SCIENTIFIC COMPUTING & IMAGING

INSTITUTE

Mission

The SCI Institute has three major long-term goals. The first goal is to perform technical research into the computational and numerical methods required for scientific computing. The second goal is to explore the paradigm of integrated problem solving environments as an efficient approach for scientists in many disciplines to solve their own computational problems. The final goal represents our desire as researchers to use scientific computing to understand our own particular disciplines, for example, numerical mathematics, biophysics, electrocardiography, bioelectric fields in the brain, and medical imaging.

Scientific Computing and Imaging Institute

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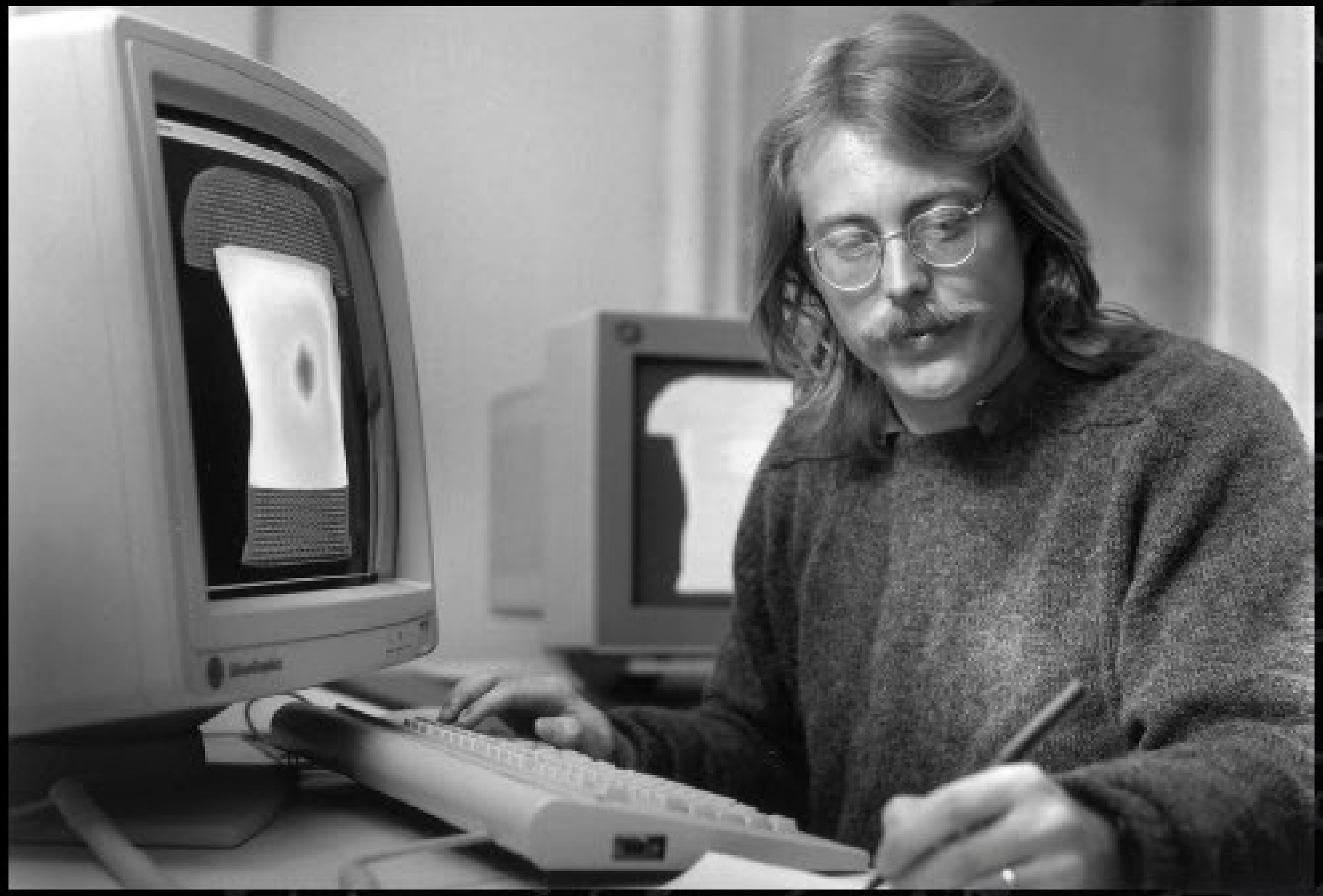


Christopher R. Johnson, Ph.D. circa 1990

The Scientific Computing and Imaging (SCI) Institute began as a small research group in 1992 when Dr. Chris Johnson joined the School of Computing (then the Department of Computer Science). The group has grown since 1992 from Dr. Johnson as a single investigator with a few graduate students to the Scientific Computing and Imaging Institute, a research organization with over 50 faculty, staff, and students.

In creating the SCI research group and developing it into the SCI Institute, Dr. Johnson built upon his diverse research background and interests, which include such aspects of scientific computing as inverse and imaging problems, adaptive methods, modeling, numerical analysis, computational problems in medicine, problem solving environments, and scientific visualization.

The early focus of SCI research was computational electrocardiography and, more generally, biomedical computing, and these remain major themes of the Institute. From the computational needs created by these applications came new themes such as geometric modeling, numerical simulation, visualization techniques and eventually integrated software environments for problem solving. The breadth of the applications has expanded to include bioelectric signals from the brain, medical imaging, surgical planning, reservoir modeling in geoscience, diffusion of air born pollutants in environmental science, and combustion in chemical and fuels engineering.

The Scientific Computing and Imaging Institute has established itself as a leader in scientific computing, scientific visualization, and imaging research. The Scientific Computing and Imaging Institute currently houses two National research centers: the NIH Center for Bioelectric Field Modeling, Simulation, and Visualization and the DOE Advanced Visualization Technology Center. We also oversee the SGI-Utah Visual Supercomputing Center. In addition, the Scientific Computing and Imaging

HISTORY

Institute is formally associated with several other National research efforts: the NSF Partners in Advanced Computational Infrastrasture (NCSA PACI), the NSF STC for Computer Graphics and Visualization, and the DOE Center for the Simulation of Accidential Fires and Explosions. For more information, visit our website at {www.sci.utah.edu}.

1992: Dr. Chris Johnson joins the Department of Computer Science.

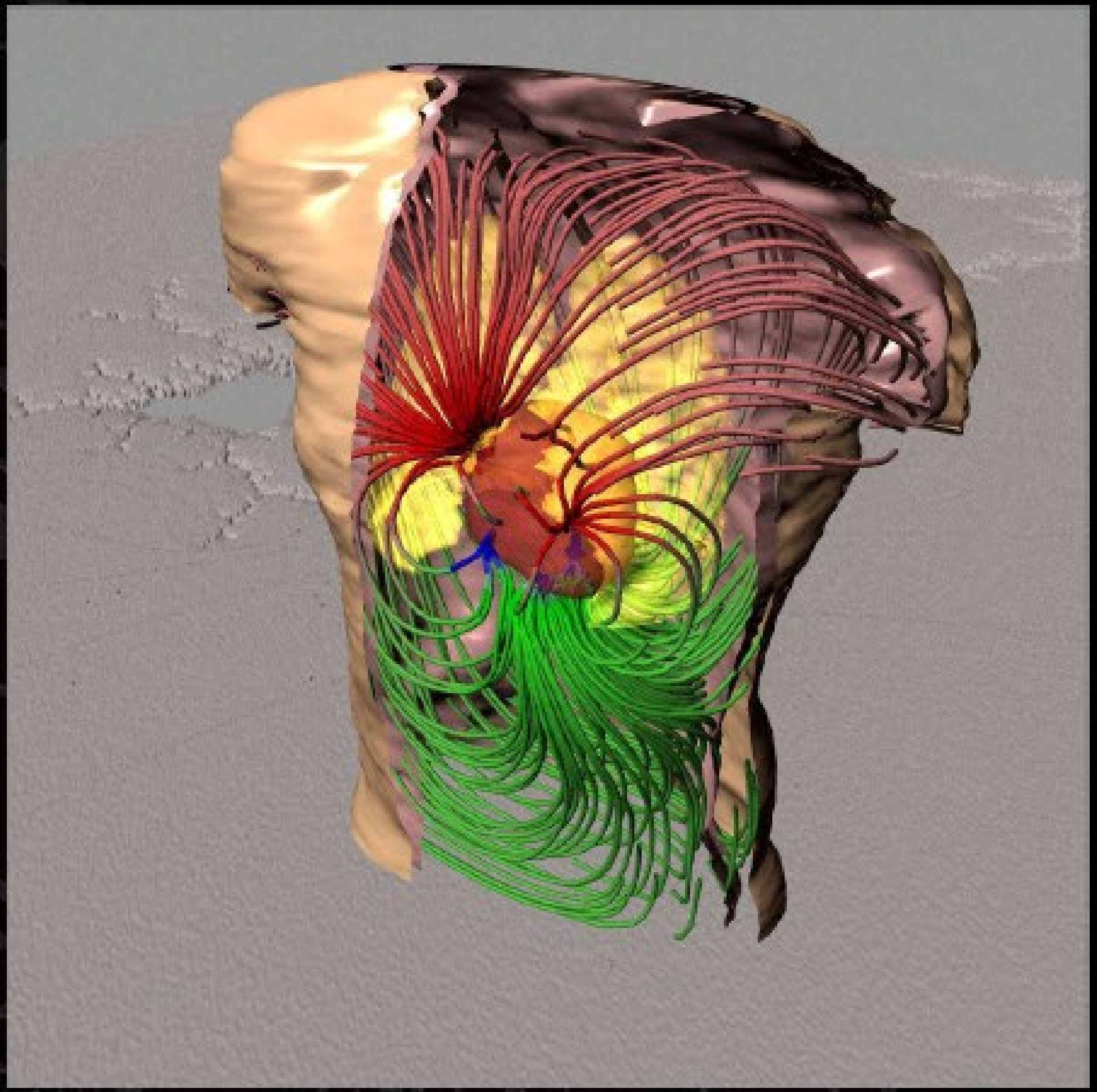
1994: With five graduate students and Dr. Rob MacLeod, forms the Scientific Computing and Imaging research group (graduate student, David Weinstein, came up with the name of the group).

1996: The SCI research group was awarded a State of Utah Center of Excellence and became the Center for Scientific Computing and Imaging.

1998: Argonne National Laboratory, Los Alamos National Laboratory, and the University of Utah are awarded funds to create the Advanced Visualization Technology Center.

1999: The SCI research center is awarded an NIH National Center for Research Resources award to create the NIH Center for Bioelectric Field Modeling, Simulation, and Visualization.

2000: The Scientific Computing and Imaging Institute becomes an official University of Utah research institute.



