Cooperative Kernels: GPU Multitasking for Blocking Algorithms

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Imperial College London, UK

FSE
Sept. 2017

“The GPU Multitasking Talk”

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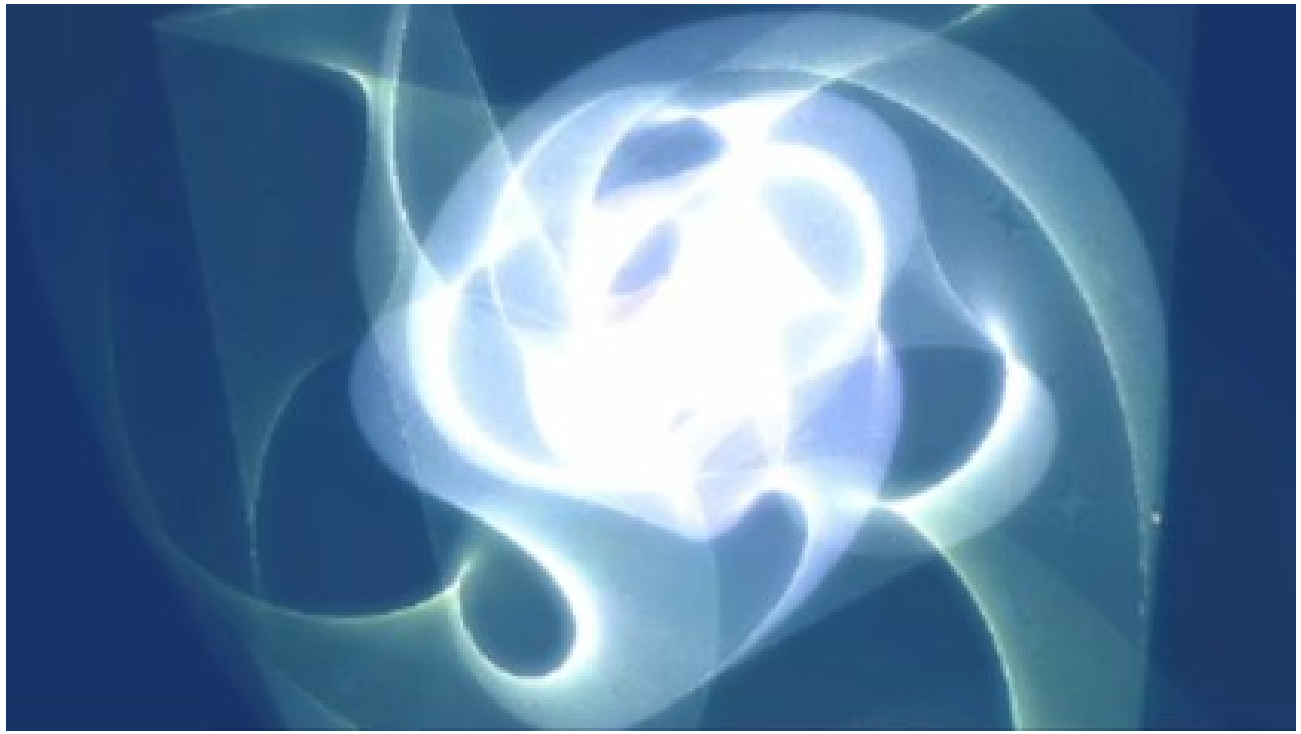
Graphics execution



from http://webglsamples.org/electricflower/electricflower.html

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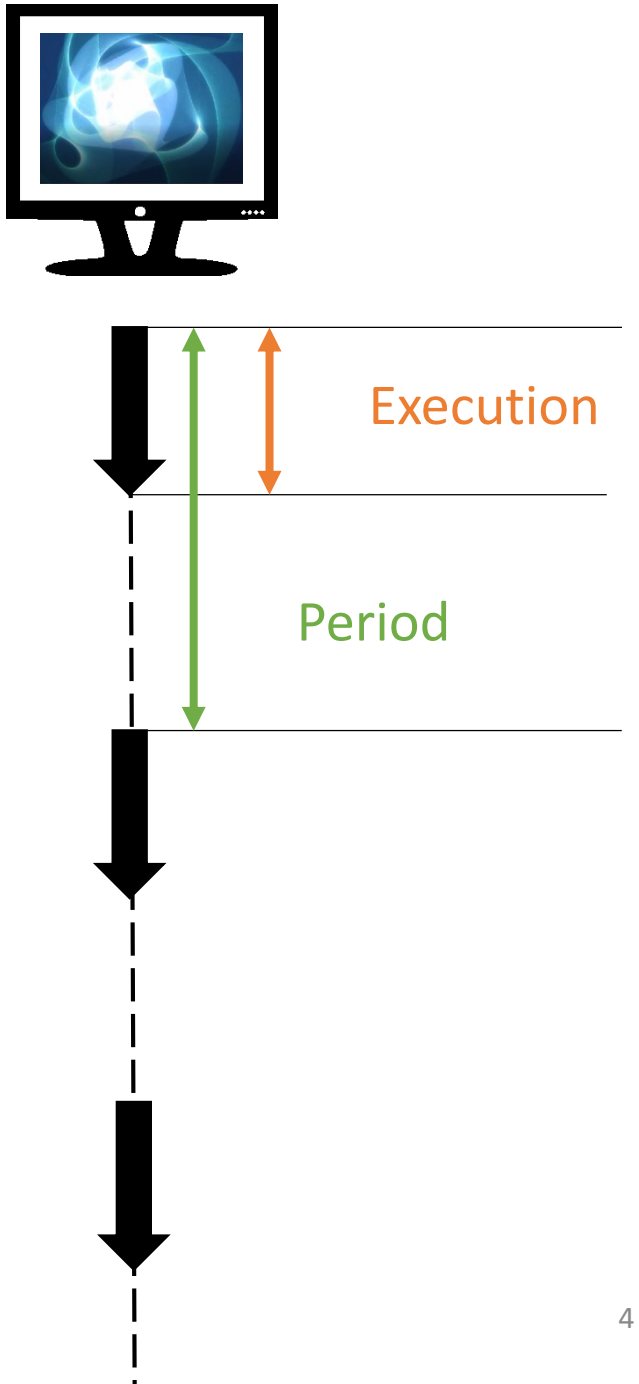

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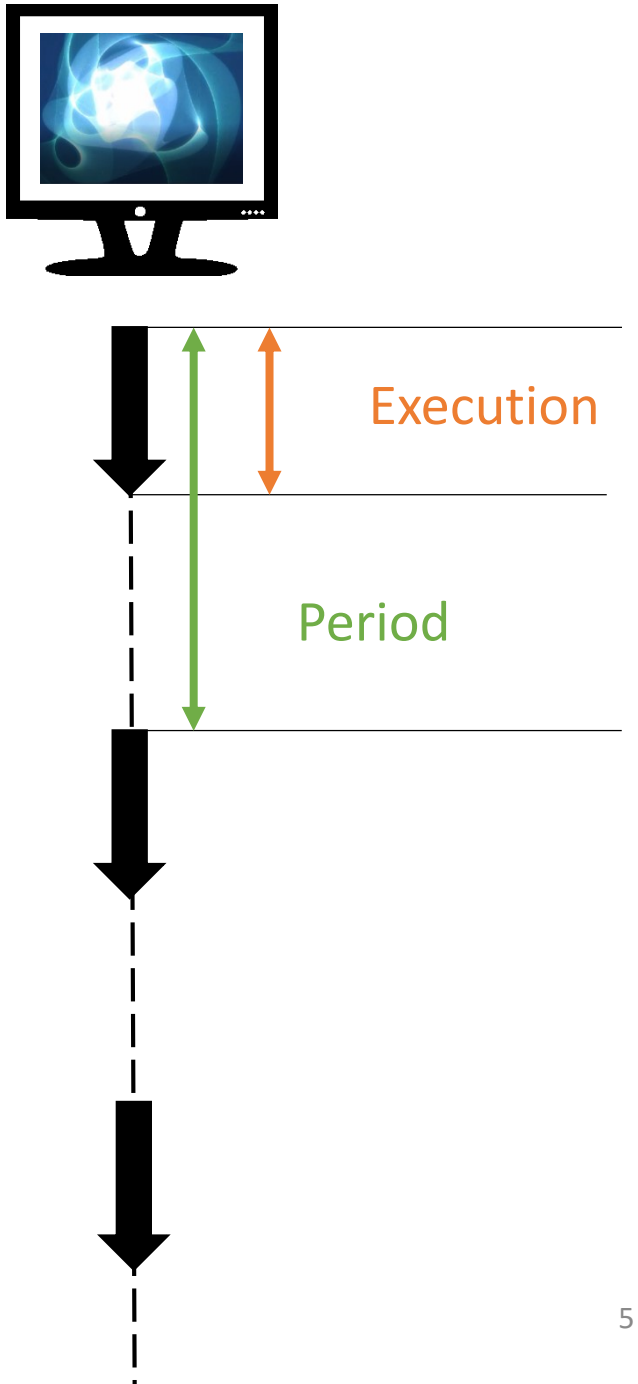
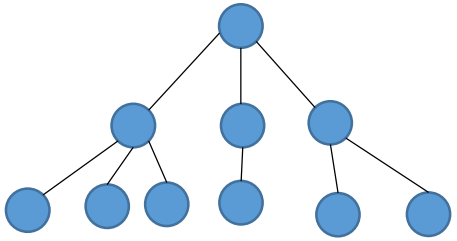
Graphics execution

Workload	Period (ms)	Execution (ms)
Light	70	3
Medium	40	3
Heavy	40	10



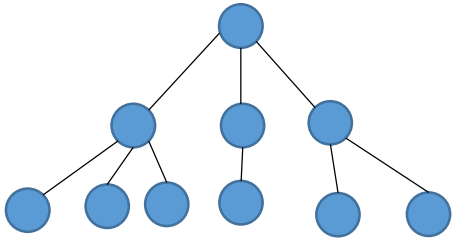
Compute execution (sssp)



Dataset	Execution (ms)
NY-road	400
CAL-road	1200
USA-road	2200

Compute GPU program == *kernel*

Compute execution (sssp)



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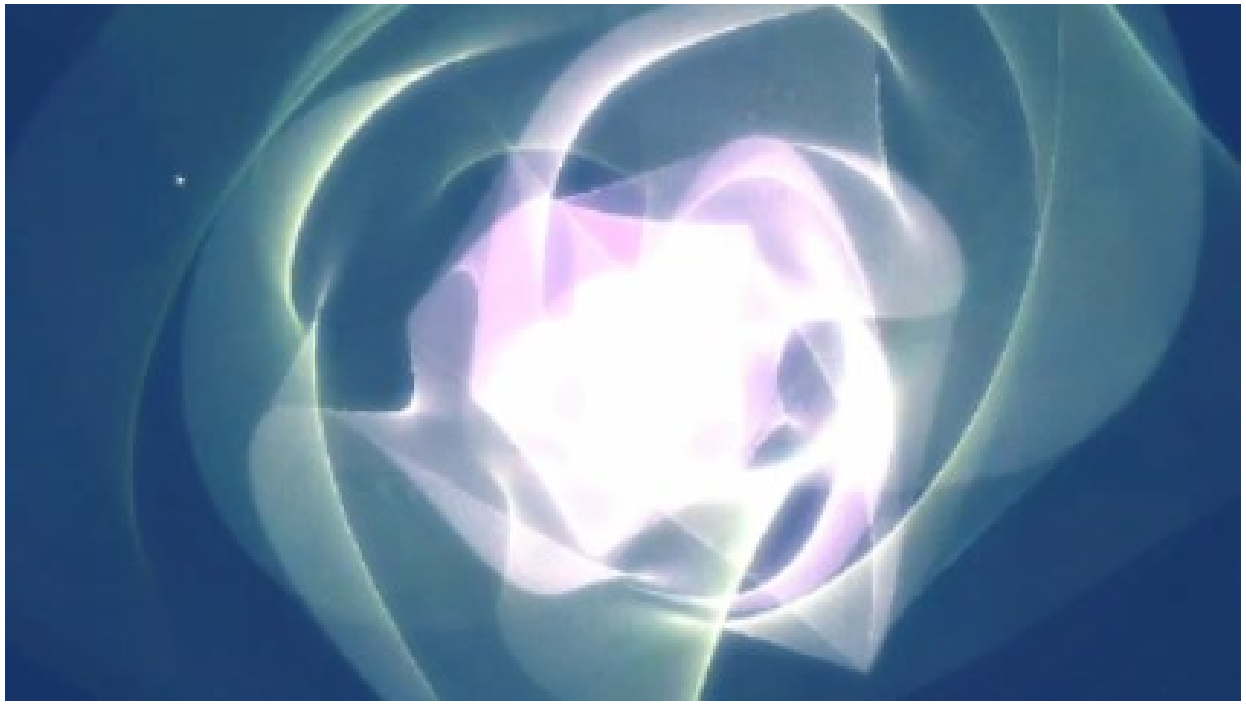

Running http://webglsamples.org/electricflower/electricflower.html
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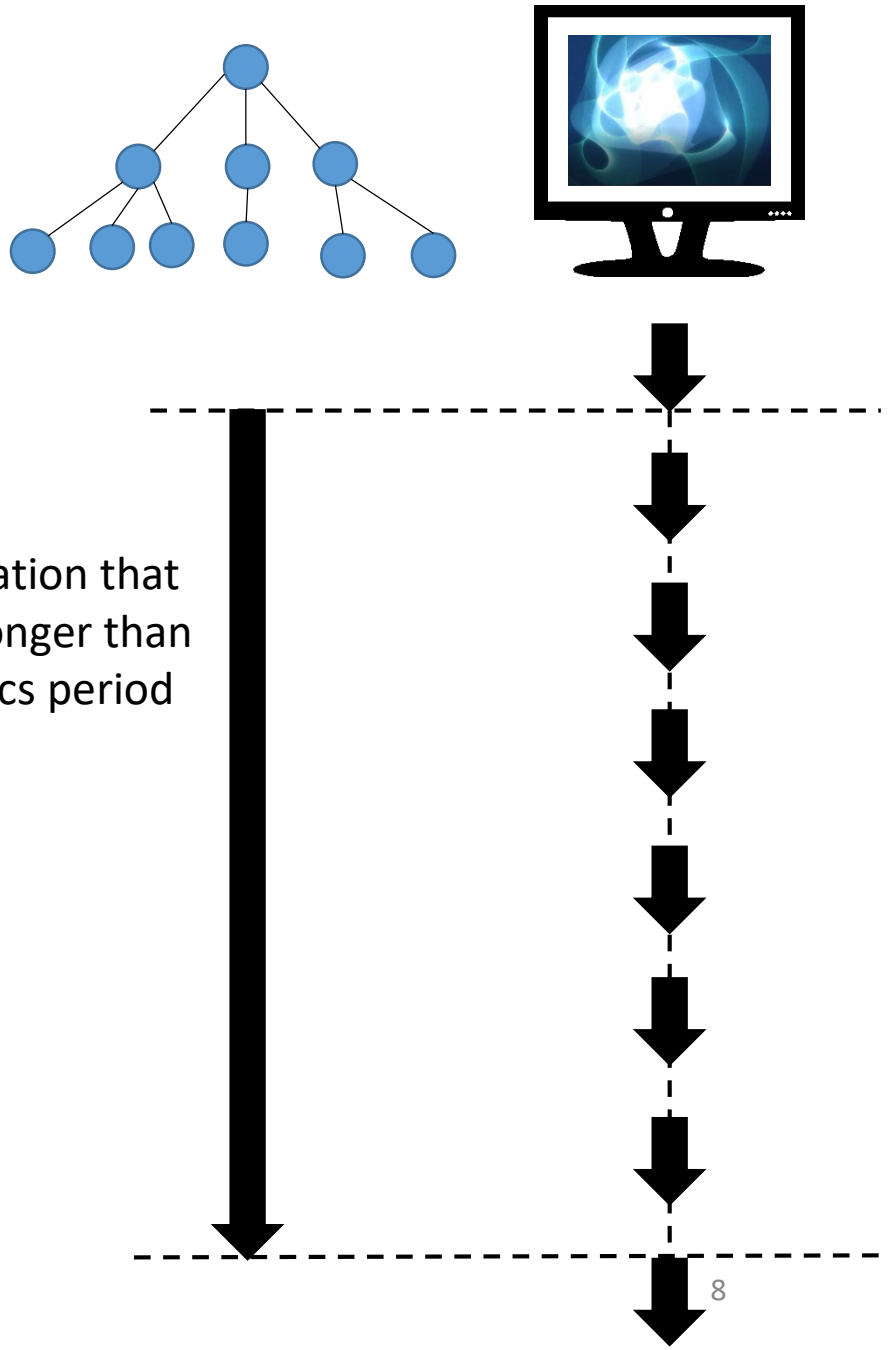

