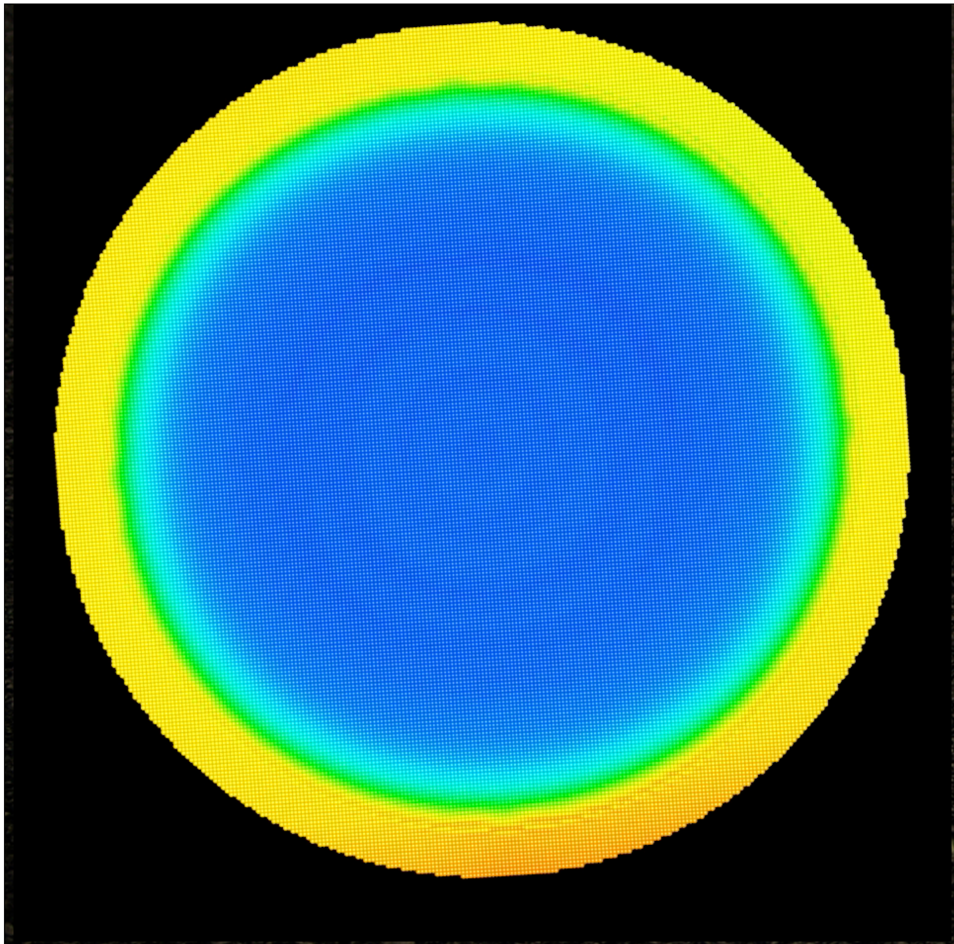


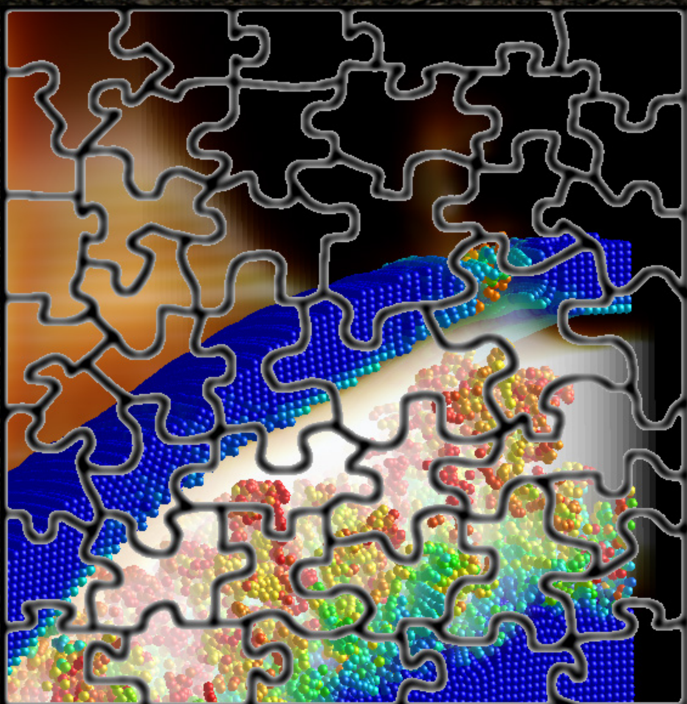
Simulating Fires and Explosives

Steven Parker
School of Computing
Scientific Computing and Imaging Institute
University of Utah/NVIDIA

www.sci.utah.edu

Composing software

Building systems out of pieces

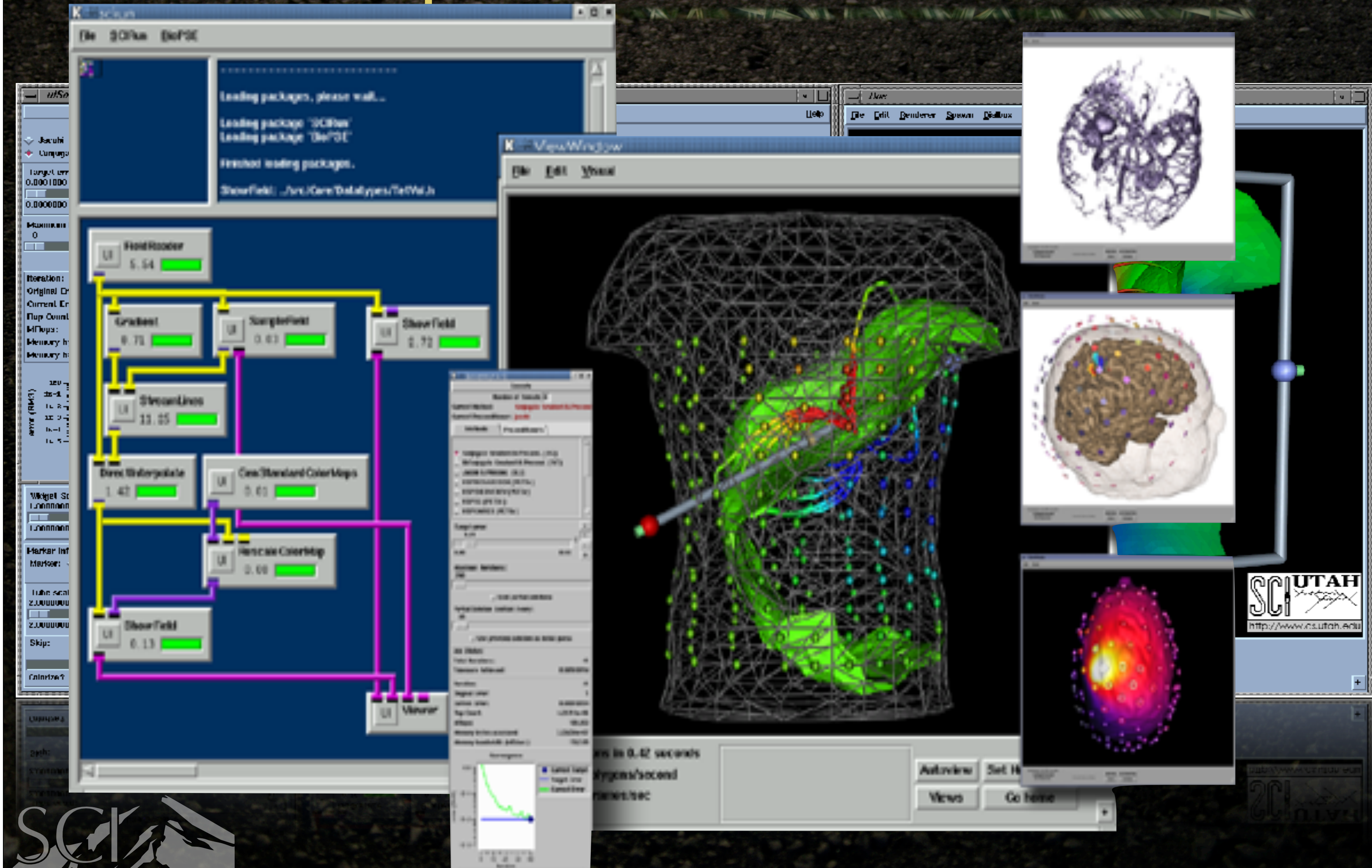


Or

www.rock101.com

www.sci.utah.edu

Component Software



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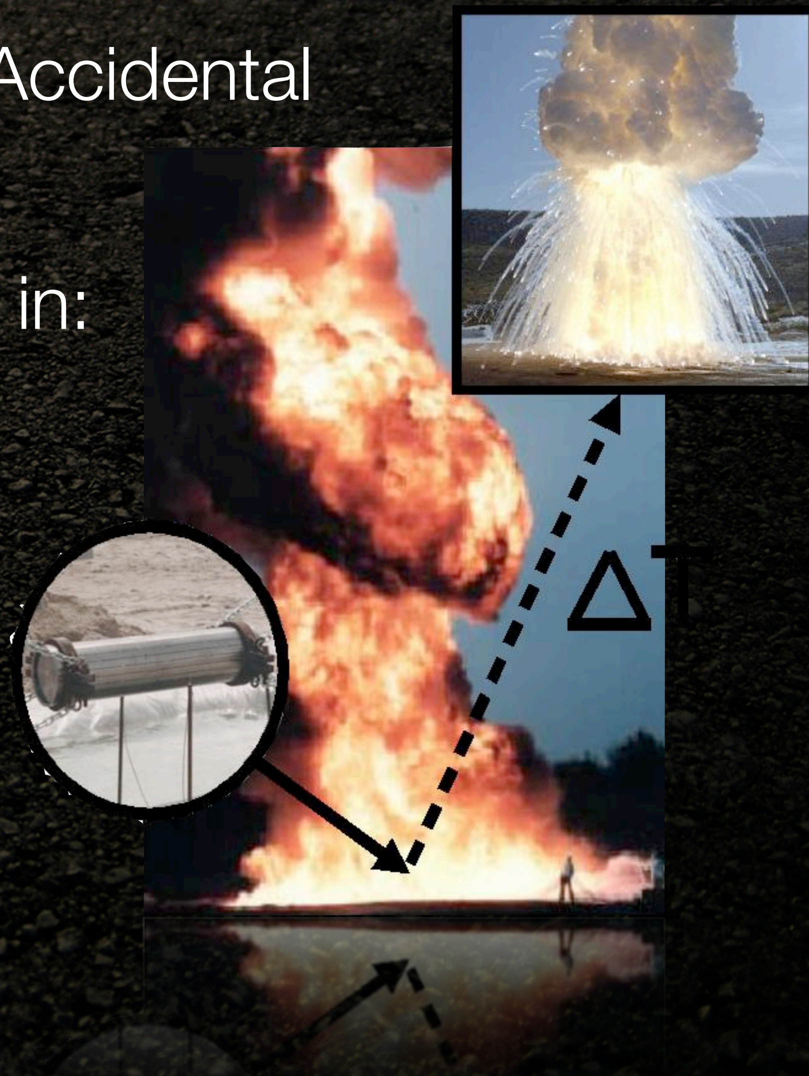
C-SAFE

Center for the Simulation of Accidental Fires & Explosions

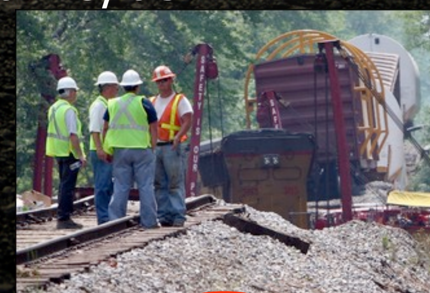
- Solve fundamental problems in:
  - Physical chemistry
  - Structural mechanics
- Coupled with:
  - Experimental verification
  - Algorithm optimization
  - Advanced visualization



Pepcon disaster
Nevada 5/88

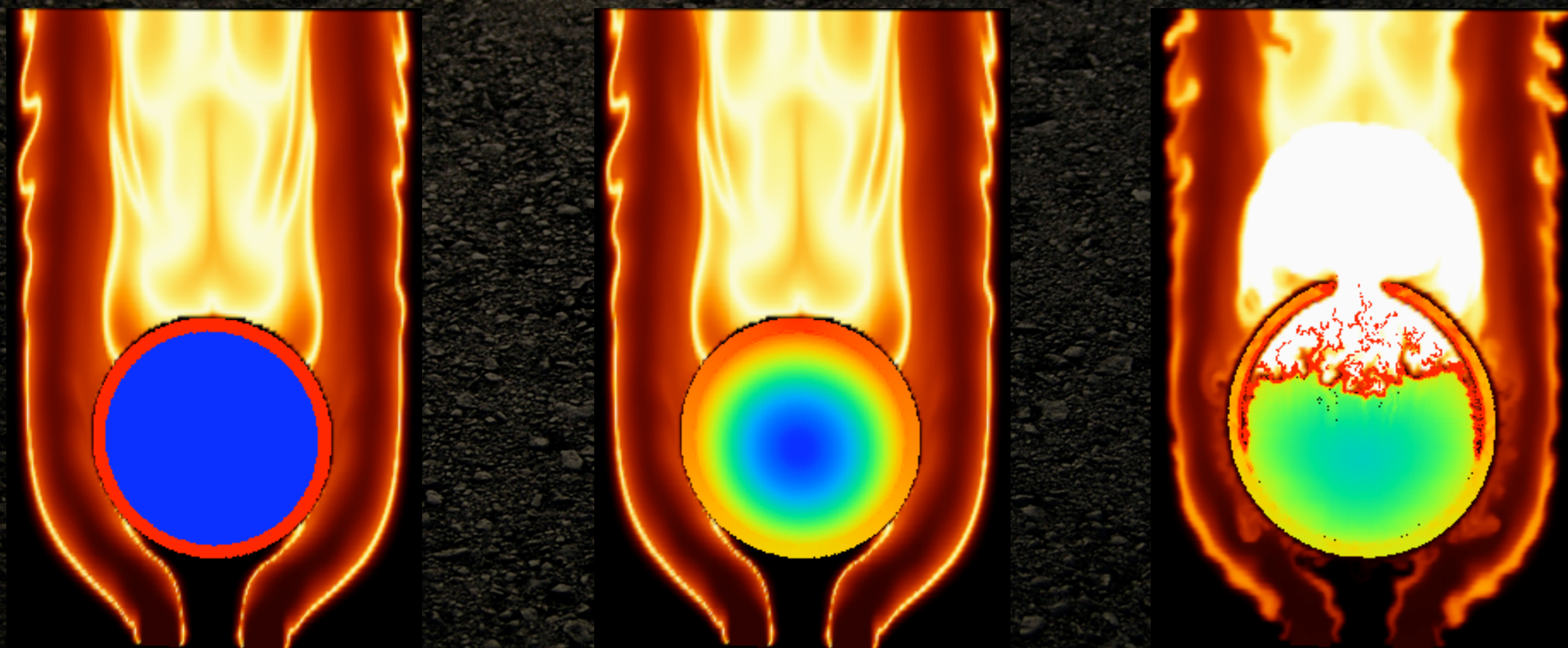
Spanish Fork Accident
Utah 8/05

Motivation



Shuttle booster derailed
Alabama 5/07

Time scales



1-10 seconds | 30-60 minutes | ~1 msec

Fire | Heat-up | Explosion

SCI
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Multi-physics challenges

