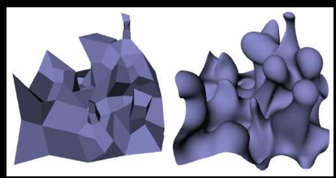
Visualization

Height Fields and Contours
Scalar Fields
Volume Rendering
Vector Fields
Tensor Fields and other high-D data
[Angel Ch. 12]

Scientific Visualization

- Generally do not start with a 3D model
- Must deal with very large data sets
  - MRI, e.g. 512 $\times$ 512 $\times$ 200 $\approxeq$ 50MB points
  - Visible Human 512 $\times$ 512 $\times$ 1734 $\approxeq$ 433 MB points
- Visualize both real-world and simulation data
- User interaction
- Automatic search



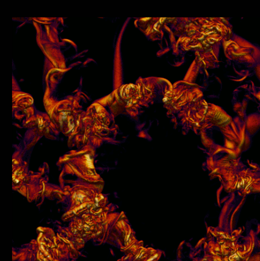
Types of Data

- Scalar fields (3D volume of scalars)
  - E.g., x-ray densities (MRI, CT scan)
- Vector fields (3D volume of vectors)
  - E.g., velocities in a wind tunnel
- Tensor fields (3D volume of tensors [matrices])
  - E.g., stresses in a mechanical part [Angel 12.7]
- Static or through time

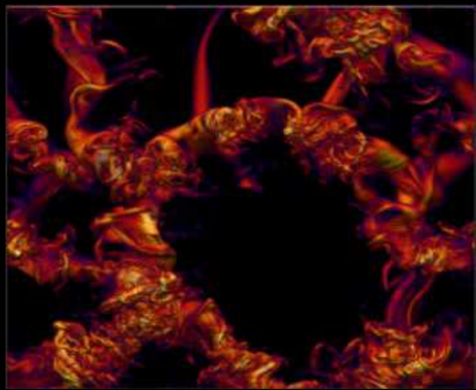
Example: Turbulent convection

- Penetrative turbulent convection in a compressible ideal gas (PTCC)
- http://www.vets.ucar.edu/vg/PTCC/index.shtml

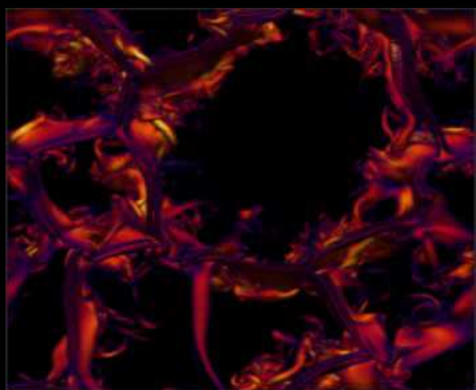
plot of enstrophy (vorticity squared) ◊



Example: Turbulent convection



Example: Turbulent convection

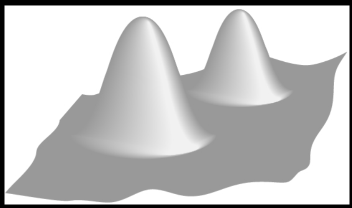


How do we visualize volume data like this?

Height Field

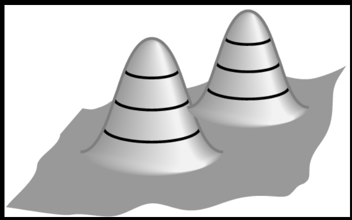
- Visualizing an explicit function

z = f(x,y)



- Adding contour curves

g(x,y) = c

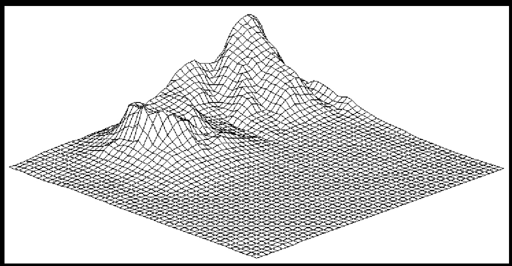


Meshes

- Function is sampled (given) at x_i, y_i, $0 \leq i, j \leq n$
- Assume equally spaced

$$\begin{aligned} x_i &= x_0 + i\Delta x \\ y_j &= y_0 + j\Delta y \end{aligned} \qquad z_{i\,j} = f(x_i, y_j)$$

- Generate quadrilateral or triangular mesh
- [Asst 1]



Contour Curves

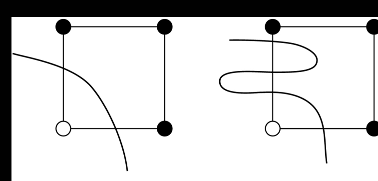
- Recall: implicit curve f(x,y) = 0
- f(x,y) < 0 inside, f(x,y) > 0 outside
- Here: contour curve at f(x,y) = c
- Sample at regular intervals for x,y

$$\begin{aligned} x_i &= x_0 + i\Delta x \\ y_j &= y_0 + j\Delta y \end{aligned}$$

- How can we draw the curve?

