Atlas Building in DTI

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Outline

- Quantitative Tract Analysis
- Atlas-Building Methodology
- Application Areas
- Experiments
- Future Work
Quantitative Tract Analysis

- Isabelle Corouge
- Tractography
- Clustering of bundles
- Tensors statistics along fiber tract bundles
FiberViewer
Problem Description

- Problem: Strategy for inter-patient comparison of DTI.

- Ideas
  - Solution should be fairly automatic
  - Atlas-building (Common coordinate system)
  - Framework that can answer many group comparison questions
    - Quantitative tract analysis
    - Region based analysis
Atlas Building in DTI

- Want to apply atlas building to DTI
- Challenges
  - Registration
  - Interpolation/Averaging
- Initial test
  - 5 DTI scans of 1 year old subjects
Registration

DTI Images (1:N) → Structural Operator → Scalar Images From Manifold Detector on FA → Atlas (Affine, Fluid) → Structural Average

H-fields (1:N) → H⁻¹-fields (1:N)
Registration Optimization

- Align template image \((I_0)\) to coordinate system using T2 atlas
- Align remaining images \((I_1-I_n)\) to template using affine alignment of structural image
- Use affine parameters to initialize diffeomorphic deformation fields for deformable registration
- Run deformable registration procedure of Joshi, Davis, et al.
Atlas formation

DTI Images

H-fields (1:N)

Rotate Tensors based on $J_H^{-1}$

Tensor Averaging

Riemannian Symmetric Space

DTI Atlas
Registration Application

- Apply deformation field to each image
  - Finite strain model for tensor reorientation (Alexander)
  - Riemannian statistics (Fletcher, Pennec)
  - Log-Euclidean scheme with linear interpolation (Arsigny)
- Average deformed tensor volumes to create affine, deformable atlases
Want images aligned by geometry of fiber tracts

FA occurs in thin manifolds
  - sheets
  - tubes

FA'' highlights fiber geometry (maximum eigenvalue)

FA'' does not directly optimize correspondence of tensor derived property
FA image and Curvature Image
FA image and Curvature Image
FA image and Curvature Image
Spatial Transformation of DTI

- Tensors contain **oriented** measurements
- Diffusion measurements are physical measurements (in s/mm^2)
- For global transformation extract the rotation component
- For deformable transformation extract the local rotation of local linear approximation
Graphic Spatial Transformation

Image A

Image B
Mathematics of Spatial Transformation

$h(x)$ is a mapping from $\mathbb{R}^3$ to $\mathbb{R}^3$. $h(x)$ can be locally approximated as a linear function.

$$h(x) = x + Fx$$

$F$ is the local Jacobian of the transformation and can be processed the same as for a global transformation. SVD can be used to extract the rotation component of $F$.

$$F = UR$$

$$D' = RDR^T$$
Processing of DTI

- Diffusion tensors are symmetric positive-definite matrices which can be interpreted as covariance matrices of Brownian motion.
- Riemannian symmetric spaces (Fletcher, Pennec)

\[
\hat{D} = \exp \left( \sum_{i=1}^{N} w_i \log(D_i) \right)
\]
DTI Atlas

- An atlas is created of the mean diffusion tensor at each voxel
- Tensor images are aligned in atlas space
  - Statistics of voxels
  - Warp of fiber tracts
Average Atlases

Affine Atlas

Deformable Atlas
ROI Properties

H-fields (1:N) → ROI in Patient Space → Compare ROI Statistics

ROI in Atlas Space
Tract Properties

- DTI Atlas
- ROI in Atlas Space

Tractography:
- Fiber Tracts in Atlas Space
- H-fields (1:N)

Geometric Warping:
- Fiber Tracts in Image Space

Measure Geometry/Diffusion
Average Atlases
Gradient Magnitude Visualization
Histogram of FA gradient magnitude

- **Affine atlas**
- **Deformable atlas**

**Axes:**
- Y-axis: Voxel Count
- X-axis: FA gradient magnitude

**Legend:**
- Red dashed line: Affine atlas
- Blue dashed line: Deformable atlas
Cumulative Histogram
Atlas-Based Tractography

Image A

Image B

Atlas
Warped Tractography

Image A

Image B
Initial Quantitative Comparison
In Progress

- Atlas construction on 50 datasets neonates, 1 year, 2 year
- Statistical analysis of fibers traced in atlas and warped to individual images
  - Tensor hypothesis testing
  - Tract analysis
Comments or Questions?