- Multiple time scales
- Multiple space scales
- Impedance matching of:
  - Mathematical description
  - Frame of reference
    - (Lagrangian vs. Eulerian)
  - Numerical algorithms
  - Software interfaces
  - Parallelization strategy
  - Interpersonal relationships

SCI
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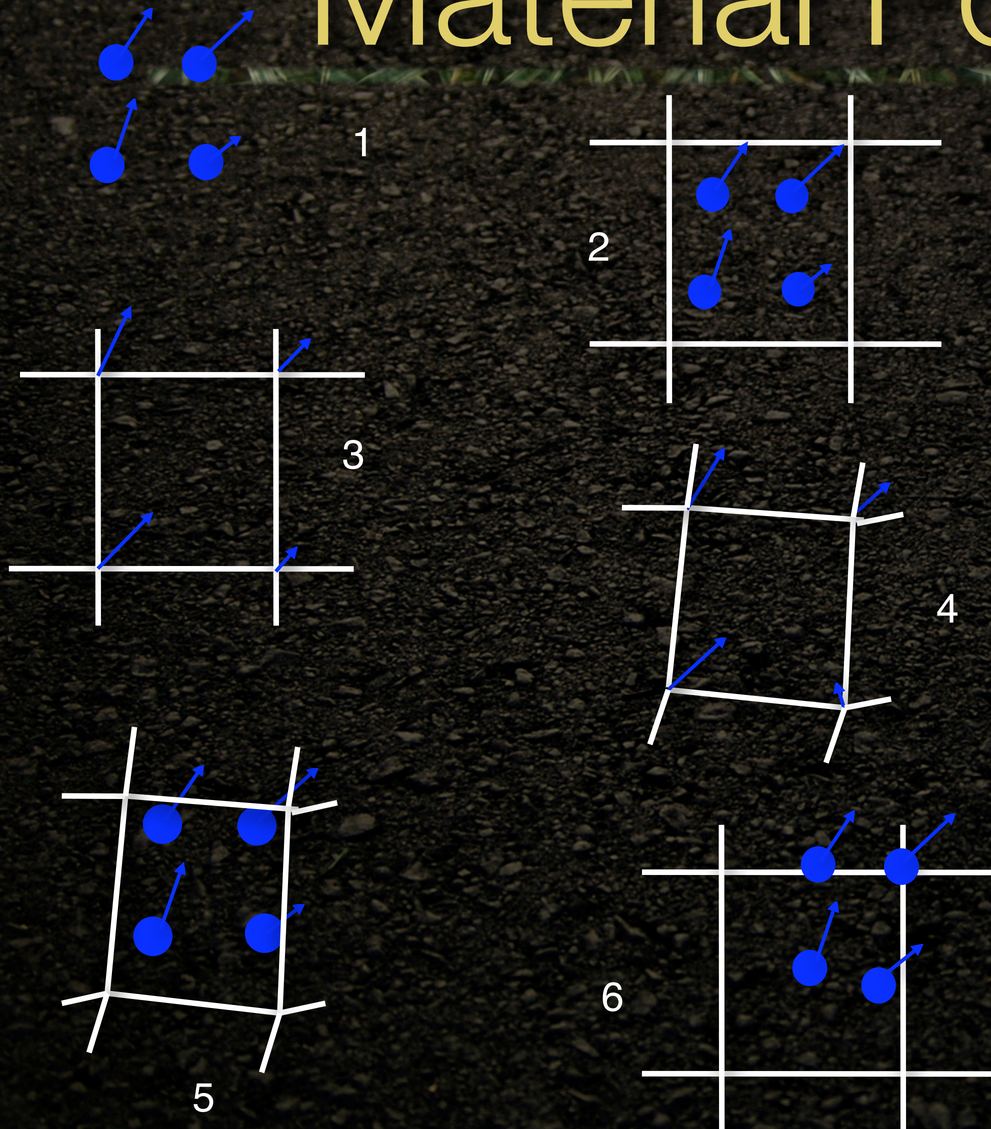
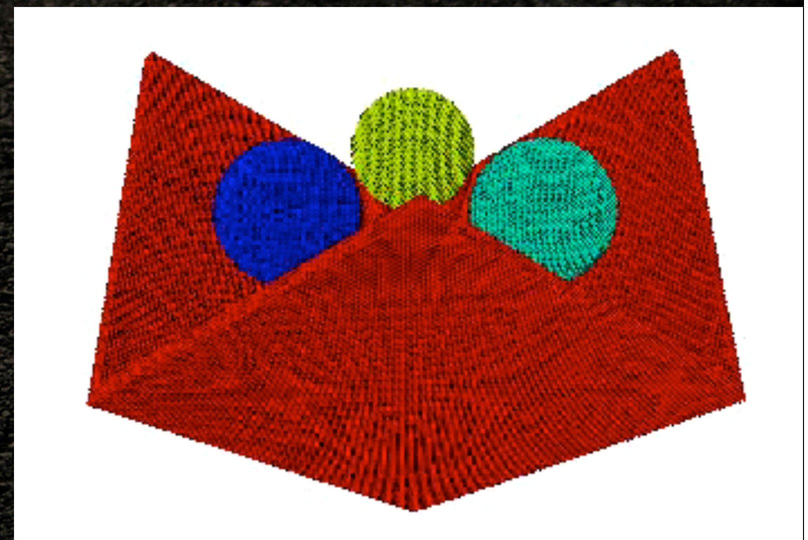
Material Point Method



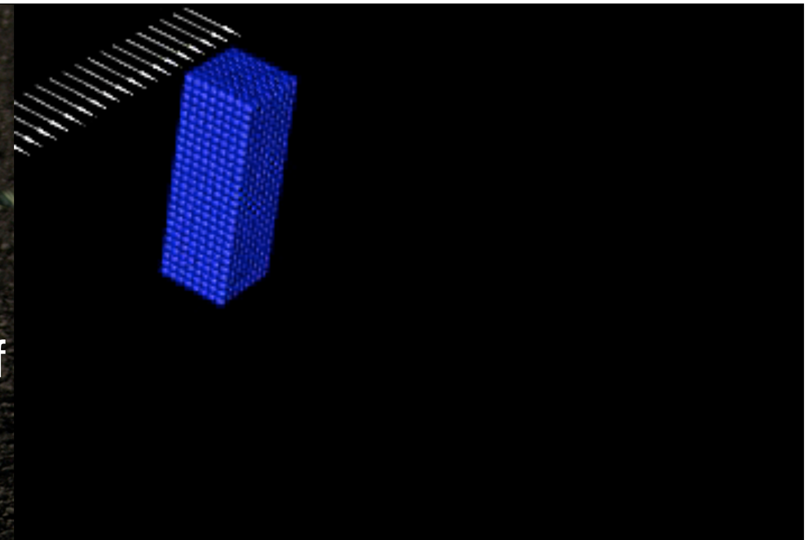


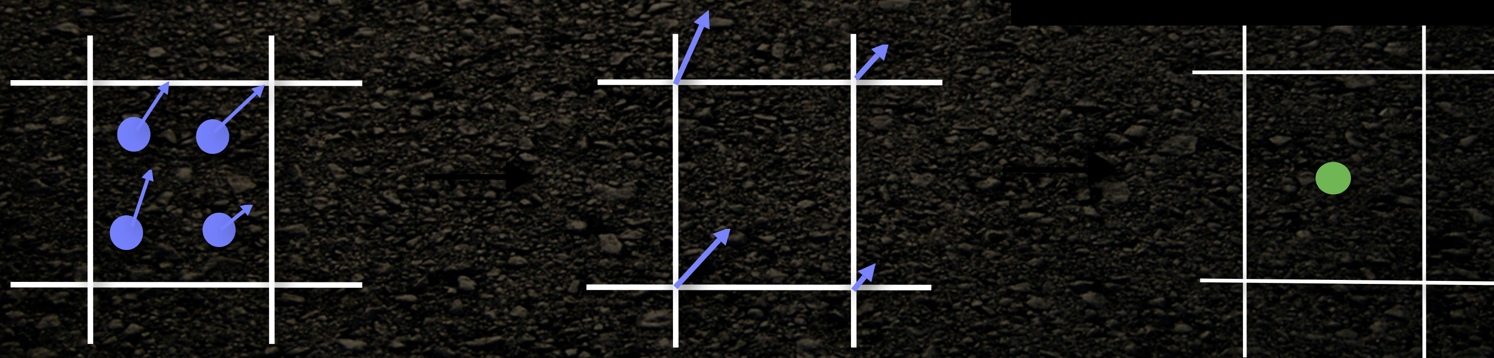
Handles deformation, contact, high strain

MPM-ICE

- ICE is a cell centered finite volume method
- MPM uses particles and nodes

Cell-centered grid used as a common frame of reference





Particle:
Mass, volume,
Temperature,
Velocity, etc.

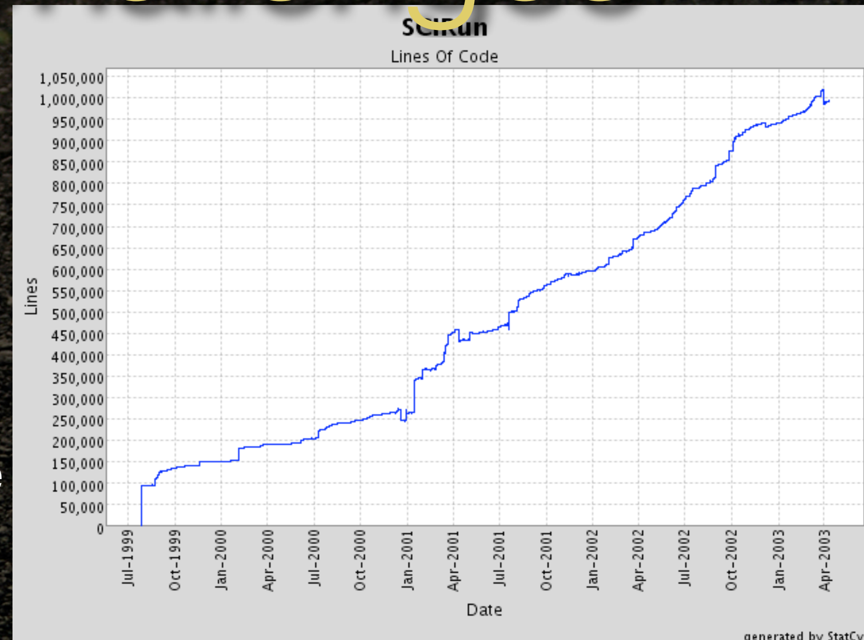
Node Centered:
Mass, volume,
Temperature,
Velocity, etc.

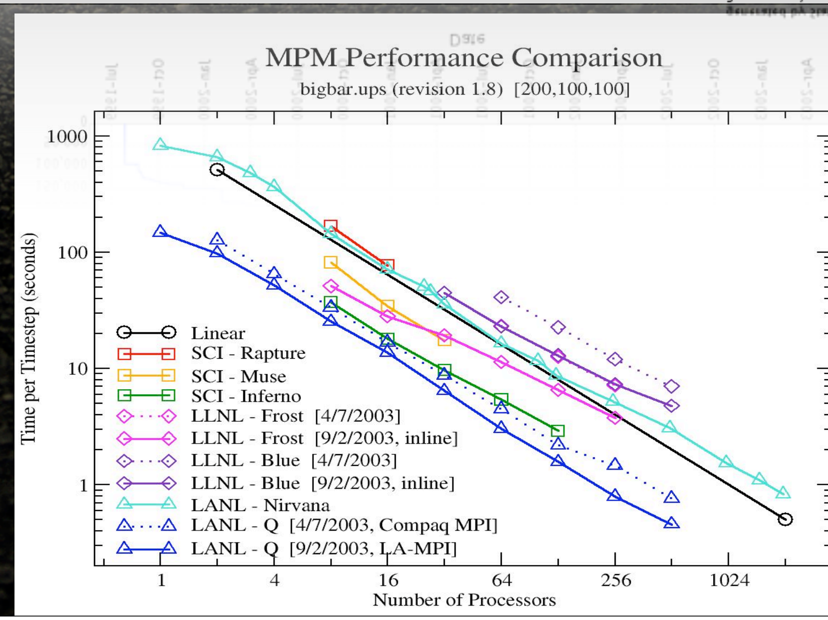
Cell Centered:
Density,
Internal Energy,
Momentum, etc.