Marching Squares

- Sample function f at every grid point x_i, y_j
- For every point $f_{i\,j} = f(x_i, y_j)$ either $f_{i\,j} \leq c$ or $f_{i\,j} > c$
- Distinguish those cases for each corner x
  - White: $f_{i\,j} \leq c$
  - Black: $f_{i\,j} > c$
- Now consider cases for curve
- Assume "smooth"
- Ignore $f_{i\,j} = 0$

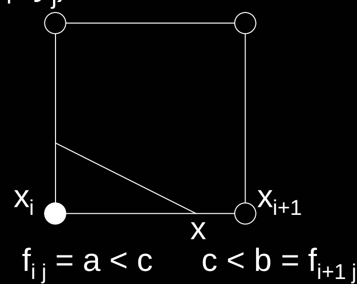


Interpolating Intersections

- Approximate intersection
  - Midpoint between x_i, x_{i+1} and y_j, y_{j+1}
  - Better: interpolate
- If $f_{i\,j} = a$ is closer to c than $b = f_{i+1\,j}$ then intersection is closer to (x_i, y_j):

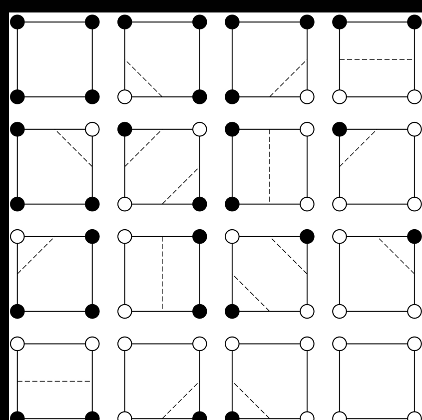
$$\frac{x - x_i}{x_{i+1} - x} = \frac{c - a}{b - c}$$

- Analogous calculation for y direction

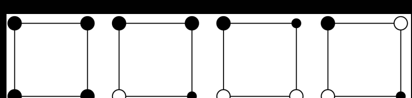


Cases for Vertex Labels

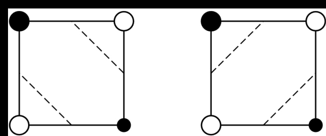
16 cases for vertex labels



4 unique mod. symmetries

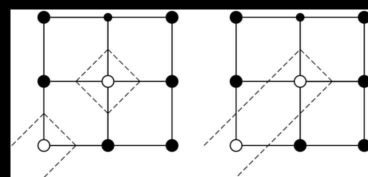


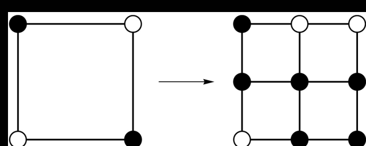
Ambiguities of Labelings



Ambiguous labels

Different resulting contours





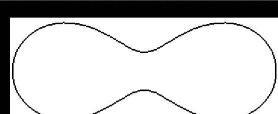
Resolution by subdivision (where possible)

Marching Squares Examples

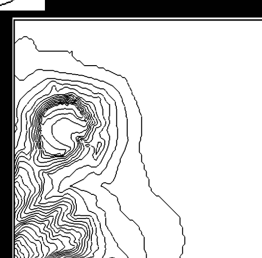
- Ovals of Cassini, 50 $\times$ 50 grid

$$f(x,y) = (x^2 + y^2 + a^2)^2 - 4a^2x^2 - b^4$$
$$a = 0.49, b = 0.5$$

Midpoint



Interpolation



Contour plot of Honolulu data

Outline

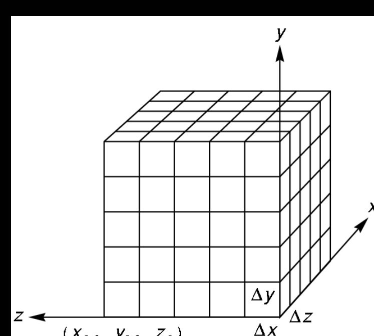
- Height Fields and Contours
- Scalar Fields
- Volume Rendering
- Vector Fields
- Tensor Fields and other high-D data

