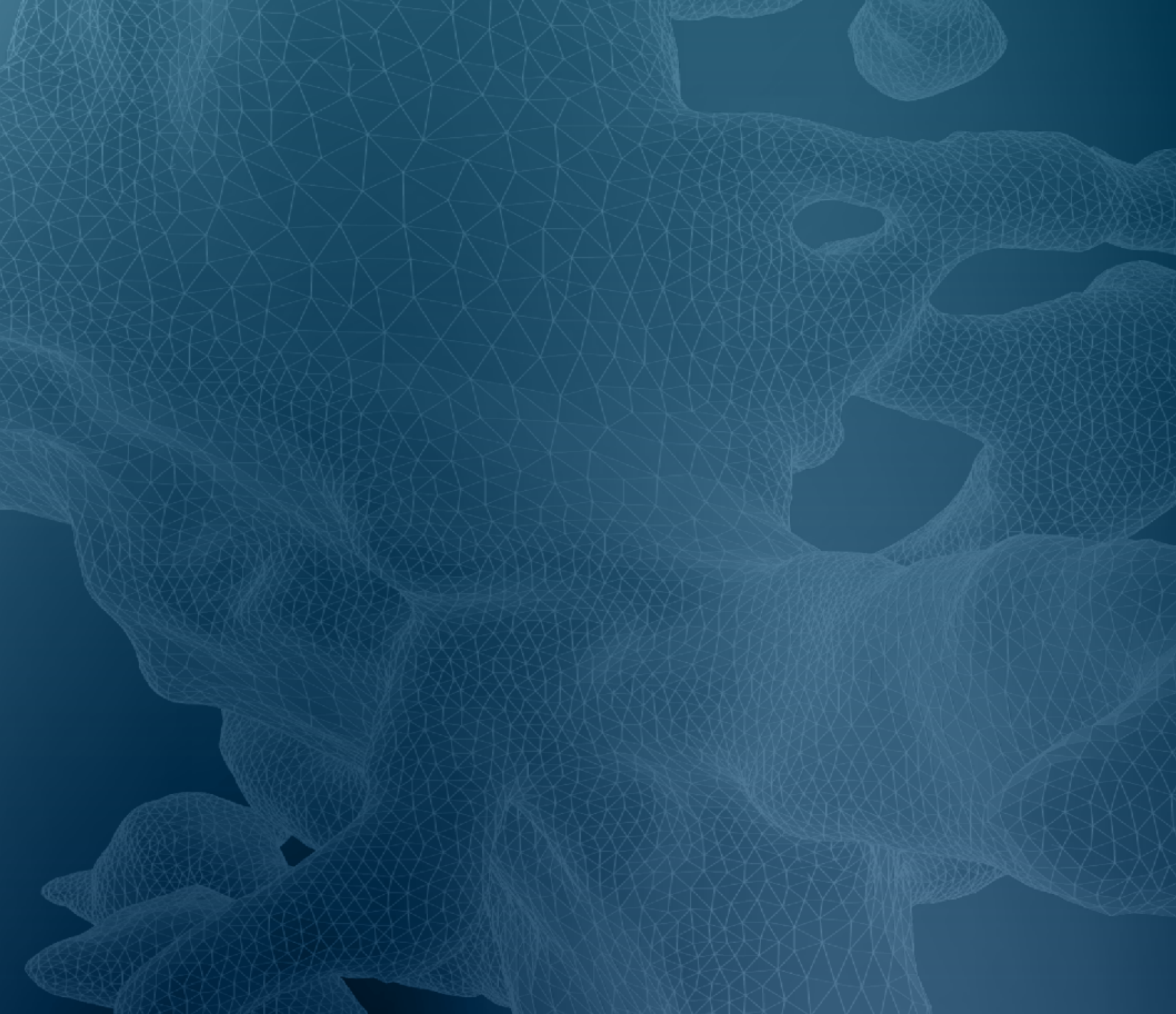
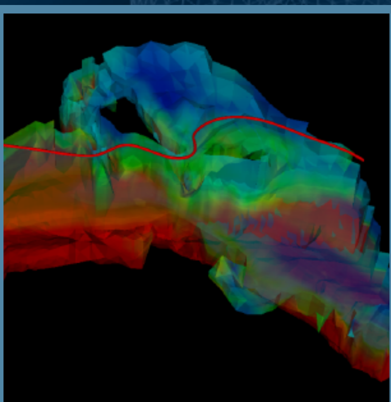
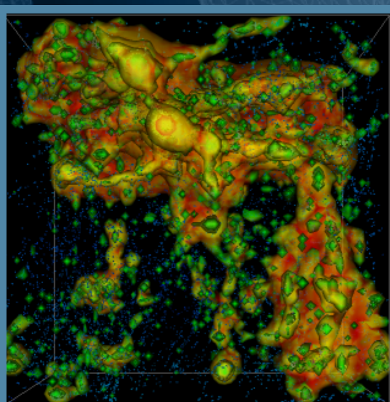
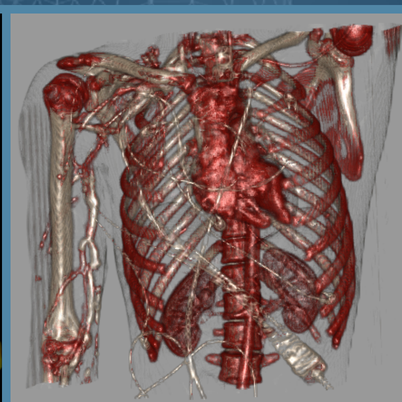
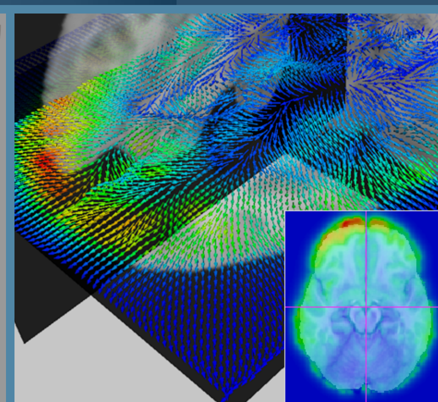


SCI INSTITUTE









Scientific Computing and Imaging Institute

OVER A DECADE OF CUTTING EDGE RESEARCH

Computing

Visualization

Image Analysis

Software Environments

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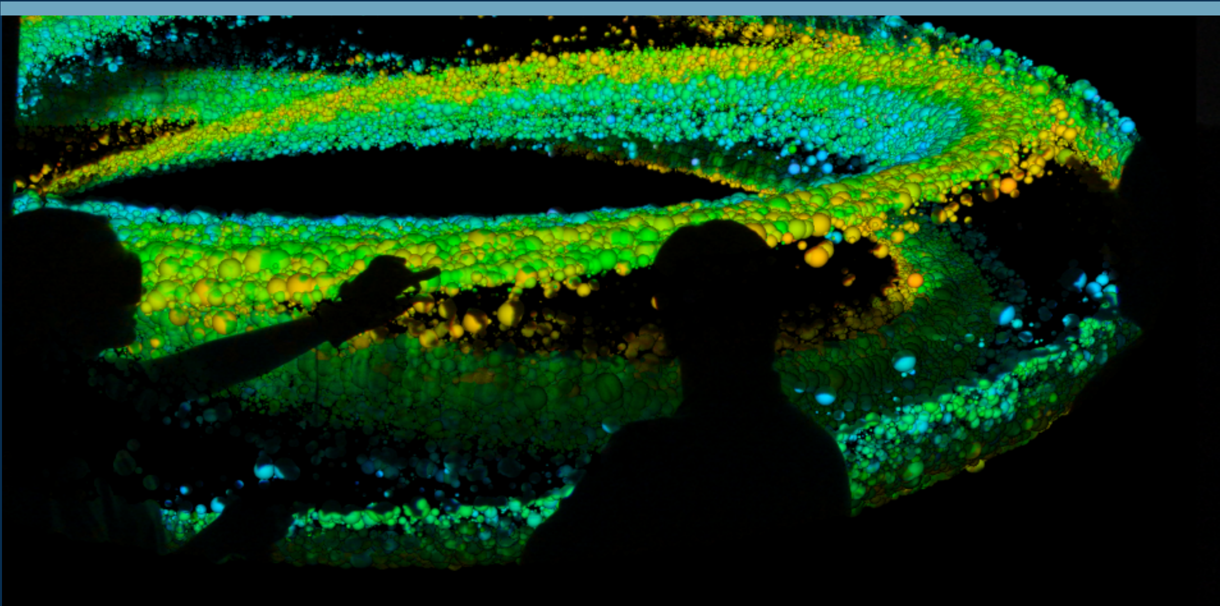
CONTENTS

If we want to reach critical mass, the only way is to work and collaborate with each other. And that is where we gather our strength.

- Mario R. Capecchi

Visualizing a series of atomic particles that are part of a 3D simulation of magnetically confined fusion energy. Such research is essential for the development of new energy sources (data courtesy Stephane Ethier of the Princeton Plasma Physics Laboratory).



THE UNIVERSITY OF UTAH

The campus of the University of Utah

THE SCIENTIFIC COMPUTING AND IMAGING INSTITUTE

The Scientific Computing and Imaging (SCI) Institute is a permanent research institute at the University of Utah. Directed by Professor Chris Johnson, the Institute now consists of over 100 faculty, students, and staff. The faculty, drawn primarily from the School of Computing and the Department of Bioengineering, is noted for its breadth of collaborations both nationally and internationally.

The SCI Institute has established itself as an internationally recognized leader in visualization, scientific computing, and image analysis. The overarching research objective is to create new scientific computing techniques, tools, and systems that enable solutions to problems affecting various aspects of human life. A core focus of the Institute has been biomedicine, but SCI Institute researchers also solve challenging computational and imaging problems in such disciplines as geophysics, combustion, molecular dynamics, fluid dynamics, and atmospheric dispersion.

SCI Institute research interests generally fall within four core tracks. The first track involves research into new techniques for scientific visualization and the development of visual analysis tools to facilitate understanding of increasingly complex and rich scientific data. The second focuses on technical research into computational and numerical methods requisite for scientific computing. The third track involves creating new image analysis techniques and tools. The final track emphasizes research and development of scientific software environments. SCI Institute researchers also apply many of the above computational techniques within their own particular specialties, including fluid dynamics, atmospheric dynamics, biomechanics, electrocardiography, bioelectric fields, adaptive techniques, parallel computing, inverse problems, and medical imaging.

The SCI Institute currently houses the NIH Center for Integrative Biomedical Computing (CIBC) and the Utah Center for Interactive Ray- Tracing and Photo Realistic Visualization. The Institute is also associated with several additional national research centers, including the DoE Center for the Simulation of Accidental Fires and Explosions (C-SAFE), the DoE Visualization and Analytics Center for Enabling Technologies (VACET), the DoE Scientific Data Management Center, the DoE Center for Technology for Advanced Scientific Component Software (TASCS), the NIH National Alliance for Medical Image Computing (NA-MIC), and the NIH Center for Computational Biology.

A particular aim and hallmark of SCI Institute research has been to develop innovative and robust software packages that are made broadly available to the scientific community under open source licensing, including the SCIRun scientific problem solving environment, BioPSE, BioImage, BioTensor, Seg3D and map3d.

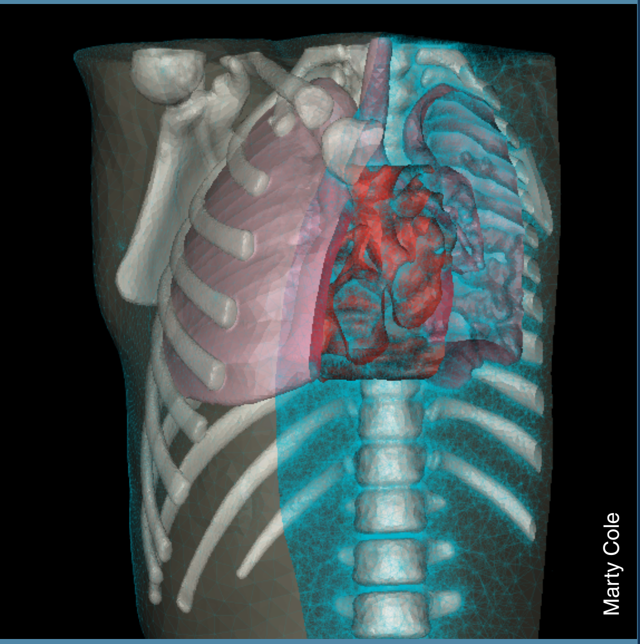
For more information about the SCI Institute:

www.sci.utah.edu

Scientific Computing

Numerical simulation of real-world phenomena provides fertile ground for building interdisciplinary relationships. The SCI Institute has a long tradition of building these relationships in a win-win fashion – a win for the theoretical and algorithmic development of numerical modeling and simulation techniques and a win for the discipline-specific science of interest. High-order and adaptive methods, uncertainty quantification, complexity analysis, and parallelization are just some of the topics being investigated by SCI faculty. These areas of computing are being applied to a wide variety of engineering applications ranging from fluid mechanics and solid mechanics to bioelectricity.

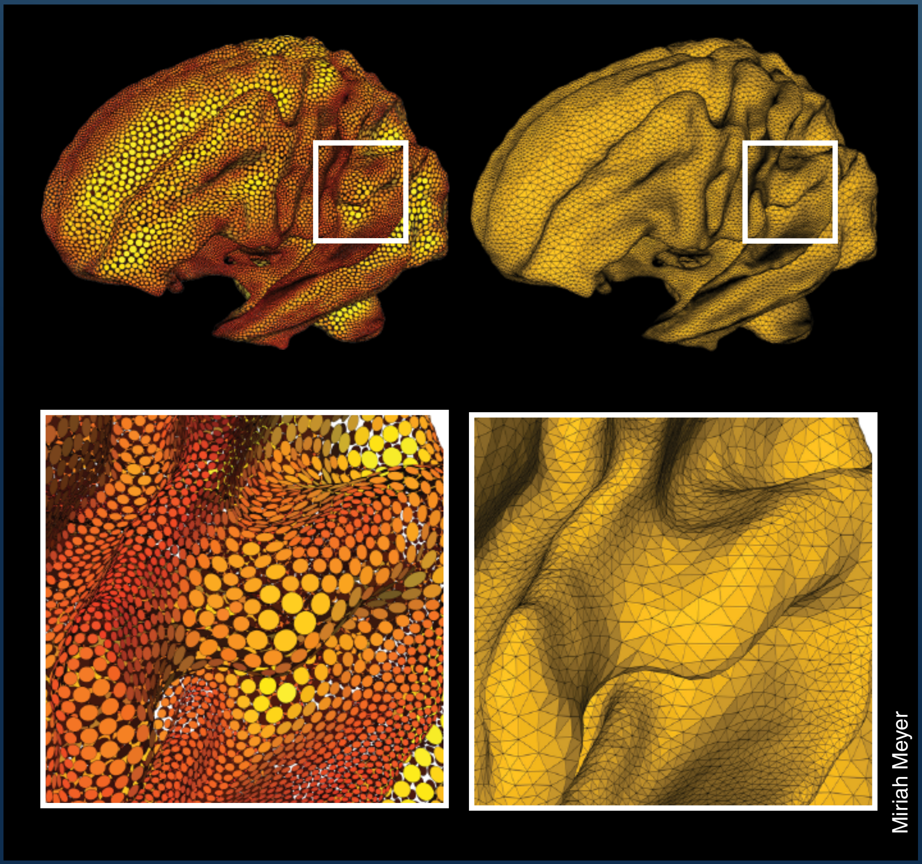
Building Better Meshes



Conformal, adaptive multimaterial meshes will allow efficient, high-quality simulations on patient specific models of cardiac defibrillation.

Dynamic Particle Systems for Adaptive Sampling of Implicit Surfaces

The generation of a set of point samples is a ubiquitous requirement in many mathematical and computational problems -- from shape statistics, to mesh generation, to visualization. Dynamic particle systems are an intuitive and controllable mechanism for producing very even distributions of points across complex implicit surfaces. Controlled by only a few constraints, these systems can robustly provide nearly-regular packings that smoothly adapt to surface features. The constraints cause particles to first stick to the zero-set of an implicit function, and then to move across the surface until particles are arranged in minimal energy configurations. Adaptivity is added into the system by scaling the distance between particles, causing higher densities of particles around surface features. The end result is an adaptive, yet very regular, set of surface points.

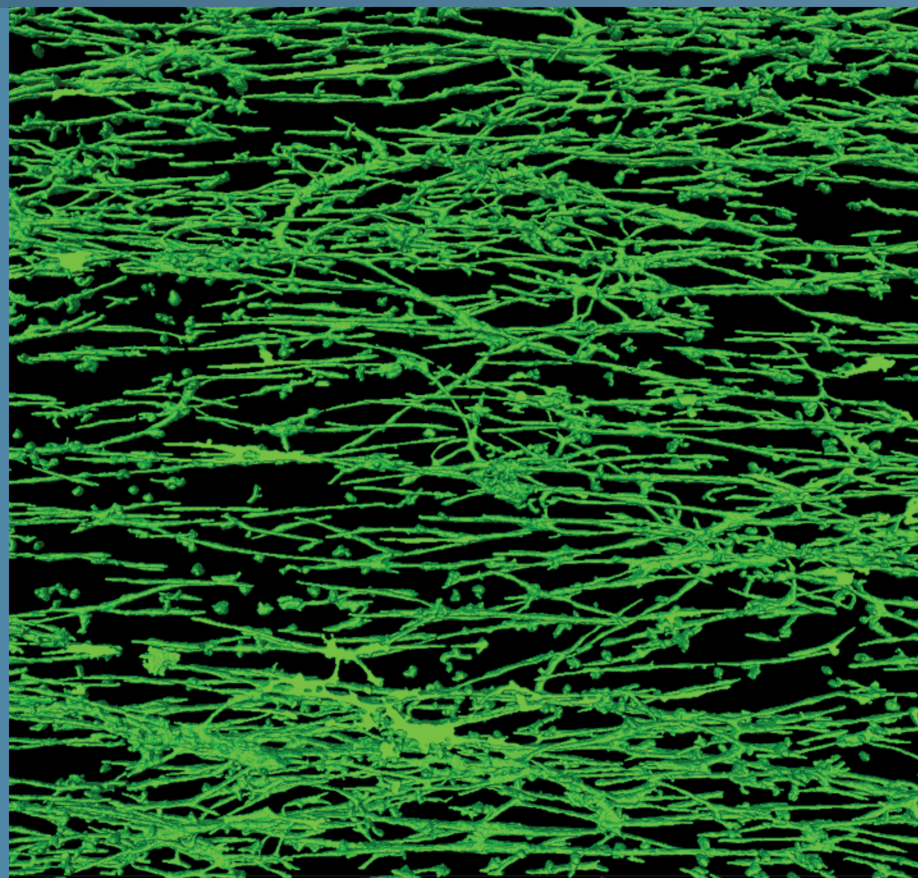


Particles on the brain and the resulting tessellation. The surface is a reconstruction of a white-matter segmentation.

