Diffusion Modeling in BrainSuite13

Justin P. Haldar

Outline

- Introduction

- Diffusion in BrainSuite13
    - Diffusion Modeling
    - Tracking
    - Analysis

- Other Resources
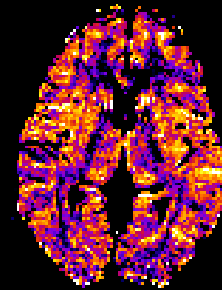
- Conclusion

Motivation

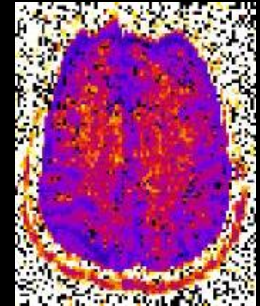- Diffusion MRI provides unique insight into tissue microstructure
  - Quantitative measures

Apparent Diffusion Coefficient
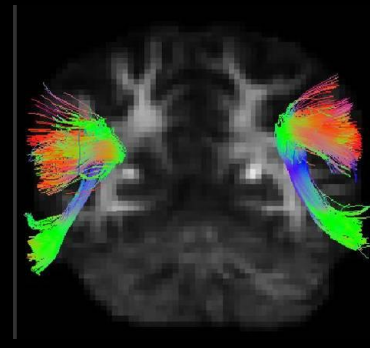
Fractional Anisotropy
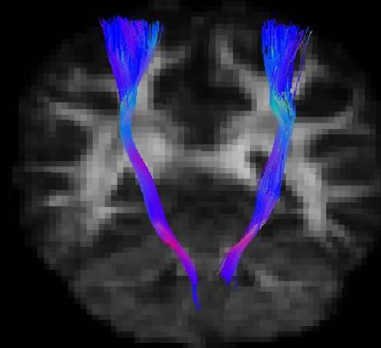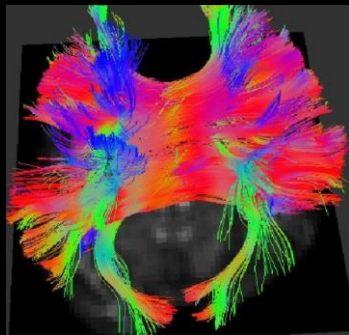
Anomalous Exponent

Kurtosis

  - Connectivity

Diffusion Imaging (in general)

1. Acquisition

- 6+ Directions
- HARDI
- Multi-Shell
- DSI
- …

2. Preprocessing

- Registration
- Distortion Correction
- Outlier Removal

3. Modeling

- DTI
- Multi-DTI
- ODF
  - FRT
  - FRACT
  - Nonlinear Methods
- DKI, CHARMED, …

4. Tracking

- Deterministic
- Probabilistic

5. Analysis

- Visualization
- Connectivity Analysis
- ROI Analysis

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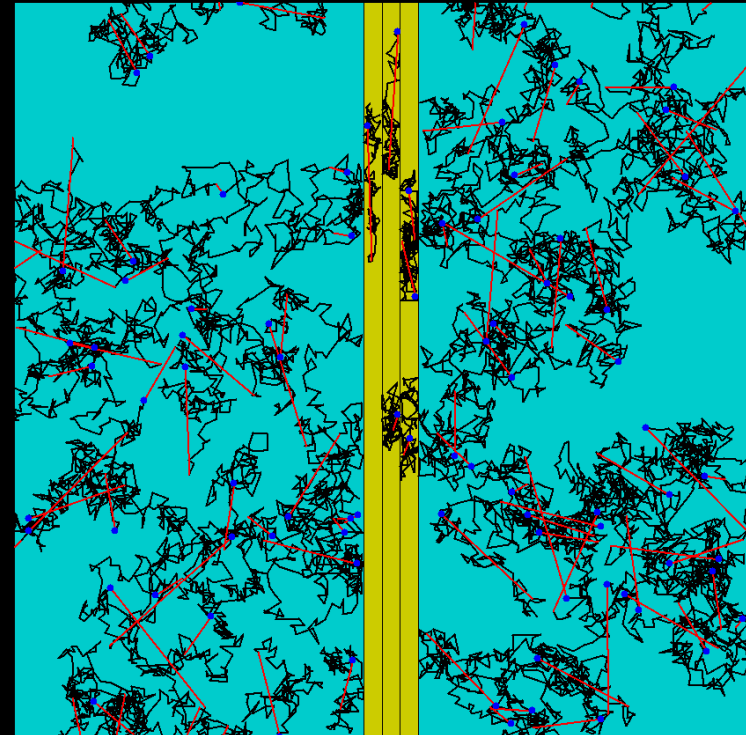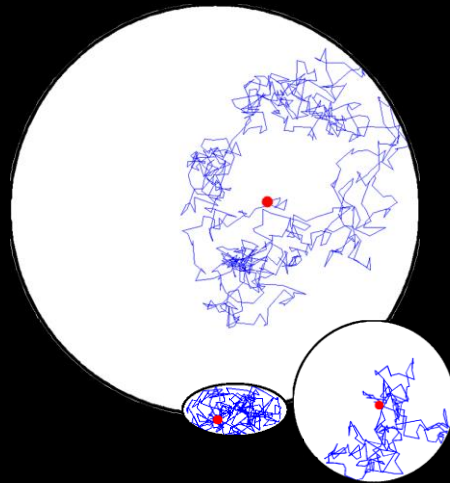- DKI, CHARMED, …

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Data Sampling

- Diffusion data is sampled from a 6D space
  - 3D Spatial
    - Where in the brain am I located? (mm scale)
  - 3D Diffusion
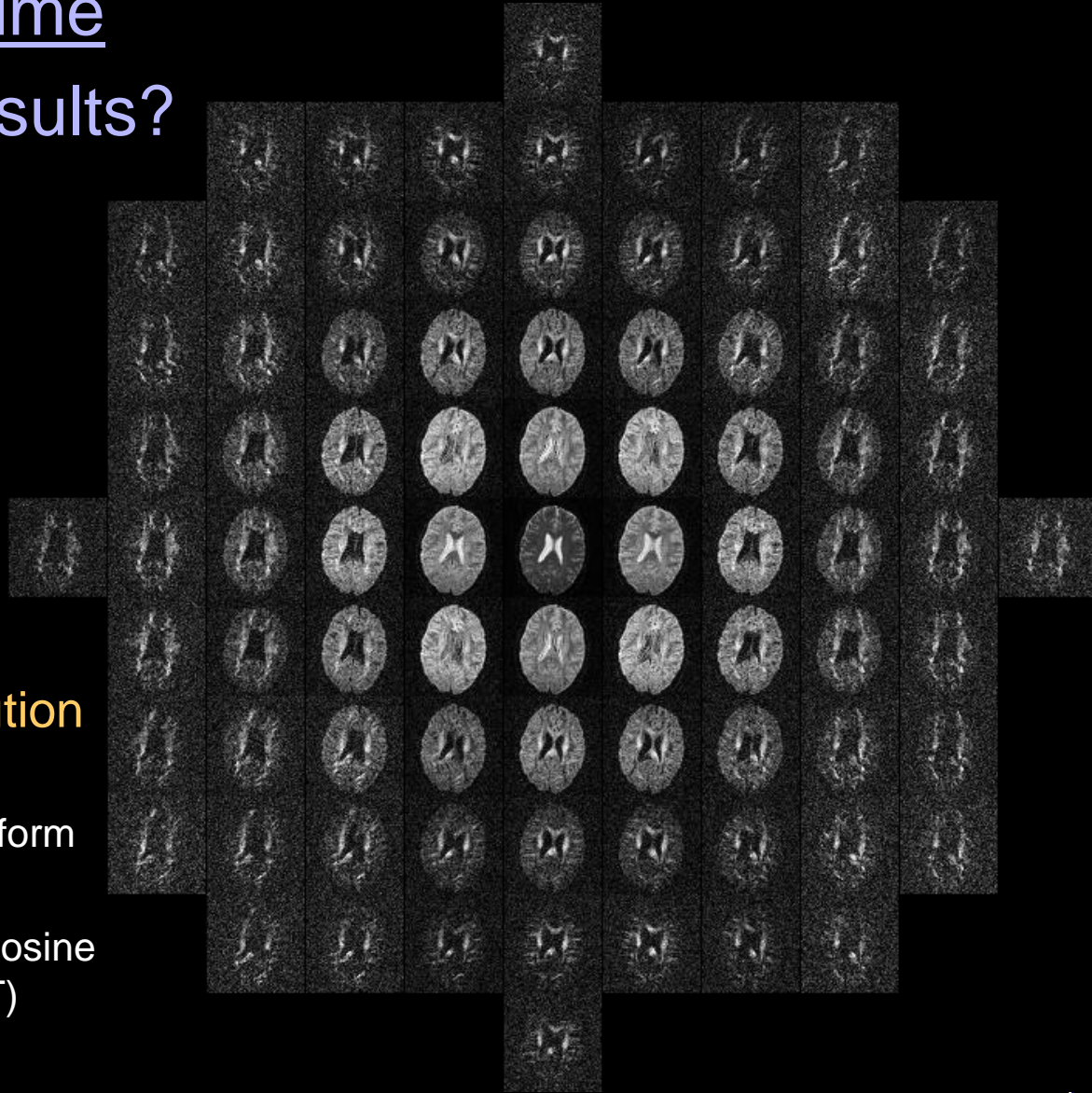   - Where do water molecules typically move? (μm scale)

