Comp/Phys/APSc 715

Tensor: Glyphs, Traces, Surfaces, Etc.

Preview Videos

- Vis2006: nlcglyph.mov
  - Tensor glyph design
- Stress Tensor visualization for implant

Tensor Fields

- One view: Mapping of input vectors to output vectors
  - Stress (x,y,z) to strain (x,y,z): force to deformation
- Another view: NxN matrix for N-space (3x3 for 3-space)
- Subset: Symmetric second-order tensor fields
  - Can be viewed as anisotropic ellipsoids
  - Three orthogonal Eigenvectors show directions
  - Associated Eigenvalues tell how much expansion/contraction along each vector
  - Largest “major” Eigenvalue, then middle and smallest “minor”
- Subset: Rotation fields
  - Spin at each location in space

Tensor Questions

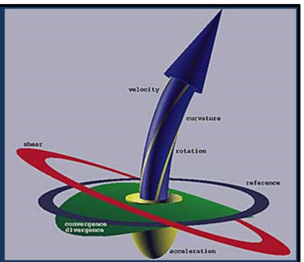
- Is the tensor anisotropic in a specific area?
- Where is the tensor sheet-like, cigar-like?
- Where would water go from here?
- Where are the most severe rotations?
- What strain effect would stress have?
- Does this technique work for 3D?

Classes of Techniques

- Glyphs
- Stream Indicators
- Hue and texture
- Deformed Surfaces
- Computer finds traces, visualization shows
- Techniques to show rotation fields
- Haptic display

Glyphs: Flow Probe

- Velocity gradient tensor
- Shear and Divergence form parts of the deformation rate tensor
- Willem de Leeuw thesis



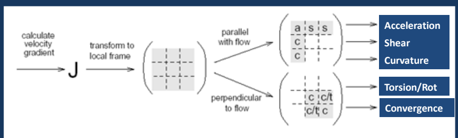
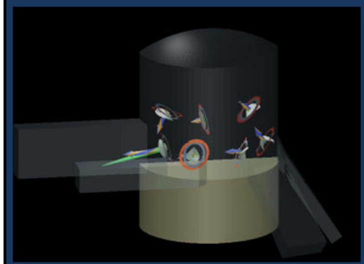
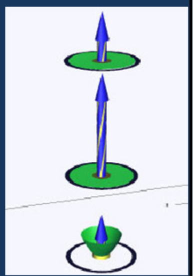


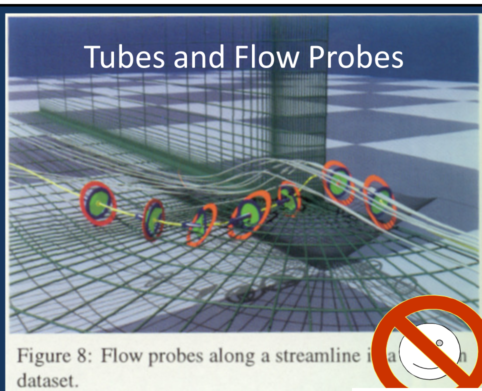
Figure 3.1: Decomposition of the probe

Two-stroke Engine, Tornado





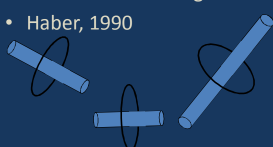
Tubes and Flow Probes

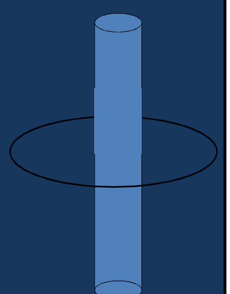


Overpowering Chartjunk

Symmetric Second-Order Stress Tensor

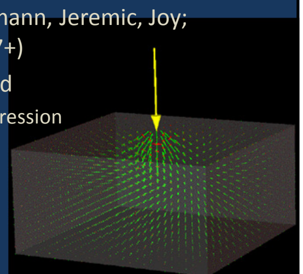
- Bar shows length and direction of largest eigenvector
- Ellipse axes show relative size of the two other eigenvectors
- Haber, 1990





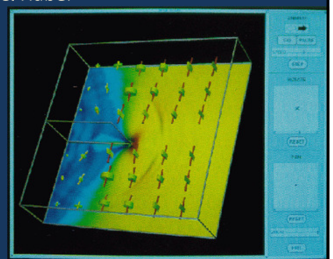
Seismic Stress Tensor: Hedgehogs

- Scheurmann, Frey, Hamann, Jeremic, Joy; U. Kaiserslautern (1997+)
- Deformation under load
  – Green lines show compression
  – Red lines show tension
  – Tripod “hedgehog”

