# An Introduction to Data Visualization and Scientific Illustration Workflow

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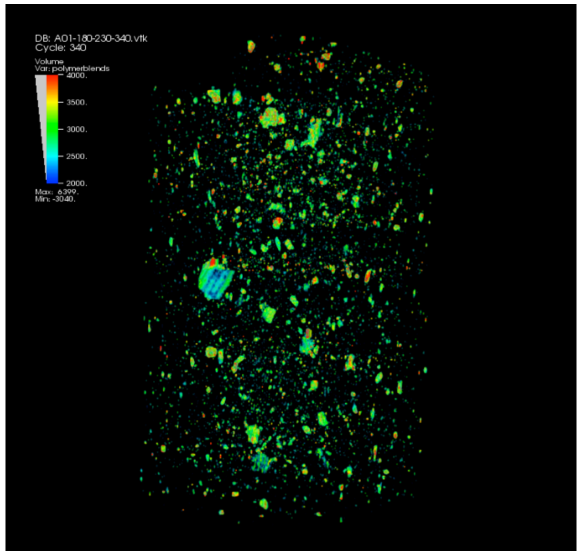
http://avsl.cct.lsu.edu/

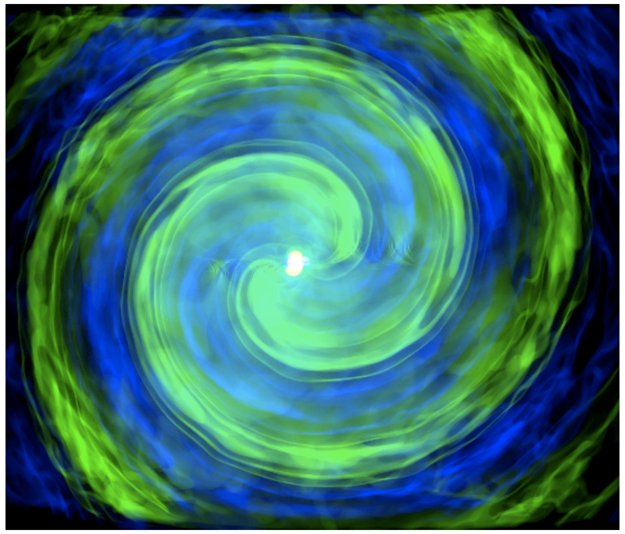
**LSU HPC Training, Nov 28, 2012**

# Introduction

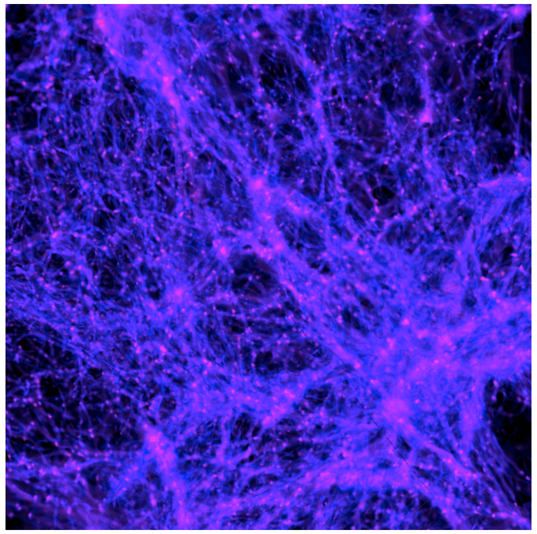
- Part of scientific research workflow
- Stimulate interdisciplinary collaboration
- Both topic and media of classroom education
- Advocate science to public




Assessment of the effectiveness of flame retardant in polymer blends with synchrotron X-ray tomography,
Data Curtesy of Dr. Leslie Butler,
Louisiana State University



Gravitational waves of black hole collision, simulated using Einstein's equation,
Data courtesy of Dr. Erik Schnetter,
Louisiana State University



Formation of the universe, simulated using the ENZO computational cosmology code,
Data courtesy of Dr. Britton Smith,
University of Colorado

# Workflow

- Storage, network : large data, 10G network on the way
- Data Format: software support, parallel-friendly
- Data Processing: registration, pattern recognition
- Data Visualization : many algorithms
- Production Pipeline:
    - *Modeling, Rigging, Camera Animation*
    - *Rendering: software, hardware, high quality, stereo*
    - *editing, sound, special effects*

# ToolSets

- Programming
  - C/C++, use of scientific libraries
  - Python, Numpy, Scipy, iPython, R
- Visualization:
  - Avizo, VisIT, VisTrails, Paraview, Osirix, Matlab, Mathematica
  - Matplotlib, PyOpenGL, glumpy, ggplot
  - Local software: Vish, pcaster
  - Scripting interface to extend the software: python, tcl,
- Modeling, Rigging, Animation:
  - Maya, Blender 3D, GoogleSketch, Illustrator
- Video Production:
  - ffmpeg, Screenflow, FinalCut, Adobe Premiere

# Interdisciplinary Connection and Research Projects

- Distributed Visualization pipeline with network testbed, NSF award, Scale'09 award.
- Enable parallel volume rendering and streamline visualization on large scale simulation data representing jet streams produced as stars or other stellar objects form and merge. Data conversion and visualization, Collaborator: Dr. Jan Staff, Department of Physics & Astronomy.
- Develop custom modules in VisTrails to analyze complex aspects of the binary star merger in quantitative detail.
  Collaborator: Dr. Joel Tohline, Department of Physics & Astronomy.
- Develop integrated workflow to process large variety of neutron and synchrotron X-ray tomography datasets in material science.
  Collaborator: Dr. Leslie Butler, Department of Chemistry. Dr. Claudio Silva, NYU-Poly
- Material science data visualization education with interactive iBook and remote backend parallel computation. Collaborator: Dr. Leslie Butler, Department of Chemistry. Dr. Chris Branton, Dr. Brygg Ullmer, CCT
- Construct an animated virtual 3D model of a singing Cardinal composed of skeletons, muscles, ligaments, and fascias guided by MRI, ultrasound images and X-ray cinematography.
  Collaborator: Dr. Dominique Homberger, Department of Biology.
- Visualization and layout optimization multi-block unstructured mesh data for numerical simulation of fracture.
  Collaborator: Dr. Blaise Bourdin, Department of Mathematics.

# Interdisciplinary Connection and Research Projects, Cont.

- Organization and camera animation for microscale porous flow visualization in Avizo. Collaborator: Dr. Karsten Thompson, and Timothy Thibodeaux, Ryan Al-Marhoun, Department of Chemical Engineering.
- Image registration and 3D Reconstruction of brain, ear, nose structure of a 55 million years old insectivore from sliced fossil image stack. Collaborator: Dr. Suyin Ting, LSU Museum of Natural Science.
- Underwater Oil spill illustration using Maya modeling and rendering software. Collaborator: Dr. Louis J Thibodeaux, Department of Chemical Engineering.
- Movie editing, camera keyframe animation, multi-view video sync, Collaborator: Dr. Werner Benger, CCT

# Science Advocation

First group of "**Visualization at LSU**" projects to showcase research at LSU in the form of Visualization: (randomly listed)

- Microscale fluid flow simulations of dispersion, solute and particle transport through porous materials.
  Research group: Dr. Karsten Thompson, and Timothy Thibodeaux, Ryan Al-Marhoun, Department of Chemical Engineering.
- Microscale shale and proppant segmentation.
  Research group: Dr. Clint Willson, and Paula **Sanematsu**, **Godfrey Mills**, Department of Civil and Environmental Engineering.
- Stellar jet streams produced as stars or other stellar objects form and merge.
  Research group: Dr. Jan Staff, Department of Physics & Astronomy.
- Binary star merge to create a new star.
  Research group: Dr.Joel Tohline and Dr.Jan Staff, Department of Physics & Astronomy.
- Turbulent flow behavior of stirred tank reactor.
  Research group: Dr. Sumanta Acharya, Department of Mechanical Engineering, and Dr.Werner Benger, Farid Harhad, CCT.
- Fracture mechanics of hot-cold surface contact.
  Research group: Dr. Blaise Bourdin, Department of Mathematics.

# Workflow Recap

- Storage, network
- Data Format
- Data Processing
- Data Visualization
- Production Pipeline

# Data Format

# Multi-block Data Layout

- Large data generation
  - *Computational: parallel IO -> multiple files*
  - *Experimental: single file large size -> concept of sub-block*
- Parallel visualization
  - *Software's data reader needs to be implemented to distribute sub-blocks among processors.*
  - *Pay attention to ghost zone*
- Multi-block data layout support:
  - *Binary: Silo, CGNS, NetCDF, Exodus*
  - *meta-file: multi-block vtk xml, XDMF, BOV*

# Data Formats : SILO

- https://wci.llnl.gov/codes/silo
- Support mesh type: gridless (point), structured meshes, unstructured-zoo and unstructured-arbitrary-polyhedral, block structured AMR, constructive solid geometry (CSG); nodal or zonal variables on the mesh
- data block: [<silo-filename>:]<path-to-mesh>
- A “virtual” multi-block object model
- Mesh Region Grouping (MRG) trees decomposition of a multi-block mesh into various regions
  - *region types: materials, parts in an assembly, levels in an adaptive refinement hierarchy, nodesets, slide surfaces, boundary conditions,etc.*
  - *MRG trees support both multiple groupings and hierarchical groupings.*
- Support by Visualization software *VisIt*

# Data Formats : CGNS

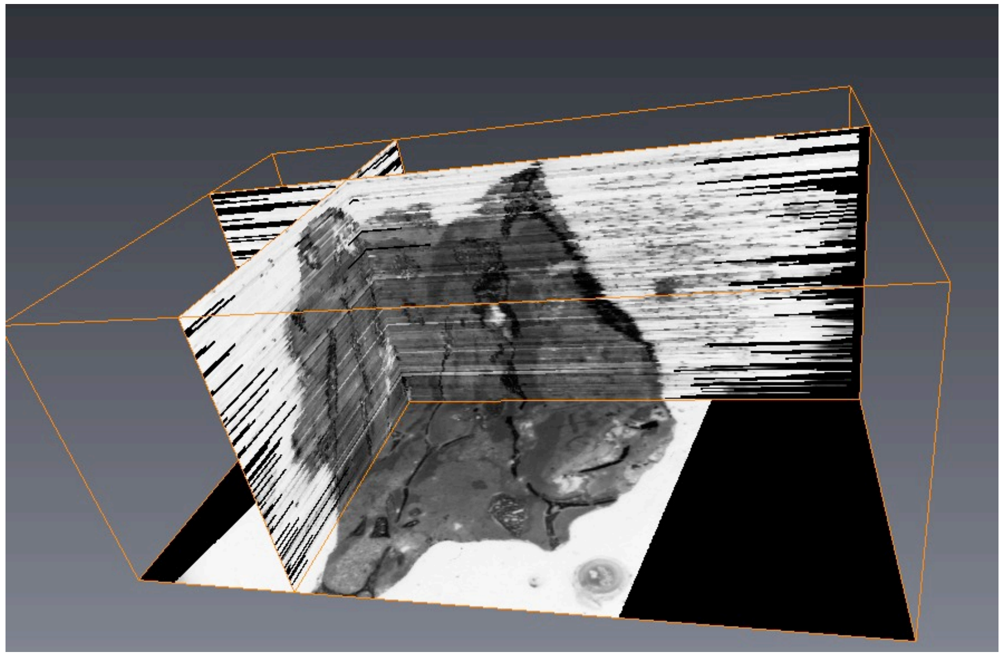
- http://www.grc.nasa.gov/WWW/cgns
  - *Documentation: entry level, user guide, mid level library, SIDS*
- Structured, unstructured, and hybrid grids
- Flow solution data, which may be nodal, cell-centered, face-centered, or edge-centered
- Multizone interface connectivity, both abutting and overset
- CFD specifics: Flow equation descriptions, including the equation of state, viscosity and thermal conductivity models, turbulence models, and multi-species chemistry models
- Time-dependent flow, including moving and deforming grids
- Support by VisIt. CGNS2.5 compatible dataset are readable by Avizo

