CSCS
Centro Svizzero di Calcolo Scientifico
Swiss National Supercomputing Centre

ETH zürich

Advanced Features Overview

Sebastian Keller, Javier Otero, Prashanth Kanduri
and Ben Cumming, CSCS

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Concurrency

Concurrency

Concurrency is the ability to perform multiple CUDA operations simultaneously, including:

- CUDA kernels;
- Copying from host to device;
- Copying from device to host;
- Operations on the host CPU.

What concurrency enables

- Both CPU and GPU can work at the same time.
- Multiple tasks can run simultaneously on the GPU.
- communication and computation can be overlapped.

The launch-execute sequence

Host code

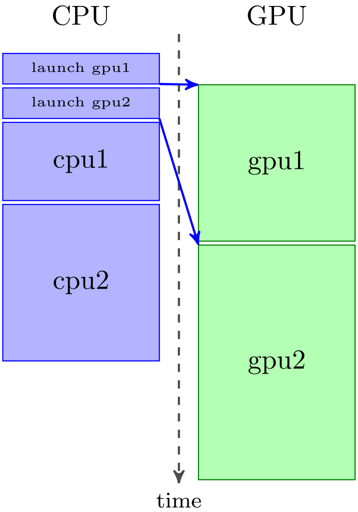
```
kernel_1<<<...>>>(...);
kernel_2<<<...>>>(...);
host_1(...);
host_2(...);
```

The host (in order):

- launch the kernels
- execute host calls sequentially

The GPU:

- executes asynchronously to host;
- executes kernels sequentially.



Overlapping Independent Operations

The CUDA language and runtime libraries provide mechanisms for coordinating asynchronous GPU execution:

- Independent kernels and memory transfers can execute concurrently on different **streams**;
- **CUDA events** can be used to synchronize streams and query the status of kernels and transfers.

Streams

A CUDA stream is a sequence of operations that execute in **issue order** on the GPU.

Streams and concurrency

- Operations in different streams **may** run concurrently
- Operations in the same stream **are** executed sequentially
- If no stream is specified, all kernels are launched in the default stream

Managing streams

- Streams can be created and destroyed:
  - `cudaStreamCreate(cudaStream_t* s)`
  - `cudaStreamDestroy(cudaStream_t s)`
- Launch a kernel on a given stream:

```
kernel<<<grid_dim, block_dim, shared_size, stream>>>(...)
```

- The default CUDA stream is the `NULL` stream, or stream 0

Basic cuda stream usage

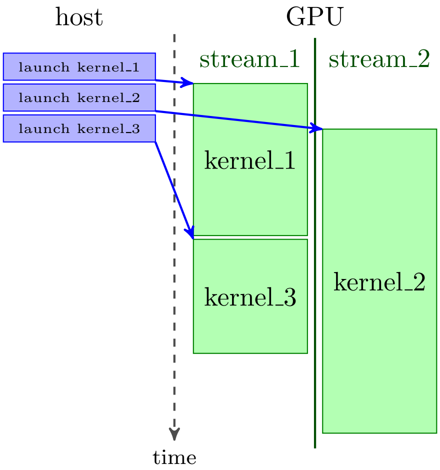
```
// create stream
cudaStream_t stream;
cudaStreamCreate(&stream);
// launch kernel in stream
my_kernel<<<grid_dim, block_dim, shared_size, stream>>>(..)

...

// release stream when finished
cudaStreamDestroy(stream);
```

Concurrent Kernel Execution

Host code

```
kernel_1<<<_,_,_,stream_1>>>();
kernel_2<<<_,_,_,stream_2>>>();
kernel_3<<<_,_,_,stream_1>>>();
```

- `kernel_1` and `kernel_3` are serialized in `stream_1`.
- `kernel_2` can run asynchronously in `stream_2`.
- **Note** `kernel_2` will only run concurrently if there are sufficient resources available on the GPU, i.e. if `kernel_1` is not using all of the SMs.



Asynchronous copy

```
cudaMemcpyAsync(*dst, *src, size, kind, cudaStream_t stream = 0);
```

- Takes an additional parameter stream, which is 0 by default.
- Returns immediately after initiating copy:
  - Host can do work while copy is performed;
  - Only if **pinned memory** is used.
- Copies in the same direction (i.e. H2D or D2H) are serialized.
  - Copies from host→device and device→host are concurrent if in different streams.

Pinned memory

Pinned (or page-locked) memory will not be paged out to disk:

- The GPU can safely remotely read/write the memory directly without host involvement;
- Only use for transfers, because it easy to run out of memory.

