LET: A Way Forward for Safe GPU Co-Scheduling

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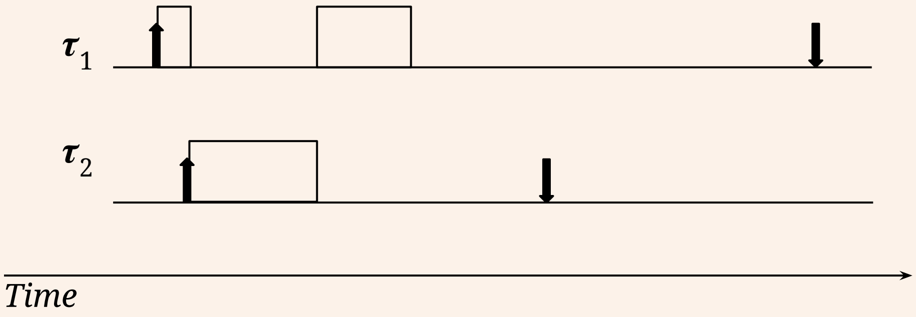
Nathan Otterness, James H. Anderson

Prerequisite: Timing Models

Tasks (implicit deadline):

- τ_1: (0.4, 2.0)
- τ_2: (0.2, 1.0)



Real-time scheduling often assumes a *Bounded Execution Time* (BET) model:

Tasks must occupy a processor for a specific time interval before their deadline.

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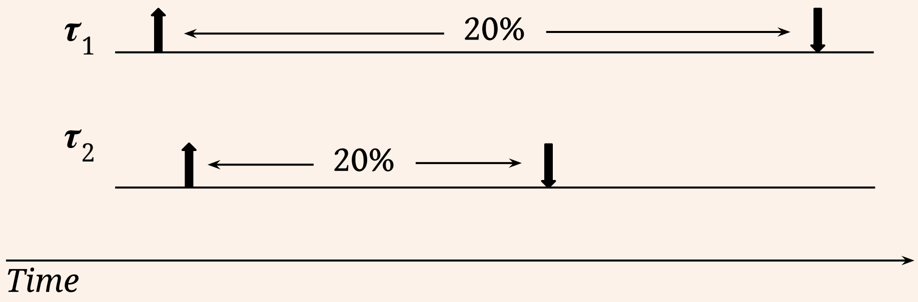

Logical Execution Time (LET):

Tasks occupy a *proportion of resources* for their *entire* period.

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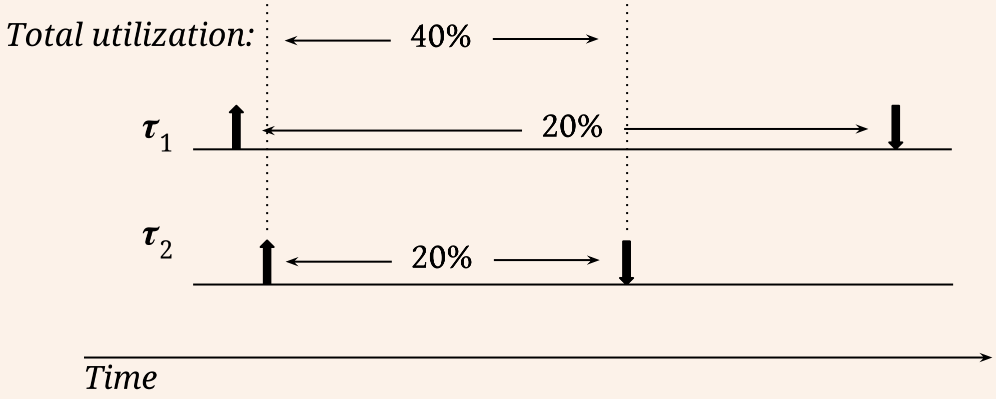

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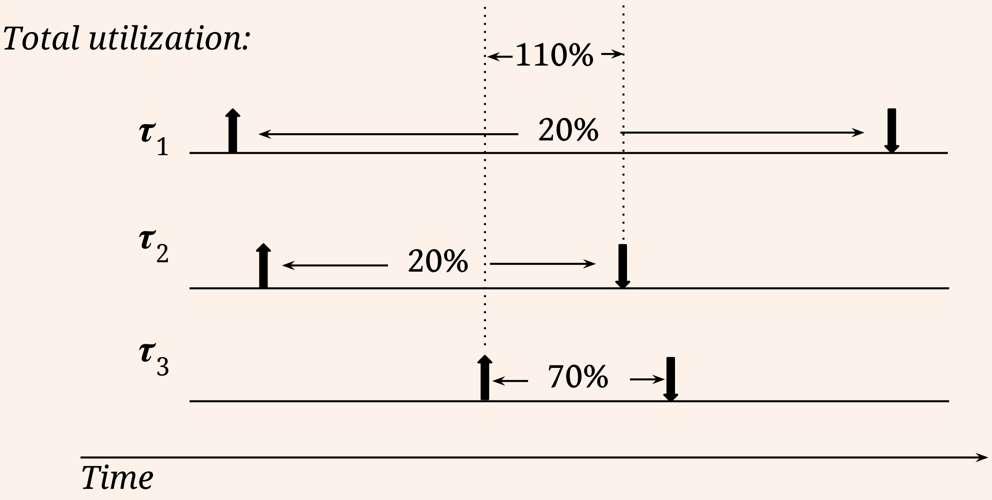
- τ_1: (0.4, 2.0), *U = 0.2*
- τ_2: (0.2, 1.0), *U = 0.2*
- τ_3: (0.35, 0.5), *U = 0.7*



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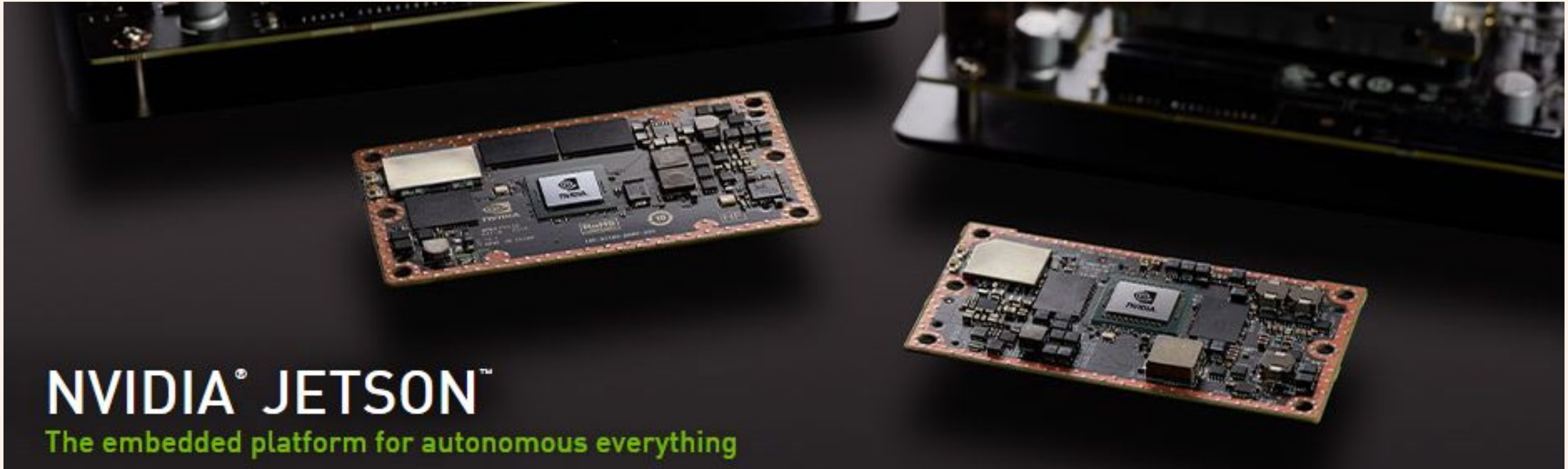
Safety-Critical GPUs

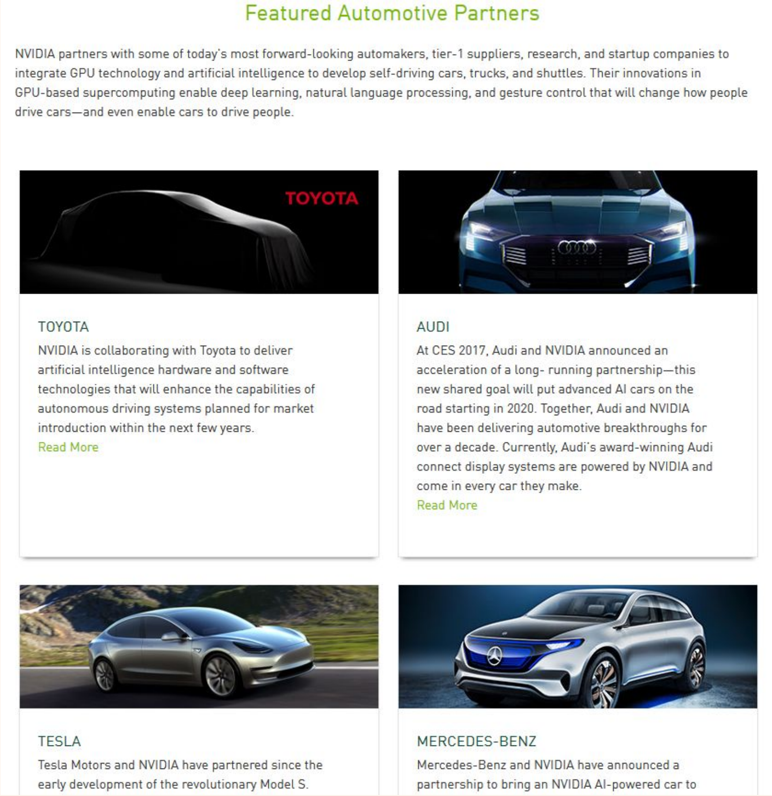


Screenshot of http://www.nvidia.com/object/embedded-systems-dev-kits-modules.html 27 March 2017

Platforms augmented with graphics processing units (GPUs), such as the NVIDIA Jetson TX1, are increasingly prevalent in embedded systems.

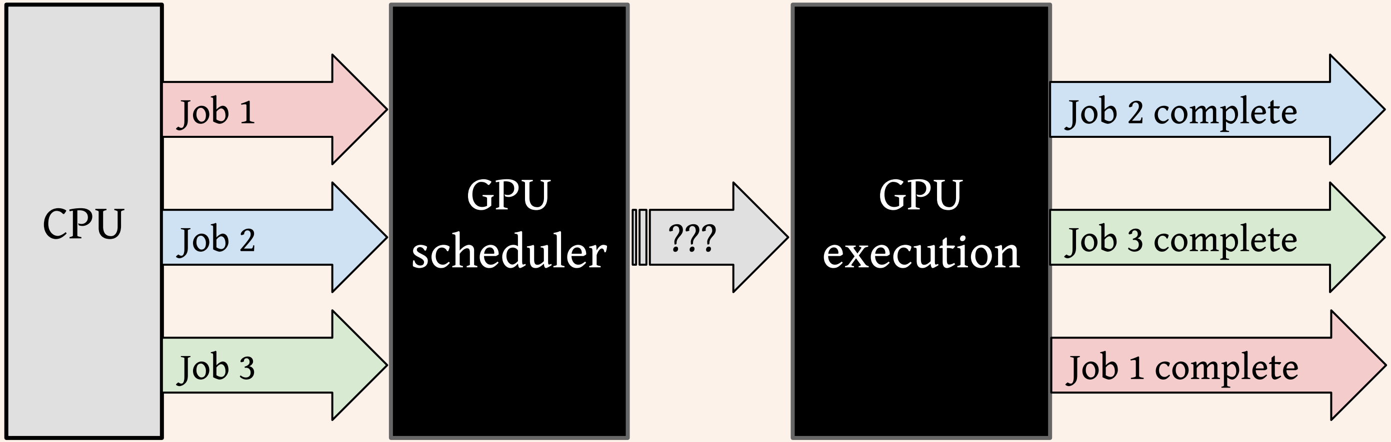
Safety-Critical GPUs

Despite a lack of documentation needed for modeling and *certification*, work is underway to incorporate GPUs into safety-critical systems.



