Image Space Tensor Field Visualization using a LIC-like Method

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Outline

1. Introduction
   - Focus
   - Tensor field visualization
   - Motivation and Goals
2. The method
   - Step 0: Input
   - Step 1: Projection to Image Space
   - Step 2: Silhouette detection
   - Step 3: Advection
   - Step 4: Compositing
3. Results
4. Problems and Further Work

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Focusing on ...

- Second-order tensor fields
- Diffusion tensors
  - positive definite
  - symmetric
  - three orthogonal eigenvectors without orientation
- Medical DTI visualization, but not limited to

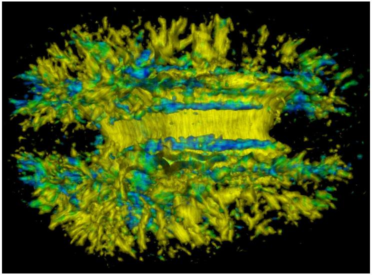
Tensor field visualization

- Inspired by methods used in Scalar- and Vector field visualization
- Often using derived metrics
- Common methods:
  - Colormaps
  - HyperLIC (Zheng et al. [ZP03])
  - Tensor Glyphs (Kindlmann [Kin04])
  - Direct Volume Rendering (foundations in [Bli82, KVH84])
  - Advection Diffusion Tensorlines (Kindlmann et al. [WKL99])
  - Hyperstreamlines (Delmarcelle et al. [DH92])

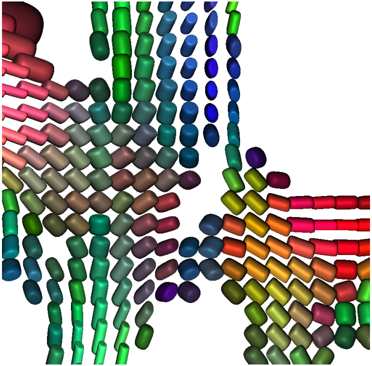
Weaknesses and Problems

- Limitation to local or global data representation
  - no smooth and interactive transition between levels of detail
- Severe limitations in data size
- Interactive performance
- Limitations in number of represented tensor attributes

Examples I

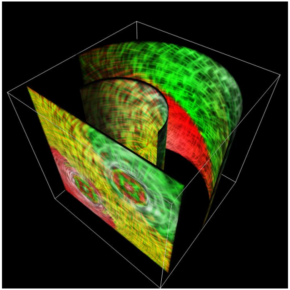


(a) HyperLIC

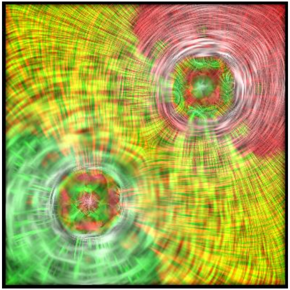


(b) Superquadrics

Figure: HyperLIC and Superquadric Tensor Glyphs



(a) Method applied to several surfaces



(b) XZ-Slice

Figure: Hotz et al. [HFHJ09]. Limitation to type of surface.

Motivation and Goals

- Easy perceptibility of structures
  - More bold representation of diffusion structures
- Continuous perception of structures during transformation
  - Often problematic with image space based methods
- Allow smooth transition between local and global structures
- Realtime ability
- Applicability on arbitrary geometry

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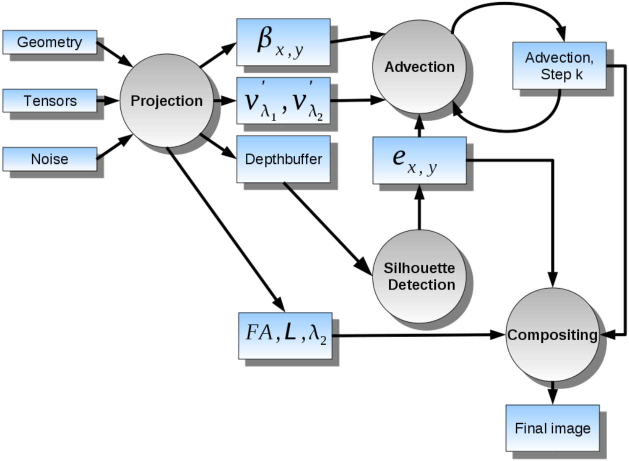
Overview I

