Diffusion Tensor Imaging (DTI)

Jan Klein\textsuperscript{1}, Ola Friman\textsuperscript{1}, Anna Vilanova\textsuperscript{2}

\textsuperscript{1} MeVis Research, Germany
\textsuperscript{2} TU Eindhoven, Netherlands
White Matter: Axons connecting Gray Matter Areas
Conventional MR Imaging

White matter seems to be homogenous in standard MR images!
Diffusion Tensor Imaging

› Non-invasive method for structural examination of brain tissue, muscle tissue (e.g., of heart).

› Clinical applications, e.g.,
  - characterizing tissue damage
  - preoperative planning
  - intraoperative planning
What is Diffusion?
Restriction of Molecular Motion

cf. Virtual Hospital (http://www.vh.org/)
Image Acquisition

- MR scanner allows to measure diffusion of water molecules.
- Diffusion is measured along a predefined 3D direction.
- High diffusion $\Rightarrow$ low signal.
Diffusion Tensor Imaging (DTI)

Diffusion strength $S$ depends on direction $g$:

$$\ln\left(\frac{S}{S_0}\right) = -g^T D g$$

- $D$ is the diffusion tensor (3x3 matrix)
- $g$ is a protocol parameter (diffusion time, ...)

Diagram showing directions $\lambda_1$, $\lambda_2$, and $\lambda_3$.
Visualizing Tensors
Standard Color Coding of DTI Images

First eigenvector: \( \vec{e}_1 = (x, y, z) \) map to \((R, G, B)\)
Unique Planar Color Coding

different orientations have different colors!

Schlüter et al. 2003

different orientations have the same color!
Glyph Visualization

Ellipsoids

Superquadrics

Cuboids

[Kindlmann et al. 04]
GPU Particle Tracing for DTI Data

Kondratieva et al., IEEE Vis 2005
Fiber Tracking
What can DTI-Based Fiber Tracking Achieve?

voxel size \( \approx 1 - 2 \text{ mm} \)

axon diameter \( \approx 1 - 2 \mu \text{m} \times 1000 \)

Fiber tracking algorithms cannot reconstruct single axons but only bundles of them.
Streamline-Based Fiber Tracking

$\mathbf{v}_1$ $\mathbf{v}_{\text{in}}$

$v_{\text{out}} \sim D \cdot v_{\text{in}}$

$D = v_1 v_1^T$

+ fits to bundles of high curvature
- susceptible to orientation uncertainty
- uses only main vectors
Deflection-Based Fiber Tracking

\[ v_{out} \sim Dv_{in} \]

with \( D = \) tensor

+ more robust to orientation uncertainty
+ uses full tensor information
- problems with high curvature
Geodesic Tracking

- Define metric based on diffusion tensor.
  - two points are close if path of high diffusion exists.
- Calculate geodesic paths in this metric.
- Do not discard tensor information → more robust.
- Computational expensive.

O'Donnel et al., MICCAI 2002
Stochastic Tracking

In every step, draw a step direction from the pdf of the underlying fiber orientation.

A probability density function of the fiber orientation in each voxel.

Friman et al., MICCAI'05
Whole Brain Fiber Tracking
Interactive Fiber Bundle Selection using an Octree
GPU-based Rendering of Fiber Tracts

No coloring

No lighting  Illuminated lines  Illuminated lines & shadowing

RGB coloring

Peeters et al., VMV'06
Fiber Clustering
Motivation for Fiber Clustering

Group geometrically similar or related fibers acquired by DTI.

- Improve perception of fiber bundles and connectivity.
- Improve interaction with fiber bundles.
- Avoid user-biased quantification results.

Klein et al., SPIE 2007
Fiber Clustering using Normalized Cuts

Brun et al., MICCAI'04

Voxel segmentation

Fiber segmentation
Brun et al., MICCAI'04
Validation of Fiber Clustering

How do we know that …

› … a method is better than the other?
› … a similarity measure is better than the other?
› … there is no parameter setting giving better results?

Validation [Moberts et al., IEEE Vis’05]

› Ground truth
› Comparison framework

Moberts et al., IEEE Vis’05
Conclusions and Future Work

- No much information can be extracted directly from the DTI raw data.
- Image analysis and visualization algorithms help understanding.
- Validation of DTI algorithms.
- Comprehensive presentation of DTI data
- Visualization and navigation tools for identifying pathologic changes
- Parallel fiber tracking, e.g., GPU-based approaches
References


