Diffusion MRI and Tractography

Tracks vs Tracts

Eleftherios Garyfallidis[1] Ian Nimmo-Smith[1]

[1]MRC Cognition and Brain Sciences Unit

WLTS, 2nd December, 2009

Outline

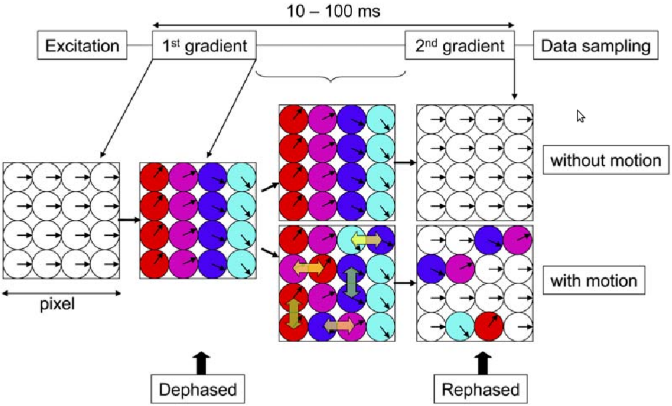
1. Motivation
   - dMRI
2. Contribution
   - Main Results
3. Software
4. Summary

What is dMRI?
Our Definition

- The dMRI signal measures the history of the random (Brownian) displacements of spin-labelled hydrogen protons (spins) resolved in the direction of a magnetic field gradient.
- Though the actual probability displacement function of the protons is unaffected by the presence or variation in the magnetic field, the cumulative phase change in the spins reflects the changes in the position-dependent spin frequency induced by the field gradient.

What is dMRI?

Example from Mori et al. Neuron 2006



What is dMRI?
b and q

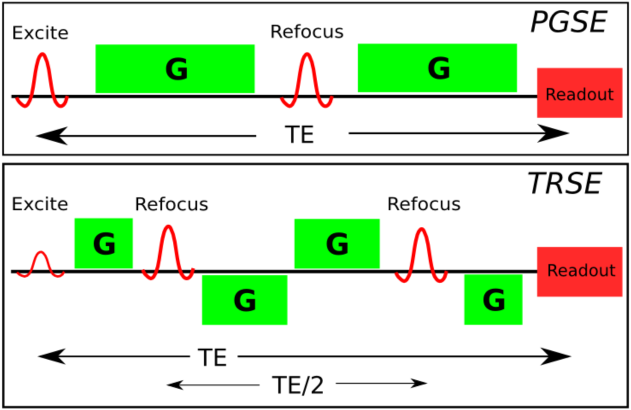
- The b-value b or *diffusion weighting* is a function of the strength, duration, temporal spacing and timing parameters of the specific paradigm.

What is dMRI?
b and q

- Q-space is the space of one or more 3D spin displacement wave vectors $\mathbf{q}$. This vector is related to the applied magnetic gradient $\mathbf{g}$ by the formula $\mathbf{q} = (2\pi)^{-1}\gamma\delta\mathbf{g}$.
- Every single vector $\mathbf{q}$ has the same orientation of the direction of diffusion gradient $\mathbf{g}$ and length proportional to the strength of the gradient g. Every single point in q-space corresponds to a 3D volume of the brain for a specific gradient direction and strength.
- b is proportional to the magnitude of $\mathbf{q}$.

Acquisition Methods.

