

Scientific Visualization

University of Houston, Fall 2012

Instructor: Guoning Chen

Course Information

- **Location:** PGH 376
- **Time:** 10am~11:30am Tuesday and Thursday
- **Office Hours:** TBA
- **Course webpage:**
http://www2.cs.uh.edu/~chengu/Teaching/SciVis_fall2012.html

Course Information

- **Prerequisites:**
 - knowledge and experience in programming (we will use C/C++)
 - Computer graphics and OpenGL
- **Textbook:** (recommended)
 - Helen Wright, Introduction to Scientific Visualization, Springer, 2006
 - Charles D. Hansen and Chris R. Johnson, Visualization Handbook, Elsevier, 2004
 - Reading materials and course notes given in class or on course page.

Course Information

- **Grading:** 5 assignments (60%) + 1 final project and presentation (30%) + course participation (10%) (based on C/C++ and OpenGL)
- **Late Policy:** Late assignments will be marked off 20% for each weekday that it is late.
- **Academic Dishonesty:** Do your own work! No code copy!

Background

What is Visualization?

What is Visualization?

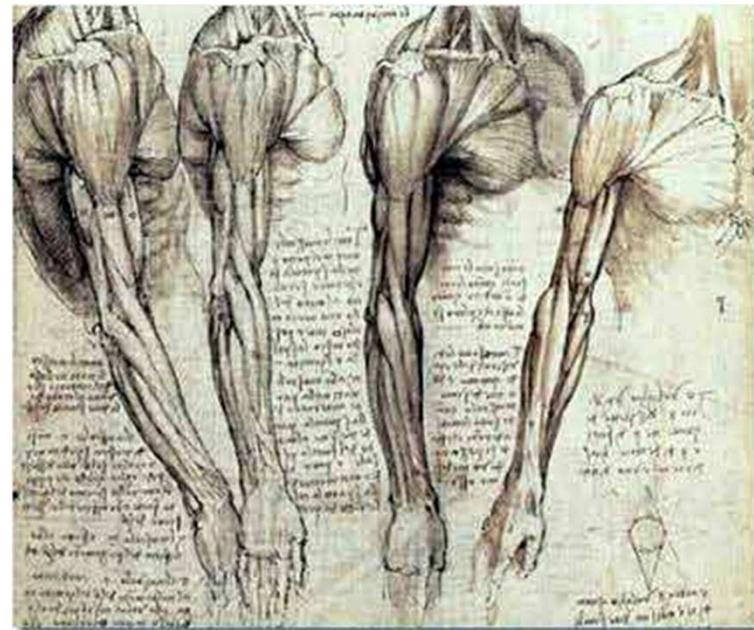
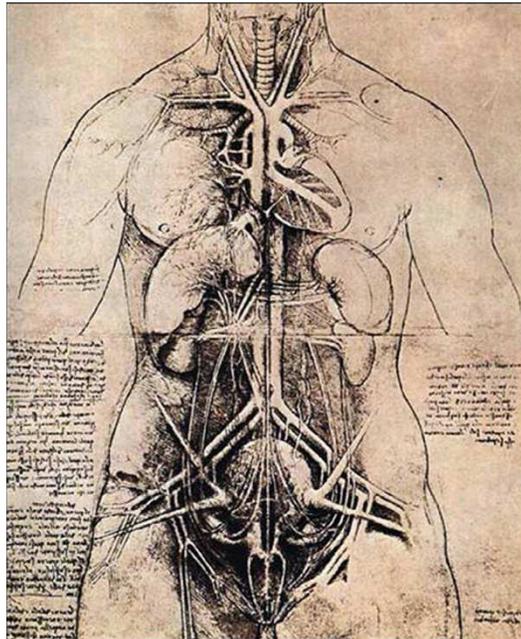
- In 1987
 - the National Science Foundation (of the U.S.) started “Visualization in scientific computing” as a new discipline, and a panel of the ACM coined the term “scientific visualization”
 - Scientific visualization, briefly defined: The use of computer graphics for the analysis and presentation of computed or measured scientific data.
- Oxford Engl. Dict., 1989
 - to form a mental vision, image, or picture of (something not visible or present to the sight, or of an abstraction); to make visible to the mind or imagination
- Visualization transforms data into images that effectively and accurately represent information about the data.
 - Schroeder et al. The Visualization Toolkit, 2nd ed. 1998

Tool to enable a User insight into Data

History of Visualization

- Visualization = rather old

L. da Vinci (1452-1519)

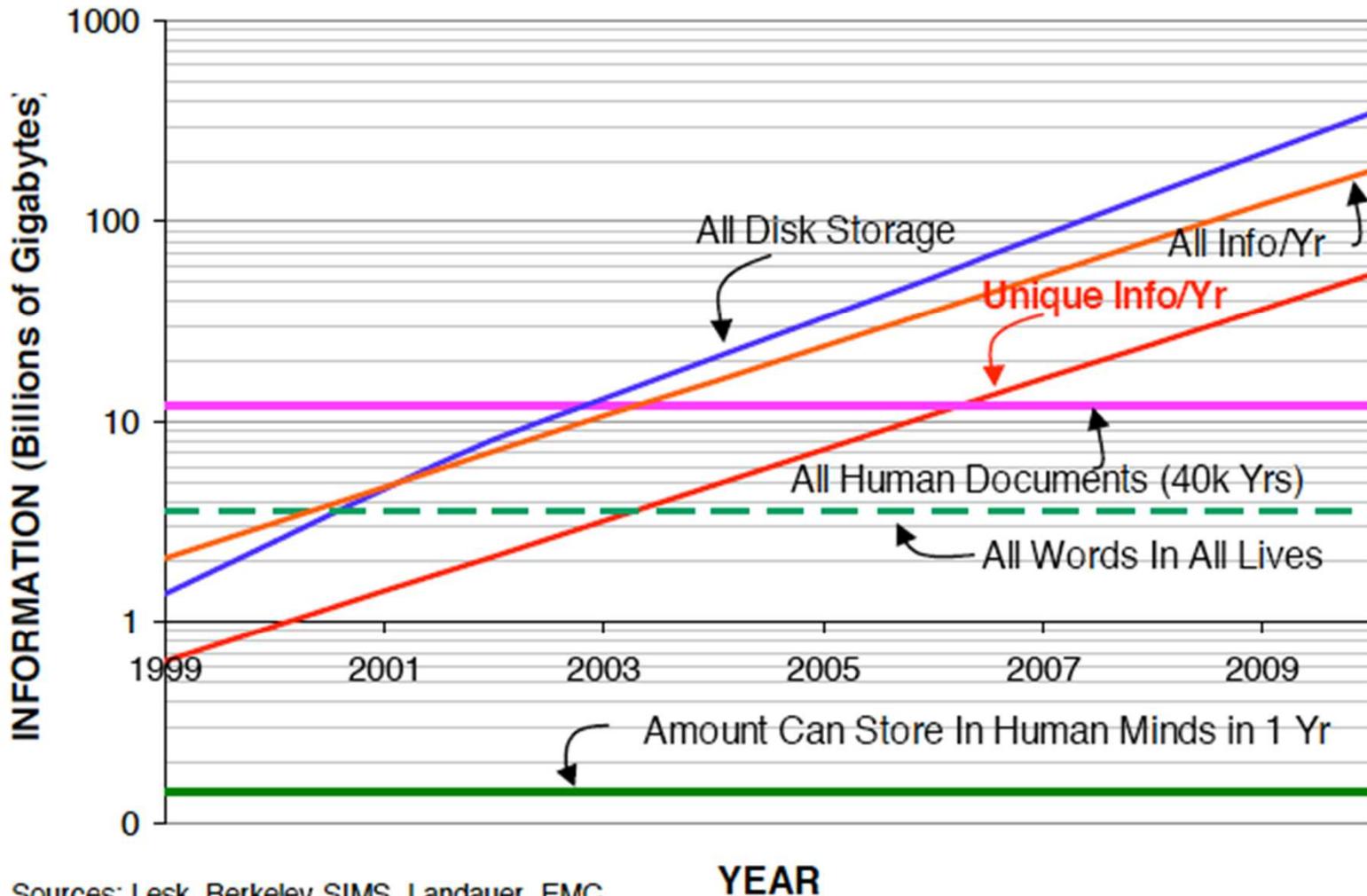


- Often an intuitive step: graphical illustration

Image source: <http://www.leonardo-da-vinci-biography.com/leonardo-da-vinci-anatomy.html>

History of Visualization

- Data in ever increasing sizes \Rightarrow graphical approach necessary



History of Visualization

- Visualization = own scientific discipline for more than 20 years
 - First dedicated conferences: 1990
 - Conferences:
 - IEEE Vis
 - EuroVis
 - PacificVis
 - Journals:
 - IEEE TVCG
 - CGF

Why is Visualization Important?

Why is Visualization Important?

- To effectively convey information to data stakeholders

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- To effectively convey information to data stakeholders

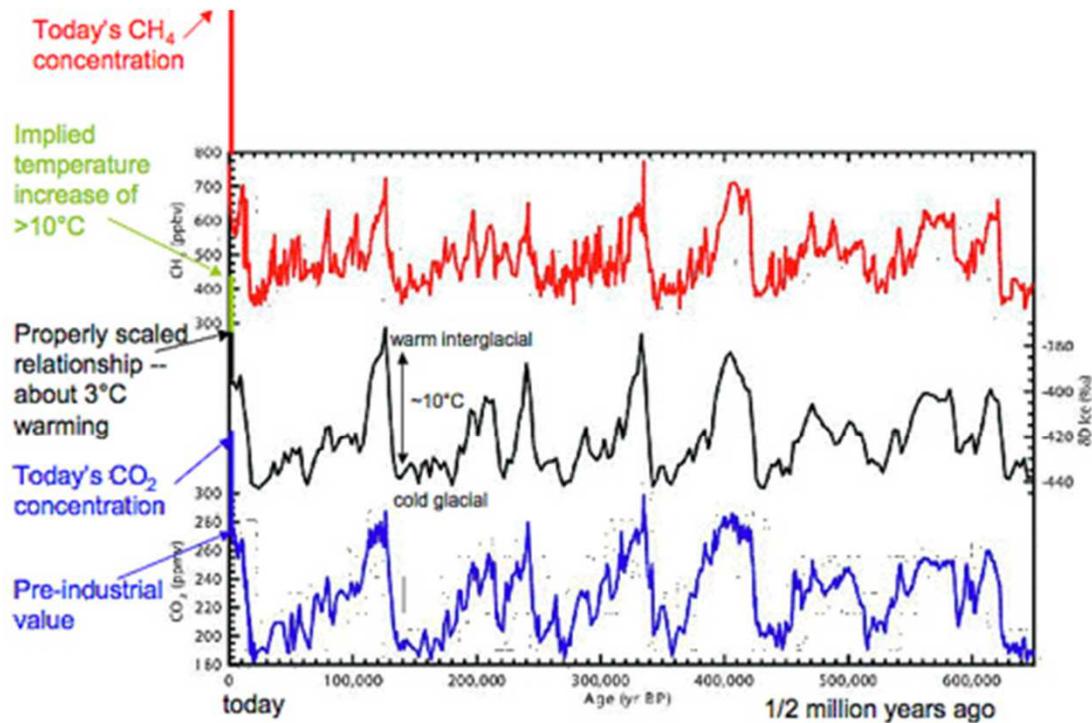
Table 7-2 Direct global warming potentials of several well-mixed trace gases relative to CO₂. The GWPs of the various non-CO₂ species are calculated for each of five time horizons (20, 50, 100, 200 and 500 years) using, as in IPCC, the carbon cycle model of Siegenthaler (1983). (Note that IPCC contained a typographical error which led to incorrect values for the direct GWP of methane.)