Scalar Fields

- Volumetric data sets
- Example: tissue density
- Assume again regularly sampled

$$\begin{aligned} x_i &= x_0 + i\Delta x \\ y_j &= y_0 + j\Delta y \\ z_k &= z_0 + k\Delta z \end{aligned}$$

- Represent as voxels

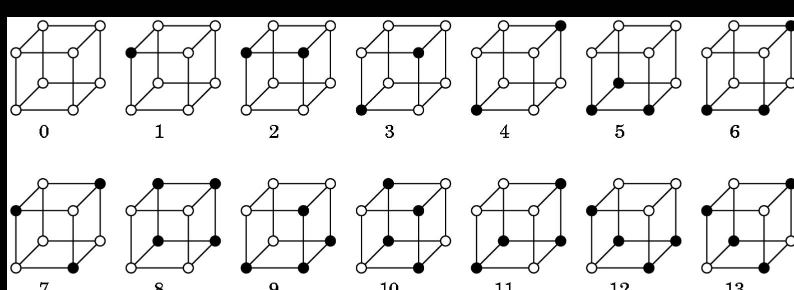


Isosurfaces

- f(x,y,z) represents volumetric data set
- Two rendering methods
  - Isosurface rendering
  - Direct volume rendering (use all values [next])
- Isosurface given by f(x,y,z) = c
- Recall implicit surface g(x, y, z):
  - g(x, y, z) < 0 inside
  - g(x, y, z) = 0 surface
  - g(x, y, z) > 0 outside
- Generalize right-hand side from 0 to c

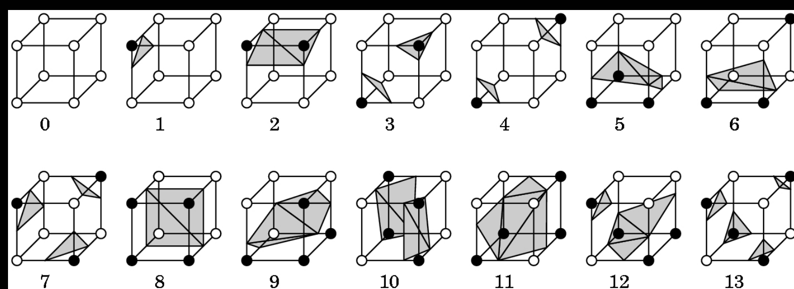
Marching Cubes

- Display technique for isosurfaces
- 3D version of marching squares
- 14 cube labelings (after elimination symmetries)



Marching Cube Tessellations

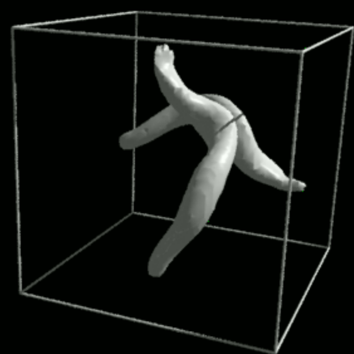
- Generalize marching squares, just more cases
- Interpolate as in 2D
- Ambiguities similar to 2D



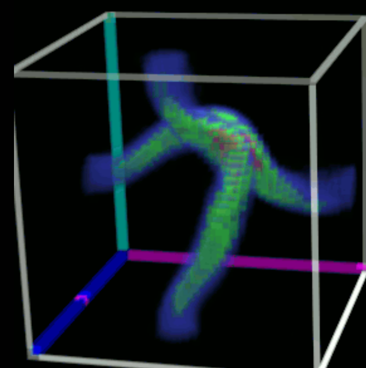
Marching Cubes Demo

Volume Rendering

- Sometimes isosurfaces are unnatural
- Use all voxels and transparency (α-values)



Ray-traced isosurface



Volume rendering

Surface vs. Volume Rendering

- 3D model of surfaces
- Convert to triangles
- Draw primitives
- Lose or disguise data
- Good for opaque objects

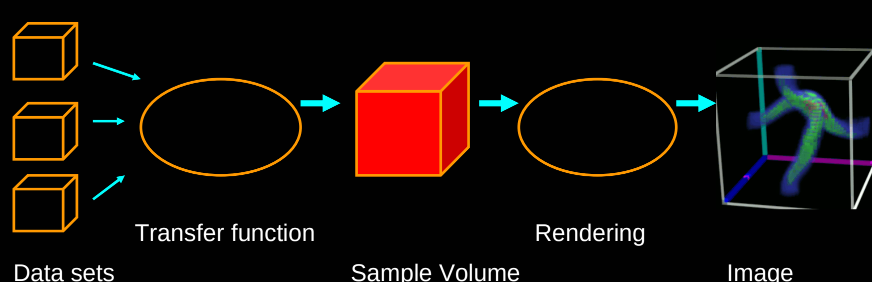
- Scalar field in 3D
- Convert to RGBA values
- Render volume “directly”
- See data as given
- Good for complex objects