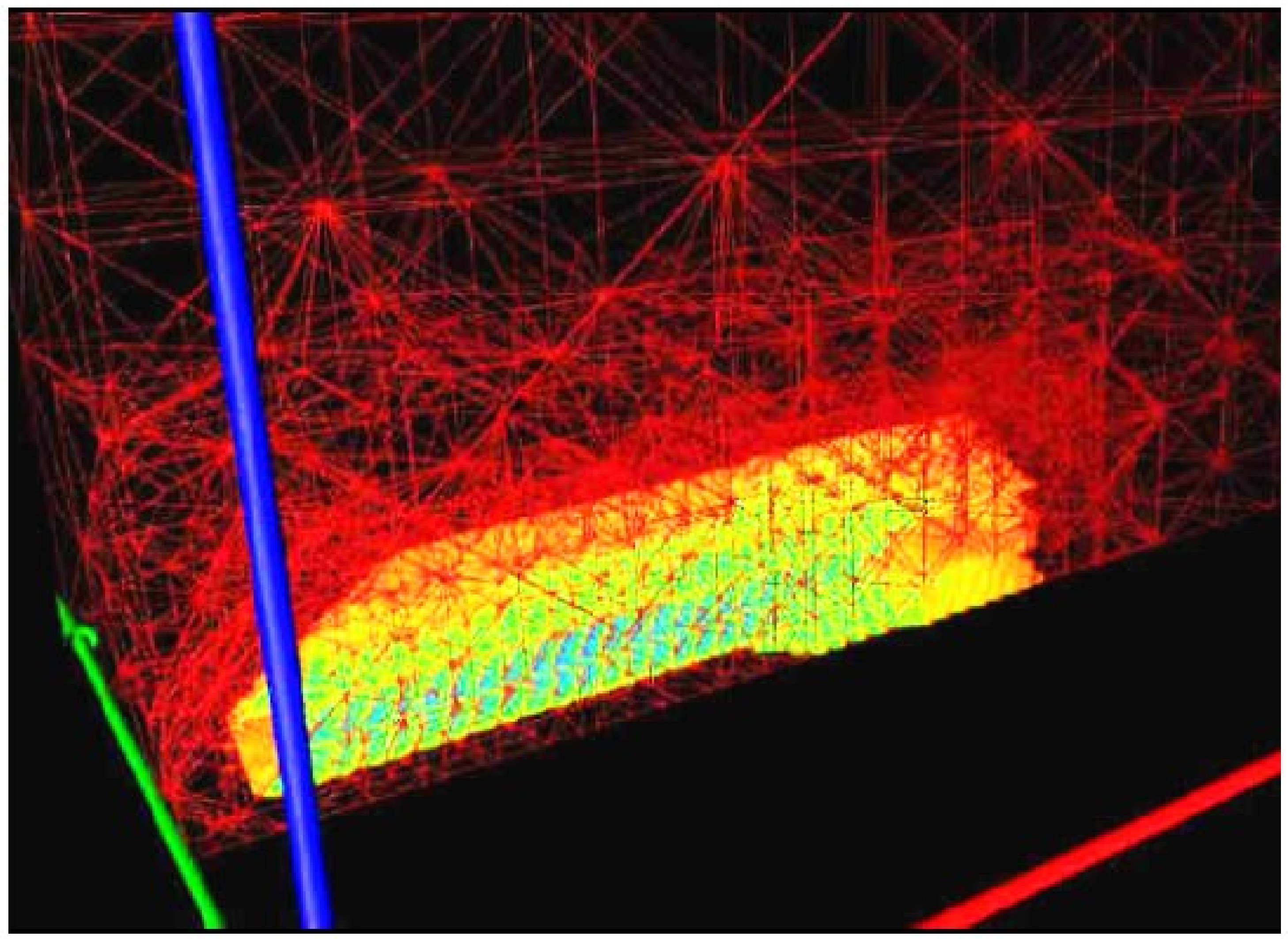
This is a graphical representation of the geometry and electrical current flow in a model of the human thorax. The model was created from MRI images taken of an actual patient. Shown are segments of the body surface, the heart, and lungs. The colored loops represent the flow of electric current through the thorax for a single instant in time, computed from voltages recorded from the surface of the heart during open chest surgery (circa 1992).

Scientific Computing

Computational Field Problems

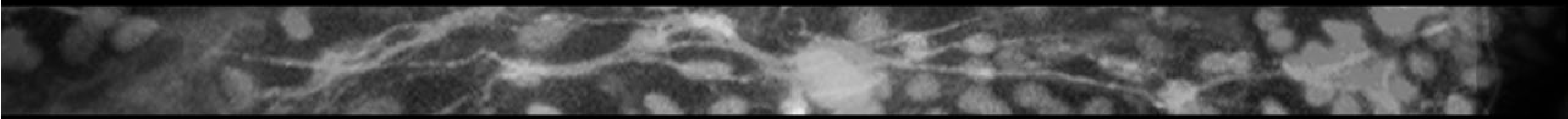
The goal of computational field problems is to calculate the distribution of a physical quantity in space. Examples include electric and magnetic fields, as well as other scalar, vector, and tensor quantities such as temperature, flow, or anisotropic propagation velocity. In real world applications, few such problems have closed form, analytical solutions so that one is quickly forced to develop numerical methods and discrete approximations of the underlying equations of the field in question.

Members of the SCI Institute have developed and implemented solution methods for many field problems with applications in biomedicine, oil and gas exploration, and environmental sciences. The challenges involved in such problems include creating approximations of the underlying governing equations, developing appropriate numerical methods capable of solving these approximations, and implementing these solutions in a tractable computational framework. The latter aspect has been an area of special interest to the SCI Institute, for which we have developed integrated problem solving environments and implemented efficient computational schemes.



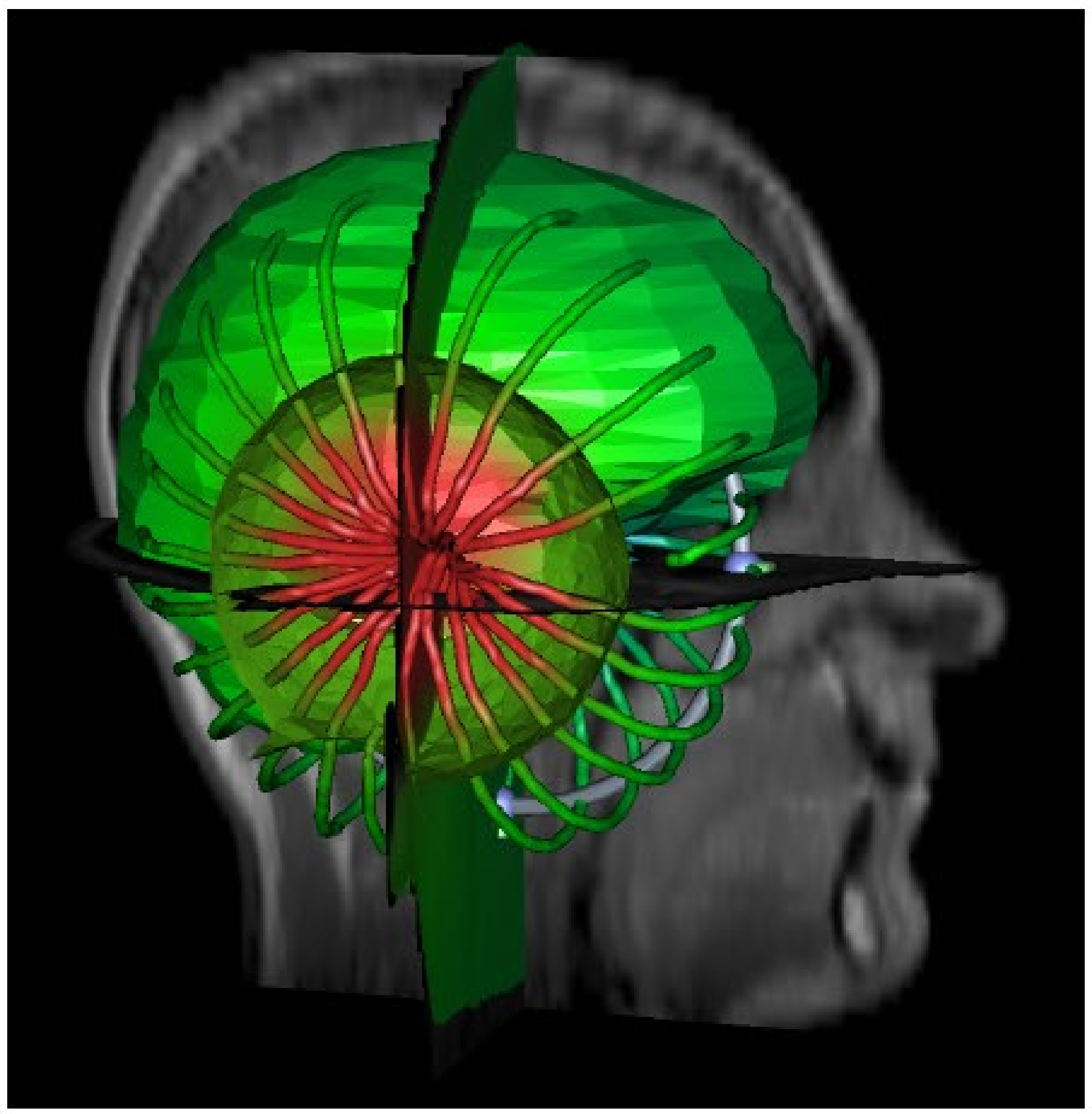
Adaptive Methods

Major limitations in the accuracy of approximations in field problems and of inverse solutions are the time and resources required for computation. The obvious approach of finding faster and larger computers is effective only to a point and rarely as efficient as schemes that seek to solve the problem in fewer mathematical steps. One family of such efficient computational methods uses the condition that most problems are not equally complicated in all regions of time and space. Any event that occurs in only a portion of the domain requires detailed computations only in that region—elsewhere a simpler, less accurate calculation will suffice. Such a scheme is known as an "adaptive method" because it adapts to the solution in a manner that reduces the overall computational cost.



Inverse and Imaging Problems

A common aspect of most imaging modalities is the need to perform reconstruction based on remote measurements from a number of sensors—such reconstructions require the solution to an "inverse problem". The goal of the reconstruction can be structural information, such as the anatomy that comes from classic medical imaging with, for example, magnetic resonance or X-rays. The aim of the inverse solution can also be functional information such as electrical activity or conductivity.



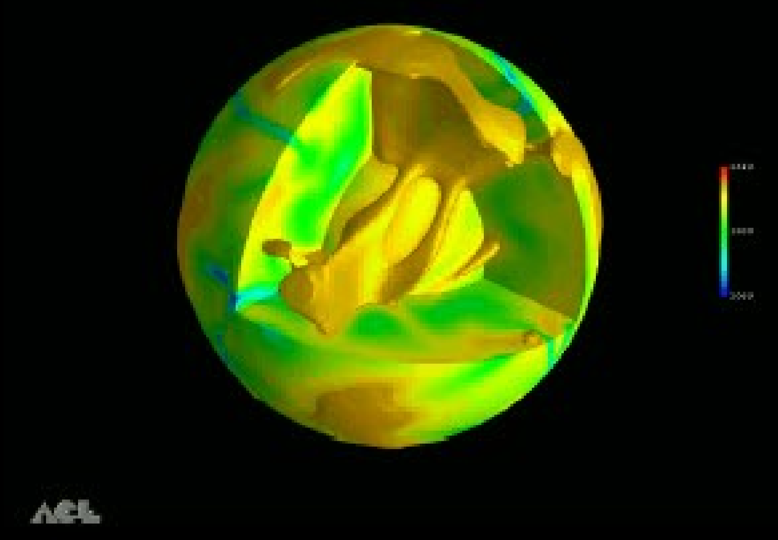
Research within the SCI Institute has included numerous types of inverse problems in imaging, with emphasis on problems in functional imaging. Examples include reconstruction of electrical sources within the heart or brain and extraction of molecular diffusion information from magnetic resonance images. Computationally, such problems frequently involve complex numerical algorithms and large systems of equations. Inverse problems are also typically ill-posed in the sense that small changes in the input data can lead to unbounded fluctuations in the solutions. Often, the major challenge of an inverse problem lies in incorporating a priori information into the solution in efficient and realistic ways. The SCI Institute has developed a number of novel means of including such information to solve a wide variety of inverse problems.

