CSC266 Introduction to Parallel Computing using GPUs
Heterogeneous Parallelism

Sreepathi Pai
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URCS
Outline

Heterogeneous Parallelism

Streams

Stream Synchronization
Heterogeneous Parallelism

Streams

Stream Synchronization
CPU/GPU systems

- SM0
- SM1
- SMn

GPU RAM

GPU

PCIe

CPU

CPU RAM
Using both the CPU and GPU

Reasons to use the CPU:

- Not enough parallelism
  - e.g. matrix multiply on small matrices
- Not SPMD
  - e.g. producer–consumer parallelism
  - task parallelism
- Legacy binary code (e.g. libraries)
Parallelism on the CPU

- Multiple Processes
  - Standard Unix way
  - fork and join
- Multiple Threads
  - Standard Windows way
  - Also pthreads
- And combinations thereof
Outline

Heterogeneous Parallelism

Streams

Stream Synchronization
The Default Stream

- Created automatically by CUDA
- All kernel launches and memory copies placed on default stream
  - If no stream specified
- All commands on the same stream execute in order
Default Streams in CUDA 7+

- Prior to CUDA 7, one default stream *per process*
  - All threads share the same stream
- After CUDA 7, *option* to have one default stream per thread
  - All threads have their own stream.
  - You have to opt-in during compilation `--default-stream` *per-thread*
  - These streams are still *blocking* streams
Creating Streams Explicitly

- Most GPU commands take an optional stream parameter
  - `kernel<<<blocks, threads, smem, stream>>>()`
  - `cudaMemcpyAsync(..., stream)`
- Stream can be 0 (default) or explicitly created stream.
  - Also called *non-default* streams
- Creating non-default streams:
  
  ```c
  cudaCreateStream()
  cudaCreateStreamWithFlags()
  cudaCreateStreamWithPriority()
  ```
Terminology

- **Non-blocking**: CPU does not wait for operation to complete
  - All kernel calls
  - called “asynchronous” in NVIDIA docs
- **Blocking**: CPU waits for operation to complete
  - All memory copies involving host but not host *pinned* memory (even those marked *Async*)
  - called “synchronous” in NVIDIA docs
- **Implicit Synchronization**: Operation acts as a “barrier”
  - Operations on non-default streams vis-a-vis default stream
  - Example:

```c
cudaStream_t a, b;

cudaCreateStream(&a)
cudaCreateStream(&b)

kernel_a<<...>, a>>>(...) // Stream A
kernel_c<<...>, 0>>>(...) // Default Stream
kernel_b<<...>, b>>>(...) // Stream B
```
Non-blocking Streams

- Streams created with \texttt{cudaStreamCreate} implicitly synchronize with the default stream
  - Wait for all existing default stream operations to complete
  - Default stream waits for existing operations on streams to complete

- Non-blocking streams do not implicitly synchronize with default stream
  - Created with \texttt{cudaCreateStreamWithFlags}
  - What you usually want
  - Or avoid mixing default streams and non-default streams

\begin{verbatim}
cudaCreateStreamWithFlags(&a, cudaStreamNonBlocking)
cudaCreateStreamWithFlags(&b, cudaStreamNonBlocking)
kernel_a<<<..., a>>>() // Stream A
kernel_c<<<..., 0>>>() // Default Stream
kernel_b<<<..., b>>>() // Stream B
\end{verbatim}
Implicitly Serializing Operations

• Some CUDA API calls implicitly act as barriers
  • Block CPU until all operations on GPU are completed
  • Prevent any other operations from starting until API is completed

• Example:
  • cudaMalloc
  • No official list

• Diagnose by looking at timeline in NVProfiler
Stuff I’m not going to cover in detail

- Unified memory interactions with streams
  - Remember managed memory cannot be accessed on both CPU and GPU at same time
  - See `cudaStreamAttachMemAsync` documentation.
- Priority Streams
  - Kernels on high-priority streams “pre-empt” over running kernels
  - Only two levels of priority supported in Kepler
  - Not widely supported
Outline

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Streams

Stream Synchronization
Test for completion

- Have non-blocking items on stream finished?
  
  `cudaStreamQuery(stream)`

- returns `cudaSuccess` if all operations on stream are complete
Wait for completion (all)

- Wait for all non-blocking items on stream to finish?
- Waiting behaviour (can be changed):
  - Busy-wait
  - Yield

  `cudaStreamSynchronize(stream)`

- You can also use `cudaDeviceSynchronize`
  - Not recommended
Targeted Waiting

- Waiting for specific events (e.g. kernel_a below)

```c
cudaCreateStreamWithFlags(&a, cudaStreamNonBlocking);
cudaMallocHost(&repeat, sizeof(int));

do {
    *repeat = 0;

    kernel_a<<<..., a>>>(repeat)
    kernel_b<<<..., a>>>(repeat)

    cudaStreamSynchronize(a);
} while(*repeat > 0);
```
Synchronizing Across Streams

- Waiting in one stream for operations in \textit{another} stream
  - A in stream 1
  - B in stream 2
  - C in ?
- Across different processes?
  - Not covered in course
Events

- Third kind of operation in stream
  - Other two are Kernels, memory copies
- Placed in order in stream with kernels and memory copies

```c
... cudaEvent_t ev;

cudaCreateEventWithFlags(&ev, flags)
cudaCreateStreamWithFlags(&s, ...);
...

cudaEventRecord(ev, s); // places ev in stream s
```

- Interesting flags:
  - `cudaEventBlockingSync`: causes CPU to yield (instead of busy-waiting)
  - `cudaEventDisableTiming`: does not record timing data
Targeted Waiting with Events

cudaCreateStreamWithFlags(&a, cudaStreamNonBlocking);
cudaCreateEventWithFlags(&ev, cudaEventDisableTiming);
cudaMallocHost(&repeat, sizeof(int));

do {
    *repeat = 0;

    kernel_a<<<..., a>>>(repeat)
    cudaRecordEvent(ev, a); // asynchronous
    kernel_b<<<..., a>>>(repeat)
    cudaEventSynchronize(ev);
}

} while(*repeat > 0);

cudaStreamSynchronize(a); // wait for everything to complete
cudaCreateStreamWithFlags(&a, cudaStreamNonBlocking);
cudaCreateStreamWithFlags(&b, cudaStreamNonBlocking);
cudaCreateEventWithFlags(&ev, cudaEventDisableTiming);
A<<<...., a>>>();
B<<<...., b>>>();
cudaEventRecord(ev_b, b):
cudaStreamWaitEvent(a, ev_b); // places wait for ev_b in a
C<<<...., a>>>(); // note implicitly waits for a
Callbacks

- Can also create callbacks on stream operations
- Fourth type of operation in stream queue
- Called when all currently queued operations on a stream are completed
  - Blocks all further operations on stream until callback finished

```c
f (cudaStream_t t, cudaError_t status, void *userData) {
...
}
```

```c
A<<<..., a>>>();
cudaStreamAddCallback(a, f, NULL, 0); // B will execute after f
B<<<..., a>>>(()); // placed on queue asynchronously
```
Further Reading

- How to Overlap Data Transfers in CUDA/C++