Gas	Lifetime (years)	Time Horizons				
		20 years	50 years	100 years	200 years	500 years
CO ₂	#	1	1	1	1	1
CH ₄	10.5	35	19	11	7	4
N ₂ O	132	260	270	270	240	170
CFC-11	55	4500	4100	3400	2400	1400
CFC-12	116	7100	7400	7100	6200	4100
HCFC-22	15.8	4200	2600	1600	970	540
CFC-113	110	4600	4700	4500	3900	2500
CFC-114	220	6100	6700	7000	7000	5800
CFC-115	550	5500	6200	7000	7800	8500
HCFC-123	1.71	330	150	90	55	30
HCFC-124	6.9	1500	760	440	270	150
HFC-125	40.5	5200	4500	3400	2200	1200
HFC-134a	15.6	3100	1900	1200	730	400
HCFC-141b	10.8	1800	980	580	350	200
HCFC-142b	22.4	4000	2800	1800	1100	620
HFC-143a	64.2	4700	4500	3800	2800	1600
HFC-152a	1.8	530	250	150	89	49
CCl ₄	47	1800	1600	1300	860	480
CH ₂ Cl ₂	6.1	360	170	100	62	34
CF ₃ Br	77	5600	5500	4900	3800	2300

SAOD Table 7.2 (p. 7.6)

Why is Visualization Important?

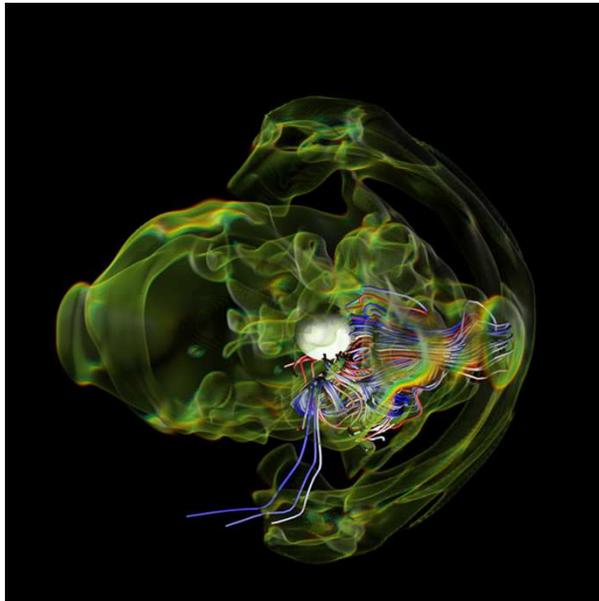
- To effectively convey information to data stakeholders



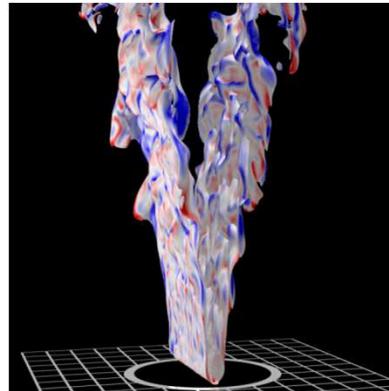
Methane, temperature (from hydrogen isotope ratios ("δD") and **carbon dioxide** from the Dome C Ice core. (EPICA Project members, 2006).

Why is Visualization Important?

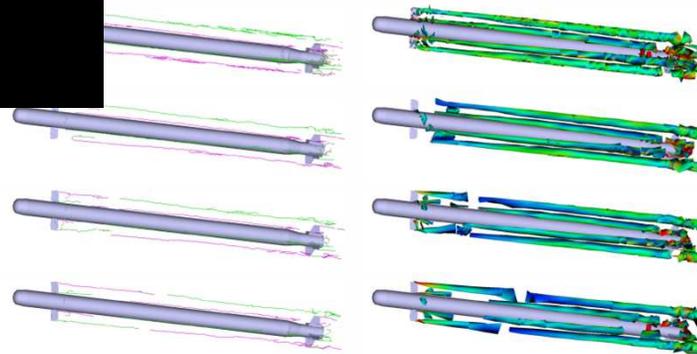
- We have seen it in medical practice
- Engineering and Science



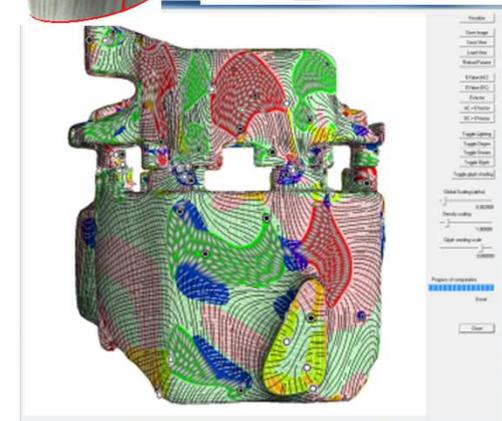
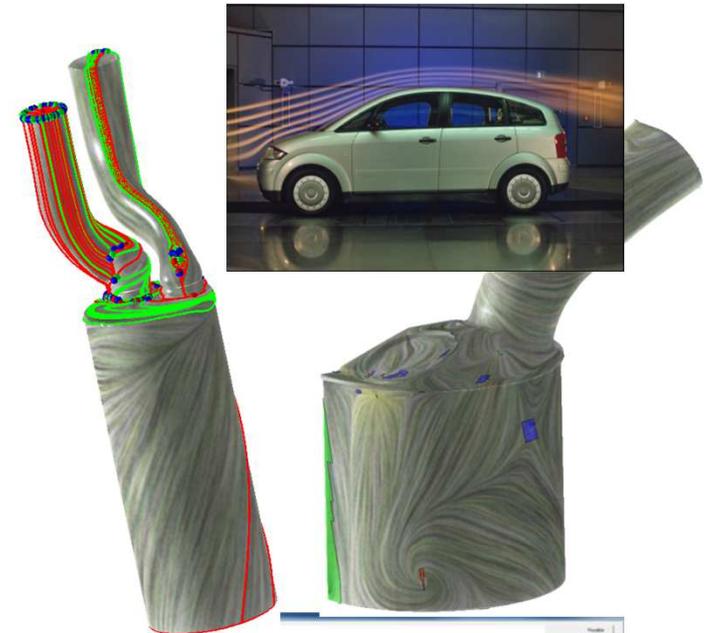
Astronomy
source: VACET



Combustion
source: VACET



Aerodynamics around missiles [Kelly et al. Vis06]



Automotive design
[Chen et al. TVCG07, TVCG08, Vis11]

Why is Visualization Important?

- Education

Why is Visualization Important?

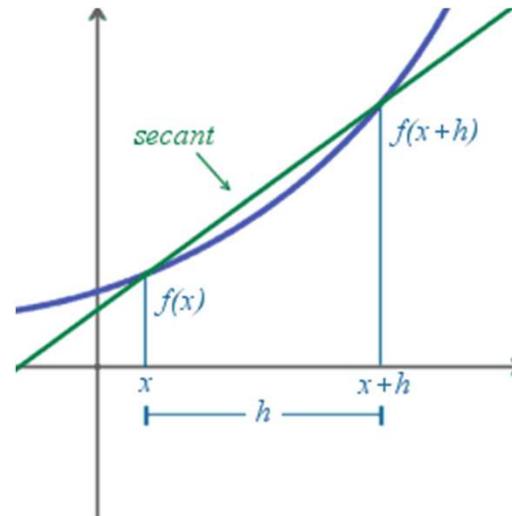
- Education

$$\frac{dy}{dx} = \lim_{h \rightarrow 0} \frac{f(x+h) - f(x)}{h}$$

Why is Visualization Important?

- Education

$$\frac{dy}{dx} = \lim_{h \rightarrow 0} \frac{f(x+h) - f(x)}{h}$$

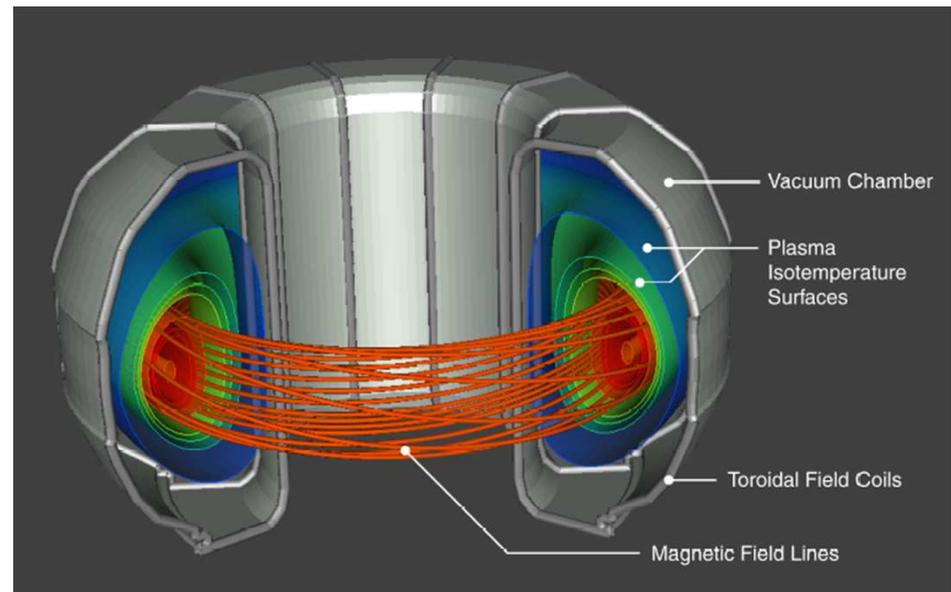


Why is Visualization Important?

- Education
- Understand mathematical concepts and physical phenomena that are invisible



Source: SuperStock



Fusion physics

Recommended site: <http://www.pbs.org/wgbh/nova/>

What Does Visualization Do?

- Three types of goals for visualization
 - ... to **explore**
 - Nothing is known,
 - Vis. used for data exploration
 - ... to **analyze**
 - There are hypotheses,
 - Vis. used for Verification or Falsification
 - ... to **present**
 - “everything” known about the data,
 - Vis. used for Communication of Results

Evolution of Visualization Research

- From direct visualization to derived information visualization.
- From simple data forms to more complex forms.
- From represent the data with fidelity to reveal new findings.
- From scientific visualization to information visualization, bio-visualization and beyond.