Tightly coupled fluid-solid interaction

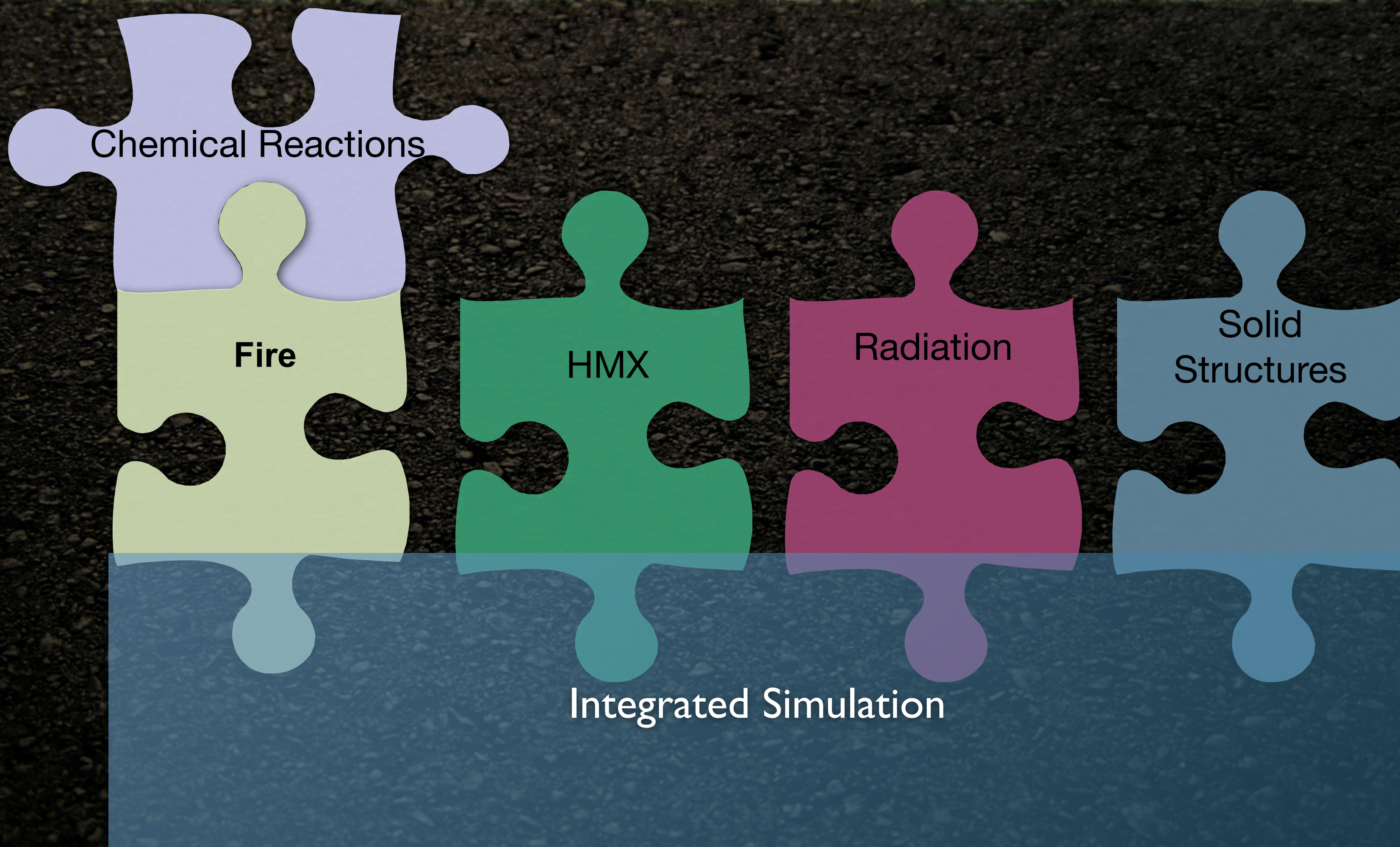
Software Challenges

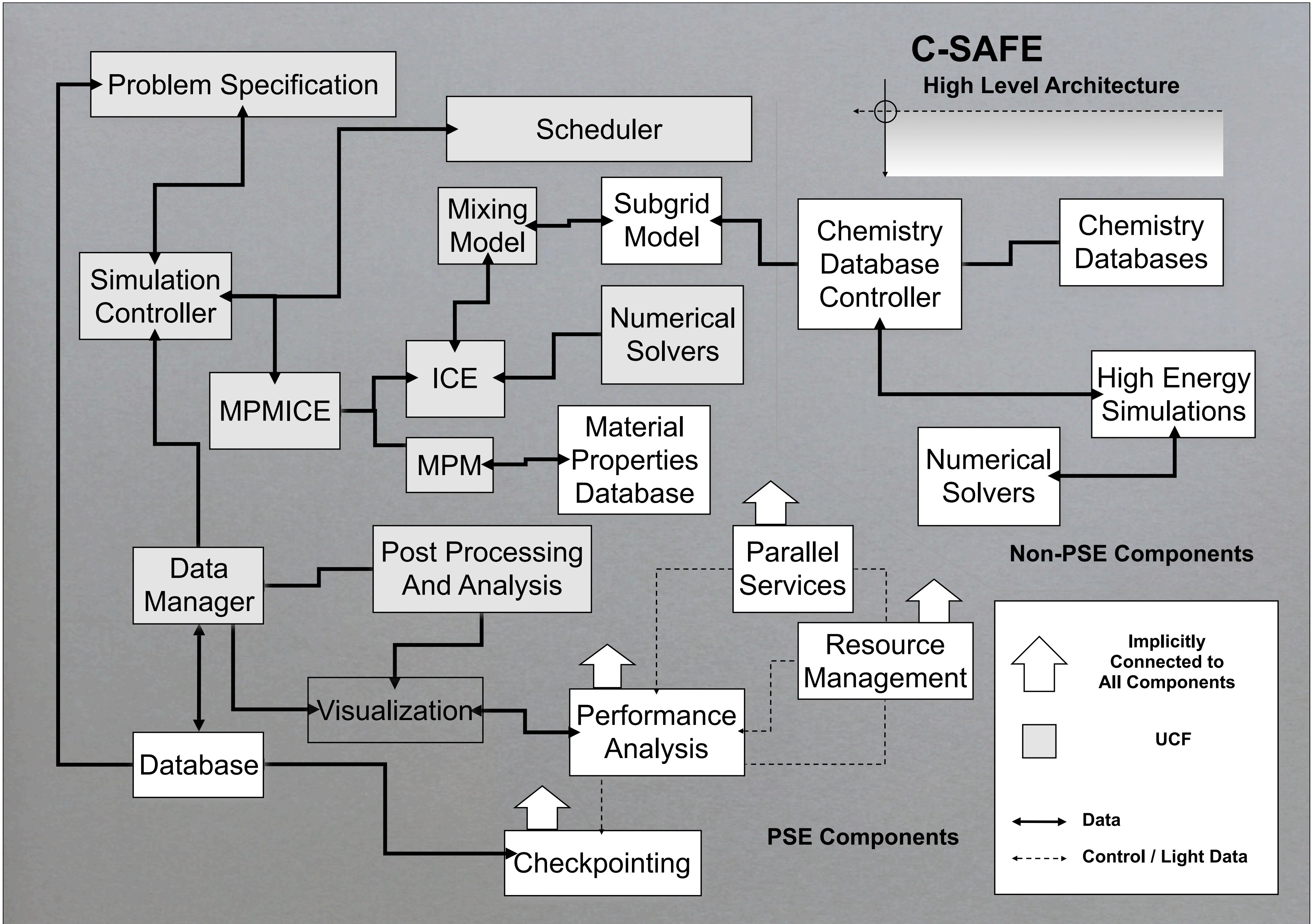
- Software integration challenges:
  - Integration requires broad expertise
  - The effort required is too large to be justified any single application
  - Applications are not always designed top-down
  - Cannot give up performance



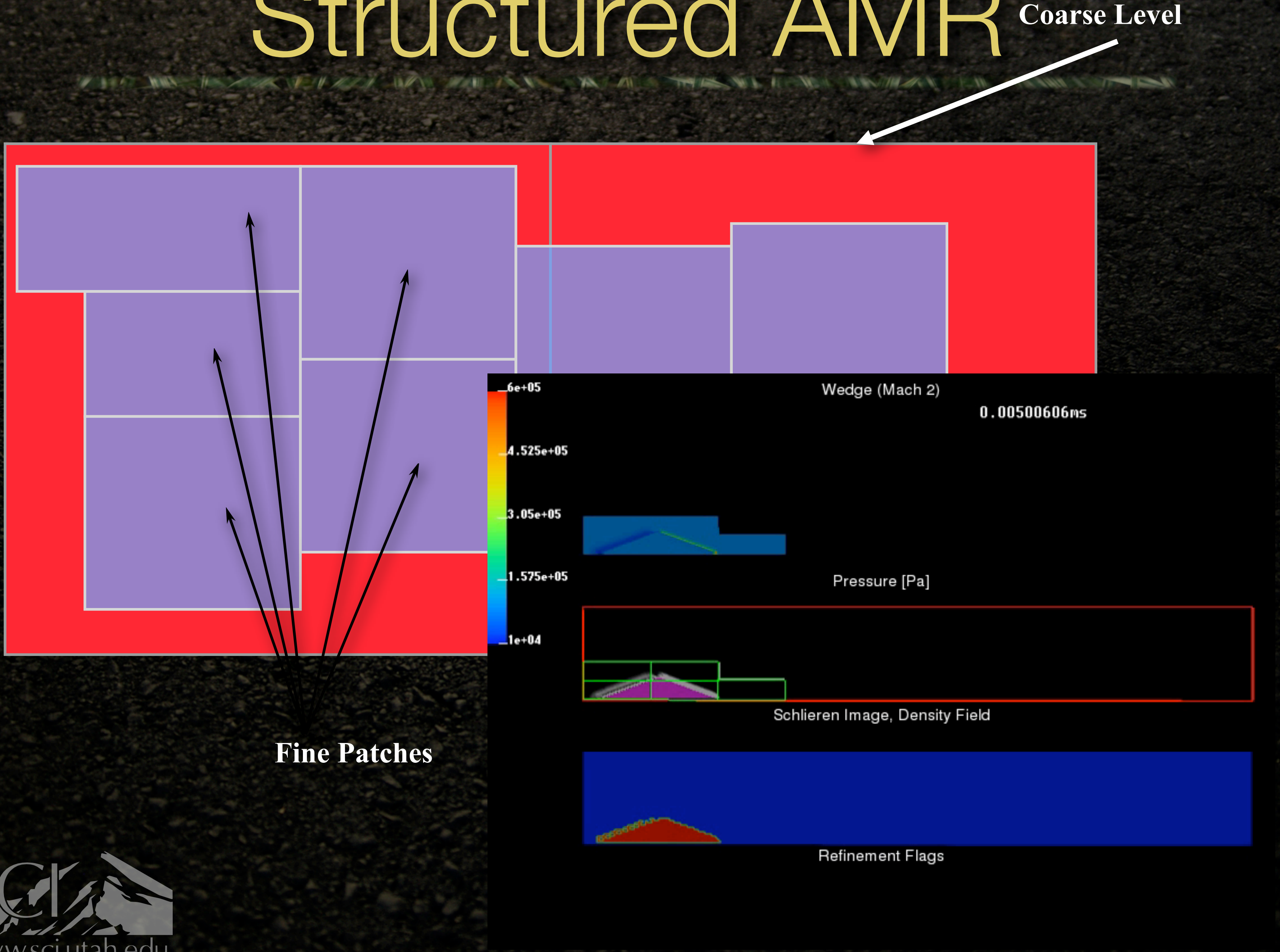


Component-based Architecture



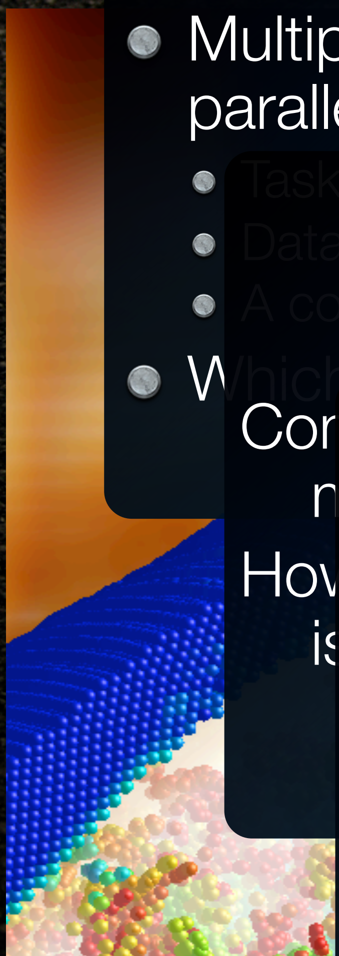

C-SAFE
High Level Architecture
Problem Specification
Scheduler
Mixing Model
Subgrid Model
Chemistry Database Controller
Chemistry Databases
Simulation Controller
Numerical Solvers
ICE
MPMICE
MPM
Material Properties Database
High Energy Simulations
Numerical Solvers
Data Manager
Post Processing And Analysis
Parallel Services
Non-PSE Components
Resource Management
Implicitly Connected to All Components
UCF
Visualization
Performance Analysis
Database
Checkpointing
PSE Components
Data
Control / Light Data

Structured AMR



Parallel Components

- Multiple ways to split up parallel work
  - Task based (MxN)
  - Data based (SCMD)
  - A combination?
- Which is ...



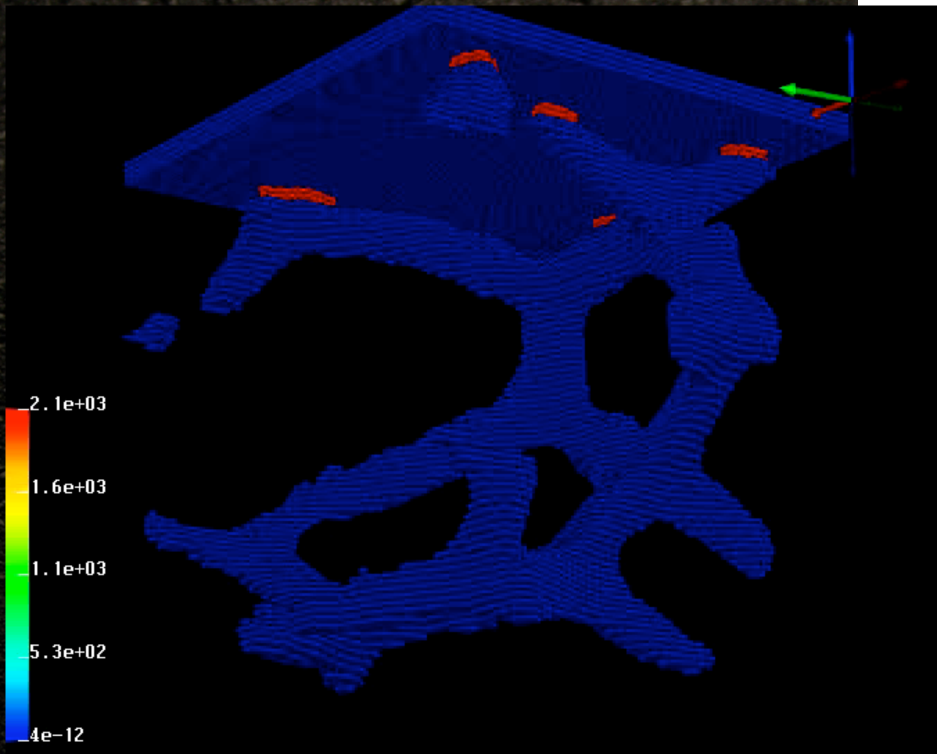
Key challenge

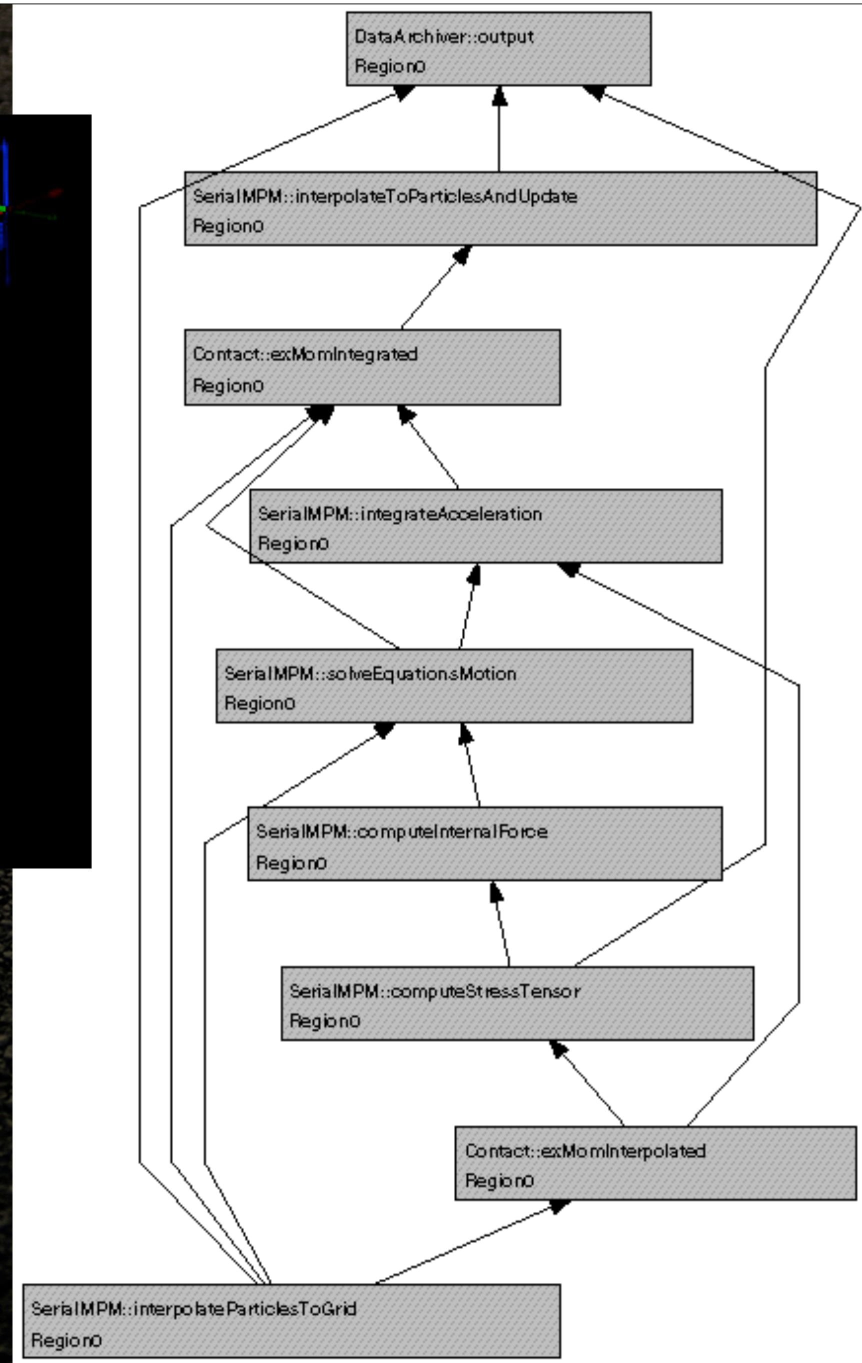
Components, by definition, make **local** decisions

