Spatio-temporal Analysis of Connectivity Patterns for White Matter Injury Detection in the Preterm Infant Brain

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Geometry for Anatomy Workshop, August 30, 2011
Motivation

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- High incidence of neurodevelopmental disability
- Believed to be a result of white matter injuries
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Hypothesis:
- Flag abnormalities via differences in brain connectivity.
Data Acquisition

The cohort:
- 205 Subjects
- Born 24-32 Weeks GA
- DTI Scan “at birth” and at term
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Scans manually scored for:
- White matter injury
- Intraventricular hemorrhages
Outline - Key Questions

1. What is normal development?
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2. How Should we Measure Connectivity?
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Capturing the Bounds of Normal Development

Idea: Age-specific DTI atlases

- Use only subject scans marked as healthy
- Three week time windows to reduce variability
- Full tensor atlases and scalar atlases \((i.e. \ FA, \ MD, \ \lambda_1, \ \cdots)\)
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**Why?**

- Provide voxel-wise mean and (co-)variance
- Provide a standard space for tractography
- Examine intra-window variance
DTI Atlas Creation Workflow

Atlas Creation by Pairwise Registration [Guimond et al., 2002]
Preliminary Atlas Results

Tensor Means:

- Repeat for scalar maps (i.e. FA, MD, $\lambda_1$, $\cdots$)
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Examining Tractography

There are limitations to tractography

- Error accumulation along tract
- Decisions are made locally & independently
- Tract Jumping
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Idea: Competitive Tractography
  - Encode DTI into graph representation
  - Tractography via graph-based random walks
  - Introduce multi-region competition
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Graph encoding by ODF Integration

- Diffusion ODF → Edge Weight
Graph encoding by ODF Integration

- Diffusion ODF $\rightarrow$ Edge Weight
- Integrate ODF over cone
Graph encoding by ODF Integration

- Diffusion ODF $\rightarrow$ Edge Weight
- Integrate ODF over cone
- We contribute an **analytical** solution
  - Avoid adding approximation error
The Effect of the Graph Encoding

Testing graph encoding with minimal path tractography

[Zalesky, TMI, 2008]

\[1\] B.G. Booth, G. Hamarneh; IEEE ISBI (2011).
Examples of Tractography Error

Tract Jumping Clearly Present
Examples of Tractography Error

Tract Jumping Clearly Present
Tractography as a Random Walk

**Idea:** Competitive Tractography

- Allow a tract to affect the position of other tracts
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**Given:**

- Graph encoding of diffusion MRI
- Random walker at node $u$
- Seed regions $\mathcal{R}_1, \ldots, \mathcal{R}_k$
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$L_u, B$: Blocks of the Graph Laplacian
- Contain the edge weights (DTI Information)
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  - Contain the edge weights (DTI Information)
- Unknown Connection Probabilities $X$
- Seeds $M$:
  - Note: Background (FA < $\tau$) included as a seed region
Preliminary Results

Tract Jumping Has Decreased
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Standard Space for Voxel-Based Analysis

29 Weeks GA → 44 Weeks GA


Standard Space for Voxel-Based Analysis

29 Weeks GA

44 Weeks GA

Longitudinal registration
Standard Space for Voxel-Based Analysis

- Longitudinal registration → Robust metric
Standard Space for Voxel-Based Analysis

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- **Idea:** Diffusion Tensor Mutual Information
Measuring DT Mutual Information

Existing Approaches:

- Dimensionality Reduction $\rightarrow$ Histogram Binning

  e.g. [van Hecke et al., TMI, 2007]
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Our Approach:
- Estimate MI from nearest-neighbour distances
- Tensor distance metrics for computing nearest-neighbours
Measuring DT Mutual Information

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Our Approach:
- Estimate MI from nearest-neighbour distances
- Tensor distance metrics for computing nearest-neighbours
- Nearest-Neighbour MI Estimator [Neemuchwala and Hero, 2005]

\[
MI(X, Y, \alpha) = \frac{1}{\alpha - 1} \log \left[ \frac{1}{N^\alpha} \sum_{i=1}^{N} \left( \frac{\eta(z_i)}{\sqrt{\eta(x_i)\eta(y_i)}} \right)^{2d(1-\alpha)} \right]
\]
Metric Evaluation$^2$

Metric Evaluation²

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   - Longitudinal Registration
   - New Metric: Full Tensor Mutual Information
Summary of Contributions

1. DTI Atlas of normal development

2. Tractography via Graph-based Random Walks

3. Full Tensor Mutual Information
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1. DTI Atlas of normal development

   DTI Scan → Register to Atlas → Voxelwise Statistical Analysis → Flag Abnormalities

2. Tractography via Graph-based Random Walks

3. Full Tensor Mutual Information

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Summary of Contributions

1. DTI Atlas of normal development
   - DTI Scan
   - Register to Atlas
   - Voxelwise Statistical Analysis
   - Flag Abnormalities

2. Tractography via Graph-based Random Walks
   - DTI Scan
   - Register to Atlas
   - Tractography
   - Voxelwise Statistical Analysis
   - Flag Abnormalities

3. Full Tensor Mutual Information
Summary of Contributions

1. **DTI Atlas of normal development**
   - DTI Scan
   - Register to Atlas
   - Voxelwise Statistical Analysis
   - Flag Abnormalities

2. **Tractography via Graph-based Random Walks**
   - DTI Scan
   - Register to Atlas
   - Tractography
   - Voxelwise Statistical Analysis
   - Flag Abnormalities

3. **Full Tensor Mutual Information**
   - DTI Scan 1
   - Register using MI
   - Tractography
   - Image Differencing
   - Visual Analysis
   - Flag Abnormalities

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Thank You

Questions?