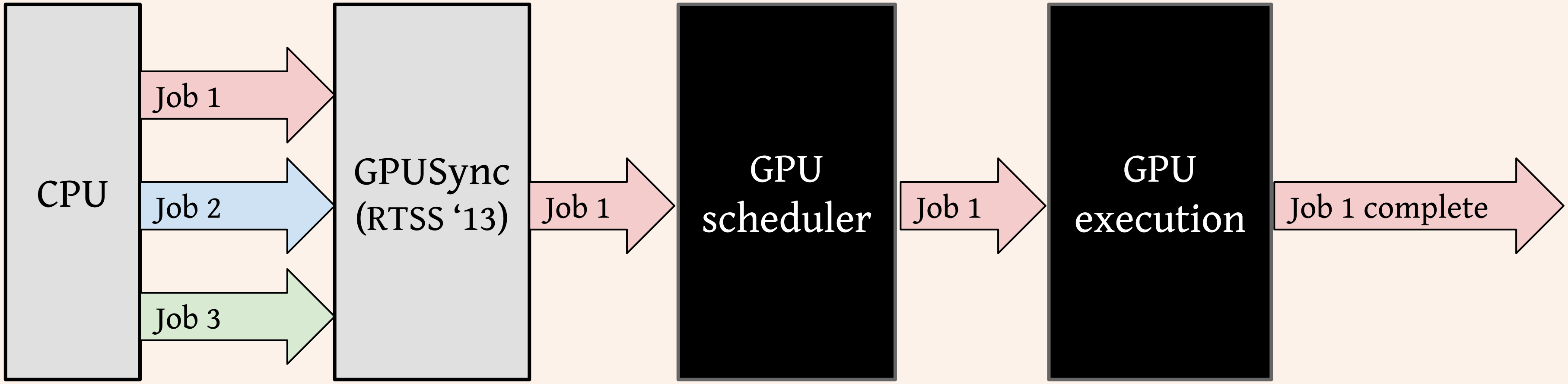
Screenshot of http://www.nvidia.com/object/automotive-partner-innovation.html 13 June 2017

GPU Co-Scheduling



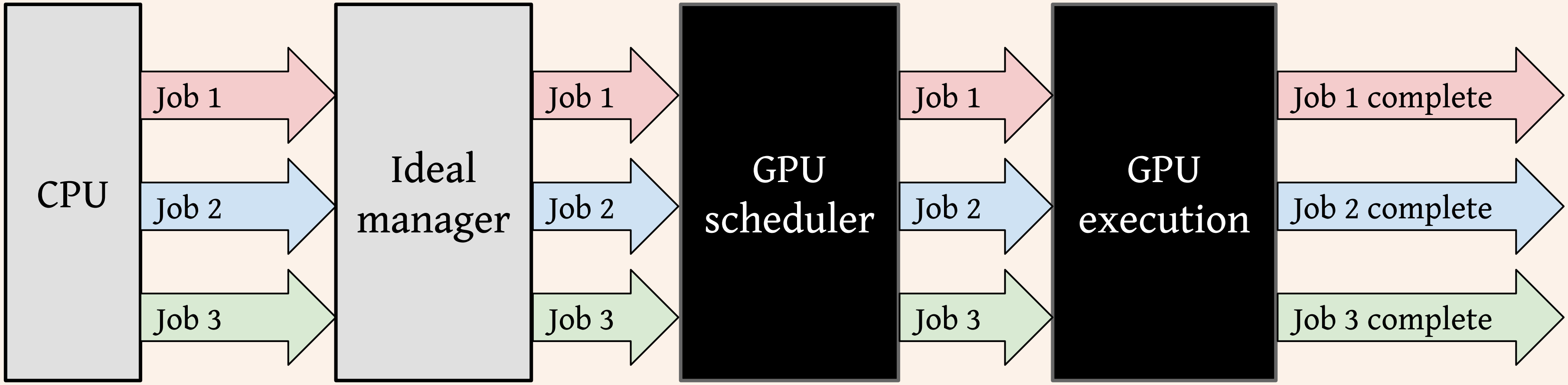
The problem with GPU co-scheduling is that a lack of information leads to a lack of predictability.

GPU Co-Scheduling



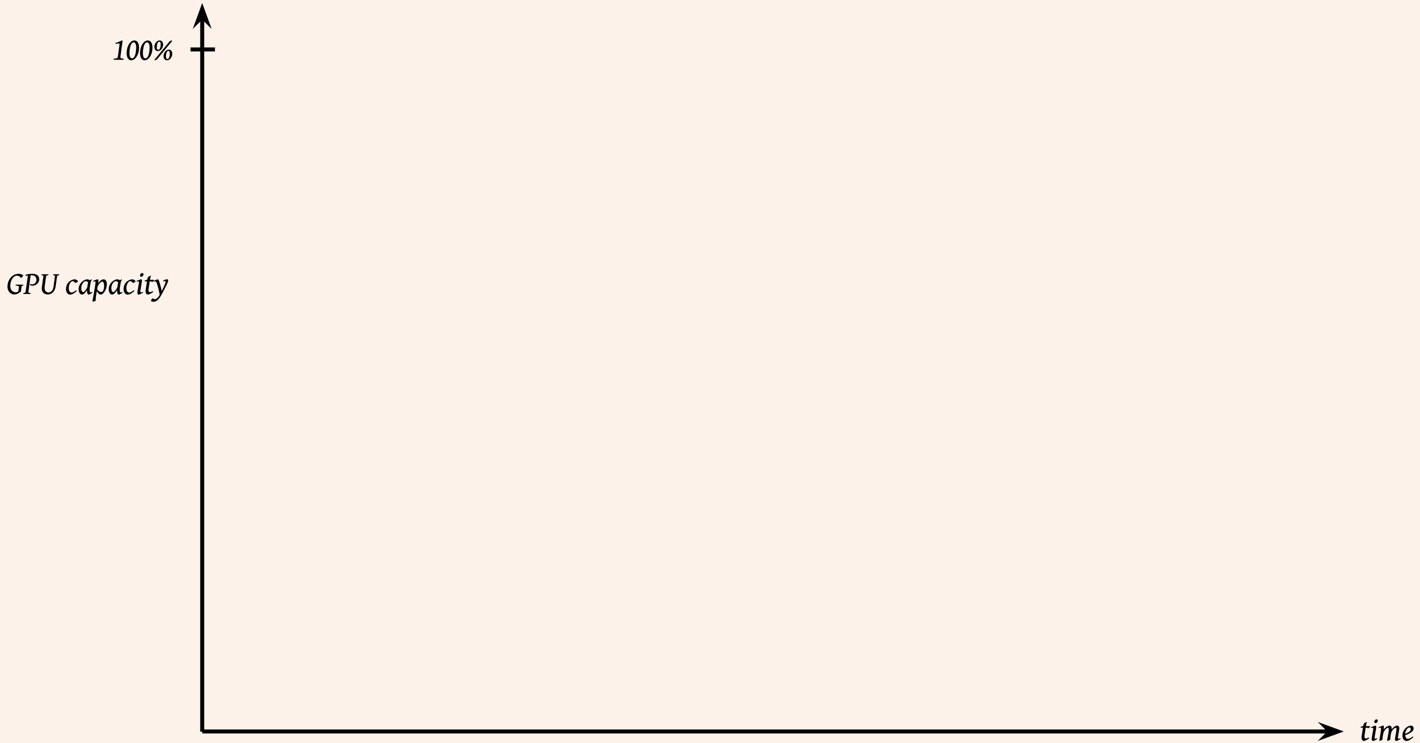
Earlier systems work around this problem by enforcing exclusive access to GPUs.

GPU Co-Scheduling



An ideal management system will enable both predictability and concurrency.

A Simplified GPU Model



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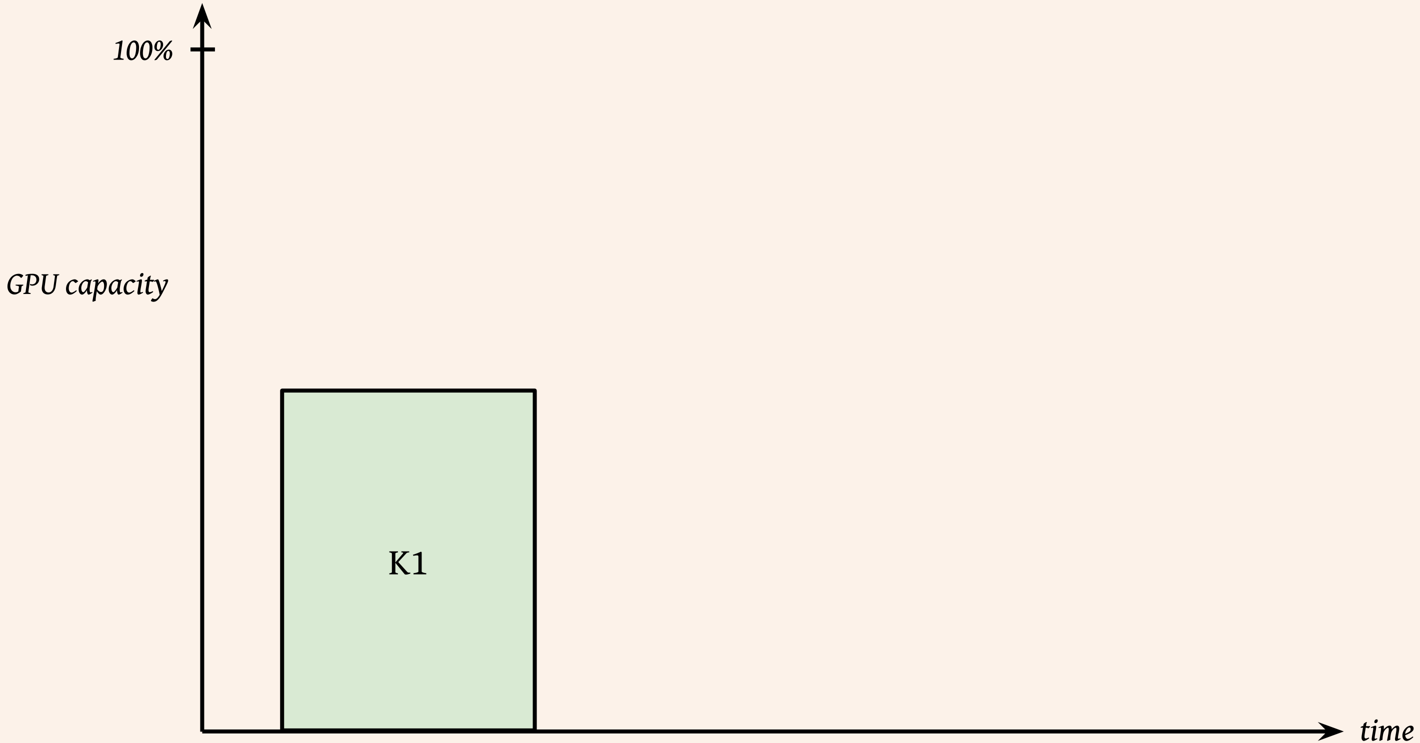

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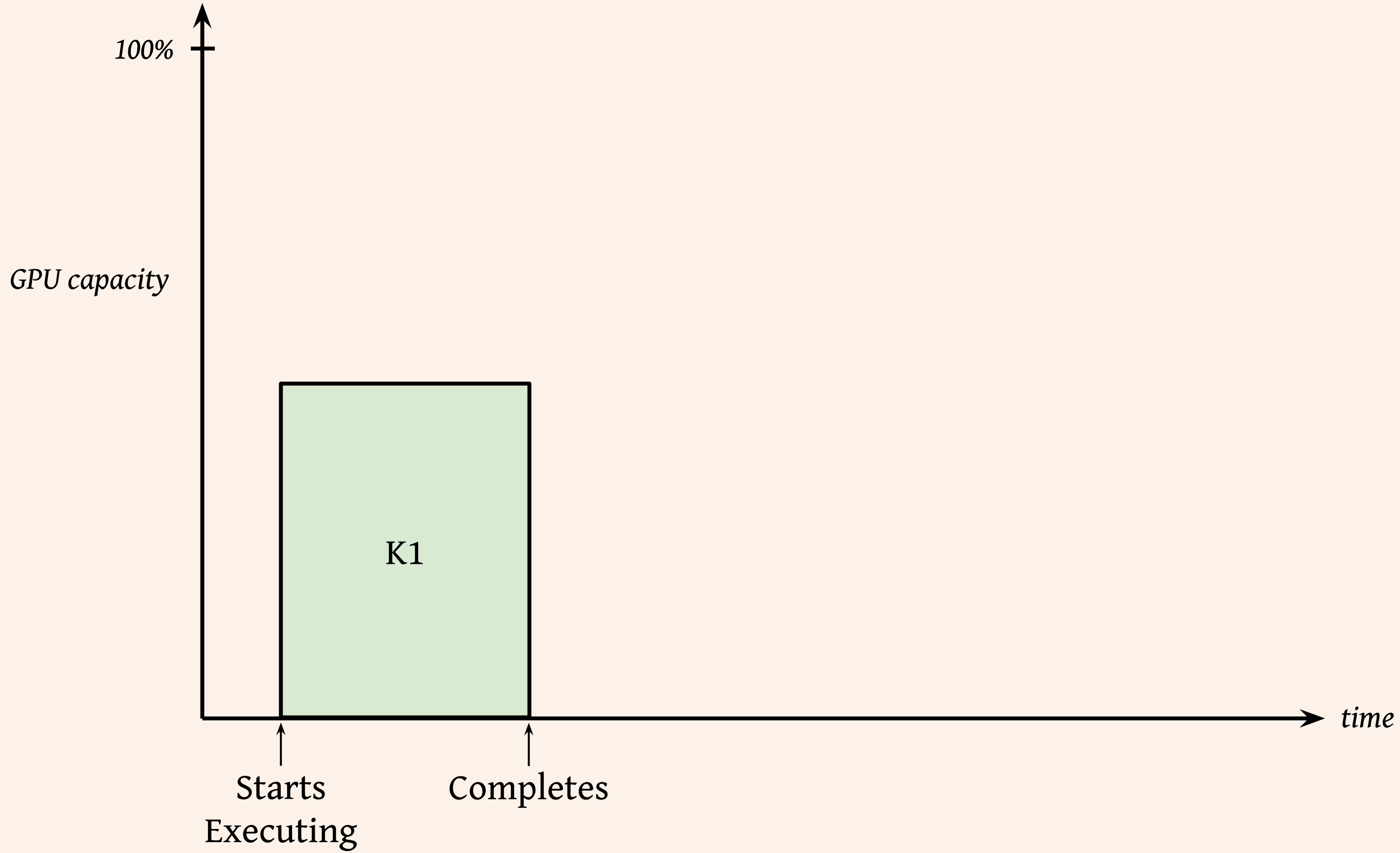

