

Medical Image Analysis

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Lecture 1. Introduction

January 23, 2007

Course Aim

- To present **mathematical** and **statistical** techniques used in the field of medical image analysis, with an emphasis on **computer algorithms**.
- MATLAB will be the instruction language.
- We will study following medical imaging problems: representation, visualization, feature extraction, denoising, image registration, morphometry (deformable), quantification and validation.

Target Audience

- This course is designed for researchers and students who wish to analyze and model medical image data quantitatively. The course material is applicable to a wide variety of medical and biological imaging problems.
- Requirement: Basic understanding of mathematical, statistical techniques and terminology.

Course Evaluation

- **3 credits:** research report + 20min oral presentation
- **2 & 1 credits:** literature review on imaging methodology
- **0 credit:** feel free to audit and participate the class activity
- Please do not recycle reports submitted to other classes (check university regulation).

Course Work

- There is no homework but participants are required to read two papers for each lecture (total 4 papers per week = 2-4 hours).
- They will be posted in <http://www.stat.wisc.edu/~mchung/teaching/MIA/reading> at least two days before each lecture. Look at the date stamp in file names and download two most up to date PDF files.

Course Topics

- digital image data
- random fields, Hilbert space, Fourier analysis, wavelets
- linear and nonlinear filters
- time series, signal analysis
- multivariate techniques - mixture model, logistic regression
- pattern recognition, shape modeling, deformable template, curve and surface geometry,
- finite element methods (FEM)

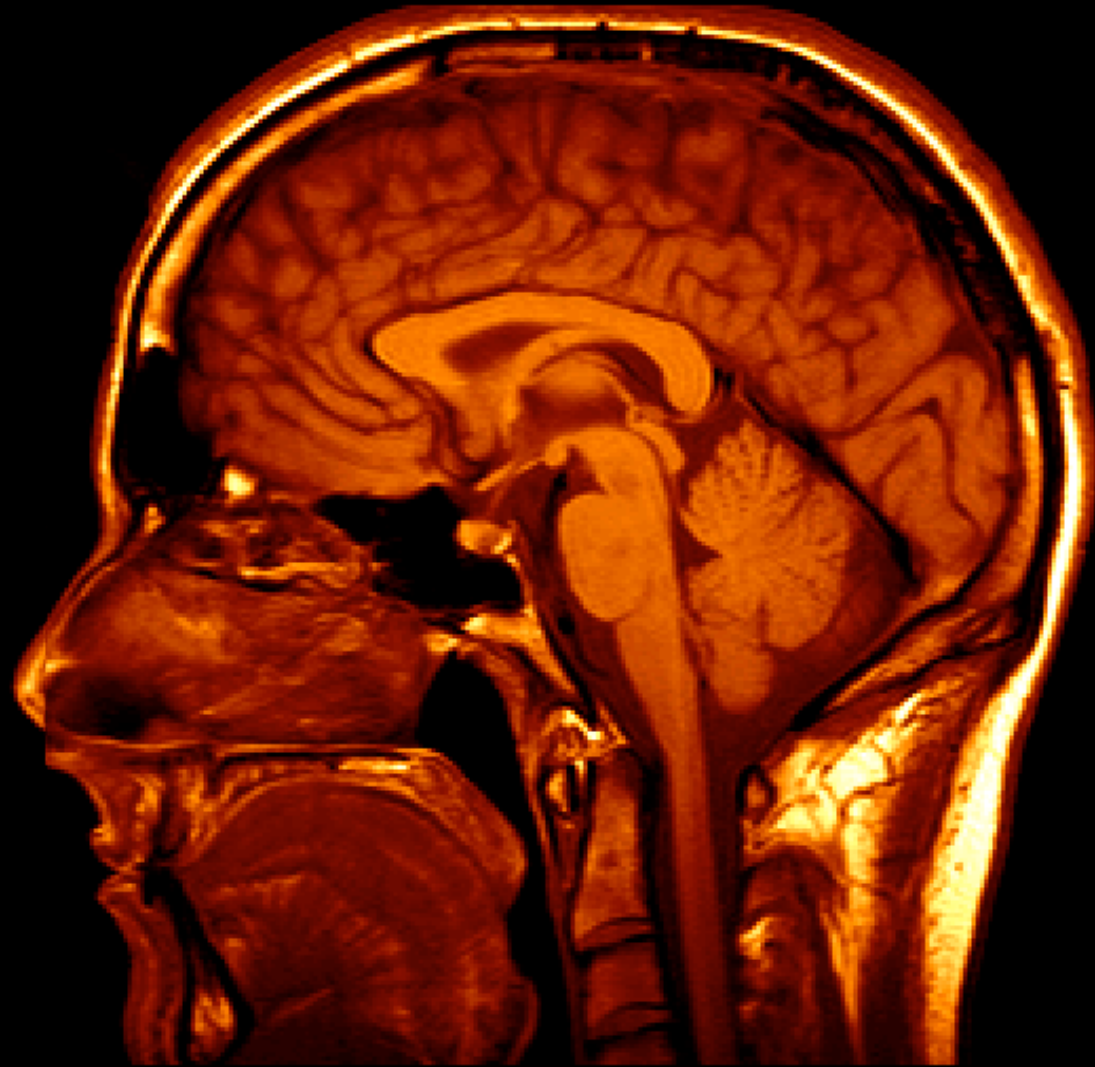
Course Topics

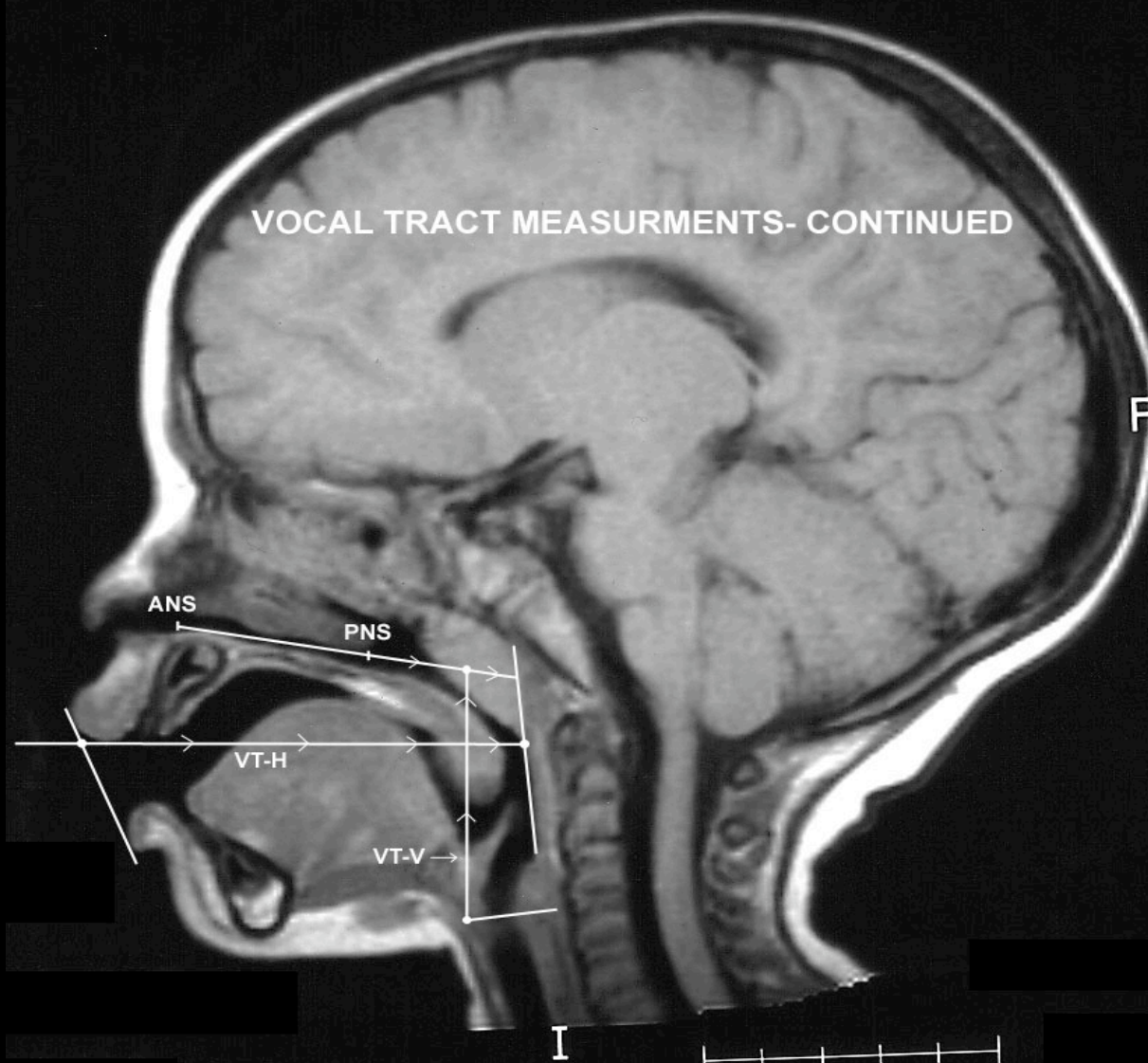
- similarity measures - correlation, mutual information, kappa index
- image simulation - random fields based
- statistical parametric mapping (SPM), multiple comparison correction
- computational statistics - EM algorithm, Newton-Raphson algorithm
- validation techniques

3D Medical Images

- Various imaging modalities can be modeled and analyzed in a similar mathematical principle.
- Examples of medical images: MRI, CT, PET, Ultrasound

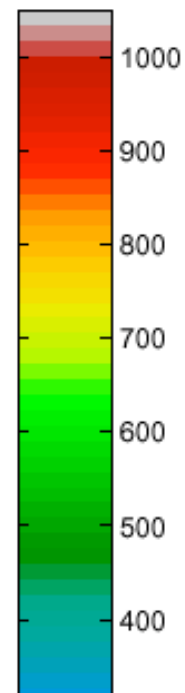
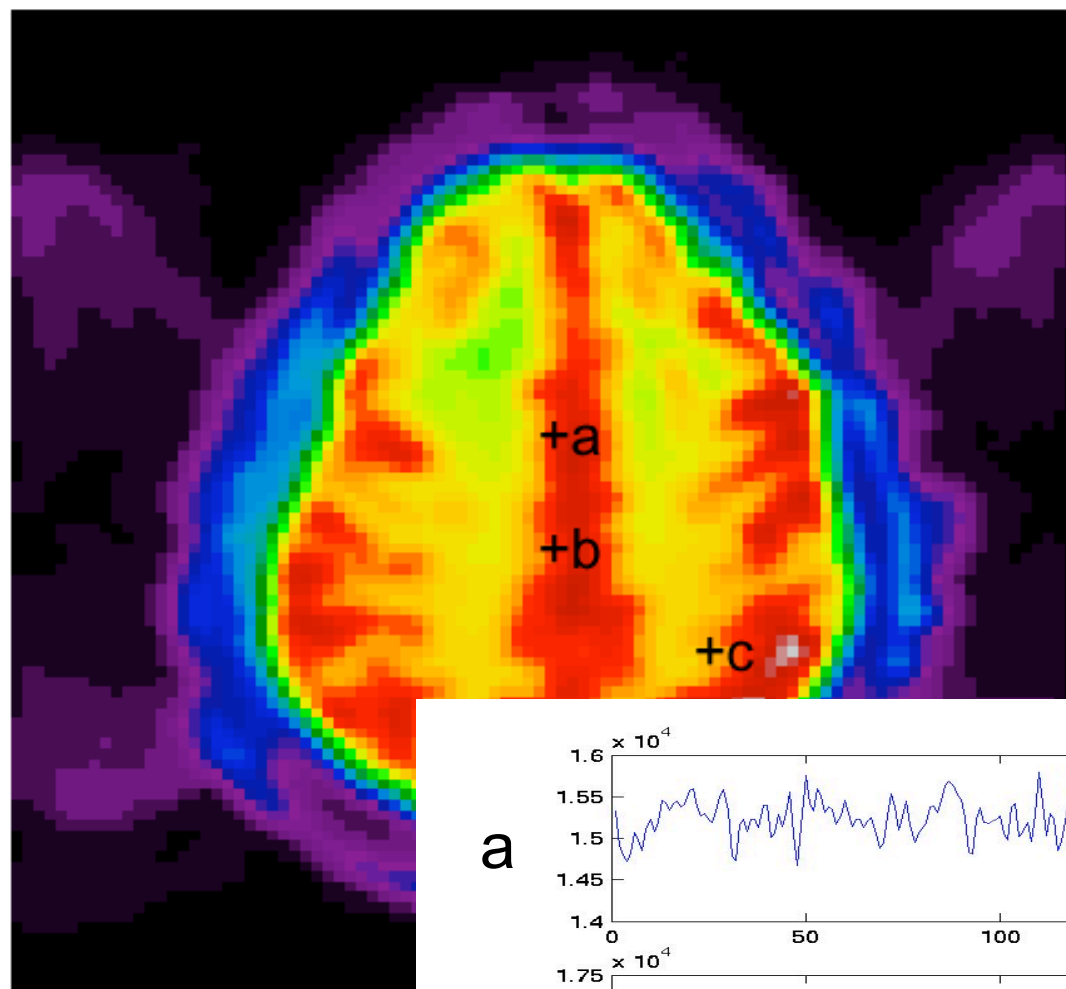
Magnetic resonance imaging (MRI)