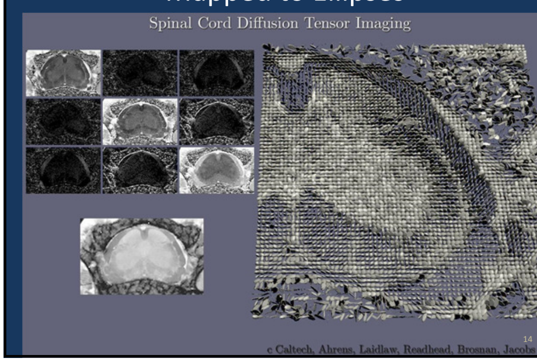


Other Hedgehogs

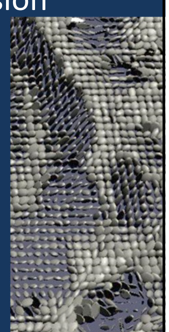
- Solid cylinder surrounds the principal cylinder
- Cheng, Koh, Lee, Vidal, & Haber
  - UIUC
- Chall, Idaszak, & Baker
  - NCSA
- Vis 1990



Second-Order Diffusion Tensor Mapped to Ellipses

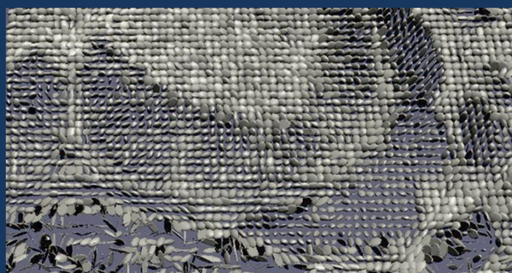


Second-Order Diffusion



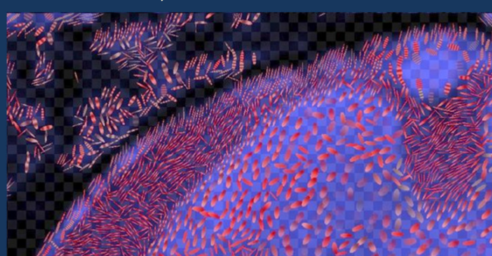
- Diffusion within mouse spinal-chord tissues
  - Anisotropic rate of diffusion in three dimensions
  - Three orthogonal eigenvectors in 3D
  - Non-negative eigenvalues
- Visualized as ellipsoid where liquid would spread
  - From a single starting point
  - At different rates along different eigenvectors
- Features
  - Matrix values at every point in space
  - Spheres represent isotropic diffusion
  - Larger ellipsoids represent faster diffusion

Detail view of ellipses

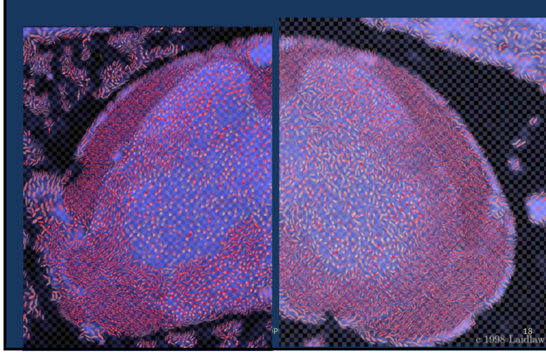


Diffusion Tensor Images

- David Laidlaw, IEEE Visualization 1998

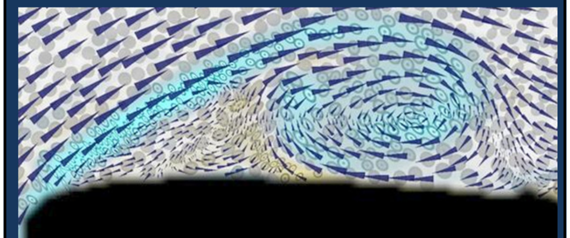


Left: Diseased; Right: Healthy



Deformation Rate Tensor

- Rate-of-Strain Tensor



Other Iconic/Glyph Techniques

- Post, Walsum, Post; Delft: Silver; Rutgers

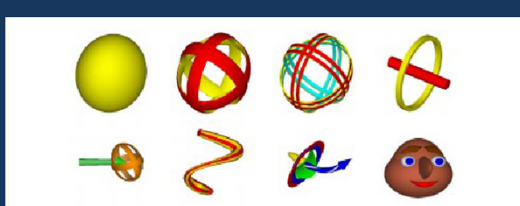
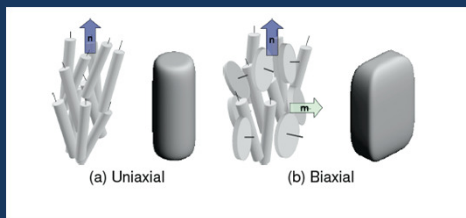