Adaptive methods are an important aspect of the scientific computing research at the SCI Institute. For example, we have developed schemes that are capable of adjusting the density of nodes in a discrete geometric model—both increasing and decreasing the density—according to an estimate of the local error of the computation. Other areas of current interest are "multigrid methods" that sequentially carry out computations at a range of densities and thus refine the solution in areas of interest based on preliminary solutions at coarse resolution. A related topic of research is developing efficient means for creating and storing geometric models in a way that allows rapid adjustment of resolution.

Scientific Visualization

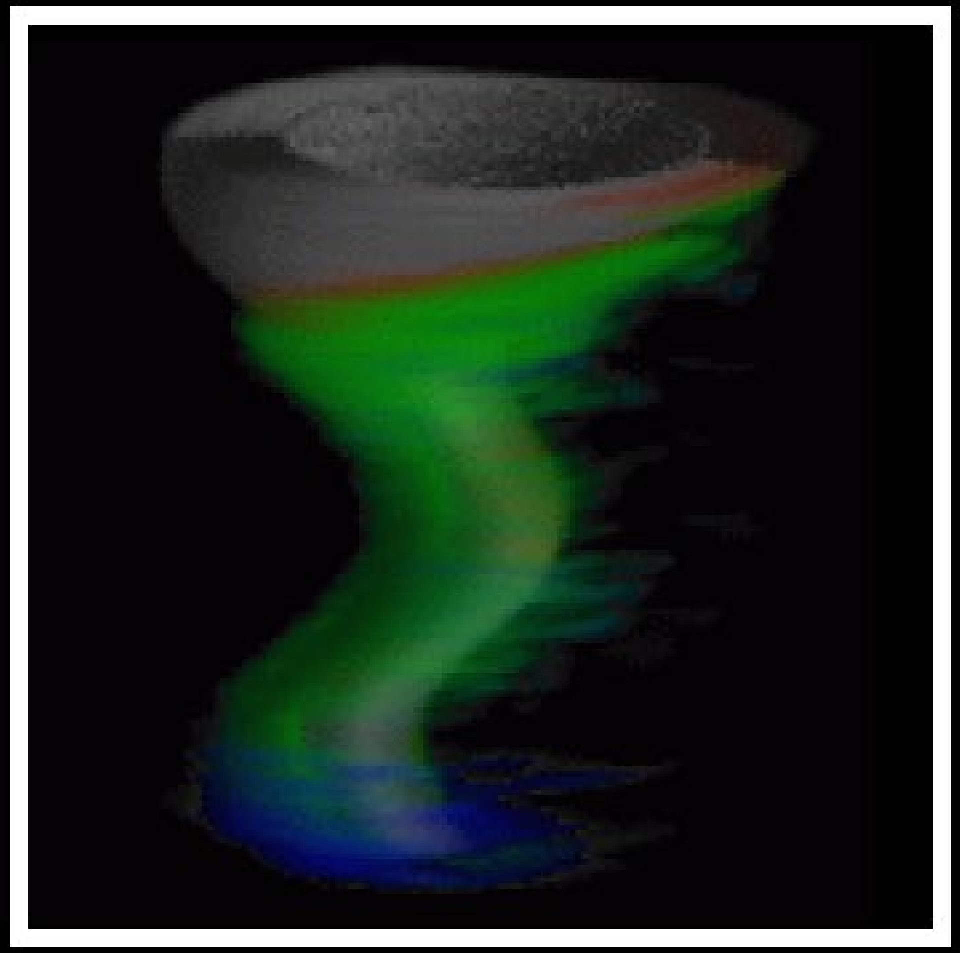
Isosurface Extraction

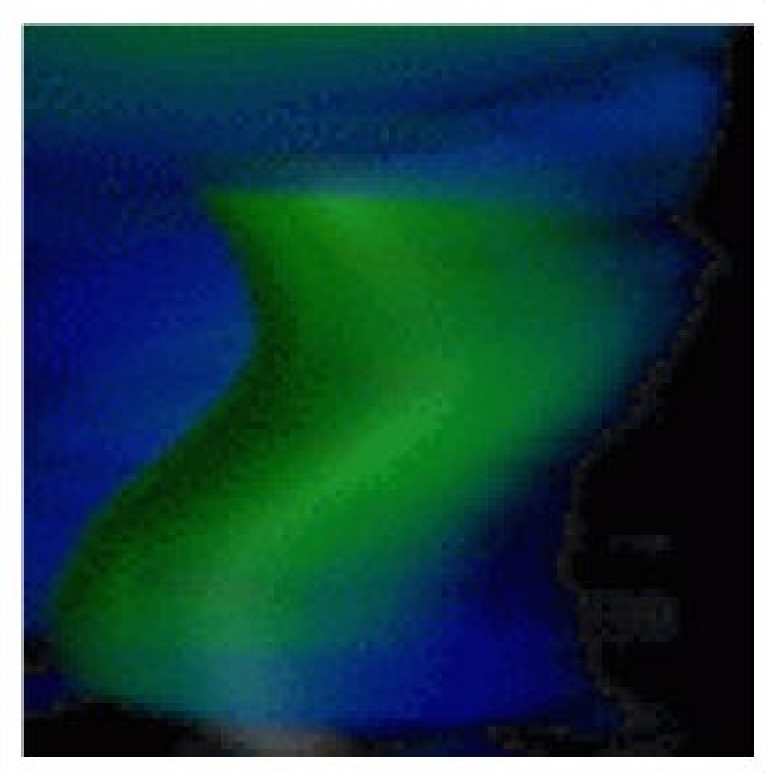
Isosurface extraction is a powerful tool for investigating volumetric scalar fields. The position of an isosurface, as well as its relation to other neighboring isosurfaces, can provide clues to the underlying structure of the scalar field. SCI Institute research in isosurface extraction techniques has resulted in the "span-space representation" which accelerates the search for isosurfaces in large-scale fields. Additionally, SCI Institute researchers have developed methods for extracting view-dependent isosurfaces, and isosurfaces from time-dependent fields.

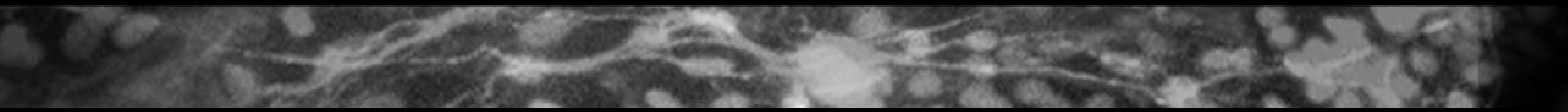


Vector Field Techniques

Visualizing vector field data is challenging because no existing natural representation can visually convey large amounts of three-dimensional directional information. Visualization researchers have adopted analogues to fluid flow and wind tunnel techniques. One result has been a set of graphical icons such as arrows, motion particles, stream lines, stream ribbons, and stream tubes that act as three-dimensional depth cues. SCI Institute researchers have developed local and global visualization techniques to explore three-dimensional vector field data. Using the Line Integral Convolution method as the underlying algorithm, the user can inject "dyes" of various colors into the 2D/3D LIC flow field and thus probe its shape and behavior.

