Introduction to Diffusion Tensor Imaging

http://csci.ucsd.edu/courses/cogs260w2018/

Prof Larry Frank

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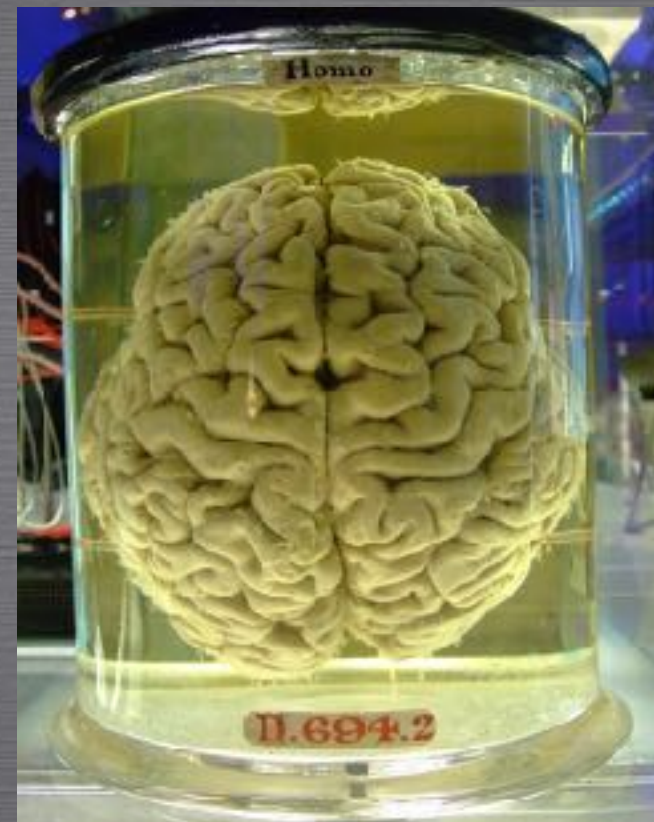
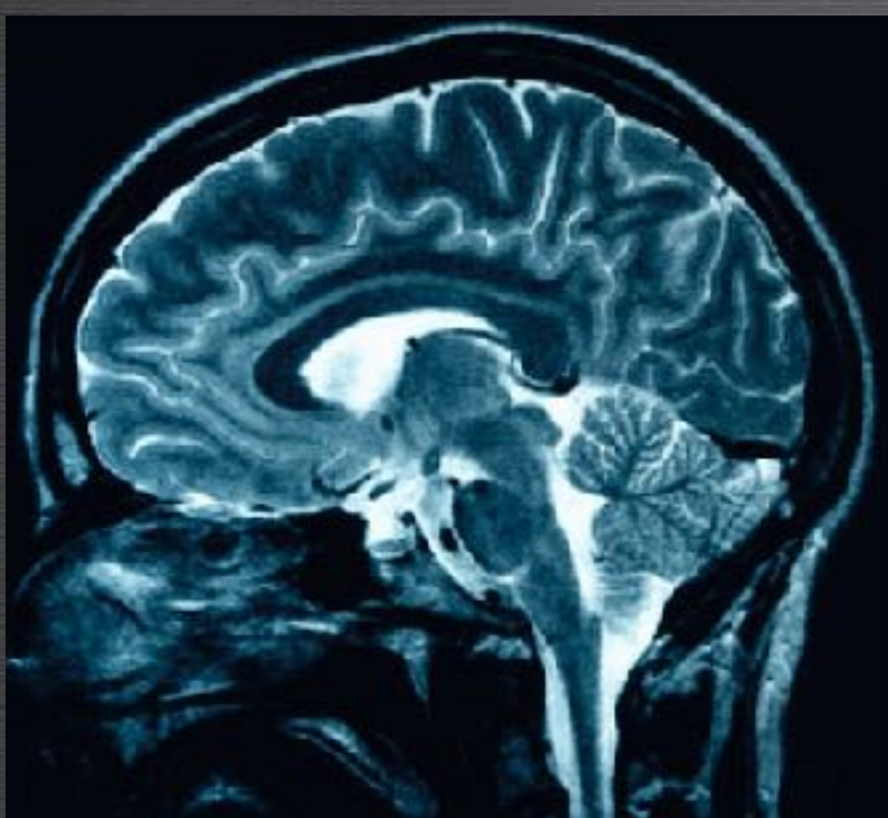
Lecture 1
Introduction and Class Outline

