

High Performance Visualization

(or how to think using most of your brain)

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University of Utah



Computational Science Pipeline

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Construct a model of the physical domain (**Mesh Generation, CAD**)

Apply boundary conditions

Numerically approximate governing equations (**FE, FD, BE**)

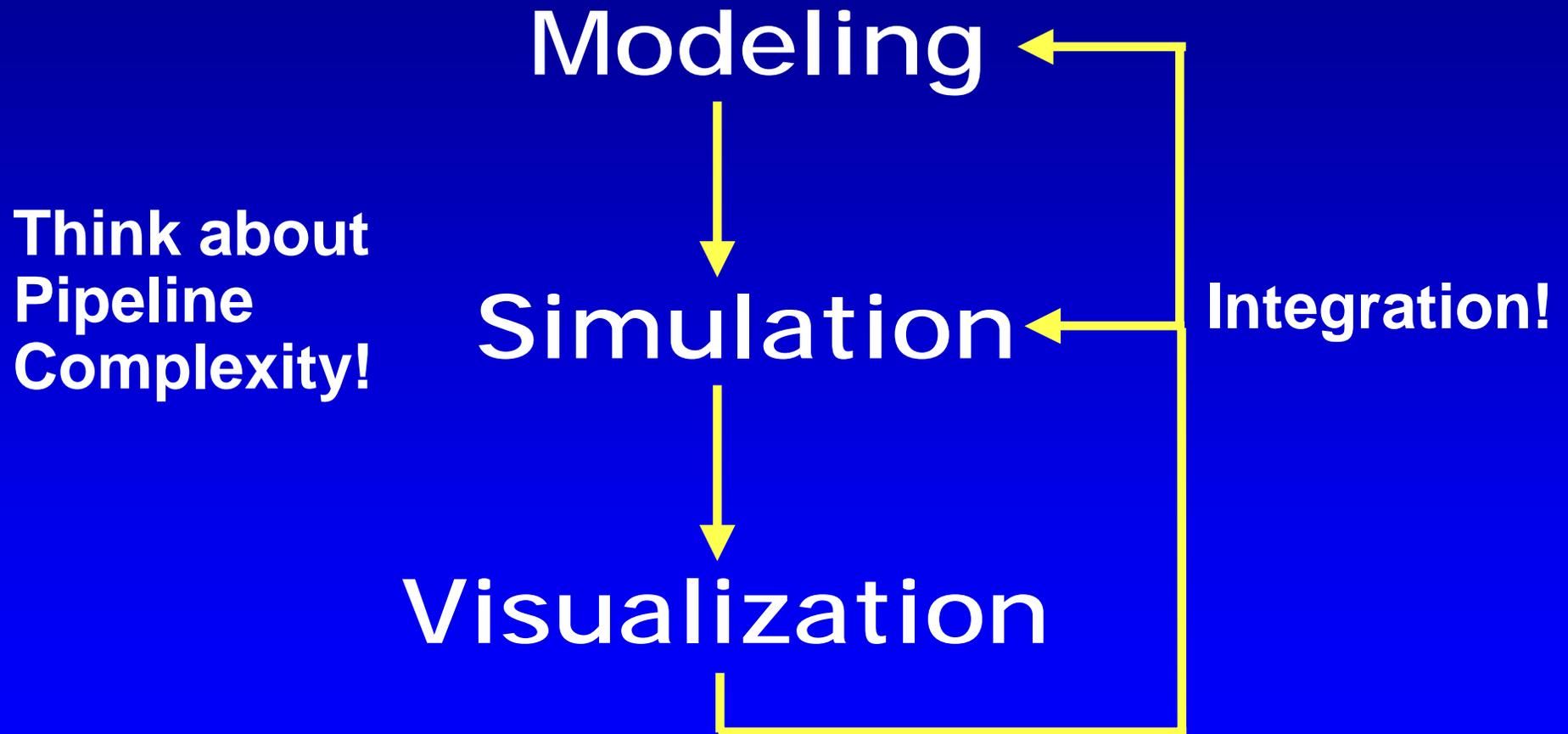
Compute (**Preconditioners, Solvers**)

Visualize (**Isosurfaces, Vector Fields, Volume Rendering**)



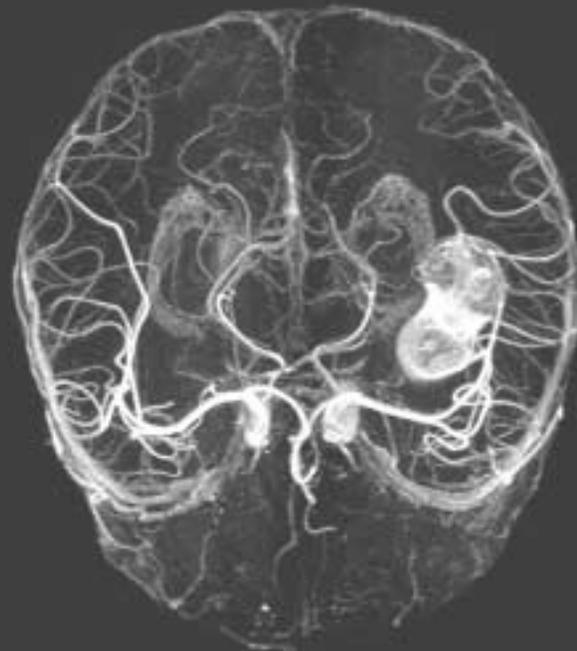
Computational Science Pipeline

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An HPV Success Story

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Why Parallel Visualization?

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Terabyte

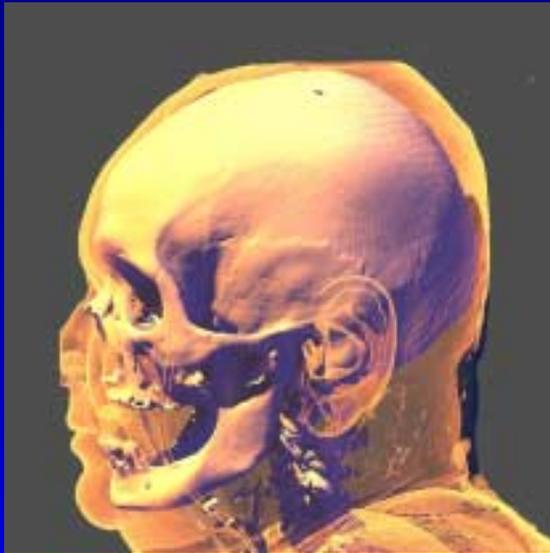


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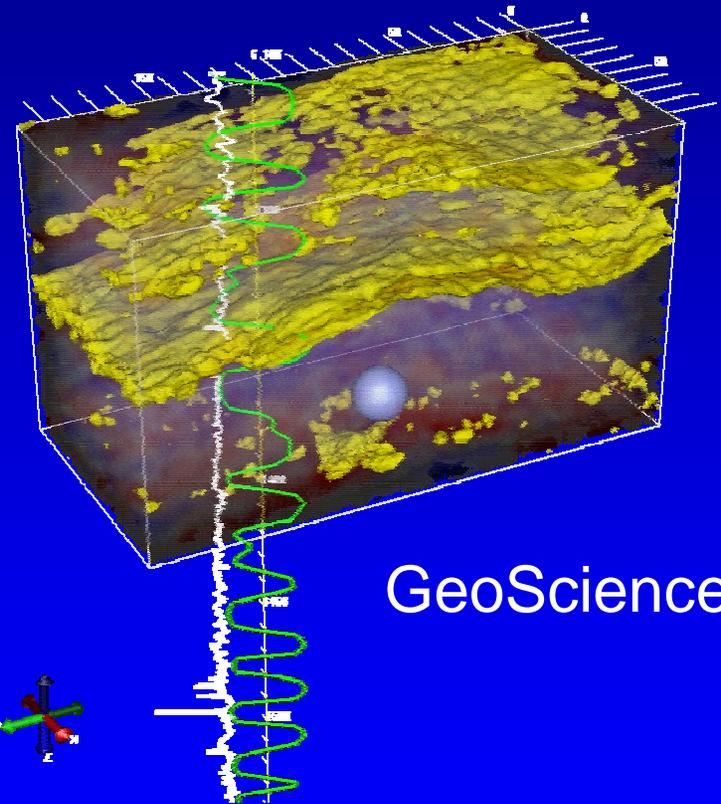


Interactive Large-Scale Visualization

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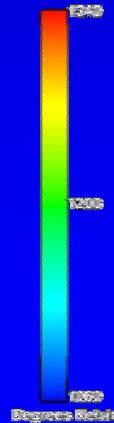
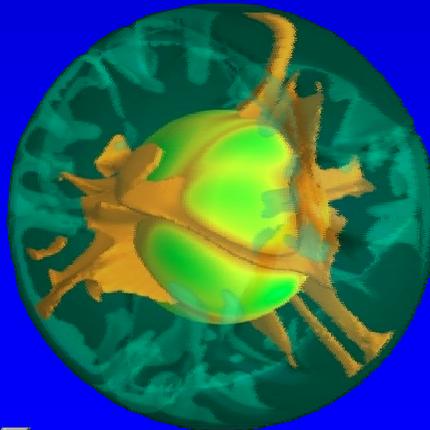


Medical



GeoScience

Scientific
Computing



ACL



The Visualization Pipeline

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- Visualization Process

Generate \Rightarrow Render \Rightarrow



- Isosurface Extraction

Search \Rightarrow Construct \Rightarrow Render \Rightarrow

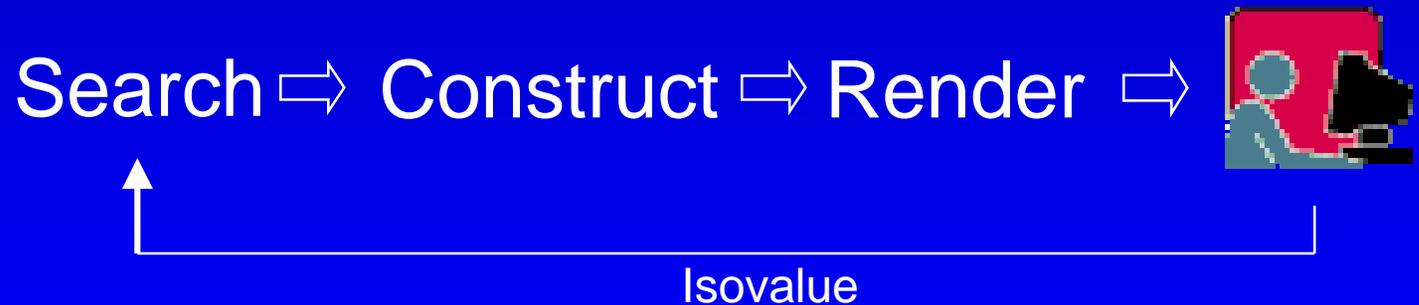
↑
Isovalue



The Visualization Pipeline

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- Dynamic extraction of isosurfaces



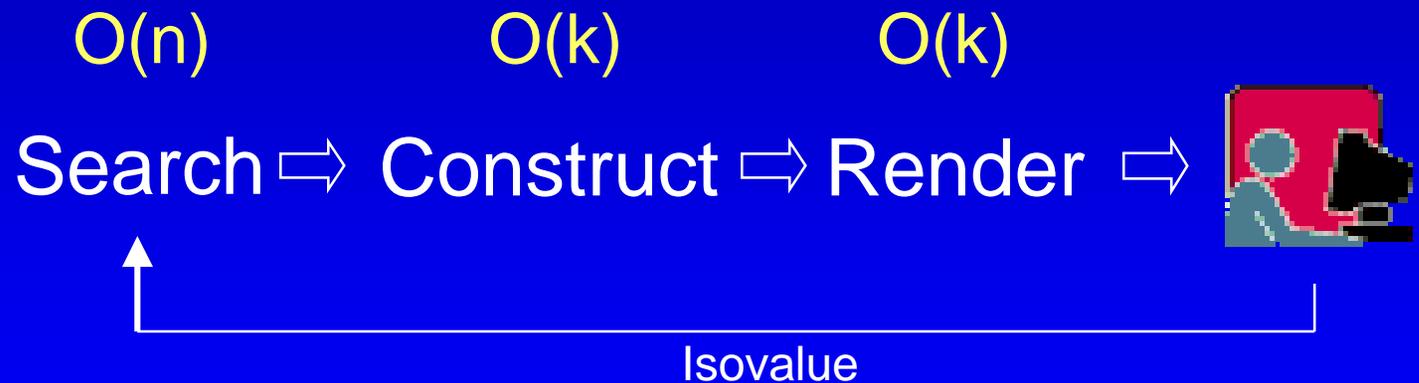
The Visualization Pipeline

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- Complexity

n: number of cells

k: number of cells an isosurface intersect



The Visualization Pipeline

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- Dynamic extraction of isosurfaces
- Rapid extractions



Large-Scale Visualization

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Marching Cubes

Wyvill, McPheeters and Wyvill 86

Lorensen and Cline 87

- **Divide and Conquer**
 - Linear Interpolation
 - Lookup table
- **Search**
Complexity: $O(n)$

New Methods

- **NOISE: $O(\sqrt{n+k})$**
- **Optimal: $O(\log(n)+k)$**
Cignoni et al. 96



Isosurface Extraction

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So, how can we do
better than optimal?



Visualization Philosophy 101

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If a polygon falls on the view plane, but no one can see it, does it still exist?

Is it still important?