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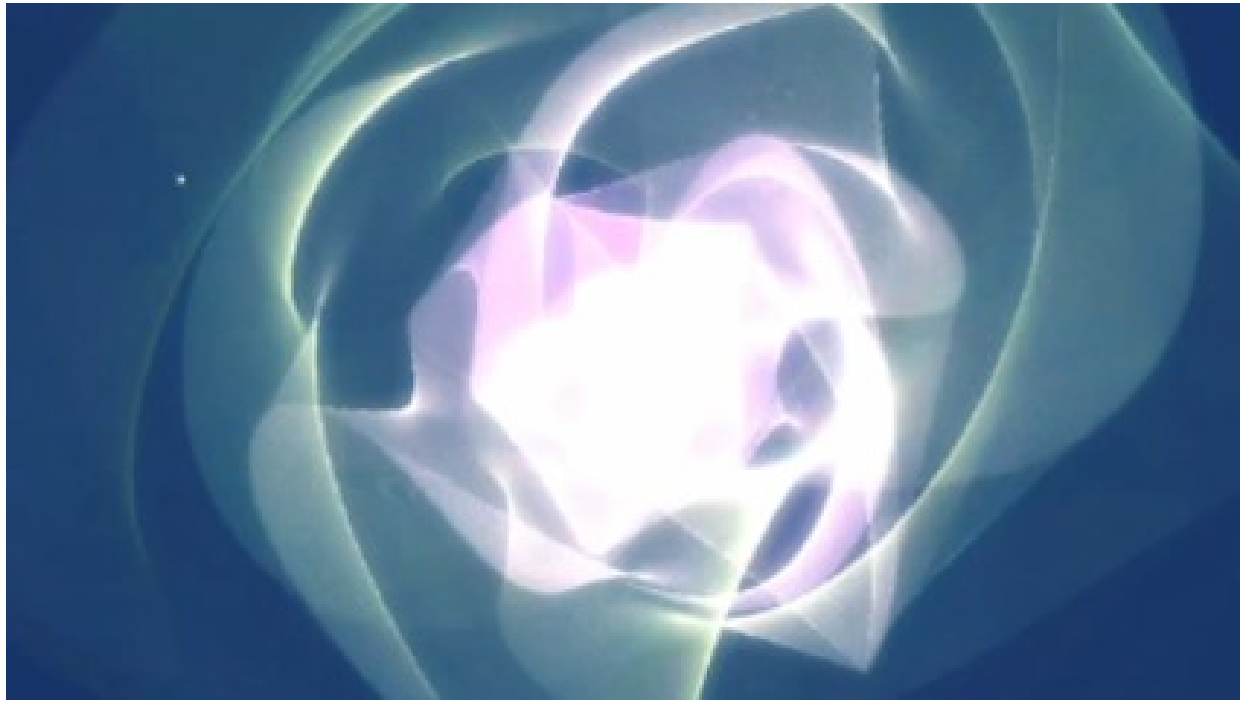

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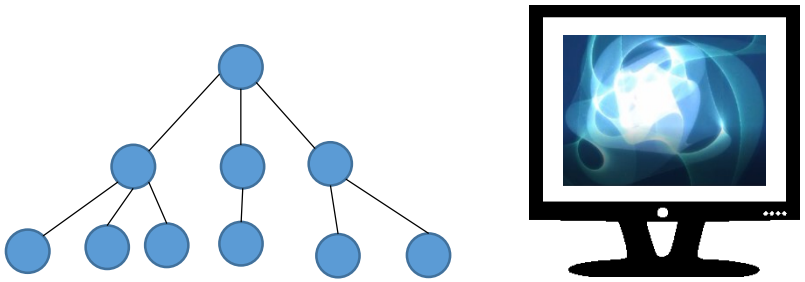

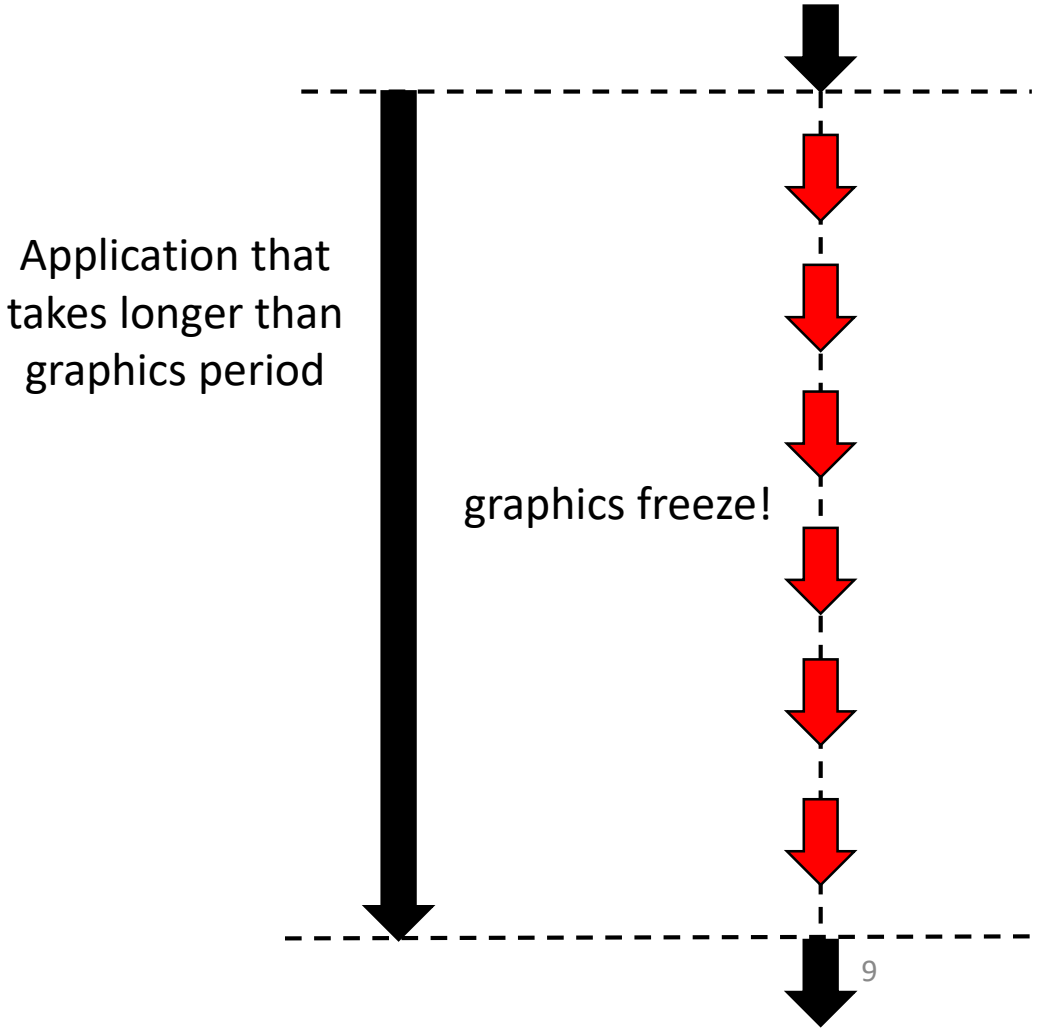

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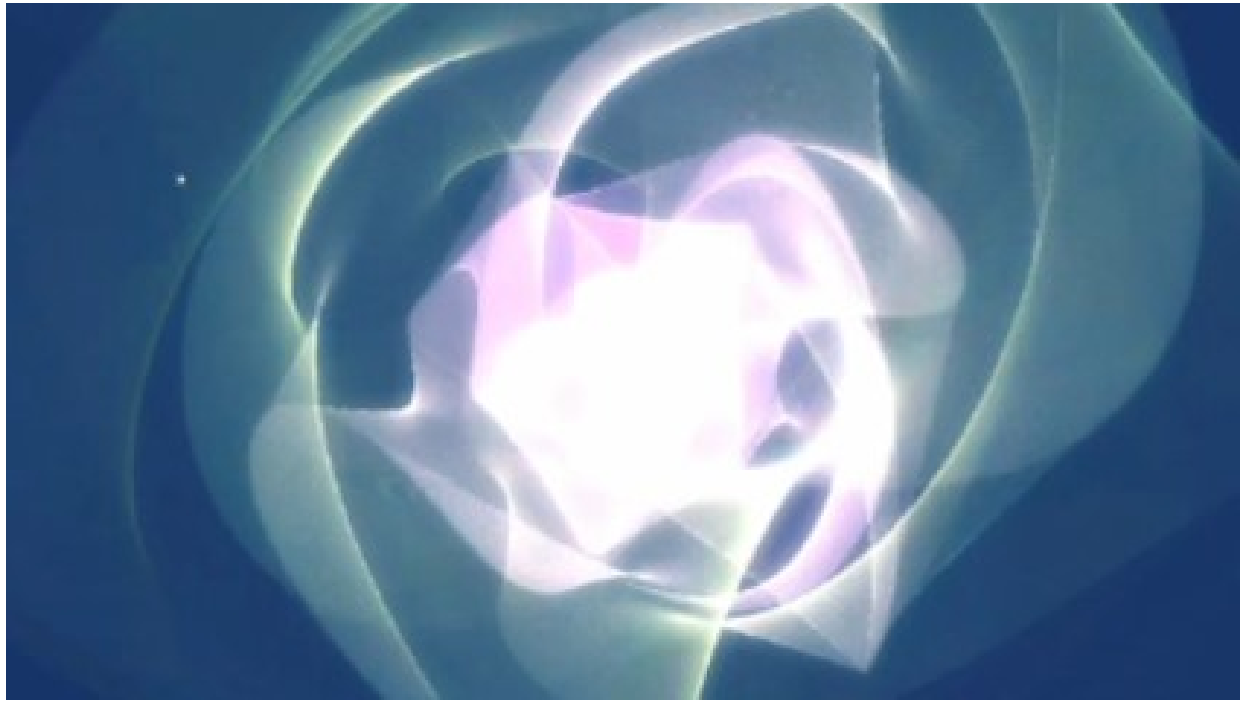

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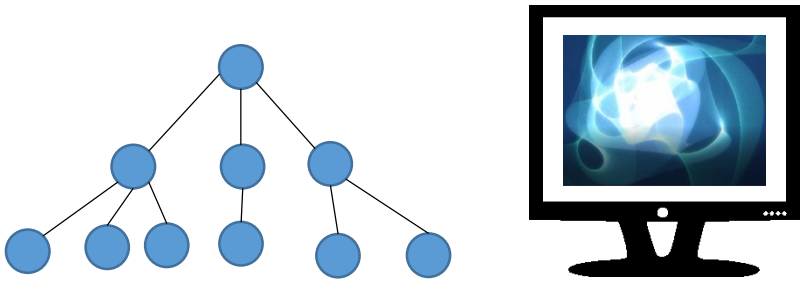

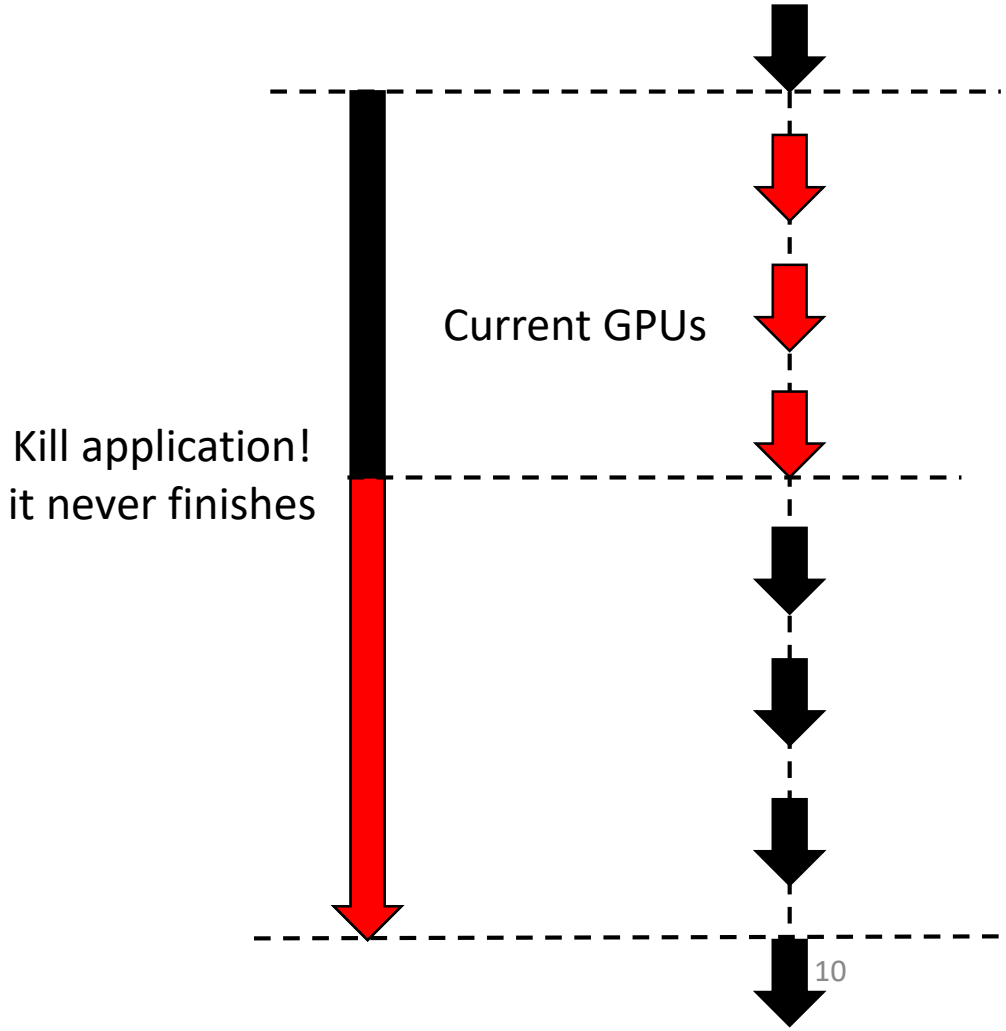

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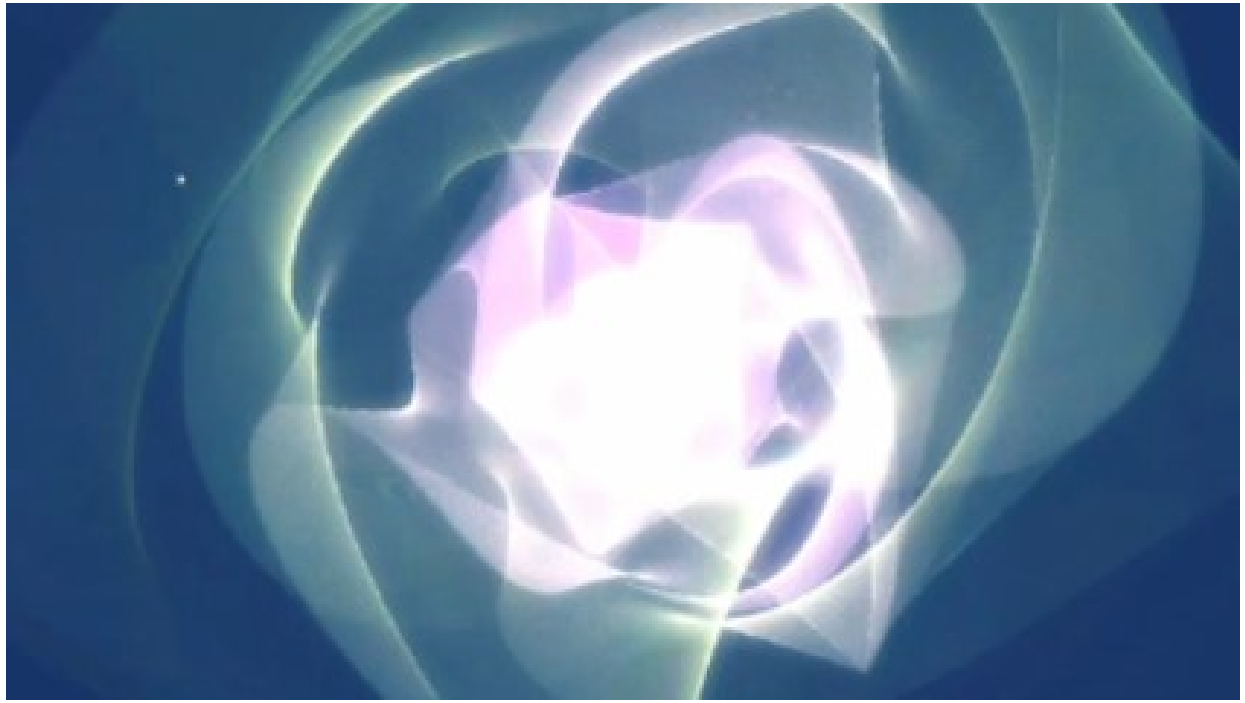