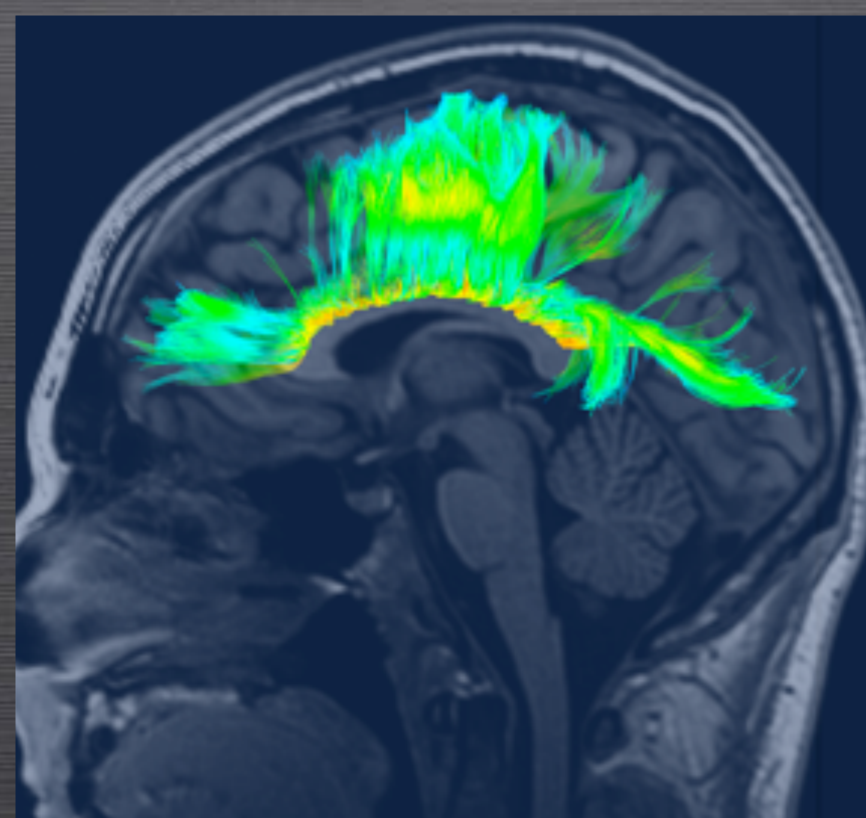
Exploring the Brain



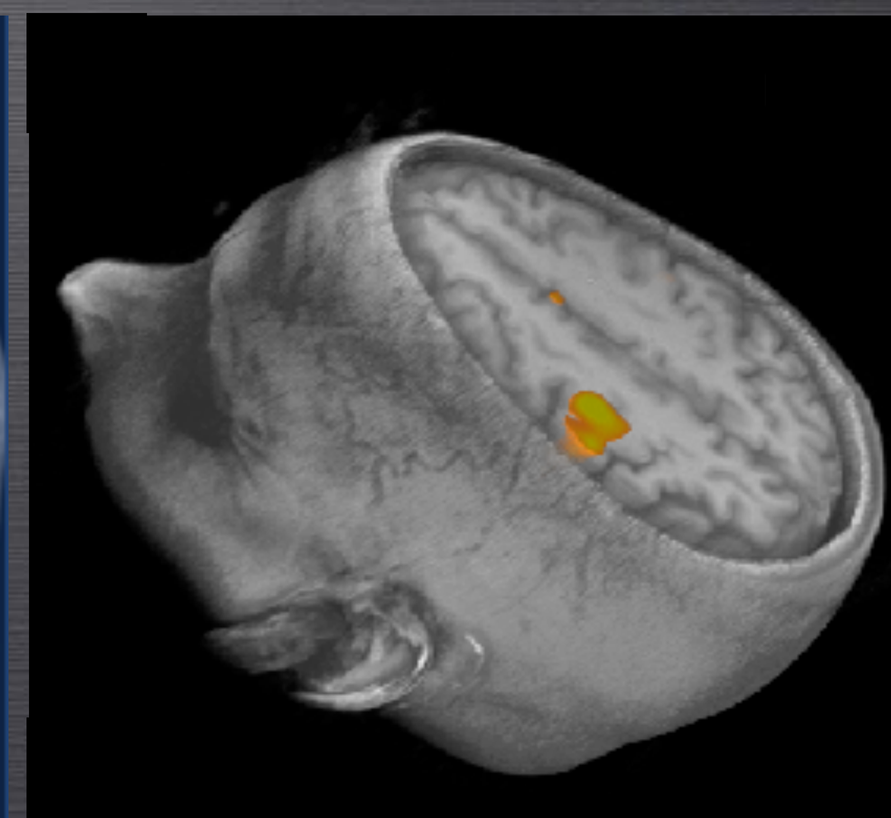
The Three Pillars of MR Neuroimaging



anatomical



Diffusion



Functional

Lecture Summary

1. Why are you here?
2. Class Objectives
3. Course outline
4. Lab Lectures (AFNI & QUEST)
5. Term Project
6. Grading
7. Readings

The Problem

ELSEVIER

NeuroImage

www.elsevier.com/locate/ynimg
NeuroImage 26 (2005) 891–899

Frontal circuitry degradation marks healthy adult aging: Evidence from diffusion tensor imaging

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Received 6 December 2004; revised 14 February 2005; accepted 23 February 2005
Available online 7 April 2005

The Problem

MRI and DTI acquisition protocol

The DTI-structural acquisition and analysis incorporated correction of spatial distortion due to main field (B_0) inhomogeneity. MRI data were acquired on a 3-T General Electric (Milwaukee, WI) Signa human MRI scanner (gradient strength = 40 mT/m; slew rate = 150 T/m/s; software version VH3). The following four sequences were collected:

(a) Structural fast spin echo (FSE; FOV = 24 cm, TR = 10,000 ms TE = 14/98 ms, thick = 2.5 mm, skip = 0, slice locations = 62);

(b) Inversion Recovery Prepared SPoiled Gradient Recalled echo (IRPrepSPGR; FOV = 24 cm, TI = 300 ms, TR/TE = 6.5/1.54 ms, thick = 1.25 mm, slices = 124);

(c) Diffusion Tensor Images (DTI; FOV = 24 cm, TR = 11,000 ms TE = 97.6 ms, thick = 2.5 mm, skip = 0, slice locations = 62, 0 (8 NEX) + 6 non-collinear diffusion directions (4 NEX, gradient orientations $+x$ $+y$, $+y$ $+z$, $+x$ $+z$, $-x$ $+y$, $-y$ $+z$, $+x$ $-z$ with a repeat of these six orientations with opposite gradient polarity, 1.45 Gauss/cm with 32 ms duration and 38 ms separation, resulting in a *b* value of 860 s/mm^2, x-dim = 96, y-dim = 96, 3472 total images);

(d) Fieldmap (FOV = 24 cm, multislice, dual echo, single-shot spiral acquisition, x-dim = 128, y-dim = 128).

The SPGR data were aligned such that two 1.25-mm slices subtended each 2.5 mm thick FSE and DTI slice with custom scanner prescription software, which computed precise slice locations. The data from the spiral acquisition for each echo were gridded and Fourier transformed, and a fieldmap was estimated from a complex difference image between the two echoes (Pfeuffer et al., 2002).

