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Interactive Simulation and Visualization in Medicine

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School of Computing

University of Utah

Computational Science Pipeline

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- Construct a model of the physical domain (Mesh Generation, CAD)
- Apply boundary conditions
- Numerically approximate governing equations (FE, FD, BE)
- Compute (Preconditioners, Solvers)
- Visualize (Isosurfaces, Vector Fields, Volume Rendering)

Computational Science - Today

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Modeling

↓

Simulation

↓

Visualization

Computational Science - Today

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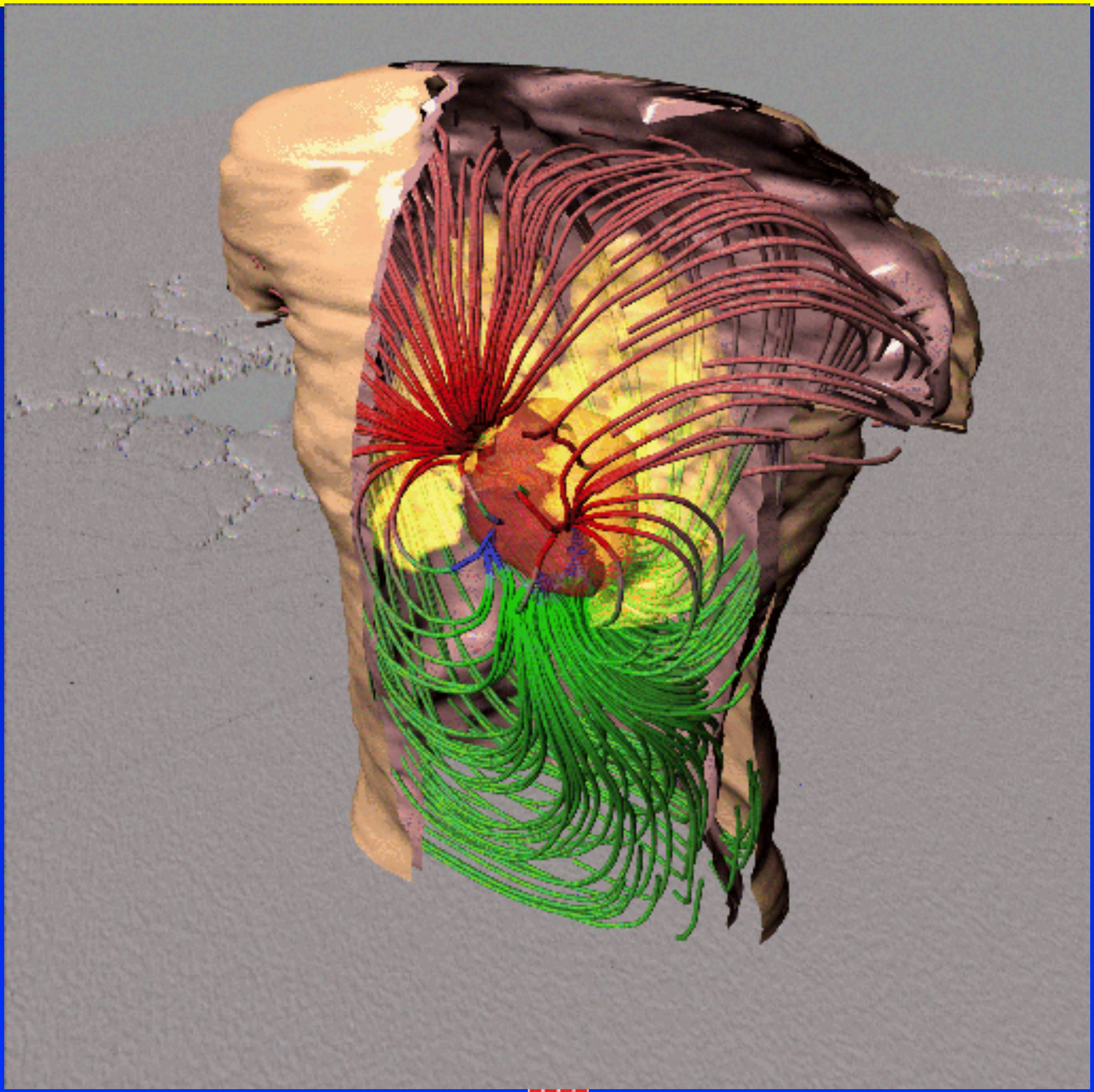

ViSC Workshop Report

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"Scientists not only want to analyze data that results from super-computations; they also want to interpret what is happening to the data during super-computations. Researchers want to ***steer*** calculations in close-to-real-time; they want to be able to change parameters, resolution or representation, and see the effects. They want to drive the scientific discovery process; they want to ***interact*** with their data...."

Computational Science - Tomorrow?

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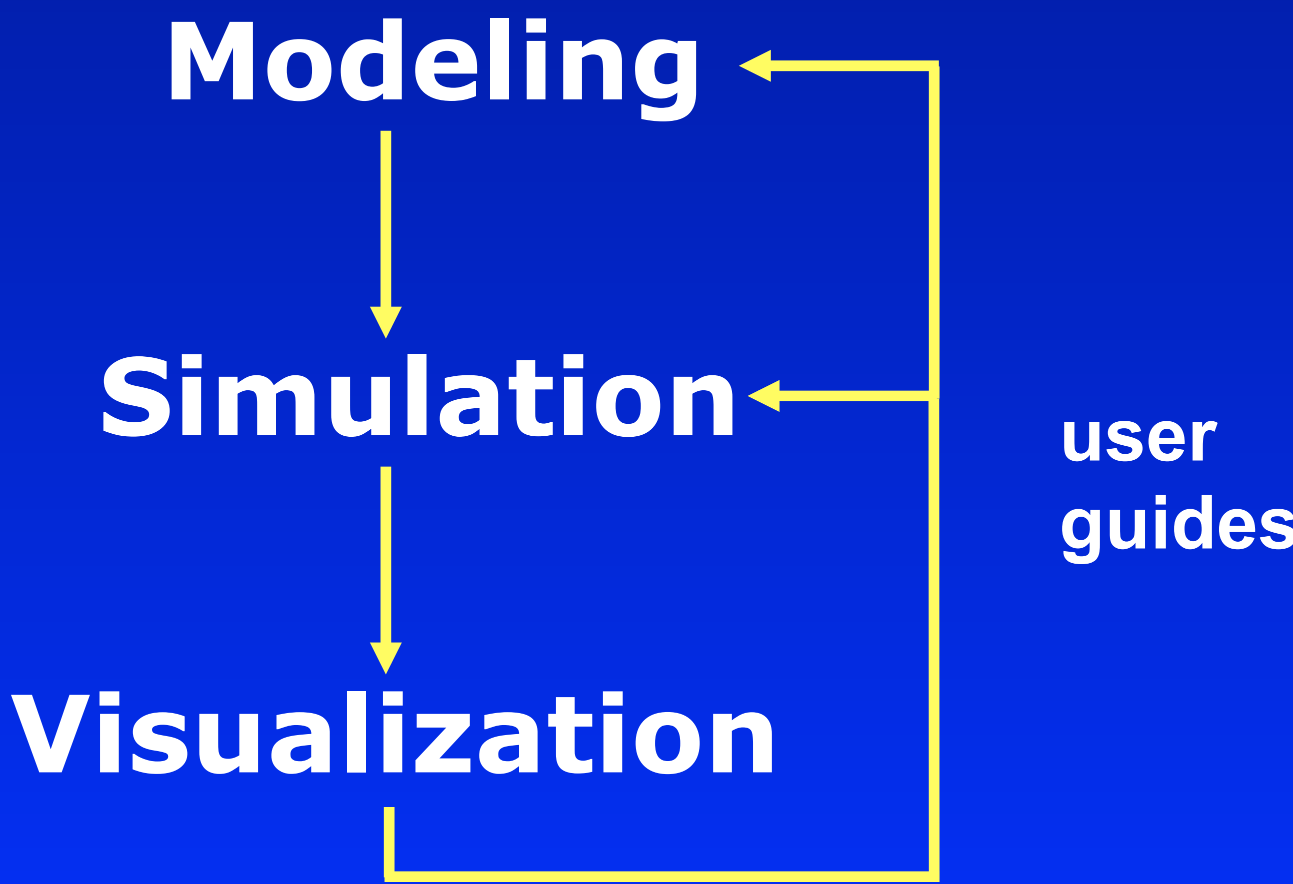
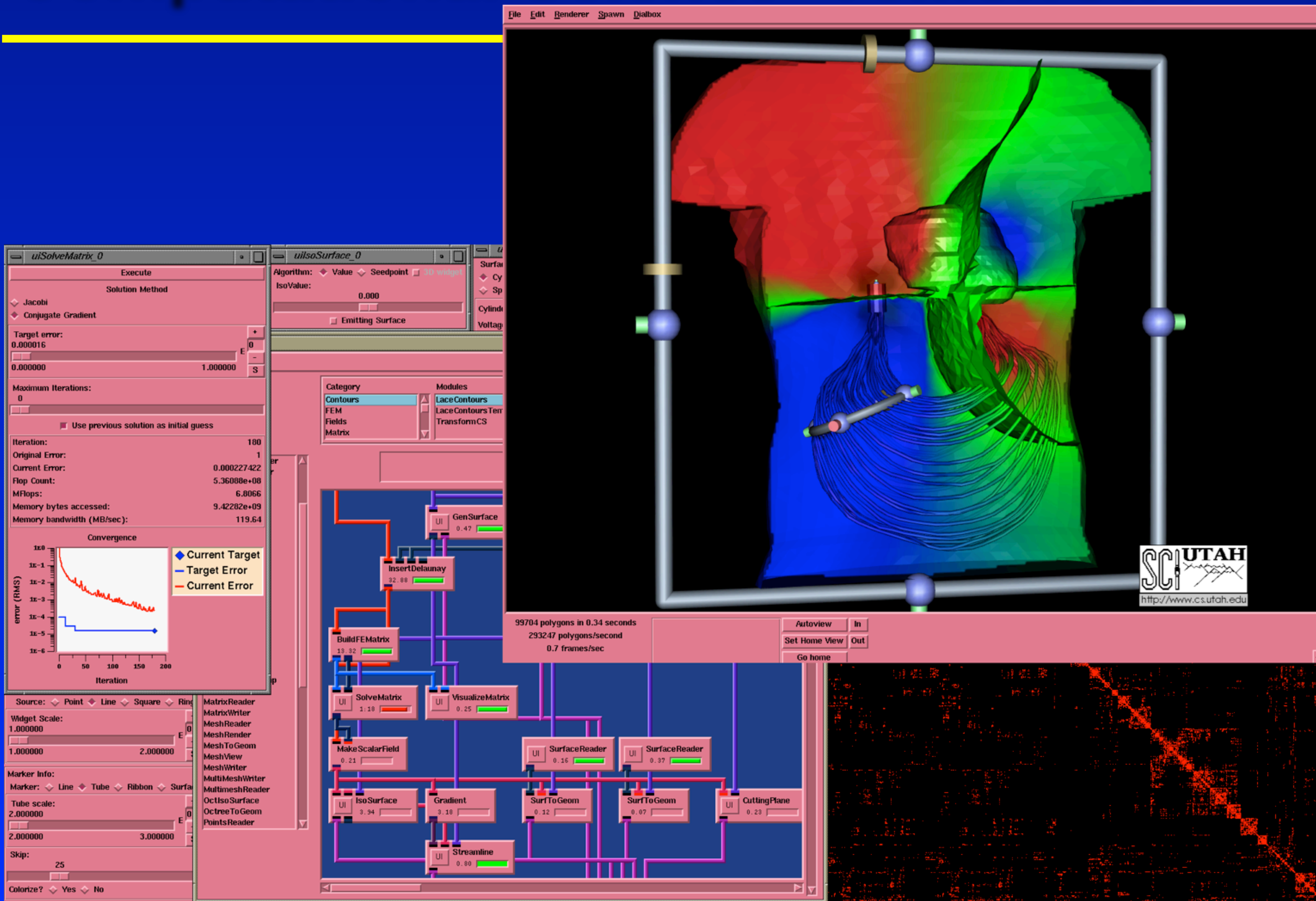