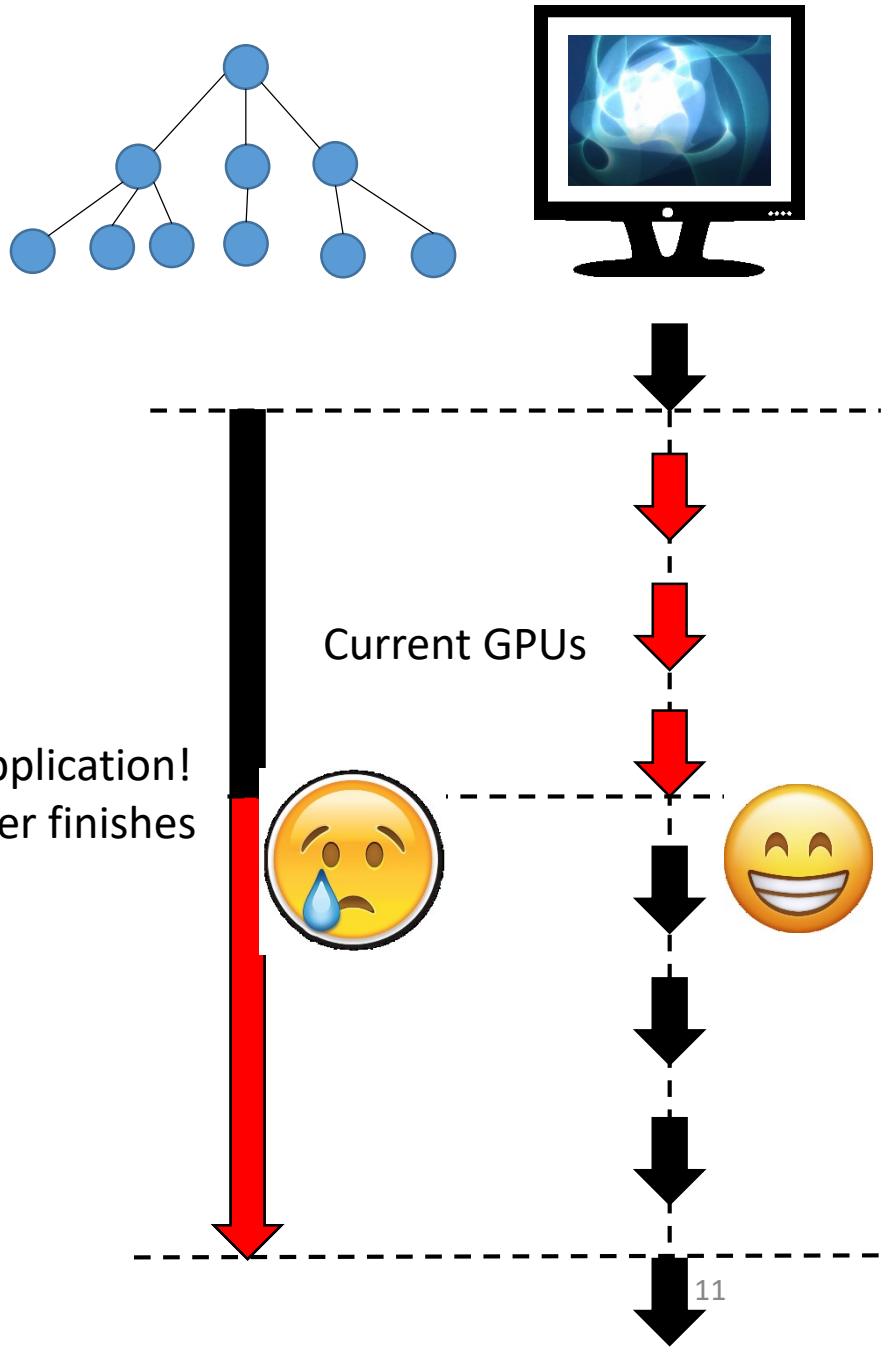

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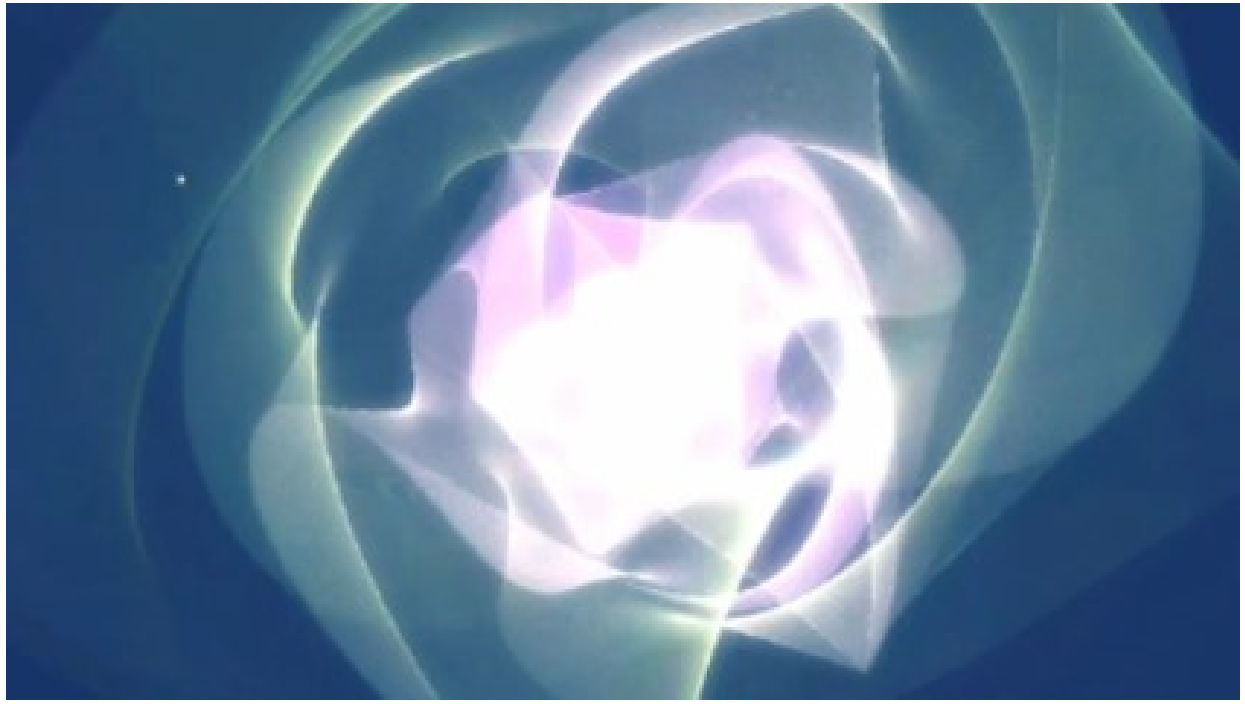

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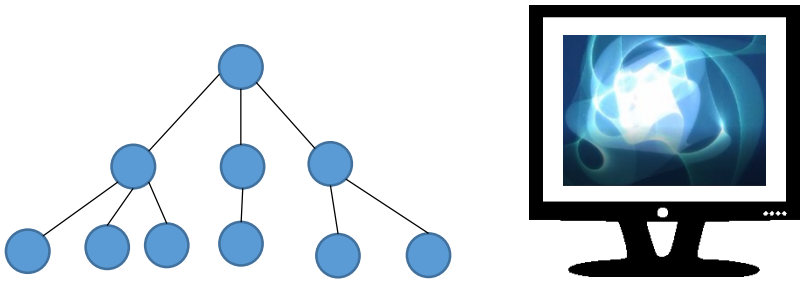

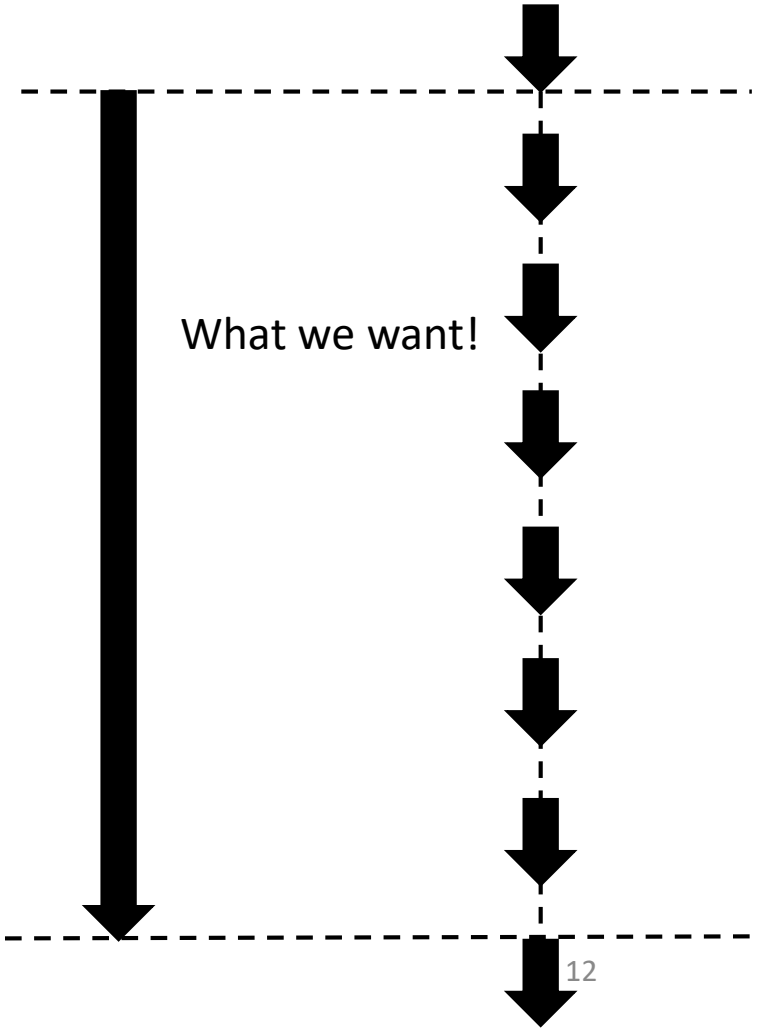

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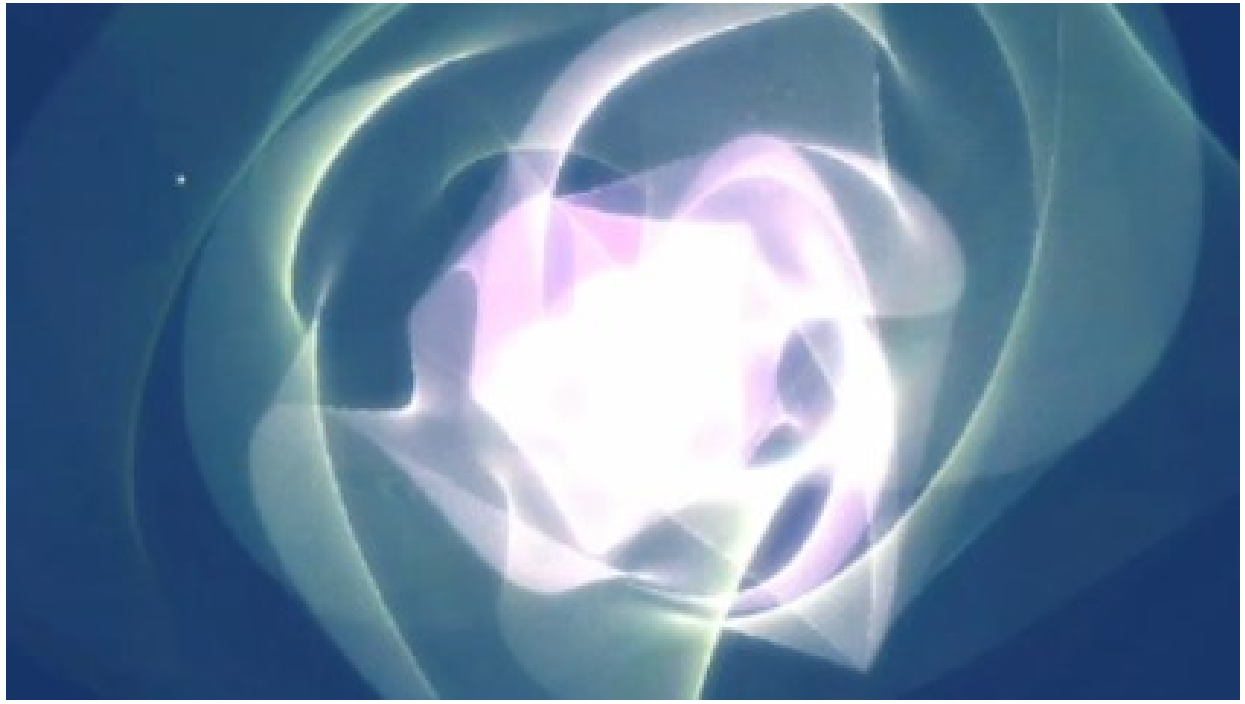

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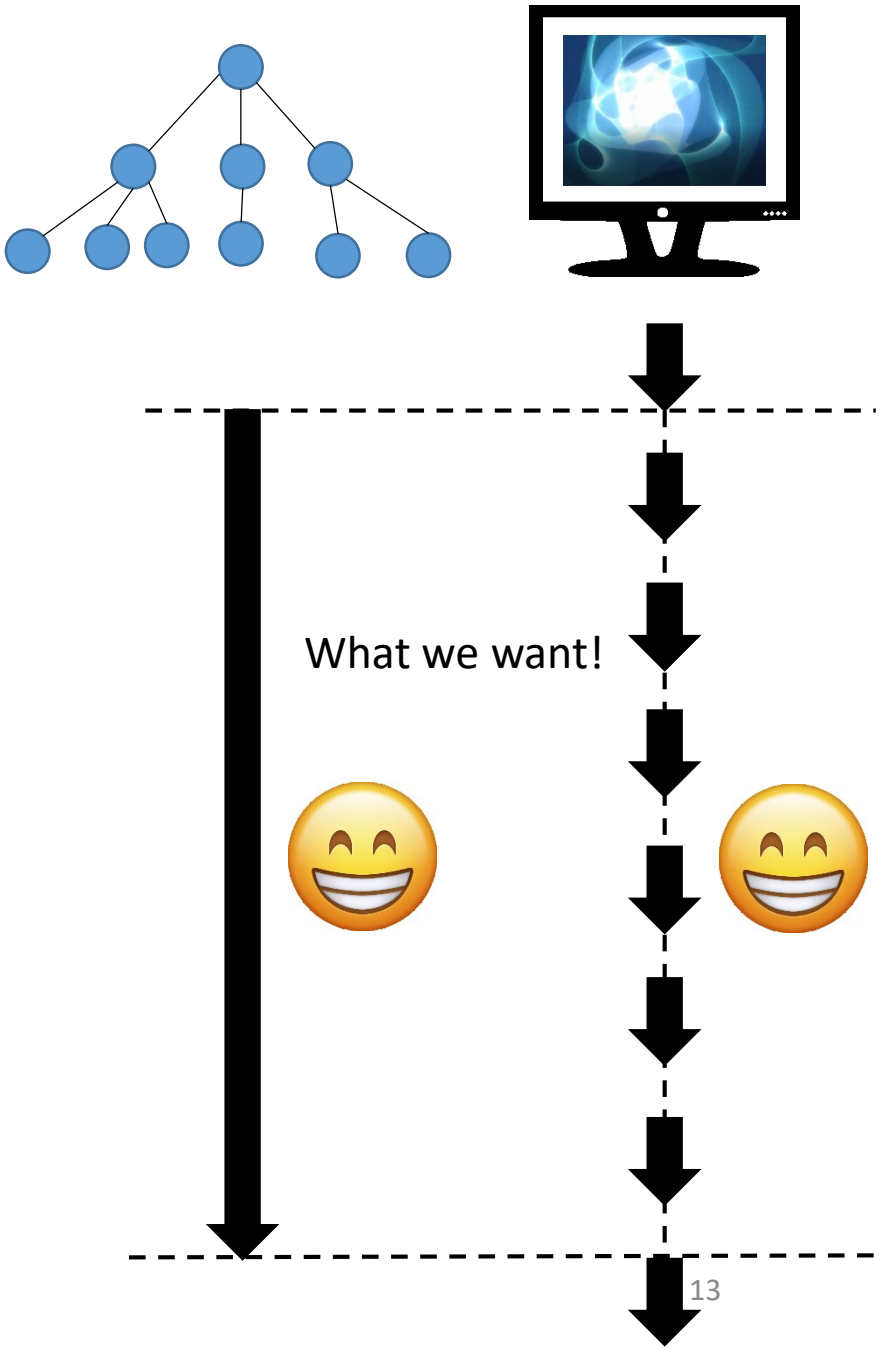