However, parallelism (scalable) is a **global** decision

Solution: Uintah

- Explicit representation of parallelism in components
- Scheduling, domain decomposition factored out of simulation components
- Enables scalability in multi-physics simulation





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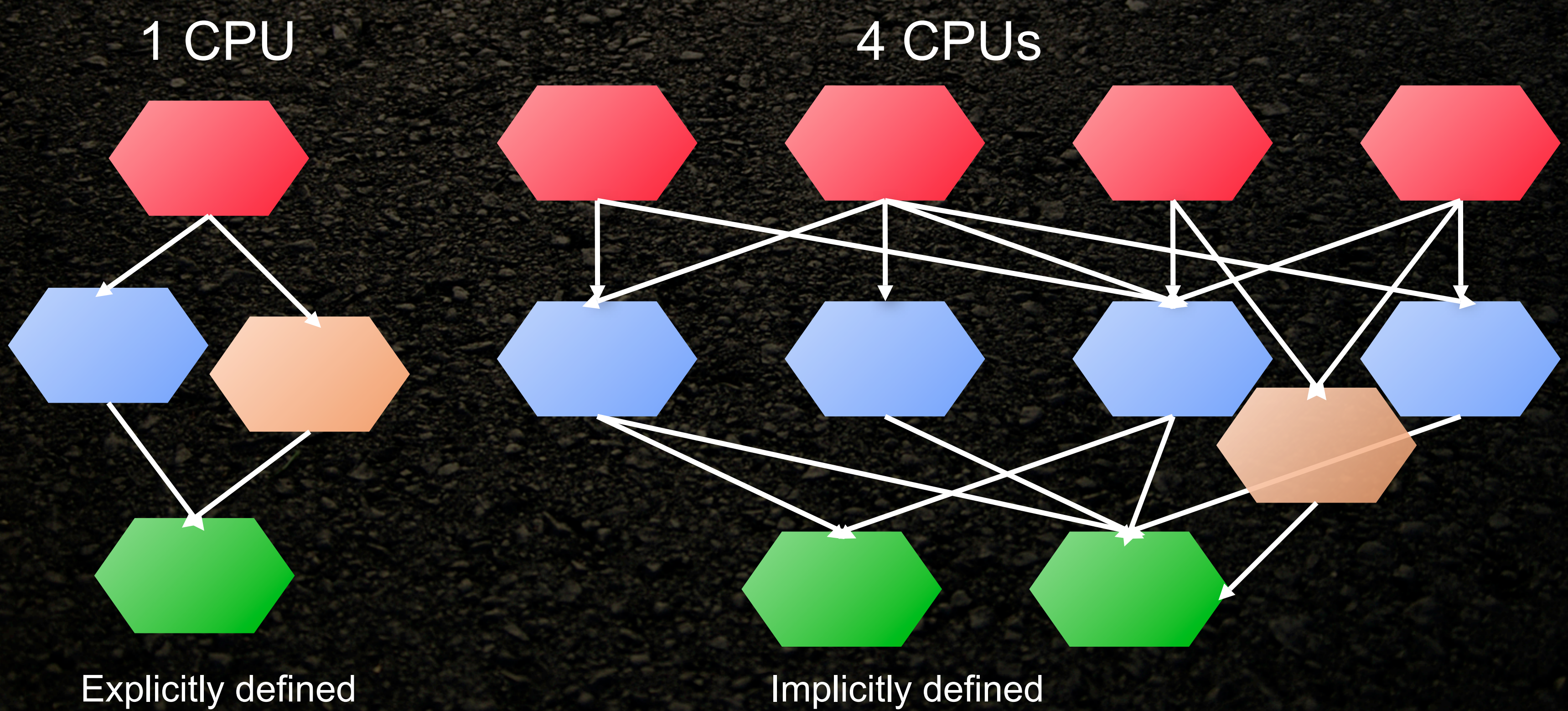
Taskgraphs

- Unique feature: explicit representation of parallelism
- Expresses data parallelism and task parallelism
- Enables compiler-like analysis of communication



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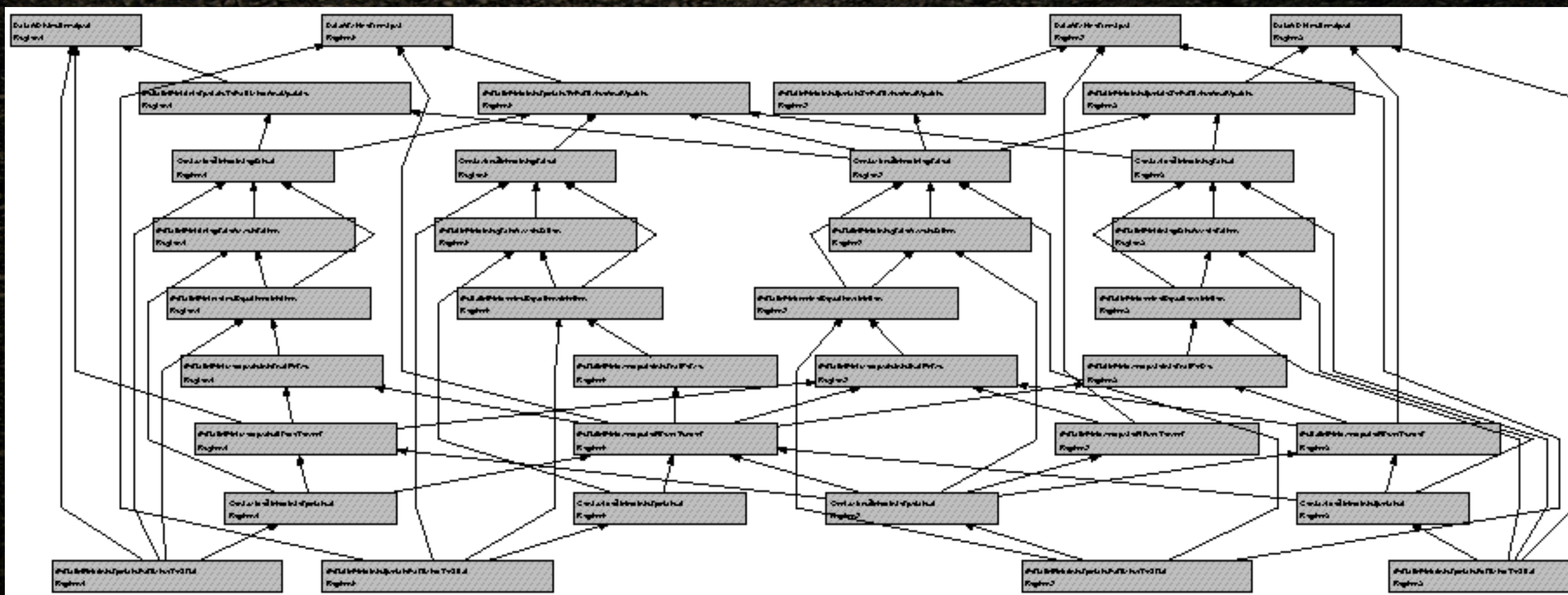
4 patches



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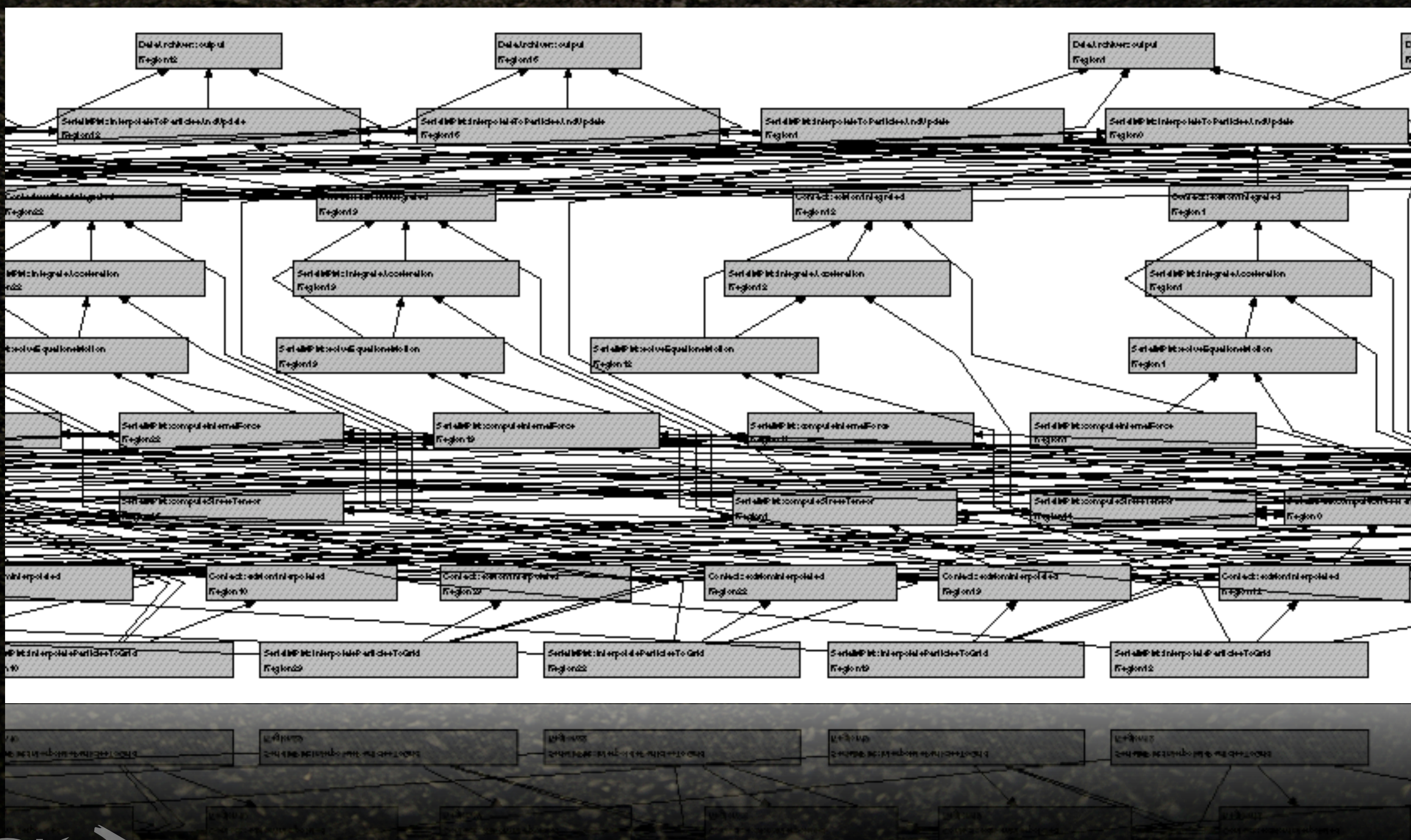
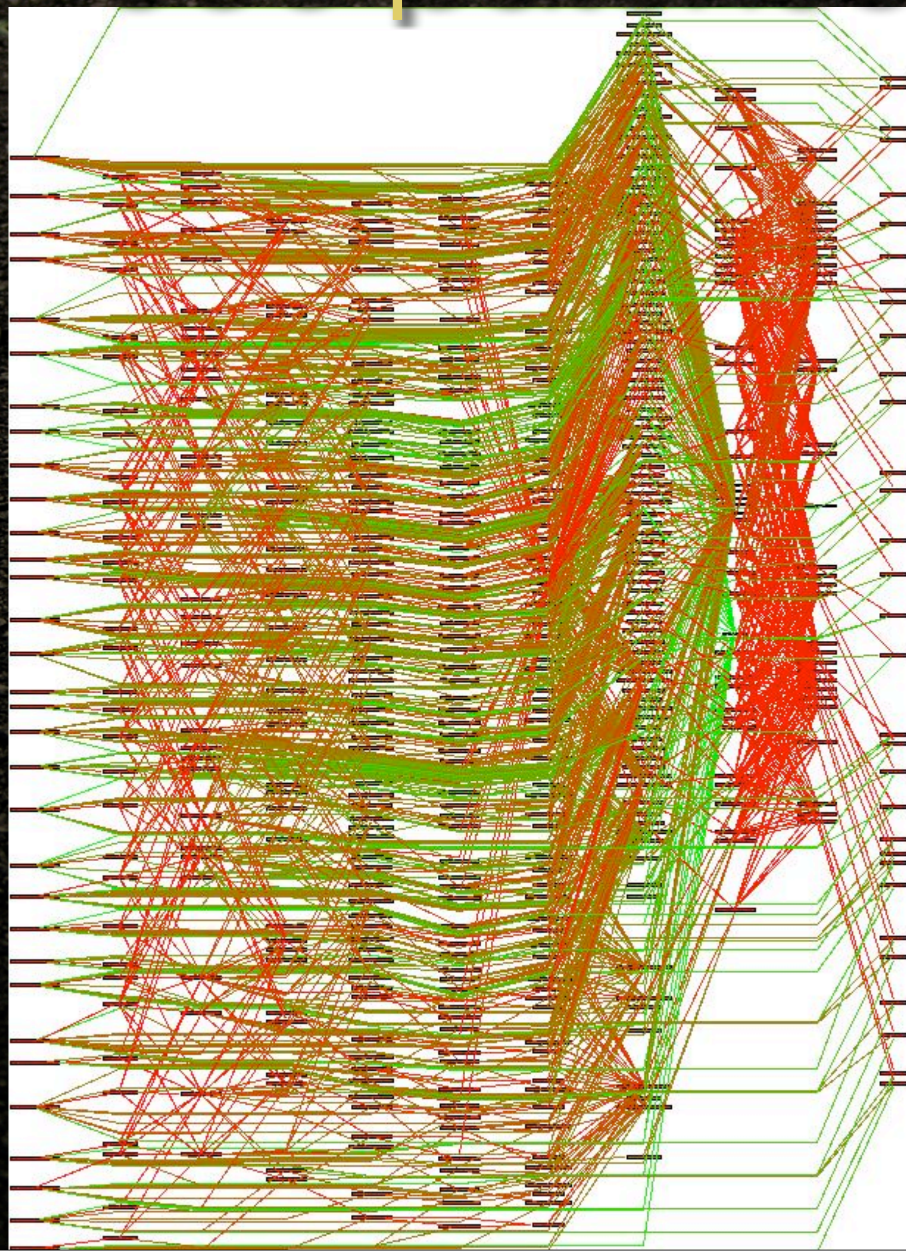
32 patches



