General-purpose programming on GPU

Asynchronous operations

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First step of 90% of GPU-based programs is uploading some data to the device.
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Last step for 100% of GPU-based programs is downloading some data back to the host.
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Is it in general negligible?
(hint: think of a video streaming application...)

Moreover: in multi-GPU applications with minimum problem interdependence, say \( n \) the number of GPUs, a typical need is \( 4 \cdot (n - 1) \) transfer requests per frame (why?)
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- Mapped memory
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See \texttt{deviceQuery} output to check yours (at runtime, check specific booleans in the \texttt{deviceProperties}).
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See `deviceQuery` output to check yours (at runtime, check specific booleans in the `deviceProperties`). Programming guide states that *when an application is run via a CUDA debugger or profiler all launches are synchronous*, but...
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There are three requirements for async memcpys: **page-locked** host memory, use of **streams** and -async calls.
Virtual allocable memory on host is bigger than physical memory (RAM). This is possible through a *paging* mechanism that swaps pages from RAM to disk and vice-versa.
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Asynchronous memcpys require host memory to be page-locked: even if calling thread is paused, the host memory area subject of transfer should not be paged.
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Allocating too much page-locked memory may decrease overall system performance; it is critical to allocate less space than physical memory.
CUDA offers two simple methods to easily allocate page-locked memory, and one to free it:

```c
cudaError_t cudaMallocHost(void **ptr, 
    size_t size [, unsigned int flags]);
```

```c
cudaError_t cudaHostAlloc(void **pHost, 
    size_t size, unsigned int flags);
```

```c
cudaError_t cudaFreeHost(void *ptr);
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cudaError_t cudaHostAlloc(void **pHost,
                       size_t size, unsigned int flags);

cudaError_t cudaFreeHost(void *ptr);
```

cudaMallocHost() is a special case of cudaHostAlloc() with default parameters: in reference manual, there is no mention to flags for cudaMallocHost() (official reason: C/C++ interoperability?).
Flags:

`cudaHostAllocDefault` : default settings; causes `cudaHostAlloc()` to emulate `cudaMallocHost()`

`cudaHostAllocPortable` : allocated memory is available to all CUDA contexts, even if created before; the default is that only allocating thread may access it

`cudaHostAllocMapped` : maps the allocation into the CUDA address space (see later)

`cudaHostAllocWriteCombined` : disable caching of mapped memory
Example:

```c
#define DIM (1024*1024)
float *harray, *harray_map;
err = cudaMallocHost(&harray, sizeof(float)*DIM);
err = cudaHostAlloc(&harray_map,
        sizeof(float)*DIM,
        cudaHostAllocPortable | cudaHostAllocMapped);

...

error = cudaFreeHost(harray);
error = cudaFreeHost(harray_map);
```
Overview

1. Introduction
2. Asynchronous operations
3. Page-locked memory
4. Streams
5. Stream behavior
6. Mapped memory
Streams are ideal structures used to communicate to the runtime the dependencies/parallelisms of memory operations and kernels.
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When stream is not specified to a kernel or memcpy operation, the default one (0) is used and operations are not concurrent.
It is possible to enqueue in a stream, other than kernel launches and memory transfers, also CUDA events; they are used as separators for timing and inter-stream dependency purposes.
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It not possible to create a real dependency graph, but with an appropriate usage of events it is possible to ensure quite complicated dependencies.
Introduction
Asynchronous operations
Page-locked memory
Streams
Stream behavior
Mapped memory

Stream 1

memcpy
H→D

event 1

kernel A

kernel B

event 2

kernel A

...

Stream 2

kernel C

memcpy
H→D

kernel A

memcpy
D→H

event 3

...

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Introduction

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Stream 1

- Copy stripe 1
  - H→D
  - Work on stripe 1
  - Copy stripe 1
  - Result D→H
  - Event 1

Stream 2

- Copy stripe 2
  - H→D
  - Work on stripe 2
  - Copy stripe 2
  - Result D→H
  - Event 2

Stream 3

- Copy stripe 3
  - H→D
  - Work on stripe 3
  - Copy stripe 3
  - Result D→H
  - Event 3

... time

One kernel at a time is executing
One memcpy at a time is executing
Kenel and memcpys in different streams execute concurrently!

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One kernel at a time is executing
Stream 1

- copy stripe 1
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- copy stripe 1
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Stream 2

- copy stripe 2
  - H→D
  - work on stripe 2
- copy stripe 2
  - result D→H
- event 2

Stream 3

- copy stripe 3
  - H→D
  - work on stripe 3
- copy stripe 3
  - result D→H
- event 3

... time

- One kernel at a time is executing
- One memcpy at a time is executing
Stream 1

- copy stripe 1
  - H→D
  - work on stripe 1
  - copy stripe 1
  - result D→H
  - event 1

Stream 2

- copy stripe 2
  - H→D
  - work on stripe 2
  - copy stripe 2
  - result D→H
  - event 2

Stream 3

- copy stripe 3
  - H→D
  - work on stripe 3
  - copy stripe 3
  - result D→H
  - event 3

... time

- One kernel at a time is executing
- One memcpy at a time is executing
- Kernel and memcpys in different streams execute concurrently!
Kernel total time is the same as it was non concurrent; but download and upload times are partially covered, reducing total transfer time from $2 \cdot t$ to $2 \cdot \frac{t}{3}$.

