CMPSCI 691AD – General Purpose Computation on the GPU

Spring 2009

Lecture 11: Performance Guidelines II

Rui Wang

Parameter Space

- Number of threads per block
- Usage of GPU resources:
  - Shared memory
  - Register space
- Optimizations can change the resource usage:
  - Data prefetching
  - Loop unrolling

Dynamic Partitioning of Resources

- Resources on each multiprocessor (G80):
  - Regsiters: 8K (or 32KB)
  - Shared memory: 16KB
  - Threads slots: 768
  - Block slots: 8
- On GT200:
  - Registers: 16K (or 64KB)
  - Threads slots: 1024

Dynamic Partitioning of Resources

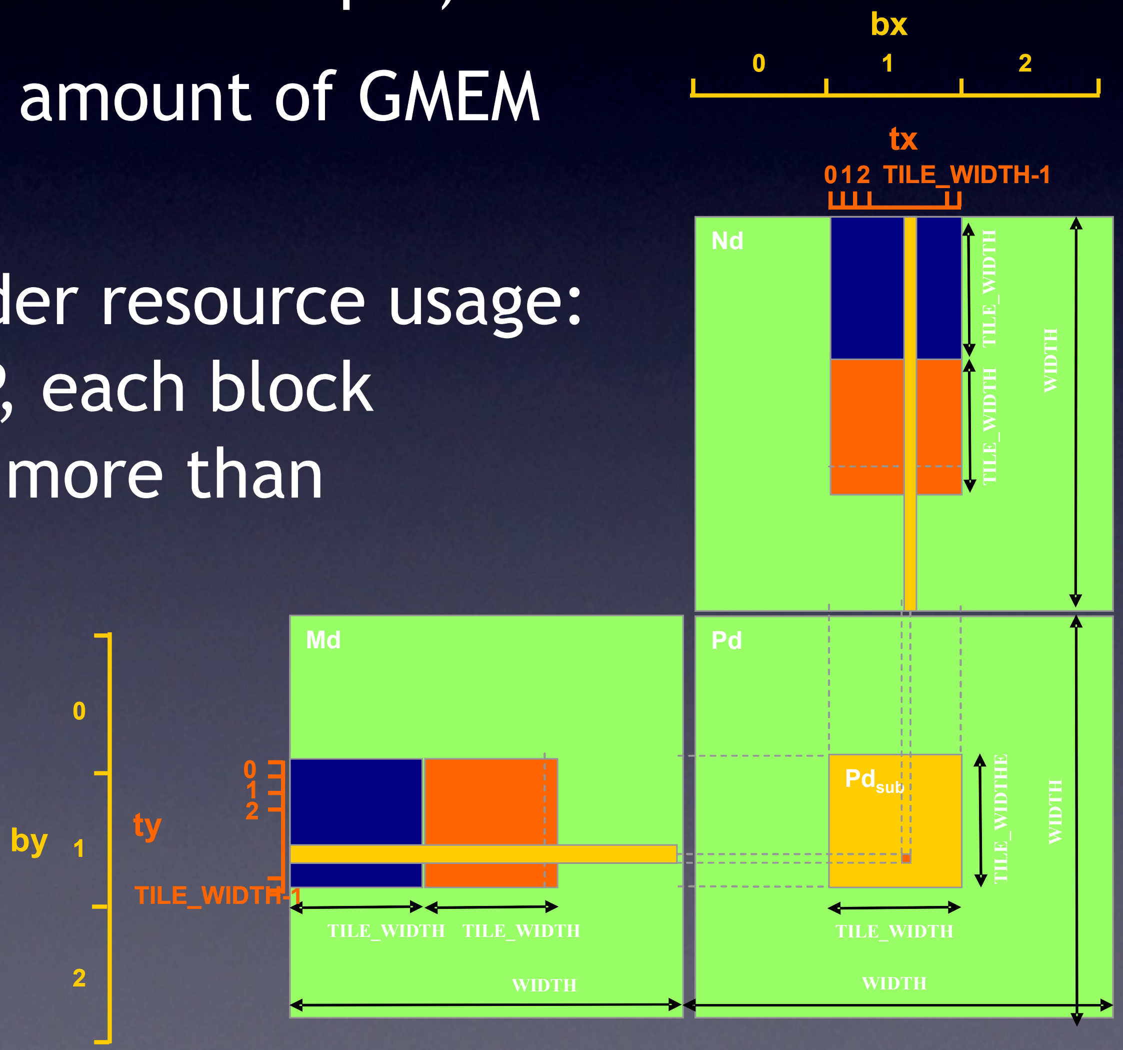
- Block is the minimum unit for scheduling on each MP.
- The number of blocks assigned to each MP depends on the bottleneck of the resource consumption.
- Example (G80):
  - 256 threads/block → 3 blocks (threads slots limit)
  - 10 regs/thread → 2560 regs/block → 3 blocks (reg limit)
  - 4KB smem/block → 4 blocks (smem limit)
  - Result: 3 blocks will be scheduled on each MP

Dynamic Partitioning of Resources

- Block is the minimum unit for scheduling on each MP.
- The number of blocks assigned to each MP depends on the bottleneck of the resource consumption.
- Example (G80):
  - 256 threads/block → 3 blocks (threads slots limit)
  - 11 regs/thread → 2816 regs/block → 2 blocks (reg limit)
  - 4KB smem/block → 4 blocks (smem limit)
  - Result: 2 blocks will be scheduled on each MP (number of threads drops from 768 to 512)

