CS 179 Lecture 6

Synchronization, Matrix Transpose, Profiling, AWS Cluster

Synchronization

Ideal case for parallelism:

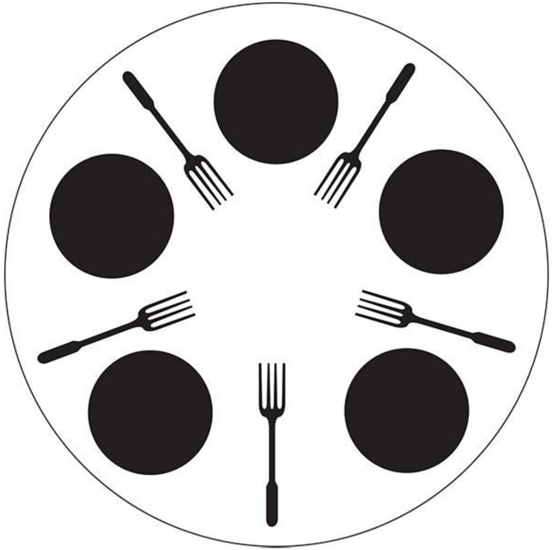
- no resources shared between threads
- no communication between threads

Many algorithms that require just a little bit of resource sharing can still be accelerated by massive parallelism of GPU

Examples needing synchronization

(1) Block loads data into shared memory before processing

(2) Summing a list of numbers



`__syncthreads()`

`__syncthreads()` synchronizes all threads in a block.

Useful for “load data into shared memory example”

No global equivalent of `__syncthreads()`

Atomic instructions: motivation

Two threads try to increment variable x=42 concurrently. Final value should be 44.

Possible execution order:

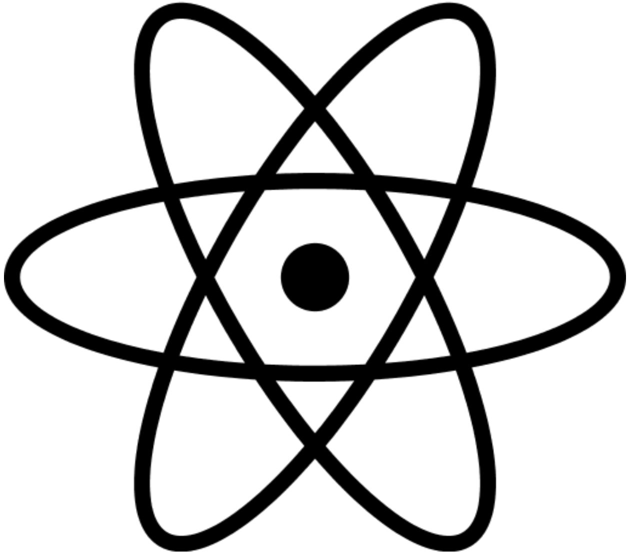
```
thread 0 load x (=42) into register r0
thread 1 load x (=42) into register r1
thread 0 increment r0 to 43
thread 1 increment r1 to 43
thread 0 store r0 (=43) into x
thread 1 store r1 (=43) into x
```

Actual final value of x: 43

:(

Atomic instructions

An atomic instruction executes as a single unit, cannot be interrupted.



Atomic instructions on CUDA

```
atomic{Add, Sub, Exch, Min, Max, Inc, Dec, CAS,
          And, Or, Xor}
```

Syntax: `atomicAdd(float *address, float val)`

Work in both global and shared memory!

The fun world of parallelism

All of the atomic instructions can be implemented given compare and swap:

```
  atomicCAS(int *address, int compare, int val)
```

CAS is very powerful, can also implement locks, lock-free data structures, etc.

Recommend Art of Multiprocessor Programming to learn more

Warp-synchronous programming

What if I only need to synchronize between all threads in a warp?

Warps are already synchronized!

Can save unneeded `__syncthreads()` use, but code is fragile and can be broken by compiler optimizations.

Warp vote & warp shuffle

Safer warp-synchronous programming (and doesn't use shared memory)

Warp vote: `__all`, `__any`, `__ballot`

```
int x = threadIdx.x; // goes from 0 to 31
__any(x < 16) == true;
__all(x < 16) == false;
__ballot(x < 16) == (1 << 16) - 1;
```

Warp shuffle

Read value of register from another thread in warp.

```
int __shfl(int var, int srcLane, int width=warpSize)
```

Extremely useful to compute sum of values across a warp (and other reductions, more next time)

First available on Kepler (no Fermi, only CC >= 3.0)

(Synchronization) budget advice

Do more cheap things and fewer expensive things!

Example: computing sum of list of numbers

Naive:

each thread atomically increments each number to accumulator in global memory

Sum example

Smarter solution:

- each thread computes its own sum in register
- use warp shuffle to compute sum over warp
- each warp does a single atomic increment to accumulator in global memory

Set 2

(1) Questions on latency hiding, thread divergence, coalesced memory access, bank conflicts, instruction dependencies

(2) Putting it into action: optimizing matrix transpose. Need to comment on all non-coalesced memory accesses and bank conflicts in code.