Branches of Visualization

- Scientific visualization (SciVis):
 - Data typically come from natural sciences and life sciences
 - Data are usually numeric and defined over a space with geometric structures
- Information visualization (InfoVis):
 - Data are typically abstract
 - Data are usually not numeric and not necessarily related to a spatial domain
- Software visualization, architecture-visualization, bio-visualization, etc
- Visual analytics

SciVis vs. InfoVis

- Scientific visualization is mostly concerned with:
 - 2, 3, 4 dimensional, spatial or spatio-temporal data
 - discretized data
- Information visualization focuses on:
 - high-dimensional, abstract data
 - discrete data
 - financial, statistical, etc.
 - visualization of large trees, networks, graphs
 - data mining: finding patterns, clusters, voids, outliers

- Remark: This is a well rich and interdisciplinary area that combines knowledge from various disciplines.

Goals and Topics

Goals of this Course

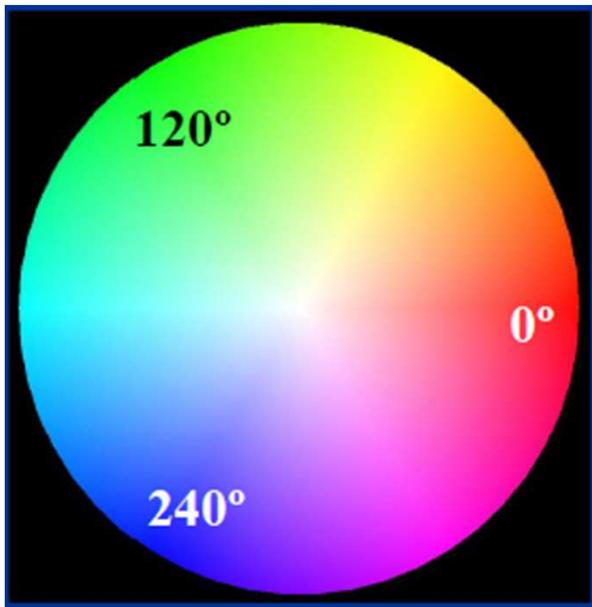
- Know the basic methods and standards of visualizations
- Familiar with classical techniques for the visualizations of various data types
- Able to develop the customized visualization techniques and systems for the practical and research needs

Topics to Be Covered in this Course

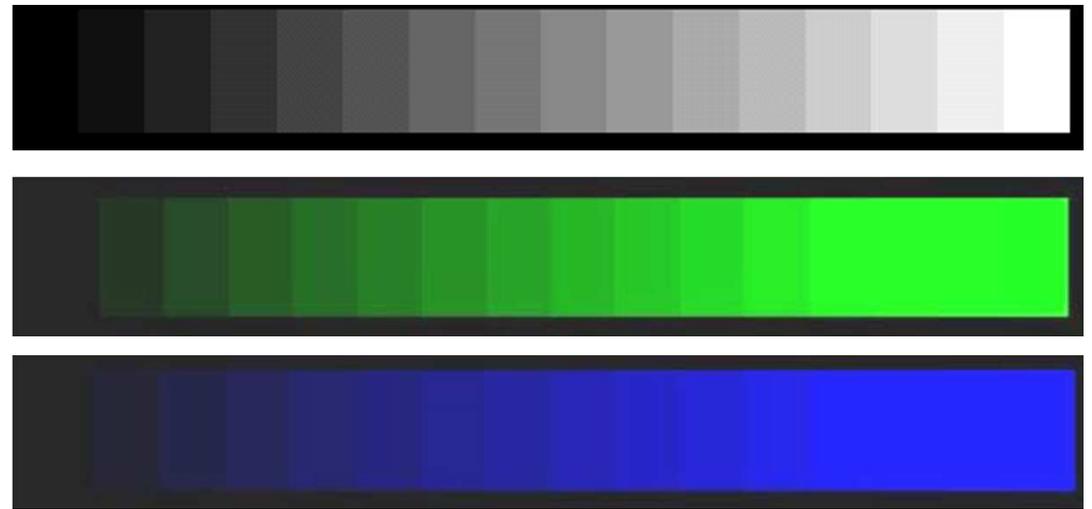
- What will be covered?
 - Colors
 - Scalar field visualization
 - Vector field visualization
 - Tensor field visualization
 - Hop topics in visualization
- Will make use of a lot of branches in mathematics
 - Calculus, trigonometry, linear algebra, discrete math, differential geometry, topology, dynamical systems, numerical algebra, etc
- Will also need knowledge in computer science
 - Algorithms, data structures, graphics, etc.
- Better to have the following as well
 - **Art and design**, Psychophysics, scientific computing

Preview of Topics

- Color theory and visual representation



HSV Color Wheel



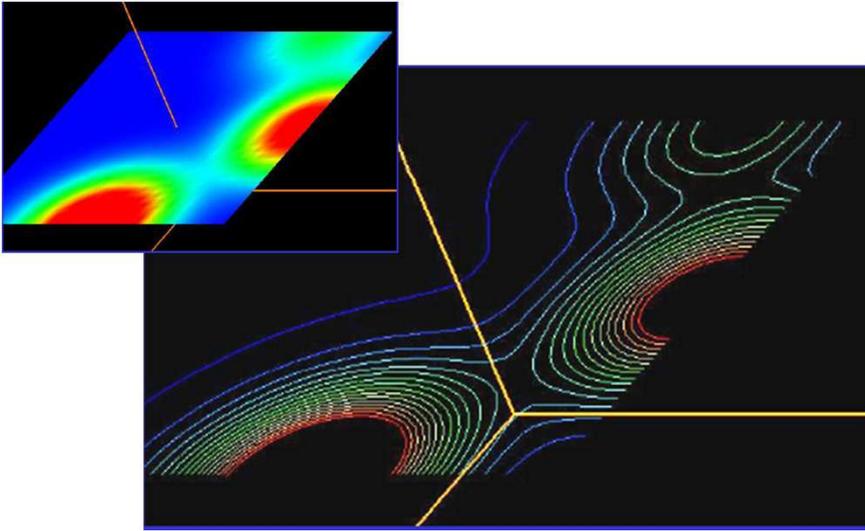
Which is brighter?

Blue: 380 nm Green: 520 nm Red: 780 nm

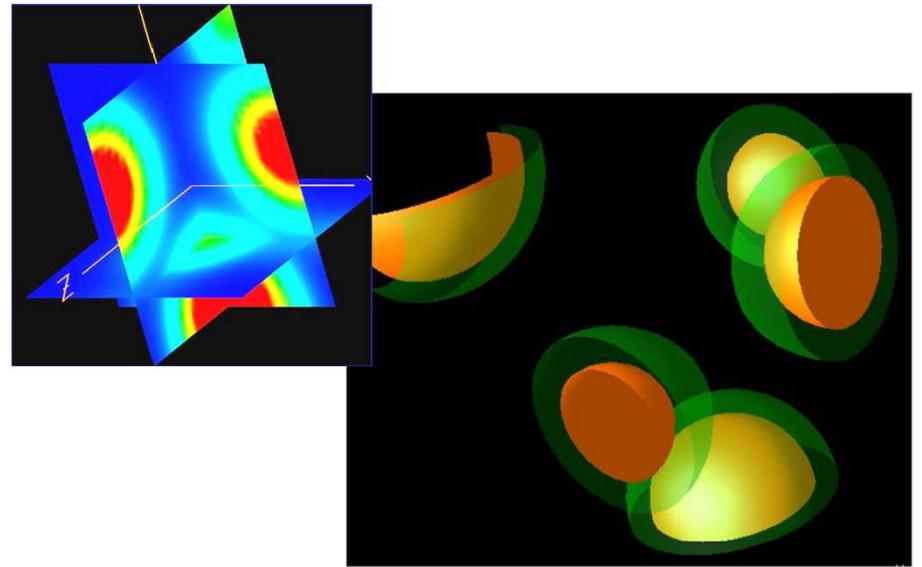


Preview of Topics

- Scalar field visualization I $s=F(x,y,z,t)$



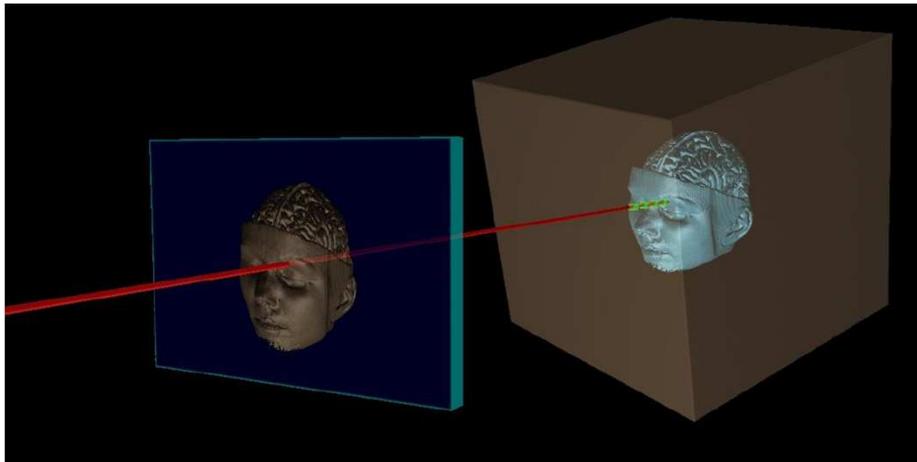
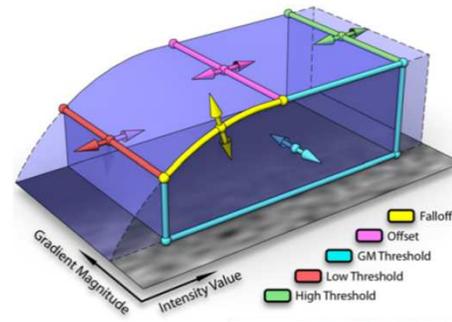
2D: Iso-contouring



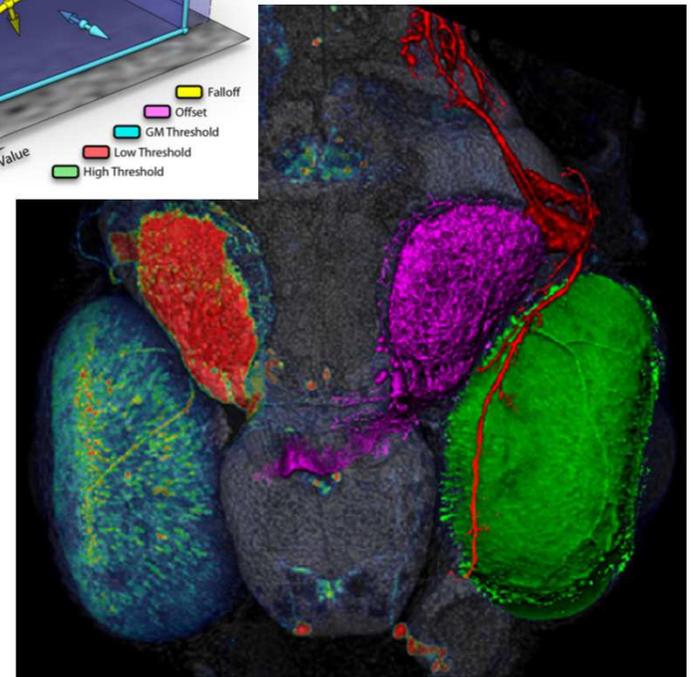
3D: Iso-surfacing

Preview of Topics

- Scalar field visualization II
 - Volume rendering
 - Ray-casting
 - Volume rendering