The Problem

DTI analysis

DTI quantification was preceded by eddy current correction using a template made from an average image created across all gradient directions and a 2-D, 6-parameter affine warp on a slice-by-slice basis (Woods et al., 1998). Using the field maps, B_0-field inhomogeneity-induced geometric distortion in the eddy current-corrected images was corrected with FUGUE (FMRIB's Utility for Geometrically Unwarping EPIs) (Jenkinson, 2003). Next, the $b = 0$ images were warped to the late echo FSE images in 3-D, first with a 12-parameter affine, followed by stepwise 2nd and 3rd order polynomial functions. This transformation was then applied to all B_0 field-corrected and eddy current-corrected averaged images (Fig. 1). Finally, using the corrected images, $b = 0$ and $b = 860$ s/mm^2, 6 maps of the apparent diffusion coefficient (ADC) were calculated. Solving 6 simultaneous equations with respect to ADCxx, ADCxy, etc. yielded the elements of the diffusion tensor. The diffusion tensor was then diagonalized, yielding eigenvalues λ_1, λ_2, λ_3, as well as eigenvectors that define the predominant diffusion orientation. Based on the eigenvalues, the fractional anisotropy (FA) and bulk mean diffusivity (the mean of the eigenvalues, <*D*>) were calculated on a voxel-by-voxel basis (Basser and Jones, 2002; Basser and Pierpaoli, 1998; Pierpaoli and Basser, 1996).

The Problem

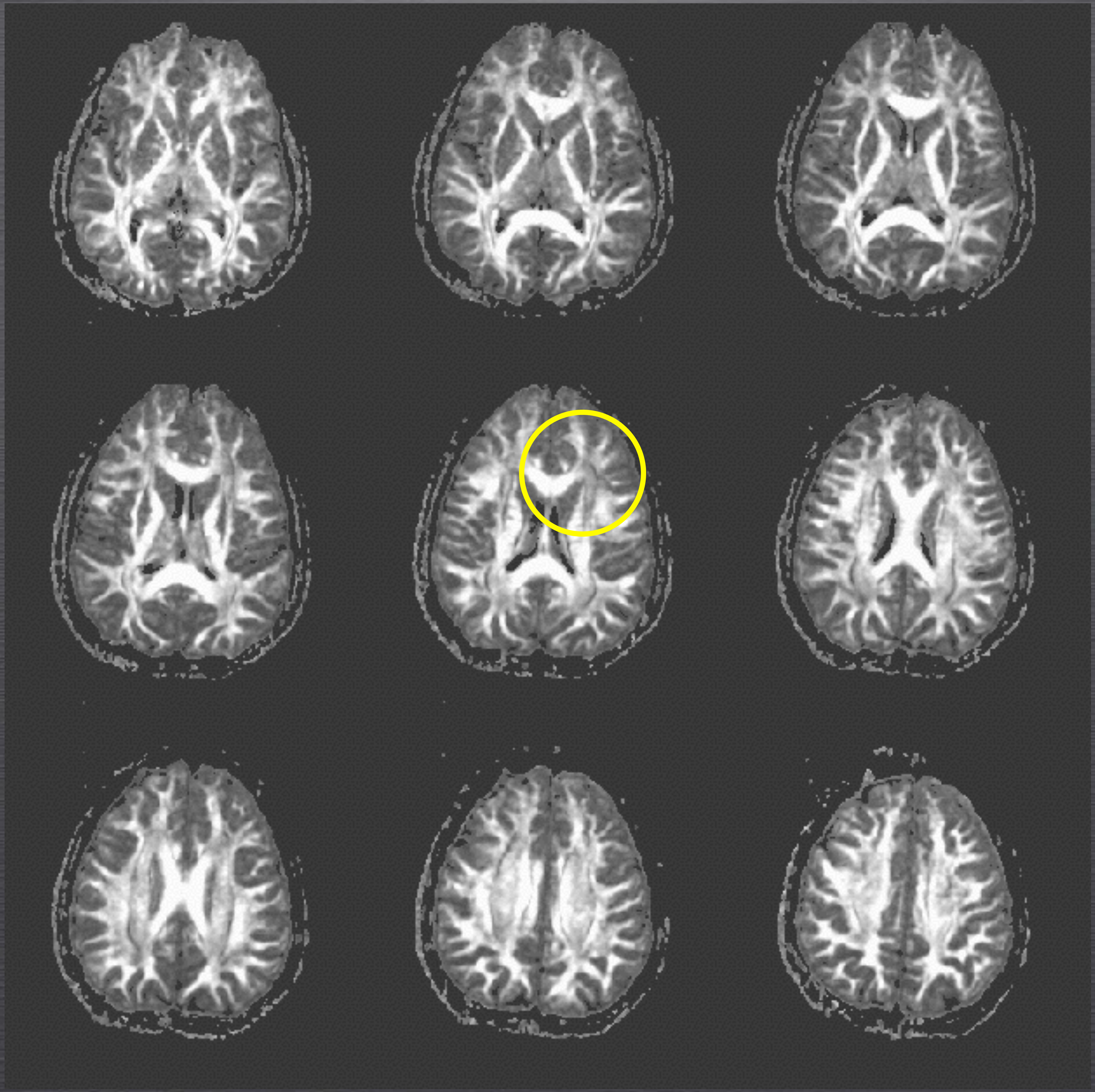
Fiber tract mapping and extensions of DTI

In fact, diffusion tensor imaging (DTI), as is used by our diffusion-based tracking method, is unable to truly resolve the crossing of multiple axon directions within a single voxel [11], [39]–[41]. Despite the fact that the information captured from DTI is limited by the second-order tensor model it applies, which assumes water molecules follow Gaussian diffusion in biological tissues, the tensor formalism is well accepted and its attributes can be obtained in a straightforward way. Furthermore, the macroscopic theory of Gaussian diffusion is modeled by Fick's first law (see (1)), which makes simulating the diffusion process by solving the diffusion equation (2) a natural fit-in to obtain information of the underlying fiber structure and connectivity. For those reasons, the tracking algorithm based on diffusion simulations is implemented to use the DTI data, which needs to be fed into the corresponding diffusion equation (2). Essentially most existing tracking techniques are banking on the diffusion tensor framework. However, it has been suggested to get around the inadequacy presented in DTI by using newly developed imaging approaches, like high angular resolution diffusion imaging (HARDI) [39]–[42], q-space imaging (QSI) [43], [44], or generalized diffusion tensor imaging (GDTI) [45], [46]. An outstanding feature of the fiber reconstruction method using diffusion simulations is that it can be seamlessly adapted to a platform established by the new imaging techniques.