Figure 4: Example icons: four ellipsoid icons, an average velocity arrow with velocity distribution ellipsoid, an interpolated tube through five positions, a velocity gradient probe, and an 18 parameter 3D Chernoff face.

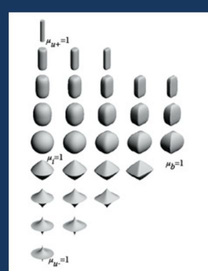
Superellipsoids for Real Symmetric Traceless Tensors

- T.J. Jankun-Kelly, Vis 2006



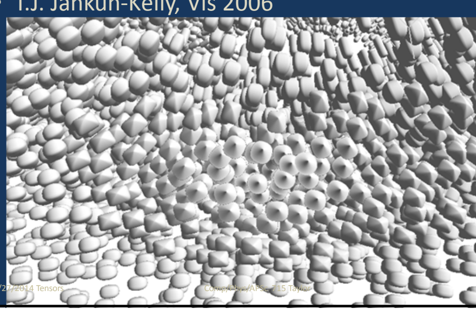
Superellipsoids for Real Symmetric Traceless Tensors

- T.J. Jankun-Kelly, Vis 2006
- Nematic Liquid-Crystal states drive glyph form



Superellipsoids for Real Symmetric Traceless Tensors

- T.J. Jankun-Kelly, Vis 2006

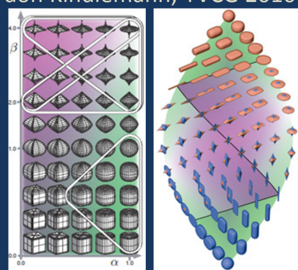


Superquadric Glyphs for Symmetric Second-Order Tensors

- Thomas Schulz, Gordon Kindlemann; TVCG 2010

Subsets of superquadric shapes are selected to form the base shapes.

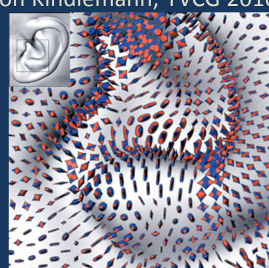
Coloration distinguishes geometrically-similar glyphs from different regions.



Superquadric Glyphs for Symmetric Second-Order Tensors

- Thomas Schulz, Gordon Kindlemann; TVCG 2010

Technique applied to the Hessian of the Laplacian zero-crossings describing the surface geometry of an earlobe



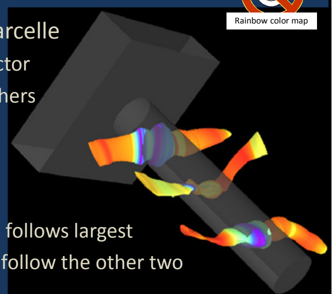
Glyphs: What are they good for?

- Is the tensor anisotropic in a specific area?
- Where is the tensor sheet-like, cigar-like?
- Where would water go from here?
- Where are the most severe rotations?
- What strain effect would stress have?
- Does this technique work for 3D?

Stream Indicators: Seismic Stress Tensor: Hyperstreamlines

Rainbow color map

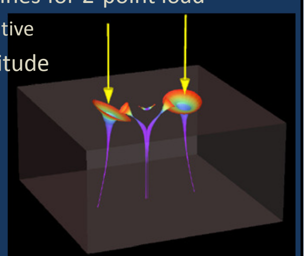
- Technique by Delmarcelle
  - Tube along eigenvector
  - Widths based on others
- Can follow any
  - Major (shown here) follows largest
  - Medium and minor follow the other two



Seismic Stress Tensor: Hyperstreamlines

Rainbow color map

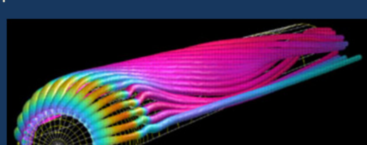
- Minor Hyperstreamlines for 2-point load
  - Compression is negative
- Hue based on magnitude



Momentum Flux Density Tensor

Rainbow color map

- Flow past a hemispherical cylinder
- Shows flow along major eigenvector
- Colored by difference in major eigenvalue compared to the other two



Streamballs Simplest

- Can advect along eigenvector like hyperstreamline
- Color similarly
- Brill, et. al.