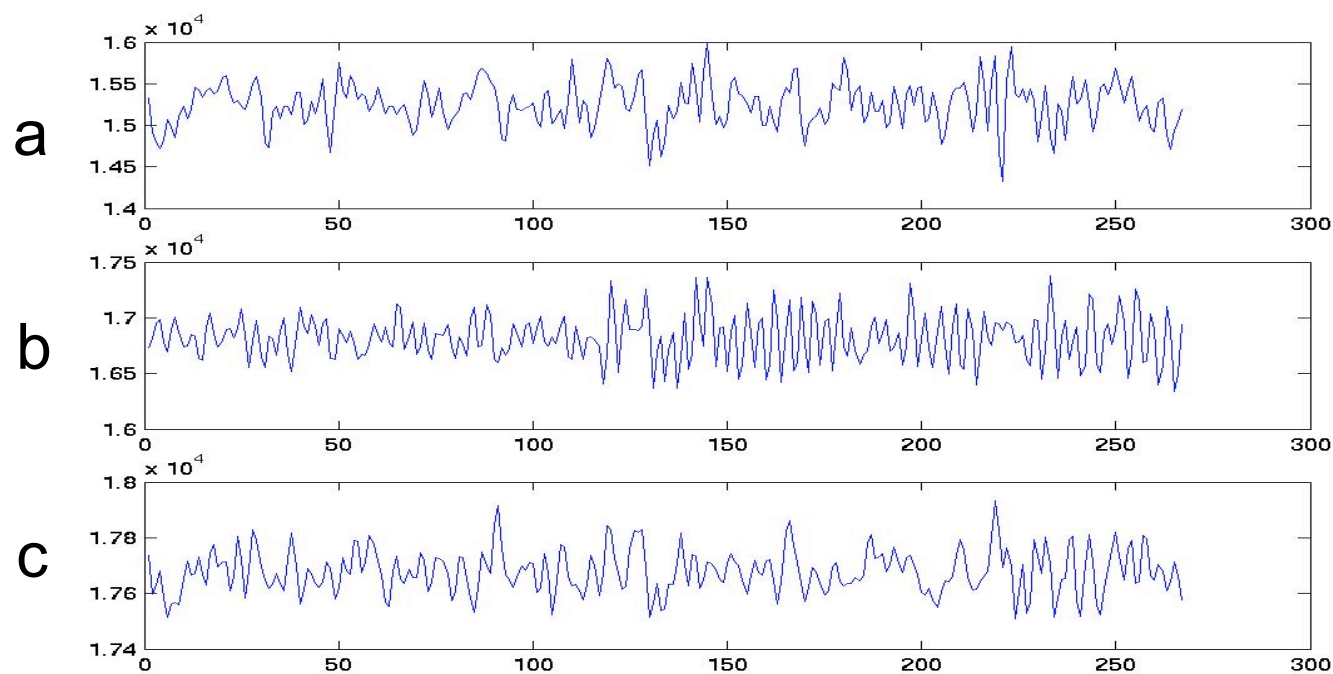


F14 (2;5)

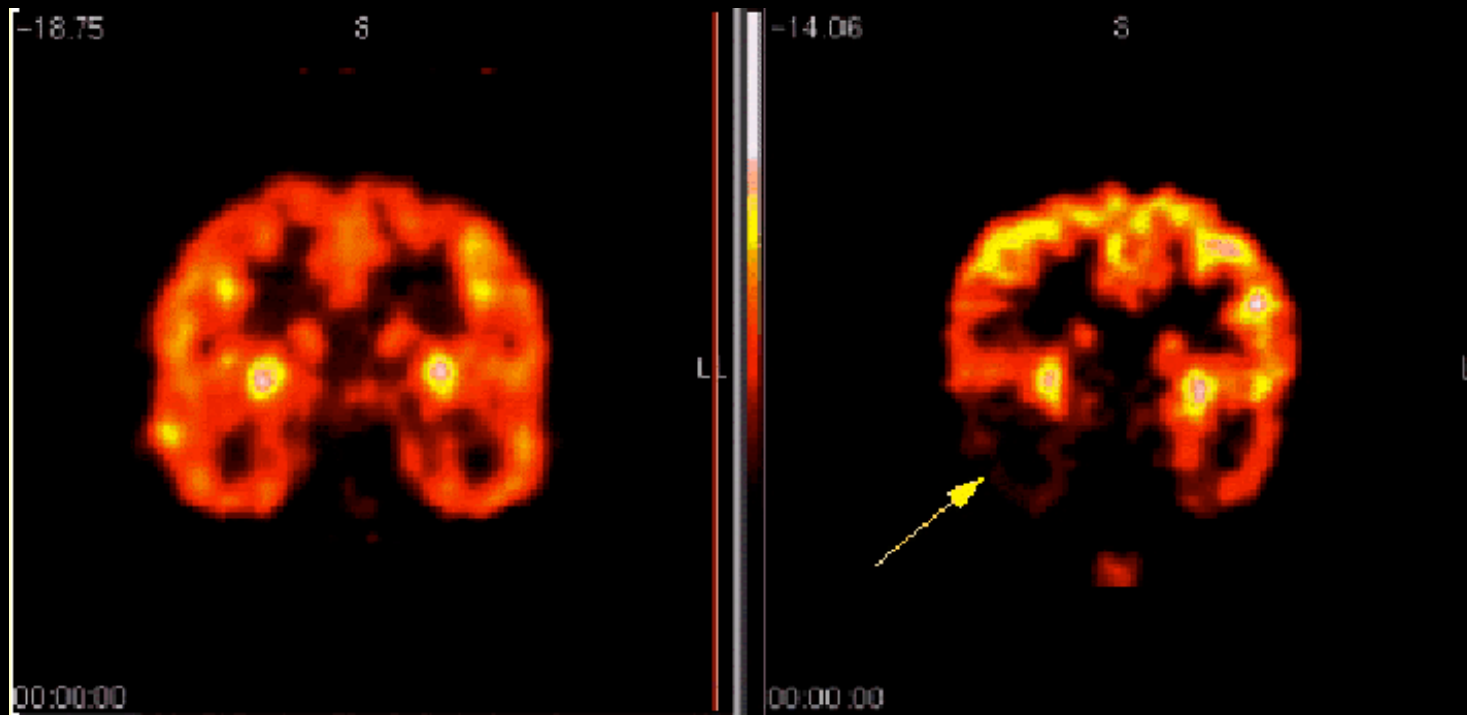
Source: Vocal tract development laboratory
University of Wisconsin-Madison



Functional MRI



Positron Emission Tomography (PET)

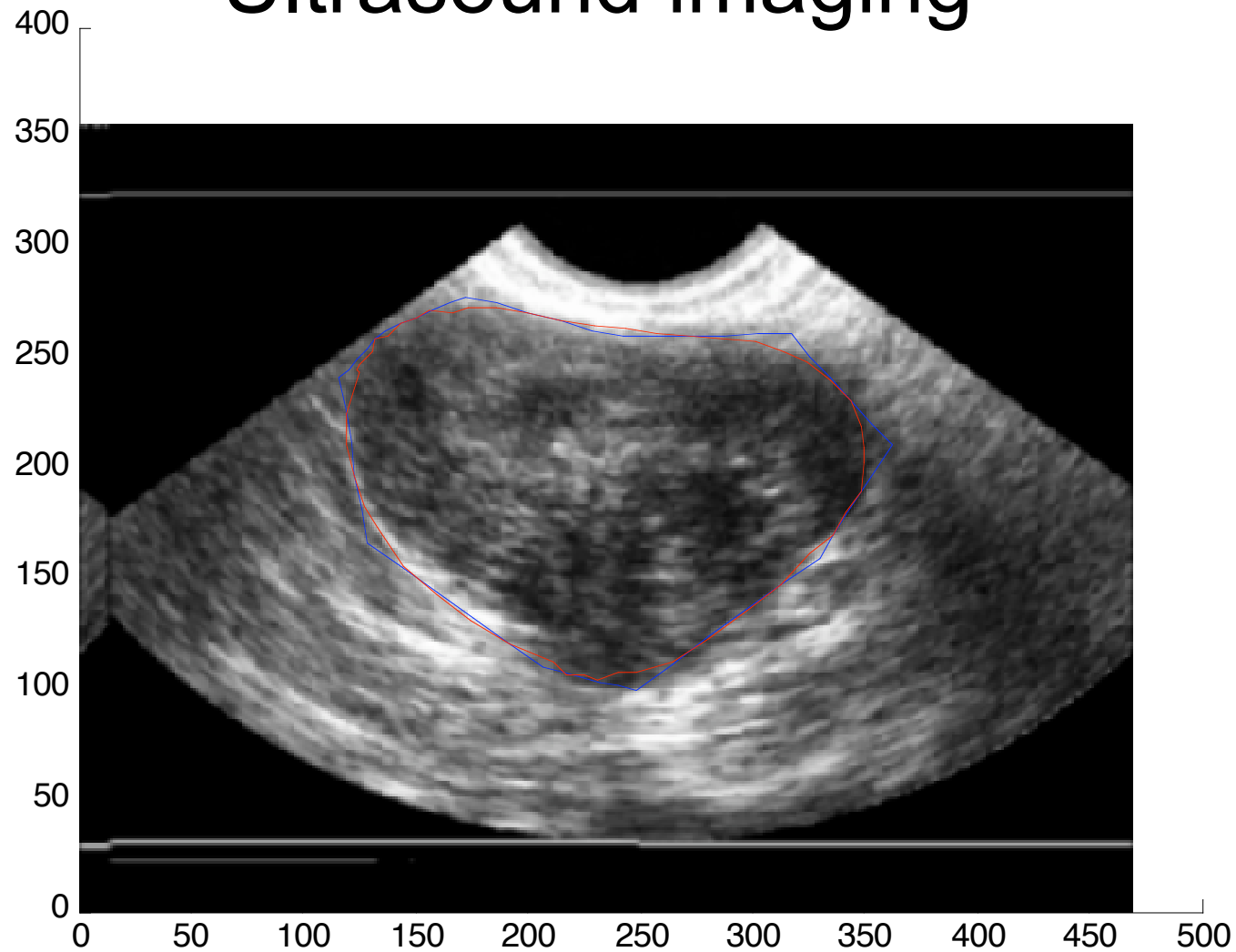


Normal Brain

Brain of 9 year old girl
suffering from epilepsy.