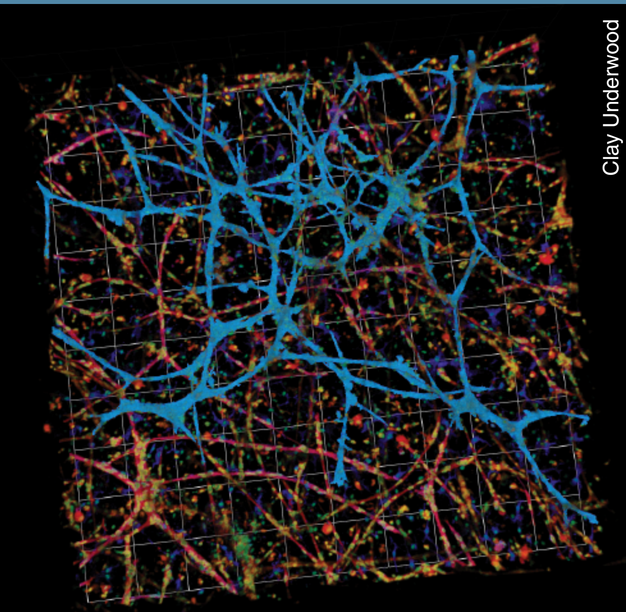
Computational Biomechanics

Biomechanics

The technical field of computational biomechanics involves the development and use of tools in computational mechanics for applications in biology and medicine. Our research focuses on the development of finite element and meshless methods to examine the mechanics of soft and hard tissues. We have created techniques to build subject- and patient-specific computational models of soft and hard tissues directly from biomedical image data such as CT, MRI and confocal microscopy. We have also formulated new constitutive models and numerical implementations that capture the nonlinear, anisotropic and viscoelastic properties of biological materials such as ligament, tendon, cartilage, meniscus and myocardium. Our last focus has been to capture the unique boundary conditions associated with biological systems such as residual stress and position-dependent anisotropy.



Clay Underwood



Clay Underwood

Volume rendering of confocal image data for angiogenesis showing the largest continuous structure (blue).

The Mechanics of Angiogenesis

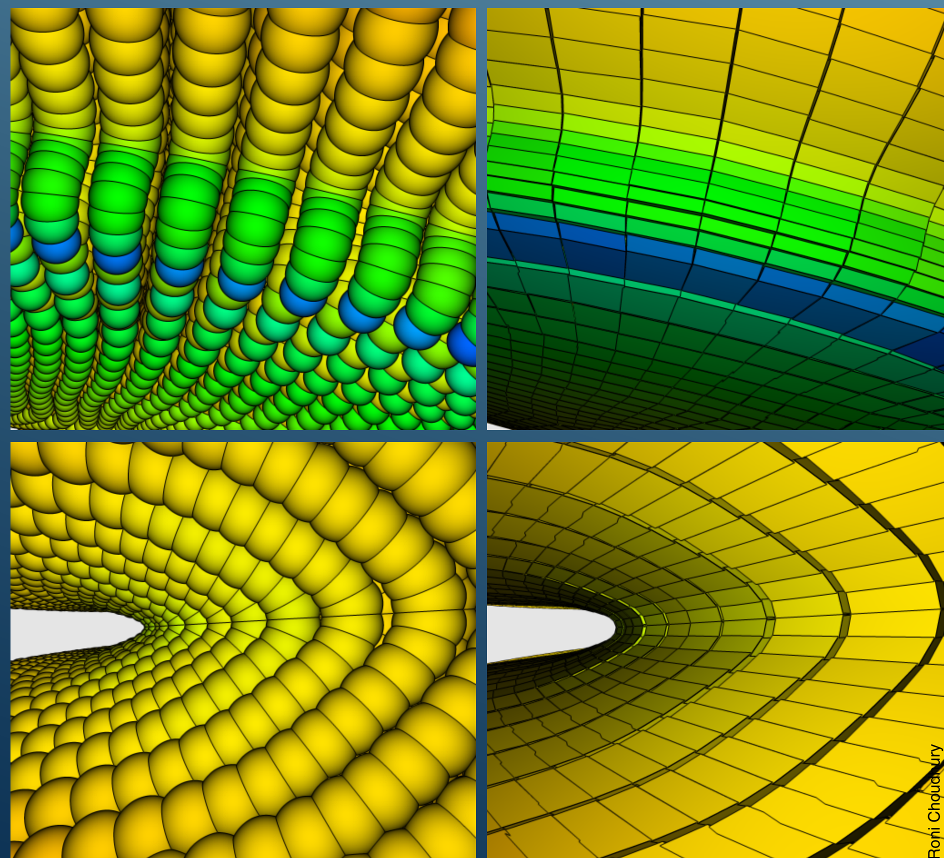
Angiogenesis, or the formation of new blood vessels, is a critical part of tissue growth and healing processes. It is well known that the endothelial cells that compose angiogenic microvessels are acutely sensitive to mechanical loading and boundary conditions, but the exact role of mechanics in angiogenesis is poorly understood. By elucidating the underlying mechanisms of this process, we hope to identify strategies for inducing, directing, and inhibiting the process of microvessel sprouting and elongation. Toward this end, we have developed computer models based on confocal image data with multiple fluorophores to elucidate the mechanisms behind angiogenic growth and interaction with the extracellular matrix.

Above: Z-projection of a 3D rendering of microvessels grown in our in vitro model. Endothelial cells within the microvessel cultures were stained with a fluorescent conjugate and three-dimensional image sets were obtained using Laser Scanning Confocal Microscopy. The growing microvessels have become aligned along the horizontal axis only due to the boundary conditions applied to the 3 dimensional collagen matrix in which they are grown. In this case, the matrix was anchored to fixed supports at each end of the horizontal axis. We are currently modeling how these microvessels are able to orient themselves under these conditions.

Visualization

Visualization

Scientific visualization, sometimes referred to as visual data analysis, uses the graphical representation of data as a means of gaining understanding and insight into the data. Scientific visualization research at SCI has focused on applications spanning computational fluid dynamics, medical imaging and analysis, and fire simulations. Research involves novel algorithm development to building tools and systems that assist in the comprehension of massive amounts of scientific data. Interactive forms of visualization are superior to static or prerecorded animations as they allow the user to control the nature and perspective of the views and thus provide better cues with which to explore complex relationships in the data. Thus, much of our visualization research focuses on creating efficient, responsive interactive displays.

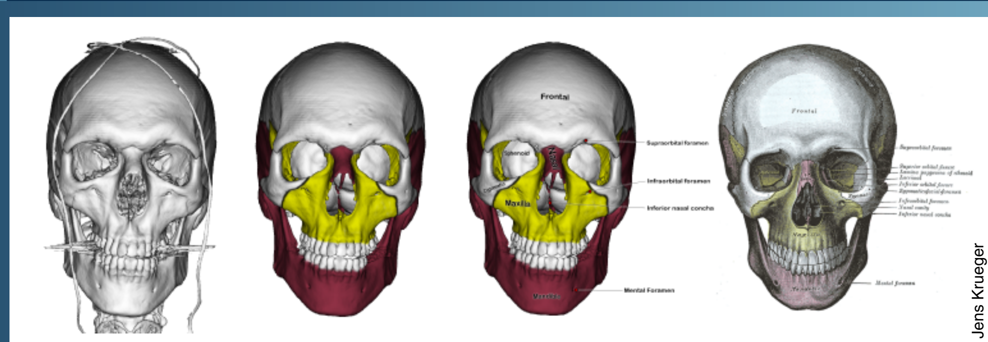


Visual Cues for Geometric Features

Top images: The spheres falsely imply that the corner of the cylinder lies along the green particles, while the hexahedra show that actually, the corner occurs in the blue particles, and the green particles show a slight bulge just above it. Bottom images: Hexahedra show the geometry of high curvature areas more clearly than spheres can through shading cues that suggest surfaces directly.

Three-Dimensional Annotation for Volume Rendering

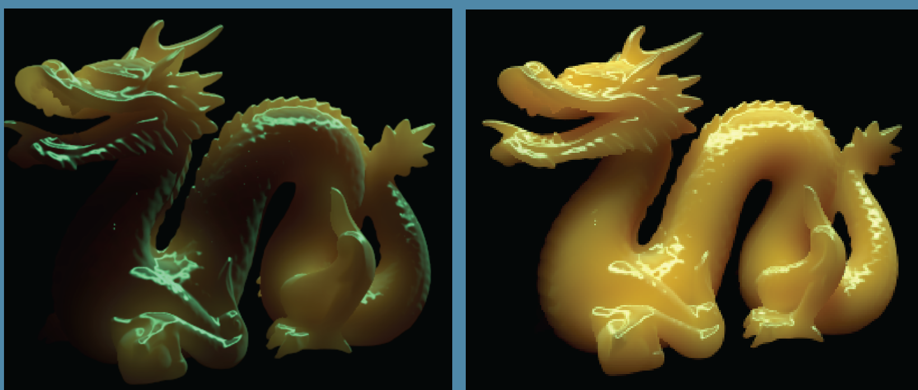
Volume rendering is a powerful means for visualizing high resolution 3D scalar fields, and if used in combination with transfer functions and different rendering styles, it allows for an effective visual communication of complex structures and relationships between them. To improve the analysis process it is often desired to not only render the data but also to interactively edit this data. One such example is the placement of annotations to give extra information about relevant structures.



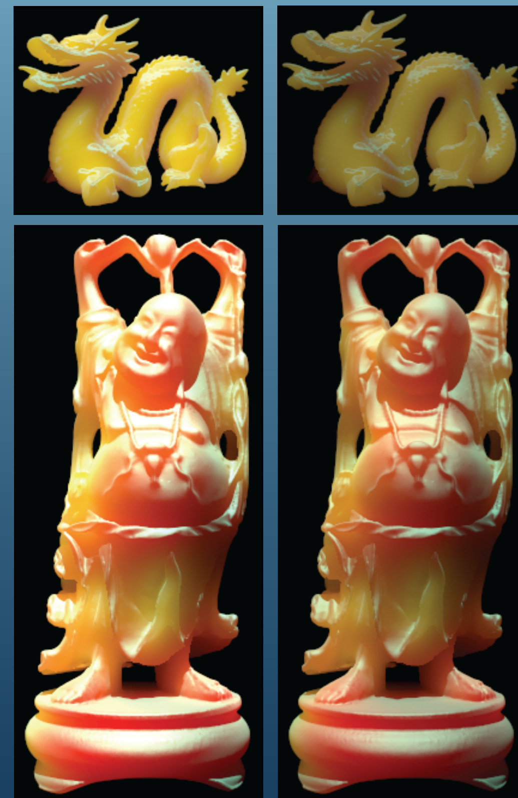
Images from volume editing session. From left to right: the head of visible human data set, unwanted structures and artifacts removed while surface color is applied, finally annotations are added. The rightmost image is taken from Gray's Anatomy for comparison.

Physical Models for the Polarized Scattering of Light

The change in polarization state due to the interaction of light with the surface and beneath the surface of an object has become increasingly important in realistic image synthesis of materials such as metallic, iridescent and pearlescent paint, skin, hair and cosmetics. This paper presents a model for the anisotropic scattering of polarized light based upon the physics of light; which is capable of calculating both partial and complete polarization using a combination of Jones and Mueller calculus, as well as incorporating self shadowing effects.



Left: A translucent dragon statue that is made of a type of nephrite jade simulated using the new theoretical reflectance models for surface and subsurface diffuse scattering. Right: Illustrates how smoothly polished a simulated nephrite jade dragon statue appears, which enhances the soft appearance of the statue and the visual realism of the image. This is due to a combination of reflectance properties from the surface scattering, the subsurface specular and subsurface diffuse scattering of light from the material.

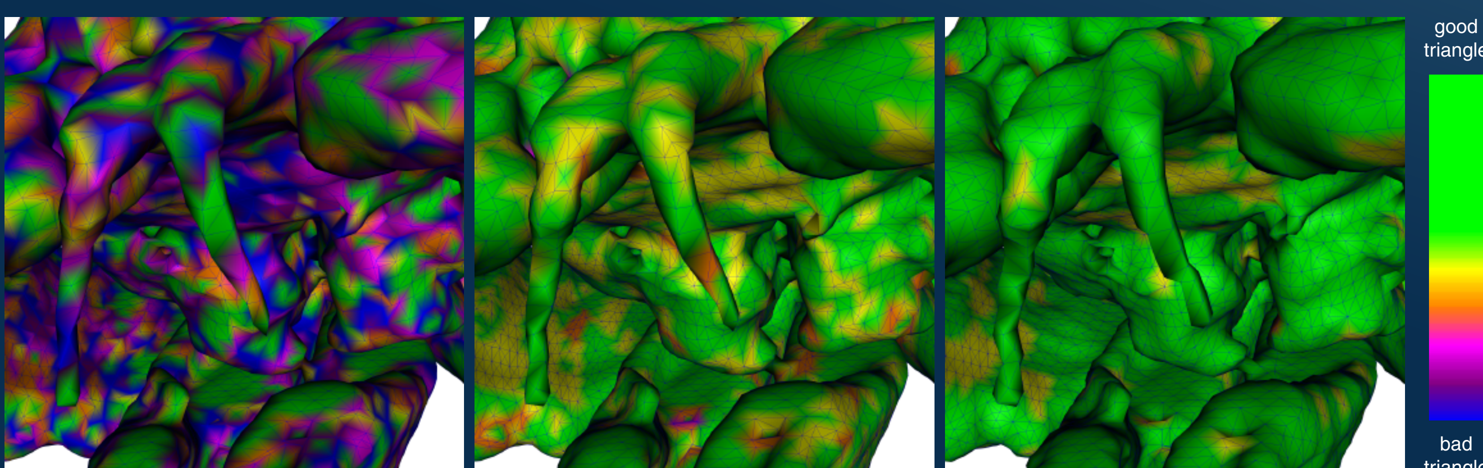


David Brayford

Dragon and Buddha statues. The Buddha is made of a multilayered material simulated using the new anisotropic theoretical reflectance model. The images in the left column were rendered without a polarized filter, while images in the right column were rendered with a polarizing filter.

Edge Groups: A New Approach to Understanding the Mesh Quality of Marching Methods

Marching Cubes (MC) is the most popular isosurface extraction algorithm due to its simplicity, efficiency and robustness and has been widely studied, improved, and extended. As part of study to improve MC results for applications in scientific computing, we have developed a new classification scheme called “Edge Groups”, which helps improve the quality of resulting surfaces. This formulation allows for a more systematic way to control the quality of triangles that make up the surface and is general enough to extend to other polyhedral cell shapes.

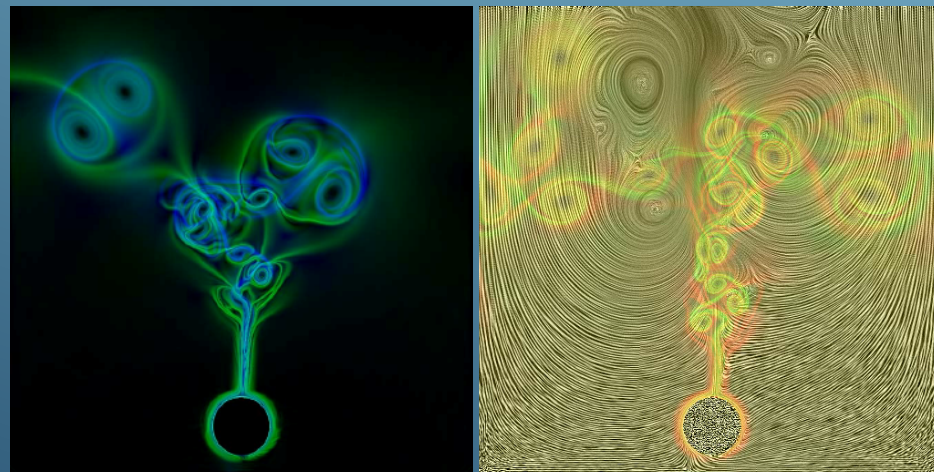


Carlos Scheideger

Comparisons on enlarged sections of a complex dataset. Left: MC using original table. Middle: Macet (an example of a triangle quality improvement technique that modifies the inner computation of MC) using original MC table. Right: Macet using displacements and the new MC table. Triangles are color-coded based on the radii-ratio quality.

Visualization of Coherent Structures in Transient 2D Flows

The depiction of a time-dependent flow in a way that effectively supports the structural analysis of its salient patterns is still a challenging problem for flow visualization research. While a variety of powerful approaches have been investigated for over a decade now, none of them so far has been able to yield representations that effectively combine good visual quality and a physical interpretation that is both intuitive and reliable. Yet, with the huge amount of flow data generated by numerical computations of growing size and complexity, scientists and engineers are faced with a daunting analysis task in which the ability to identify, extract, and display the most meaningful information contained in the data is becoming absolutely indispensable.



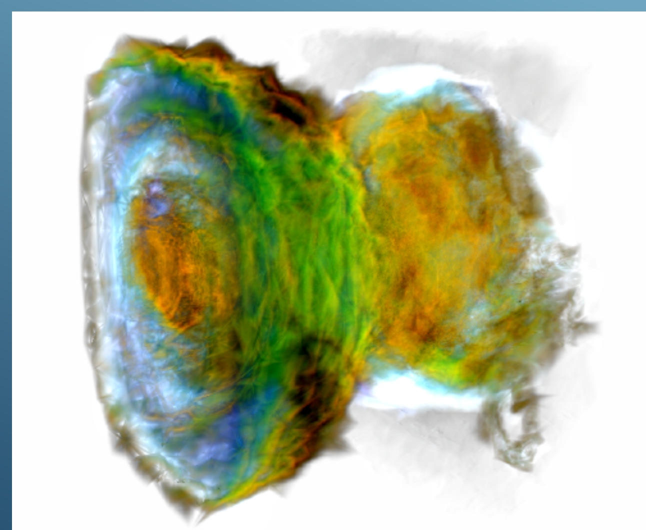
Guo Shi Li

Comparison: Direct FTLE visualization (left), and a combination of both FTLE and UFLIC (right).

Direct Volume Rendering

Creating insightful visualizations from both simulated and measured data is an important problem for the visualization community. For scalar volumes, direct volume rendering has proved to be a useful tool for data exploration. With the use of a transfer function, scalar values can be mapped to colors and opacities to identify and enhance important features. Though some automatic techniques have been developed for transfer function specification, the exploration process still involves tuning the parameters manually until the desired visualization is produced. A great deal of research has recently been performed to assist the user in this specification task with interactive widgets. These tools generally assist the user by allowing them to create and manipulate widgets over one or more dimensions of histogram information of the data.

The user interface for interactive transfer function specification is shown for the time-varying Turbulent Jet dataset using a 2D time histogram.



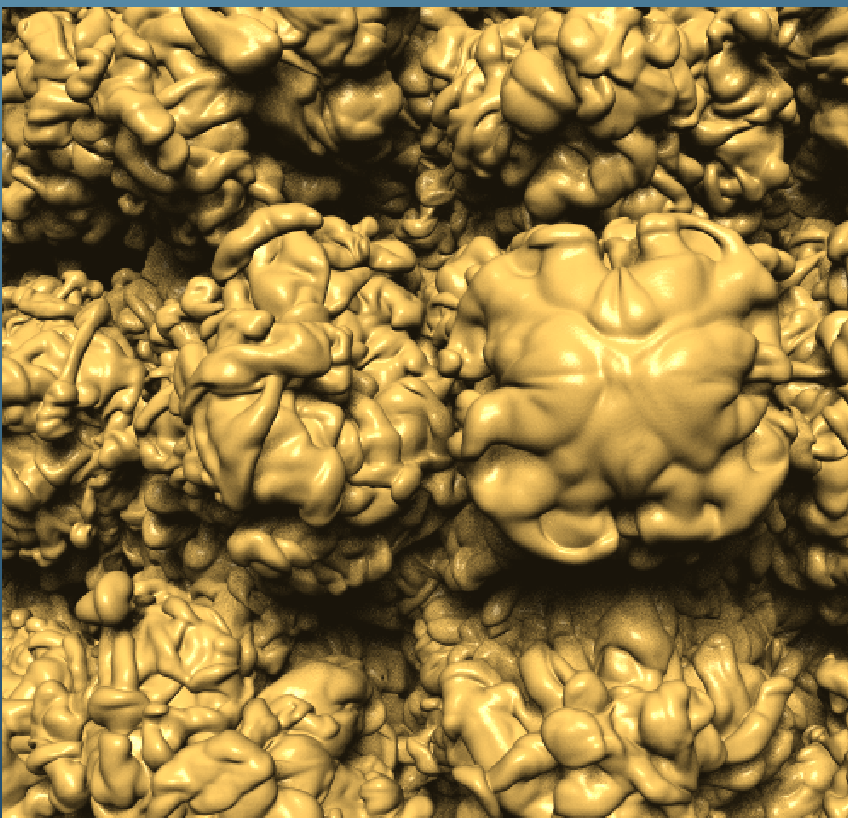
Erik Anderson

Steve Callahan

Direct volume rendering example showing several different transfer functions. The data set comes from a computed tomography (CT) scan of a chest.