Diffusion Data is Complicated

- Sampling in 6D = <u>time</u>
- How to interpret results?

- Solution:
  - Models!
  - In BrainSuite13:
    - Diffusion Tensor Imaging (DTI)
    - Orientation Distribution Functions (ODFs)
      - Funk Radon Transform (FRT)
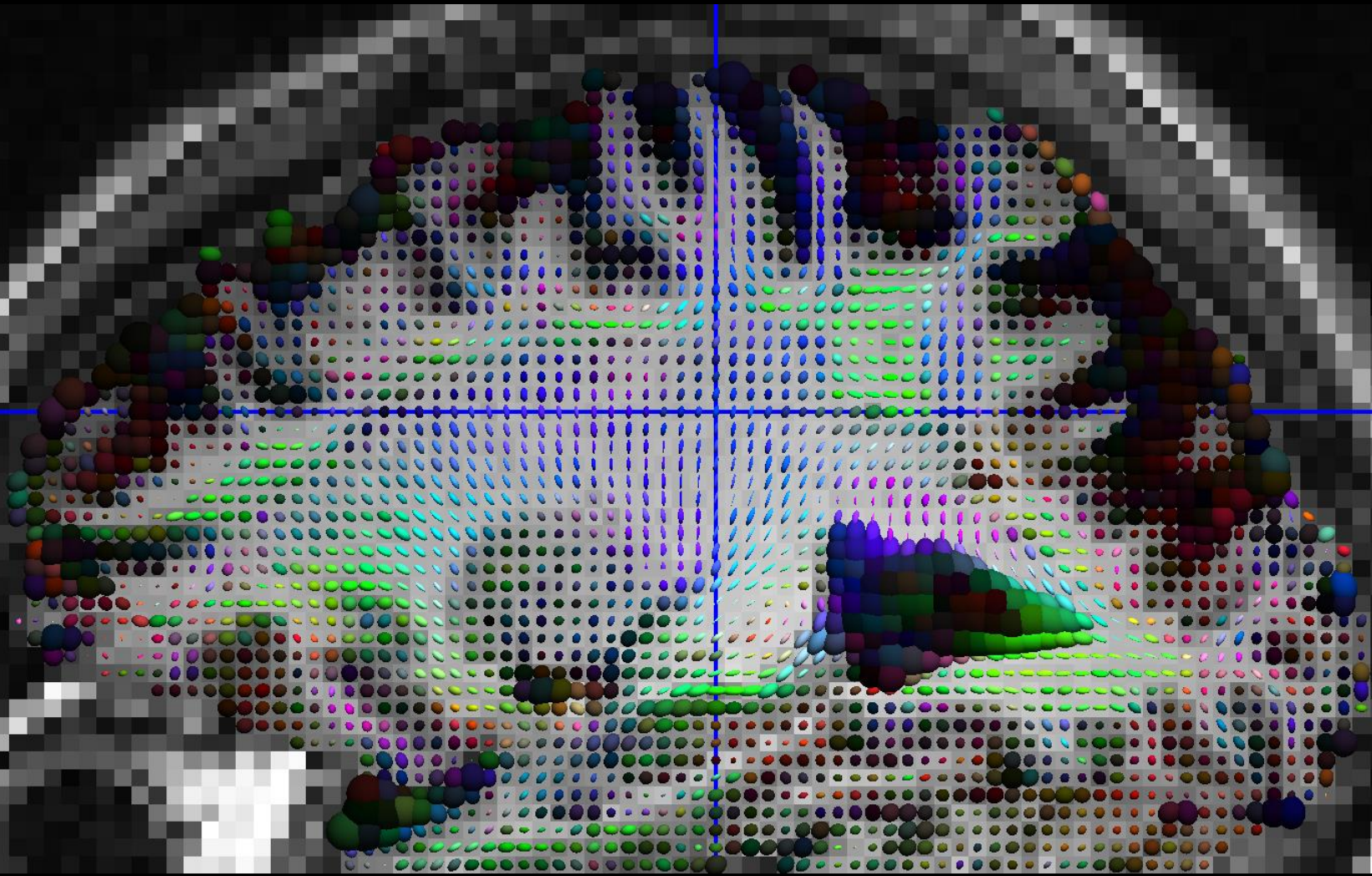   - Funk Radon and Cosine Transform (FRACT)

DTI

- Diffusion Tensor Imaging:
  - A simple model with 7 degrees of freedom
    - 3 orthogonal directions
    - 3 diffusivities along each direction
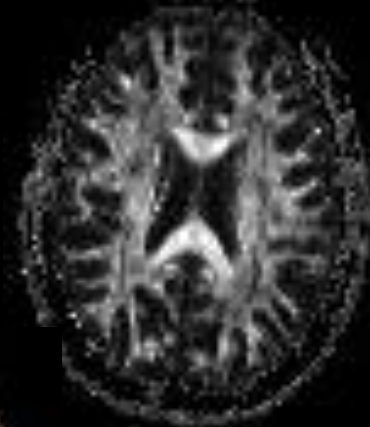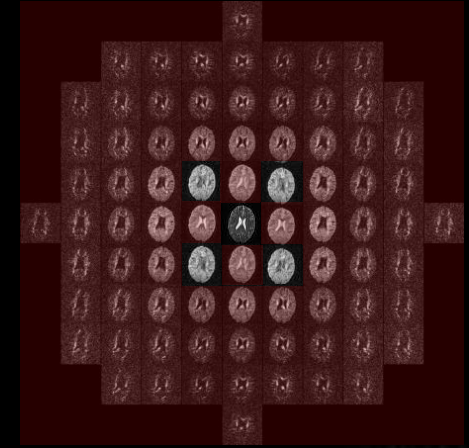   - 1 baseline image intensity
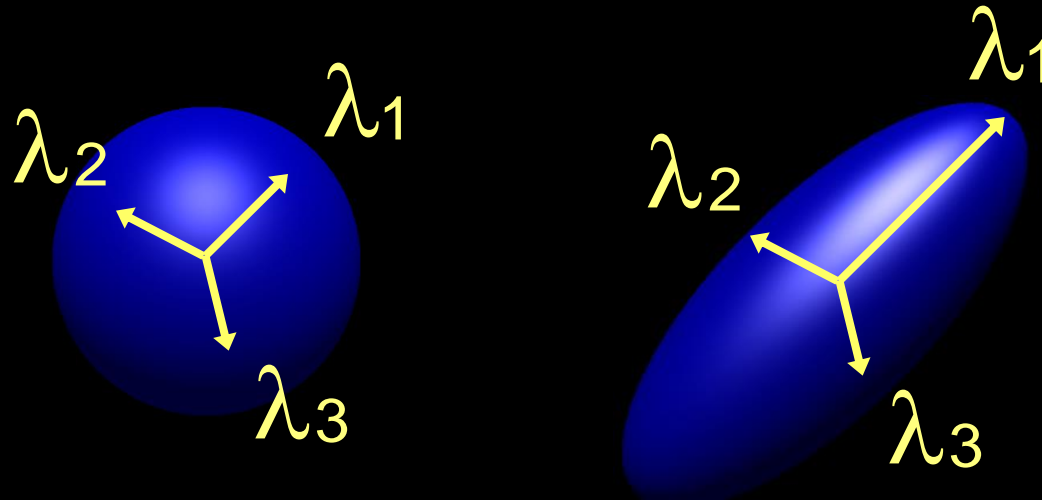
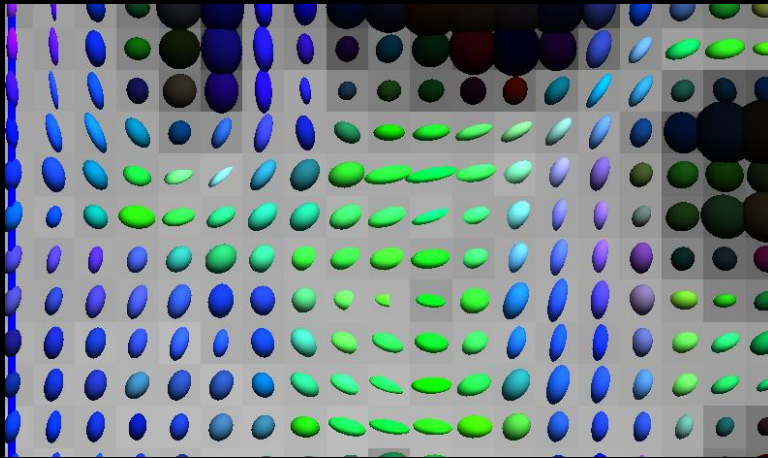# DTI in BrainSuite13