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Streamballs Variety

- Can change connectivity, color, texture, microgeometry
- Brill, et. al.

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Stream Indicators: What are they good for?

- Is the tensor anisotropic in a specific area?
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- Where would water go from here?
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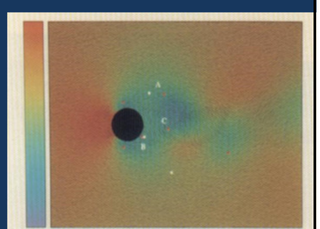
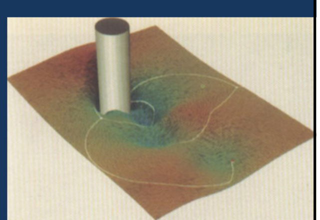
Hue and Texture: Symmetric, Second-Order Tensor Fields

- Delmarcelle & Hesselink
- Vector flow by texture
- Hue by magnitude of largest compressive eigenvector
- Dots show degenerate points (>1 eigenvector parallel)



Symmetric, Second-Order Tensor Fields

- Delmarcelle & Hesselink
- Vector flow by texture
- Hue by magnitude of largest compressive eigenvector
- Dots show degenerate points (>1 eigenvector parallel)
- Lines separate field into topological regions



Strain-Rate Tensor

- Sigfridsson, Ebbers, Heiberg, & Wigstrom, Vis 2002.

Noise blurred by eigenvalue

Larger values blur more

Relative values only (normalized)

L1 > L2 > L3

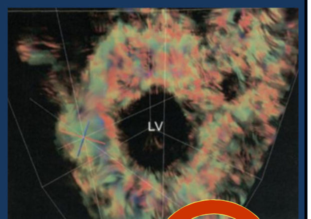
Color by degree of anisotropy

R = (L1 – L2) / L1 (Linear)

G = (L2 – L3) / L1 (Planar)

B = L3 / L1 (Isotropic)

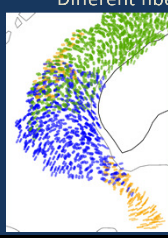
Glyph shows zoom-in to planar region

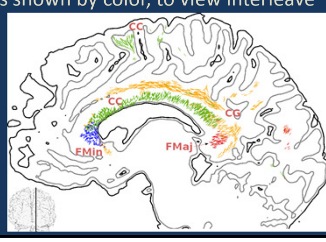


Occlusion and confusion

Fiber Stippling for Probabilistic Tracts

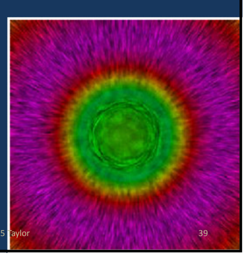
- Goldau, Wiebel, et. al. VisBio 2011
  - Stipple shape controlled by fiber properties
  - Different fibers shown by color, to view interleave





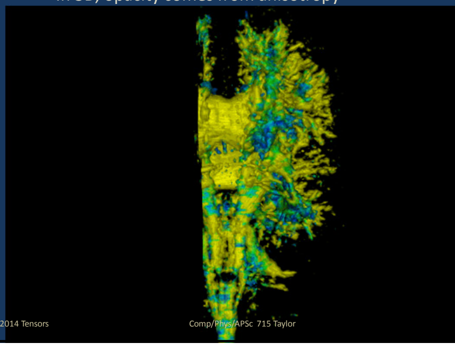
Deformation of Noise Texture

- Zheng and Pang, Vis2003, HyperLIC
- Start with a uniform 2D/3D noise texture
- Blur (flow) texture
  - Along eigenvectors
  - Blurs where large & isotropic
  - LIC where anisotropic



Deformation of Noise Texture

- Zheng and Pang, Vis2003, HyperLIC
- In 3D, opacity comes from anisotropy



Hue and Texture: What are they good for?