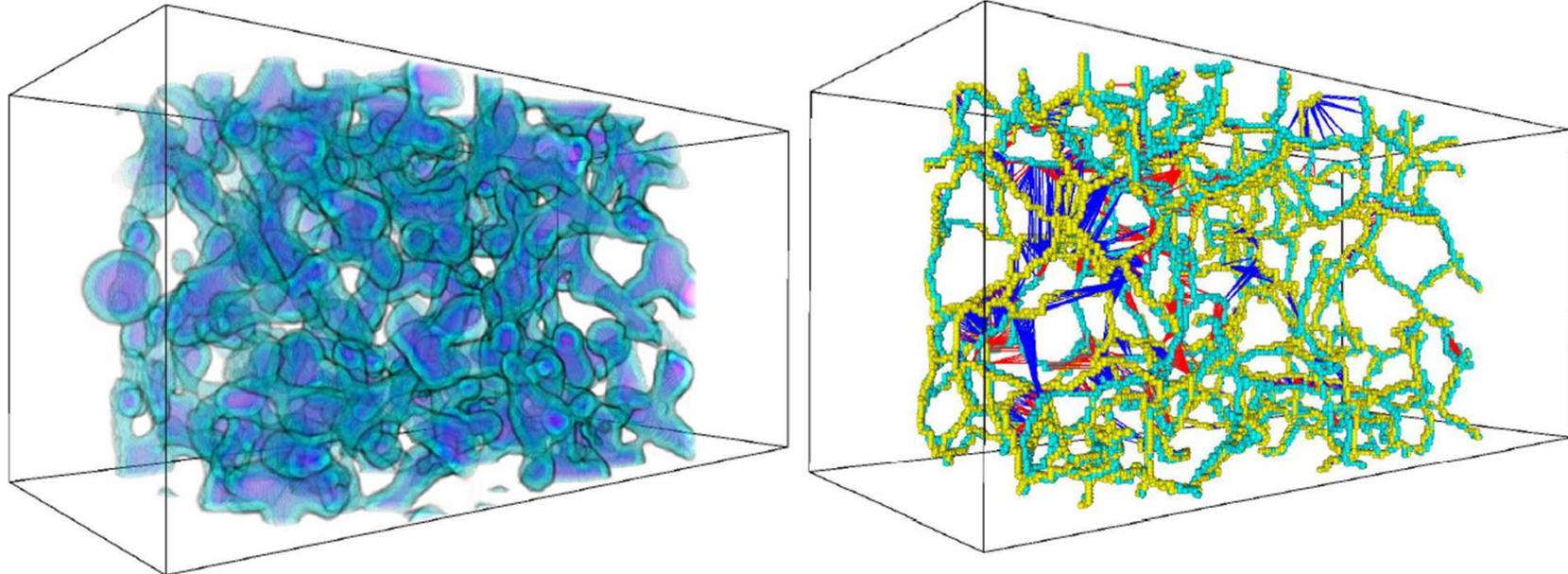
Ray-casting illustration



Zebra fish head (image by Fluorender)

Preview of Topics

- Scalar field visualization III
 - Topology



The impact of the ball entering the porous solid from the left

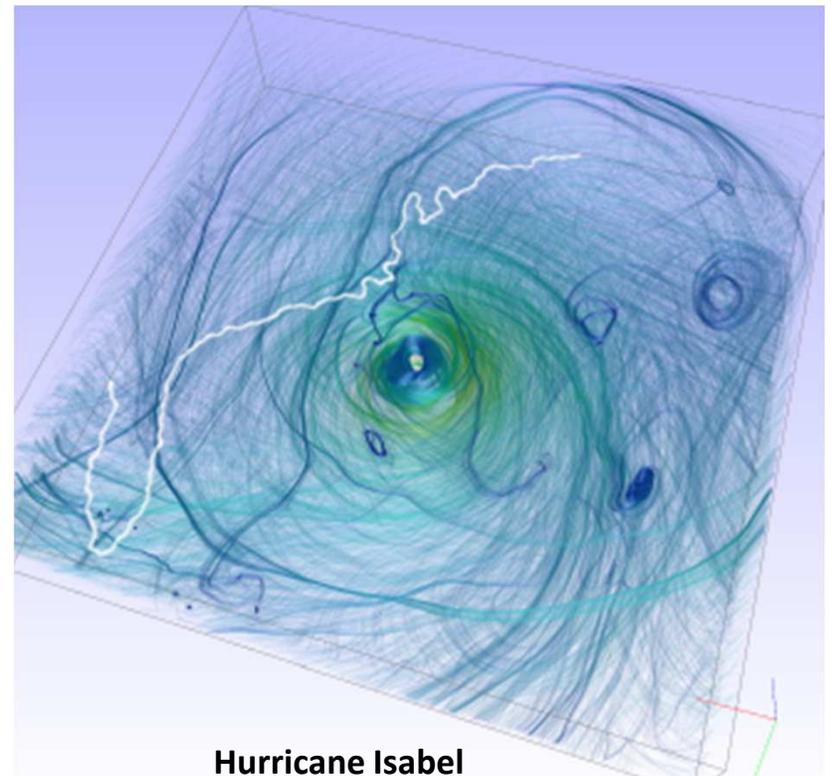
Preview of Topics

- Vector field visualization I
 - Hedge-Hodge
 - Particle tracing
 - Integration-based

$$\vec{V} = \vec{F}(x, y, z, t)$$



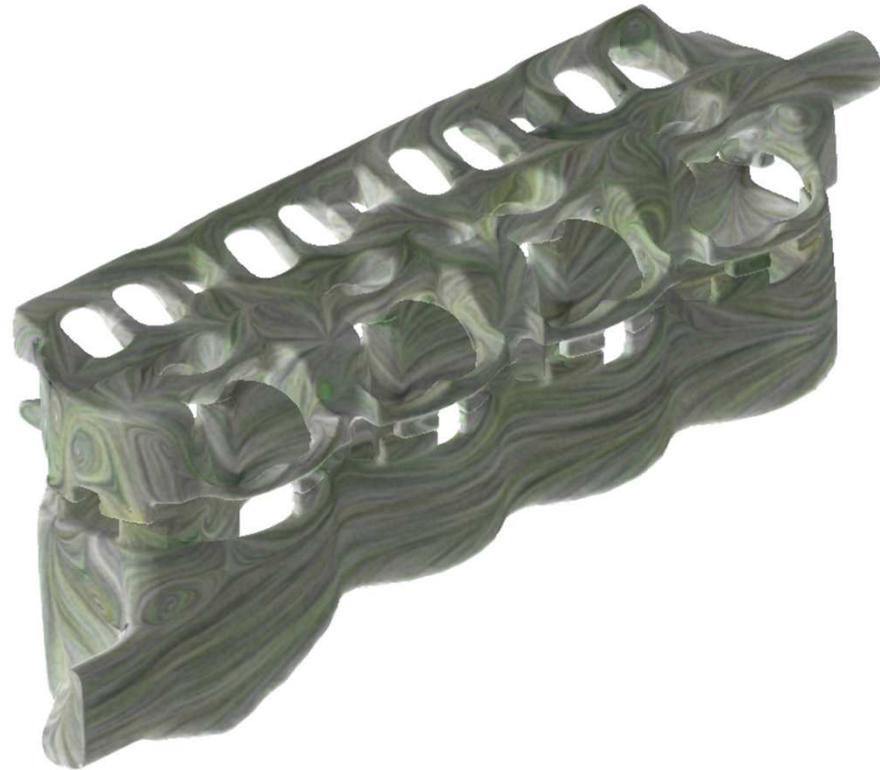
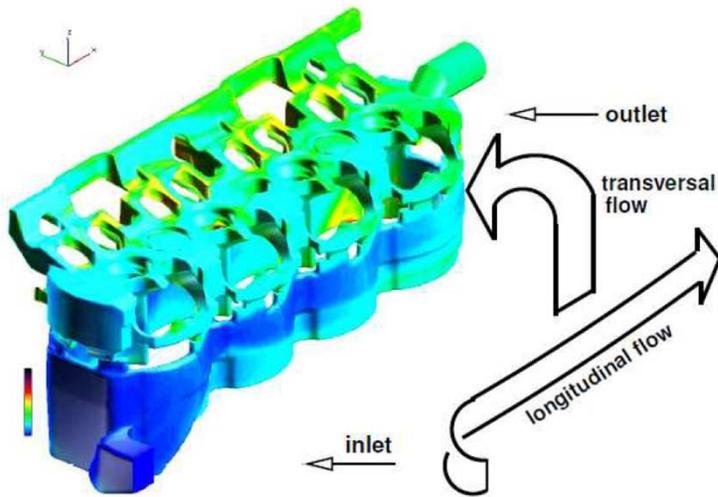
Migration Fields [Clark and Vakakis 1992]