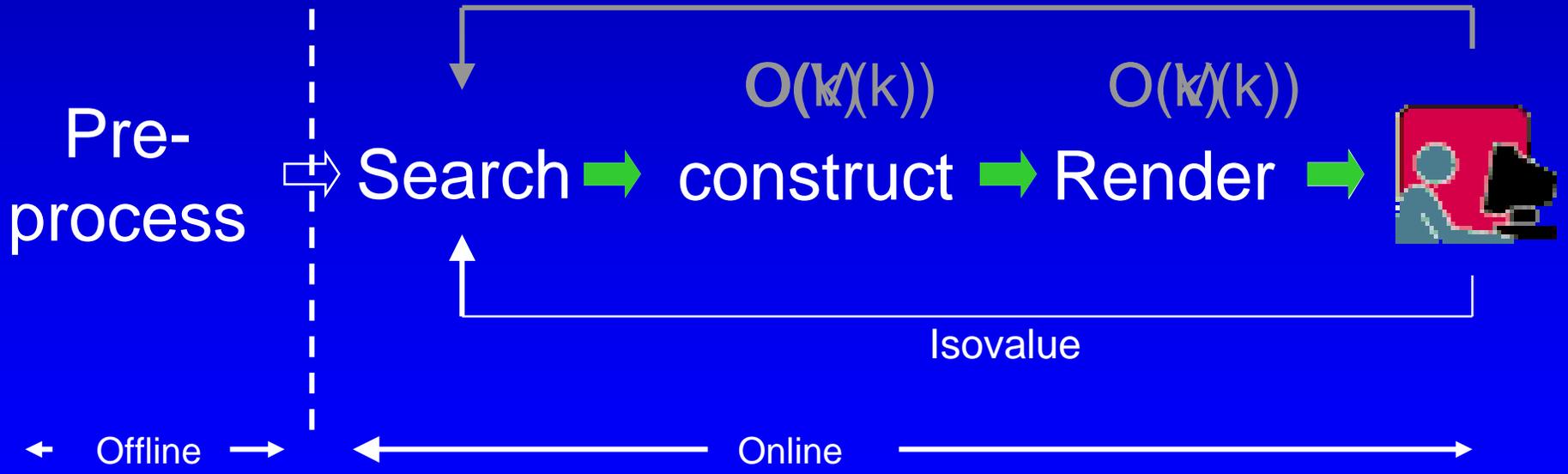


The Visualization Pipeline

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Reduce the amount of data

- Reduce during the search...
View point

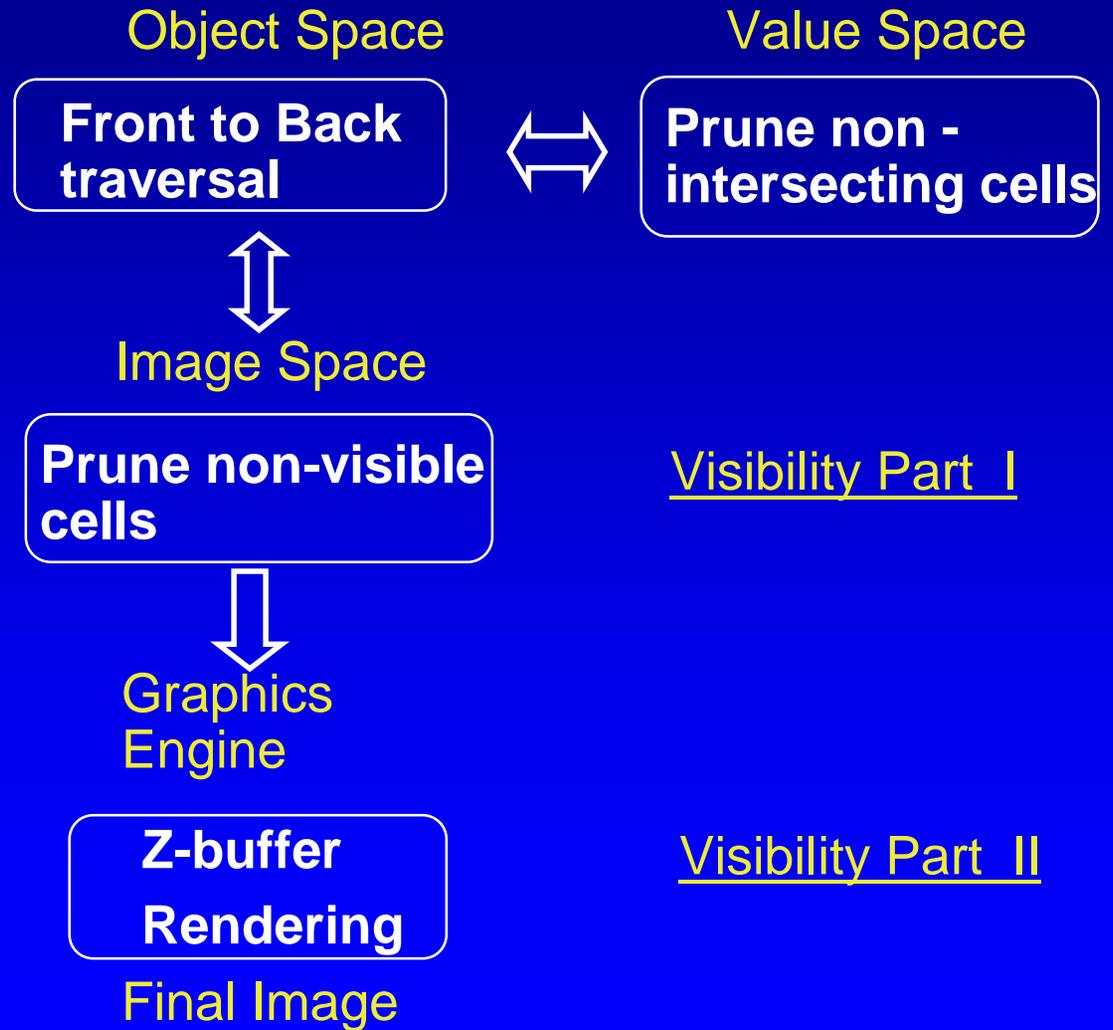


A View-dependent Approach

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Flow chart

Software
Hardware

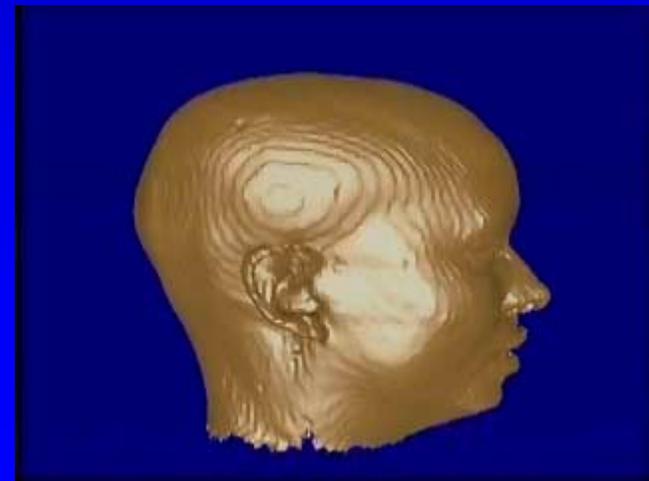
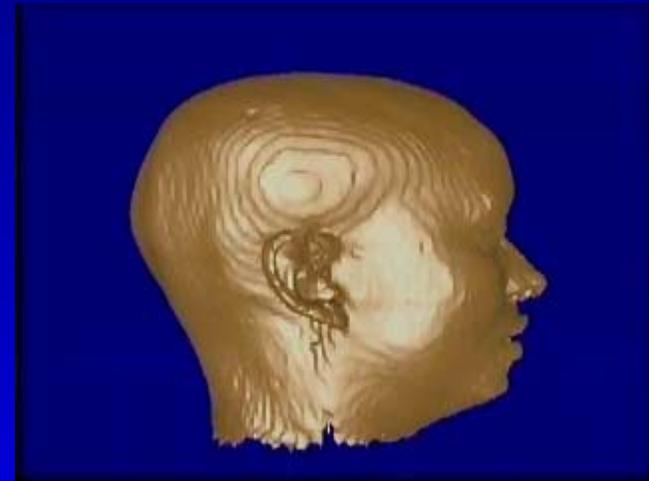
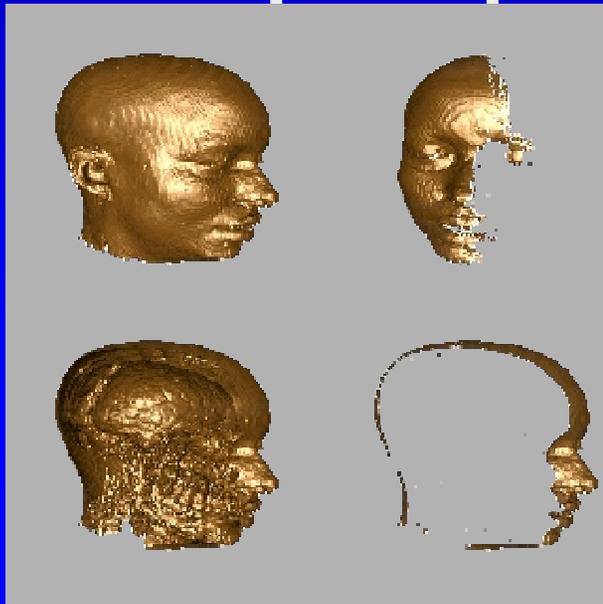


A View-dependent Approach

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Attractive for:

- Remote visualization
- Large data sets
- Sub-pixel polygons



Visible Woman

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	Full	View
	Isosurface	depend
Polys	2,246,000	246,000
Create	177 sec	72 sec
Render	2.32 sec	0.25 sec



Why Not Always Use Polygons?

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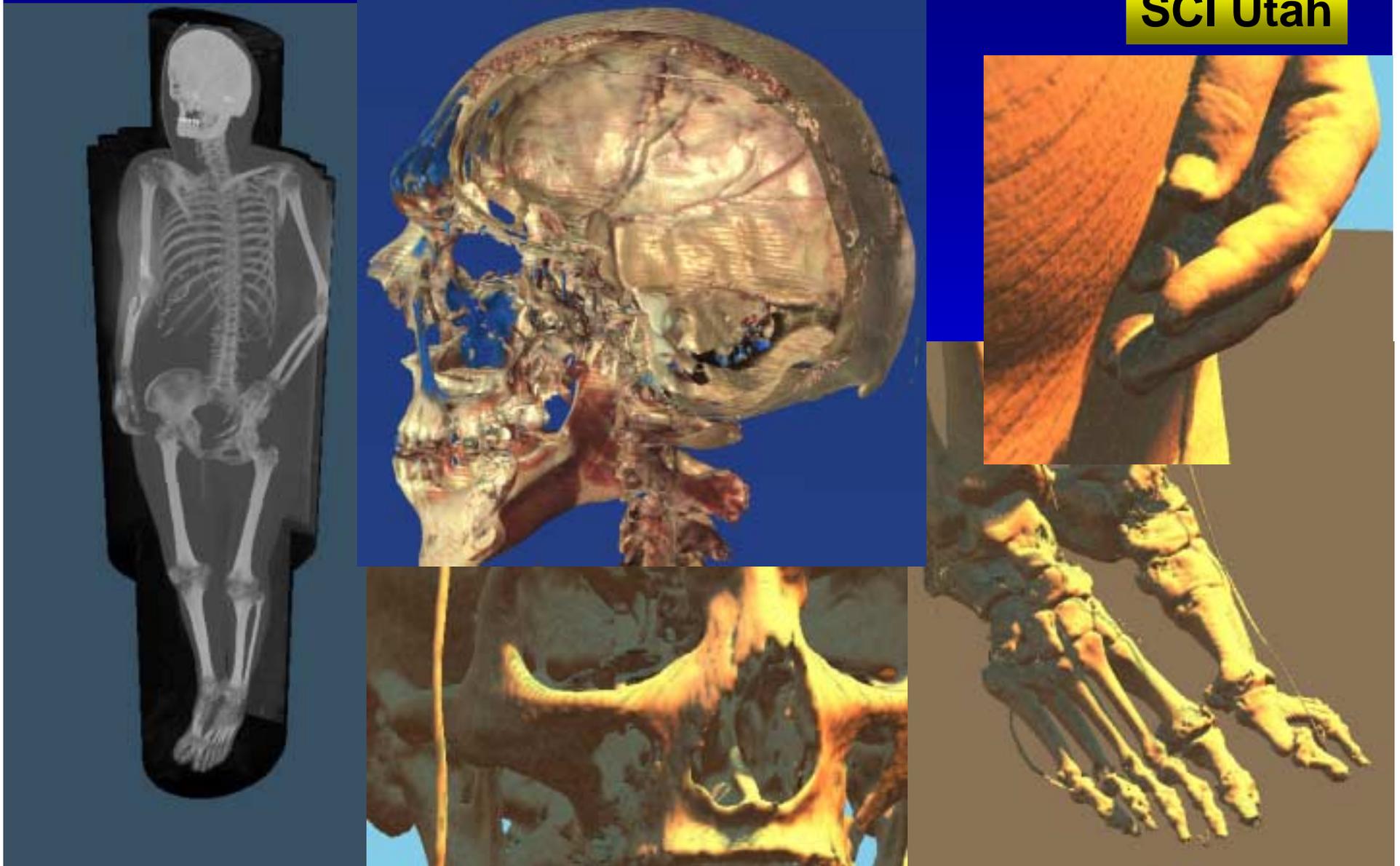
Marching cubes and similar algorithms can generate millions of polygons for large data sets

- **Reduce by decimation (e.g. Shekhar et. al '96)**
- **View dependent (e.g. Livnat and Hansen '98)**



Real-Time Ray Tracer

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Real-Time Ray Tracer (RTRT)

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Implemented on SGI Origin 3000
ccNUMA architecture - up to
512 processors (now working
on a distributed version)

Approximately linear speedup

Load balancing and memory
coherence are key to
performance



35 Million Spheres

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**Interactive Ray Tracing
University of Utah**

All images 600x400 recorded
directly from screen on
60 195MHz R10k SGI Origin 2000



Real-time Surface Rendering

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Real-time Volume Rendering

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Time Dependent Visualization