Multi-tasking

Program P1 with 3 workgroups

workgroup queue

GPU with 3 compute units

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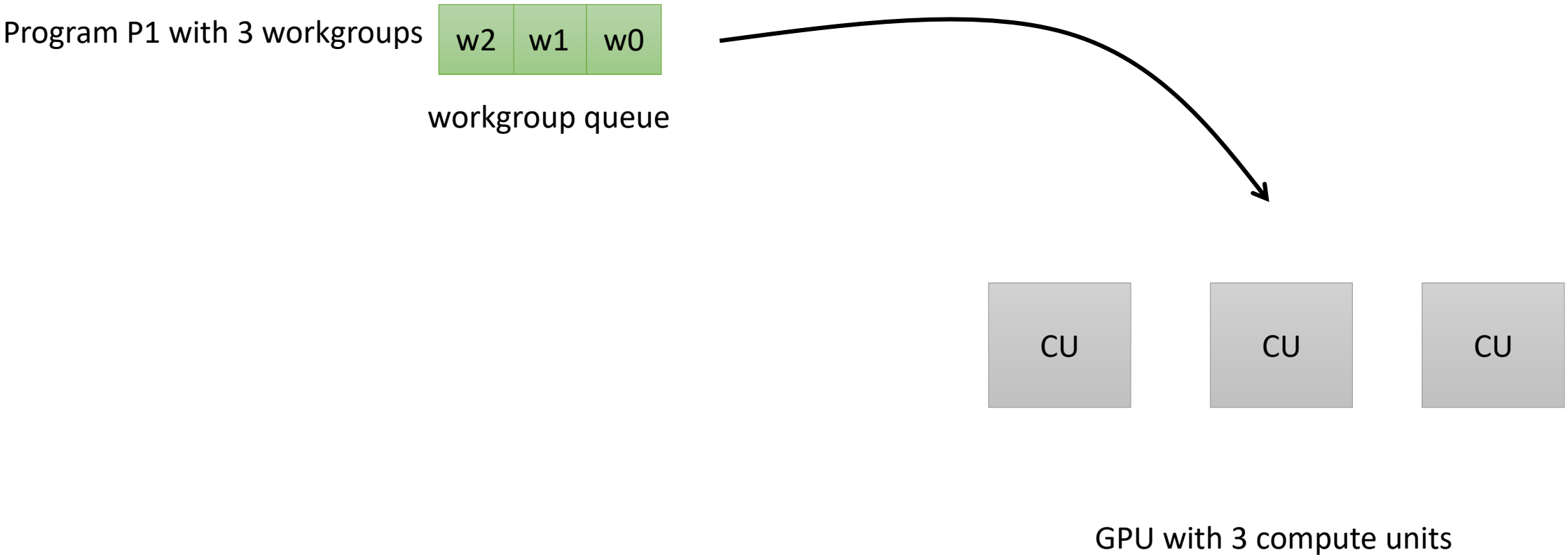

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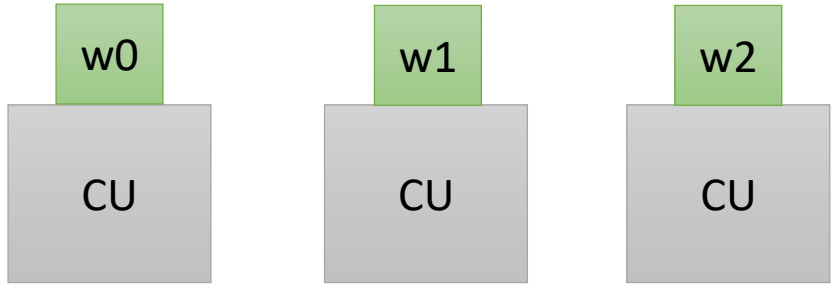

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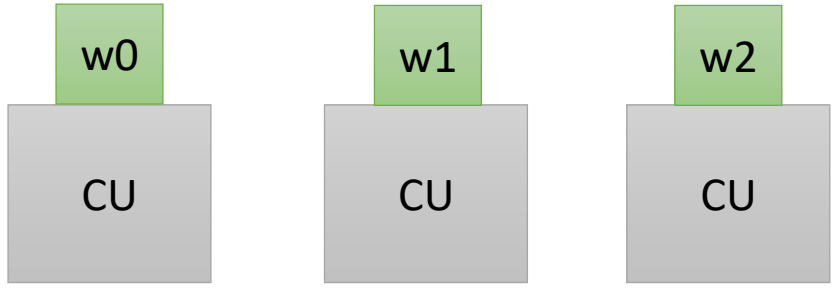

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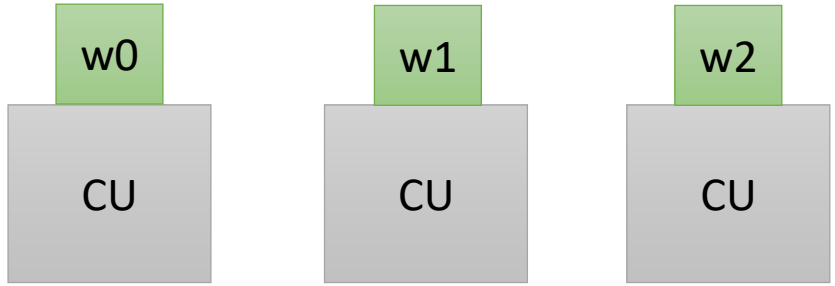
Current GPUs just have P2 wait for P1, causing frame skips



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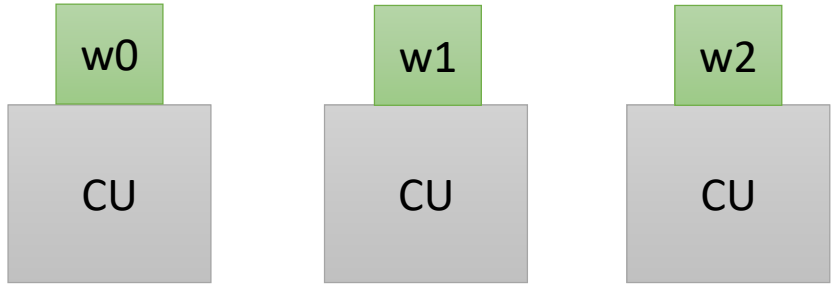

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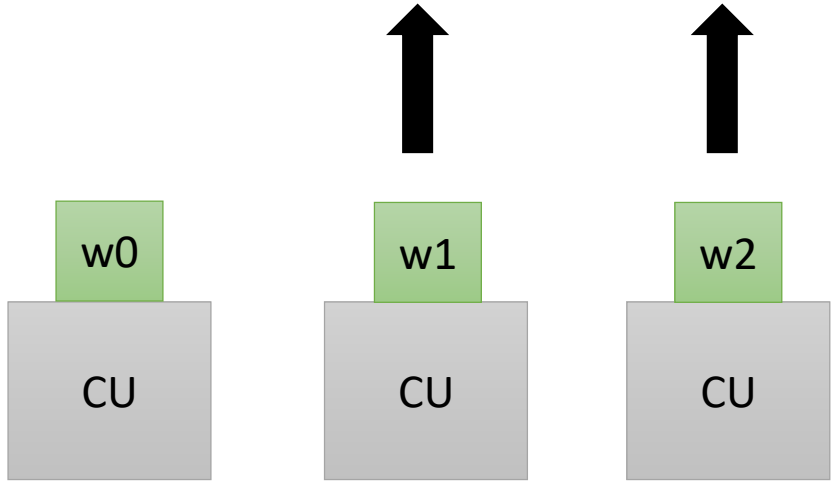

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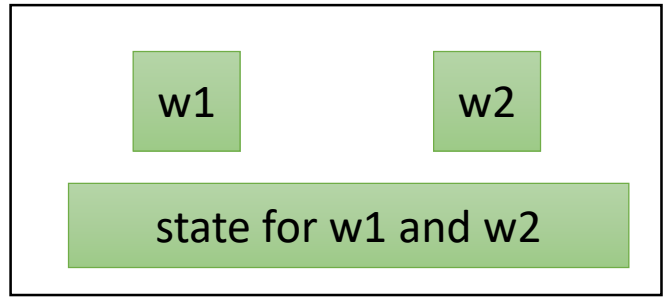

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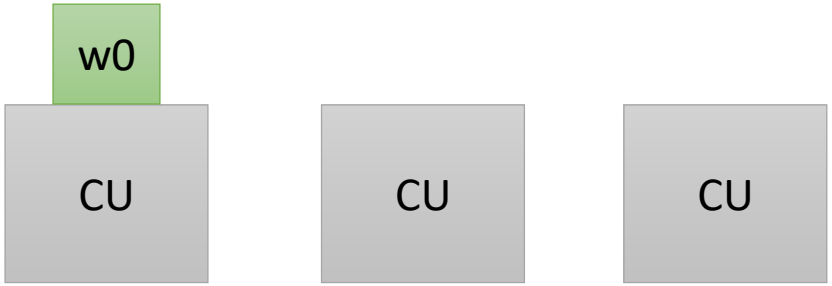

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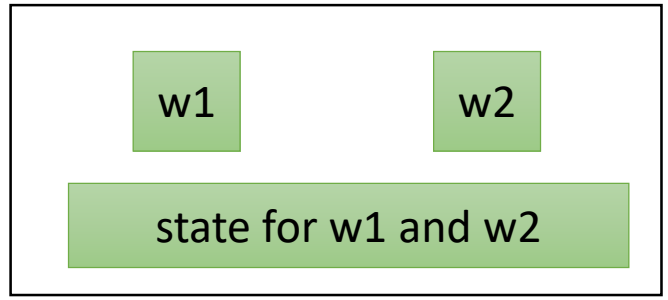

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P2 can execute on these 2 CUs

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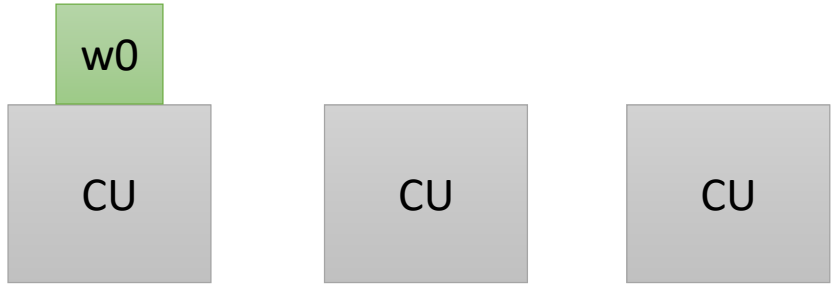

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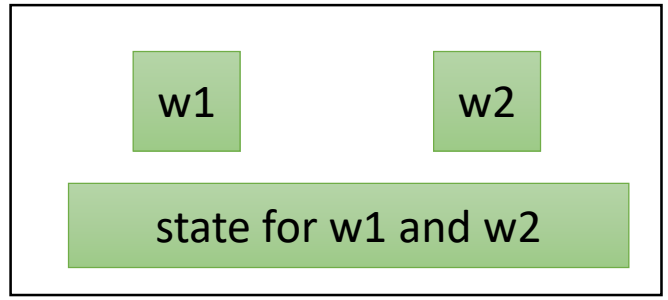

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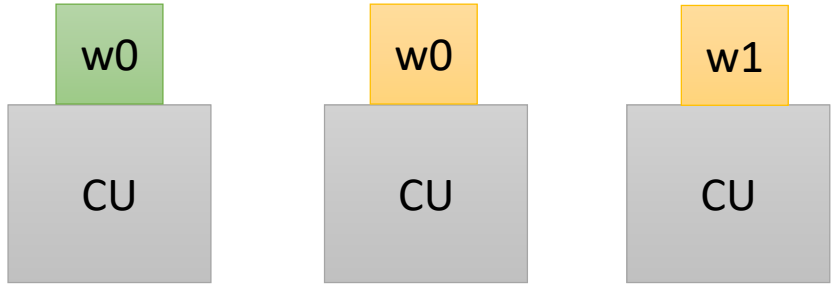

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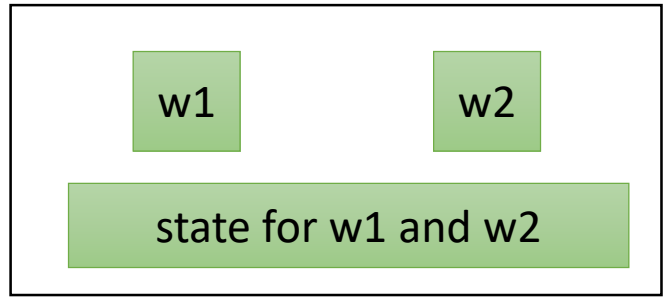

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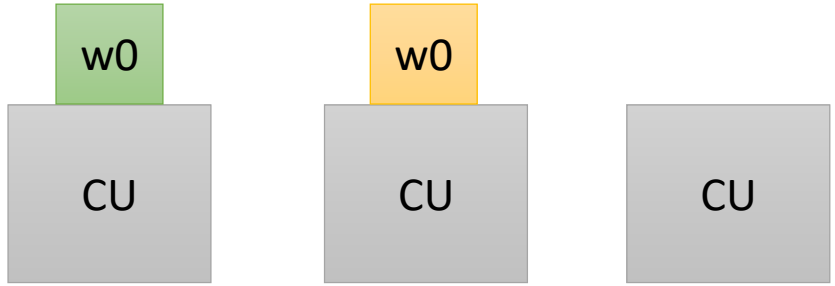

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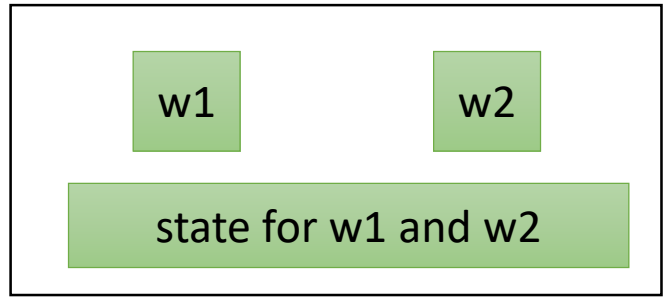

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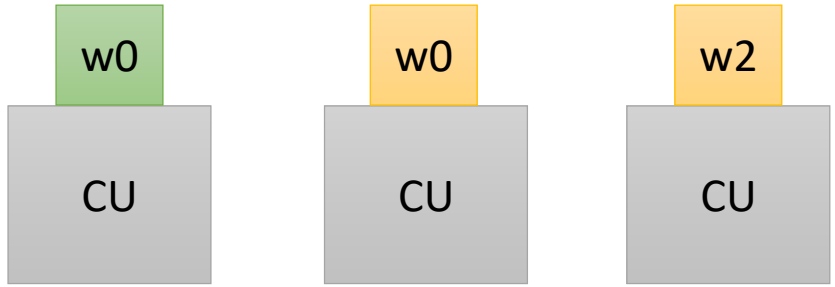