Sample Applications

- Medical
  - Computed Tomography (CT)
  - Magnetic Resonance Imaging (MRI)
  - Ultrasound
- Engineering and Science
  - Computational Fluid Dynamic (CFD)
  - Aerodynamic simulations
  - Meteorology
  - Astrophysics

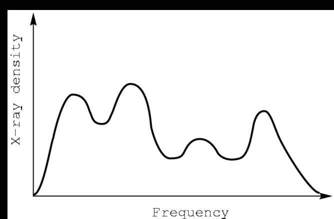
Volume Rendering Pipeline

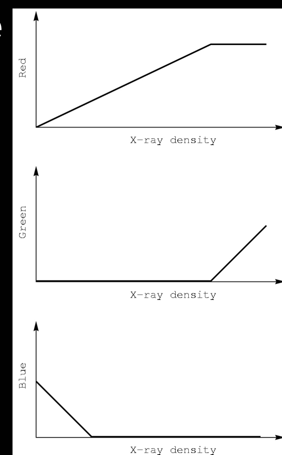
- Transfer function: from data set to colors and opacities
  - Example: $256 \times 256 \times 64 \times 2 = 4$ MB
  - Example: use colormap (8 bit color, 8 bit opacity)



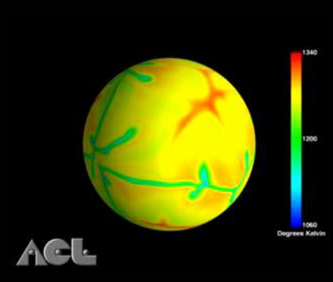
Transfer Functions

- Transform scalar data values to RGBA values
- Apply to every voxel in volume
- Highly application dependent
- Start from data histogram
- Opacity for emphasis

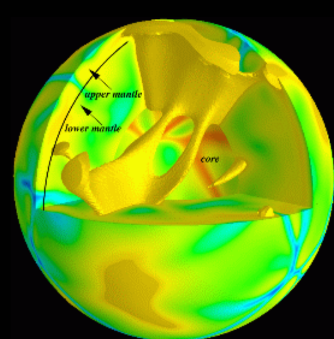




Transfer Function Example



Mantle Convection



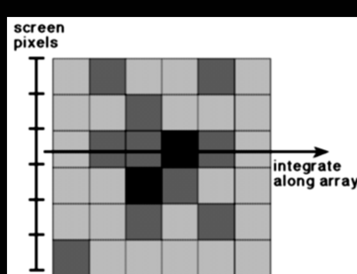
Scientific Computing and Imaging (SCI)
University of Utah

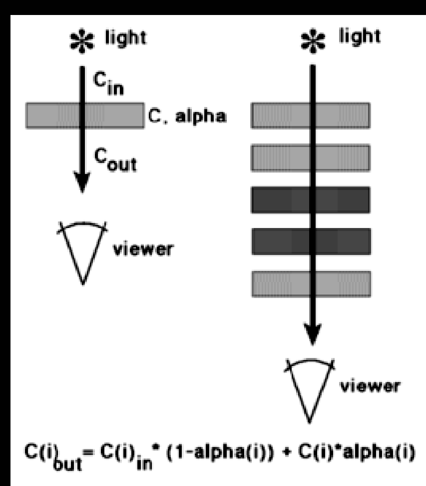
Types of Volume Rendering

- Three volume rendering techniques
  - Volume ray casting
  - Splatting
  - 3D texture mapping
- Ray Casting
  - Integrate color and opacity along ray

