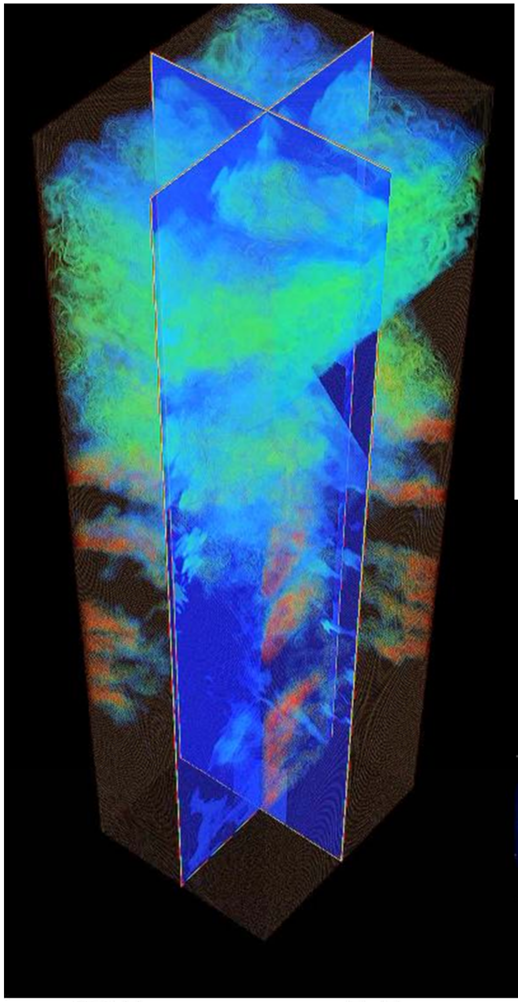
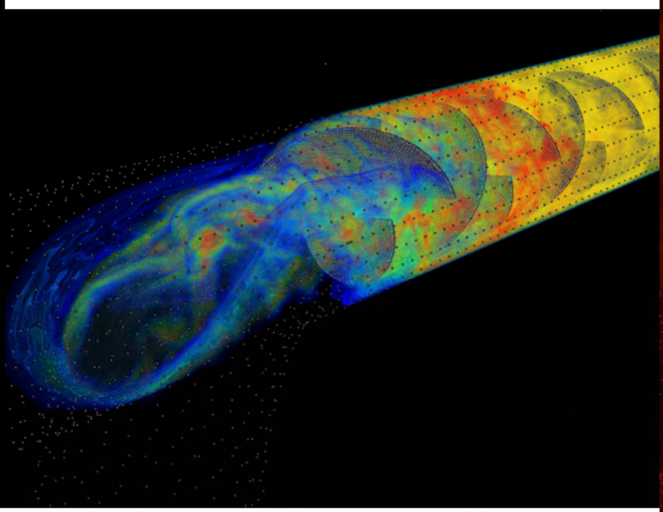
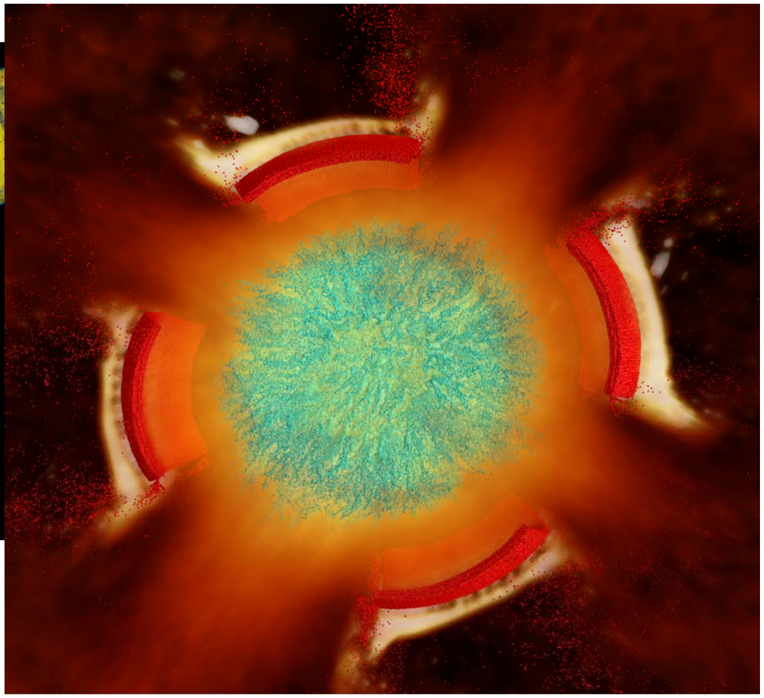




The Uintah Framework: A Unified Heterogeneous Task Scheduling and Runtime System



Qingyu Meng, Alan Humphrey, Martin Berzins

Thanks to: John Schmidt and J. Davison de St. Germain, SCI Institute
Justin Luitjens and Steve Parker, NVIDIA

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DOE for funding the CSAFE project (97-10), DOE NETL, DOE NNSA
NSF for funding via SDCI and PetaApps