Hurricane Isabel

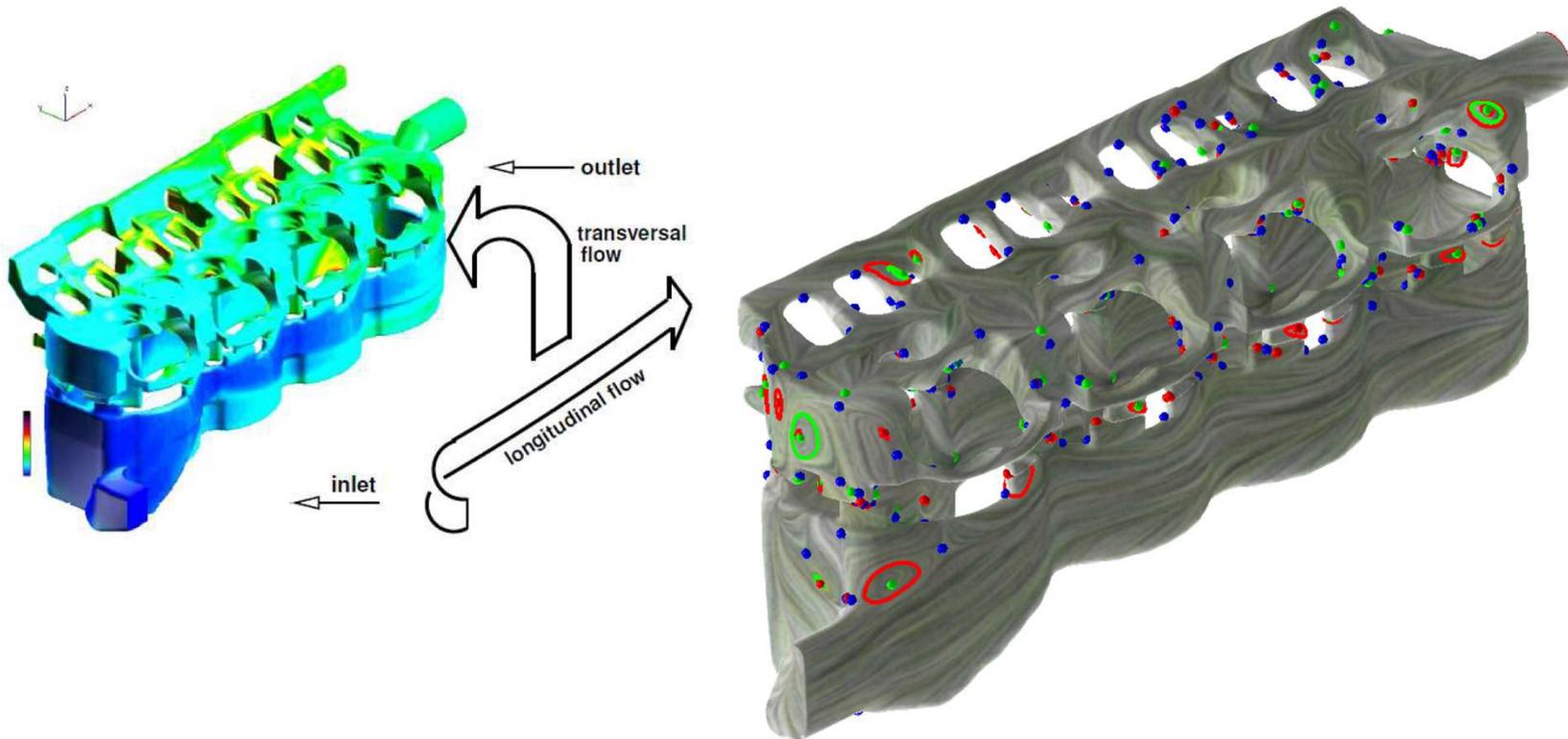
Preview of Topics

- Vector field visualization II
 - Texture-based



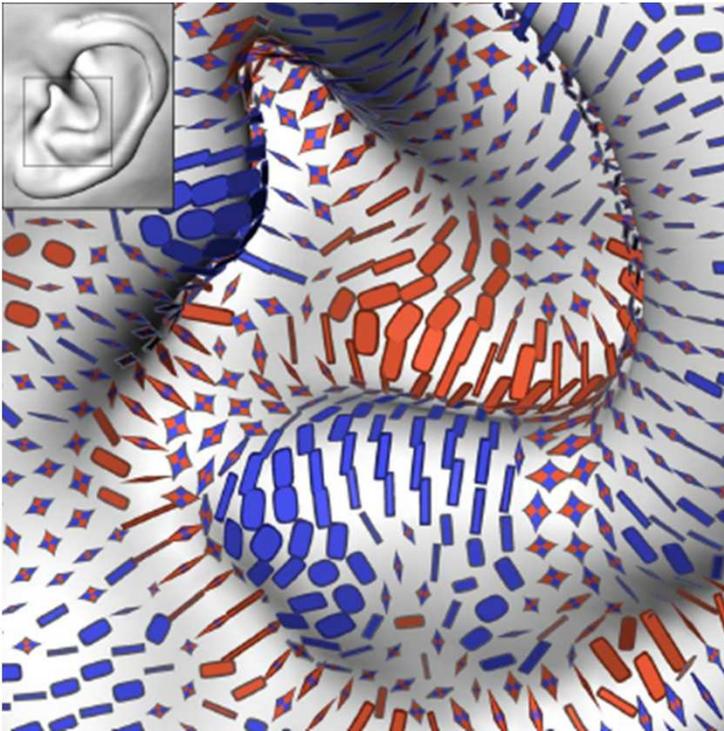
Preview of Topics

- Vector field visualization III
 - Topology



Preview of Topics

- Tensor field visualization I
 - Glyph-based



Schultz and Kindlmann, IEEE Vis10

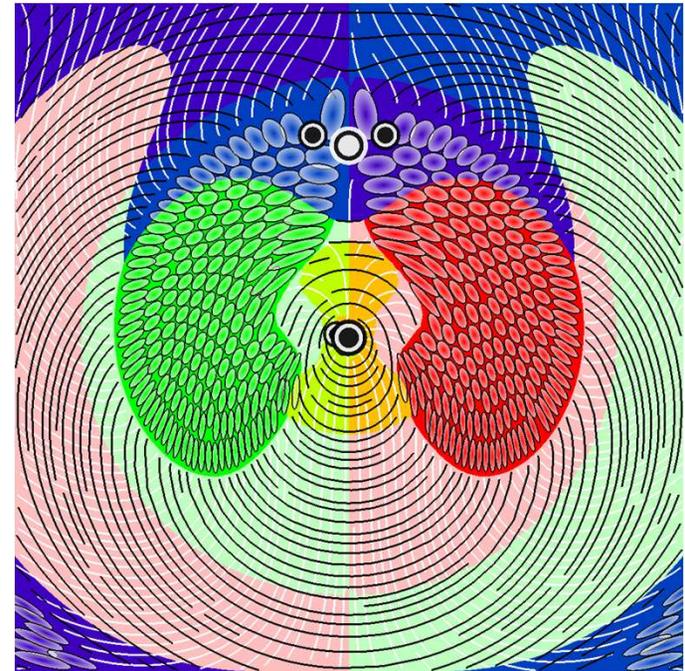
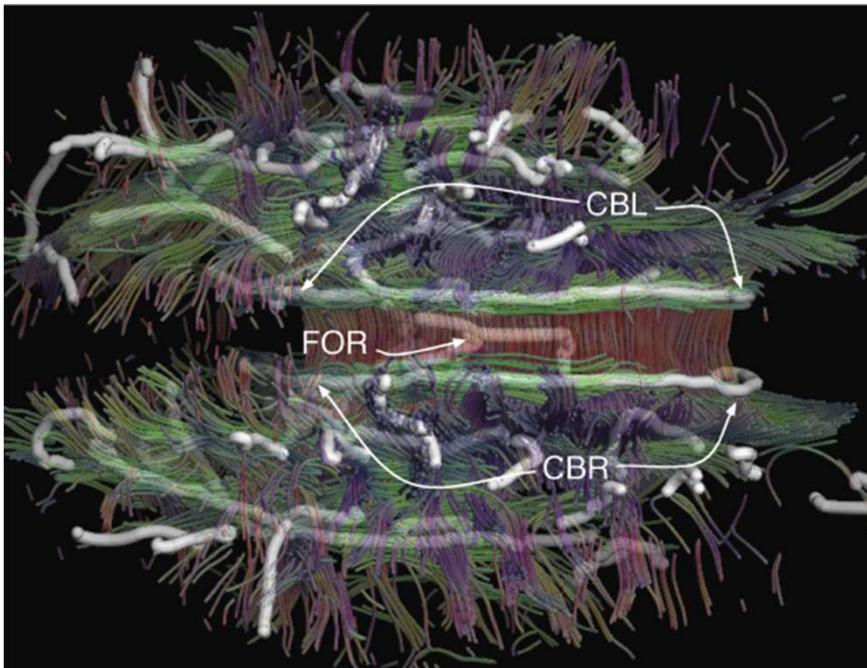


Kindlmann and Westin, IEEE Vis06

Preview of Topics

- Tensor field visualization II
 - Integration-based
 - Texture-based

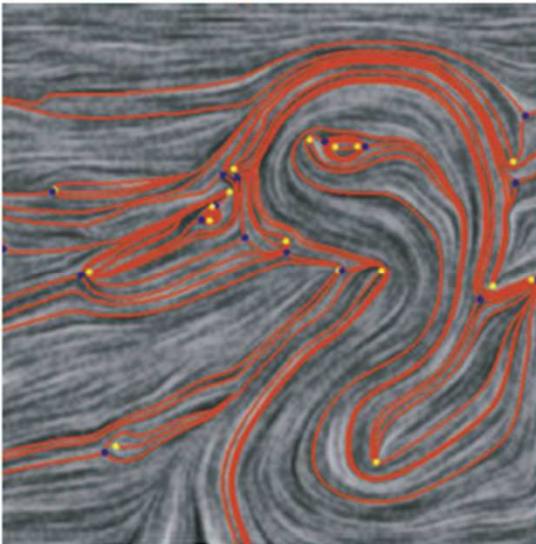
$$T = \begin{bmatrix} T_{00}(x, y, z) & & \\ & \ddots & \\ & & \end{bmatrix}$$



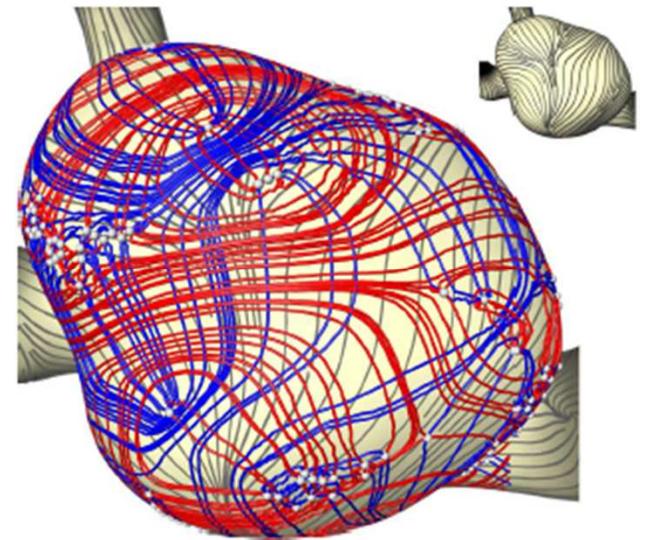
DTI data [Tricoche et al. 2008]

Preview of Topics

- Tensor field visualization III
 - Topology



Edge field [Zhang et al. TVCG07]

