### Introduction

The Uintah Computational Framework (UCF) is a software framework that provides an environment for solving fluid-structure interaction problems on structured adaptive grids on large-scale science and engineering problems involving the solution of partial differential equations.

**Uintah Applications:**
- Explosions
- Plume Fires
- Industrial Flares
- Shape Charges
- Virtual Soldier
- CPU Microchip Flow
- Foam Compaction
- Angiogenesis
- Sandstone Compaction

Uintah uses a combination of fluid-flow solvers and particle-based methods for solids, together with adaptive meshing and a novel asynchronous task-based approach with fully automated load balancing.

### Challenges

Solve complex fluid structure interaction problems on parallel computers.
- **Full physics** - strong coupling between the fluid and solid phases with a full Navier-Stokes representation of fluid phase materials and the transient, nonlinear response of solid phase materials including chemical or phase transformation between the solid and fluid phases.
- **Multi-material** - each material is given a continuum description and is defined over the complete computational domain.

With original MPI only approach, Uintah can successfully scale up to 98K cores.
- **Adaptive Mesh Refinement Algorithms**
- **Measurement-based Load Balancing**
- **Out-of-order Task Execution**
- **Data Migration**

**Poor weak scaling efficiency** – 23% at 98K cores.
- **Hard to load balance**
- **High communication cost**

**Solution**

Hybrid MPI/threads approach: Re-design Runtime System

### Improvements

Reducing Particle Relocation Communication Costs
- Move particles to new patches after each timestep
- Cross patch boundary: just re-indexing
- Cross processor boundary: MPI scatter record (expensive!)
- Thread/MPI: Fewer particles cross processor boundary

Load Balancing Improvements
- Enable work stealing: all tasks in the same node can be executed by any idle cores on that node
- Larger workload region: more patches on each node, easier to make them even
- The average load imbalance value was reduced from 60% to 25%

Using Lock-free Data Structures
- Overhead of de-centralized scheduler: pthread read/write locking cost on shared data
- Using atomic instruction set
- Variable reference counting: fetch_and_add, fetch_and_sub
- Redesign data warehouse variable container
- Allow multiple threads update without waiting
- Add variable: compare_and_swap
- Reduce variable: test_and_set

Speed up 2.4X vs MPI only

### Results

With fully distributed hybrid MPI/thread scheduler and lock-free data warehouse, Uintah can successfully scale up to 256K cores with 95% weak scaling efficiency and 68% strong scaling efficiency.

**Weak scaling efficiency comparison with new hybrid scheduler and old MPI only scheduler.**

### References


### Acknowledgement

This work was supported by the National Science Foundation under subcontracts No. OCI0721659, the NSF OCI PetaApps program, through award OCI0805068 and by DOE INCITE award CMB015 for time on Jaguar.

---

**Uintah Applications:**

- Explosions
- Plume Fires
- Industrial Flares
- Shape Charges
- Virtual Soldier
- CPU Microchip Flow
- Foam Compaction
- Angiogenesis
- Sandstone Compaction

---

**Uintah Framework Hybrid Task-based Parallelism Algorithm**

Qingyu Meng and Martin Berzins. Scientific Computing and Imaging Institute, University of Utah