# Data Formats : XDMF

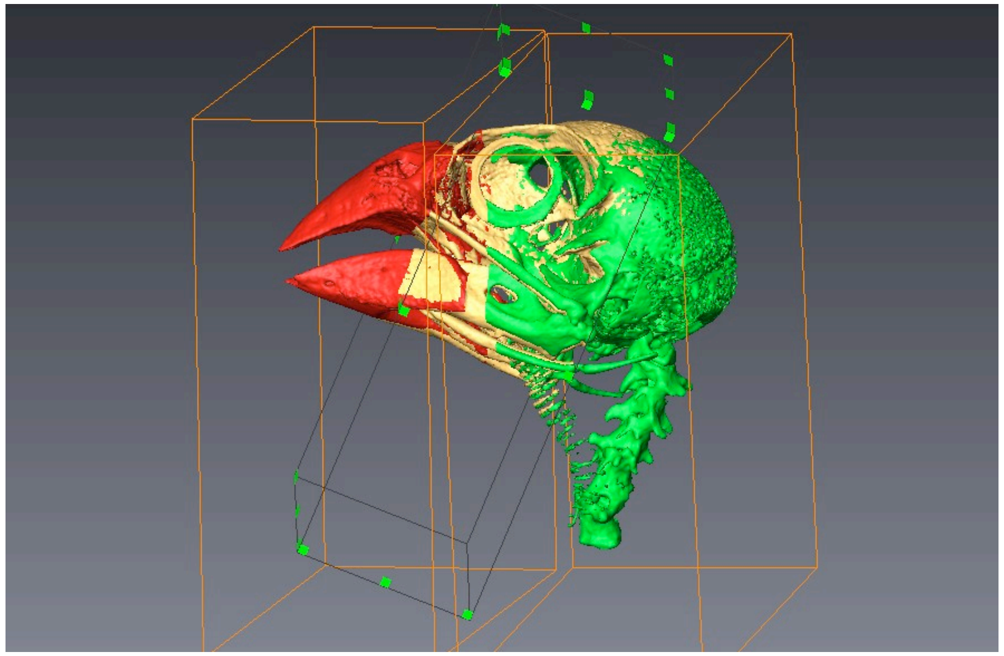
- http://www.xdmf.org/index.php/Main_Page
- Light data is stored using XML, Heavy data is typically stored using HDF5.
    - *A DataItem can provide the actual values or provide the physical storage (which is typically an HDF5 file).*
    - *Grid contains a Topology, Geometry, and zero or more Attribute elements*
- Grid Type:
    - *Collection: "Spatial" or "Temporal"*
    - *Tree - a hierarchical group*
    - *SubSet - a portion of another Grid*
- XML Inclusions (XInclude) to combine multiple xdmf files
    - *<xi:include href="EB_spatial-ts50.xmf" xpointer="xpointer(//Xdmf/Domain/Grid)" />*

# Data Processing

# Registration



Data Courtesy of Dr. Suyin Ting, LSU Natural Science Museum



Data Courtesy of Dr. Dominique Homberger, Department of Biology, LSU

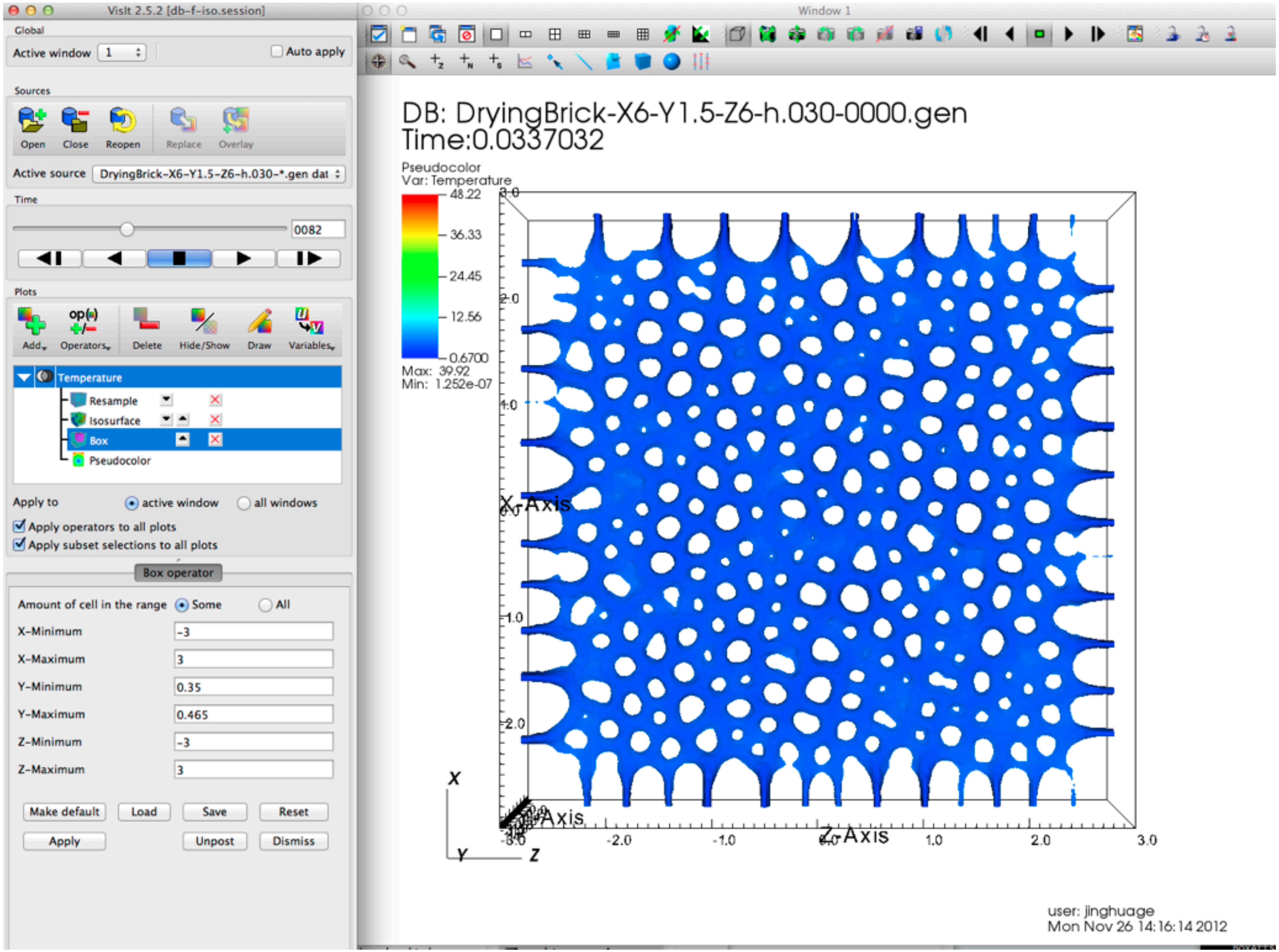
- Medical Imaging
  - *CT/MRI to PET/CT*
  - *contrast-enhanced CT to non-contrast-enhanced CT*
  - *Ultrasound to CT*
- Register stack of 2D images, or multiple 3D datasets
- Affine and elastic transformation
- Feature based, intensity based, similarity based
- Some support from: ImageJ, Avizo

# Data Visualization

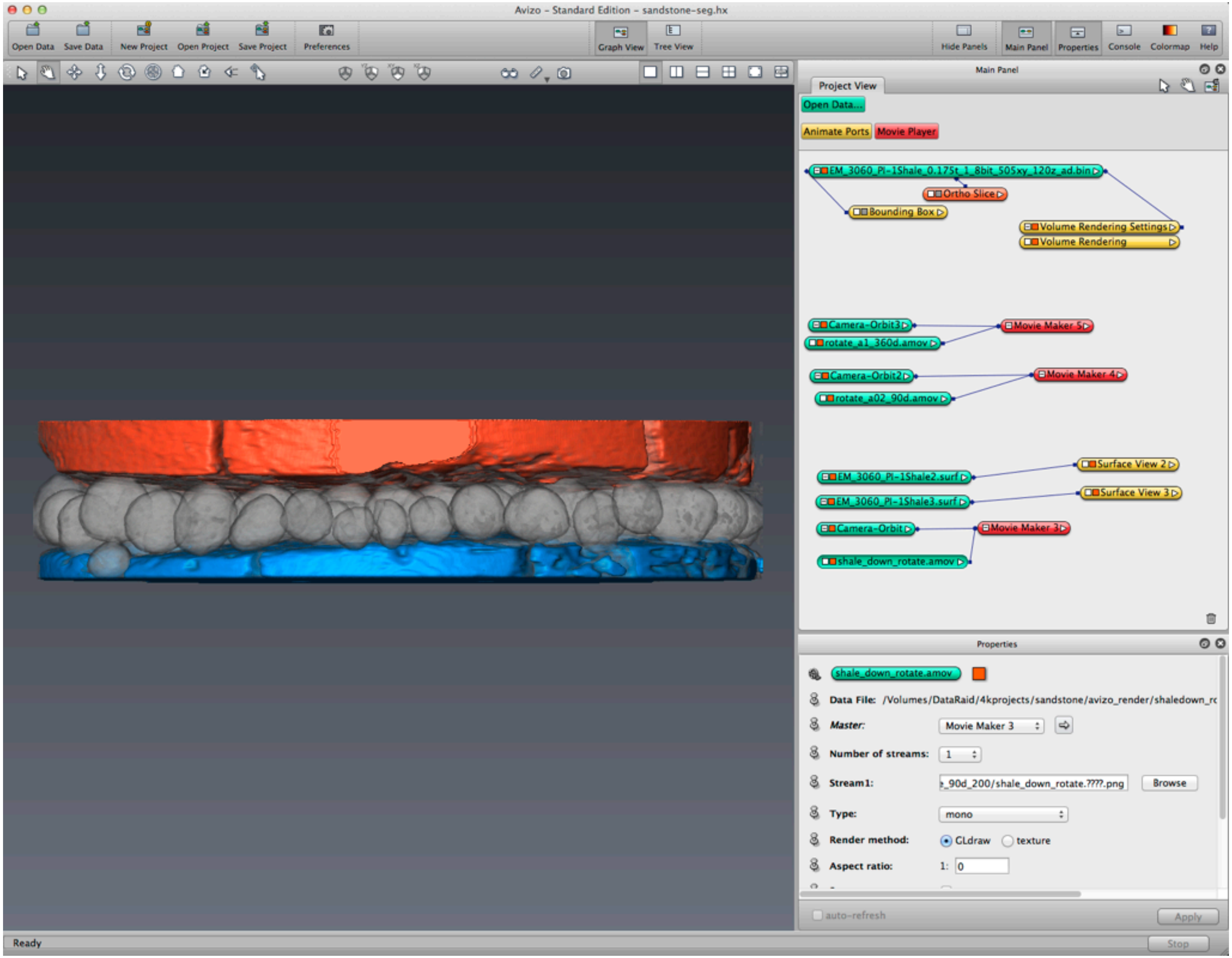
# Visualization Algorithms

- Represent data values: color, elevation, geometry size;
- Data selection: profile, slicing, iso-surface/volume;
- Volume rendering: 3D texture, Ray-casting;
- Segmentation: multi-threshold; semi-automatic; manual;
- Quantification Analysis: watershed segmentation; connected components; filter and sieve; color by distance;
- Streamline, pathline, particle tracing, line integral convolution (LIC)
- Data evaluation over Time: Calculate the time when a condition occurs;
- New algorithms from visualization research

