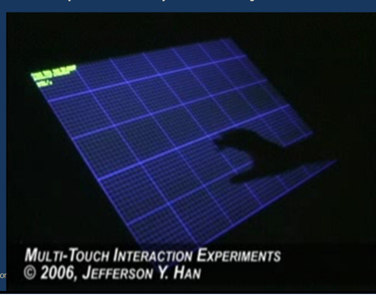
# Comp/Phys/Mtsc 715

Lecture 2: Motivation and Toolkits



## Examples of Direct Manipulation

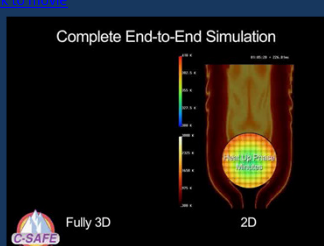
- Jeff Han: http://mrl.nyu.edu/~jhan/ftirtouch/





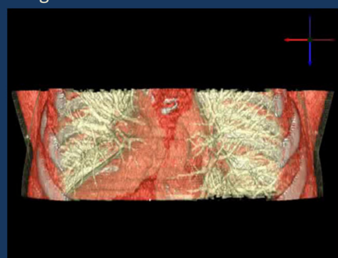

## Videos from Utah on the Web

- C-SAFE Fire and Explosive Container Simulation
  - Link to movie



## Videos from Utah on the Web

- 4D CT Image Data





## Administrative

- If you didn't get email… let me know in email!
- ParaView/Volview Installation and Tutorials
  - Do this soon so we can weed out any bugs…
  - Blog for uploading should be up now
- Ideas for final projects
  - Send me email with potential projects right away
- Be sure you've got the Ware book, version 3!
  - Start reading!

## Keller & Keller Multiform

- Which was your favorite visualization example?
- Of the pair or group of images within your favorite visualization, which is best?
  - Often, each is better for a particular question
  - Having several at hand is better than any single



## My Favorite

- Keller & Keller, p. 147

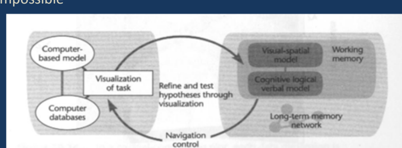
## Human-Machine Problem Solving System

- Human is good at
  - Hypothesis formation
  - Goal-directed search
  - Pattern recognition
  - Decisions in the presence of error and uncertainty
- Computer is good at
  - Perfect recall of facts
  - Quantitative display of complex models
- Interface
  - Visual channel is highest-bandwidth from computer to human
  - Haptic channel is the only bi-directional modality (except laser eye-beams)



## Ware: Problem-Solving Loop

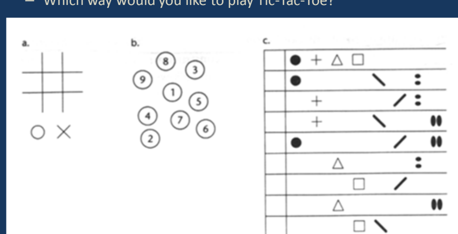
- People solve problems with diagrams differently from the way they do it without diagrams
- Strong Claims!
  - Visualizations function as memory extensions
  - Visualizations enable cognitive operations that would otherwise be impossible






## Visual Spatial Reasoning

- External representations guide and constrain thinking
  - Which way would you like to play Tic-Tac-Toe?



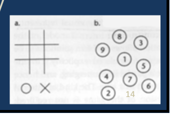
## Human Memory Structures

- Iconic Memory
  - Image of last thing seen still in pictorial form
  - Trace of last burst of sound heard
- Working Memory
  - 7 +/- 2 “chunks” of information can be stored
  - Requires concentration to hold > ~3 seconds
- Long-Term Memory
  - Episodic memory, motor skills, reading, etc.
  - Network of linked concepts



## Visual Spatial Reasoning

- Cognitive operations can take place directly in the visual representation
  - No internal model is needed for Tic-Tac-Toe a)
  - Internal computation needed for version b)
- The problem can be partially externalized
  - Frees user from having to do some operations
  - Provides increase in overall capacity



## Why Visualize?

- Domain Scientist:
  - "I'd rather be in the lab!"
- Computer Scientist:
  - "I'd rather be developing algorithms!"