Managing pinned memory

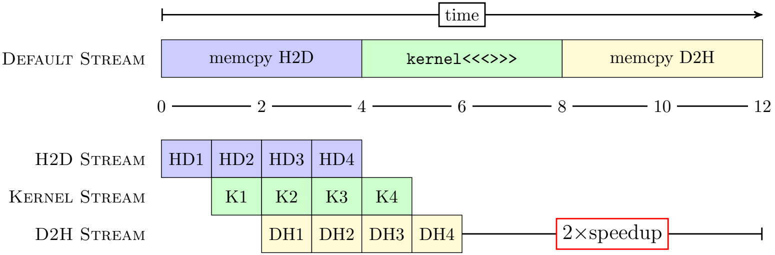
`cudaMallocHost(**ptr, size);` and `cudaFreeHost(*ptr);`

- Allocate and free pinned memory (`size` is in bytes).

Asynchronous copy example: streaming workloads

Computations that can be performed independently, e.g. our `axpy` example:

- Data in host memory has to be copied to the device, and the result copied back after the kernel is computed.
- Overlap copies with kernel calls by breaking the data into chunks.



CUDA events

CUDA events can be used to coordinate operations on different GPU streams:

- Synchronize tasks in different streams, e.g.:
  - Don't start work in stream a until stream b has finished;
  - Wait until required data has finished copy from host before launching kernel.
- Query status of concurrent tasks:
  - Has kernel finished/started yet?
  - How long did a kernel take to compute?

Managing events

- Create and free `cudaEvent_t`.

`cudaEventCreate(cudaEvent_t*);` and `cudaEventDestroy(cudaEvent_t);`

- Enqueue an event in a stream.

```
cudaEventRecord(cudaEvent_t, cudaStream_t);
```

- Make host execution wait for event to occur.

```
cudaEventSynchronize(cudaEvent_t);
```

- Test if the work before an event in a queue has been completed.

```
cudaEventQuery(cudaEvent_t)
```

- Get time between two events.

```
cudaEventElapsedTime(float*, cudaEvent_t, cudaEvent_t);
```

Using events to time kernel execution

```
cudaEvent_t start, end;
cudaStream_t stream;
float time_taken;

// initialize the events and streams
cudaEventCreate(&start);
cudaEventCreate(&end);
cudaStreamCreate(&stream);

cudaEventRecord(start, stream); // enqueue start in stream
my_kernel<<<grid_dim, block_dim, 0, stream>>>();
cudaEventRecord(end, stream);   // enqueue end in stream
cudaEventSynchronize(end);      // wait for end to be reached
cudaEventElapsedTime(&time_taken, start, end);

std::cout << "kernel took " << 1000*time_taken << " s\n";

// free resources for events and streams
cudaEventDestroy(start);
cudaEventDestroy(end);
cudaStreamDestroy(stream);
```

Copy→kernel synchronization

```
cudaEvent_t event;
cudaStream_t kernel_stream, h2d_stream;
size_t size = 100*sizeof(double);
double *dptr, *hptr;

// initialize
cudaEventCreate(&event);
cudaStreamCreate(&kernel_stream);
cudaStreamCreate(&h2d_stream);

cudaMalloc(&dptr, size);
cudaMallocHost(&hptr, size); // use pinned memory!

// start asynchronous copy in h2d_stream
cudaMemcpyAsync(dptr, hptr, size,
                cudaMemcpyHostToDevice, h2d_stream);
// enqueue event in stream
cudaEventRecord(event, h2d_stream);
// make kernel_stream wait for copy to finish
cudaStreamWaitEvent(kernel_stream, event, 0);
// enqueue my_kernel to start when event has finished
my_kernel<<<grid_dim, block_dim, 0, kernel_stream>>>();

// free resources for events and streams
cudaEventDestroy(event);
cudaStreamDestroy(h2d_stream);
cudaStreamDestroy(kernel_stream);
cudaFree(dptr);
cudaFreeHost(hptr);
```

Exercises

1. Open `include/util.hpp` and understand `copy_to_{host/device}_async()` and `malloc_pinned()`
2. Open `include/cuda_event.h` and `include/cuda_stream.h`
   - what is the purpose of these classes?
   - what does `cuda_stream::enqueue_event()` do?
3. Open `async/memcopy1.cu` and run
   - what does the benchmark test?
   - what is the effect of turning on `USE_PINNED`?
     Hint: try small and large values for `n` (8, 16, 20, 24)
4. Inspect `async/memcopy2.cu` and run
   - what effect does changing the number of chunks have?
5. Inspect `async/memcopy3.cu` and run
   - how does it differ from `memcopy2.cu`?
   - what effect does changing the number of chunks have?