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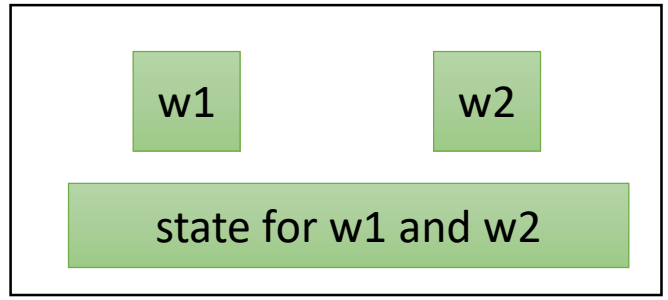

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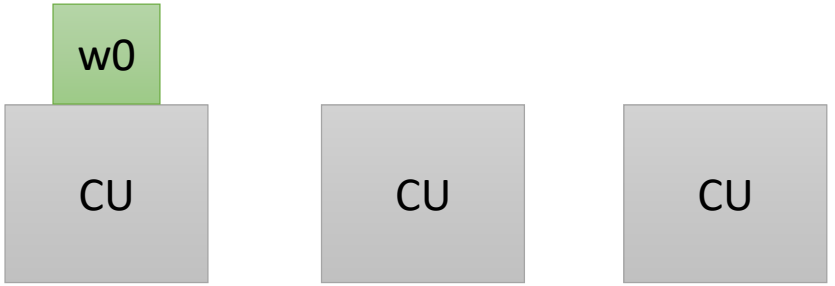

GPU with 3 compute units

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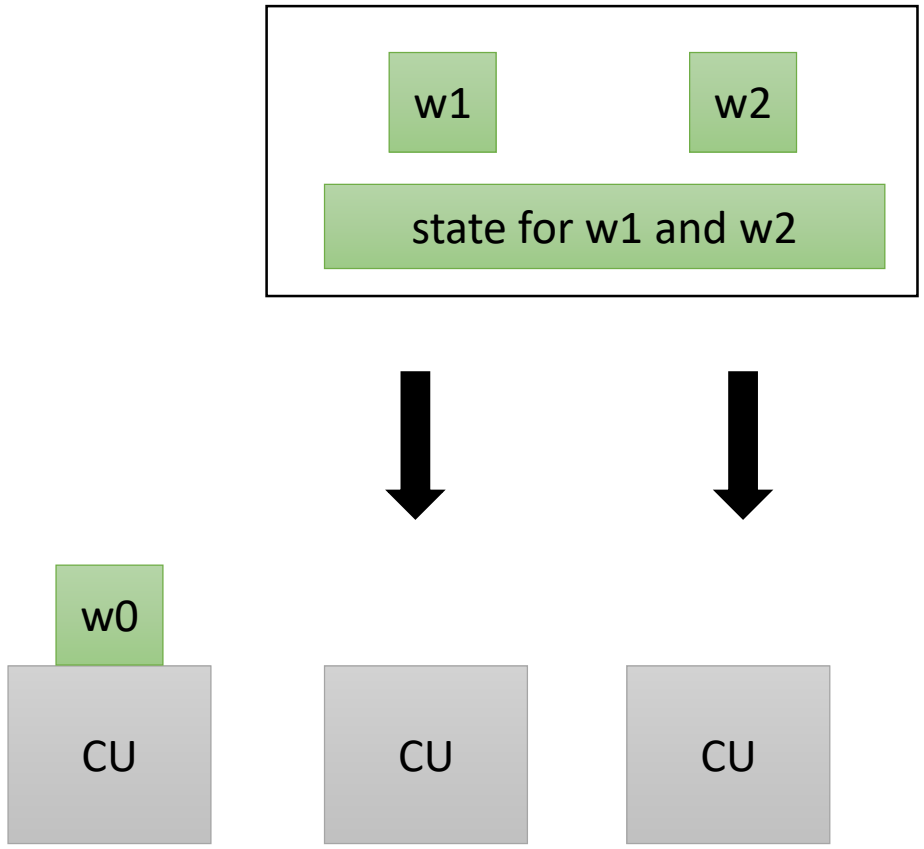

GPU with 3 compute units

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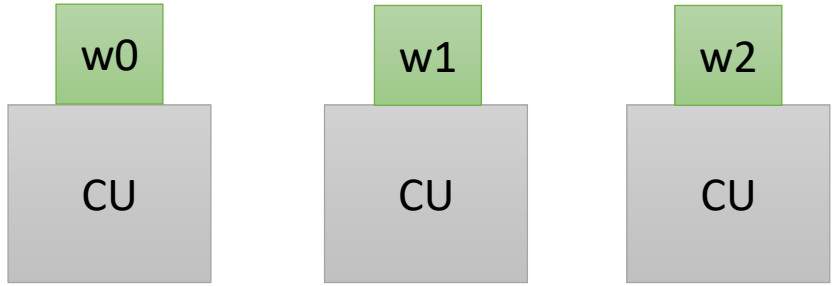
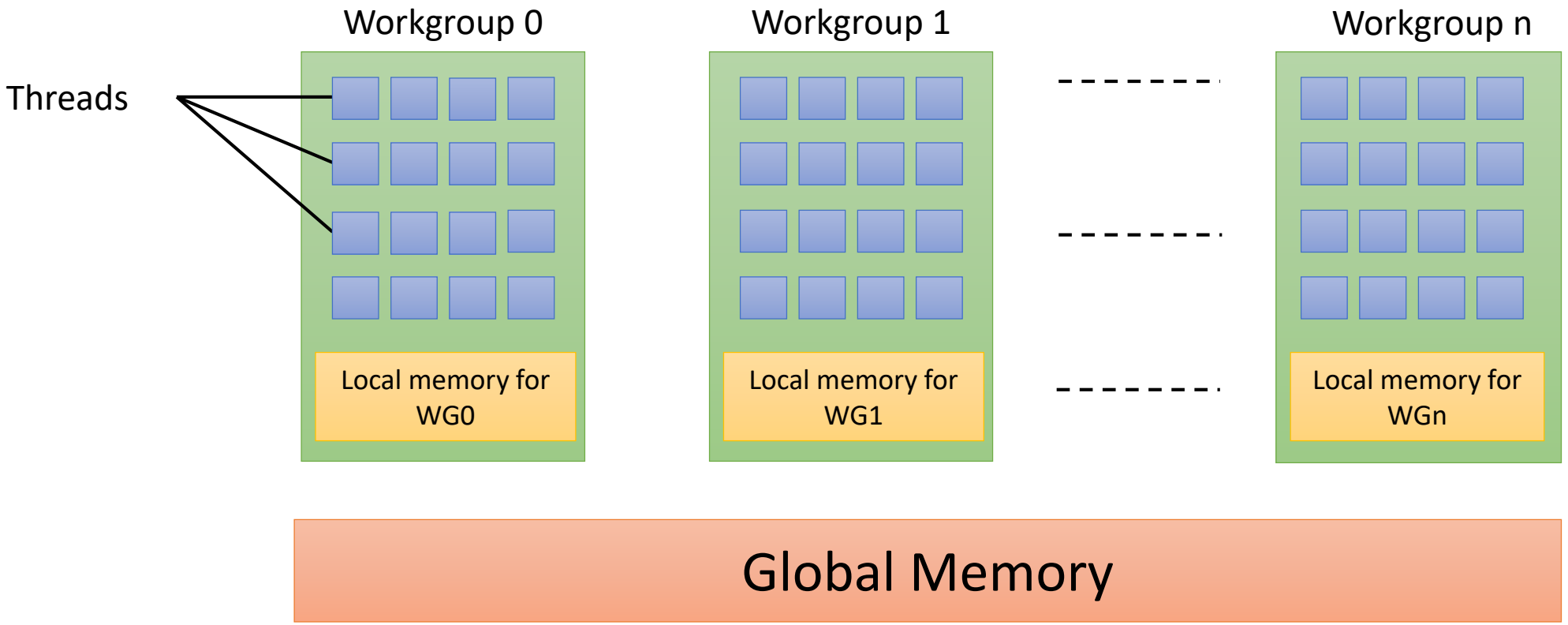
Easy, just need to save state!



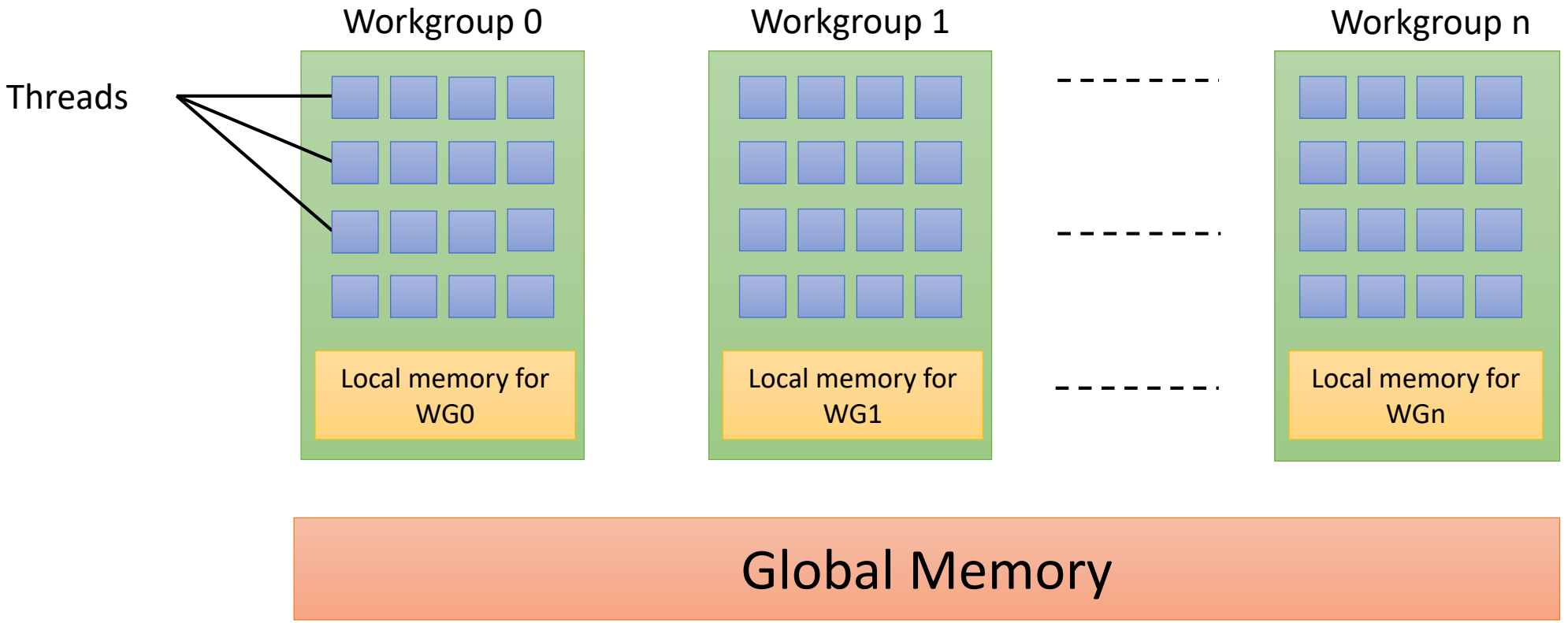
GPU with 3 compute units

GPU programming model



GPU programming model

Saving state for a workgroup is **EXPENSIVE**! includes PC, registers for all threads and local memory



Example application

- Example: Frontier based sssp graph traversal

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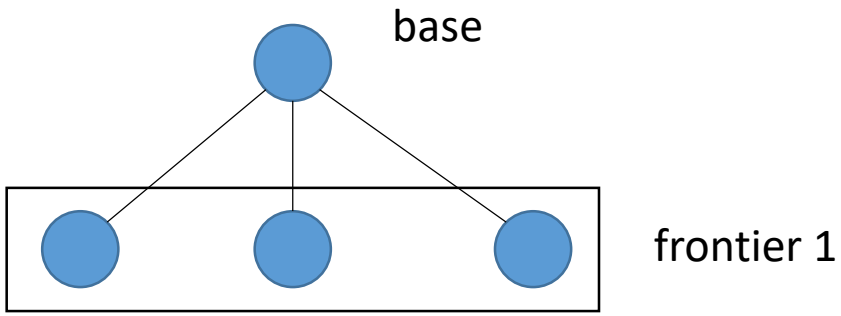

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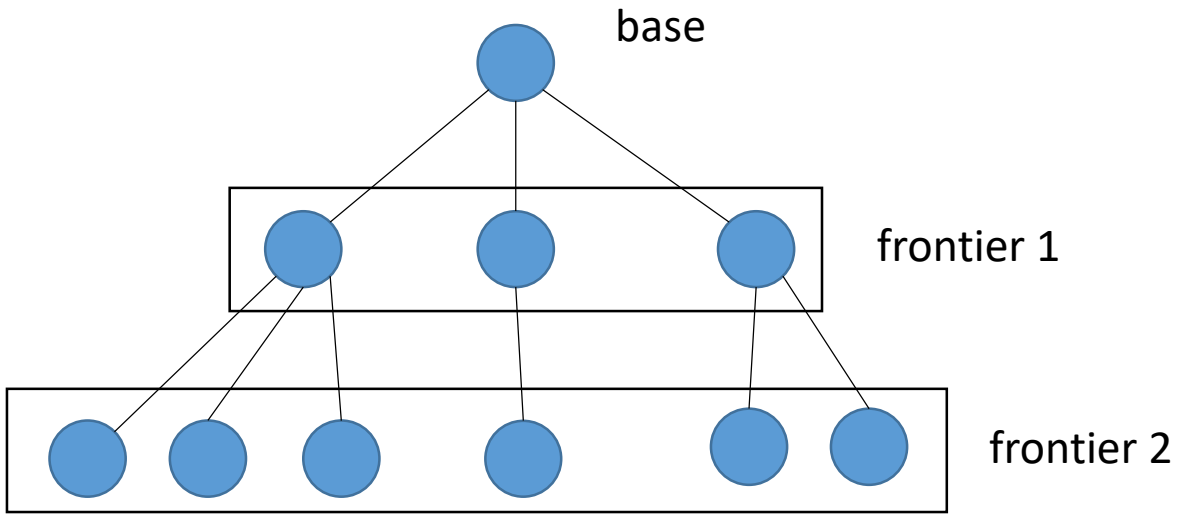

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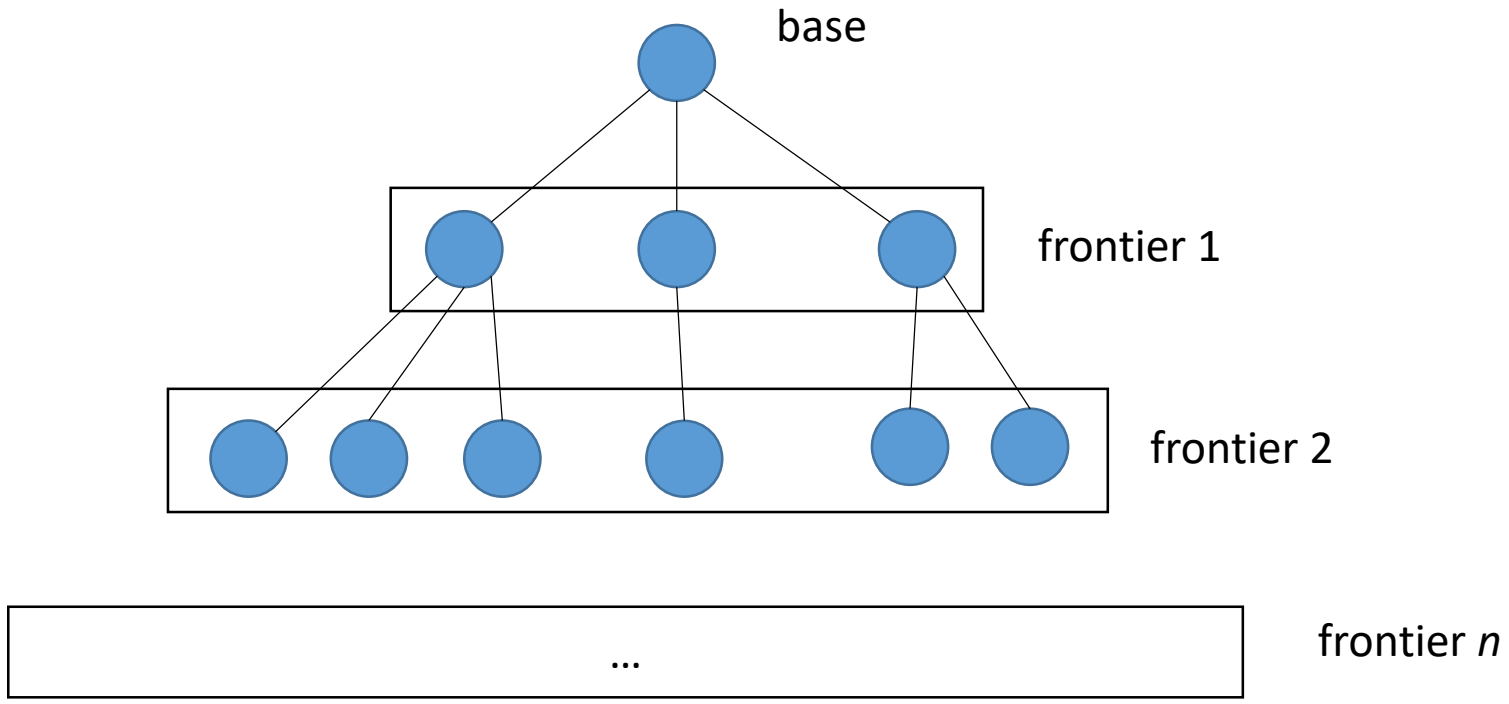