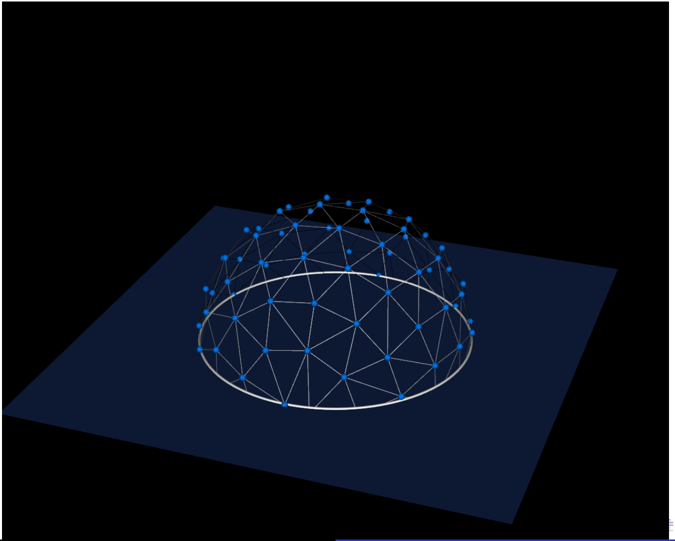
Pulsed Gradient Spin Echo and Twice Refocused Spin Echo



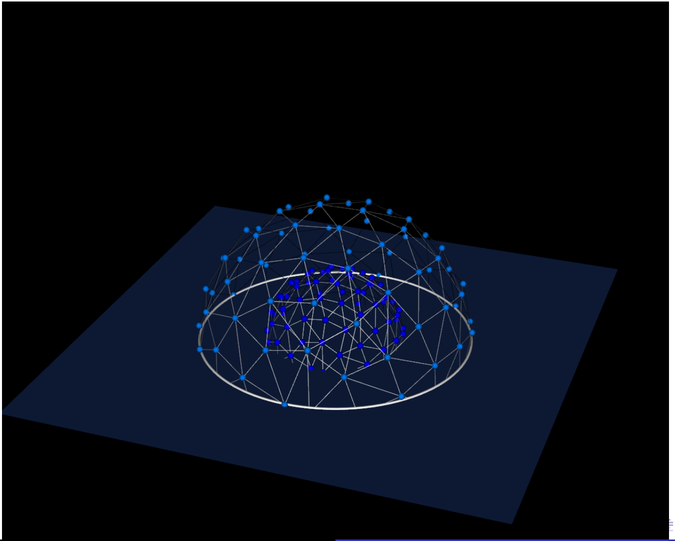
Diffusion Modelling
DTI, DSI, Q-Ball, PAS, ++

1. DTI - Diffusion Tensor Imaging
2. HARDI - High Angular Resolution Diffusion Imaging
3. DSI - Diffusion Spectrum Imaging
4. QBI - Q-Ball Imaging
5. PAS - Persistent Angular Structure