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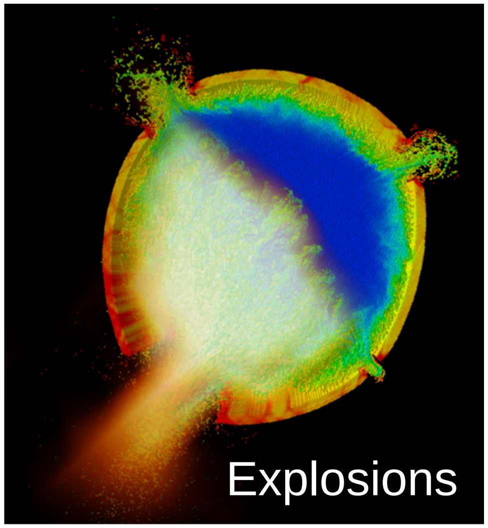
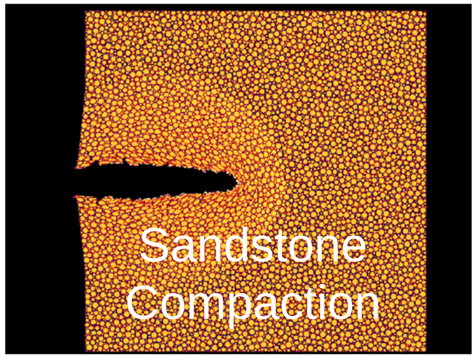
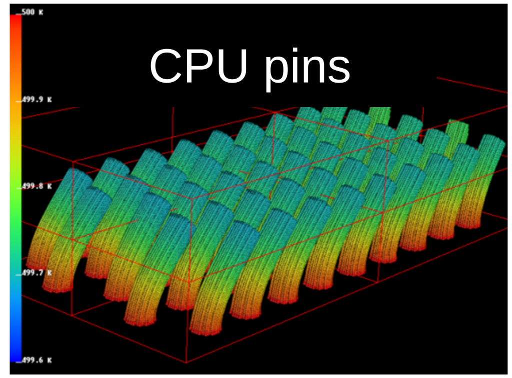
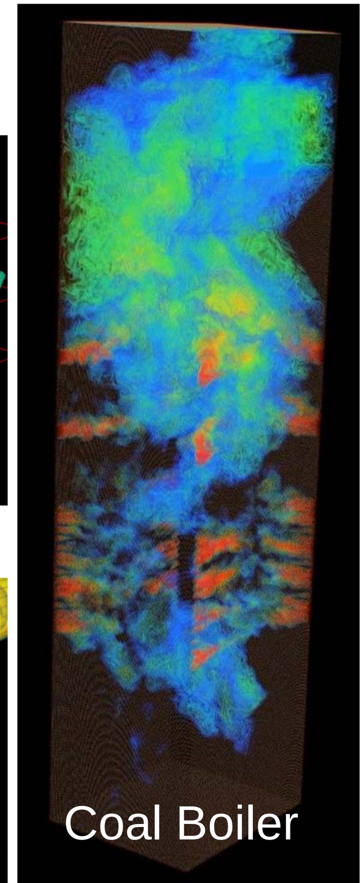
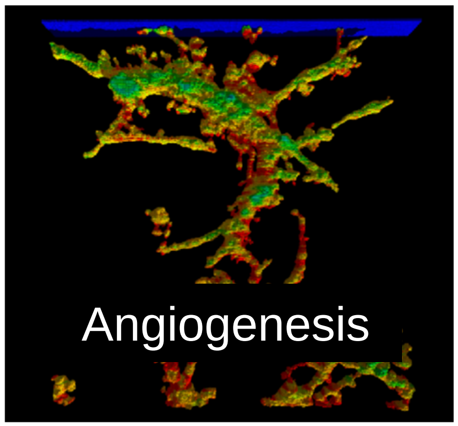
Current and Past Uintah Applications