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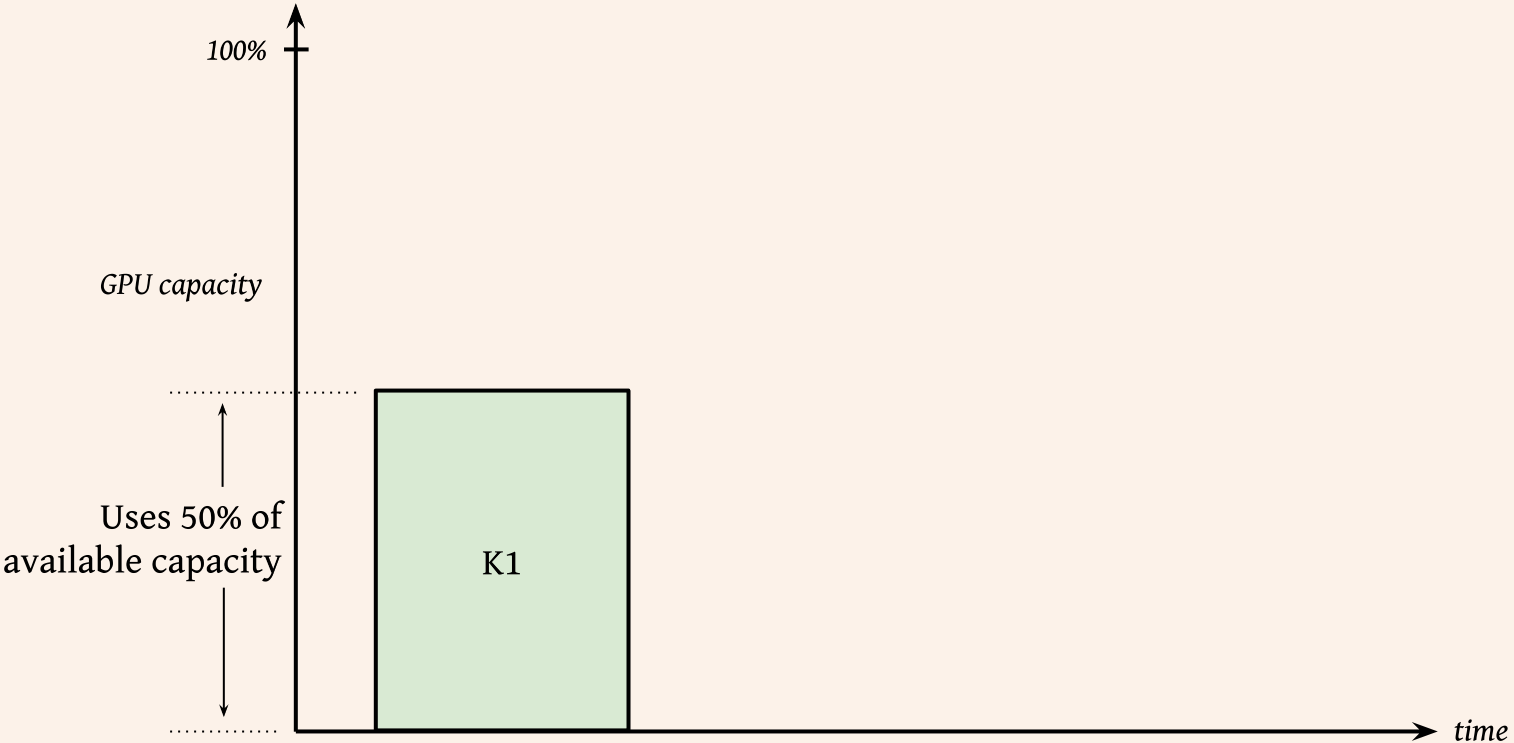

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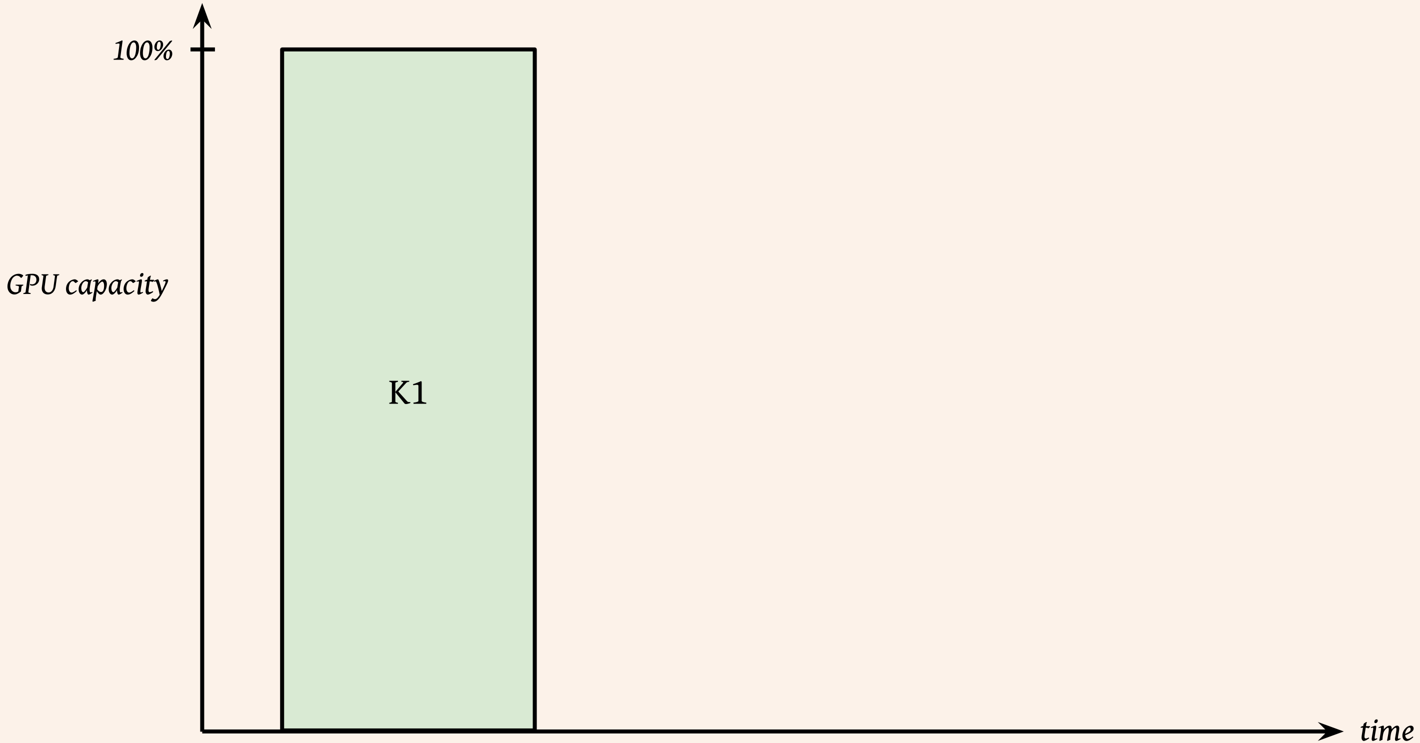

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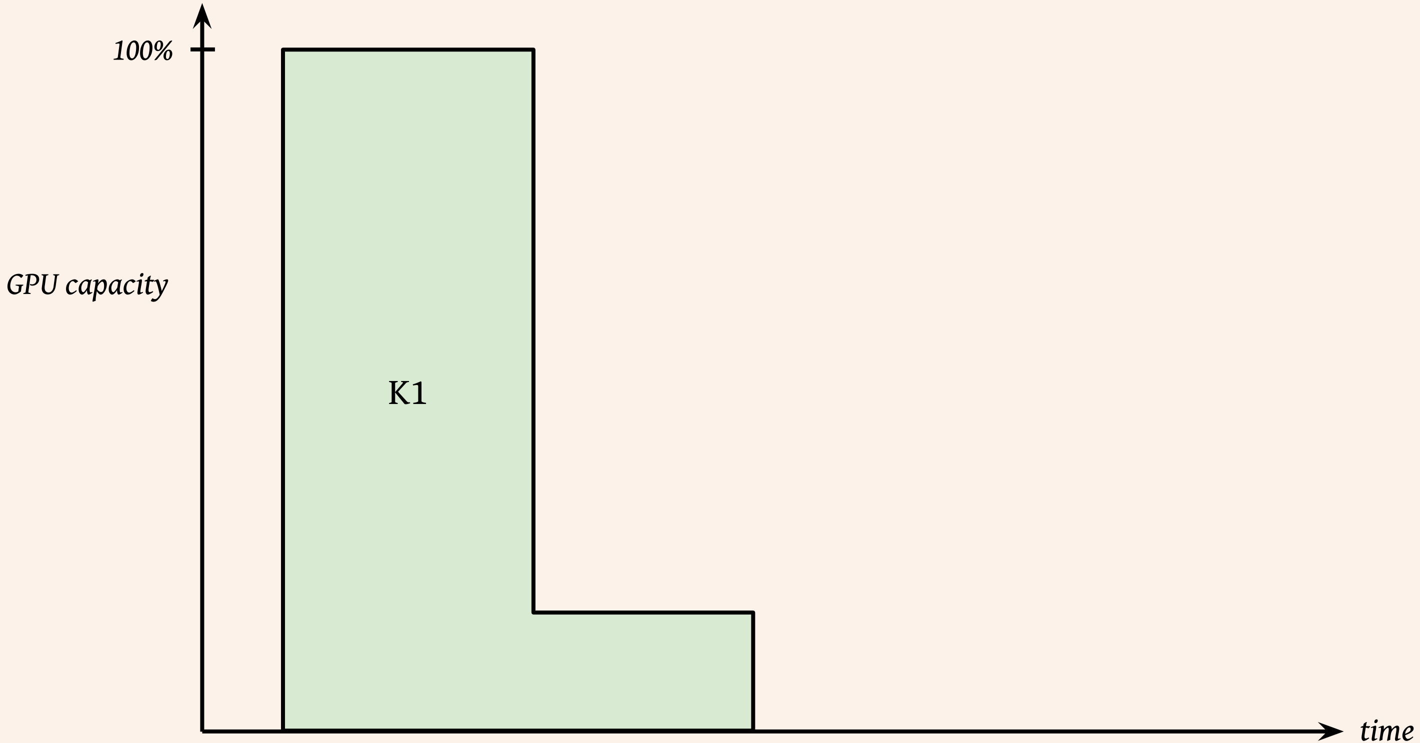

Approaches to Co-Scheduling

Different ways to Co-Schedule GPU Tasks:

- Every task is a separate CPU process (no GPU middleware).
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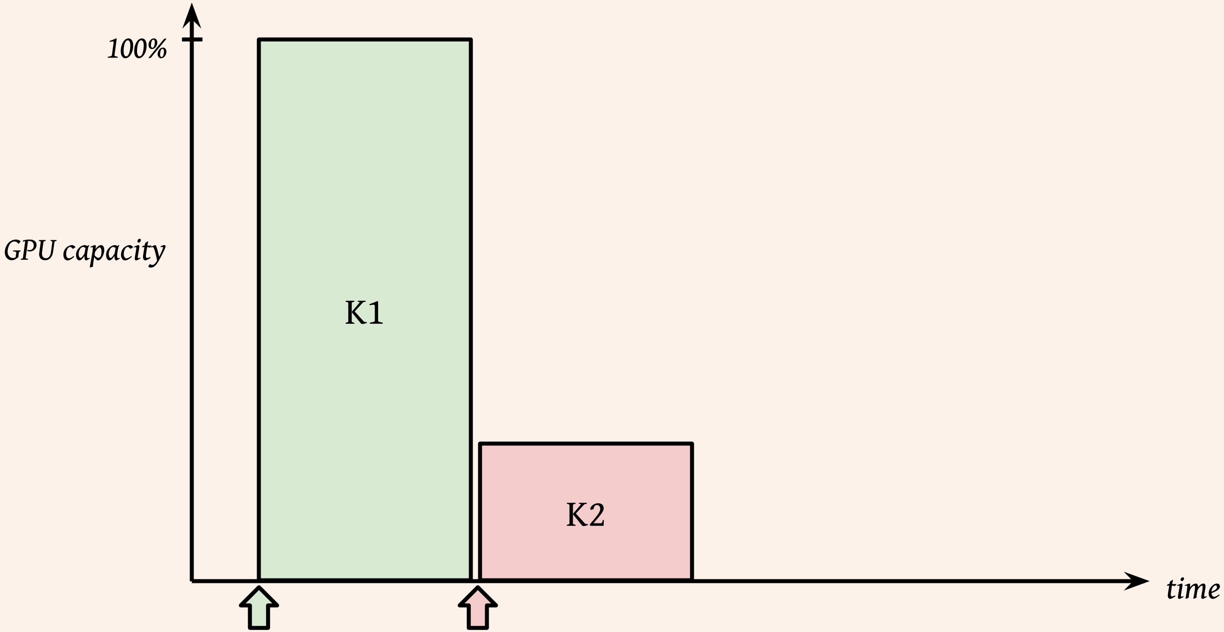
Multi-process Co-Scheduling