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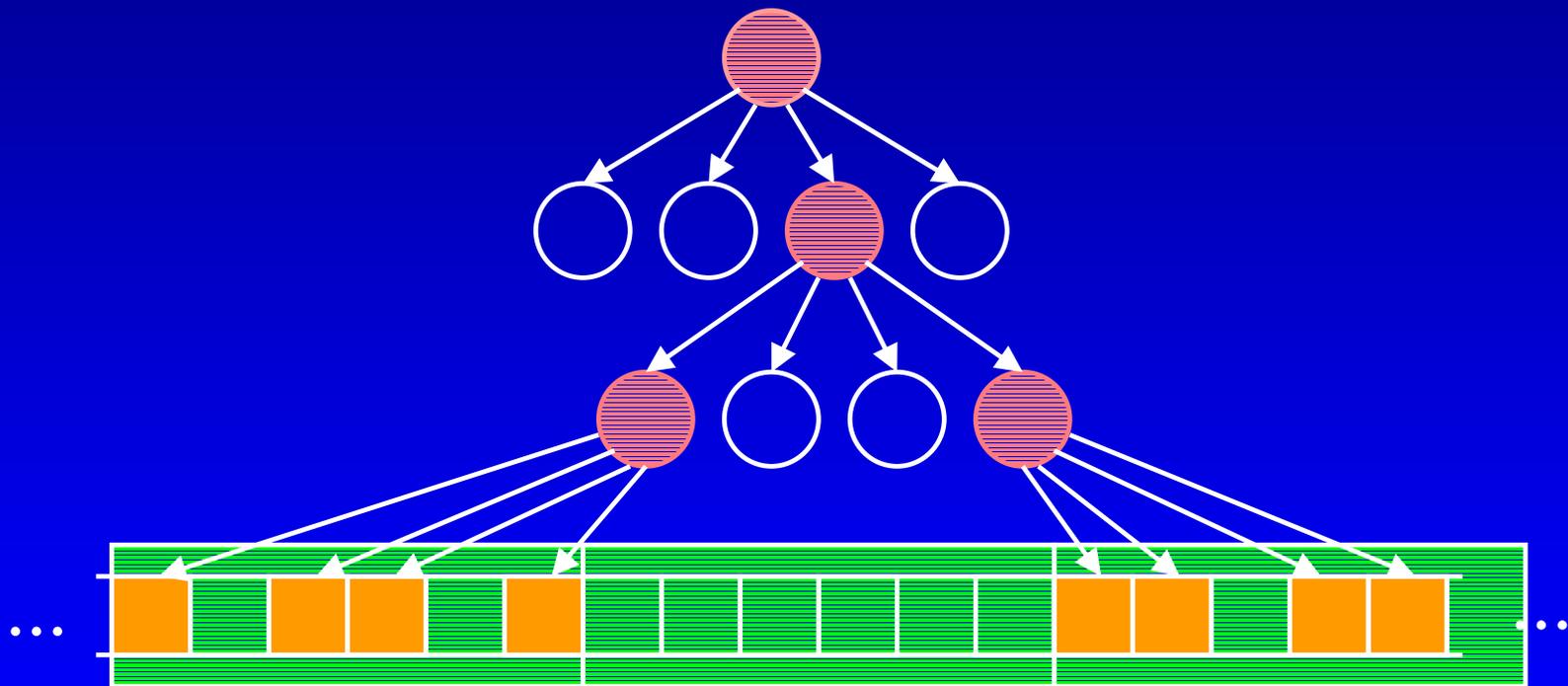
Terascale Data = multiple
time steps

T-BON – Temporal Branch
on Need Algorithm



T-BON Algorithm

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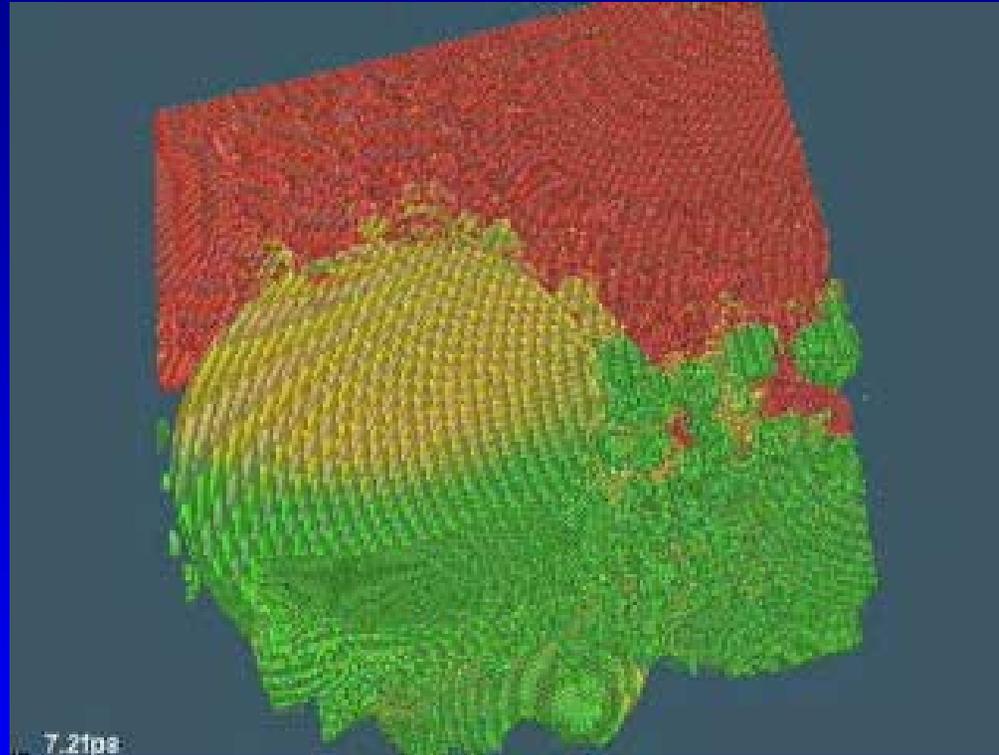
● (hatched) = $\min < \text{iso} < \max$
○ = $(\min > \text{iso}) \parallel (\text{iso} > \max)$

■ □ = data points
■ (hatched) = disk block



MPM Simulation - 512 CPUs

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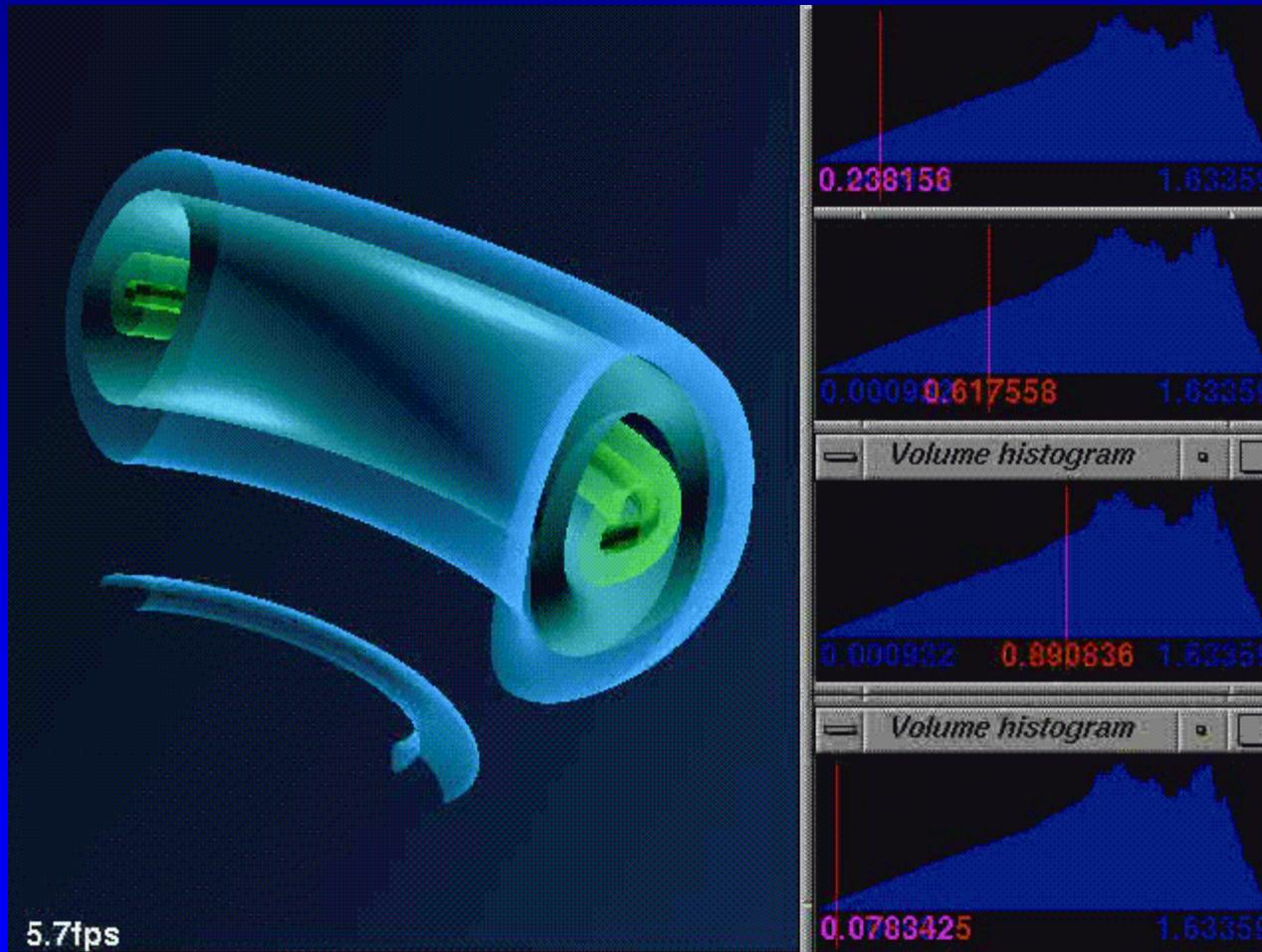


*6.8 million particles, 22 timesteps interactively
visualized using the real-time ray tracer
(10-12 fps)*



Fusion Data (General Atomics)

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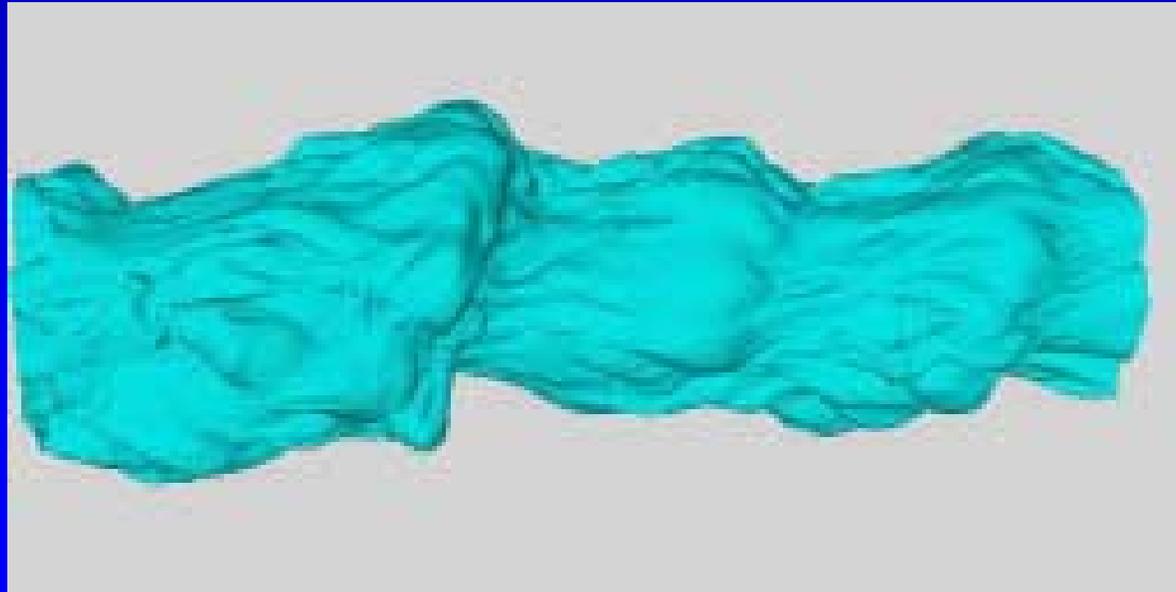


