SCI INSTITUTE

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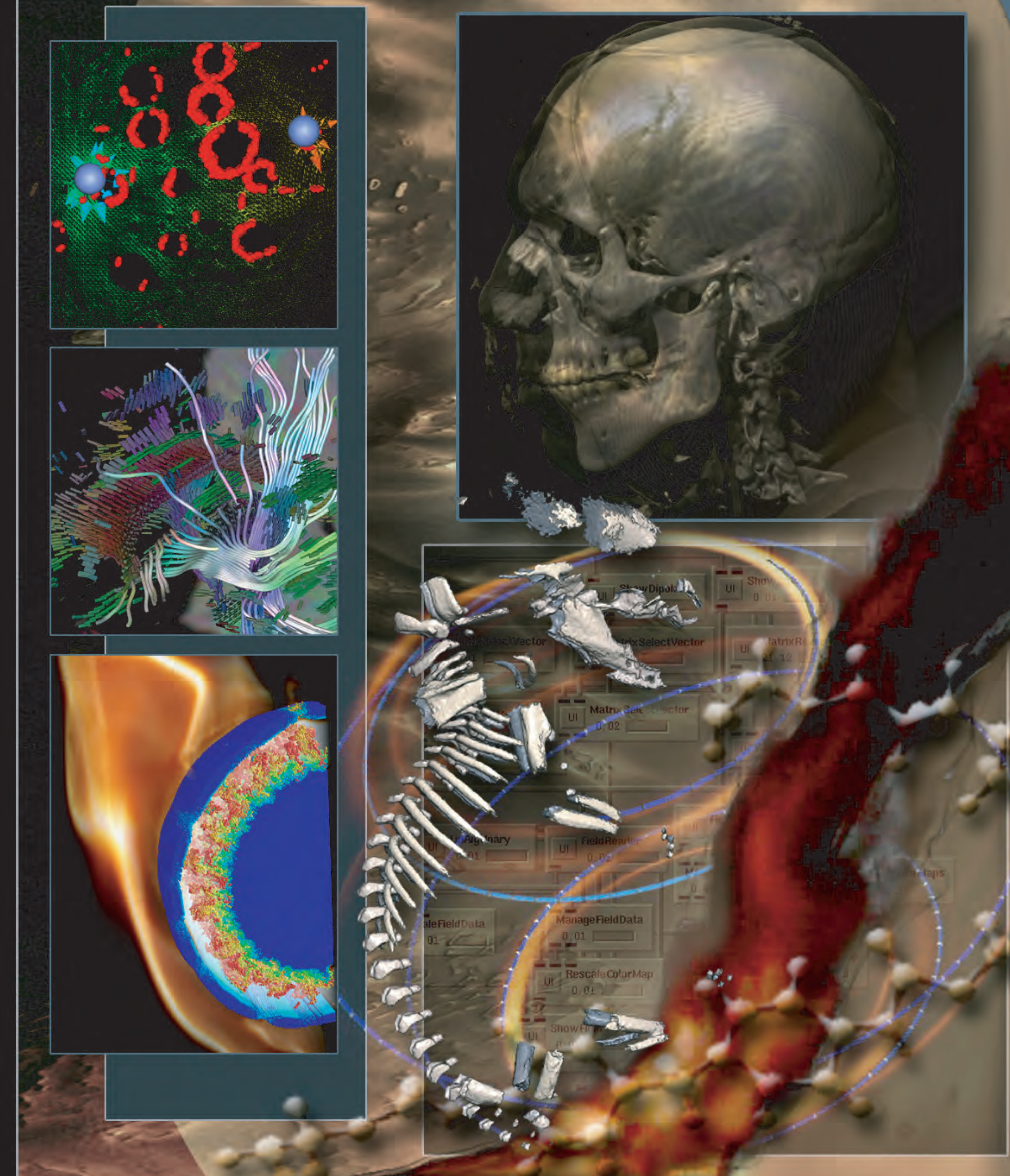
SCIENTIFIC COMPUTING AND IMAGING INSTITUTE

UNIVERSITY OF UTAH



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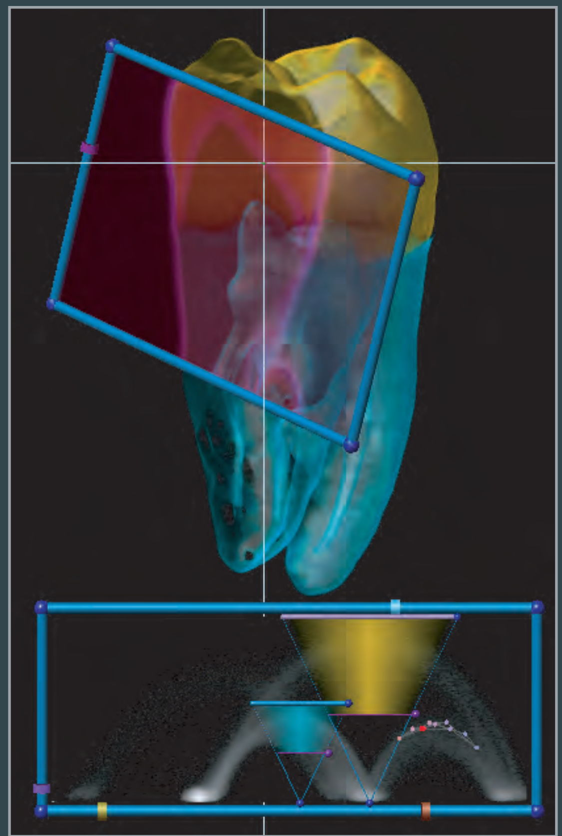
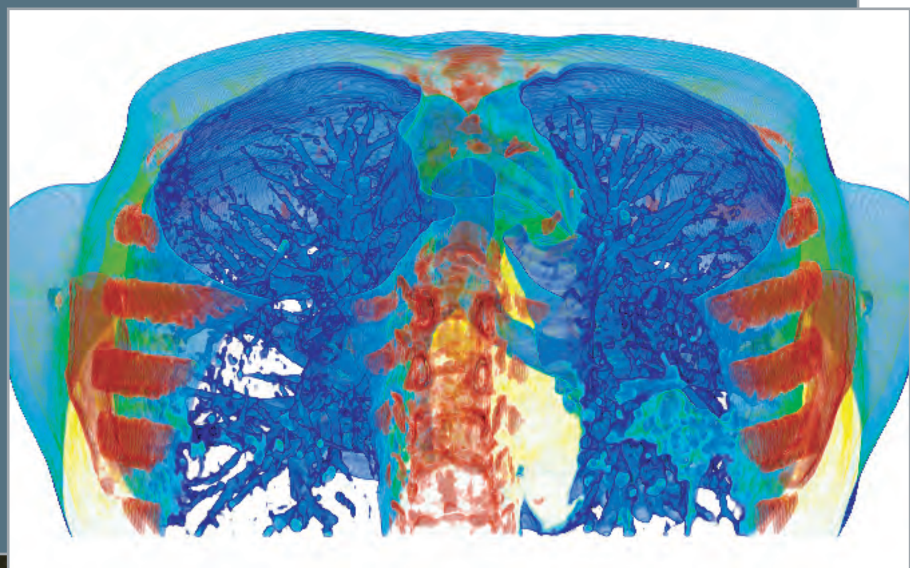


Multidimentional Transfer Function Showing Human Tooth CT



Above: A single slice from time dependent lung data visualized within SCIRun showing a large tumor within the left lung.

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SCI Institute Overview

The Scientific Computing and Imaging Institute (SCI Institute) is one of the permanent research institutes at the University of Utah. The SCI research group was created in 1994 and formally become an institute in 2000. The SCI Institute is directed by Professor Chris Johnson and consists of approximately 90 faculty, students, and staff.

The Scientific Computing and Imaging Institute has established itself as a leader in engineering and research in the areas of scientific computing, scientific visualization, and imaging. The overarching research goal of the SCI Institute is to create new scientific computing techniques, tools, and systems with which to solve problems affecting various aspects of human life. The focus of the Institute has been largely in medicine, but we have also solved computational and imaging problems in other application areas such as geophysics, chemical engineering, molecular dynamics, aerospace fluid mechanics, combustion, and atmospheric dispersion.

The SCI Institute has four 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 third goal is to research new techniques for scientific visualization, and to develop visual analysis tools that help increase the understanding of complex scientific data. The final goal represents our desire, as researchers, to use scientific computing to understand our own particular disciplines, for example, numerical mathematics, fluid dynamics, atmospheric dynamics, biophysics, electrocardiography, bioelectric fields in the brain, and medical imaging.

The Scientific Computing and Imaging Institute currently houses two research centers: the NIH Center for Bioelectric Field Modeling, Simulation, and Visualization and the DOE Advanced Visualization Technology Center. In addition, the Scientific Computing and Imaging Institute is formally associated with several other National research efforts: the NSF Partners in Advanced Computational Infrastructure (NCSA PACI), three DOE SciDAC Centers, the DOE Center for the Simulation of Accidental Fires and Explosions, and two NIH National Centers for Biomedical Computing.

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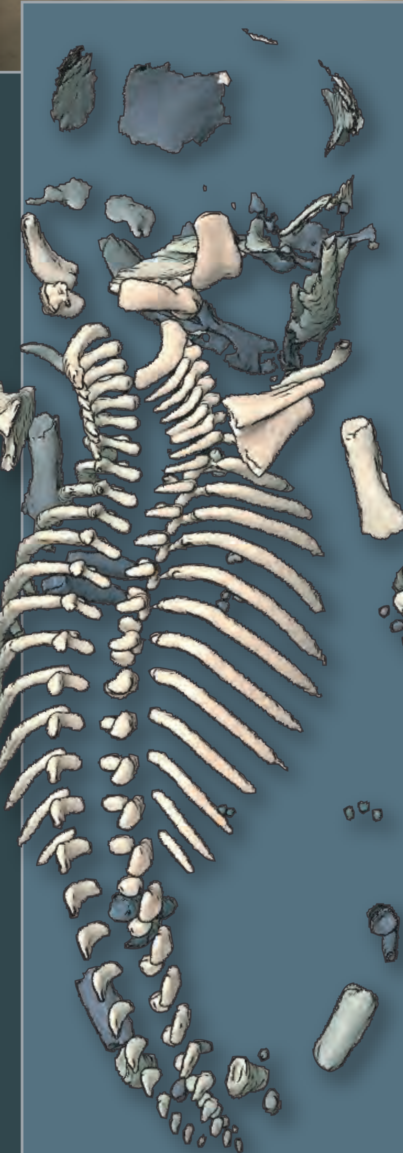


Volume rendering of a CT scan of a normal mouse embryo using a transfer function which utilizes a two dimensional opacity function, curvature-based constant-thickness contours, and warm-to-cool depth shading.

The University of Utah campus in autumn.

Inset: The Joseph Merrill Engineering Building (MEB) - home to the SCI Institute.

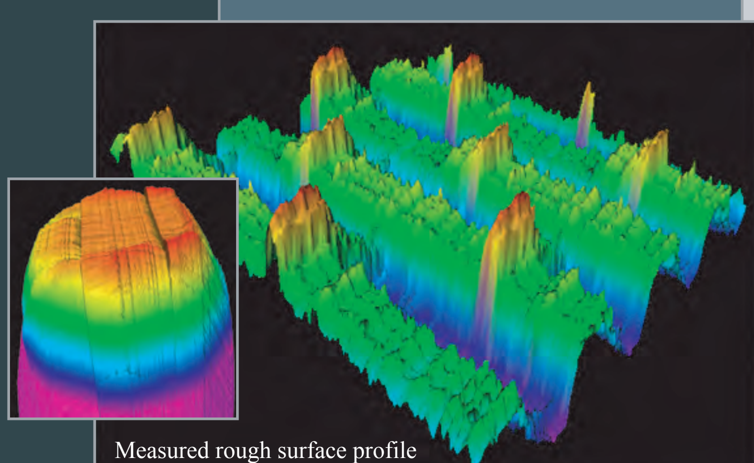
Computational Mechanics

Computational Mechanics is the development and application of numerical techniques to solve problems in solid and fluid mechanics. An interdisciplinary team of scientists and engineers in the SCI Institute are focused on the development and application of numerical techniques based around the finite element method and the Material Point Method.

Adaptive Mesh Refinement (AMR) provides a way to resolve multiple scales by refinement based on derivatives. It also provides estimates of quantities of interest such as critical time of container fragmentation and the energy release.