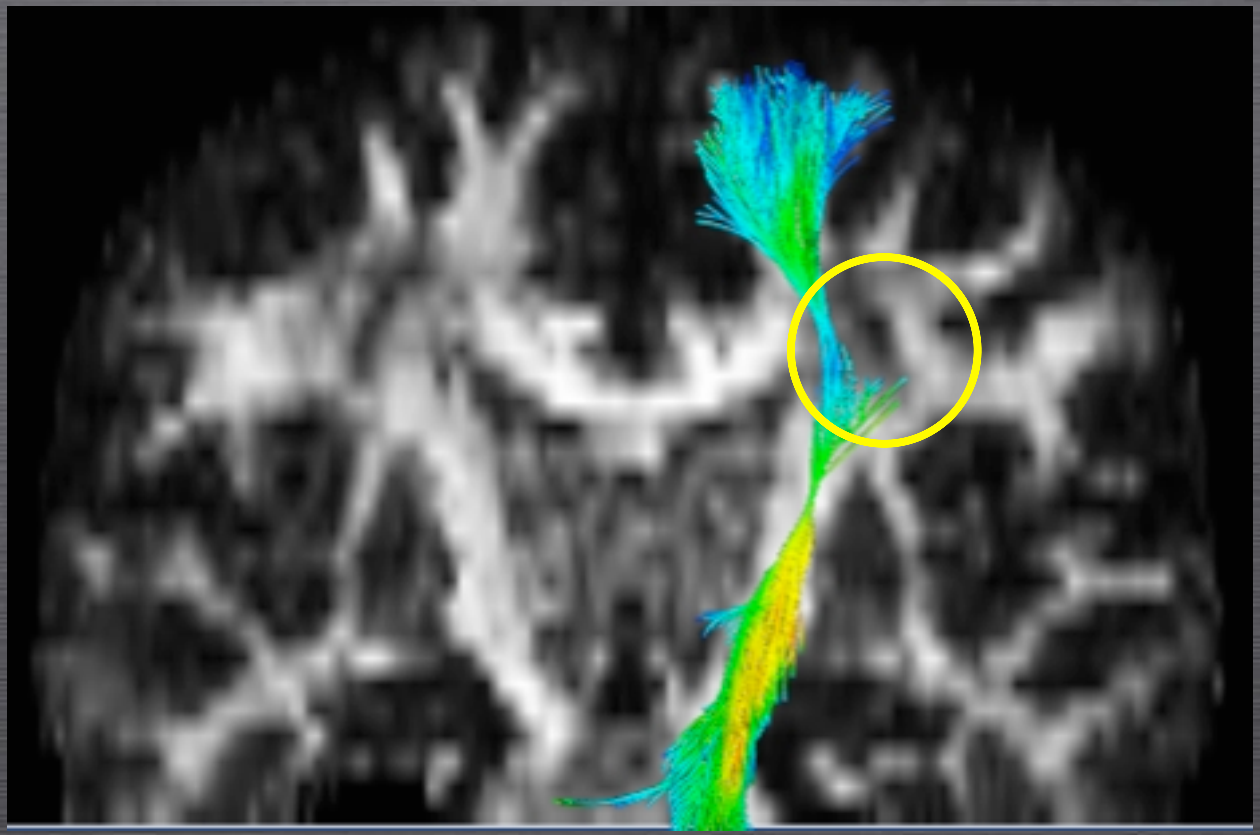
The Goal

Understand the basic "standard method" and its limitations

DTI Derived White Matter Map



Tractography



Standard DTI

The Goal

By end of class, have a ***working*** knowledge of the state-of-the-art method

Course Logic

Preliminary Mathematics

Diffusion

MRI

MRI diffusion sensitivity

Diffusion weighted imaging (DWI)

DWI analysis

Course Logic

Preliminary Mathematics

Basic structures

Scalars, Vectors
Matrices, Tensors
Complex Numbers

Transformations

Rotations
Fourier Transforms

Linear Algebra

Least squares
Eigensystems

Course Logic

Diffusion

Classical Diffusion

Flux, concentration,
continuity
diffusion equation

Probability theory

Random walk
diffusion equation

Course Logic

MRI

NMR — signal creation and detection

Spatial localization — Gradients
Fourier reconstruction

Image formation(MRI) — Pulse sequences
Fourier reconstruction

Course Logic

MRI diffusion sensitivity

diffusion in gradients — signal loss

DTI — diffusion weighting, sampling

Course Logic

DWI analysis

DWI pre-processing

distortion correction
image registration

Standard DTI

diffusion tensor
anisotropy
tractography

Heterogeneous voxel DWI
(State-of-the-art)