Source: Montreal Neurological Institute

Ultrasound imaging

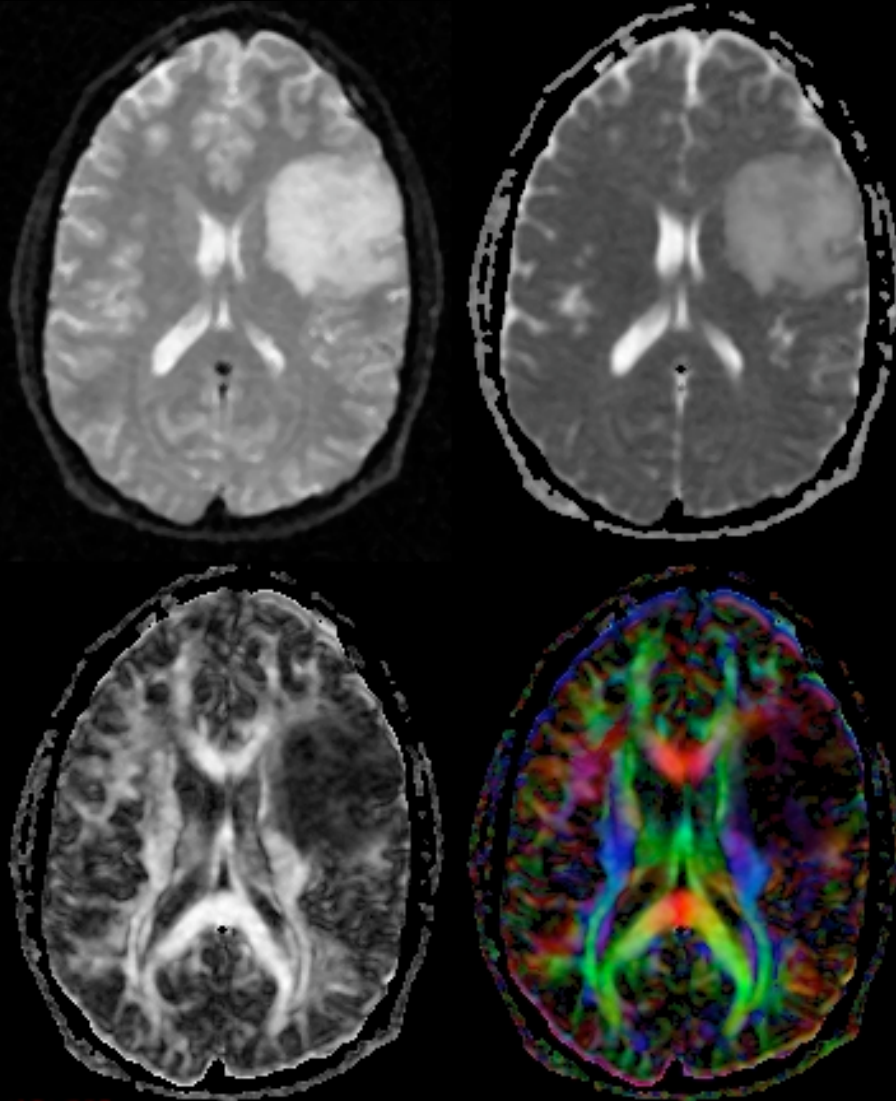


Active contour based cancer segmentation

Computed Tomography (CT) imaging



Diffusion tensor imaging (DTI)



<12>019

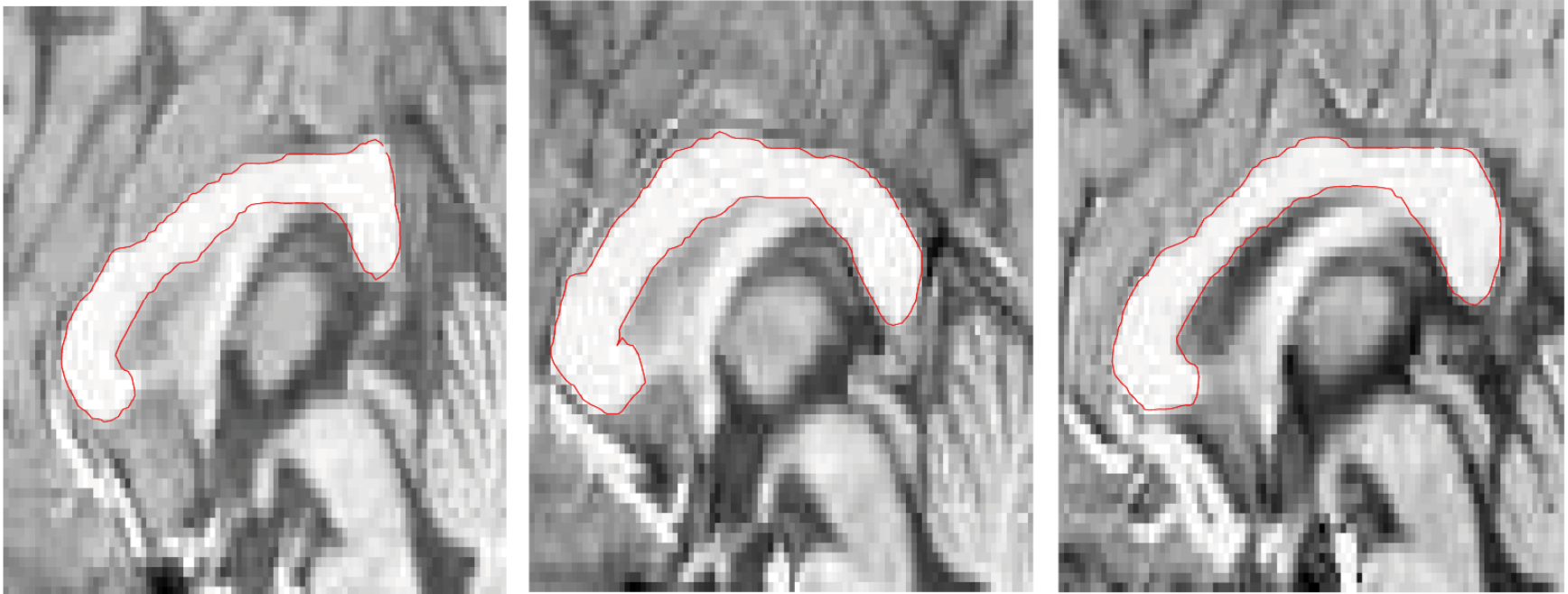
Tensor data =
3 by 3 matrix values
at each point.

Source: Andrew Alexander
University of Wisconsin-Madison

Main analytic issues

- **Image segmentation:** cancer, anatomical substructures
- **Image registration:** proper alignment within and between subject images
- **Imaging measurements:** Imaging based biomarkers, quantification of image characteristics
- **Image statistics:** Data analysis on imaging markers
- **Validation:** validation of the above procedures

Active contour based corpus callosum segmentation



Source: Shubing Wang
University of Wisconsin-Madison

1. Image segmentation

Skull

Outer
Cortical
Surface

Gray
Matter

Inner
Cortical
Surface

White
Matter

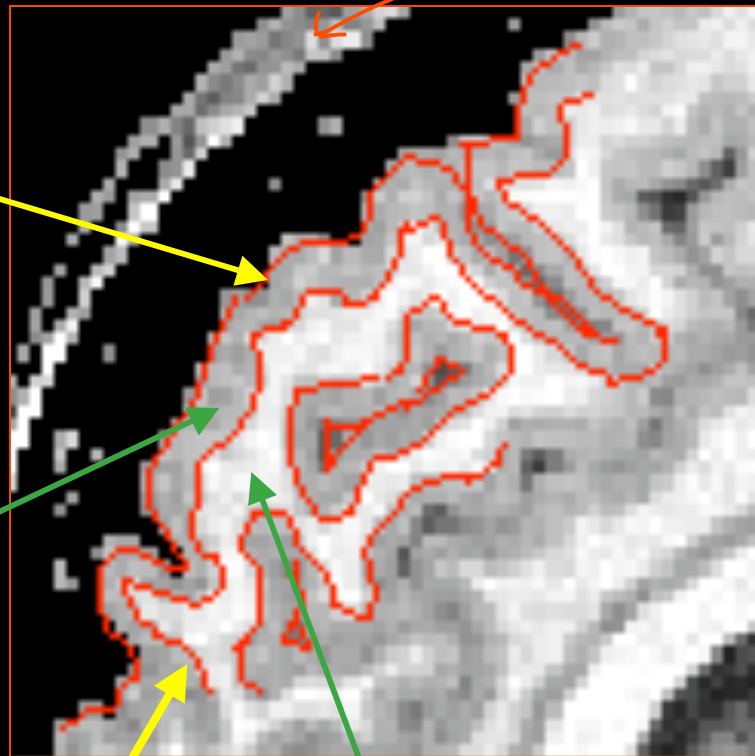
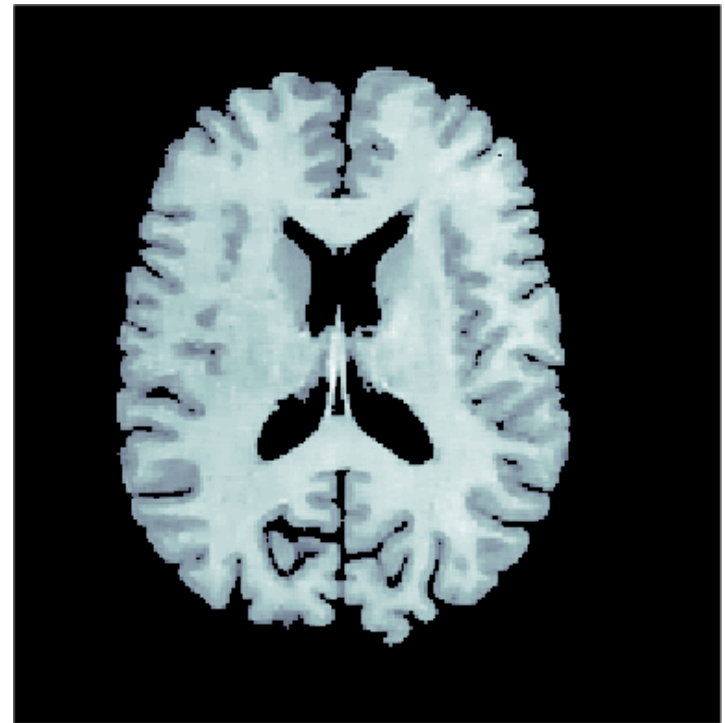
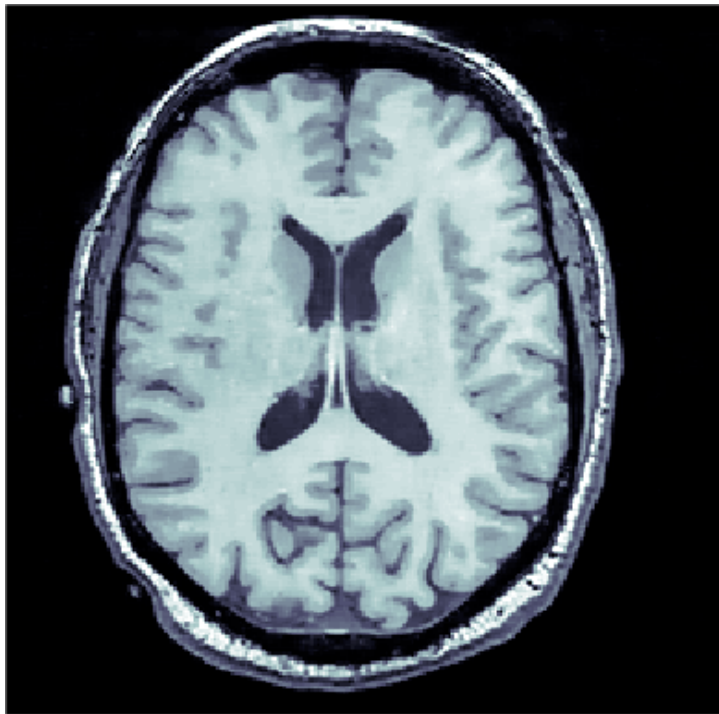