Computational Science -Tomorrow?



Computational Steering

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If this is so great, why is it just starting to “catch on”?

- Scientists greedy for CPU cycles
- Faster machine - Larger problems
- Different sets of expertise
- It’s hard to make it all work well!

SCIRun

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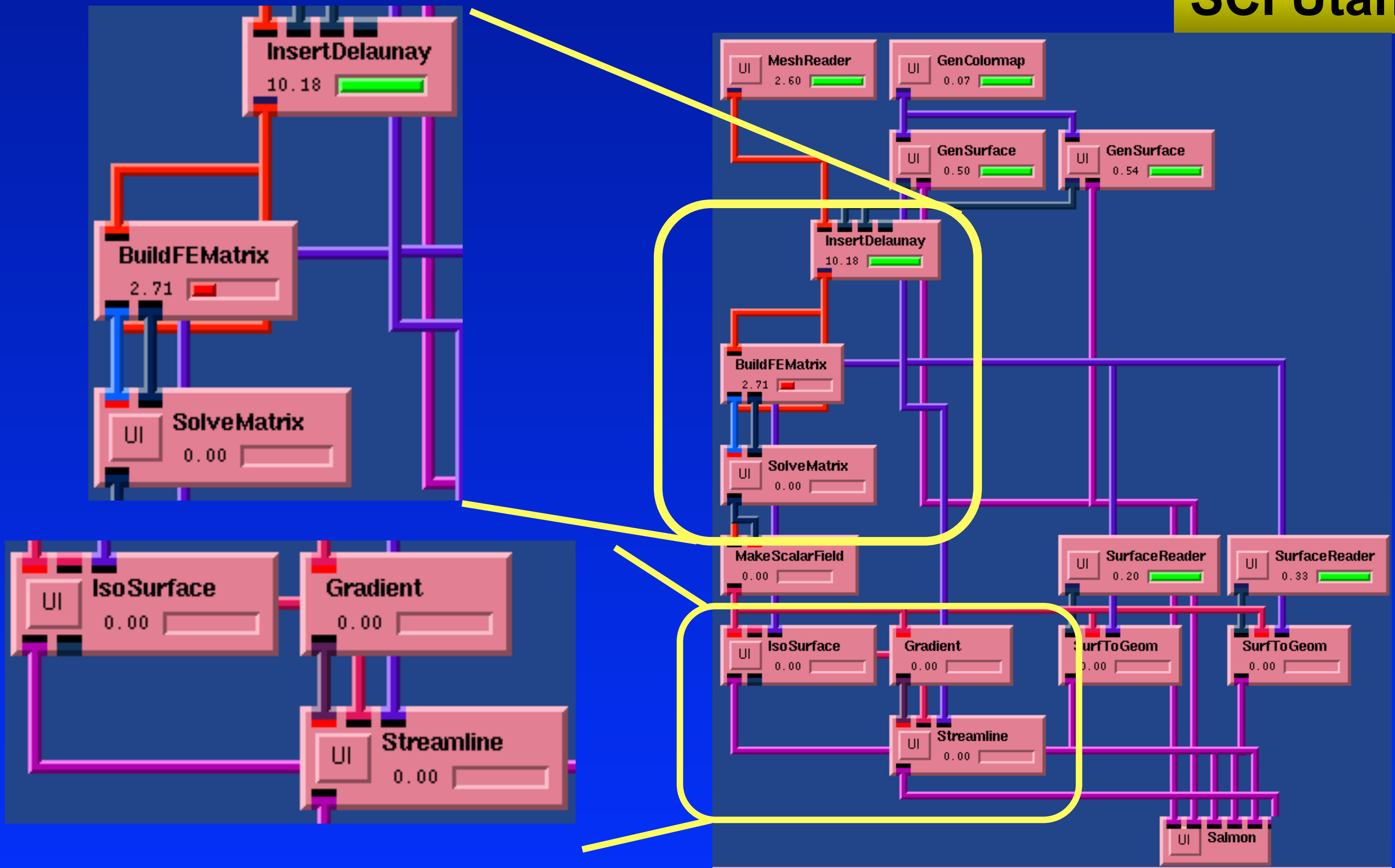

Application Needs

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- *What if* questions (a "computational workbench")
- Iterative design (medical device design)
- Time-critical (diagnosis, surgery)

"Minor" Challenges

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- Accommodating parallelism
- Large data sets
- Complex physics/physiology
- Existing code
- 3D user interaction
- Efficiency
- Fault tolerence
- Etc., etc., etc.

Device Design: Defibrillation

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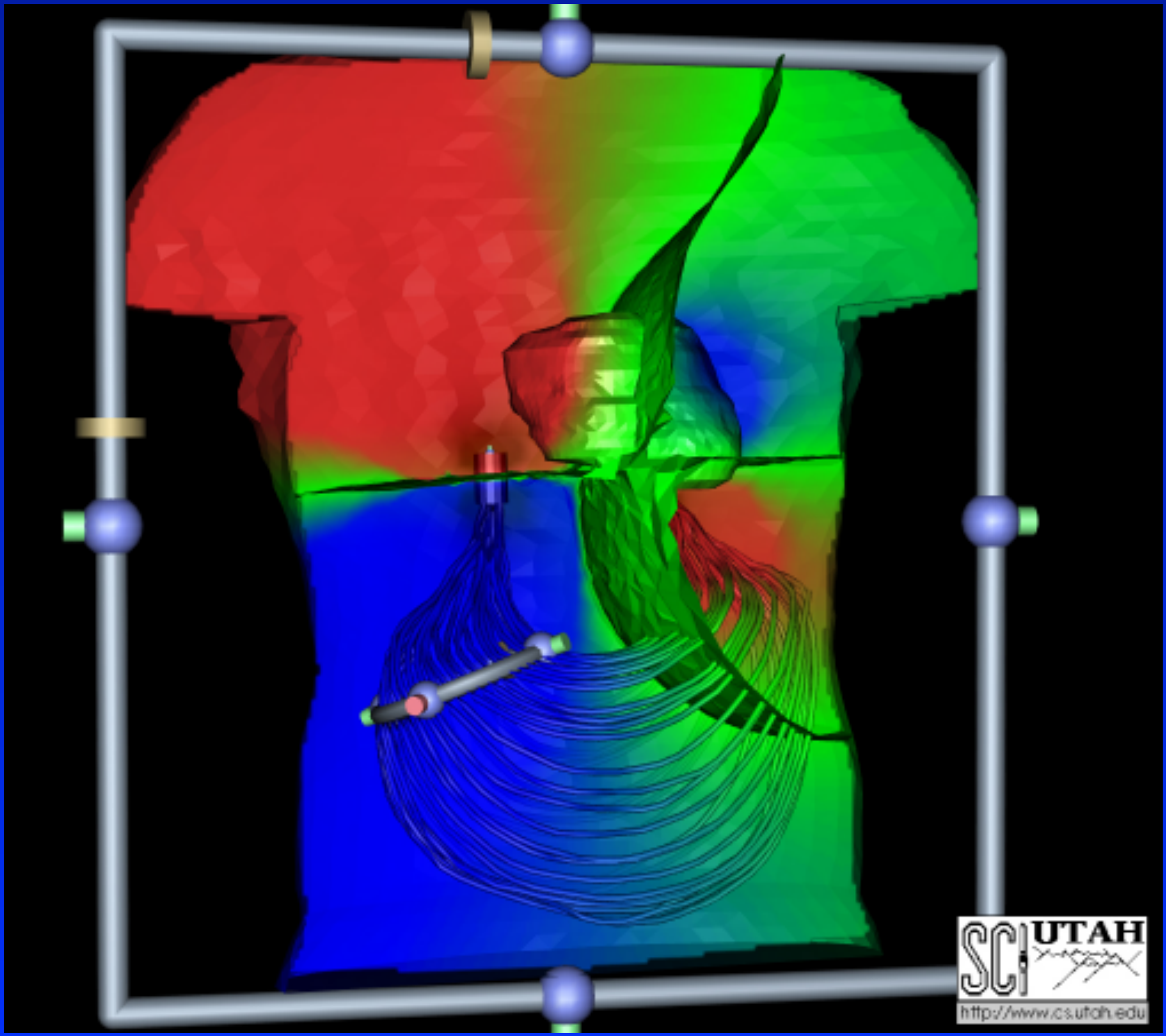

