N,
                     float* d_P,
                     int Width) {
  int row = blockIdx.y * blockDim.y + threadIdx.y;
  int col = blockIdx.x * blockDim.x + threadIdx.x;
  float P_val = 0;

  for (int k = 0; k < Width; ++k) {
    float M_elem = d_M[row * Width + k];
    float N_elem = d_N[k * Width + col];
    P_val += M_elem * N_elem;
  }
  d_p[row*Width+col] = P_val;
}
```

Kernel Invocation and Copy Results

```
   int block_size = 64;

    // Setup the execution configuration
    dim3 dimGrid(Width/block_size, Width/block_size);
    dim3 dimBlock(block_size, block_size);


   // Launch the device computation threads!
   MatrixMulKernel<<<dimGrid, dimBlock>>>(d_M, d_N, d_P,
Width);

    …
```

Size of matrix limited by the number of threads allowed on a device

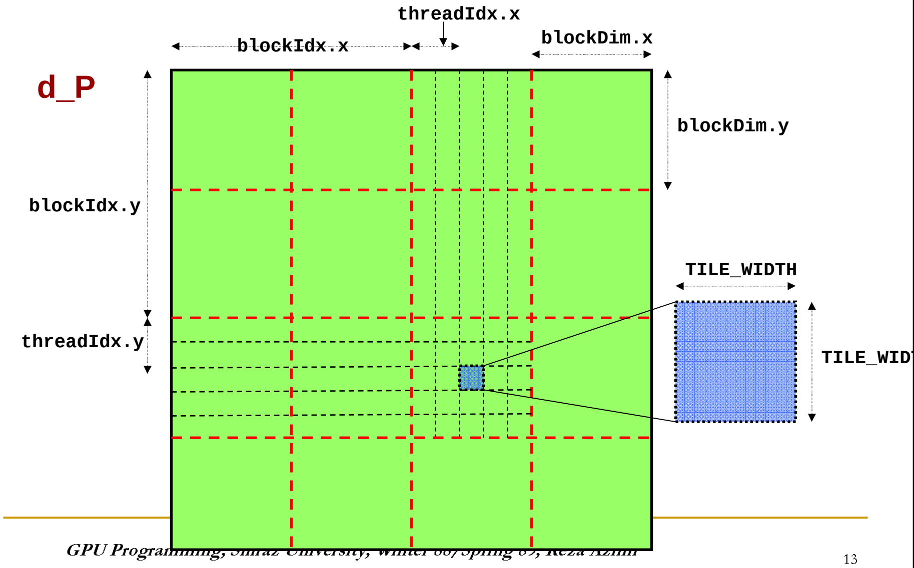
GTX 280 Thread Limitations

- Max Number of Threads per Block: 512
- Max Number of Blocks per Streaming Multiprocessor: 8
- Number of Streaming Multiprocessors: 30
- Total Number of Threads Available =

30 x 8 x 512 = 122880

Let me double-check this!

Combining the Two Solutions



Combining the Two Solutions

```
__global__ void MatrixMulKernel(float* d_M,
                     float* d_N,
                     float* d_P,
                     int Width) {
  int start_row = blockDim.y * blockIdx.y + threadIdx.y * TILE_WIDTH;
  int end_row = start_row + TILE_WIDTH;
  int start_col = blockDim.x * blockIdx.x + threadIdx.x * TILE_WIDTH;
  int end_col = start_col + TILE_WIDTH;

  for (int row = start_row; row < end_row; row++) {
     for(int col = start_col; col < end_col; col++) {
        float P_val = 0;
        for (int k = 0; k < Width; ++k) {
           float M_elem = d_M[row * Width + k];
           float N_elem = d_N[k * Width + col];
           P_val += M_elem * N_elem;
        }
        d_p[row*Width+col] = P_val;
     }
  }
}
```