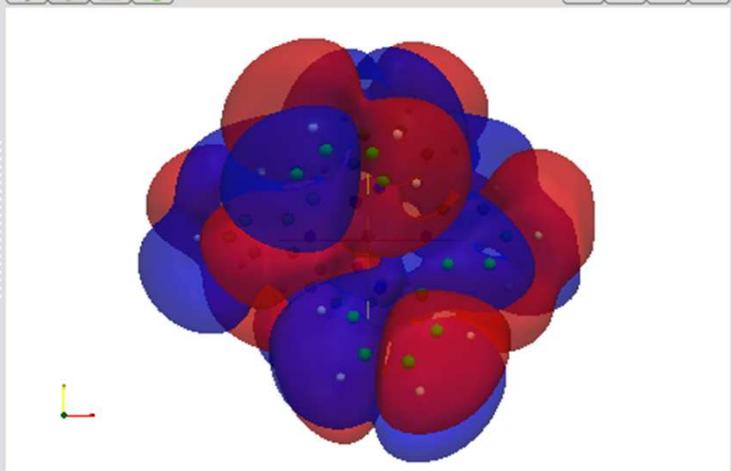
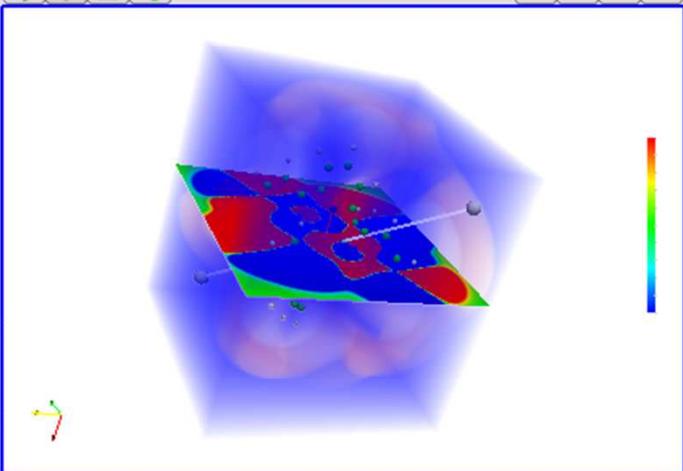


Strain tensor field [Auer and Hotz EuroVis11]

Preview of Topics

- Visualization systems
 - General purpose (open source)

- builtin:
 - TpyRu.cube
 - Output
 - Glyph1
 - Gridded Data
 - Slice1
 - PlotOverLine1**
 - Contour1
 - Contour2
 - Histogram1



Object Inspector

Properties Display Information

Apply Reset Delete

Source: High Resolution Line Source

Show Line

Point1: 29.07739 20.28716 19.92404

Point2: 141.1771 120.3064 121.1877

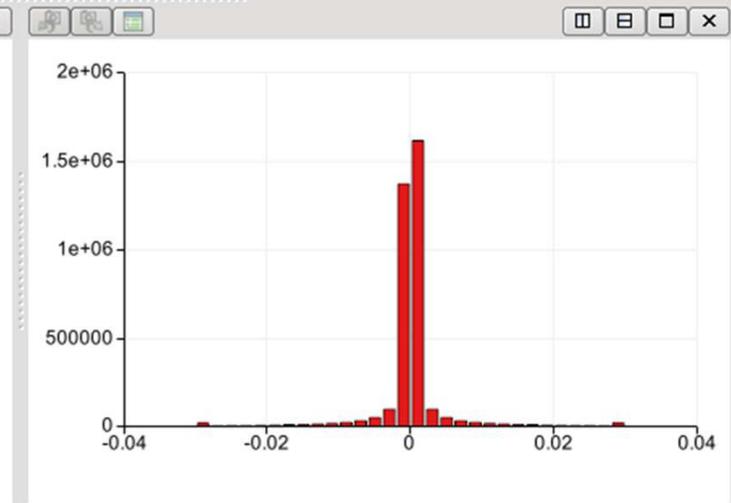
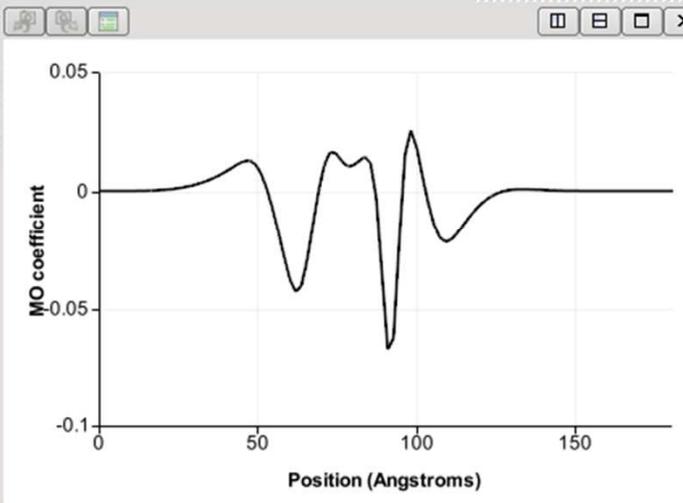
X Axis

Y Axis

Z Axis

Resolution: 100

Note: Move mouse and use 'P' key to change point position



Visit 1.6

File Controls Options Windows Help

Selected files

1: prism0p020.shp

ReOpen Replace Overlay

Active window Maintain limits Replace plots

1 view data Auto update

Active plots Hide/Show Delete Draw

1:Pseudocolor - value

Plots Operators PlotAtts OpAtts Variables

Apply operators and selection to all plots

Engines

Engine Information

Number of processors: 1

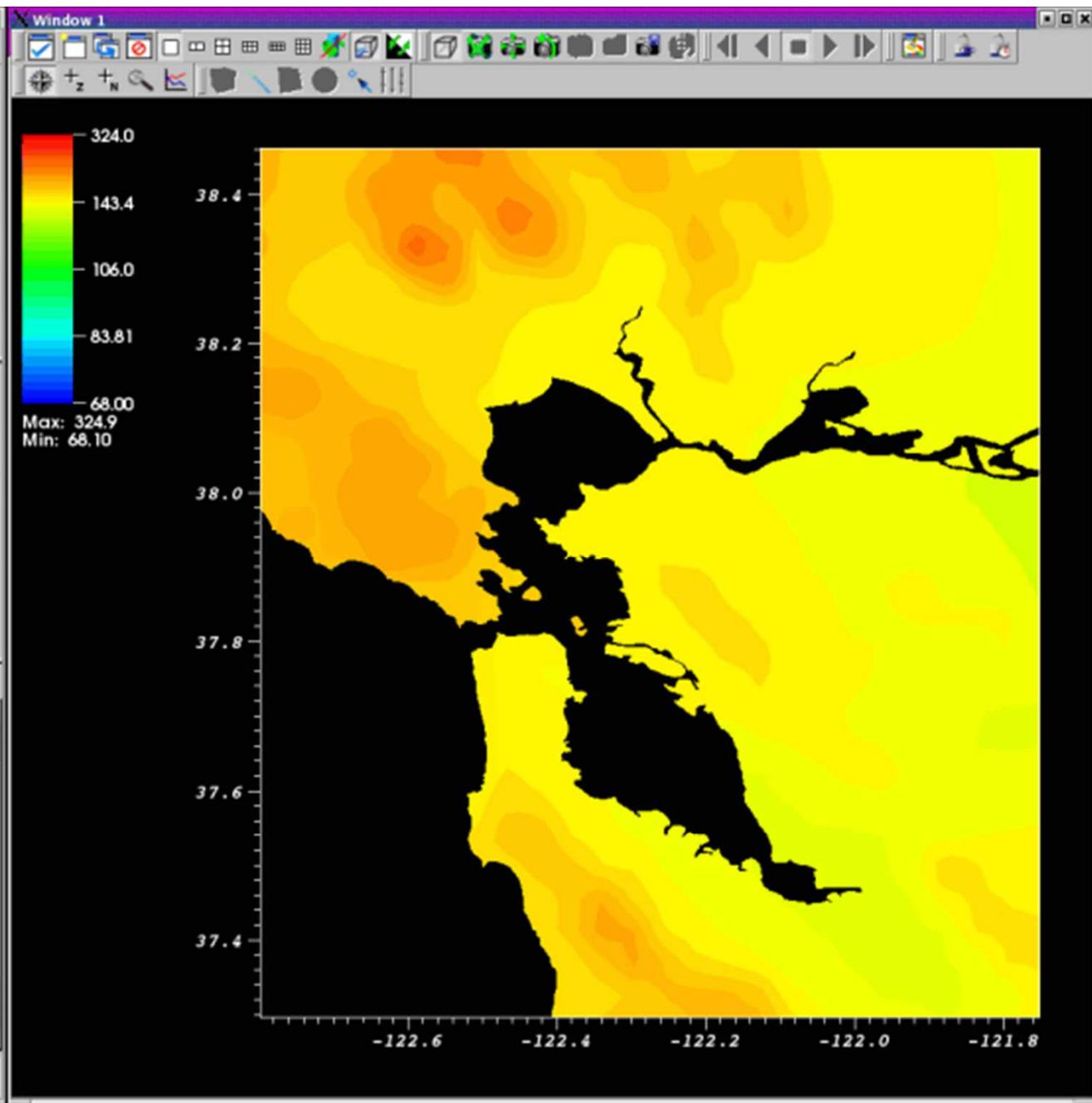
Number of nodes: Default

Load balancing: Static

Total Status:

Stage Status:

Interrupt Clear cache Close engine



Preview of Topics

- Hot topics in visualization
 - Illustrative visualization



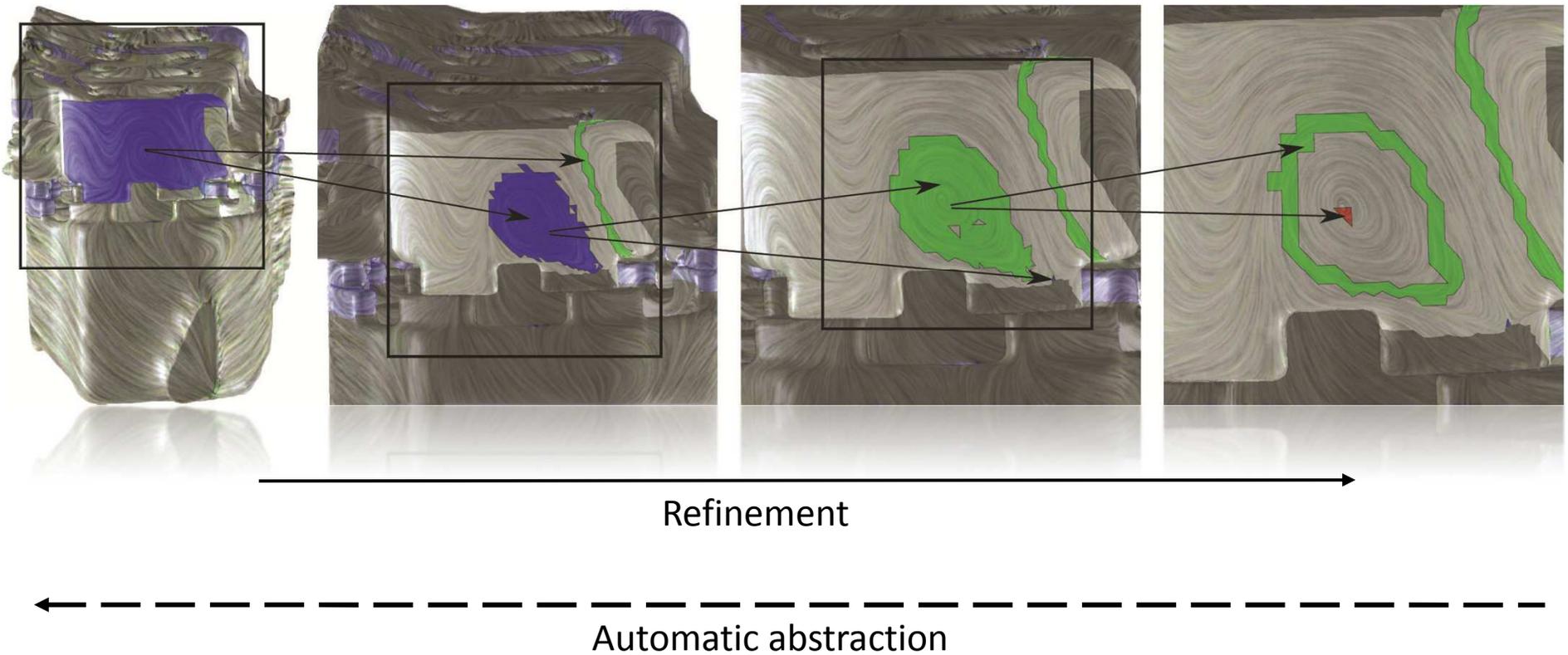
Depth-Dependent Halos: Illustrative Rendering of Dense Line Data

