GAMER
(GPU-accelerated Adaptive-MEsh-Refinement)
&
Out-of-core Computation

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Outline

- AMR
- AMR + GPUs
  - Performance ( Hydrodynamics / Poisson / Overall )
  - Optimization
- AMR + GPUs + OOC (out-of-core)
- Conclusion and Future Work
AMR Scheme in GAMER

- Refinement unit: patch (containing a fixed number of cells, e.g., $8^3$), similar to FLASH
- Hierarchical oct-tree data-structure
- Individual time-step
CPU-GPU Collaboration

- Two main tasks in AMR:

1. **Patch construction**: decision making, interpolation, complex data-structure, data assignment …
   ~ complicated, but consume less time
   - CPUs

2. **3-D hydrodynamic + Poisson solvers**: 
   ~ straightforward, but time-consuming
   - GPUs
   - feed with hundreds of patches simultaneously
Multi-GPU Example
Performance: Hydrodynamic Solver

- Second-order relaxing TVD scheme
- Data transfer between CPU and GPU is overlapped by GPU computation
- Currently the ghost-zone interpolation is performed by CPU
- One T10 GPU vs. one Xeon E5520 CPU core
  - Speed-up ratio: 23.9x
Performance: Poisson Solver

- **Root level**: fast Fourier transform (FFT)
  - use **CPUs** only
- **Refinement levels**: successive overrelaxation method (SOR)
  - use **GPUs**
- **Coarse-grid interpolation** is performed by GPU
- **One T10 GPU vs. one Xeon E5520 CPU core**
  - Speed-up ratio: **40.9x**

![Graph showing speed-up ratio vs. number of patch groups per stream (N_y)]
Performance: Overall

- **GPU vs. CPU**
  - # of GPUs: 1 ~ 16
  - One GPU in each computing node

- Purely baryonic cosmological simulation
  - Root level: 256³
  - 5 refinement levels
  - Effective resolution: 8192³

- **Speed-up ratio**
  - 10.23x (1 GPU vs. 1 CPU core)
  - 10.05x (16 GPUs vs. 16 cores)

- z=100 to z=0, 16 GPUs
  - 8 hours (725 root-level steps)
Optimization:

Concurrent Execution between CPU and GPU

- Speed-up ratio: $10.23x \rightarrow 16.25x$
Future Optimizations

- To be honest, # of CPU cores / GPUs per node is usually 2~4

- Issue: Fluid solver: CPU time >> GPU time
  1. Perform the ghost-zone interpolation in GPU
  2. Relaxing TVD scheme is not very computation-intensive
     - Adopt a more accurate scheme, e.g., PPM, approximate/exact Riemann solver ...

- SOR method is too slow ...
  - Multi-grid, FFT, super-stepping ...

- Not load-balance → space-filling curve

- 128 GPUs benchmark tests are on the way!
AMR + GPUs + Out-of-core
Motivation

- **Performance**: GPU / CPU → 10x
  - 1 small simulation
  - 10 small simulations
  - 1 larger simulation ?

- **Memory**: Hard disk / Ram → 10x ~ 100x
  - Limited memory
  - 1 ~ 8 TB memory per node ?
Issue I: Hard Disk Bandwidth

- Single HD: ~100 MB/s → Multiple HDs ??
- Prototype: 8 HDs → 750 MB/s
  - Distribute data by direct I/O, not RAID
  - More detailed control of data storage

Spartan
Issue II: Out-of-core + AMR

- Just apply the same domain decomposition as the case using MPI only

**BLUE number: MPI rank**
- In different nodes
- Updated in parallel
- Data transfer: network
- MPI_Send, MPI_Recv

**RED number: OOC rank**
- In the same node
- Updated sequentially
- Data transfer: hard disk
- OOC_Send, OOC_Recv
Performance I: Uniform Mesh

- Resolution: \(2048^3\) grids
- Total memory requirement: \(~ 400\) GB
  - 50x larger than the ram in our prototype system
- Decomposed into \(8^3\) OOC ranks in a single node
- Each OOC rank works on \(256^3\) grids
Performance II: AMR

- Root level: $512^3$
- 5 refinement levels
- Effective resolution: $16,384^3$
- Total memory requirement: ~100 GB
  - 12.5x larger than the ram in our prototype system
- Decomposed into $4^3$ OOC ranks in a single node
Future Work

- More physics
  - I want to write my own MHD code
  - Dark matter particles
  - Cooling, feed-back, radiation transfer …

- Out-of-core computation
  - Optimization
  - Multi-node test

- OpenMP + MPI + GPU
  - Fully exploit the computing power of a single node

- OpenCL

- Open source
Conclusion

- **GAMER**: GPU-accelerated Adaptive-MEsh-Refinement Code
  - GPU hydrodynamic and Poisson solvers
  - Parallelized (multi CPUs + multi GPUs)
  - A framework of AMR + GPUs → general-purpose, flexible
  - 16x faster than CPUs (N GPUs vs. N CPU cores in NAOC)

- **Optimizations**
  - Concurrency of memory copy and kernel execution
  - Concurrency of CPU work and GPU work

- **Out-of-core**
  - Increase the simulation size: 10x ~ 100x
  - Small-scale GPU cluster vs. large-scale CPU cluster