Time-critical: Neurosurgery

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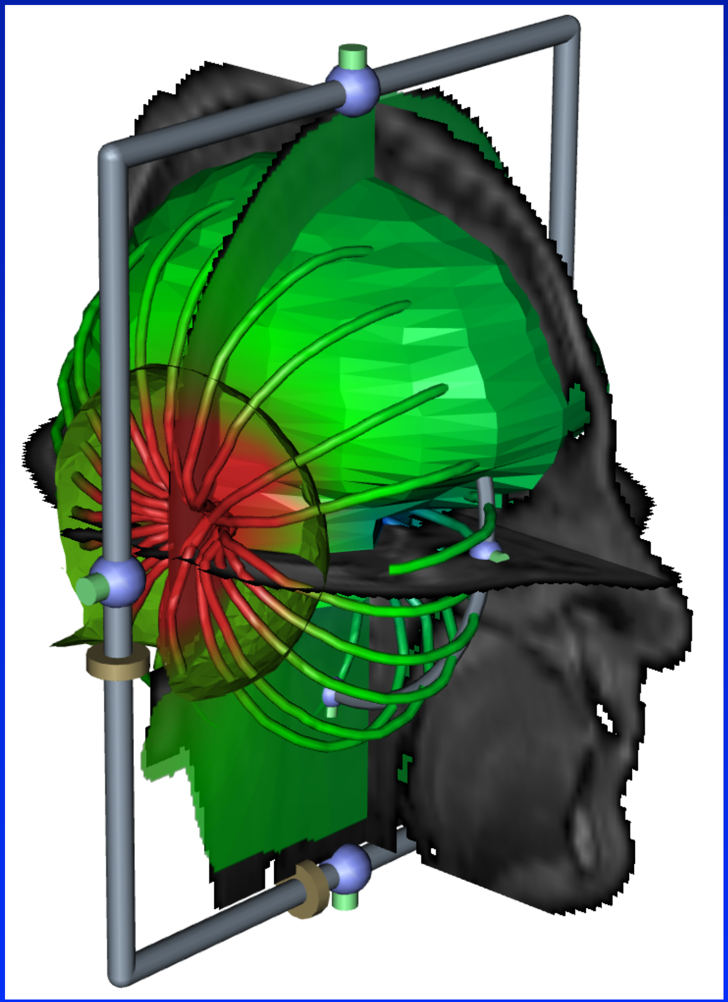
Harvard & Brigham Women's Hospital



Interactive Large-Scale Visualization

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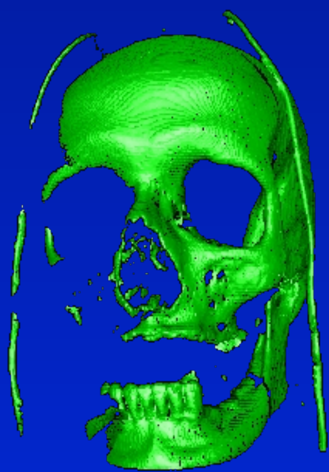
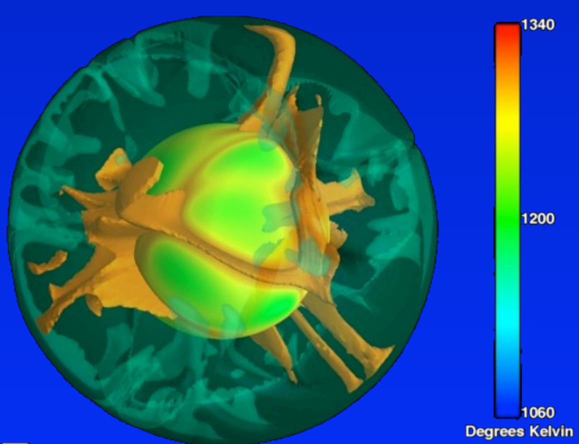
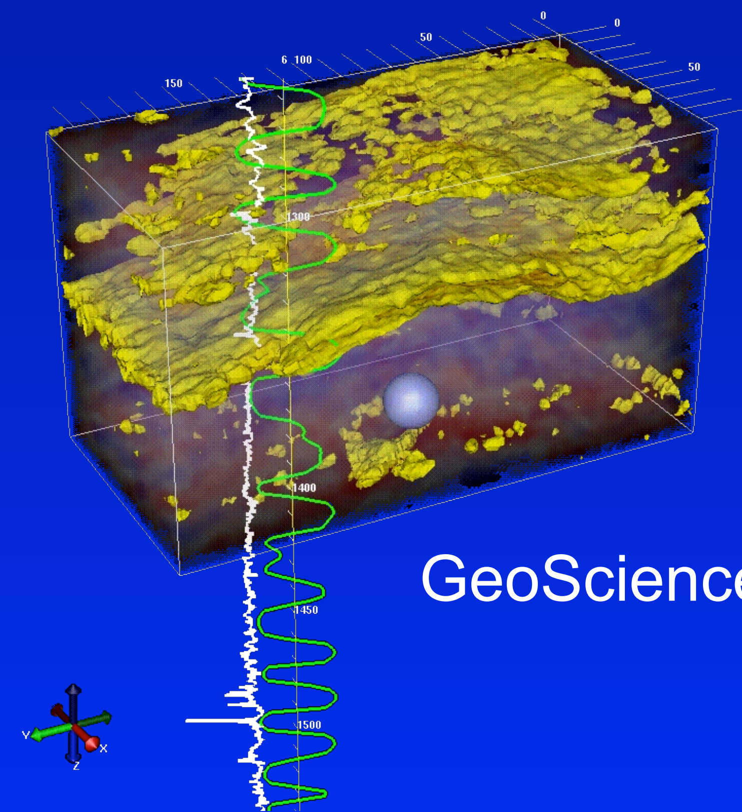


Medical

Scientific Computing





GeoScience

Visualization at All Levels

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Application level

- Streamlines, cutting planes, isosurfaces, surface maps, etc.

System level

- module profiling
- memory allocator visualization
- more in progress...

Convergence

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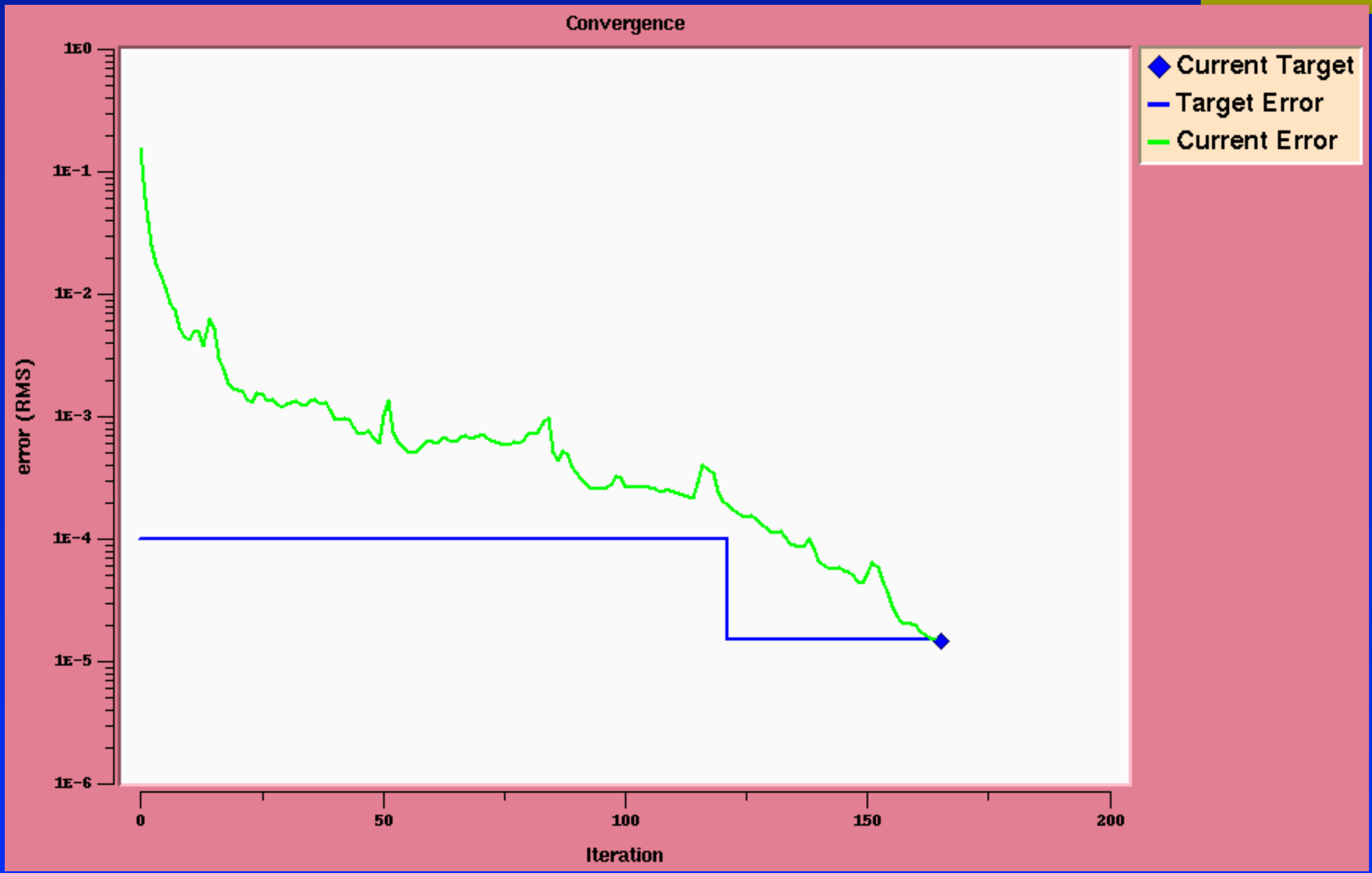