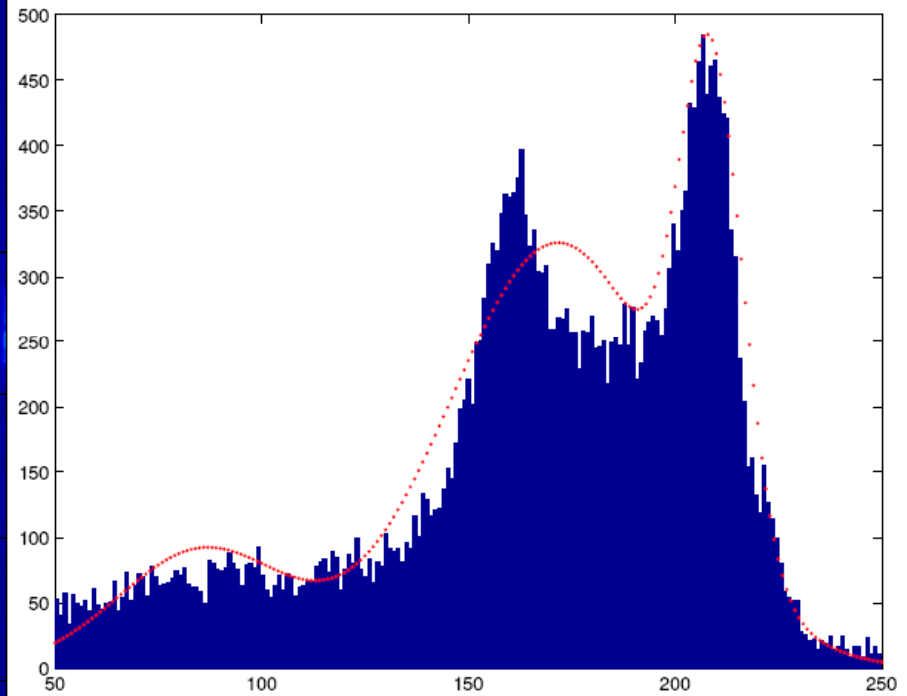
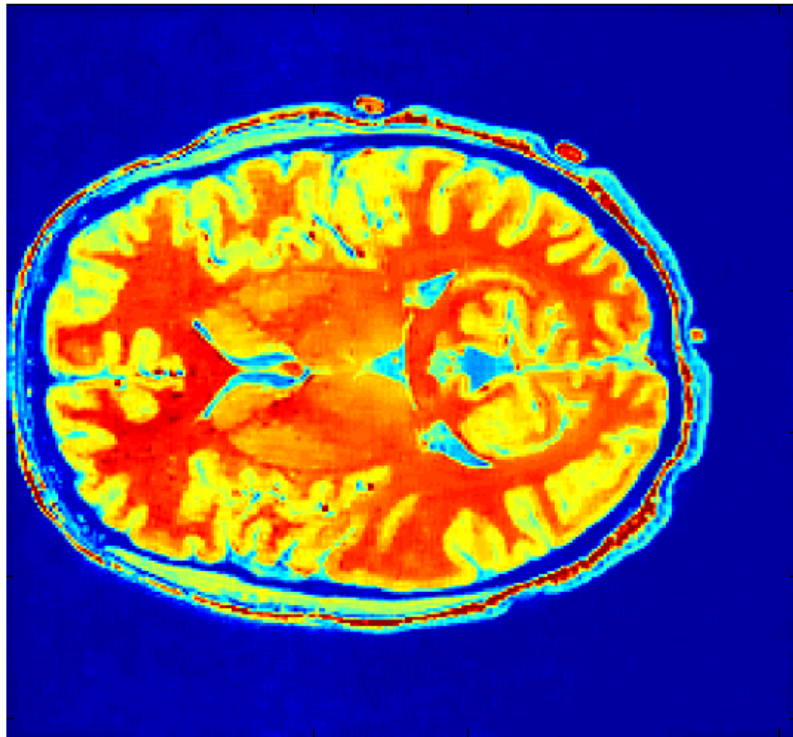
Image segmentation is
necessary to quantify
anatomical substructures

Segmentation based on maximum likelihood Gaussian mixture model



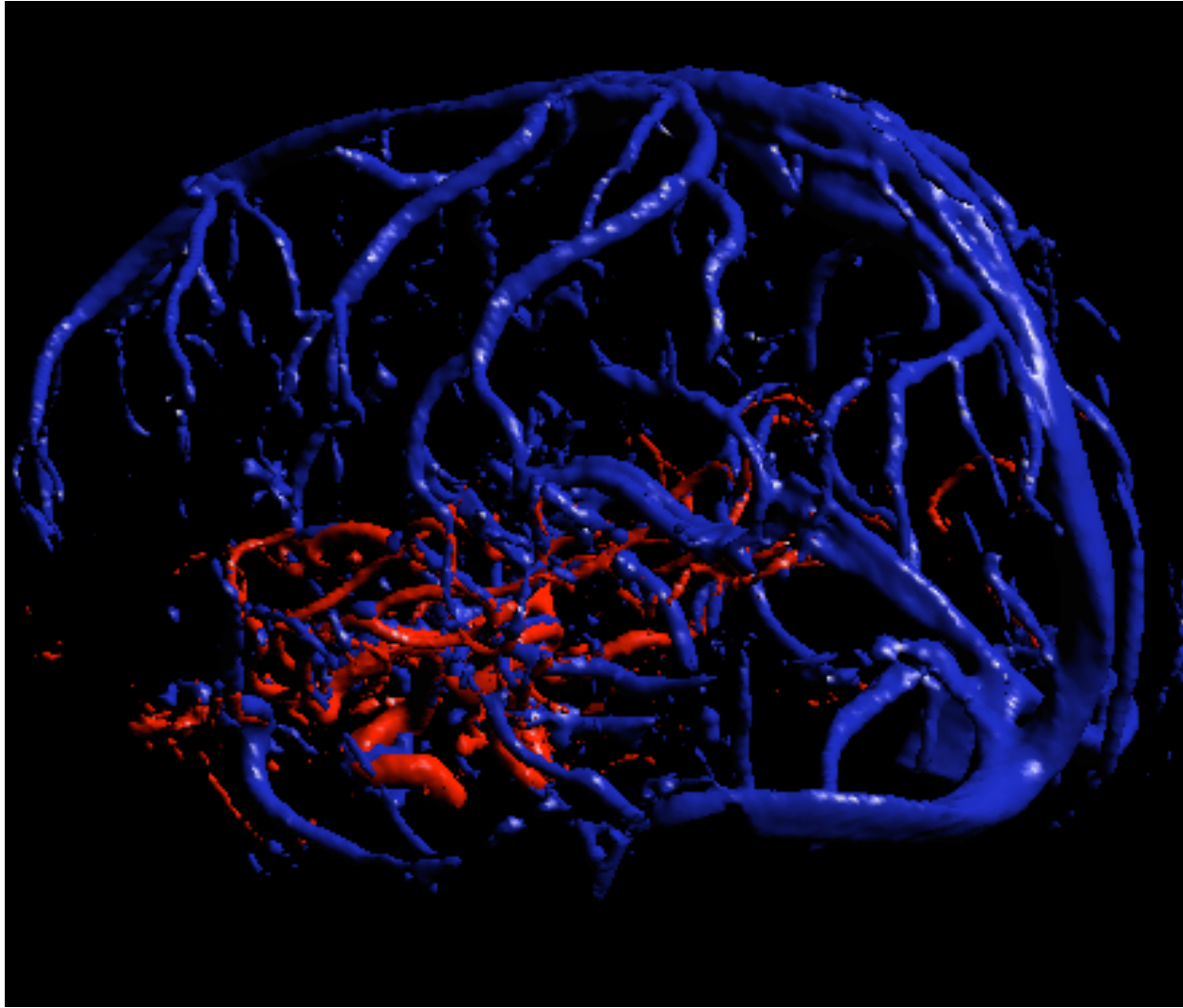
Automatic skull stripping can remove unwanted anatomical regions automatically.

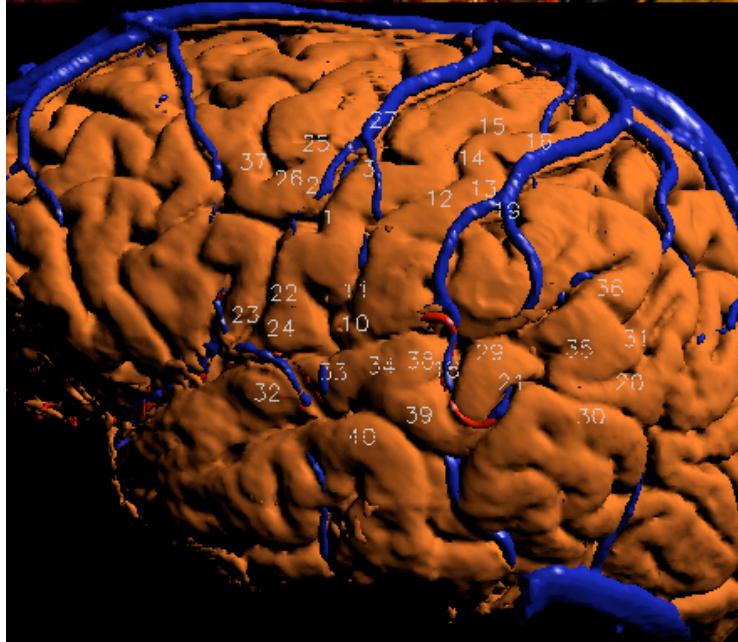
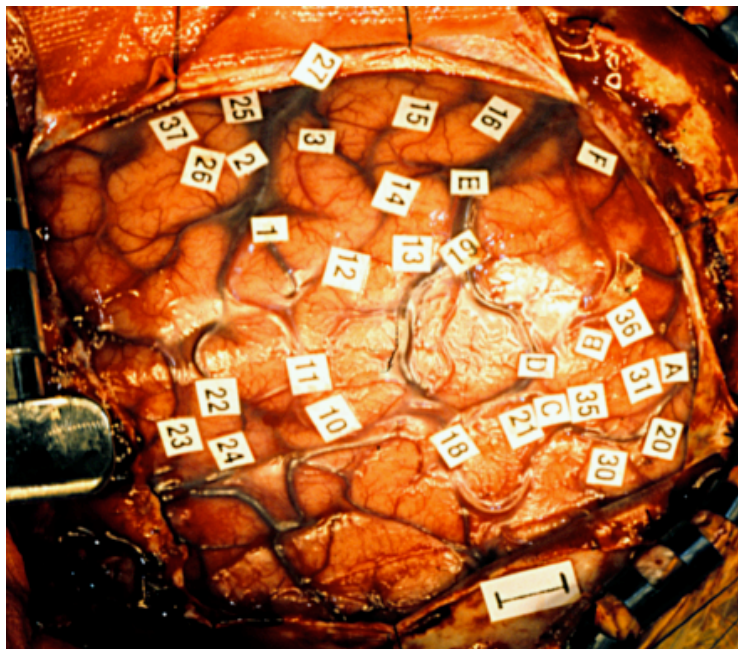
Gaussian mixture modeling - EM algorithm