RTRT Video

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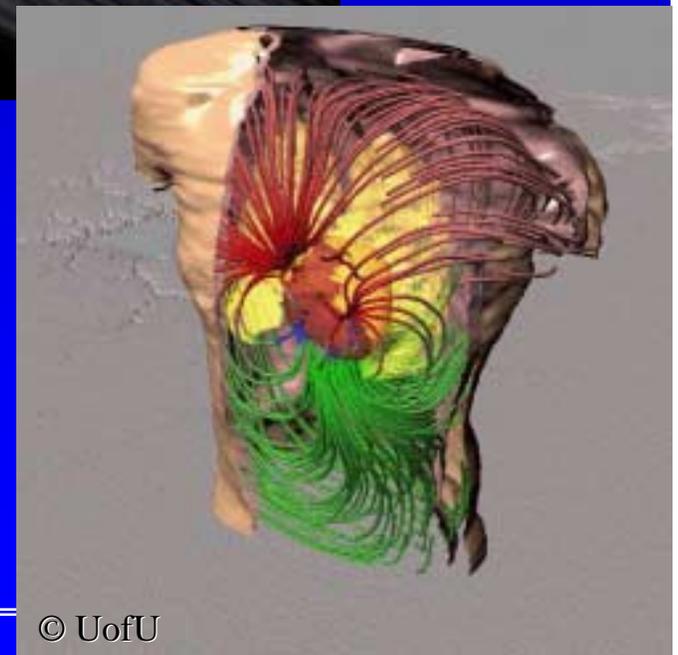
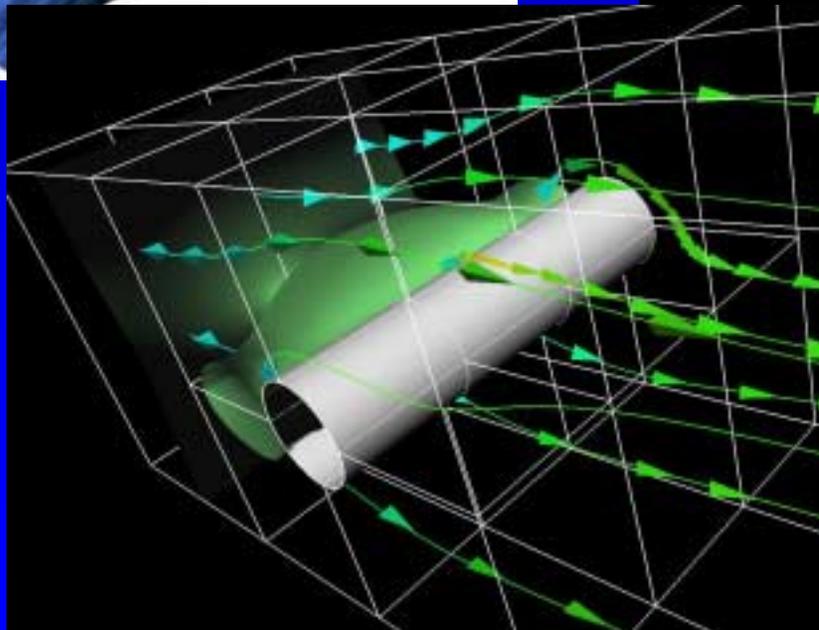
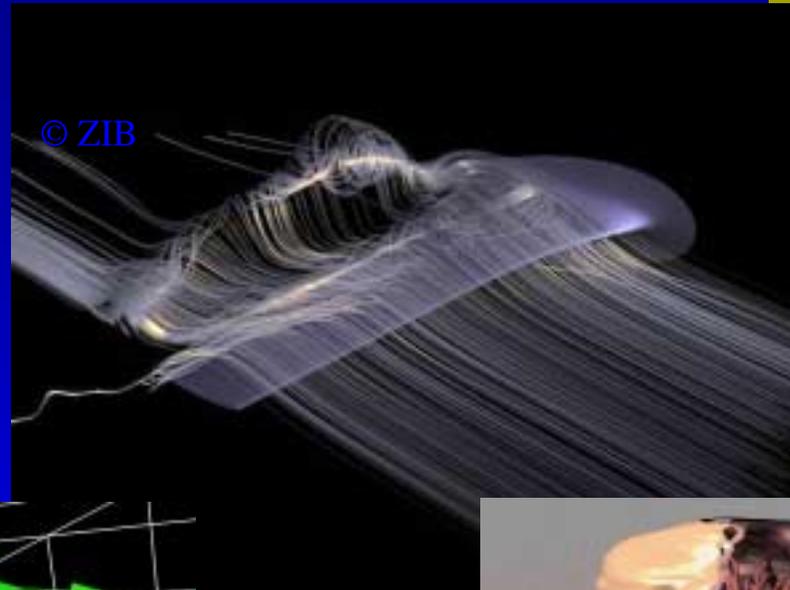
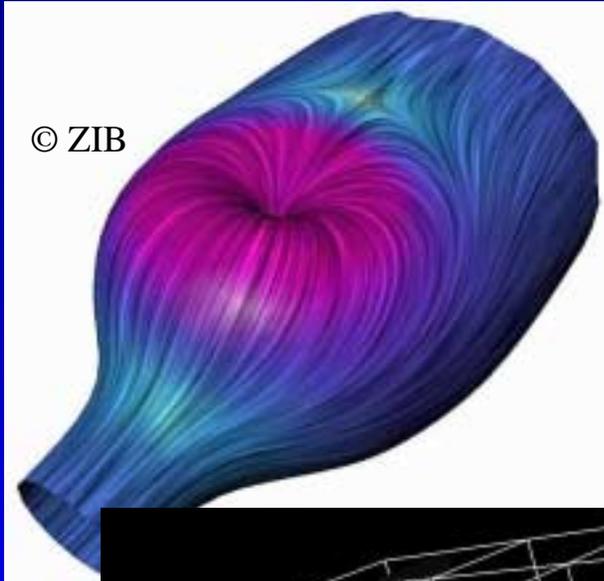
Jet Shockwave: 256x256x256 (DOE AVTC)

- Kelvin-Helmholz instability (supersonic jet)
- Time dependent interactive visualization



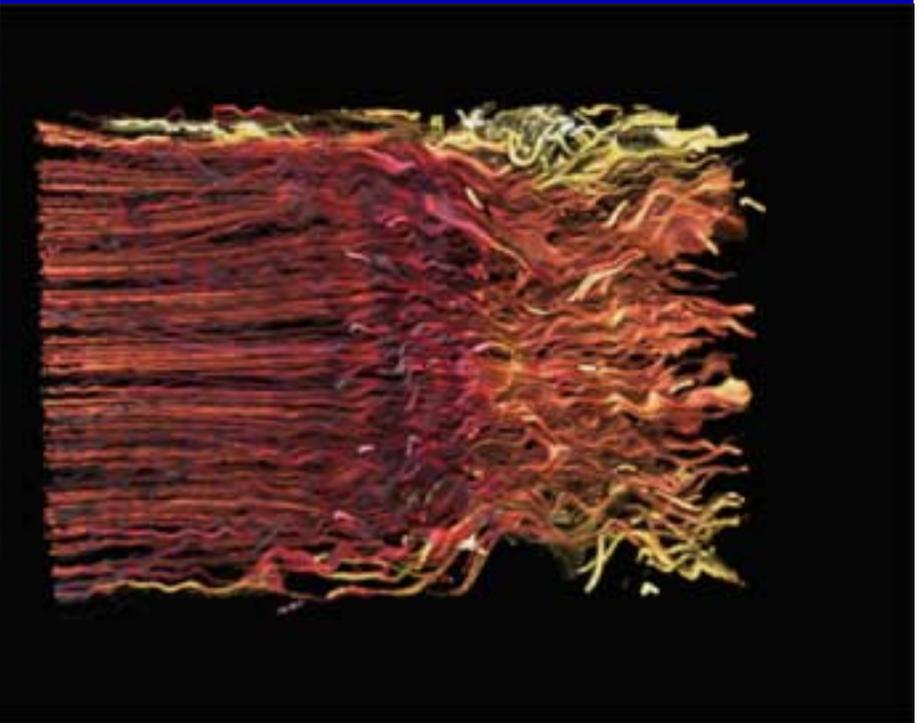
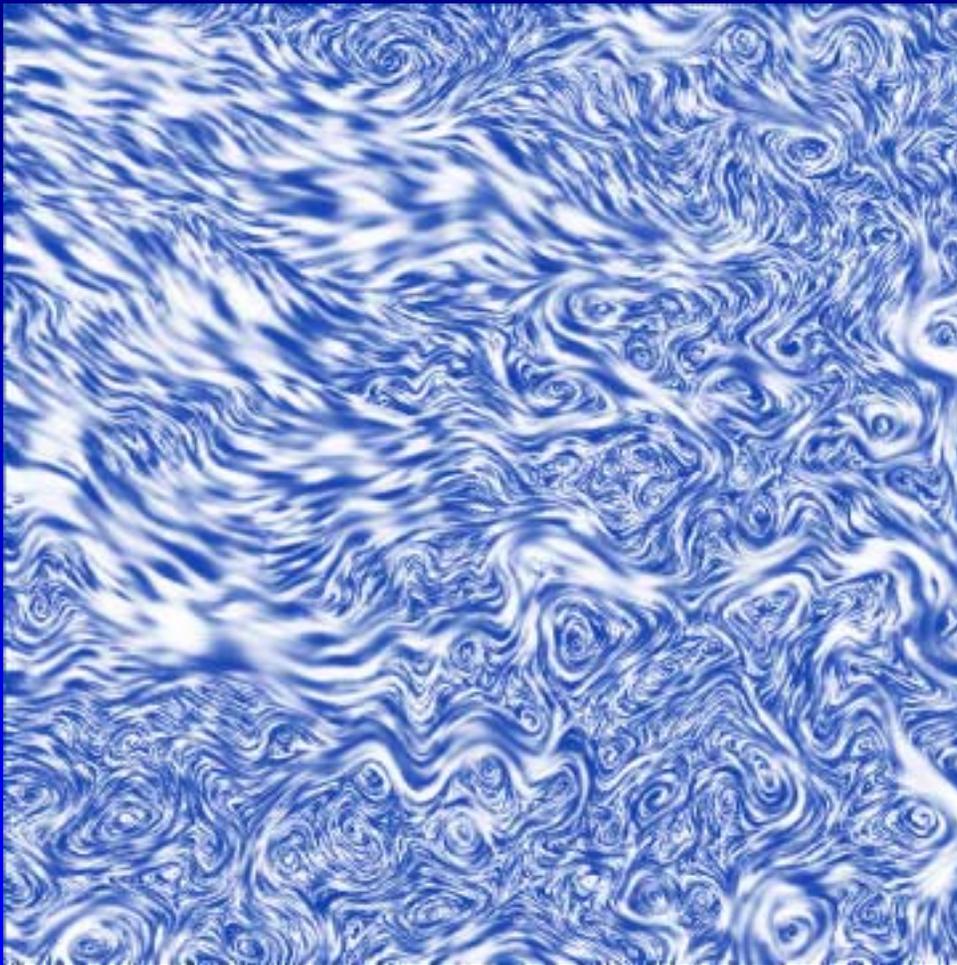
Vector Fields

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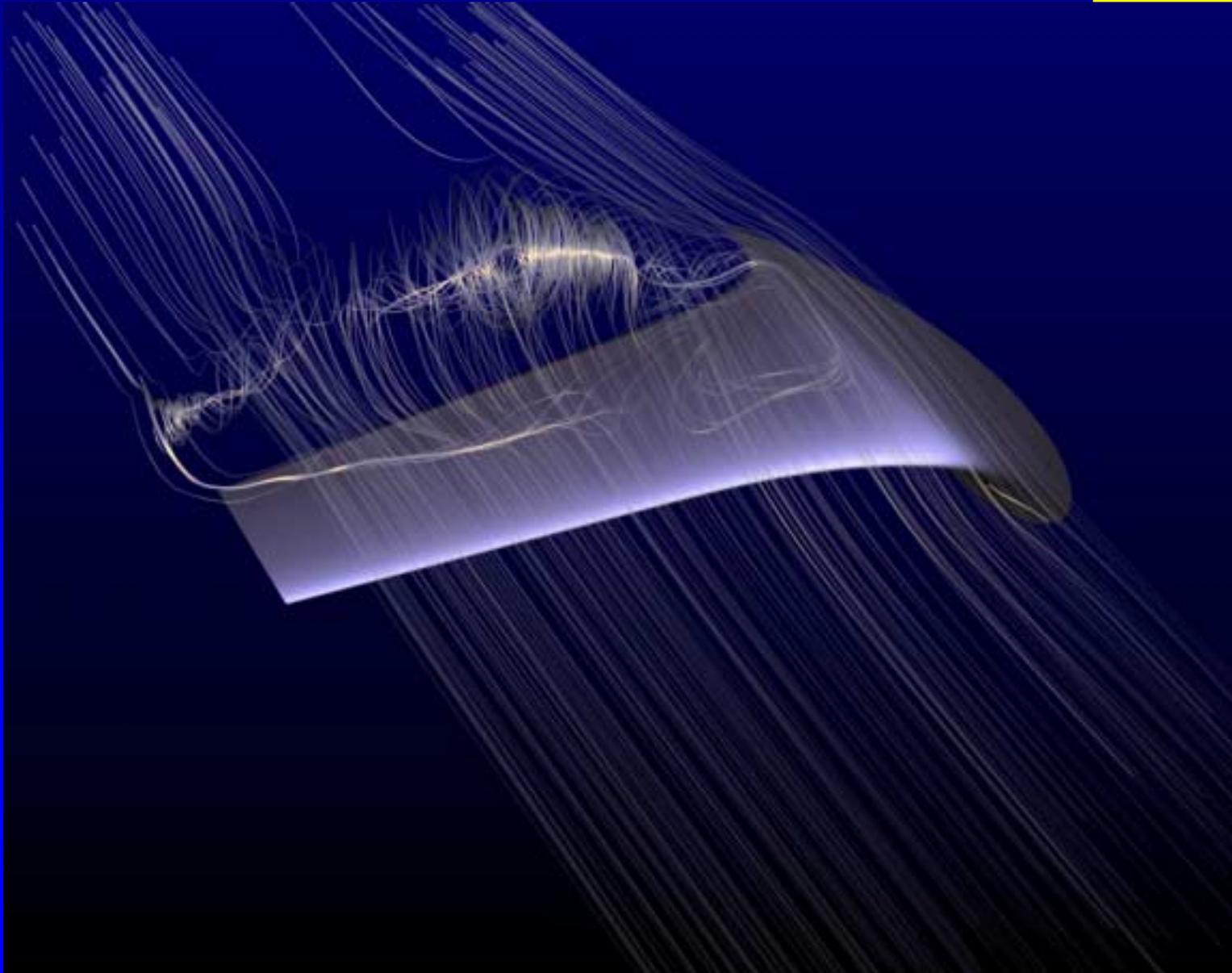


LIC Flow (Banks and Interrante)

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Illuminated Lines - C. Hege, ZIB