Numerical Feedback

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Iteration:	237
Original Error:	1
Current Error:	9.43408e-05
Flop Count:	8.97562e+07
MFlops:	167.099
Memory bytes accessed:	1.45805e+10
Memory bandwidth (MB/sec):	2942.4

3D Widgets

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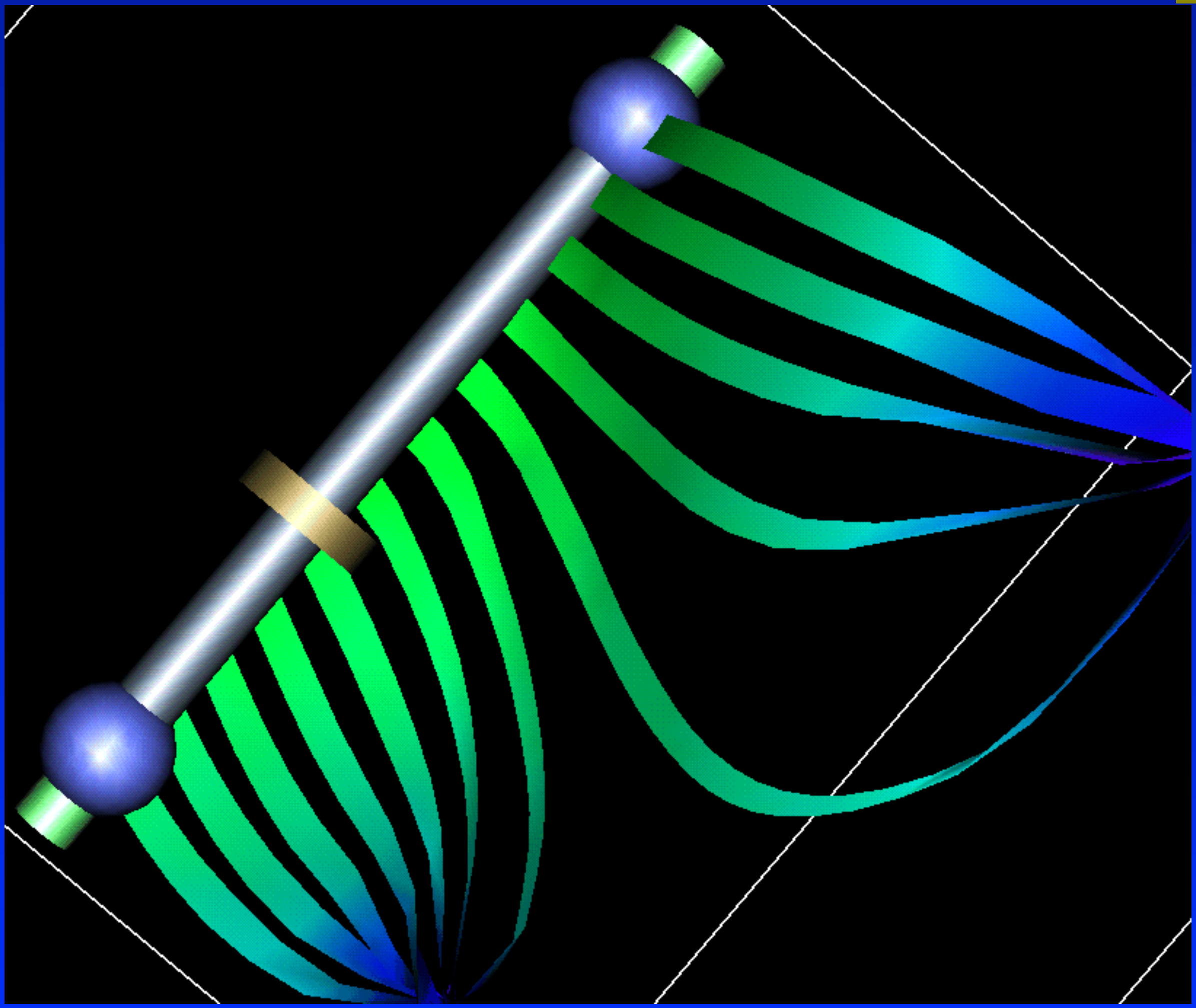

Real-Time Ray Tracer

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Maximum Intensity Projection

35 million spheres

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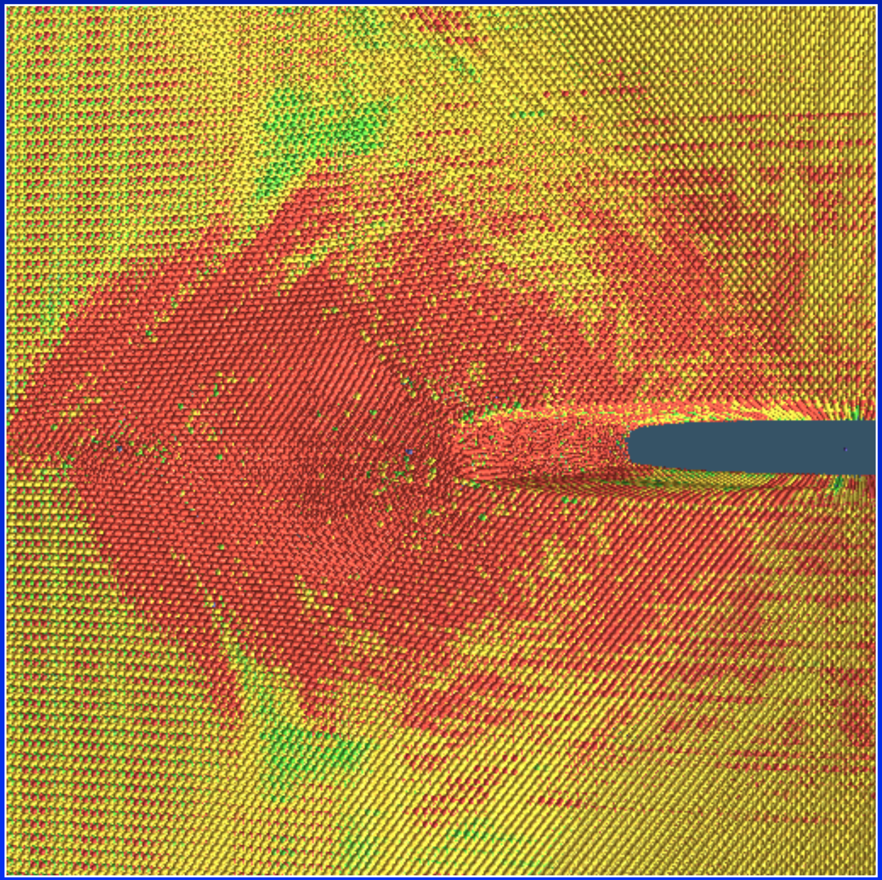