## Domain Scientist Reply

- "If Mathematics is the Queen of the Sciences, then Computer Graphics is the Royal Interpreter." [Brooks1991]
  - Experiments and simulations produce reams of data values
  - Science is about *understanding*, not numbers
  - Vision is the highest-bandwidth channel between the computer and the scientist
  - Puts the numbers back into a relevant framework and allows understanding of large-scale features, or detailed features in context



## Computer Scientist Reply

- CS is a synthetic discipline: Toolsmiths!
- Driving Problem Approach
  - Fred Brooks' approach to Computer Science
  - Forces you to do the hard parts of a problem
  - Acid test for whether your system is useful
  - Teaches you a little about other disciplines
- It's a *lot* of fun to be there when your collaborator uses the tool to discover or build something new

## Bringing Multiple Specialties to Bear

- Enables attacks on problems that a single discipline cannot work on alone
  - Advanced interfaces to SPM: Physics, Computer Science
  - Physical properties of DNA: Chemistry, Physics
  - Properties and shape of Adenovirus: Gene Therapy, Physics and Computer Science
  - CNT/DNA computing elements: Computer Science, Physics, Chemistry, Biochemistry



## Reality Checks

- Jargon
- Funding
- Credit



## Reality Checks

- Jargon
- Funding
- Credit
- "Wasted" time
  - The cost is time spent as a servant to their needs.
  - The rewards are the set of new ideas and rich data you can feed into your work.

## Useful Visualizations

- "Scientific visualization is not yet a discipline founded on well-understood principles. In some cases we have rules of thumb, and there are studies that probe the capabilities and limitations of specific techniques. For the most part, however, it is a collection of *ad hoc* techniques and lovely examples. Here are collected examples where visualization was found to be useful for particular insights or where it enabled new and fruitful types of experiments." – Fred Brooks [Taylor2000]

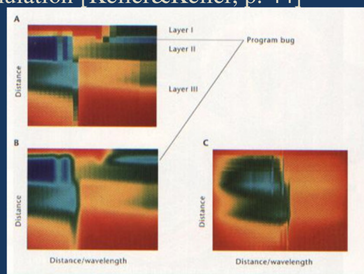


## Practical Scientific Visualization Examples

- Examples of scientific insight from visualization, by category
  - Viewing Spatial Data as Spatial Data
  - Viewing *Transformed* Spatial Data
  - Combining Multiple Data Sets
  - Natural View Changes and Interaction
  - Other Techniques
- Other example visualizations

## Spatial: Showing 2D as 2D

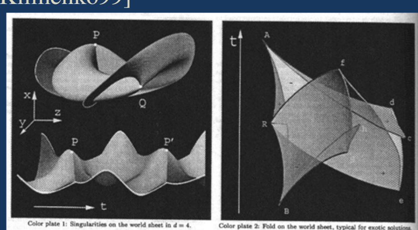
- LLNL: accuracy of a material mix dynamic simulation [Keller&Keller, p. 44]






## Spatial: Showing Surfaces as Surfaces

- Freiburg: String Theory manifold properties [Klimenko99]



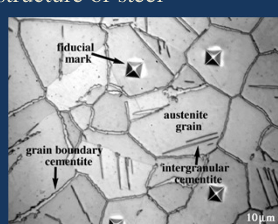

Color plate 1: Singularities on the world sheet in d = 4.

Color plate 2: Fold on the world sheet, typical for exotic solutions.



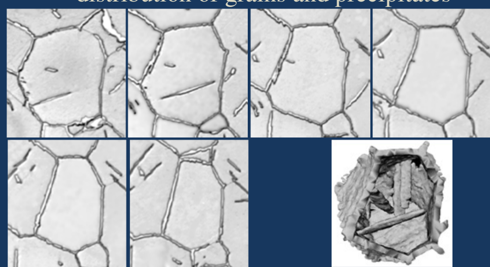
## Spatial: Showing 3D as 3D

- NRL: Internal microstructure of steel [Lanzagorta98]
  - "The Visible Steel"
  - Sliced the steel
  - Scanned with SEM
  - Segmented each
  - Reconstructed



## Spatial: Showing 3D as 3D

- Goal: understand morphology and distribution of grains and precipitates





## Spatial Data: Take-home

- Whereas projection and measurement techniques can provide better quantitative results to some particular known questions, viewing data in its natural spatial extent can provide insight and understanding.