500 patches



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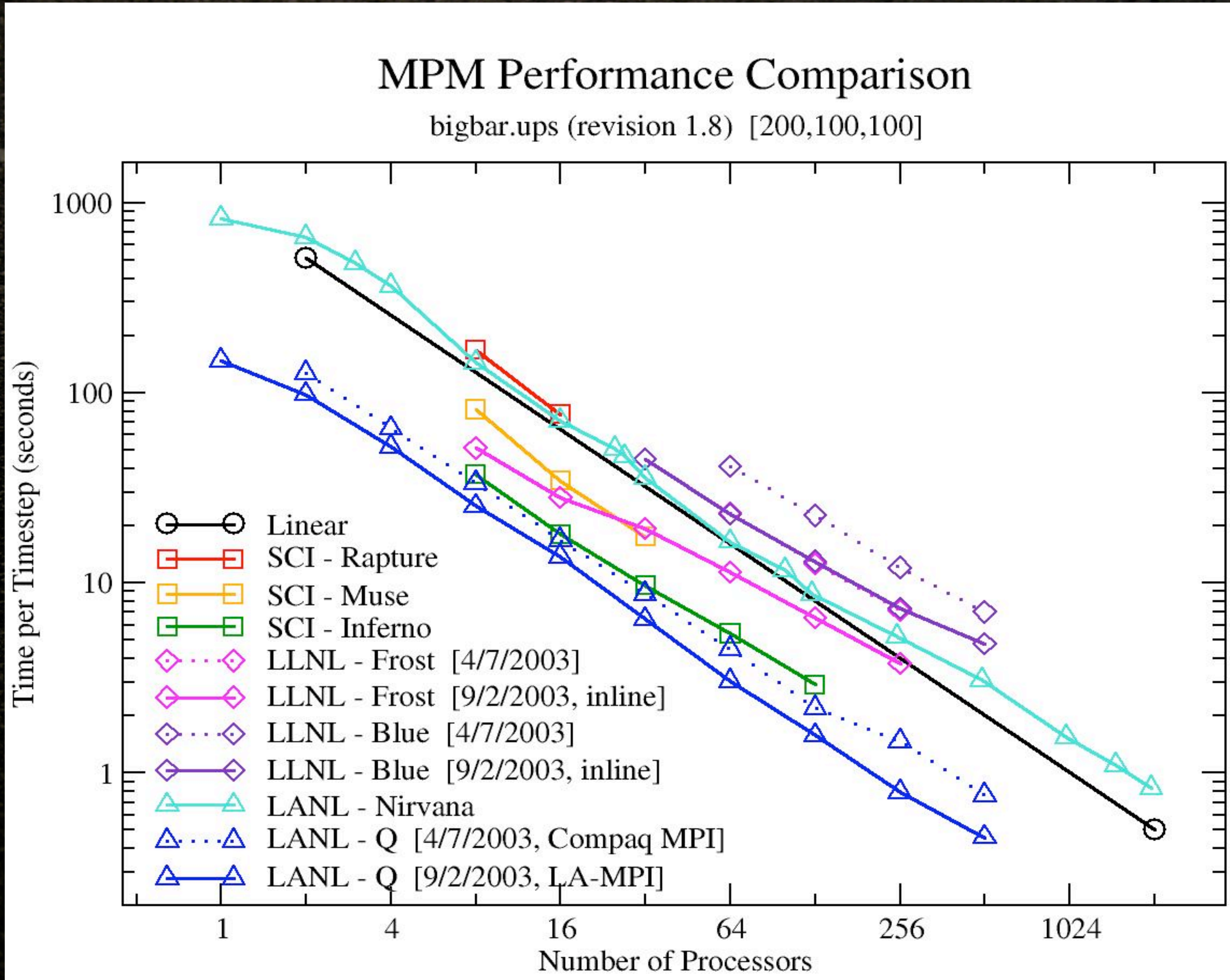
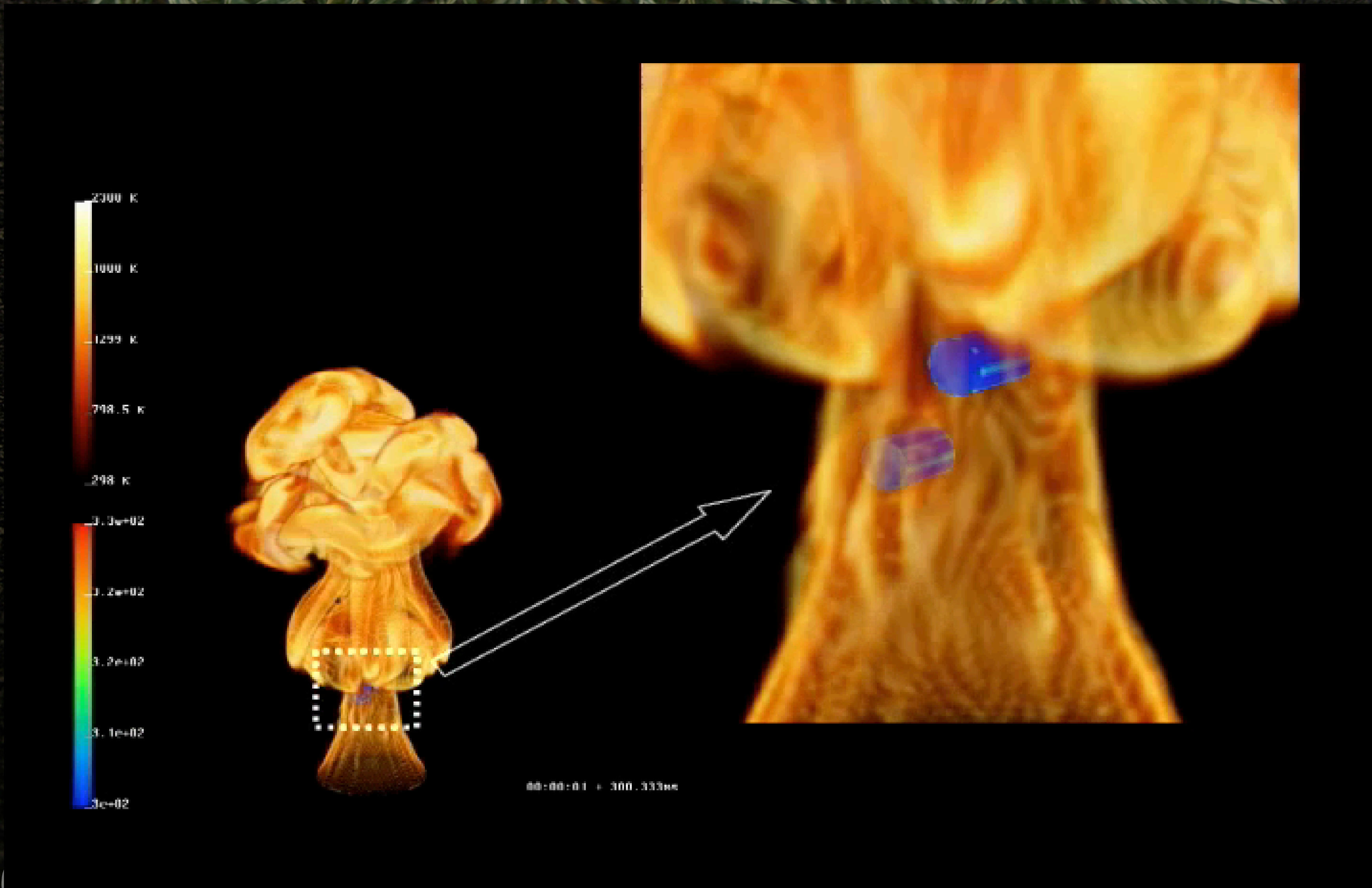
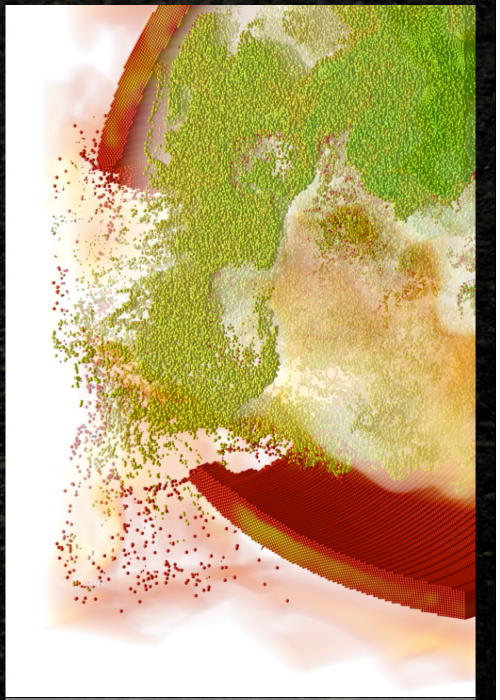

MPM Performance Comparison
bigbar.ups (revision 1.8) [200,100,100]
Time per Timestep (seconds)
1000
100
10
1
Number of Processors
1
4
16
64
256
1024
Linear
SCI - Rapture
SCI - Muse
SCI - Inferno
LLNL - Frost [4/7/2003]
LLNL - Frost [9/2/2003, inline]
LLNL - Blue [4/7/2003]
LLNL - Blue [9/2/2003, inline]
LANL - Nirvana
LANL - Q [4/7/2003, Compaq MPI]
LANL - Q [9/2/2003, LA-MPI]

Space scales



End-to-end Parameter Study

- Predict:
  - Time to explosion
  - Violence of explosion (various metrics)
- As a function of:
  - Pool fire diameter (0.5 meters to 1 meter)
  - Wind speed (0 to 4 m/s)
  - Position relative to fire
- Constants:
  - Device parameters (geometry, material)
  - Fuel
  - Methods/models



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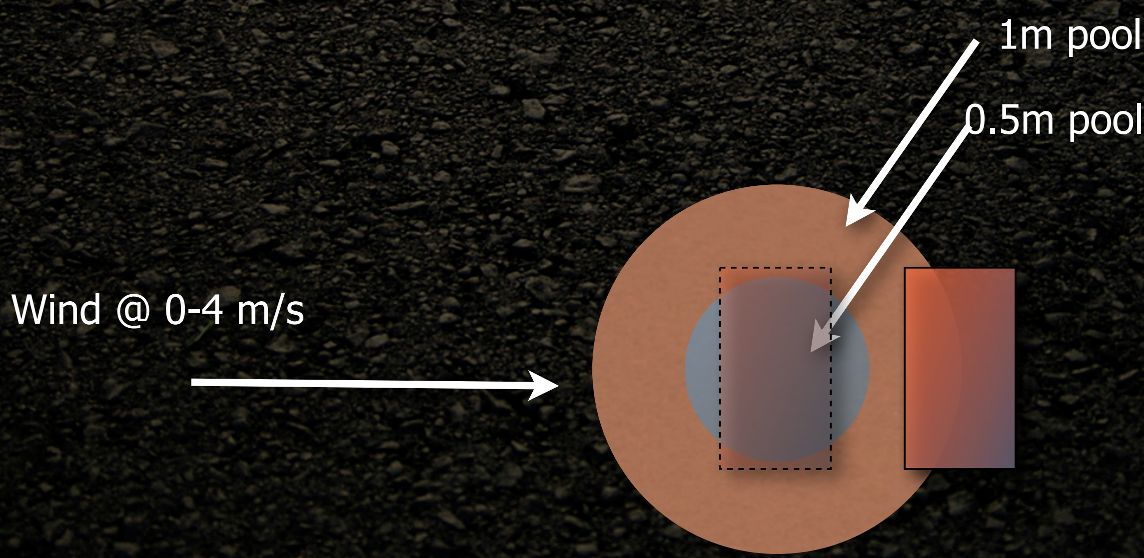
Scenario parameters

- Range of pool diameters 0.5m to 1m
- Examine locations only in wind plane
- Container centered or downwind