Interactive Ray Tracing

Ray Tracing



Interactive ray tracing research (IRT) at SCI focuses on developing new algorithms and other optimizations for ray tracing complex scenes at multiple (15 or more) frames per second. Driven by applications in scientific visualization and traditional graphics, IRT uses only CPU resources to render datasets of hundreds of millions of polygons or tens of gigabytes of scientific data. Due to it's lower complexity, IRT can actually outperform even high-end GPUs for large datasets. One large user of IRT is the University of Utah's Center for Simulation of Accidental Fires and Explosions, which employs our tools to visualize complex datasets consisting of millions of particles representing an explosive device subjected to a fire. In addition to performance for large datasets, IRT enables use of more sophisticated shading techniques that enhance realism for graphics applications and help convey complex spatial information in scientific datasets.

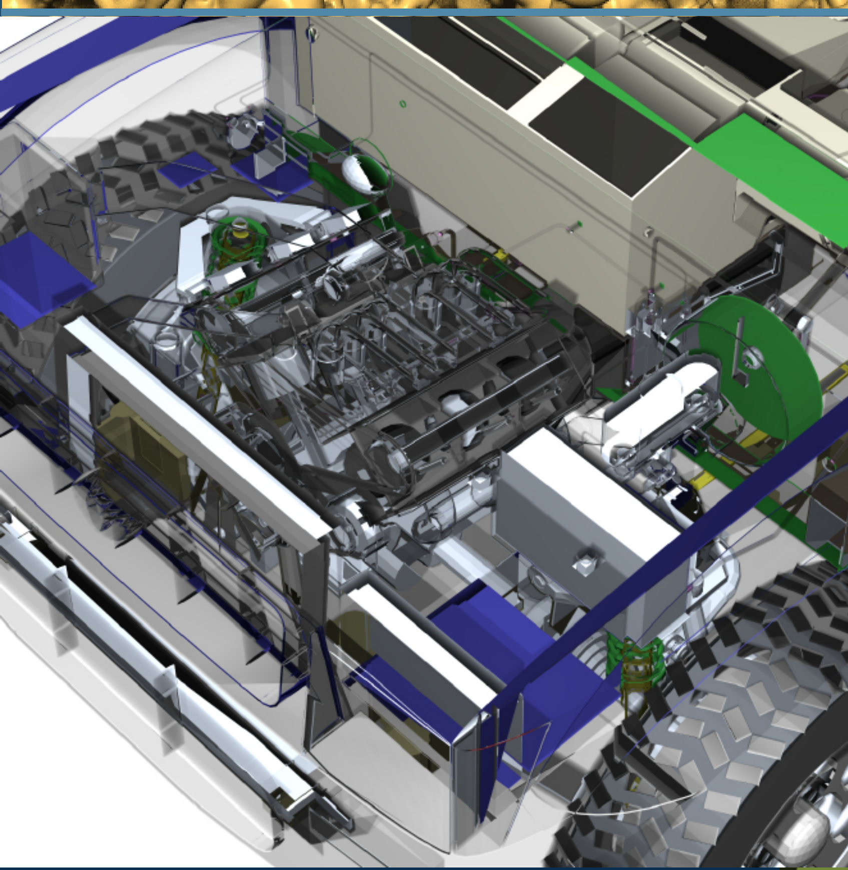
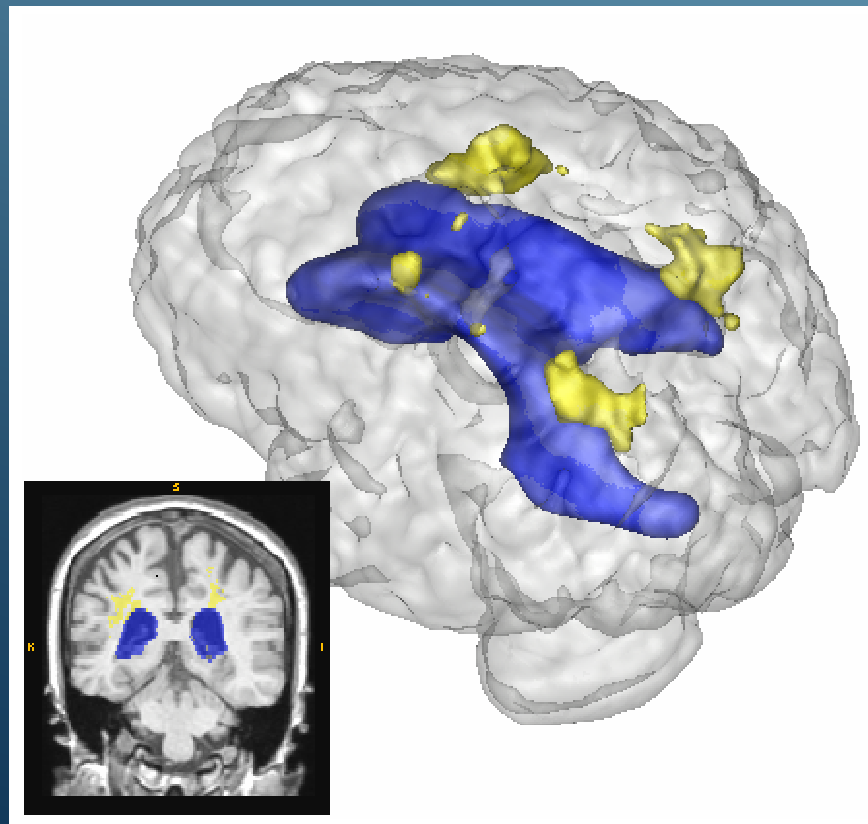


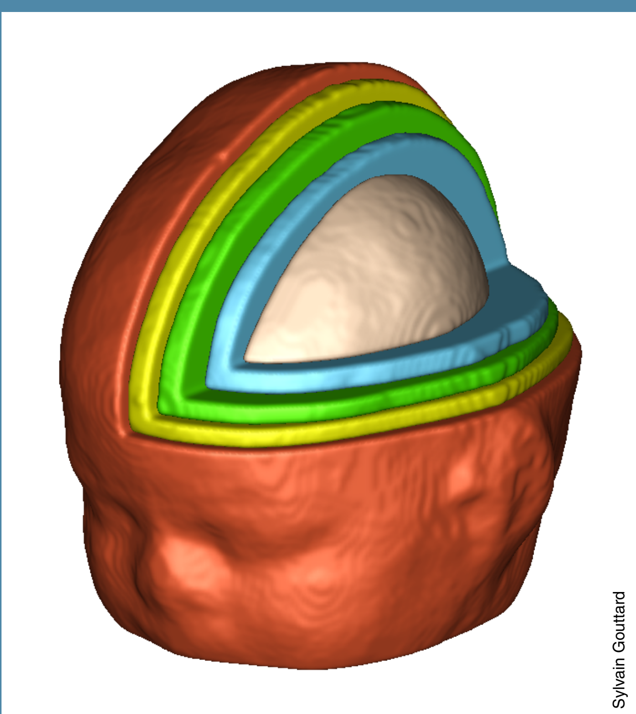
Image Analysis

SCI's imaging work addresses fundamental questions in 2D and 3D image processing, including filtering, segmentation, surface reconstruction, and shape analysis. In low-level image processing, this effort has produced new methods for modeling image statistics, which have resulted in better algorithms for denoising and reconstruction. Work with particle systems has led to new methods for visualizing and analyzing 3D surfaces. Our work in image processing also includes applications of advanced computing to 3D images, which has resulted in new parallel algorithms and real-time implementations on graphics processing units (GPUs). Application areas include medical image analysis, biological image processing, defense, environmental monitoring, and oil and gas.

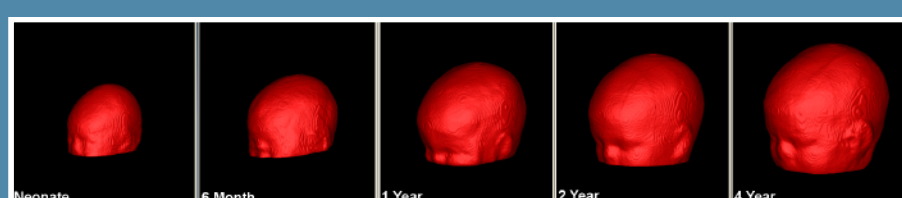


Marcel Prastawa

Quantification, analysis and display of brain pathology such as white matter lesions as observed in MRI is important for diagnosis, monitoring of disease progression, improved understanding of pathological processes and for developing new therapies. The Utah Neuroimage Analysis Group develops new methodology for extraction of brain lesions from volumetric MRI scans and for characterization of lesion patterns over time. The images show white matter lesions (yellow) displayed with ventricles (blue) and transparent brain surface in a patient with an autoimmune disease (lupus). Lesions in white matter and possible correlations with cognitive deficits are also studied in patients with multiple sclerosis (MS), chronic depression, Alzheimer's disease (AD) and in older persons.



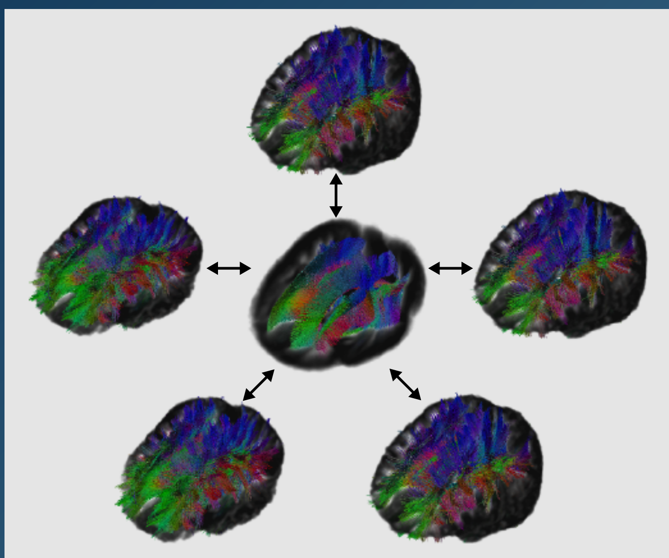
Sylvain Gouttard



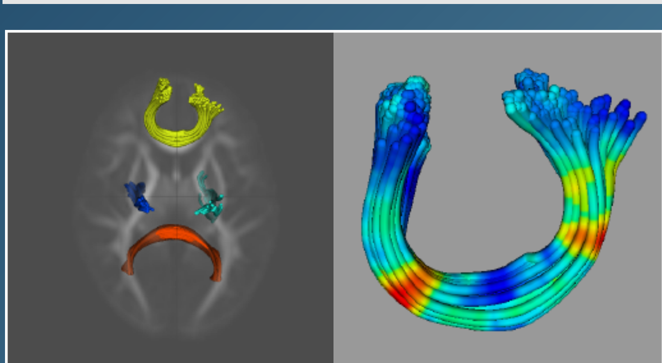
Sylvain Gouttard

Improved MRI methodology for infant imaging: We study head/brain growth and create statistical models of neonates, 6mo, 1yr, 2yr and 4yr. Based on these models, the MGH group creates new parallel coils for the scanner. We then get these parallel images and combine them back with new signal processing.

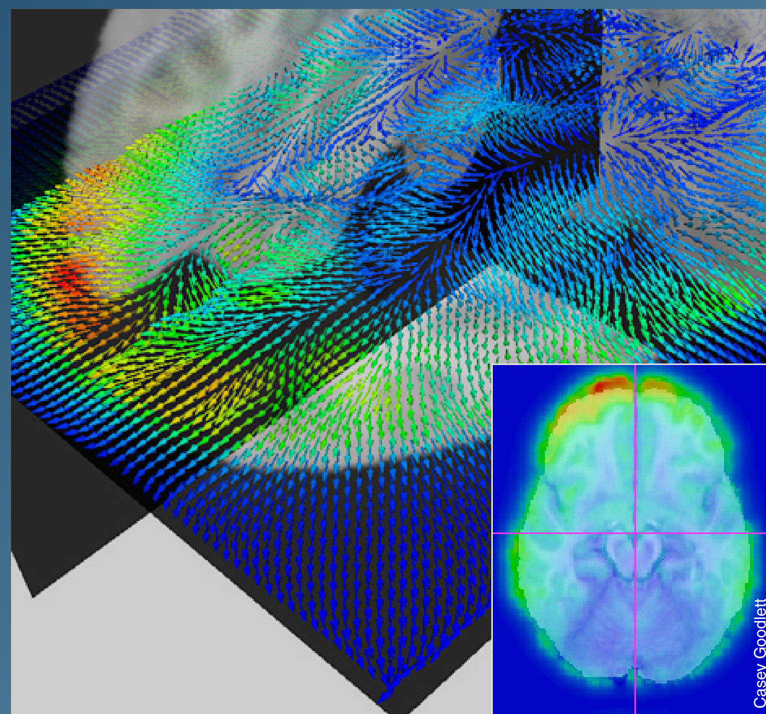
Diffusion tensor magnetic resonance imaging (DT-MRI) is relatively new imaging technique which provides new insight into the structure of brain white matter by measuring the local diffusion of water in the brain. In this project associated with the national alliance for medical image computing (NAMIC) images are combined from a population, as shown in figure 1, into a template atlas which reflects the average properties of the population. White matter bundles are extracted from in the template atlas to serve as a coordinate system for measuring diffusion properties and how they differ between populations. In a study of neurodevelopment in association with the CONTE center at University of North Carolina - Chapel Hill, an atlas was developed based one subjects at one and two years of age. Figure 2 shows fiber bundles extracted from this template atlas. Statistical comparison of the diffusion properties between one and two year olds indicates significant changes the may reflect underlying changes in myelination and axon development. Figure 3 shows differences in the fractional anisotropy (FA), a measure of diffusion tensors which is thought to reflect axon development, from one to two years. The red regions indicate the largest increase of the FA value.



Casey Goodlett

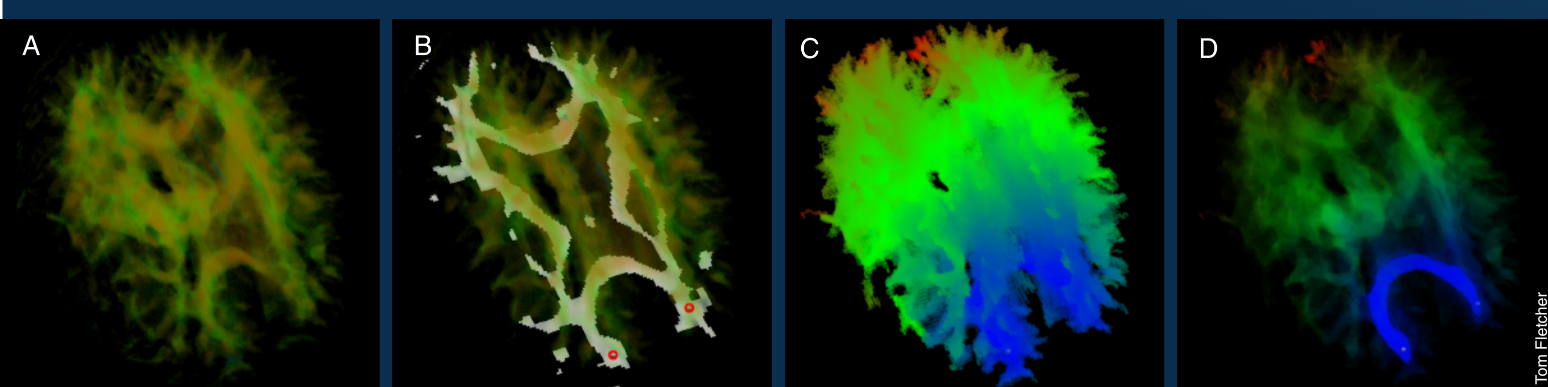


Casey Goodlett



Longitudinal growth of a population of infant brains from two to four years of age. Red and green mark regions of largest growth. Studying the early developing brain is of utmost interest for a better understanding of the variability of normal growth and of changes of growth trajectories in children at risk for mental illness.

The goal of this form of visualization is to identify the voxels in the diffusion tensor MRI volume that trace out paths linking two regions of the brain based on an optimization algorithm. The resulting paths may show the paths of functional communications between different parts of the brain.



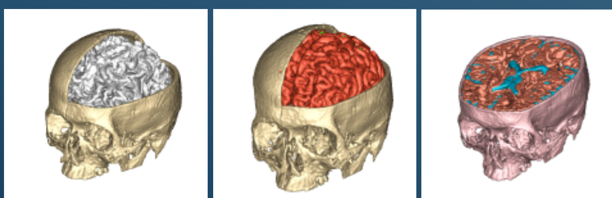
Tom Fletcher

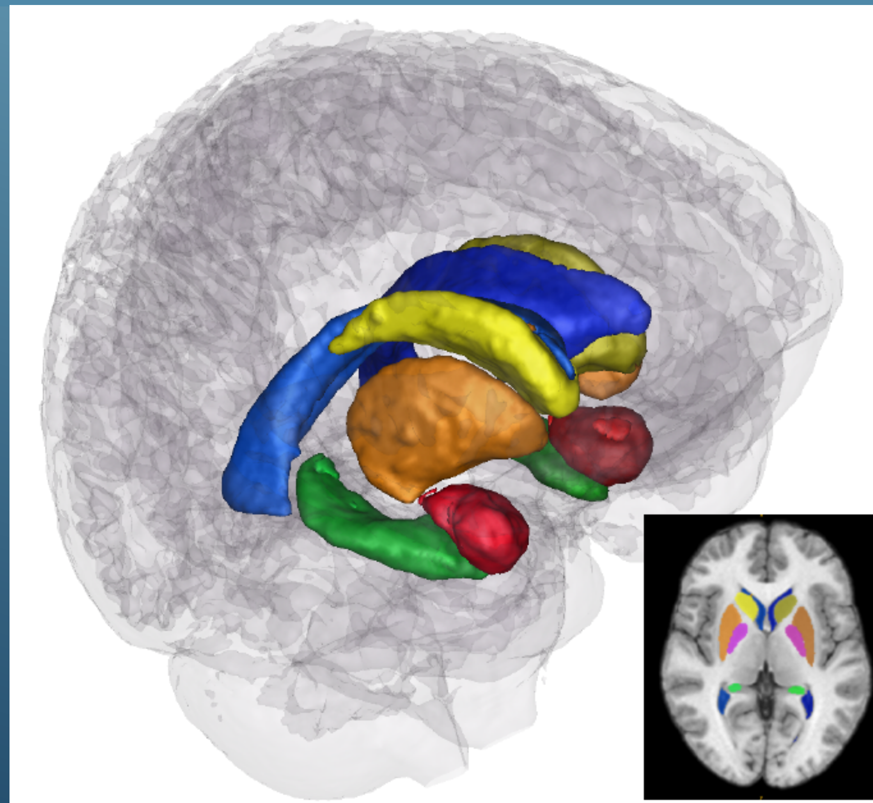
A) Input DT-MRI volume; B) Seed points (marked as red circles); C) Cost volume (blue to red : low to high); D) Volumetric path along genu (blue).