- Move problem to image space
- Divide into small parallelizable parts
  - Utilize GPU parallelism
- Implementation using OpenGL, GLSL and Framebuffer Objects
  - But smaller float precision
  - Many limitations
- Textures as transport media

Overview II



Geometry
Tensors
Noise
Projection
$\beta_{x,y}$
$v'_{\lambda_1}, v'_{\lambda_2}$
Depthbuffer
Advection
Advection, Step k
$e_{x,y}$
Silhouette Detection
FA, L, λ_2
Compositing
Final image

Noise

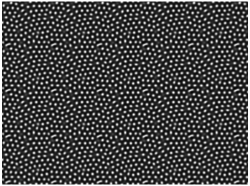


Figure: Tiled 100x100 pixel reaction diffusion texture with $D_a = 0.125$ and $D_b = 0.031$.

- Initial calculation of input noise
  - Reaction Diffusion ([Tur52])
  - Create once, reuse every pass
- Since computational expensive: tiling

Geometry and Tensors

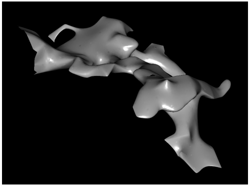
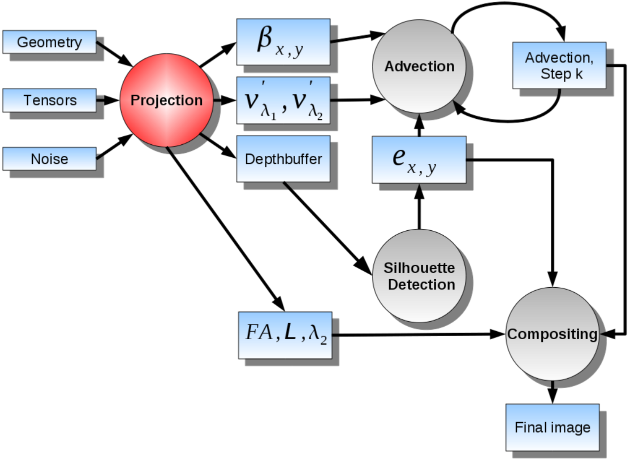


Figure: Input geometry with Phong lighting.

- Geometry calculated using arbitrary metric and algorithm
- Tensors uploaded as two 3D texture coordinates
- Requirements to geometry:
  - Smooth normals
  - Not self-intersecting

Step 1: Projection to Image Space



Tensor projection I

- Tensor interpolated using GPU
- Projection to geometry surface ($n = s \cdot v_{\lambda_3}$):

$$T' = P \cdot T \cdot P^T \text{ mit } P = \begin{pmatrix} 1 - n_x^2 & -n_y n_x & -n_z n_x \\ -n_x n_y & 1 - n_y^2 & -n_z n_y \\ -n_x n_z & -n_y n_z & 1 - n_z^2 \end{pmatrix}.$$

- Eigenvalue decomposition using Hasan et al. [HBPA01]
  - Eigenvalues: λ_i with $i \in \{1, 2\}$
  - Eigenvectors: v_{λ_i} with $i \in \{1, 2\}$
- Eigenvectors still in geometries object coordinate system

Tensor projection II

- Projection to image space using OpenGL's Modelviewmatrix M_M and Projectionmatrix M_P: $v'_{\lambda_i} = M_P \times M_M \times v_{\lambda_i}$, with $(i \in 1, 2)$ and $v'_{\lambda_i} \in \mathbb{R}^2$
- May not need to be orthogonal anymore $(< v'_{\lambda_1}, v'_{\lambda_2} > \neq 0)$
- Scale to $[0, 1]$: $v''_{\lambda_i} = \frac{1}{2} + \frac{1}{2} * \frac{v'_{\lambda_i}}{\|v'_{\lambda_i}\|_\infty}$ with $i \in \{1, 2\}$ and $\|v'_{\lambda_i}\|_\infty \neq 0$