- Is the tensor anisotropic in a specific area?
- Where is the tensor sheet-like, cigar-like?
- Where would water go from here?
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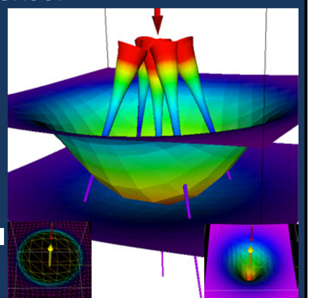
Deformed Surfaces: Point-Load Stress Tensor

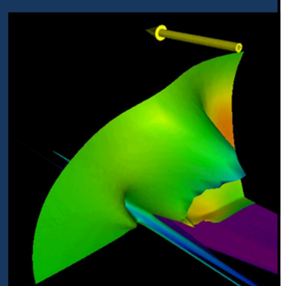
- Boring and Pang
- Deformation of sheet
  - Exaggerated
  - Colored by magnitude
- Minor hyperstreamlines
  - Colored by magnitude
- Insets:
  - Lateral strain
  - Normal strain
- Show the movie



Rainbow color map

Delta-Wing Rate-of-Strain

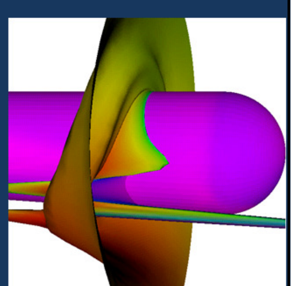
- Boring & Pang
- Surface Deformation
- Show Movie



Rainbow color map

Cylindrical Cap and Flow

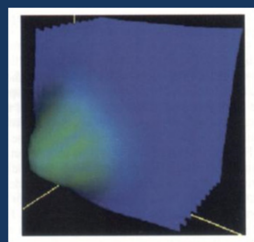
- Boring & Pang
- Deformation by
  - Rate of strain
  - Normal component only
  - Extrusions = tensile
  - Depressions = compressive
- Show Movie



Rainbow color map

Zheng and Pang, Vis 2002

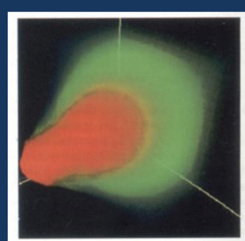
- Deformation due to load
  - Single Point Load
  - Opaque Surfaces
  - Colored by remaining tensor magnitude



Severe occlusion

Zheng and Pang, Vis 2002

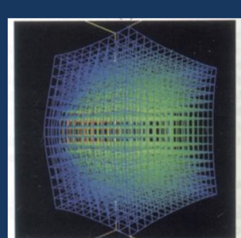
- Deformation due to load
  - Single Point Load
  - Transparent volumes
  - Colored by initial tensor magnitude



Lack of occlusion

Zheng and Pang, Vis 2002

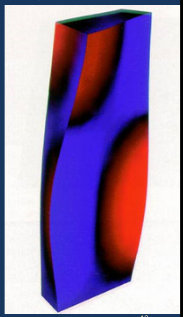
- Deformation due to load
  - Single Point Load
  - Wireframe grid
  - Colored by initial tensor magnitude
- Viewed from the back



Rainbow color map

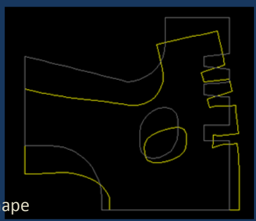
Deformation of Rectangle

- http://www.cs.auckland.ac.nz/~burkhard/PhD/img12.html
- Cube coordinates displaced by vector data
  - Second torsional mode of vibration for an object
- Scalar offset mapped to double-ended color
  - Red moves along surface normal
  - Black is little or no motion in direction of normal
  - Blue moves opposite surface normal



Deformation of Shape

- http://146.134.8.133/femtools/img/2ved04.gif
- Advect shape by field
- Shows strain
- Could animate
- 2D or 3D shape
- Here, color nominal
  - Original vs. deformed shape



Deformation of Shape

- Bender et. al. IEEE Transactions on Vis. & Comp. Gfx., Vol 6. No. 1. 2000. Pp. 8-23

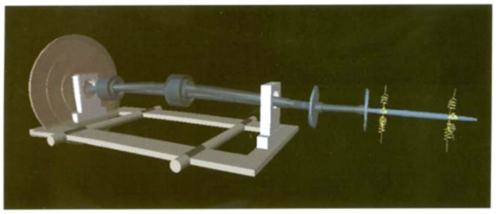
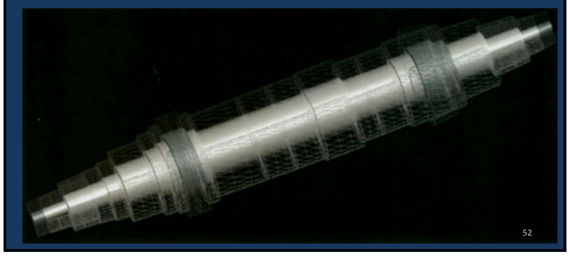