Extracting Anatomical Structures

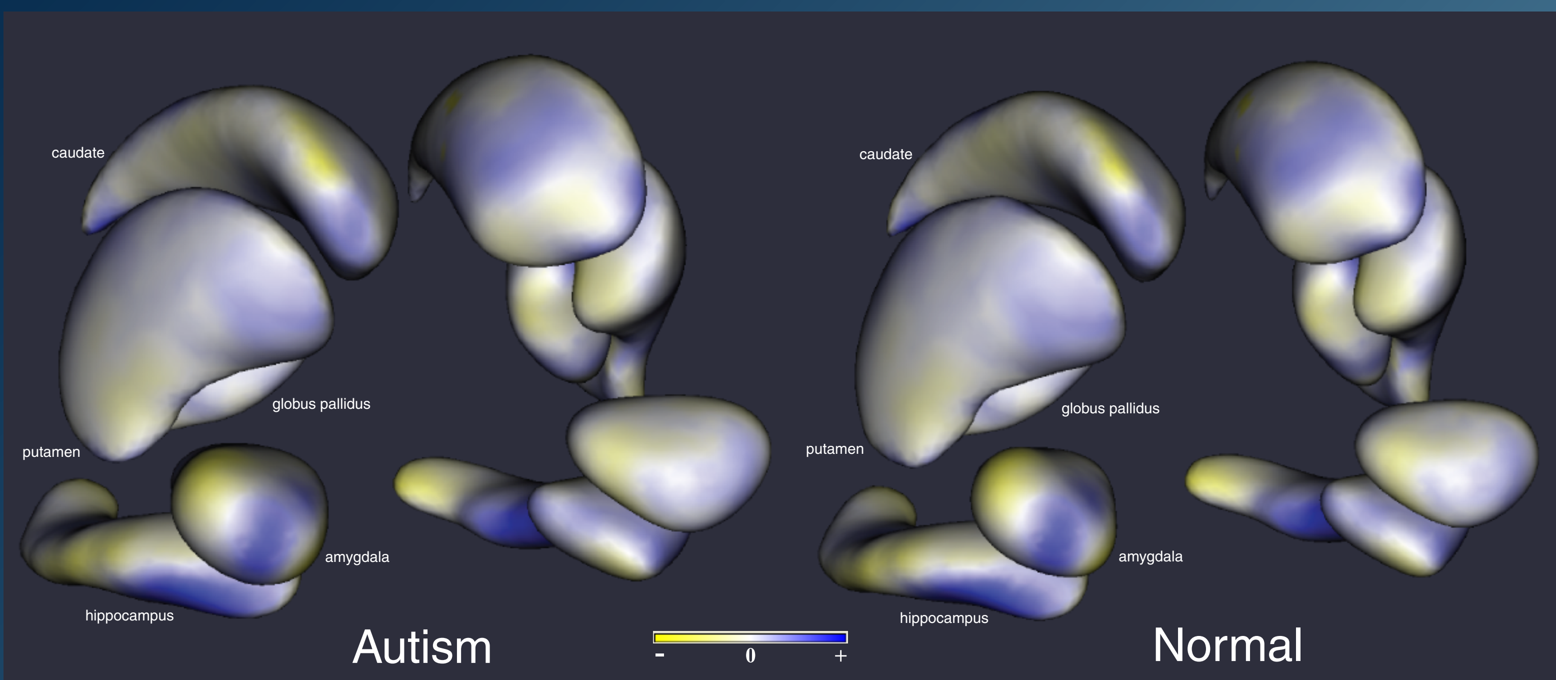
The ability to create accurately segmented three dimensional models from imaging devices such as MRI, PET, CT, and others is crucial to the understanding of structural development.

The right image shows the result of automatic extraction of anatomical structures from a patient MRI using software developed by the Utah Center for Neuroimage Analysis. Measurements of subcortical brain structures are of specific interest in studying structure-to-function relationship. Research in autism, schizophrenia and Alzheimer's disease is particularly interested in volumes and shape of hippocampus (green), amygdala (red) and caudate (yellow). Below shows the segmentation of skull, white and gray matter.





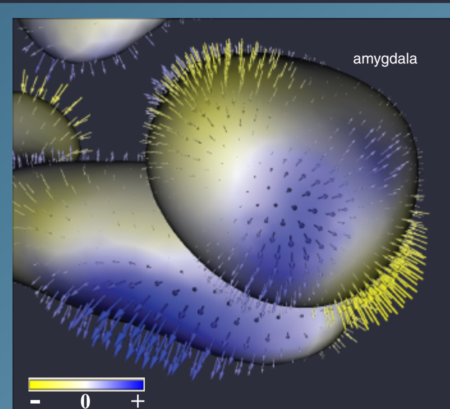
Sylvain Gouttard



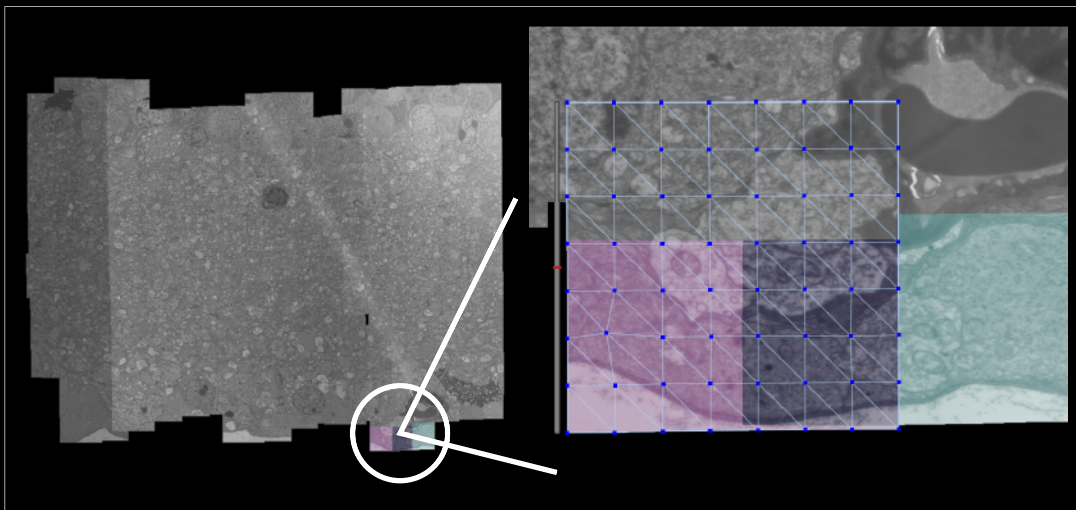
Josh Cates

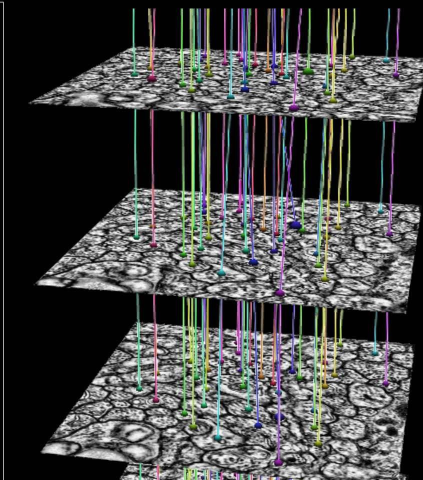
Shape Analysis of Neuroanatomical Structures

We have developed a new method for constructing statistical representations of ensembles of similar shapes that uses particle systems to represent surfaces non parametrically and optimally sample surface point correspondences. We used this method to generate models for two clinical datasets: normal vs. Autistic neurological development. Hypothesis testing on these models using a non parametric permutation test of the Hotelling T-squared metric (including false-discovery-rate (FDR) correction) reveals significant group differences. Colormap indicates the magnitude and direction of the linear discriminant.



Axon Tracking in Serial Block-Face Scanning Electron Microscopy





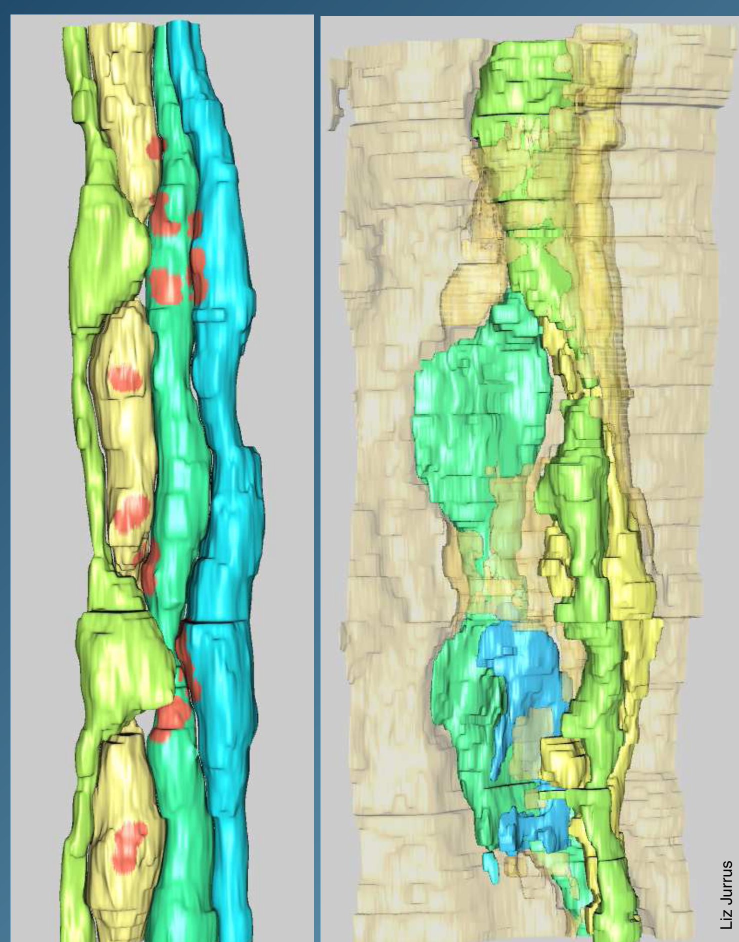
Tolga Tasdizen, Ross Whitaker, Robert Marc, Chi-Bin Chien, Bryan Jones, Liz Jurrus, Pavel Koshevoy, Samuel Gerber, Melissa Hardy, Winfred Denk

We address the problem of building three-dimensional connectivity maps for neurons from sectional electron microscopy. Sectional data consists of a stack of very high-resolution, two-dimensional images that are oriented to capture cross sections of elongated neuronal processes. High magnification serial microscopy images have the potential to expand the field of neurophysiological modeling by providing ground-truth neuroanatomical data. However, their complexity and vast size make them impractical for human interpretation. This project aims at building automatic and semi-automatic tools to assist researchers in analyzing such data.

Semi-Automated Reconstruction of the Neuromuscular Junctions in the C. elegans

For a nervous system to function, it must be wired properly. Specifically, neurons need to find their targets and form synapses. The neuron maintains such connections for years, accommodating growth of the organism and making allowance for other neurons that synapse to access the same target. Fulfilling these functions make topological demands on neurons and their targets. To study this process we are reconstructing the neuromuscular junctions in the nematode C. elegans.

To determine the topology of this complex synaptic region we have reconstructed a segment of the ventral nerve cord from serial electron micrographs. The data are registered and assembled automatically and then reconstruction of individual neurons is performed using a modified path finding approach.



(a) 3D renderings of the four neurons competing for information from the muscles. The location of the synapses, which were extracted from user specified locations, are shown in red on the neurons. (b) Similar rendering of the muscles that run alongside the motor neurons.

Scientific Software Environments

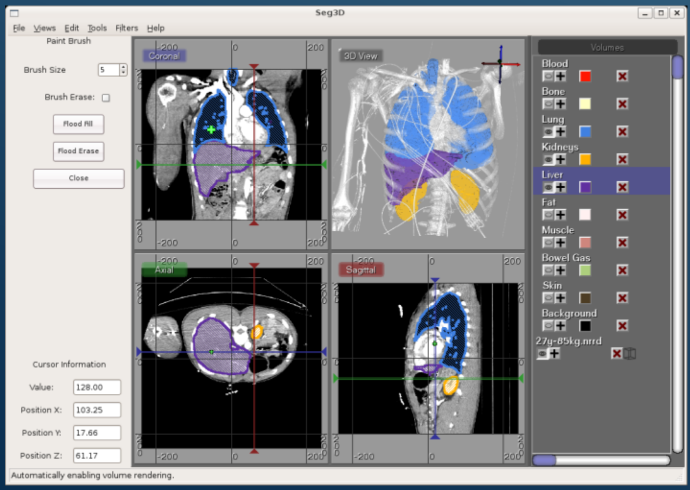
SCIENTIFIC SOFTWARE ENVIRONMENTS

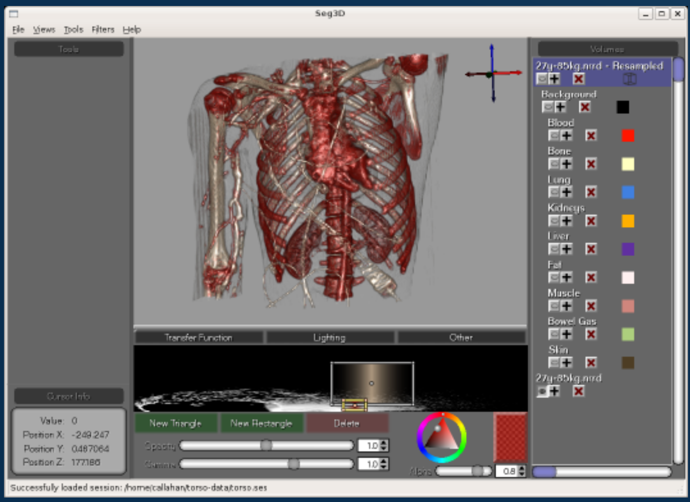
Software at the SCI Institute is developed in close collaboration with application users to satisfy real needs within their research communities. We use a robust, yet agile software process that is fully open-source to produce software environments that integrate leading-edge algorithms in image processing, scientific visualization, and scientific computing. Software products include the SCIRun scientific software problem solving environment for geometric modeling, simulation, and visualization; BioPSE for biomedical computing and visualization; Uintah, designed for combustion, computational fluid dynamics, and mechanical modeling which is implemented on large-scale and distributed with shared memory architectures, map3d, an application to display and edit complex, three-dimensional surface models and associated scalar, time-dependent data; and VisTrails, providing data and process management support for exploratory computational tasks. Recently, the SCI Institute has been developing powerful, stand-alone applications. These software applications include ImageVis3d (formerly BioImage), a high performance volume rendering tool for image and other scalar volume data, BioTensor, a program that processes and visualizes diffusion tensor images, Seg3d, for volume segmentation and image processing, BioMesh3D, for creating tetrahedral and hexahedral meshes; and FusionViewer, for visualizing 3D scalar and vector magnetic fusion data

Seg 3D

Seg3D is a free volume segmentation and processing tool developed by the NIH Center for Integrative Biomedical Computing at the University of Utah Scientific Computing and Imaging (SCI) Institute. Seg3D combines a flexible manual segmentation interface with powerful higher-dimensional image processing and segmentation algorithms from the Insight Toolkit. Users can explore and label image volumes using volume rendering and orthogonal slice view windows.

- Fully 3D interface with multiple volumes managed as layers
- Automatic segmentation integrated with manual contouring
- Volume rendering with 2D transfer function manipulation in real-time
- Image processing and segmentation from the Insight Toolkit (ITK)
- Real time display of ITK filtering output allows for computational steering
- 64-bit enabled for handling large volumes on large memory machines
- Supports many common biomedical image formats
- Open source with BSD-style license
- Cross platform: Windows, OSX, and Linux





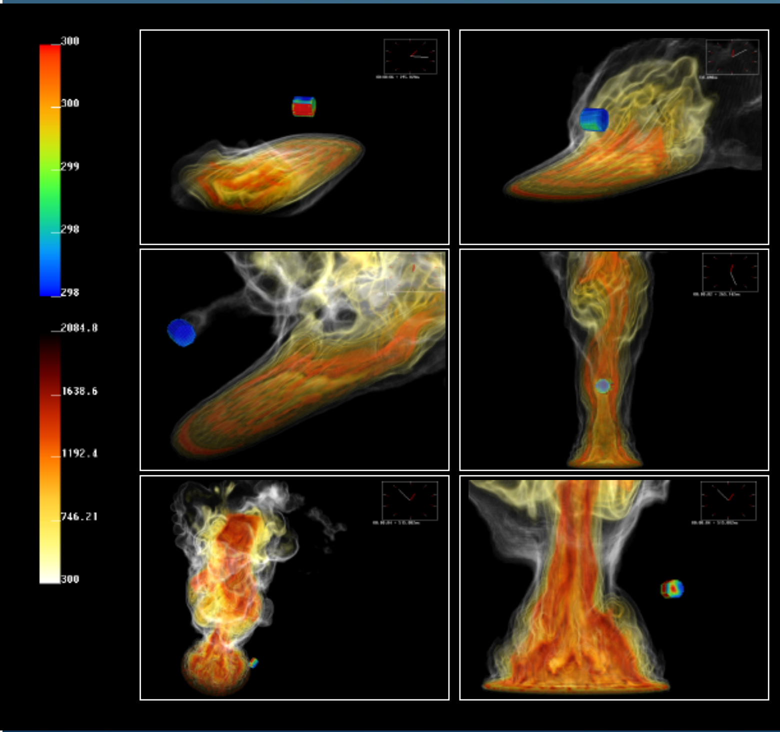
Software available for download

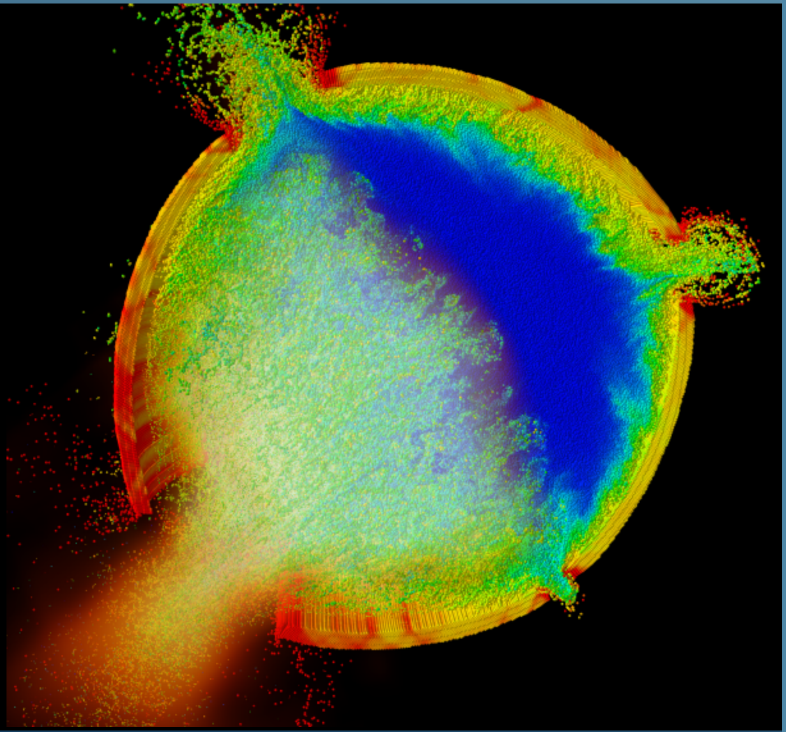
SCIRun/BioPSE (NIH)	FEBio (NIH)
ImageVis3d (NIH)	PreView (NIH)
Seg3d (NIH)	Postview (NIH)
BioTensor (NIH)	WinFiber3D (NIH)
BioFEM (NIH)	GAGSim3D (NIH)
map3d (NIH)	WarpLAB (NIH)
FusionViewer (DOE)	
VisTrails (NSF)	

http://software.sci.utah.edu

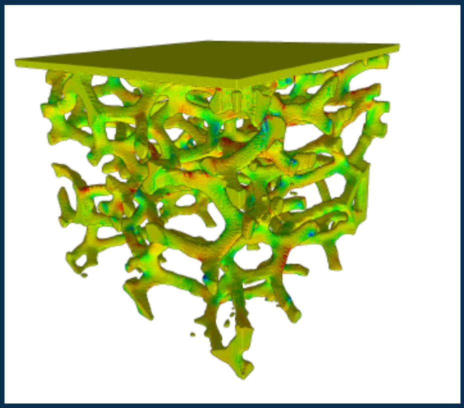
Uintah Computational Framework

A major success in our computing efforts has been the Uintah Computational Framework (UCF). The UCF is a component based software system with capabilities such as semi-automatic parallelism, automatic checkpoint/restart, load-balancing mechanisms, resource management, and scheduling. The UCF exposes flexibility in dynamic application structure by adopting an execution model based on software or "macro" dataflow. Computations are expressed as directed acyclic graphs of tasks, each of which consumes some input and produces some output (input of some future task). These inputs and outputs are specified for each patch in a structured grid. Tasks are organized in a UCF data structure called the task graph and assigned to processing resources by the scheduler. Load balancing is done by using a fast space filling curve algorithm.