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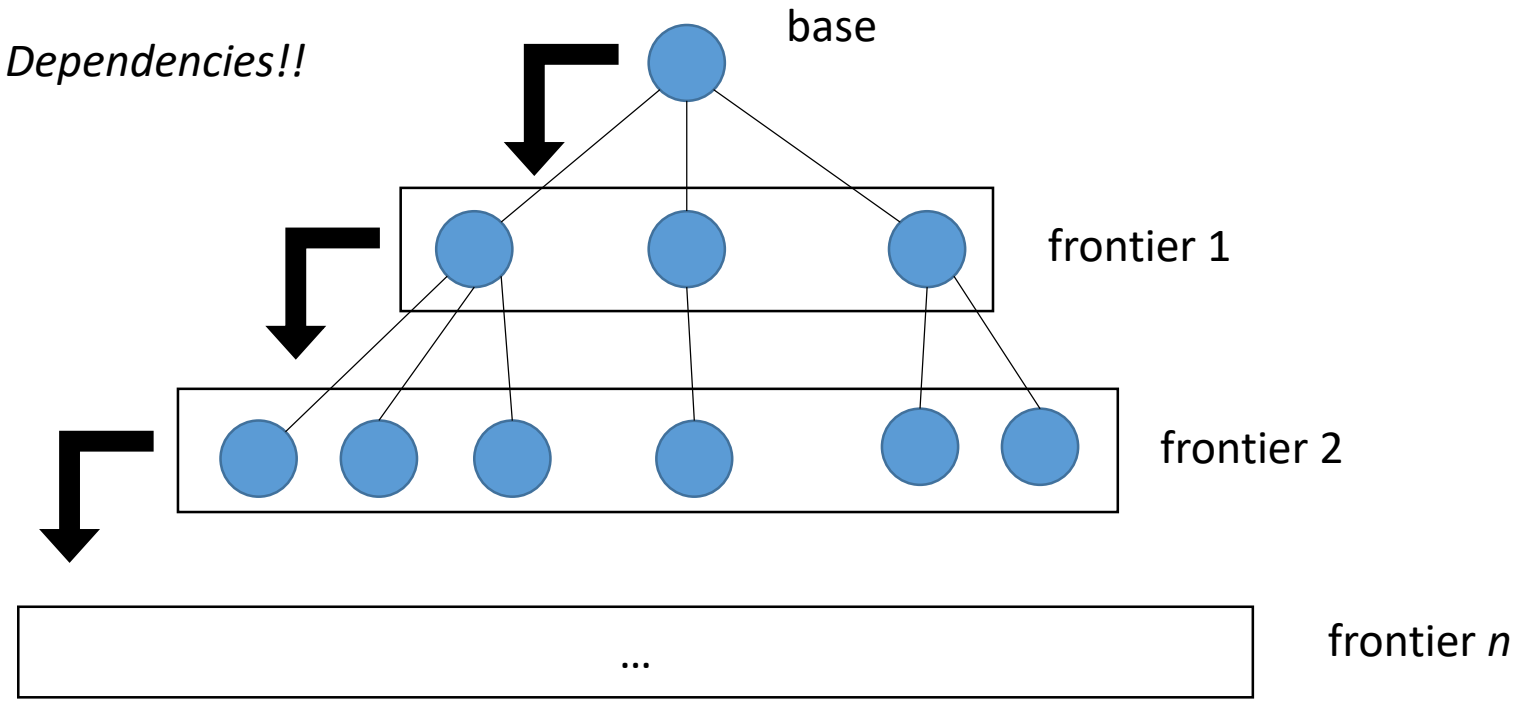

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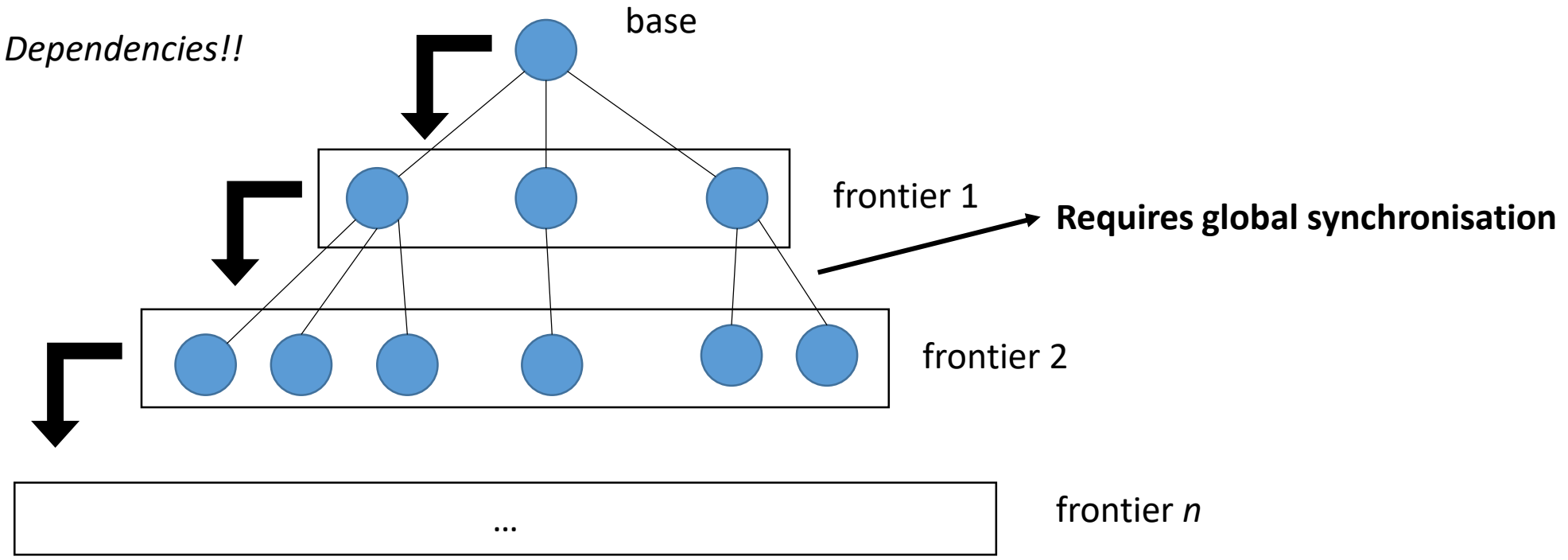

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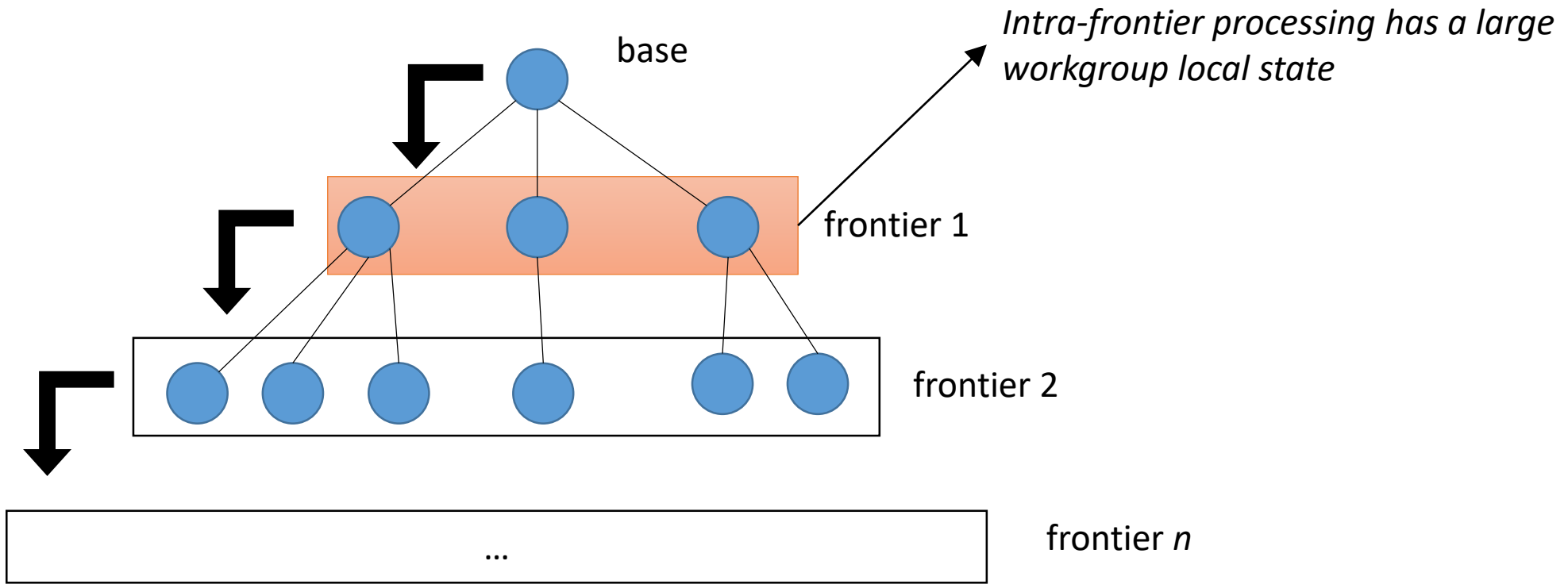

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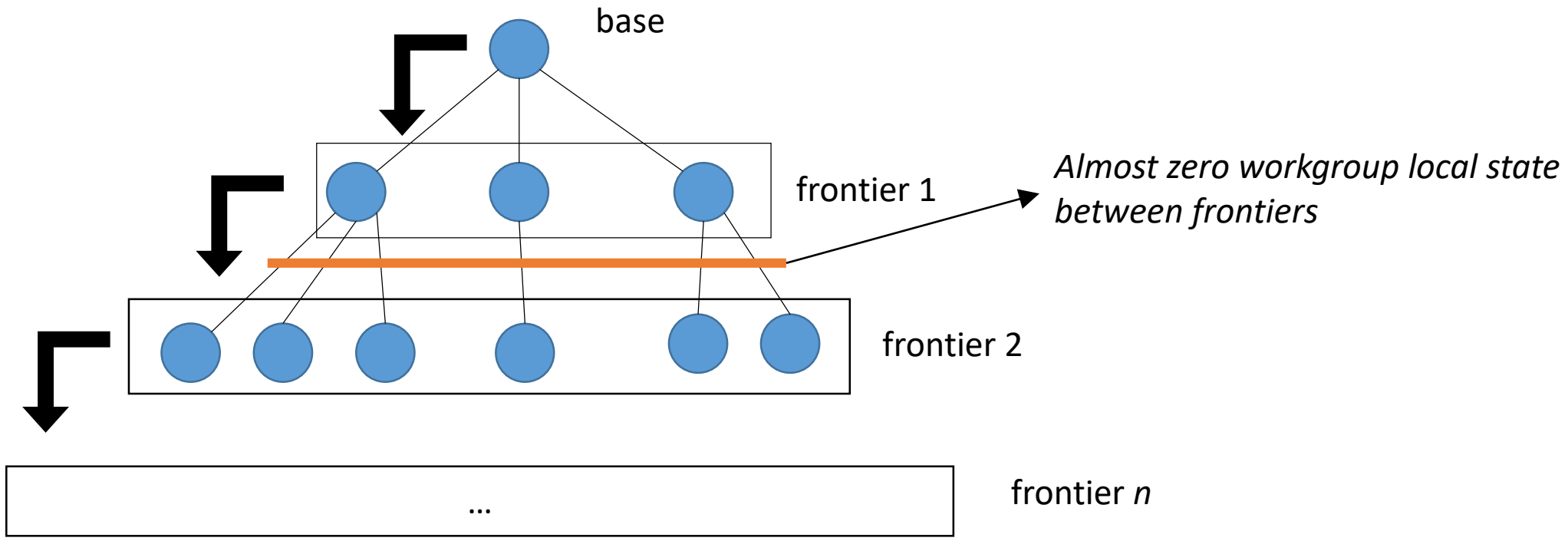

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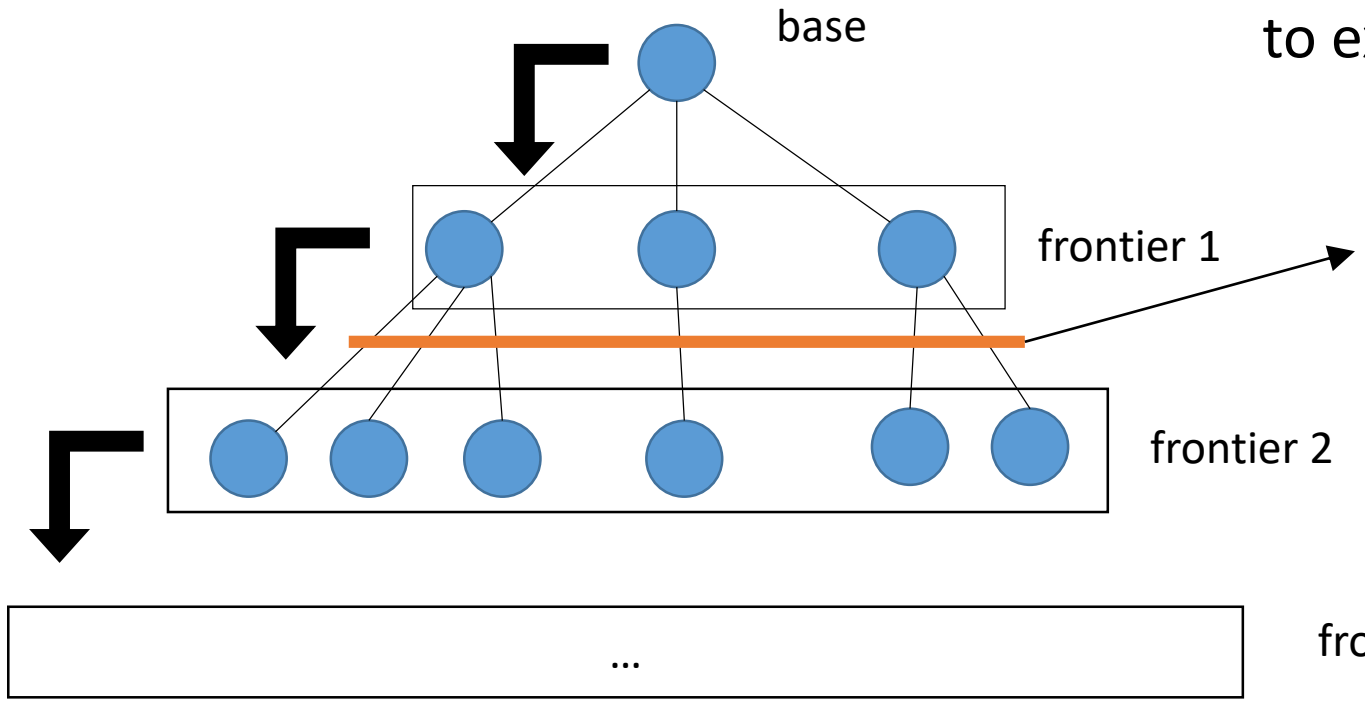
What if programmers had a way to express this?