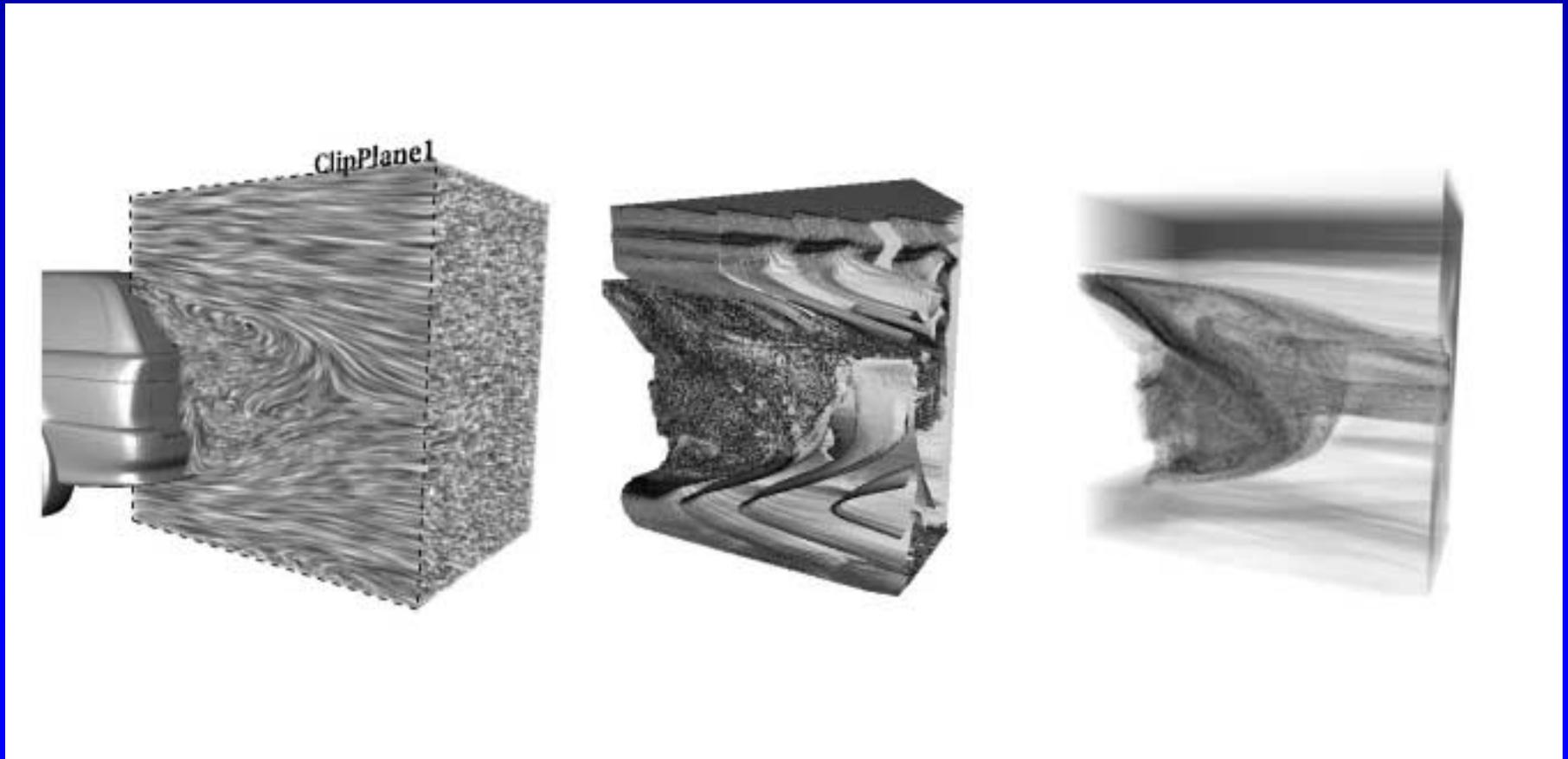


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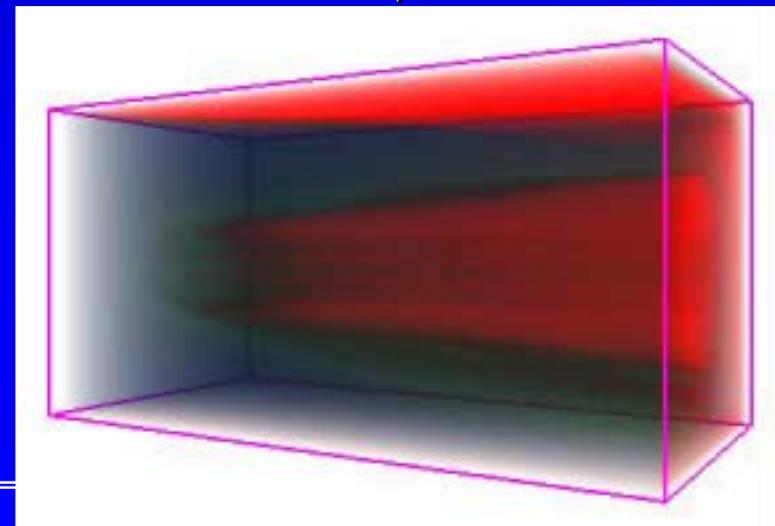
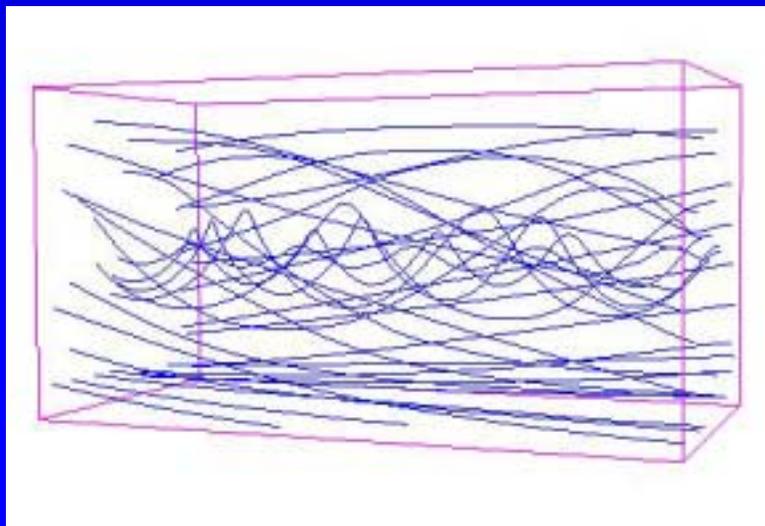
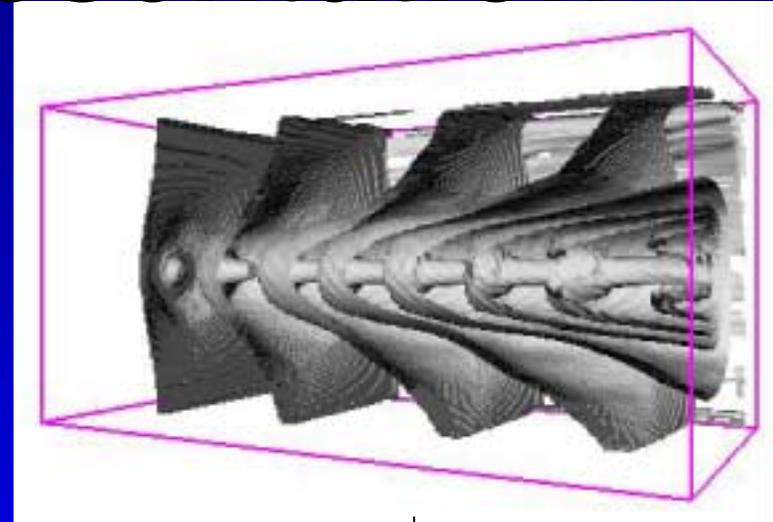
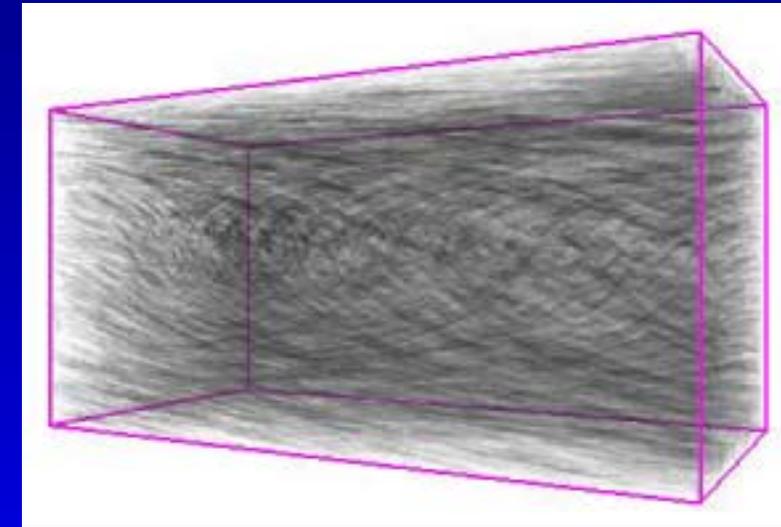
Level-Set Method for Flow Visualization

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The flow field, level-sets and their curvature