Fig. 14. Vibrating turbine

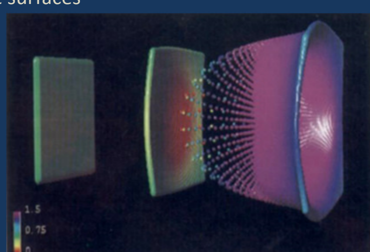
Deformation of Shape

- Bender et. al. IEEE Transactions on Vis. & Comp. Gfx., Vol 6. No. 1. 2000. Pp. 8-23



Streamballs as Surfaces

- Can deform like surfaces
- Color similarly
- Brill, et. al.



Deformed Surfaces: What are they good for?

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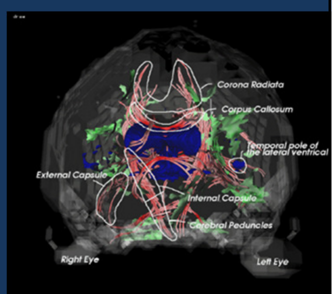
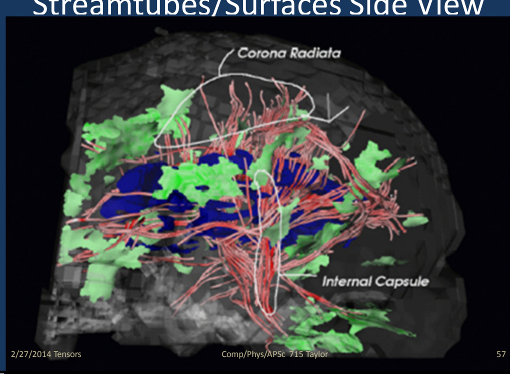
- What strain effect would stress have?
- Does this technique work for 3D?

Computed: Streamtubes and Streamsurfaces

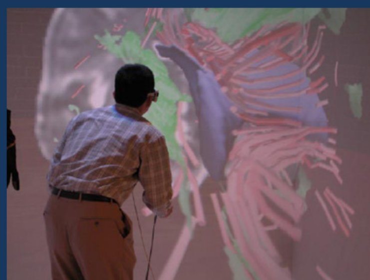
- Tubes
  - Flow mostly along line
  - Along principal direction of diffusion
  - Cross-section is ellipse
  - Saturation shows anisotropy
- Surfaces
  - Where diffusion larger in 2 directions than 3rd
  - Perpendicular to slowest
  - Saturation shows anisotropy
- Annotated landmarks



Streamtubes/Surfaces Side View



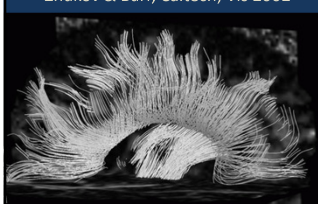
Getting Into the Data



White-Matter Fiber Tracing

- Zhukov & Barr, Caltech; Vis 2002

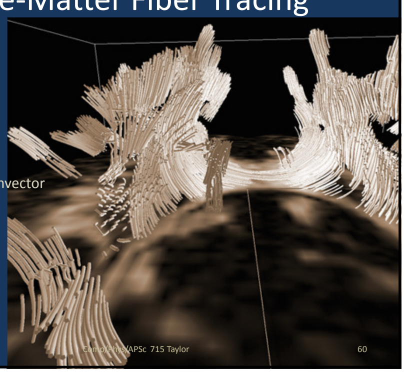
In this paper we develop a new technique for tracing anatomical fibers from 3D diffusion tensor fields. The technique extracts salient tensor features using a local regularizing technique that allows the algorithm to cross noisy regions and bridge gaps in the data.



We applied the method to human brain diffusion tensor DT-MRI data and recovered identifiable anatomical structures that correspond to the white matter brain-fiber pathways.