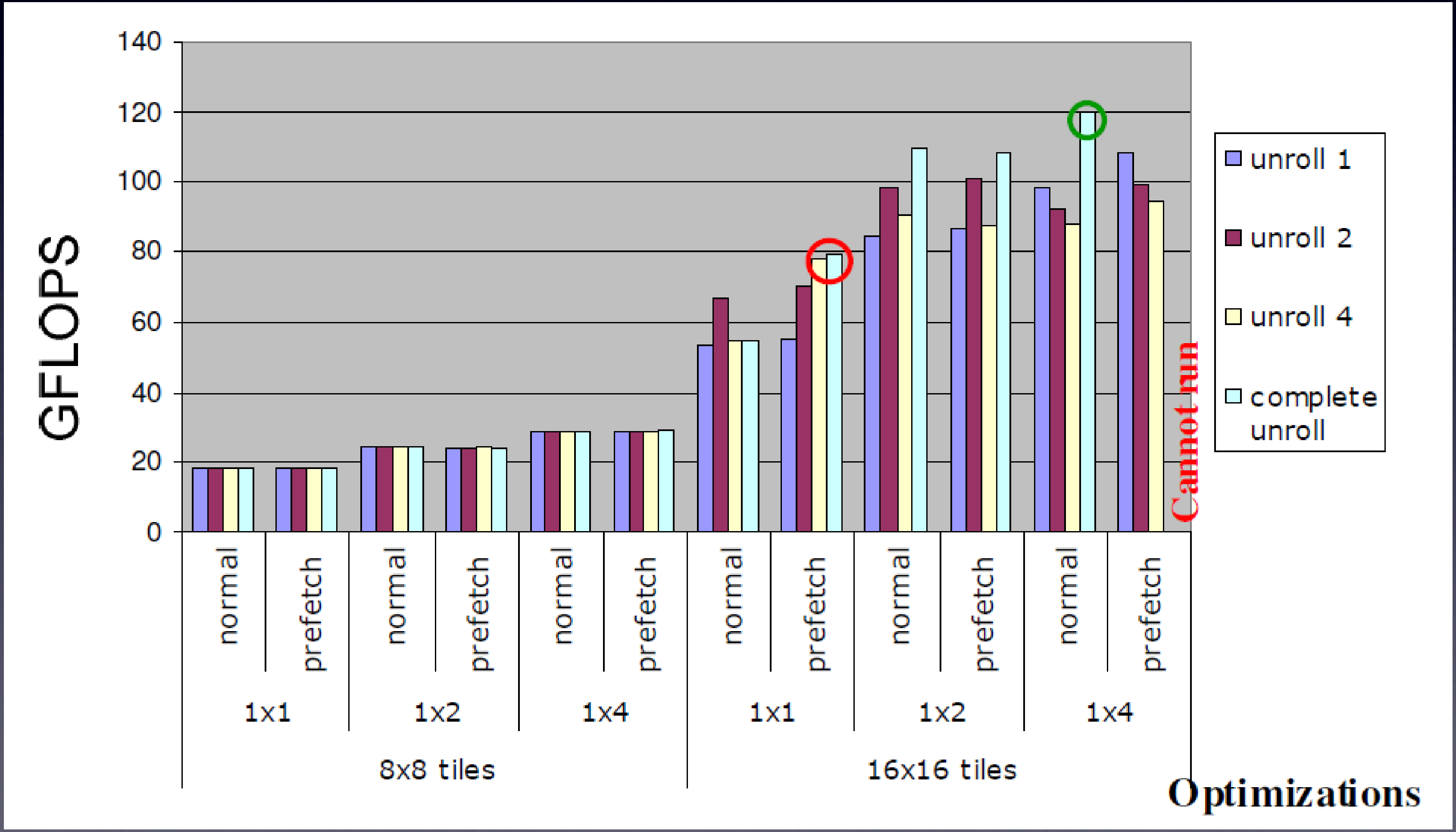
Thread Granularity

- Sqeeze more work in each thread can reduce redundant work (take matrix mult as an example)
  - Tiling can reduce the amount of GMEM accesses
  - However, must consider resource usage: given 3 blocks per MP, each block can consume slightly more than 5KB of SMEM.