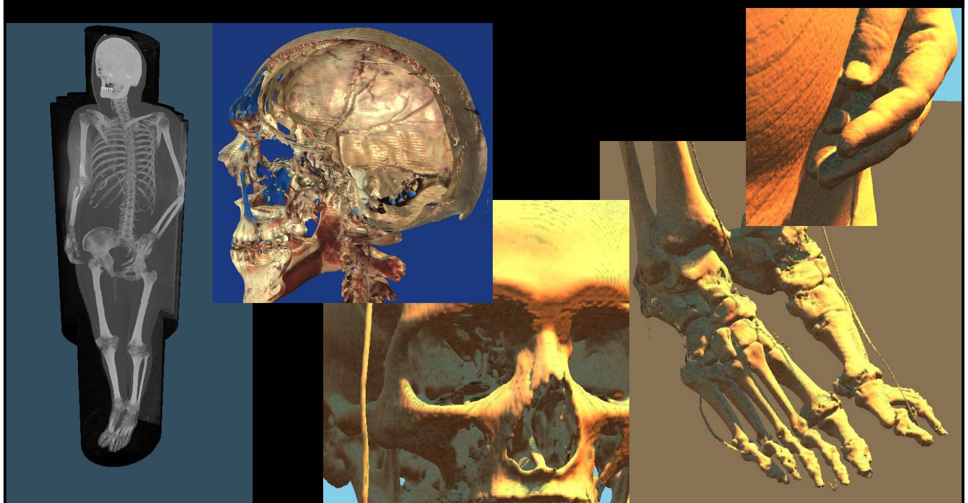
Ray Casting – Accumulating Opacity

- α = 1.0 is opaque
- Composite multiple layers according to opacity



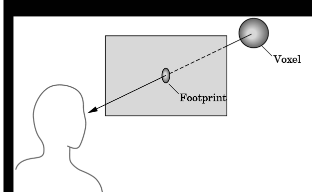


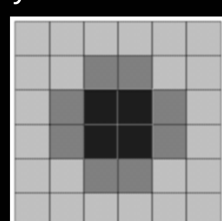
Real-Time Ray Tracer (Utah)



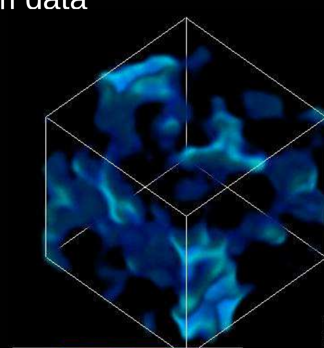
Splatting

- Wonderfully simple
- Working back-to-front (or front-to-back), draw a “splat” for each chunk of data
- Easy to implement, but not as accurate as ray casting
- Works reasonably for non-uniform data



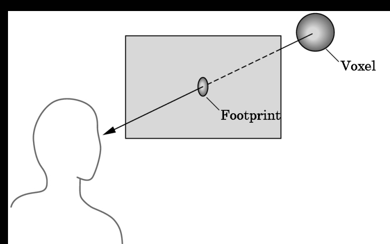


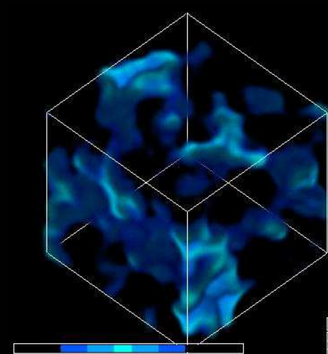
closeup of a splat



Splatting

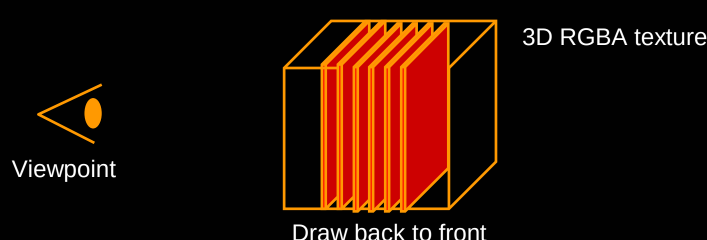
- Alternative to ray tracing
- Assign shape to each voxel (e.g., Gaussian)
- Project onto image plane (splat)
- Draw voxels back-to-front
- Composite (α-blend)





3D Textures

- Alternative to ray tracing, splatting
- Build a 3D texture (including opacity)
- Draw a stack of polygons, back-to-front
- Efficient if supported in graphics hardware
- Few polygons, much texture memory



Example: 3D Textures

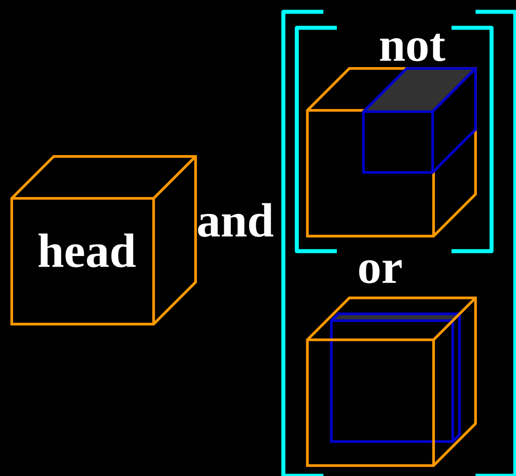
Emil Praun'01

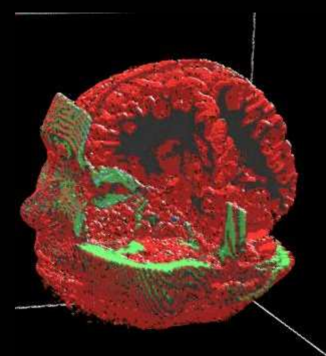
Example: 3D Textures

Emil Praun'01

Other Techniques—CSG is Easy

- The transfer function can be used to mask a volume or merge volumes
- You are still confined to the grid, of course





