ECE408/CS483/CSE408 Spring 2020
Applied Parallel Programming

Lecture 6:
More on Tiling

Objective

- To learn to handle boundary conditions in tiled algorithms

How to Handle Matrices of Other Sizes?

- Lecture 5's tiled kernel
  - assumed integral number of tiles (thread blocks)
  - in all matrix dimensions.

  How can we avoid this assumption?

- One answer: add padding, but not easy to reformat data, and adds transfer time.

  Other ideas?

Let's Review Our Kernel

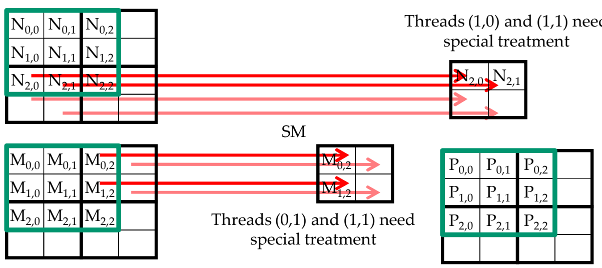
```
__global__ void MatrixMulKernel(float* M, float* N, float* P, int Width)
{
    __shared__ float subTileM[TILE_WIDTH][TILE_WIDTH];
    __shared__ float subTileN[TILE_WIDTH][TILE_WIDTH];

    int bx = blockIdx.x;  int by = blockIdx.y;
    int tx = threadIdx.x; int ty = threadIdx.y;

    // Identify the row and column of the P element to work on
    int Row = by * TILE_WIDTH + ty; // note: blockDim.x == TILE_WIDTH
    int Col = bx * TILE_WIDTH + tx; //       blockDim.y == TILE_WIDTH
    float Pvalue = 0;

    // Loop over the M and N tiles required to compute the P element
    // The code assumes that the Width is a multiple of TILE WIDTH!
    for (int m = 0; m < Width/TILE_WIDTH; ++m) {
        // Collaborative loading of M and N tiles into shared memory
        subTileM[ty][tx] = M[Row*Width + m*TILE_WIDTH+tx];
        subTileN[ty][tx] = N[(m*TILE_WIDTH+ty)*Width+Col];
        __syncthreads();
        for (int k = 0; k < TILE_WIDTH; ++k)
            Pvalue += subTileM[ty][k] * subTileN[k][tx];
        __syncthreads();
    }
    P[Row*Width+Col] = Pvalue;
}
```

Second Tile Load for Block (0,0)



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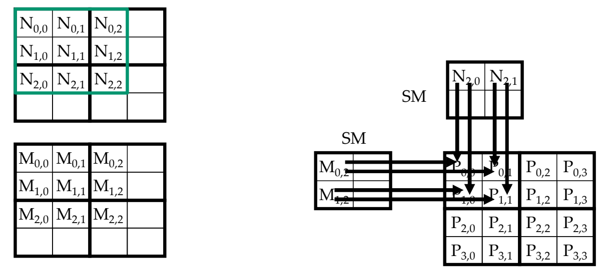
Second Tile Use for Block (0,0), k of 0



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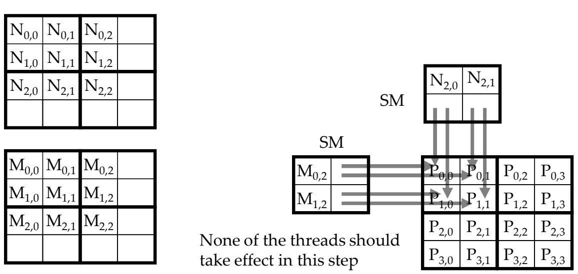
Second Tile Use for Block (0,0), k of 1



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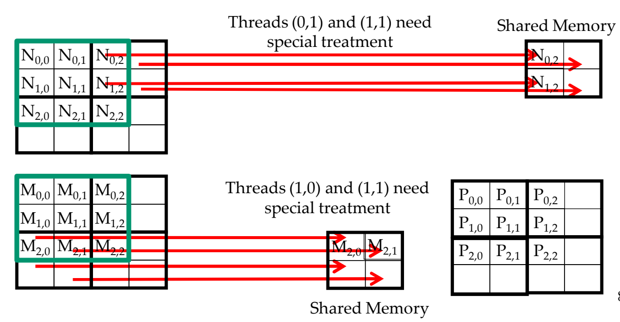
First Tile Load for Block (1,1)



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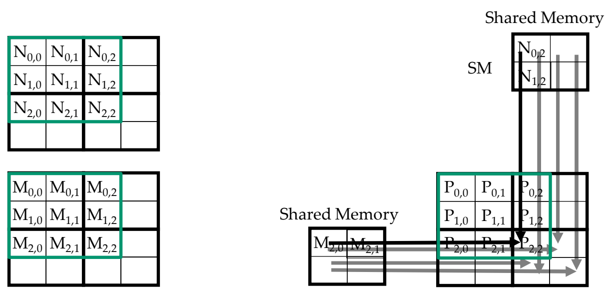
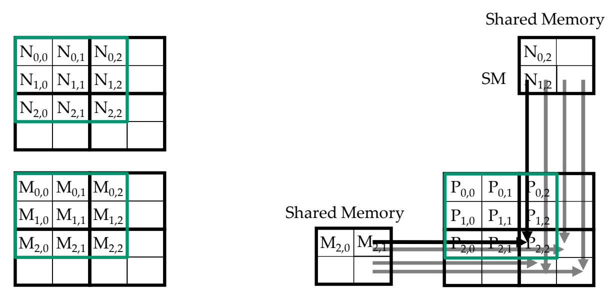
First Tile Use for Block (1,1), k of 0