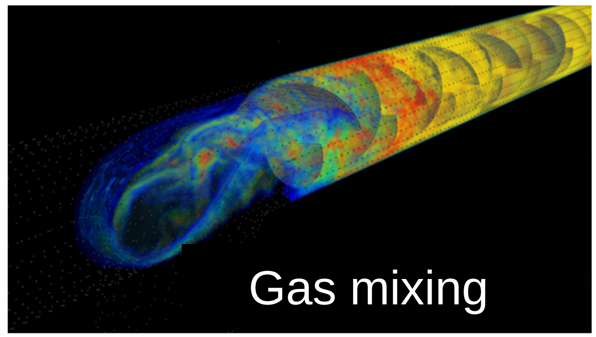

Explosions


Sandstone Compaction

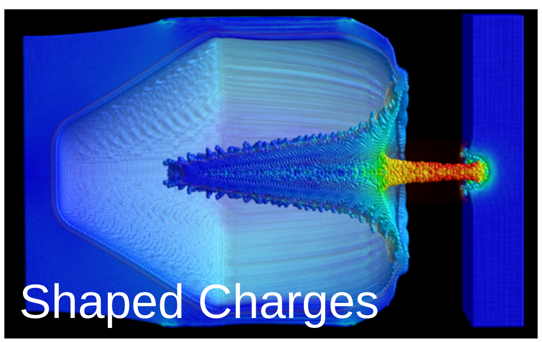

CPU pins

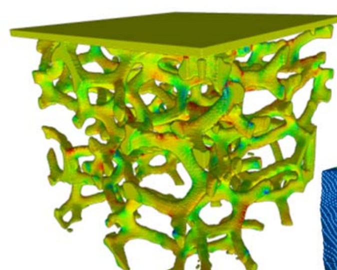

Coal Boiler

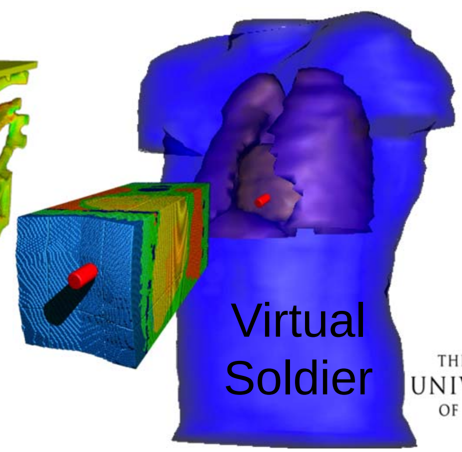

Angiogenesis


Gas mixing


Fires


Shaped Charges


Foam Compaction


Virtual Soldier

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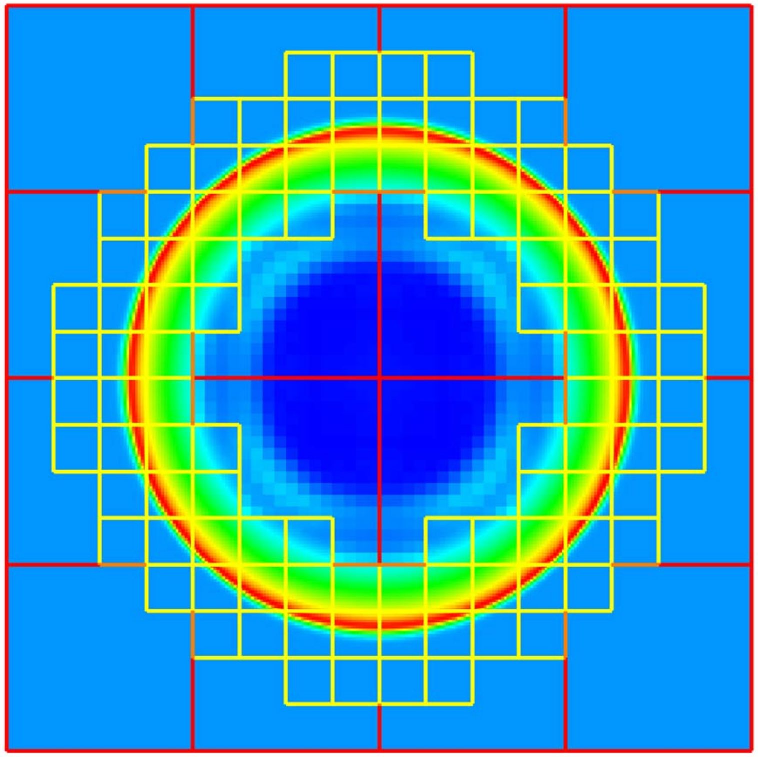
Uintah Data Parallelism

Uintah uses both data and task parallelism



Gird and Patches
(Physical Domain)

- Structured Grid(Flows) + Particles System(Solids)
- Patch-based Domain Decomposition for Parallel Processing
- Adaptive Mesh Refinement
- Dynamic Load Balancing
  - Profiling + Forecasting Model
  - Parallel Space Filling Curves
  - Data Migration

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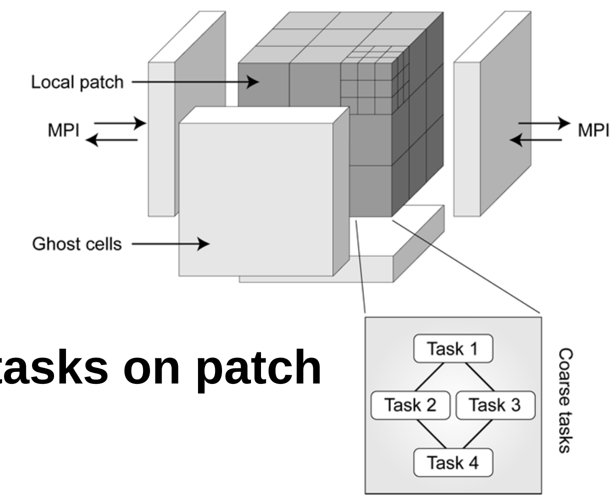
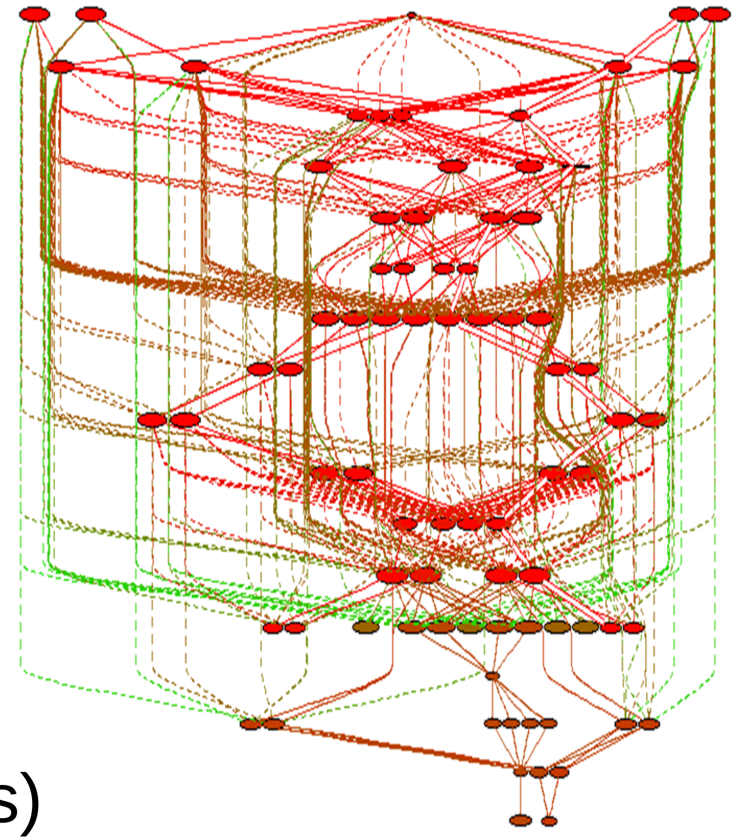
Uintah Task Parallelism and Uintah Task Graph

Patch-based domain decomposition



tasks on patch

Compile



Task Graph

- User defines Uintah Tasks:
  - **Serial** code (call back functions)
  - **Input** and **output** variables
- **Distributed**: only creates tasks on local patches
- Framework analyzes task dependencies and creates TG
  - **Automatic** MPI message generation
  - **Dynamic** Task Execution (Data Driven Overlap)

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Uintah Runtime System: How Uintah Runs Tasks

- **Memory Manager**: Uintah Data Warehouse (DW)
  - Variable dictionary (hashed map from: Variable Name, Patch ID, Material ID keys to memory)
  - Provide interfaces for tasks to
    - Allocate variables
    - Put variables into DW
    - Get variables from DW
  - **Automatic Scrubbing** (garbage collection)
  - **Checkpointing & Restart** (data archiver)
- **Task Manager**: Uintah schedulers
  - Decides when and where to run tasks
  - Decides when to process MPI