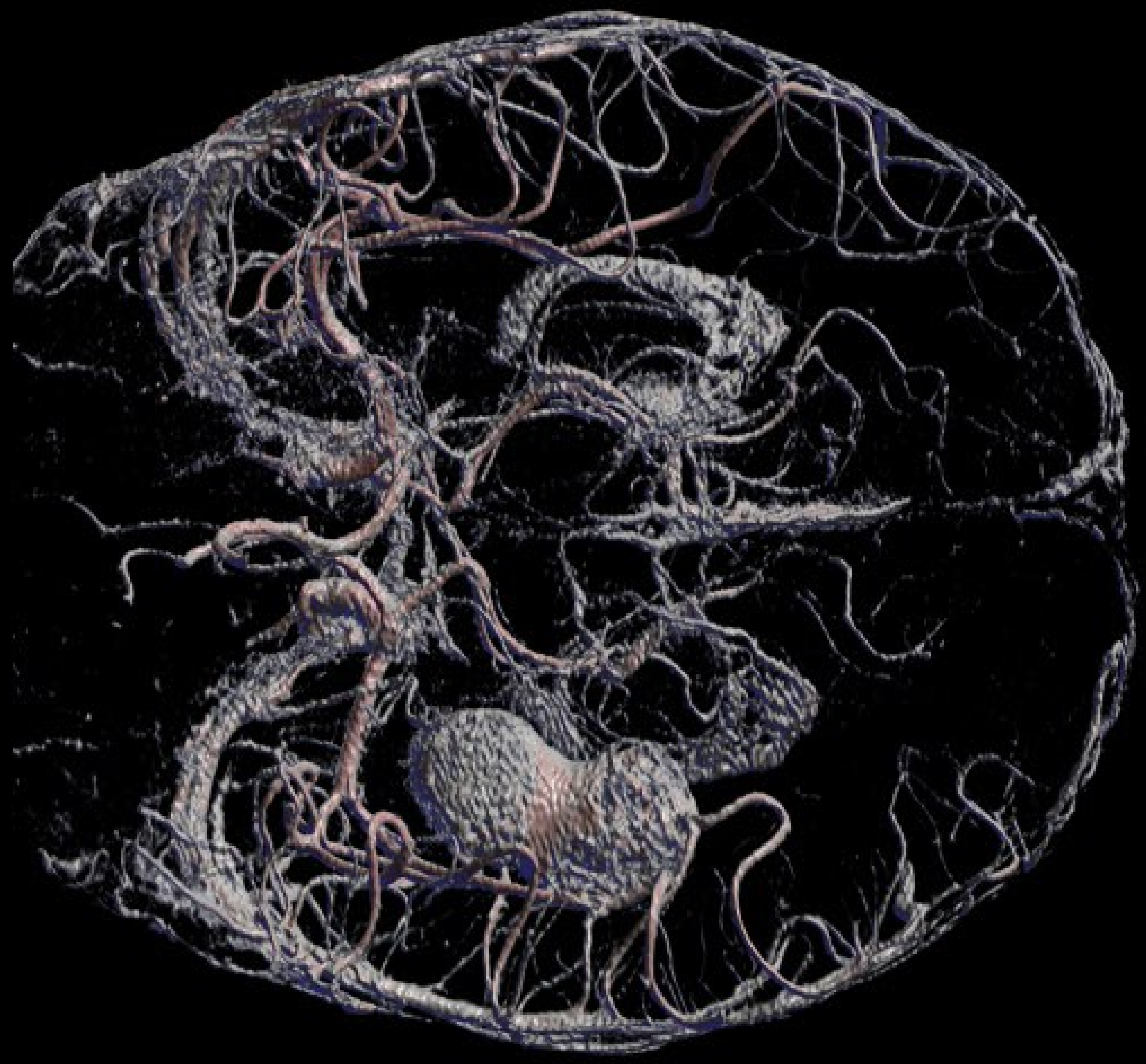






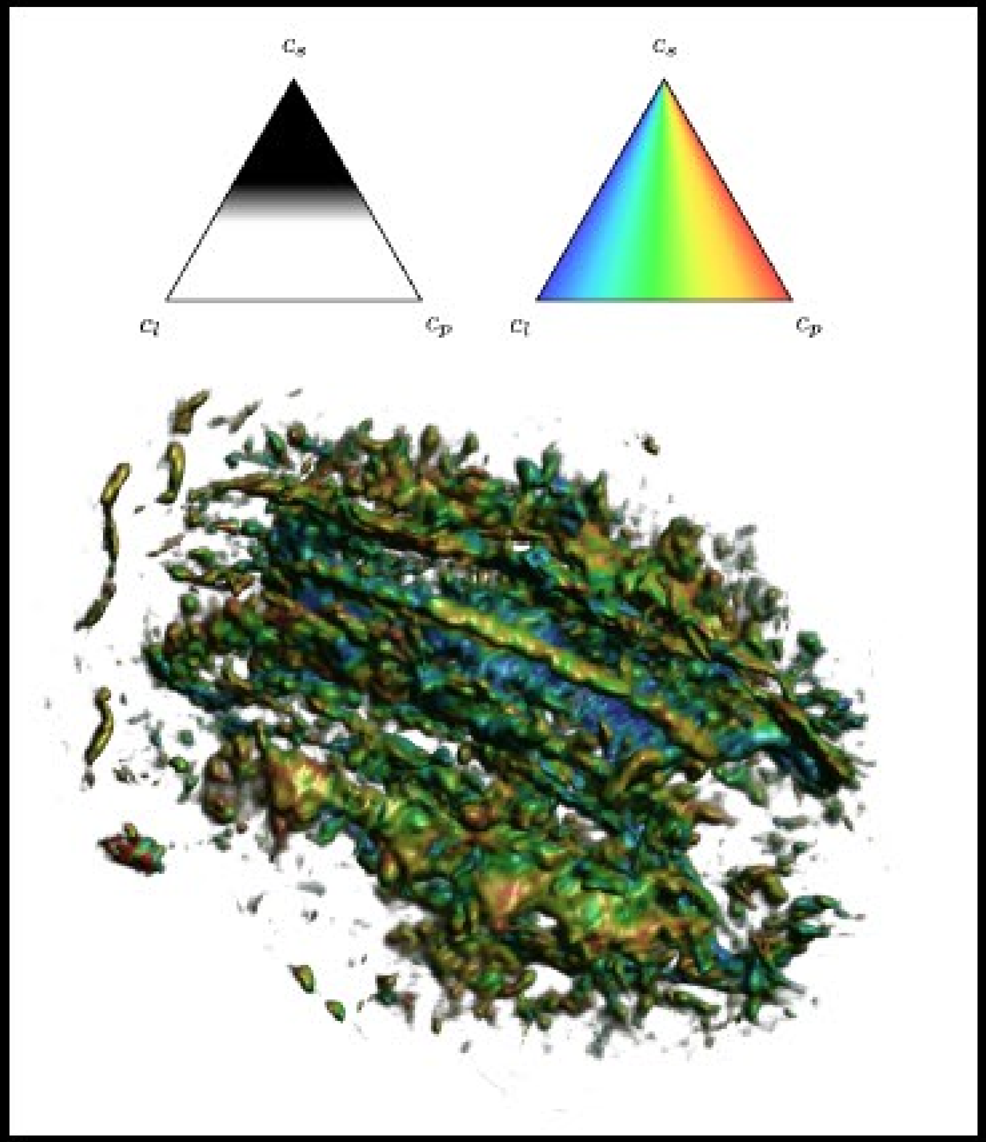
Volume Rendering

Direct volume rendering is a method of displaying three-dimensional volumetric scalar data as a two-dimensional image. The individual values in the dataset are made visible by an assignment of optical properties, such as color and opacity, which are then projected and composited to form an image. The main advantage of direct volume rendering is that it requires no intermediate calculation of geometric information and thus can be dramatically more efficient than other techniques. SCI Institute researchers have focused on semi-automatic methods for transfer function generation, volume rendering techniques for time-dependent data, and multi resolution volume rendering methods.



Tensor Field Techniques

The simulation of a physical system often requires one to characterize the material property of the various media within the simulation domain, such as density, electrical or thermal conductivity, or diffusivity. SCI Institute researchers have developed novel methods for visualizing diffusion tensor data generated from MRI scans of the human brain. These visualization methods can be used for analyzing anatomic structures, diagnosing pathologies, and searching for pathways within the brain.



Scientific Visualization

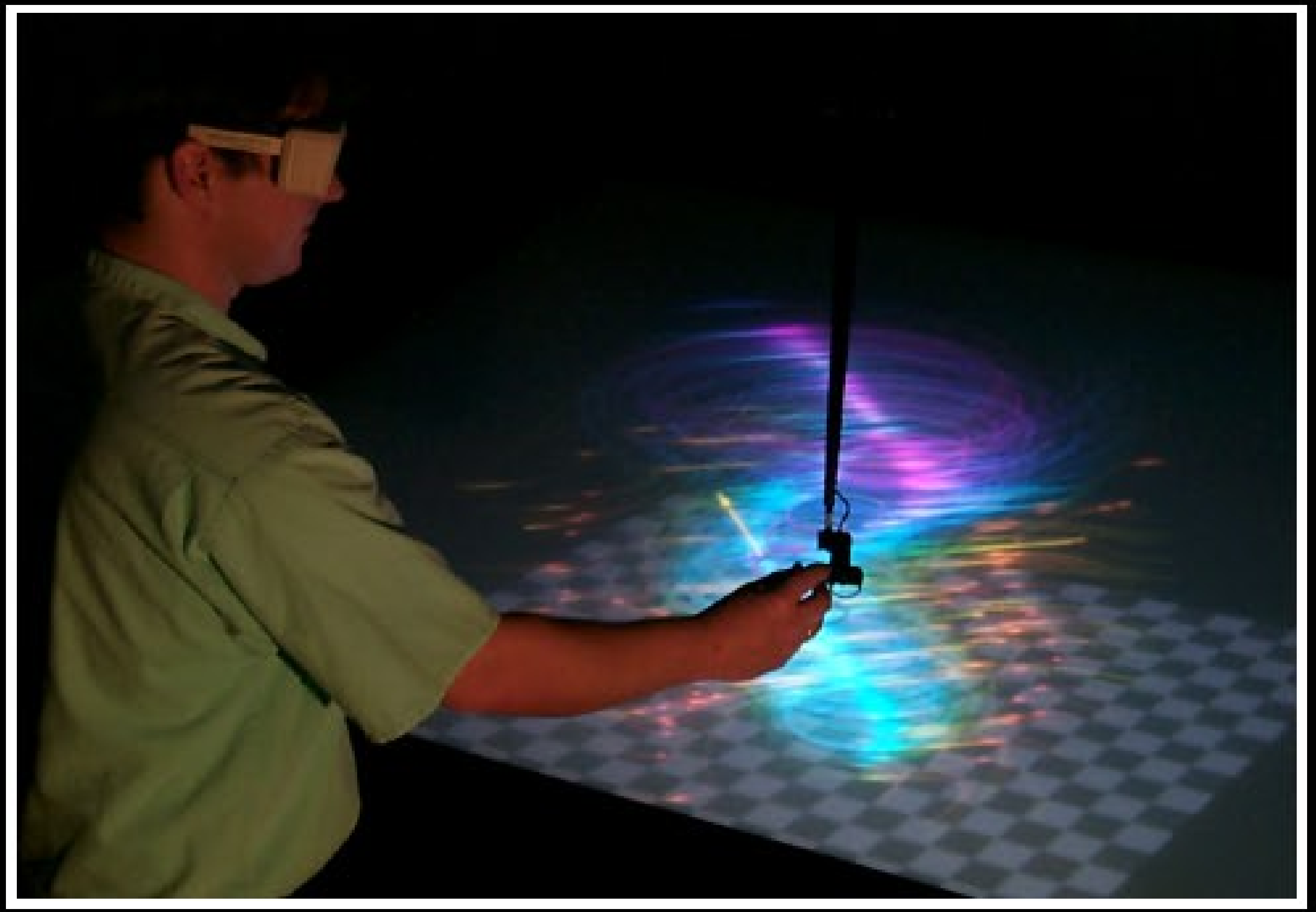
Parallel Rendering

Very large data sets present challenging visualization problems that are often suitable for schemes in which multiple processors can work in parallel on the same image. Ray tracing is one well established approach in volume visualization that has a high degree of intrinsic parallelism.

Researchers in the SCI Institute have developed highly efficient, parallel implementations of ray tracing algorithms and used to them to perform "real-time ray tracing" on very large data sets. The examples below are from what is known as the visible woman project—almost 1 Gigabyte of image data that we are able to render in full resolution at rates of 6-15 frames per second.

Immersive Environments

Since natural interaction results from multi-modal, first-person experience, SCI Institute researchers are investigating techniques for synergistic data rendering within virtual environments. This provides more informative interaction than is possible with conventional visualization methods. VR facilities at the SCI Institute include a Powerwall, a Fakespace Immersive Workbench, and a variety of position tracking and interaction devices, including a custom device, the I3Stick. In addition, the Immersive Workbench has a SensAble Technologies PHANToM 3.0 haptic interface collocated with its workspace, thus enabling users to touch manifestations of datasets in a virtual setting. Current research includes the development of a high-performance VR software infrastructure, calibration techniques for magnetic trackers and haptic interfaces, and paradigms for interactive, multi-modal data rendering.