Benefits of DTI

- Only need to sample 7 images
  - In practice ~30 is preferred
  - Sampling is very flexible
- Quantitative information:
  - Mean Diffusivity
    - $(\lambda_1 + \lambda_2 + \lambda_3)/3$
  - Fractional Anisotropy
    - $\sqrt{\dfrac{3}{2}}\dfrac{\sqrt{(\lambda_1 - \bar{\lambda})^2 + (\lambda_2 - \bar{\lambda})^2 + (\lambda_3 - \bar{\lambda})^2}}{\sqrt{\lambda_1^2 + \lambda_2^2 + \lambda_3^2}}$
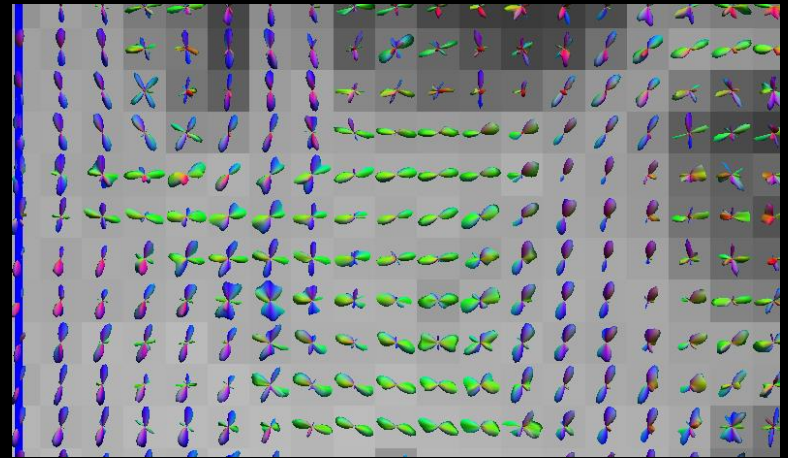
- Tissue Orientation
  - Enables tracking

Limitations of DTI

- Model is almost never valid
    - (But it still provides good biomarkers for microstructure)

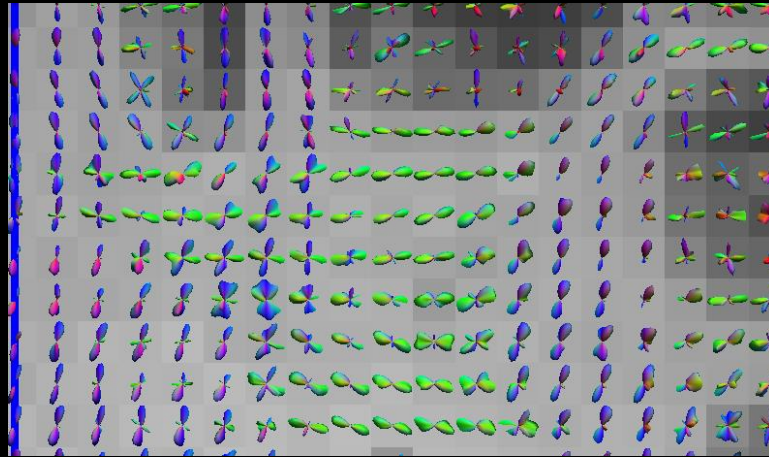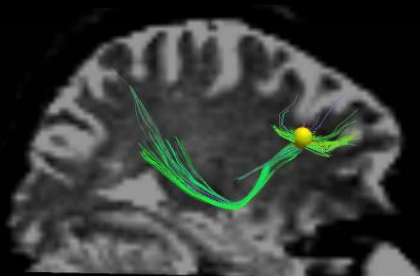- Cannot model multiple orientations in a single voxel

DTI

ODFs

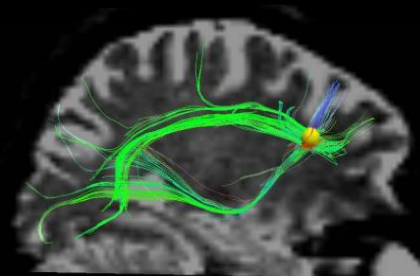# Orientation Distribution Functions

- Give the ability to model multiple orientations in a single voxel

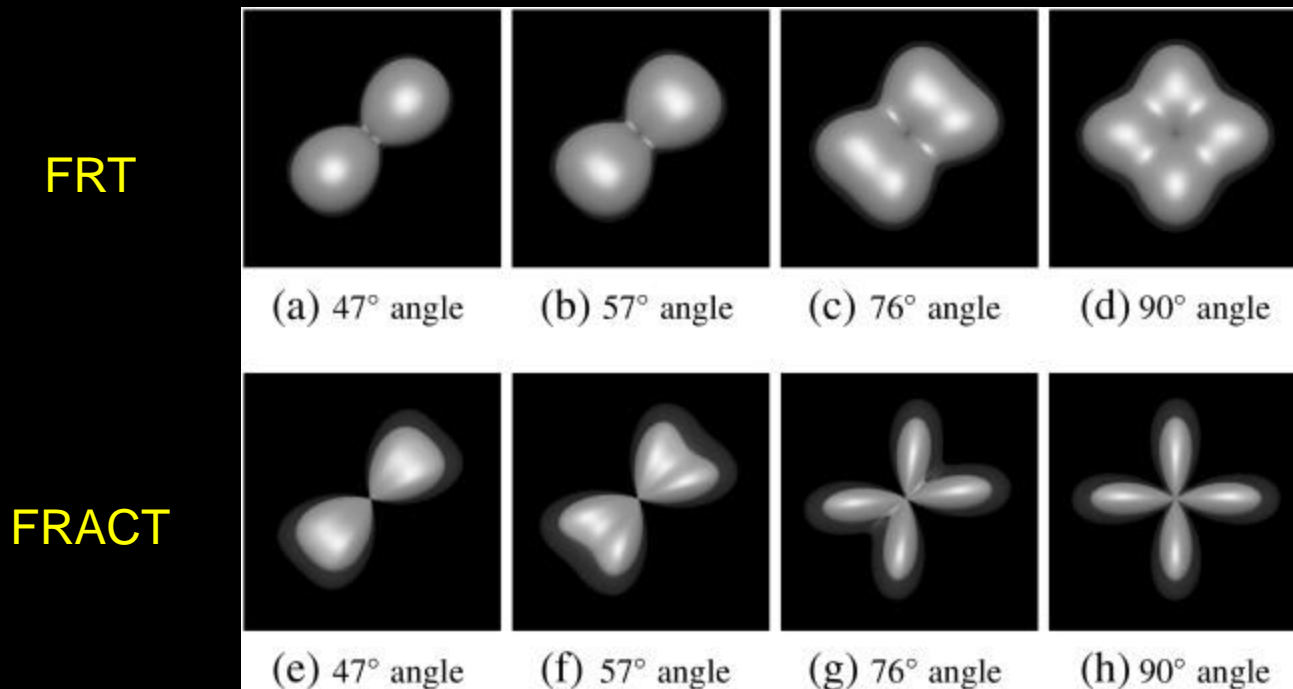- Enables better tracking in complicated regions with multiple fiber crossings