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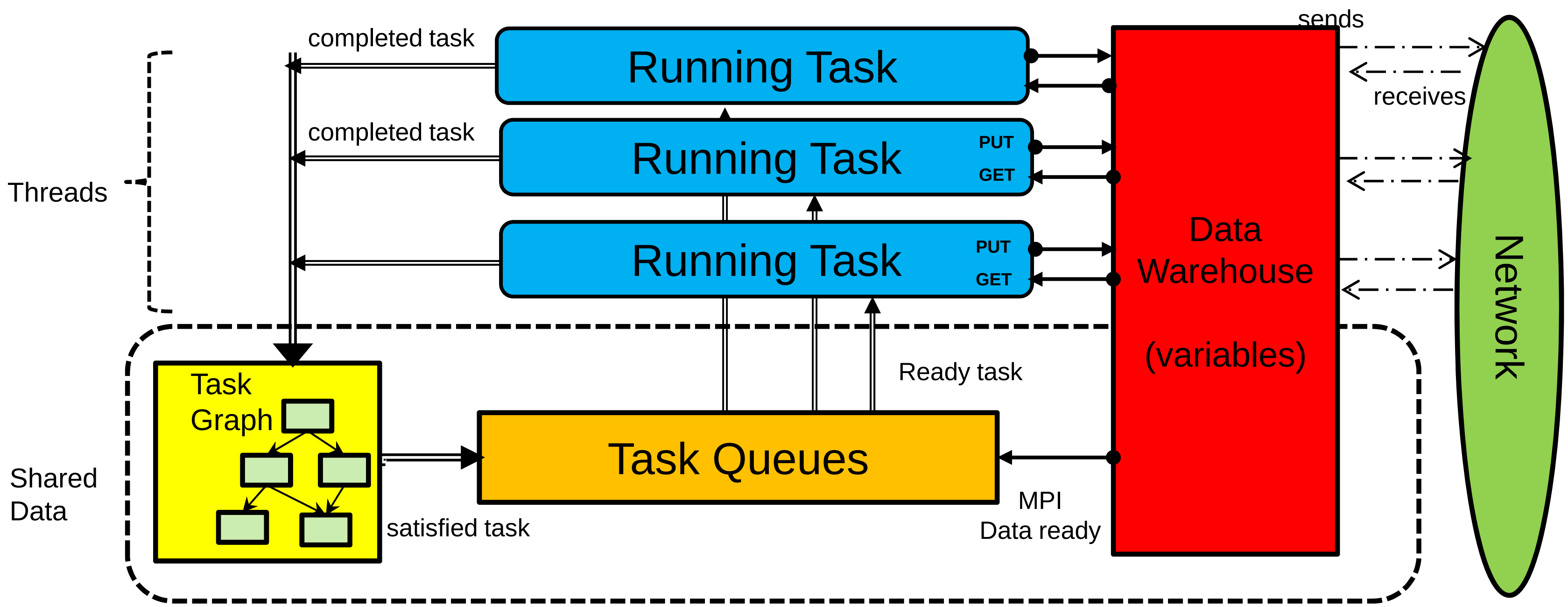
Thread/MPI Scheduler (De-centralized)



- **Memory saving:** reduce ghost copies and metadata
- **Work stealing** inside node: all threads directly pull tasks from task queues, no on-node MPI
- **Full Overlapping**: All threads process MPI sends/receives and execute tasks
- Use **lock-free** data structure (avoid locking overhead)

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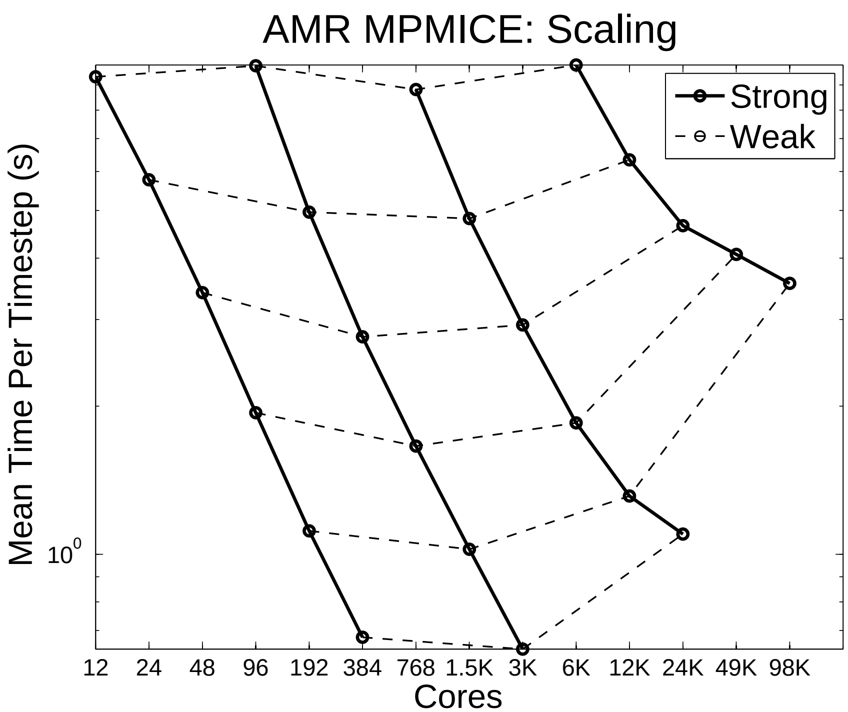
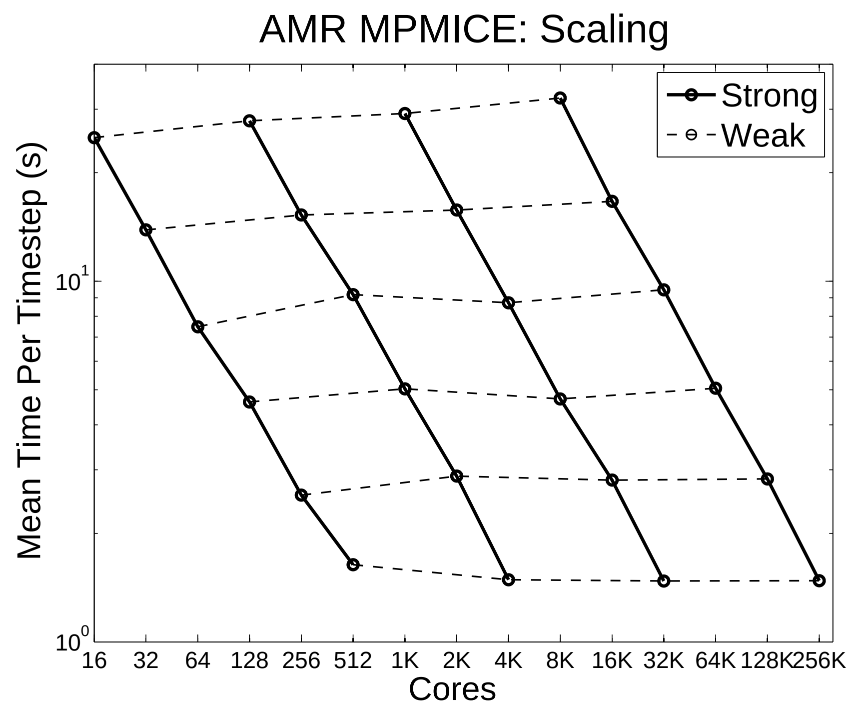
Scalability Improvement