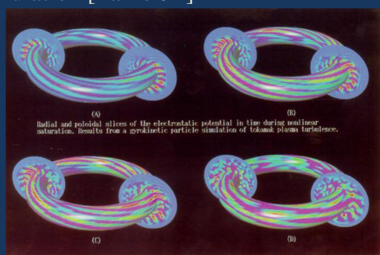


## Transformed Spatial Data

- Rspace program for planning X-ray crystallography data collection [Brooks88]

## Transformed Spatial Data

- Princeton & Rutgers: Plasma Turbulence Simulation [Parker94]






## Transformed Spatial Data: Take-home

- Mapping data from a simulation or experiment into the coordinate system that is most natural for viewing it can make it easier to interpret.

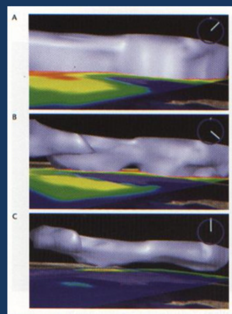


## Combining Multiple Data Sets

- Brown: Rate of Strain, Turbulent Charge, Velocity, and Vorticity [Kirby99]

## Combining Multiple Data Sets

- PSC: Time-dependent Ozone simulator compared with Experiment Results [Keller&Keller p. 88]





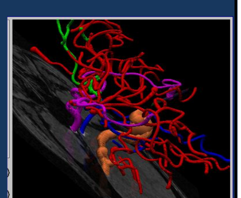
## Combining Multiple Data Sets

- JPL: Overlay of local simulation and remote video for robot arm [Bejczy90]



## Combining Multiple Data Sets

- UNC: Visual Overlay of CT/MRI scan data with the surgical instrument location during surgery enables improved navigation and interoperative planning.
- UNC: Registration of MRI and MR Angiogram Data Enables surgeons to determine which arteries should be blocked. [Bullit]



## Combining Multiple Data Sets: Take-home

- The simultaneous, registered display of multiple data sets can provide improved understanding of the relationship between them. This has been especially effective in medical visualization, for the comparison of radiographic data and actual anatomy.



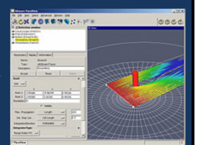


## Available Toolkits

- Visualization Applications
  – ParaView, VolView, VisIt, VTK Designer, EnSight, Tecplot, ImageSurfer, DataTank, Eye-Sys, VAPOR, MayaVi, Exposure, OpenWalnut, VolumeShop, OpenView
- Computation/Analysis + Visualization
  – ImajeJ, NIH Image, Scion for PC (ImageJ), MATLAB, and Mathematica
- Programming Toolkits
  – The Visualization ToolKit (VTK), Insight ToolKit (ITK), VisAD and Vis5D (also “visualization spreadsheet”), SCIRun, D3, Ggobi, Weave
- Graphical Programming Toolkits
  – VisTrails, Open Data Explorer (OpenDX), Iris Explorer (now marketed by NAG), Advanced Visual Systems (AVS/Express), Amira, Nodebox

## Visualization Applications (1/15)

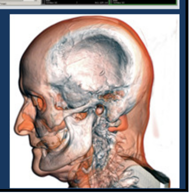
- ParaView
  - http://www.paraview.org
  - Kitware, Inc. and Sandia are primary developers
  - Based on VTK
  - Open-source, freely-available
  - Scriptable and extensible
  - Runs on desktop or parallel computers
  - We'll be using this in homeworks for the class





## Visualization Applications (2/15)

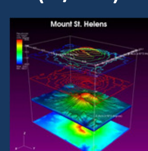
- VolView
  - http://www.volview.org
  - Based on VTK
  - Kitware, Inc.
  - Free
  - Manuals and support available
  - Primarily developed for medical
  - We'll be using this in homeworks for the class

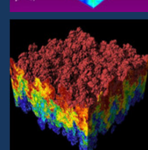




## Visualization Applications (3/15)

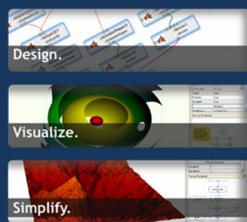
- VisIt
  - http://www.llnl.gov/visit
  - From LLNL
  - Designed for very large datasets
  - Based on VTK
  - Open-source, freely available
  - Scriptable and extensible