DWI-ESP
anisotropy
tractography

Course Logic

By the time we get to standard
Diffusion Tensor Imaging,
it will seem obvious,

... an assemblage of parts
you already know

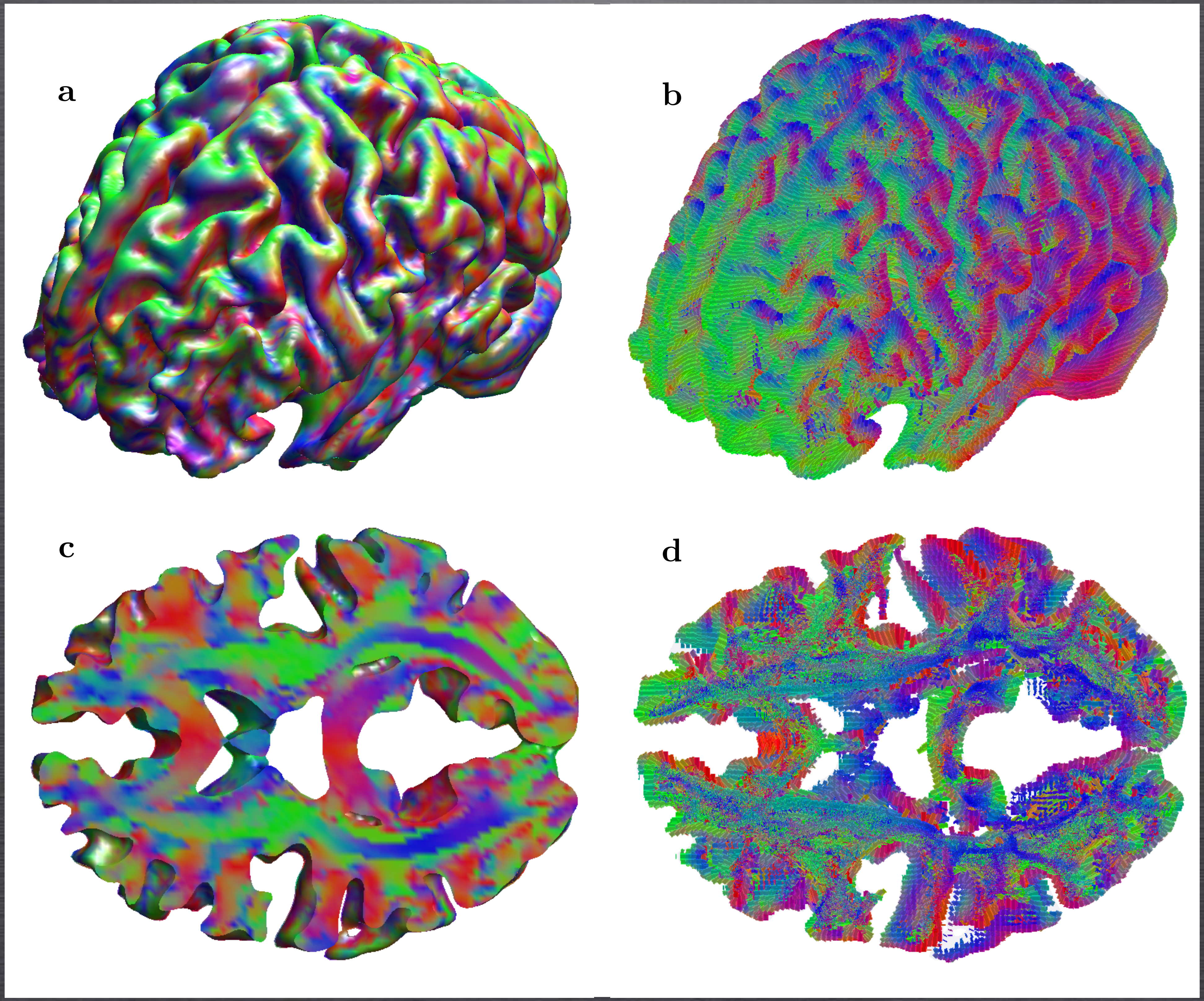
Course Logic

Our ultimate goal, however, is to learn

DWI-ESP

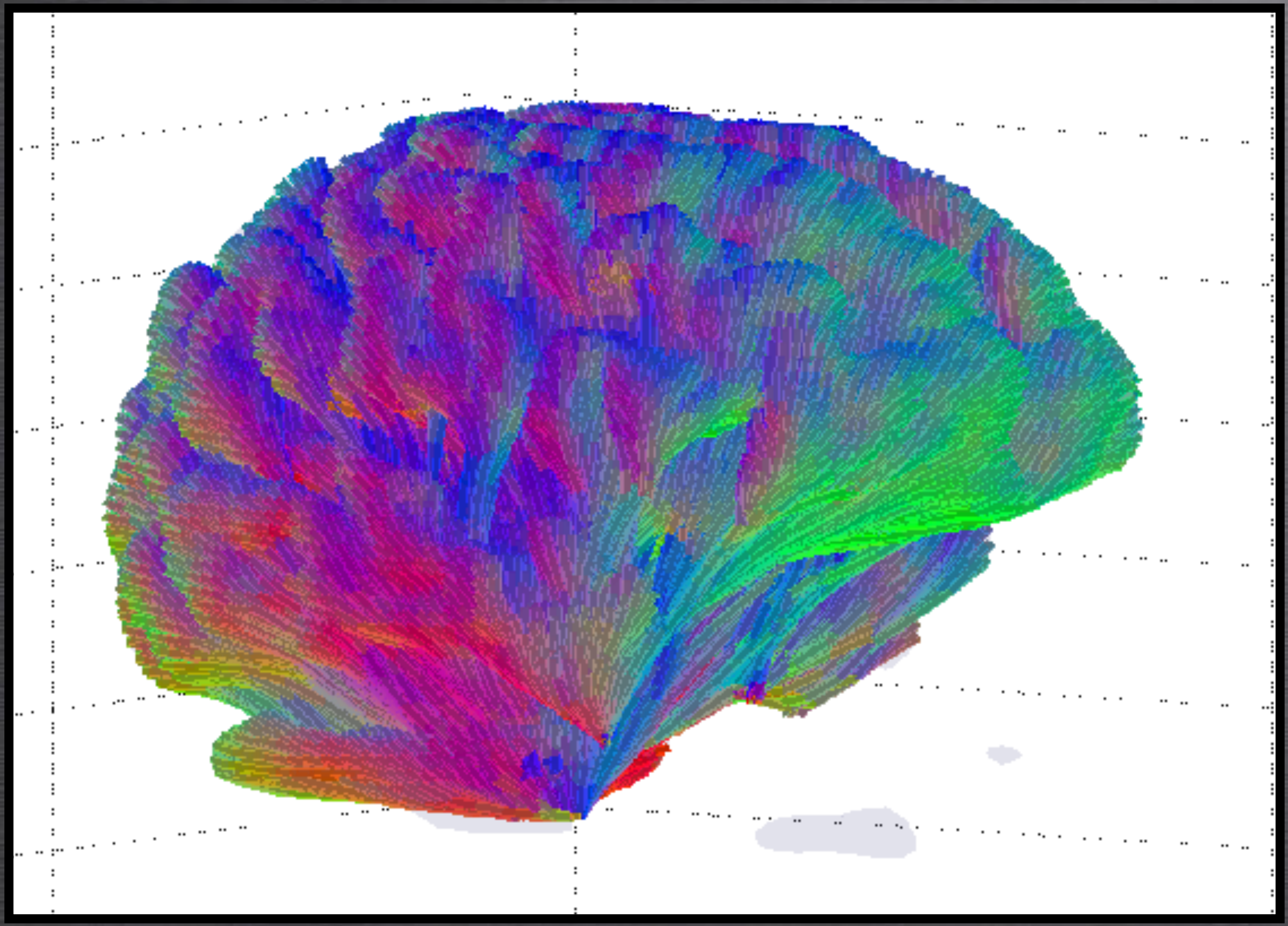
A new method
More complicated, but worth it!