Almost zero workgroup local state between frontiers

Our solution

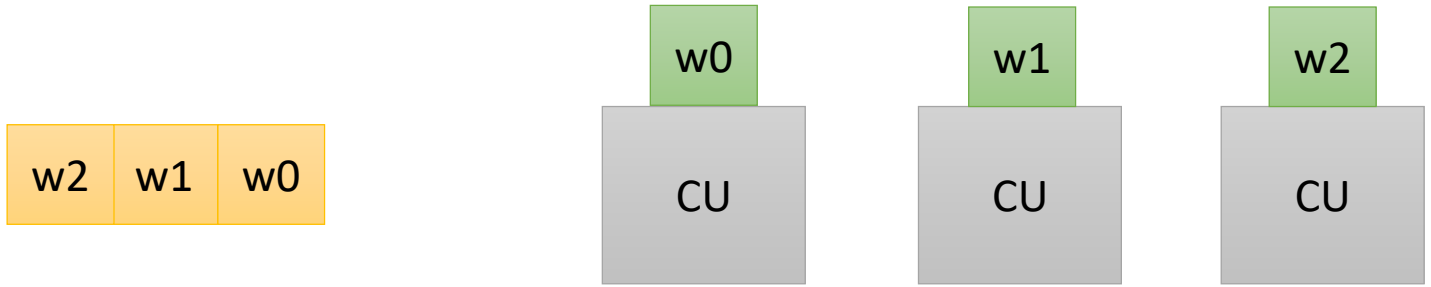
- **Cooperative kernels**: Long running kernels (e.g. graph traversal) that could interrupt short running kernels (e.g. graphics)

- Cooperative kernels must *share* resources via new programming constructs which enable

- Framework provides cooperative kernels *guaranteed* execution

Cooperative kernel workgroup functions

- `offer_kill`
  - Scheduler can kill calling workgroup if needed
  - Kills workgroups in descending id order



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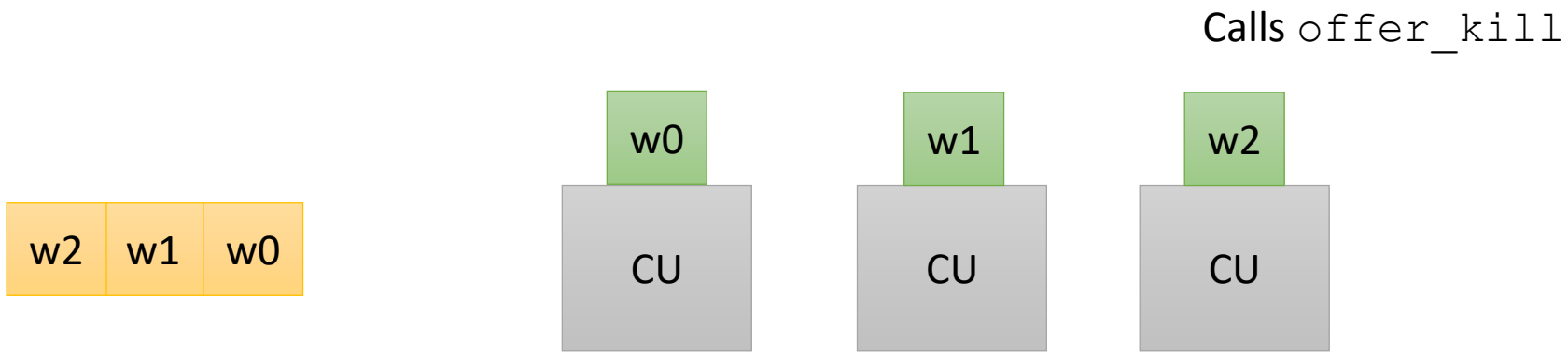

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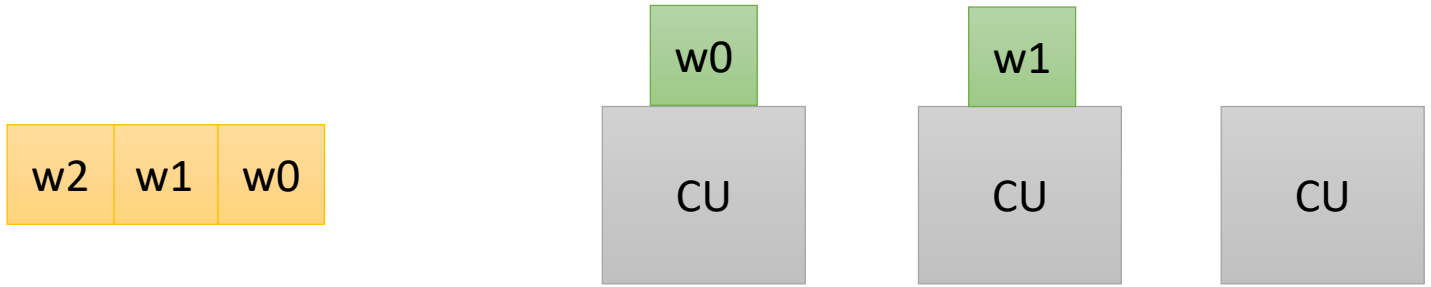

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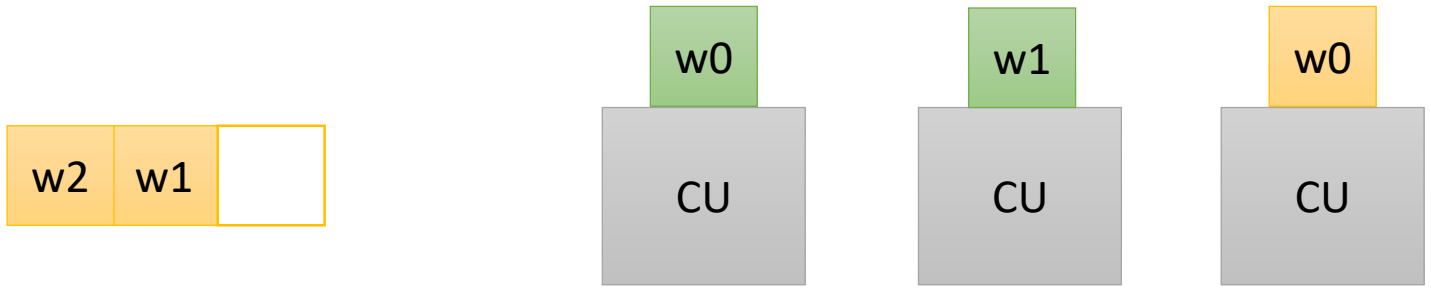

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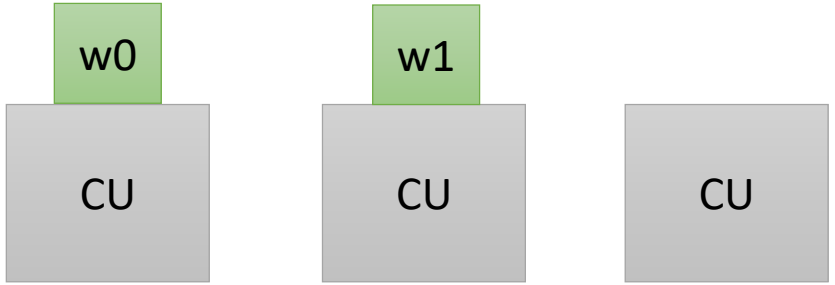

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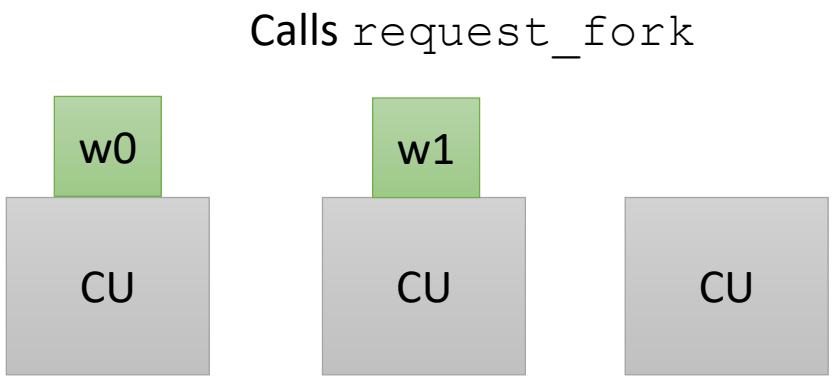

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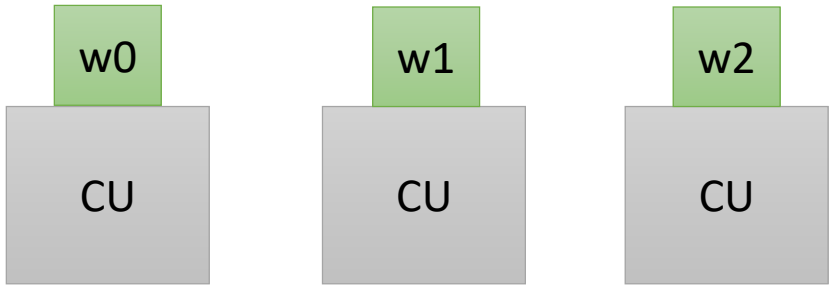
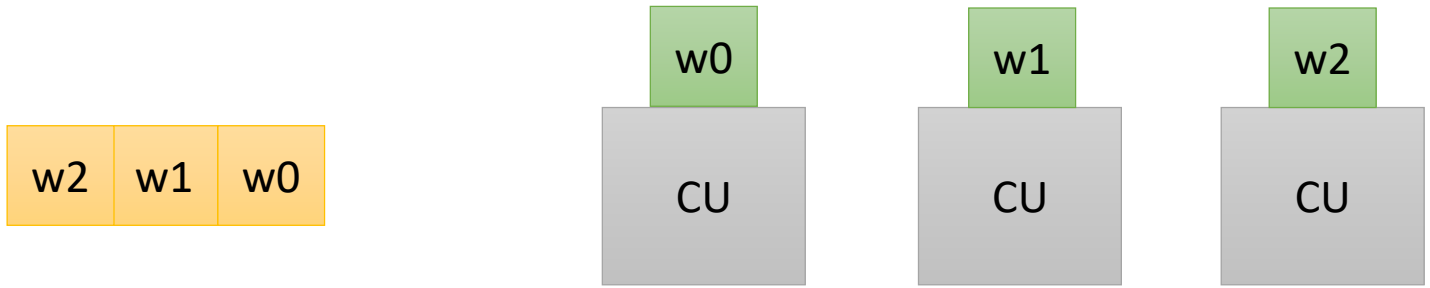


Cooperative kernel workgroup functions

- `resizing_barrier`
  - A barrier where workgroups may leave/join



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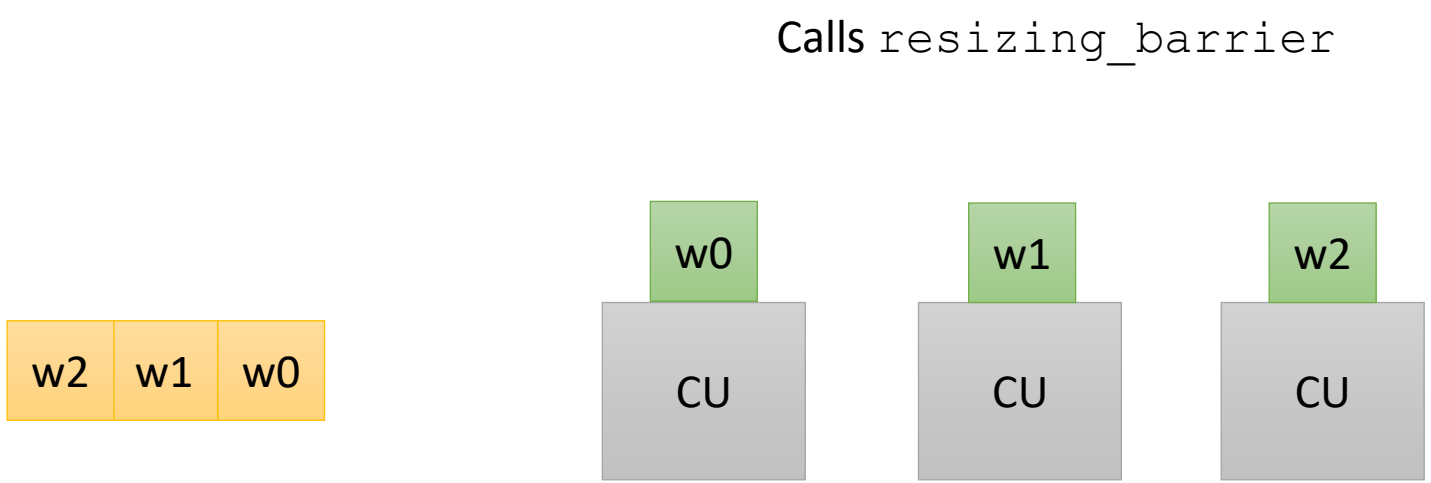

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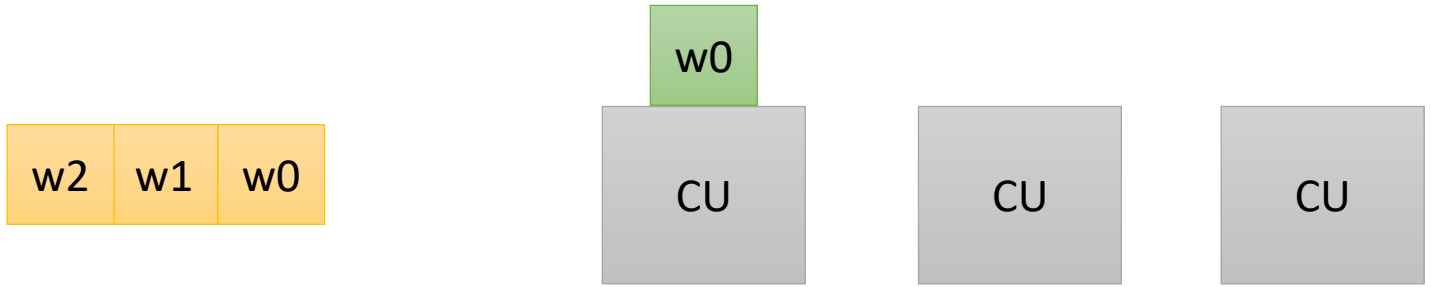

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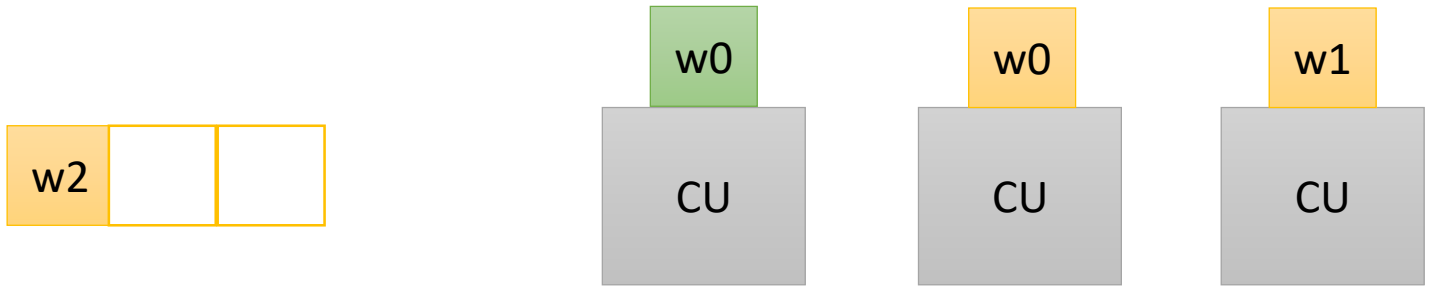