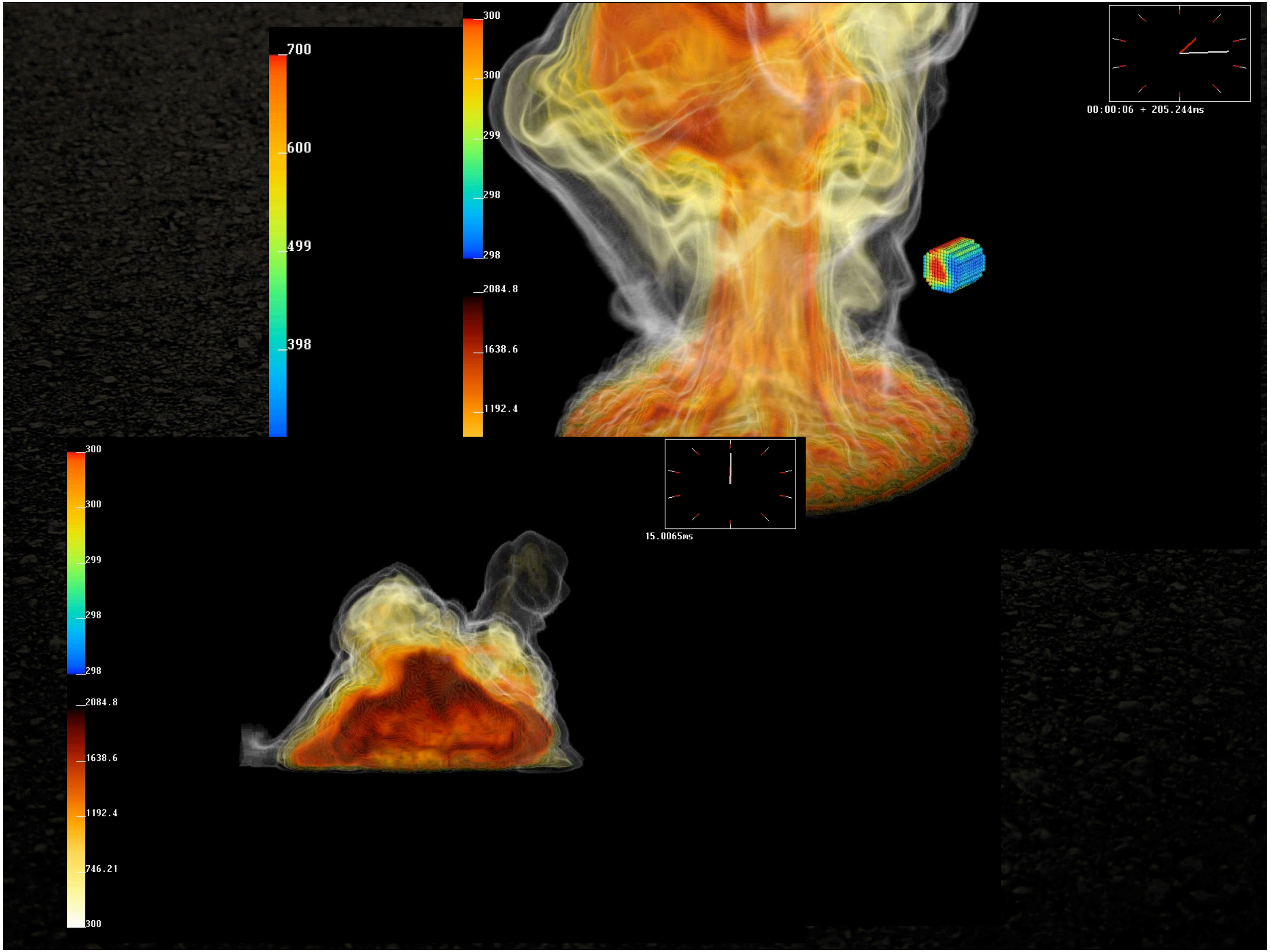
Top view

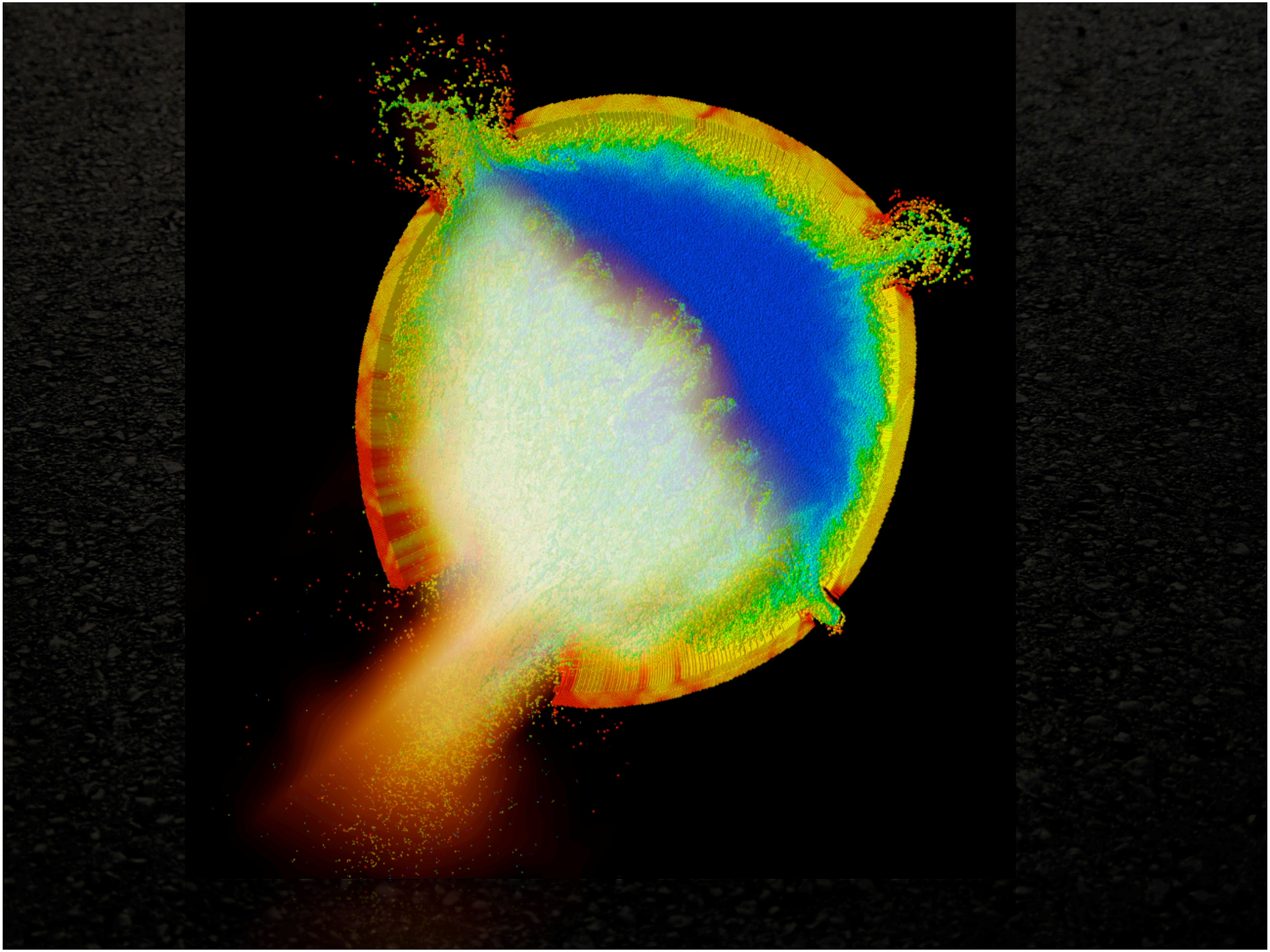
*Containers not to scale

Location

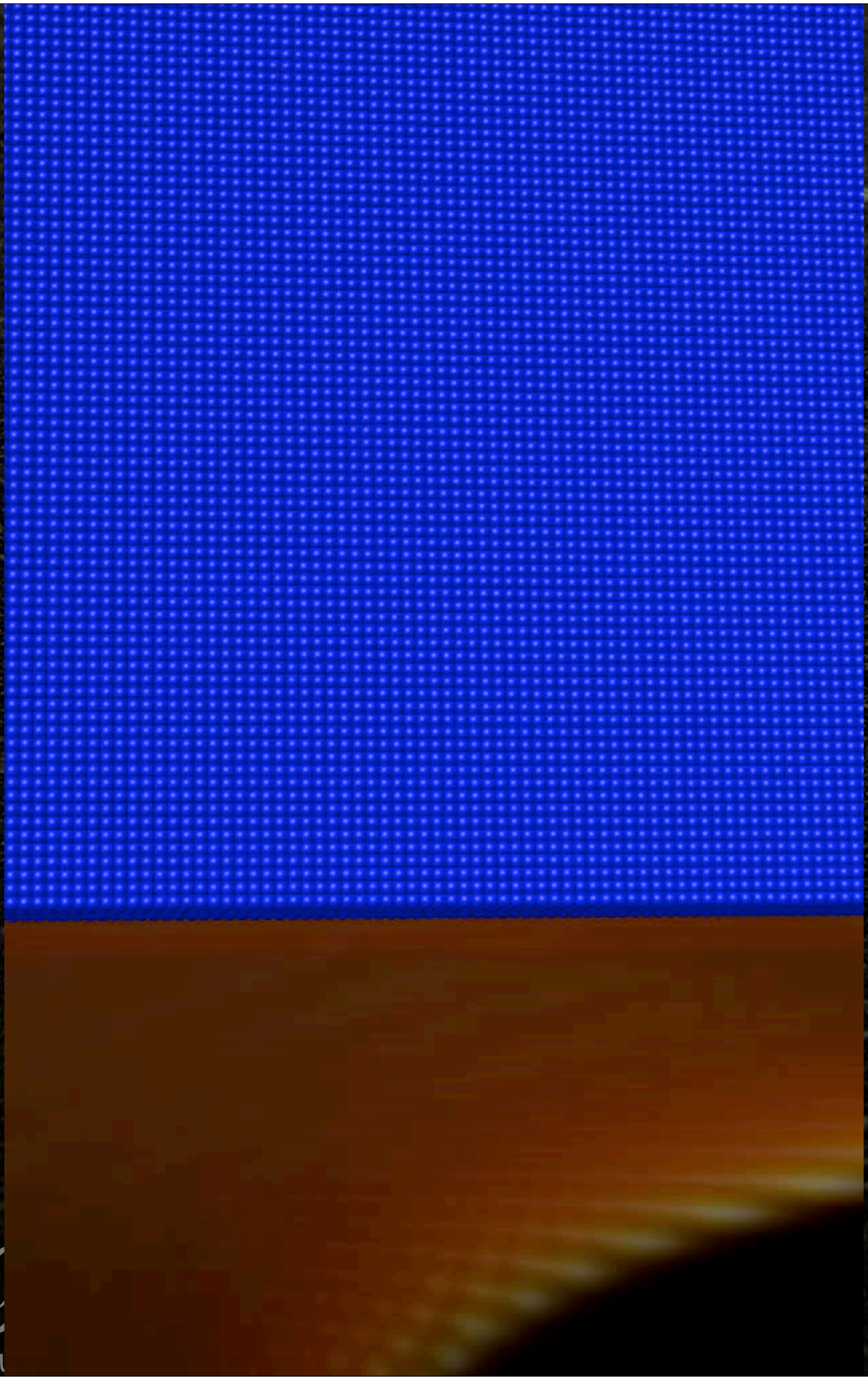
- Examine locations both absolute and relative to fire diameter

*Containers not to scale


700
600
499
398
300
300
299
298
298
2084.8
1638.6
1192.4
00:00:06 + 205.244ms
15.0065ms
300
300
299
298
298
2084.8
1638.6
1192.4
746.21
300

