MGPUSim: Enabling Multi-GPU Performance Modeling and Optimization

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Multi-GPU Systems

- **Deliver high computing power**
- **Commonly used for:**
  - Machine learning training and inference
  - Large scale physics simulation
- **Exploit new communication features**
  - Shared Virtual Memory / Unified Memory
  - Demand paging / peer-to-peer memory access
  - System-level atomic operations
- **Require complex modeling capabilities**
  - Capture complex interactions between GPUs
- **Performance analysis for multi-GPU systems is necessary and difficult**

Current GPU Simulators

- **Model dated GPU architectures**
  - New GPU architectures have new multi-GPU communication features
- **Lack flexibility**
- **Have limited simulation scalability**
- **A systematic solution and a new GPU architecture simulator are needed**

Simulator Requirements

- **No magic**
- **Parallel simulation**
- **Traking data w/ timing**
- **No busy ticking**
- **Extension w/o modification**

Akita Simulator Framework

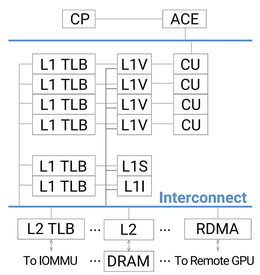
AKITA

https://gitlab.com/akita/akita

- **Implemented in the Go programming language**
- **Highly flexible**
  - Easy to replace components since they follow strong software engineering principles
- **Enables high performance simulation**
  - Pure event-driven simulation
  - Skips redundant simulated state updates
  - Parallel simulation w/o accuracy loss
- **Akita: a high performance simulator framework that can generate a number of high performance CPU/GPU simulators**

MGPUSim

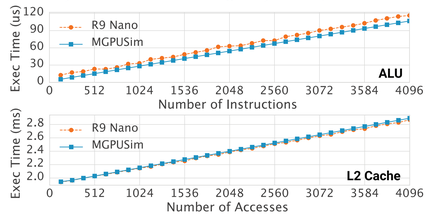
- **Models AMD GCN3 ISA**
  - 6-stage pipeline, w/ concurrent instruction issue
  - Write-through L1 cache, write-back L2 cache
  - Address translation with TLBs and IOMMUs
  - Peer-to-peer memory access using RDMA engines



- **MGPUSim is designed for multi-GPU simulations**
  - To be demonstrated with 2 design studies (Lcality API and Progressive Page-Splitting Migration)

Simulator Validation

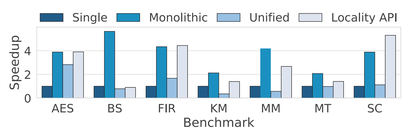
- **Microbenchmark validation**
  - 57 microbenchmarks (all show similar trends as the *ALU* and *L2 Cache* microbenchmark below)
  - High fidelity when simulating key components



- **Full Benchmark validation**
  - 5.5% average error in terms of execution time
- **Parallel simulation perfomance**
  - 3.5X speedup in functional emulation (4-core)
  - 2.5X speedup in detailed timing simulation (4-core)
- **MGPUSim is fast and accurate**

Locality API

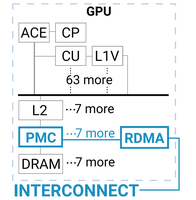
- **Unified GPU model**
  - Easy to program, but low performance
  - Lack of control on data/compute placement
- **Memory Placement API**
  - Remaps pages in consecutive virtual memory address spaces for each GPU
- **Compute Placement API**
  - Launches sub-kernels to each individual GPU



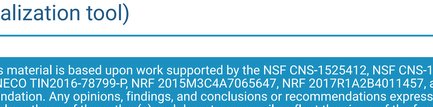
- **Locality API can reduce inter-GPU traffic and improve performance by 1.6X**

PASI (Progressive Page-Splitting Migration)

- **Page migration**
  - Employs Page Migration Controllers (PMC) to migrate pages
  - Better utilizes interconnect bandwidth and data locality



- **ESI coherency protocol**
  - Forms a Cache-Only Memory Architecture for multi-GPU systems
  - Allows GPUs to share pages with a "Shared" (S) state
  - Uses the "Exclusive" (E) state for managing writes



- **Page splitting**
  - Exploits a large initial page size to improve TLB coverage
  - Progressively splits shared pages, up to a minimum size
  - Adaptively finds an efficient page size and placement
- **PASI: 2.6X speedup compared to an unified 4-GPU system**

Takeaways

- **Akita framework**
  - A highly flexible simulator framework
  - High performance parallel simulation
- **MGPUSim**
  - Extensively validated AMD GCN3 Simulator
  - Multi-GPU simulation made easy
- **Locality API & PASI**
  - Design studies that demonstrate the flexibility and utility of MGPUSim
  - Explores effective multi-GPU memory management
- **Future work**
  - Modeling RISC-V based CPU architectures
  - Adding useful features to Akita (e.g. checkpointing, a visualization tool)

For more information, please visit **bit.ly/mgpusim**

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