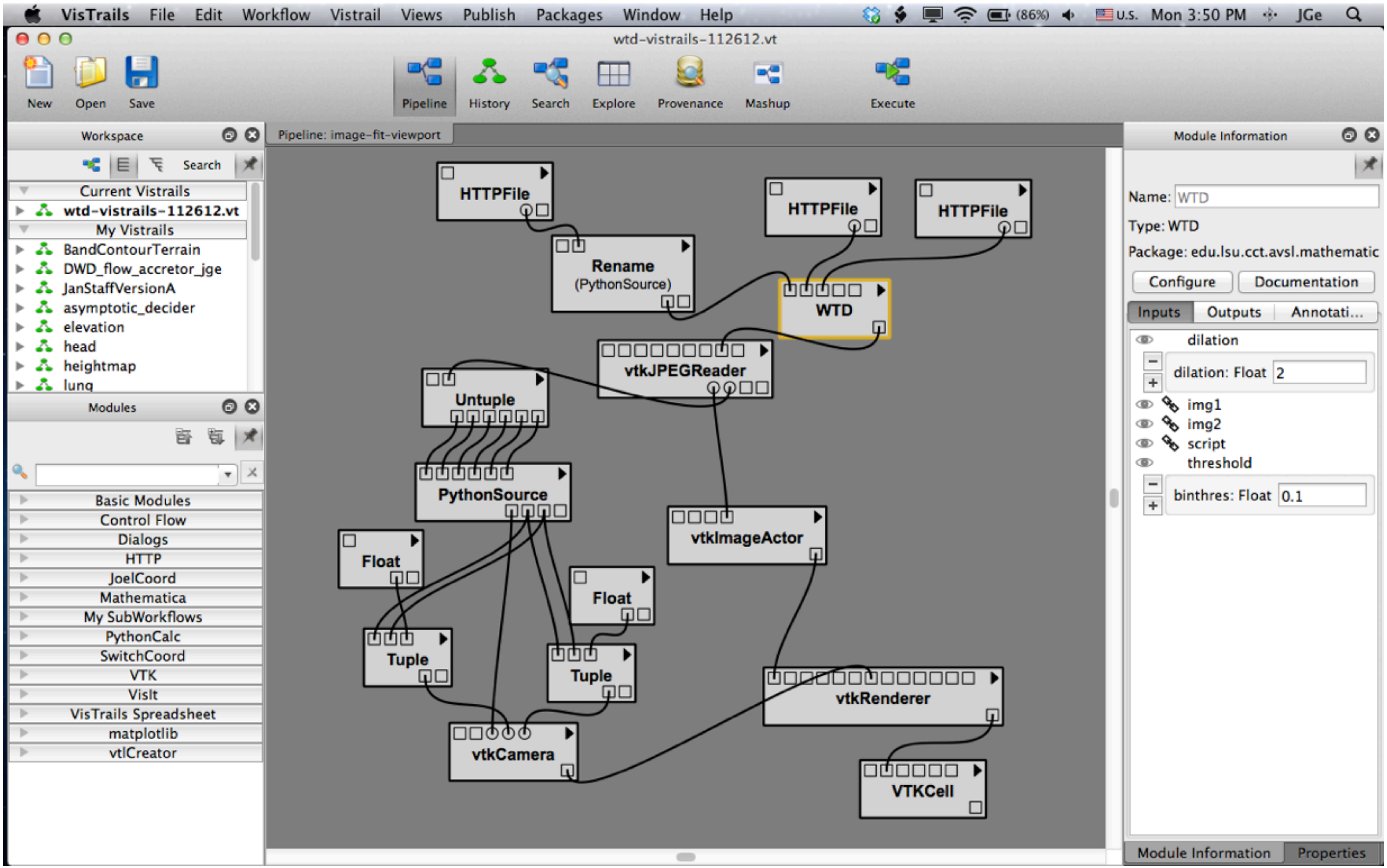
# Visualization in VisIT



# Visualization in Avizo

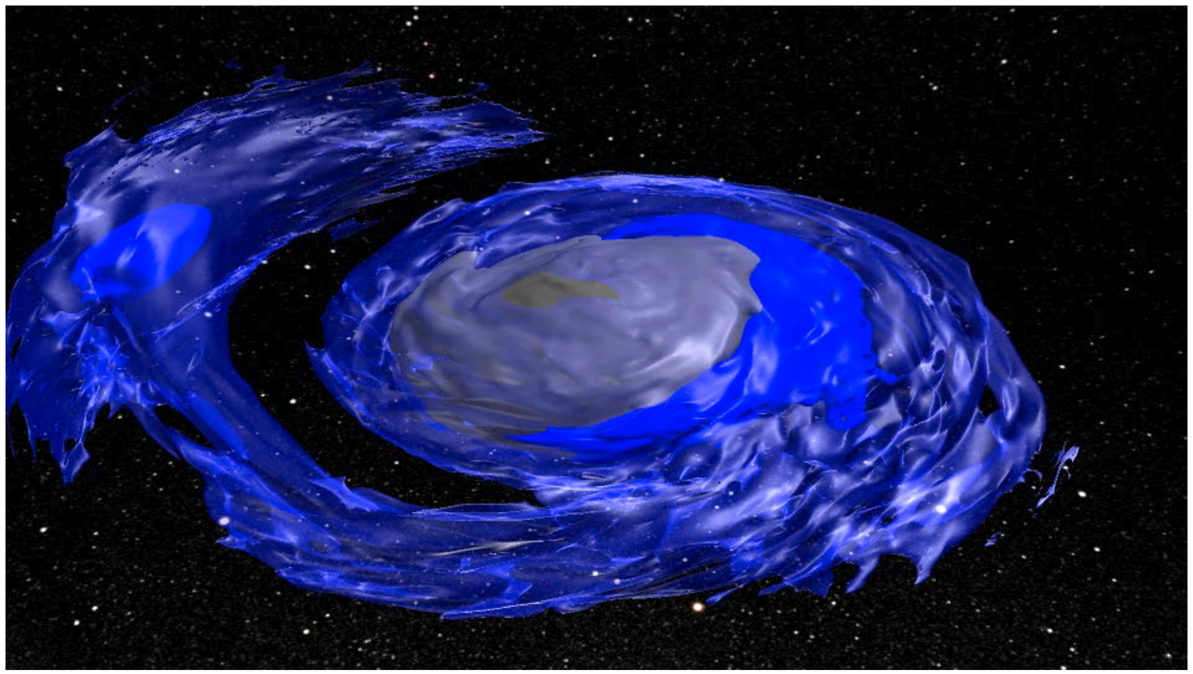


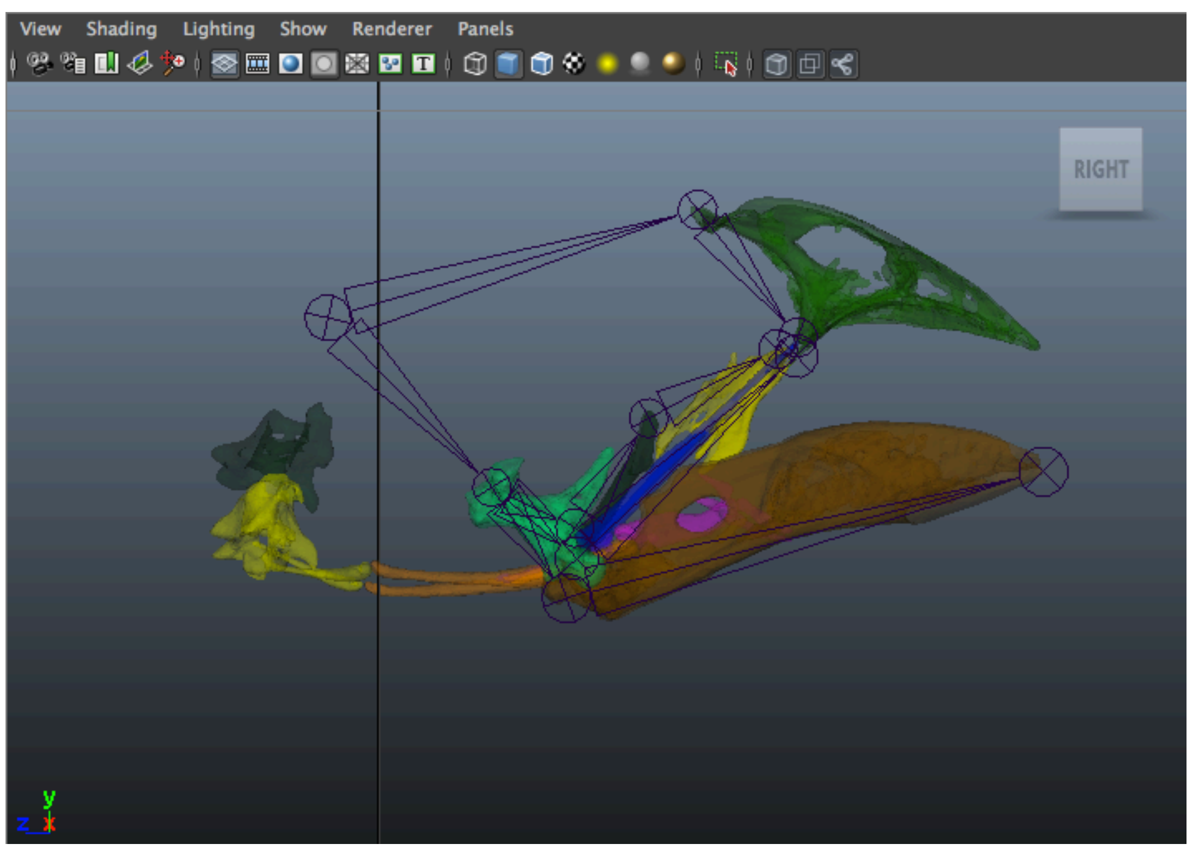
# Visualization in VisTrails



# Production Pipeline

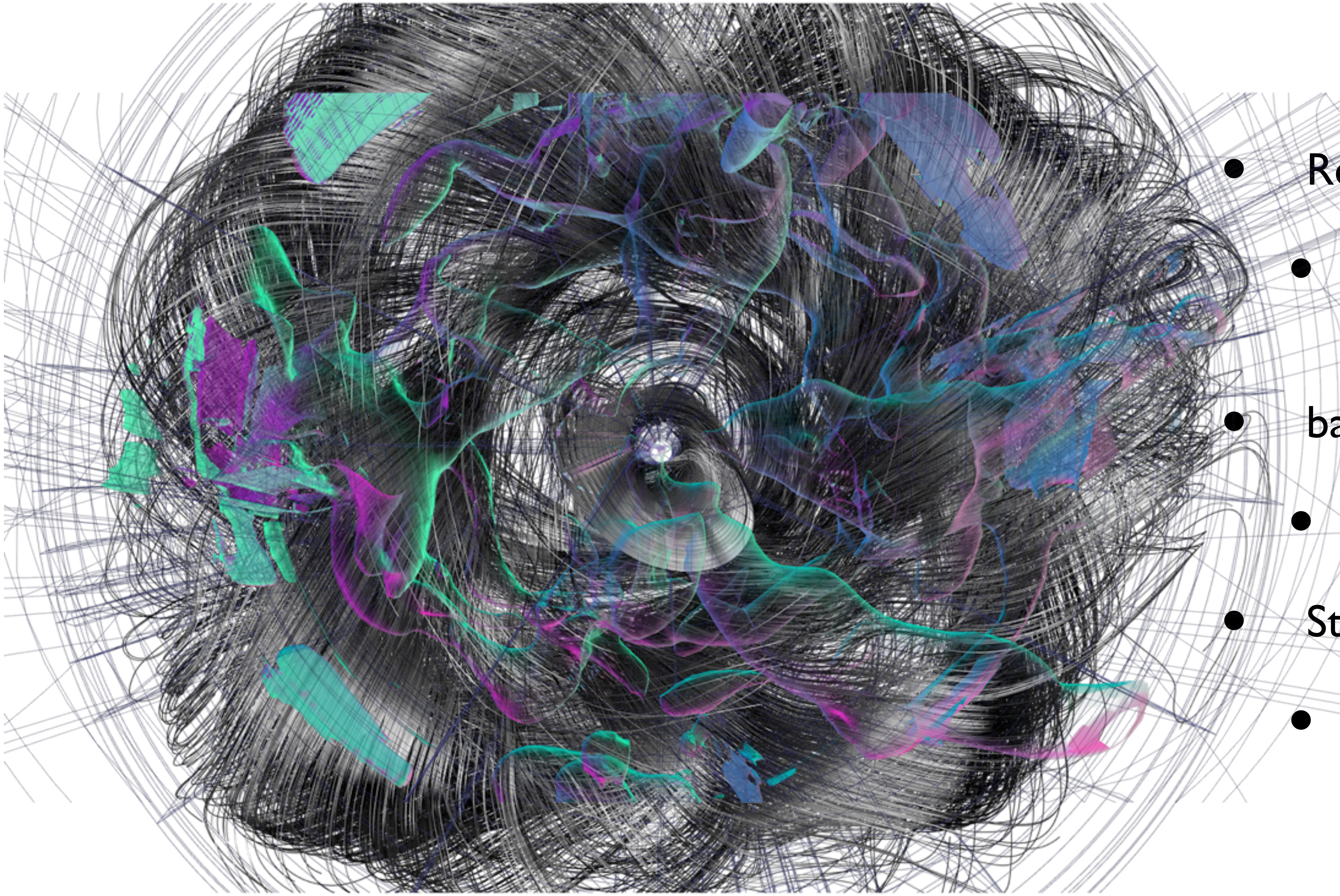
# Modeling, Rigging, Animation






- Import/export objects among software
- Create models
- Character animation
  - *joints, skeleton, muscle*
- Camera animation
  - *keyframe animation*
  - *standard camera path import/export*

