Supporting Preemptive Task Executions and Memory Copies in GPGPUs

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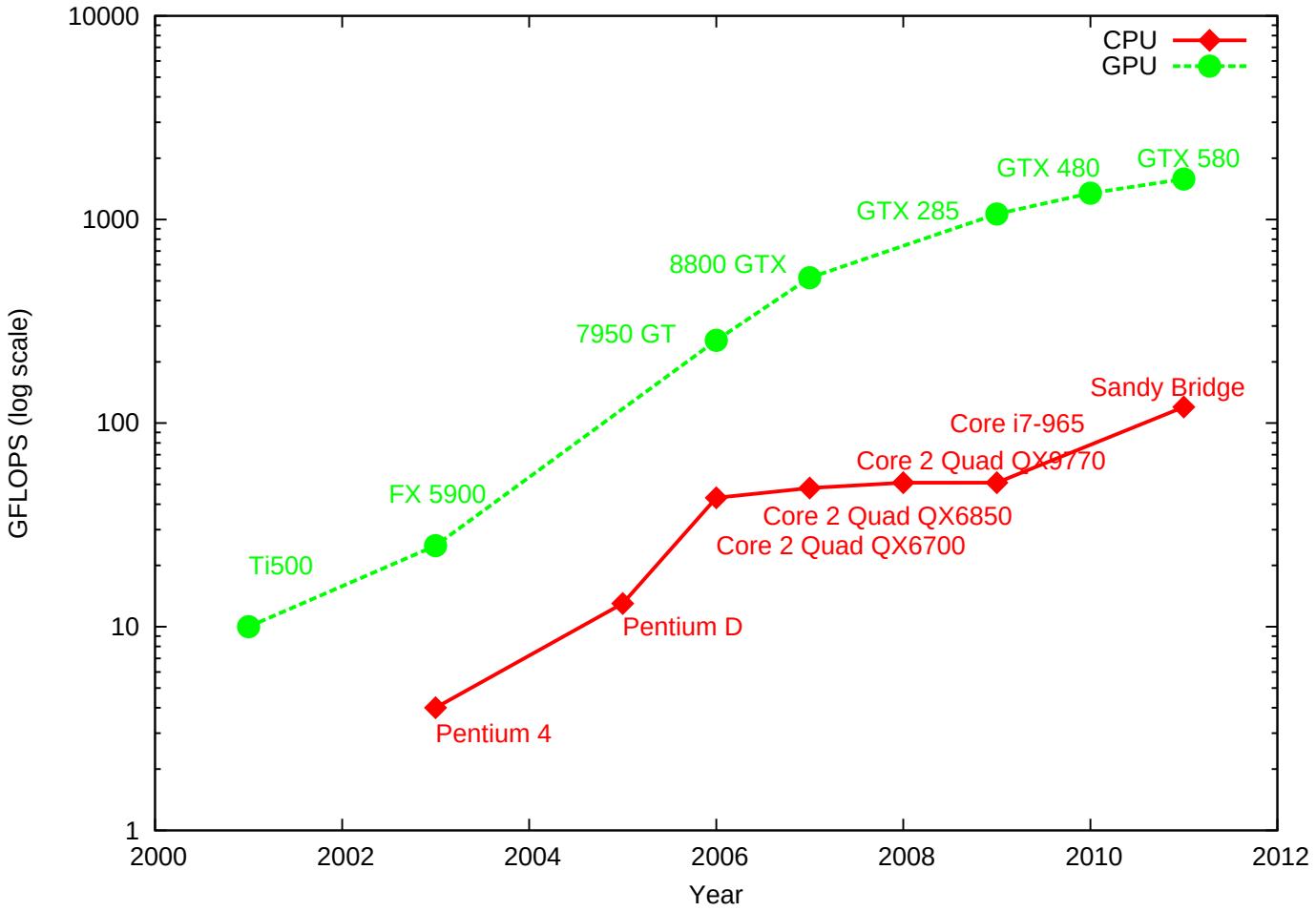
Why GPU for real-time computing?

- Nvidia Fermi hosts 512 Single Instruction Multiple Threads (SIMT) cores
  - Each thread can keep track of its state
  - Zero context switching overhead
- Well written code can achieve up-to 10x speed-up over the CPU
- Cost/Performance yield is high compared to the CPU
- GPUs can improve real-time application performance significantly