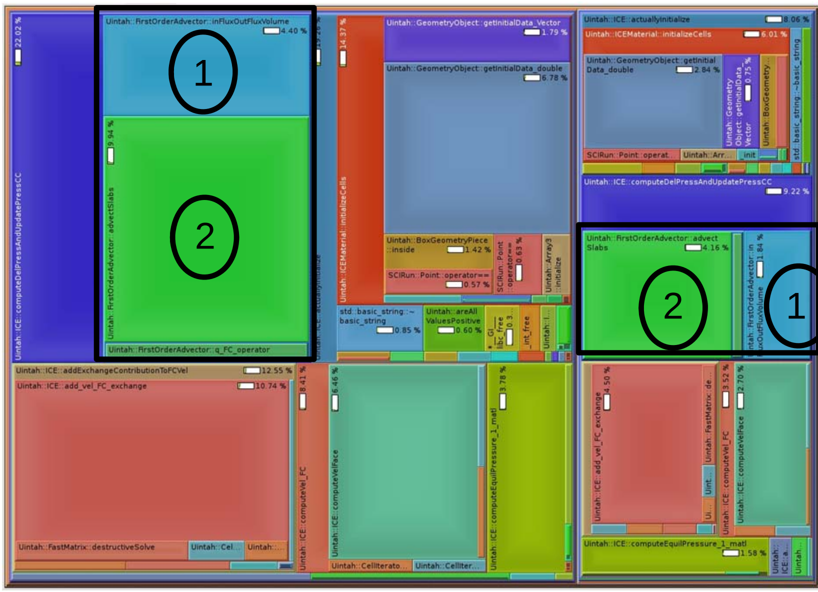
Original Dynamic MPI-only Scheduler



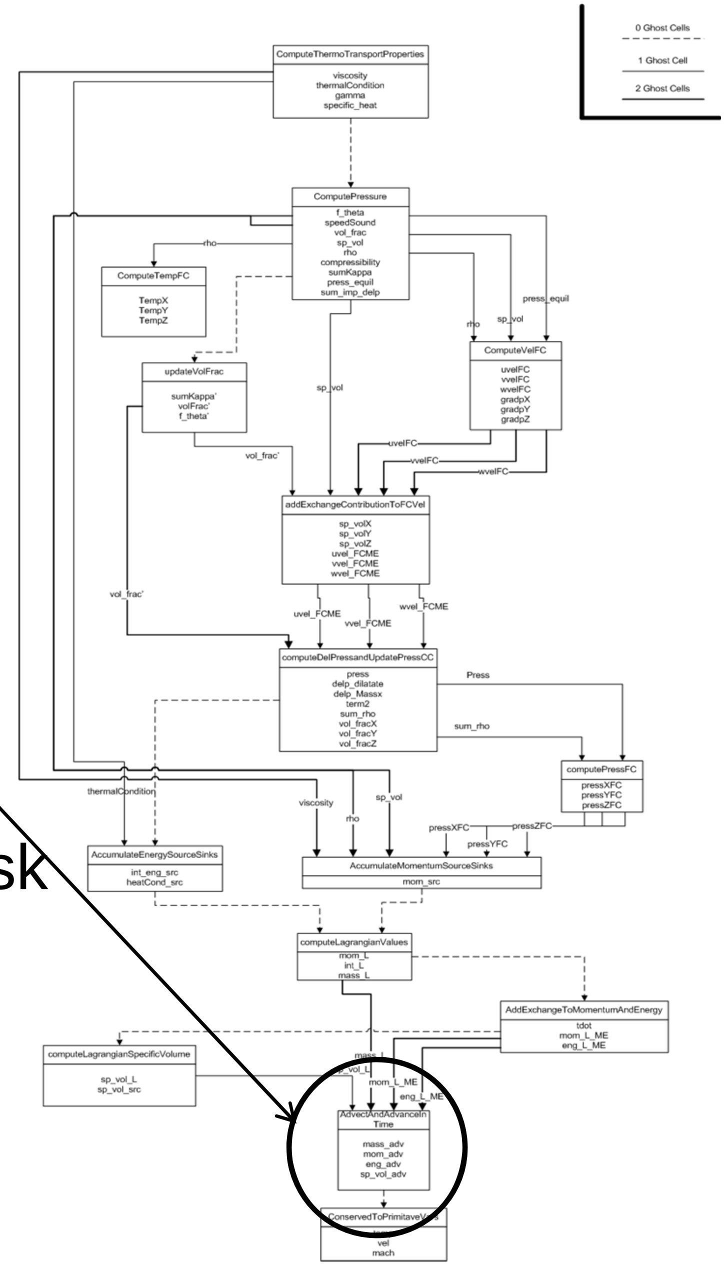
De-centralized MPI/Thread Hybrid Scheduler
(with Lock-free Data Warehouse)