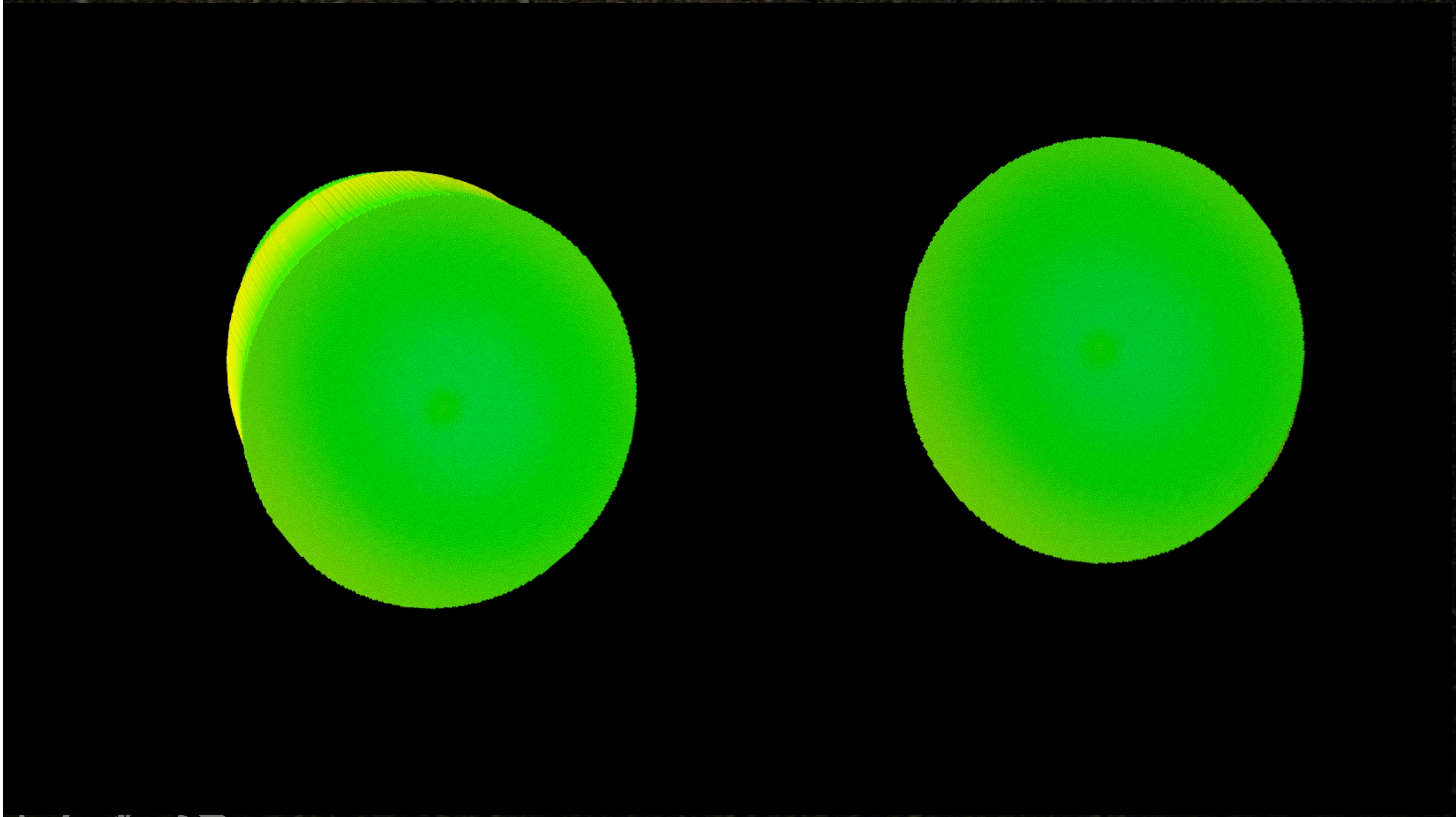


Closeup

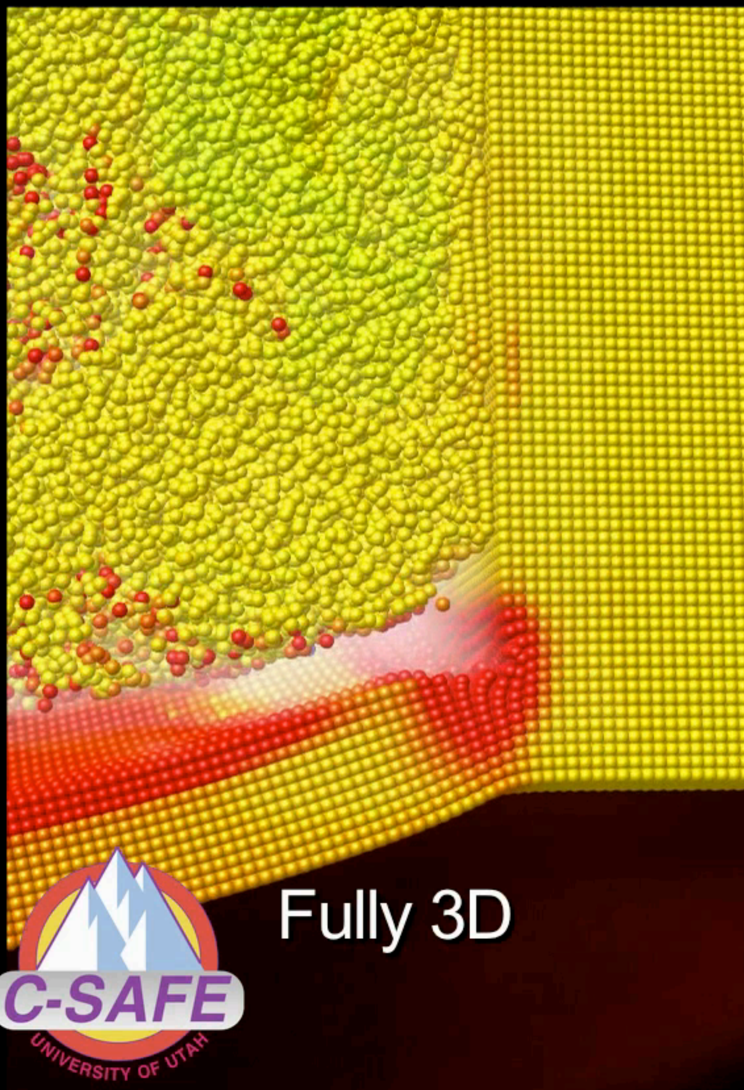


- Pressurization of infinitely small boundary between explosive and container

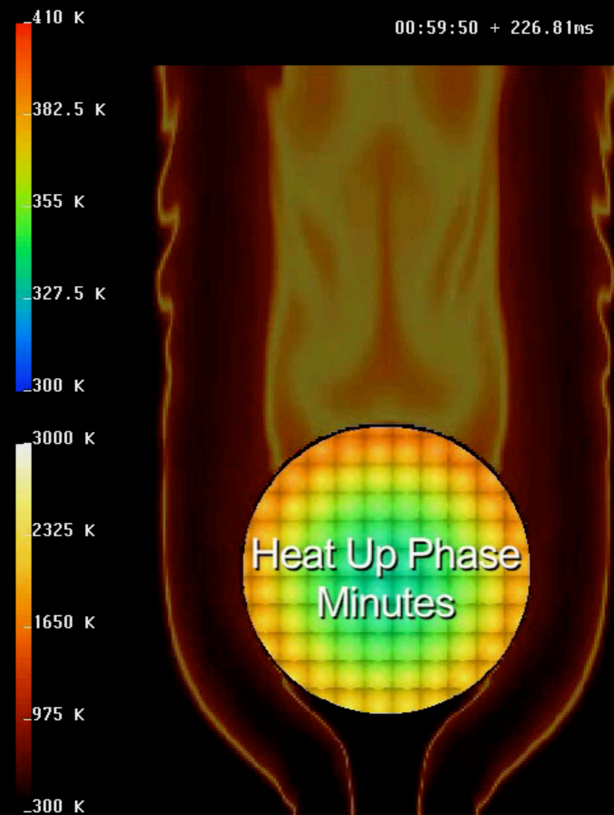
Explosion



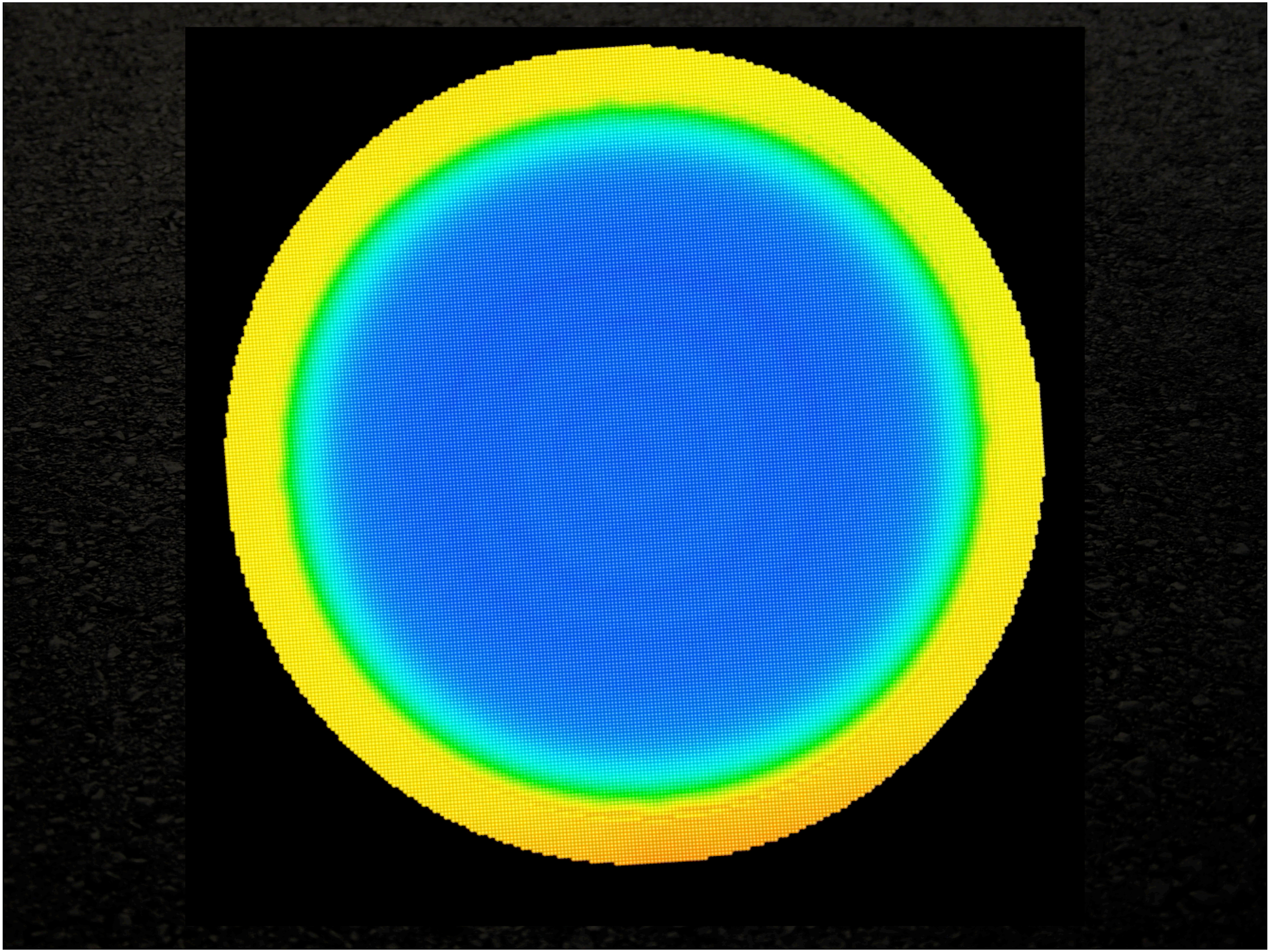
Complete End-to-End Simulation



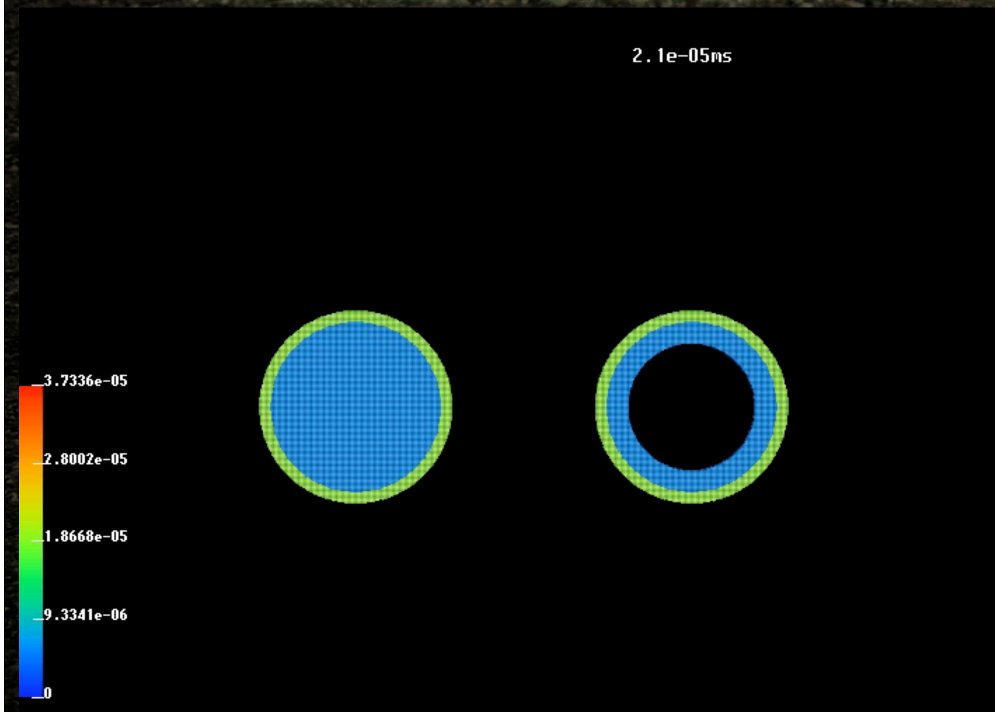
Fully 3D



2D



AMR bore hole studies




PM 3:04:4
PM 3:04:45
PM 3:04:46

Experimental Comparisons

AISI 1026 Steel Pipe
4 in. length
0.25 in. thickness

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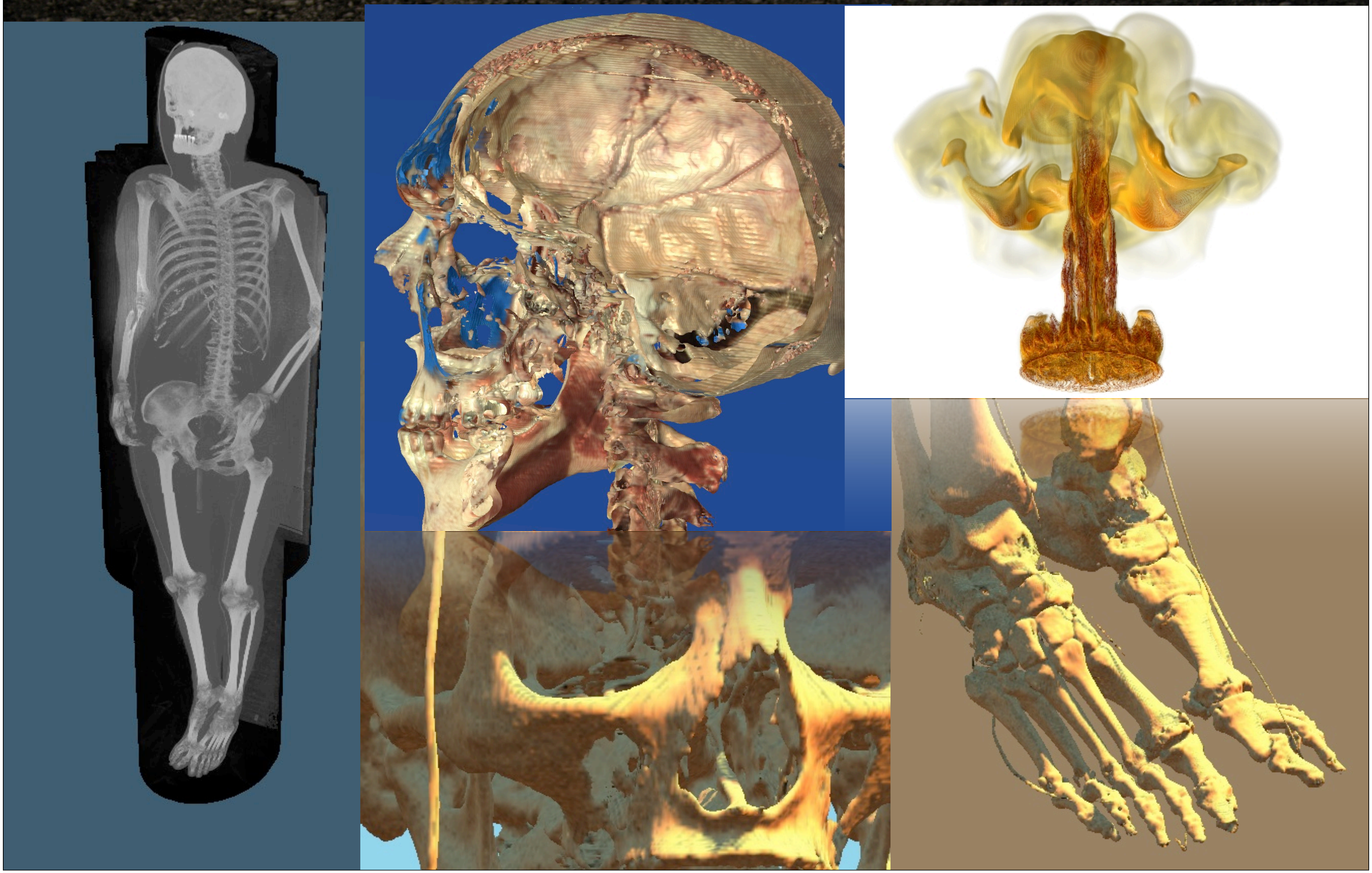
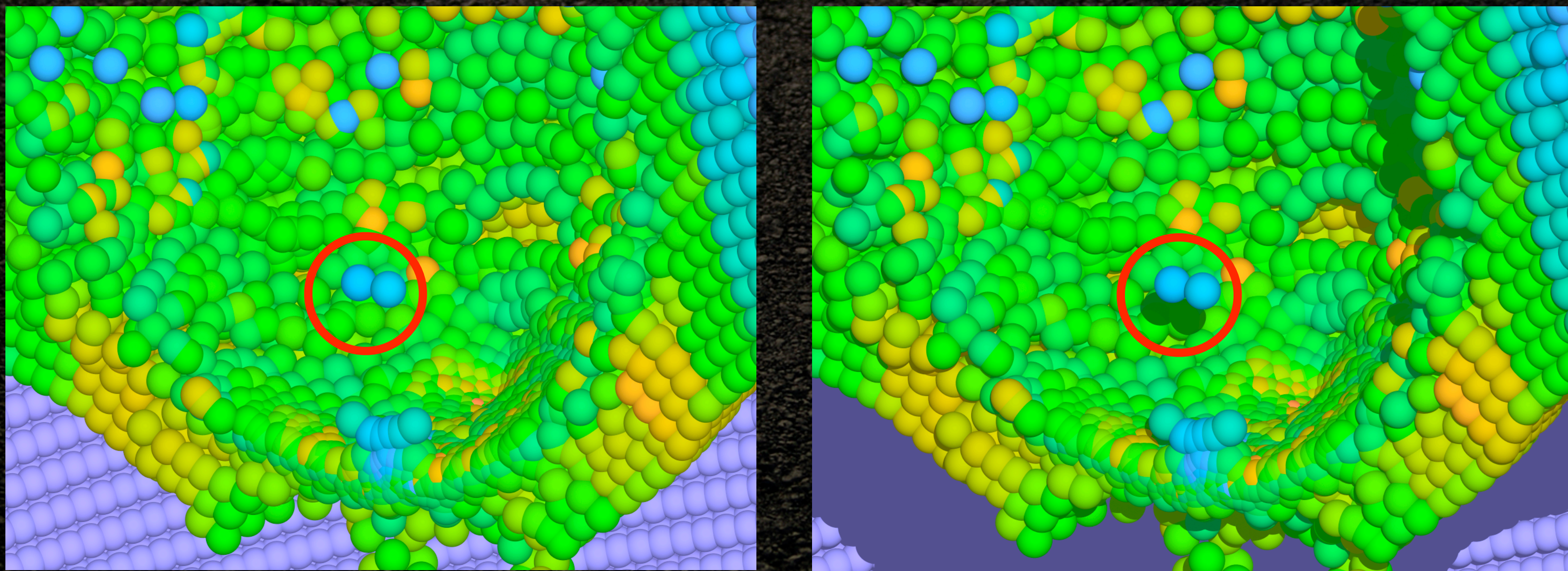
Visualization