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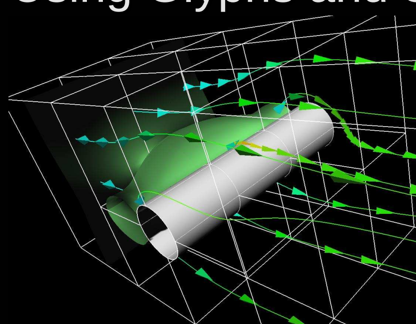
Vector Fields

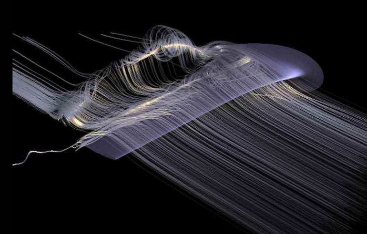
- Visualize vector at each (x,y,z) point
  - Example: velocity field
  - Example: hair
- Hedgehogs
  - Use 3D directed line segments (sample field)
  - Orientation and magnitude determined by vector
- Animation
  - Use for still image
  - Particle systems

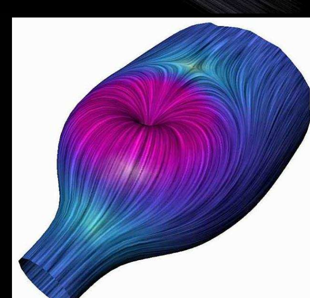
Blood flow in
human carotid artery

Using Glyphs and Streaks



Glyphs for air flow





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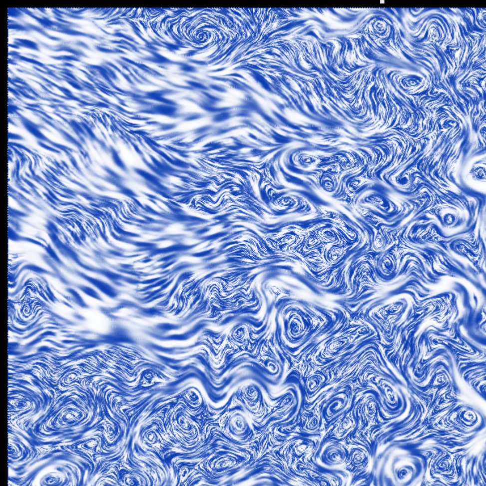
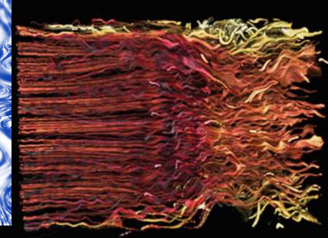
More Flow Examples