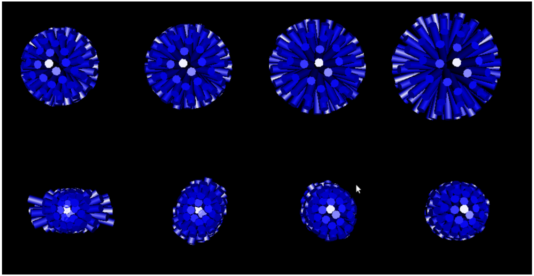
HARDI q-space



Hybrid HARDI



Diffusivities

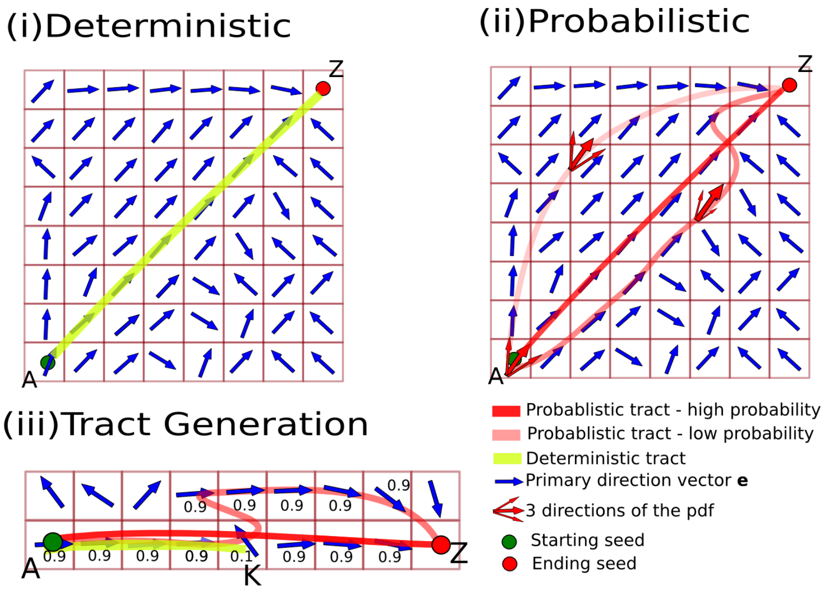


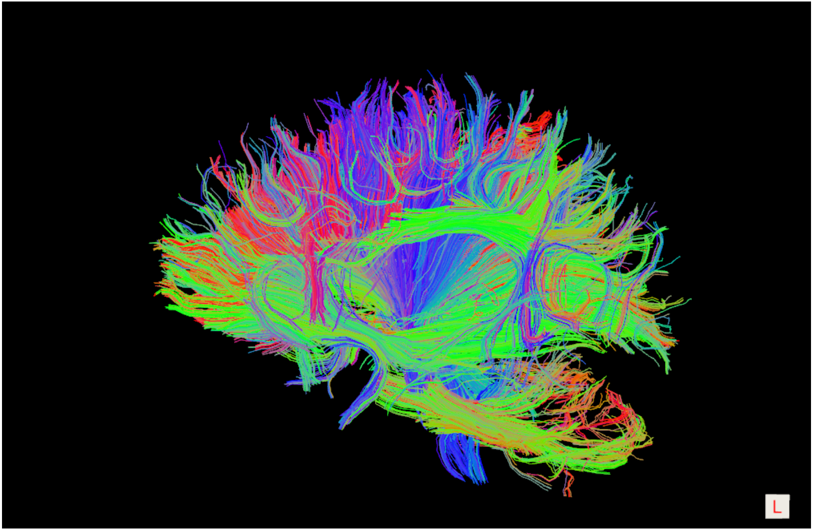
Upper row: Isotropic, Lower row: Anisotropic

Tractography

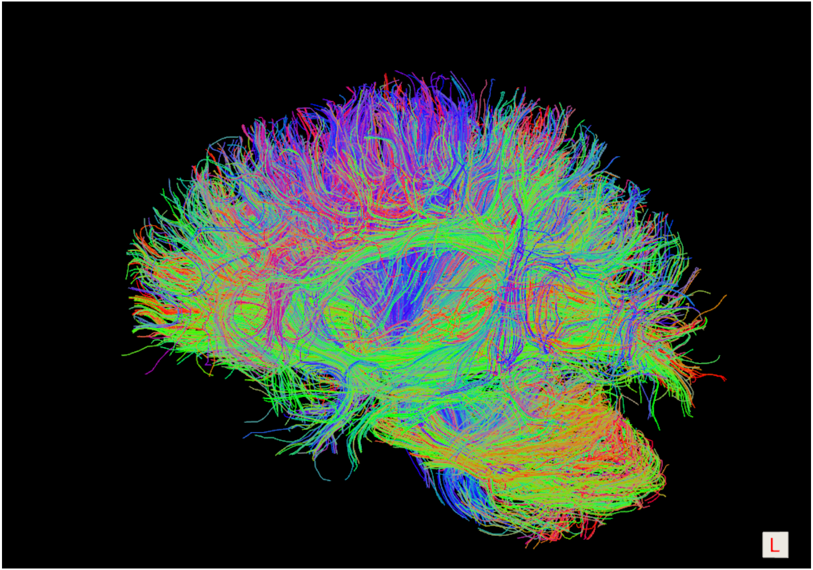
	Deterministic	Probabilistic
Voxel Noise Resistance	More	Less
Bogus Tracts	Yes	Yes
Execution Time	Fast	Slow
Memory Size	Less	More
Biased on Tract Length	No	Yes (towards shorter tracks)