Starting Example: Sequential Execution

Reported in:

- *An Evaluation of the NVIDIA TX1 for Supporting Real-time Computer-Vision Workloads* (RTAS'17)
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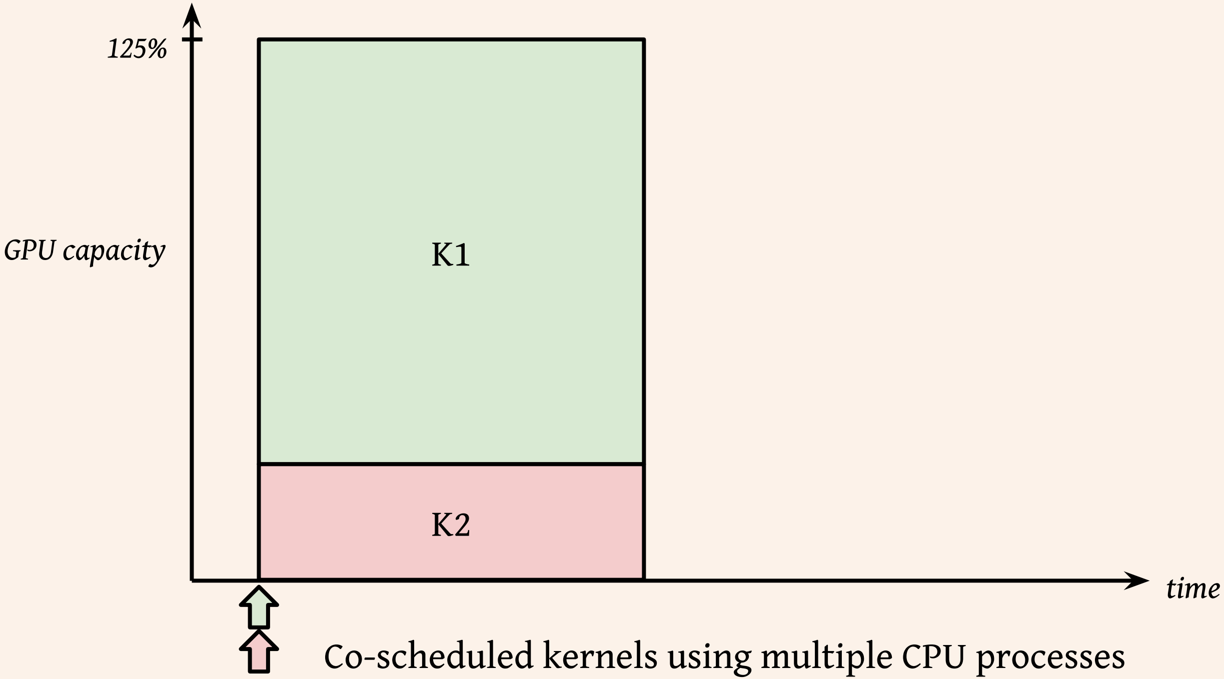

Co-scheduled kernels using multiple CPU processes

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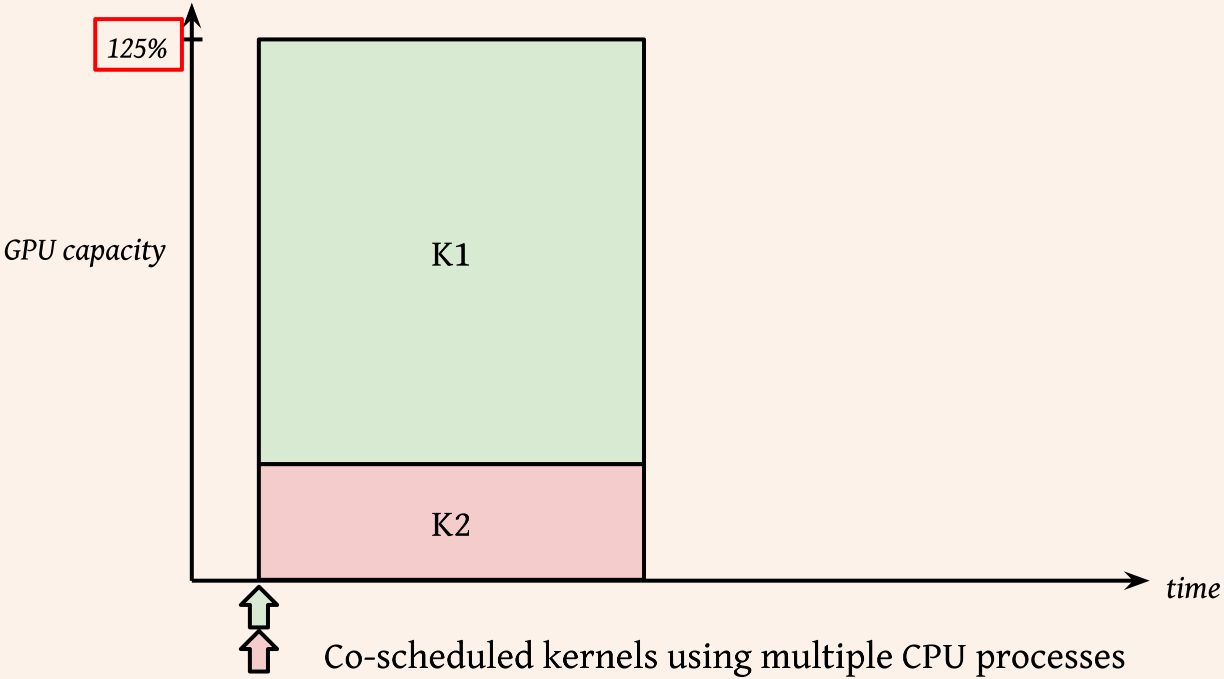

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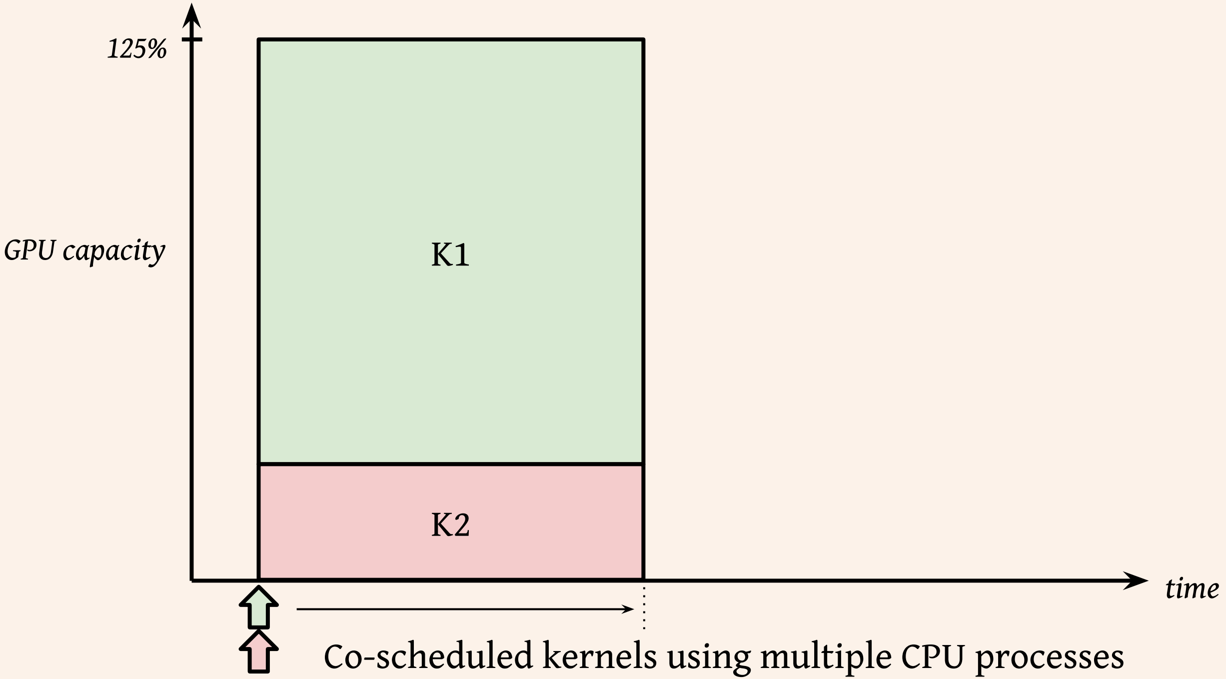

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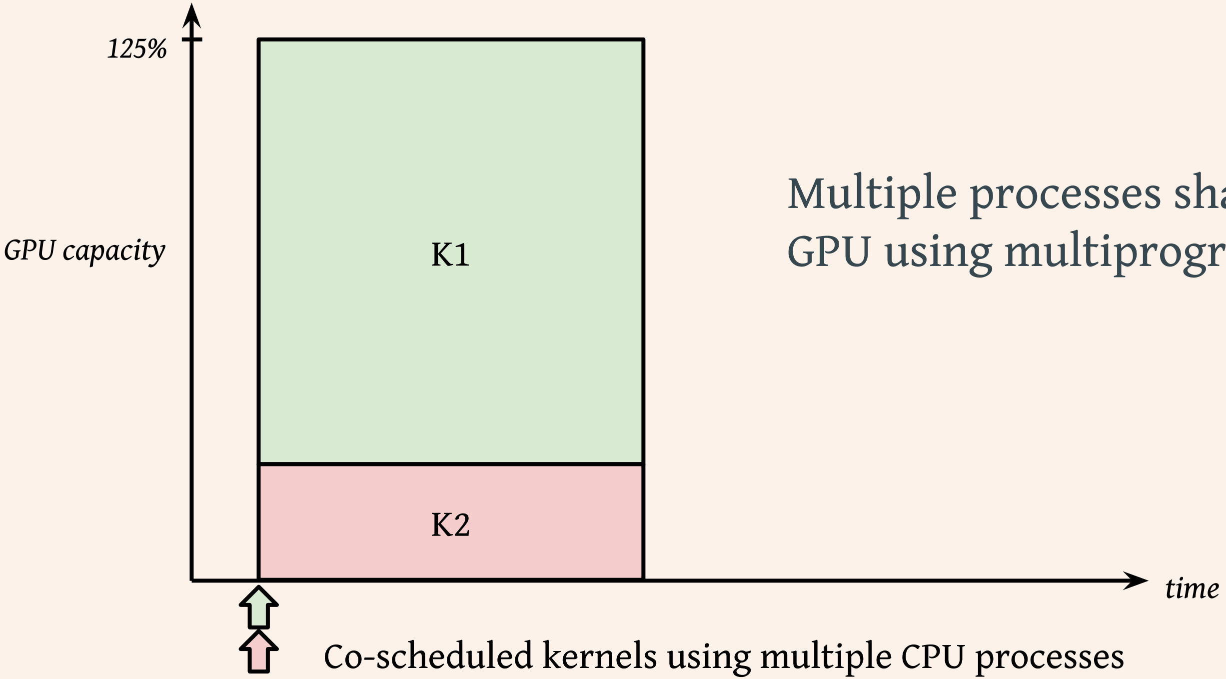

Co-scheduled kernels using multiple CPU processes

Multiple processes share the GPU using multiprogramming.

