Improving gem5's GPUFS Support

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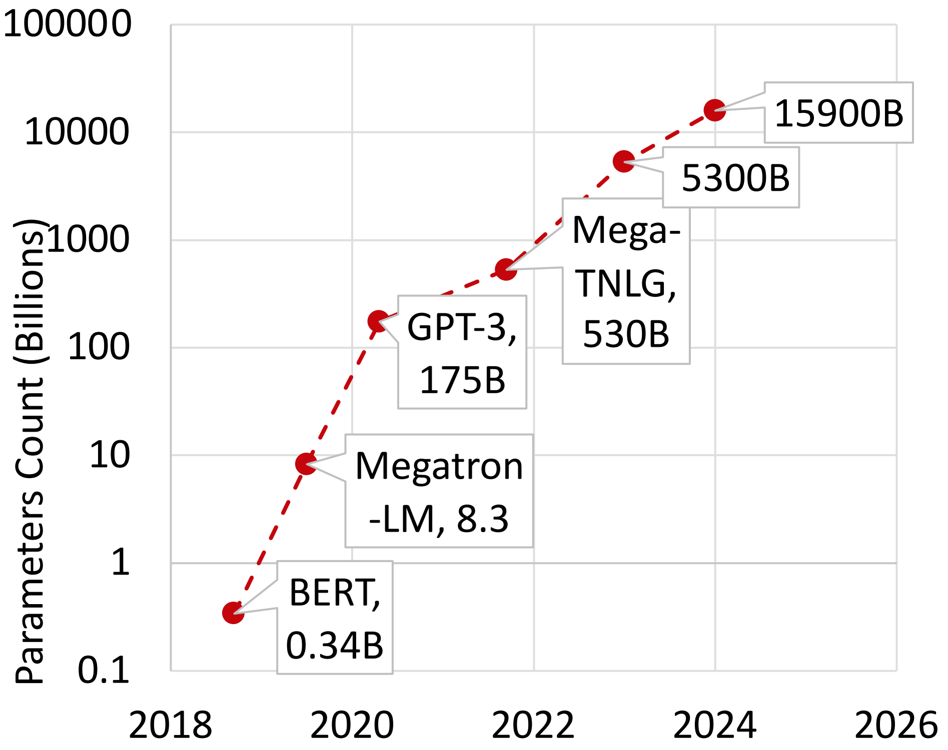
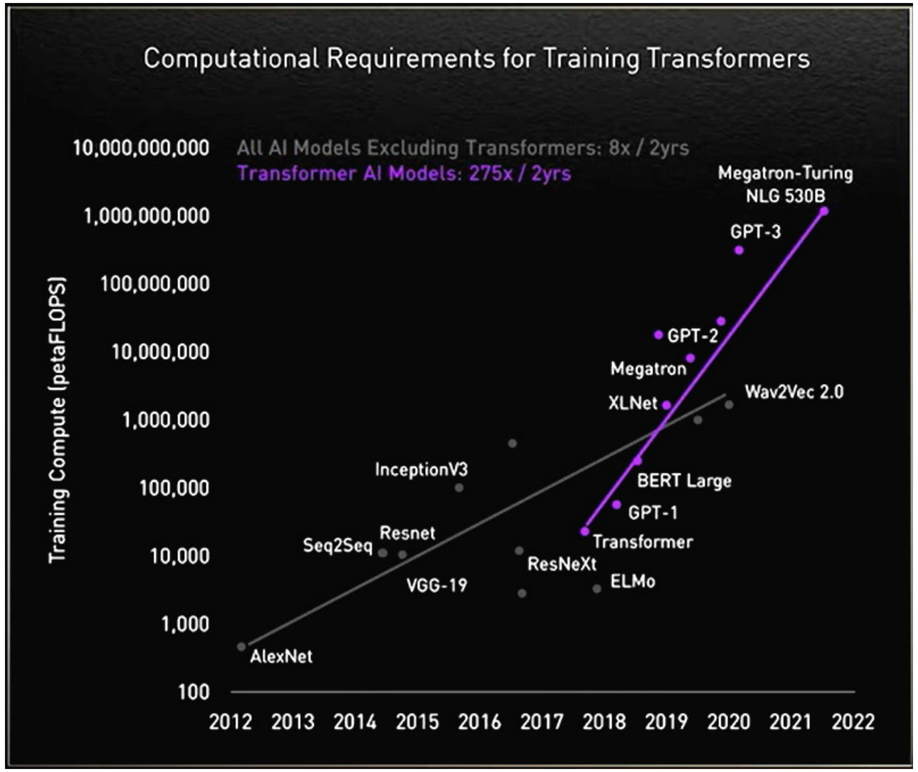
Outline