DTI

ODF

FRT vs. FRACT

- BrainSuite13 Provides two ODF methods:
  - Funk Radon Transform [1]
    - Most prevalent ODF method in other software
  - Funk Radon and Cosine Transform [2]
    - Higher angular resolution

FRT

FRACT

(a) 47° angle   (b) 57° angle   (c) 76° angle   (d) 90° angle

(e) 47° angle   (f) 57° angle   (g) 76° angle   (h) 90° angle

[1] Tuch, *Magn Reson Med* 52:1358-1372, 2004.
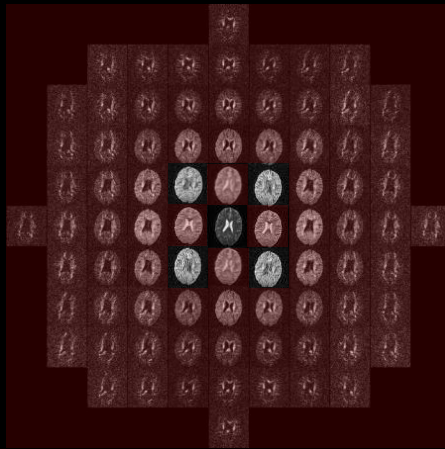[2] Haldar and Leahy, *NeuroImage* 71:233-247, 2013.

DTI vs FRT vs FRACT
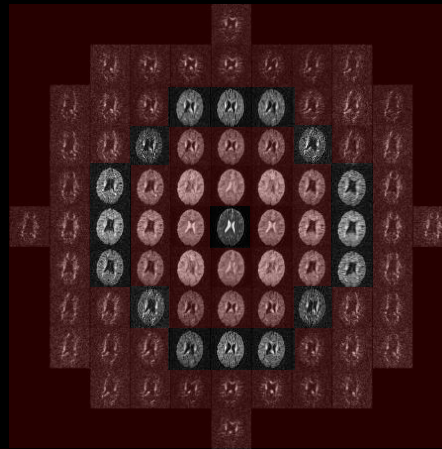

DTI

FRT
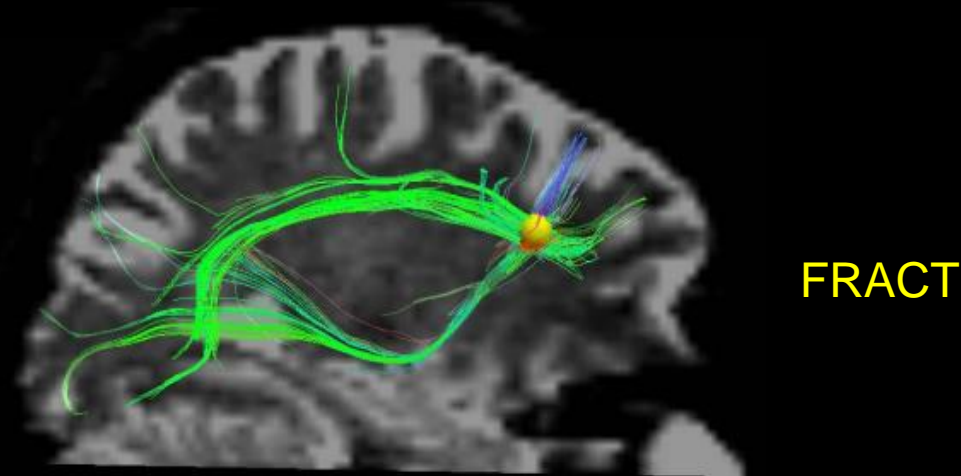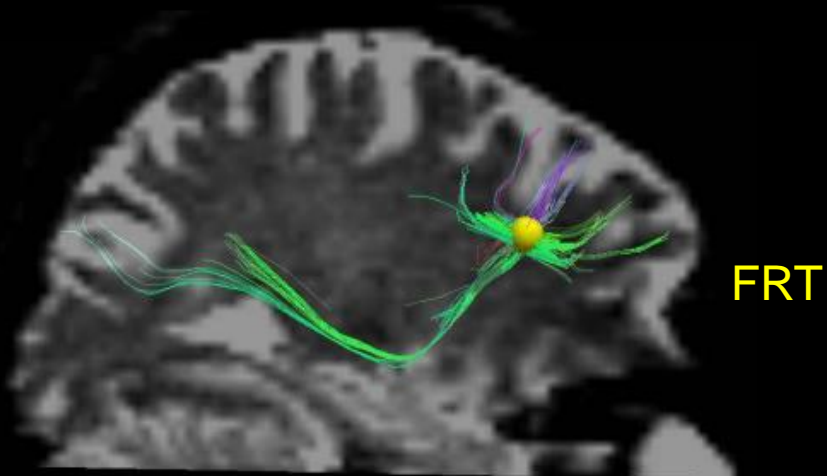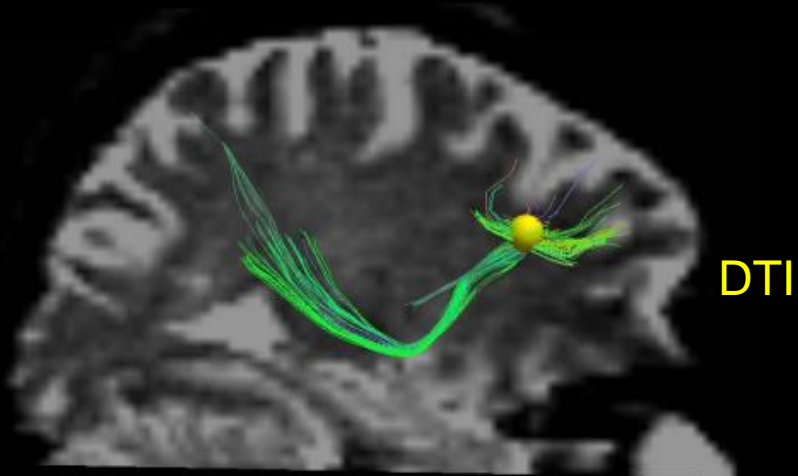
FRACT

Limitations of FRT+FRACT

- Requires more data than DTI
  - 64+ directions recommended (often more is needed)