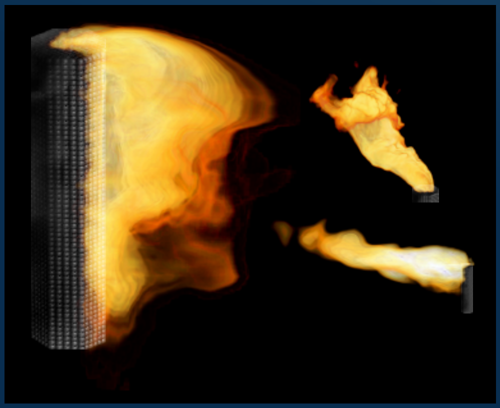


C-SAFE has under taken a sensitivity analysis of our fire/container simulations to study the effect of variations in a number of variables. These variables include 1) pool fire diameter (0.5 and 1.0m fires), 2) wind speed (0 and 4 m/s), 3) container position relative to the fire (in or next to the fire), and 4) fuel evaporation rate (1.6 and 6.4 mm/min). Below are visualizations of several of these simulations. During the first part of the simulation, the average heat flux from the fire to the container is calculated. This heat flux is then used during the heat-up phase of the simulation, leading to the explosion phase.



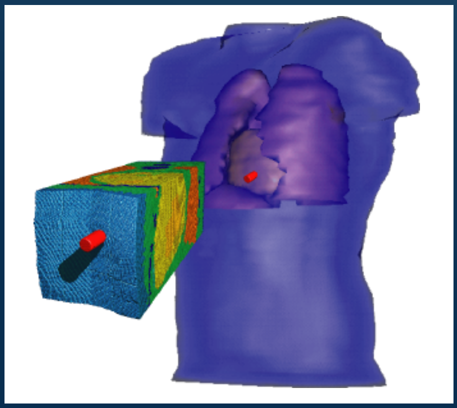
MPM Foam Compaction

Material Point Method simulation of compaction of a 1 mm cubed sample of reticulated foam. Initial geometry was collected via micro-CT with each voxel in the 3D image chosen to represent either the parent material, or void, depending on the image intensity. Individual particles are colored by equivalent stress.



Flare Simulations

Carried out on the LLNL machines LCR, Thunder, and ALC. Number of processors ranged from 54 to 120 depending on the domain size which was typically 1m x 1m x 3m and each simulation was resolved to 1 cm3. The prediction of the flame shape and tilt using large eddy simulation (LES) is consistent with the experiments. The prediction of pollutant emissions is currently being studied.

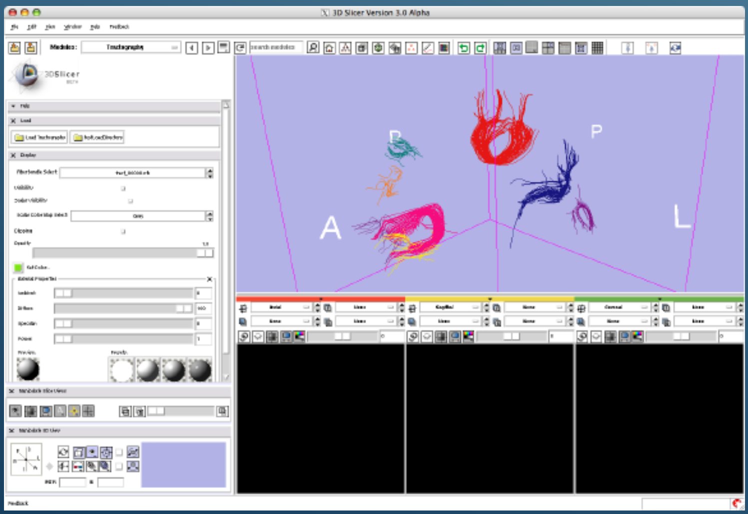


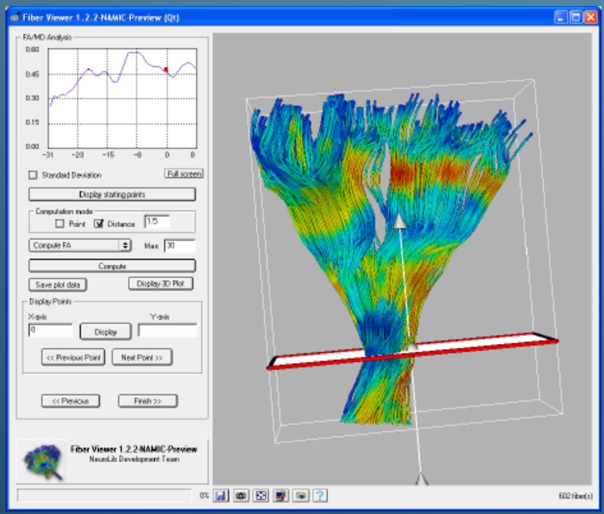
MPM Torso Injury Model

Initial configuration depicting an MPM simulation of a bullet impacting a segment of the human torso. The segment is colored according to material types, including fat, bone, heart tissue, lung, blood and viscera. Because of its ability to treat large deformation and inter-penetration of materials , MPM lends itself well to these types of simulations.

Case study: 3D Slicer and FiberViewer

3D Slicer (www.na-mic.org) is an comprehensive, integrated, open-source environment for medical image visualization and analysis developed as part of the national alliance for medical image computing (NA-MIC) funded as a national center for biomedical computing (NCBC) through the NIH Roadmap for Medical Research. Slicer includes modules for segmentation, registration, diffusion tensor image (DTI) analysis, and many other features. In particular, the SCI institute has contributed modules for DTI analysis including regularization and smoothing. DTI analysis software from the NeuroLib library for neuroimage processing (www.ia.unc.edu/dev) such as FiberViewer has been made compatible with Slicer in order to allow an integrated analysis process. Clinical users are able to load diffusion weighted imgages into Slicer to perform preprocessing, tensor estimation, and fiber tracking. Data exported from Slicer can then be loaded into the FiberViewer tool to enable the study of diffusion statistics along fiber bundles of interest. This provides a complete environment for end users to process DTI data for clinical studies.



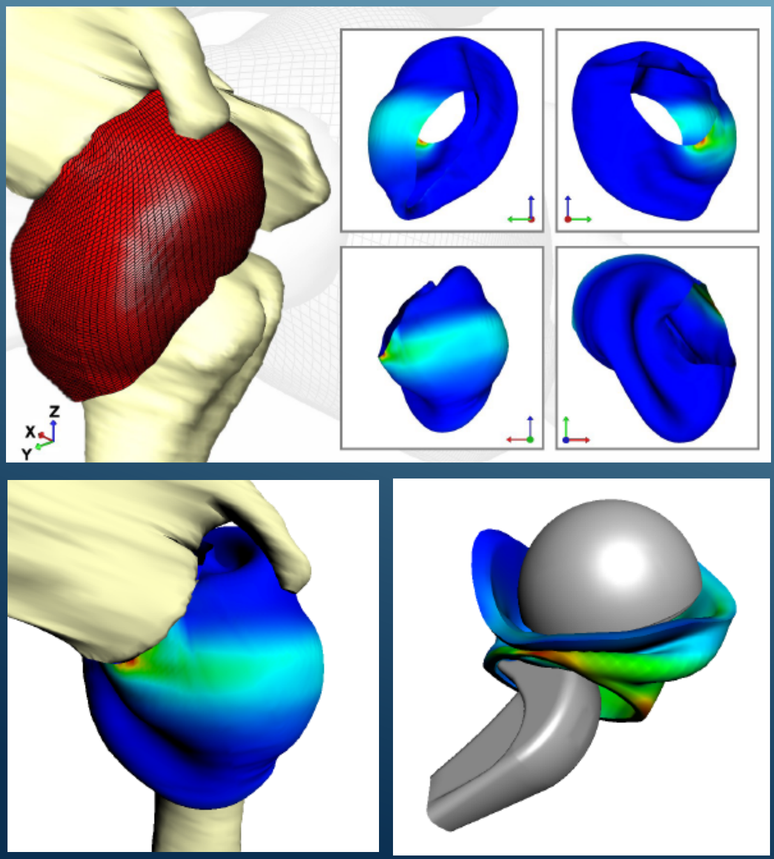


Case Study: FEBio

Computational modeling has become a standard methodology in biomechanics, both for interpreting experimental results and as an investigative approach. The finite element (FE) method is by far the most common numerical technique that is used for this purpose. Investigators have primarily used commercial software that is neither geared toward biological applications nor sufficiently flexible to follow the latest developments in the field. This lack of a tailored software environment has hampered research progress, as well as dissemination and sharing of models and results. To address these issues, we developed FEBio, a nonlinear implicit FE framework, designed specifically for analysis in computational solid biomechanics.

FEBio supports several non-linear constitutive models such as isotropic hyperelasticity and several transversely isotropic hyperelastic models, which can be used to model materials such as muscles, ligaments, tendons. An active contraction model is also available for use with the anisotropic materials. This can be used e.g. to model active contraction of skeletal and cardiac muscle. FEBio also supports a poro-elastic constitutive model useful for simulating materials that consist of both a solid and a fluid phase (e.g. articular cartilage). Rigid bodies are available as well and can be linked together using kinematic joints or can be connected to deformable bodies. FEBio supports a wide set of boundary conditions, such as prescribed displacements, nodal forces and pressure forces. A general frictionless contact-model is available to support more complex boundary conditions such as sliding interfaces.

To facilitate problem development and post-processing of the results we have also developed a pre- and postprocessor, named PreView and PostView respectively. Both software programs offer the user a graphical user interface. All the software is available free of charge from our website (http://mrl.sci.utah.edu).



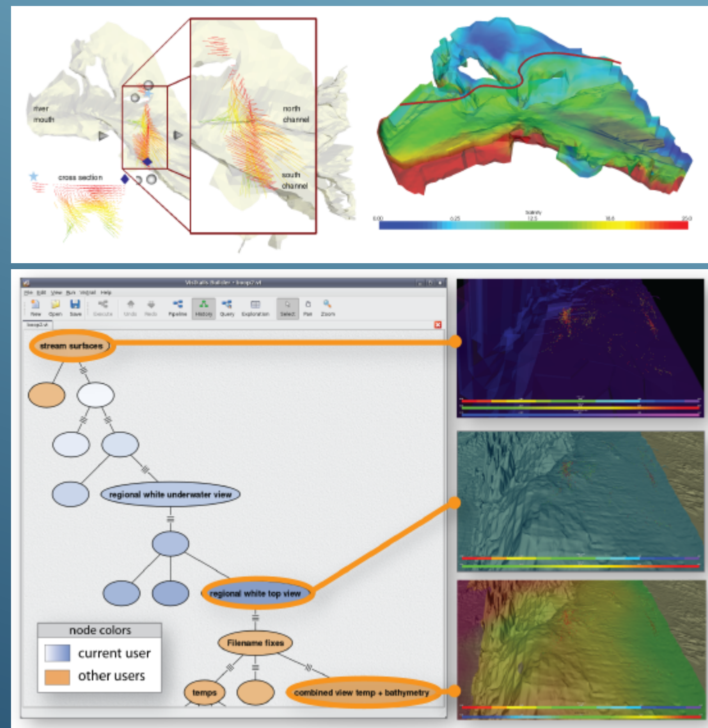
Steve Maas

Top, bottom left: Finite element predictions of shoulder capsule strain during a clinical exam for anterior stability. bottom right: Finite element predictions of hip capsule strain during a test for total-hip implant dislocation.

Case Study: VisTrails

VisTrails is a new scientific workflow management system developed at the University of Utah that provides support for data exploration and visualization. Whereas workflows have been traditionally used to automate repetitive tasks, for applications that are exploratory in nature, very little is repeated---change is the norm. As an engineer or scientist generates and evaluates hypotheses about data under study, a series of different, albeit related, workflows are created while a workflow is adjusted in an interactive process. VisTrails was designed to manage these rapidly-evolving workflows. VisTrails streamlines the creation, execution and sharing of complex visualizations, data mining or other large-scale data analysis applications. By automatically managing the data, metadata, and the data exploration process, VisTrails allows users to focus on the task at hand and relieves them from tedious and time-consuming tasks involved in organizing the vast volumes of data they manipulate. VisTrails provides infrastructure that can be combined with and enhance existing visualization and workflow systems.

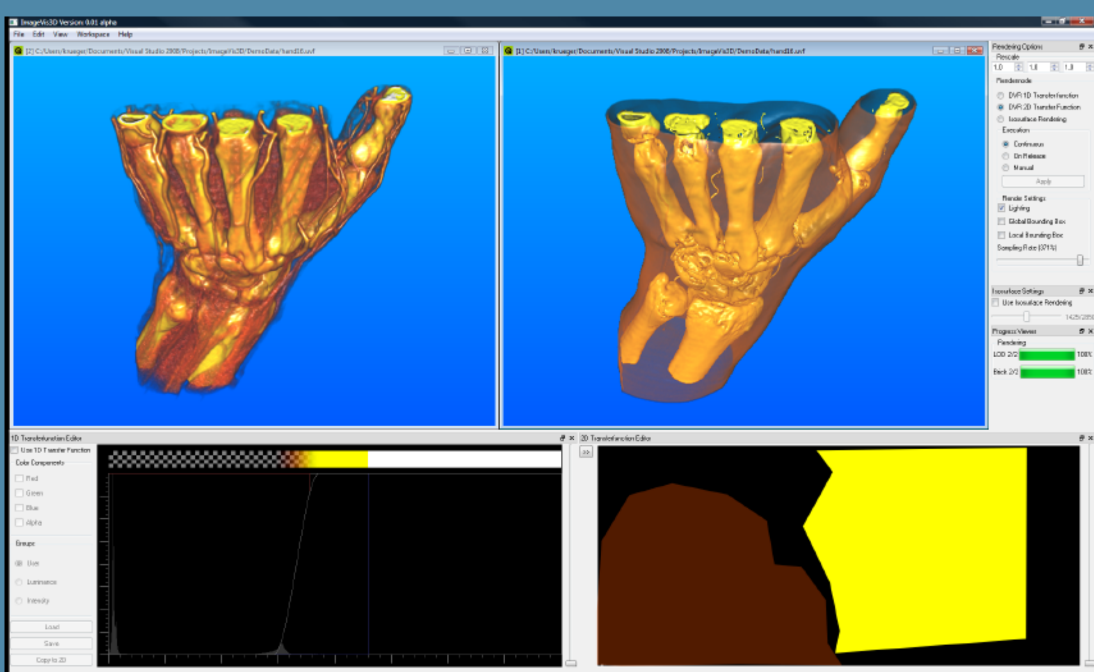
Although VisTrails was originally built to address the needs of exploratory scientific applications, the infrastructure it provides is very general. This became clear as the system was demoed to people from different domains, both from industry and academia. VisTrails has the potential to reduce the time to insight in virtually any exploratory task.

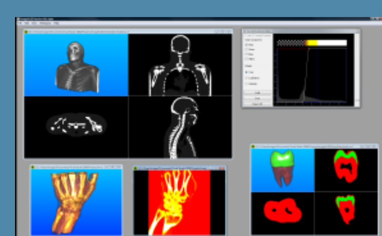


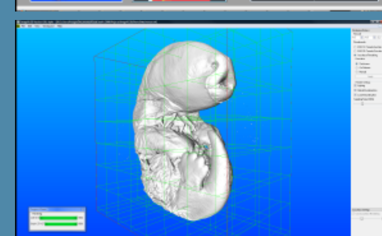
Top: The source of the upstream salt flux in the C-MOP River estuary model was difficult to find using 2D guess-and-check methods. By sweeping a plane through the field interactively, analysts were able to find the region of interest instantly. 3D visualization of the whole field provides a comprehensive view of the physics. Embedding a manipulable streamline and coloring by salinity illustrates the salt flux in an intuitive manner. Bottom: Users collaborate to generate visualizations. VisTrails captures all adjustments made to a workflow, producing provenance history that represents the workflow's evolution.

Case Study: ImageVis3d

ImageVis3D is a new volume rendering program developed by the NIH/NCRR Center for Integrative Biomedical Computing (CIBC). The main design goals of ImageVis3D are: simplicity, scalability, and interactivity. Simplicity is achieved with a new user interface that gives an unprecedented level of flexibility (as shown in the images). Scalability and interactivity for ImageVis3D mean that both on a notebook computer as well as on a high end graphics workstation, the user can interactively explore terabyte sized data sets. Finally, the open source nature as well as the strict component-by-component design allow developers not only to extend ImageVis3D itself but also reuse parts of it, such as the rendering core. This rendering core for instance is planned to replace the volume rendering subsystems in many applications at the SCI Institute and with our collaborators.







Left: the ct hand dataset rendered with a 1D and a 2D transfer function.
Above: though the name implies 3d, 2d visualizations are available.
Bottom: the monodelphis rendered as an isosurface with visualization of the bricking scheme. Data courtosy of Charles Keller.