Preview of Topics

- Hot topics in visualization
 - Illustrative visualization
 - Multi-scale and multi-resolution methods

Preview of Topics

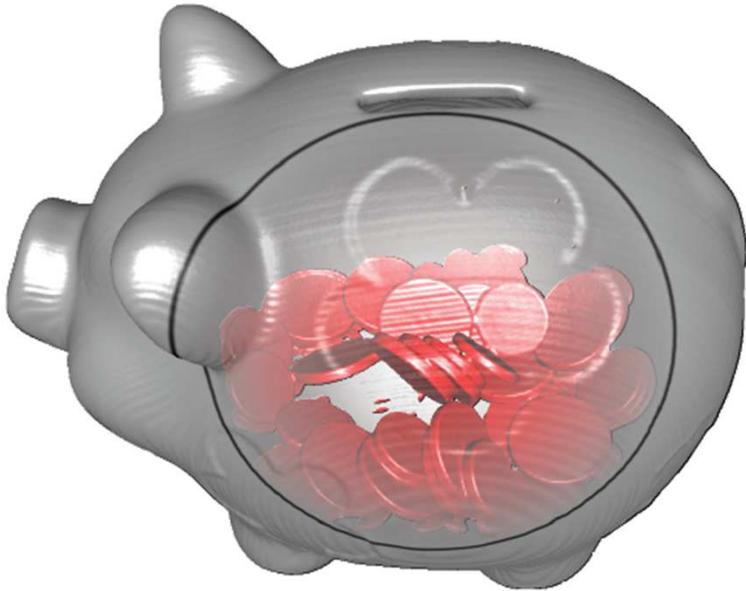
- Hot topics in visualization



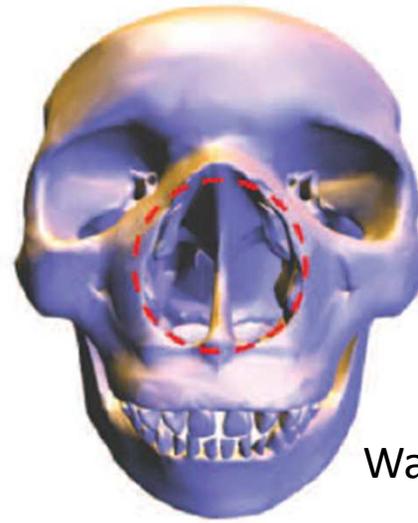
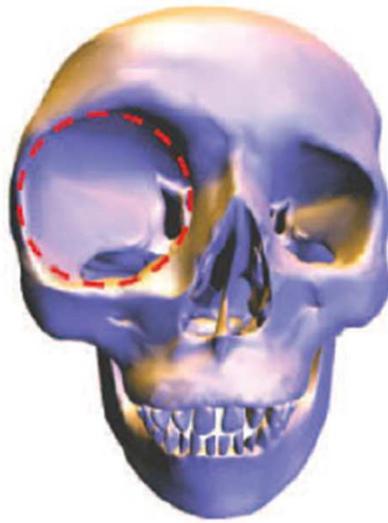
Preview of Topics

- Hot topics in visualization
 - Illustrative visualization
 - Multi-scale and multi-resolution methods
 - Focus + context methods

Preview of Topics



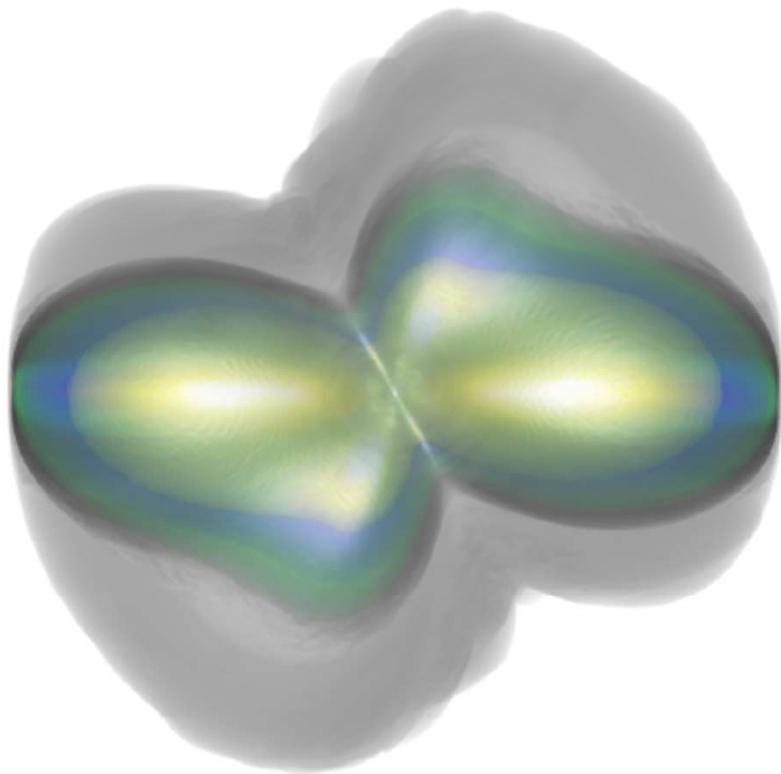
Kruger and Fogal [WC2009]



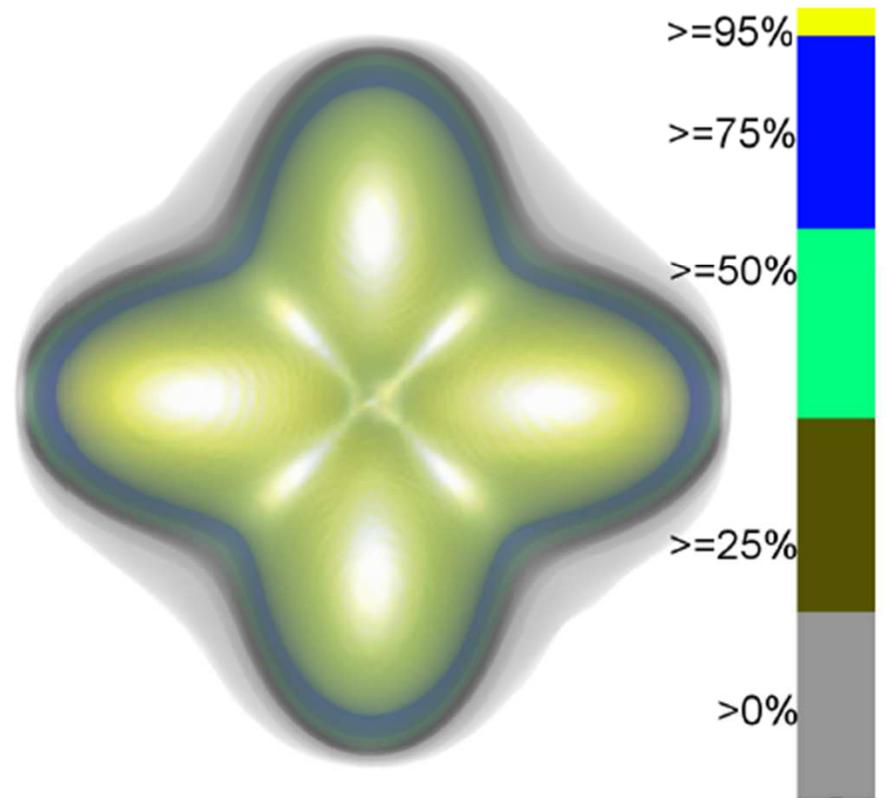
Wang et al. [IEEE Vis08]

Preview of Topics

- Hot topics in visualization
 - Illustrative visualization
 - Multi-scale and multi-resolution methods
 - Focus+content methods
 - Uncertainty visualization



(a) b -value 7000 s/mm², SNR=10, (0.6,0.4) 60°



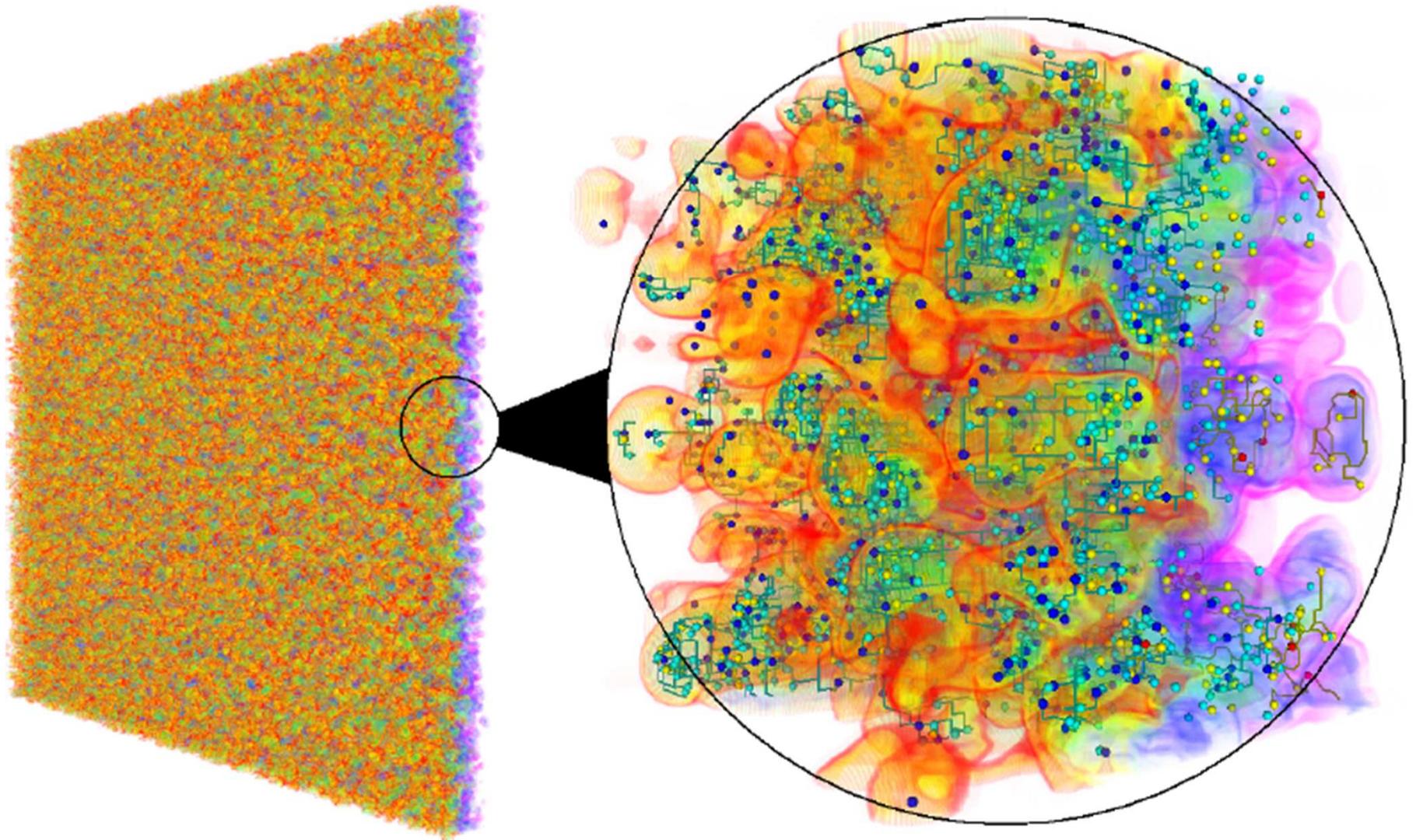
(b) b -value 1000 s/mm², SNR=20, (0.5,0.5) 90°