CPU vs. GPU: Peak Performance

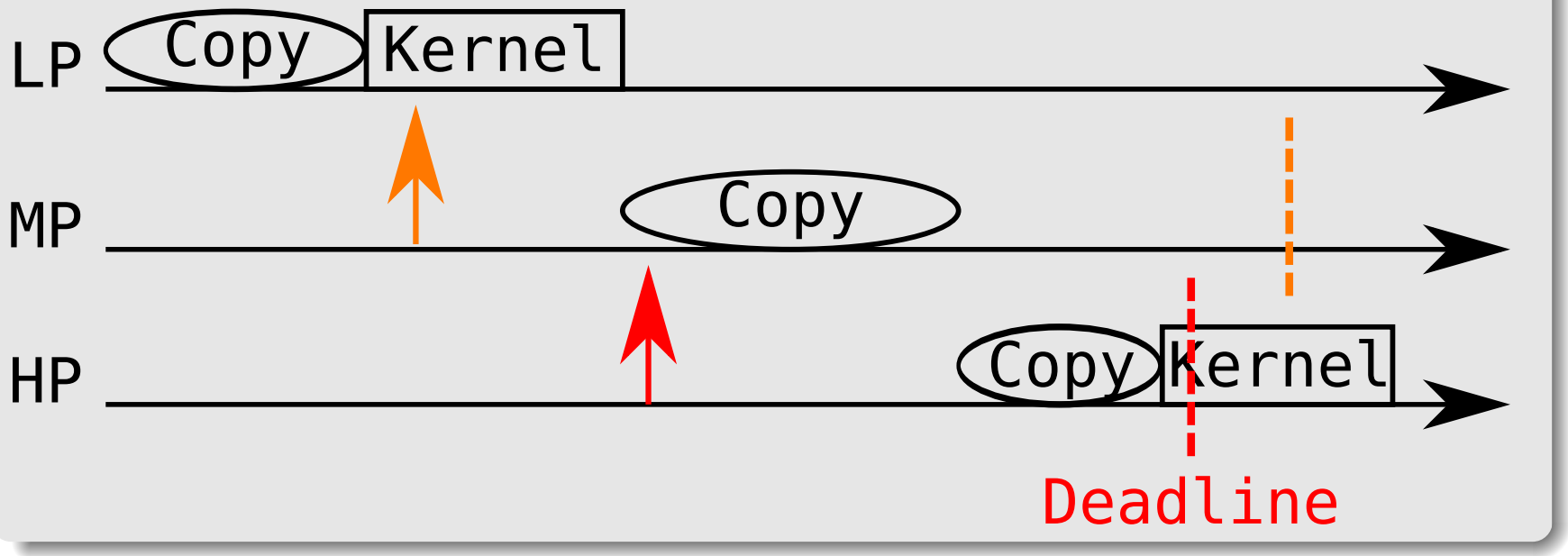


Priority Inversion

- GPU is command driven
  - Copy input data to device
  - Execute device code on copied data, produce output
  - Copy device output to the host memory
- GPU commands are non-preemptive
  - Subject to priority inversions
  - Relatively hard to do schedulability analysis

