Diffusion Tractography

- Goal of tractography
- Estimating Fibre Orientations - BEDPOSTX
- Probabilistic Tractography - PROBTRACKX
- ProbtrackX outputs
- Tractography limitations
ProbtrackX outputs

Known white matter tracts

Connectivity matrices

ROI by ROI

voxel by ROI

voxel by voxel
Adding Prior Knowledge to Tractography

- Because of the uncertainty propagation, the spatial distribution of paths is often very wide.
Adding Prior Knowledge to Tractography

Once a seed is specified, prior anatomical knowledge can be imposed to assist the dissection of a specific tract.

- **Waypoint ROI**
  If a curve does not go through, it is discarded.

- **Exclusion ROI**
  If a curve goes through, it is discarded.

- **Termination ROI**
  If a curve goes through, it is terminated.
Adding Prior Knowledge to Tractography

Cortico-spinal tract

Seed: M1, hand area

No ROIs
Adding Prior Knowledge to Tractography

Cortico-spinal tract

Seed: M1, hand area

Exclusion: Mid-Sagittal plane
Adding Prior Knowledge to Tractography

Cortico-spinal tract

Seed: M1, hand area

Waypoint: Internal Capsule
Adding Prior Knowledge to Tractography

Corpus Callosum

Seed: dorsal PMC

No ROIs
Adding Prior Knowledge to Tractography

Corpus Callosum

Seed: dorsal PMC

Waypoint: Corpus Callosum
Surfaces as constraints

No surface constraint

Surface as termination mask
How to use masks in standard space?

- Register to standard space
  - \( b0 \) or \( FA \) -> \( T1w \) -> standard \( T1w \)
  - \( FA \) -> standard \( FA \)
- Don’t transform masks -> diffusion space
- Don’t transform diffusion -> standard space

Tell probtrackX about transform:
Xtract: generating tracts for you

https://fsl.fmrib.ox.ac.uk/fsl/fslwiki/XTRACT
Connectivity - Why do we care?

- Tractography provides non-invasive localisation and semi-quantitative biomarkers
ProbtrackX outputs

Known white matter tracts

Connectivity matrices
ROI by ROI
voxel by ROI
voxel by voxel
Connectivity between ROIs

Resulting matrix:
**Connectivity between ROIs**

- Seed from **blue**
- Other ROIs are waypoints
- Fill first row of matrix

Resulting matrix:

<table>
<thead>
<tr>
<th>Target ROIs</th>
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<tbody>
<tr>
<td><img src="image" alt="Target ROIs" /></td>
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<table>
<thead>
<tr>
<th>Seed ROIs</th>
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<td><img src="image" alt="Seed ROIs" /></td>
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</table>
Connectivity between ROIs

- Seed from yellow
- Other ROIs are waypoints
- Fill first row of matrix

Resulting matrix:

Seed ROIs

Target ROIs

Connectivity between ROIs
Connectivity between ROIs

- Seed from **green**
- Other ROIs are waypoints
- Fill first row of matrix

**Resulting matrix:**

<table>
<thead>
<tr>
<th>Seed ROIs</th>
<th>Target ROIs</th>
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*Note: The matrix represents connectivity between ROIs, with seed ROIs on the left and target ROIs on the right. The filled row indicates the connection pattern.*
Connectivity between ROIs

- Seed from copper
- Other ROIs are waypoints
- Fill first row of matrix

Resulting matrix:

<table>
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[Image of brain and connectivity diagram]
Connectivity between ROIs

\[ P(\text{Seed} \leftrightarrow \text{Target}) = \frac{P(\text{Seed} \leftarrow \text{Target}) + P(\text{Seed} \rightarrow \text{Target})}{2} \]

Resulting matrix:
Connectivity between ROIs
Connectivity between voxels and ROIs

Resulting matrix:

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Connectivity between voxels and ROIs

Resulting matrix:

Seed voxels

Target ROIs

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Connectivity between voxels and ROIs

Resulting matrix:

Seed voxels

Target ROIs

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Connectivity between voxels and ROIs

Resulting matrix:

Seed voxels

Target ROIs

etc…
Segmenting the thalamus

VL $\rightarrow$ M1

MD $\rightarrow$ PFC

no contrast on conventional MRI

Behrens et al, 2003
(probabilistic tractography)

Rouiller et al, 1998
(BDA anterograde tracing)
Segmenting the thalamus

Prior cortical parcellation

Resulting matrix:

Target ROIs

<table>
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Seed voxels in Thalamus

Behrens et al. Nat Neuro 2003
Johansen-Berg et al. Cereb Ctx 2005
Segmenting the thalamus

Prior cortical parcelalition

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Segmenting the thalamus

Prior cortical parcellation

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Seed voxels in Thalamus

Behrens et al. Nat Neuro 2003
Johansen-Berg et al. Cereb Ctx 2005
Segmenting the thalamus

Prior cortical parcellation

Hard thalamic parcellation

Behrens et al. Nat Neuro 2003
Johansen-Berg et al. Cereb Ctx 2005
Correspondence between functional activations and connectivity-defined volumes

Executive Tasks

Motor Tasks
DBS for treatment of tremor in Parkinson's

Pouratian et al. JNS 2011
Connectivity between voxels and ROIs
Connectivity between voxels

Resulting matrix:

<table>
<thead>
<tr>
<th>ROI 1 voxels</th>
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<tbody>
<tr>
<td></td>
<td>ROI 2 voxels</td>
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<td>ROI 2 voxels</td>
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Connectivity between voxels

Resulting matrix:

ROI 1 voxels

ROI 2 voxels

Seed

Matrix 1

Seed

Mask 2

Matrix 2

Mask 1

Matrix 3
Connectivity between voxels
Dense connectome

Cortical seed (matrix1)

WM seed (matrix3)
Medial area 6 contains two distinct regions with very different connectivity: SMA and Pre-SMA.

Can we define a border based on a change in connectivity profile?
Changes in connectivity profiles

Medial Frontal Cortex

Seed voxels

Rest of brain

Seed voxels

Rest of brain
Changes in connectivity profiles
Medial Frontal Cortex

Seed voxels

Rest of brain

Cross-correlation matrix

clustering algorithm
Changes in connectivity profiles
Medial Frontal Cortex

- Clusters in the re-ordered matrix represent seed voxels with similar connectivity
- Breaks between clusters represent where connectivity patterns change

Johansen-Berg et al. 2004