See timeline profiling of SDK sample simpleStreams
To enqueue a kernel launch in a given stream with high level API, pass the stream as the fourth parameter:

```c
cudaStreamCreate(&mystream);
...
my_kernel<<< numBlocks, numThreads, 
0, mystream >>> ( [args] );
```
To enqueue a kernel launch in a given stream with high level API, pass the stream as the fourth parameter:

```c
CUDA_STREAM_CREATE(&mystream);
...
my_kernel<<<numBlocks, numThreads, 0, mystream>>>([args]);
```

Memory transfer methods are identical but with a stream parameter and -async suffix:

```c
CUDA_ERROR_T cudaMemcpyAsync(
  void *dst,
  const void *src,
  size_t count,
  enum cudaMemcpyKind kind,
  cudaStream_t stream=0);
```
To enqueue a kernel launch in a given stream with high level API, pass the stream as the fourth parameter:

```c
cudaStreamCreate(&mystream);
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my_kernel<<<numBlocks, numThreads, 0, mystream>>>([args]);
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Memory transfer methods are identical but with a `stream` parameter and `-async` suffix:

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    void *dst,
    const void *src,
    size_t count,
    enum cudaMemcpyKind kind,
    cudaStream_t stream=0);
```

There is a `-async` version of every `memcpy` method. Note default null stream.
Let's see a typical usage example.

**Creation:**

```c
#define NSTREAMS 4
cudaStream_t stream[NSTREAMS];
for (int i = 0; i < NSTREAMS; ++i)
cudaStreamCreate(&stream[i])
```
Let’s see a typical usage example.

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```c
#define NSTREAMS 4

cudaStream_t stream[NSTREAMS];

for (int i = 0; i < NSTREAMS; ++i)
    cudaStreamCreate(&stream[i])
```

**Destruction:**

```c
for (int i = 0; i < NSTREAMS; ++i)
    cudaStreamDestroy(stream[i]);
```
Enqueueing:

```c
// use multiple for cycles: prefer breadth first
for (int i = 0; i < NSTREAMS; ++i)
  cudaMemcpyAsync(inputDevPtr + i * size,
                   hostPtr + i * size, size,
                   cudaMemcpyHostToDevice, stream[i]);

for (int i = 0; i < NSTREAMS; ++i)
  MyKernel<<<100, 512, 0, stream[i]>>>(
    outputDevPtr + i * size,
    inputDevPtr + i * size, size);

for (int i = 0; i < NSTREAMS; ++i)
  cudaMemcpyAsync(hostPtr + i * size,
                  outputDevPtr + i * size, size,
                  cudaMemcpyDeviceToHost, stream[i]);
```
Synchronization:

```c
// Wait for compute device to finish
cudaError_t cudaThreadSynchronize();

// Wait for a stream to complete everything
cudaError_t cudaStreamSynchronize(cudaStream_t stream);

// Waits for an event to complete
cudaError_t cudaEventSynchronize(cudaEvent_t event);

// Makes the given stream to wait for given event before any future operation is starte (inter-stream synchronization)
cudaError_t cudaStreamWaitEvent(cudaStream_t stream, cudaEvent_t event, unsigned int flags);
```

See the programming guide for more methods (e.g. queries) and implicit synchronization mechanisms.
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No operations are checked but the first in every queue. This means that operations enqueued with a depth-first policy will be executed serially.
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(queue scheme)
Some GPUs, especially in notebooks, are integrated on the mainboard and their global memory is a part of the system RAM “shared” with the CPU.
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In these special cases, do we really need explicit transfers?
If we allocate a host buffer with flag `cudaHostAllocMapped` the buffer is prepared to be *mapped* to a subrange of the address space of the device; then, we can obtain a device pointer, pointing to the same physical address, with `cudaHostGetDevicePointer`:
If we allocate a host buffer with flag `cudaHostAllocMapped` the buffer is prepared to be *mapped* to a subrange of the address space of the device; then, we can obtain a device pointer, pointing to the same physical address, with `cudaHostGetDevicePointer()`:

```c
// flags must be 0
cudaError_t cudaHostGetDevicePointer(
    void **pDevice, void *pHost,
    unsigned int flags);
```
// alloc buffer
cudaHostAlloc((void**)&host_array,
    sizeof(float)*SIZE, cudaHostAllocMapped);

// init data
for(i=0; i < SIZE; i++)
    host_array[i]=(float)rand();

// get mapped pointer (flags must be 0)
cudaHostGetDevicePointer((void**)&device_pointer,
    (void*)host_array, 0);

// launch kernel: direct access to buffer!
vectorAdd<<<nbblocks, nthreads>>>((device_pointer, SIZE);
The mapped buffer is cached. We can disable caching using the flag `cudaHostAllocWriteCombined` when allocating.
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Standing on the programming guide, reading from a "write combined" buffer may be much faster (up to 40%), but writing on it from host may be expensive. It is recommended only when device reads alot, host writes only once.
Hands on code: asynchronous operations & timeline profiling