NIH/NCRR

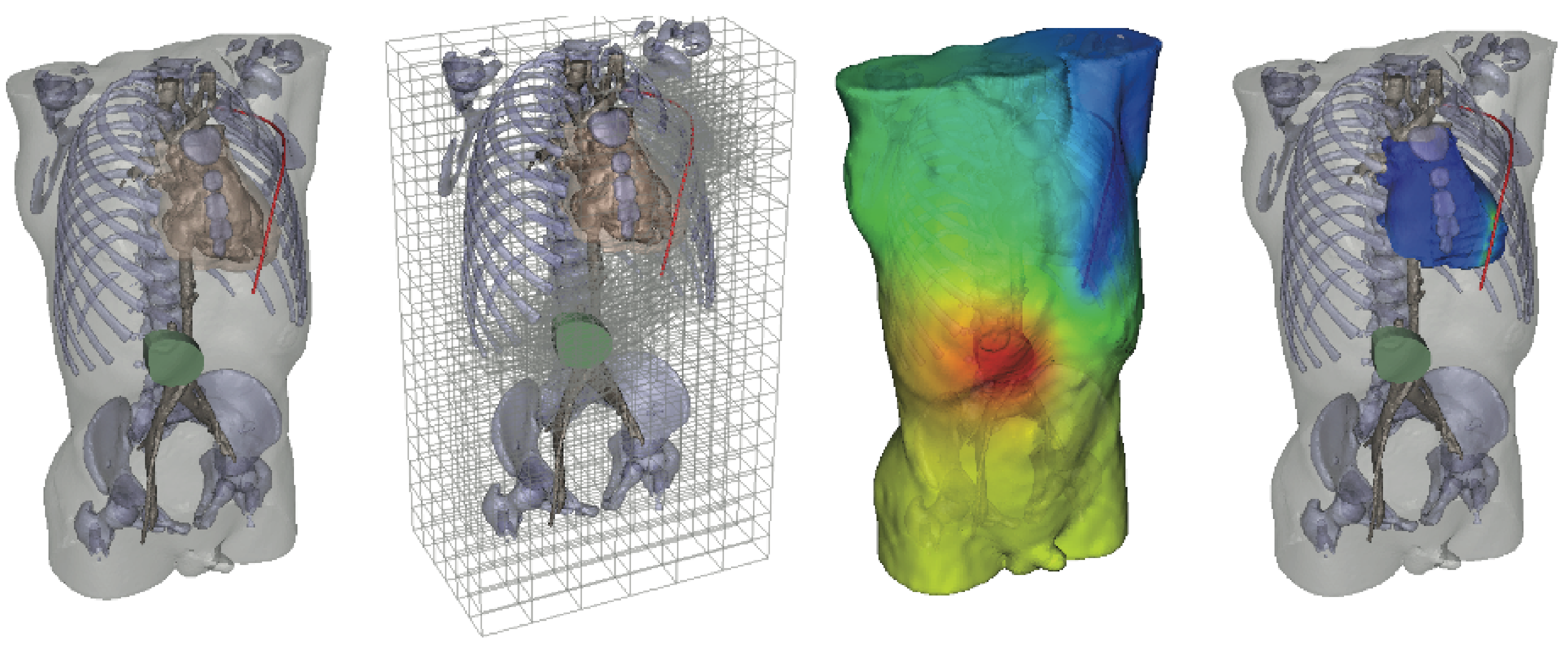
Center for Integrative Biomedical Computing

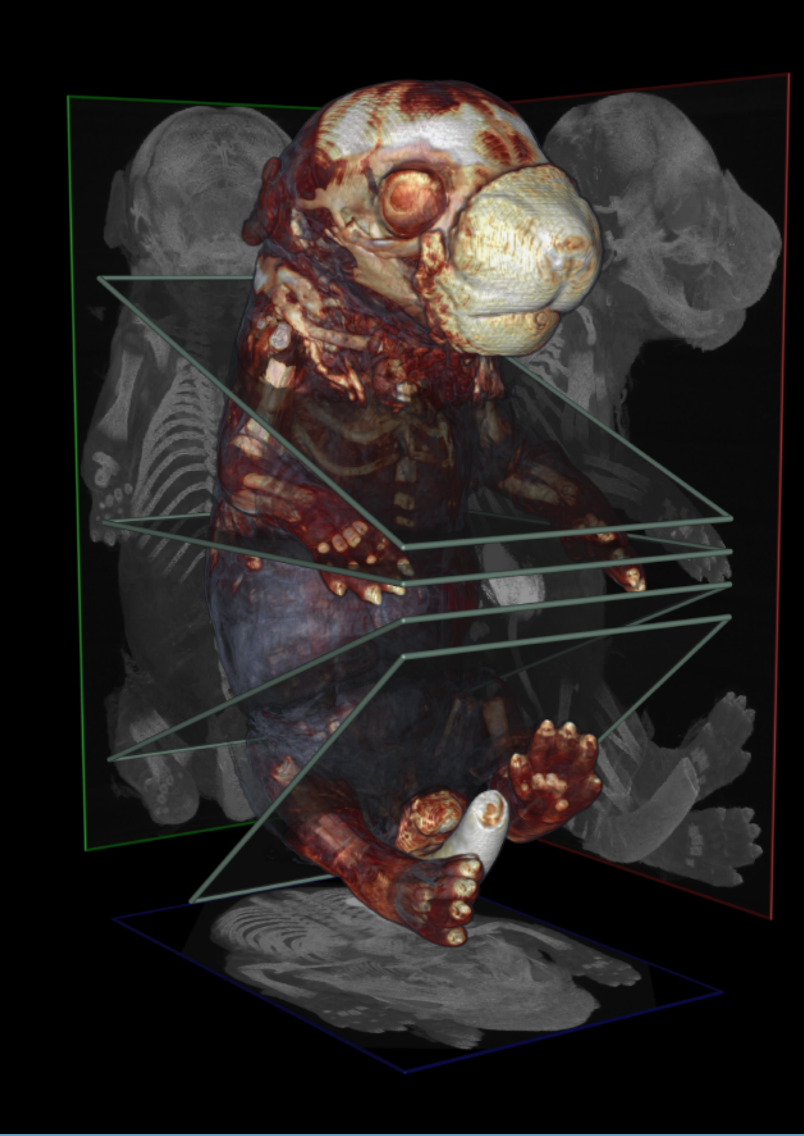
www.sci.utah.edu/cibc

The overall goals of the CIBC are the creation and dissemination of biomedical technology, algorithms, and software for the mathematical modeling, simulation, and visualization of physiological phenomenon applied to problems in clinical and biological research and applications. The Center provides unique computational resources supporting clinical and biological researchers both in fundamental breakthroughs in basic biomedicine and in application of new science and technology to health care. The Center develops software (SCIRun, BioPSE, Seg3D, BioImage, BioTensor, BioFEM and soon BioMesh3D and ImageView3D), distributes it freely to the biomedical community, carries out training, and supports formal and informal collaborators. The Center also carries out technical development and original research in several related areas, including three-dimensional image analysis, scientific visualization, biomedical simulation, bioelectric field problems, problem-solving environments, and software engineering. The CIBC has a strong, ongoing emphasis on software simulation of bioelectric fields, with clinically oriented collaborations in cardiac defibrillation and the diagnosis/treatment of epilepsy. In addition, the CIBC has expanded in recent years to include applications of statistical shape analysis and three-dimensional visualization to mouse genetics and neuroimaging and applications of image and geometry processing to cell biology.

Simulation Study of Cardiac Defibrillation in Children

Implantable Cardiac Defibrillators (ICDs) save the lives of patients with unstable heart rhythms and 100,000 patients receive these devices per year in the US. Their use in children is less frequent and less standardized than in adults so that determining efficient electrode placement is challenging and uncertain. We are collaborating with J. Triedman, M.D. at Children's Hospital Boston and M. Jolley, M.D. at Stanford University to develop interactive finite element (FEM) computational models to test electrode locations for their effectiveness in defibrillation in children. The models come from CT or MRI scans segmented into tissue types and then meshed for FEM. The system also includes a library of realistically shaped ICD case and wire electrodes and an interactive interface allows the user to easily place and move the electrodes in the model to evaluate different implantation locations. To date we have fully segmented three CT scans, from 2, 10, and 27 year-old subjects, and have created a database of approximately 100 suitable electrode locations per model, which we are testing for bioelectric field strength and homogeneity. Initial findings have included evaluating the effectiveness of standard locations in adults and novel locations in children.



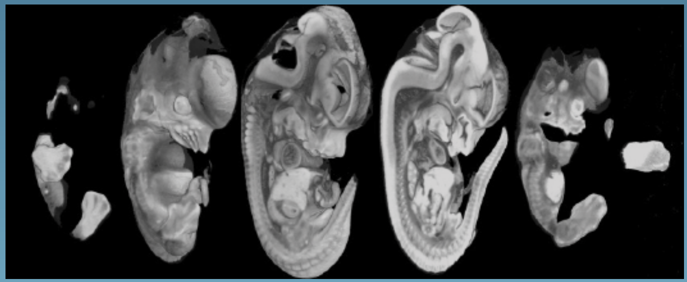


Dave Weinstein, Charles Keller

Virtual Histology

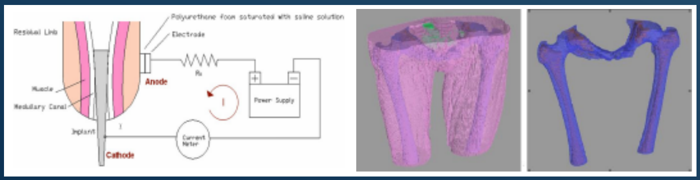
Virtual Histology™ is ideally suited for characterizing soft tissue and skeletal anatomy in developing embryos, fetuses and a variety of soft tissue specimens. The imaging reagent, designed for use with microCT, is differentially absorbed by the various tissues. As a result of the unique contrast enhancement, exquisite visualizations in 2D and 3D are possible.

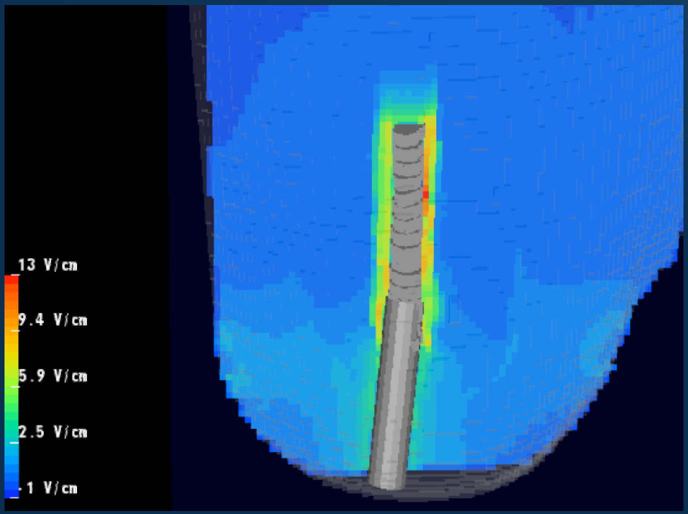
Comparable to a dissection microscope, Virtual Histology ™ can provide greater than 6µm isometric voxel resolution enabling detailed analysis. It is an excellent methodology for the examination of fine structures in a range of soft tissue specimens. The crisp, clean images provide a degree of anatomic detail that approximates routine histology as viewed by light microscopy. The significant advantage is clearly the non-destructive nature of microCT-based Virtual Histology™ allowing the researcher to change the angle of view from axial, sagittal, coronal and even arbitrary oblique planes based on the anatomic feature of interest offering new perspectives on developmental defects.



Stimulation of Bone Growth for Prosthetic Devices in Amputees

Young, otherwise healthy amputees form a small but growing population of patients, many of them the casualties of combat, and there is a persistent need in this group for improvements in the fixation of prosthetic limbs. A recent approach to this problem is to embed metallic posts into the remnant bone of the limb and thus provide a stable fixation point that reduces the abrasion and contact wounds of the typical stump-and-socket prosthetic fixation. One drawback to this approach is the long (many months) healing time required for full embedding of the implant, a process we hope to accelerate through the application of an electric field across the interface from the bone to the implant. It is known that electric fields facilitate bone growth so that attachment of external stimulating electrodes could accelerate bone/implant attachment and reduce healing time. However, this is a novel application of the concept with no previous data to help determine optimal electrode location or applied field values. We are using patient specific, image based modeling to create simulations of the limb, the implant, and the spatial distributions of electric fields that result from application of surface electrodes.

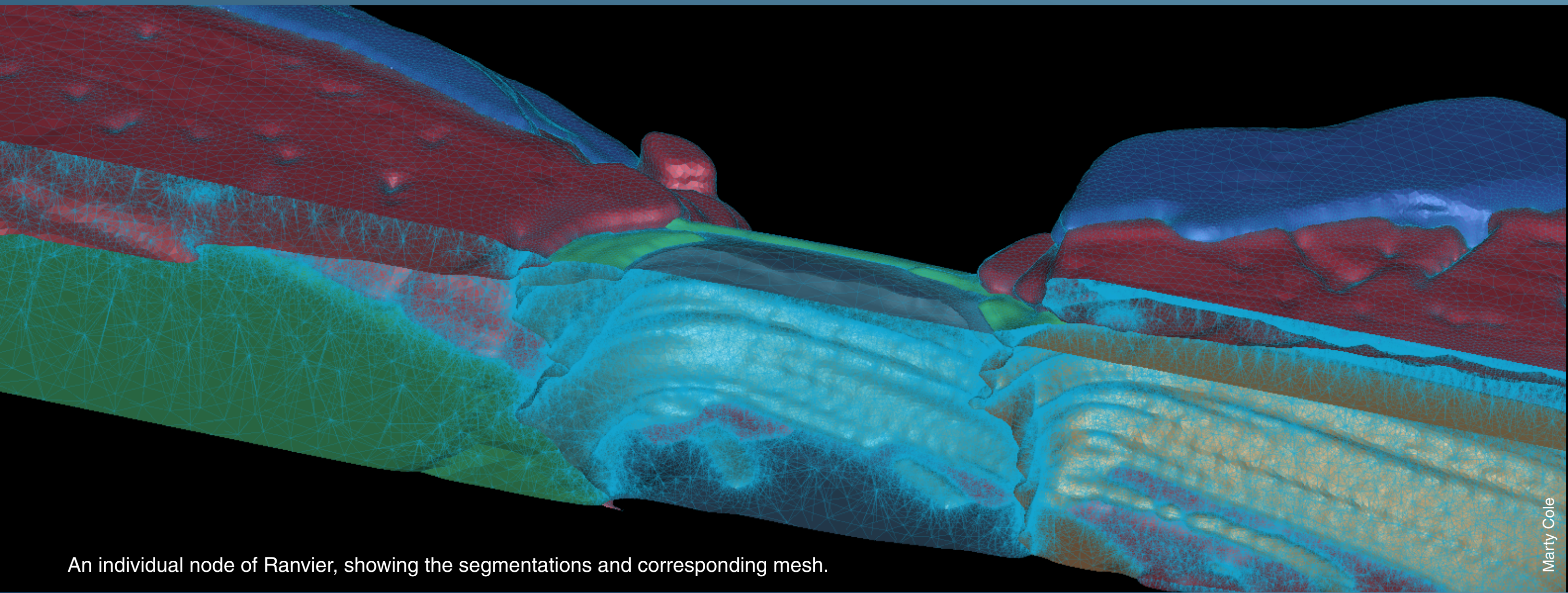




Center for Integrative Biomedical Computing

Cellular Structure and Function

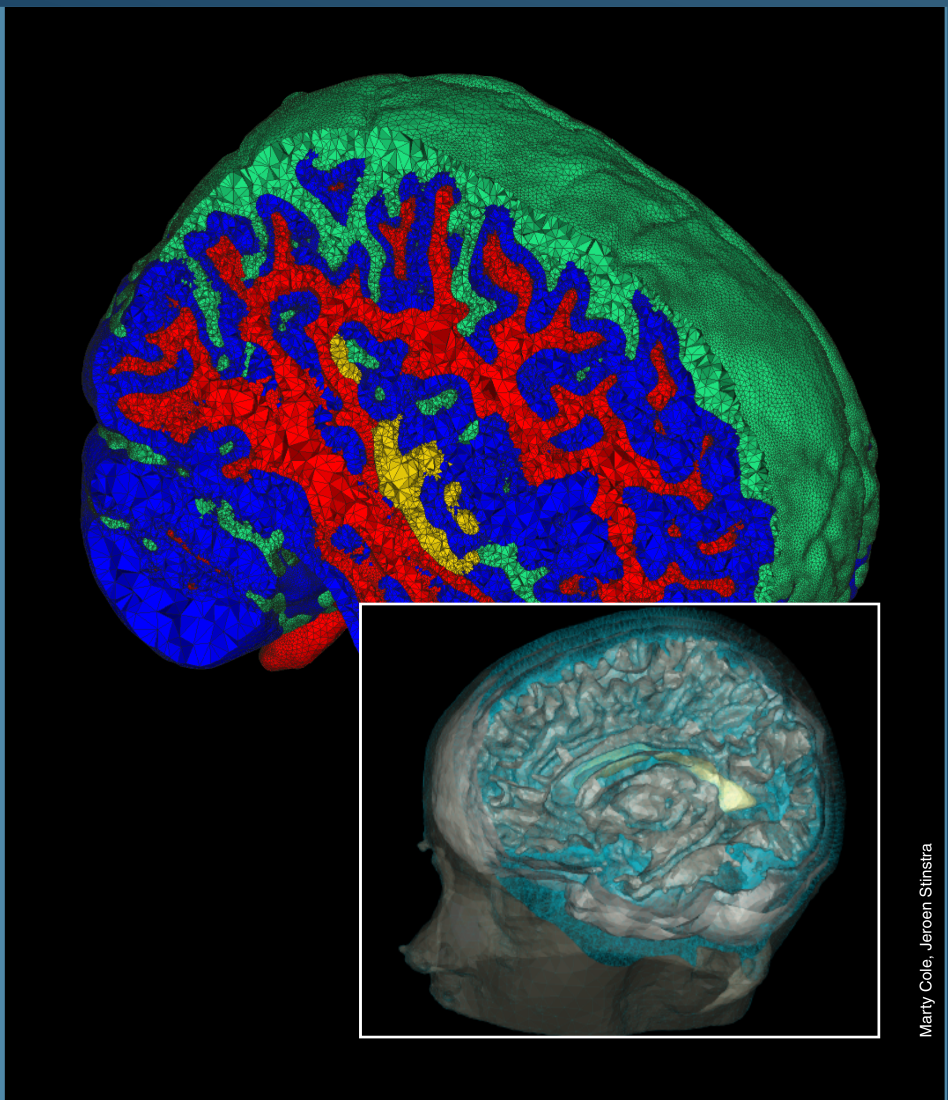
The National Center for Microscopy and Imaging Research (NCMIR) at the University of California San Diego, is an NIH NCRR Biomedical Technology Research Center established to develop advanced, computer-aided microscopy for acquisition of structural and functional data. The CIBC is collaborating with NCMIR to develop image analysis algorithms and software to help biomedical researchers explore and understand structural and functional relationships within cells and tissues through a range of scales from macromolecular complexes to organelles and multi-component structures like synapses.



An individual node of Ranvier, showing the segmentations and corresponding mesh.

Epilepsy Detection and MRI

The goal of this collaboration is to develop and validate a new approach to characterizing epileptogenic foci and thereby make curative surgery available to a larger population at an earlier age. We will achieve this by developing an optimized MRI and EEG analysis strategy to enable improved pediatric epilepsy surgical planning (ESP). The primary outcome of pediatric ESP is identification of epileptogenic foci in order to determine if the subject is a candidate for neurosurgery. The nature and location of these foci determine if they may be targeted for neurosurgical resection. Today, Children's Hospital sees two to four pediatric patients a week for extended evaluation. The pediatric ESP process of imaging acquisition and analysis, utilizing MRI and scalp EEG, is largely a qualitative process. The ambiguity of foci determination and localization increases the difficulty of carrying out effective patient care. However, recent technical advances in data acquisition for EEG and MRI, and most importantly in improved algorithms for patient specific post-acquisition processing, offer the possibility of dramatically improved accuracy. This improved accuracy is made possible by the provision of stronger constraints on the inverse problem of EEG source localization and by the fusion of source localization data from EEG, conventional MRI and DT-MRI.