The objective of this research is the identification, development and prototyping of Adaptive Mesh Refinement (AMR) algorithms for use in the Uintah PSE. Studies of the Arches, MPM, and ICE codes have shown that AMR algorithms that are relevant to C-SAFE as well as transport, combustion, radiation and particle methods do exist. The interface between coarse and fine meshes need high-accuracy and solution-preserving interpolation.

Adjoint Methods for Error Estimation in Quantities of Interest is widely used in engineering design research. For example, Vendetti and Drarmofal show that in an aerofoil calculation, 37K points are used in refinement based on pressure gradients to capture drag (figure 1) where the direct use of refinement linked to drag only needs 4k points (figure 2).


Measured rough surface profile

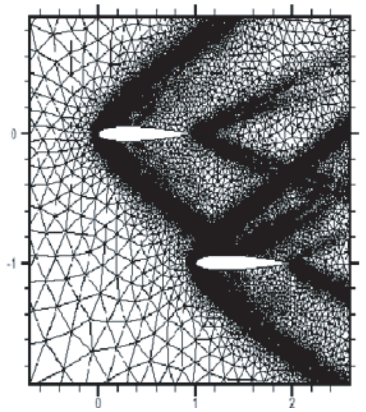


Figure 1

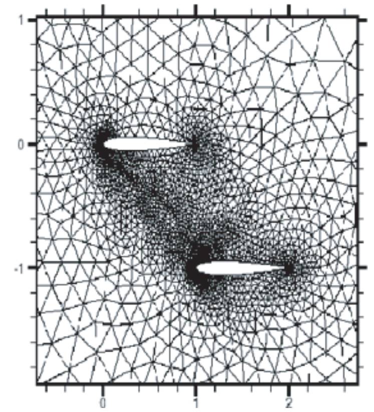
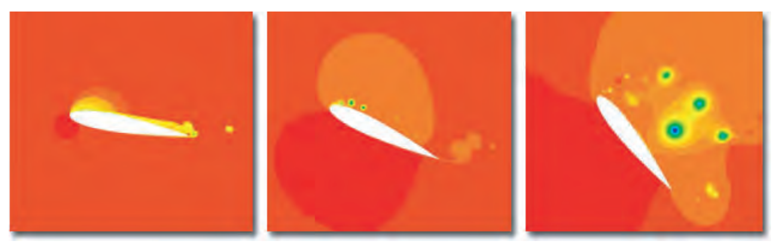


Figure 2

De-Aliasing on Non-Uniform Grids use de-aliasing rules when evaluating non-linear terms with polynomial spectral methods on non-uniform grids, analogous to the de-aliasing rules used in Fourier spectral methods. These rules are based on the idea of super-collocation followed by a Galerkin projection of non-linear terms. Research demonstrates that accuracy and stability can be greatly enhanced using this approach.

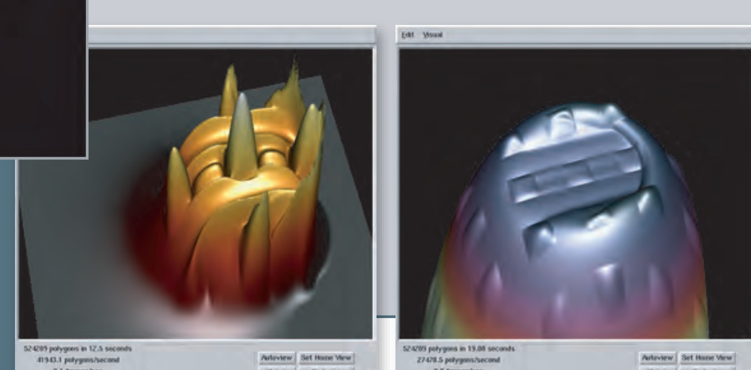

Compressible flow past a pitching airfoil at Re=45,000.

EHL and Grid Computing

Martin Berzins, Chris Goodyear

Here we focus on the efficient numerical solution of elasto-hydrodynamic lubrication problems; a branch of tribology concerned with the separation of two bodies by a lubricant film, in relative motion, under an applied load. Examples include: journal bearings, gear teeth, and ball bearings.

To achieve efficiency and durability of machine components, it is important to understand and predict the performance of lubricants under extreme conditions.

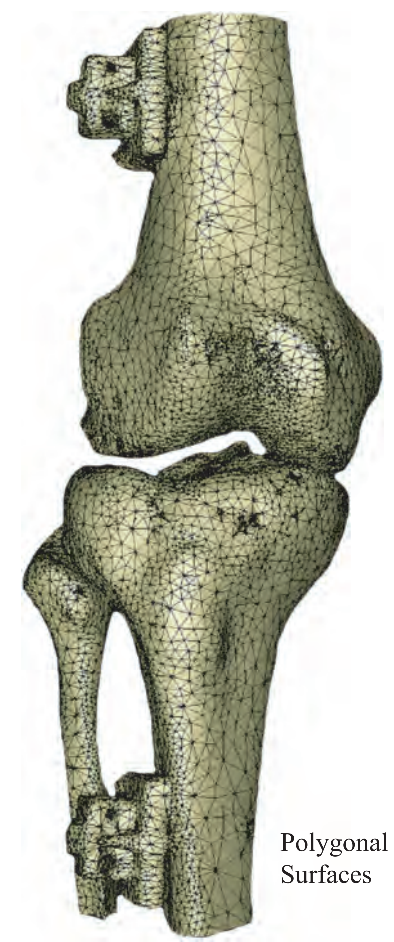

EHL PSE 'Ellipse' running inside SCIRun. The numerical solver outputs solution profiles each timestep for visualization.

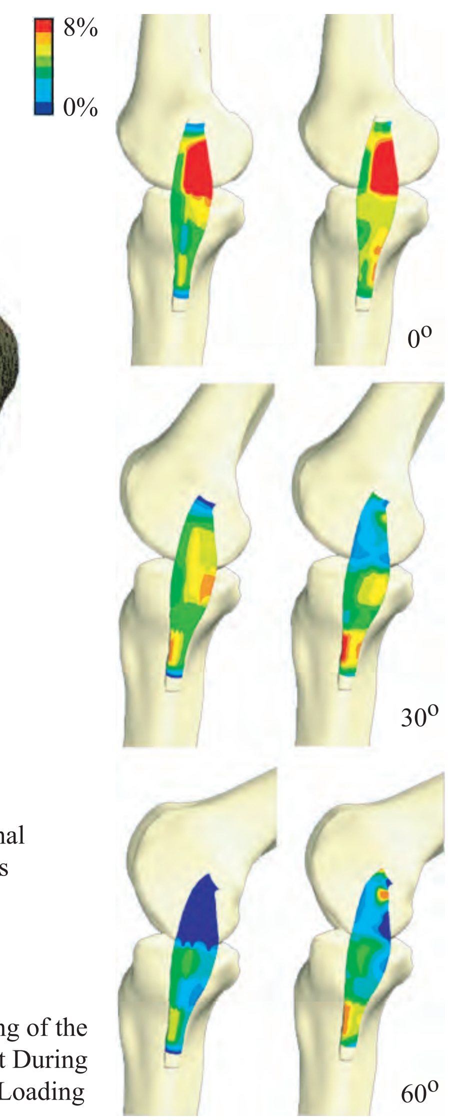
Computational Biomechanics

Jeff Weiss

Research in computational biomechanics focuses on the use of the numerical discretization methods to study the mechanics of biological soft and hard tissues. We have developed techniques to build subject-specific finite element models directly from medical image data such as CT, MRI, OCT or microscopy images. We have also developed constitutitve models and finite element implementations that capture the nonlinear, anisotropic and viscoelastic properties of materials such as ligament, tendon, cartilage, meniscus and bone. We have focused on capturing boundary conditions that are unique to biomechanics such as residual/initial stress and position-dependent anisotropy. The techniques have been applied to the mechanics of the knee, shoulder, articular cartilage, the hip and pelvis.

Computational Modeling of Knee Mechanics. The emerging field of computational biomechanics offers a new set of tools for studies of solid and fluid biomechanics, providing information that would otherwise be difficult or impossible to obtain from experiments. In particular, the finite element (FE) method has provided a generalized procedure to analyze the stress/strain response of a structure.


Polygonal Surfaces

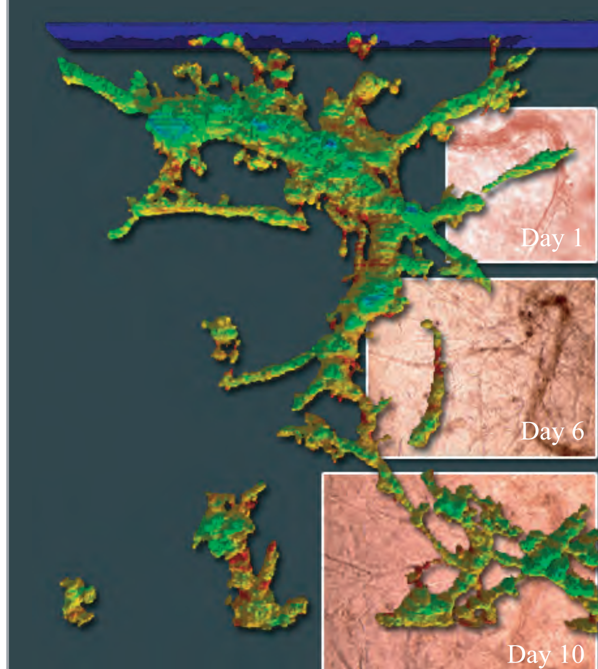


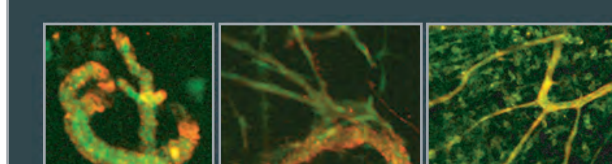
Subject-specific Modeling of the Medial Collateral Ligament During Valgus Loading

Mechanics of Angiogenesis

A recently funded project is examining the mechanics of angiogenesis – the formation of new blood vessels from existing vessels. Angiogenic microvessels are composed of vascular endothelial cells, which are highly responsive to the local state of mechanical stress and strain. Further, these cells take on an invasive phenotype that can lead to alterations in the material properties of the extracellular matrix (ECM).

Below: Representative phase micrographs of the in vitro angiogenesis system consisting of cultured intact microvessels in 3D collagen gels. By using a spatial discretization based on the Material Point Method, we can predict local stresses around the tips of growing capillaries. Results show a volume rendering of von Mises stress on the MPM discretization for simulation of a culture under tensile loading. The MPM particle distribution was generated directly from 3D confocal image data, so computational simulations can be performed on a subject-specific basis.
in smoothly progressing through the stages of the application.



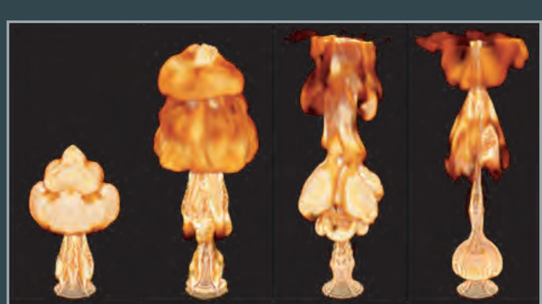

Day 0 Day 8 Day 28

Rat microvessel constructs implanted in scid mouse. Red = smooth muscle cells, Green = endothelial cells.