White-Matter Fiber Tracing

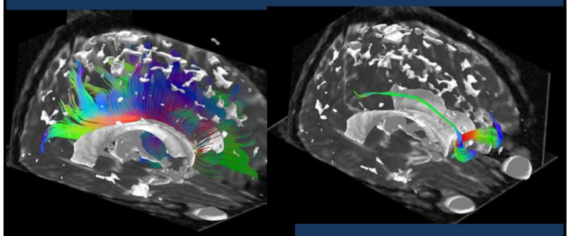
- Zhukov & Barr
  - Caltech
  - Vis 2002
- Trace streamlines
  - Along major Eigenvector



White-Matter Fiber Tracing

- Zhukov & Barr, Caltech; Vis 2002
- Streamlines along major eigenvector

Color mixing



White-Matter Fiber Tracing

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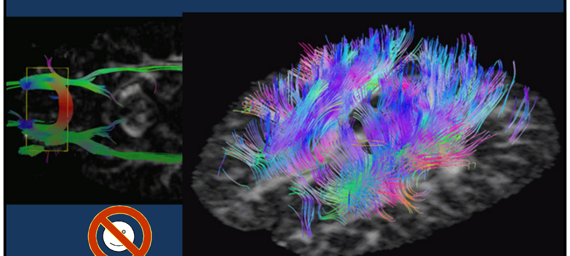


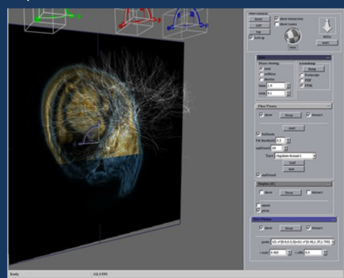
Color mixing

Adding Halos

- Interactive volume rendering of thin thread structures within multivalued scientific data sets
  - Wenger, Keefe, Zhang & Laidlaw 2004
- Left: no halos, middle: halos, right: halos shifted away from the viewer

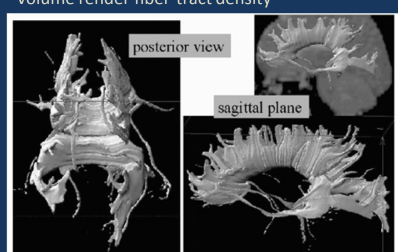
Multi-source Streamlines

- Vis 2005, Blaas et. al.



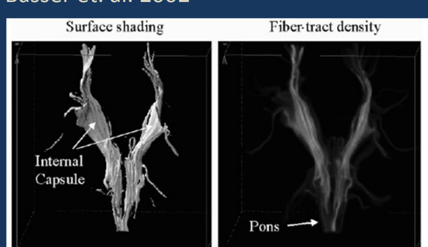
In-Vivo Tractography

- Basser et. al. 2002
  - Volume render fiber-tract density



In-Vivo Tractography

- Basser et. al. 2002



Computed Tubes and Surfaces: What are they good for?

- Is the tensor anisotropic in a specific area?
- Where is the tensor sheet-like, cigar-like?
- Where would water go from here?
- Where are the most severe rotations?
- What strain effect would stress have?
- Does this technique work for 3D?

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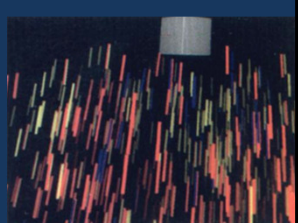
Rotation Field

- Livingston, Vis '97
- Tracker Orientation Errors
- Cube is tracker source
- Spinning colored tuftes
  - Red, green, and blue sides
  - Animate
    - Spin around axis
    - Speed by error magnitude
    - Shows subtle differences



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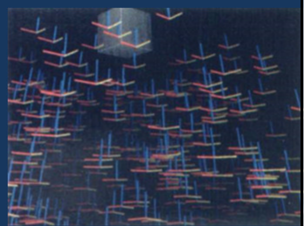
Rotation Field

- Livingston, Vis '97
- Tracker Orientation Errors
- Cube is tracker source
- Orienting axes
  - Rotated by error amount
  - Best when fly-through
  - Animate to shift from starting orientation to final



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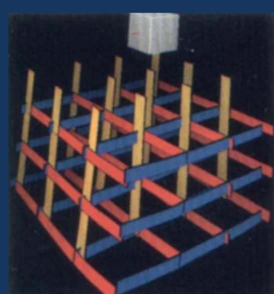
Rotation Field

- Livingston, Vis '97
- Tracker Orientation Errors
- Cube is tracker source
- Axis streamlines
  - Not hyperstreamlines (along eigenvectors)
  - Integrate along the rotated coordinate axis
  - Tile adjacent ones to provide strips