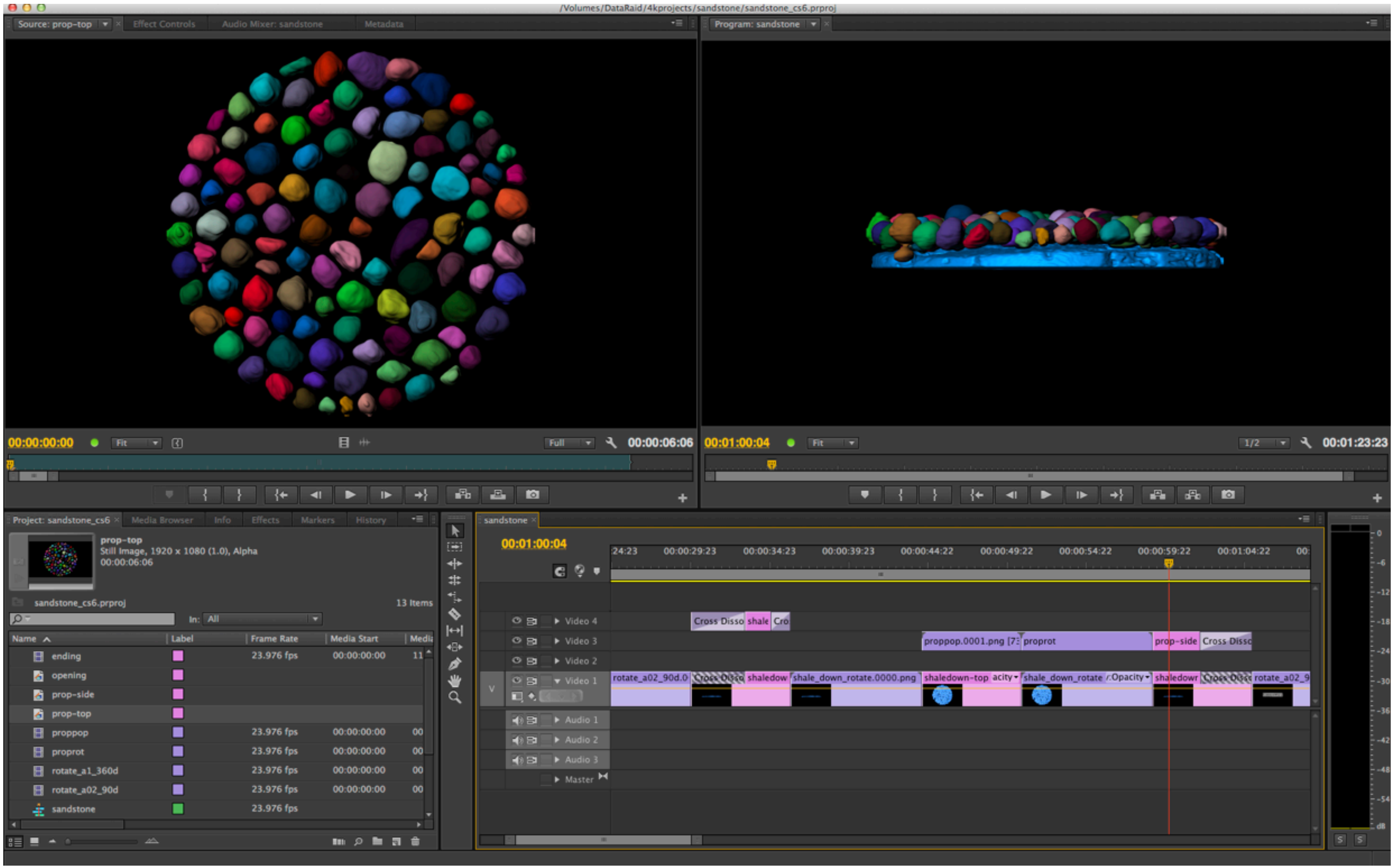
# Rendering



Turbulent flow in a stirred tank, streamline and isosurfaces
Visualization produced by Dr. Werner Benger, CCT, LSU
Visualization software: Vish
[http://sciviz.cct.lsu.edu/projects/vish/](http://sciviz.cct.lsu.edu/projects/vish/)

- Render quality
  - software/hardware/mental ray;
- batch rendering (parallel)
  - Maya, VisIt
- Stereo render
  - render anaglyph, or render as separate images and composite as you like

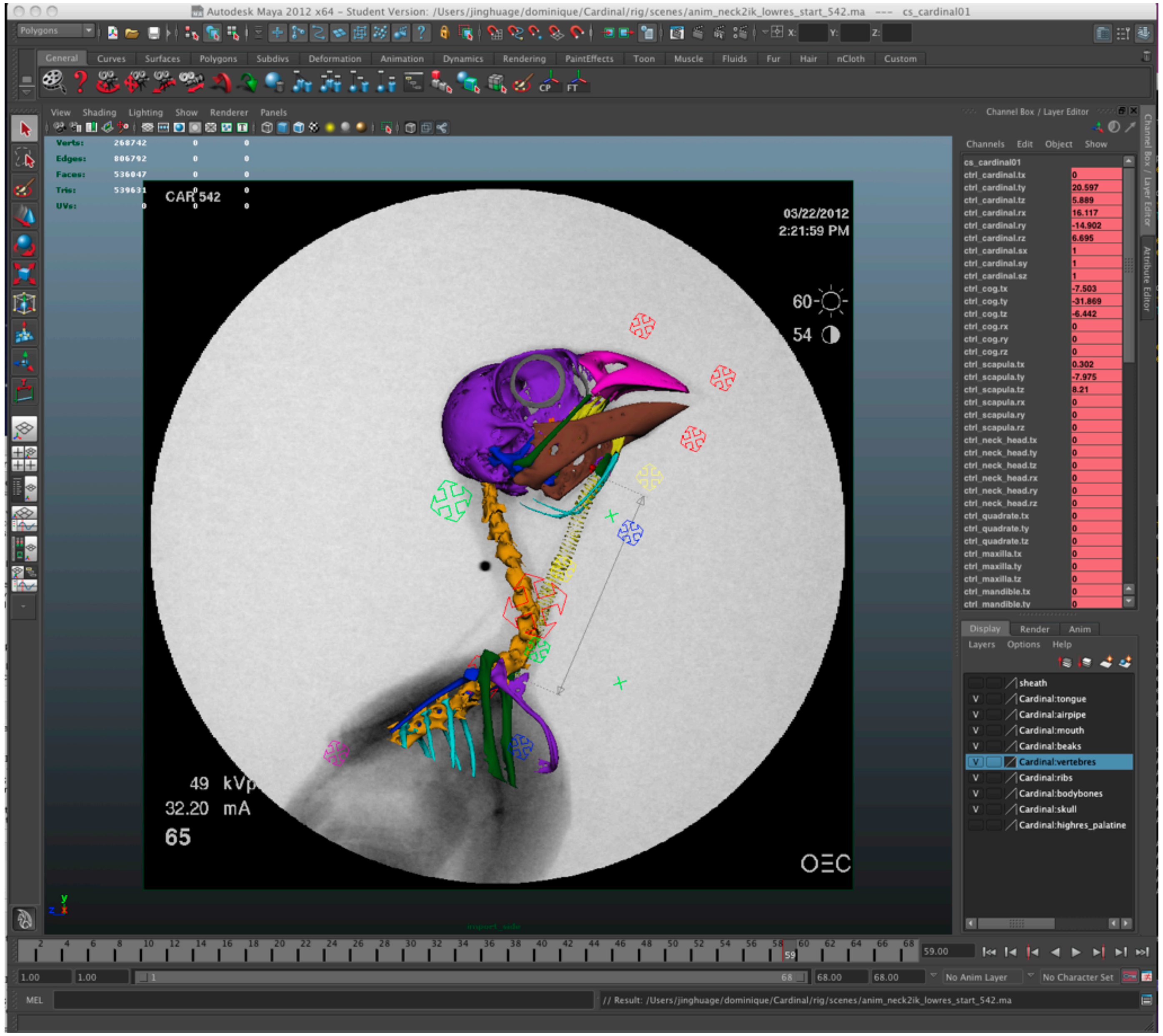
# Editing in Adobe Premiere



# Projects Review

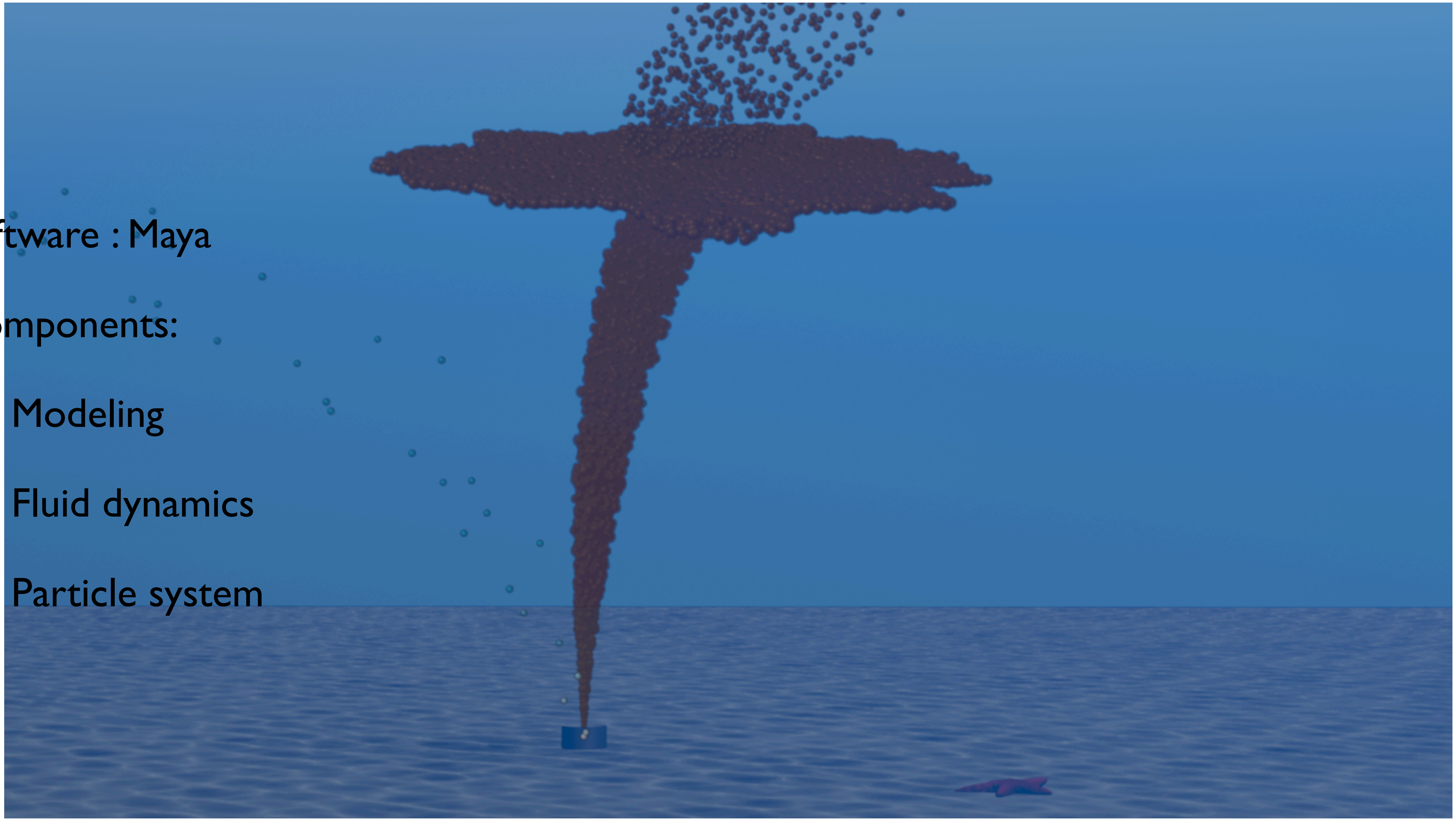
# Rig the Cardinal

- Software : Maya
- Components:
  - Rigging
  - Animation
- X-ray cinemagraphy trained kinematics