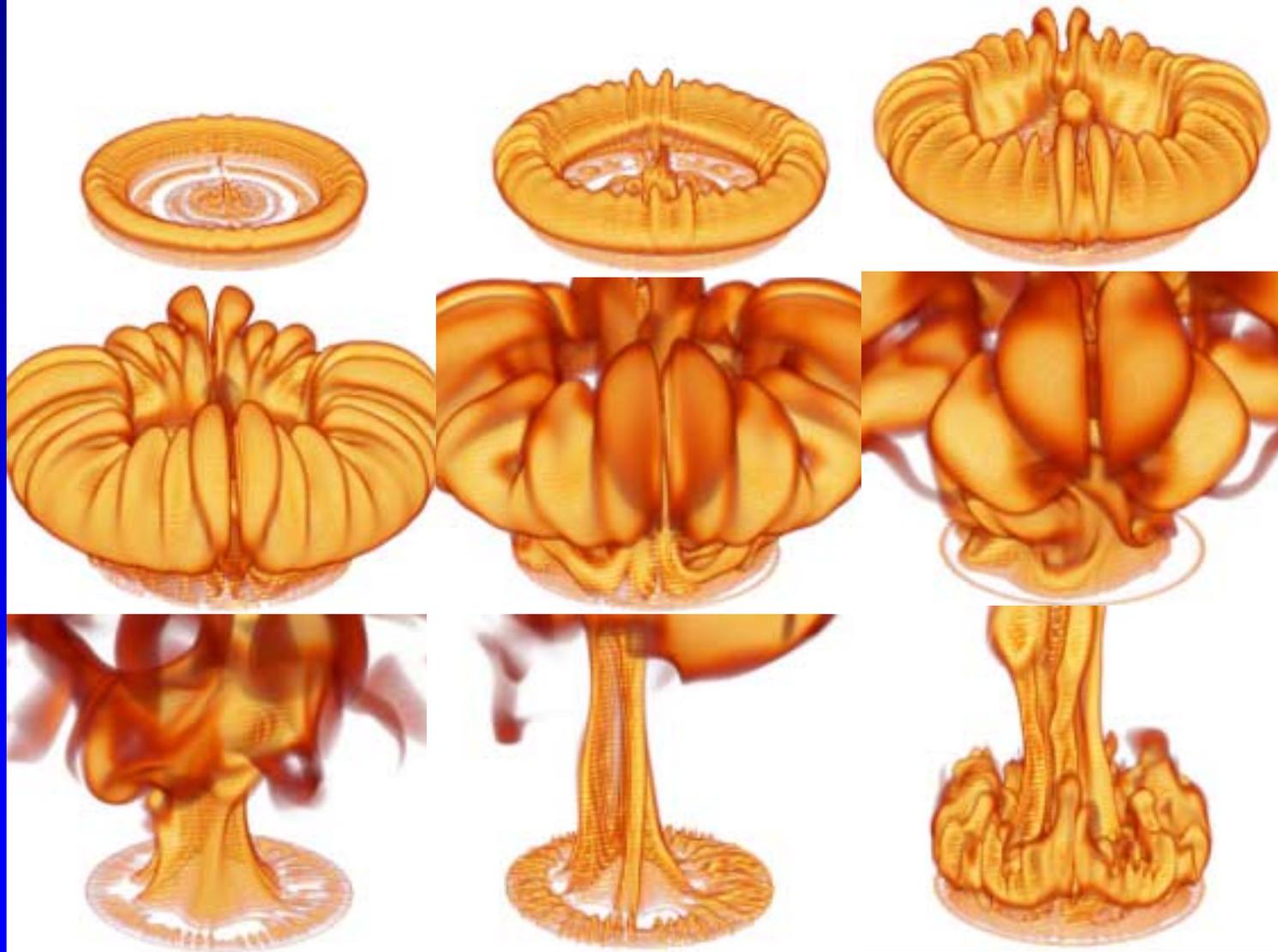


Flow surfaces – a level-set representation



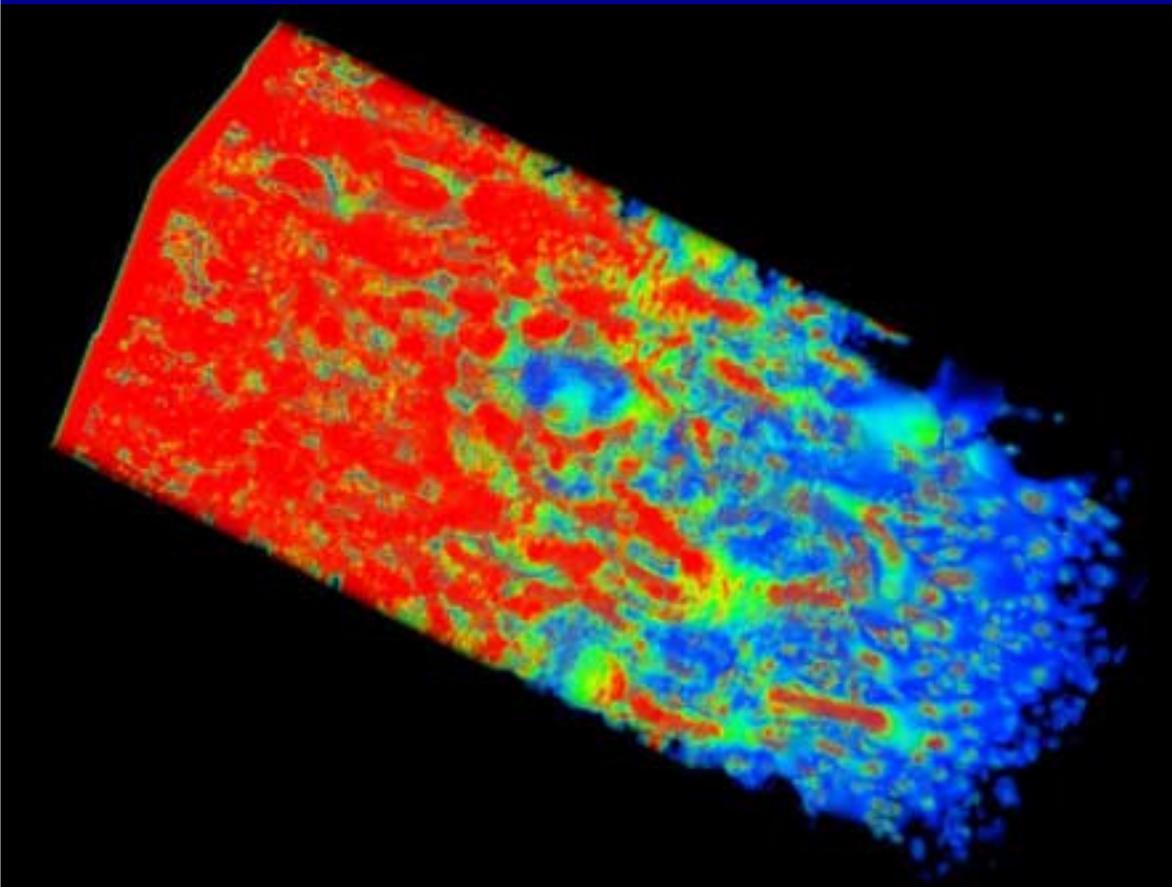
Fire Simulation – Volume Rendering

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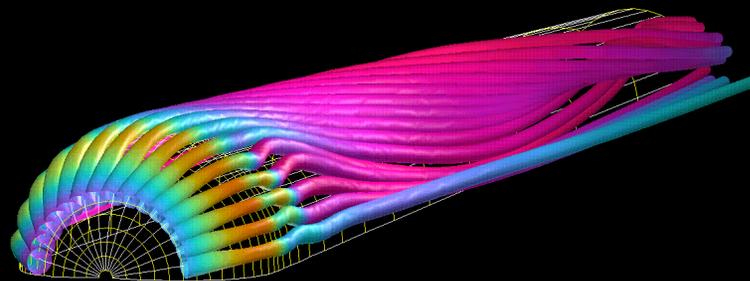
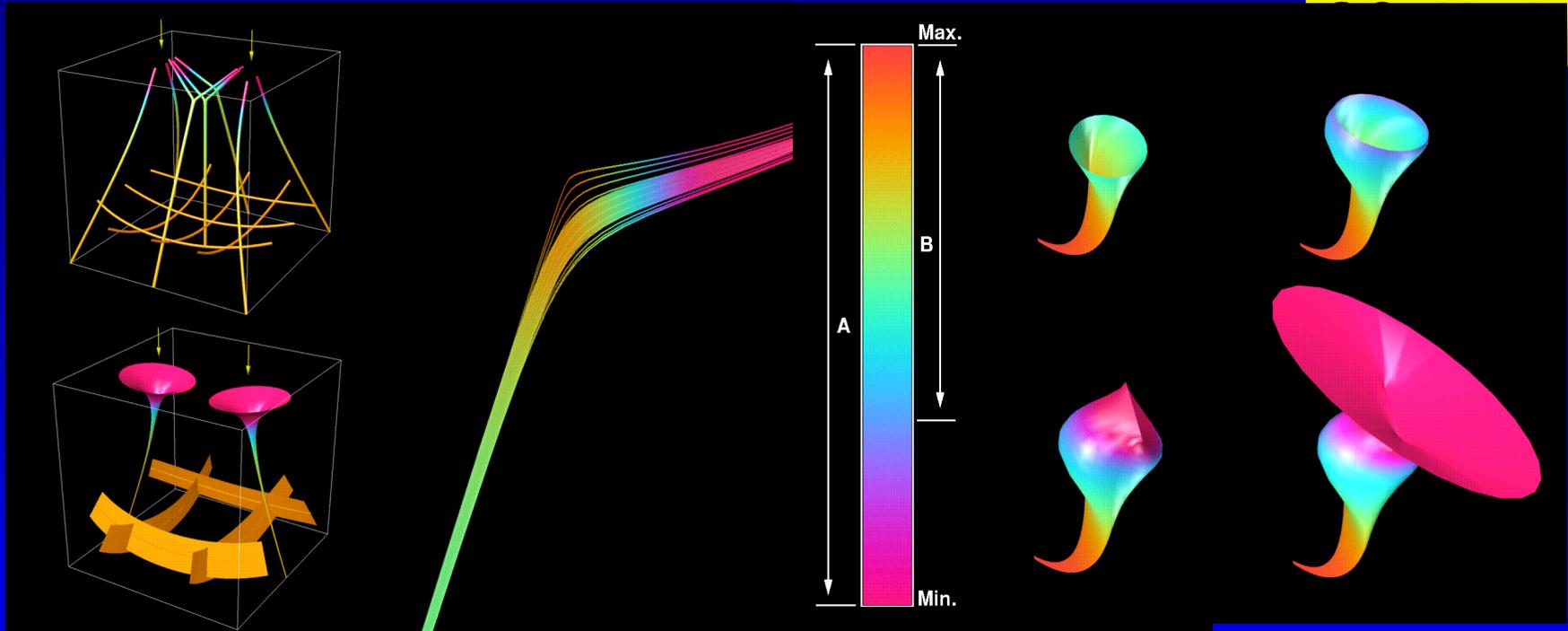


Materials and Fire Simulation Videos

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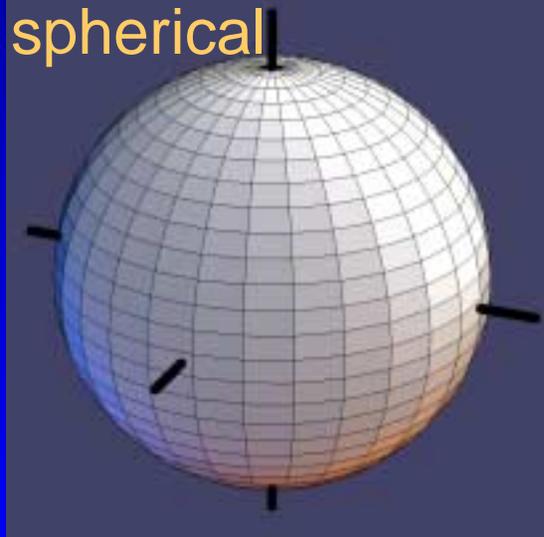


Tensor Visualization - Hesselink



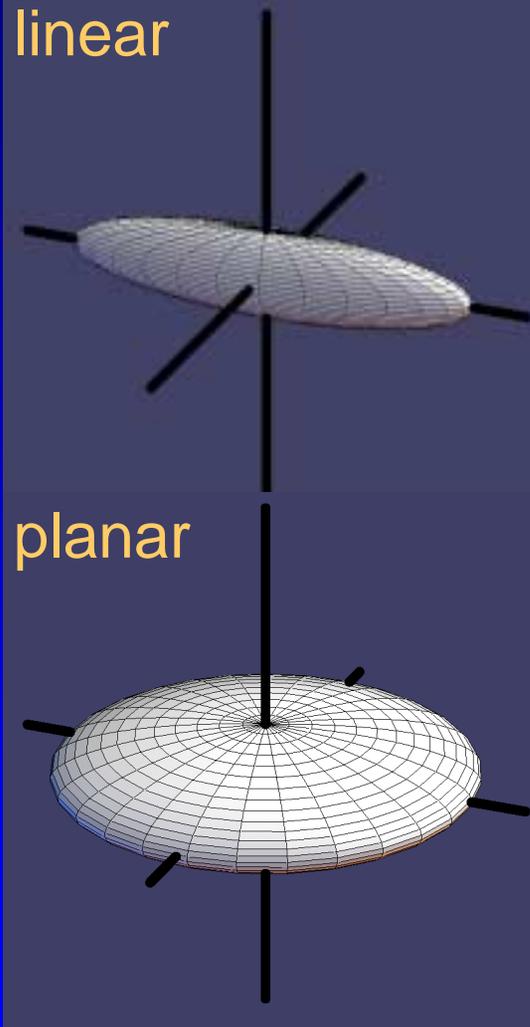
Diffusion in 3D

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spherical

isotropic



linear

planar

anisotropic

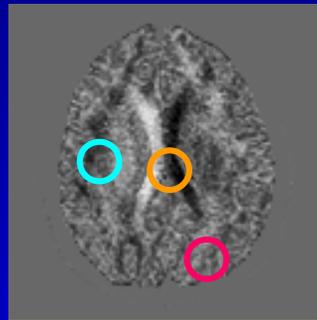
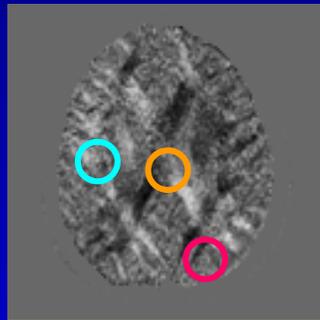
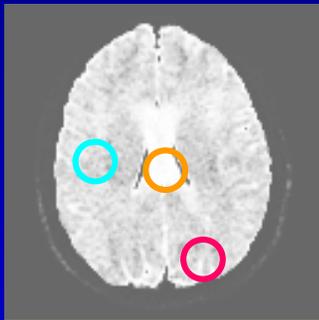
- Ellipsoids represent variety of possible diffusion patterns
- Diffusion Tensor: 3x3 semi-positive definite symmetric matrix
- Ellipsoid is image of unit sphere under diffusion tensor matrix



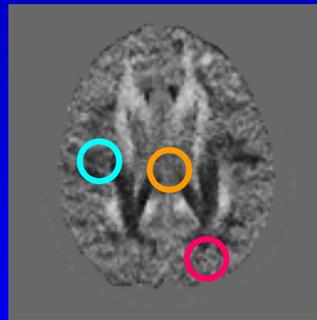
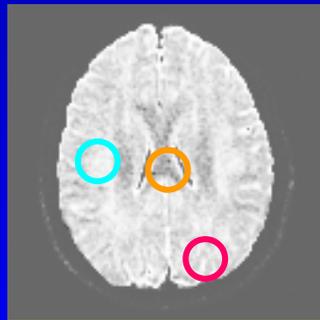
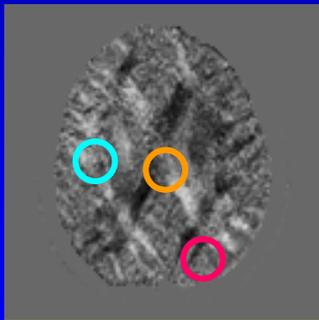
Diffusion MRI of Brain

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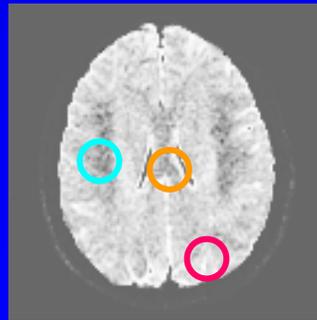
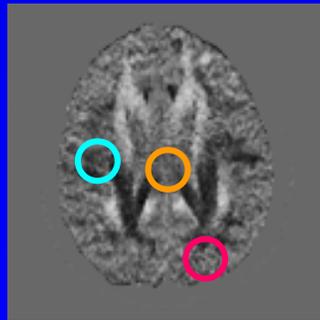
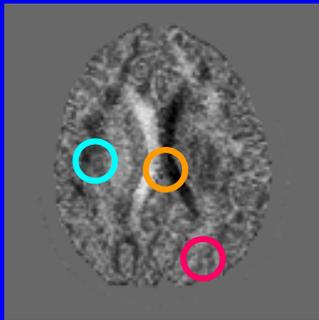
Anisotropy high along white matter fiber tracts



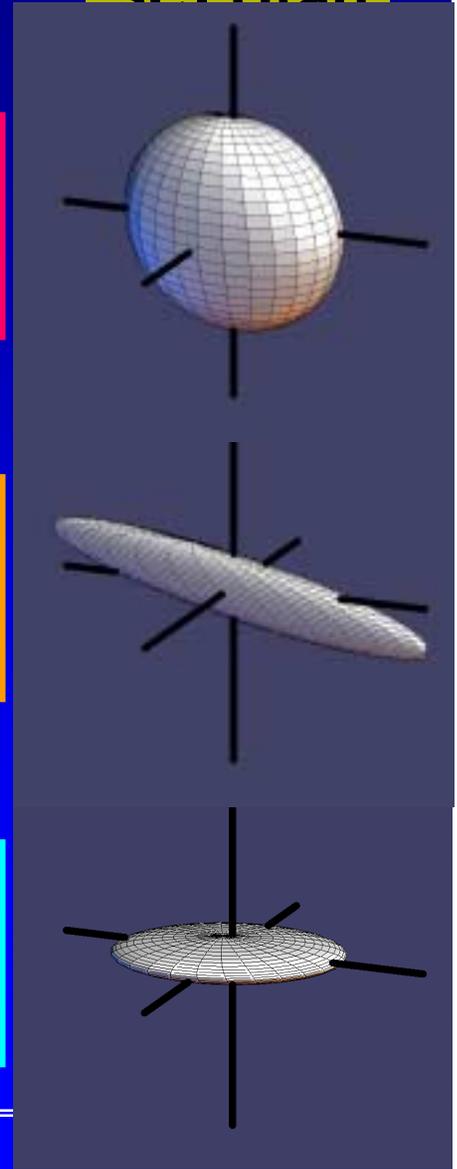
2.1	-0.1	-0.2
-0.1	2.0	-0.0
-0.2	-0.0	2.1



3.7	0.3	-0.8
0.3	0.6	-0.1
-0.8	-0.1	0.8



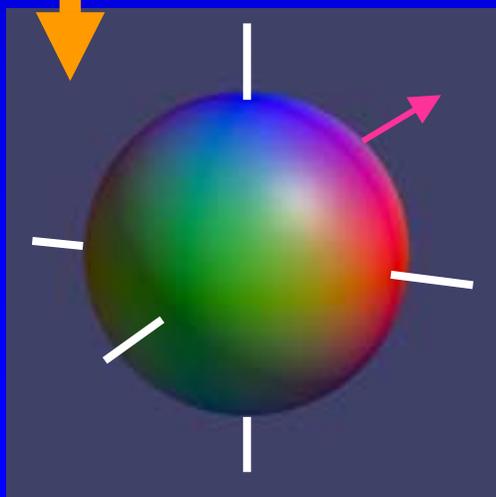
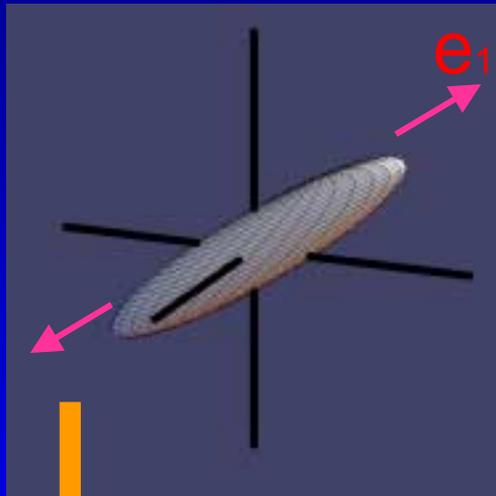
1.7	0.1	-0.1
0.1	2.3	-0.3
-0.1	-0.3	0.3