- Achieve much better CPU Scalability
- 95% weak scaling efficiency on 256K cores (Jaguar XK6)
- Use GPUs to accelerate Uintah Components

First step to GPU



Generated by Google profiling tool, visualized by Kcachegrind



- **Profile** & find most time consuming task
- **Port** task's serial CPU code to GPU
- Call CUDA API **inside task** code
- Framework **unaware** of GPU(s)
- **Result**: ~2x speedup (stencil code)
  - must hide PCIe latency

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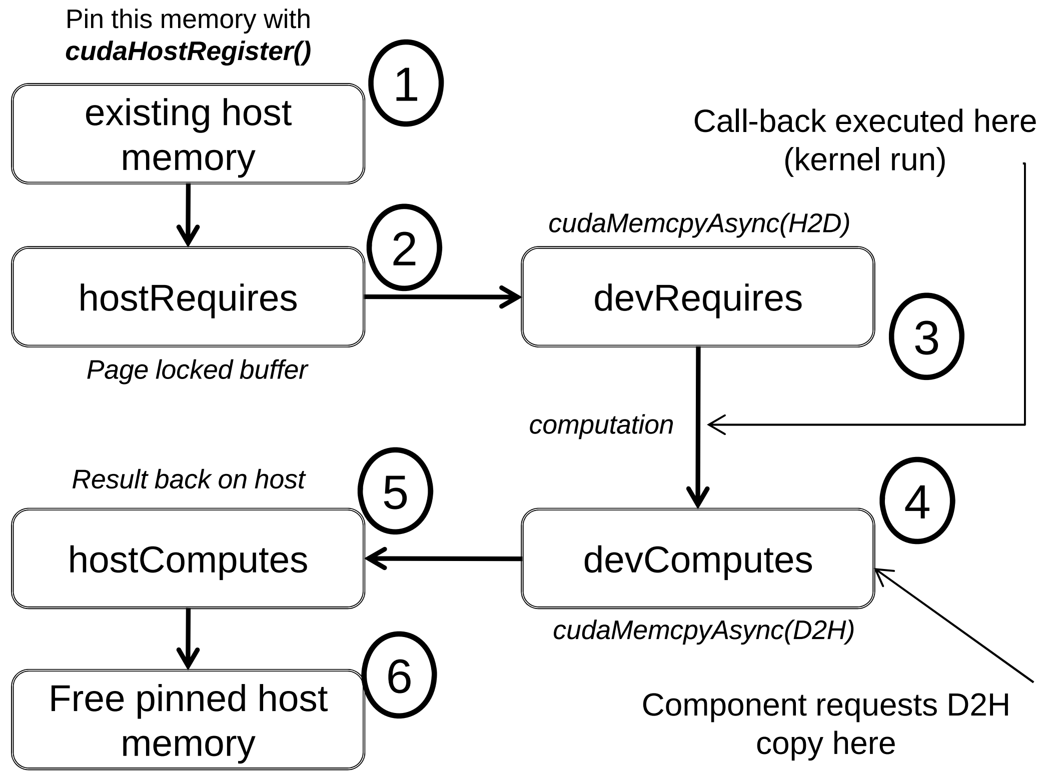
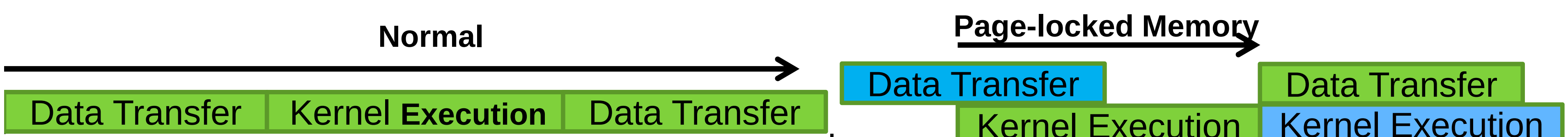
Uintah GPU Task Management

Framework manages all CUDA data movement (NOT inside task)

- Use ***Asynchronous API***
- **Automatically** generate CUDA stream for each dependency
- **Concurrently** execute kernels and memcopies
- **Prefetching** data before task kernel execute
- **Multi-GPU** support
- Two call back functions for both CPU version and GPU version: **Compatible** for non-GPU nodes