Visualization of the uncertainty in two diffusion shapes. (a) Two fibers crossing at 60 degrees with relative weight of 0.6:0.4 and SNR of 10. (b) Two fibers crossing at 90 degrees with equal weight and SNR of 20 (with much less uncertainty).

Jiao et al.[PacificVis2012]

Preview of Topics

- Hot topics in visualization
 - Illustrative visualization
 - Multi-scale and multi-resolution methods
 - Focus+content methods
 - Uncertainty visualization
 - Large-scale data visualization



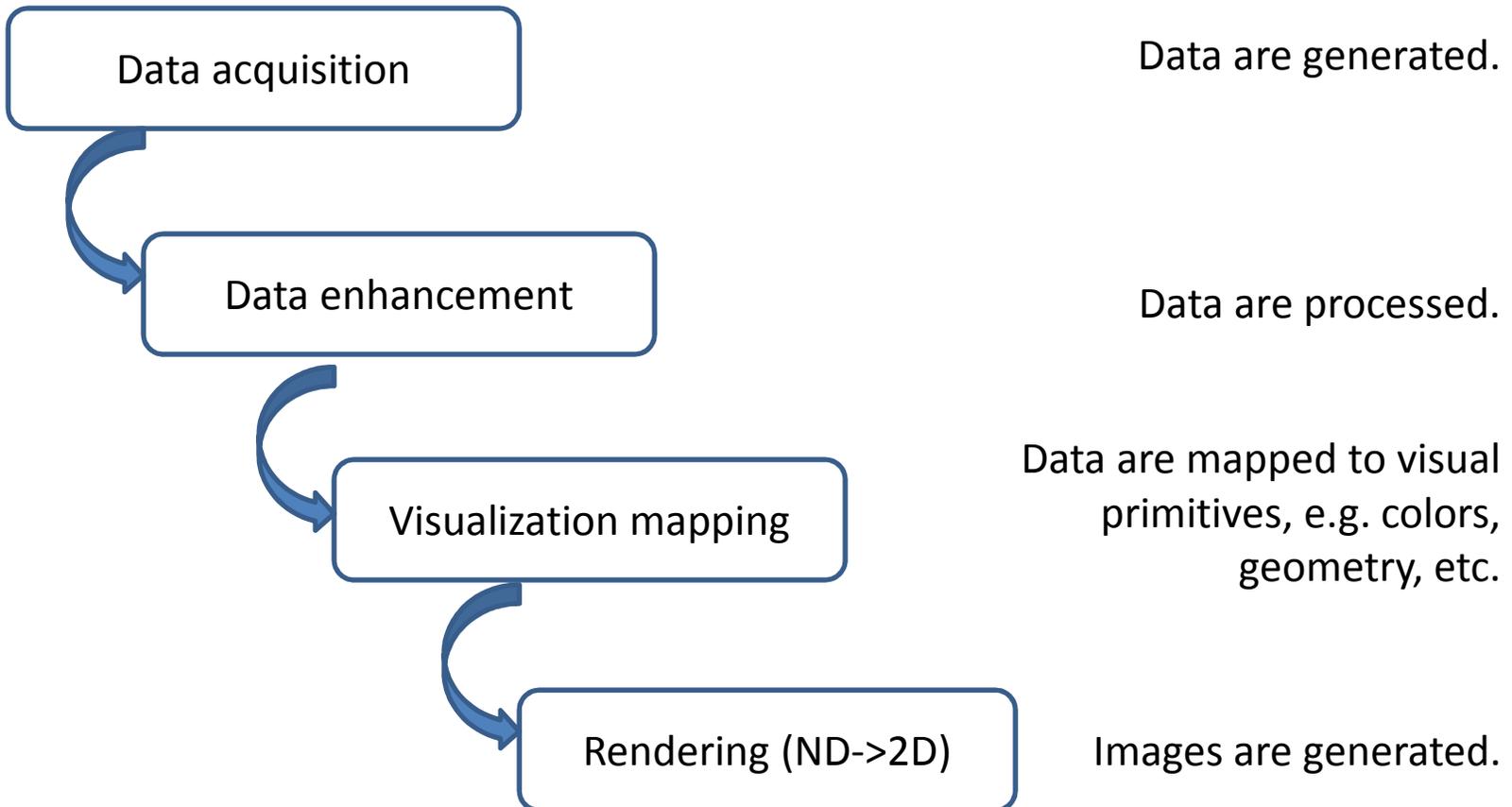
A single time step of a dataset of a simulated Rayleigh-Taylor instability simulating the mixing of two fluids

Preview of Topics

- Hot topics in visualization
 - Illustrative visualization
 - Multi-scale and multi-resolution methods
 - Focus+content methods
 - Uncertainty visualization
 - Large-scale data visualization
 - Advanced (novel) applications

Visualization Pipeline

Visualization Pipeline Overview



Visualization Pipeline – Step 1

- Data acquisition
 - Real world
 - Measurements and observations, e.g., CT/MRI, GIS (MB), seismic data (GB), Hubble Space Telescope (TB)...
 - Theoretical world
 - Mathematical and technical models -> e.g., Structural mechanics (MB), CFD simulation (GB)
 - Artificial world
 - Data that is designed, e.g. drawing (MB), game industry (GB)

Visualization Pipeline – Step 2

- Data enhancement
 - Filtering, e.g, smoothing (noise suppression)
 - Resampling, e.g., on a different-resolution grid
 - Data Derivation, e.g., gradients, curvature
 - Data interpolation, e.g., linear, cubic, ...

Visualization Pipeline – Step 3

- Visualization mapping = data is renderable
 - Iso-surface calculation
 - Glyphs, Icons determination
 - Graph-layout calculation
 - Voxel attributes: color, transparency, ...

Visualization Pipeline – Step 4

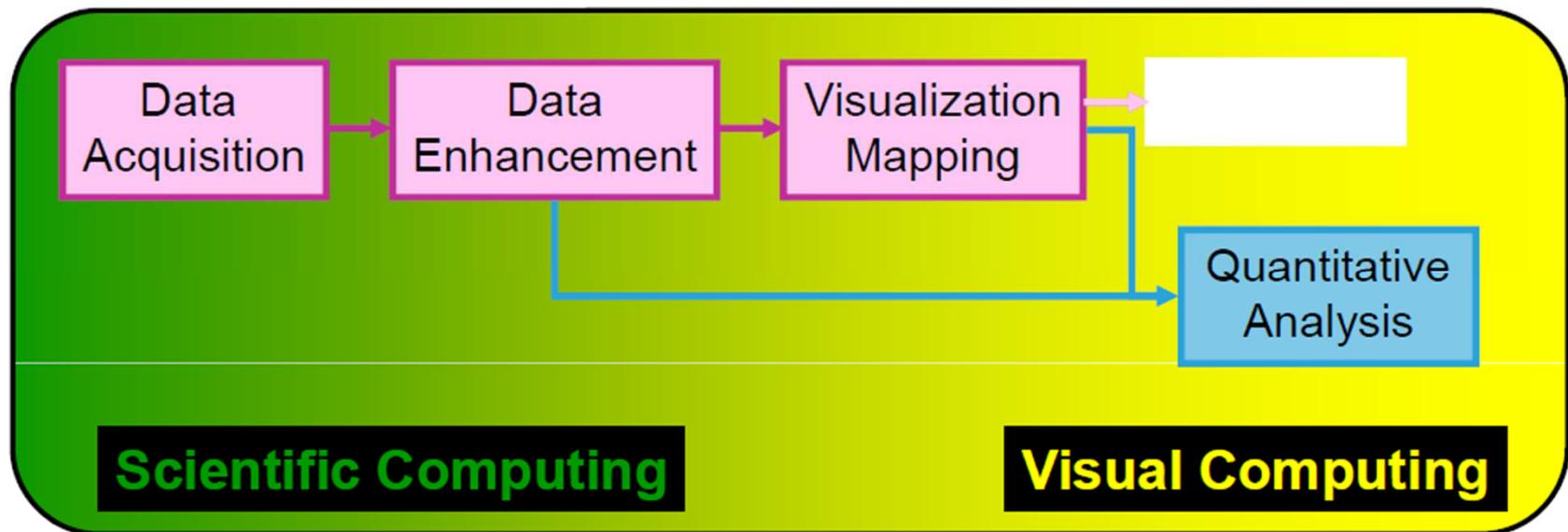
- Rendering = image generation with Computer Graphics
 - Visibility calculation
 - Illumination
 - Compositing (combine transparent objects,...)
 - Animation

Mike's Visualization Pipeline-

Seven Steps to Creating a Visualization

- 1. Get the data. Find out something about it. Units? Spatial dimension? Data dimension?
- 2. *Formulate a scientific strategy.* What do you want to show? How do you want to show it? What final format/medium do you need it in?
- 3. Import the data. (This often takes more time than you would ever expect...)
- 4. Create a *simple* program, network, script, etc.
- 5. Incrementally embellish it. Save it often!
- 6. Choose what quantities you want to interact with. Change the interaction styles to match the quantities being modified.
- 7. Create the final output. Pay attention to your color choices!

Computation Science – Visual Computing



- Visual Computing
 - Computer graphics
 - Visualization
 - Image processing
 - Computer vision
 - Human computer interaction

By Eduard Gröller, Helwig Hauser

Reading

- Robert S. Laramée, How to Read a Visualization Research Paper: Extracting the Essentials
<http://cs.swan.ac.uk/~csbob/research/how2read/laramee09how2read.pdf>