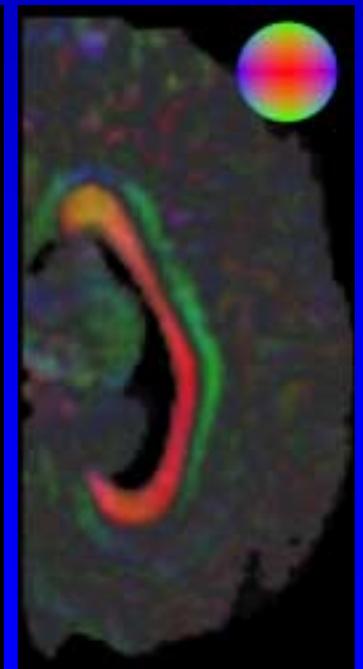
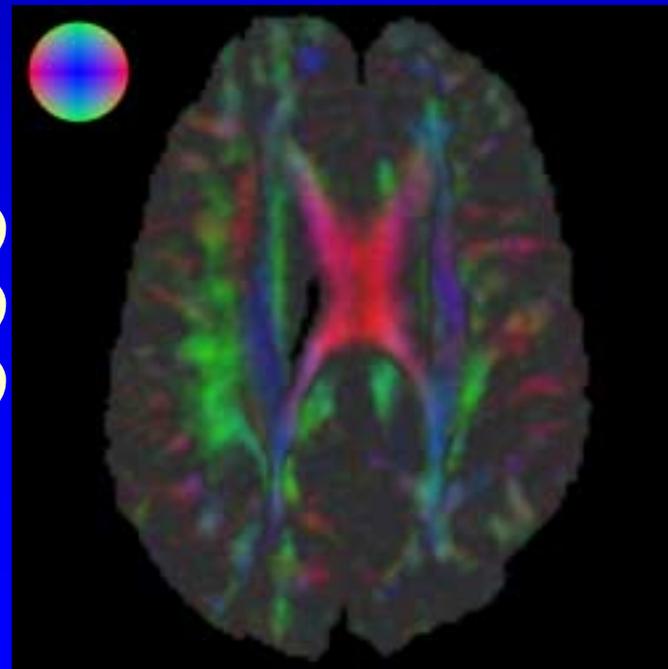
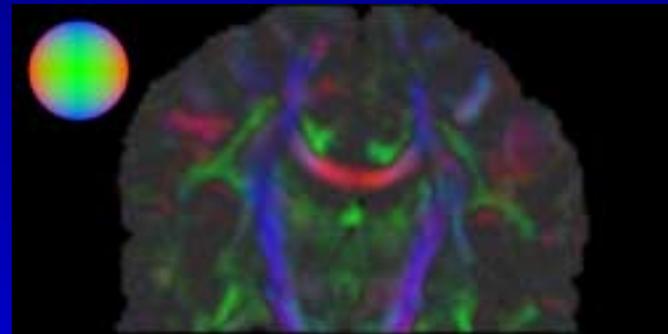
Colormap e_1 (Pierpaoli '97, Jones '97)

Principal eigenvector, anisotropy
determine color

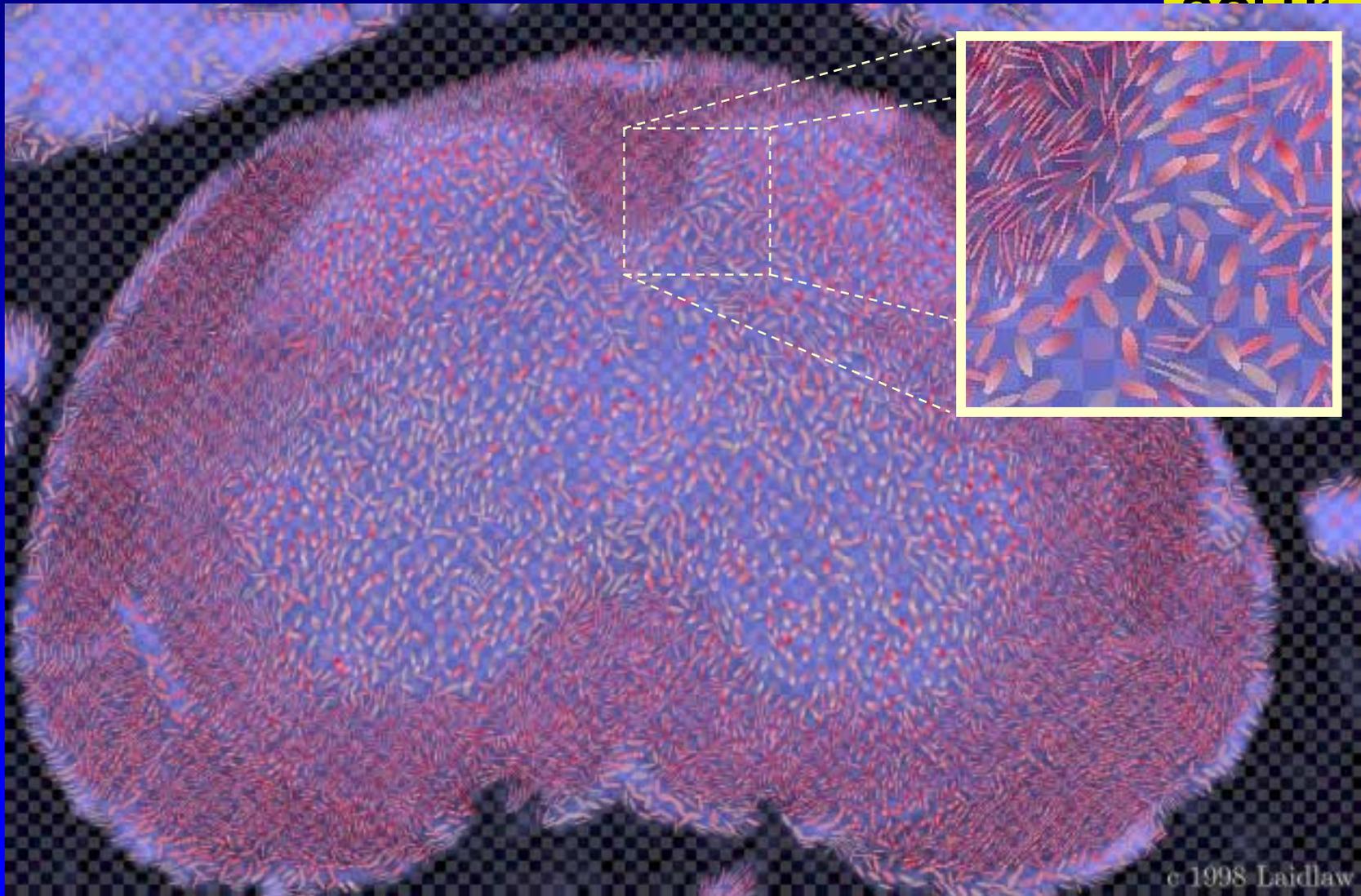
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$R = \text{abs}(x)$
 $G = \text{abs}(y)$
 $B = \text{abs}(z)$



Brush Strokes (Laidlaw '98)



Barycentric Maps

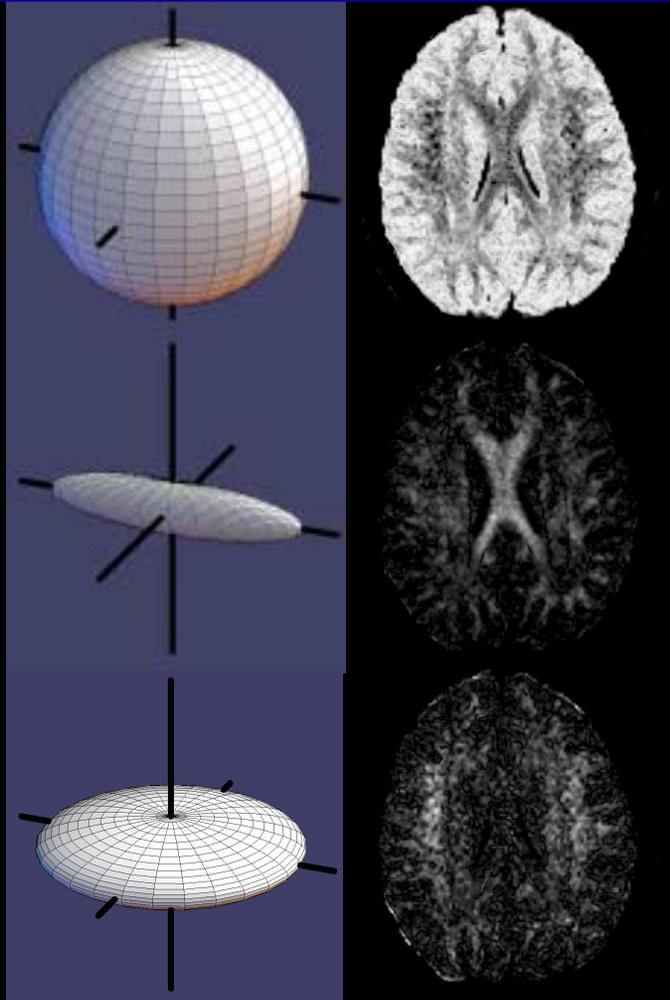
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Metrics for different types of anisotropy (Westin et al. '97)

$$C_s = \frac{3\lambda_3}{\lambda_1 + \lambda_2 + \lambda_3}$$

$$C_l = \frac{\lambda_1 - \lambda_2}{\lambda_1 + \lambda_2 + \lambda_3}$$

$$C_p = \frac{2(\lambda_2 - \lambda_3)}{\lambda_1 + \lambda_2 + \lambda_3}$$

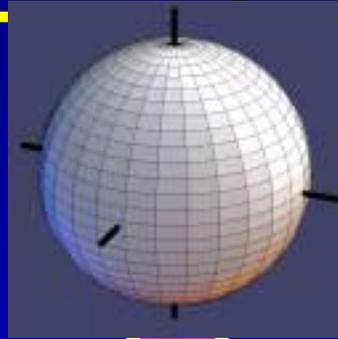


Barycentric Maps: Vol Rend

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Use space as domain of opacity function