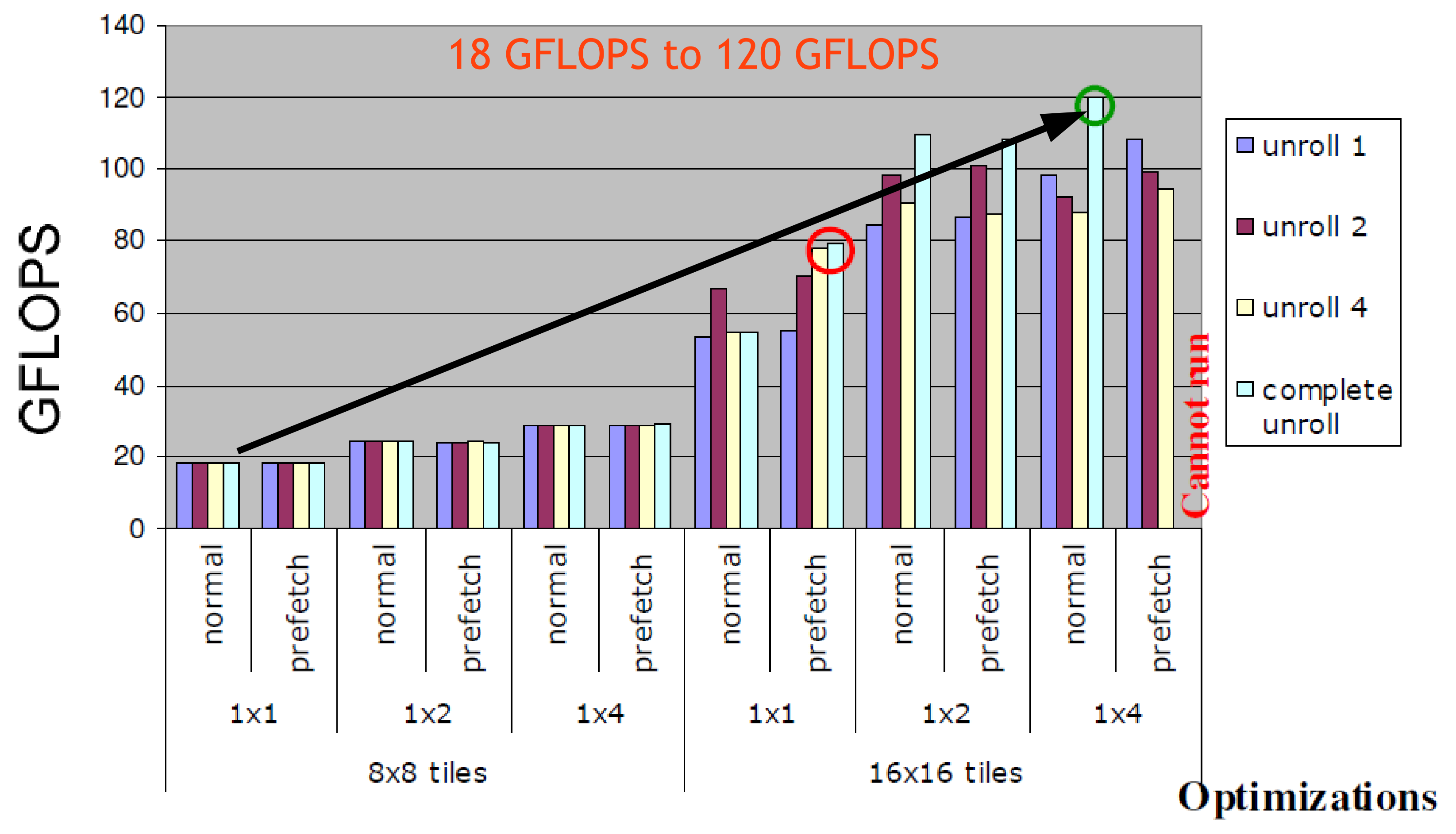
Thread Granularity

- Results of performance, by varying block size, loop unrolling, data prefectching, thread granularity.



Thread Granularity

- Results of performance, by varying block size, loop unrolling, data prefectching, thread granularity.