Collaborators:
Dr. Dominique Homberger, Department of Biology, Louisiana State University
Dr. Rod Suthers, Indiana University

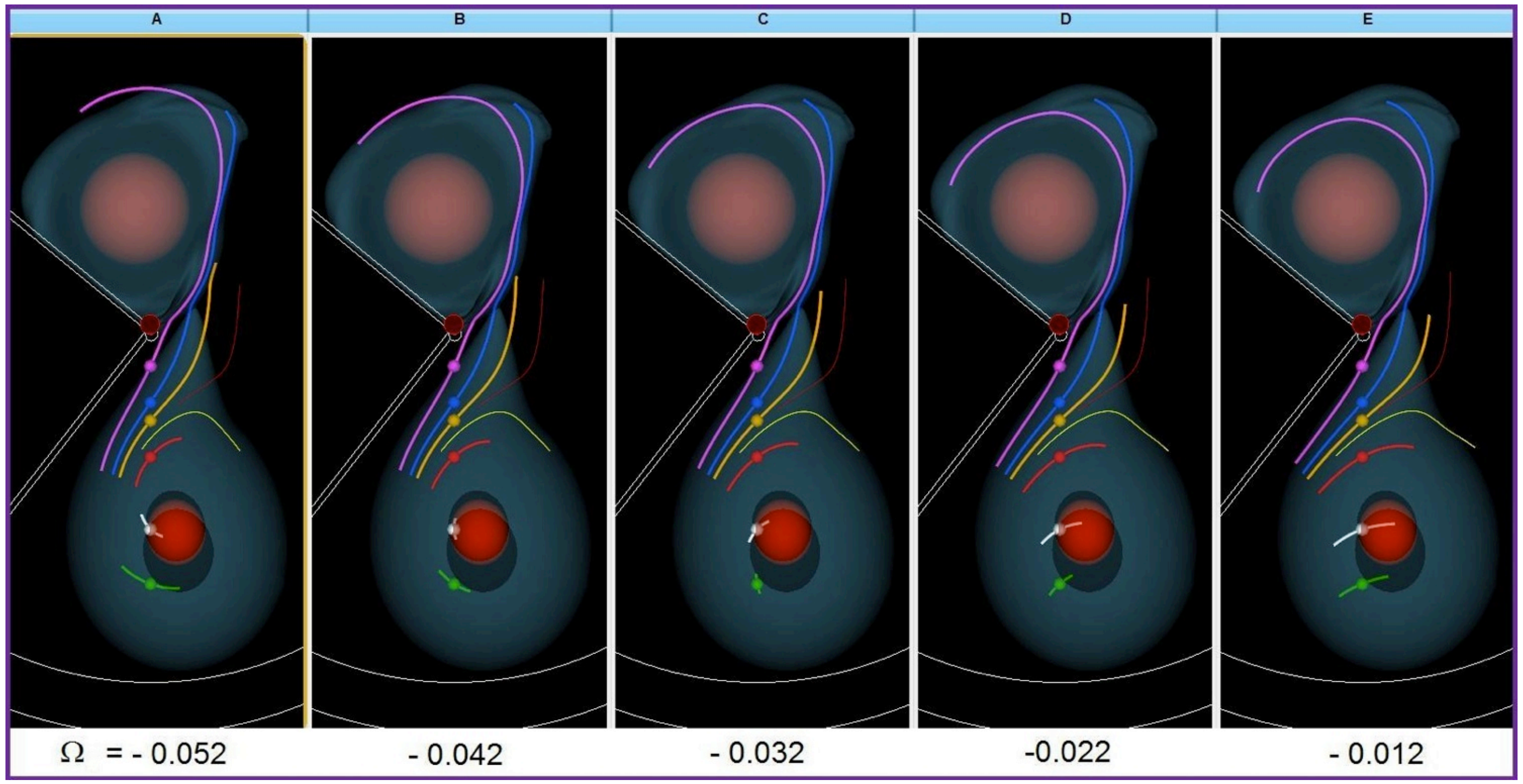
# Deep Water Horizon Oil Spill



- Software : Maya
- Components:
    - Modeling
    - Fluid dynamics
    - Particle system

Science input: Dr. Louis JosephThibodeaux,
Department of Chemical Engineering, Louisiana State University

# Binary Star Merge



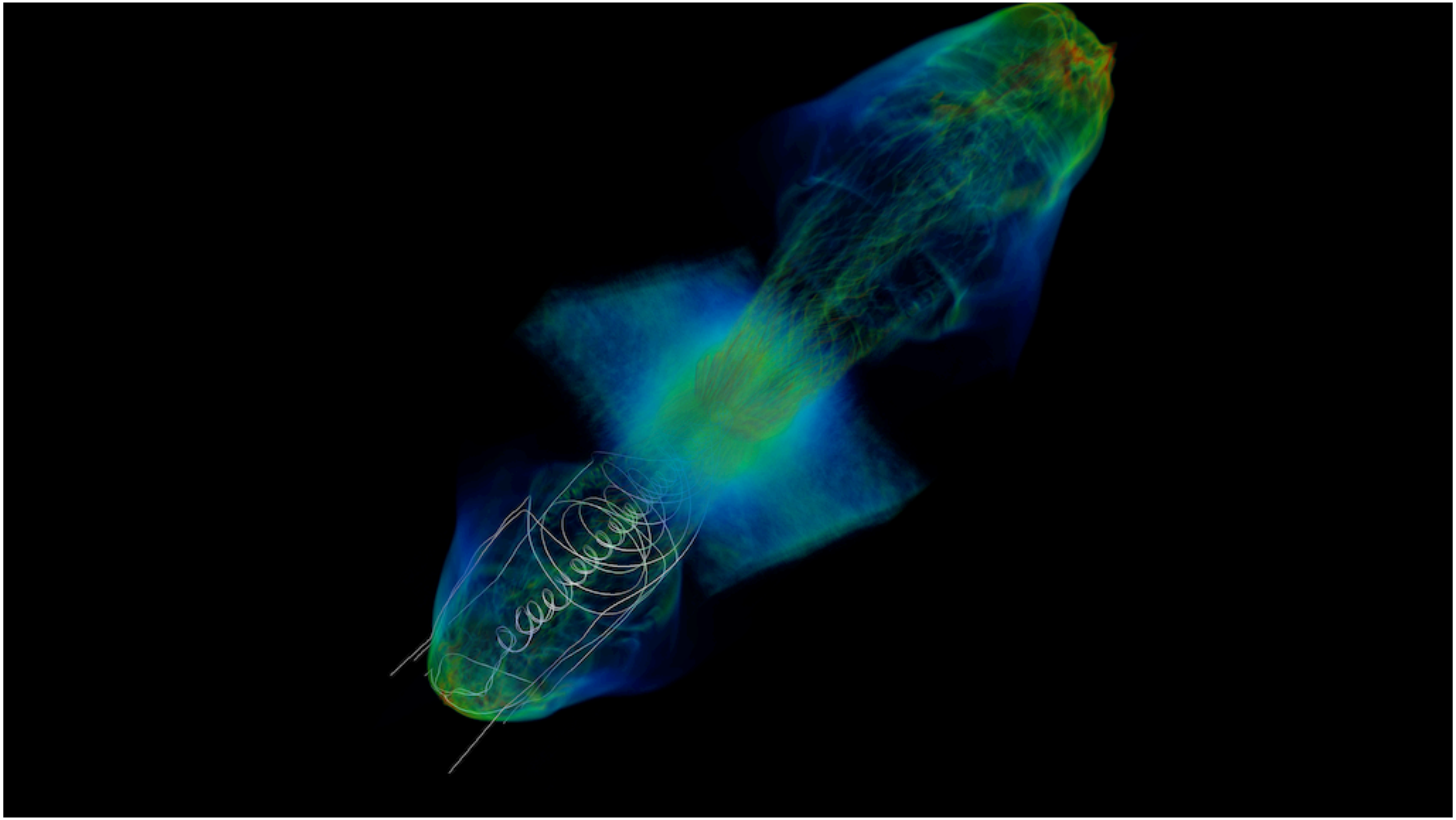

Key rotational frequencies associated with fluid flows in simulations of merging binary stars.
Image made by Dr. Joel Tohline, Louisiana State University

- Project description: Customized python module in VisTrails in analysis of merging binary star simulations
- Lead Scientist: Dr. Joel Tohline (Dept. of Physics & Astronomy, 2009)
- Goal: The CFD simulation of mass-transferring binary star system is modeled on a cylindrical-coordinate grid that rotates with a frequency Ω. We want to use the viz tool to help identify the rotation frequency.

**Publication:**

J. E. Tohline, J. Ge, W. Even, E. Anderson, "A Customized Python Module for CFD Flow Analysis within VisTrails", Computing in Science & Engineering, pp 68-73, Vol. 11, No. 3, May/June 2009

