CSCS
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Advanced Features Overview

CSCS Summer School 2025

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Concurrency

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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

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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.

Launch-Execute Sequence

Host Code

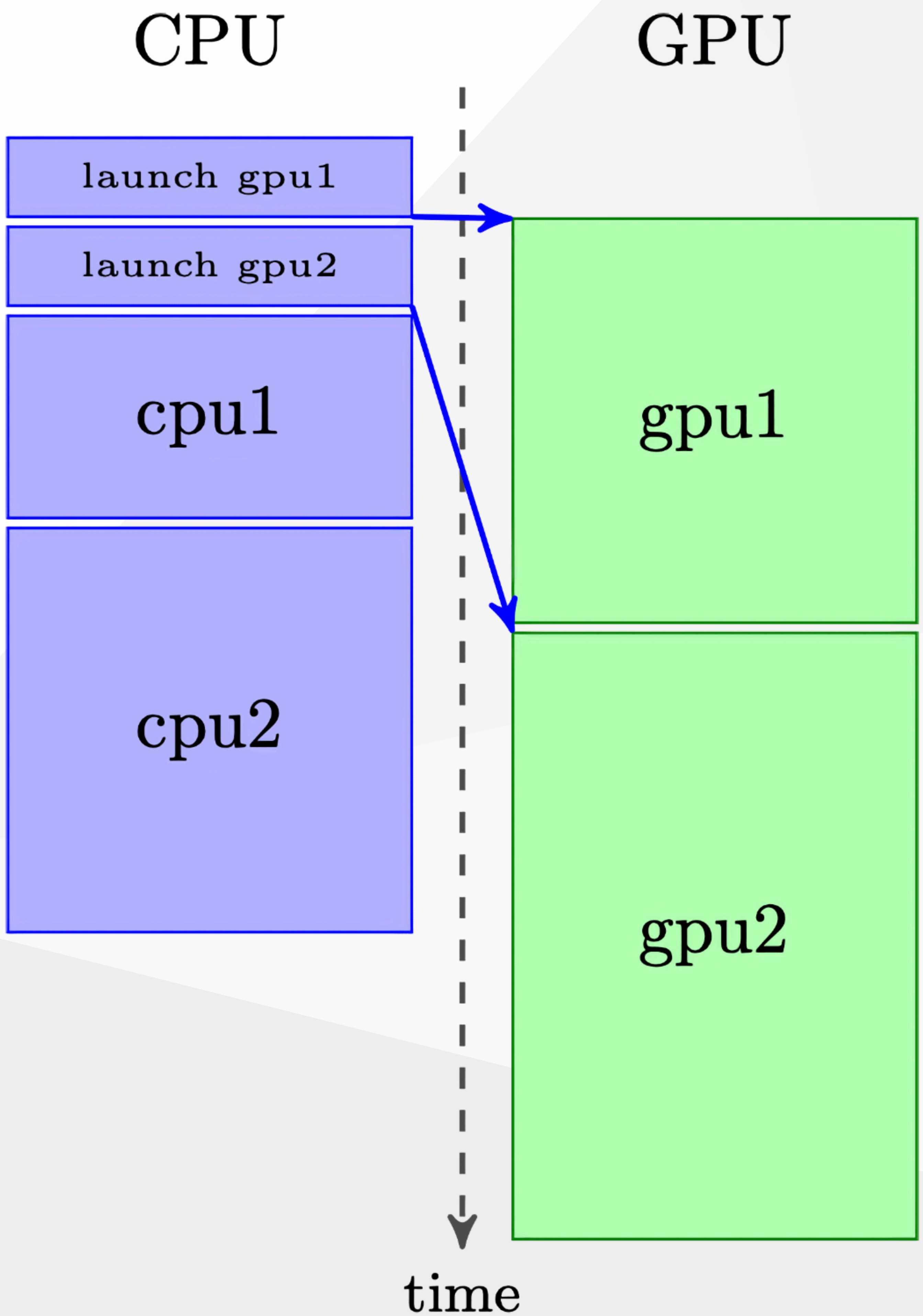
```
kernel_1<<<...>>>(...);
kernel_2<<<...>>>(...);
host_1(...);
host_2(...);
```

The host (in order):