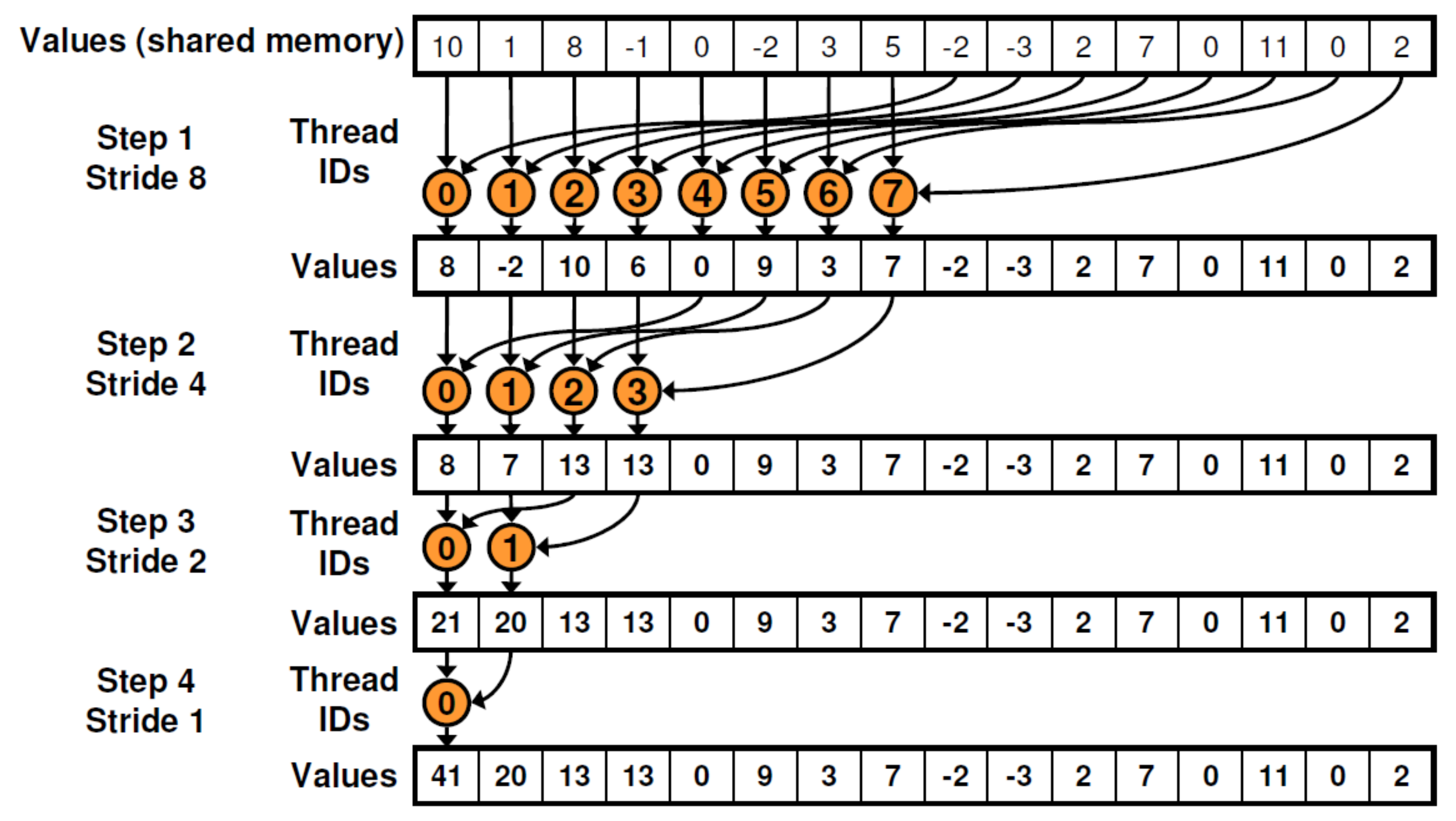


Thread Granularity

- Parameterizing your applications helps adaptation to different GPUs
- You can try to make applications self-tuning (like FFTW)
  - Experiment different configurations, discovers and saves the optimal one.

Performance Optimization Example

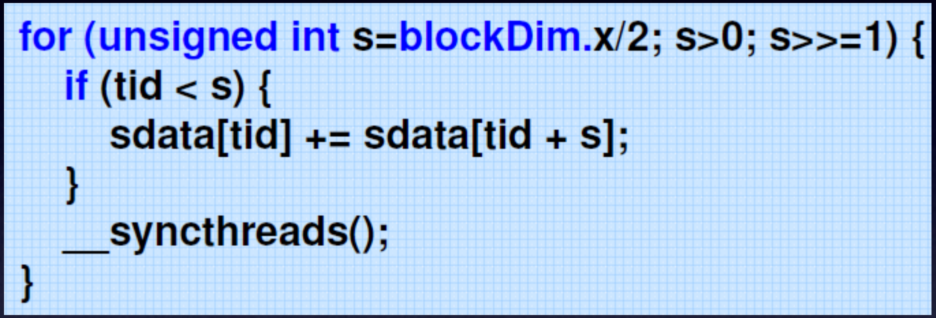
- Let's take another look at parallel reduction:



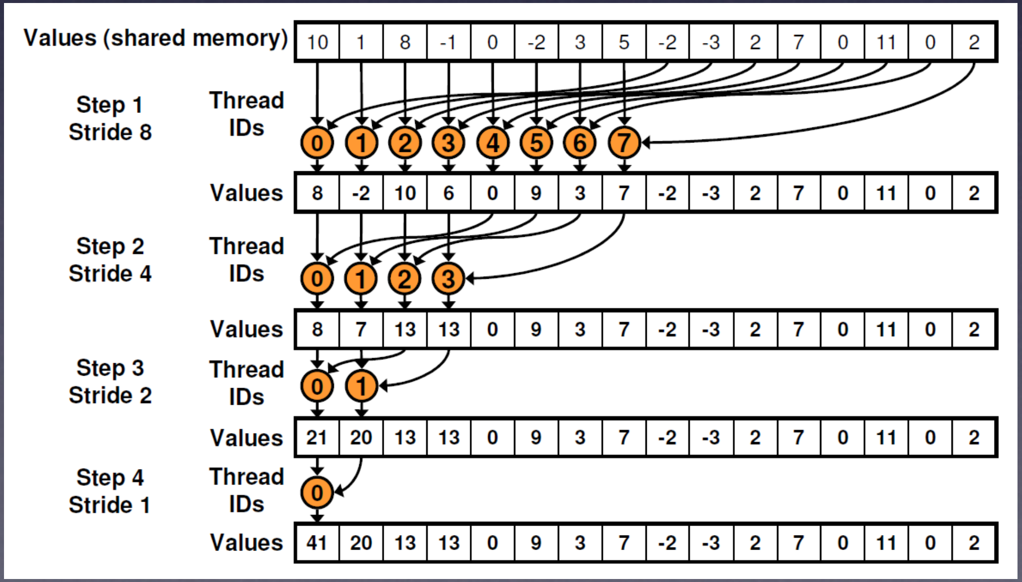
Values (shared memory)	10	1	8	-1	0	-2	3	5	-2	-3	2	7	0	11	0	2
Step 1 Stride 8 — Thread IDs	0	1	2	3	4	5	6	7								
Values	8	-2	10	6	0	9	3	7	-2	-3	2	7	0	11	0	2
Step 2 Stride 4 — Thread IDs	0	1	2	3												
Values	8	7	13	13	0	9	3	7	-2	-3	2	7	0	11	0	2
Step 3 Stride 2 — Thread IDs	0	1														
Values	21	20	13	13	0	9	3	7	-2	-3	2	7	0	11	0	2
Step 4 Stride 1 — Thread IDs	0															
Values	41	20	13	13	0	9	3	7	-2	-3	2	7	0	11	0	2