Using shadows



Shadows help to clarify the position of individual particles

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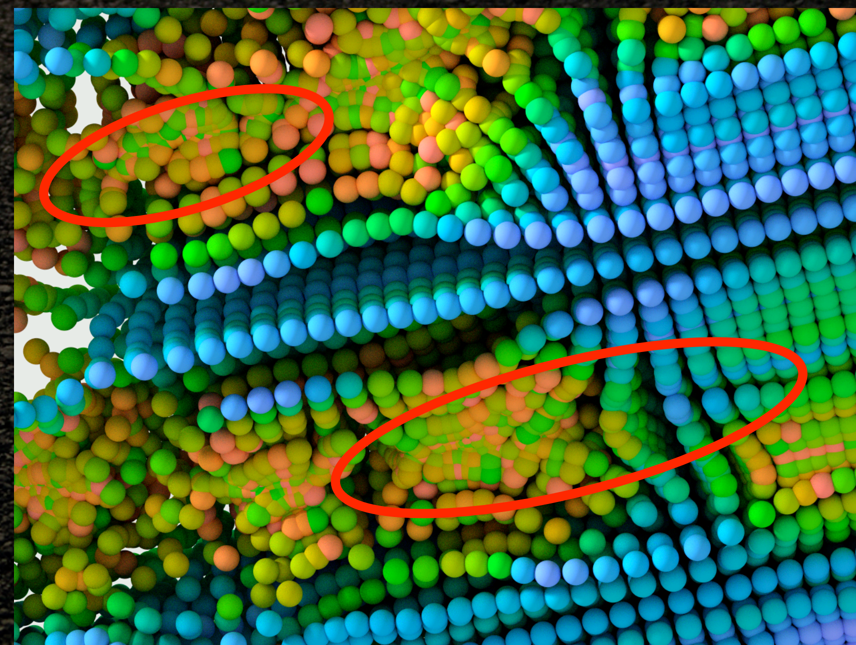
Using global illumination

Local shading + shadows

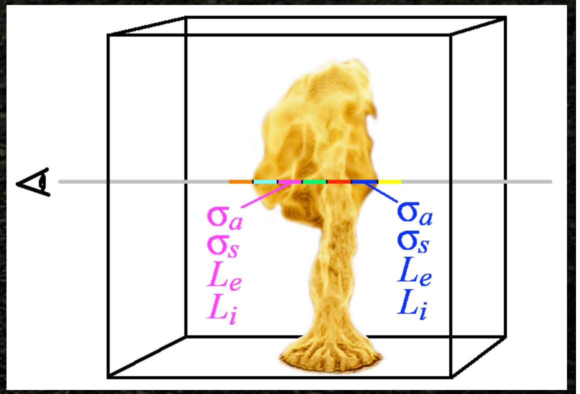


Global illumination

Advanced illumination models enhance subtle detail

Realistic Fire Rendering

- Compute emission, absorption and refraction at visible wavelengths
- Handles both quasi-continuous emission from soot and discrete spectral emissions from other chemical species
- Model S-potential response of human photoreceptors to reproduce perceived colors

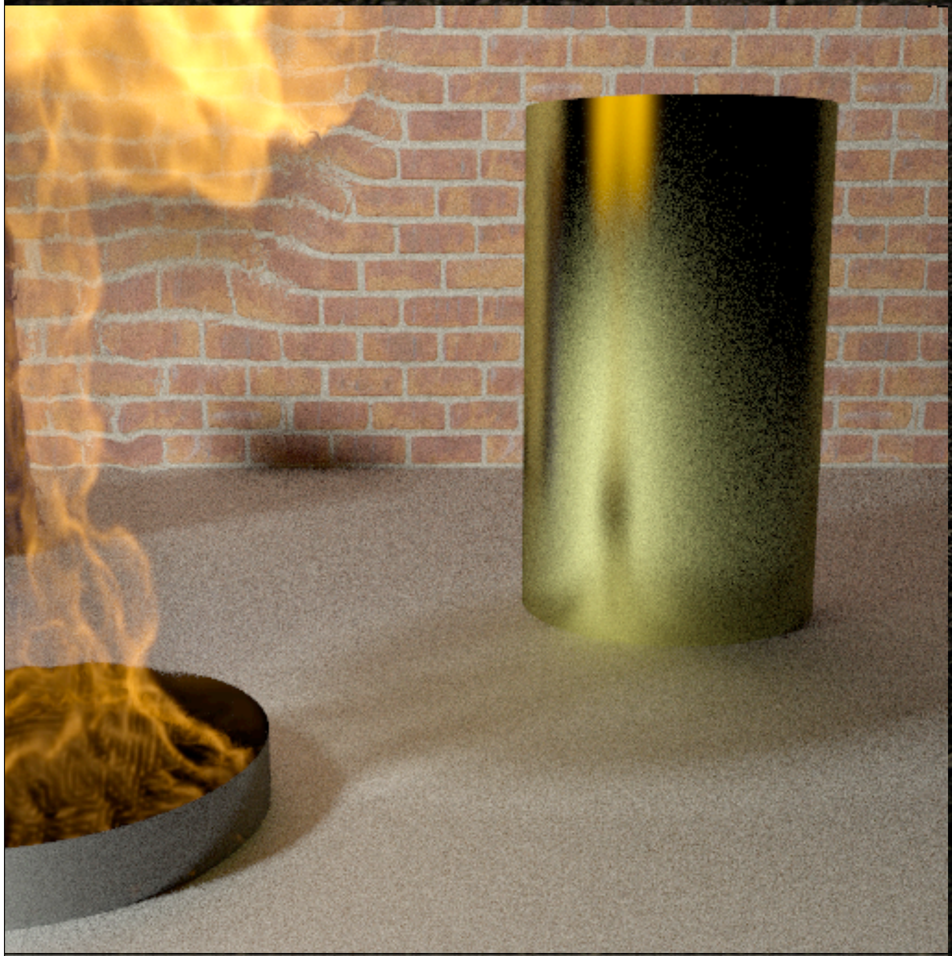


Visual Adaptive Response

Night

Day

Thermal Refraction



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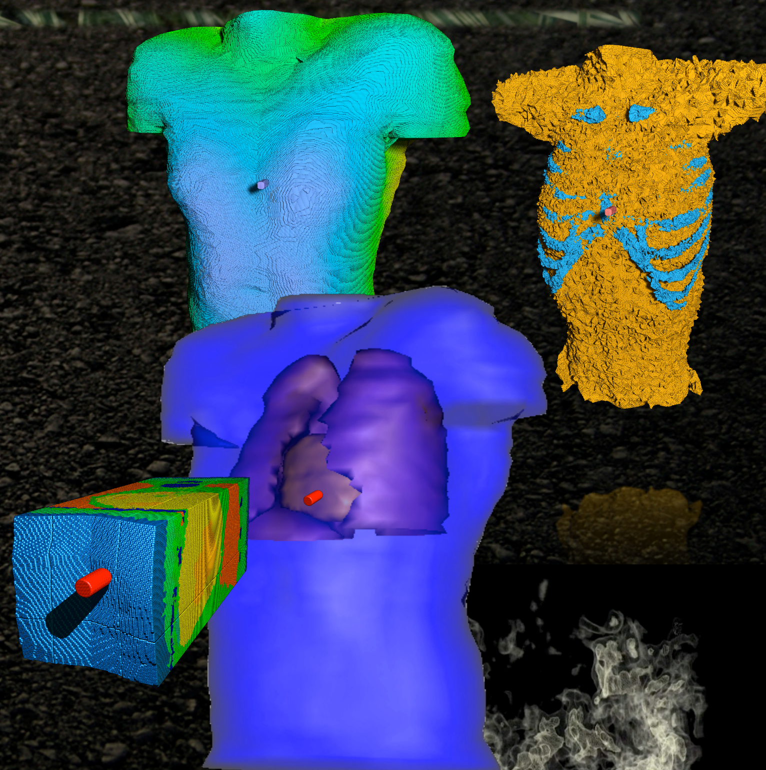
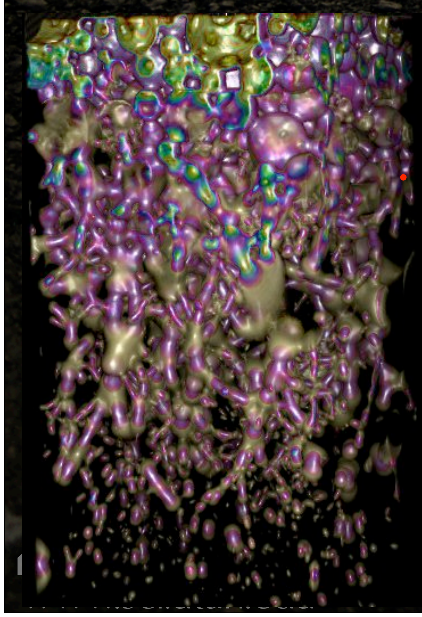
Physically-Based Realistic Flame Rendering Using Ray Integration

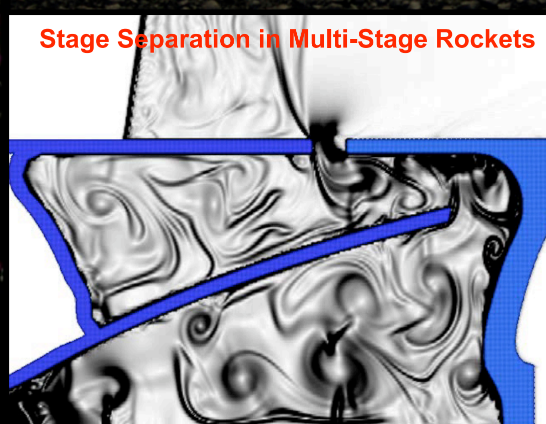
Heptane Pool
Fire Simulation

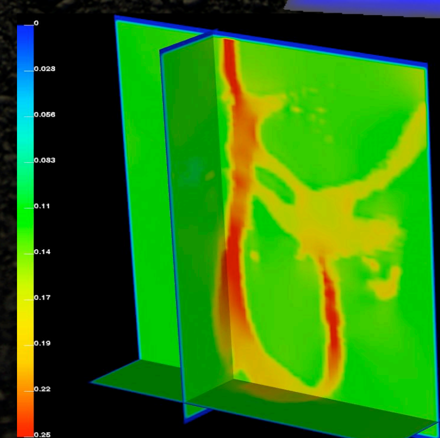
Uintah uses

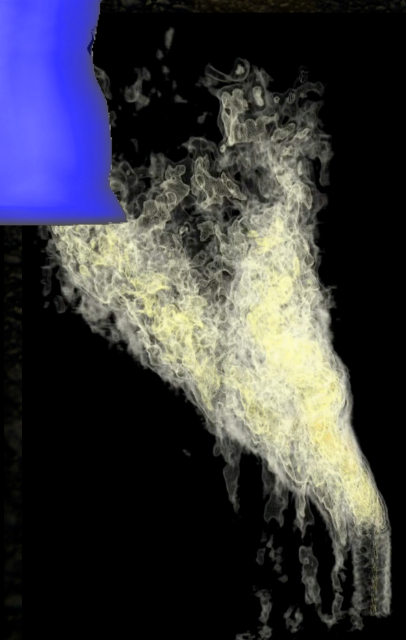
- Fluid-structure interaction
  - Vocal fold modeling
  - Wound analysis
  - Blast-wave/vehicle interaction
- Fires
  - Flare simulation
  - Oxy-fired coal



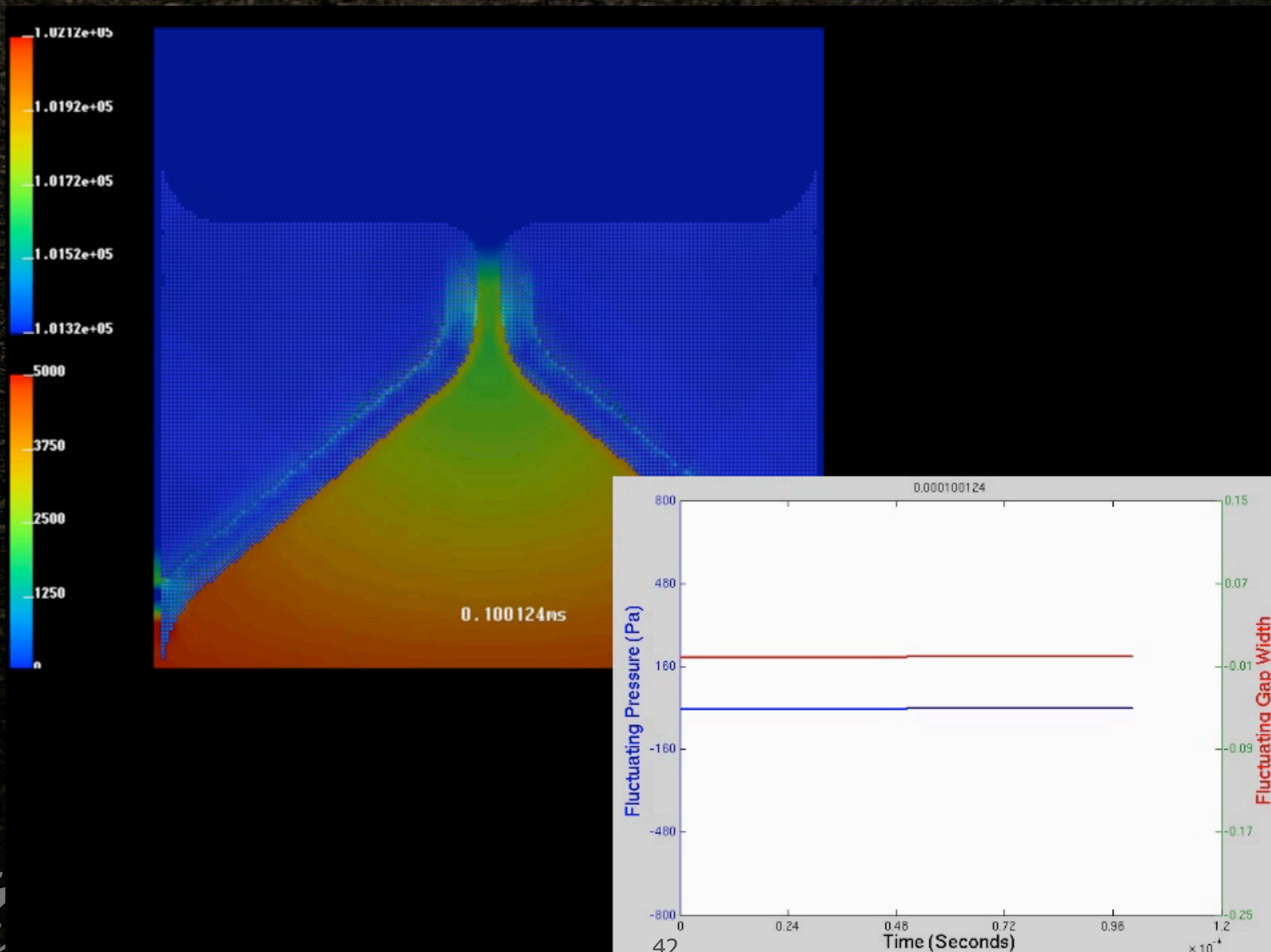








Vocal fold modeling



Conclusions

- Interdisciplinary efforts require:
  - Patience
  - Respect
  - Improvements in all areas of Software Engineering, Numerical Methods, Modeling, etc.

Acknowledgements

- Department of Energy ASC program
- SCI Institute
- Center for Simulation of Accidental Fires and Explosions

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Questions?