Example Priority Inversion

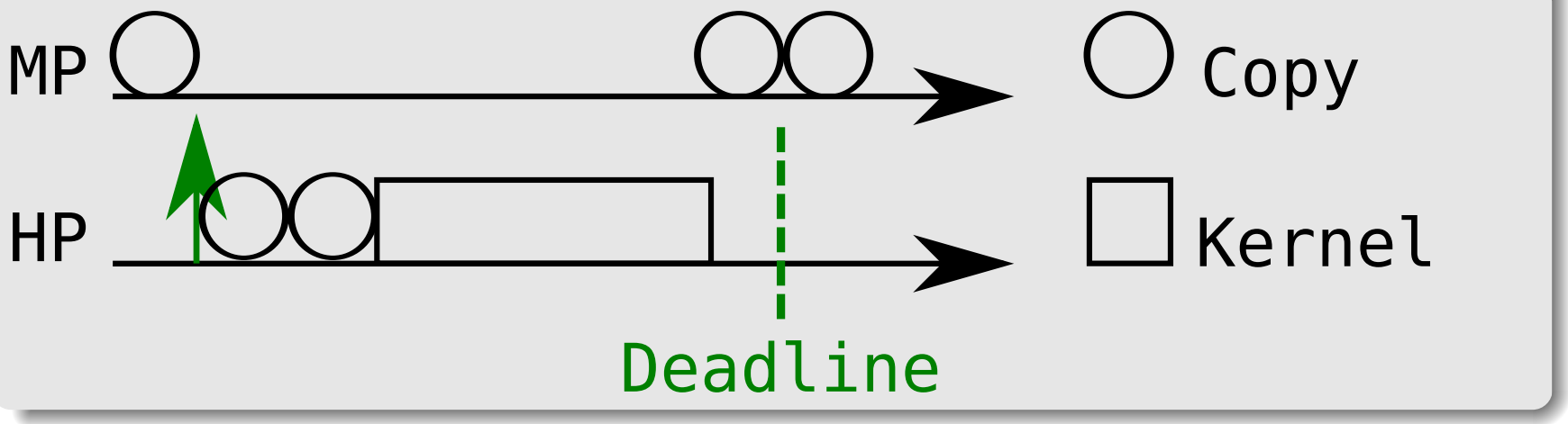
Example



Preemptive Memory Copies

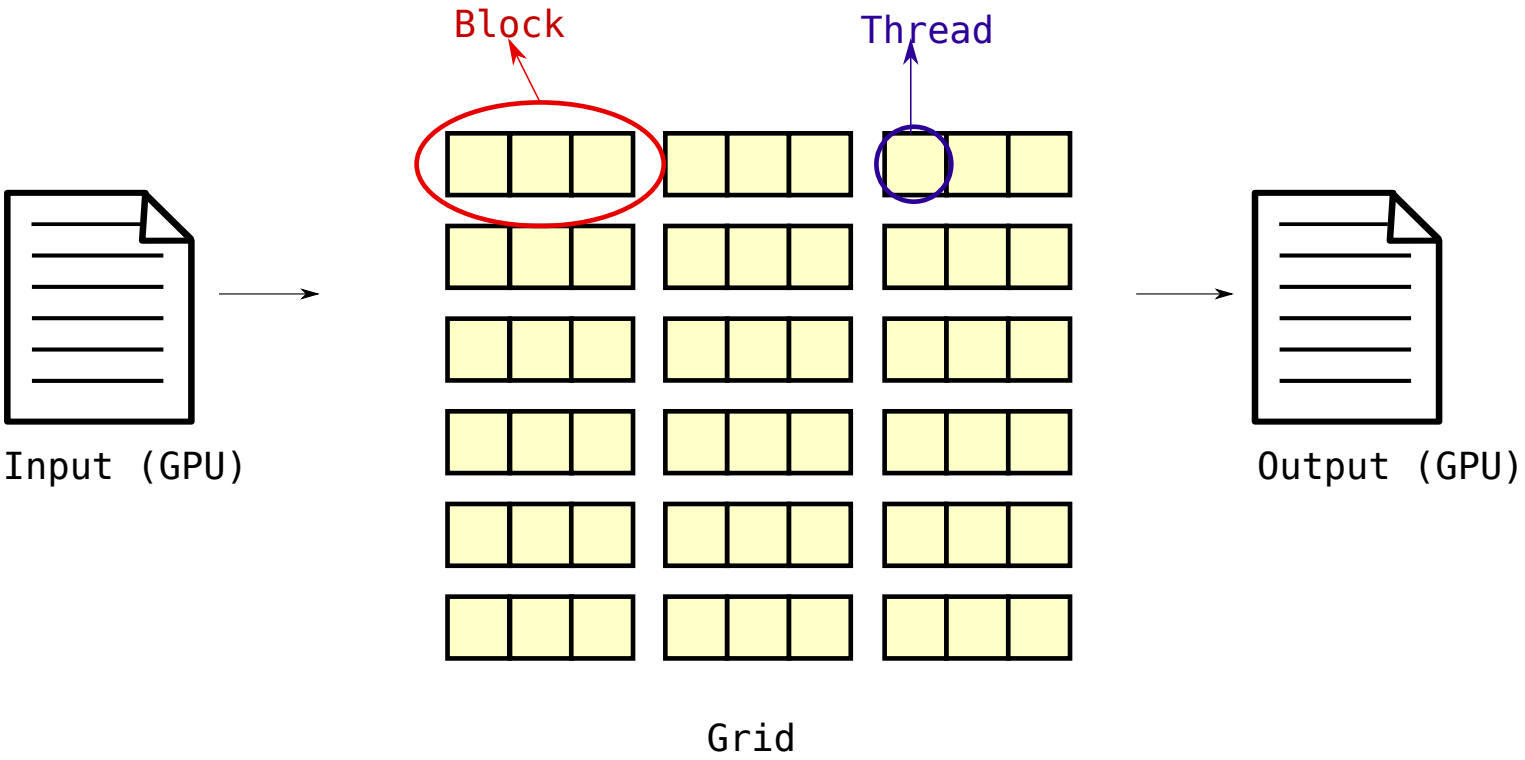
- Data transfers are non-preemptive in both directions
  - Transfer speed is predictable
- Instead of doing one big transfer, do multiple memcopies of small chunks
  - Preemption between memcopies of two chunks

Example



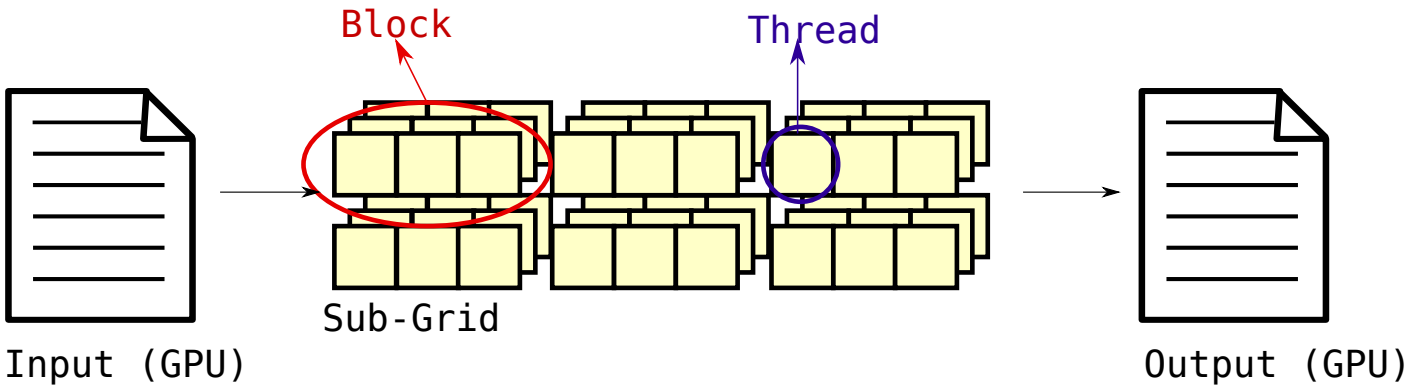
Kernel Execution

- Kernel executions are non-preemptive in GPUs
  - A kernel is executed by a grid of CUDA thread blocks
  - CPU issues the execute command and waits until completion