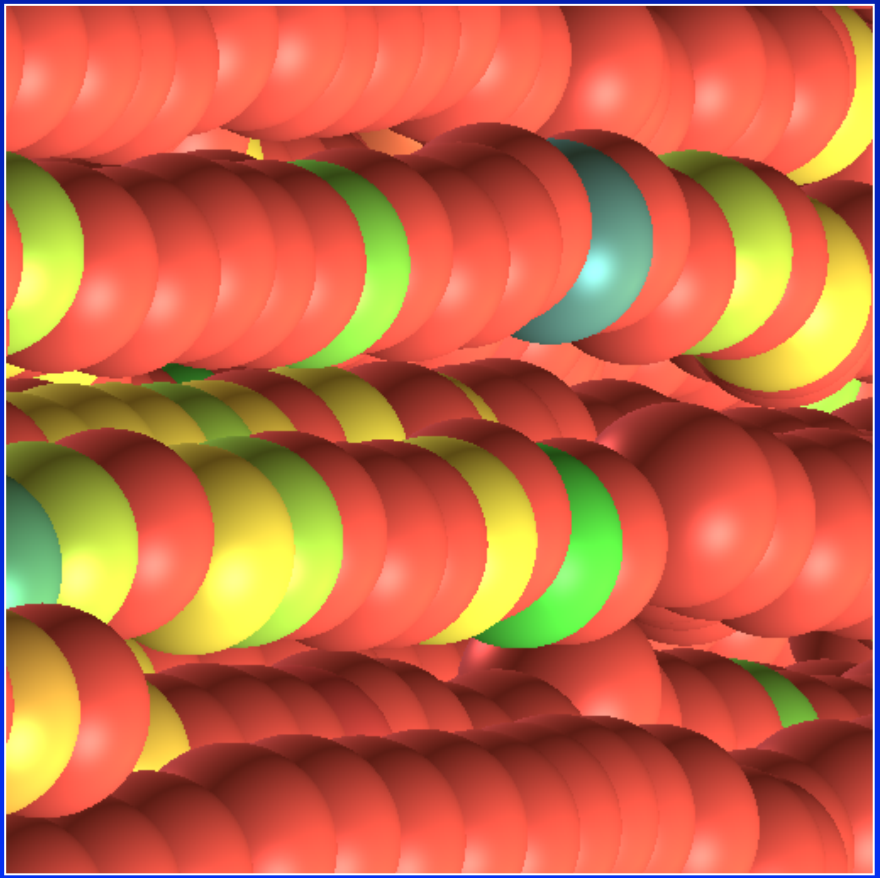

Adaptive Finite Elements

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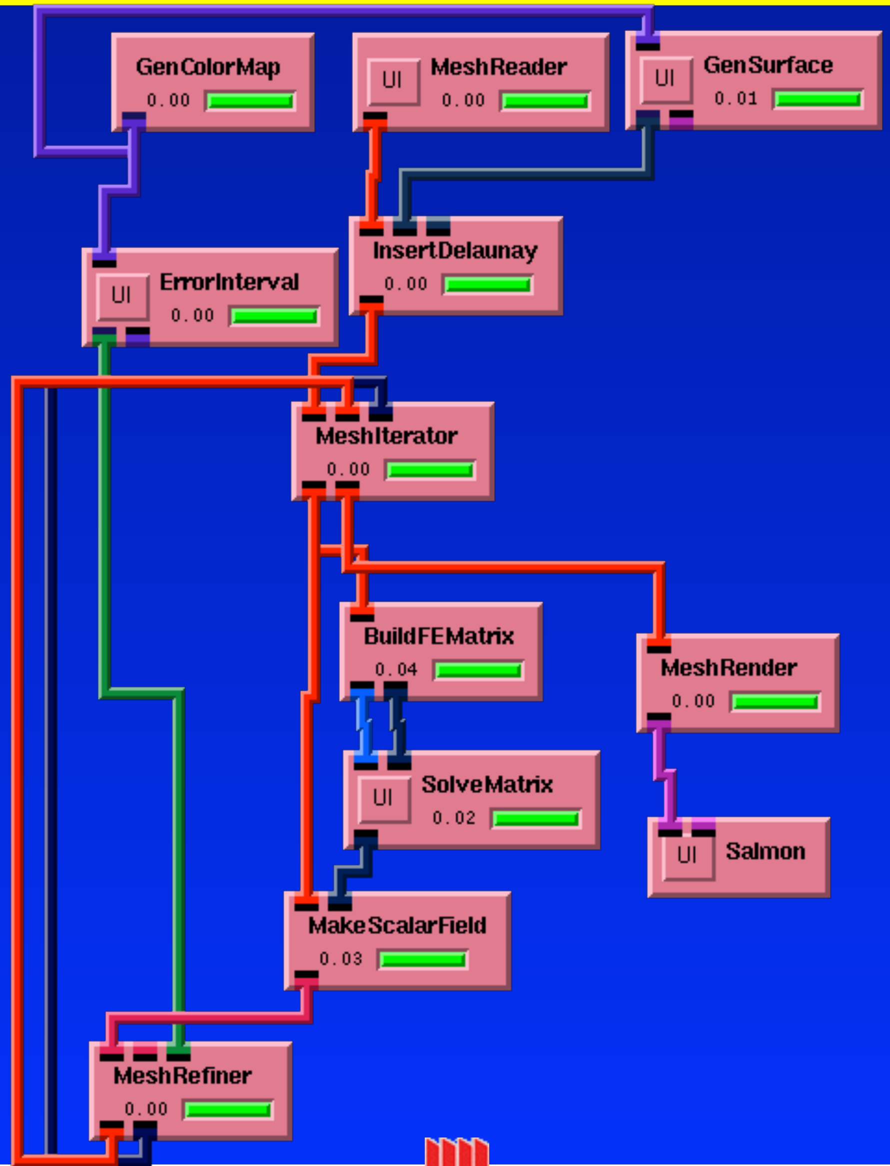
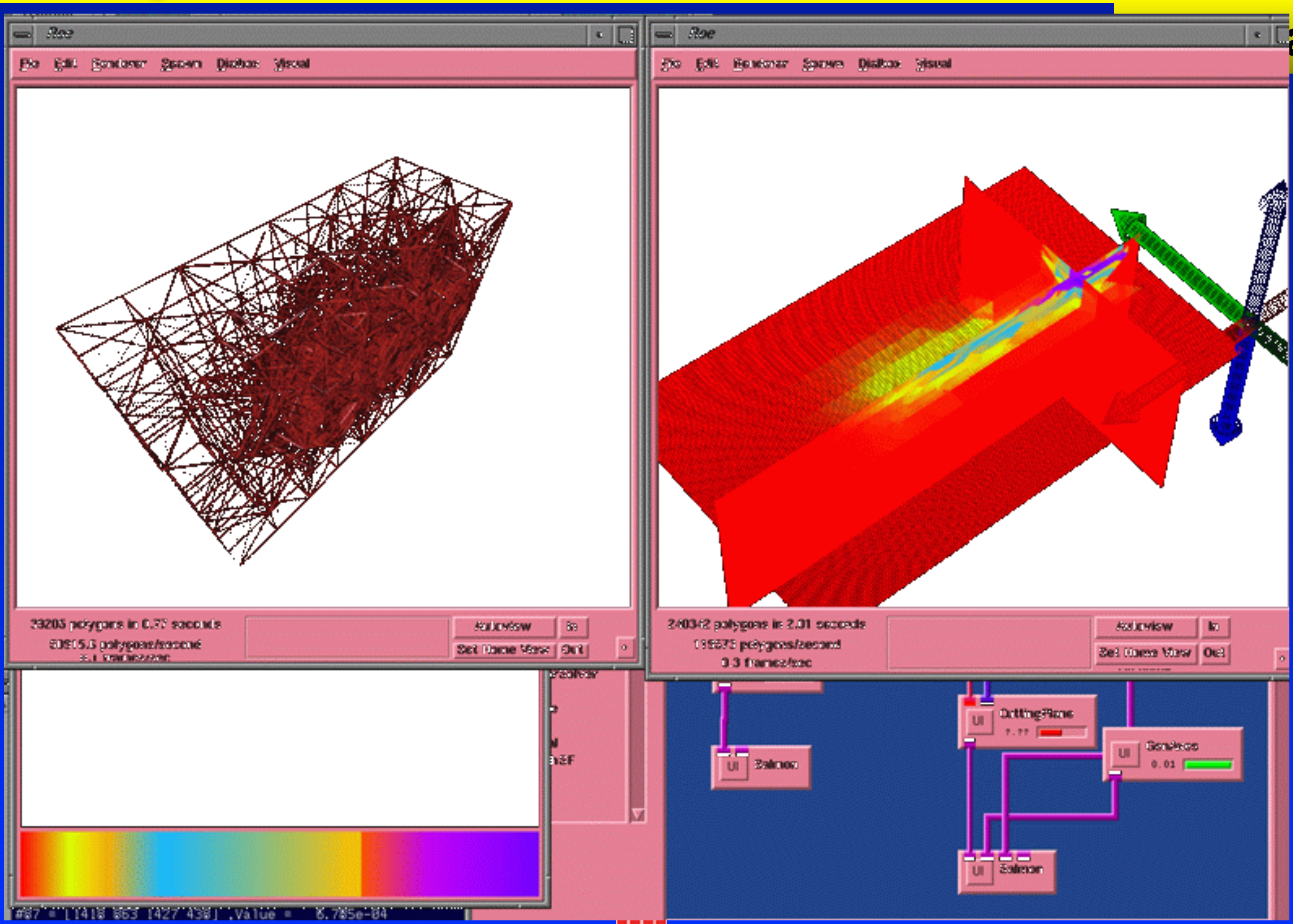