Large Scale Scientific Visualization

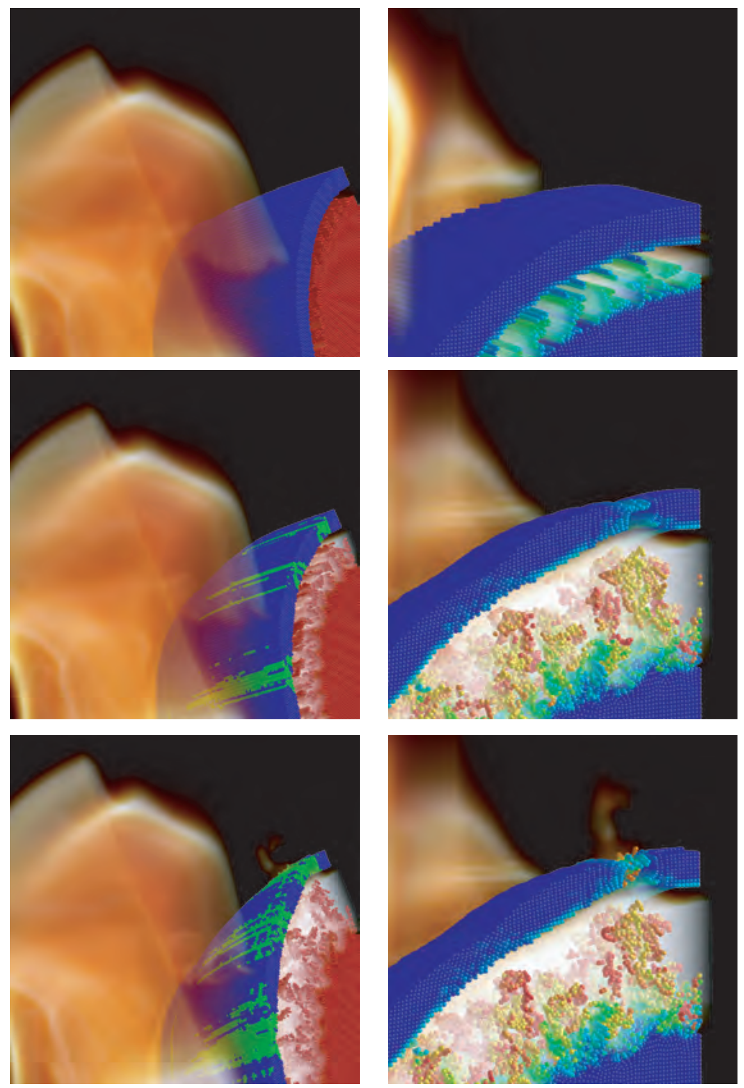
The University of Utah has created an alliance with the DOE Advanced Simulation and Computing (ASC) to form the Center for the Simulation of Accidental Fires and Explosions (C-SAFE). It focuses specifically on providing state-of-the-art, science-based tools for the numerical simulation of accidental fires and explosions, especially within the context of handling and storage of highly flammable materials. The objective of C-SAFE is to provide a system comprising a problem-solving environment in which fundamental chemistry and engineering physics are fully coupled with non-linear solvers, optimization, computational steering, visualization and experimental data verification.

Above: Pool fire test facility. Below: Volume rendering of a JP8-surrogate fire produced by the integrated Arches/ICE simulation. This 160^3 simulation ran on ALC for approximately 60 hours on 120 processors.



Volume Rendering with Large Particle Data Sets

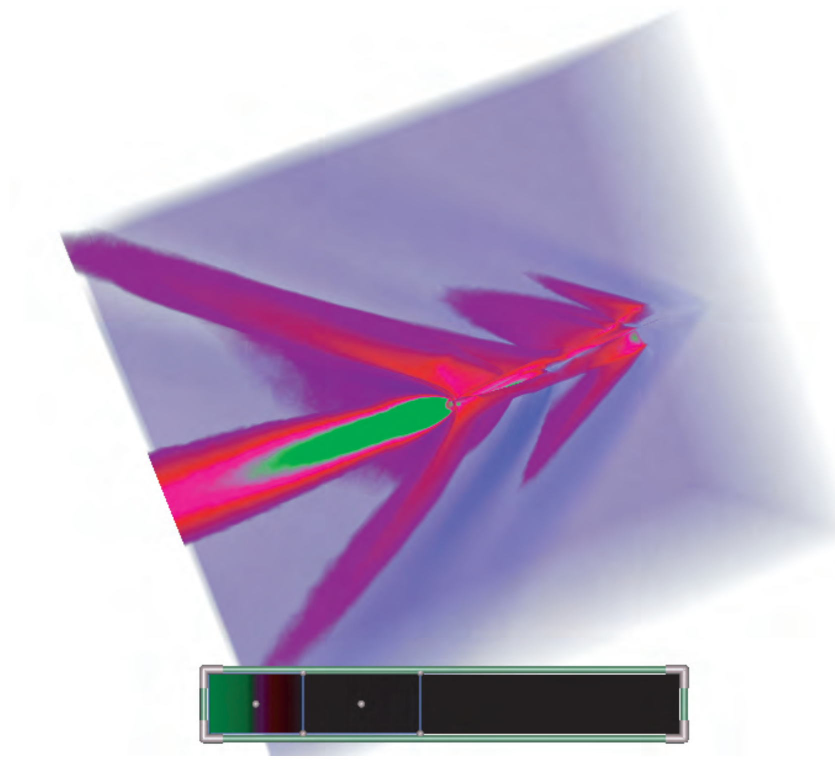
Understanding the results generated by the integrated simulations require visualizations that provide application scientists with the ability to see how components of the simulation interact. Here, particles simulated using the Material Point Method (MPM) are rendered using the Real Time Ray Tracer (RTRT). In addition, the temperature field is volume rendered by RTRT using software based ray casting. Multiple time steps are loaded into memory to give the user an interactive antimated time dependent view of the data. The user may pause, adjust the animation rate, or select specific time steps they wish to view. Users are also able to dynamically adjust the various color maps and transfer functions that are applied to the data.



Shown in these images is data generated by C-SAFE scientists as part of the project's integrated simulation of a container in a pool fire. 170 time steps of data were loaded into memory using approximately 11 GB of RAM. Each time step contained 1 million particles (each with 6 floating point values) and 2.6 million floating point voxels. Using an SGI Origin 3800, the data was rendered at interactive speeds on 50 processors.

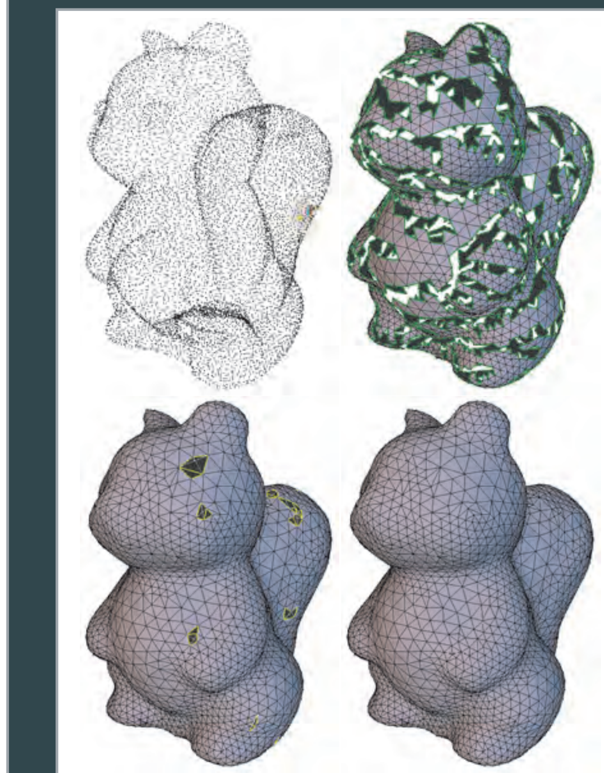
Visualization and Geometric Computing

Advanced geometric algorithms play an increasingly important role in the advancement of science. The need to model and visualize complex geometry is pervasive in essentially every area of the scientific endeavor. This is true regardless of whether a scientist is modeling molecules or simulating large-scale physical phenomena. SCI researchers are active in the development of robust practical solutions to large-scale geometric problems that arise in many areas of visualization and scientific computing.

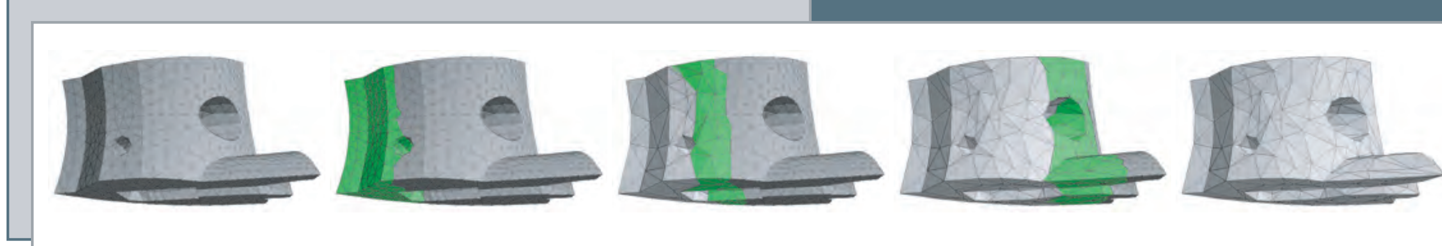


Unstructured grids are extensively used in modern computational science and, thus, play an important role in scientific computing. Their generality and complexity present many unique problems for visualization algorithms, often causing major performance issues. We are developing novel techniques for handling time-varying unstructured data, including efficient techniques for volume rendering, isosurface computation, and data simplification. The figure above shows a volume rendering of a large unstructured dataset containing 1.4 million tetrahedra. It was rendered interactively using our new HAVS algorithm on a PC equipped with an ATI 9800 Pro.

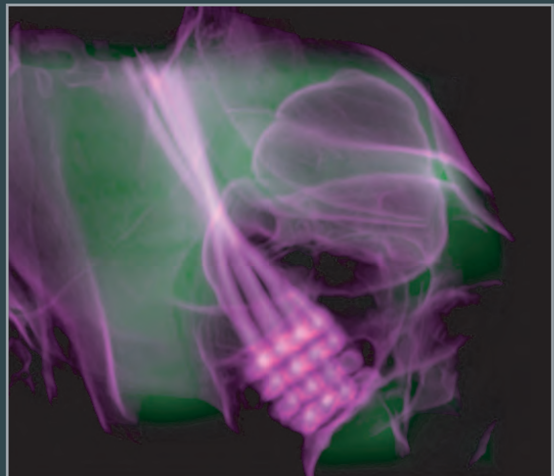
Point-based modeling and rendering is an emerging area of graphics and visualization. Points provide an important alternative modeling technique. Part of the appeal of points is their generality: every shape can be represented by a set of points on its boundary, where the degree of accuracy typically depends only on the number of points. We have been active in the development of the foundations of point-based graphics, and are actively researching new techniques. Below we see several stages of the "reconstruction" of a surface from a set of point samples using a technique recently developed at SCI.



Large-scale scientific visualization aims to handle very large datasets (in general, much larger than the main memory of any single computer) by developing techniques that decouple the performance of the algorithms from the available hardware resources. The goal is to develop fully scalable techniques that can adapt to any hardware configuration. The figure below shows a recent simplification algorithm that we have developed, where only a subset of the data (marked in green) is in memory at any given time.



Small Animal Imaging



Biomedical applications of small animal imaging create opportunities to extend scientific impact of visualization research. Specifically, scientists can quickly explore and understand volumetric scans of their specimens with effective pairing of non-linear image filtering and direct volume rendering. Microscopic computed tomography imaging is a powerful modality for small animal imaging. Collaboration Collaborative work on volume rendering at the University of Utah between the Scientific Computing and Imaging (SCI) Institute and the Department of Bioengineering provides information about the three-dimensional configuration of an electrode array implanted into the auditory nerve of a feline. Collaborative work between the SCI Institute and the division of Pediatric Hematology-Oncology in the department of Pediatrics at the University of Utah found that volume rendering shows promise as a tool for visualizing bone tissue in the mouse embryo, although the signal-to-noise characteristics of the data require the use of sophisticated image pre-processing.

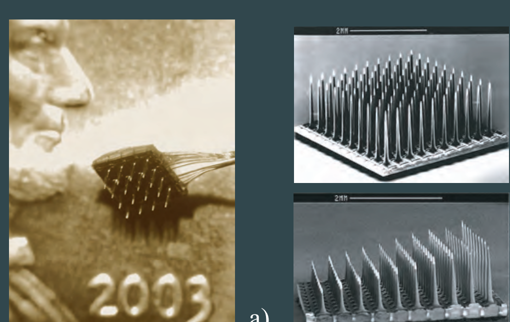


Figure 1: Utah Electrode Arrays developed by the Center for Neural Interfaces. The 4-by-4 array (a), photographed on a penny for scale, was implanted in the feline skull for this study. Arrays with more electrodes have also been created (b), including a slanted array (c) for varying the depth of focal stimulation.

Implanted Electrode Array

Gordon Kindlmann, Dave Weinstein

The Utah Electrode Array has been implanted into the cochlear nerve of felines in order to develop the delicate surgical technique required, and to test the stability of the implant for long periods of time. Non-invasive imaging is required to assess the correct location of the electrode array within the auditory nerve, and in relation to the modiolus.