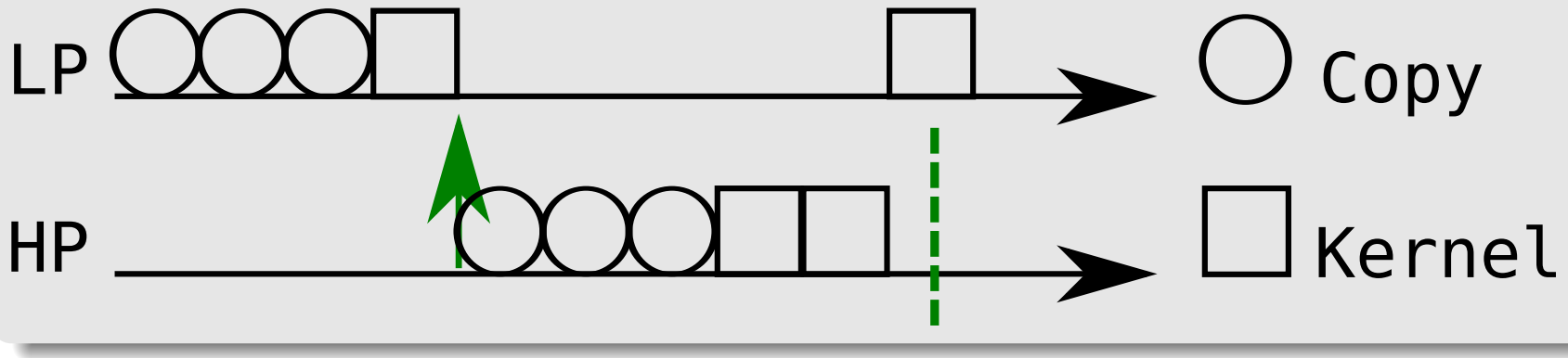
Preemptive Kernels

- Instead of executing a complete CUDA grid, execute **sub-grids**
  - Exploit lack of block level synchronization in Cuda
    - Blocks are assumed to execute independently
    - Concurrently executing blocks are unknown to each other
  - Preemption between **sub-kernel boundaries**



Kernel Preemption

Example

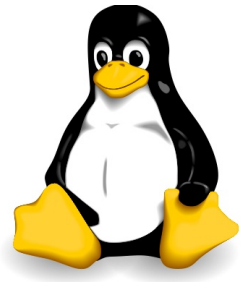


Overlapping Preemptive Memcopies and Subkernels

- Separate queues for memcopies and kernel executions per-task
  - Fixed priority scheme
  - CUDA can overlap memory copies and kernel executions of different tasks
    - As not only memcopies but also (sub)kernels are preemptive, PKM can overlap a subkernel execution and memcopy of different tasks regardless of their priorities
    - Overlapping a high priority memcopy and a **non-preemptive** low-priority kernel incurs priority inversion
  - Each queue entry stores a timestamp and task specific parameters

Performance Evaluation

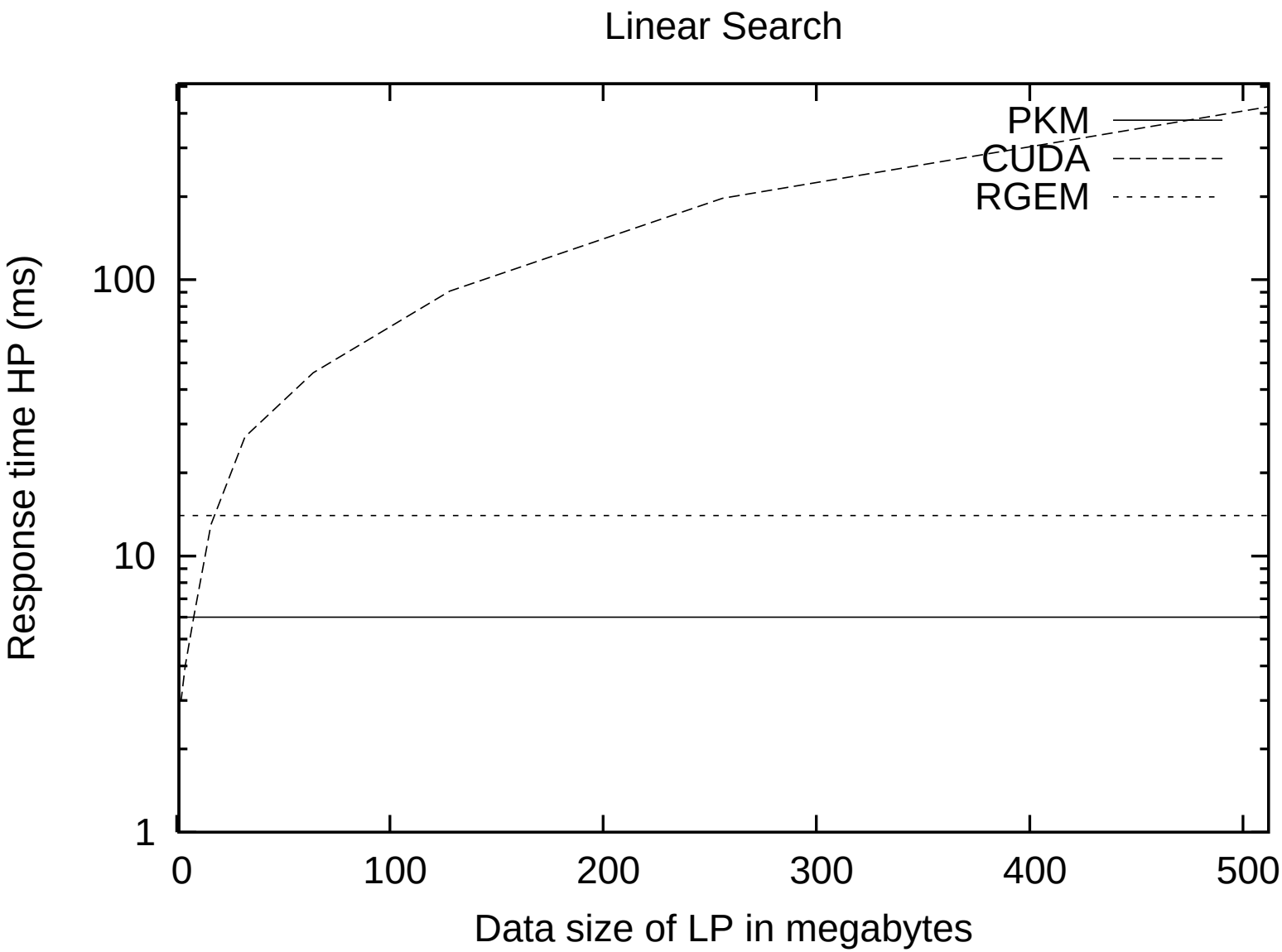
- Experimental Setup
  - GPU: NVIDIA GeForce GTX 460
  - CPU: AMD Athlon II X4 630
  - Memory: 4GB RAM, 500GB HD
  - OS: Linux 2.6.32.21 kernel
  - Micro-benchmarks:
    - Linear Search: Search the input for a given string
    - Matrix Multiplication: Multiply two matrices



