MISC. CUDA TOPICS

2D arrays, performance profiling

2D ARRAYS IN CUDA

```
// host code
int A[10][20] = …;
A[5][6] = 17;
cudaMemcpy(d_A, A, …);

// device code
__device__ kernel(d_A) {
   d_A[5][6] = 17;
}
```

2D ARRAYS IN CUDA

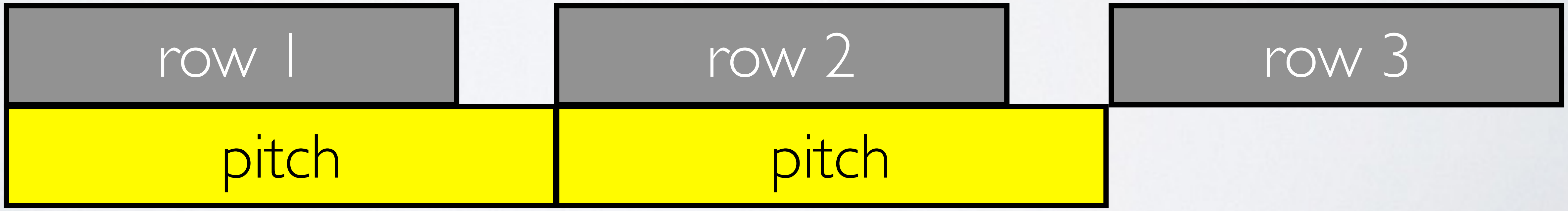
- 2 problems
  - don't know array bounds: d_A is an int*
  - rows beyond the first may not be optimally aligned

2D ARRAYS IN CUDA

Conventional C memory layout

misalignment can harm global memory coalescing

CUDA **pitched memory**



CUDA PITCHED MEMORY

- 2D array indexing involves row, column and **pitch**

```
cudaError_t cudaMalloc3D(cudaPitchedPtr* pitchedDevPtr,
                         cudaExtent extent)

cudaExtent make_cudaExtent(
   size_t w, // bytes
   size_t h, size_t d) // elements
```

- How do we index a pitched 2D array?

```
int* i = (int*)((char*)BaseAddr + Row * Pitch) + Col;
```

CUDA PITCHED MEMORY

- Must use **pitch-aware** memcpy/memset

```
cudaError_t cudaMemcpy2D(
     void* dst,
     size_t dpitch, // bytes
     const void* src,
     size_t spitch, size_t width, // bytes
     size_t height, // rows
     cudaMemcpyKind kind)
```

CUDA PITCHED MEMORY GOTCHAS

- **pitch is always specified in bytes**
- height/depth are specified **in elements**
  - in terms of rows/2D slices, respectively
- cudaMallocArray and friends use the Texture Cache
  - optimized layout for graphics textures that uses a space-filling curve for memory layout
  - https://en.wikipedia.org/wiki/Z-order_curve