CT imaging does not discern the feline auditory nerve, but is positioned at the center of the modiolus, the "bore" of the cochlea. The visualization task for this dataset is determining if the tips of the electrode array are correctly positioned to the path of the nerve, as indicated by surrounding bone surfaces. Direct volume rendering provides a way of visualizing objects in the dataset, because of different radio opacities of bone, air, and the electrode array. (Fig. 1) In this case, inspecting a histogram of the CT values generated the one-dimensional transfer functions that determine opacity and color.

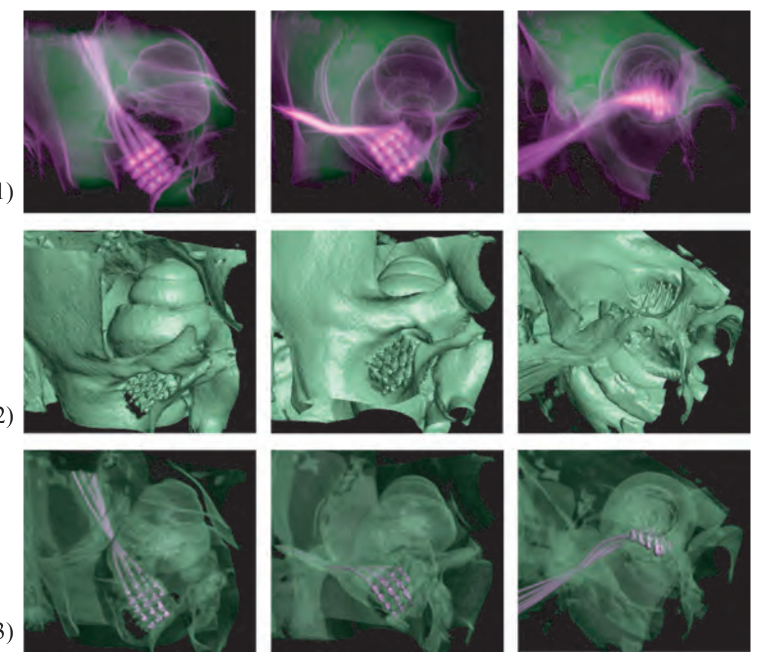


Fig. 2: Volume renderings of electrode array implanted in feline skull. The volume is gradually rotated upward in columns (a), (b), and (c), from seeing the side of the cochlea exterior in (a), to looking down the path of the cochlear nerve in (c). From top to bottom, each row uses different rendering styles; (1) volume renderings with opaque bone; (2) volume renderings with translucent bone, showing the electrode leads in magenta, and summation projections of CT values (green) and gradient magnitudes (magenta).

The data for this investigation was acquired with a General Electric EVS RS-9 computed tomography scanner at the University of Utah Small Animal Imaging Facility. The scanner generates 16-bit volumes roughly one gigabyte in size, with a spatial resolution of 21 x 21 x 21 microns.

Non-Linear Filtering and Visualization of Bone Scans

Gordon Kindlmann

CT datasets are often considered less noisy than other modalities, such as ultrasound or clinical MRI. Small animal imaging CT scans, however, can present significant signal-to-noise challenges. Contrast is one challenge, because tissues of interest do not always have markedly different radio-opacity than their surroundings. The developing bones of a mouse embryo, for example, are partially and unevenly calcified. Regions consisting solely of cartilage are indistinguishable in their CT value from soft tissue. Additionally, the size of some features approach the limits of the imaging resolution. In combination with the effects of partial voluming, it can be difficult distinguishing CT values inside and outside small features. This hampers the creation of a meaningful visualization.

Fig. 3: Development of Transfer Function for CT Bone Rendering. Volume renderings of CT scan of normal mouse embryo use a transfer function that starts with a two-dimensional opacity function (left), with curvature-based constant-thickness contours (middle), and warm-to-cool depth shading (right).

Simian: Interactive Volume Rendering

Joe Kniss

The goal of Simian is to make volume rendering more interactive, intuitive, and expressive. Generating images using traditional volume rendering methods can be difficult. Even with experience and training, the process of isolating features of interest in a dataset can be one of trial and error. Simian's combination of hardware-based volume rendering (for interactivity), direct manipulation widgets (for intuitiveness), and multi-dimensional transfer functions (for expressiveness) minimize trial and error, allowing scientists, engineers, and physicians to efficiently answer questions about their data.

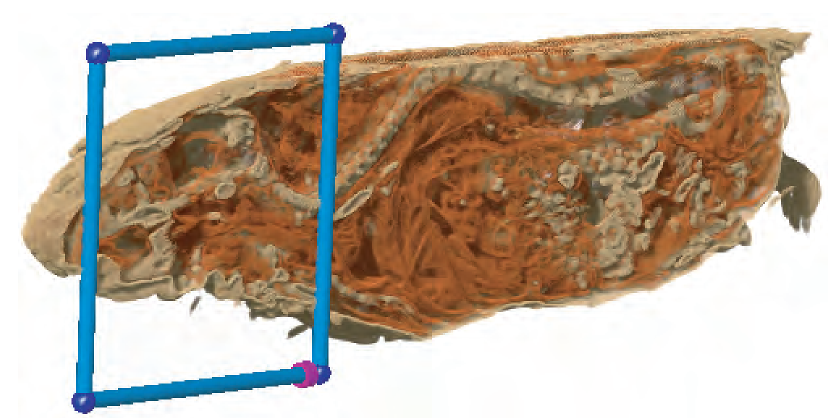
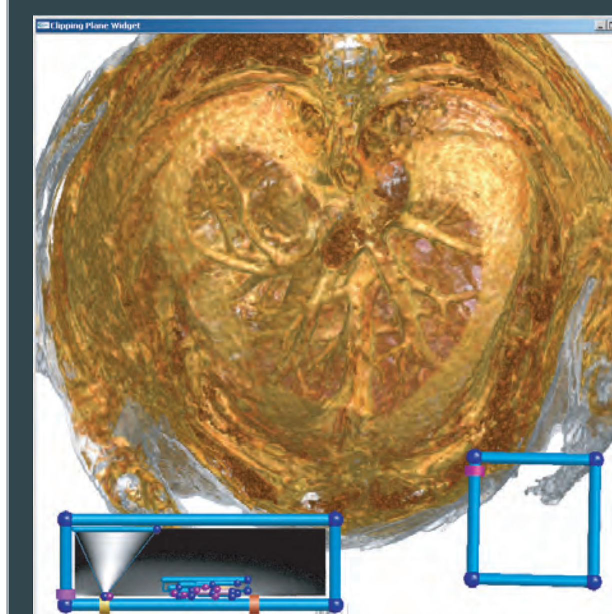


Fig. 4: Two views of a CT scan of a normal mouse embryo (18 day gestation) using curvature-based constant-thickness contours and warm-to-cool depth shading. This image provides qualitative feedback for bone structure; a careful segmentation would be required to identify and separate individual bones.

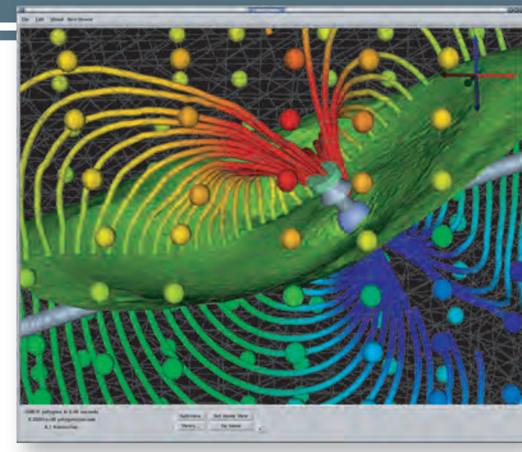


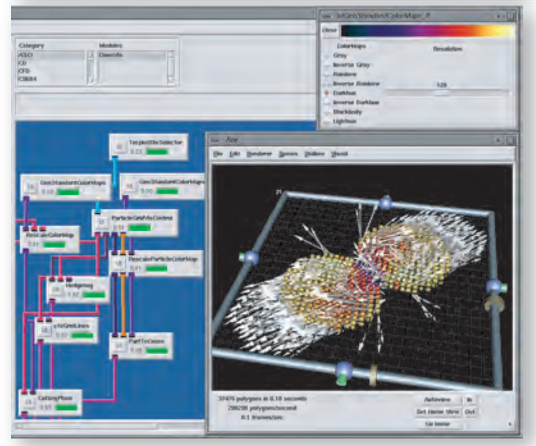
Cross sections from high resolution mouse MR from Duke In Vivo Microscopy Lab visualized using Simian.

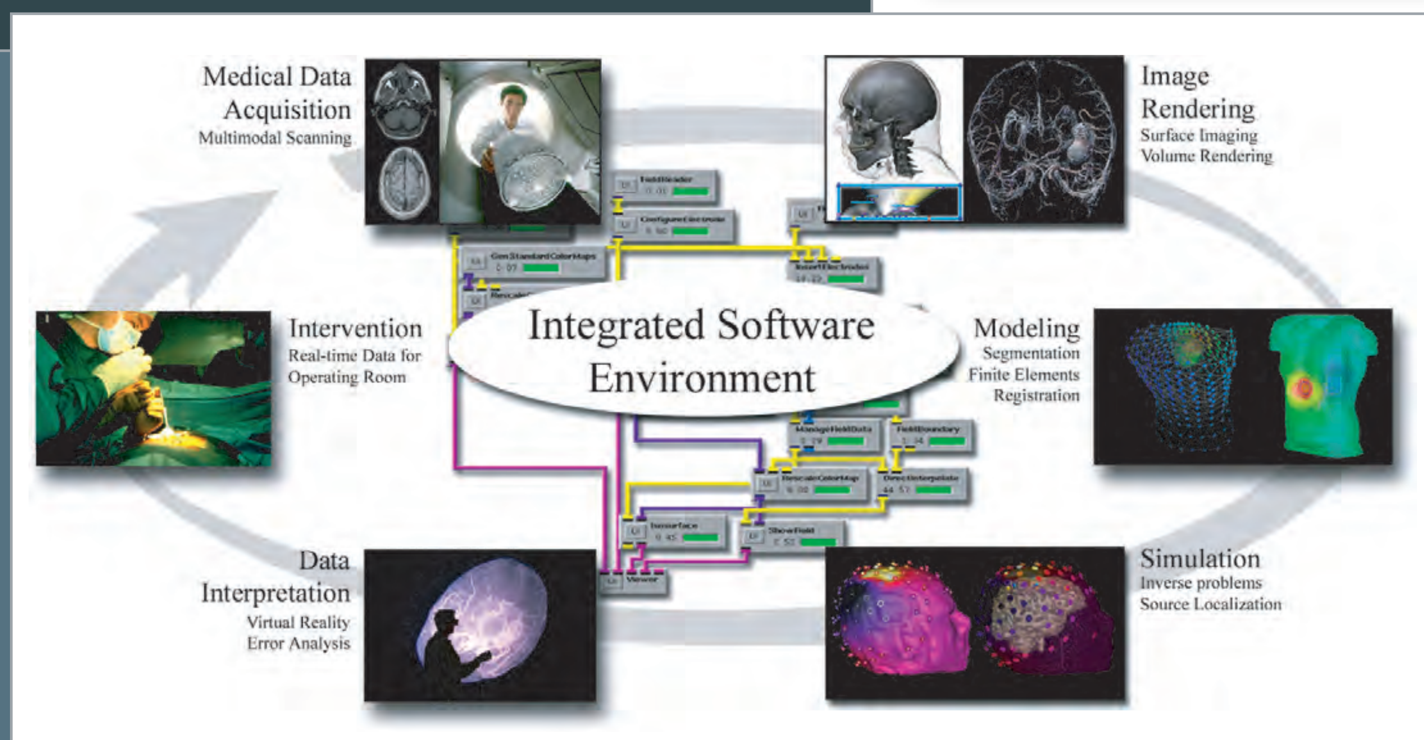
PROBLEM SOLVING ENVIRONMENTS: SCIRun, BioPSE, Uintah

The most effective approach to using computational tools is to integrate computing functions into one seamless, ubiquitous environment. SCIRun is that tool. Best described as a computational workbench, with SCIRun, all aspects of the modeling, simulation, and visualization processes are linked and controlled graphically within the context of a single application program. By tackling such a large integrated systems approach, the SCI Institute draws upon its multidisciplinary approach to science and research in geometric modeling, simulation, scientific visualization and software environments.