Imaging meets Electrophysiology to Help People with Heart Troubles

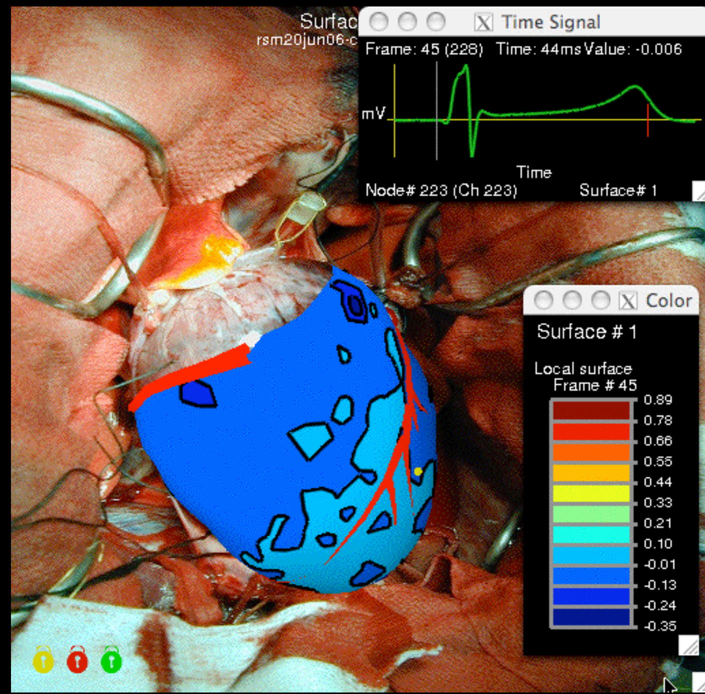
Atrial fibrillation (AF) is the most common—and perhaps most insidious—form of heart rhythm disturbance. In AF, the upper two chambers (the left and right atria) of the heart lose their synchronization and beat erratically and inefficiently, reducing the pumping capacity of the heart and elevating the heart rate, eventually leading to a stroke. The same condition in the lower chambers (ventricles) of the heart is fatal within minutes and defibrillators are necessary to restore coordination. In the atria, death is stealthy and occurs over years.

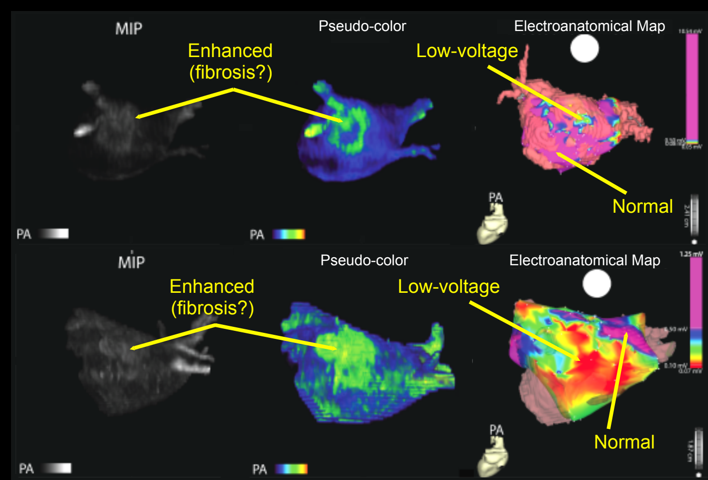
A group of scientists and physicians at the University of Utah is addressing the growing problem of AF through a combination of high tech interventional therapy, multimodal medical imaging, image processing and analysis, and computer science. The treatment known as "atrial ablation" requires that large areas of the posterior wall of the left atrium be rendered electrically inactive. This part of the heart is the origin of the fibrillation and by suppressing its electrical activity, the heart can return to—and, more importantly, stay in—normal rhythm. To carry out ablation, the physician, under image guidance, places a catheter in the left atrium and uses it to apply radiofrequency energy to heat a series of small spots on the atrial wall.

Medical imaging is at the "heart" of this project as it plays a role at all stages. The imaging specialists Drs. Parker, DiBella, and Kholmovski, all from the Utah Center of Advanced Imaging Research (UCAIR), have developed new ways of using magnetic resonance imaging (MRI) to visualize the walls of the atria, which are only a few millimeters in thickness, a task previously considered almost impossible in a beating heart. The cardiology team, Drs. Marrouche and McGann, then recognized that the MRI images of the atrial walls of some patients looked different from others and set the image processing team, Dr. MacLeod and specialists at the Scientific Computing and Imaging (SCI) Institute, the task of visualizing and quantifying these differences.

The results were striking and allowed the team to create a method that appears to identify and measure regions of the heart that are most altered by the AF. The resulting index can serve to differentiate between good and bad candidates for treatment. This discovery represents a potential breakthrough in treatment as there is no other way to determine suitability of patients before the procedure.

The team aims to transform the integration of imaging modalities and especially the role of MRI during the ablation procedures. MRI is the only modality capable of seeing the effects of ablation and thus has the potential to monitor the formation of the lesions that suppress unwanted electrical activity. MRI can also provide images of the lesions as they progress from acute injury to stable scars and thus offers the only noninvasive means to follow patient progress during the procedure and in the following weeks and months.





Rob MacLeod

Top: Heart surface potentials rendered with map3d. The figure shows a single time instant from a real time animation of the electric potential (voltage) measured on the surface of a heart--a surface potential map--and visualized with map3d. The latest version of map3d allows the user to integrate an image of the actual surface (in this case of a heart) into the interactive display of time signals on that surface. Colors indicate voltage levels, as show in the figure legend and the time signal in the upper right hand corner shows with a vertical yellow bar the instant in time from which comes the single map.

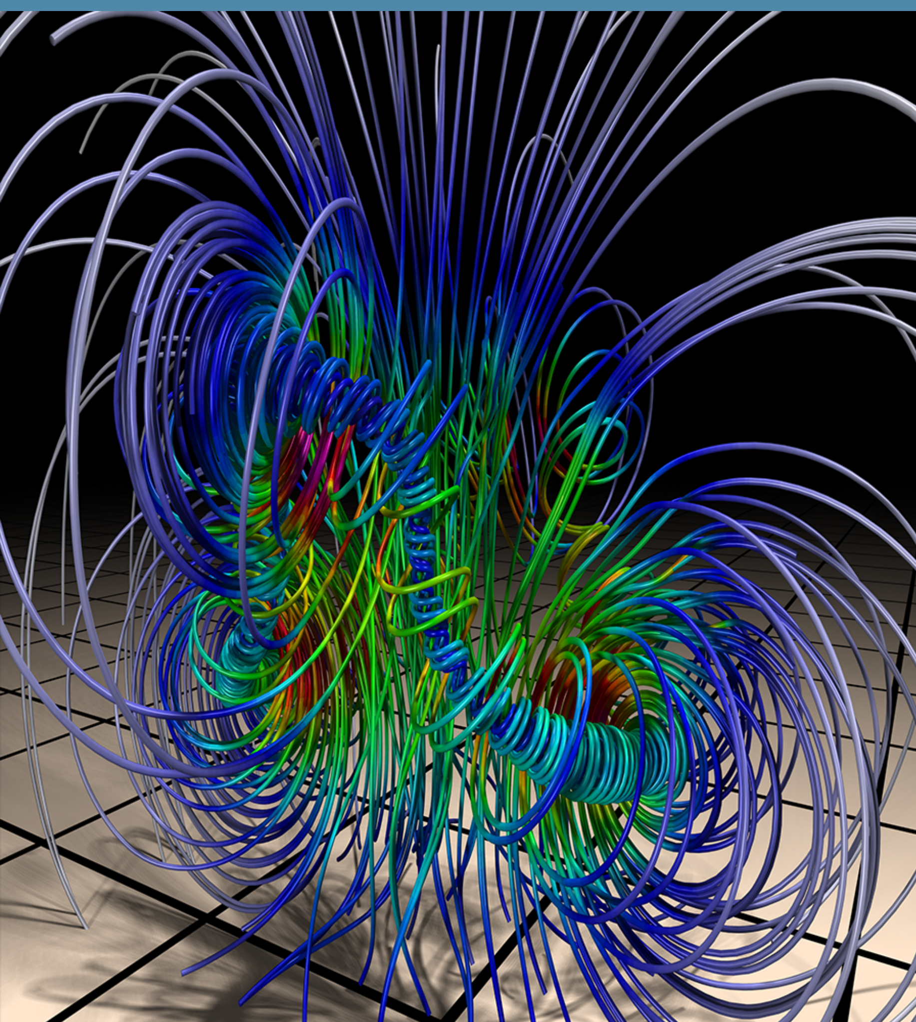
Bottom: Comparison of delayed enhanced MRI imaging and electroanatomical mapping of patients undergoing treatment for atrial fibrillation. The rows of figures show posterior view of the left atrium from two different patients, both of whom suffer from atrial fibrillation that was treated with a technique known as pulmonary vein antrum isolation (PVAI). The leftmost image in each row shows the raw MRI data , the middle image in each row shows the same data but with color coding in order to enhance regions of fibrosis. The rightmost images show electroanatomical mapping with magenta indicating electric potentials of normal amplitude and all other colors identifying regions with reduced amplitude. Note the correlation between highlighted regions in the MRI and areas of low electric potential in the electroanatomical map. The images are available noninvasively while the electroanatomical maps require insertion of catheter electrodes into the heart.

DOE SciDAC VACET

Visualization and Analytics Center for Enabling Technologies

www.vacet.org

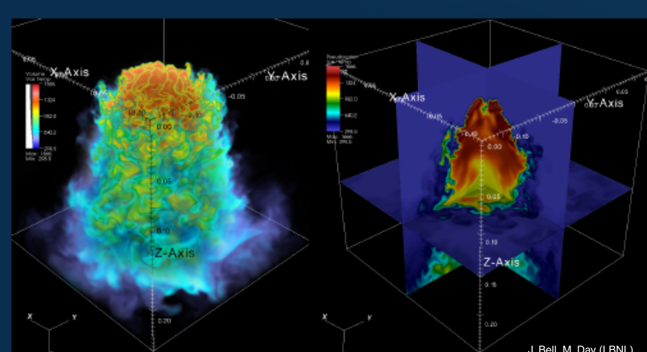
Visualization and Analytics Center for Enabling Technologies (VACET) was launched in 2006 as one of nine centers under the Department of Energy's Scientific Discovery through Advanced Computing (SciDAC-2). The Center focuses on leveraging scientific visualization and analytics software technology as an enabling technology for increasing scientific productivity and insight. Advances in computational technology have resulted in an "information big bang," which in turn has created a significant data understanding challenge. This challenge is widely acknowledged to be one of the primary bottlenecks in contemporary science. The vision of our Center is to respond directly to that challenge by adapting, extending, creating, and deploying visualization and data analysis technologies for our science stakeholders. With the combined expertise of SCI and our other partners, we are well positioned to be responsive to the needs of a diverse set of scientific stakeholders using a range of visualization, mathematics, statistics, computer and computational science and data management technologies.



Above: Streamlines visualization of two vortex cores merging. Image produced by Dave Pugmire (ORNL) using AMR data produced by APDEC's Chombo code.

Production Quality, Parallel Capable AMR Visualization

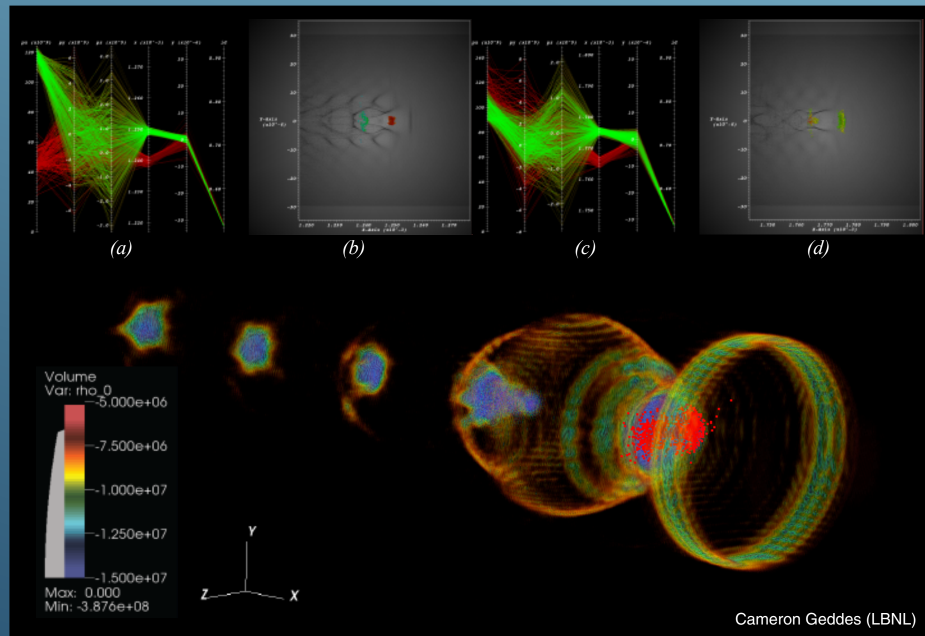
VACET are leaders in production quality, parallel adaptive mesh refinement (AMR) visualization and analysis software infrastructure. We have recently deployed such production quality AMR visualization software infrastructure to SciDAC scientific researchers. This result has numerous direct benefits to those researchers. First, it allows them to "buy rather than build", thereby resulting in a direct cost savings of scientific staff: they no longer need to develop and maintain AMR visualization software. Second, the VACET technology allows them to effectively use parallel computing infrastructure to perform interactive visual data analysis to help answer scientific questions in domains like combustion and astrophysics. Third, since the VACET technologies is deployed at DOE's open computing facilities as well as on the scientists' desktop, this result is an example of successfully bridging the gap across research, development and production deployment activities within DOE's science programs.



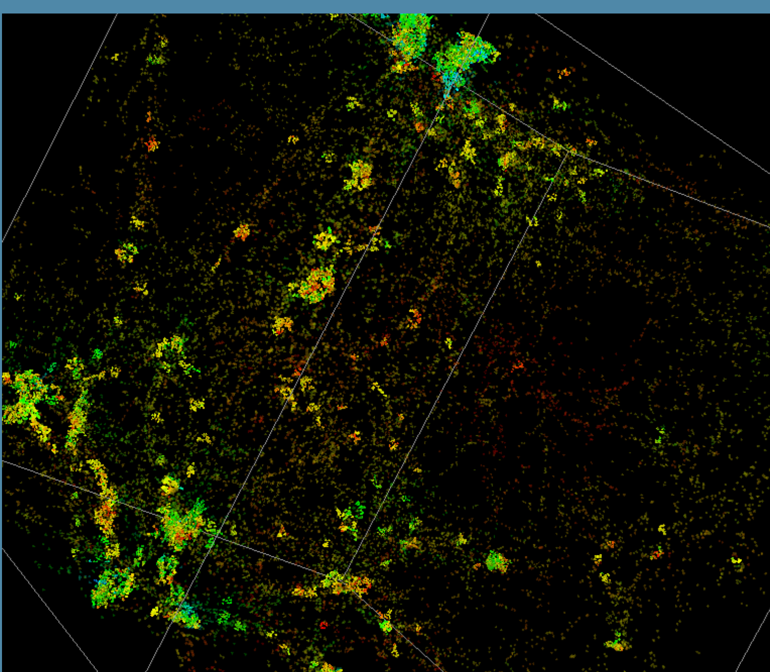
Right: Production quality visualization of an AMR simulation of a hydrogen flame. Sample data courtesy of J. Bell and M. Day, Center for Computational Sciences and Engineering, LBNL. Inset: (a) Streamlines visualization of two vortex cores merging. Image produced by Dave Pugmire (ORNL) using AMR data produced by APDEC's Chombo code. (b) Psuedocolor plot of a 2D mapped AMR grid. (c) Psuedocolor plot of a 3D mapped AMR grid.

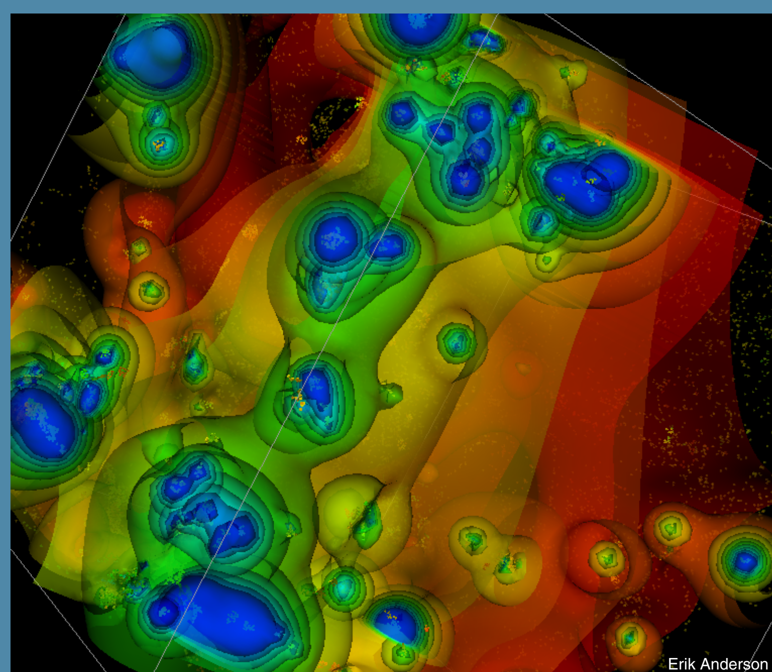
Accelerator Modeling: High Performance Visual Data Analysis

Laser wakefield simulations model the behavior of individual particles as well as the behavior of the plasma electric and magnetic fields. Output from these simulations can become quite large: todays datasets, such as the ones we study here, can grow to be on the order of 200GB per timestep, with the simulation producing approximately 100 timesteps. The scientific challenge we help address in this study is first to quickly find particles that have undergone wakefield acceleration, then trace them through time to understand acceleration dynamics, and perform both visual and quantitative analysis on the set of accelerated particles. In the past, accelerator scientists would perform the "trace backwards" step using scripts that performed a search at each timestep for a set of particles. Runtimes for this operation were on the order of hours. Using our implementation, those runtimes are reduced from hours to seconds.



Top: a) Parallel coordinates and b) pseudocolor plot of the beam at $t = 27$. Corresponding plots c,d) at $t = 37$. The context plot, shown in red, shows both beams selected by the user after applying a threshold of $px > 8.872\ 10^{10}$ at $t = 37$. The focus plot, shown in green, indicates the first beam that is following the laser pulse. In the pseudocolor plots b) and d), we show all particles in gray and the selected beams using spheres colored according to the particle's x-momentum, px. The focus beam is the rightmost bunch in these images. At timestep $t = 27$, the particles of the first beam (green in figure a) show much higher acceleration and a much lower energy spread (indicated via px) than the particles of the second beam. At later times, the lower momentum of the first beam indicates it has outrun the wave and moved into decelerating phase, e.g at timestep $t = 37$.
Bottom: Volume rendering of the plasma density and the selected focus particles (red)





Cosmology and Astrophysics

Understanding the explosive nature of stellar supernovae and the subsequent production of elements is one of the more challenging problems undertaken by SciDAC. The set of astrophysics efforts supported by SciDAC and our Center range from modeling supernova explosions to cosmology and early universe formation. The computational astrophysics projects produce very large, multi-field, time-varying data at DOE's open computing facilities and poses many challenges in visualization.

A simulation of the universe as it forms from the big bang until the present. The simulation code, Enzo, was run on a supercomputer at Los Alamos National Laboratory. Each galaxy is represented as a single particle. The multi-colored surfaces indicate different densities in space. Regions enclosed in orange and red, called halos, represent clusters of galaxies, while low density regions, called voids, are indicated by regions not enclosed in any surface.