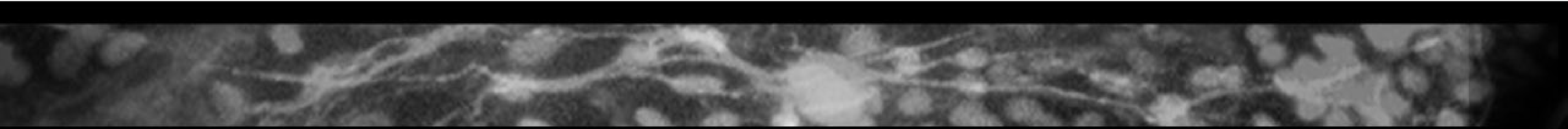
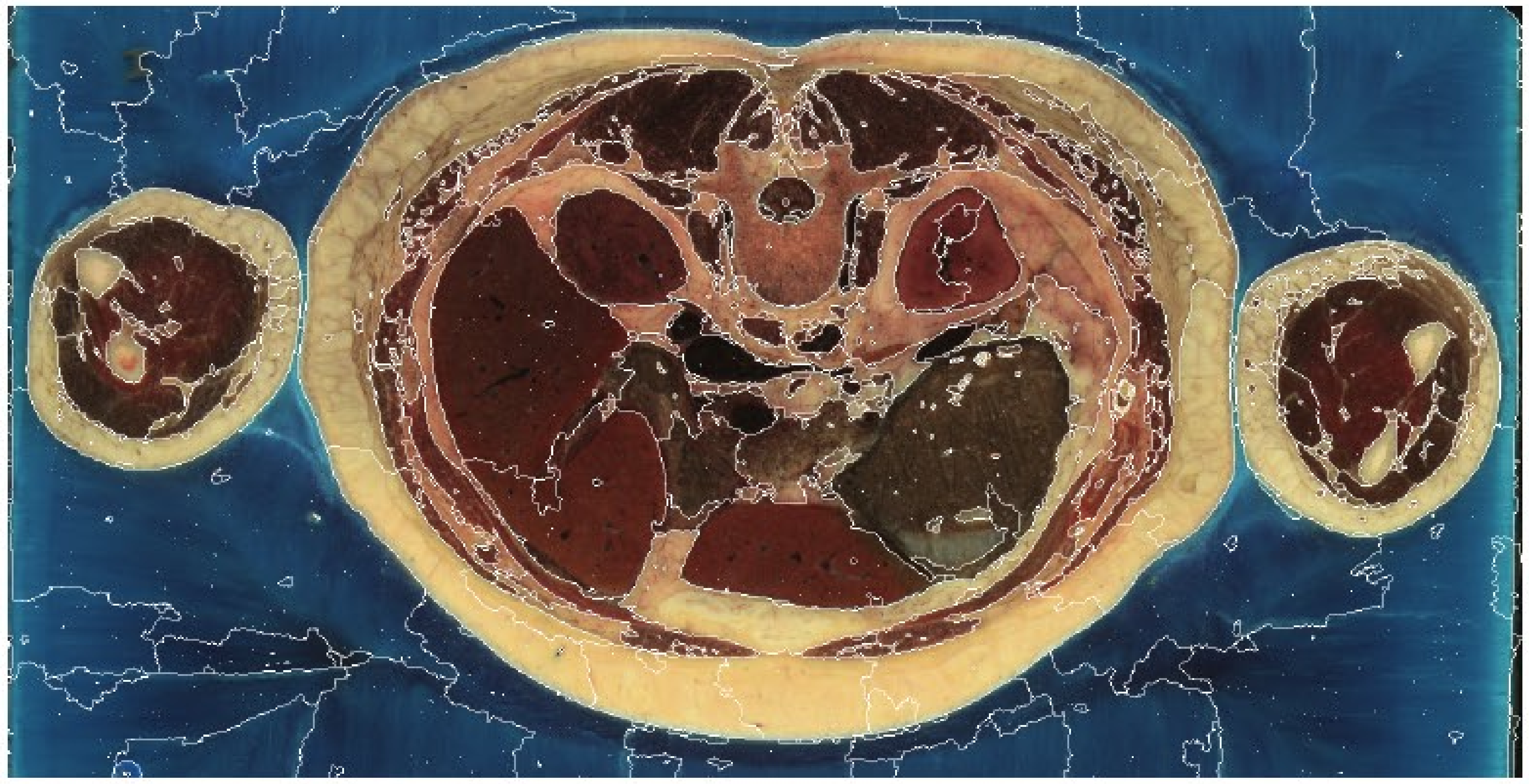


Image Processing

Image processing and analysis plays an important role in many applications of scientific computing and imaging. Image data from a wide range of sources including medical scanners, scientific instruments, and digital cameras, can provide valuable insights, *if* the data can be converted to a useful form. In some cases this processing consists of filtering, producing a better, clearer image from one that is noisy, faded, or distorted. In other cases, images must be analyzed, to extract higher-level knowledge about image structure for successive processing to begin.

Researchers in the SCI Institute study techniques for image processing that fall within a conceptual framework that relies on the *geomectric structure* of images. This conceptual framework also allows us to construct processing algorithms that are the solutions of certain kinds of partial differential equations. Treating images as functions leads to a family of techniques for preprocessing and filtering, feature extraction, segmentation, and surface modeling.

As part of this effort the SCI Institute participates in the *Insight* project, a consortium of researchers from 10 different industrial and academic instituations. This consortium is supported by the National Library of Medicine to build an advanced, object-oriented image-processing toolkit that will be used to analyze the data associated with the Visible Human Project. This figure shows the results of combining vector-valued, anistropic filtering; geometric feature detection; and morphological watersheds to produce a segmention (white lines) of the Visible Male.



Problem Solving Environments

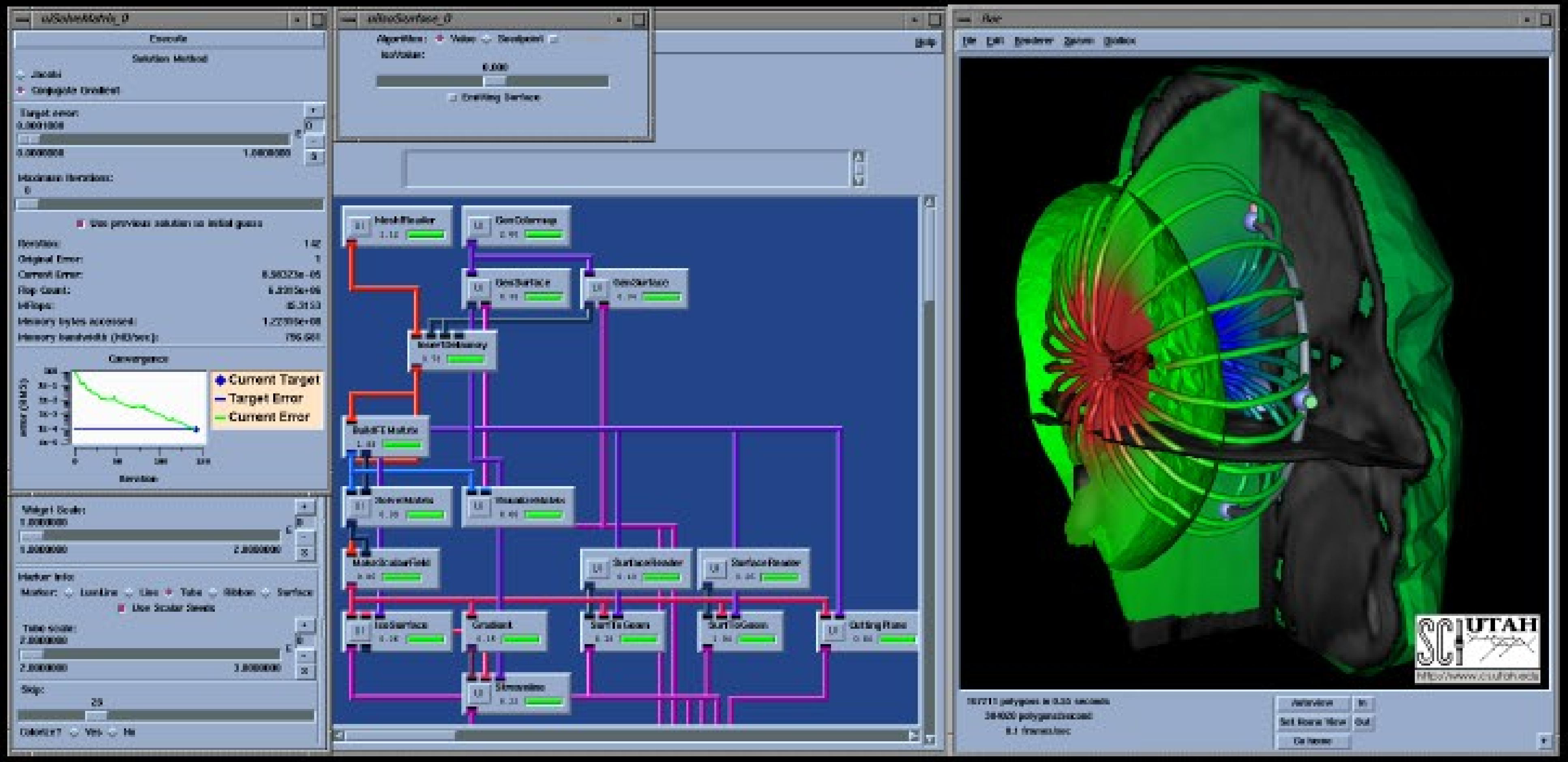
PSE

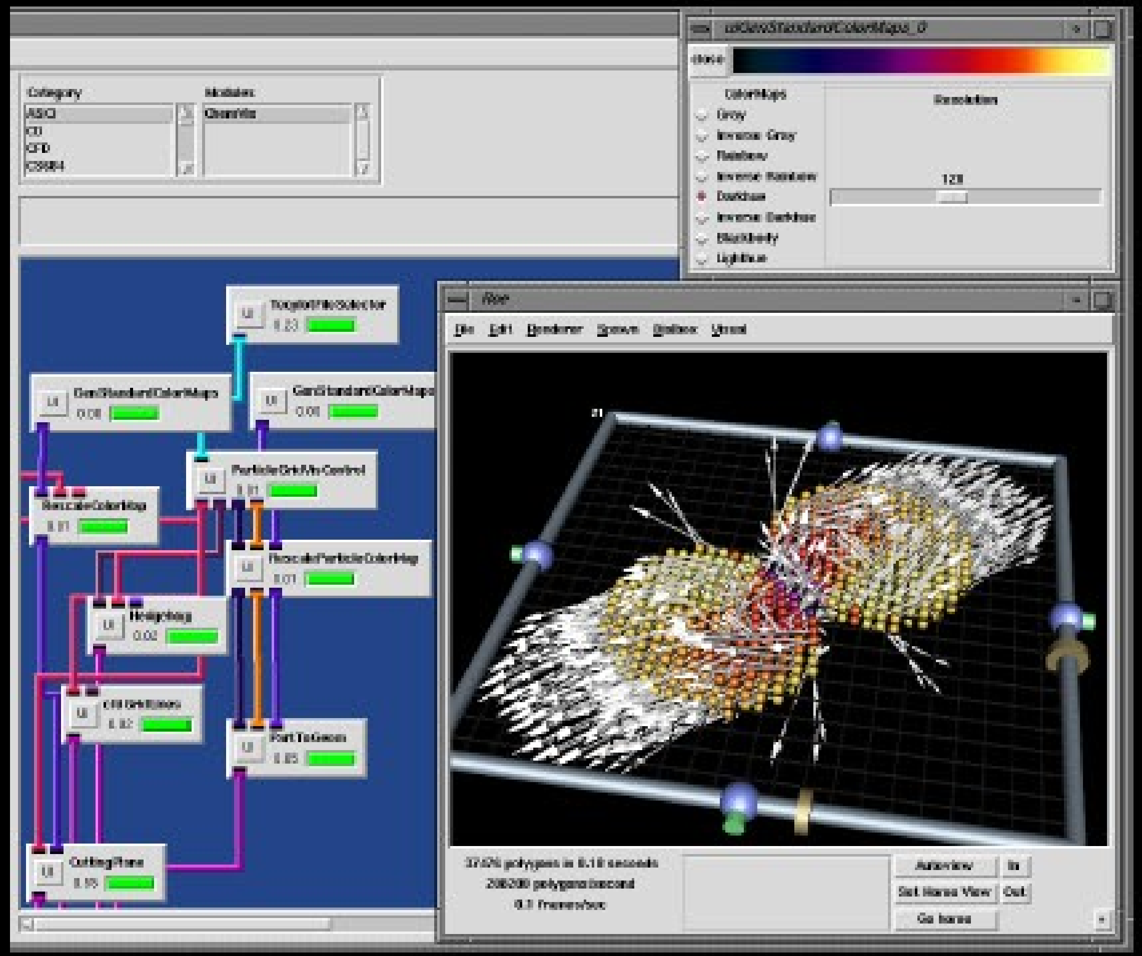
Implementing advanced computational methods and scientific visualization techniques can lead to complicated pieces of software. Coupling these different pieces together in interesting ways further increases the complexity. In order to manage this complexity, we perform research in Problem Solving Environments–software that provides scientists with a range of computational tools flexibly integrated into a single "workbench".