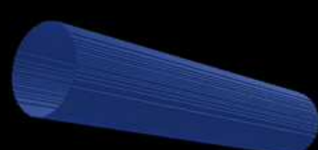




Banks and Interrante

Example: Jet Shockwave

P. Sutton
University of Utah

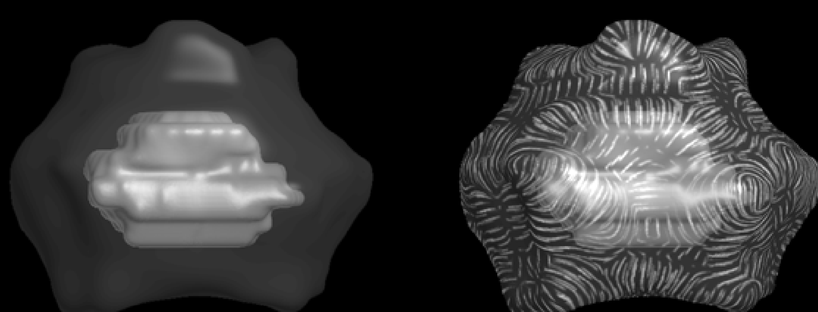


http://www.sci.utah.edu/

Visualization in 3D environments

CAVE, Brown

Lines can also be used to show shape

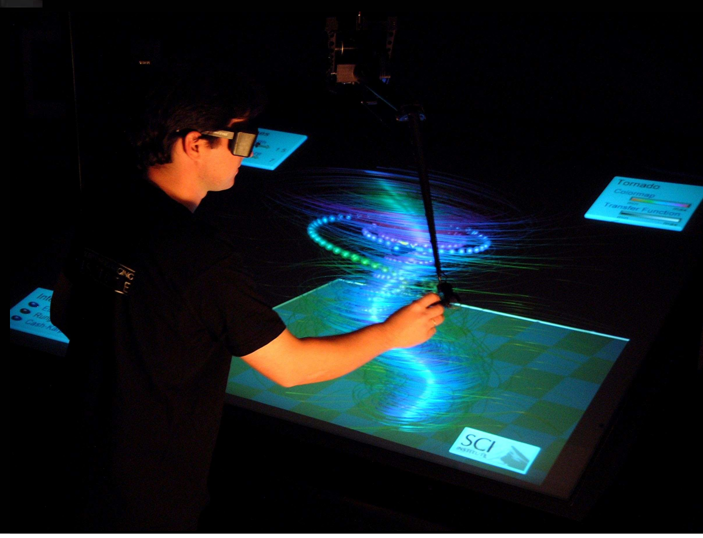


Draw lines in directions of principal curvature

Victoria Interrante

Interaction: Data Probe

SCI, Utah



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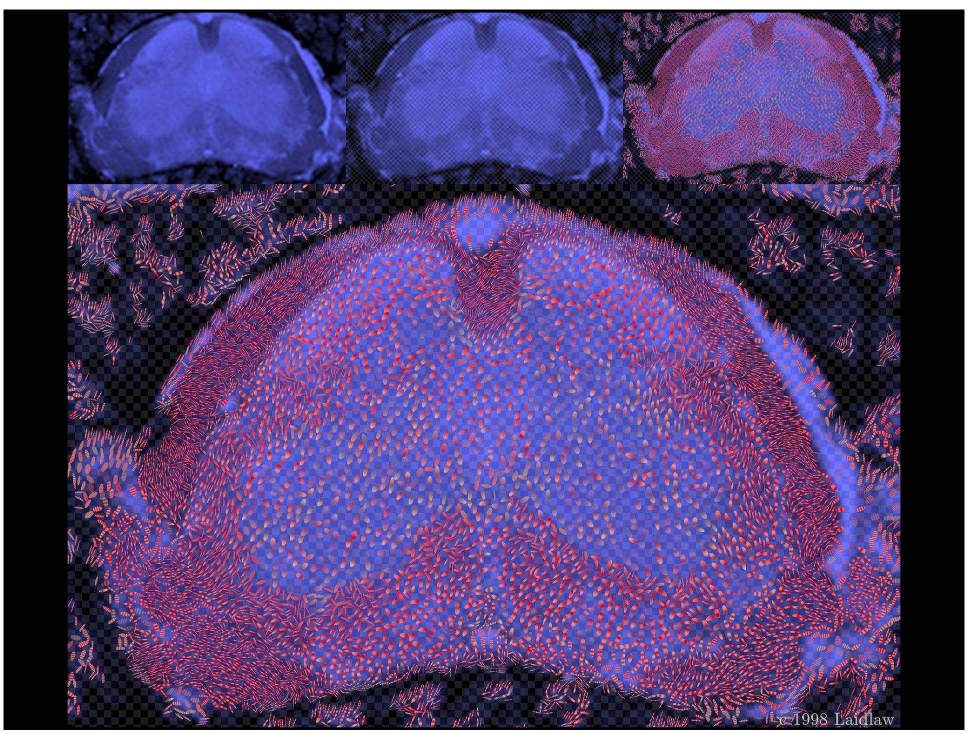
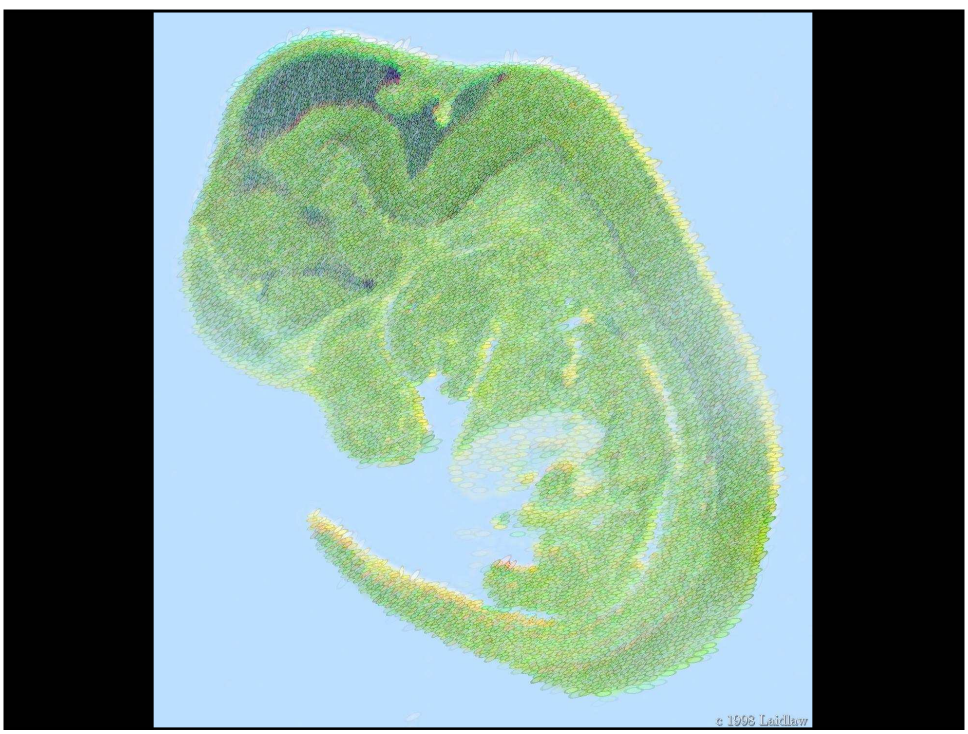
High-Dimensional Data