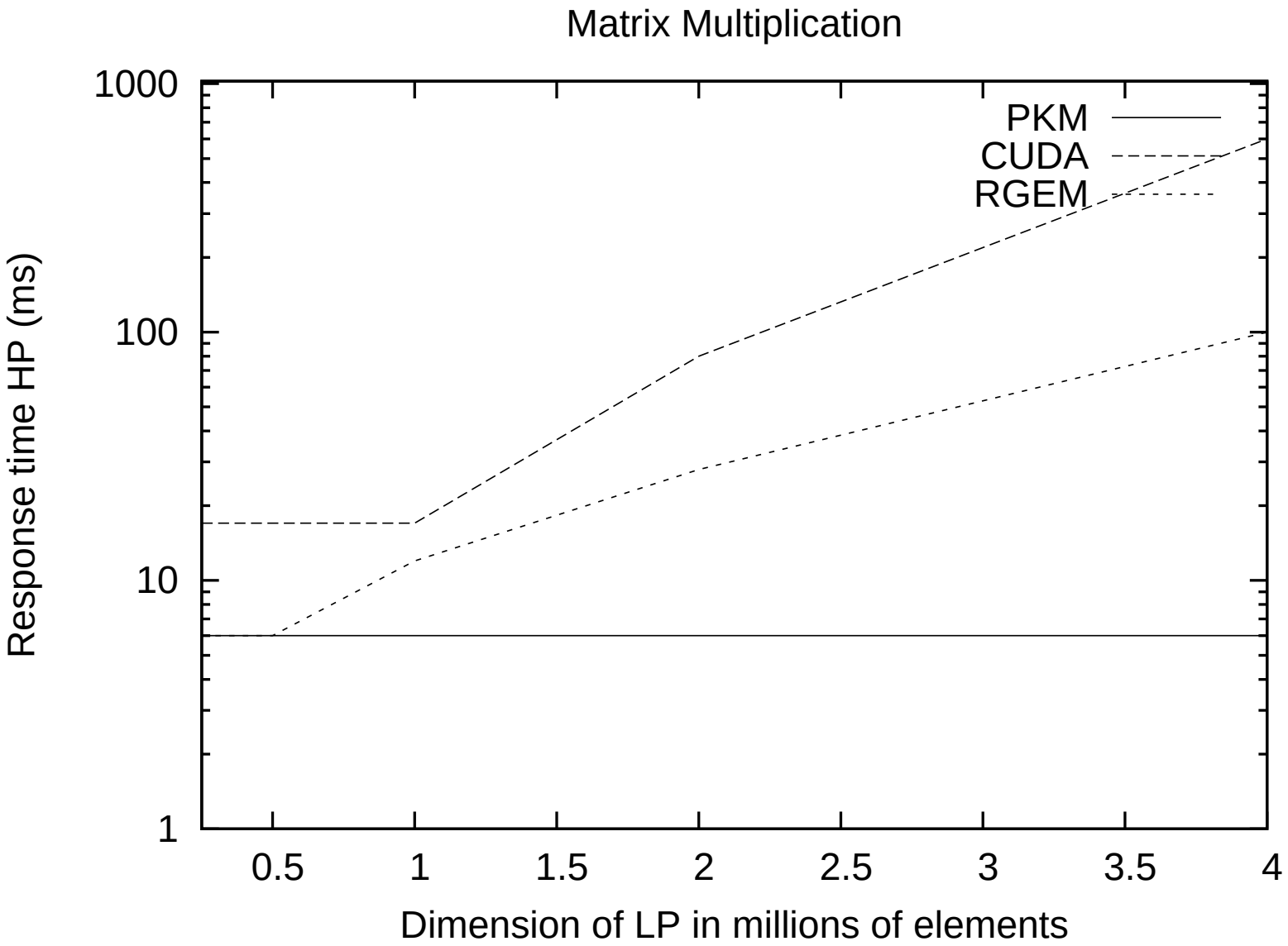
Baselines: CUDA and RGEM (RTSS '11)

- RGEM (Responsive GPGPU Execution Model) decreases the response time of high priority tasks via **preemptive memory copies**
- RGEM does **not** support **kernel preemption**
- Both PKM and RGEM use Direct Memory Access (DMA) to copy data between host and device
  - RGEM makes an extra copy between application and RGEM buffers in the OS kernel space
    - This extra copy of RGEM is eliminated in the experiments to favor RGEM