Noise Texture Mapping I

- To ensure consistency during transformation
- Many methods available
  - Texture Atlases ([PCK04, IOK00])
  - Reaction Diffusion directly on the geometry ([Tur91])
  - 3D textures ([WE04])
  - Mostly computational expensive or geometry dependent results
- Own heuristics developed
  - Not C^1 constant
  - May introduce minor distortions
  - Allows seamless scaling
  - Good trade-off between computation time and visual quality

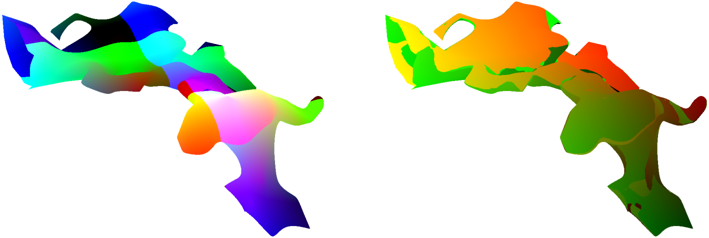
Noise Texture Mapping II

- Transformation of vertex v_g to *voxelized* space:

$$v_{voxel} = v_g \cdot \begin{pmatrix} l & 0 & 0 & -b_{min_x} \\ 0 & l & 0 & -b_{min_y} \\ 0 & 0 & l & -b_{min_z} \\ 0 & 0 & 0 & 0 \end{pmatrix}$$

- l is its size, b_{min} origin of voxel space in world coordinates
- Discretize to voxels borders $v_{hit} = v_{voxel} - \lfloor v_{voxel} \rfloor$
- Texture coordinate t is then defined as:
  $t = (v_{hit_i}, v_{hit_j})$, with $i \neq j \neq k \wedge (n_k = max\{n_i, n_j, n_k\})$

Noise Texture Mapping III)



(a) v_{hit} (b) t

Figure: Illustration of v_{hit} and t for illustration.

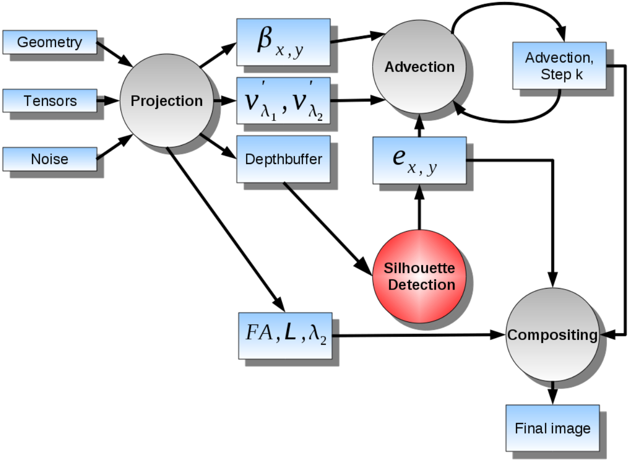
Noise Texture Mapping IV

Figure: Noise mapped to surface ($\beta_{i,j}$).

Further calculations

- Phong intensity $\mathcal{L}$
- Mean Diffusivity
- Fractional Anisotropy
- Colormapping: $c^{FA \cdot v_{\lambda_i}}(T) = \frac{|v_{\lambda_i}|}{\|v_{\lambda_i}\|} * FA(T)$