- Works only for data on the sphere
  - better with high b-value data

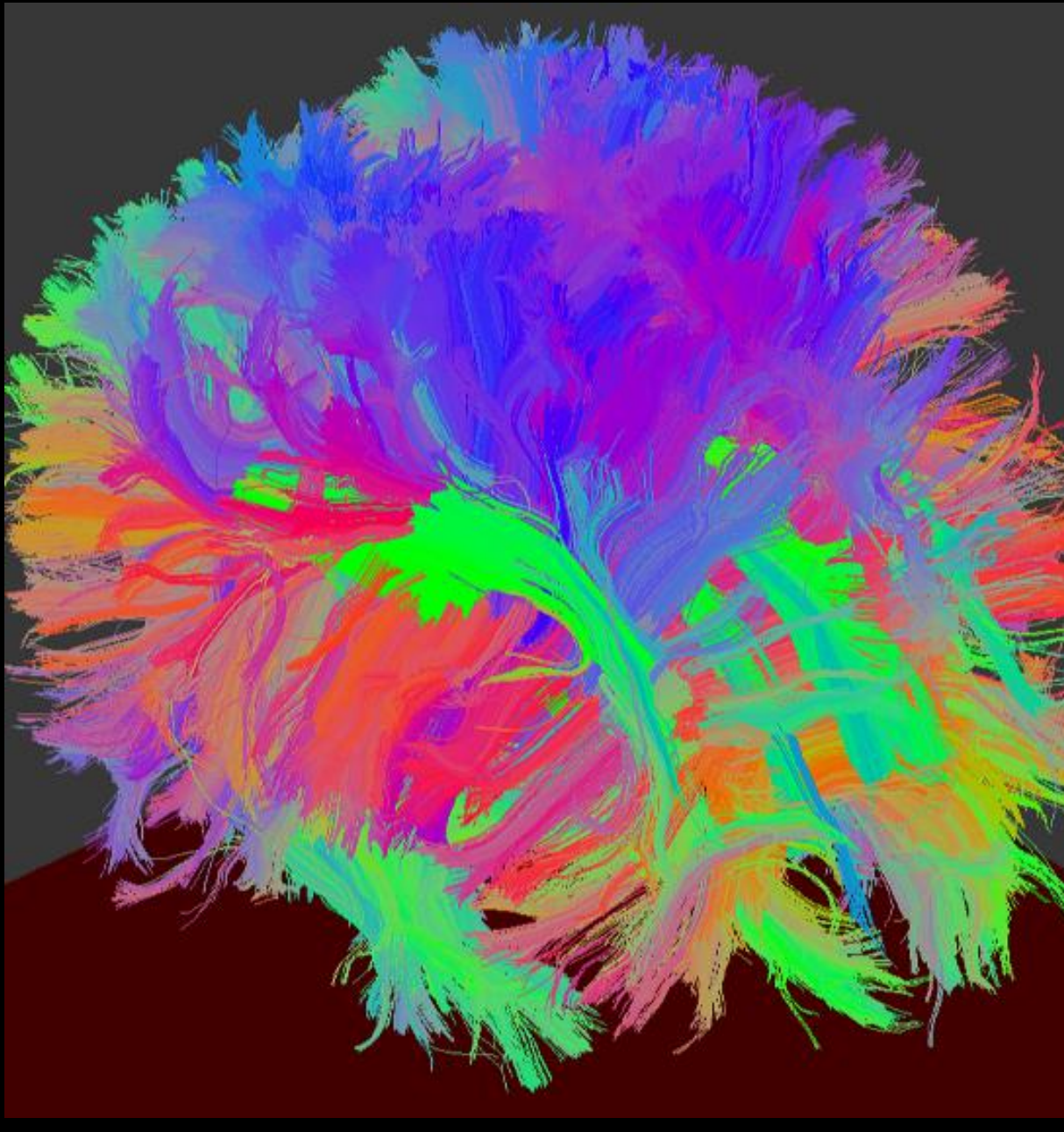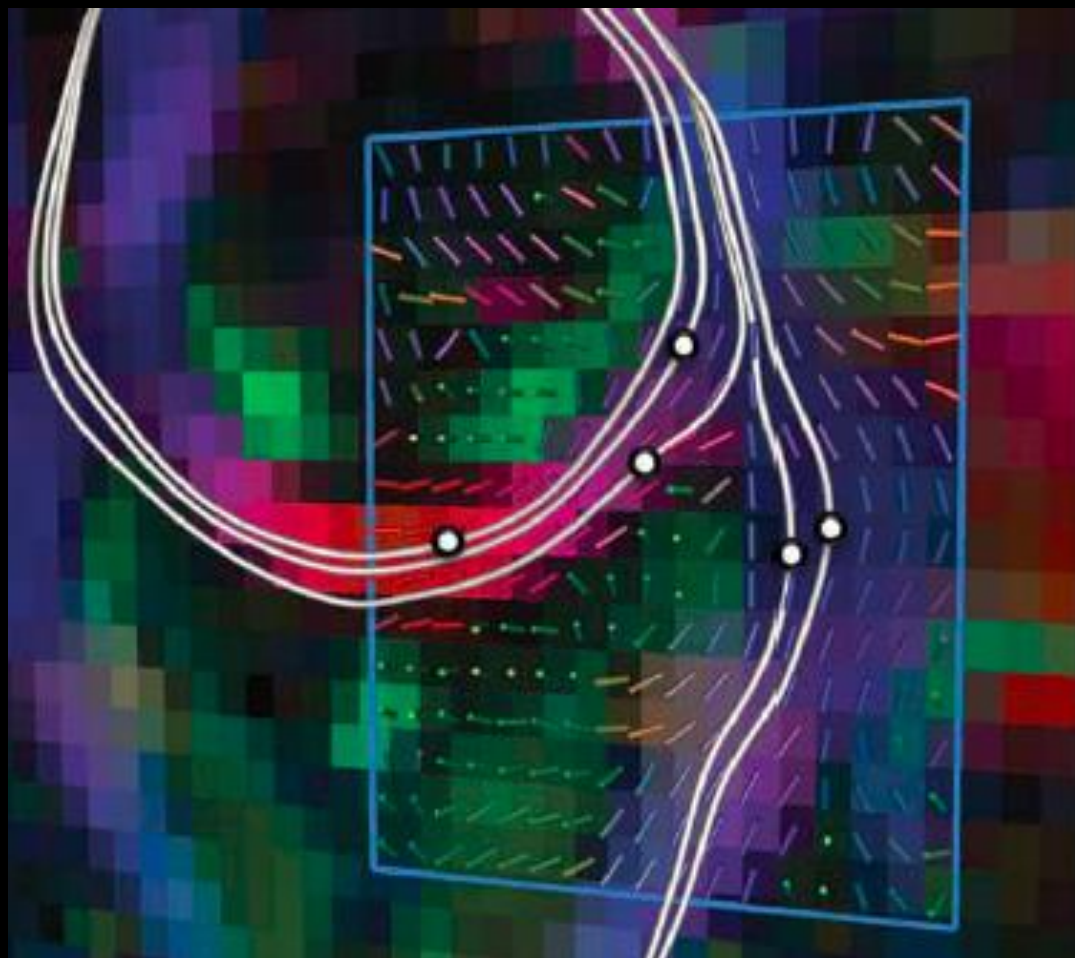- More sensitive to noise than DTI

DTI   ODF

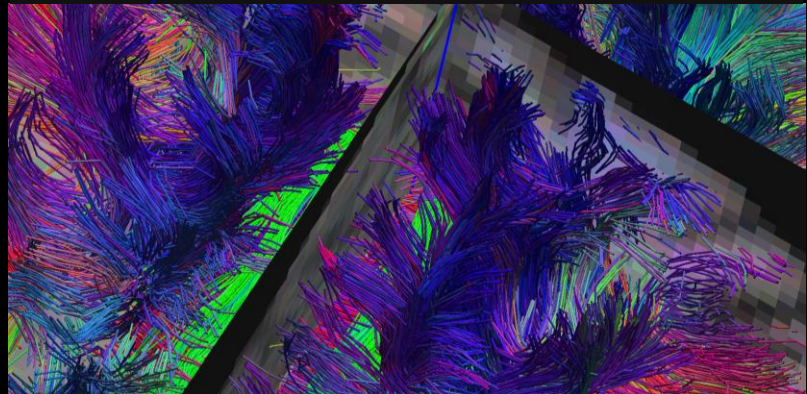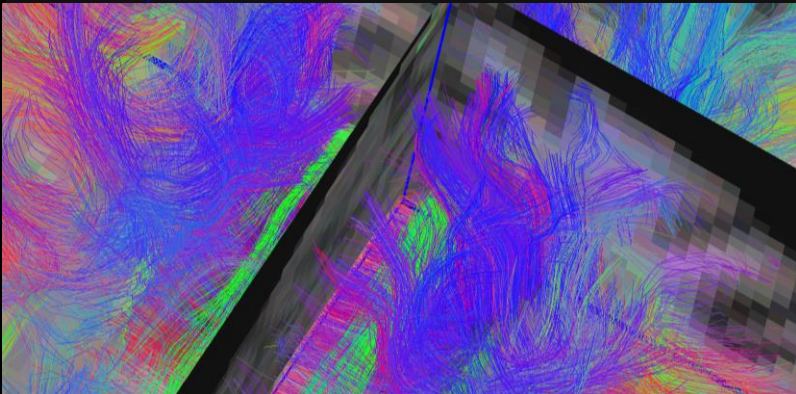# Tracking