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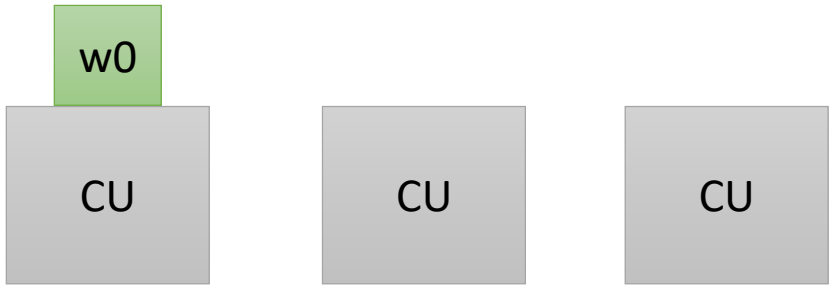

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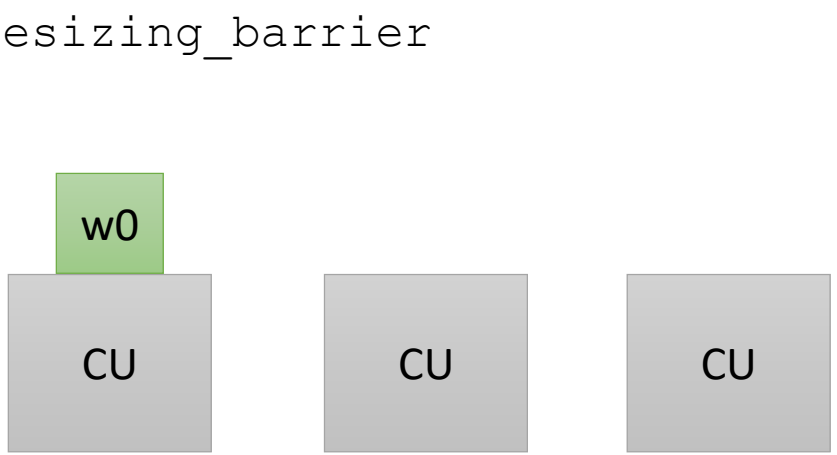

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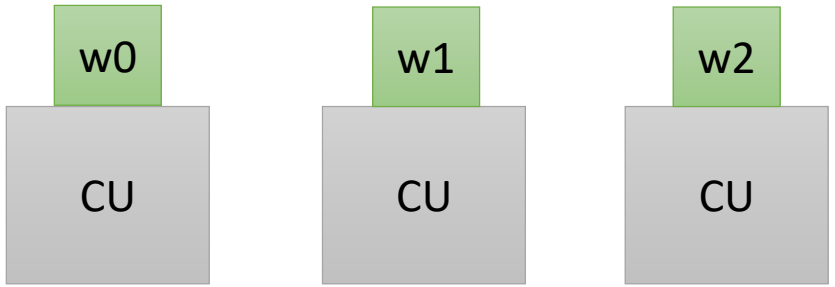
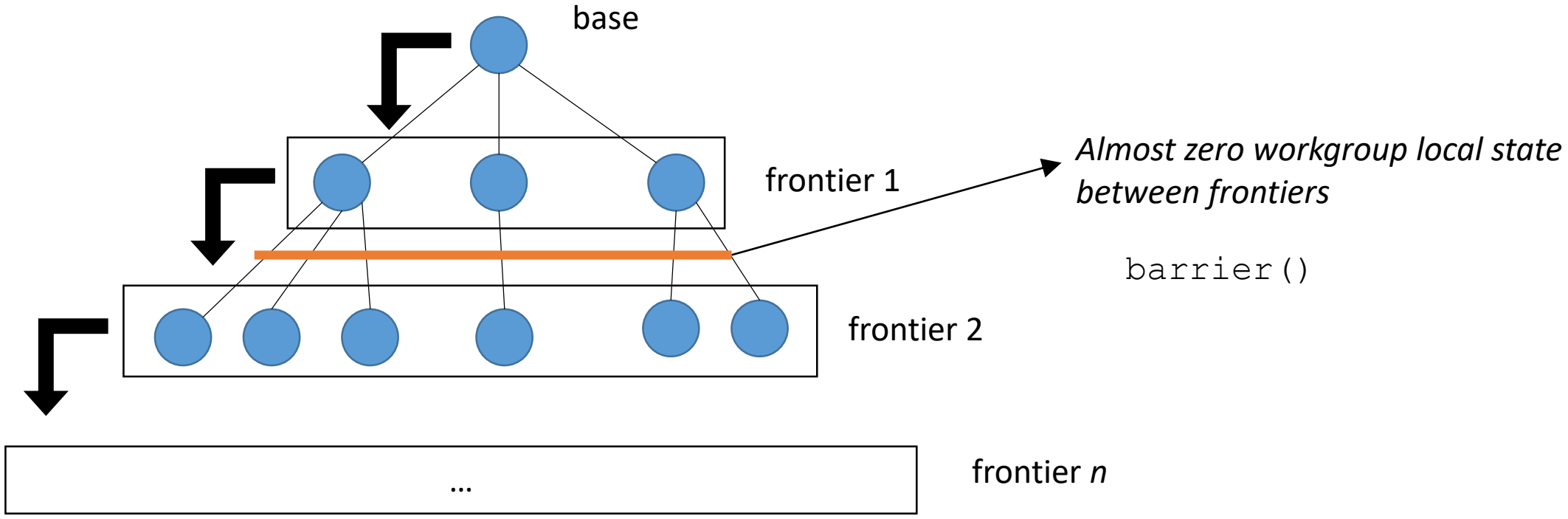


Example application



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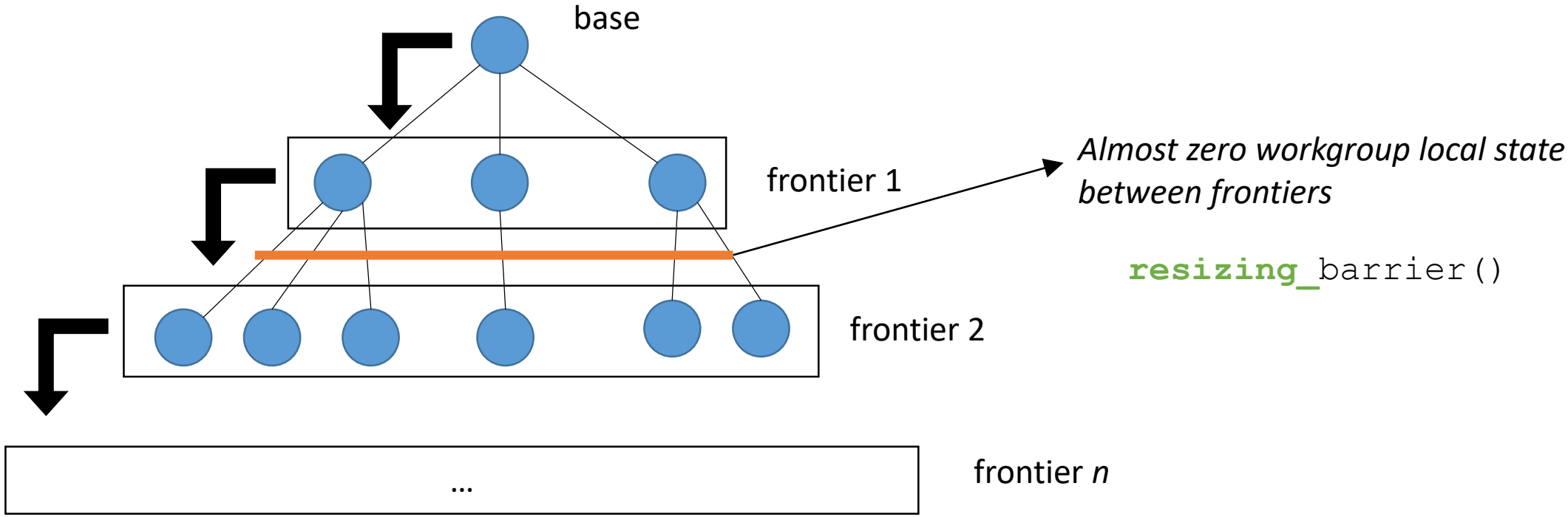
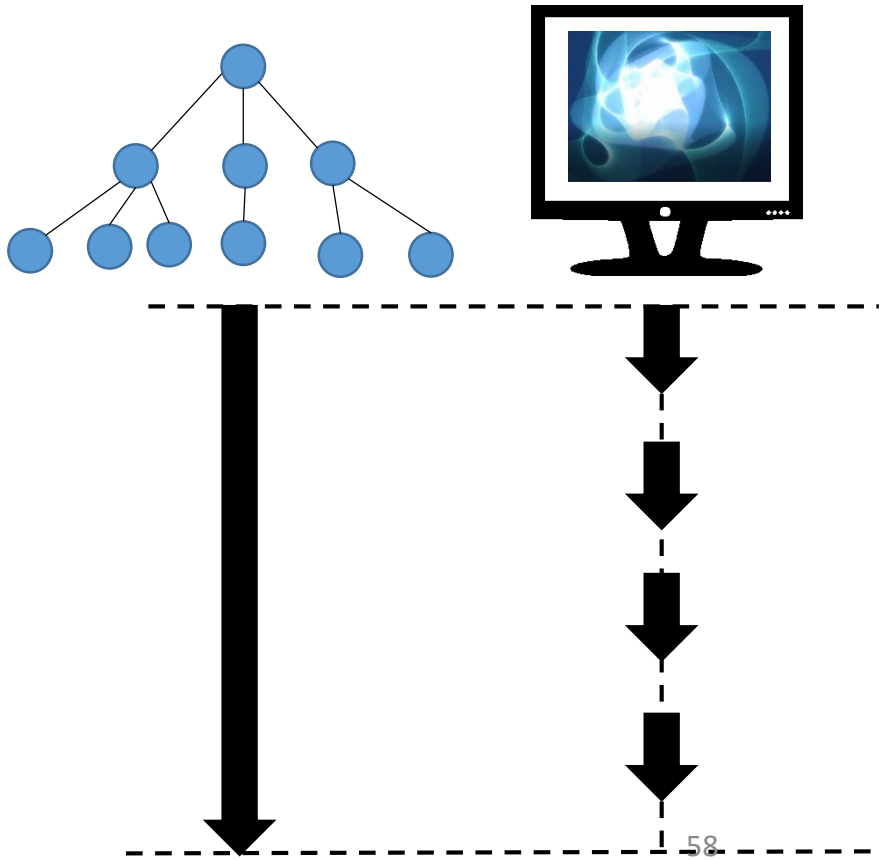


Evaluation (ease of programming?)

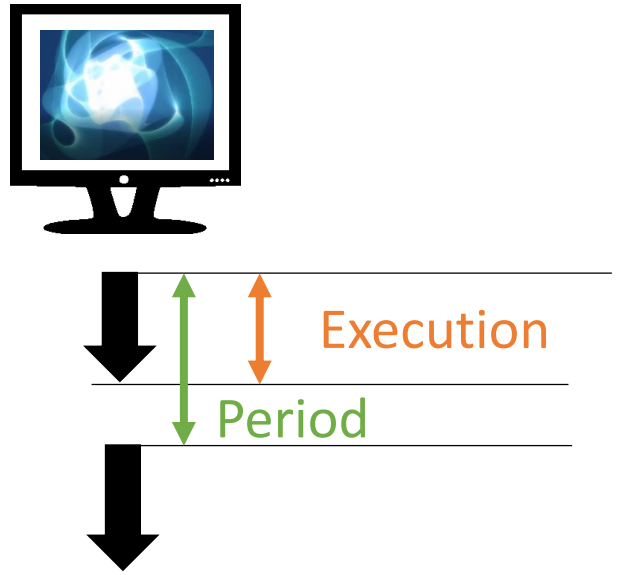
- Porting existing applications to use cooperative kernels
- Two types of applications:
  - 6 global barrier applications
    - Changed all global barriers to resizing barriers
  - 2 work stealing applications
    - added 1 call to offer_kill and request_fork
- DSL can automatically generates cooperative kernels

Evaluation (does it actually work?)

- Prototype implementation models two task systems
- We experiment multi-tasking:
  - 8 long-running applications
  - 3 graphics workloads
- We run on Intel Iris 6100 GPU
- Prototype overhead: 10% (upper-bound!)



Graphics workloads

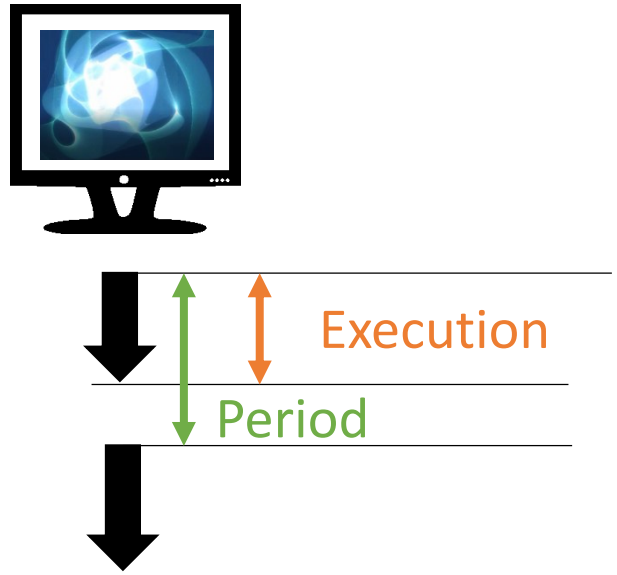


Can we reach the deadlines for smooth graphics?

Workload	Period	Execution (full GPU)	Cooperative overhead	Compute units
Light	70 ms	3 ms		
Medium	40 ms	3 ms		
Heavy	40 ms	10 ms		

Geo. mean

Graphics workloads



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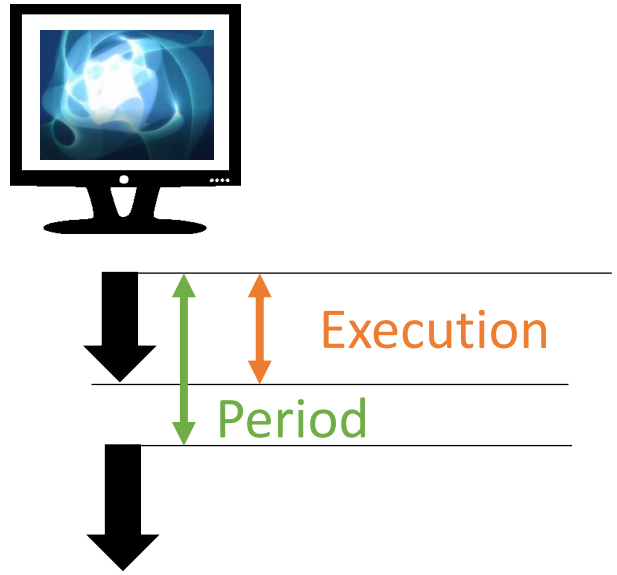

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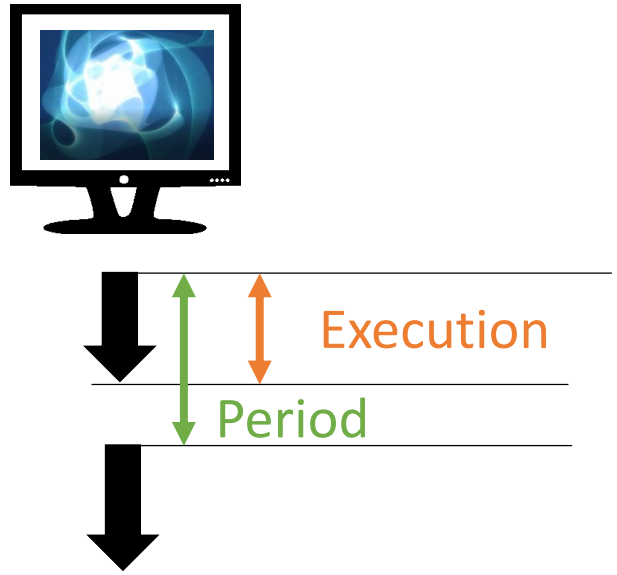

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Heavy	40 ms	10 ms	1.28x	50%
			Geo. mean	

Cooperative Kernels: GPU Multitasking for Blocking Algorithms

- GPU multitasking is a complex unsolved issue
- Our solution provides **3 new primitives** for programmers to interact with scheduler for **efficient GPU multitasking**
- Prototype implementation achieves soft real-time constraints for compute + graphics

Tyler Sorensen https://www.doc.ic.ac.uk/~trs15/