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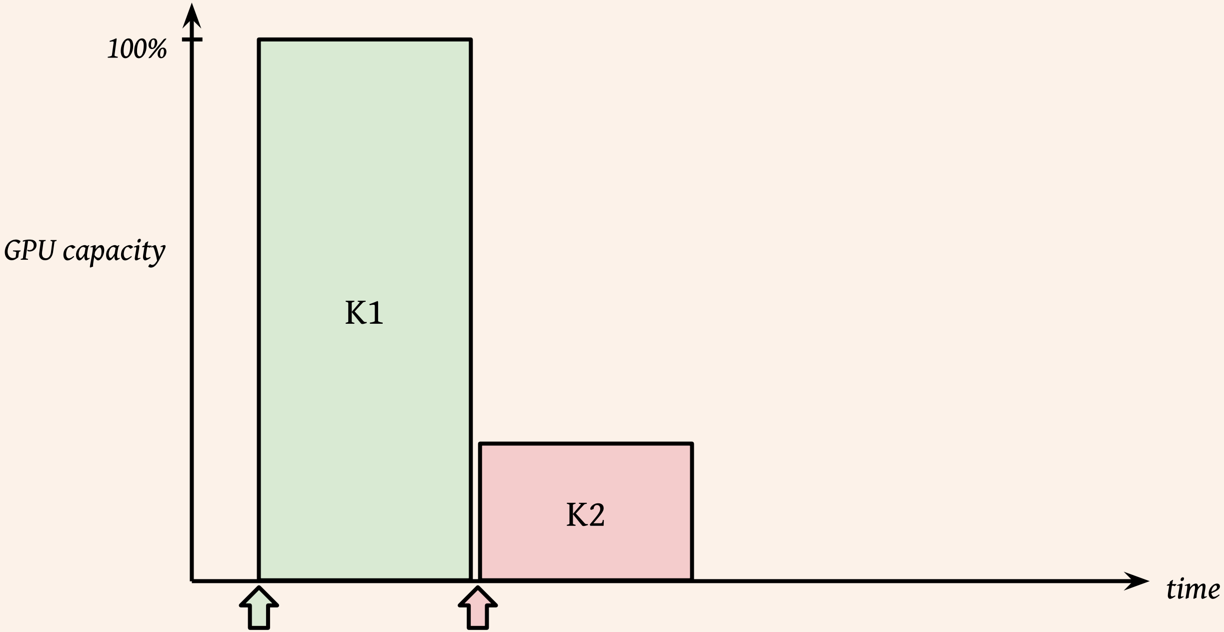

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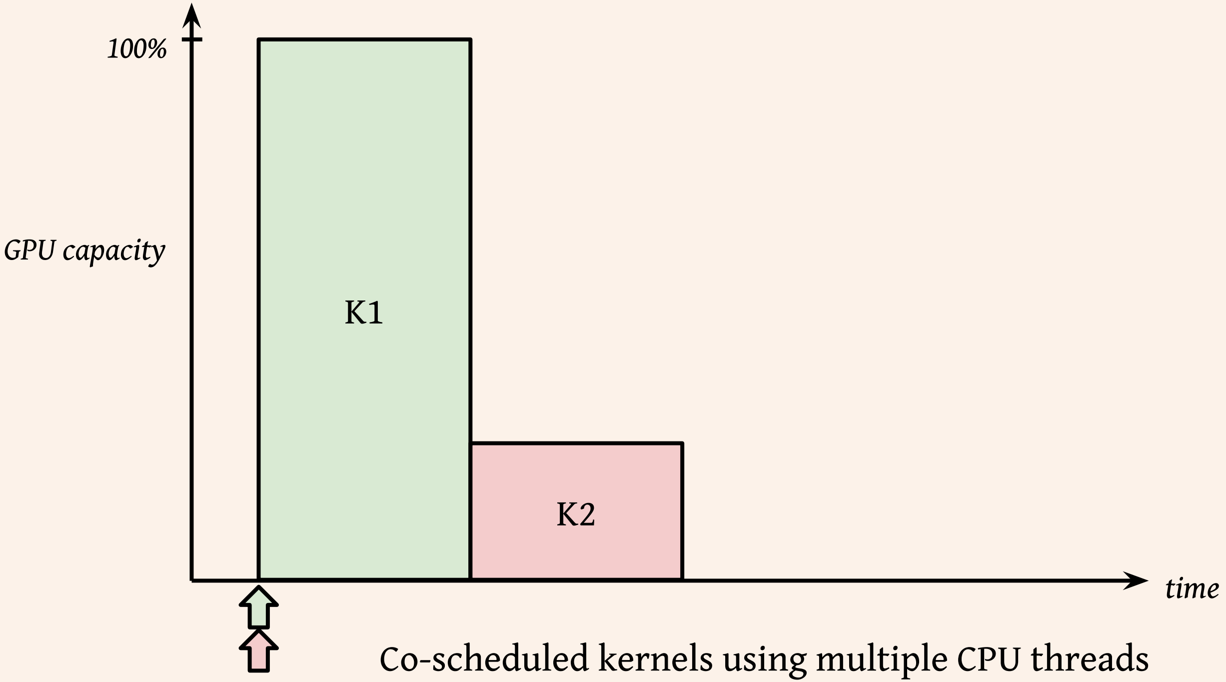

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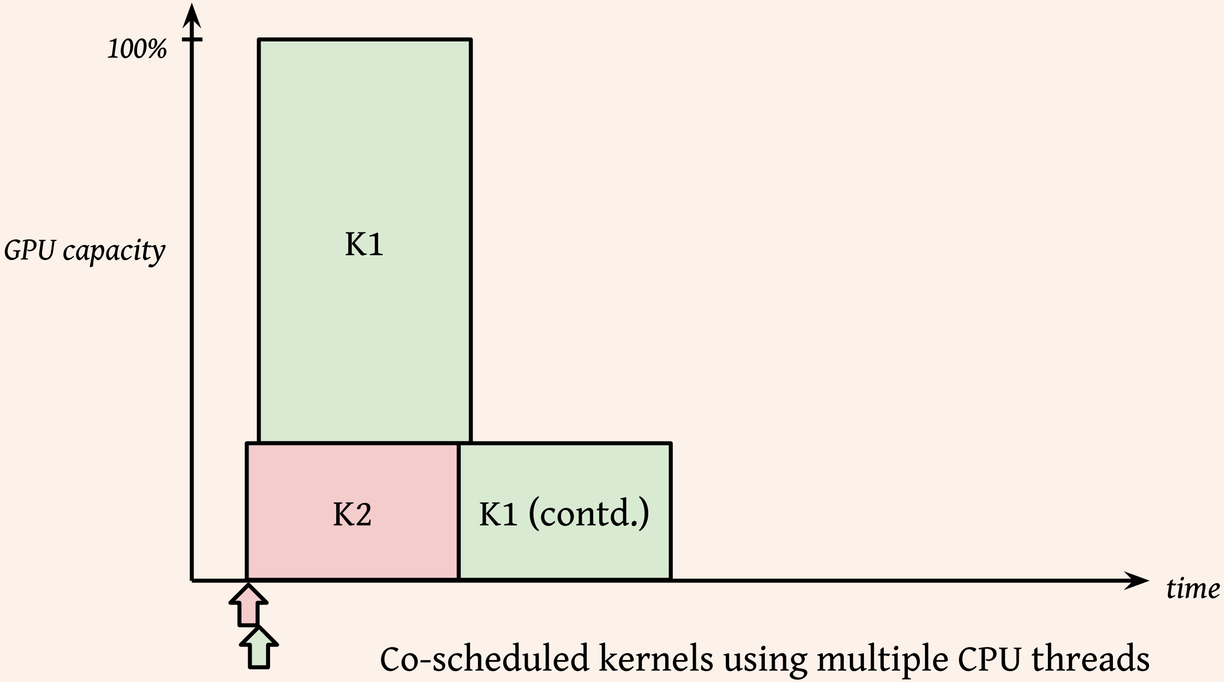

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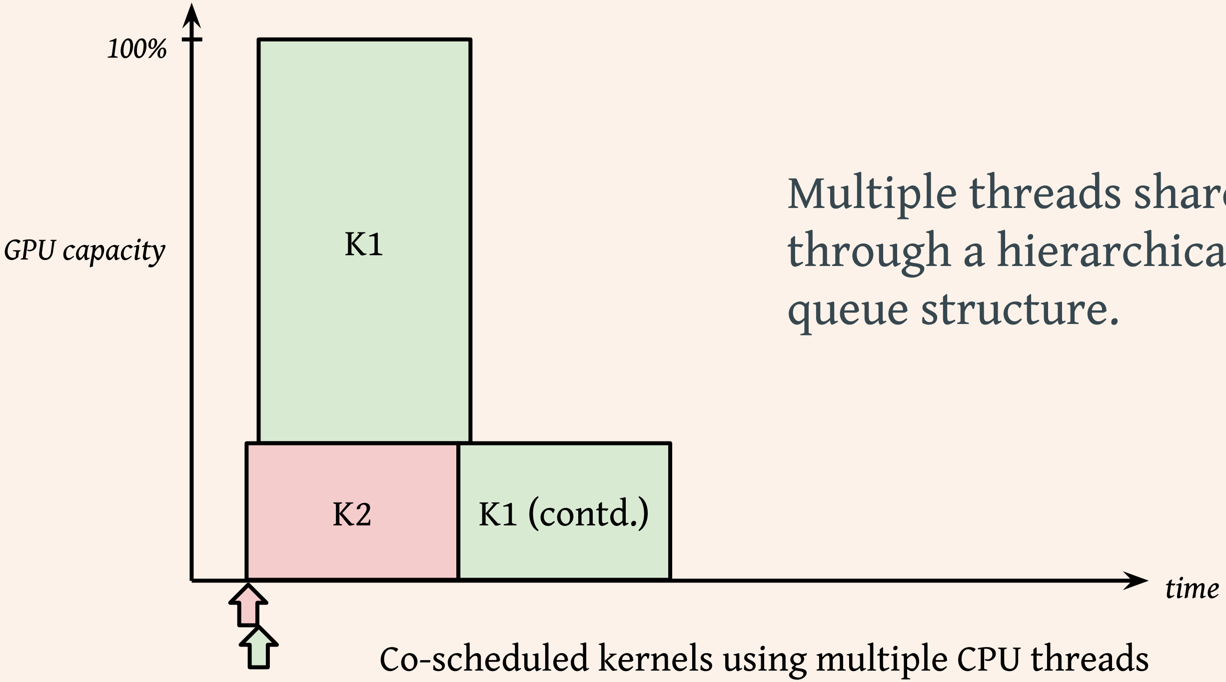

Co-scheduled kernels using multiple CPU threads

Multiple threads share the GPU through a hierarchical FIFO queue structure.

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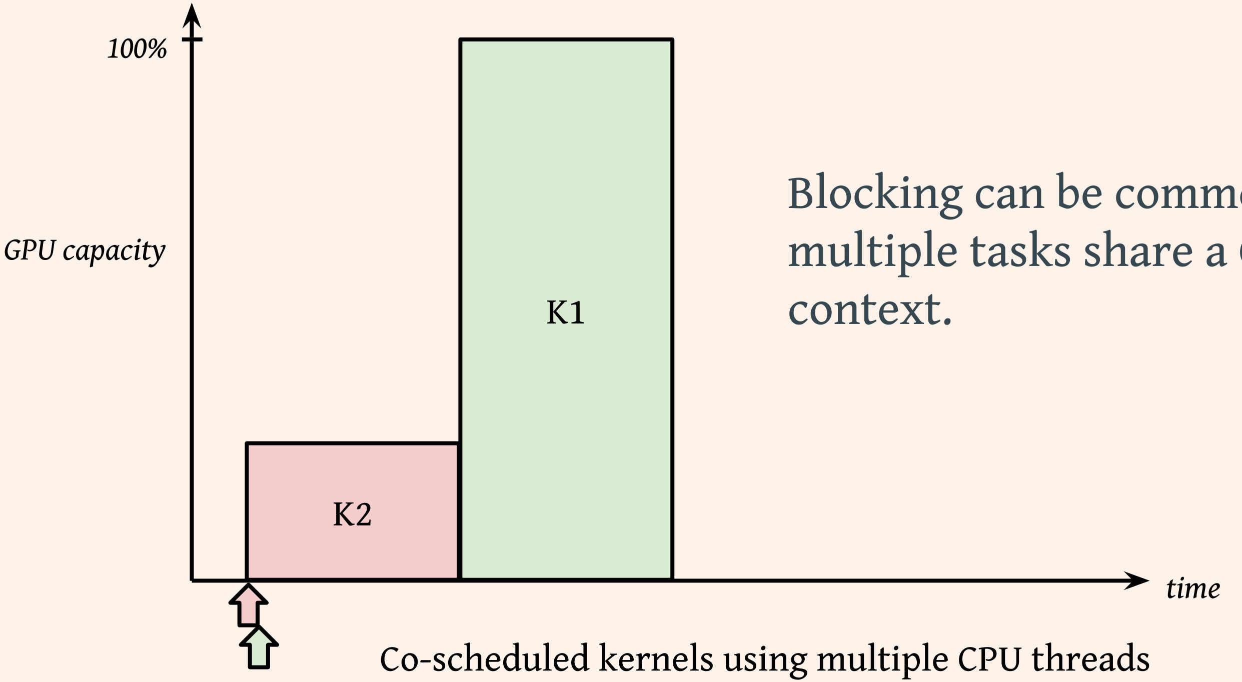

Co-scheduled kernels using multiple CPU threads

Blocking can be common when multiple tasks share a CUDA context.