- Introduction
- Proposal
- Progress
- Conclusion and Future Work

Introduction : Challenges in Application Scaling



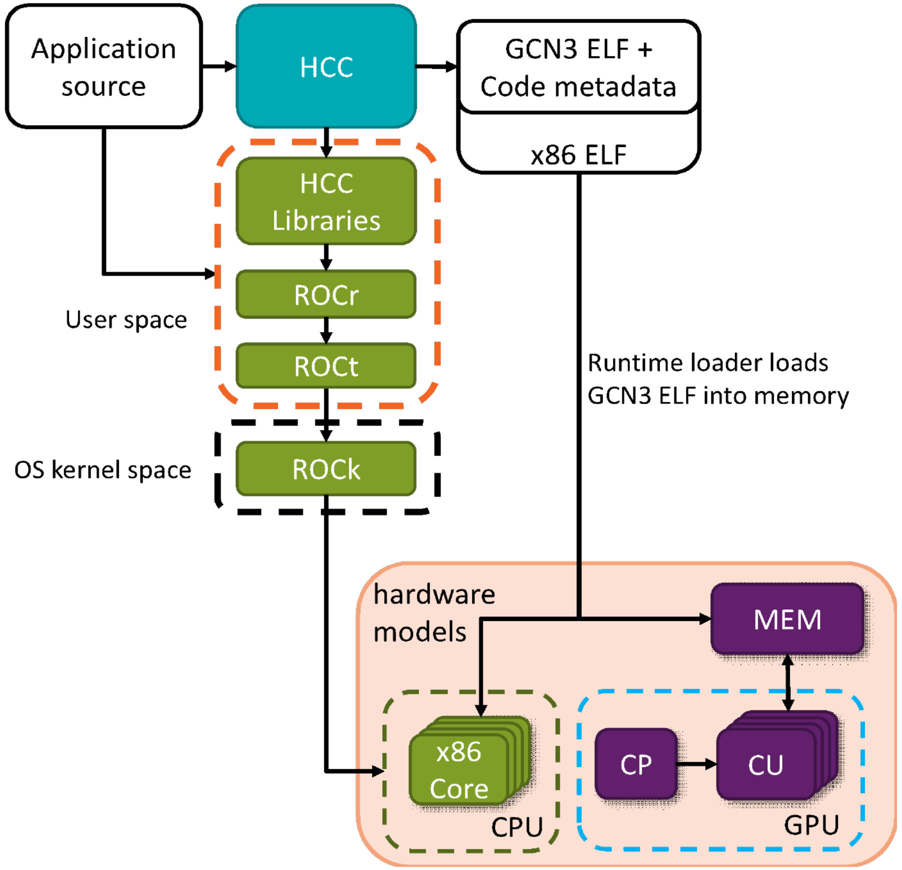


Simulating entire workloads would take months (or years) in modern gem5

How do we make it faster?