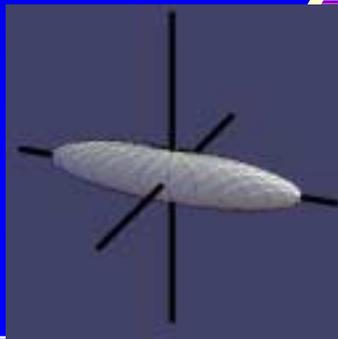
$$C_s = 1$$



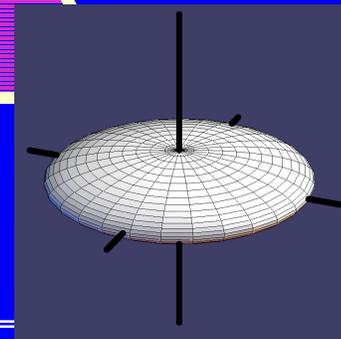
$$C_p = 0$$

$$C_l = 0$$

$$C_l = 1$$



$$C_s = 0$$

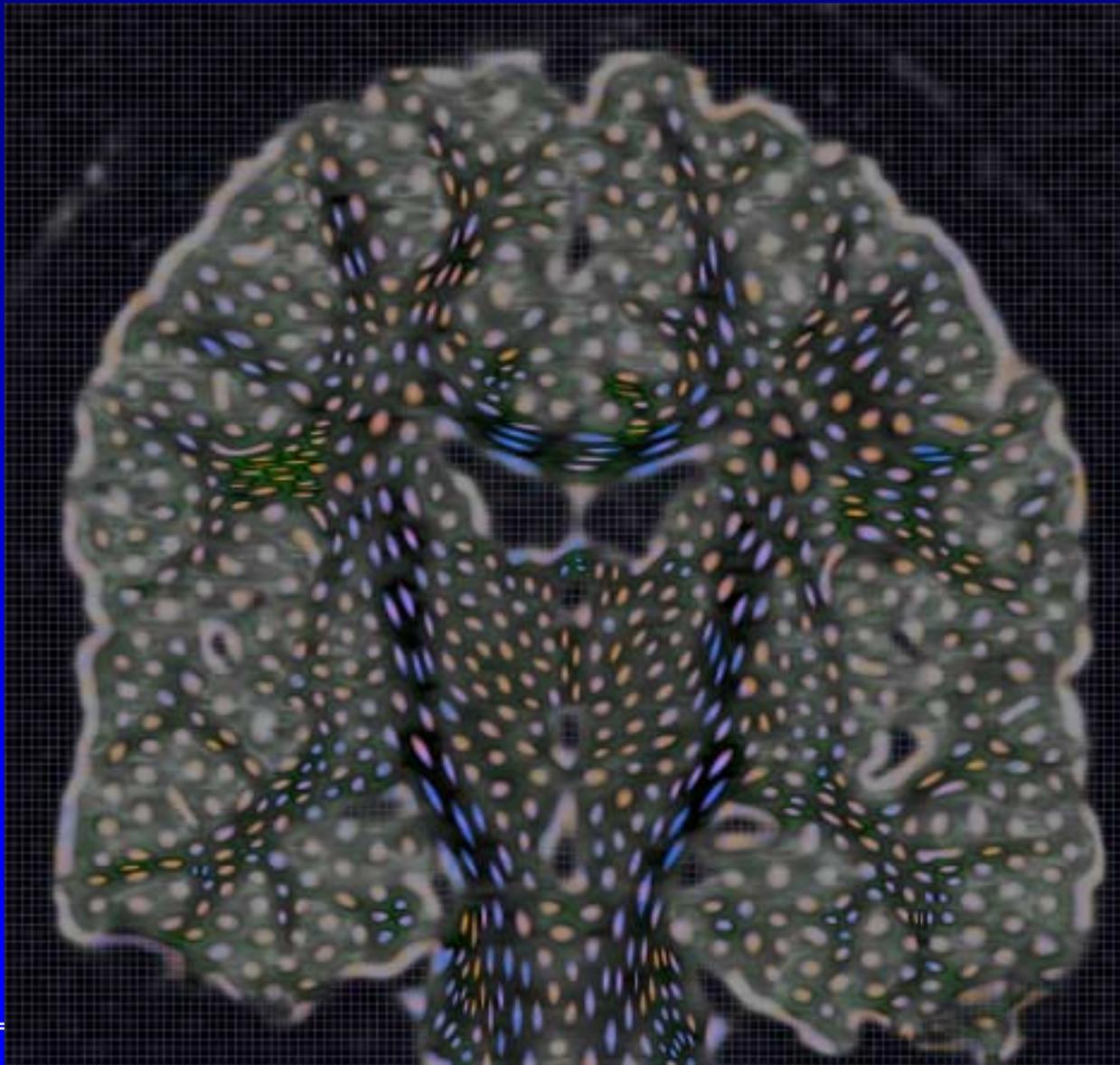


$$C_p = 1$$



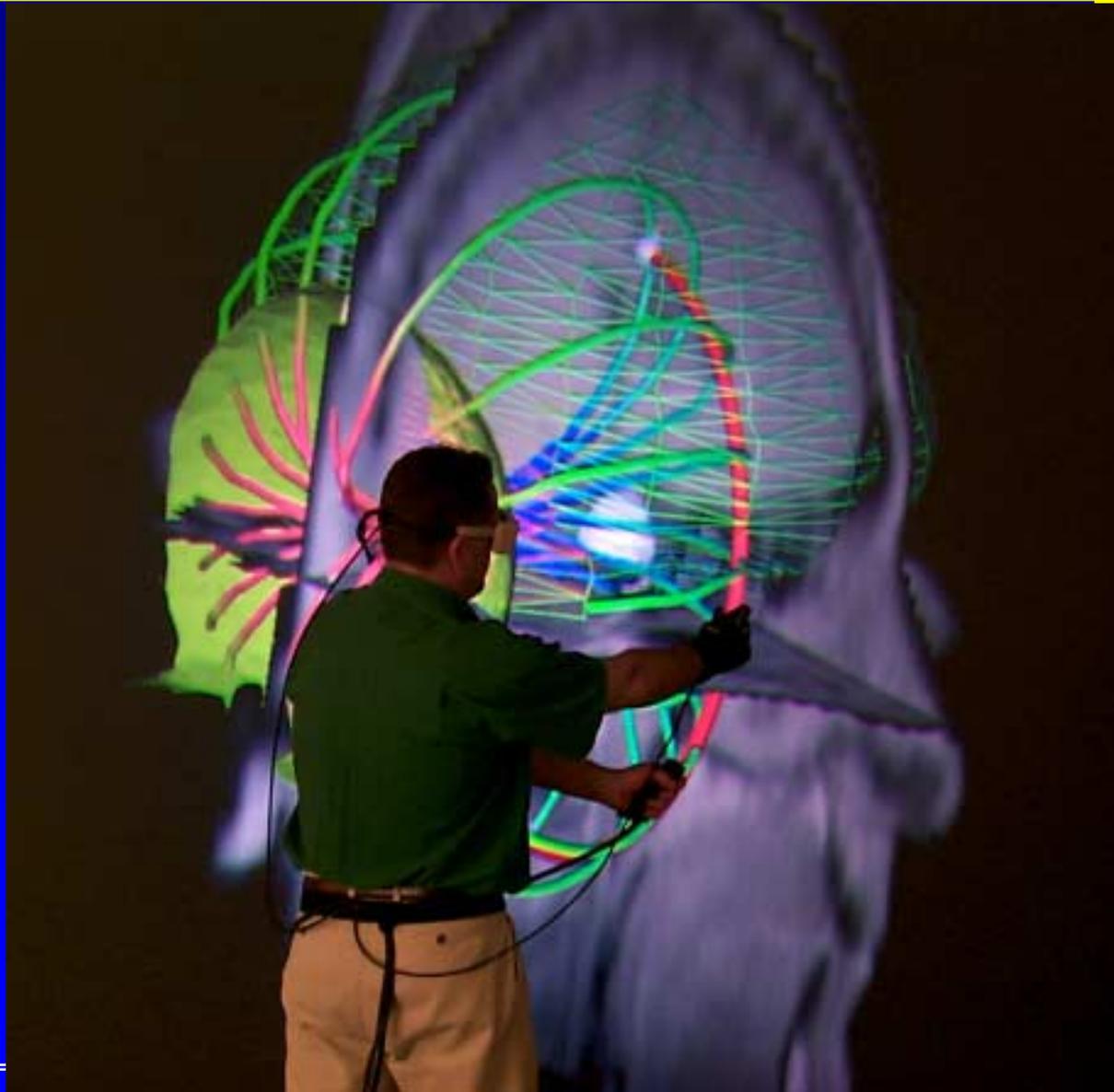
Diffusion Tensor Video

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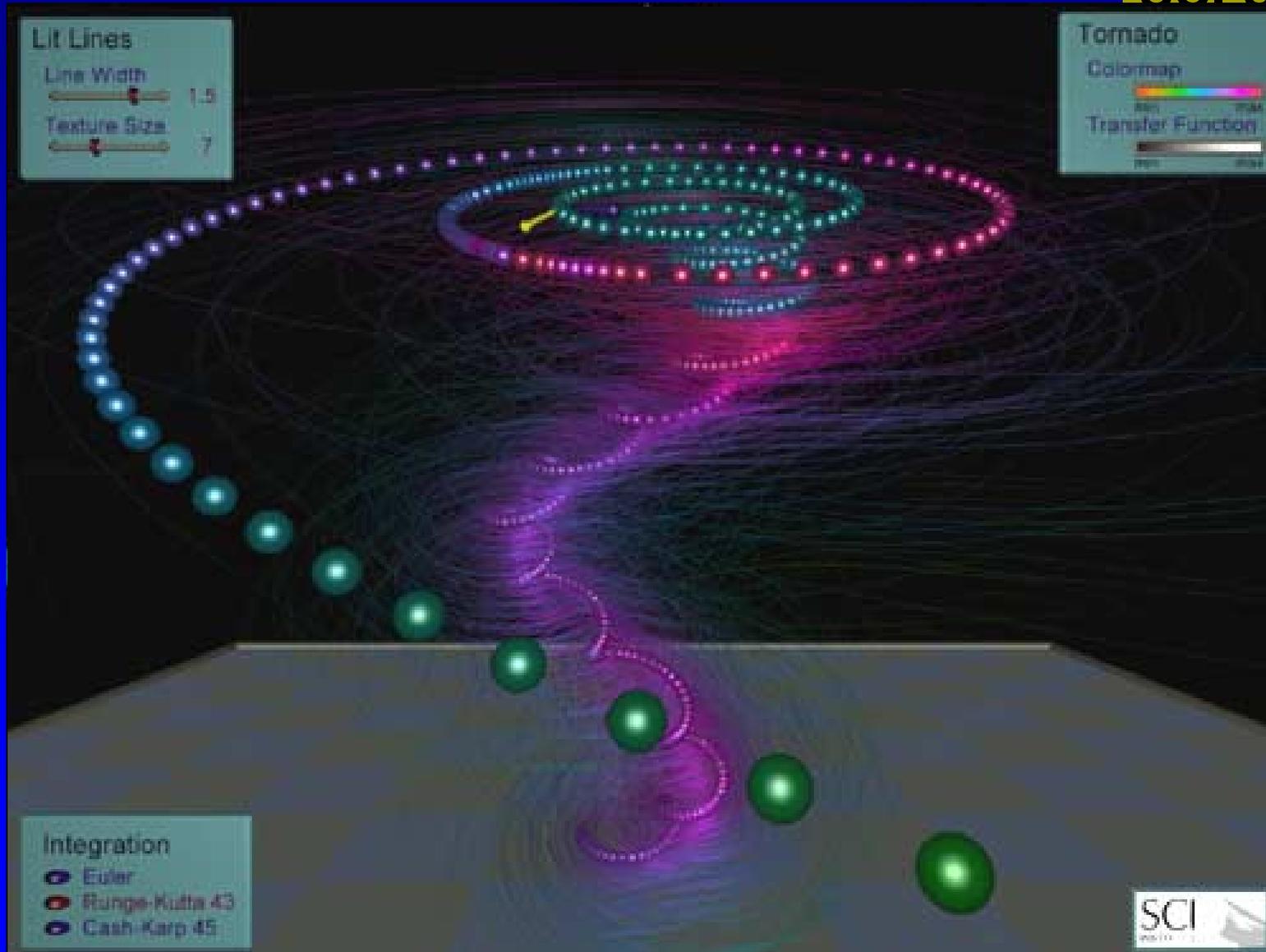
Multiple Fields

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Multiple Fields - Haptics

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Immersive CFD Visualization

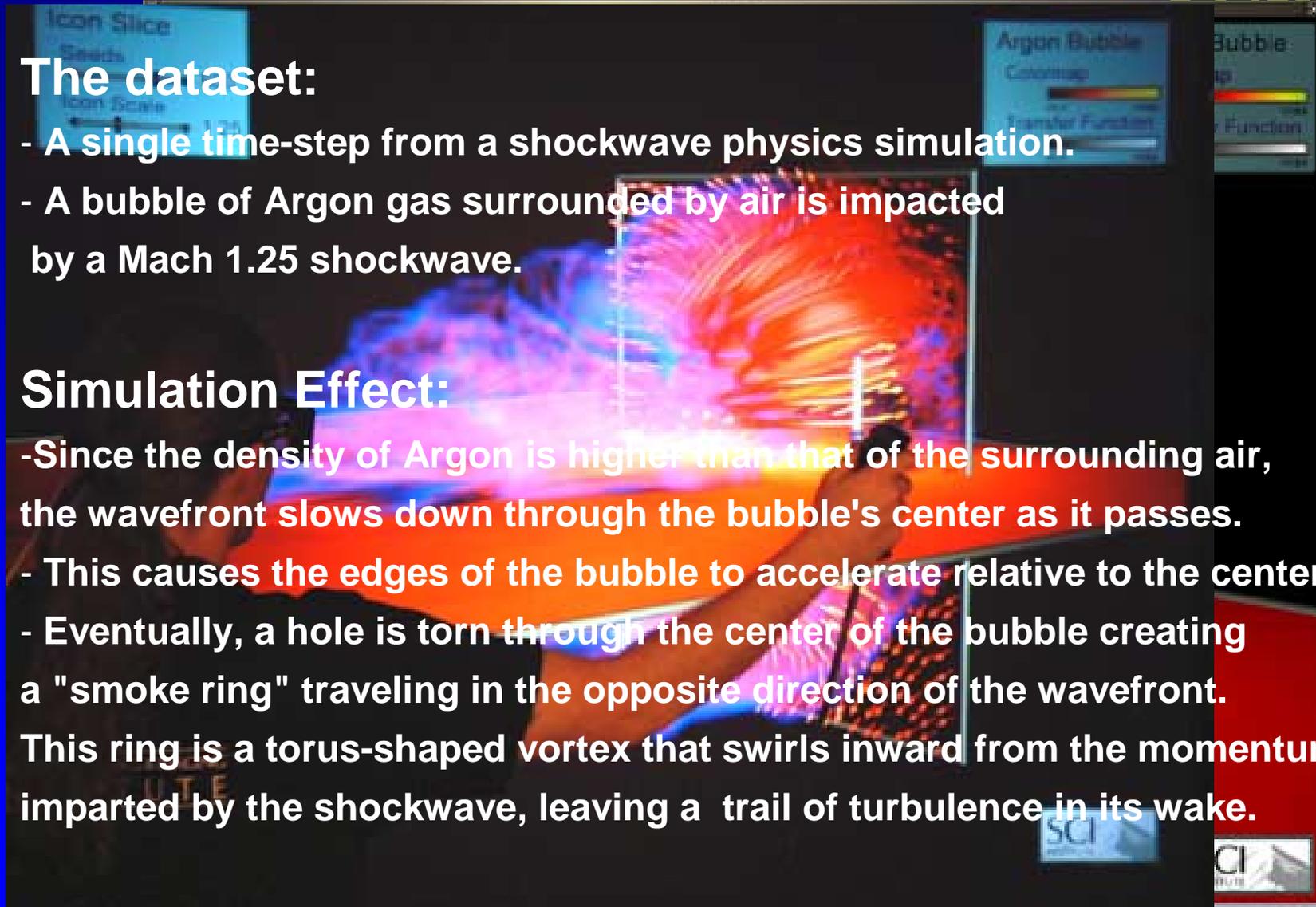
Utah

The dataset:

- A single time-step from a shockwave physics simulation.
- A bubble of Argon gas surrounded by air is impacted by a Mach 1.25 shockwave.

Simulation Effect:

- Since the density of Argon is higher than that of the surrounding air, the wavefront slows down through the bubble's center as it passes.
 - This causes the edges of the bubble to accelerate relative to the center.
 - Eventually, a hole is torn through the center of the bubble creating a "smoke ring" traveling in the opposite direction of the wavefront.
- This ring is a torus-shaped vortex that swirls inward from the momentum imparted by the shockwave, leaving a trail of turbulence in its wake.



Future of HPC Visualization

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(My) Top Visualization Research Issues

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**Error and Uncertainty Visual
Representation**

Performance Visualization

Quantify Effectiveness

Time Dependent Visualization

Pipeline Complexity

Think About the Science

Interesting Feature Detection

**Leverage both Hardware and Software
Methods**

Multi-field Visualizaton



Why Didn't I Talk About:

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Those Cool, Fast PC Graphics Cards?

Visualization on Clusters?

Visualization on the Grid?

Access Grids?

Visualization on Large, Multi-Projector Walls?

Ask Me During the Panel Discussion



Acknowledgements

SCI Utah

DOE ASCI and SciDAC

NSF

NIH NCRR and BISTI

SGI Visual Supercomputing
Center

Visual Influence



Scientific Computing and Imaging



More Information

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