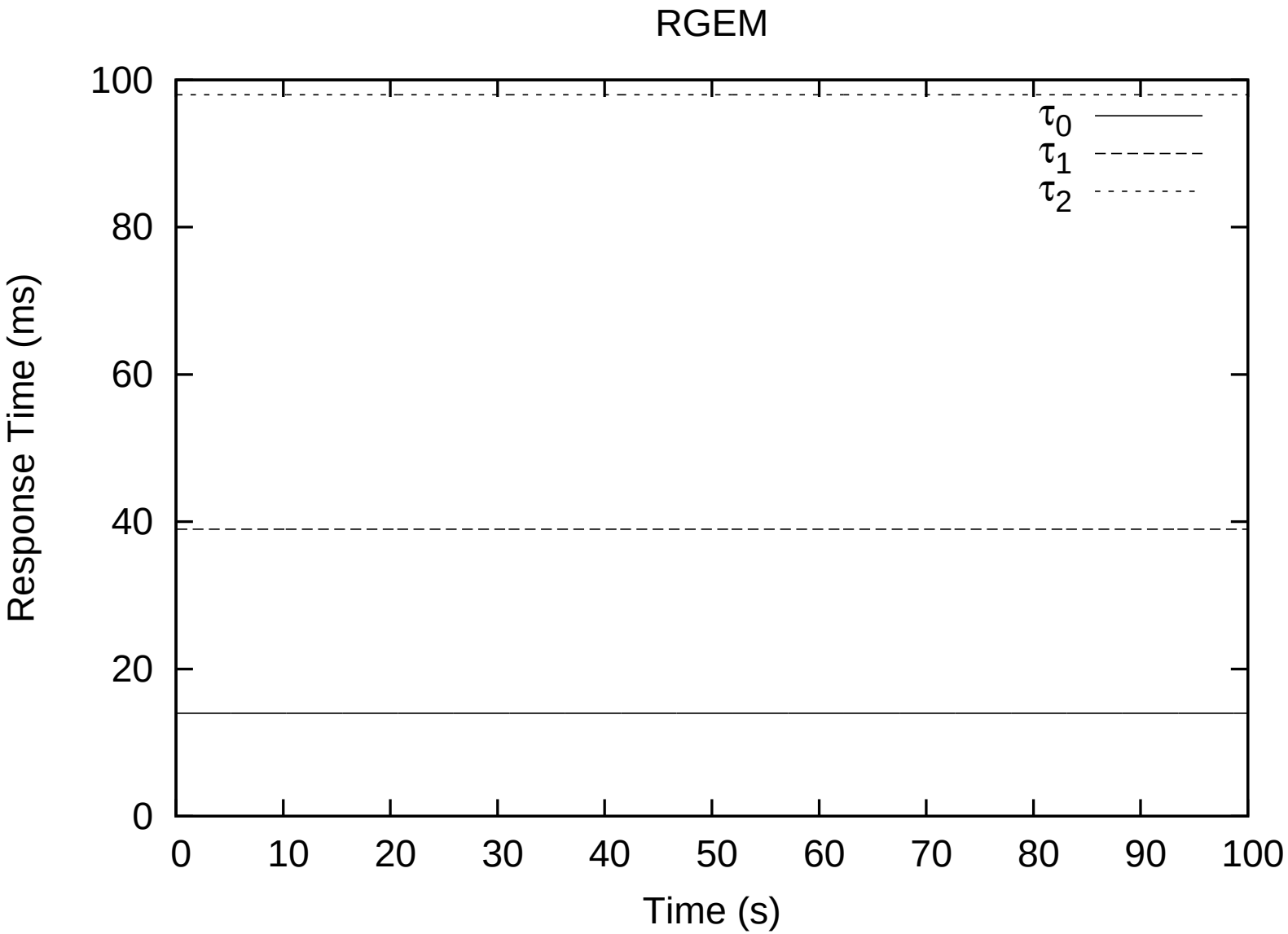
Experimental Results



Experimental Results



Experimental Results



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