## Visualization Applications (4/15)

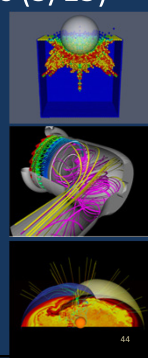
- VTK Designer
  http://www.vcreatelogic.com/products/vtkd
  - Based on VTK
  - Freely-available






## Visualization Applications (5/15)

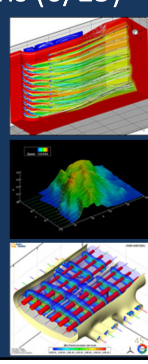
- EnSight
  - http://www.ensight.com
  - Commercial software
  - Company based in Apex, NC
  - RENCI has a few licenses for this software
  - Meshing modules available
  - Interfaces for popular CFD codes





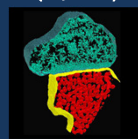
## Visualization Applications (6/15)

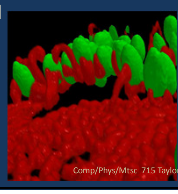
- Tecplot
  - http://www.tecplot.com
  - Commercial software
  - SDK for developers
  - Scriptable

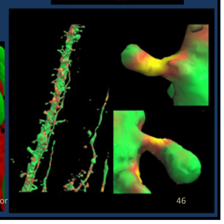


## Visualization Applications (7/15)

- ImageSurfer II
  - http://www.imagesurfer.org
  - Designed for multivariate 3D bio
  - Can handle time-varying data
  - VTK-based



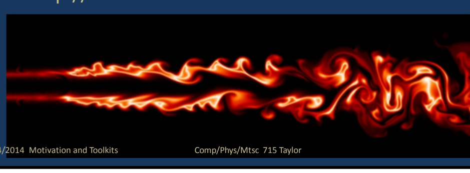






## Visualization Applications (8/15)

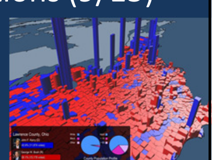
- DataTank (Mac)
  - Can read data files
  - Couples to simulation
  - Query and computation on data sets supported
  - http://www.visualdatatools.com

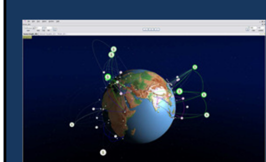


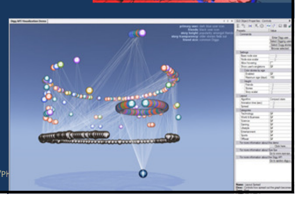


## Visualization Applications (9/15)

- Eye-Sys
  - http://www.eye-sys.com
  - Commercial software
  - Info-vis focus

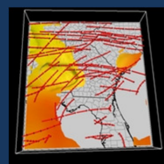
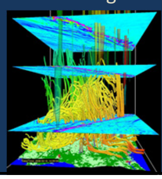
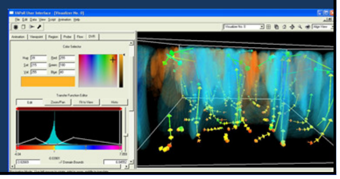






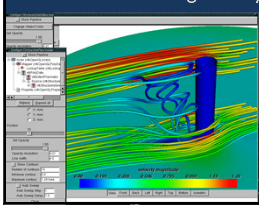
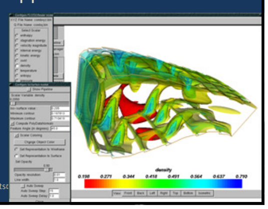
## Visualization Applications (10/15)

- VAPOR
  - http://www.vapor.ucar.edu
  - Free software
  - Weather visualization focus
  - Integrates with IDL

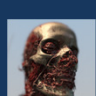
## Visualization Applications (11/15)

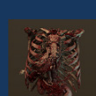
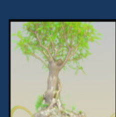
- MayaVi2
  - http://mayavi.sourceforge.net
  - Open-source software (VTK based)
  - Embedding into Python apps