Table: Deterministic vs Probabilistic Tractography


(i)Deterministic
Z
A
(ii)Probabilistic
Z
A
(iii)Tract Generation
0.9
0.9 0.9 0.9 0.9
A 0.9 0.9 0.9 0.9 0.1 0.9 0.9 0.9 Z
K
Probablistic tract - high probability
Probablistic tract - low probability
Deterministic tract
Primary direction vector **e**
3 directions of the pdf
Starting seed
Ending seed

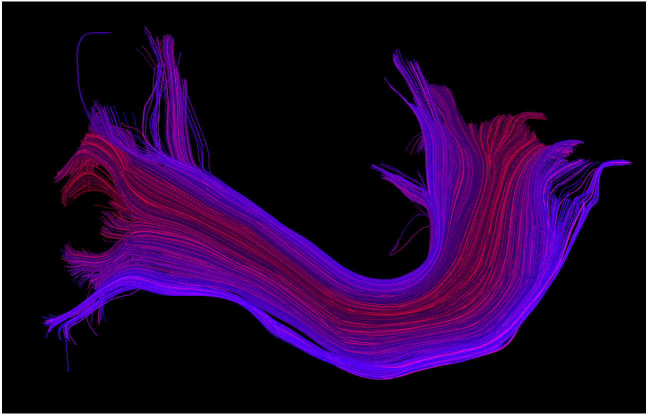


DTK & TrackVis with FACT option



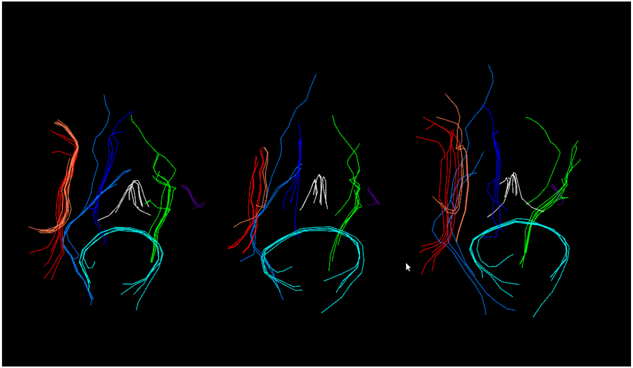
DTK & Trackvis with RK2 option

Distances - Avg. Min.



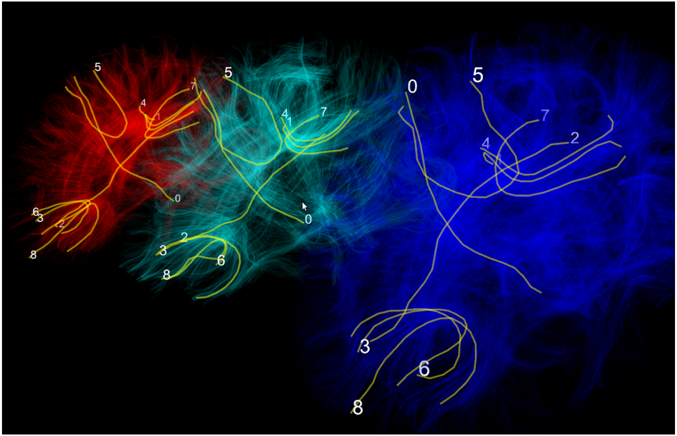
Arcuate Fasciculus
Red means very similar with the reference track.
Blue means not very similar with the reference track.

Detecting Tracks



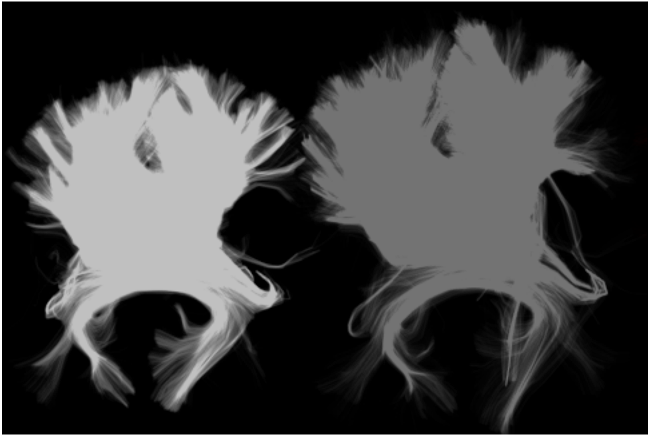
Detecting corresponding tracks in 3 different brains.