First Tile Use for Block (1,1), k of 1



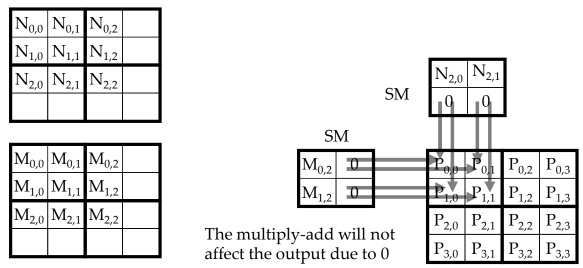
Major Cases in Toy Example

- Threads that calculate valid P elements but can step outside valid input
  - Second tile of Block(0,0), all threads when k is 1
- Threads that do not calculate valid P elements
  - Block(1,1), Thread(1,0), non-existent row
  - Block(1,1), Thread(0,1), non-existing column
  - Block(1,1), Thread(1,1), non-existing row/column

Solution: Write 0 for Missing Elements

- Test during tile load:
  is **target within input matrix**?
  - **If yes**, proceed to **load**;
  - **otherwise**, just **write 0** to shared memory.
- The **benefit**?
  - **No specialization during tile use**!
  - Multiplying by 0 guarantees that unwanted terms do not contribute to the inner product.

Second Tile Use for Block (0,0), k of 1

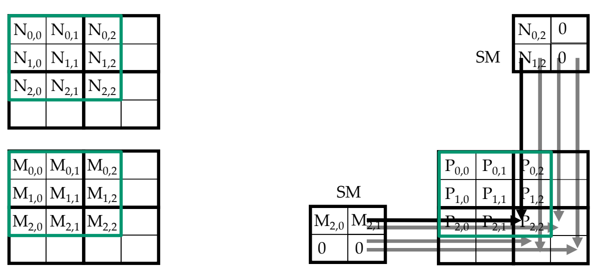


What About Threads Outside of P?

- If a **thread is not within P**,
  - All terms in sum are 0.
  - No harm in performing FLOPs.
  - No harm in writing to registers.
  - **Must not be allowed to write to global memory!**

So: **Threads outside of P calculate 0, but store nothing.**

First Tile Use for Block (1,1)



Modifying the Tile Count

```
8.  for (int m = 0; m < Width/TILE_WIDTH; ++m) {
```

The bound for **m** implicitly assumes that Width is a multiple of **TILE_WIDTH**. We need to round up.

```
for (int m = 0; m < (Width - 1)/TILE_WIDTH + 1; ++m) {
```

For non-multiples of **TILE_WIDTH**:
- quotient is unchanged;
- add one to round up.

For multiples of **TILE_WIDTH**:
- quotient is now one smaller,
- but we add 1.

Modifying the Tile Loading Code

We had …

```
// Collaborative loading of M and N tiles into shared memory
9.    subTileM[ty][tx] = M[Row*Width + m*TILE_WIDTH+tx];
10.   subTileN[ty][tx] = N[(m*TILE_WIDTH+ty)*Width+Col];
```

Note: the tests for M and N tiles are NOT the same.

```
if (Row < Width && m*TILE_WIDTH+tx < Width) {
    // as before
    subTileM[ty][tx] = M[Row*Width + m*TILE_WIDTH+tx];
} else {
    subTileM[ty][tx] = 0;
}
```


And for Loading N…

We had …

```
// Collaborative loading of M and N tiles into shared memory
9.    subTileM[ty][tx] = M[Row*Width + m*TILE_WIDTH+tx];
10.   subTileN[ty][tx] = N[(m*TILE_WIDTH+ty)*Width+Col];
```

Note: the tests for M and N tiles are NOT the same.

```
if (m*TILE_WIDTH+ty < Width && Col < Width ) {
    // as before
    subTileN[ty][tx] = N[(m*TILE_WIDTH+ty)*Width+Col];
} else {
    subTileN[ty][tx] = 0;
}
```


Modifying the Tile Use Code

We had …

```
12. for (int k = 0; k < TILE_WIDTH; ++k)
13.     Pvalue += subTileM[ty][k] * subTileN[k][tx];
```

Note: **no changes are needed**, but we might save a little energy (fewer floating-point ops)?

```
if (Row < Width && Col < Width) {
    // as before
    for (int k = 0; k < TILE_WIDTH; ++k)
        Pvalue += subTileM[ty][k] * subTileN[k][tx];
}
```


Modifying the Write to P

We had …

```
16. P[Row*Width+Col] = Pvalue;
```

We must test for threads outside of P:

```
if (Row < Width && Col < Width) {
    // as before
    P[Row*Width+Col] = Pvalue;
}
```

Some Important Points

- For each thread, conditions are different for
  - Loading M element
  - Loading N element
  - Calculation/storing output elements
- Branch divergence
  - affects only blocks on boundaries, and
  - should be small for large matrices.
- What about rectangular matrices?

**ANY MORE QUESTIONS?
READ CHAPTER 4!**