SCIRun began development in 1992 and was the original implementation of the computational framework. This computational workbench infrastructure has been the origin of many significant application-specific "packages." The two major examples are the DOE sponsored Uintah system (top, currently operating within the CSAFE project), and the NIH sponsored BioPSE system (bottom). The target applications of the Uintah project are combustion, computational fluid dynamics, and mechanical modeling which is implemented on large-scale, and distributed with shared memory architectures. The primary goal of the BioPSE project was to create software for geometric modeling, simulation, and visualization for solving bioelectric field problems, and to make the source code for these problem solving environments publicly available to the scientific community. We anticipate that the collection of these packages will grow, as the advantages of the SCIRun infrastructure become available to scientists and engineers of all disciplines.







Starting with images acquired from one or more modalities, we render and compare the three-dimensional data sets, create geometric models from the image sets, which can then form the basis for additional visualizations, or for simulations of the underlying function. In a completely closed loop environment, it is then possible to analyze the measured and simulated data and feed the results to direct experiment or clinical intervention

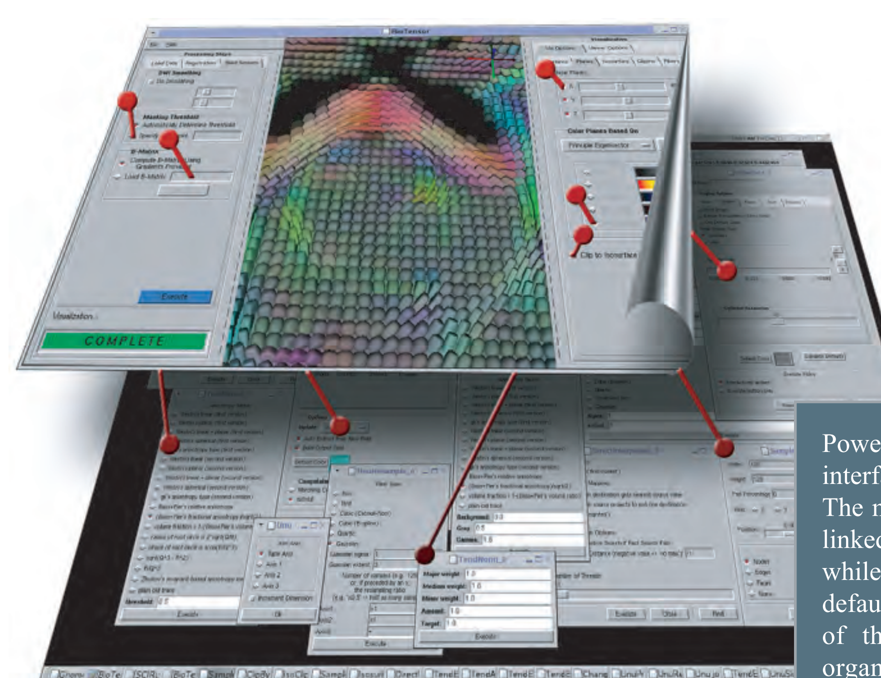
SCIRun PowerApps

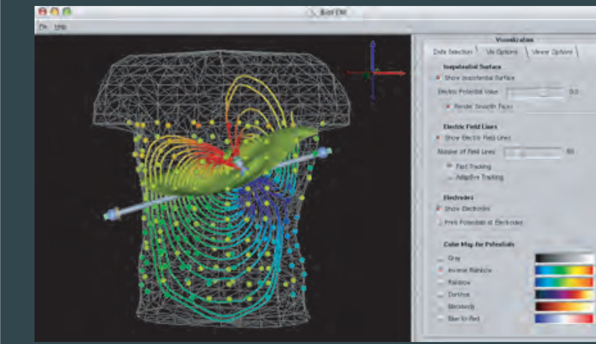
Historically, one of the major hurdles to SCIRun/BioPSE becoming a tool for the scientist or engineer has been SCIRun's dataflow interface. While visual programming is natural for computer scientists, who are accustomed to writing software and building algorithmic pipelines, it is overly cumbersome for application scientists. Even when a dataflow network implements a specific application (such as the forward bioelectric field simulation network provided with BioPSE and detailed in the BioPSE Tutorial), the user interface (UI) components of the network are presented to the user in separate UI windows, without any semantic context for their settings. Historically, there has not been a way to present the filename entries in their semantic context, for example to indicate that one entry should identify the electrodes input file and the other should identify the finite element mesh file.

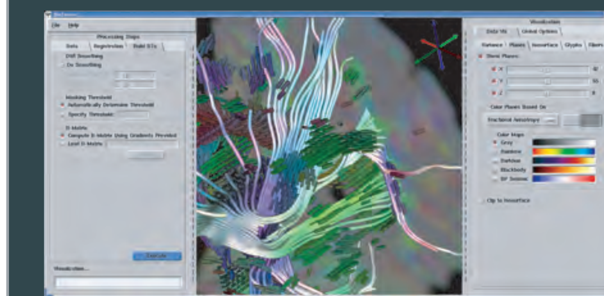
With the 1.20 release of BioPSE/SCIRun, PowerApps were introduced. A PowerApp is a customized interface built atop a dataflow application network. The dataflow network controls the execution and synchronization of the modules that comprise the application, but the generic user interface windows are replaced with entries that are placed in the context of a single application-specific interface window.

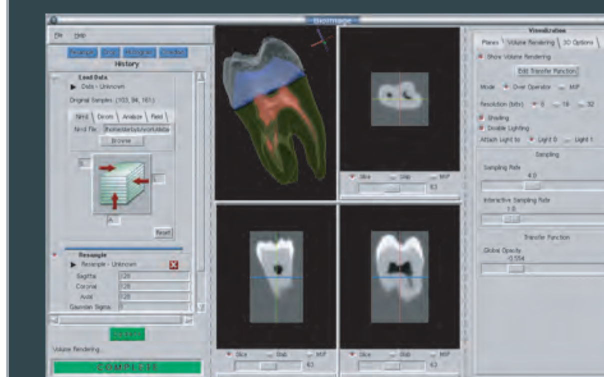
There are currently four PowerApps available: BioFEM (for finite element problems); BioTensor (for post-processing and visualization of DWI MRI data); BioImage (for the processing and visualization of 3-dimensional data); and FusionViewer (for visualizing 3D scalar and vector magnetic fusion data).

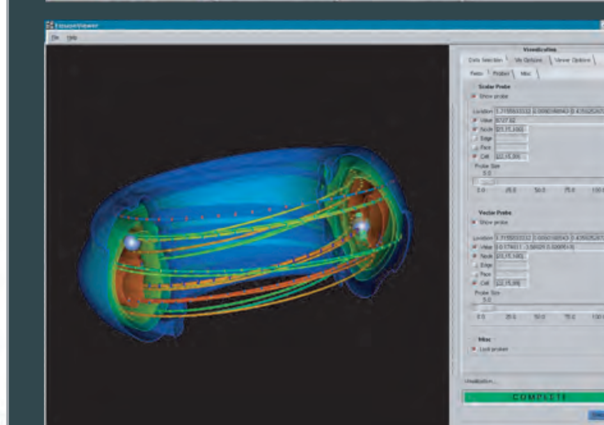
SCIRun (with PowerApps) is free of charge to researchers, students, and educators, and is available for download at http://software.sci.utah.edu









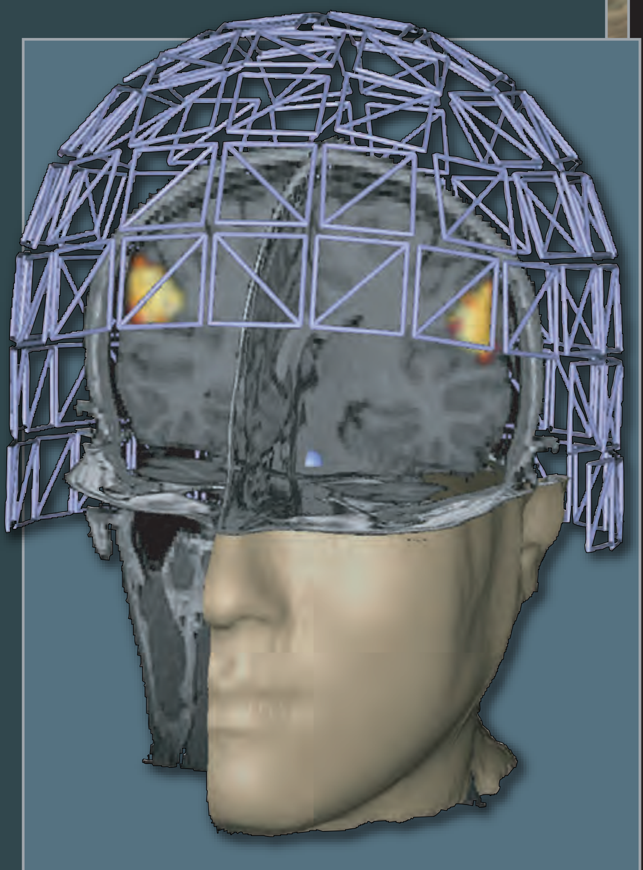


PowerApps replace the multitude of generic dataflow user interface (UI) windows with a single customized interface. The most important controls from the dataflow interface are linked to contextually labeled variables on the PowerApp UI, while the other dataflow variables are assigned appropriate defaults, reducing the visual complexity and generic labels of the dataflow UI windows. The UI components are organized into logical groups and assists the user in smoothly progressing through the stages of the application.

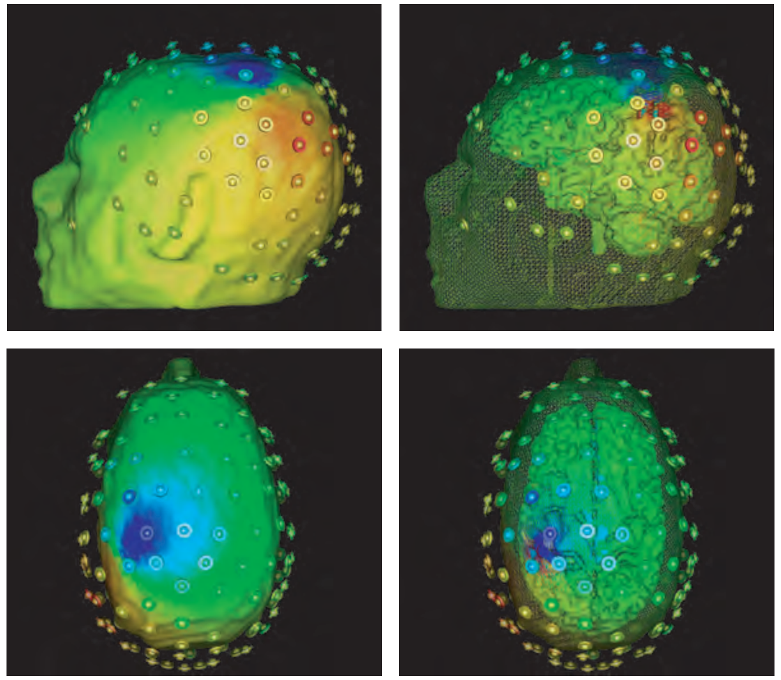
Forward and Inverse Problems

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.

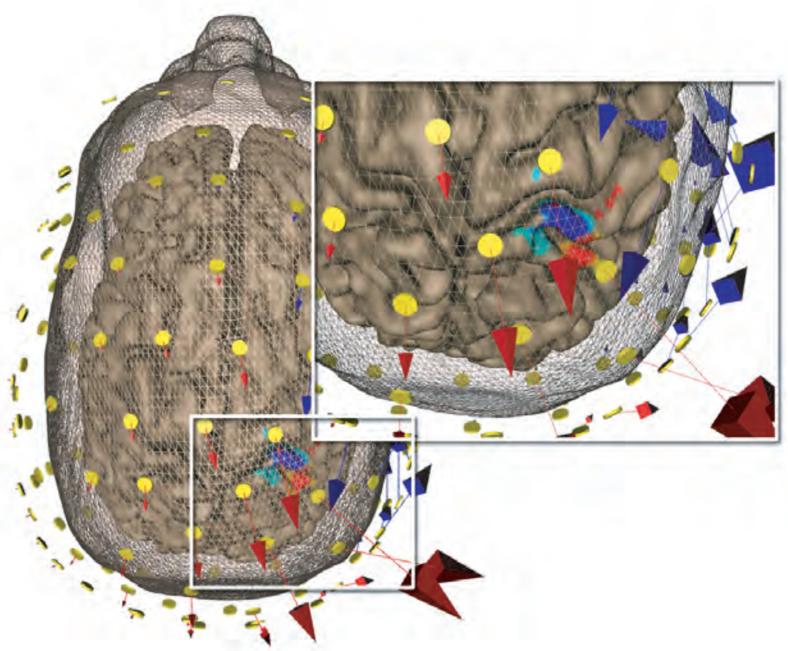
Research within the SCI Institute has included numerous types of inverse problems in imaging, with emphasis on problems in functional imaging. Examples include reconstruction of electrical sources within the heart or brain and extraction of molecular diffusion information from magnetic resonance images.