Stages of GPU task in Uintah runtime



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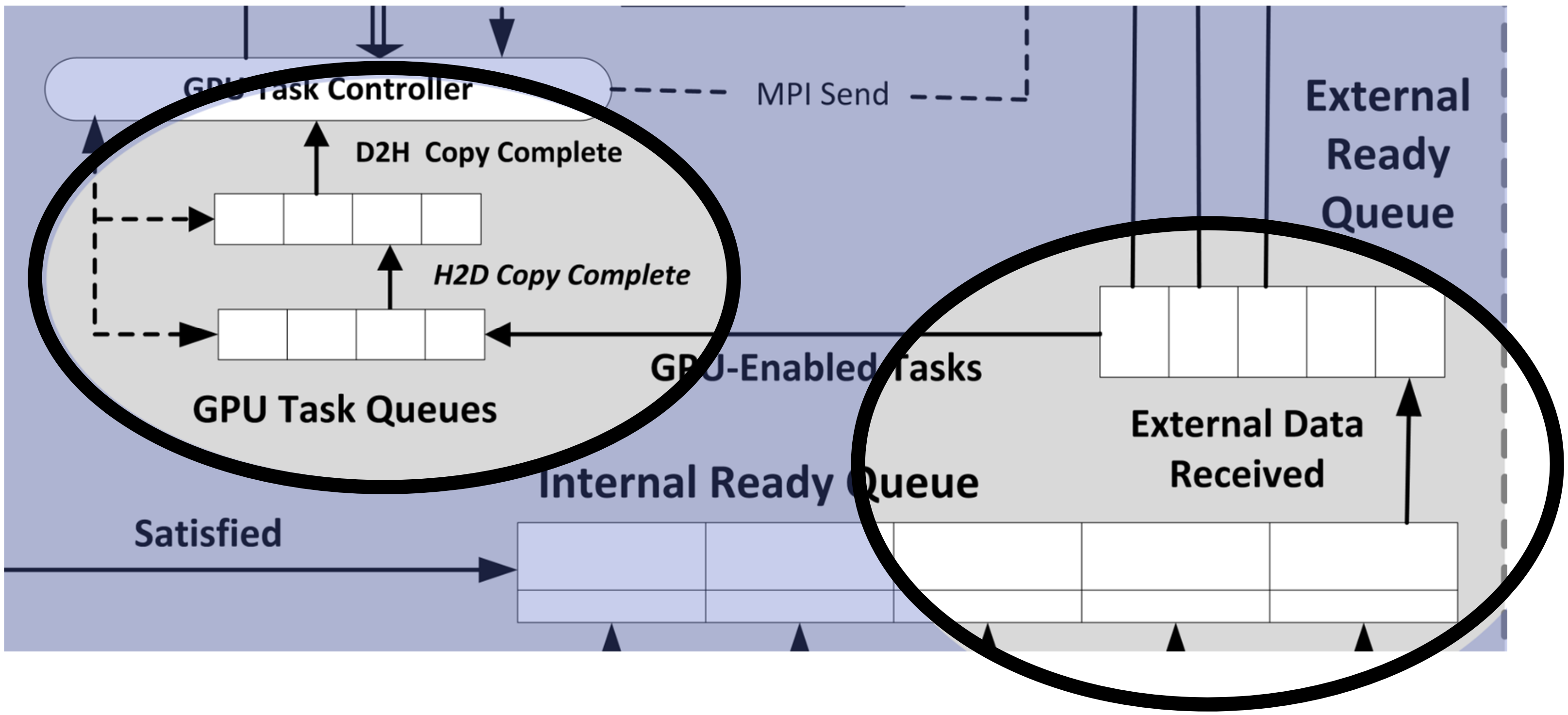
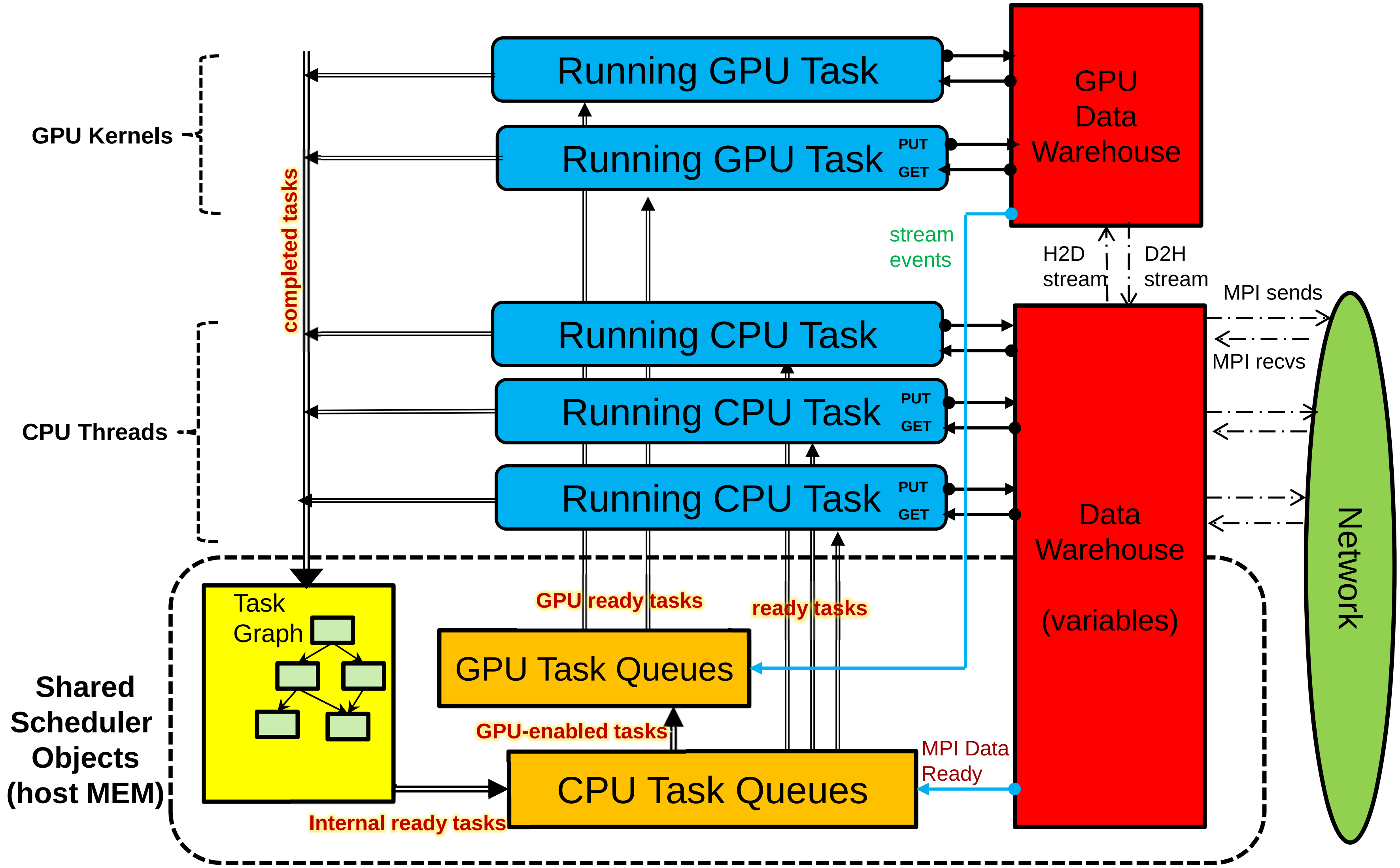
Multistage Task Queues Architecture



Fully Overlap computation with PCIe transfers and MPI communication

Unified Heterogeneous Scheduler & Runtime



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GPU RMCRT Speedup Results
(Multi-Node)