Performance Optimization Example

- Let's take another look at parallel reduction:



```
for (unsigned int s=blockDim.x/2; s>0; s>>=1) {
    if (tid < s) {
        sdata[tid] += sdata[tid + s];
    }
    __syncthreads();
}
```



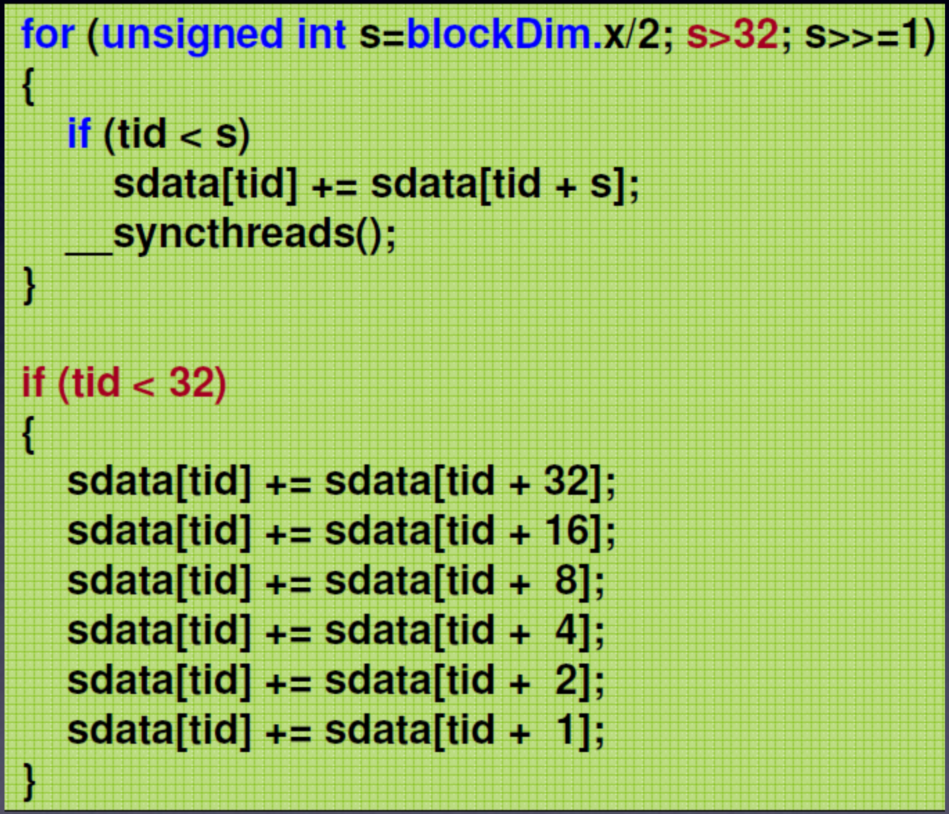
Values (shared memory)	10	1	8	-1	0	-2	3	5	-2	-3	2	7	0	11	0	2
Values	8	-2	10	6	0	9	3	7	-2	-3	2	7	0	11	0	2
Values	8	7	13	13	0	9	3	7	-2	-3	2	7	0	11	0	2
Values	21	20	13	13	0	9	3	7	-2	-3	2	7	0	11	0	2
Values	41	20	13	13	0	9	3	7	-2	-3	2	7	0	11	0	2

Performance Optimization Example

- Let's take another look at parallel reduction:
  - As reduction proceeds, # of active threads decreases, especially when s <= 32, only one warp
  - Instructions execute in lock-step within a warp
  - Therefore, when s <= 32
    - We don't need __syncthreads() any more
    - No if (tid < s) necessary because it doesn't save any work