Source: Shubing Wang
University of Wisconsin-Madison

Angiogram: image of blood vessels





Exit

> AF980803 E8033 S7 /1

Brain Site #36
Right 63.4389
Superior 7.91634
Anterior -34.2939
is NOT language-essential

Camera Controls
Light Controls
Number Sizes
MRI Window Width+Level
Isosurface experiments
Match Eyepoints
SAVE MAP

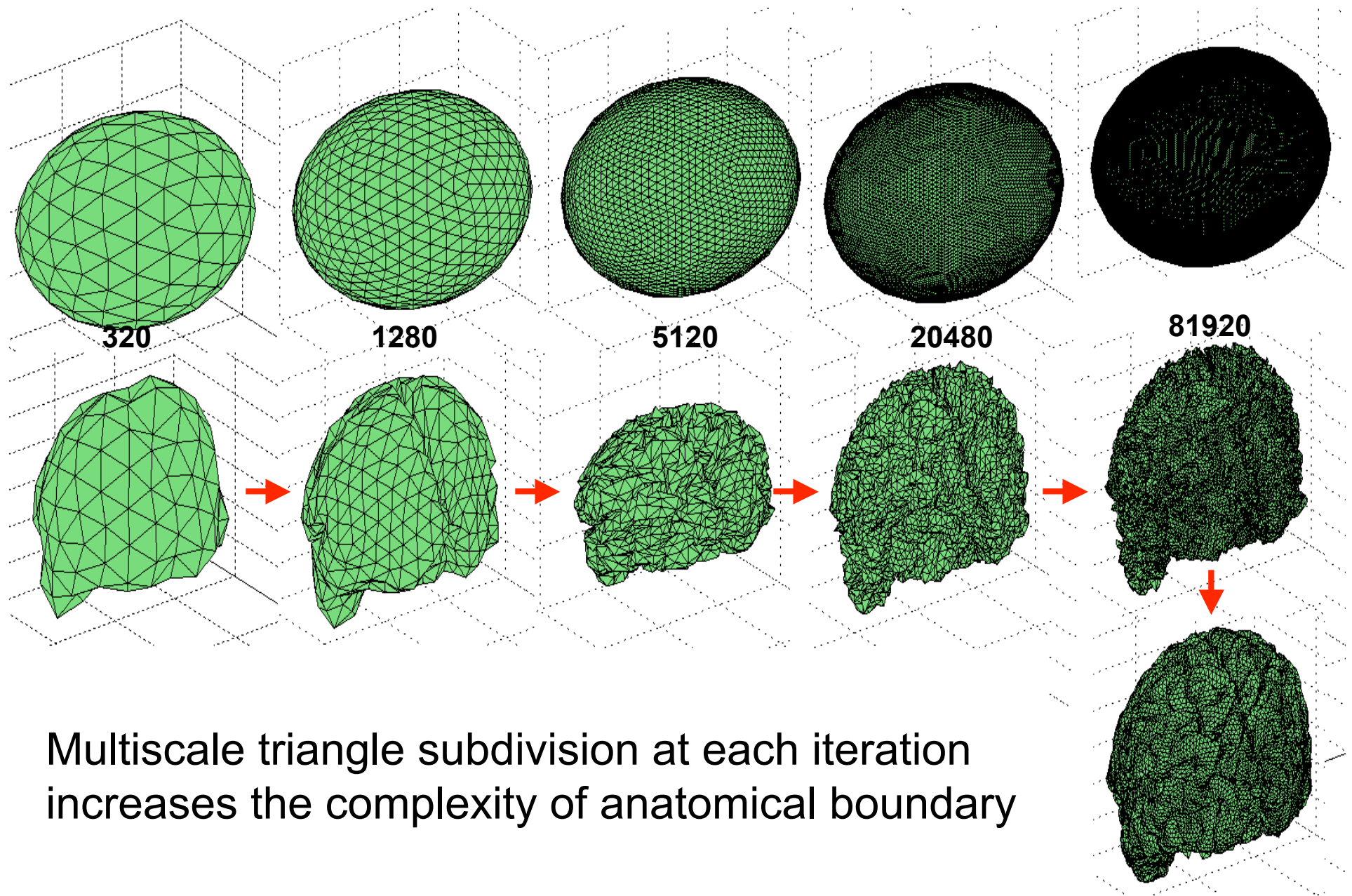
Cortex color
Artery color
Vein color

Snapshot Menu

6 / 8 4 5
9
17
28
41 42 43
46 47 48 49 50

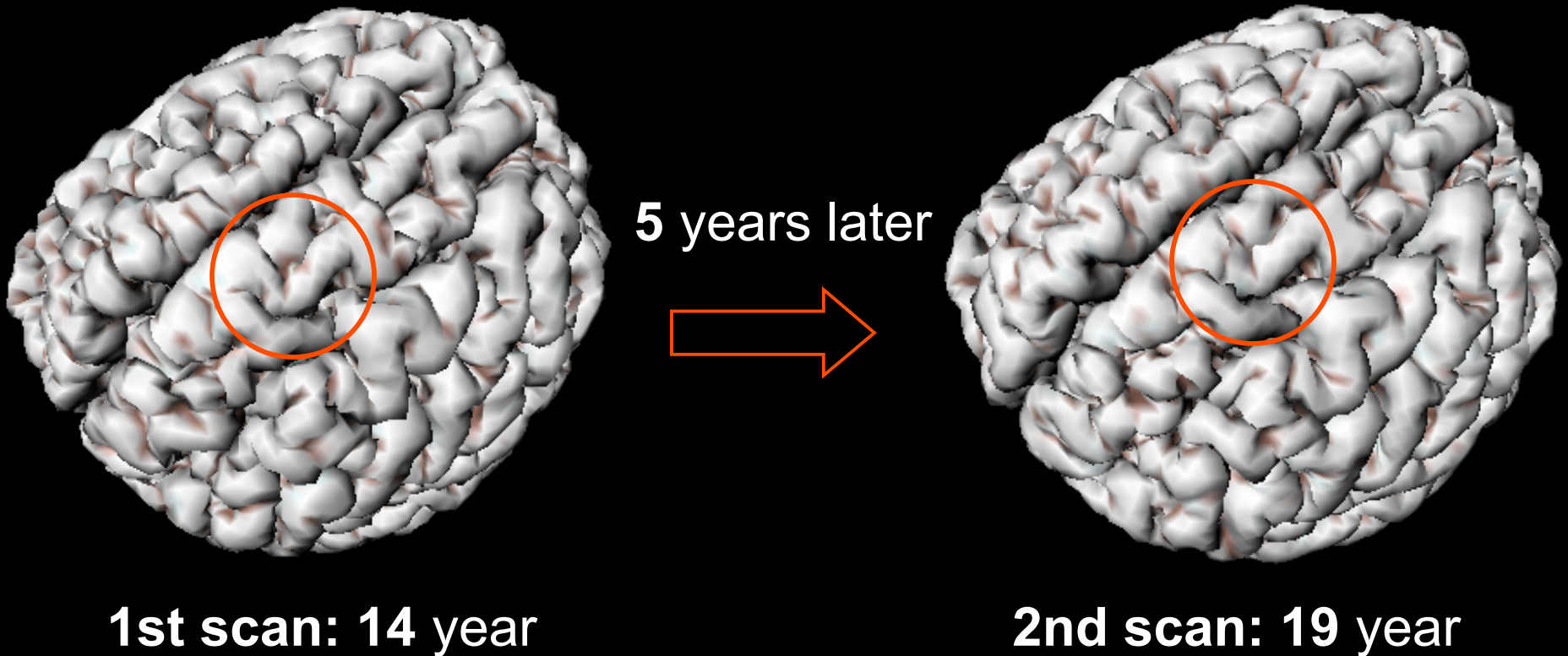
Source: Jim Brinkley
University of Washington

Deformable surface algorithm McDonalds *et al.* (2001) NeuroImage

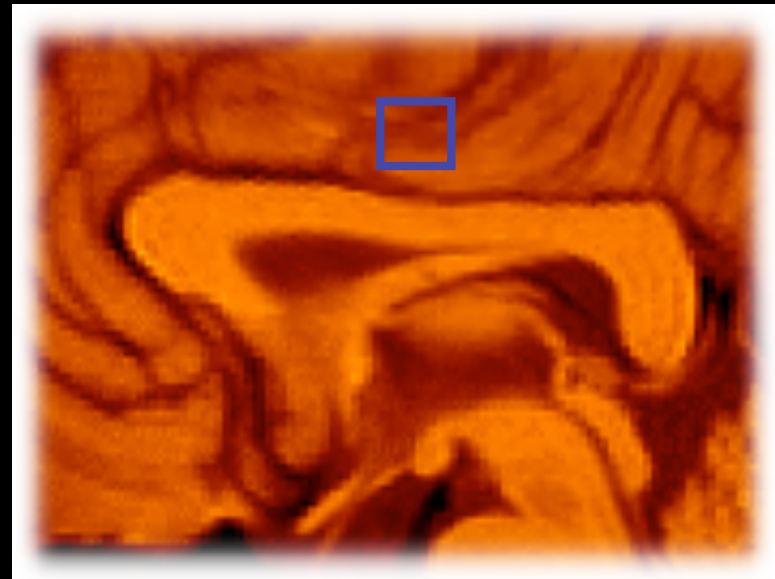
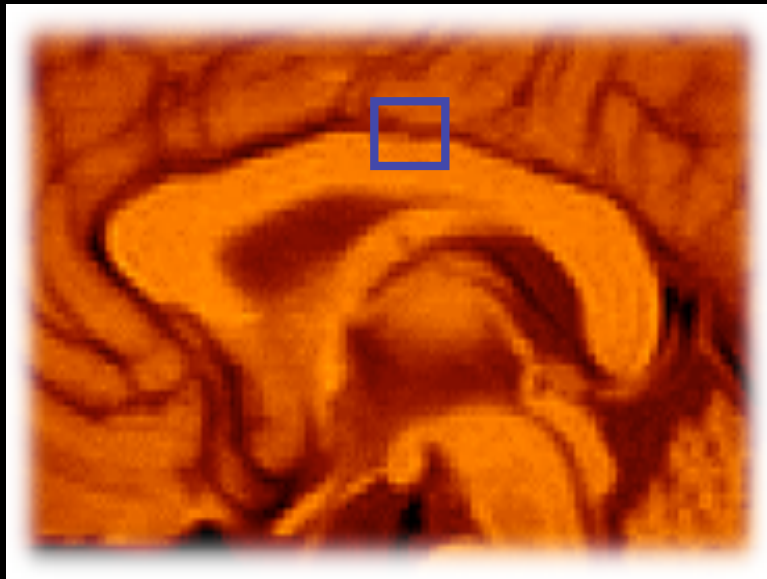