Deterministic Tractography

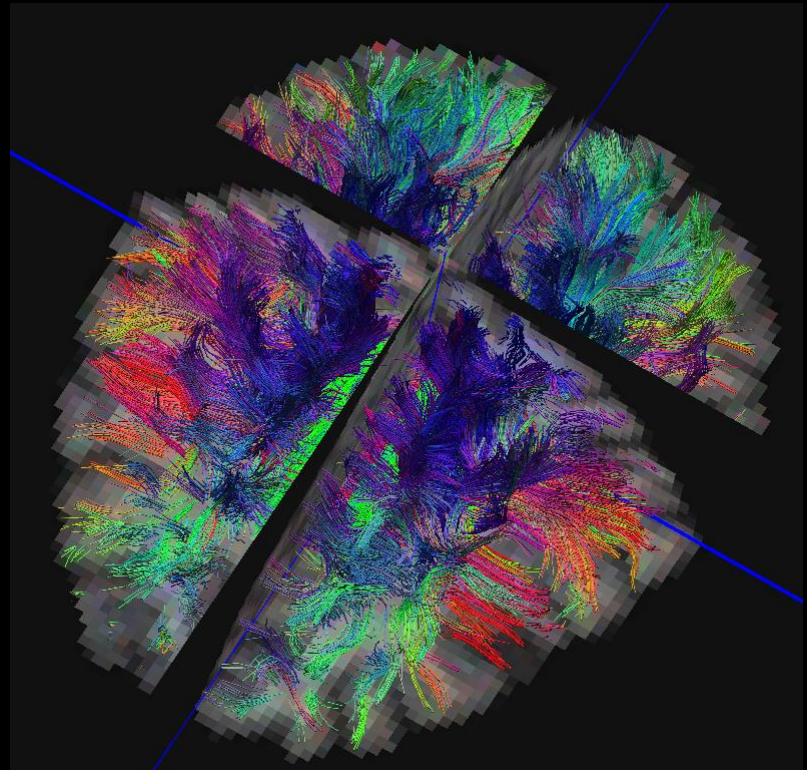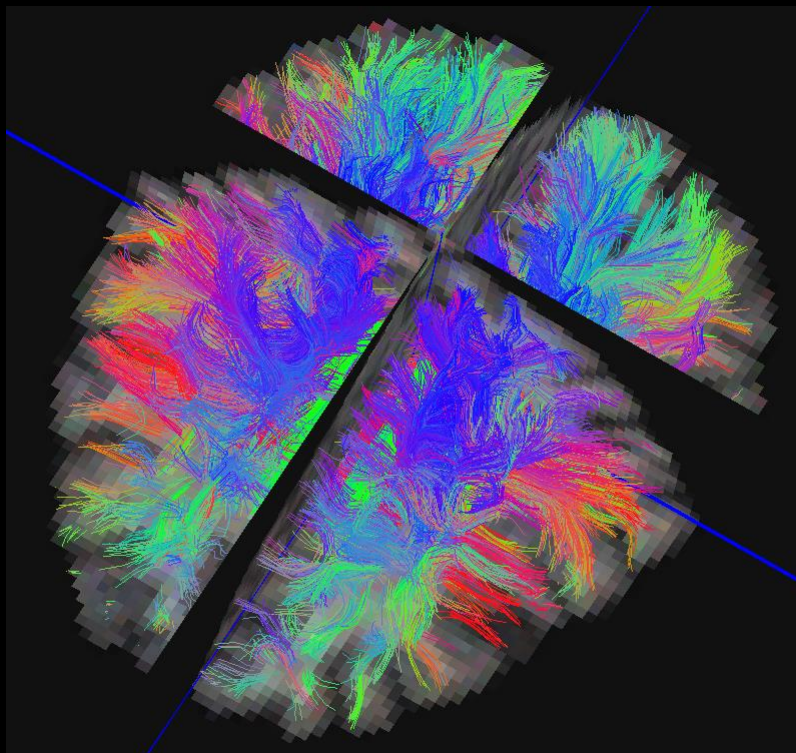- Start at seed locations
  - 'Tract Seeding'
- Follow major orientations
  - 'ODF sampling'
  - 'Stepsize'
- Know when to stop
  - 'Threshold' parameters

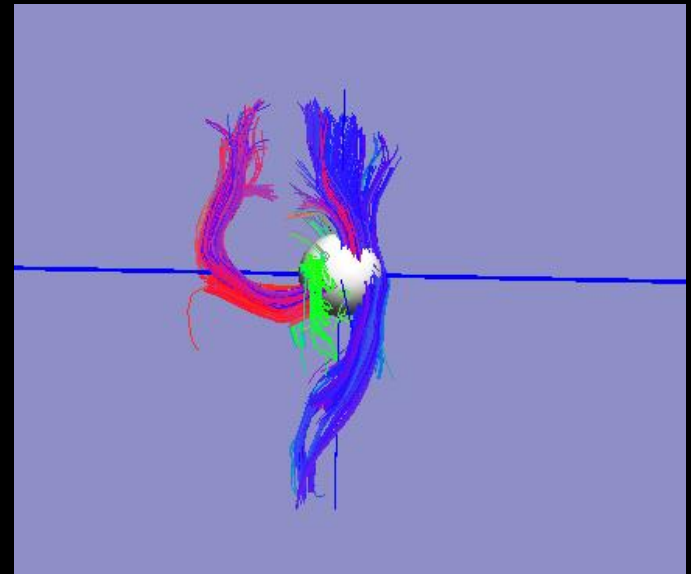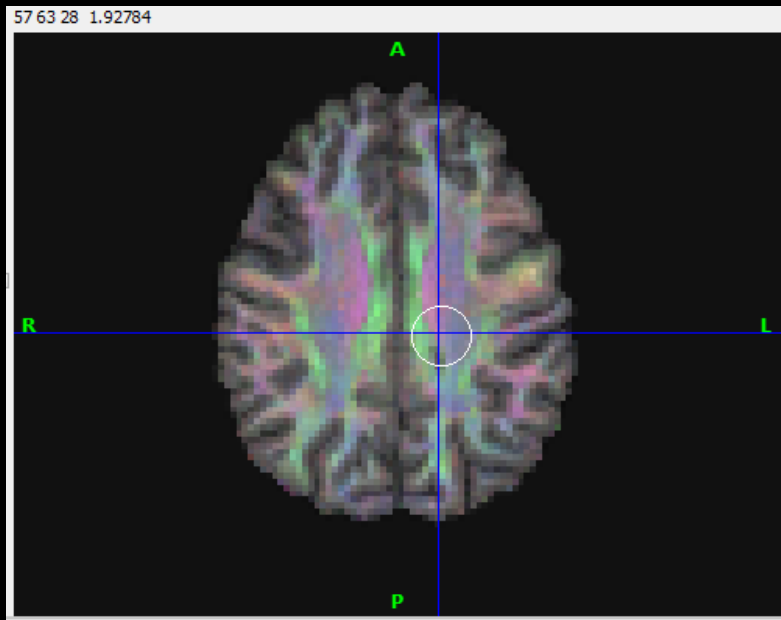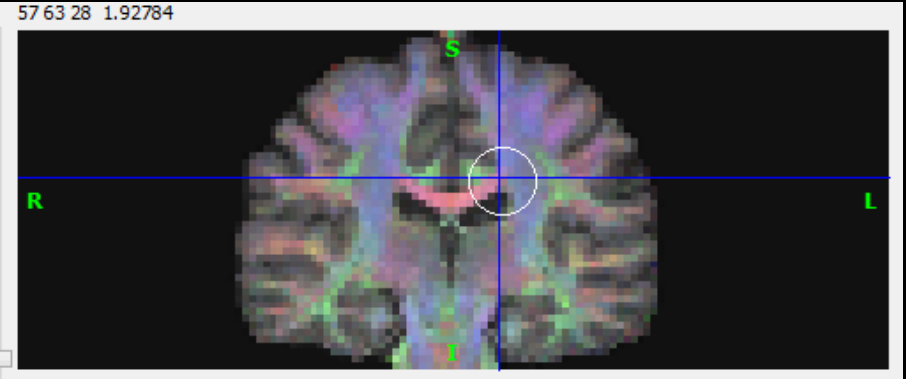| Tract Seeding	1	seeds/voxel
Stepsize	0.25	in mm
Max # of steps	500	
Angle Threshold	0.99	[0,1]
FA Threshold	0.05	[0,1]
ODF Sampling	20	
GFA/l2 Threshold	0.01	