# MHD Jet

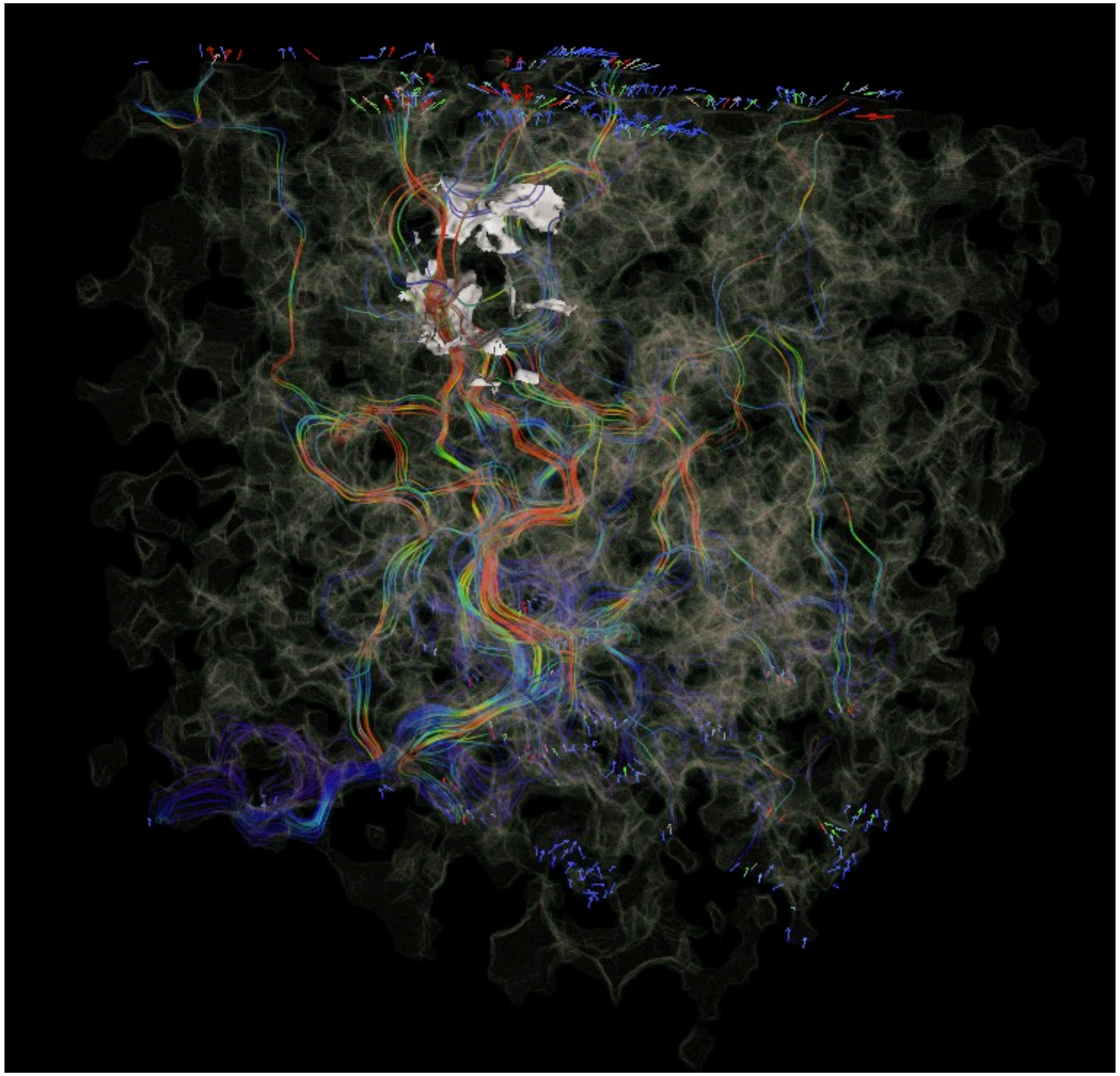


Visualization of tera-scale dataset simulating jet streams produced in the universe as stars or other stellar objects form and merge.

Visualization produced by Dr. Jan Staff

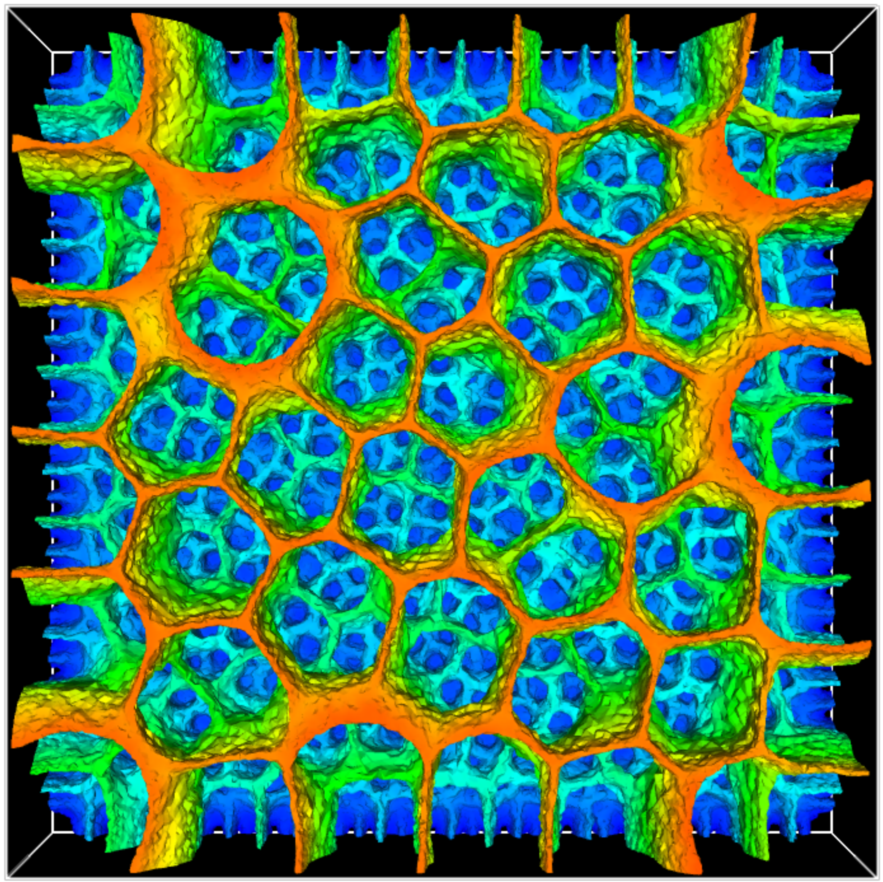
Department of Physics & Astronomy, Louisiana State University

# Porous Flow through Microscale Sandstone

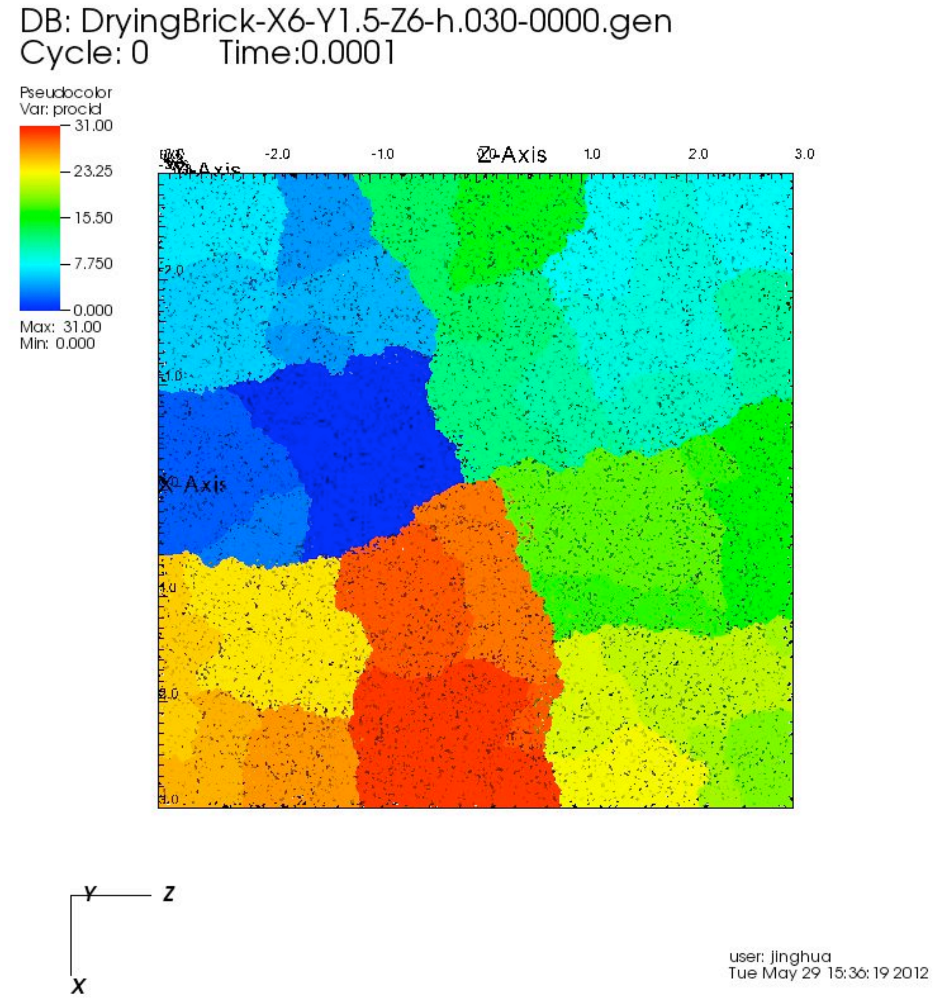


- Project Description: Microscale fluid flow simulations of dispersion, solute and particle transport through porous materials.
- Lead scientist:
  Dr. Karsten Thompson, and Timothy Thibodeaux, Ryan Al-Marhoun, Department of Chemical Engineering.
- Goal: 4k Movie visualizing the fluid flow through porous materials. Visualization features: streamlines, animated particles, vector glyphs, volume rendering, and flow-matching camera motion.
- http://www.youtube.com/watch?v=moXeE2wIujI

# Dryingbrick



Brittle fracture structures in micro scale
Visualization produced by Dr. Blaise Bourdin
Department of Mathematics,
Louisiana State University

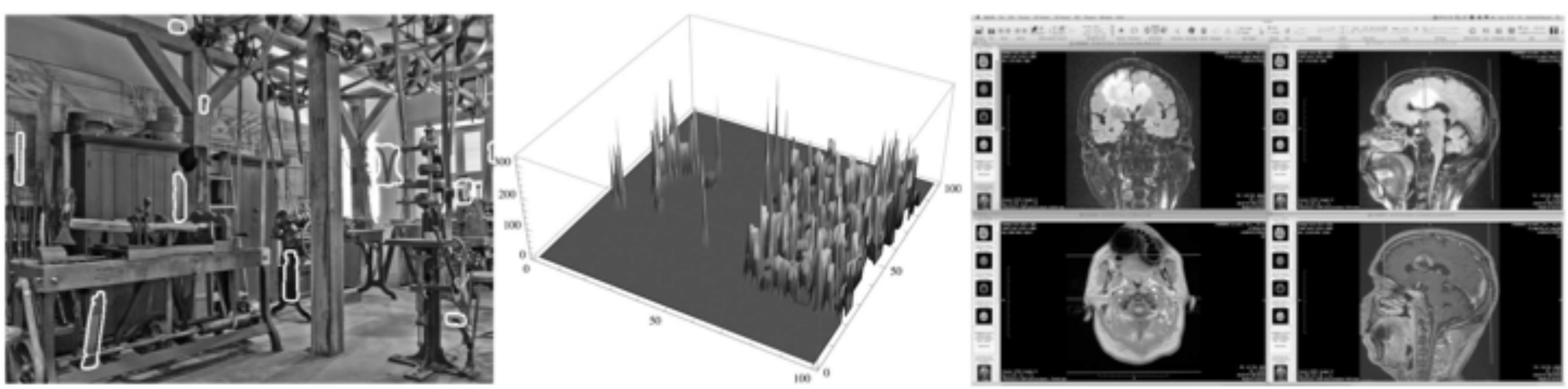



**DefineScalarExpression("procid", "procid(Mesh)")**
**AddPlot("Pseudocolor", "procid")**

# Education & Training

# Multidisciplinary Visualization Education and Training

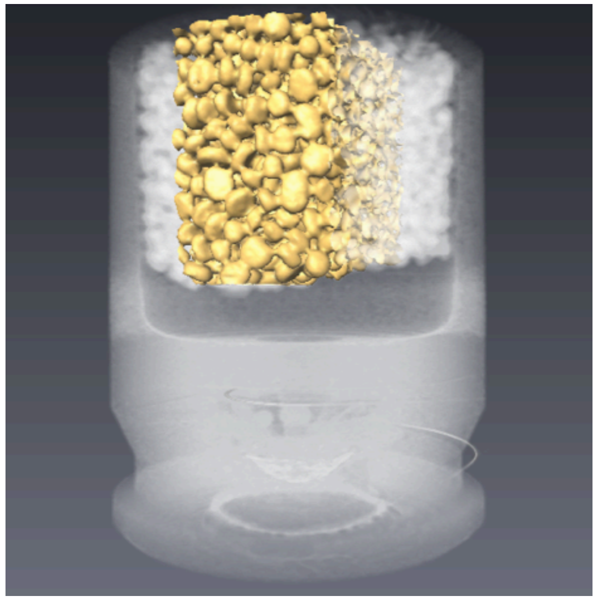
- Spring'13: Co-Teach the **multidisciplinary 3D visualization** course again, under Honor's college (HNRS 3035), with Dr. Butler
  - Past offering : Spring'12, at Department of Chemistry (CHEM 4581); Spring'11, from Honor's college (HNRS 3035) with Dr. Butler and Dr. Homberger
  - Course objective: Teach about multi-disciplinary students image processing and data visualization and analysis operations using real scientific datasets (anatomy, tomography, visible human)
  - Visualization software : Mathematica, ImageJ, Avizo, VisIt, (VisTrails)
  - Location and class material: Frey 101, ipad with ibook