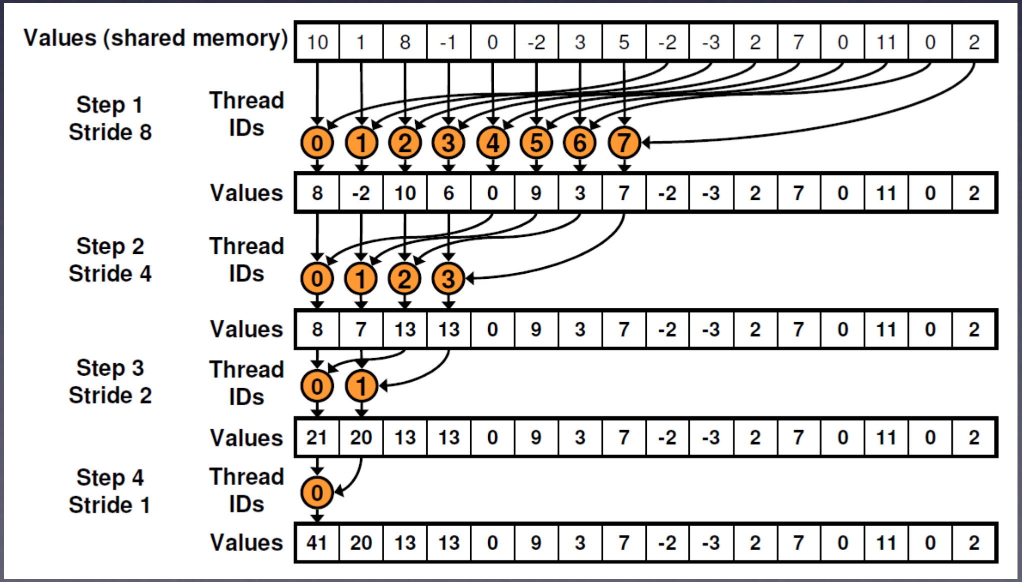
Performance Optimization Example

- Unroll the last warp:



```
for (unsigned int s=blockDim.x/2; s>32; s>>=1)
{
    if (tid < s)
        sdata[tid] += sdata[tid + s];
    __syncthreads();
}

if (tid < 32)
{
    sdata[tid] += sdata[tid + 32];
    sdata[tid] += sdata[tid + 16];
    sdata[tid] += sdata[tid +  8];
    sdata[tid] += sdata[tid +  4];
    sdata[tid] += sdata[tid +  2];
    sdata[tid] += sdata[tid +  1];
}
```



Values (shared memory)	10	1	8	-1	0	-2	3	5	-2	-3	2	7	0	11	0	2
Values	8	-2	10	6	0	9	3	7	-2	-3	2	7	0	11	0	2
Values	8	7	13	13	0	9	3	7	-2	-3	2	7	0	11	0	2
Values	21	20	13	13	0	9	3	7	-2	-3	2	7	0	11	0	2
Values	41	20	13	13	0	9	3	7	-2	-3	2	7	0	11	0	2

Performance Optimization Example

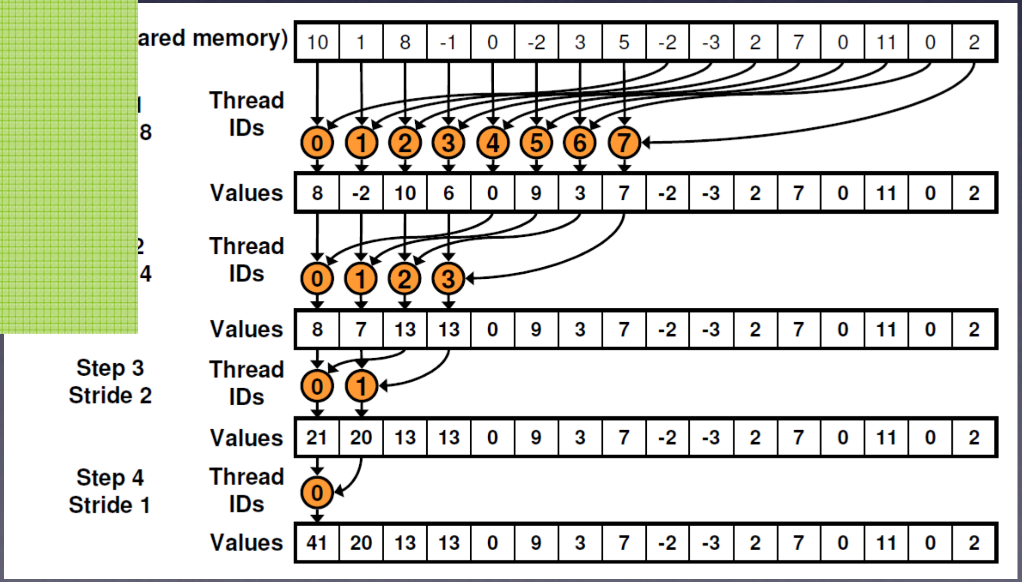
- Completely unroll the loop
  - We know that the block size is limited by the GPU to 512 threads, so we know the loop actually doesn't execute for many times
  - 512 → 256 → 128 → 64 → 32 … → 1
  - So we can completely unroll the loop

Performance Optimization Example

- Completely unroll the loop:

```
if (blockSize >= 512) {
   if (tid < 256) { sdata[tid] += sdata[tid + 256]; } __syncthreads();
}
if (blockSize >= 256) {
   if (tid < 128) { sdata[tid] += sdata[tid + 128]; } __syncthreads();
}
if (blockSize >= 128) {
   if (tid <  64)  { sdata[tid] += sdata[tid +   64]; } __syncthreads();
}

if (tid < 32) {
   if (blockSize >=  64) sdata[tid] += sdata[tid + 32];
   if (blockSize >=  32) sdata[tid] += sdata[tid + 16];
   if (blockSize >=  16) sdata[tid] += sdata[tid +  8];
   if (blockSize >=   8)  sdata[tid] += sdata[tid +  4];
   if (blockSize >=   4)  sdata[tid] += sdata[tid +  2];
   if (blockSize >=   2)  sdata[tid] += sdata[tid +  1];
}
```