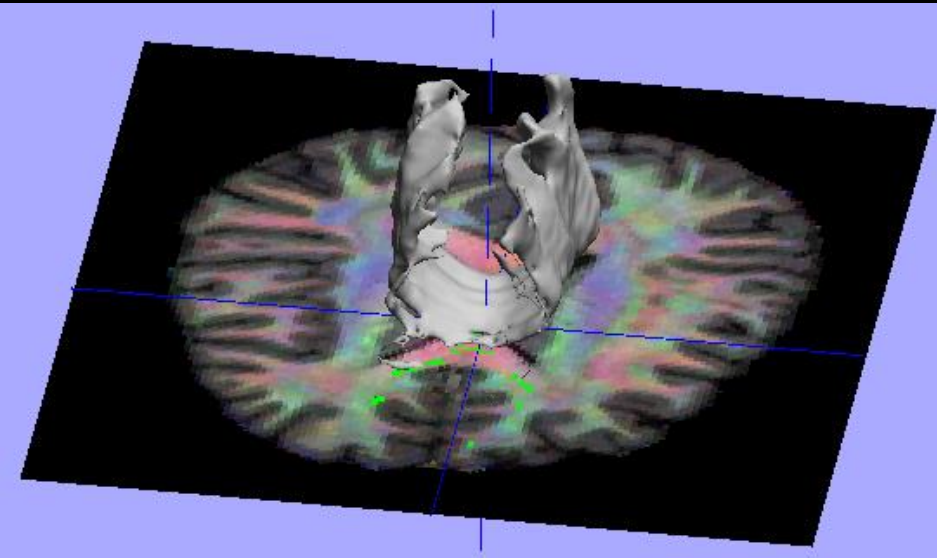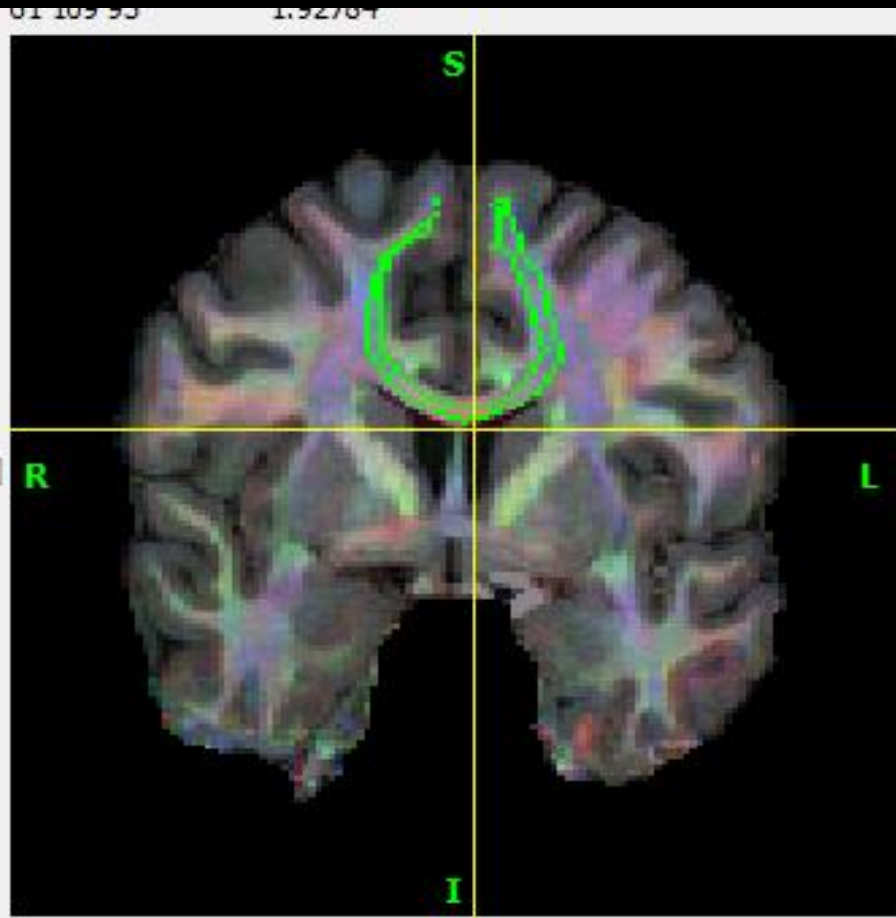Tournier 2011

17

Render as Tubes

Sphere Filtering
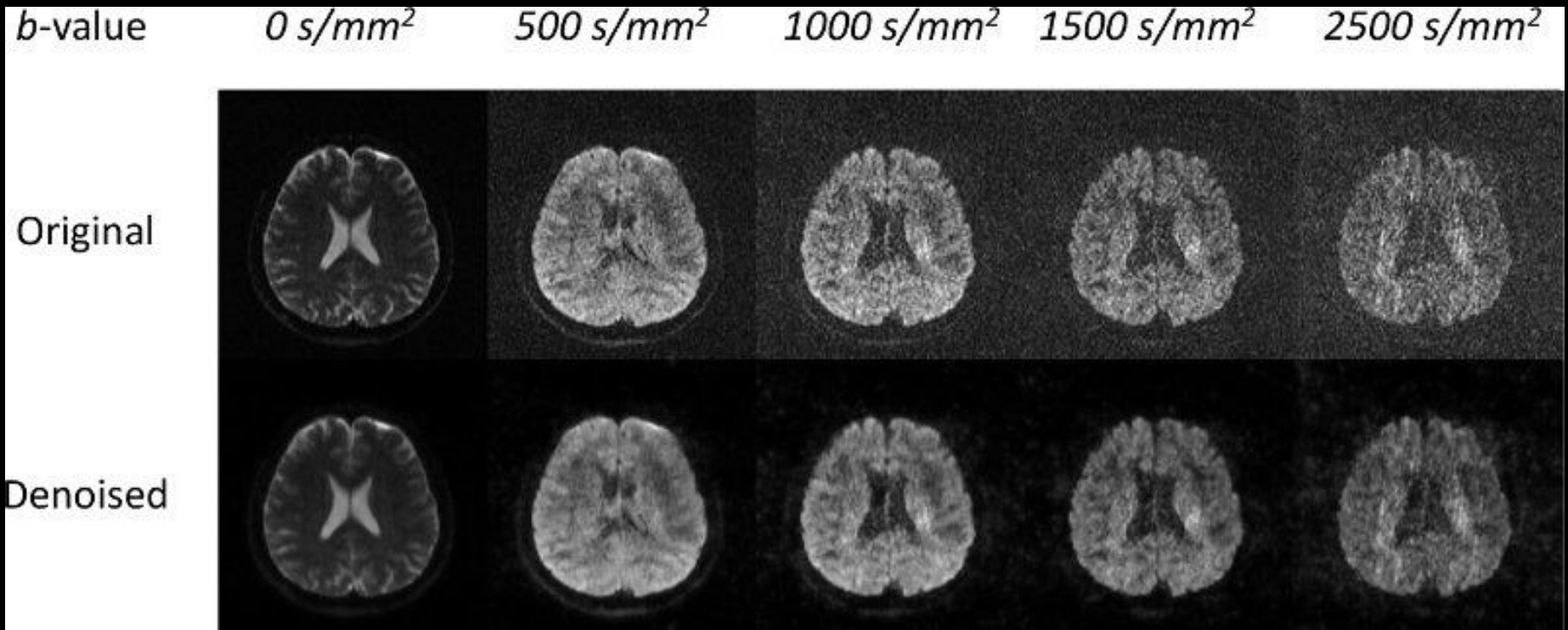
Connectivity
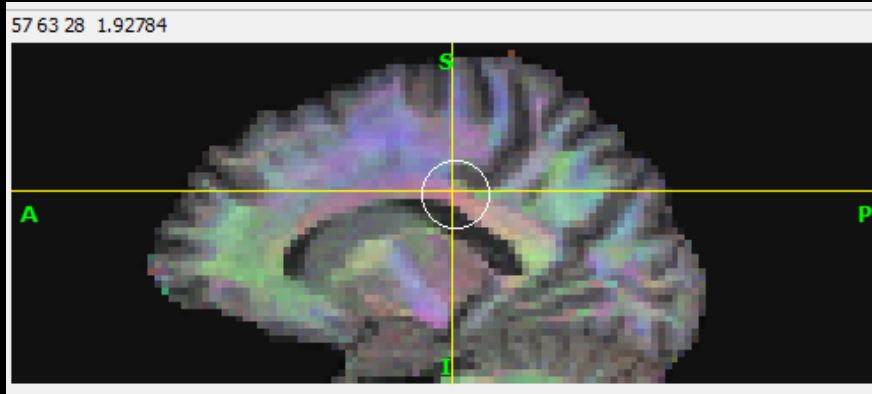
Track-Based ROI Tool