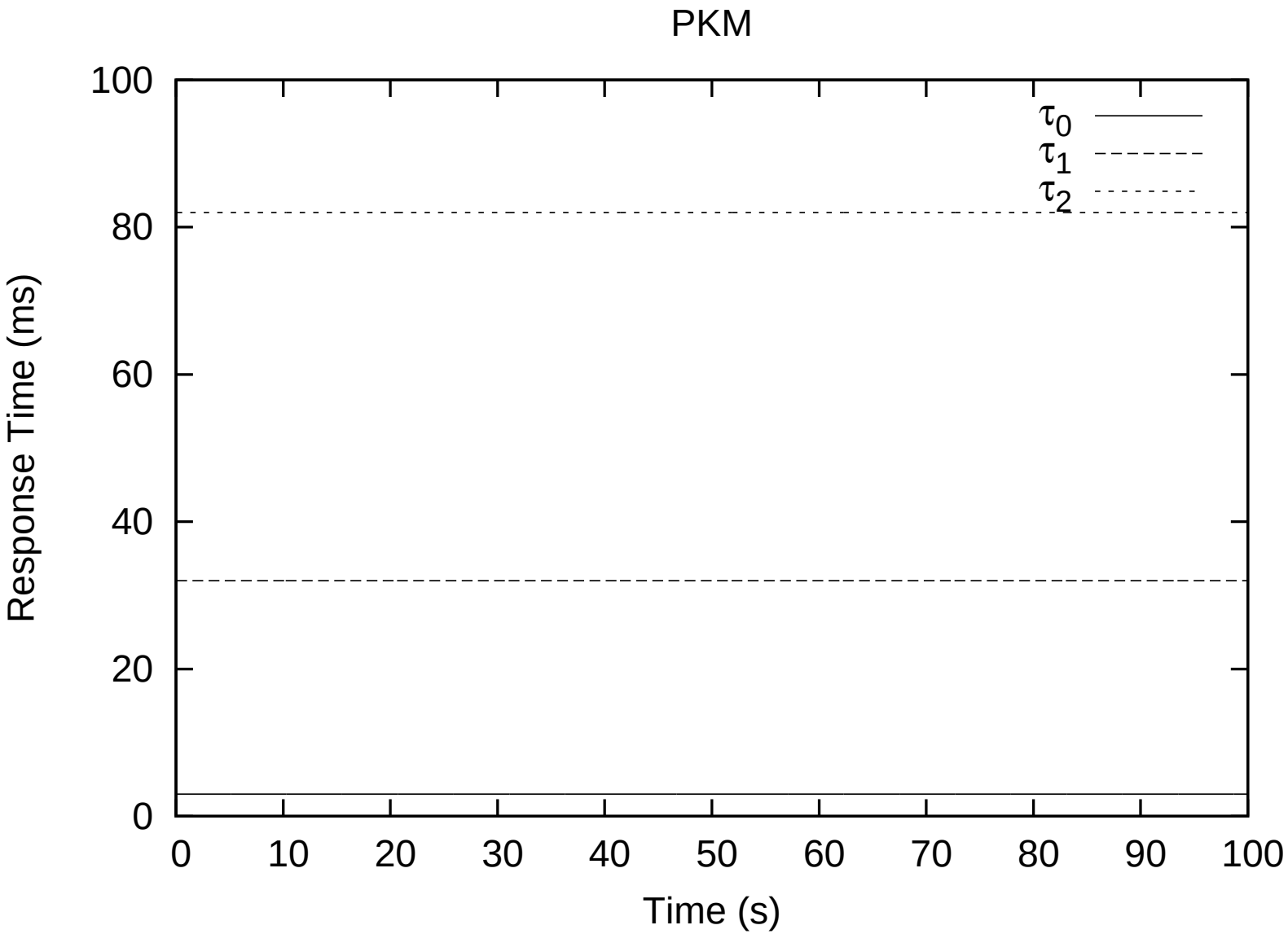

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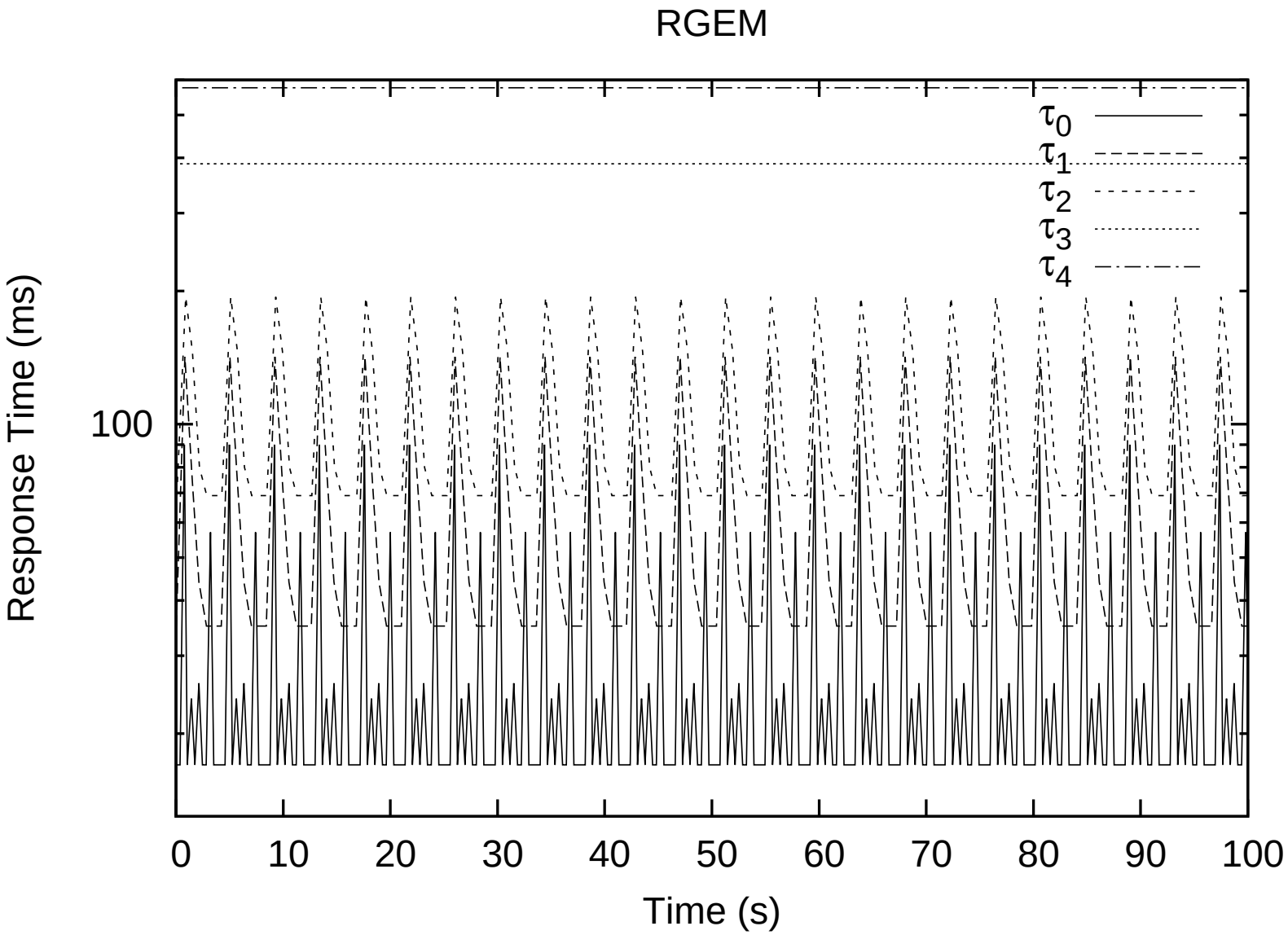