2. Image Registration

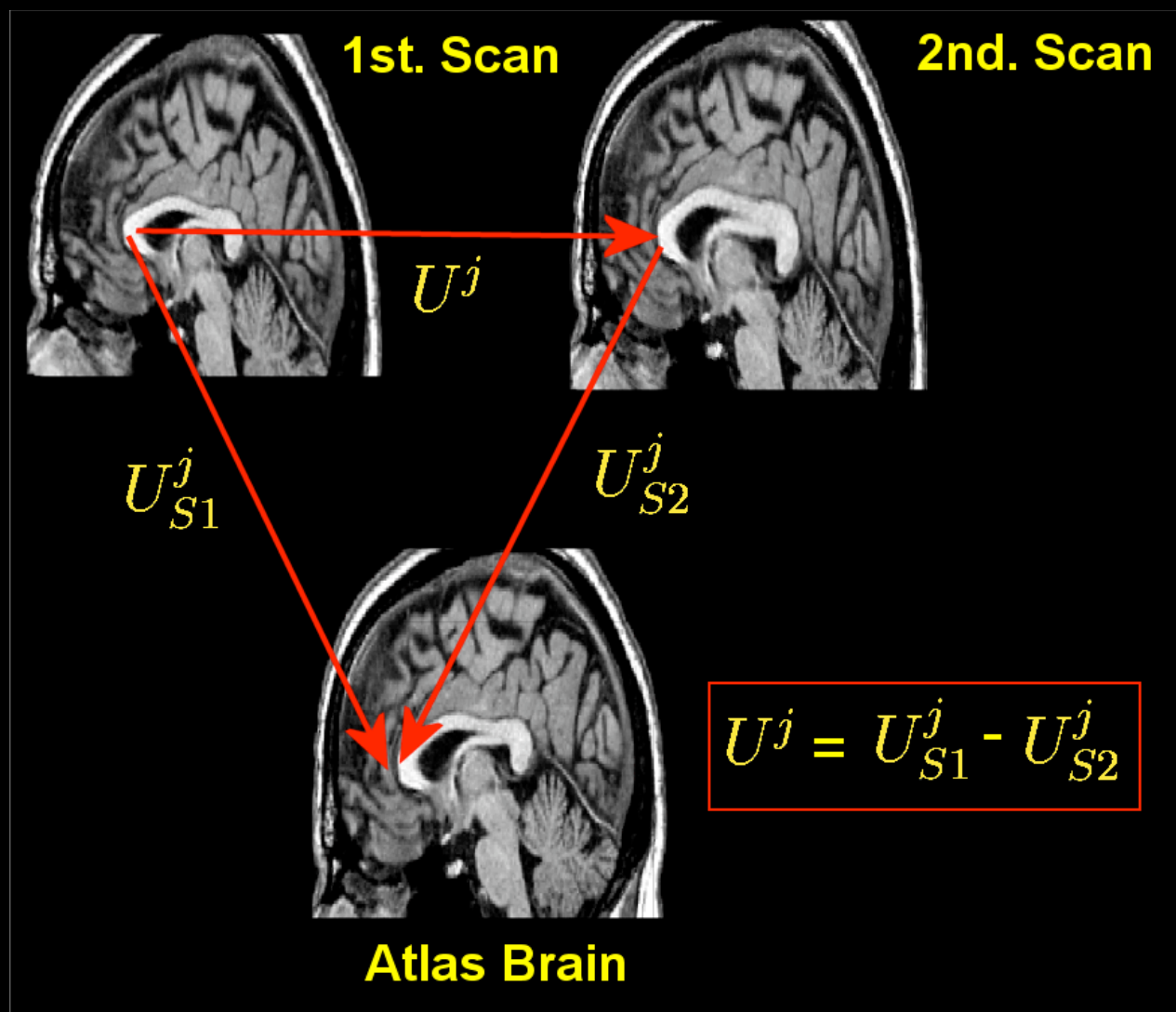
Need to establish anatomically corresponding voxels within subject or between subjects for comparison.



The aim of image registration is to find a smooth one-to-one mapping that establishes a reasonable anatomical correspondence automatically.



Displacement vector fields



Deformation vs. Displacement

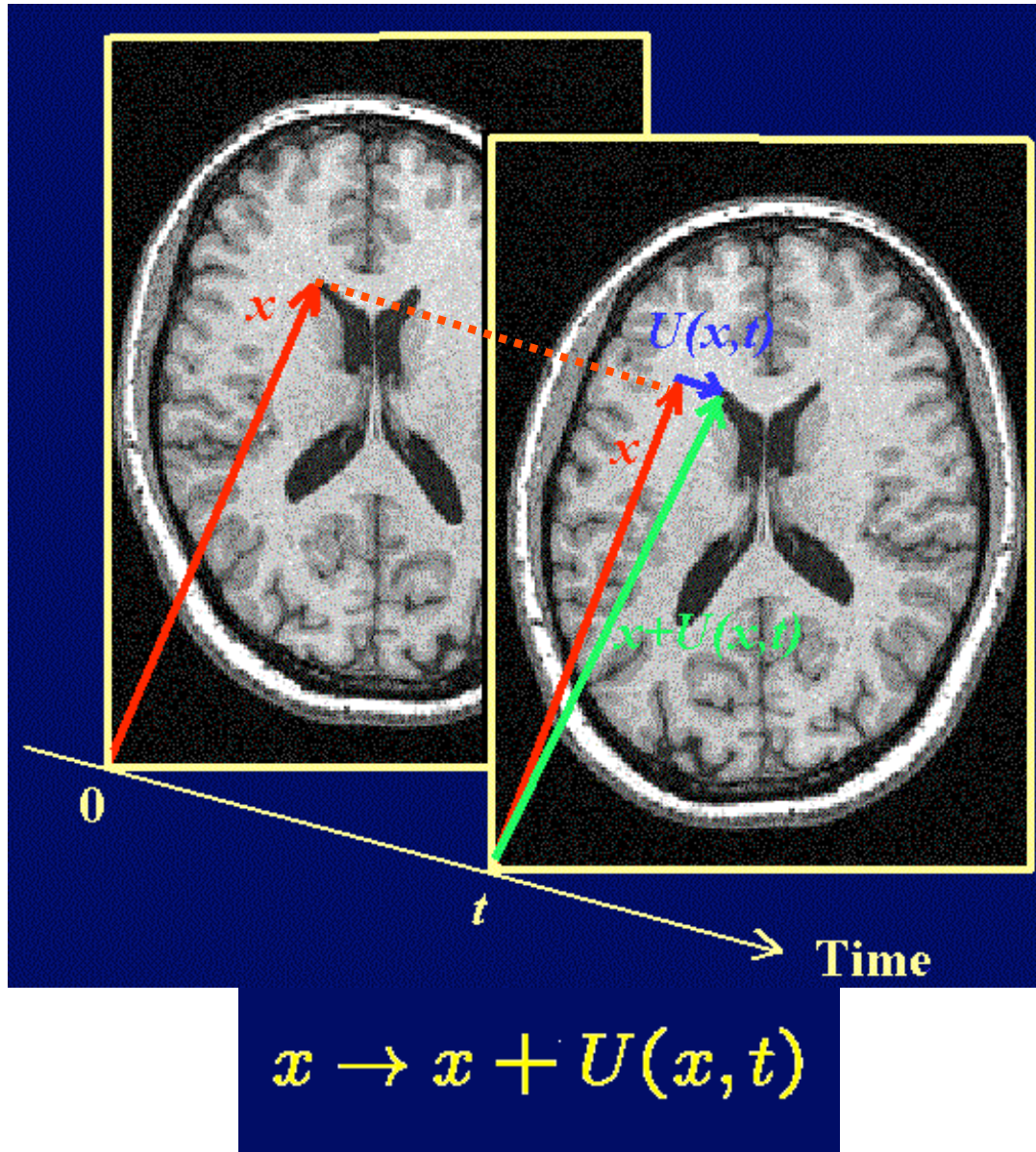


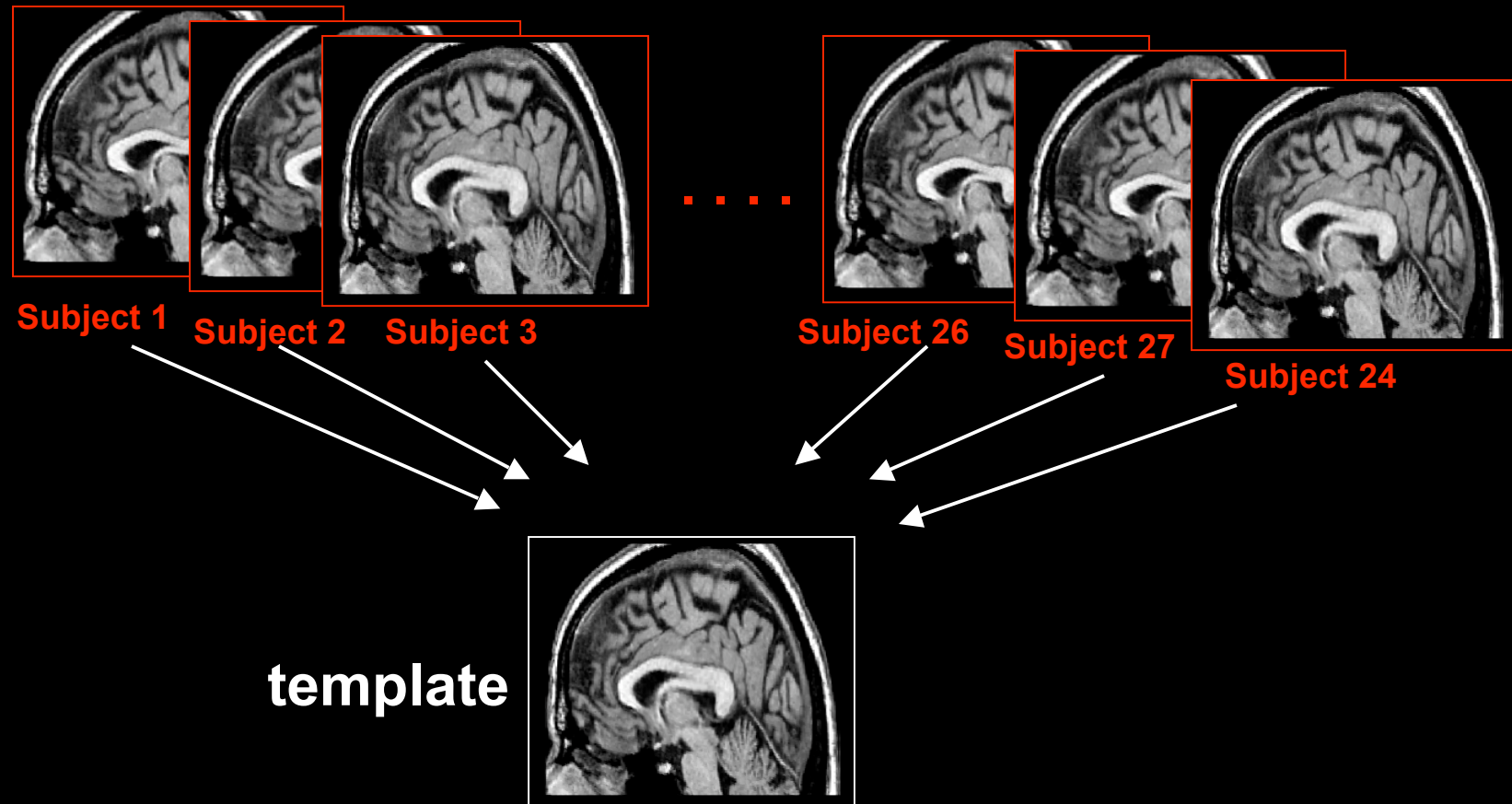
Image registration algorithms

- Elastic deformation based
- Fluid dynamics based
- Intensity correlation based
- **Basis function approach**
- Bayesian approach

