Interactive Visualization of Diffusion Image Data and its Models

Gordon Kindlmann

Outline

• Intro to modality
• Single tensor parameters, applications
• Beyond single tensor fit
• Visualization of DWI and model
Diffusion imaging detects anisotropy

White Matter
fiber bundle
Cross-section:

Anisotropy: directional variation in diffusivity

Microstructure of bundles directionally constrains water diffusion along fiber direction (LeBihan et al. 1985)

Diffusion-weighted MRI measures “apparent diffusion coefficient” (ADC) along many directions

Tensors from diffusion-weighted images

Single Tensor Model (Basser 1994) \( A_i(b, g) = A_0 e^{-b g_i^T D g_i} \)

Linear regression

Derived scalars:
- Bulk mean diffusivity
- Fractional Anisotropy (FA)
Tractography

• Path integral of principal eigenvector

• Various parameter settings…

(demo)
Tensor Shape = model parameters

\[ D = R \Lambda R^{-1} \]

\[ = \begin{bmatrix} v_1 & v_2 & v_3 \end{bmatrix} \begin{bmatrix} \lambda_1 & 0 & 0 \\ 0 & \lambda_2 & 0 \\ 0 & 0 & \lambda_3 \end{bmatrix} \begin{bmatrix} v_1 \\ v_2 \\ v_3 \end{bmatrix} \]

Tensor shape parameterizations

**Cylindrical Coordinates: \( \{K_i\} \)**

- \( K_1 = \text{tr}(D) \)
- \( K_2 = |E| \)
- \( K_2 = \text{mode} \)

**Spherical Coordinates: \( \{R_i\} \)**

- \( R_1 = |D| \)
- \( R_2 = \text{FA} \)
- \( R_3 = \text{mode} \)

\[
\begin{align*}
\text{tr}(D) &= D_{xx} + D_{yy} + D_{zz} \\
|D| &= \sqrt{\text{tr}(D^T D)} \\
E &= \text{deviatoric}(D) \\
&= D - \text{trace}(D) \cdot I/3 \\
\text{Mode} &= \det(E/|E|) \\
&\text{(Criscone 2000)}
\end{align*}
\]
Clinical DTI Applications: Model Parameters

- Changes in FA due to pathology
  - Really the mainstay of DTI applications
- Change in FA/trace relationship
  - E.g. Tumor Infiltration Index (Lu et al. ‘04)
- Less so: Connectivity around tumors
- Point: model parameters are reliably measured, biologically meaningful, clinically significant
- High-level point: don’t lose track of why we do imaging and medical image analysis

Beyond the Single Tensor Model

- Two (or more) Tensors
  \[ A_i = A_0 \left( \alpha e^{-bg_i^T D_1 g_i} + (1 - \alpha) e^{-bg_i^T D_2 g_i} \right) \]
- No model: Spherical harmonics
- Diffusion Orientation, Funk-Radon Transforms
  - ADC peaks != fiber directions
  - Fiber crossing resolution
- Tension with clinical applications
Visualization as a data & model inspection

- Visualize **underlying** DWI data
  - How noisy is it?
  - Does data support complex analysis?
- Inspect relationship of DWI to single tensor model
  - Systematic errors highlight fiber crossings
- General ideas:
  - Use intuition of old (single tensor model) as **guide**
  - Use visualization to **illuminate** the path forward
  - Experience lends **perspective** to canned routines
Synthetic Data

• (again) using intuition about old as guide to new…

ADC profile colored by single-tensor error
Synthetic Data

• (again) using intuition about old as guide to new…

ADC profile colored by single-tensor error

• How does it look in real data?

(demo)
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