Source:
1. https://developer.nvidia.com/blog/using-deepspeed-and-megatron-to-train-megatron-turing-nlg-530b-the-worlds-largest-and-most-powerful-generative-language-model/
2. https://blogs.nvidia.com/blog/2022/03/25/what-is-a-transformer-model/

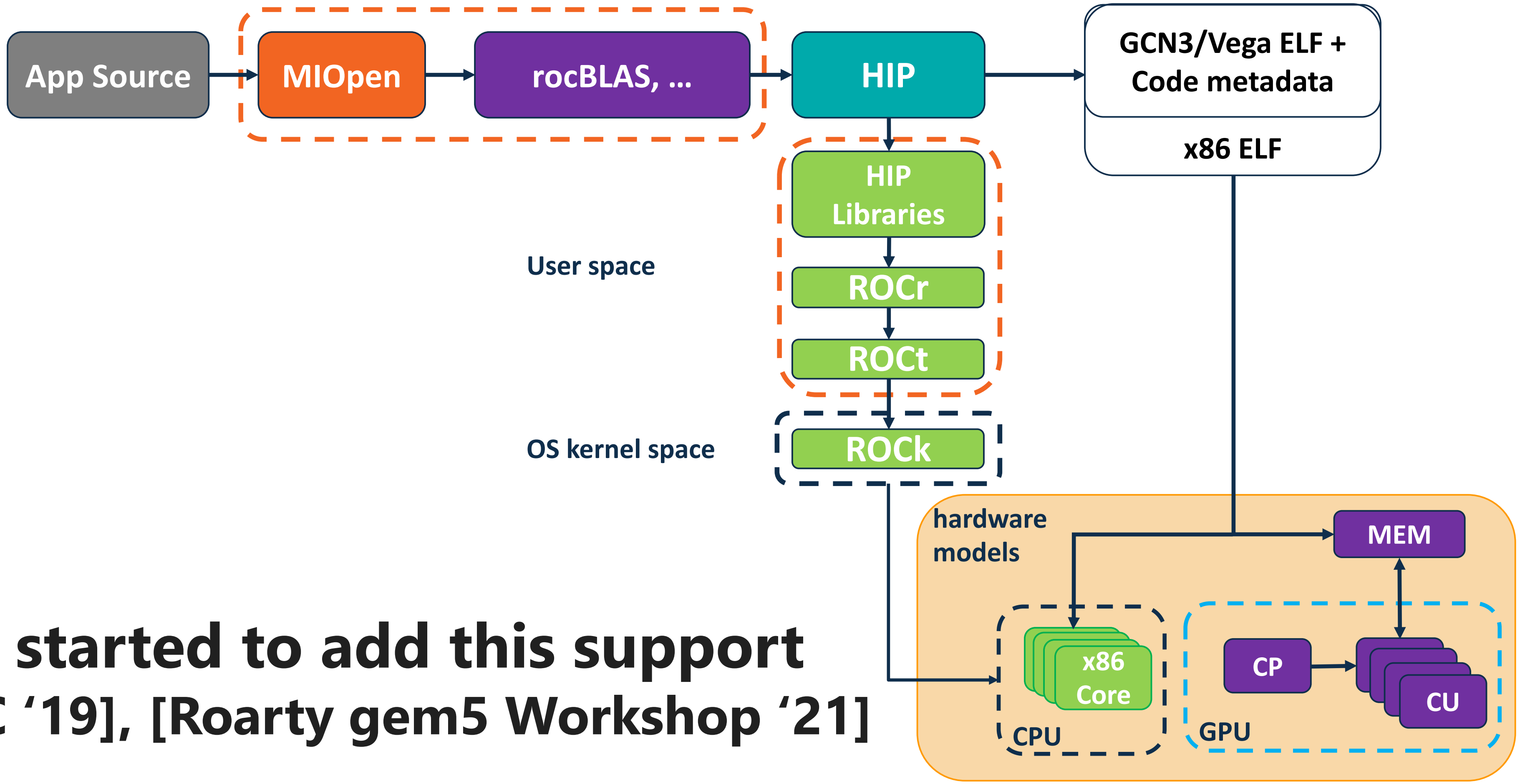
Introduction : Prior CPU-GPU Support in gem5