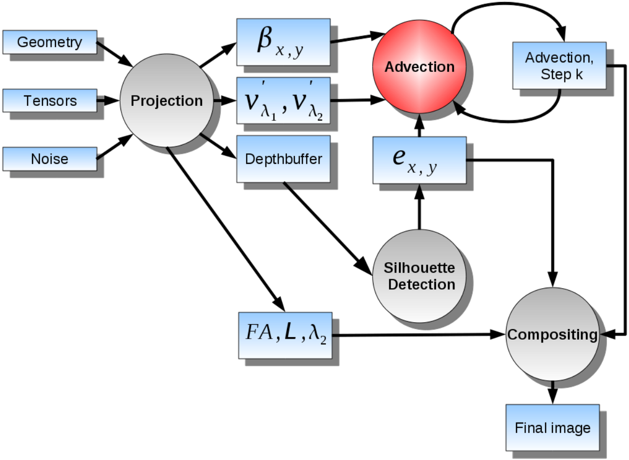
Step 2: Silhouette detection I



Step 2: Silhouette detection II

- Creation of silhouette texture
  $e : (x, y) \rightarrow s$, with $x, y, s \in [0, 1]$ using depthbuffer
- Fold using Laplace filter kernel: $D^2_{xy} = \begin{bmatrix} 0 & 1 & 0 \\ 1 & -4 & 1 \\ 0 & 1 & 0 \end{bmatrix}$

Step 3: Advection I



Step 3: Advection II

- Access to discrete, intermediate LIC-textures P^{λ_1} and P^{λ_2} using: $f_P : (x, y) \to p$, with $x, y, p \in [0, 1]$
  - Interpolation
- Iteration on both textures for each pixel:

$$\forall x, y \in [0, 1] : \forall \lambda \in \{\lambda_1, \lambda_2\} :$$

$$p_0^\lambda = \beta_{x,y},$$

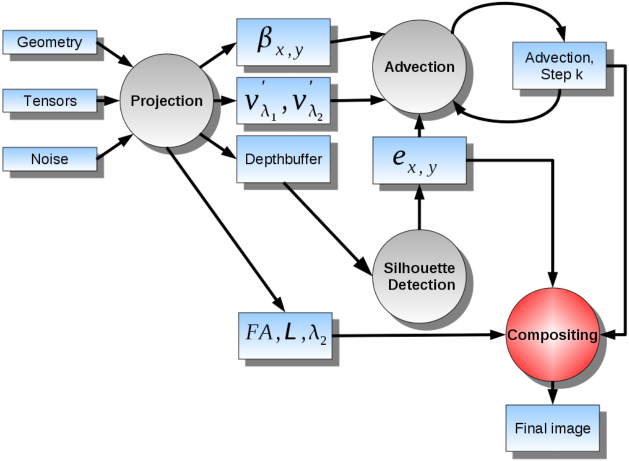
$$p_{i+1}^\lambda = k \cdot \beta_{x,y} + (1 - k) \cdot \frac{f_{p_i^\lambda}(x + v'_{\lambda_x}, y + v'_{\lambda_y}) + f_{p_i^\lambda}(x - v'_{\lambda_x}, y - v'_{\lambda_y})}{2}.$$

  - k describes "roughness" (the smaller k is, the more smooth the final image looks)
  - Advection needs to be done in both directions, since eigenvectors do not have an orientation
  - Stop iteration if $|p_i^\lambda - p_{i+1}^\lambda| < \epsilon$

Step 3: Advection III

Figure: Advection of Eigenvector field v'_{λ_1} after 10 iterations.

Step 4: Compositing I



Step 4: Compositing II

- Final step after *i* iterations
  - Possible to stretch advection iterations over multiple frames
- Clipping using MD, FA or another metric
- Set depthbuffer information
- Depth-enhancing ([CCG$^+$08]) for better plasticity
- Very flexible
  - blend in colormaps

Step 4: Compositing III

- Color for each pixel with advected textures $P_i^{\lambda_1}$ and $P_i^{\lambda_2}$:

$$R = \frac{r \cdot f_{p_k^{\lambda_2}}(x,y)}{8 \cdot f^2_{p_k^{\lambda_1}}(x,y)} + e_{x,y} + light(\mathcal{L}_{x,y}),$$

$$G = \frac{(1-r) \cdot f_{p_k^{\lambda_1}}(x,y)}{8 \cdot f^2_{p_k^{\lambda_2}}(x,y)} + e_{x,y} + light(\mathcal{L}_{x,y}), \text{ and}$$

$$B = e_{x,y} + light(\mathcal{L}_{x,y}).$$

  - Silhouette texture: e and Light: $\mathcal{L}$
  - r defines ratio between both eigenvector fields in the final image