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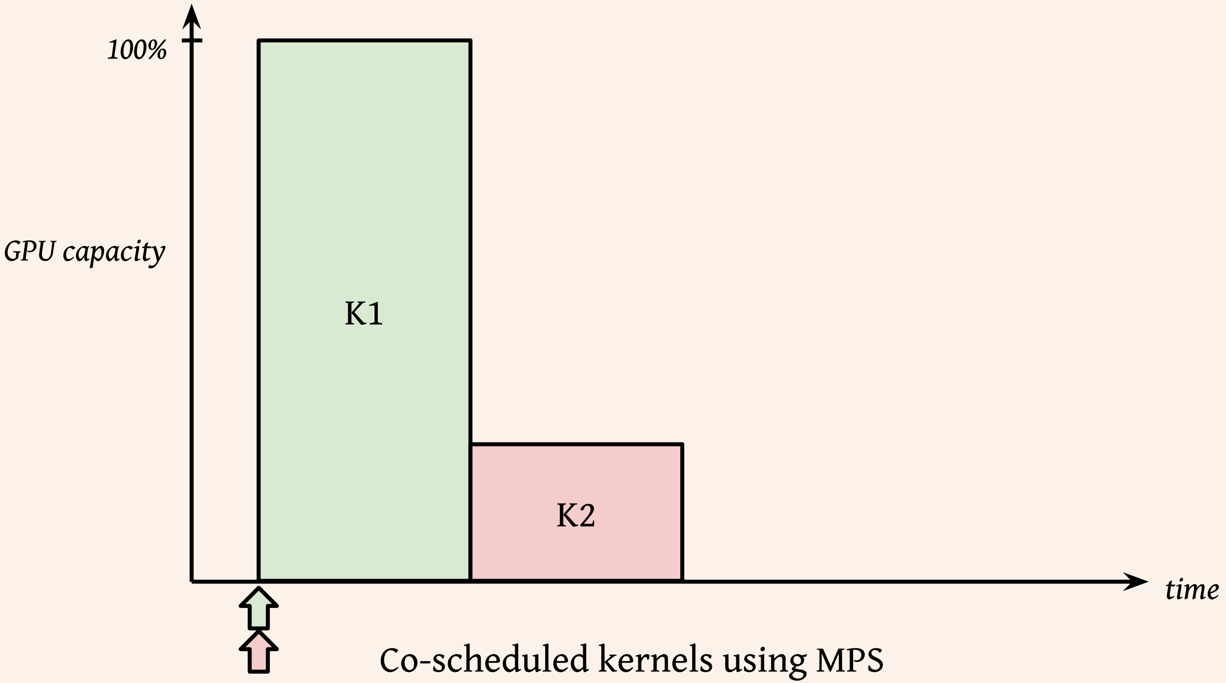
Multi-process Co-Scheduling with MPS



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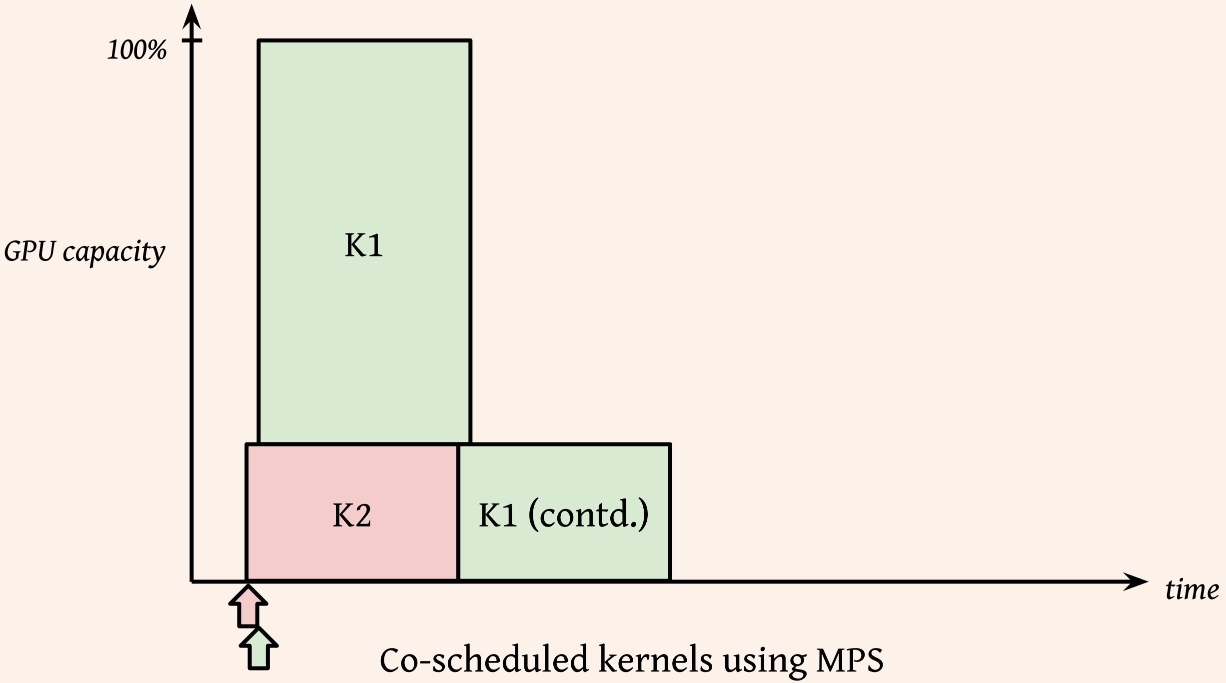

Co-scheduled kernels using MPS

Which one is best for safety-critical systems?

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The *best* system:

- Is easy to schedule (e.g. supports preemption).
- Does not require modifying existing CUDA programs.
- Fully utilizes the GPU when possible.

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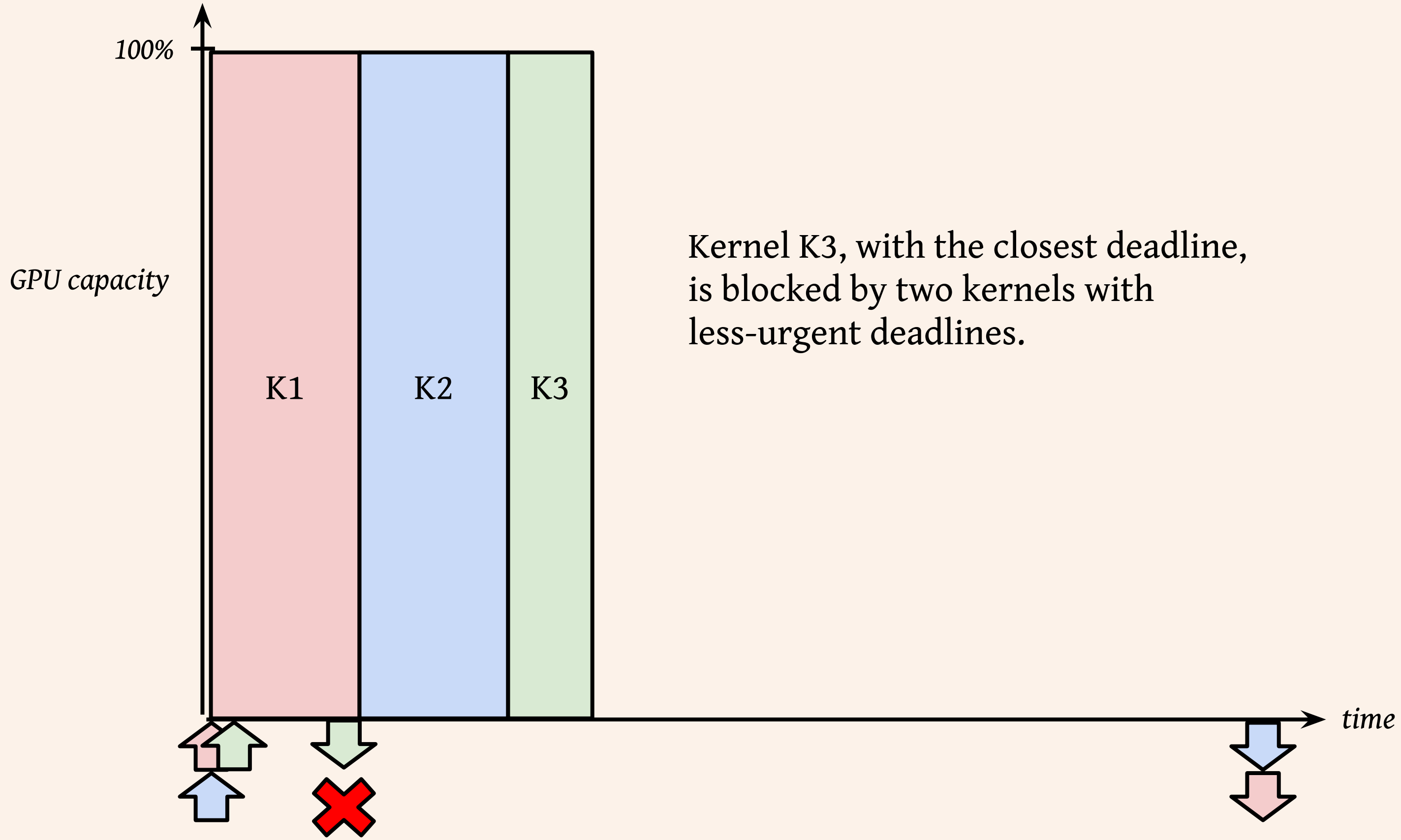
Sporadic kernels under MPS (or threads)



Kernel K3, with the closest deadline, is blocked by two kernels with less-urgent deadlines.