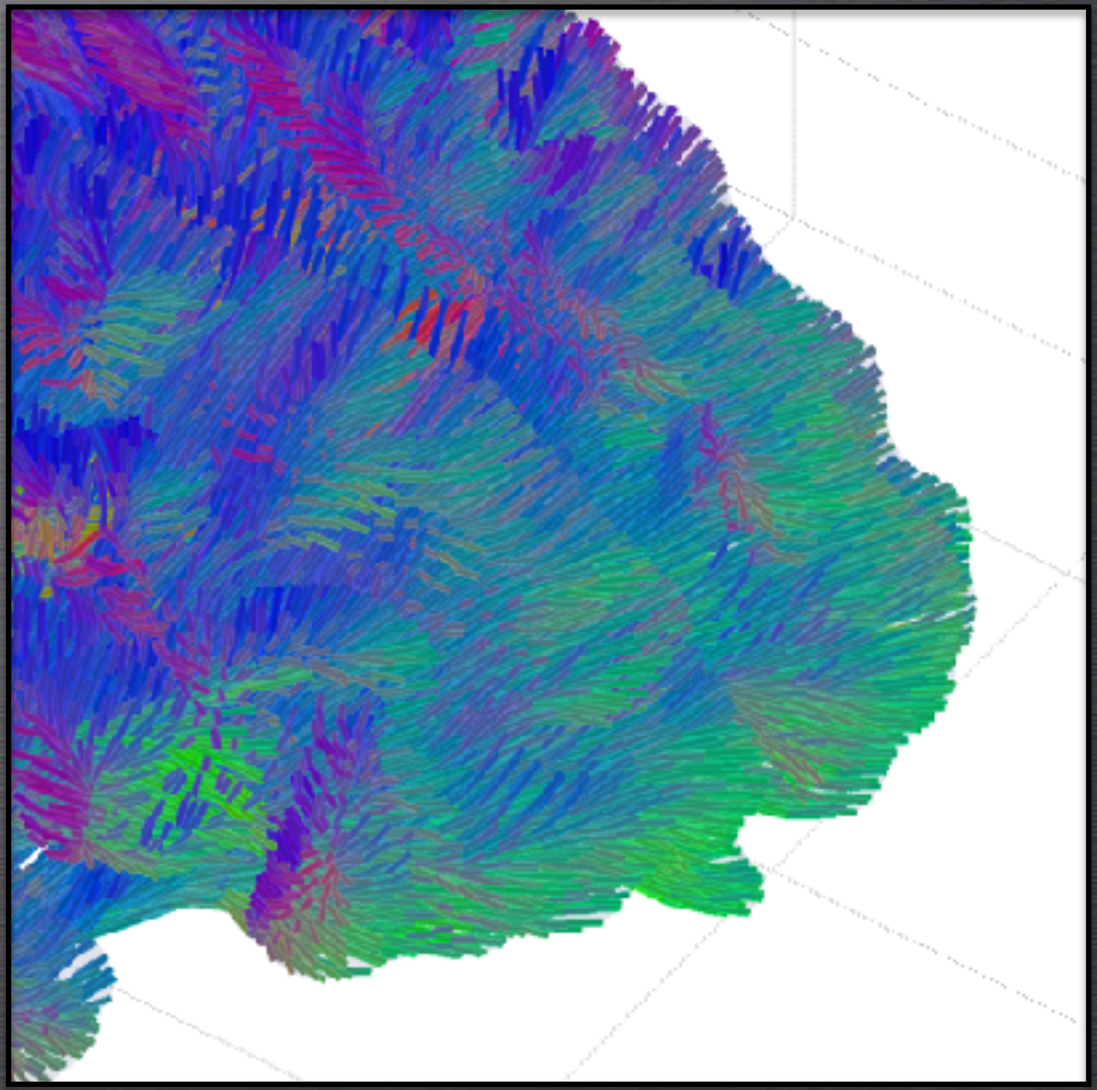
The Goal



anisotropy tractography

CFMRI Autism Study





in collaboration with the lab of Dr Axel Mueller

Lab Lectures

The two lab lectures will focus
on getting practical experience with
the QUEST platform