Deformation field expressed in polynomial basis

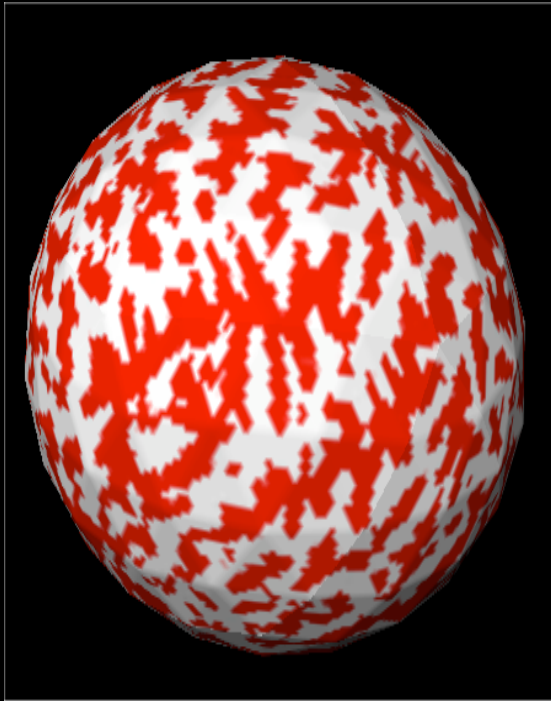
	x'=	y'=	z'=	
	-1.212161e+02	-1.692117e+02	1.239336e+00	
+	2.846339e+00	9.860215e-01	-4.670216e-03	x
+	4.541216e-01	3.344188e+00	-1.022118e-02	y
+	2.277959e+00	1.849708e+00	9.958860e-01	z
+	-9.744798e-03	-4.951447e-03	1.253383e-05	x^2
+	-4.519879e-03	-4.248561e-03	-2.655254e-05	x*y
+	-9.122374e-04	-9.371881e-03	4.040382e-05	y^2
+	-1.624103e-02	-3.371953e-03	2.356452e-06	x*z
+	-3.519974e-03	-2.799626e-02	9.228041e-05	y*z
+	-1.572948e-02	-1.688950e-03	5.386545e-05	z^2
+	2.495023e-05	4.120123e-06	3.604820e-08	x^3
+	3.232645e-06	1.739698e-05	1.044795e-07	x^2*y
+	1.074305e-05	4.357408e-06	-9.302004e-10	x*y^2
+	-1.059526e-06	1.699618e-05	1.166377e-07	y^3
+	5.512034e-06	9.330769e-06	-2.219099e-08	x^2*z
+	1.275631e-05	-9.233413e-06	1.236940e-07	x*y*z
+	-5.236010e-07	3.234824e-05	-6.819396e-07	y^2*z
+	9.506628e-05	1.214112e-05	-1.238024e-07	x*z^2
+	2.016546e-05	1.475354e-04	-1.693465e-08	y*z^2
+	3.377913e-06	-7.093638e-05	-2.757074e-07	z^3

Image registration of multiple subjects

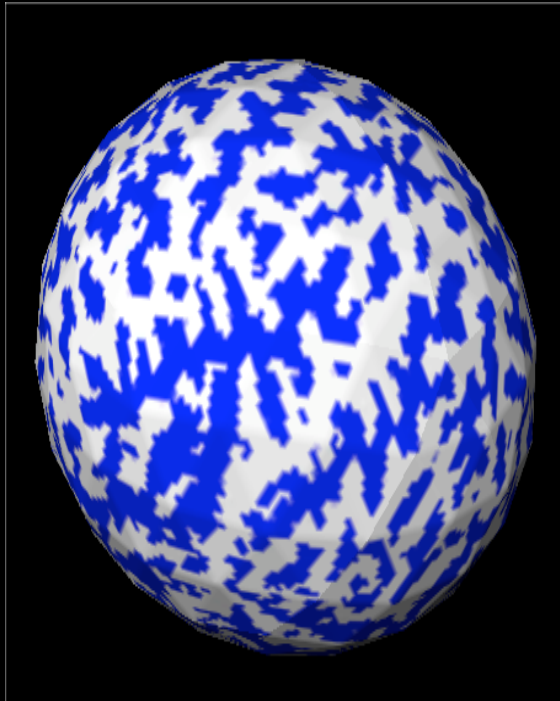


The subsequent statistical analysis is performed on this template.

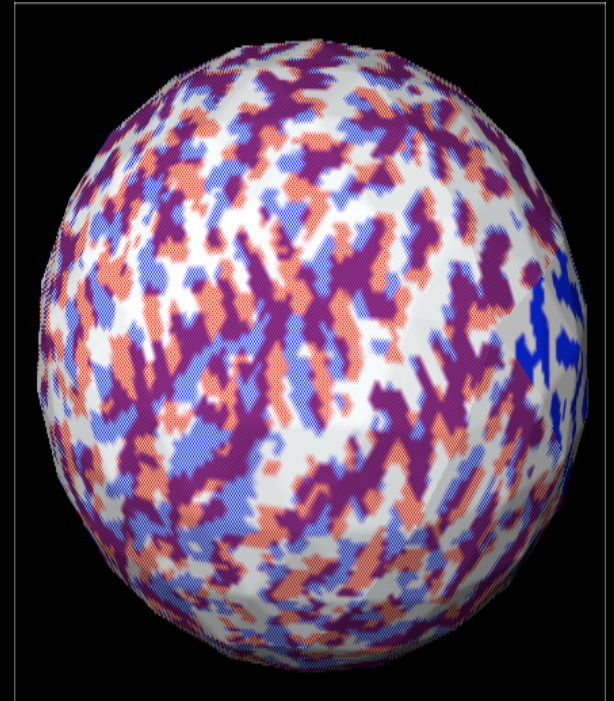
Surface-to-Surface registration sulcal pattern (surface) matching



14 year



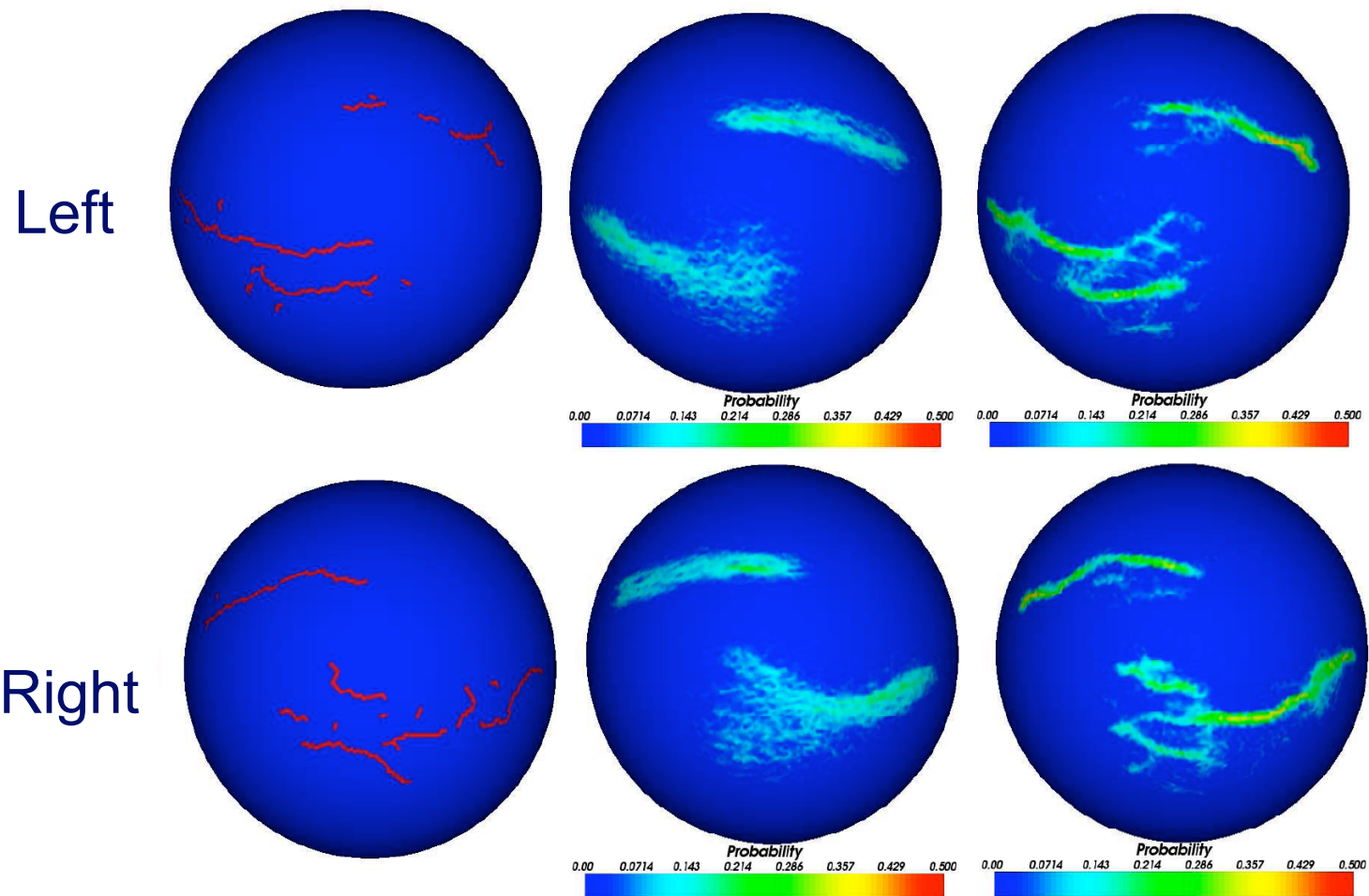
19 year



superimposition

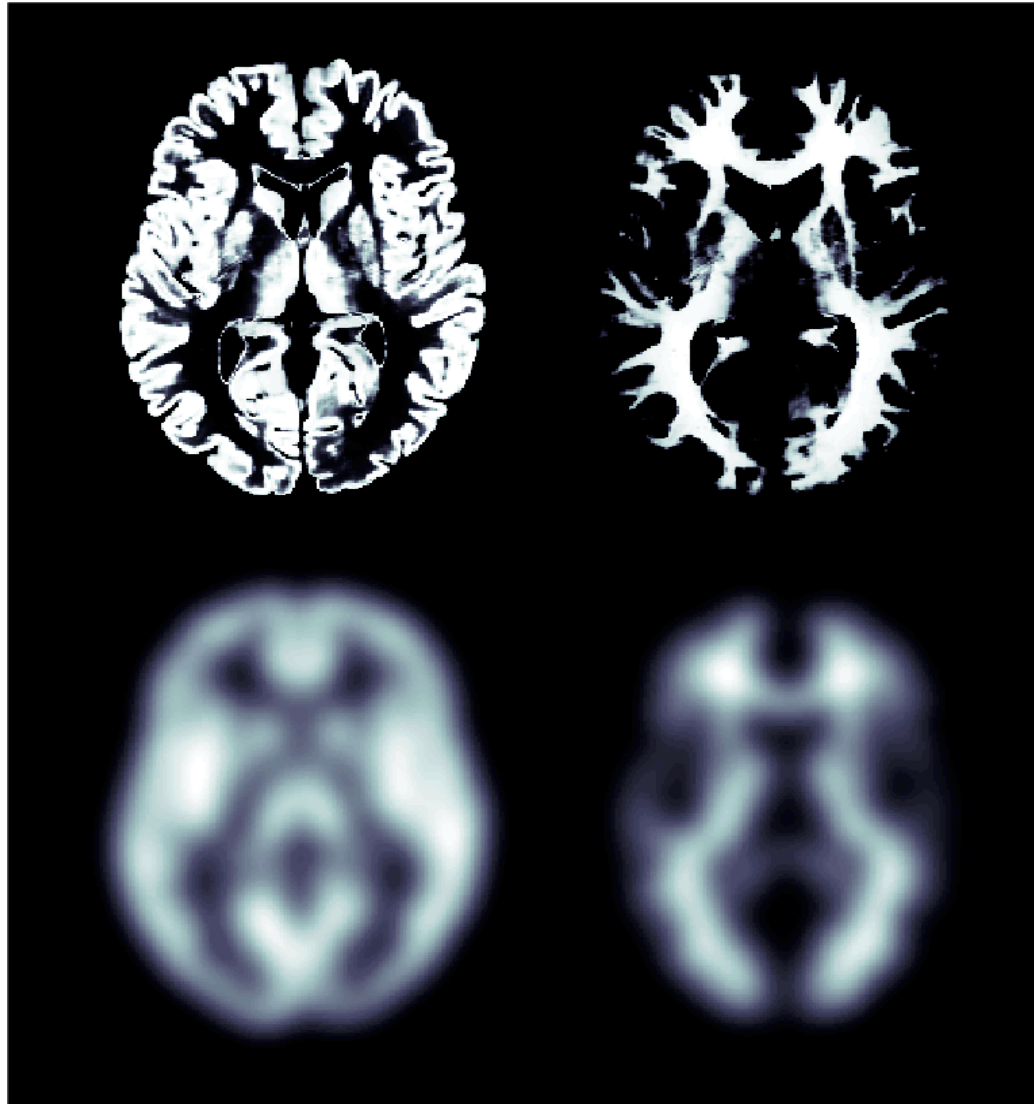
Validation based on 149 subjects

NeuroImage (2005)