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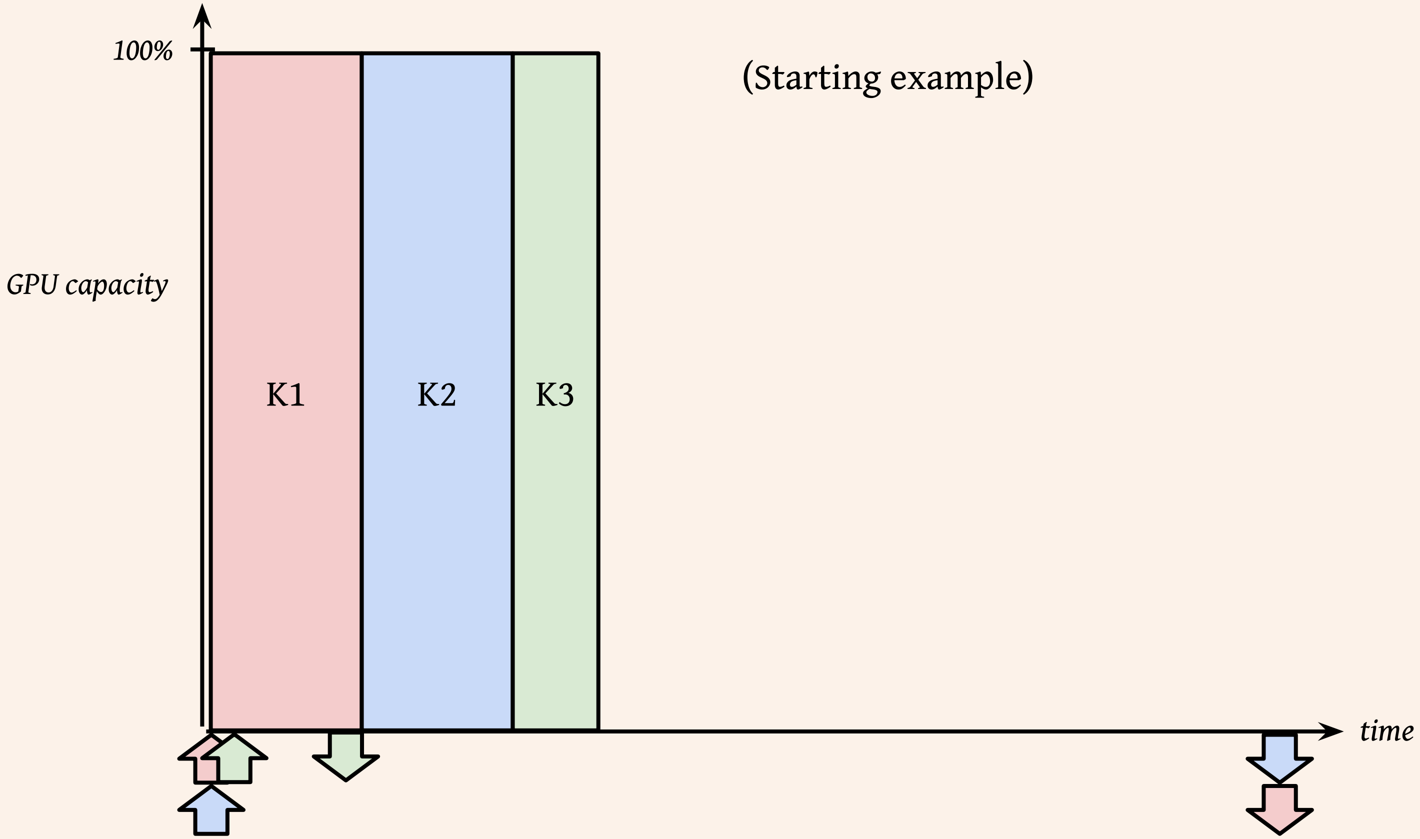
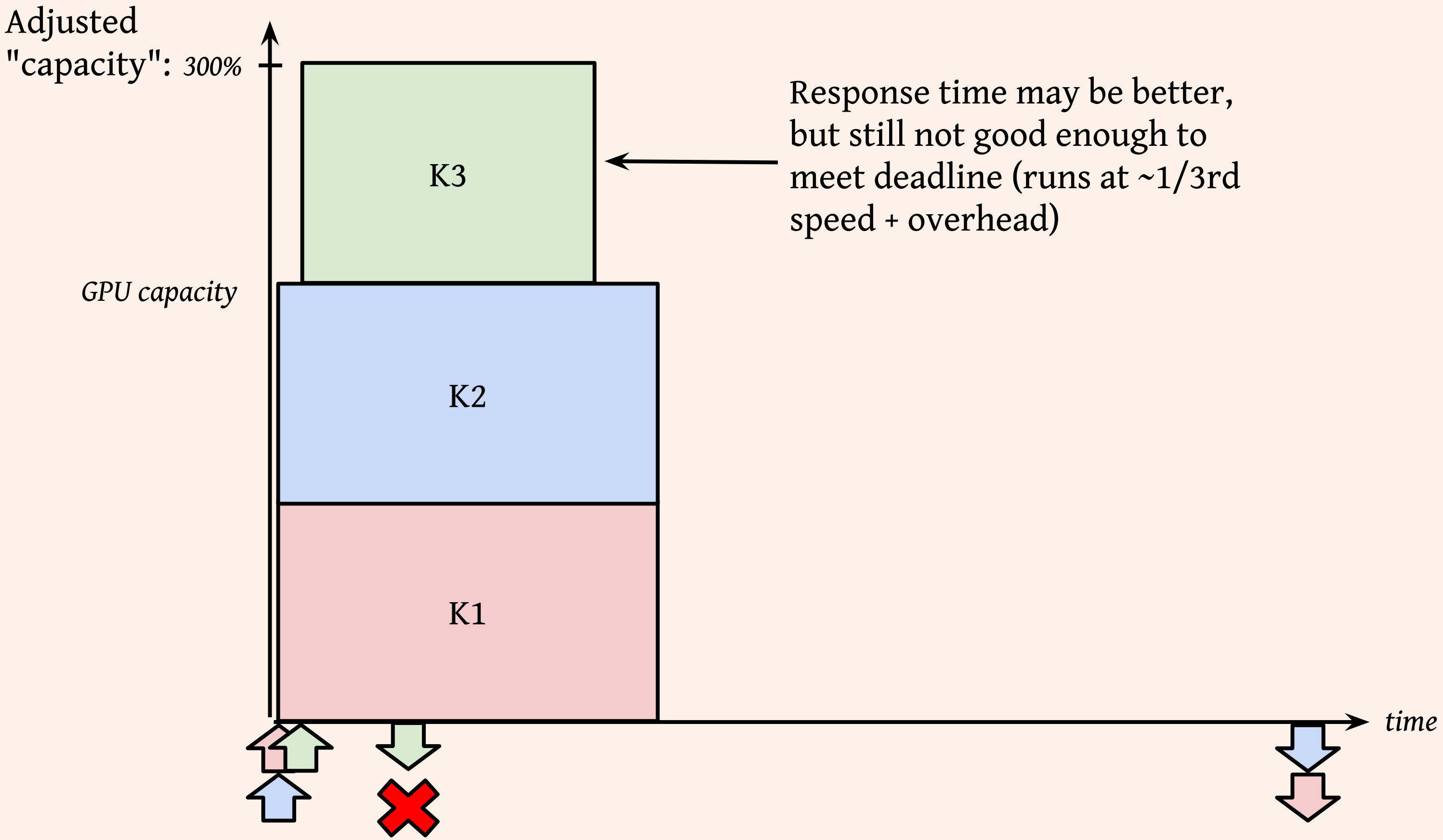
Sporadic kernels using Multiprogramming



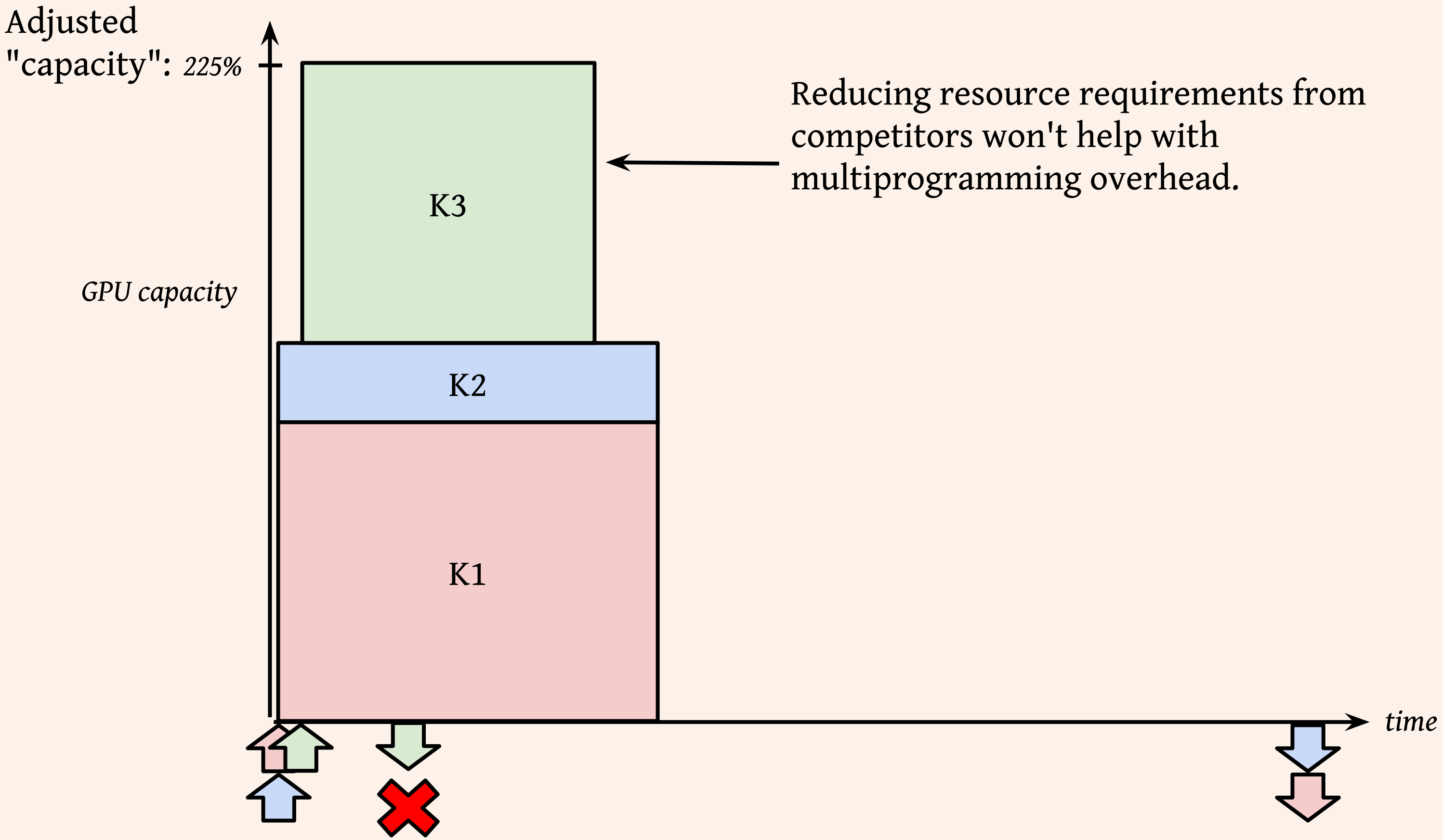
(Starting example)

Multiprogrammed kernels



Response time may be better, but still not good enough to meet deadline (runs at ~1/3rd speed + overhead)

Multiprogrammed kernels



Reducing resource requirements from competitors won't help with multiprogramming overhead.

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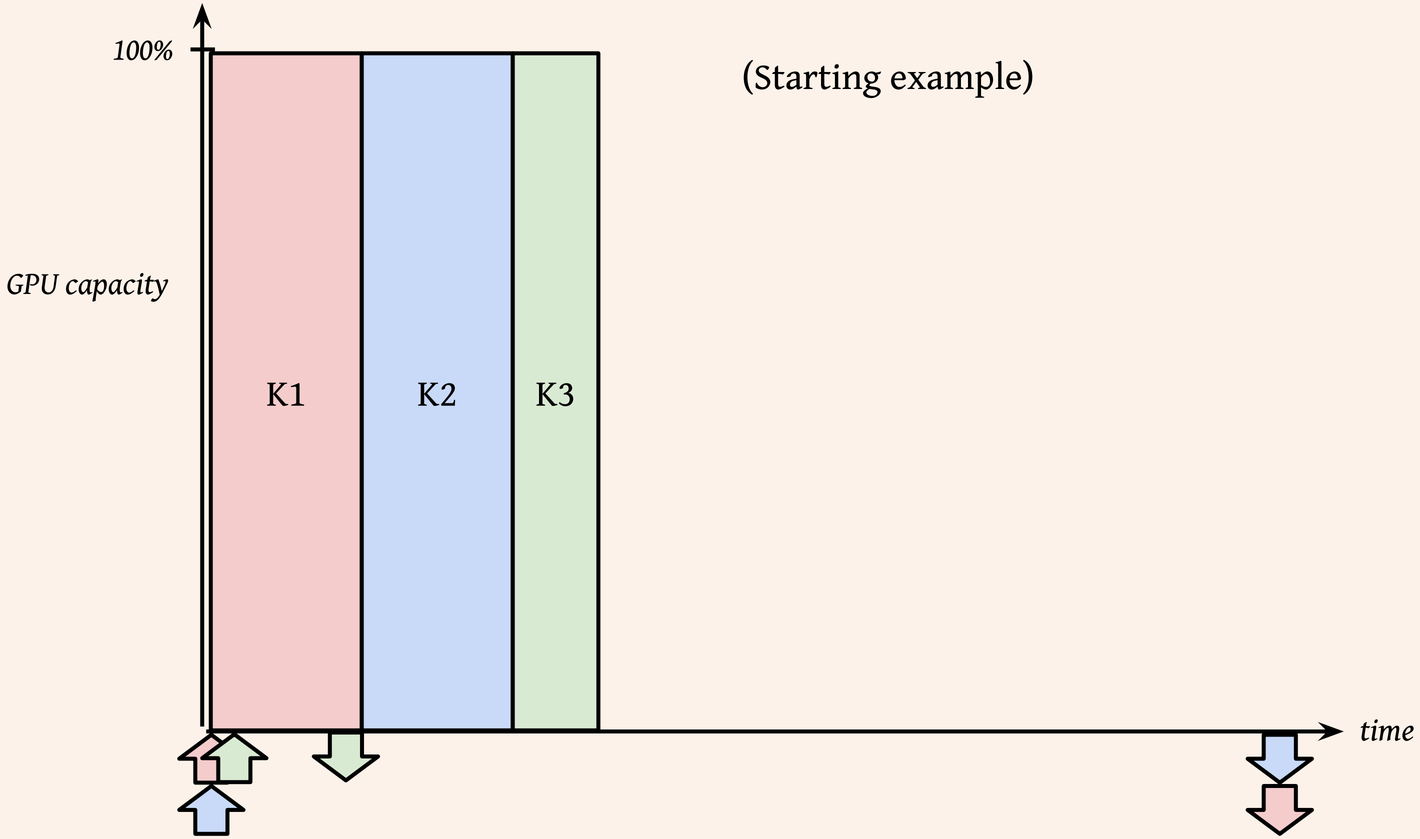
- Fully utilizes the GPU when *necessary*. ✔

Applying LET to Volta MPS



(Starting example)