- Execution-driven, cycle-level
  - Models complex CPUs & GPUs
  - Rapid prototyping of new features
  - Validate simulation with execute-in-execute
- Prior work [Gutierrez et al. HPCA '18]
  - Runs unmodified ROCm 1.6 user stack
  - Simulates HIP and HCC applications
  - HCC/HIP are AMD's GPGPU languages

Solid foundation, but does not support ML workloads

Introduction : ML Support in gem5 CPU-GPU system



We have started to add this support

[Alsop IISWC '19], [Roarty gem5 Workshop '21]

Introduction : GPUFS Support

- Introduced in gem5 v22.0
  - Previously only supported SE mode with ROCm 4.0
  - FS mode supports ROCm 4.2
- Running in SE mode required either a specific host environment containing the ROCm stack or a Docker container that encapsulated this environment
  - GPUFS removes all host requirements
- Improves simulation speed by functionally simulating memory copies
- Adds KVM CPU-GPU support

Introduction : What is KVM CPU

- Kernel-based Virtual Machine (KVM):
  - Open-source virtualization technology built into Linux. Turns Linux into a hypervisor that allows the host machine to run a virtual machine

- KVM CPU allows simulation to fast-forward by running the CPU instructions directly on the virtual machine, instead of timing CPU models
  - Requires the application binary to be compiled for the host machine architecture

- Can be used in CPU-GPU systems to fast forward through CPU code

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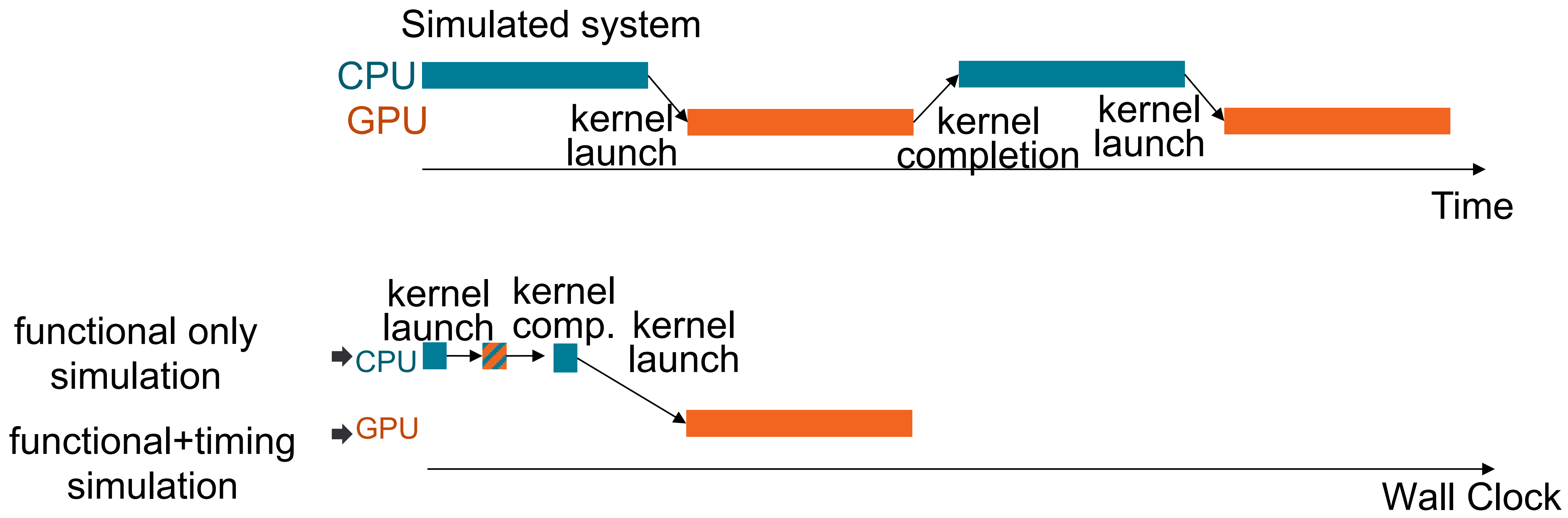
Our Vision to Run Large-Scale Workloads