## Visualization Applications (12/15)

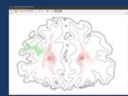
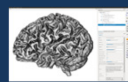
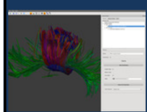
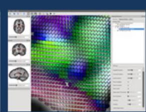
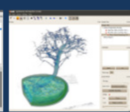
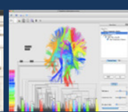
- Exposure Render
  - http://code.google.com/p/exposure-render
  - Open-source volume renderer
  - CUDA-accelerated, rapid, high-quality rendering

## Visualization Applications (13/15)

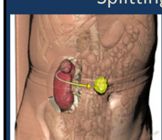
- OpenWalnut
  - http://www.openwalnut.org
  - Open-source VolVis software (LGPL)
  - Linux, Mac, Windows
  - Medical/brain focus

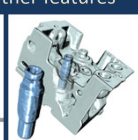
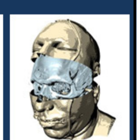









## Visualization Applications (14/15)

- VolumeShop
  - http://www.cg.tuwien.ac.at/volumeshop
  - Free for non-commercial use
  - Volume rendering
  - Splitting, reveal, and other features





## Visualization Applications (15/15)

- OpenView
  - http://openview.kitware.com
  - Information Visualization application
  - Alpha version for Mac only

## Computation/Analysis + Vis 1/2

- ImageJ
  - http://rsbweb.nih.gov/ij
  - Acquire, display, edit, enhance, analyze and animate images
- MATLAB
  - http://www.matlab.com
  - 2D and 3D plots, isosurfaces, streamlines, color maps
  - Image analysis and filtering

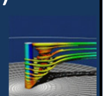


## Computation/Analysis + Vis 2/2

- Mathematica
  - http://www.wolfram.com
  - Data plotting, isosurfaces, vector visualization, color maps



## Programming Toolkits (1/7)



- Visualization Toolkit (VTK)
  - http://www.vtk.org
  - Open-source, object-oriented free software
  - Written in C++, with Tcl, Python, and Java language bindings
  - Large collection of visualization algorithm implementations, file readers, and display programs
  - Documentation and support provided by Kitware
  - Book, example code, and tutorials available
  - Higher level than OpenGL, tuned for visualization
  - Data pipeline model
  - Aimed at programmers

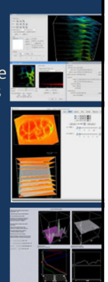
## Programming Toolkits (2/7)

- Insight ToolKit (ITK)
  - http://www.itk.org
  - Sponsored by the National Library of Medicine
  - For segmentation and registration of visible human
  - Open-source, object-oriented free software
  - C++ libraries, heavily templated
  - Kitware is involved in the development
    - Should work well with VTK (there are filters to go from VTK to ITK and vice versa)
  - UNC is also involved in the development
  - Example code and applications available
  - Aimed at programmers



## Programming Toolkits (3/7)

- VisAD and Vis5D
  - http://www.ssec.wisc.edu/~billh/visad.html
  - Freely available toolkit developed by Bill Hibbard at the University of Wisconsin for geospatial data (also works for other data types: VisBio)
  - Java component library for interactive and collaborative visualization
  - Tutorials available online
  - “Visualization spreadsheet” for certain operations and data sets, no programming necessary
  - Distributed collaboration built in, to enable multiple scientists at different locations to work together

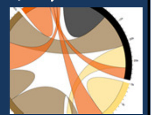




## Programming Toolkits (4/7)

- SCIRun
- http://software.sci.utah.edu/scirun.html
- Open-source workbench from Utah
- Visual programming + custom modules
- Couples modeling, simulation and visualization
- Handles steering of parallel simulations

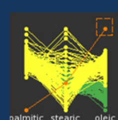
## Programming Toolkits (5/7)



- D3
  - http://mbostock.github.com/d3
  - Web Information-visualization focused
  - JavaScript
  - Binds data to a DOM, then transform
  - Built to be fast
  - Makes use of CSS3, HTML5, and SVG



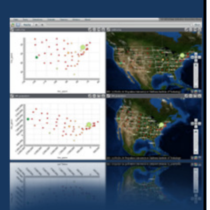
## Programming Toolkits (6/7)




- GGobi
  - http://www.ggobi.org
  - High-dimensional vis focus
  - Open source
  - Includes animated tours through N-space