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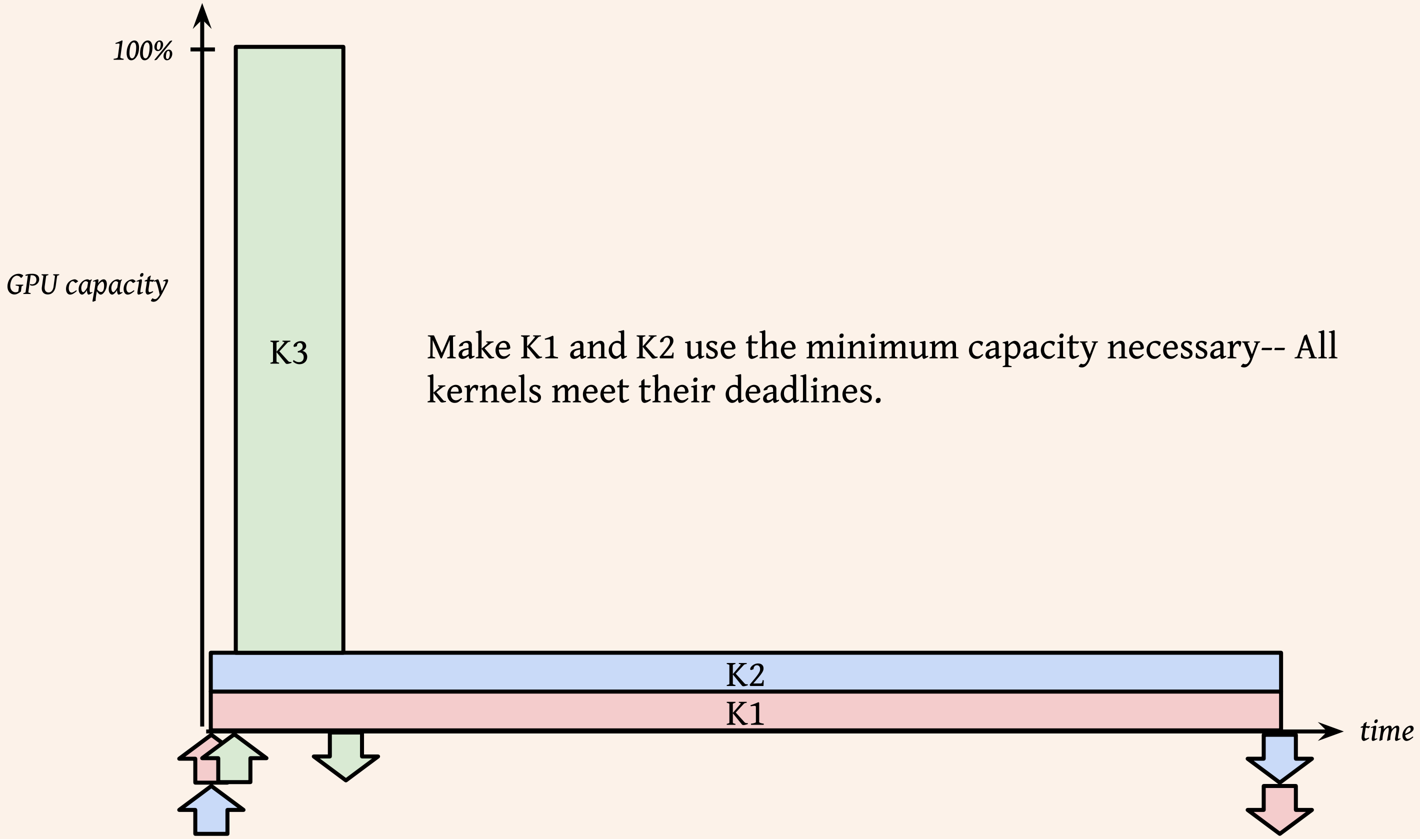


Make K1 and K2 use the minimum capacity necessary-- All kernels meet their deadlines.

What needs to be done?

This is still ongoing work. The next steps include:

1. Determining formulas relating GPU utilization to execution time.
   (This can actually be measured per-*task* rather than per-*kernel*.)
2. Write a management system that dynamically sets utilization limits based on the formulas and tasks' deadlines.

Potential Problems

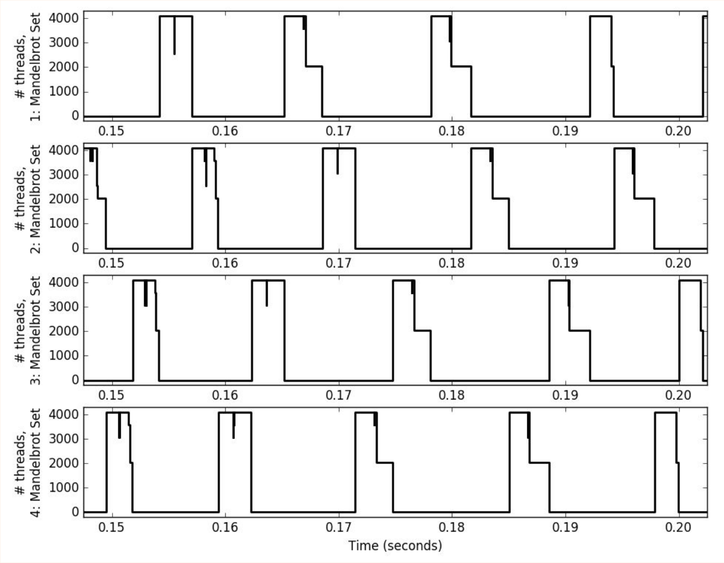
- Volta GPUs are currently expensive and in short supply.
- Embedded GPUs (so far) do not support MPS, regardless of GPU architecture.
- There's no guarantee that future GPU architectures will support setting resource limits.

Conclusion

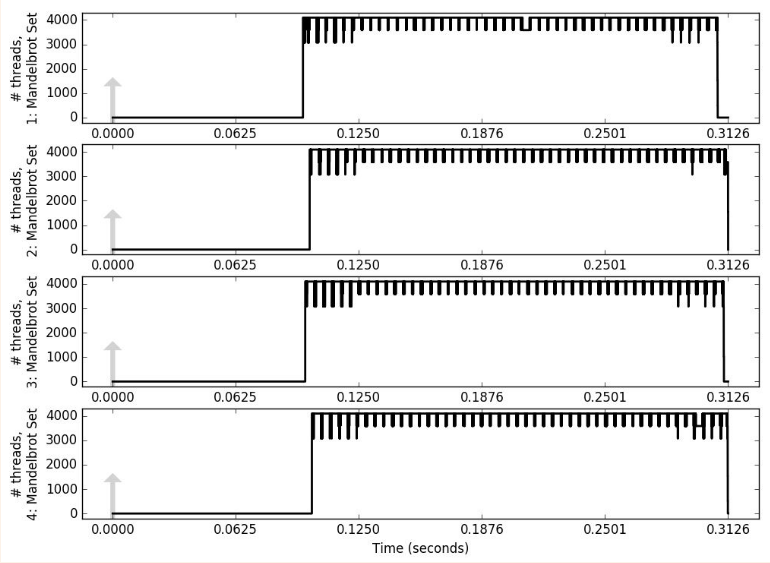
Safe, predictable real-time scheduling seems possible, when applying the principles of LET to GPU resource partitioning on Volta-architecture GPUs.

GPU Co-Scheduling with Processes

Maxwell GPU Architecture (TX1)



Pascal GPU Architecture (TX2)



When GPU tasks are launched from separate CPU processes (CUDA contexts), co-scheduling is achieved via multiprogramming.

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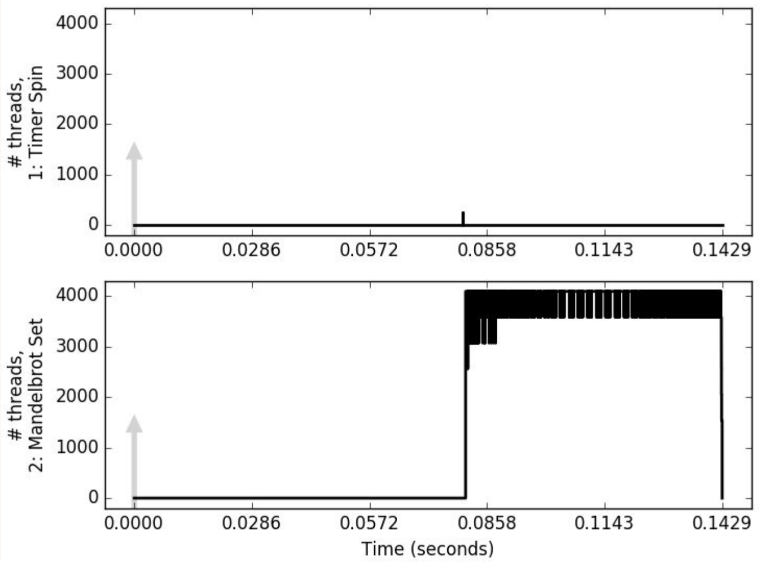
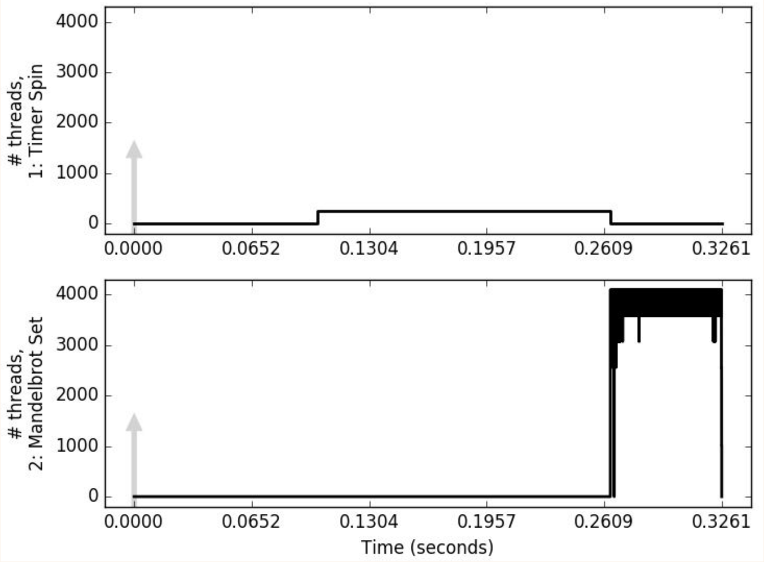
GPU Co-Scheduling with Processes

Small, short-lived competing workload



Small, long-lived competing workload



Multiprogramming on Maxwell GPUs leads to blocking.

GPU Co-Scheduling with Processes

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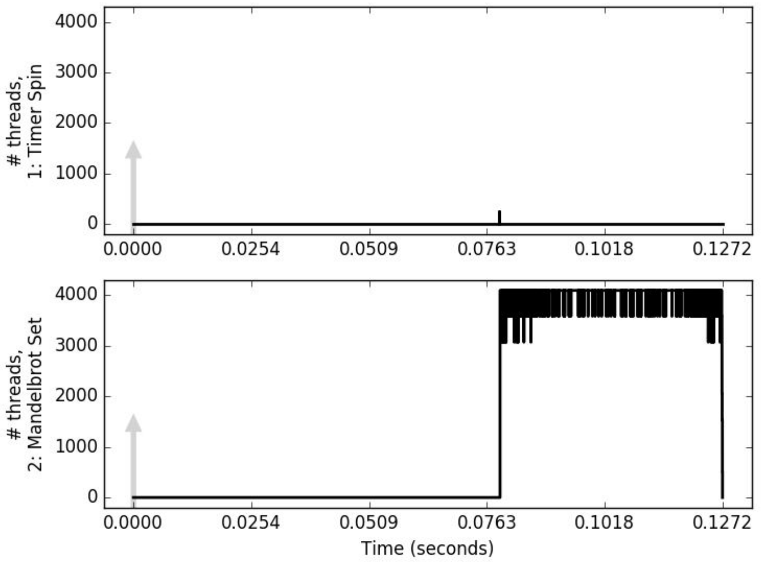

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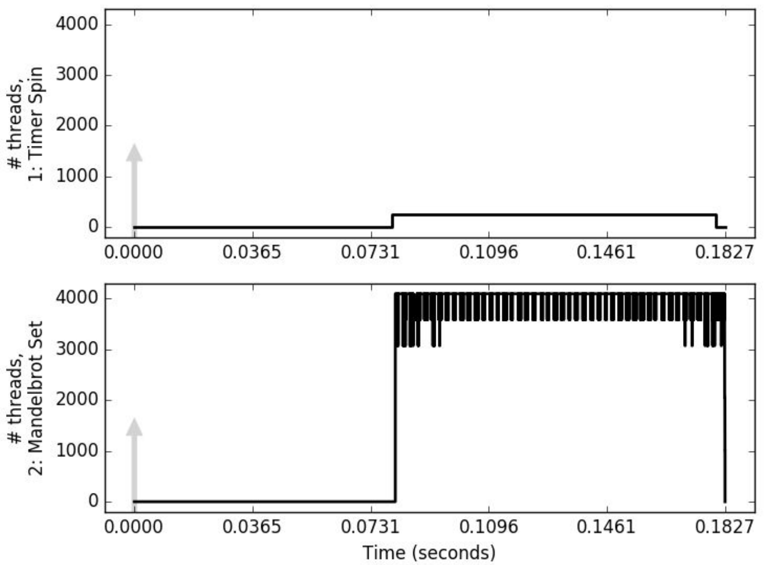

Multiprogramming on Pascal GPUs leads to disproportionate performance loss.