Adaptive Finite Elements



Time-dependent Adaptation

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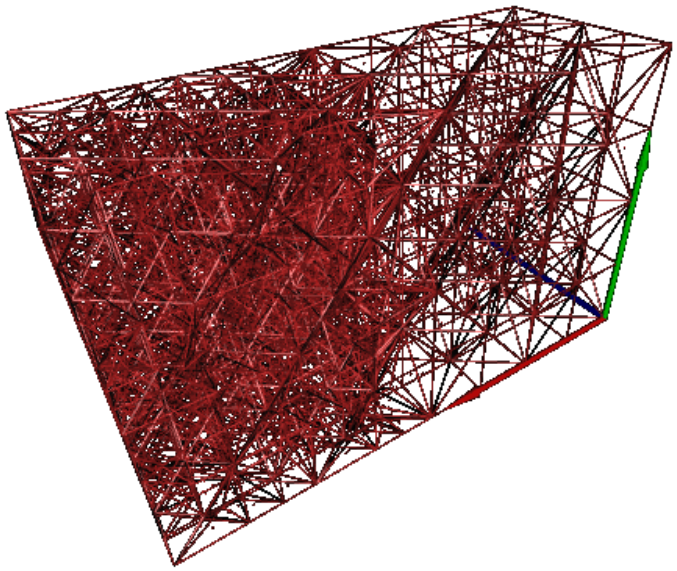

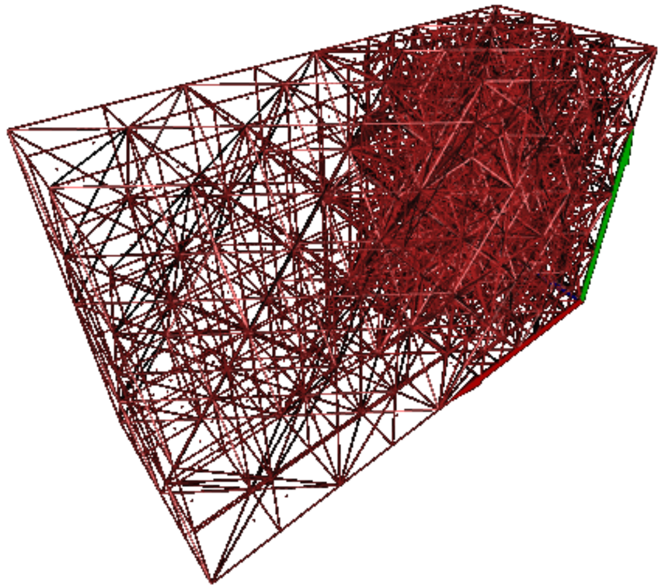

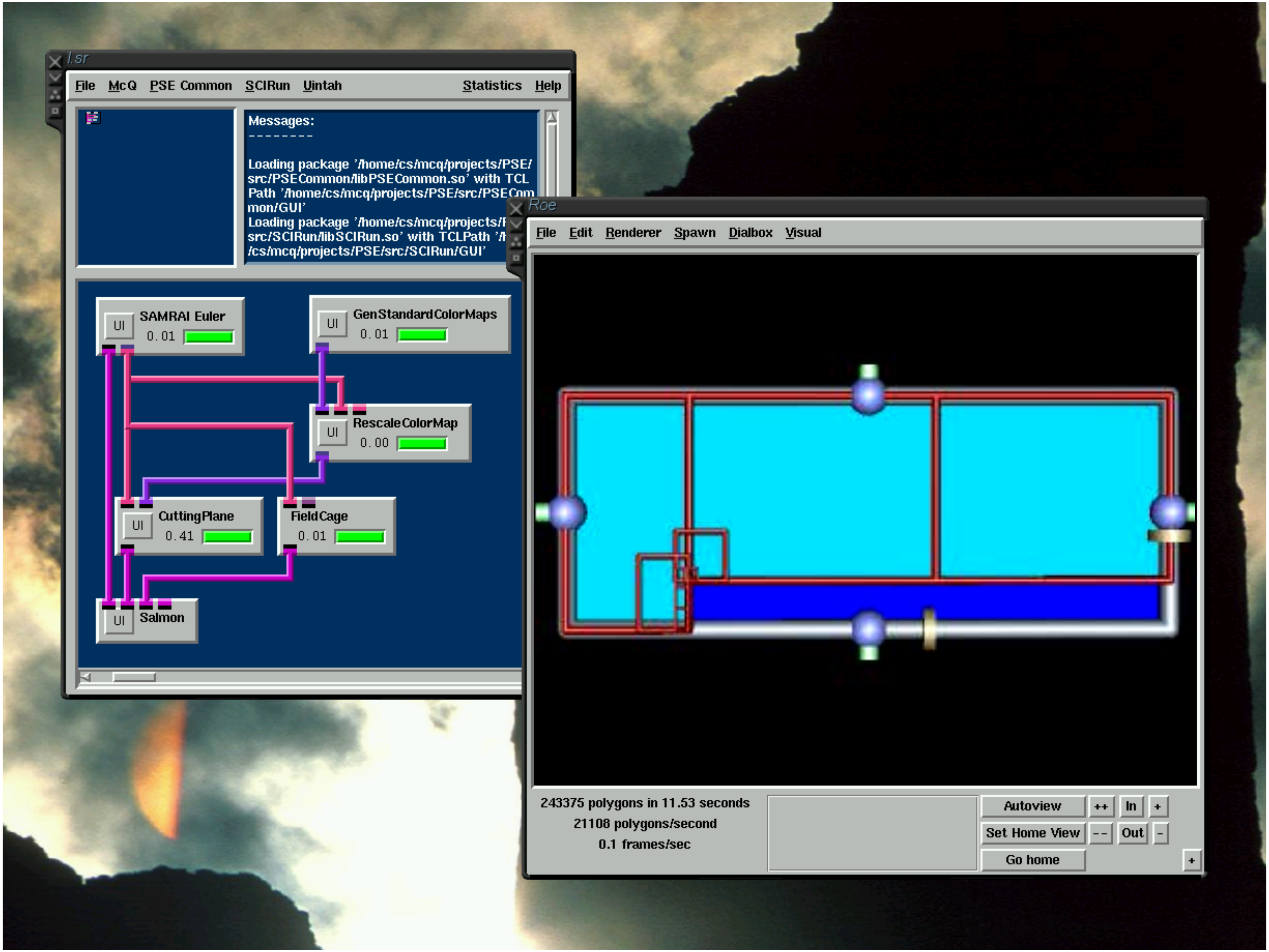

l.sr
File McQ PSE Common SCIRun Uintah Statistics Help
Messages:
Loading package '/home/cs/mcq/projects/PSE/src/PSECommon/libPSECommon.so' with TCL Path '/home/cs/mcq/projects/PSE/src/PSECommon/GUI'
SAMRAI Euler
0.01
GenStandardColorMaps
0.01
RescaleColorMap
0.00
CuttingPlane
0.41
FieldCage
0.01
Salmon
Roe
File Edit Renderer Spawn Dialbox Visual
243375 polygons in 11.53 seconds
21108 polygons/second
0.1 frames/sec
Autoview
Set Home View
Go home
In
Out

Geo Science Application

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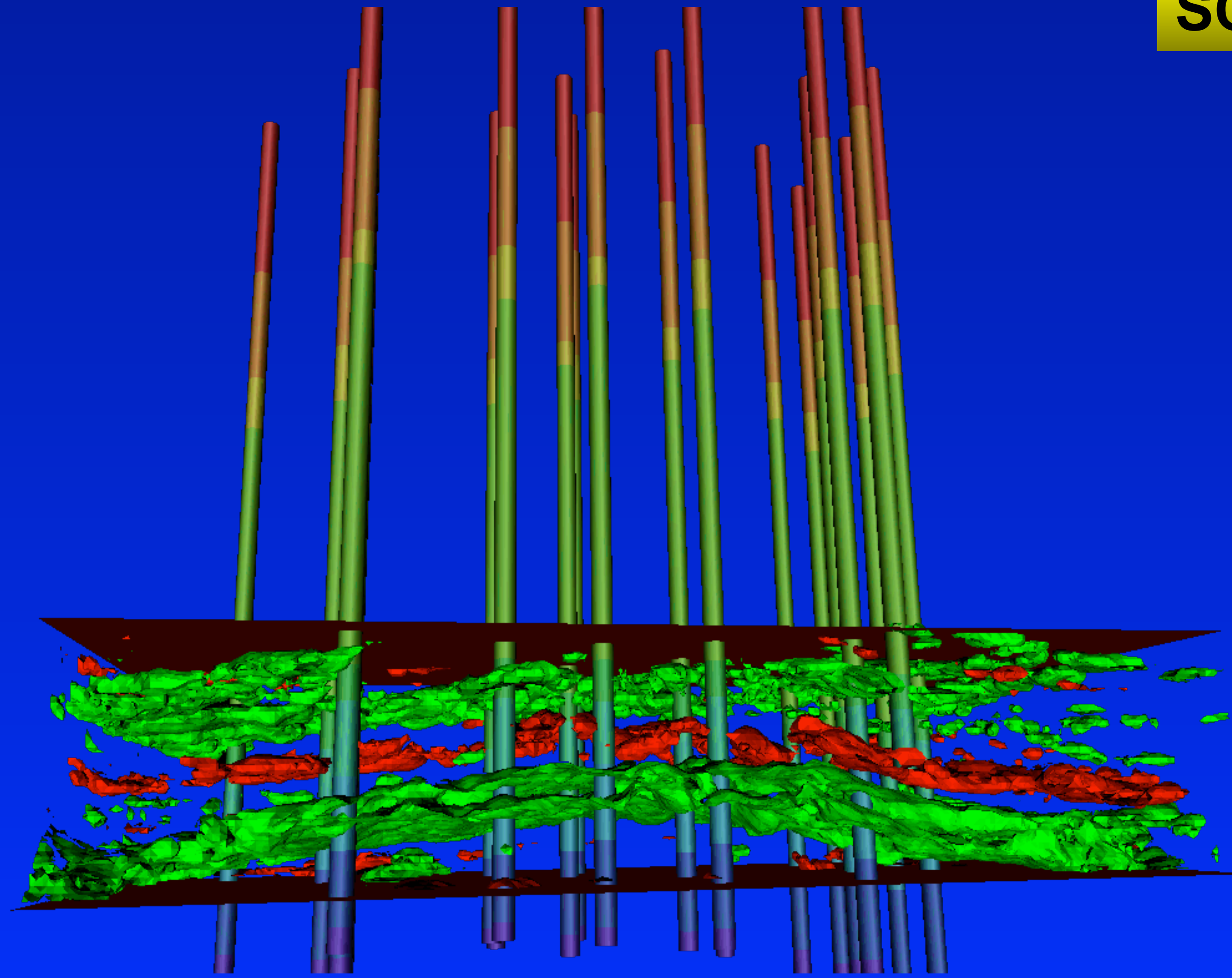