- Not all parts of the application are equally interesting
  - Some functions/code blocks are “more important” to its behavior
- Applications are simulated multiple times when evaluating new ideas
- **Key Insight** – some regions of the application can be run with low fidelity without affecting the way the other parts interact with the underlying hardware
  - Can use KVM CPU support in GPUFS to do this

Mixed Fidelity for Less Important Application Phases

- May not want to fully simulate certain phases of applications
- Solution: leverage gem5's KVM CPU to functionally simulate these phases



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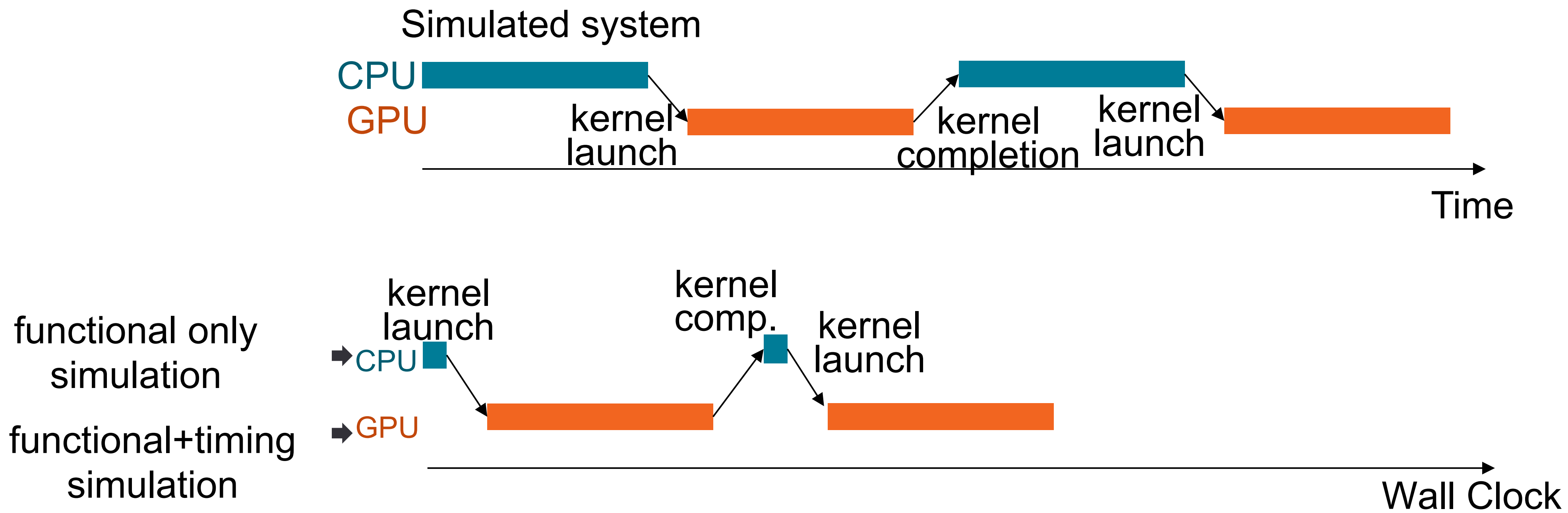
Using KVM CPUs : How Much Does This Help?

- First Step : Utilized KVM support to fast forward through CPU code



Using KVM CPUs : How Much Does This Help?