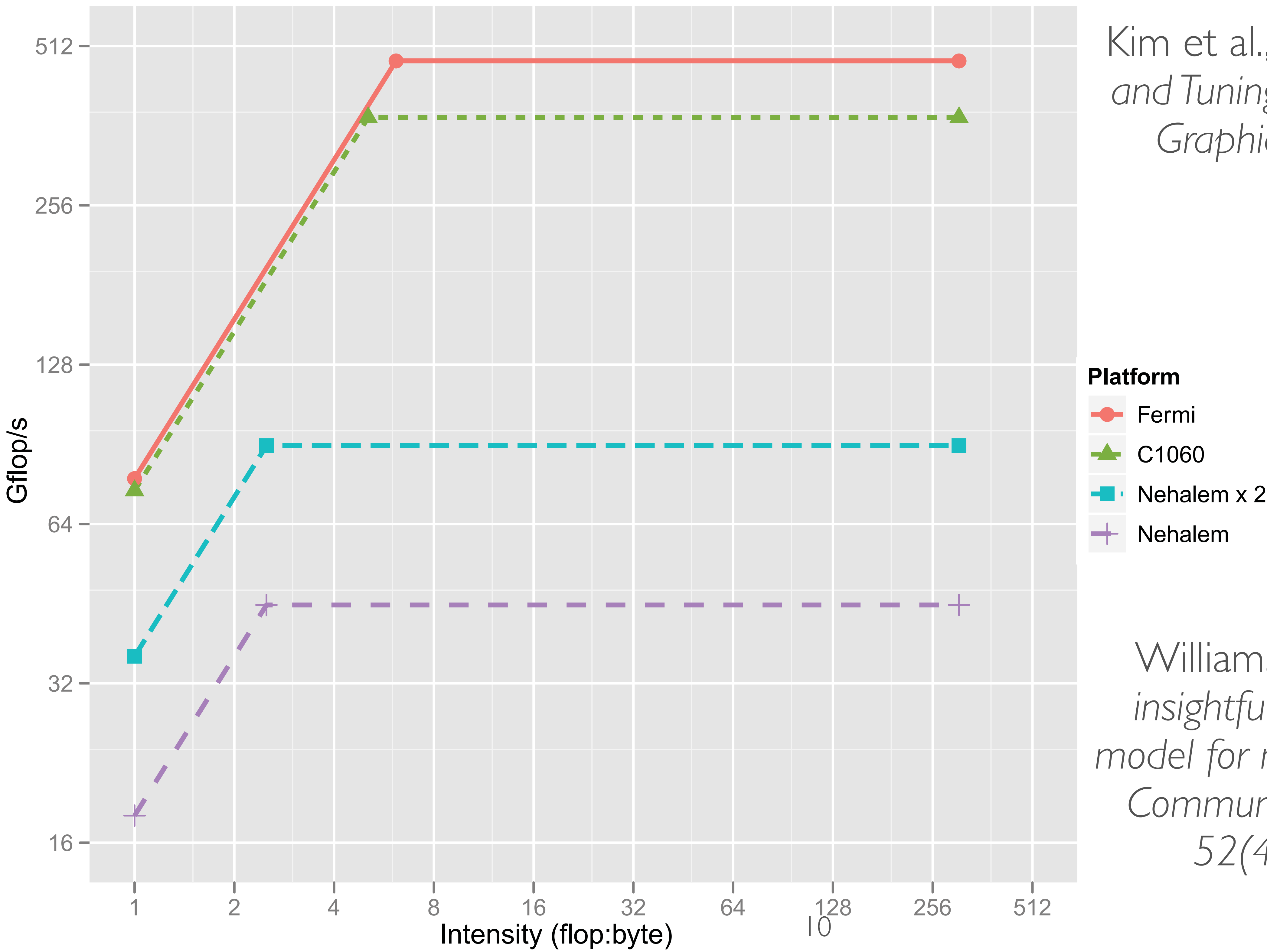
WHEN CAN I STOP OPTIMIZING?

- Our GPUs: Nvidia GK104 (~GeForce 600)
- (global) memory bandwidth: **160 GB/s**
- compute bandwidth: 1536 “CUDA cores” x 800MHz = **1.2 TFlops** (~**2.4TFlops** with FMA)
- are we *memory* or *compute* limited?

ARITHMETIC INTENSITY

- GK104 ideal flop-to-byte ratio = 1200/160 = **7.5**
- what is blurGlobal's behavior?
  - 5600 fliop per thread
  - 450 mop per thread (4B each!)
  - ~3.1 fliop-to-byte ratio

ROOFLINE ANALYSIS



Kim et al., *Performance Analysis and Tuning for General Purpose Graphics Processing Units*

Williams et al., *Roofline: An insightful visual performance model for multicore architectures. Communications of the ACM, 52(4):65, April 2009*

HOW FAST IS blurShared?

- 4096 x 3072 pixels = 12.6M pixels * 5600 fliop/pixel = 70 Gfliop

- blurShared runs in 50ms = 0.05s

- 70 Gfliop / 0.05s = **1.4 Tfliops**

- not too shabby!

WHEN CAN I STOP OPTIMIZING?

- max Flops/Fliops depends on what instructions you/compiler use
- memory bandwidth depends on which memory you use

CUDA PROFILING LINKS

- Nvidia's Nsight profiler (integrated into Visual Studio) is pretty slick
  - Video tutorial: https://www.youtube.com/watch?v=vt7Hvj4oviQ&feature=player_detailpage
    - memory coalescing discussion starts at 41:40
  - http://docs.nvidia.com/gameworks/index.html#developertools/desktop/nsight/analysis_tools_overview.htm%3FTocPath%3DDeveloper%2520Tools%7CDesktop%2520Developer%2520Tools%7CNVIDIA%2520Nsight%2520Visual%2520Studio%2520Edition%7CNVIDIA%2520Nsight%2520Visual%2520Studio%2520Edition%25205.2%7CAnalysis%2520Tools%7C_____0