Step 4: Compositing IV

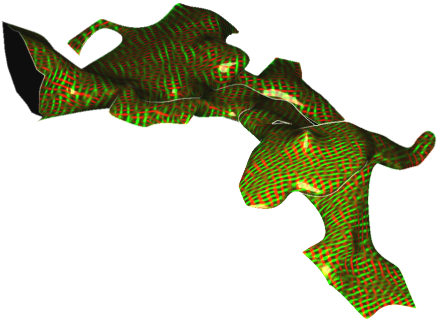


Figure: Composited image showing diffusion-directions through a fabric like structure.

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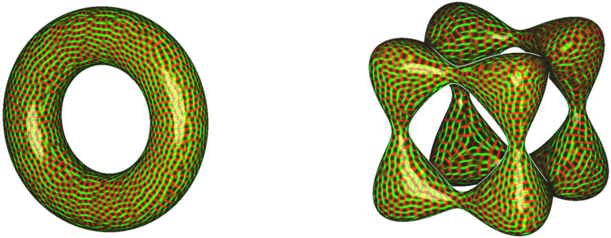
Artificial Datasets



(a) Torus (b) Tangle

Figure: Implicit, C^1 steady surfaces ([KHH+07])

Small part of DTI dataset

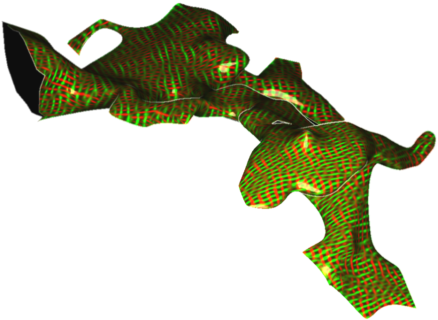


Figure: Small part of Corpus Callosum in a DTI dataset. (58624 triangles, 30 FPS (Geometry: 69%))

Neural Fibers (DTI)

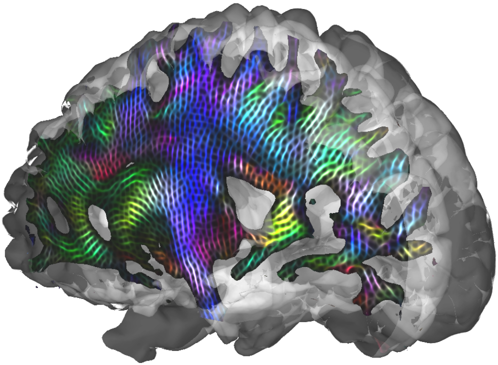


Figure: Diffusion along neural fibers (Anwander et al. [ASH+09]). (41472 Triangles, 32 FPS (Geometry: 72%))

Single Point Load (Mechanics)

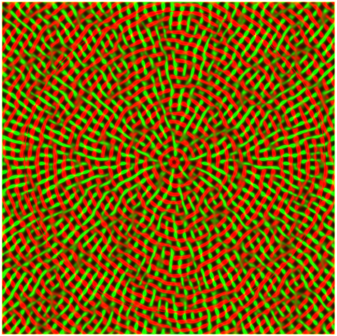


Figure: Single Point Load dataset.

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Problems

- Noise texture mapping strongly dependent on quality of normals
- Minor blurring effects
- Lighting with Phong often not optimal for spatial perception of geometry

Further Work

- Reduction of rendered geometry for further performance improvement
  - Since geometry rendering is lion's share in overall rendering time
- Extend to tensor fields of higher order
- Variation of spot sizes and density in initial noise texture
  - Corresponding to eigenvalues
  - As in [HFHJ09]

Thank You for listening

Questions?

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