

Heterogeneous computing with performance modelling

Some advanced topics

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Streams

- ▶ As mentioned during the lecture 1.basics, the syntax

```
|| kernel_name<<< blocks , threads >>>( ... );
```

places a kernel `kernel_name` into a **stream**.

- ▶ By default, the kernel is placed into the **NULL stream** (stream 0).
- ▶ The operations in a stream are executed **in order**.
 - ▶ Kernels are executed in the order they are issued.
 - ▶ Only one kernel can be active at any given time.
- ▶ Blocking functions, such as `cudaMemcpy`, wait until the NULL stream is empty.
 - ▶ Kernels and memory transfers do not overlap.

Streams (create, destroy and synchronize)

- ▶ A CUDA program can contain several streams.

- ▶ A stream is created with

```
|| __host__ cudaError_t cudaStreamCreate(cudaStream_t* pStream)
```

- ▶ A stream is destroyed with

```
|| __host__ __device__ cudaError_t cudaStreamDestroy(cudaStream_t stream)
```

- ▶ A stream is synchronized with

```
|| __host__ cudaError_t cudaStreamSynchronize(cudaStream_t stream)
```

- ▶ This causes the host thread to wait until the stream is empty.

Streams (asynchronous functions)

- Most familiar CUDA functions have asynchronous variants:

```
--host__ __device__ cudaError_t cudaMemcpyAsync (
    void* dst, const void* src, size_t count, cudaMemcpyKind kind,
    cudaStream_t stream = 0 )

--host__ __device__ cudaError_t cudaMemcpy2DAsync (
    void* dst, size_t dpitch, const void* src, size_t spitch,
    size_t width, size_t height, cudaMemcpyKind kind,
    cudaStream_t stream = 0 )

--host__ __device__ cudaError_t cudaMemsetAsync (
    void* devPtr, int value, size_t count, cudaStream_t stream = 0 )

--host__ __device__ cudaError_t cudaMemset2DAsync (
    void* devPtr, size_t pitch, int value, size_t width, size_t height,
    cudaStream_t stream = 0 )

--host__ cudaError_t cudaMemPrefetchAsync (
    const void* devPtr, size_t count, int dstDevice,
    cudaStream_t stream = 0 )
```

- Note that all functions default to the NULL stream.
 - You can use asynchronous commands without creating a stream.

Streams (kernels and a few comments)

- ▶ A kernel is spaced into a specific stream with the following notation:

```
|| kernel_name<<< blocks , threads , smem , stream >>>( ... );
```

- ▶ Note that the NULL stream is special¹.
 - ▶ Other streams cannot run in parallel with the NULL stream.
 - ▶ Other streams synchronize implicitly with the NULL stream.
- ▶ In particular, the `cudaDeviceSynchronize()` function **synchronizes all streams**.
- ▶ Blocking data transfer functions, such as `cudaMemcpy`, also synchronize all streams.

¹`cudaStreamNonBlocking` flag changes this.

Streams (page-locked host memory)

- ▶ Host and device share the same memory address space.
 - ▶ A device cannot always access the host memory and vice versa.
- ▶ A device can access **page-locked** host memory:

```
--host__ cudaError_t cudaMallocHost ( void** ptr, size_t size )  
--host__ cudaError_t cudaHostAlloc (   
    void** pHost, size_t size, unsigned int flags )  
--host__ cudaError_t cudaFreeHost ( void* ptr )  
--host__ cudaError_t cudaHostRegister (   
    void* ptr, size_t size, unsigned int flags )  
--host__ cudaError_t cudaHostUnregister ( void* ptr )
```

- ▶ In most cases, the flag should be `cudaHostAllocDefault` or `cudaHostRegisterDefault`.
- ▶ Page-locked memory can be accessed with higher bandwidth than regular pageable memory (`malloc()`).
 - ▶ Page-locked memory is much slower than the global memory.
- ▶ **Memory that is used in asynchronous data transfers should be page locked.**

Streams (example)



Events

- ▶ Streams can be monitored and coordinated with **events**.
- ▶ An event must first be created:

```
|| __host__ cudaError_t cudaEventCreate ( cudaEvent_t* event )  
|| __host__ __device__ cudaError_t cudaEventDestroy ( cudaEvent_t event )
```

- ▶ The cudaEventDestroy() function is safe, i.e., it frees all associated resources only after the event is no longer needed.
- ▶ After begin created, **an event can be placed into a stream:**

```
|| __host__ __device__ cudaError_t cudaEventRecord (  
    cudaEvent_t event, cudaStream_t stream = 0 )
```

- ▶ Events can be used for host thread synchronization:

```
|| __host__ cudaError_t cudaEventSynchronize ( cudaEvent_t event )
```

- ▶ The host thread waits until the stream has reached the event.

Events (continuation)

- ▶ We can query the status of an event:

```
|| __host__ cudaError_t cudaEventQuery ( cudaEvent_t event )
```

- ▶ If the stream has reached the event, cudaSuccess is returned. Otherwise, cudaErrorNotReady is returned.
- ▶ A stream can be made to wait until an other stream has reached an event:

```
|| __host__ __device__ cudaError_t cudaStreamWaitEvent (  
    cudaStream_t stream, cudaEvent_t event, unsigned int flags = 0 )
```

- ▶ Two events can be used for timing:

```
|| __host__ cudaError_t cudaEventElapsedTime (  
    float* ms, cudaEvent_t start, cudaEvent_t end )
```

- ▶ Returns the elapsed time between two events (in milliseconds).

Managed memory

- ▶ Modern GPUs can manage the memory automatically:

```
// allocate managed memory
double *x;
cudaMallocManaged(&x, n*sizeof(double));

// initialize memory
for (int i = 0; i < n; i++)
    x[i] = 2.0 * rand()/RAND_MAX - 1.0;

// issue the kernel directly
dim3 threads = 256;
dim3 blocks = (n+threads.x)/threads.x;
ax_kernel<<<blocks, threads>>>(n, alpha, x);

cudaDeviceSynchronize();
cudaFree(x);
```

- ▶ The host must call `cudaDeviceSynchronize()` before accessing the data.

Managed memory (continuation)

- ▶ When a memory buffer that has been allocated with the `cudaMallocManaged` function is accessed, one of the following events occurs:
 1. If the corresponding memory page (4096 bytes) exists in the host/device memory, then the memory request is served by the memory controller or the caches.
 2. If the corresponding memory page does not exist in the host/device memory, then
 - 2.1 a page fault is triggered,
 - 2.2 memory transfer is initialized for the **entire page**, and
 - 2.3 the thread(s) pause until the memory transfer is ready.
- ▶ Fetching the entire page can be costly if the memory is accessed randomly. One must also pay attention to alignment.
- ▶ You can also prefetch the data to the global memory:

```
|| cudaMemPrefetchAsync(addr, size, cudaGetDevice(&device));
```

Hands-ons

- ▶ Five hands-ons under `hands-ons/4.advanced`:
 - 1.`async` Learn how to use streams and asynchronous data transfers.
 - 2.`multi_gemm` Learn how to manage multiple streams.
 - 3.`pipeline` Learn how to pipeline computation and data transfers.
 - 4.`managed` Learn how to use managed memory.
 - 5.`lu` Learn what type of computations are suitable for GPUs.
- ▶ Solutions can be found under `solutions/4.advanced`.