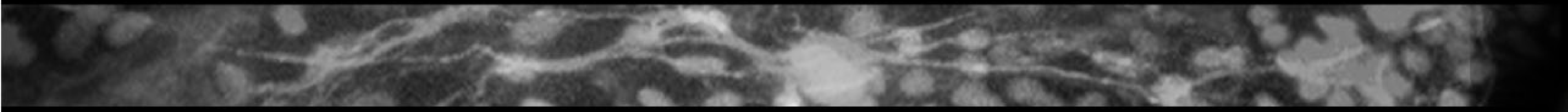
SCIRun

SCIRun is a Problem Solving Environment (PSE), and a computational steering software system. SCIRun allows a scientist or engineer to interactively steer a computation, changing parameters, recomputing, and then revisualizing all within the same programming environment. The tightly integrated modular environment provided by SCIRun allows computational steering to be applied to the broad range of advanced scientific computations that are addressed by the SCI Institute.

Implementation of a computational steering environment requires a successful integration of many aspects of scientific computing. Specific examples include performance analysis, geometric modeling, numerical analysis, and scientific visualization, all of which need to be effectively coordinated within an efficient computing environment. SCIRun is both a tool for the applications scientist or engineer as well as a testbed for new approaches in integrated large-scale scientific computing.







Uintah

Uintah is a derivative of SCIRun that targets large-scale simulations running on distributed memory supercomputers.

BioPSE

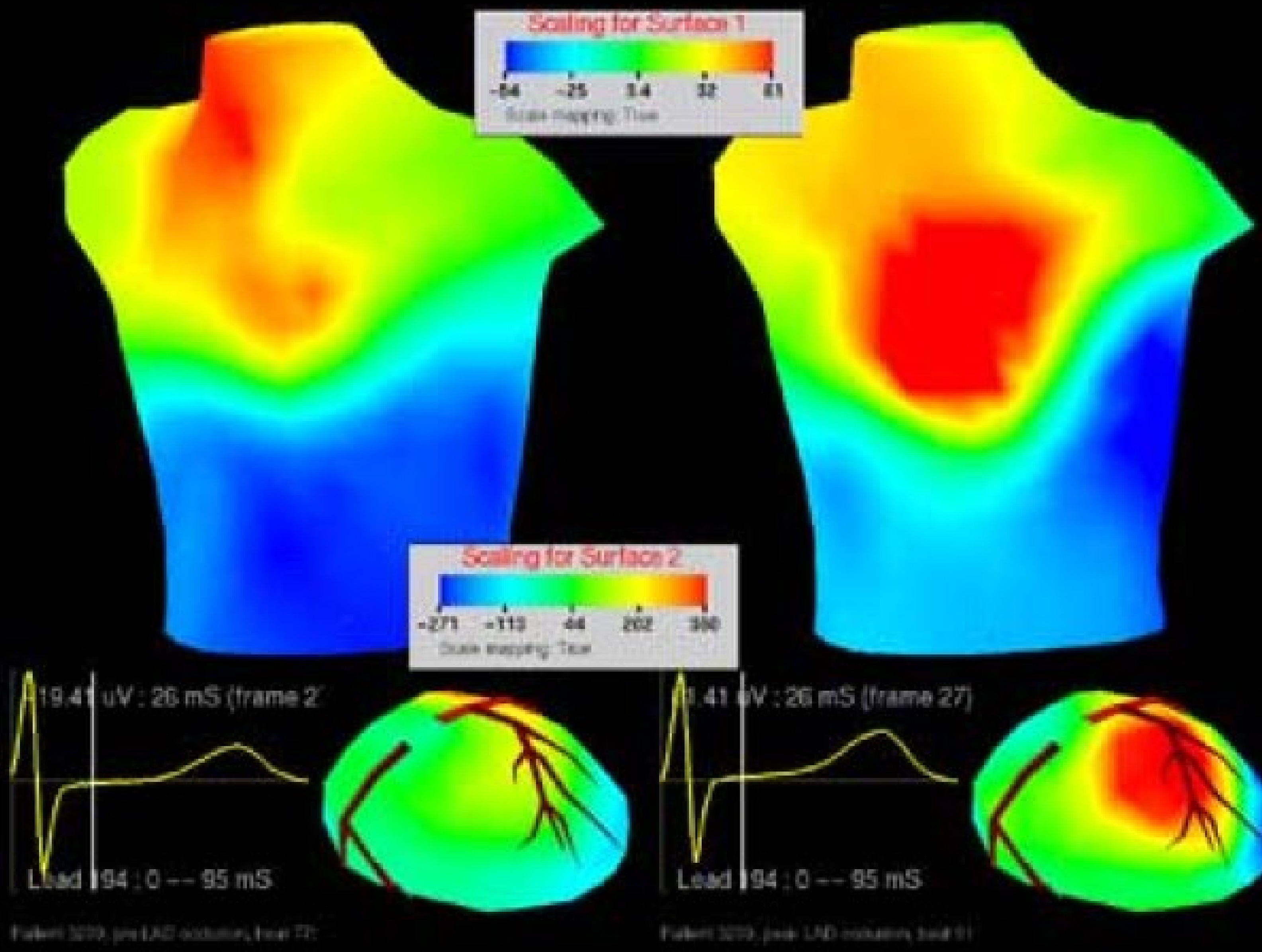
BioPSE extends the SCIRun problem solving environment by adding modules and functionality specifically tailored to bioelectric field problems.

Common Component Architecture

This is a current and ongoing collaboration between the Scientific Computing and Imaging Institute (SCI) at the University of Utah and the Department of Energy National Laboratories (and other University research groups). With representatives from these facilities, the Common Component Architecture (CCA) Working Group was formed "to develop a specification for a component architecture for high-performance computing." This goal has long been a central theme of the SCIRun problem solving environment.

Map3d

Map3d is a scientific visualization application developed at the Cardiovascular Research and Training Institute (CVRTI) to display and edit complex, three-dimensional geometric models and the scalar data associated with those models. Map3d was originally written in ANSI-C using the Graphics Library (GL) from Silicon Graphics Inc. Recently we have developed a version based on the OpenGL standard that runs not only on SGI workstations but also Linux and Windows platforms.

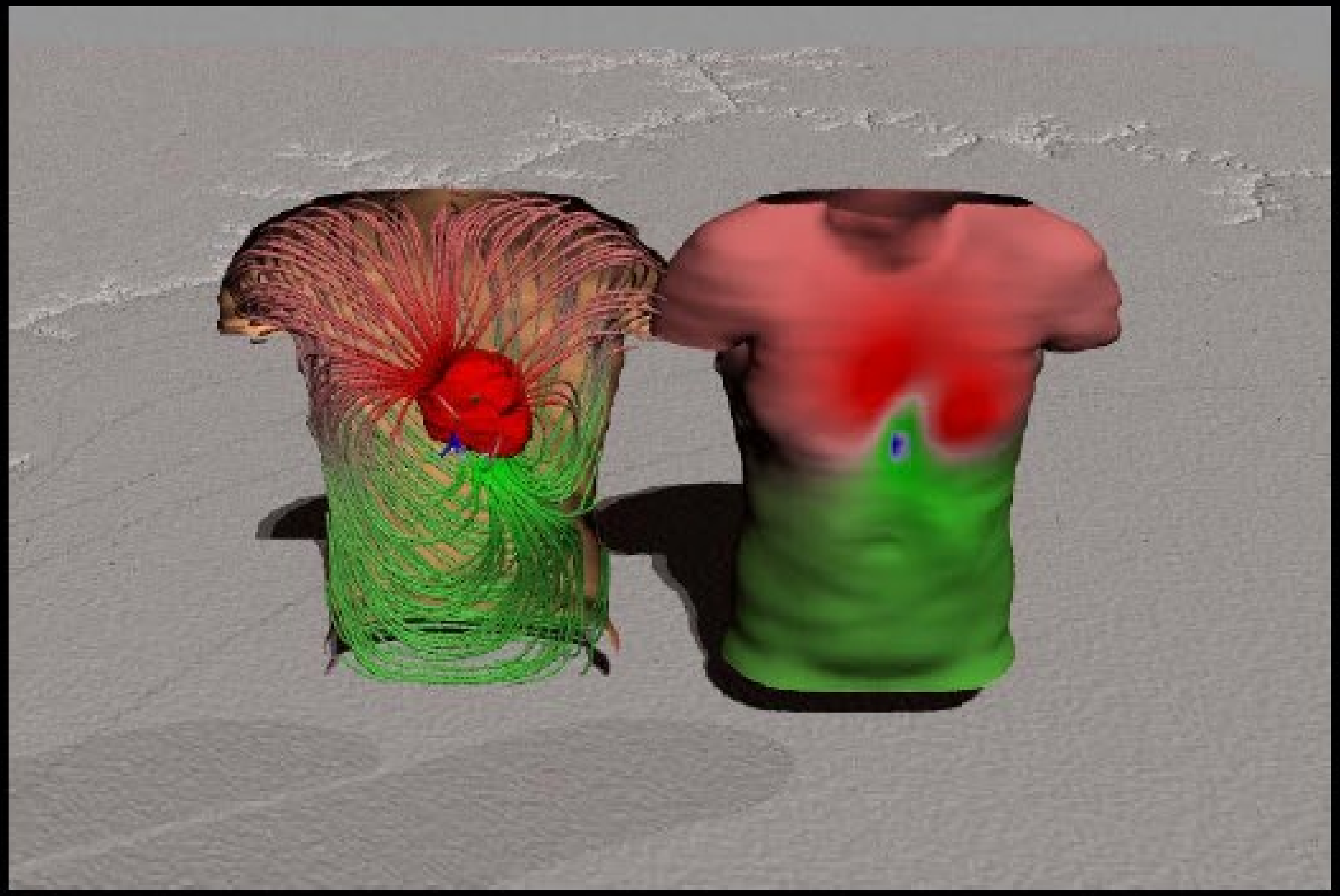


Medical

Applications of scientific computing to topics in biomedicine are a mainstay of SCI Institute research. The main area of interest continues to be the study of bioelectric fields. Electric and magnetic fields originate from sources within the body and can also be imposed externally, typically as a means of diagnosis or treatment.