## Programming Toolkits (7/7)



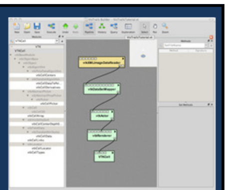
- Weave
  - http://oicweave.org
  - UMass Lowell
  - Web-based visualization platform
  - Supports novices and advanced
  - Web-based presentation
  - Supports Collaboration

## Graphical Programming Toolkits

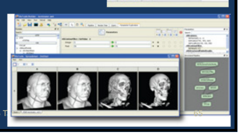
- Aim to provide easy-to-use interface between data and visualization
- Aim to be used directly by scientists
- Collection of pre-built modules implement various visualization techniques
- Try to be extensible, but not as easy to extend as the programming toolkits (where you can easily insert your own code)



## VisTrails

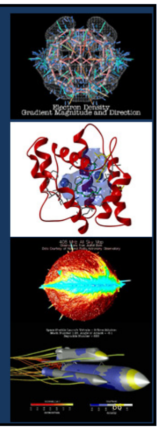


- From Utah
  - http://www.vistrails.org
  - Open-source scientific workflow management system
  - VTK modules integrated, simulation and analysis modules can be added
  - Tracks versions of workflows (save snapshots of different parameter sets)
  - Data exploration spreadsheet
  - Visualization by analogy





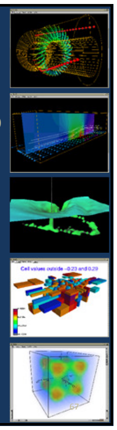
## OpenDX



- Open Data Explorer
  - http://www.opendx.org
  - Was IBM Data Explorer
  - Freely-available, open source software, earlier was commercial.
  - Book and support available from vizsolutions.com
  - Mail lists and user group

## Iris Explorer

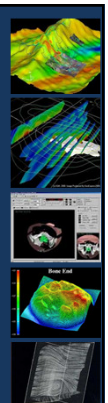
- http://www.nag.com/welcome_iec.asp
- Purchased, supported software
- Online user manuals
- Online tutorials





## AVS and AVS/Express

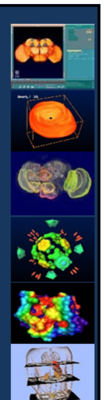
- http://www.avs.com
- Commercial, supported software
- AVS 5.0 is continuation of earlier software running on Unix platforms
- AVS/Express also runs on Windows
- Online tutorials and manuals, good help and within-program information





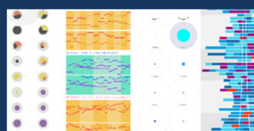
## Amira

- http://www.amiravis.com
- 3D visualization and volume modeling
- Segmentation tools
- Commercial, supported software
- Online user’s guide, tutorials, reference guide
- Rachael Brady used at Duke
- Free trial



## Nodebox

- http://nodebox.net
- Information Visualization
- Open source
- Integrates into design workflow





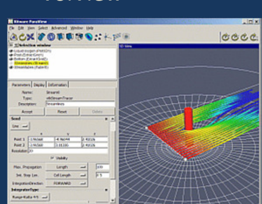

## More InfoVis Tools

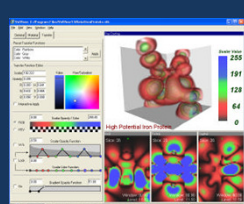
- http://selection.datavisualization.ch
  - Arbor.js, CartoDB, Chroma.js
  - Circos, ColorBrewer, Cubism.js
  - D3.js, Dance.js, Data.js
  - DataWrangler, Degrafa, Envision.js
  - Flare, GeoCommons, Gephi
  - Google Chart Tools, Fusion Tables, Refine
  - Impure, JavaScript InfoVis, Kartograph
  - …



## This Semester, Using VTK-derived Products

- ParaView
- VolView





# Comp/Phys/Mtsc 715

Some Important Things:

Perceptual Issues, Choosing Mappings, Multivariate Display, Data Manipulation, Interaction among Disciplines



## Perceptual Issues

- Luminance is used for detail and shape
- The Human Visual System sees Differences
  - Luminance, size, hue, speed, …
  - Good for viewing the environment
  - Cannot determine absolutes precisely
- Preattentive Processing
  - Map goals into preattentively-seen channels