- launches 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`

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Basic CUDA Streams Usage

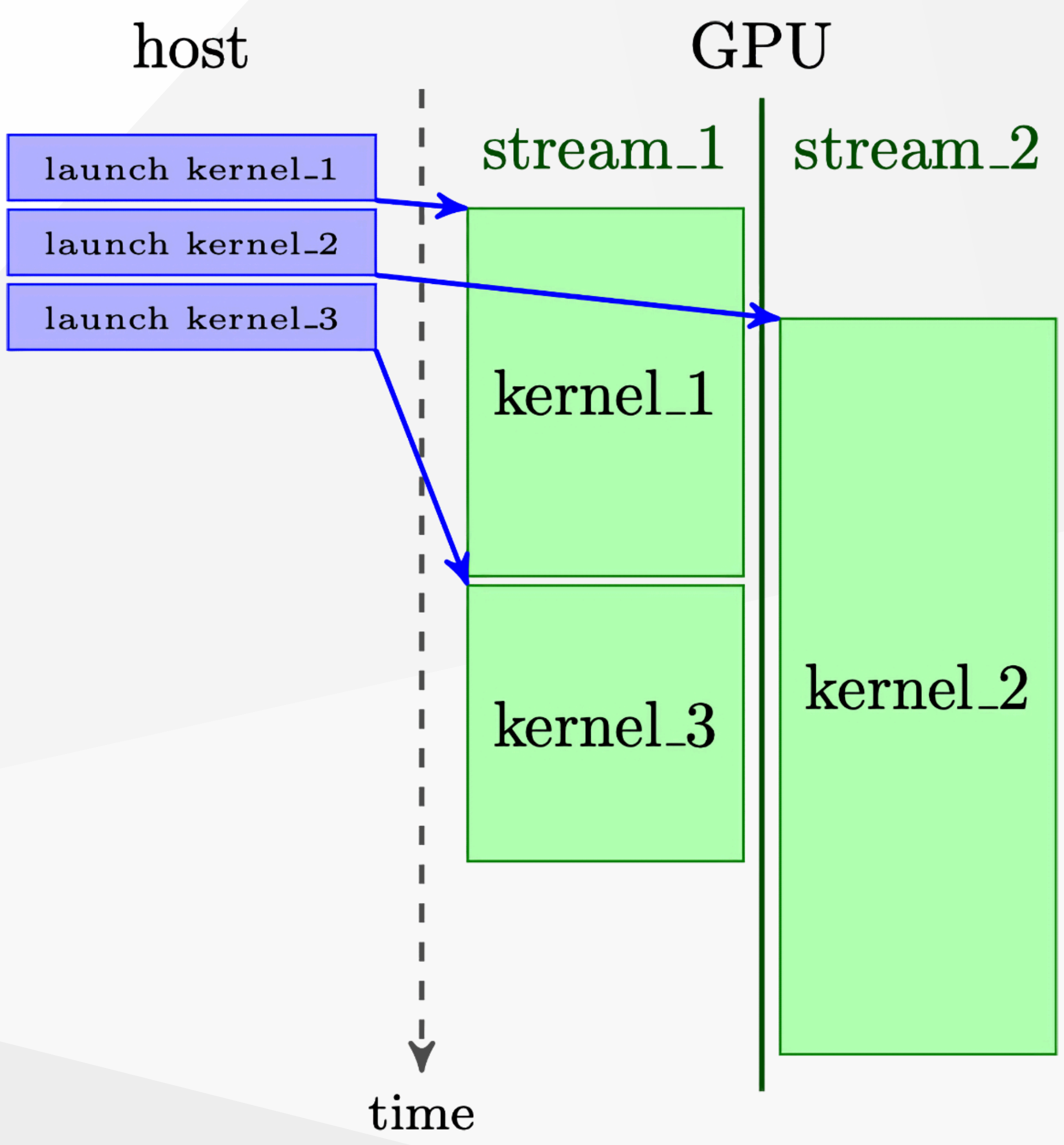
```
// create stream
cudaStream_t stream;
cudaStreamCreate(&stream);
// launch kernel in stream
my_kernel<<<grid_dim, block_dim, shared_size, stream>>>(..)
...
// release stream when finished
cudaStreamDestroy(stream);
```

Concurrent Kernel Execution

Host Code

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

- `kernel_1` and `kernel_2` 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:

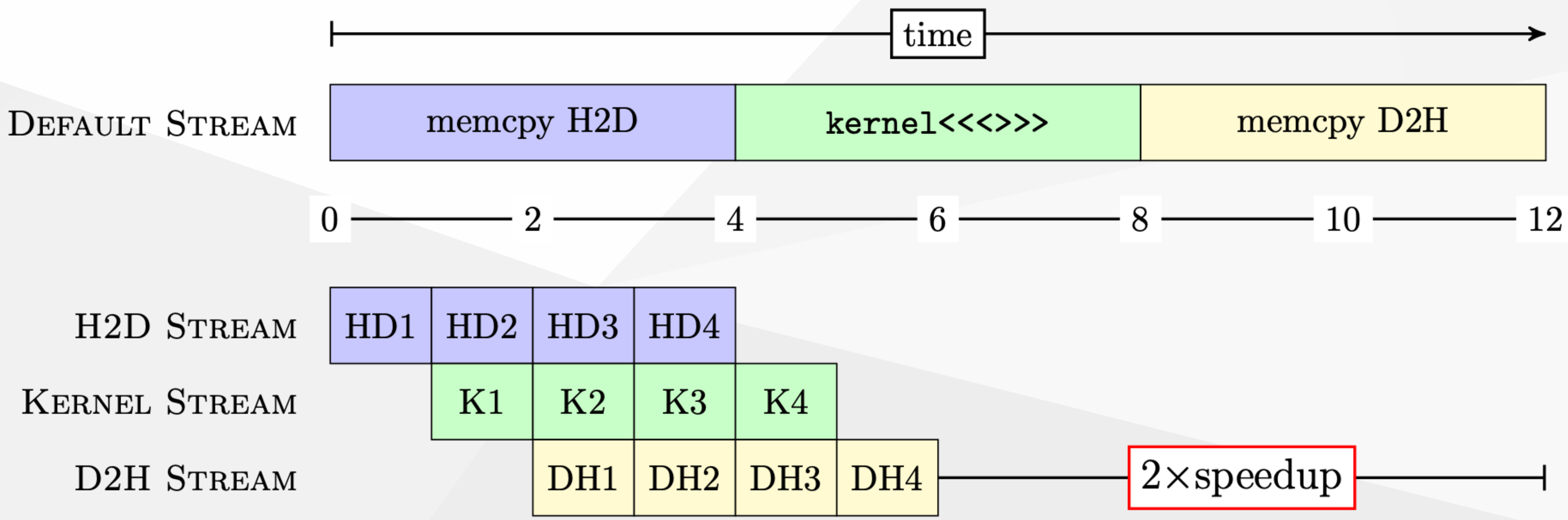
- The GPU can safely remotely read/write the memory directly without host involvement;
- Only use for transfers, because it easy to run out of memory

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*);` & `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);
```