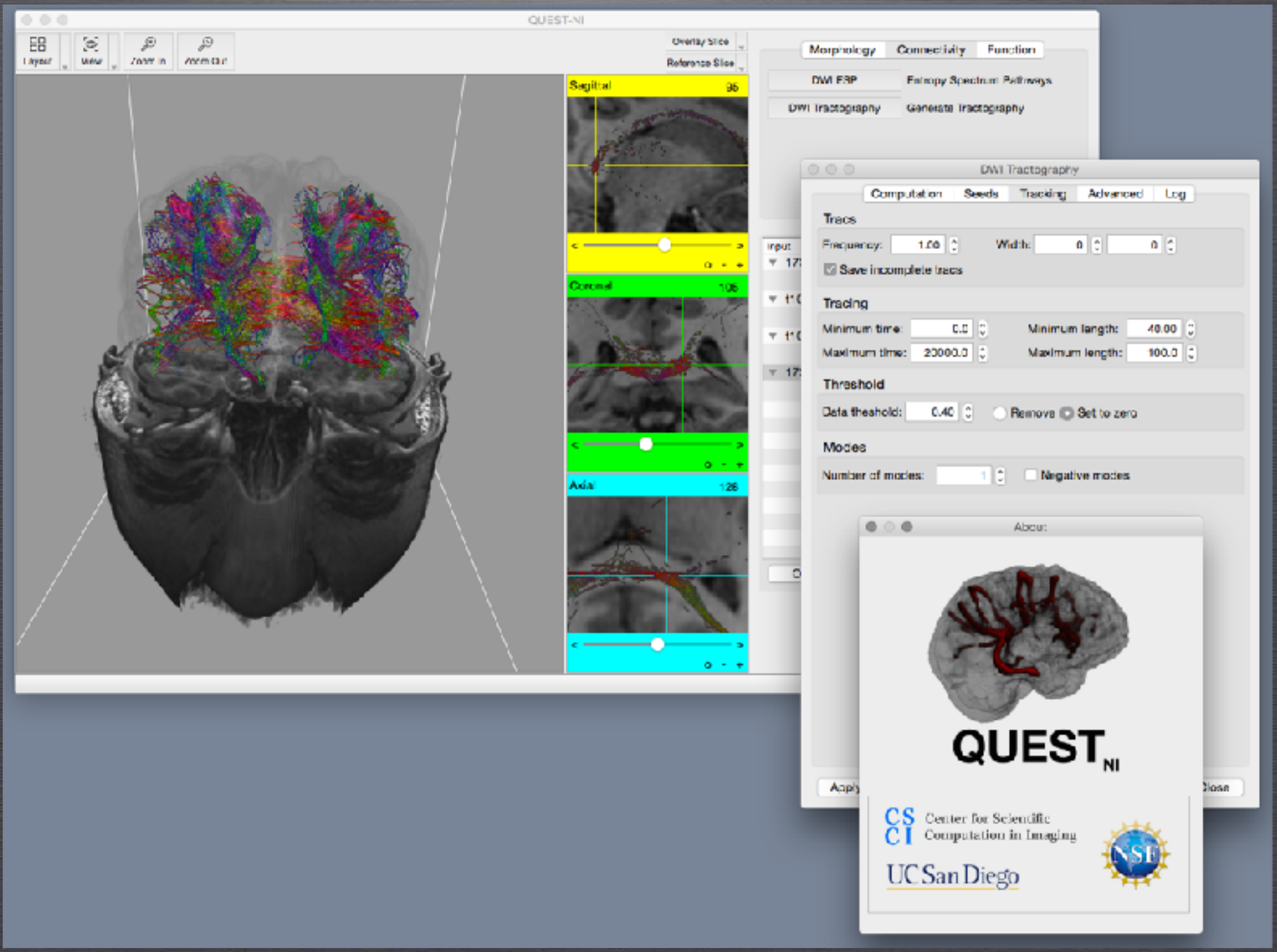
Requirement

AFNI and the QUEST Plugin must be working
onto your computer prior to these lectures.
Thomas will assist people who need help with this.