Detecting Tracks (cont.)



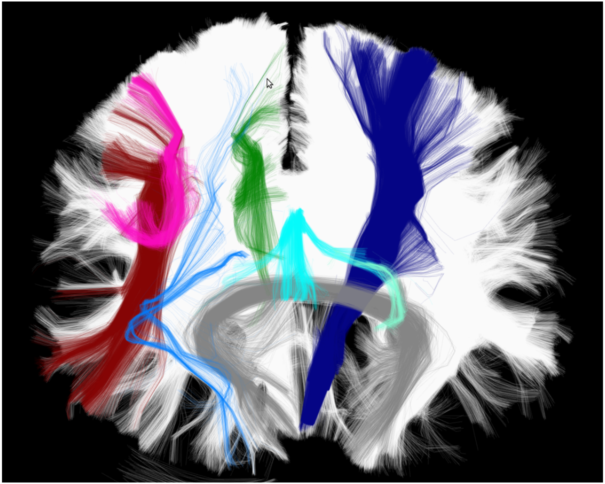
With a different dataset (obtained in the CBU) and visualising the rest of the tracks as well.

Detecting & Removing Corpus Callosum

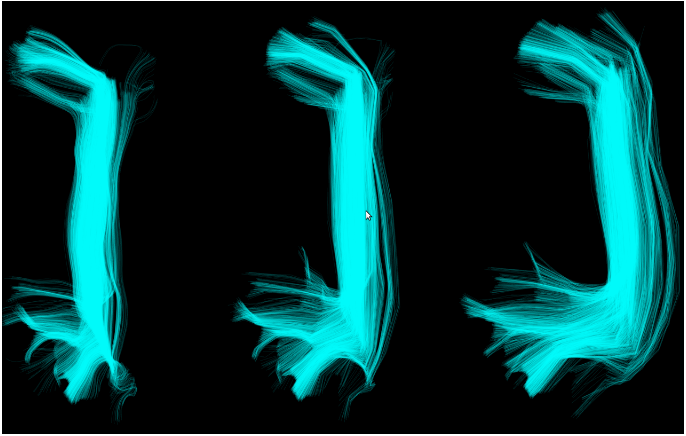


Corpus Callosum detected in two different brains

Supervised Learning

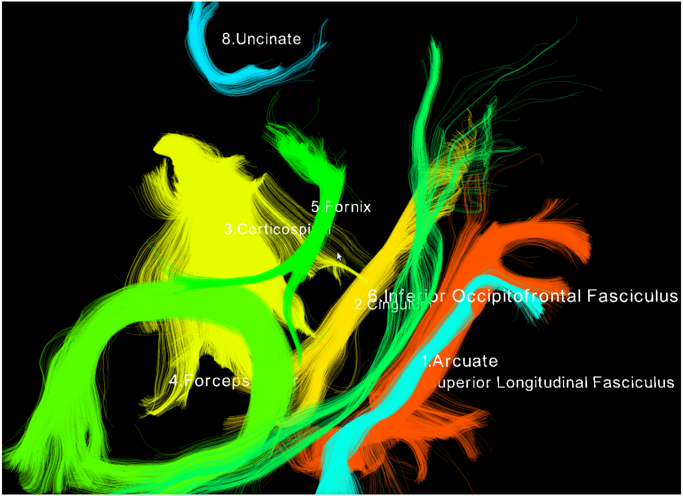


Smart Downsampling



Left: Raw, Center: MDL(Approximate Trajectory Partitioning), Right: Simple Downsampling along the track.