## Data Manipulation

- Apply appropriate transformation to data
  - Map into appropriate space (lat/long → sphere)
  - Remove artifact (flattening AFM data)
- Various tricks for loading data into Paraview



## Choosing Mappings

- The continuous rainbow color map is never the best choice, and is often misleading
- No continuous color map shows interval data
- Translucency without texture hides shape
- Evaluate visualizations objectively on tasks



## Multivariate Display

- Cannot layer >3 dense techniques
  - Preattentively separate into sparse channels
- The best technique depends on the task
  - Strengths of technique → important data
  - Different tasks may require different displays
- Combine multiple techniques for one task

## Interaction with Scientists

- Communicate across jargon boundary
  - Some things are names to be repeated back
  - Explanations of deeper concepts
- Learning domain-independent goals and tasks
  - Science goals, not visualization techniques
  - Beyond what they think is easy
- Embed visualization into workflow
  - Importing from scientist format
  - Enabling quantitative querying





## Extra Slides:

## Videos from Utah on the Web

- NIMROD Fusion Reactor Simulation

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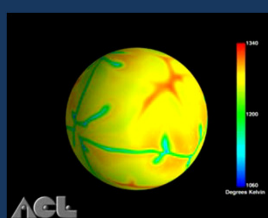
## Videos from Utah on the Web

- Mantle Convection Model: Link to movie



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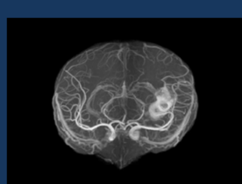
## Videos from Utah on the Web

- A Flythrough of MRA using MIP



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## Videos from Utah on the Web

- The Visual Haptic Workbench



## Videos from Utah on the Web

- Diffusion tensor visualization

Papa Juhl, way to go!

QuickTime™ and a
YUV420 codec decompressor
are needed to see this picture.

## Videos

- SCI in the news: "Holograms in Medicine"
- nanoMultiVis: Spots, Slivers
- SIGGRAPH '96
  - 26: Ultrasound augmented reality
  - 27: Image-Guided Streamline Placement





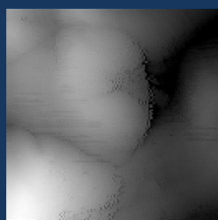
## Natural View Changes and Interaction

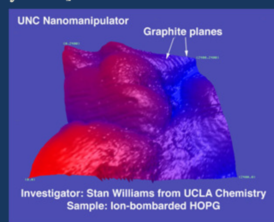
- Utrecht: Stereo volume-visualization improves clinical results. [Zuiderveld96]


Figure 5: Small aneurysm of the left medial cerebral artery as seen from two viewing directions (MRA).

## Natural View Changes and Interaction

- UNC: Flyover view of 3D surface reveals insights not seen in 2D/line views [Taylor93]








## Natural View Changes and Interaction

- Utah: *SCIRun* program produced a hologram from a 3D data set that was placed over patient anatomy (person viewed through holographic plate).
- Surgeons reviewed plan based on holographic and immersive stereo volume-rendering display.
- Surgical plan changed, operation was a success. [Johnson99]

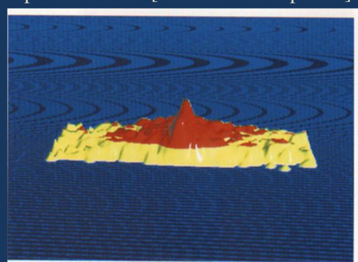


## Natural View Changes and Interaction: Take-home

- You can think of each frame in a real-time display of the surface as a new filter applied to the data set, with the user in control of the filter parameters (viewpoint, lighting direction) through natural motions of head and hand. People are adept at understanding the structure of 3D surfaces this way, having learned this skill over a lifetime.
- Intuitive exploration can produce insight.