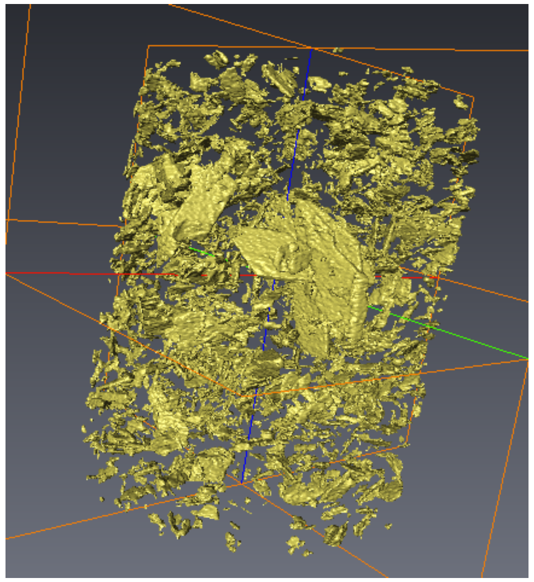


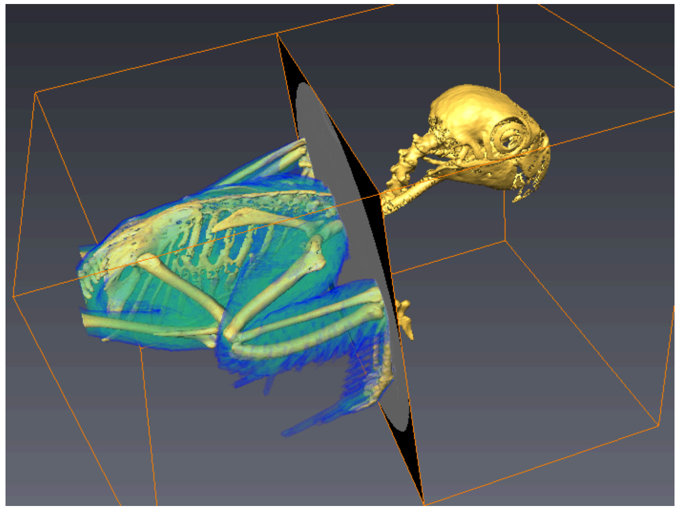
Examples of Mathematica processing and a public-domain MRI data sets.
Image made by Dr. Leslie Butler. Louisiana State University

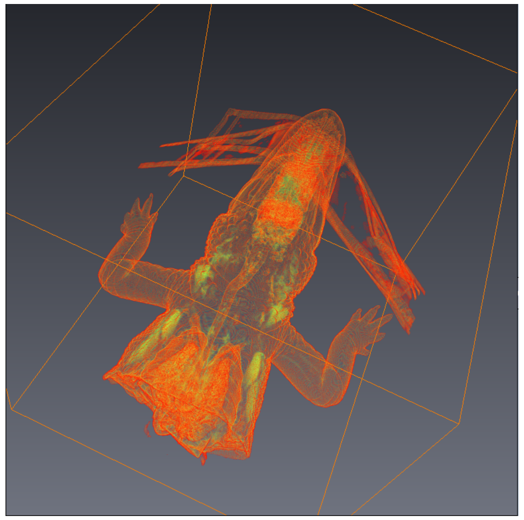
# Real Scientific Datasets Used in Class

- Material science datasets prepared by Dr. Butler
  - Fabricated devices: cartridge and NMR MAS rotor
  - Migmatite: neutron and X-ray data sets
  - Polymer blends: traditional and Greek golden ratio data acquisition
  - Volcanic basalts at different X-ray energies
- Biology datasets prepared by Dr. Homberger
  - Complete specimen of an African Grey Parrot
  - Intact head, neck, and shoulder of the American Alligator
  - Intact Spiny Dogfish Shark (Squalus acanthias)
  - Intact head of a female Northern Cardinal (Cardinalis cardinalis)
  - More complex anatomical specimen such as Budgerigar, Anolis Lizard, Finger of a human.









# Student projects showcase
## HNRS 3035, Spring'11

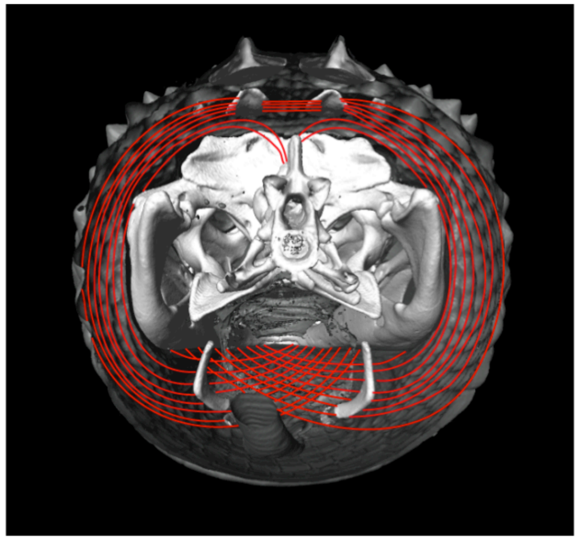
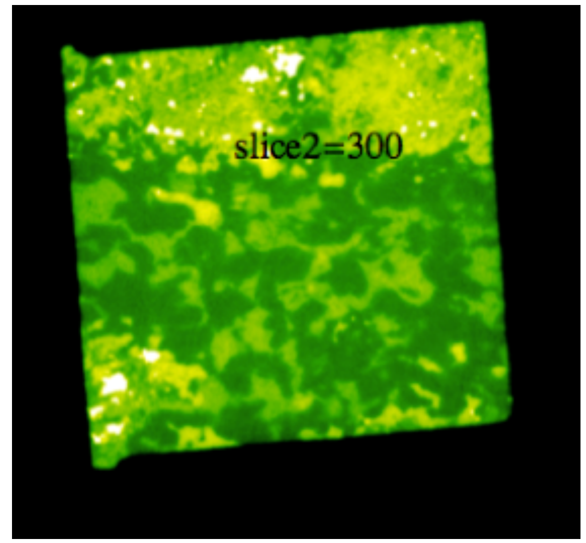
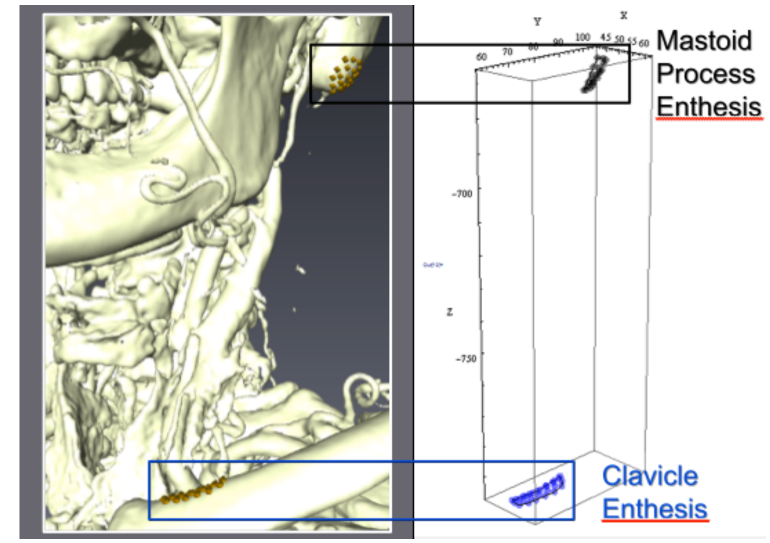


Illustration of the cranio-cervical envelope in the alligator,

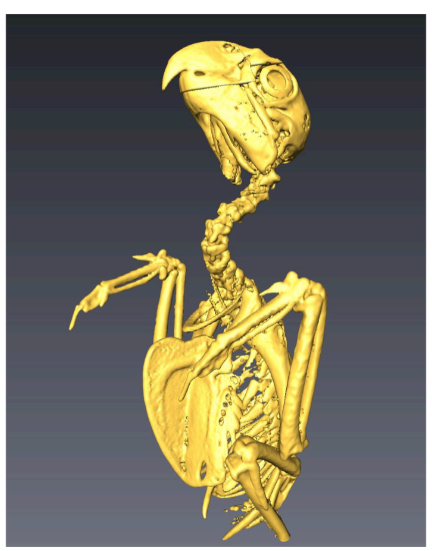
By Brooke Hopkins



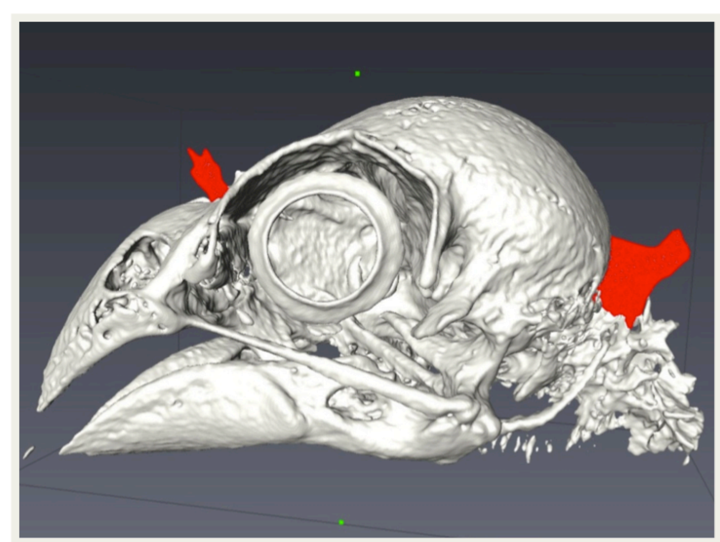

Weighted combination of X-ray and Neutron data sets revealing both internal and surface details,
By Dominique Gautreau



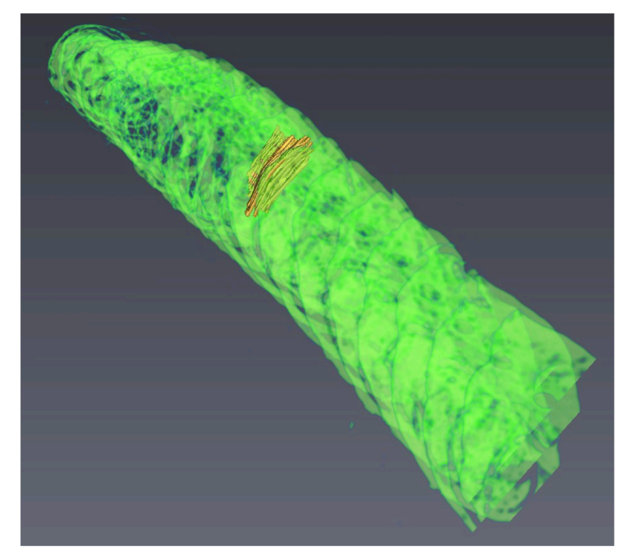

Visualization and analysis of the human shoulder suspensory apparatus,
By Michelle Osborn