ared memory) 10 1 8 -1 0 -2 3 5 -2 -3 2 7 0 11 0 2

Thread IDs 0 1 2 3 4 5 6 7

Values 8 -2 10 6 0 9 3 7 -2 -3 2 7 0 11 0 2

Thread IDs 0 1 2 3

Values 8 7 13 13 0 9 3 7 -2 -3 2 7 0 11 0 2

Step 3 Stride 2 Thread IDs 0 1

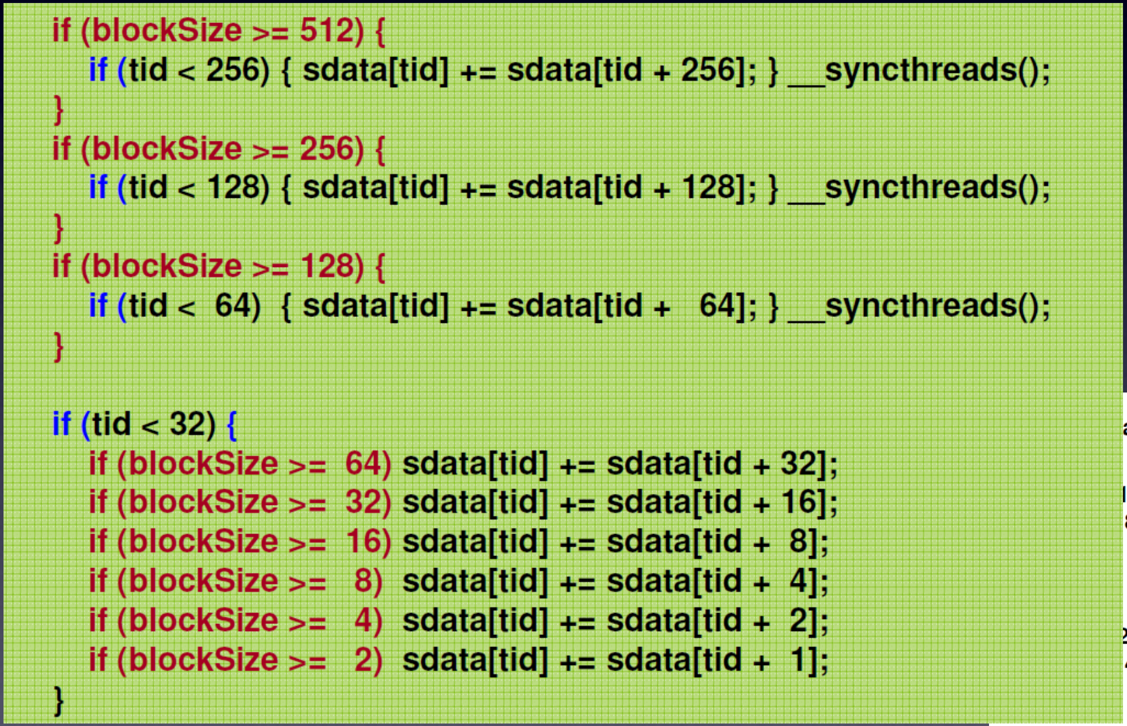
Values 21 20 13 13 0 9 3 7 -2 -3 2 7 0 11 0 2

Step 4 Stride 1 Thread IDs 0

Values 41 20 13 13 0 9 3 7 -2 -3 2 7 0 11 0 2

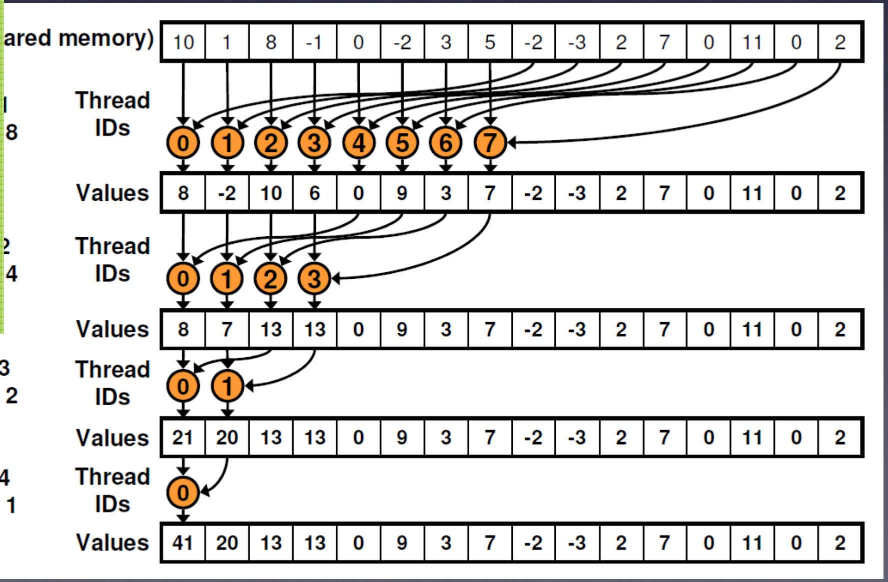
Performance Optimization Example

- Completely unroll the loop:
  use templates to help remove the if's at compile time