Labelling Bundles



Detecting Bundles

Algorithmic Description

1. Normalize ICBM atlas with all brains.
2. Generate and pick some extra fibers.
3. For a value in the atlas generate the tracks.
4. Compare these tracks with the reference tracks.
5. Expand i.e. glue similar tracks.
6. Compare with the training set.
7. If far away go to 5 else Done!

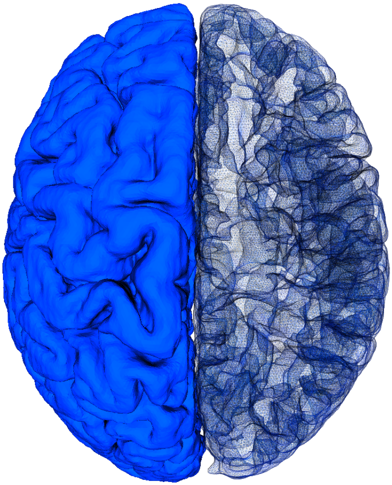
What we learned?

1. Arcuate L
2. Cingulum L
3. 'Corticospinal R + Cerebral peduncle R
4. Forceps Major
5. Fornix
6. (Sagittal stratum) L + Inferior Occipitofrontal Fasciculus L
7. Superior Longitudinal Fasciculus L
8. Uncinate R
9. Cingulum R

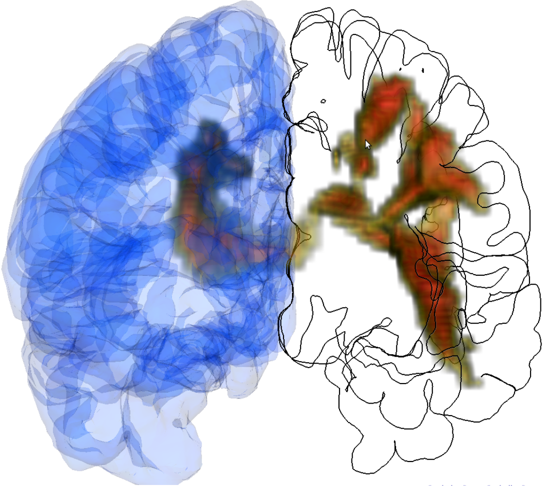
What we learned?

1. Corticospinal L + Cerebral peduncle
2. Forceps Minor
3. Corpus Callosum Body
4. (Sagittal stratum) R + Inferior Occipitofrontal Fasciculus
5. Superior Longitudinal Fasciculus R
6. Uncinate L
7. Middle cerebellar peduncle
8. Medial lemniscus R
9. Medial lemniscus L
10. Tapatum R
11. Tapatum L

Cortical Rendering



+ Subcortical Rendering



Dipy + Fos

- All our software is written using open and free tools.
- All programming in Python for fast code or Cython for fast execution.
- Dipy is for core functions e.g. bundle detection or tensor calculation.
- Dipy has the potential to be part of nipy specific for diffusion problems.
- Fos is our engine for 3d visualization and animation.
- Fos at the moment is using VTK but we are replacing it with just Opengl for cutting edge performance.
- We have also implemented many other tools e.g. reading/writing b-values from dicom files +++

Collaborators

- Supervisor: Dr. Ian Nimmo-Smith, MRC-CBU.
- Dr. Matthew Brett, University of Berkeley.
- Dr. Guy Williams, WBIC.
- Dr. Marta Correia, MRC-CBU.
- Dr. Christian Schwarzbauer, University of Aberdeen.
- Dr. Vassilis Tsiaras, University of Crete.
- Dr. George Vogiatzis, Toshiba Research.
- Dr. Adam Hampshire, MRC-CBU.
- Dr. Sami Boudelaa, MRC-CBU.
- Dr. Mirjana Bozic, MRC-CBU.
- Mr. John Griffiths, University of Cambridge.
- And a BIG thank you to Dr. Rik Henson.

Summary

- We showed you results from the voxel level to the fiber level.
- With our main contribution on automatic detection of tracks and bundles.
- Outlook
    - Coming soon ... Statistics on detected tracks.
    - Create our own Track Atlas.
    - Even more stuff.