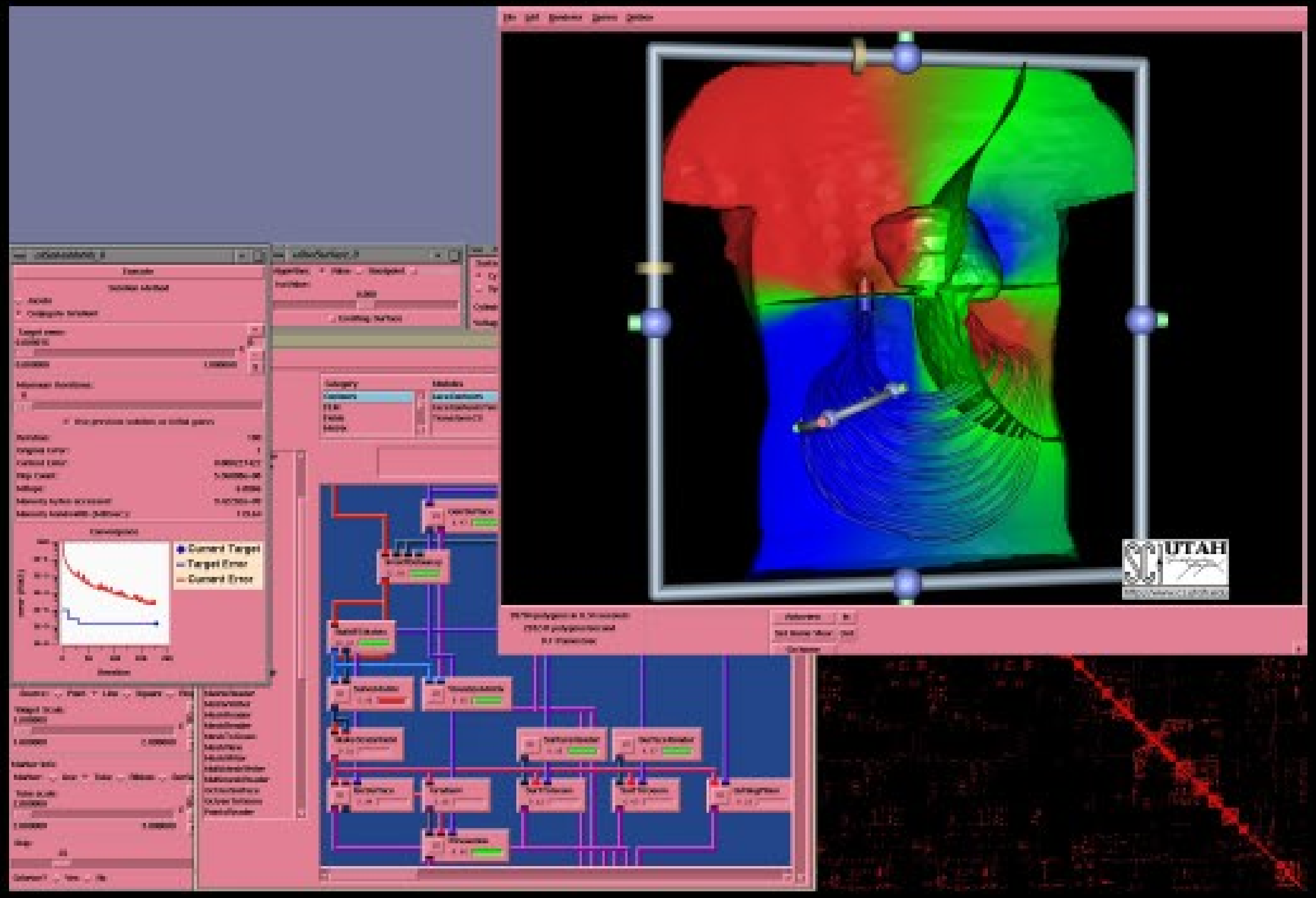
Bioelectric fields from the heart are responsible for the electrocardiogram (ECG) and SCI Institute research in this area is very active. The overall goal of this research is to represent the electric sources and their behavior in the body by means of a realistic simulation model of the human thorax. Such a model would provide a means of better understanding how much information about the state of the heart is available on the body surface. We have developed geometric models of the human thorax, as well as computational tools for representing the sources of electric fields in the heart.

Current areas of interest include developing methods to better estimate the electrical activity in the heart from ECG measurements on the body surface, the "inverse problem of electrocardiography".

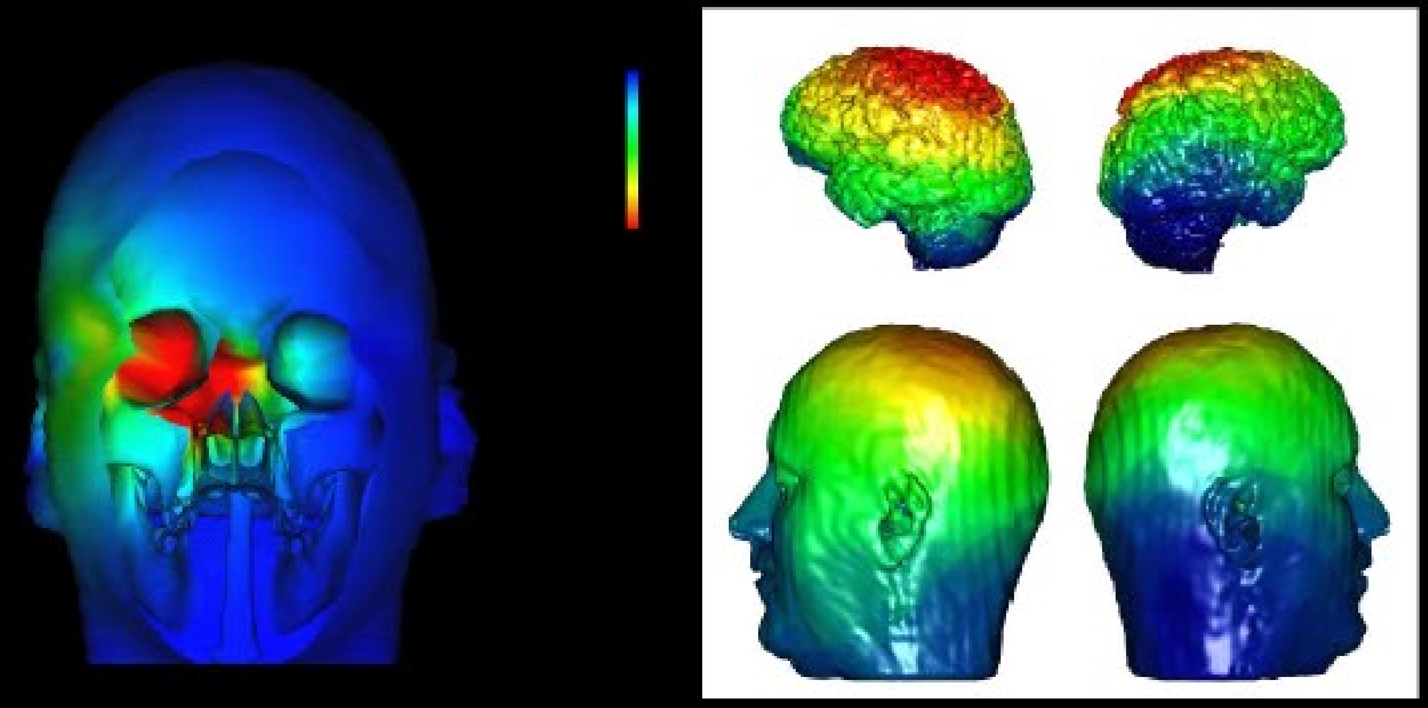


A second specific project in cardiac fields is to develop computation tools for defibrillation. Defibrillators are essential devices in emergency medicine but in recent years have also become implantable. Patients with known instabilities in the electrical activity of the heart can receive potentially life saving protection. The SCI

Institute has developed tools for placing electrodes anywhere within an inhomogeneous geometric model of the human thorax and calculating the resulting electric fields.



The brain is also a source of bioelectric fields, and the SCI Institute is developing computer tools to image those fields. Computational methods offer a means to extract from these complex signals such information as the location of focal epilepsy, pathways of communication in the normal and abnormal brain, and perhaps even the evolution of learning. To reach these goals, we have developed high resolution models of the human head from magnetic resonance images and applied advanced signal processing and numerical simulation techniques.



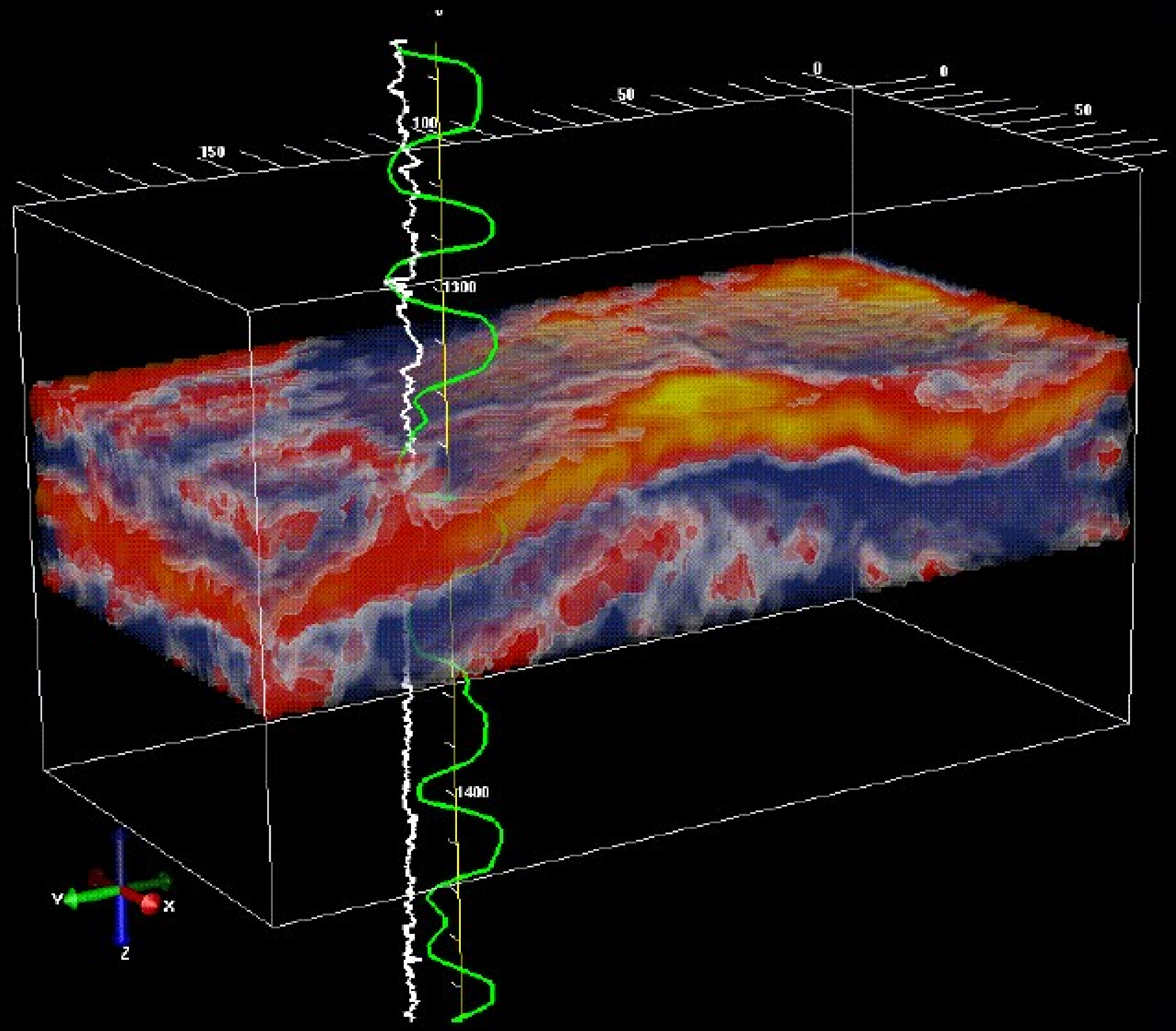
Support for this research has recently come from the NIH National Center for Research Resources, which has funded a new Center for Bioelectric Field Modeling, Simulation, and Visualization within the SCI Institute and the Cardiovascular Research and Training Institute. The aim of this center is to develop and release to the scientific community an integrated problem solving environment based on SCIRun but optimized for use in bioelectric computation.