- Select voxels based on tracks

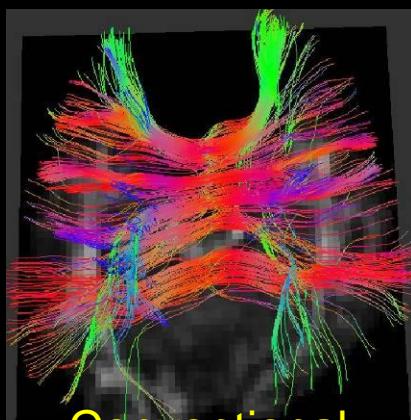- To be released soon – contact us for more info

Denoising

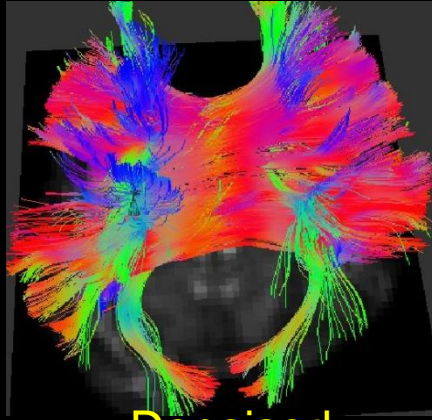[1] Haldar, Wedeen, Nezamzadeh, Dai, Weiner, Schuff, Liang, *Magn Reson Med* 69:277-289, 2013.
[2] Varadarajan and Haldar, *IEEE ISBI*, 2013, pp. 708-711.

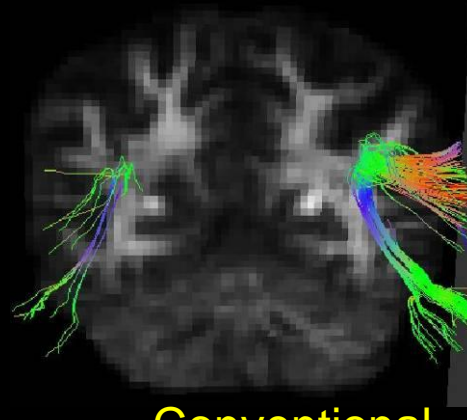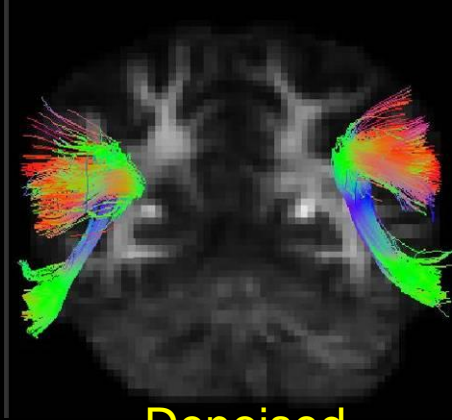http://mr.usc.edu/download/joint-denoising-for-diffusion-mri-magnitude-images
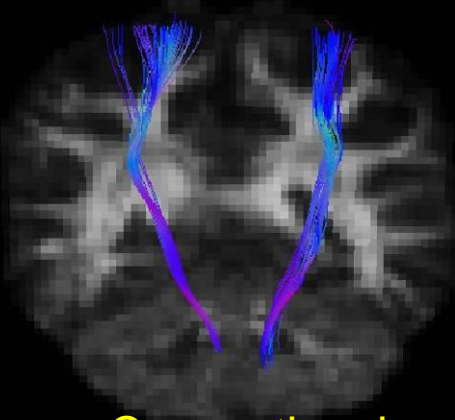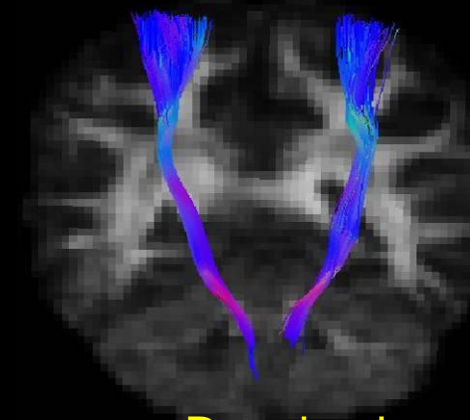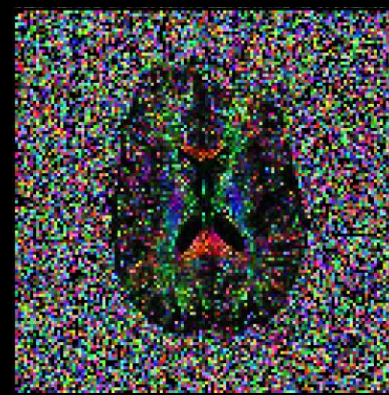
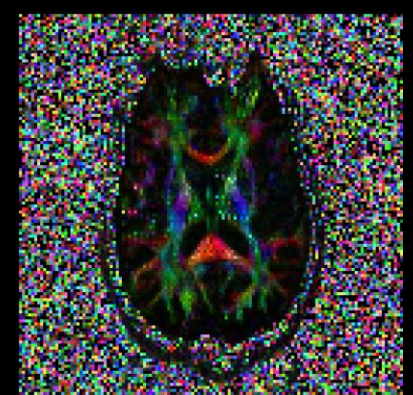# Denoising

Conventional   Denoised   Conventional   Denoised

Conventional   Denoised   Conventional   Denoised

http://mr.usc.edu/download/joint-denoising-for-diffusion-mri-magnitude-images

Biases and Errors

- Make sure you know the limitations of tractography and diffusion MRI before you interpret it

Twenty-five Pitfalls in the Analysis of Diffusion MRI Data[†]

NMR Biomed. 2010; **23**: 803–820

Derek K. Jones[a]* and Mara Cercignani[b]

Challenges and limitations of quantifying brain connectivity *in vivo* with diffusion MRI

Derek K Jones

Imaging Med. (2010) **2**(3), 341–355

White matter integrity, fiber count, and other fallacies: The do's and don'ts of diffusion MRI

NeuroImage 73 (2013) 239–254

Derek K. Jones [a,b,*], Thomas R. Knösche [c], Robert Turner [c]

Overview

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- 6+ Directions
- HARDI
- Multi-Shell
- DSI
- …

2. Preprocessing

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