## Other Techniques

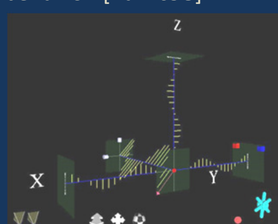
- Sandia: Highlighting Critical Values Reveals Unexpected Values [Keller&Keller p. 107]





## Other Techniques

- Mississippi State: Making the Invisible Visible reveals behavior. [Banks98]



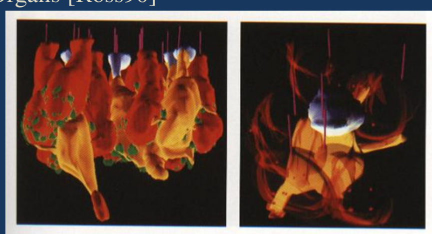



## Other Example Visualizations

- www.avs.com
- www.iavsc.org
- www.opendx.org
- www.kitware.com

## Spatial: Showing 3D as 3D

- NASA Ames: Mammalian Gravity-Sensing Organs [Ross90]



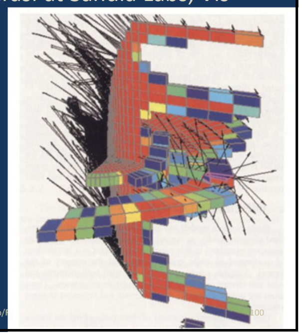


## Spatial: Showing 3D as 3D

- Volume Rendering enables planning transplants [Hemminger95]
  - Volume rendering enabled the proper planning of partial, living-donor lung transplants. In this procedure, one of the lobes of the donor's lung is transplanted to the recipient. In order to avoid damaging the neighboring lobe in the donor, surgeons need to know just where to cut the bronchial tubes and blood vessels. When this planning was done based on CT slices, there was often damage to the neighboring lobe. Volume rendering allowed the surgeries to be planned so that this could usually be avoided.

## Spatial: Showing 3D as 3D

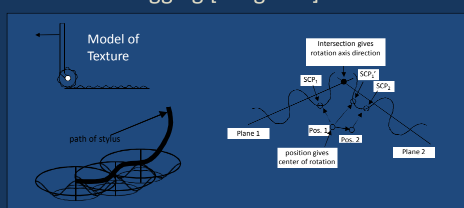
- Crossno, Rogers, and Garasi at Sandia Labs, Vis 2002
  - Exploding wire sim
  - Color = volume frac
    - Low-volume cells culled
  - Inverted cell highlighted
  - Arrows = magnetic force





## Transformed Spatial Data

- UNC: Visualization of forces in surface space aided in debugging [Seeger00]



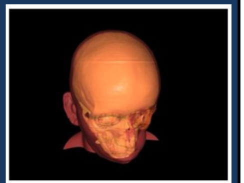



## Combining Multiple Data Sets

- The first protein whose structure was solved from crystallography data without first building a physical model was Bovine Cu,Zn-superoxide dismutase in 1974 by Dave and Jane Richardson using the UNC GRIP system (a density fitting system). [Brooks99] Now, this is how protein fitting is routinely done.
- The 3D embedding of the model within the measured density is what allows the fitting to work at all.

## Combining Multiple Data Sets

- Utah: Simulation of energy absorption within a human head (from MRI data) from a cell phone antenna, overlaid on model of head, phone, and antenna. [Pandit96]
- Stanford: Reconstructive surgery planning overlays mirror image of good side of face with section of hipbone and damaged side. [Montgomery98]



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## Natural View Changes and Interaction

- UNC: a biochemist visiting the UNC Molecular Graphics resource, worked for over two hours in a head-mounted display system with a wide-area tracker looking at his molecule "for the first time", though had seen it many times before on a 2D screen. Due to his improved understanding compared to previous views, he discovered that he had fit part of the molecule incorrectly.
- UNC: Using the UNC *Sculpt* steerable molecular simulation system, Duke biochemist Jane Richardson examined the *Felix* custom-designed protein to understand what could make it stable. She used the online optimization to keep the subunits together while she flipped one whole subunit over to the other side.

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## Other Techniques

- Aarhus: Viewing a *transformed* time series as a time series. [Besenbacher91]
  - Viewed high-speed STM scans during crystal formation as variable-time movies.
  - "Such information, which cannot be obtained by any other means, is very decisive for a full understanding of both the growth mode of reconstructed phases and the resulting static structure."

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## Extra Readings

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- Rheingans, Penny, "Are We There Yet? Exploring with Dynamic Visualization," *IEEE Computer Graphics and Applications*, 22 (1), Jan/Feb 2002. pp. 6-10.



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