Geoscience

Another area of collaborative SCI Institute research is large-scale geoscience simulation and visualization. Together with members of the Energy Geosciences Institute (EGI) at the University of Utah and a major U.S. oil company, SCI researchers have incorporated a three-dimensional oil and gas reservoir simulator into the SCIRun problem solving environment.

With SCIRun the researcher can configure a simulation, monitor and control it during the execution, and then initiate a new simulation based on the final or partial results. Real time feedback during the simulation is in the form of a graph of the convergence of the solution and presentation of intermediate solutions. The user can change the target error for the simulation in real time, examine the visualization of the intermediate results, or manipulate the input to the simulation.

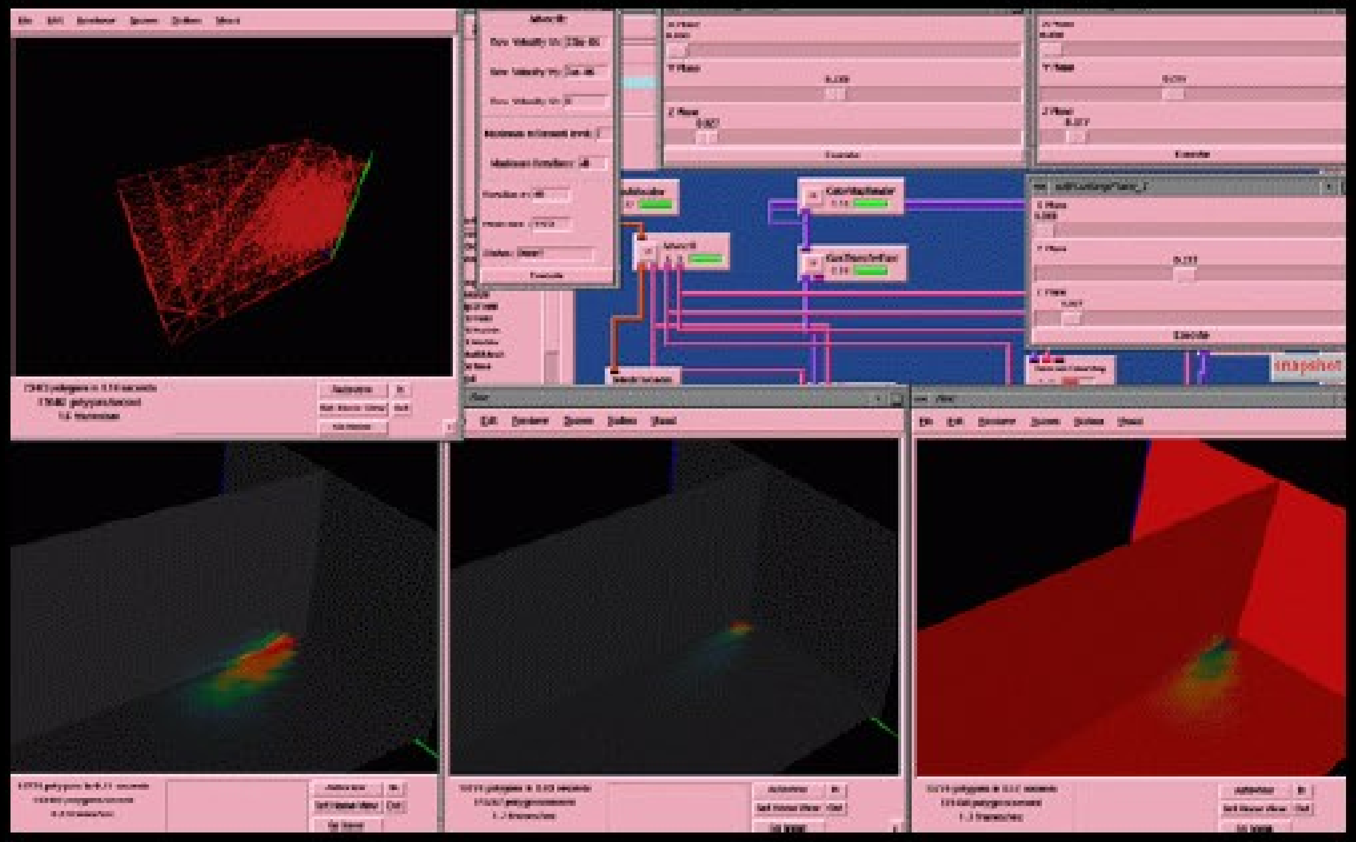
One special feature of the simulator is the ability to move well locations interactively during the simulation and thus explore many "what-if?" scenarios. The user can also change the strength of the flow of a well and determine whether the well is a "producer" or an "injector". These changes can be applied while the simulation is in progress, which in turn will cause the simulation to stop and restart automatically based on the new parameters. Below are shown two sample visualizations of large-scale seismic data visualization.

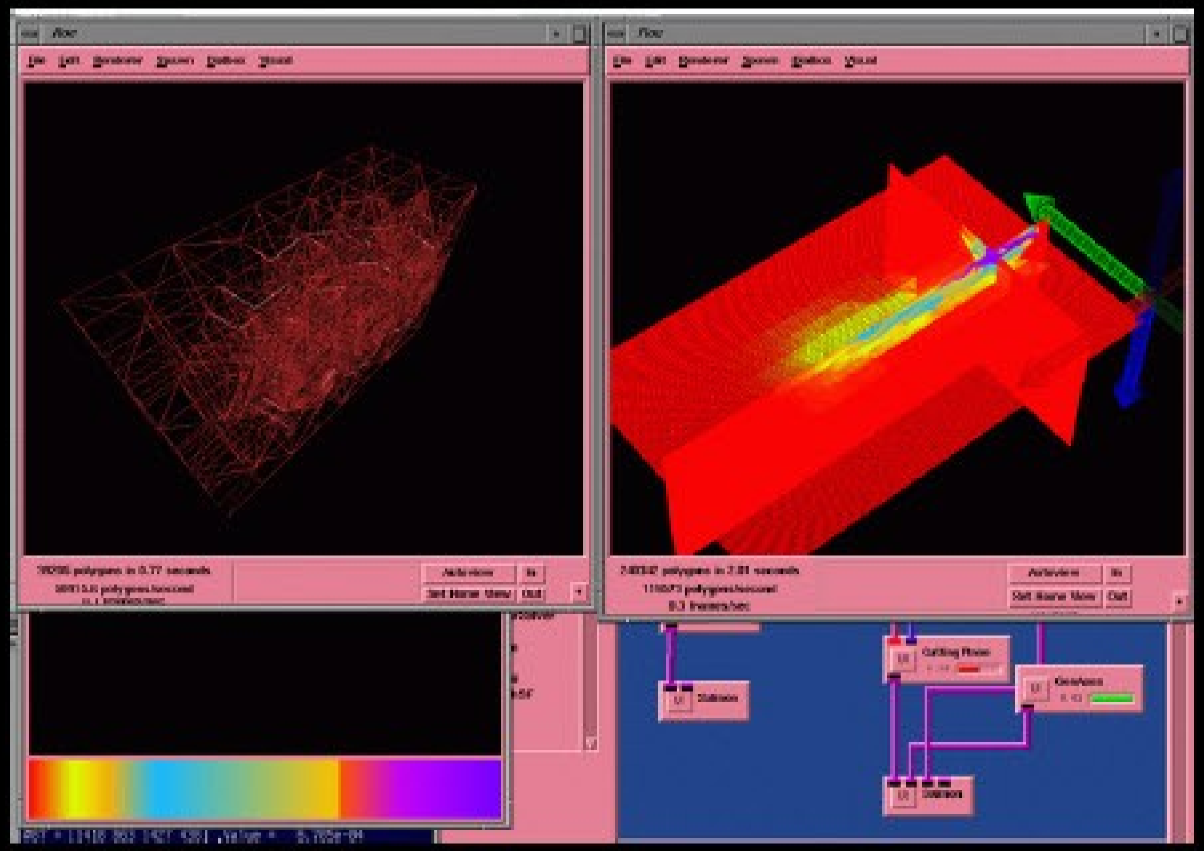


Environmental

The SCI Institute has actively collaborated with Martin Berzins, Co-Director of the Computational PDE Unit at the University of Leeds in the UK on a project to model atmospheric diffusion of pollutants from smokestacks. The specific goal of this research was to simulate the generation of atmospheric ozone that results from mixing emission from a power plant with polluted air. The resulting ozone appears many kilometers downwind of the plant so that this model must cover large distances. The only realistic approach to combining large space scales with the high resolution required to capture the dynamics of chemical mixing is to use adaptive methods. The scientist must adjust model resolution based on the time course of the mixing and shifting of the pollutants. To perform such adjustments required a computational steering framework in which the user could manage the adaptive process based on graphical output from the simulation. This problem required that existing programs from Dr. Berzin's lab become part of an integrated problem solving environment that included efficient visualization and steering capabilities.

SCIRun provided the necessary software environment for this problem. We were able to merge Dr. Berzin's programs into the modular structure of SCIRun and carry out the required scale adjustments and produce realistic simulations.





COLLABORATION

The Access Grid

The Access Grid is an experimental system that links people in virtual spaces, such as teamwork sessions, remote training programs, and distance education classes. The Access Grid is part of a nationwide Grid being prototyped to link people, large databases, high-performance computing resources, and visualization environments into a seamless, integrated environment as ubiquitous as the nation's electrical power grid and as easy to use as the Web.

University of Oregon

At the University of Utah

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Department of Mechanical Engineering
Department of Mathematics
Department of Neurosurgery
Department of Physics
Department of Radiology
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