Focusing inversion is an inverse method for reconstructing sharp, focused images from smooth measured data. Applying this technique to the MEG source localization problem, we are able to resolve multiple focal sources.



In the **Inverse EEG Application**, the goal is to localize an equivalent dipole source in a finite element model of a patient's head. Given EEG measurements from electrodes placed at known locations on a patient's scalp, and a discretized tetrahedral volume mesh with each labeled with the appropriate conductivity of the underlying anatomy, we solve a source localization inverse problem to identify the position and moment of the dipole within the domain which best reproduces the EEG measurements.

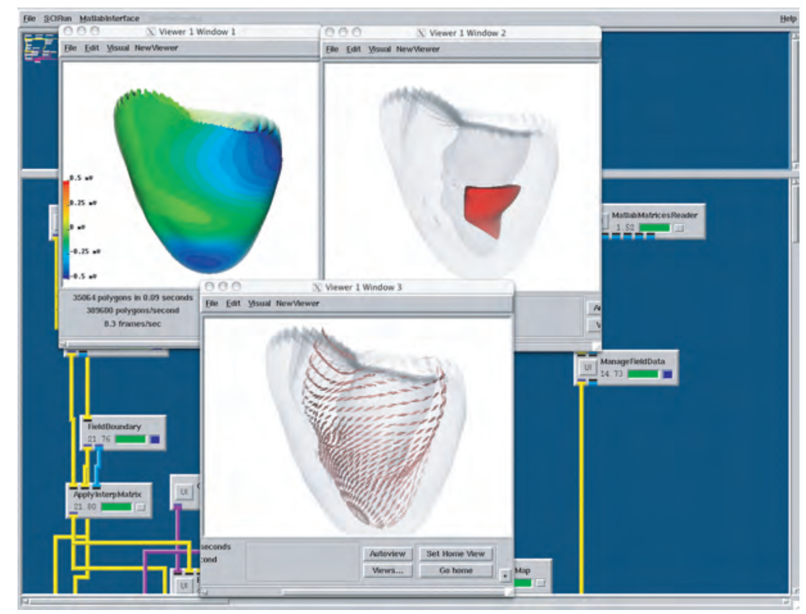


The **Inverse MEG Application**. The magnetic field vectors for each detector with dipole in right occipital cortex. The red arrows indicate a positive normal component of the magnetic field, and the blue arrows indicate a negative normal component. The colored brain cortex indicates the relative electric potential strength.

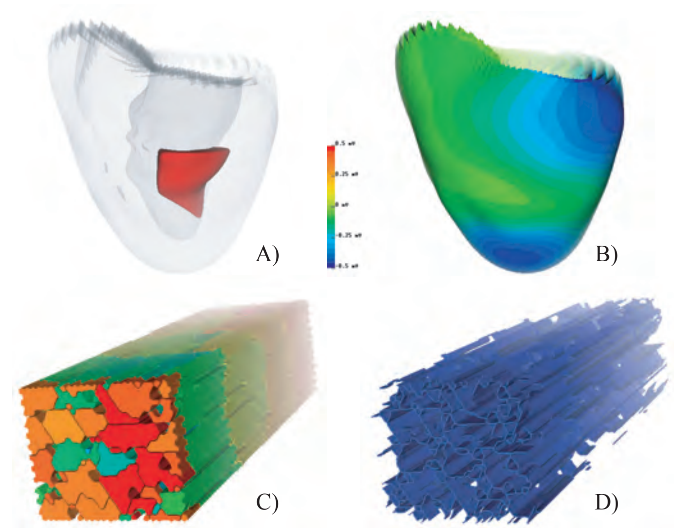
Visualizing Cardiac Ischemia

Rob MacLeod, Bruce Hoppenfeld, Dave Weinstein

Cardiac ischemia occurs when a coronary artery (which delivers oxygen-rich blood to the heart) is either partially or completely blocked. As a result of this blockage, blood flow and oxygen delivery to the heart muscle are limited. The most common cause of cardiac ischemia is plaque build-up in the arteries due to the long-term effects of coronary artery disease. This narrows the arteries to the point where the amount of blood flowing through the arteries is not enough for the heart during times of physical exertion or emotional stress.



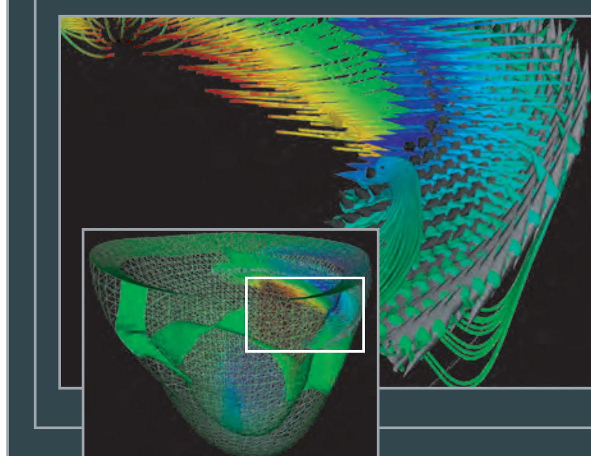
Visualizing an anisotropic model of the ventricles of a dog heart. Using SCIRun, we can simultaneously visualize epicardial potentials, an ischemic region and the fiber orientation at a certain depth. Having interactive coupled displays is very useful in analyzing the data.



Below: A multi-field visualization of the electric field of the heart during the ST segment of a simulated heart beat. The model of an otherwise healthy heart muscle contains a large region of simulated ischemic tissue (with reduced action-potential amplitude). As seen in the results from this complex computational simulation, the ischemic region alters the normal electric field and the resulting "injury currents" lead to characteristic electricardiographic markers of ischemia.

The electric field lines of the heart are depicted as rainbow-colored tubes connecting regions of positive and negative voltage. The color-coding of the tubes indicate the simulated voltage values in the heart tissue along their paths: red is positive, blue is negative, and green is near zero. We are also displaying the same pseudo-coloring of potential on the epicardial surface (cut away to reveal the inside), and an iso-potential surface that has been tracked through the heart volume.

Superimposed over the electric field data, we have included gray arrow-glyphs to depict the local fiber orientation of the underlying myocardial tissue.



A) An in image of a model used to simulated the effects of ischemia (deficient blood supply to a certain region of the heart). The area that is assumed to be ischemic is depicted in red. The outline of the heart and the ventricles are depicted in grey.

B) Using this model we were able to compute the potential distribution at the epicardium (outer surface of the heart) during the ST interval. An example of such a distribution is shown in the figure.

C) In order to predict the electrical properties of cardiac tissue we created a model at tissue level. In this image the stacking of cells is depicted. The latter was used tocalculate the anisotropy of cardiac tissue in the intracellular domain.

D) The shape of the extracellular space surrounding the cells and was used for computing the electrical properties in the extracellular space.

Image and Signal Processing

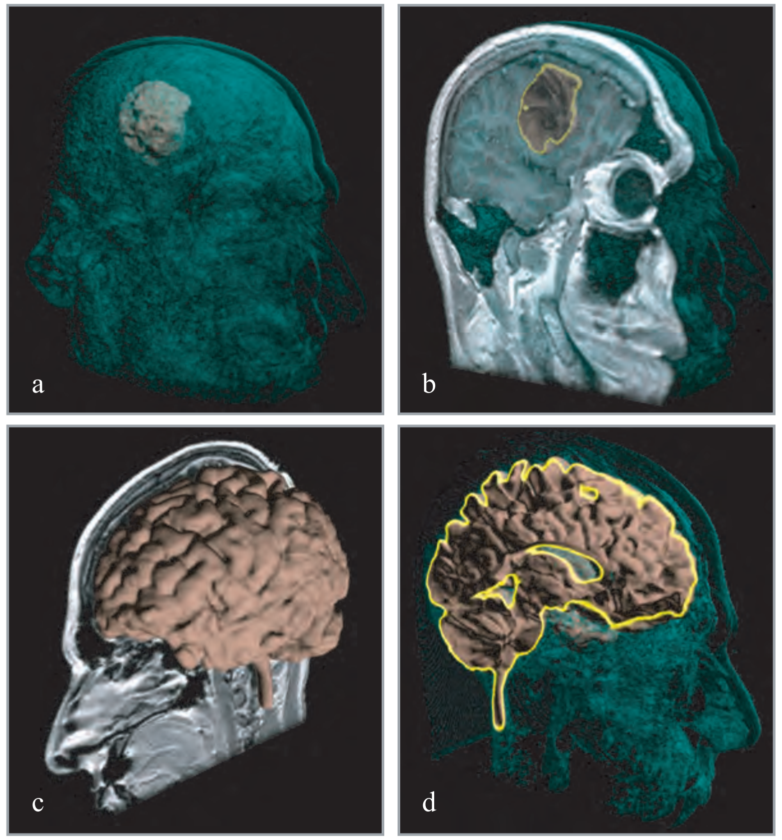
Ross Whitaker, Tolga Tasdizen, Josh Cates

Image processing and analysis play an important role in many applications of scientific computing and imaging. Image data comes from a wide variety of sources including medical scanners, scientific instruments, and digital cameras. Usually, it is necessary to process these images before they can provide useful information. To construct geometric models from image data, it is sometimes necessary to combine and align image data from different sources, or to extract the boundaries between different regions within the images.

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

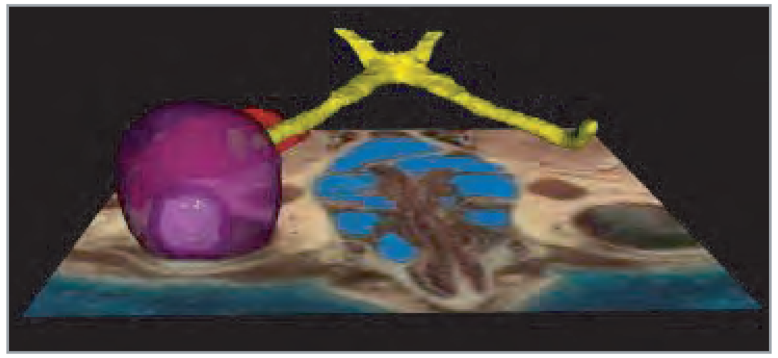
Visualization of Spiny Dendrite Using Level-Set Surface Models. Microscopic electron tomography produces noisy 3D data, which can be visualized using level-set surface model, which fits the data while preserving some level of continuity and smoothness.

Electron tomography data courtesy of Mark Ellisman, National Center for Microscopy and Imaging Research



Level set segmentation. Deformable isosurfaces, implemented with level-set methods, have demonstrated a great potential in visualization for applications such as segmentation, surface processing, and surface reconstruction.

a) Interactive level set segmentation of a brain tumor from an MRI with volume rendering for context. b) A clipping plane showing the source data, the volume rendering, and the segmentation simultaneously. c,d) The cerebral cortex segmented from the same data. The yellow band indicates the intersection of the level-set model with the clipping plane.



A three dimensional segmentation of the right eyeball, optic nerve, and associated musculature from a section of the Visible Female color cryosection data.