ASCI

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C-SAFE Uintah Network

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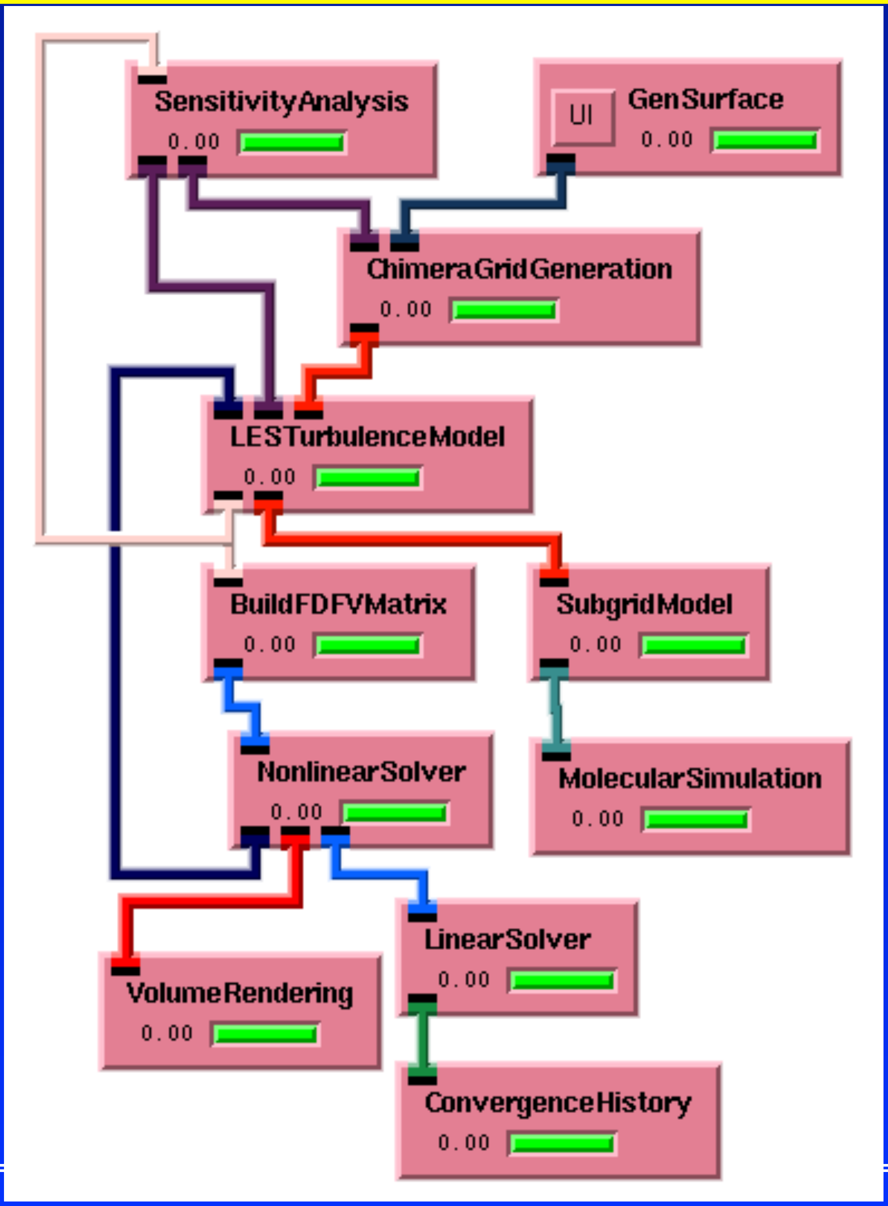

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ASCI
Blue Mountain
Los Alamos National Lab

Goals

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- Help foster interest/research in PSEs/Components
  - Computational Workbench
- Help realize a common API for PSEs/Components
  - Common Component Architecture (CCA) Forum
    - www.acl.lanl.gov/cca-forum

More Information

SCI Utah

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www.cs.utah.edu/~sci

The frustration of using bad software…

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SCIRun Ports

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Requirements:

- OpenGL
- Tcl
- p-threads

Unix

- single and multiprocessors

PC - NT and Linux

SCIRun Availability

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- Not generally available yet
- Approx. 10 beta users now
- Research version available as soon as we finish documentation
- Commercial license available from Visual Influence:
- www.visualinfluence.com

Conclusions

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Computational steering (interactive computing) can be a more efficient paradigm for iterative design problems and time-critical computational problems

Future Work

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- Detachable User Interfaces
- Distributed Memory Implementation
- More Modules
- New Applications
- **Finish Documentation!!**

Acknowledgements

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DOE ASCI

NSF PACI and PFF

SGI Visual Supercomputing Center

Utah Centers of Excellence

Visual Influence

Applications 1

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Mark Ellisman – UCSD, NPACI, NCRR

- Linking expensive data acquistion devices – high resolution microscopes
- Compare data from the microscopes with data from simulation and databases
- Data size – 2K^3 (will be 4K^3 within a couple of years) – lots of computing – currently using distributed workstations using Globus

Mark Ellisman - cont

SCI Utah

- Time critical because of mass loss
- Data -> Modeling ->Analysis ->

Visualization->Database->Feedback (and feedforward) throughout

Could enable further science/ applications with protein structures (and others)

Useful for extending (via simulation and/or experimentation) functional information within multilayer databases

Joel Saltz

SCI Utah

- U. Of Maryland, Johns Hopkins
- Alpha Project (NPACI) with Mary Wheeler (UT Austin) on reservoir simulation
- Tighten the loops between production information, sensor data and simulation data.
- Satellite data, classification, visualization, large-scale data query and processing.

Joel Saltz - cont

SCI Utah

- Patient specific diagnosis and treatment – need to access and register distributed data, integrate radiology, microscopy, pathology data
- Applications in drug delivery, interventional radiology, etc.

John Miller

SCI Utah

- Center for Computational Biology – Montana State
- Figure out how the brain works
- How information is encoded
- Senors – receive data, coupled with information from a large database, then via a combination of experimental and simulation data, control parameters to manipulate the system (the visual system, for example)

John Miller - cont

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Massive data streams – analyze on the fly – use this data to interact with a model drawing parameters from databases – and do it VERY fast.

Avis Cohen

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- Long running simulations for stochastic differential equations – doesn't need to be interactive.
- Spinal cords – chips that stimulate spinal cords in adaptive way such that it can take sensory feedback and maintain a particular motor pattern.
- Use an adaptive analog system
- Understanding algorithms for input/output of systems

Carlos Felippa

SCI Utah

- Aerospace engineering
- Multiphysics, embedded systems with real-time control
- Reconfigurable systems
- Heirarchical systems
- Model systems and control
- Robust against uncertainty
- Figure out commonalities

Michael Creutz

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- Particle physicist
- Long running computational jobs
- Visualization not useful (yet)

Charbel Farhat

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- Univ. of Colorado – Aerospace engineering
- Data driven embedded systems
- Feedback control of embedded systems – need automatic system for a control
- Autocallibration between experimental apparatus and simulation

Sandy Boyson

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- University of Maryland
- Currently there are long (weeks) delays in market feedback/ analysis
- Situational awareness sensory data of Army troops – what to do with all the data, how to use the data for real-time response – how do you manage such situations

Abhi Deshmukh

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- U. Of Mass.
- Distribution systems of transportation networks, getting feedback from people on the road and planning shortest path
- Using algorithms based upon how ants find food

Jacobo Bielak

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- CMU – seismology
- Need a heirarchy of problems and methods/techniques
- Some are real-time, some aren't
- What if questions
- Design questions
- Real-time (related to prediction and control)

Jacobo Bielak - cont

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- Earthquake ground motion
- Is there a design criteria based upon ground motion (not real-time at this time)
- What if – how does the underlying structure relate to ground motion – does it depend upon the local of the source.
- Why now? – more/better/cheaper sensors and integration with simulation
- Distributed collaboration, steering, and visualiziation

Daniel Weber

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- U. Of Oklahoma
- Center for Analysis and Prediction of Storms
- Numerical weather prediction systems – large-scale (1000 CPUs)
- Run at higher resolution (1K on a side)
- Registration of multiple modalities of input data (radar, doppler, etc)
- Actually works

Daniel Weber - cont

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- Feedback – cycling using updated data
- This is the right time to take the next step (entire US)

Robert Lodder

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- Univ. of Kentucky – cardiac catherization

Common Themes

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Hardware Needs:

- Need more cycles
- Need more bandwidth

Software Needs:

Decision process

- Objective functions
- Value of information
- Treatment of uncertainty
- Perception
- Stopping rules

New Applications

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Radio astronomy – 90 radio telescopes – full sky survey – pulsars, comets, variable stars – are time-dependent – need a tight connection between data collection, then move the specific type of telescope towards the location – must have dynamic link or experiment doesn't work.