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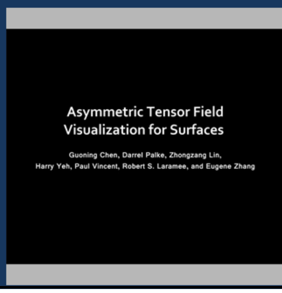
Combined 2D Techniques

- Asymmetric Tensor Field Vis for Surfaces
  - Chen, Palke, et. al.; TVCG 2011



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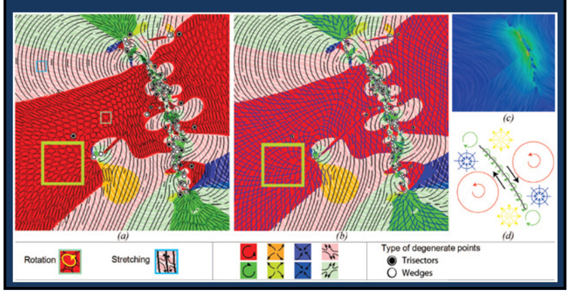
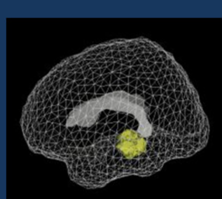
Combined 2D Techniques

- Asymmetric Tensor Field Vis for Surfaces
  - Chen, Palke, et. al.; TVCG 2011



Combined Display

- www-sop.inria.fr/epidaure/personnel/ayache/ayache.html



2006 images, show with Quicktime

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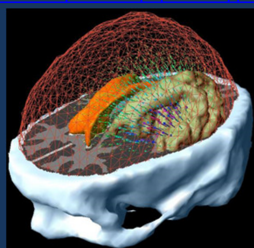
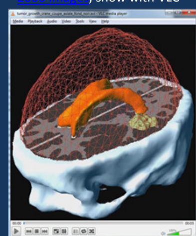
Combined Display

- www-sop.inria.fr/epidaure/personnel/ayache/ayache.html

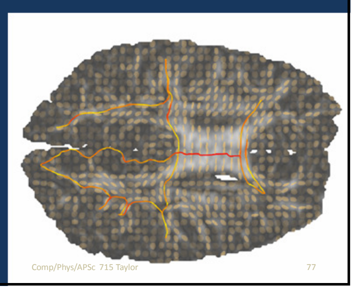


2006 images, show with VLC



Haptic Diffusion Tensor Display

- A Constraint-Based Technique for Haptic Volume Exploration: Vis 2003; Ikits, Brederson, Hansen, Johnson
- Anisotropic drag
  - along Eigenvectors
  - by Eigenvalues



Summary (From 2003)

- Is it isotropic? Ellipsoids, Stream ind (color compares 2), Hue&Tex in 2D, Deformation(color)
- Sheet or cigar: Ellipsoids, Stream is hard, others not.
- Where would water diffuse? Stream for 1, hue&tex, Deform
- Where severe rotation? FlowProbe, Flowtubes, Streamballs for surface
- What strain caused by stress? Glyph, Deformation
- Does it work for 3D? Glyphs have occlusion trouble, tricks let hue&text, great care or 2D subsets for deformations
- All: "Computed" depends on what you computed

Summary (from 2002)

		E	f	I s	TP a	Isotropic/anisotropic tensor field?
		E		I s	TP	Where is it sheet-like, where cigar-like?
H	P	e	f	I S	W TP A	Where would water go from here?
h	P				W a R	Where are the most severe rotations?
				I S	W A	What strain effect does stress cause?
	p			I S	W A R	Does it work in 3D?

(H)ue/velocity, Flow (P)robe, (E)llipsoids, (F)lat/2D ellipses,

(I)cons (includes P,E,F), Hyper(S)treamlines, (W)arped surface,

(TP) Tubes and Planes, (A)dvect shape, (R)otation (anim. axis)

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- http://www.cs.auckland.ac.nz/~burkhard/PhD/introduction.html
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- Dickinson, "A unified approach to the design of visualization software for the analysis of field problems," SPIE Three-dimensional visualization and display technologies vol 1083, pages 173-180. 1989. Tensor field lines.
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- Diffusion tensor images on spinal chords: David Laidlaw, David Kremers, Eric T. Ahrens, and Matthew J. Avalos, Siggraph Technical Slide Set, 1998.
- Diffusion tensor image on airfoil flow: David Laidlaw, Matthew J. Avalos and David Kremers, Siggraph Technical Slide Set, 1998.
- Flow Probe: Willem de Leeuw and van Wijk, "A probe for local flow field visualization," Vis 93, 39-45.
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