Visualization of a clean skeleton of CT scan bird,
By Elise Orellana



Use of metal markers in 3D CT scan of cardinal head,
By Caroline Blevins



Detecting Myoseptal Tissue in a Lamprey,
By Bradley Wood

# Student projects showcase
## CHEM 4581, Spring'12

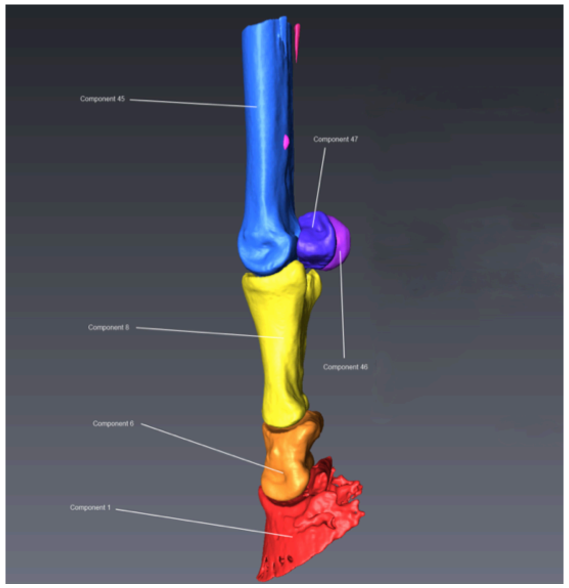
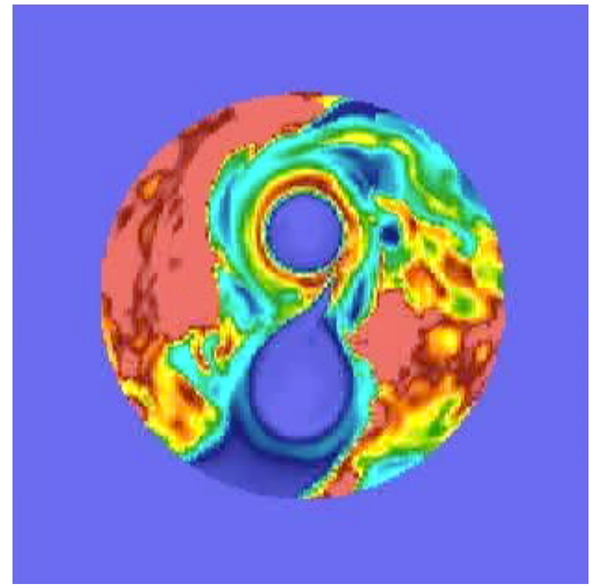
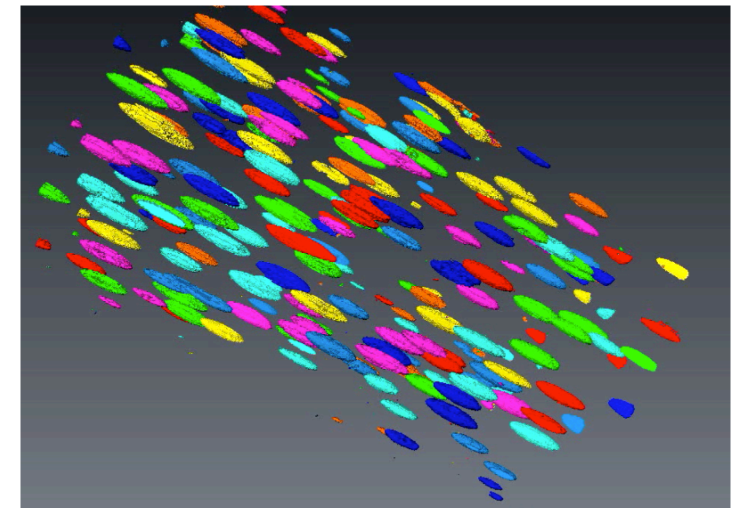


Illustration of the horse hoof bone segmentation,

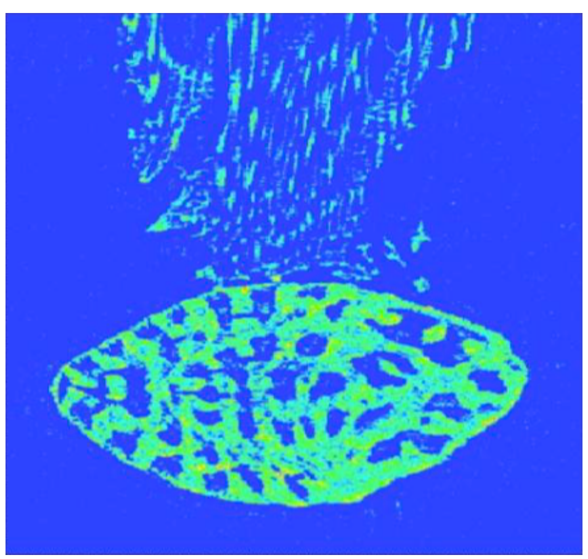
By Andrew Galatas



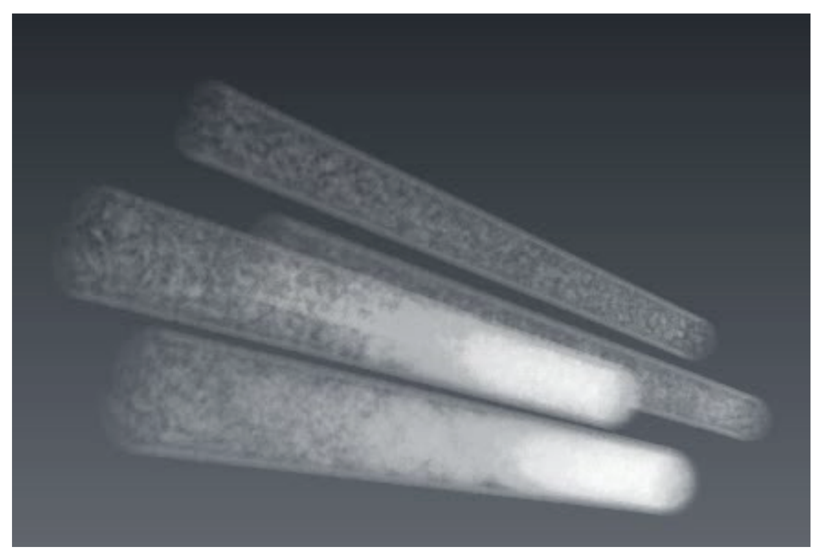
Visualization of a time-varying Merging White Dwarf simulation.
By Kundan Kadam



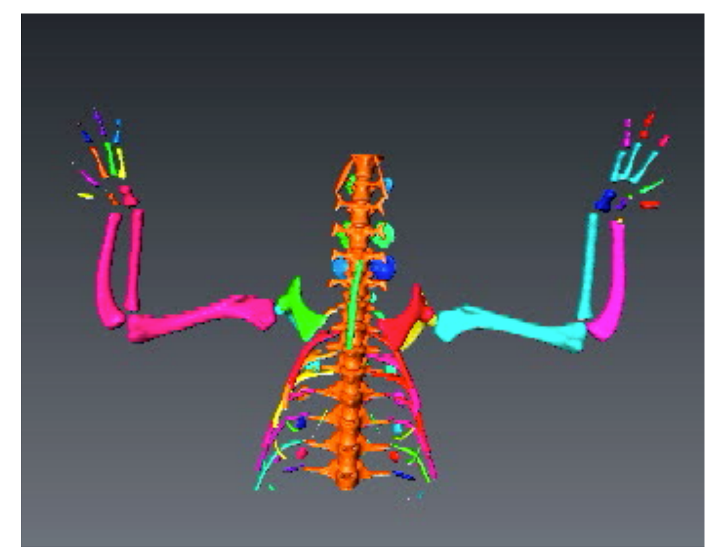
Air bubbles in Polymer blends,
By Troy Loeffler



Visualization of foraminifera samples (APS 2001)
By Chaitanya Joshi



hydrogen storage,
By Lucy Kiruri



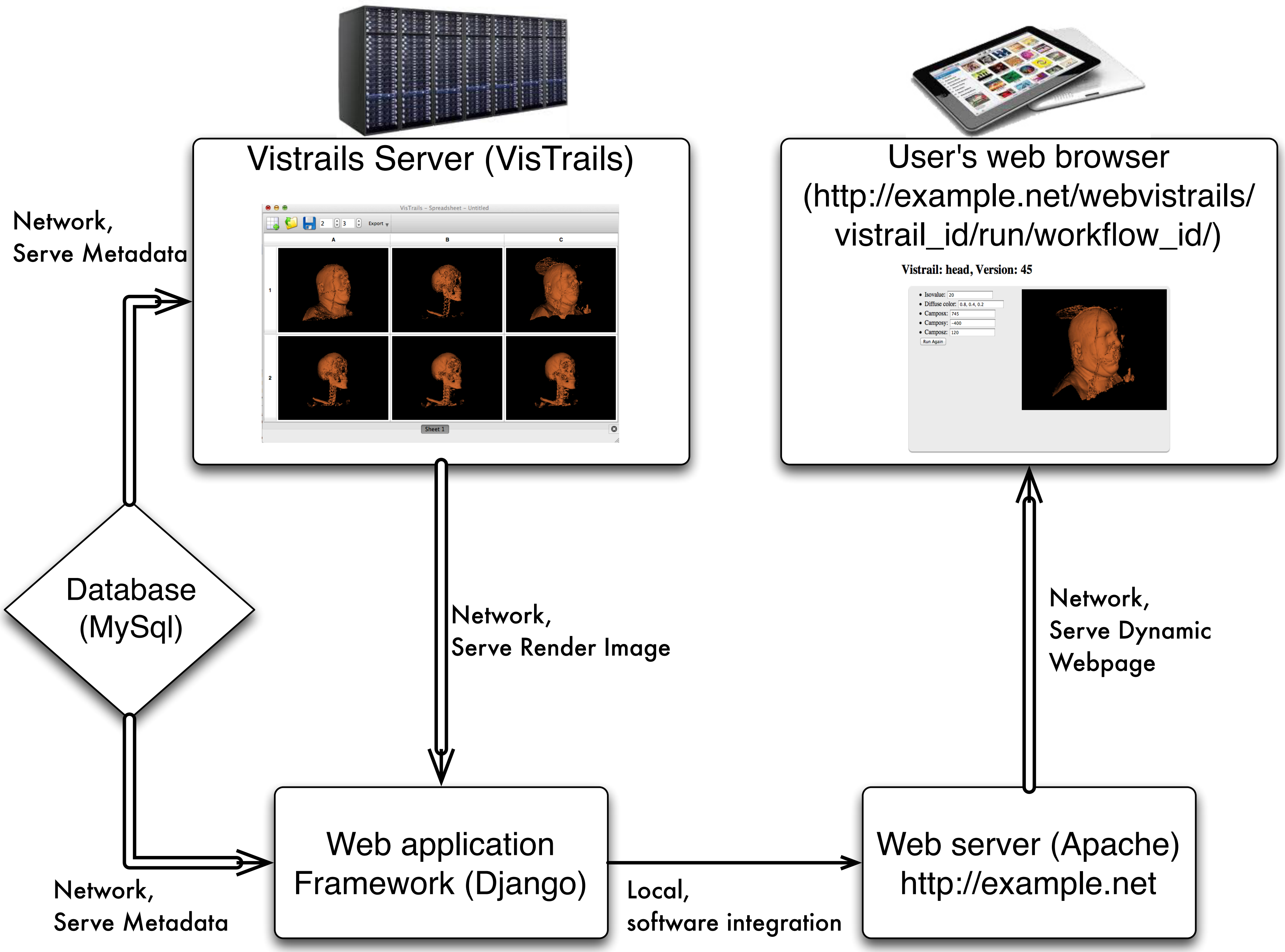
Alligator body bone segmentation,
By Mutairu Olatinwo

# System Development

# WebVistrails: Components

- Web application framework (Django)
  - Web server (Apache)
  - Dynamic webpages, Python programming
  - HTML 5 and Javascript
- Vistrails server run on HPC and serve as Web Service
  - Integrate with more visualization softwares: VisIt, Mathematica
  - Provide provenance and workflow
- Vistrail workflows saved in relational database
- Dataset retrieved from data server (HTTP)

# iBook with HPC backend : Diagram



# Questions?

Further discussion: jinghuage@cct.lsu.edu