What Will DDDAS Enable?

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- Better weather prediction because of data feedback
- Enable new level of physiological experiments because of the tight coupling between analysis and experiment – this would alter the way some experiments are done
- Next level of embedded systems – ability to react to uncertain or unpredictable input

Why Now?

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- Leverage existing NSF programs
- Think tactfully about implementation of new programs
- Networking/interconnectivity, cycles, disks, and new algorithms are enabling new applications
- New sensors/data is available

Dynamic Data-Driven Application Systems

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Applications Group I

Chris Johnson
Jacobo Bielak
Janice Coen
Mark Ellisman
John Miller
Klaus Schulten
Avis Cohen
Michael Creutz
Greg McRae
Sandy Boyson
Abhi Deskhmukh
Robert Lodder
Joel Saltz
Carlos Felippa
Charbel Farhat
Daniel Weber

Bad Day

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Anonymous ftp to:

sci2.cs.utah.edu

cd to /pub

Download badday.mpg

DDAS Motivation

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Reduce time to adapt to new conditions and to decide how to allocate resources to respond to the change

- Experiments on short-lived processes (e.g. physiology)
- Capture sporadic astronomic events
- Active control of structures during an earthquake
- Disturbances in a chemical plant
- Early warning systems (fire, tornado, earthquakes, hurricanes, pollution, floods)

DDAS Motivation – cont.

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- Financial and management systems (supply-chain coordination)
- Crisis management (terrorist attacks, epidemics)
- Adaptive structures (car suspension, buildings, space structures)
- Autonomous systems (decision processes)
- Interactive system analysis and control of experiments
- Predict extreme geospace conditions (space weather)

Overview

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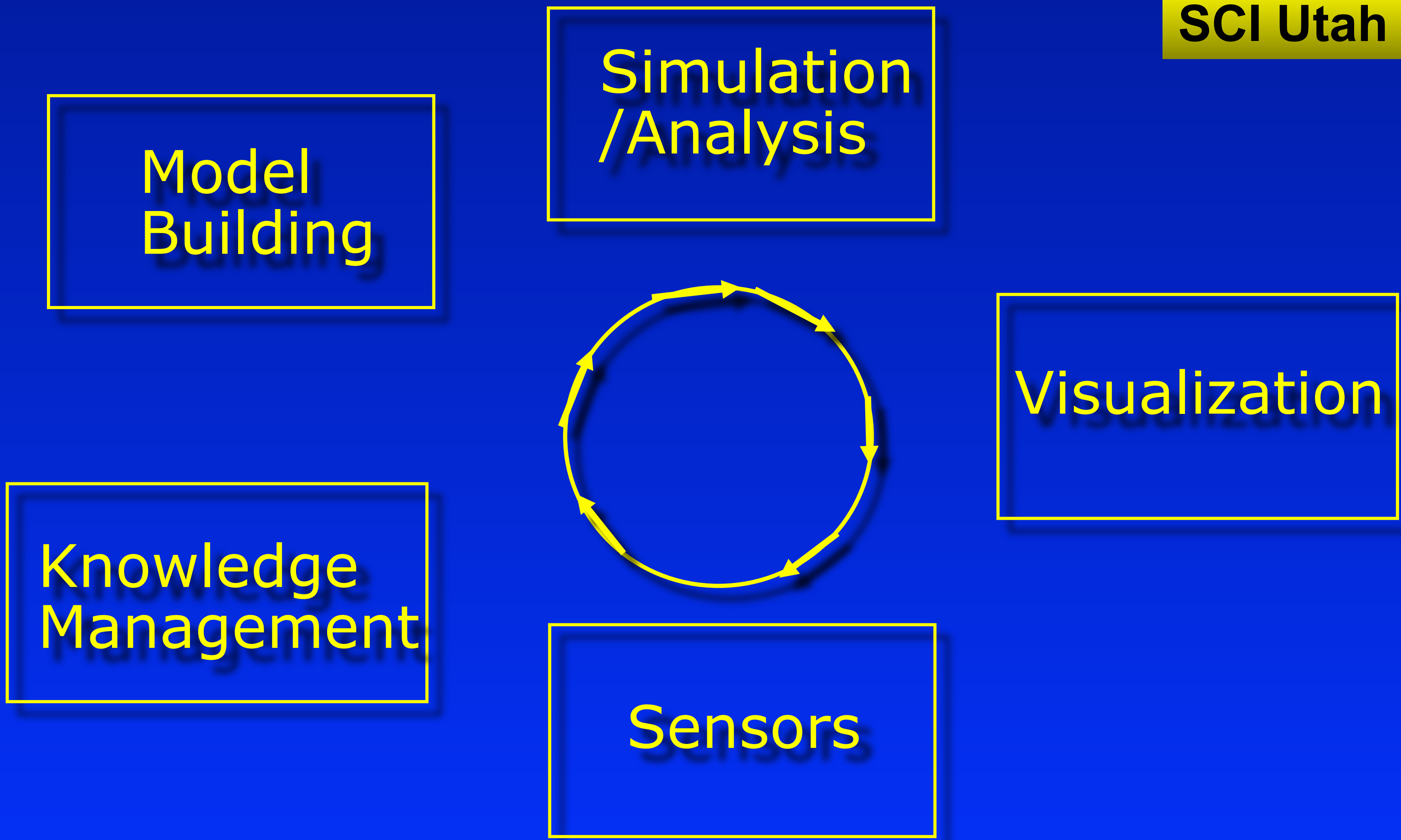

Data Driven System Characteristics

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- Real-time
- Feedback and Control (closing the loop, robust)
- How uncertainty controls the output and parameter selection (sensitivity analysis)
- Model reduction
- Relationships to sensors

Data Driven System Characteristics

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- Predictive modeling (combinations of hardware and software)
- Better techniques to solve large-scale inverse problems (inverse correlation)
- Relationships between space/time scales and measurements
- Computational Workbenches

DDDAS Adaptive Observation

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Infusing data into the simulation and improving the model for the next simulation

- Understand where errors are and understand where more data is needed
- Understand where to get the initial conditions

Why Now?

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There is a convergence of computing, networking, algorithmic, sensor, software, and application technologies. Integration of these technologies affords taking "the next step" in many application areas.

- Can't do the kinds of experiments unless one can interact with large systems (for example – neuroscience)
- Use simulation more than a posteri way – DDDAS can move us beyond that
- Now we have computational resources (hardware and software) to approach realistic problems

But…

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- Artificial department boundaries are an impediment to creating needed expertise
- Computational Science at NSF is not well defined
- Sociologically issues with regard to the interaction of theory, experiment, and computation
- Education/training a large issue for computational scientists

Enabling Technologies

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- Model Building
- Algorithms
- Sensors
- Computational systems
- Visualization and analysis
- Database management systems
- Communications
- Integration software

Algorithms

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Mathematical development

- Improved Bayesian methods for model-based experimental design, parameter estimation, state estimation, sensor placement
- Inverse methods for large-scale integro-partial differential equation
- Identification of time-varying systems
- Uncertainty propagation
- Time-series analysis
- Solution of large-scale nonlinear programming problems

Sensors/Actuators

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Can dramatically change the way one looks at a problem, but requires interaction across many disciplines to build and use them, e.g.

- Chemical lab on a chip
- Molecular markers
- Noninvasive (and very invasive) physiological monitoring
- Microelectronics (smart materials)
- Remote sensing
- Adaptive optics (multiple mirror telescopes)
- Particle tracking
- Damage detection

All have high data rates

Visualization

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Interactive visualization techniques for large data

- Graphical user interface design
- Haptics, visual and other feedback mechanisms
- Scientific and higher dimensional data streams
- Distributed collaborative visualization (workstation and VR)
- Remote visualization (compression, view dependent, perception-based)

Data Management

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Need to interact and manage large data

- Visual databases
- Distributed databases
- Interaction
- Legacy (heritage) databases
- Develop of tools for supporting interactive dataset manipulation
- Tools to couple simulations to databases
- Merging different measurements of the same process (e.g. registration)

Communications

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Communication (between humans and machines) infrastructure to facilitate interaction (both locally and remotely) and to expand the potential for collaboration (between humans)

- Bandwidth (more) management (connect adaptively to systems)
- Compression technologies (feature detection, multiresolution, etc.)
- Fast wireless and distributed sensors
- Sensors that send out upon need and/or demand
- Smart sensors that compute locally and send updated/changed information

Integration Software

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- Encourage open source
- Common API (to software and to sensors)
- Common component software architecture
- Dealing with heritage codes
- Role of filters and wrappers (scripting languages, etc.)

Related Reports and Initiatives

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- 1998 NSF Workshop on PSEs (Abdali)
- 1998 DOE Report on Large Data Visualization
- 1999 NIH Report on Biomedical Computing
- Model Based Simulation – caswww.colorado.edu/ MBS.Workshop.d/index.html
- DOE ASCI Program
- PITAC Report

Industry Relations

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- Students (although we need cooperative programs to allow students to finish degrees)
- Spawn new industries and multi-industry collaborations
- Tighter connections between industry data output and use in academic models/simulations (airlines, weather, FAA example)
- Pricing models based upon need/ consumption

Implementation

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- DDDAS is cross/multi-disciplinary in nature!
- Don't implement in ITR
- Cross directorate reviewing required
- Need to figure out computational science within NSF
- Need all directorates on board
- Need LOTS of $$
- Some projects beyond the current 3-5 year limits
- Balance the risk portfolio to include more speculative endeavors

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