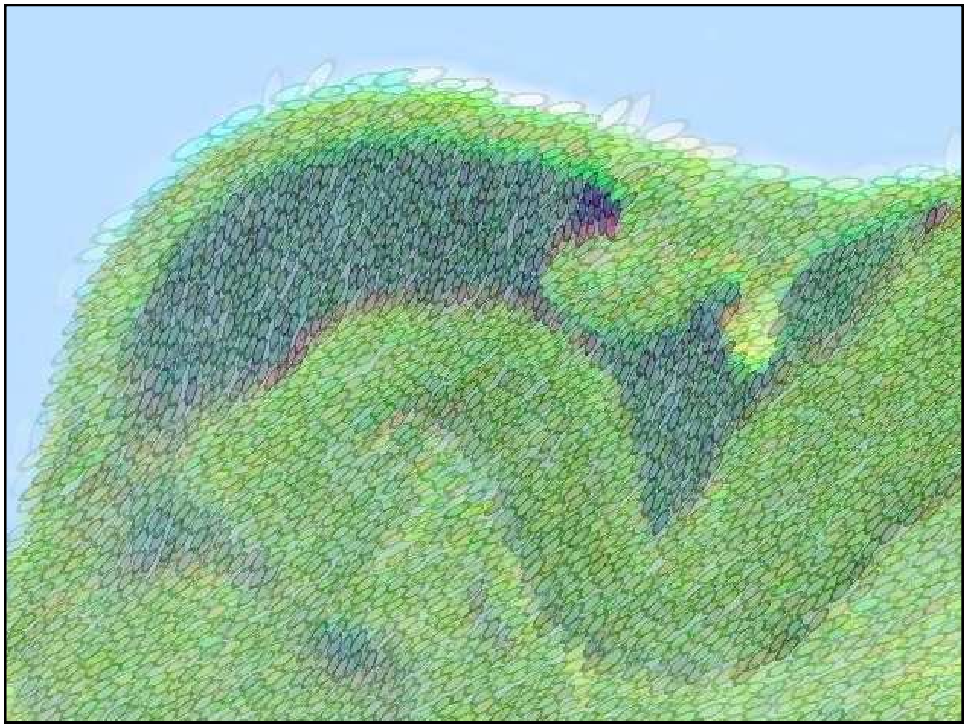
- How do we display data that is very high dimensional?
- One idea is to draw inspiration from art

David Laidlaw, Brown




c 1998 Laidlaw


c 1998 Laidlaw



Summary

- Height Fields and Contours
- Scalar Fields
  - Isosurfaces
  - Marching cubes
- Volume Rendering
  - Volume ray tracing
  - Splatting
  - 3D Textures
- Vector Fields
  - Hedgehogs
  - Animated and interactive visualization
- Tensor Fields and other High-Dimensional Data
  - NPR and other art-motivated techniques

Top Visualization Research Issues

- Error and Uncertainty Visual Representation
- Perceptual Issues
- Quantify Effectiveness
- Time Dependent Visualization
- Pipeline Complexity
- Think About the Science
- Interesting Feature Detection
- Leverage both Hardware and Software Methods
- Multi-field Visualization

From Chris Johnson, Utah