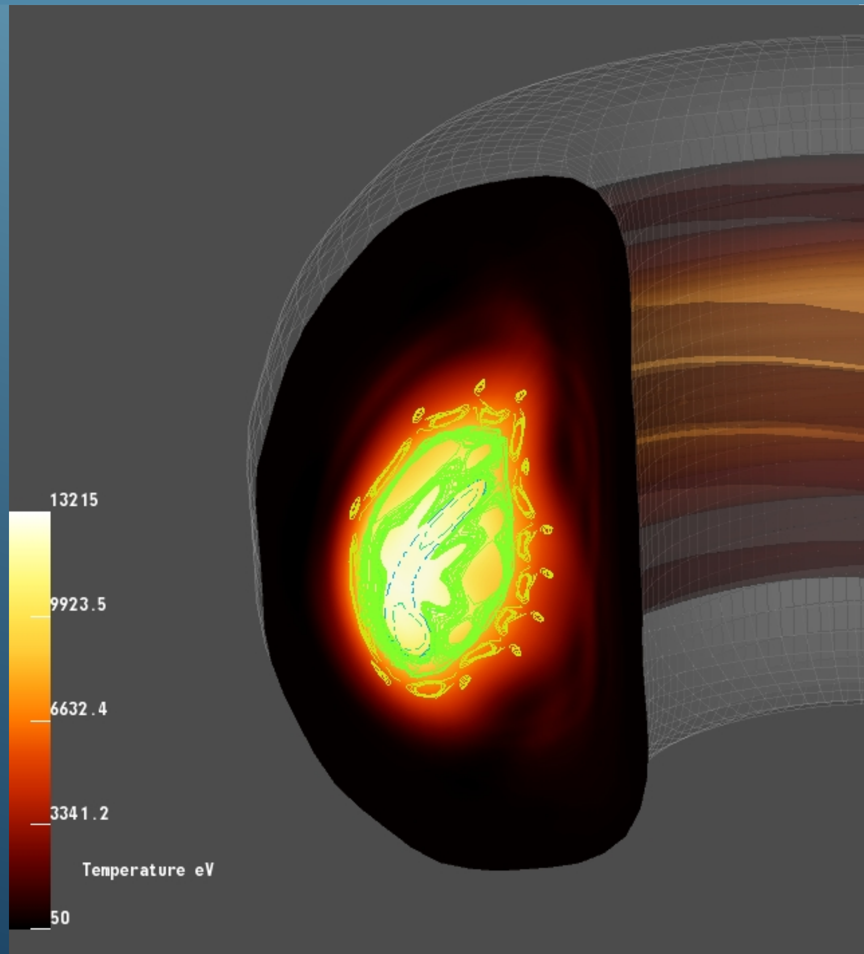
VACET Visualization and Analytics Center for Enabling Technologies

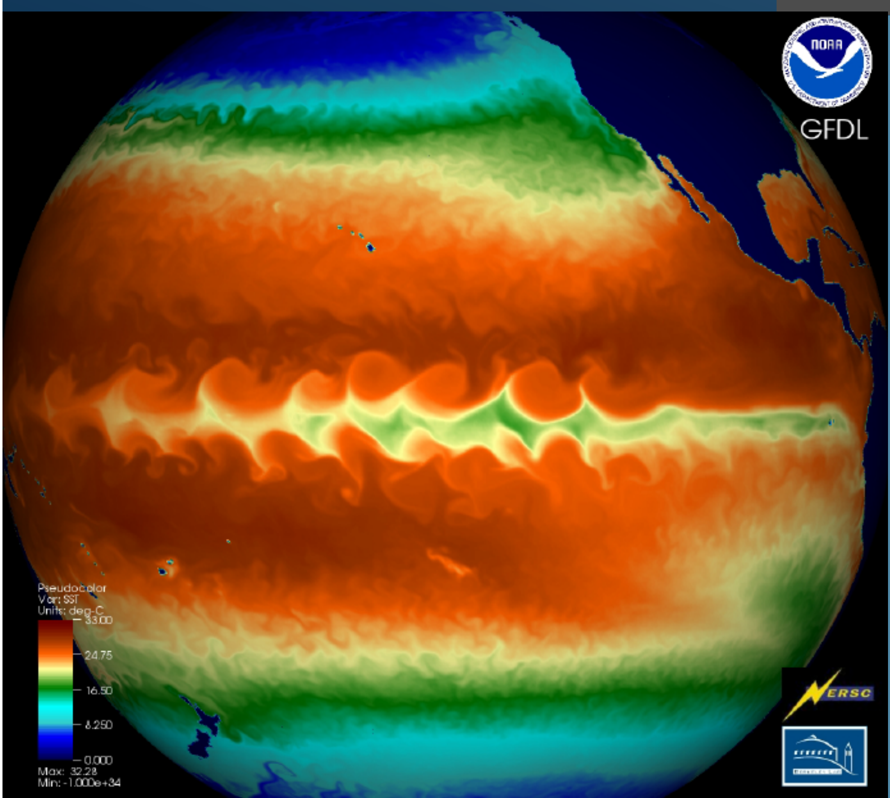
Fusion

Understanding the complex behavior of magnetically confined fusion plasmas is an important goal of DOE's many fusion projects. The fusion community uses many different simulations to model the effects of physical and electromagnetic phenomena that contribute to plasma stability and effective plasma containment. These phenomena include radio frequency heating, stellerator and tokamak geometries, magnetic field evolution, and eddy stability.

Right: **Visualization of the Magnetic Field and Plasma Temperature in D III-D Shot 87009**

This visualization shows the break up of the magnetic field into a series of island chains, with a predominant 2:1 mode, left along with isosurfaces of the plasma temperature, right. The topology of the magnetic field is visualized using an analysis tool that produces a Poincaré map. Because the plasma equilibrates much more rapidly parallel to the magnetic field lines than perpendicular to the magnetic field lines, visualizing the magnetic field topology is necessary to the understanding how the plasma energy is deposited on the material wall. As the field becomes stochastic, the plasma cools rapidly. This cooling is highlighted by a series of transparent iso-temperature surfaces. Though the temperature profile remains as a series on nested contours they have deformed based on the topology of the magnetic field.



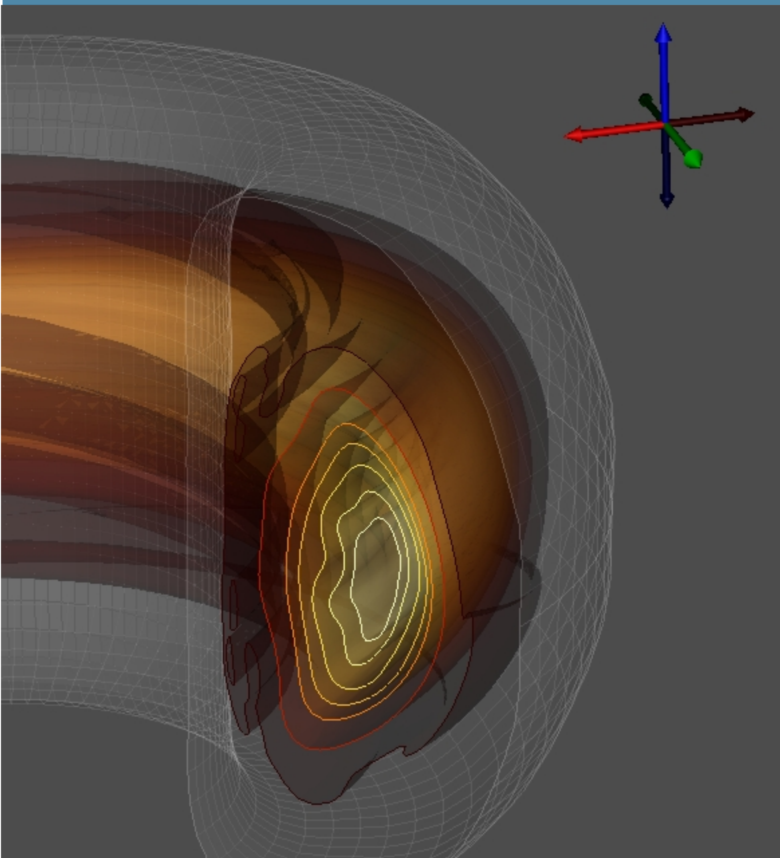


High-resolution models offer not only a closer look at physical elements of the climate, such as tropical storms, but they also enable researchers to conduct a more in-depth analysis of climate change as higher-resolution phenomena in the ocean and atmosphere are resolved. Winner of "People's Choice" award at SciDAC 2008.

Climate Visualization

The general goals of the climate research effort within SciDAC is to understand large scale climate change dynamics over very long time periods. To ensure confidence and accuracy in their simulations, climate scientists must couple many different simulation methods into a single "meta-simulation" that combine ocean, atmospheric, land use, vegetation, biochemistry, ecosystem dynamics, and other models. As a consequence, climate simulations often contain as many as 200 variables per grid point. Accurate simulations require a fairly short timestep – between 15 minutes and 6 hours. Performing hundreds of years of simulated time results in hundreds of terabytes of data. Since the emphasis is on large scale climate change rather than regional weather simulation, the spatial grids are generally not very large. The data-intense areas are generally multivariate and temporal. However, computational climate efforts are increasing in spatial resolution to support regional models suitable for weather forecasting. So-called "ensemble runs" of a given climate model produce hundreds of different simulation data sets leading to a substantial challenges in data management and comparative analysis. Such simulations are expected to provide broad insight into the impacts of human activity over long time periods, provide policy-relevant information about energy policies, and help to predict the trends of natural disasters.

www.vacet.org

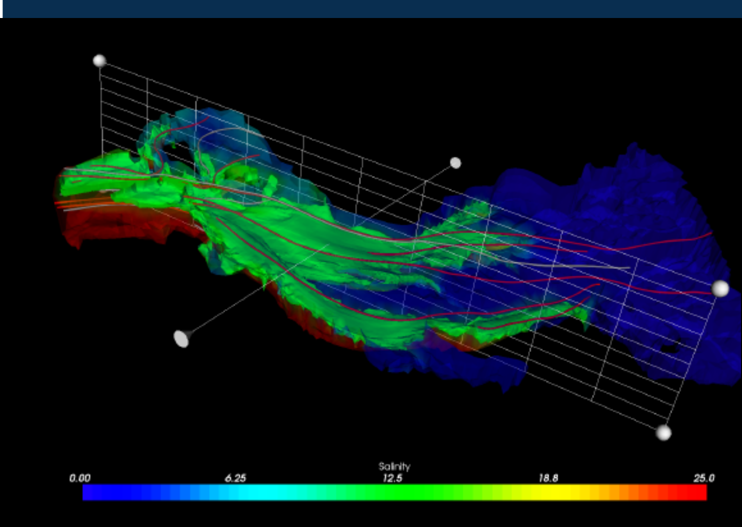


Simulation performed by Scott Kruger using the NIMROD code on the IBM SP RS/6000 computer at the National Energy Research Center. Visualization and Analysis performed by Allen Sanderson using the SCIRun Problem Solving Environment.

Environmental Management

DOE is responsible for cleanup and management of several facilities from the Cold War weapons production era as well as for monitoring contaminant behavior in groundwater waste disposal and storage areas. Simulations of groundwater flow are the basis for understanding and predicting environmental impact. These simulations also include multi-phase and reactive chemistry components to capture the effect of water-based transport and the effects underground chemical reactions.

Below: CORIE is an environmental observation and forecasting system (EOFS) for the Columbia River. The goal of this multi-decade project is to predict complex circulation and mixing processes in a system encompassing the lower river, the estuary, and the near-ocean.



Claudio Silva

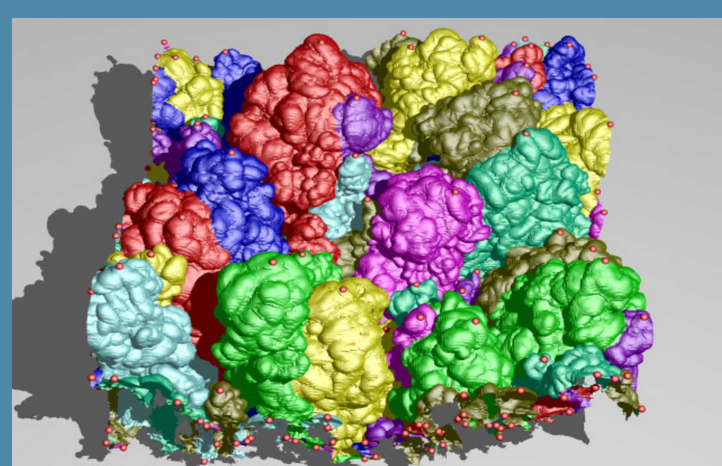
Topological Analysis Provides Deeper Insight into Hydrodynamic Instabilities

From *SciDAC Review,* winter 2007

The VACET group at Lawrence Livermore National Laboratory, led by Valerio Pascucci (now with Utah), has developed the first feature-based analysis of extremely high-resolution simulations of turbulent mixing. The focus is on Rayleigh-Taylor instabilities, which are created when a heavy fluid is placed above a light fluid and tiny vertical perturbations in the interface create a characteristic structure of rising bubbles and falling spikes. Rayleigh-Taylor instabilities have received much attention over the past half-century because of their importance in understanding many natural and man-made phenomena, ranging from the rate of formation of heavy elements in supernovae to the design of capsules for inertial confinement fusion. However, systematic, detailed analysis has been difficult due to the extremely complicated features found in the mixing region.

Members of VACET, the Visualization and Analytics Center for Enabling Technology funded under SciDAC, at Livermore developed a novel approach to the analysis of the complex topology of the Rayleigh-Taylor mixing layer based on robust Morse theoretical techniques. This approach systematically segments the envelope of the mixing interface into bubble structures and represents them with a new multi-resolution model allowing a multi-scale quantitative analysis of the rate of mixing based on bubble count. This analysis enabled new insights and deeper understanding of this fundamental phenomenon by highlighting and providing precise measures for four fundamental stages in the turbulent mixing process that scientists could previously only observe qualitatively.

This work has been documented in a paper named "best application paper" at the IEEE visualization conference and later presented at the International Workshop on the Physics of Compressible Turbulent Mixing. Follow-up work also allowed, for the first time, direct comparison of two simulations based on different physics models, grid point resolutions, and initial conditions. Although comparison by superposition of the simulations could not yield a meaningful result, the new topological approach highlighted fundamental similarities through a multi-scale feature-based comparison. This, in turn, validated the lower resolution large eddy simulation with respect to the higher resolution direct numerical simulation.



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We were excited to relocate this past summer to our new home, the spectacular John E. and Marva M. Warnock Engineering Building, named for University alumni John and Marva Warnock. The SCI Institute is the building's principal research occupant, with space dedicated to faculty, staff, graduate student offices configured to optimize interaction, and specialized research facilities such as the David Evans Visualization Center, which will be a state-of-the-art research laboratory, collaboration, and presentation facility.

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There is an American proverb that says: "It doesn't work to leap a twenty-foot chasm in two ten-foot jumps." Everyday the SCI Institute is engaged in far reaching scientific computing and imaging research in which we attempt to leap the twenty-foot chasm. This leap is not possible without the help we receive from our donors. Federal research funds have become more restricted and more risk adverse, so that only the ten-foot jump is possible. The SCI Institute needs support from its donors to help us in leaping the chasm required to bring far reaching advances to all the fields touched by scientific computing and imaging.

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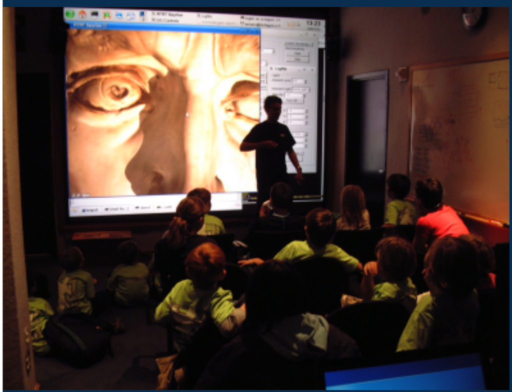

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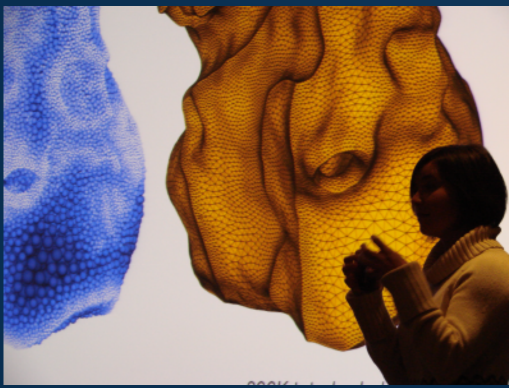

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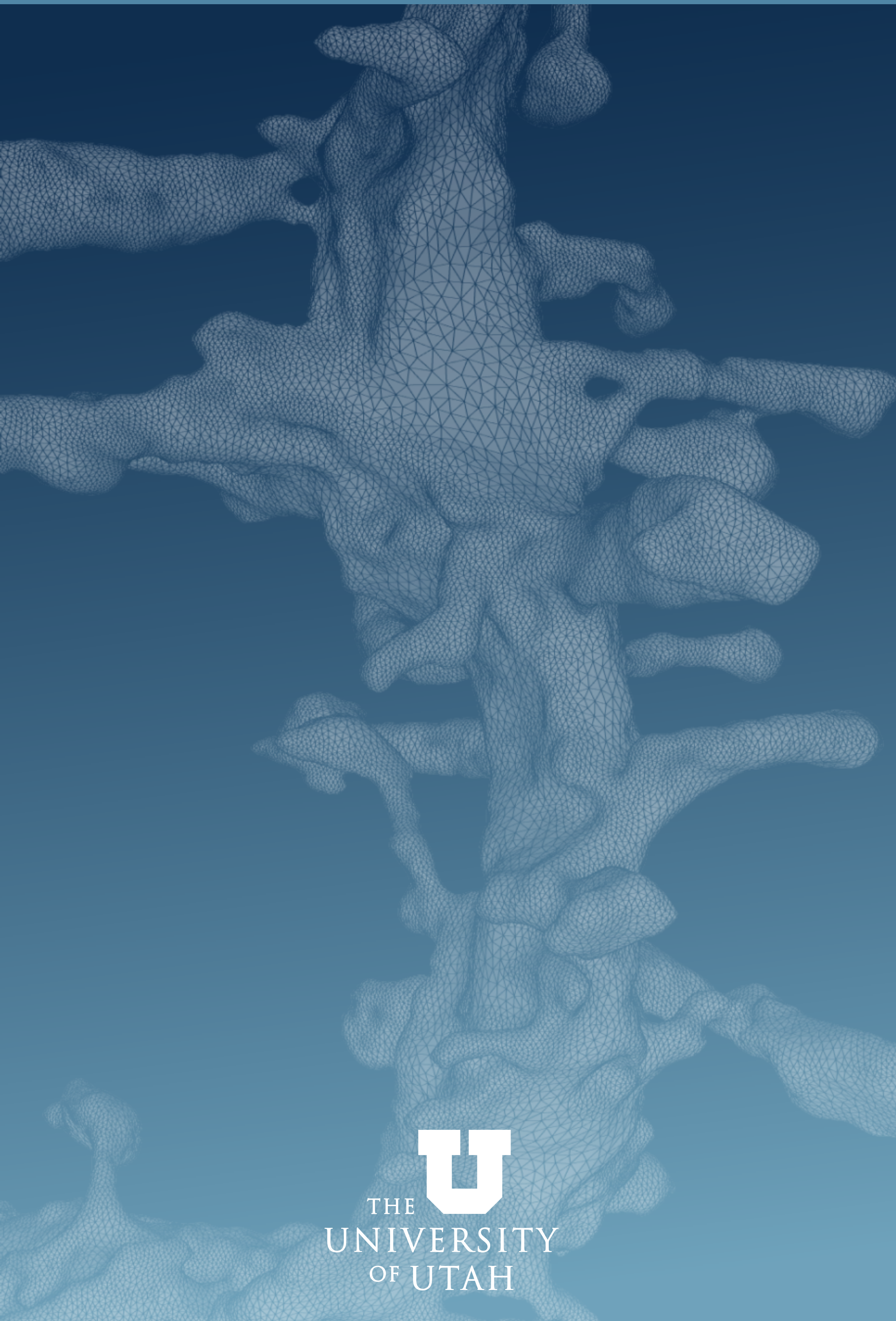

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