Matrix transpose

A great IO problem, because you have a stride 1 access and a stride n access.

Transpose is just a fancy `memcpy`, so `memcpy` provides a great performance target.

Matrix Transpose

```
__global__
void naiveTransposeKernel(const float *input, float *output, int n) {
 // launched with (64, 16) block size and (n / 64, n / 64) grid size
 // each block transposes a 64x64 block

 const int i = threadIdx.x + 64 * blockIdx.x;
 int j = 4 * threadIdx.y + 64 * blockIdx.y;
 const int end_j = j + 4;

 for (; j < end_j; j++) {
     output[j + n * i] = input[i + n * j];
 }
}
```

Shared memory & matrix transpose

Idea to avoid non-coalesced accesses:

- Load from global memory with stride 1
- Store into shared memory with stride x
- `__syncthreads()`
- Load from shared memory with stride y
- Store to global memory with stride 1

Choose values of x and y perform the transpose.

Avoiding bank conflicts

You can choose `x` and `y` to avoid bank conflicts.

A stride `n` access to shared memory avoids bank conflicts iff `gcd(n, 32) == 1`.

Two versions of the same kernel

You have to write 2 kernels for the set:

(1) `shmemTransposeKernel`. This should have all of the optimizations with memory access I just talked about.

(2) `optimalTransposeKernel`. Build on top of `shmemTransposeKernel`, but include any optimizations tricks that you want.

Possible optimizations

- Reduce & separate instruction dependencies (and everything depends on writes)
- Unroll loops to reduce bounds checking overhead
- Try rewriting your code to use 64-bit or 128-bit loads (with `float2` or `float4`)
- Take a warp-centric approach rather than block-centric and use warp shuffle rather than shared memory (will not be built on top of `shmemTranspose`). I'll allow you to use this as a guide

Profiling

profiling = analyzing where program spends time

Putting effort into optimizing without profiling is foolish.

There is a great visual (GUI) profiler for CUDA called `nvpp`, but using it is a bit of a pain with a remote GPU.

`nvprof` is the command line profiler (works on minuteman)

so let’s check that out!

`nvprof` demo

If you didn’t catch the demo in class (or even if you did), this blog post and the guide will be useful.

Profiler tips

List all profiler events with `nvprof --query-events` and all metrics with `nvprof --query-metrics`.

Many useful metrics, some good ones are `acheived_occupancy`, `ipc`, `shared_replay_overhead`, all of the utilizations, all of the throughputs.

Some useful events are `global_ld_mem_divergence_replays`, `global_st_mem_divergence_replays`, `shared_load_replay`, `shared_store_replay`

Profile example (1)

```
[emartin@minuteman:~/set2]> nvprof --events
global_ld_mem_divergence_replays,global_st_mem_divergence_replays --
metrics achieved_occupancy ./transpose 4096 naive
==11043== NVPROF is profiling process 11043, command: ./transpose 4096
naive
==11043== Warning: Some kernel(s) will be replayed on device 0 in order
to collect all events/metrics.
Size 4096 naive GPU: 33.305279 ms

==11043== Profiling application: ./transpose 4096 naive
==11043== Profiling result:
==11043== Event result:
```

Profile example (2)

```
Invocations                                 Event Name      Min        Max        Avg
Device "GeForce GTX 780 (0)"
     Kernel: naiveTransposeKernel(float const *, float*, int)
           1          global_ld_mem_divergence_replays           0          0          0
           1          global_st_mem_divergence_replays 16252928   16252928   16252928

==11043== Metric result:
Invocations                           Metric Name                       Metric Description
     Min        Max        Avg
Device "GeForce GTX 780 (0)"
     Kernel: naiveTransposeKernel(float const *, float*, int)
           1                     achieved_occupancy                     Achieved Occupancy
0.862066   0.862066   0.862066
```

Profiling interpretation

Lots of non-coalesced stores, 83% occupancy for naive kernel transpose

Amazon Cluster

Submit jobs with qsub. You must specify -l gpu=1 for cuda

```
>qsub -l gpu=1 job.sh
```

Binaries can be run directly if the binary option is specified

```
>qsub -l gpu=1 -b y ./program
```

Script and binaries are run in your homedir by default. Use the -cwd option to run in the current folder

```
~/set10/files/>qsub -l gpu=1 -cwd job.sh
```

Amazon Cluster (2)

View running jobs with qstat

```
>qstat
```

The stdout and stderr are in stored in files after the job completes. These files have the job number appended.

```
>qsub -l gpu=1 -cwd job.sh

>ls

job.sh.o5

job.sh.e5
```

Amazon Cluster (3)

Login requires ssh keys

```
>ssh -i user123.rsa user123@54.163.37.252
```

Can also use the url instead of the ip

ec2-54-163-37-252.compute-1.amazonaws.com

Windows users must use puttygen to convert to putty format

Keys will be distributed to each haru account