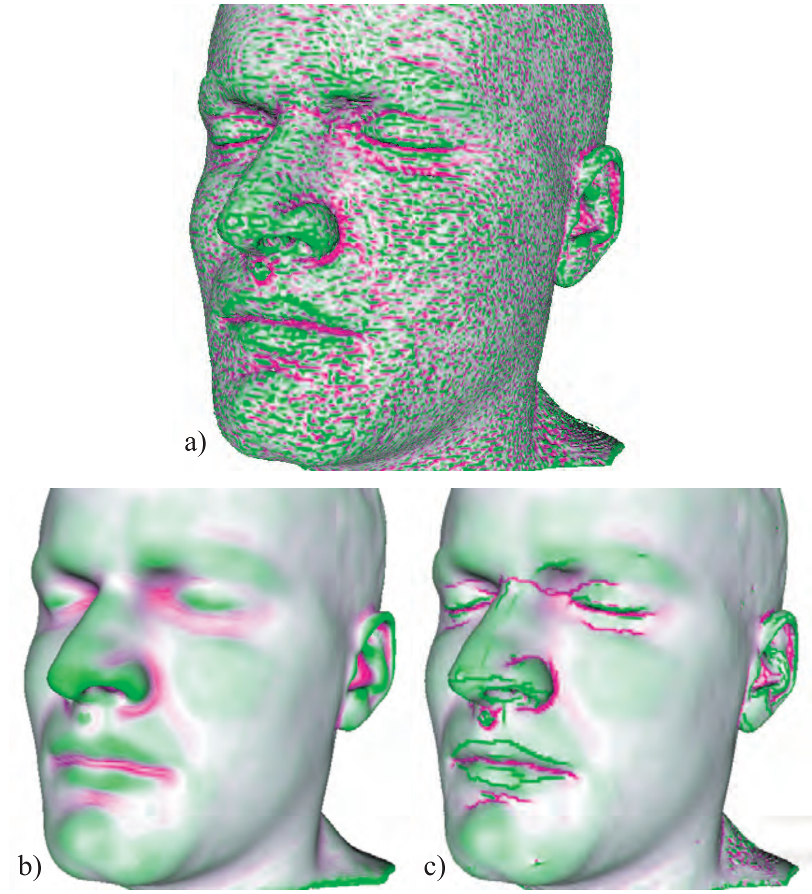


Figure 1

Surface processing. We have introduced a two-step approach to implementing geometric processing. This computational approach uses level set surface models; therefore, they are not dependent on any underlying parameterization. Figure 1: a) The skin isosurface is extracted from a MRI dataset. Mean curvature is computed and colormapped on to the same surface. b) Mean curvature computed after isotropic smoothing. Noise is smoothed but details are eliminated. c) Mean curvature computed after anisotropic smoothing of the surface. Noise is smoothed and details are preserved. Figure 2 shows the results on height field data.

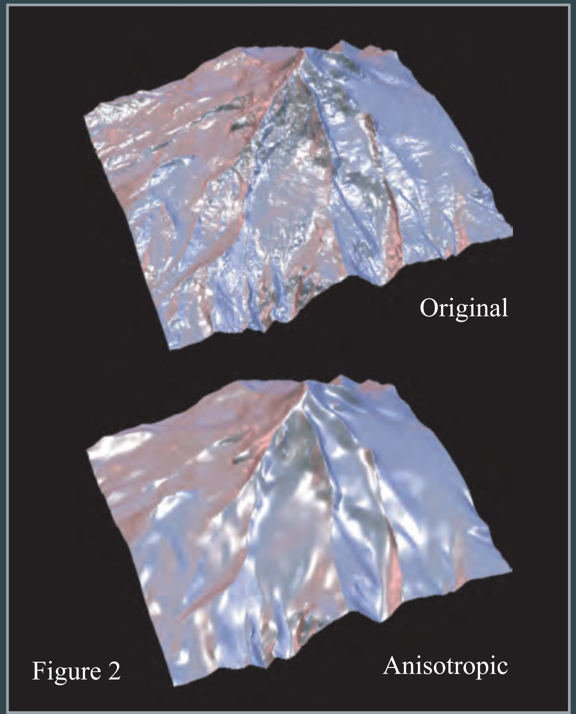


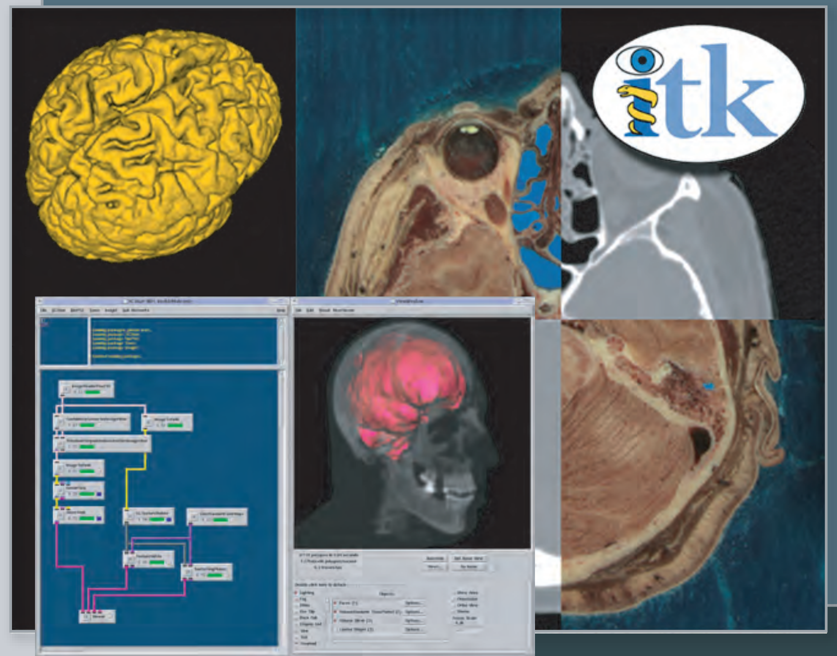
Figure 2

The Insight Segmentation and Registration Toolkit

Josh Cates

The Insight Toolkit (ITK) is an open source, freely available, object-oriented software package for medical image processing, segmentation, and registration. ITK was was funded by the US National Library Of Medicine at the National Institutes of Health to facilitate analysis of the Visible Human Project data sets. Methods in the toolkit are applicable to a wide variety of clinic data such as CT, MRI, ultrasound, PET, fluoroscopy and microscopy.

The most aggressive hope for this project has been the creation of a self-sustaining, open-source software development community in medical image processing. With the creation of an open repository built from common principles, we hope to help focus and concentrate research in this field, reduce redundancy of development, and promote cross-institution communication.

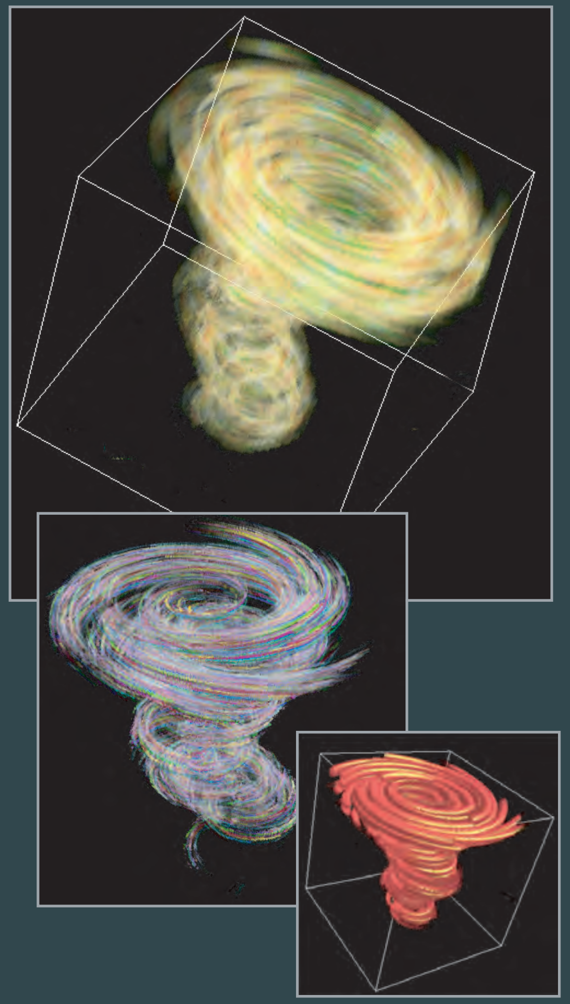


Vector Field Methods

Visualizing Three Dimensional Directional Information

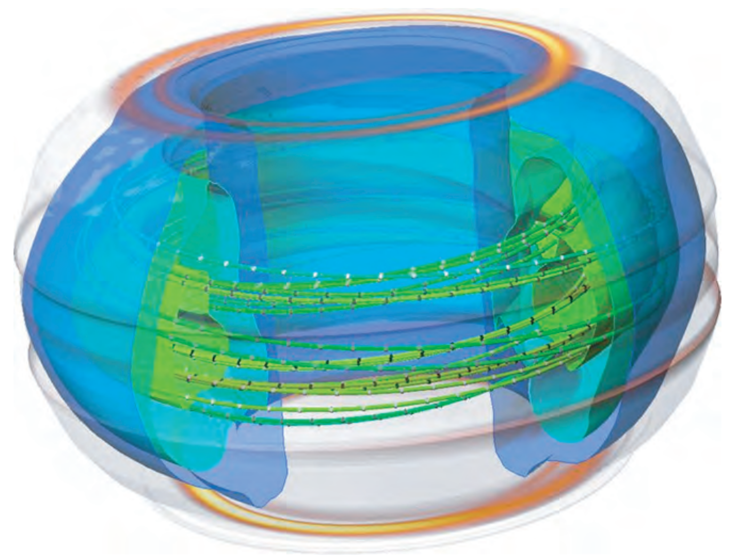
Visualizing vector field data is challenging because no existing natural representation can visually convey large amounts of three-dimensional directional information. Visualization researchers have adopted analogues to fluid flow and wind tunnel techniques. One result has been a set of graphical icons 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.

Below we see Chameleon - an interactive texture-based technique for visualizing three-dimensional vector fields. The goal of Chameleon is to provide a general volume rendering framework allowing the user to compute three-dimensional flow textures interactively, and to modify the appearance of the visualization on the fly.



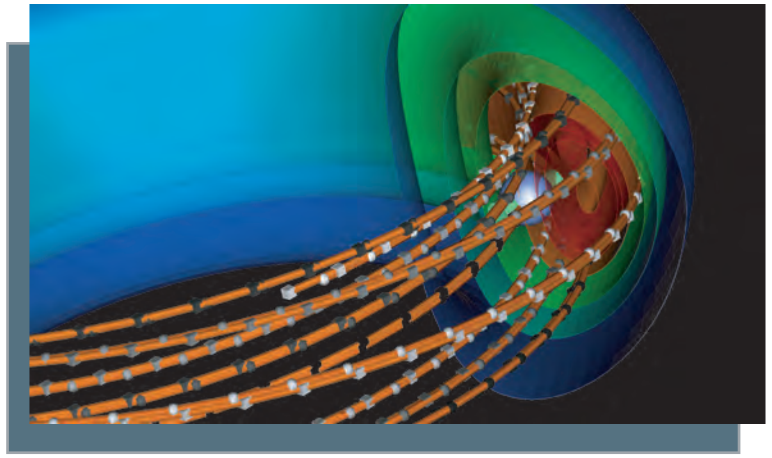
The Fusion Collaboration

Allen Sanderson



Visualizing streamlines that are periodic and wrap back on themselves without returning to their initial starting position pose several unique challenges. In the case of magnetic field lines in Magnetohydrodynamic (MHD) simulations of 3D Tokamak Plasma it is further complicated because the field lines are not only periodic but also intertwined. To be useful for fusion research it is often necessary to analyze two streamlines that originate in close proximity and follow their path as they proceed through the data. If the streamlines follow approximately the same path the system is stable. However, if they diverge the system might become stochastic. If this happens, the magnetic field is no longer able to contain the plasma ending the fusion reaction.

The solution to this problem was to utilize SCIRun and add different glyphs to each streamline, coloring the glyphs based on their distance from the starting point. Adding a different glyph to each streamline makes them easily identifiable no matter where one is looking. At the same time, by coloring each glyph based on the distance from the starting point, it is easy to know approximately where one is along the streamline.