All CPU cores vs Single GPU				
	Nodes	**CPU(sec)**	**CPU+GPU (sec)**	**Speedup (x)**
Keeneland Initial Delivery System	1	319.769	8.49714	38 X
	2	163.773	7.68571	21X
	4	70.0943	4.80571	14X
	8	39.5686	2.62857	15X
	16	20.2414	3.52857	6X *
	32	18.8043	2.73857	6X *
	64	9.11571	2.95714	3X *

- **CPU Core – (2) Intel Xeon 6-core X5660 (Westmere) @2.8GHz**
- **GPU – (1) Nvidia M2090**

*** GPU implementation quickly runs out of work, scaling breaks down**

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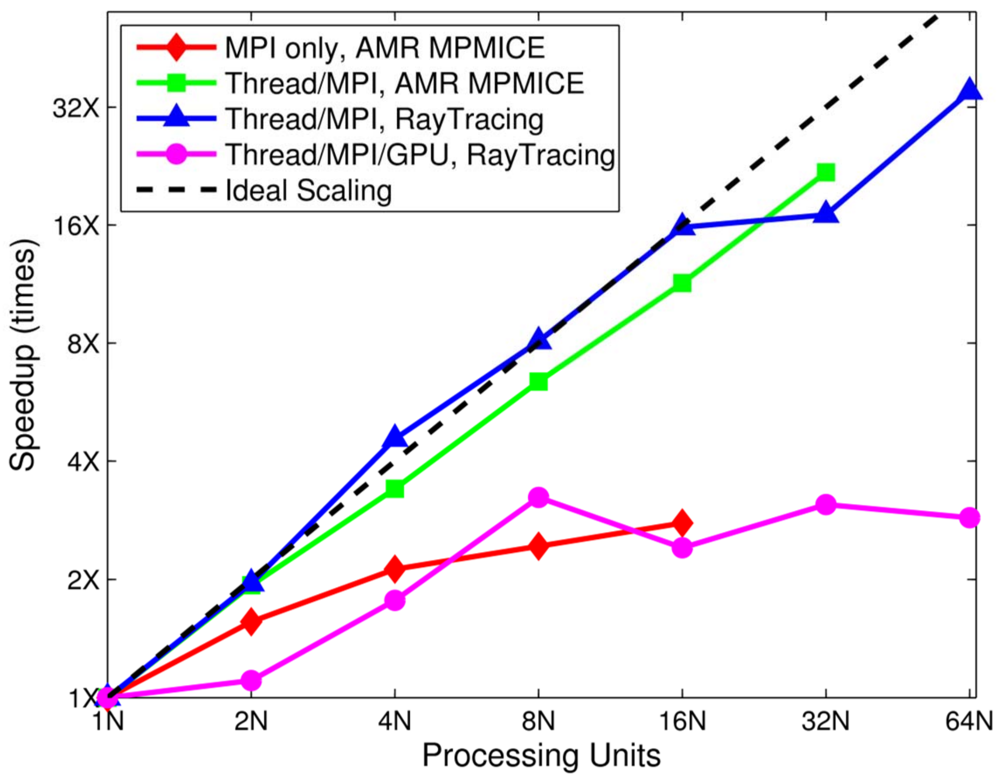
Scaling Comparisons



- Uintah strong scaling results when using:
  - MPI-only
  - Multi-threaded MPI
  - Multi-threaded MPI w/ GPU
- Two Problems:
  - AMR MPMICE

    Nearest neighbors communication

    3.62 billion particles
  - GPU-enabled ray tracer

    All-to-all communication

    100 rays per cell 128^3 cells

Uintah Scaling Overview

- MPI only AMR MPMICE: N=6144 CPU cores; Largest = 98K CPU cores
- Thread/MPI AMR MPMICE: N=8192 CPU cores; **Largest=256K CPU cores**
- Thread/MPI RayTracing: N=16 CPU cores; Largest=1024 CPU cores
- Thread/MPI/GPU RayTracing: N=16 CPU and 1 GPU; **Largest=1024 CPU and 64 GPU**

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Future Work

- **Scheduler – Infrastructure**
  - GPU affinity for multi socket/GPU nodes
  - Support Intel MIC (Xeon Phi) offload-mode
  - PETSc GPU interface utilization
  - Mechanism to dynamically determine whether to run GPU or CPU version task
  - Optimize GPU codes for Nvidia Kepler
    - CUDA 5.0 – Dynamic Parallelism
    - GPU sub-scheduler

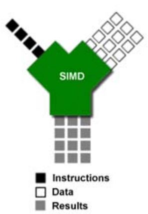
Questions?

Alstom Clean Coal Boiler Simulation
Monte Carlo Ray Tracing on GPU, Flow simulation on CPU

Software Homepage http://www.uintah.utah.edu/

Using GPUs in Energy Applications

- **ARCHES** Combustion Component
  - Alstom Clean Coal Boiler Problem
- Need to approximate radiation transfer equation
- Reverse Monte Carlo Ray Tracing (RMCRT)



  - Rays mutually exclusive - traced simultaneously
  - Ideal for **SIMD** parallelization of GPU
- Offload Ray Tracing and RNG to GPU(s)
  - CPU cores can perform other computation

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Performance Comparisons

Master-Slave Model vs. Unified

Execution Times – CPU Only					
#Cores	**2**	**4**	**8**	**16**	**32**
Master Slave	57.28	20.72	9.40	4.81	2.95
Unified	29.79	15.70	8.23	4.54	2.78

Execution Times – With GPU						
#Cores	**2**	**4**	**6**	**8**	**10**	**12**
Master Slave	4.55	4.09	3.95	3.68	3.64	3.34
Unified	3.82	3.52	3.09	2.90	2.50	2.09

CPU Problem*:* Combined MPMICE problem using AMR

Run on single Cray XE6 node with two 16-core AMD Opteron 6200 Series (Interlagos cores @2.6GHz) processors

GPU Problem*:* Reverse Monte Carlo Ray Tracer

Run on a single 12-core heterogeneous node (two Intel Xeon X5650 processors each with Westmere 6-core @2.67GHz, (2) Nvidia Tesla C2070 GPUs and (1) Nvidia GeForce 570 GTX GPU)

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