- Cycle Level GPU Simulation : 10-50 KIPS
- Functional KVM Simulation : 100s MIPS
  - KVM CPU emulating GPU : 10s MIPS
- Conservative speedup for a kernel containing 2B SIMD instructions:
  - 11 hours of cycle-level GPU simulation
  - 3 minutes to execute on KVM CPU – single threaded

On-going Work: full set of results for GPU workloads

Further Refinement : Checkpoints

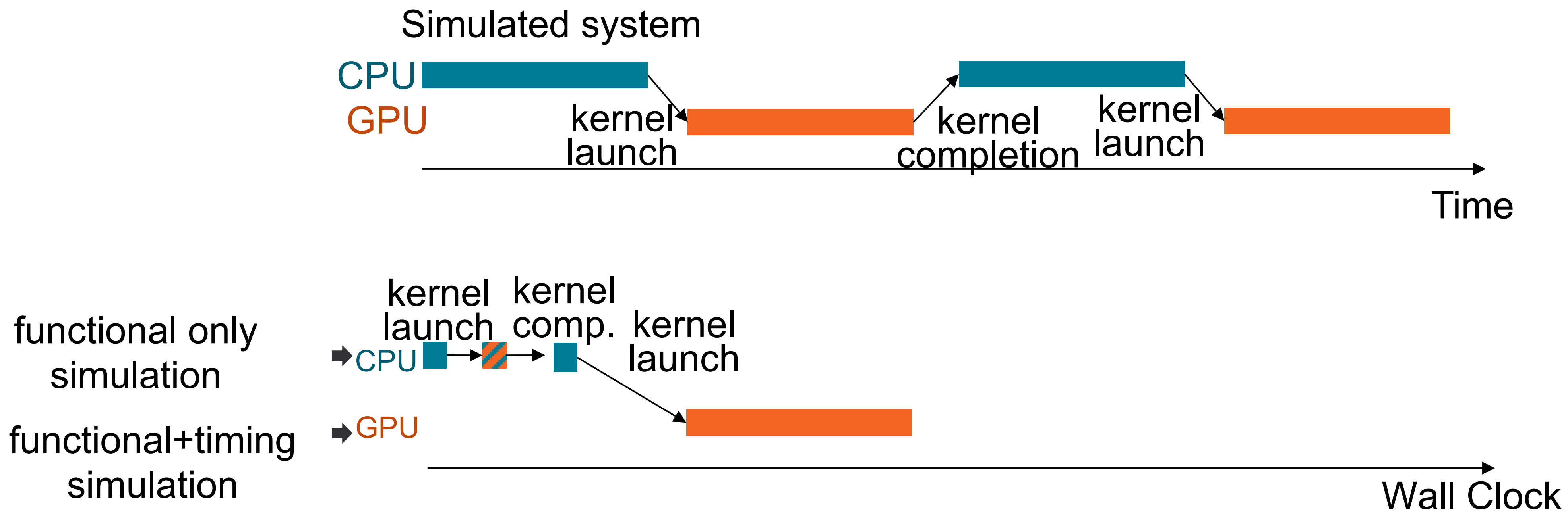
- Users often simulate the same application many times
- Can speedup the execution by not redoing the less important parts
- Solution: create checkpoints (ala CPU SimPoints)
  - Capture the state of the execution when a checkpoint is taken
  - Restore this state the next time the application is run
  - Resume execution from the next instruction after restoration
- Previously only possible for CPUs
  - Added support in GPUs, leveraging gem5’s FS mode and m5 operations

Can We Do Even Better (Faster)?

- Current Task: convert less-important GPU kernels into CPU code
- Update LLVM GPU backend to emit CPU code for kernels
- Use KVM CPU (low fidelity) or another CPU model (medium fidelity)
- Most important phases get max fidelity, others get less fidelity

Can We Do Even Better (Faster)?

- Functionally simulate GPU kernels on CPU
- Preliminary results : only 1.58x – 3x slower on KVM vs bare metal (1 thread)



Mixed Fidelity makes gem5 much closer to real HW

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Conclusion and Future Work

- Large-scale applications that run on the GPU models take extremely large simulation times
- Our updates are the first in a series to significantly reduce runtime for such workloads
- Significantly improves usability and reduce barriers to entry for simulation
- Future Work
  - Profile ML workloads to find regions that can be annotated for checkpointing
  - Integrate other accelerators into mainline gem5
  - Support accelerator fast-forwarding and checkpointing
  - Additional publicly available applications and resources

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