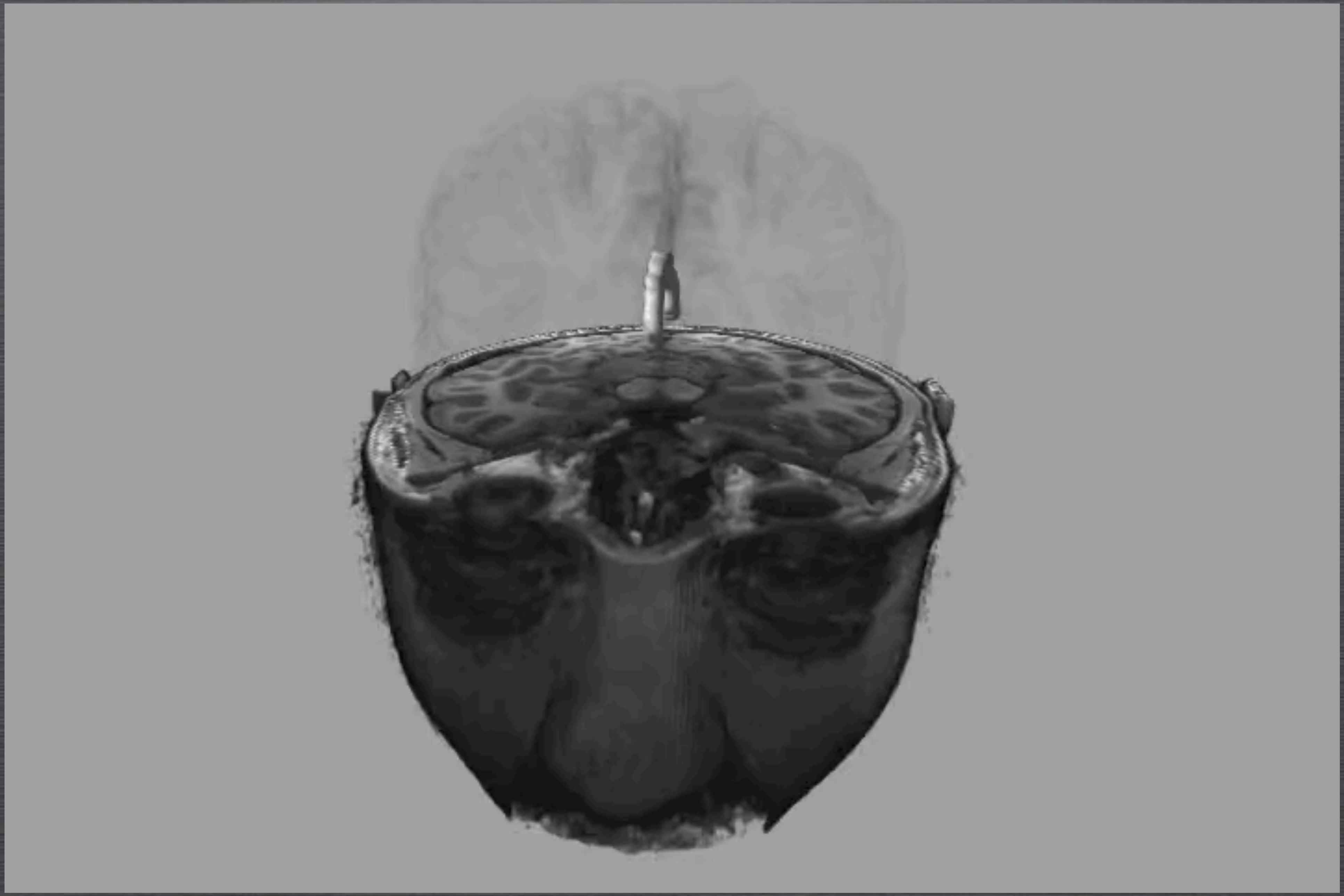
Lab Lectures

https://afni.nimh.nih.gov

Lab Lectures



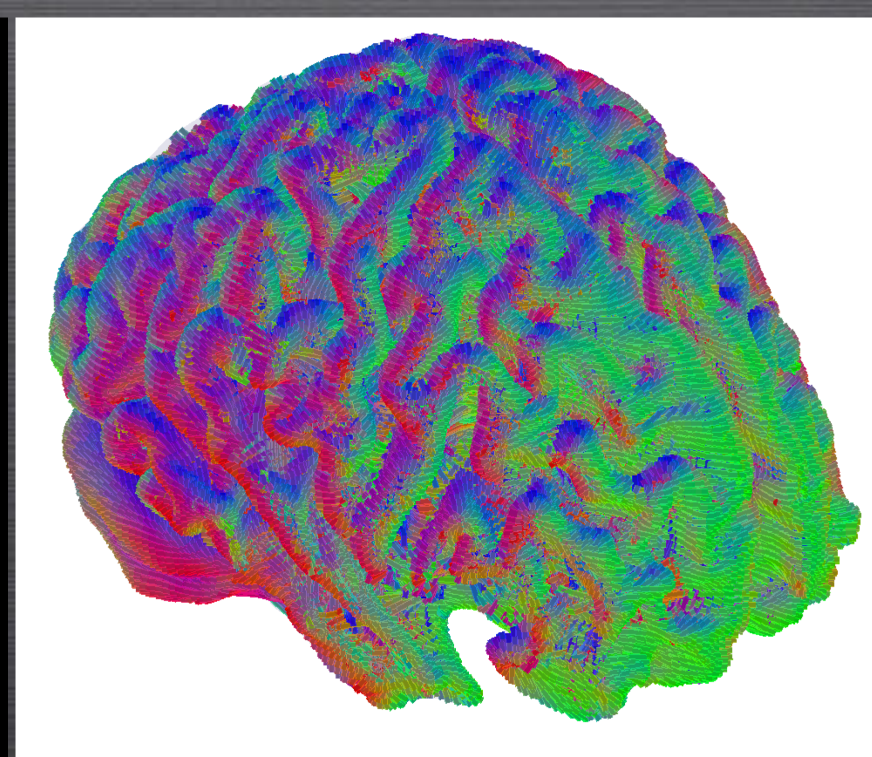
Lab Lectures



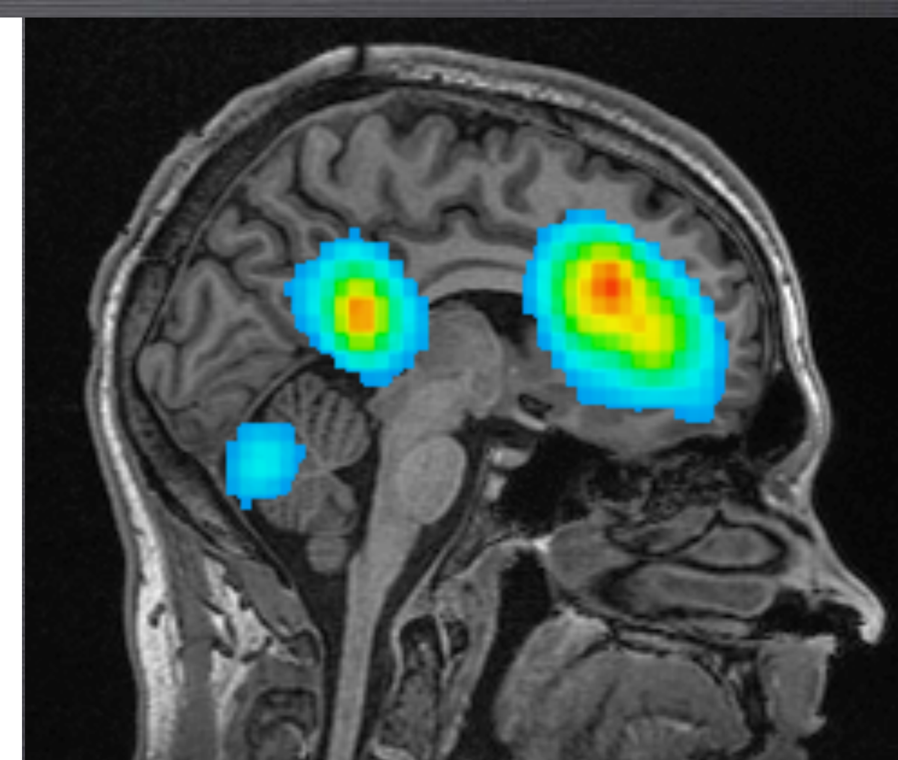
The Three Pillars of Neuro-MRI

Morphology Connectivity Function

SWD



DTI-ESP



FMRI-ESP

Term Project

Write a review paper on an application of DTI relevant to your interests

- Importance of your application
- Why DTI is useful for your application
- Review and critique of 5 (min) related papers
- Summary of current status of field

Grading

40% attendance
30% homework
30% final project

Office Hours

Wed 12-2

La Jolla Village Professional Center

(behind Rock Bottom Brewery)

Suite B227

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