GPU programming basics

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2D convolution: tile boundaries
**2D Image Matrix with Automated Padding**

- It is sometimes desirable to pad each row of a 2D matrix to multiples of DRAM bursts
  - So each row starts at the DRAM burst boundary
  - Effectively adding columns
  - This is usually done automatically by matrix allocation function
  - Pitch can be different for different hardware

- Example: a 3x3 matrix padded into a 3x4 matrix

| Height is 3 |
| Width is 3 |
| Channels is 1 (e.g. gray level image) |
| Pitch is 4 |

```
Padded elements
```

```
\[
\begin{array}{ccc}
M_{0,0} & M_{0,1} & M_{0,2} \\
M_{1,0} & M_{1,1} & M_{1,2} \\
M_{2,0} & M_{2,1} & M_{2,2} \\
\end{array}
\]
```

```
height
```

```
width
```
Row-Major Layout with Pitch

Row*Pitch + Col = 2*4 + 1 = 9

Padded elements
Sample image struct

// Image Matrix Structure declaration

typedef struct {
    int width;
    int height;
    int pitch;
    int channels;
    float* data;
} Image_t;
Setting Block Size

```c
#define O_TILE_WIDTH 12

#define BLOCK_WIDTH (O_TILE_WIDTH + 4)

dim3 dimBlock(BLOCK_WIDTH,BLOCK_WIDTH);

dim3 dimGrid((Image_Width-1)/O_TILE_WIDTH+1, (Image_Height-1)/O_TILE_WIDTH+1, 1)

• In general, BLOCK_WIDTH should be
• O_TILE_WIDTH + (MASK_WIDTH-1)
```
Using constant memory and caching for Mask

- Mask is used by all threads but not modified in the convolution kernel
  - All threads in a warp access the same locations at each point in time
- CUDA devices provide constant memory whose contents are aggressively cached
  - Cached values are broadcast to all threads in a warp
  - Effectively magnifies memory bandwidth without consuming shared memory
- Use of `const __restrict__` qualifiers for the mask parameter informs the compiler that it is eligible for constant caching, for example:

  ```c
  __global__ void convolution_2D_kernel(float *P, float *N, int height, int width, int channels, const float __restrict__ *M);
  ```
Shifting from output coordinates to input coordinate

```c
int tx = threadIdx.x;
int ty = threadIdx.y;
int row_o = blockIdx.y*O_TILE_WIDTH + ty;
int col_o = blockIdx.x*O_TILE_WIDTH + tx;

int row_i = row_o - mask_radius;
int col_i = col_o - mask_radius;
```
Taking Care of Boundaries (1 channel example)

```c
if((row_i >= 0) && (row_i < height) &&
   (col_i >= 0)  && (col_i < width)) {
    Ns[ty][tx] = data[row_i * width + col_i];
} else{
    Ns[ty][tx] = 0.0f;
}

• Use of width here is OK if pitch is set to width (no padding)
```
Calculating output

Some threads do not participate in calculating output

```c
float output = 0.0f;

if(ty < O_TILE_WIDTH && tx < O_TILE_WIDTH){
    for(i = 0; i < MASK_WIDTH; i++) {
        for(j = 0; j < MASK_WIDTH; j++) {
            output += M[i][j] * Ns[i+ty][j+tx];
        }
    }
}
```
Writing output

• Some threads do not write output (1 channel example)

```c
if(row_o < height && col_o < width)
    data[row_o*width + col_o] = output;
```
Credits

- These slides report material from:
  - NVIDIA GPU Teaching Kit
Books