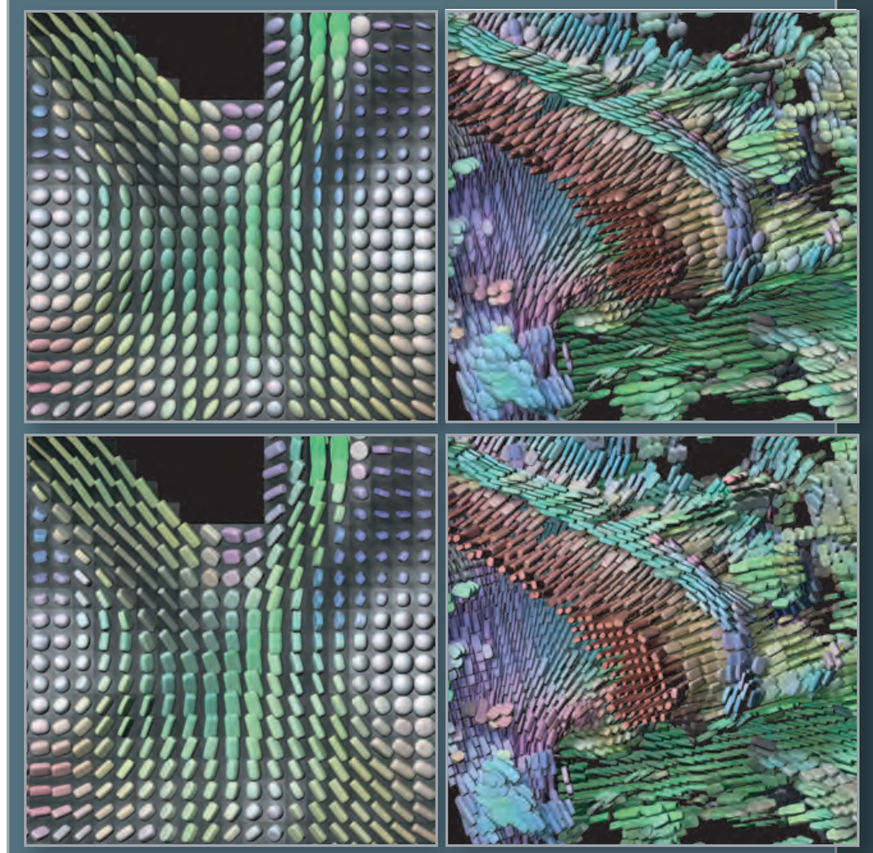


Diffusion Tensor MRI

Gordon Kindlmann

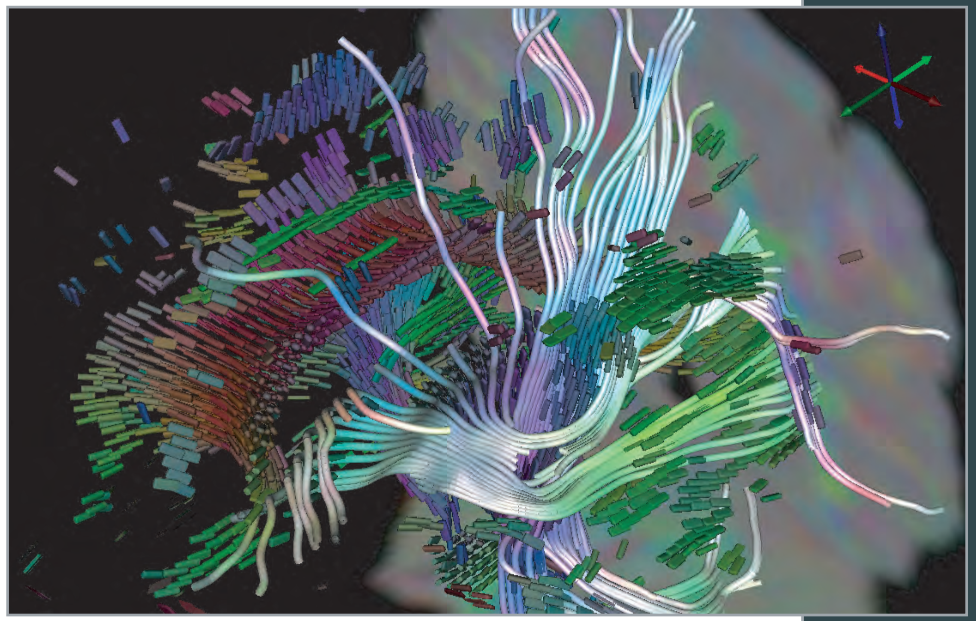
Unlike scalar and vector data, high-dimensional tensors are not always intuitive to visualize, due in part to the multivariate nature of individual tensor samples. Glyphs convey tensor variables by mapping the tensor eigenvectors and eigenvalues to the orientation and shape of a geometric primitive, such as a cuboid or ellipsoid. Though widespread, cuboids and ellipsoids have problems of asymmetry and visual ambiguity. Cuboids can display misleading orientation for tensors with underlying rotational symmetry. Ellipsoids differing in shape can be confused, from certain viewpoints, because of similarities in profile and shading. We are addressing the problems of asymmetry and ambiguity with a new tunable continuum of glyphs based on superquadric surfaces. Superquadric tensor glyphs enjoy the necessary symmetry properties of ellipsoids, while also imitating cuboids and cylinders to better convey shape and orientation, where appropriate. The new glyphs are demonstrated on fields of diffusion tensors from the human brain.

With diffusion tensor imaging (DTI), diffusion anisotropy effects can be fully extracted, characterized, and exploited, providing even more exquisite details on tissue microstructure. The most advanced application is certainly that of fiber tracking in the brain, which, in combination with functional MRI, might open a window on the important issue of connectivity. DTI has also been used to demonstrate subtle abnormalities in a variety of diseases (including stroke, multiple sclerosis, dyslexia, and schizophrenia) and is currently becoming part of many routine clinical protocols.



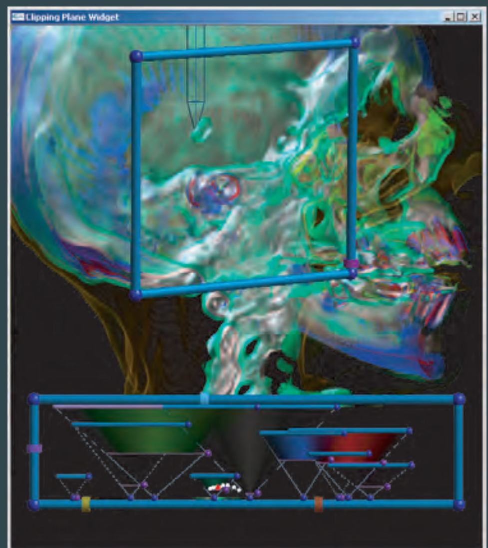
Top: Slice of DT-MRI dataset of brain visualized with ellipsoids (top) and superquadrics (bottom).

Bottom: 3-D region of DT-MRI dataset of brain visualized with ellipsoids (top) and superquadrics (bottom).



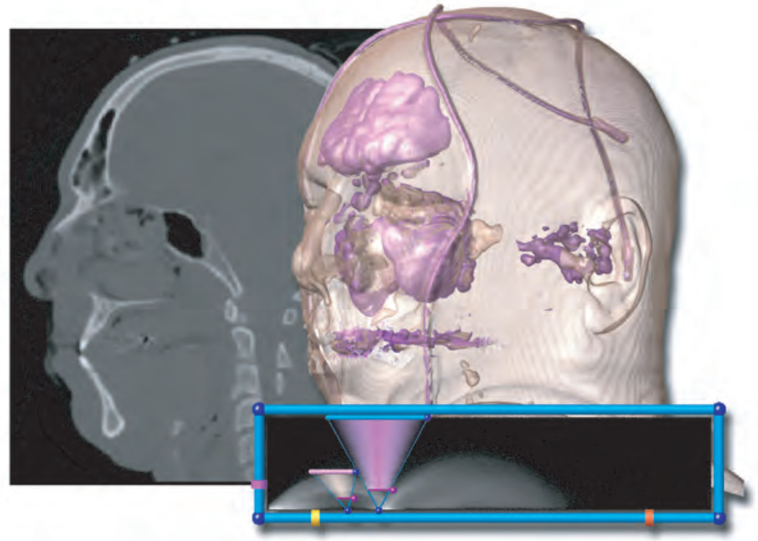
Tensorlines and superquadric glyphs
Some tensor-line fiber tracts and superquadric tensor glyphs used to depict some of the white matter structure in a DT-MRI scan. The tensorlines have been highlighted for emphasis. Determining the extent to which the the computed fiber tracts actually correspond to white matter pathways is a subject of ongoing work.

Volume Rendering With Multi-Dimensional Transfer Functions

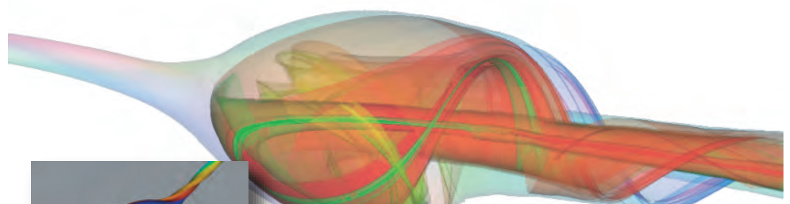


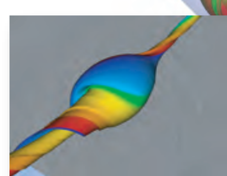
Interactive volume rendering is an important visualization technique. It allows scientists to quickly gain understanding of bio-medical, industrial, and simulation data. Interactivity provides a user with valuable feedback and a visualization experience that cannot be attained with a single image or movie. Recent advancements in commodity programmable graphics hardware allow not only interactive volume rendering, but image quality and shading options that rival sophisticated software based volume rendering techniques. Unfortunately, hardware memory limitations restrict the size of interactively renderable datasets. We have been developing a parallel pipelined approach for visualizing volumetric datasets which are orders of magnitude larger than those that can be interactively rendered on a single graphics card.

Most direct volume renderings produced today employ one-dimensional transfer functions, which assign color and opacity to the volume based solely on the single scalar quantity which comprises the dataset. Though they have not received widespread attention, multi-dimensional transfer functions are a very effective way to extract materials and their boundaries for both scalar and multivariate data. However, identifying good transfer functions is difficult enough in one dimension, let alone two or three dimensions. We have developed a set of direct manipulation widgets and new interaction modalities that make specifying a transfer function intuitive and convenient. We have also utilized modern graphics hardware to both interactively render with multi-dimensional transfer functions and to provide interactive shadows for volumes. The transfer functions, widgets, and hardware combine to form a powerful system for interactive volume exploration.

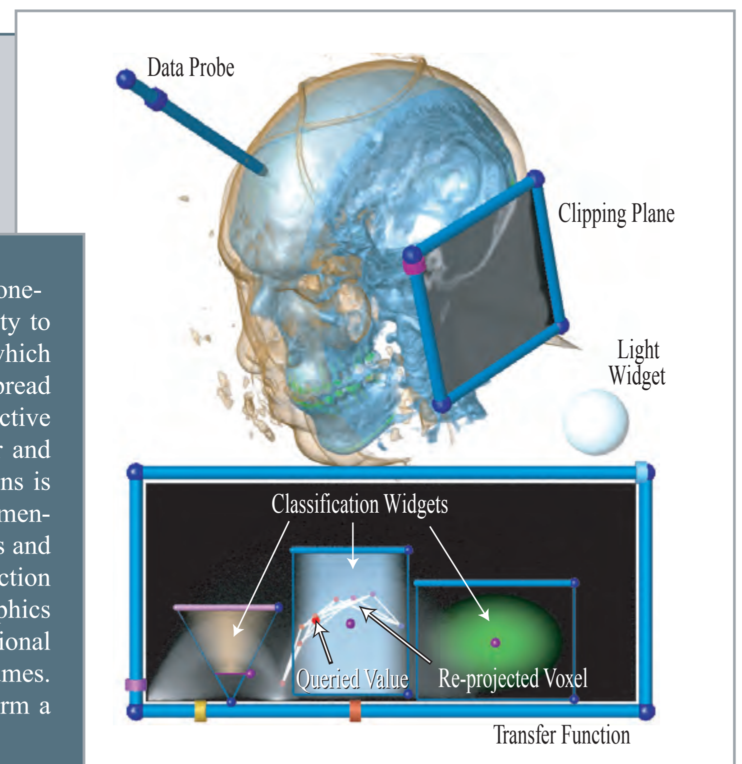


An example of X-ray Computer Tomography of the Visible Male. A 2D slice and the volume rendered image with sinus cavities highlighted.





Volume rendered visualization of vortex flow structures in aerodynamics applications.



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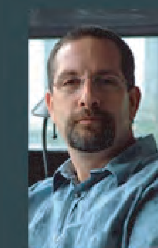

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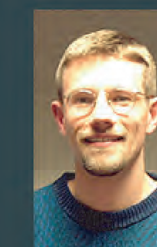

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