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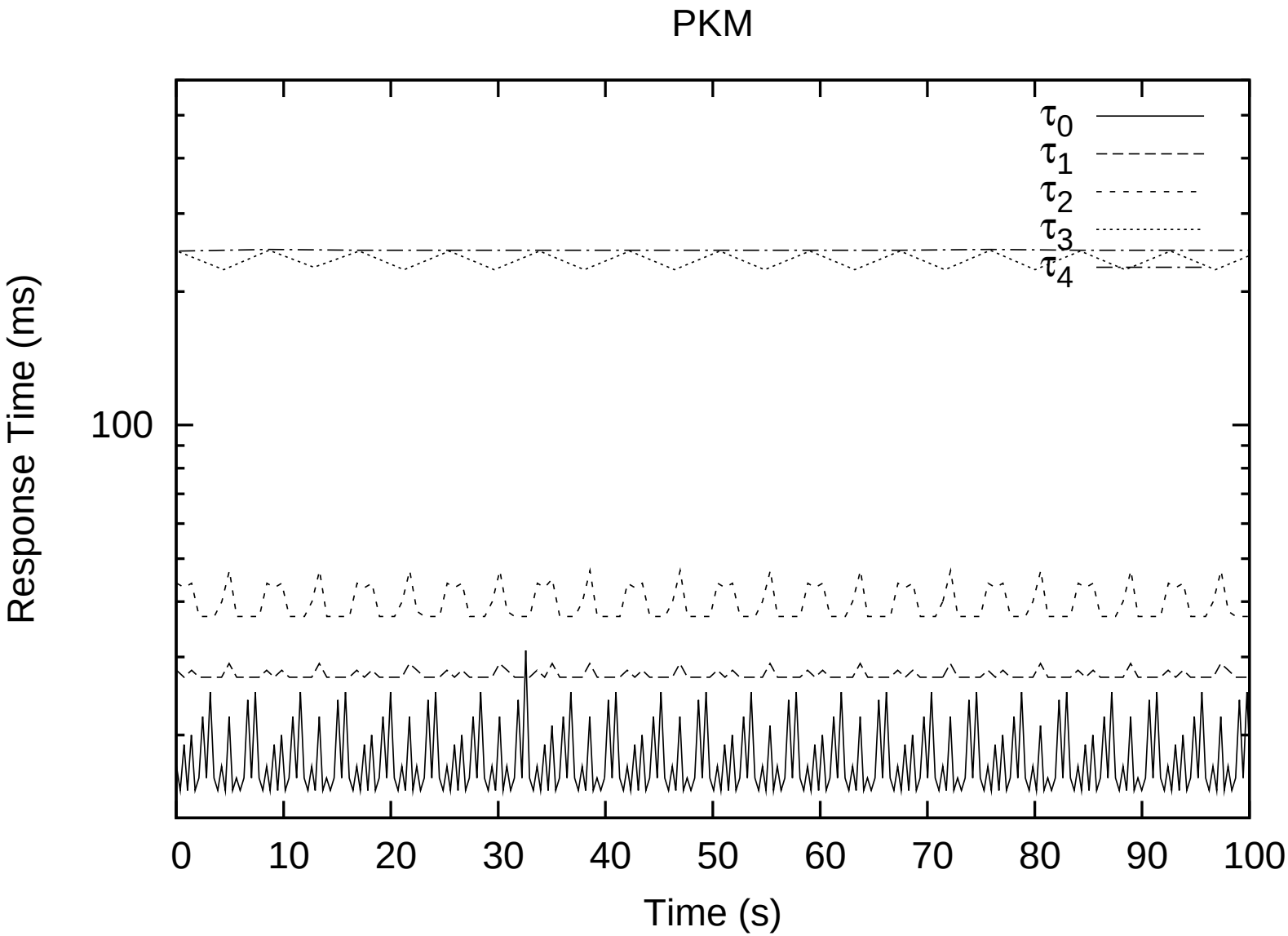

Conclusions

- GPGPUs can provide significant computational power to real-time applications
- Preemptive copies and kernel executions to alleviate potential priority inversion
- Greatly simplifies methods to hide data transfer overhead due to preemptive memcopies and subkernel execution

Future Work

- Schedulability analysis
- Support for dynamic priority scheme
- QoS adaptation
- More advanced applications, e.g., image processing for CPS applications

Thank You

Questions?