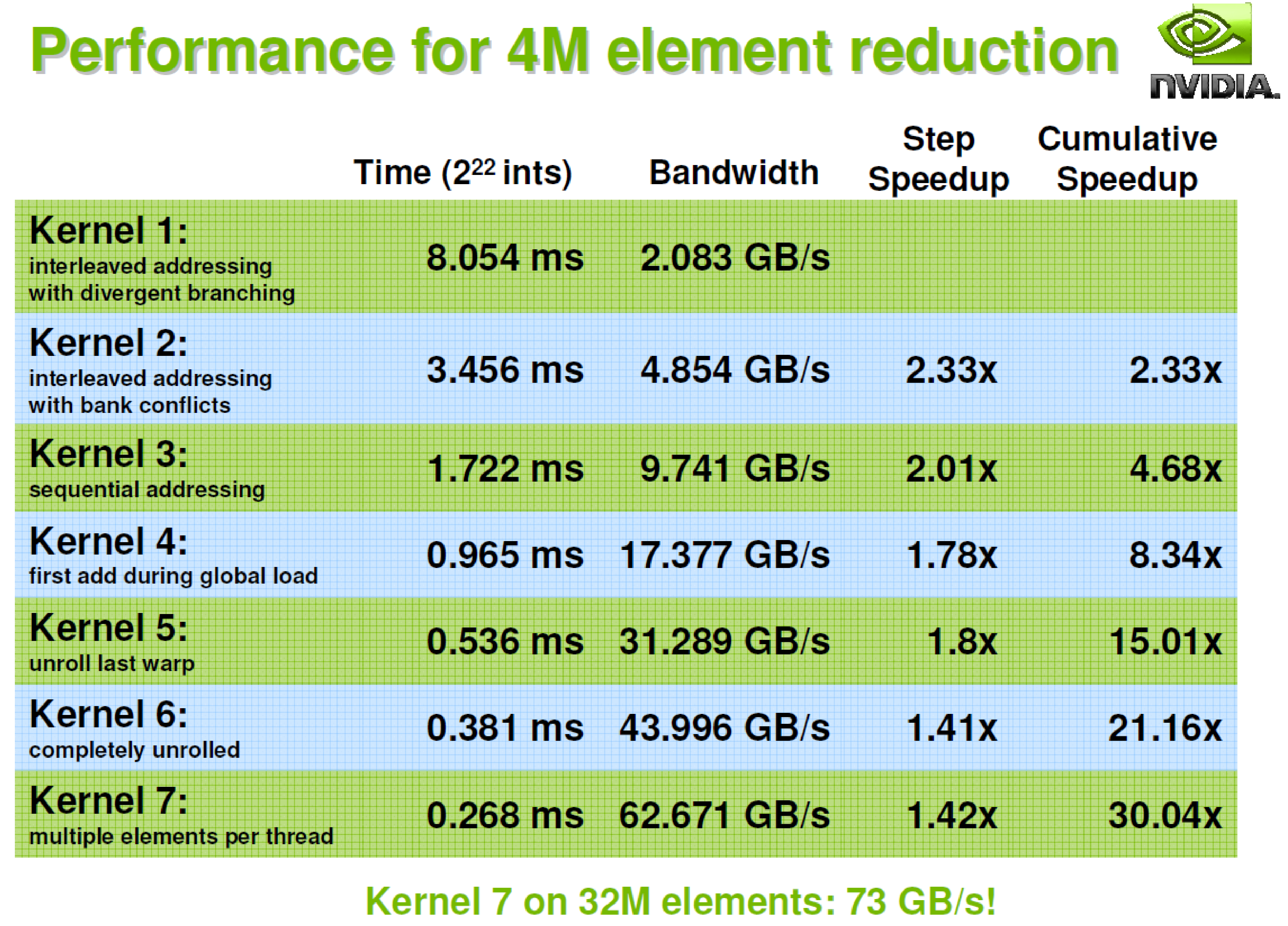


```
if (blockSize >= 512) {
    if (tid < 256) { sdata[tid] += sdata[tid + 256]; } __syncthreads();
}
if (blockSize >= 256) {
    if (tid < 128) { sdata[tid] += sdata[tid + 128]; } __syncthreads();
}
if (blockSize >= 128) {
    if (tid <  64)  { sdata[tid] += sdata[tid +   64]; } __syncthreads();
}

if (tid < 32) {
    if (blockSize >=  64) sdata[tid] += sdata[tid + 32];
    if (blockSize >=  32) sdata[tid] += sdata[tid + 16];
    if (blockSize >=  16) sdata[tid] += sdata[tid +  8];
    if (blockSize >=   8)  sdata[tid] += sdata[tid +  4];
    if (blockSize >=   4)  sdata[tid] += sdata[tid +  2];
    if (blockSize >=   2)  sdata[tid] += sdata[tid +  1];
}
```



Performance Optimization Example



Performance for 4M element reduction

	Time (2^{22} ints)	Bandwidth	Step Speedup	Cumulative Speedup
Kernel 1: interleaved addressing with divergent branching	8.054 ms	2.083 GB/s		
Kernel 2: interleaved addressing with bank conflicts	3.456 ms	4.854 GB/s	2.33x	2.33x
Kernel 3: sequential addressing	1.722 ms	9.741 GB/s	2.01x	4.68x
Kernel 4: first add during global load	0.965 ms	17.377 GB/s	1.78x	8.34x
Kernel 5: unroll last warp	0.536 ms	31.289 GB/s	1.8x	15.01x
Kernel 6: completely unrolled	0.381 ms	43.996 GB/s	1.41x	21.16x
Kernel 7: multiple elements per thread	0.268 ms	62.671 GB/s	1.42x	30.04x

Kernel 7 on 32M elements: 73 GB/s!