Central and temporal sulcus

3. Imaging measurements: what to measure?



Gray matter

White matter

Binary masks: 0 or 1



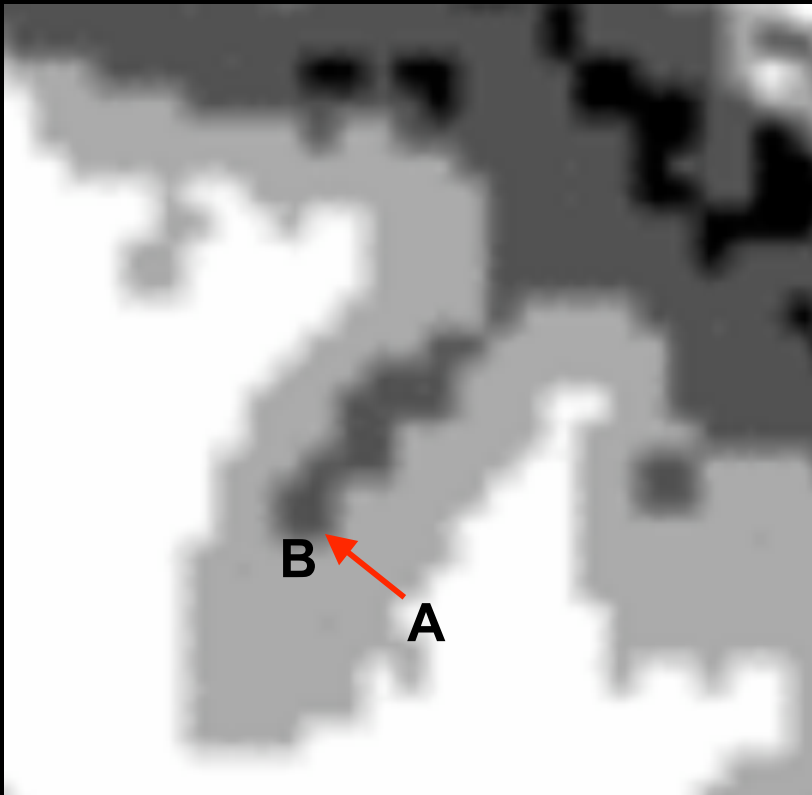
**Gaussian
kernel smoothing**



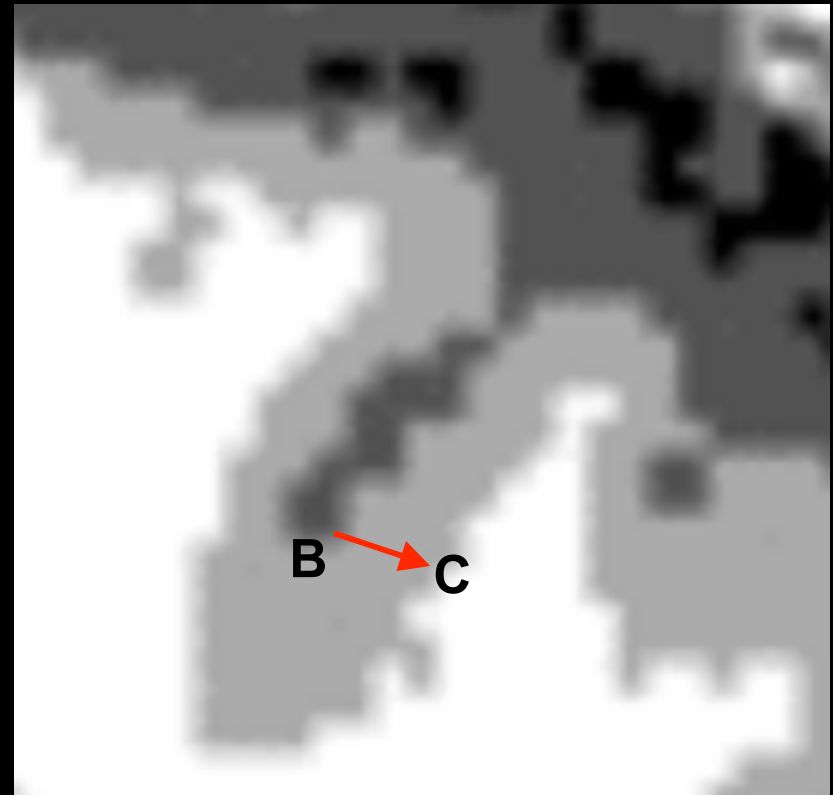
Probability map [0 , 1]

Cortical thickness

Inconsistent mathematical definitions. There are five proposed methods of measuring distance between tissue boundaries.

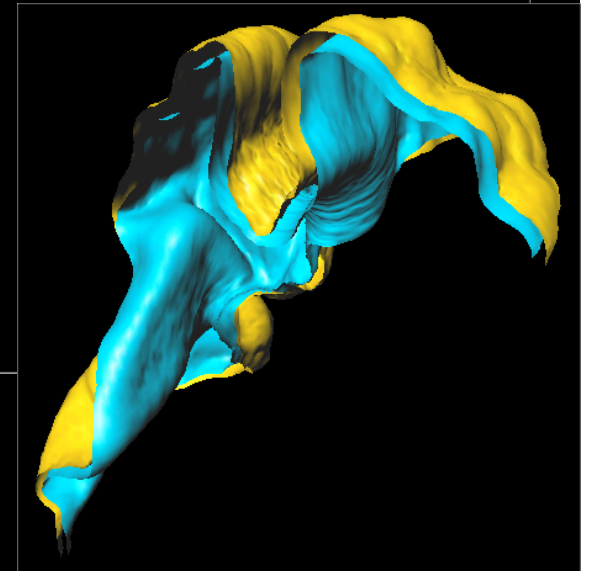
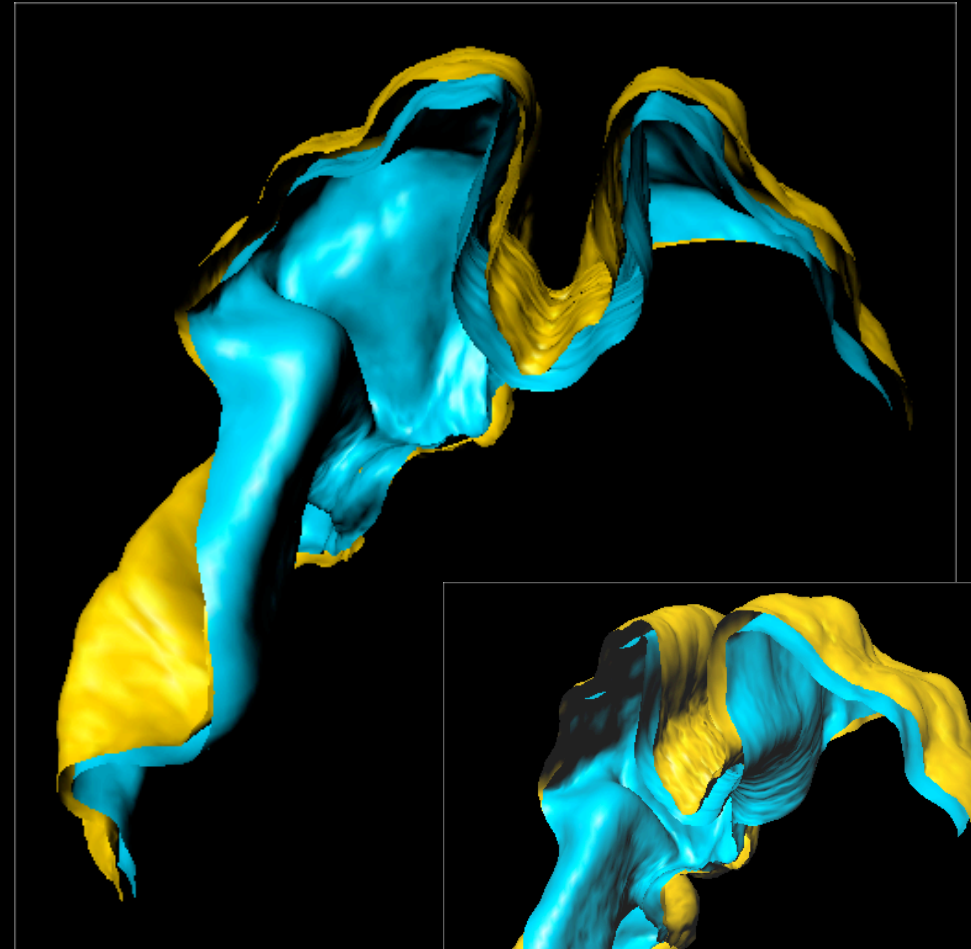
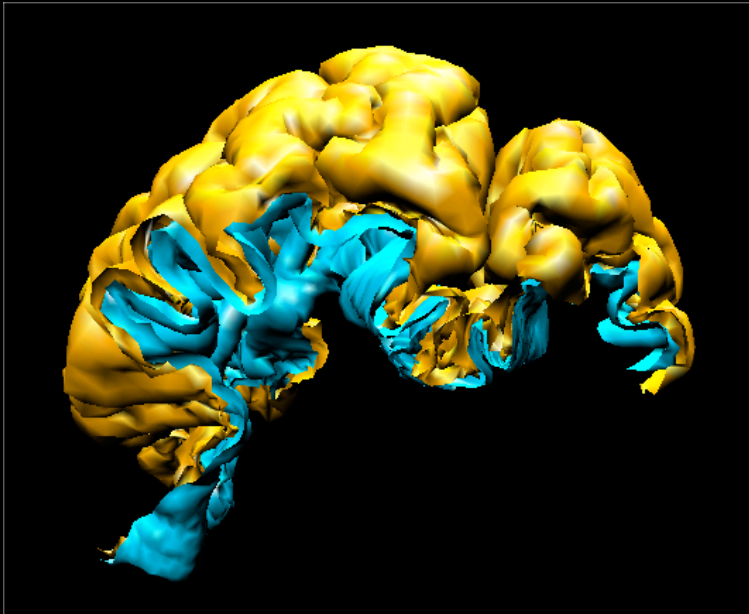


orthogonal projection from A to B

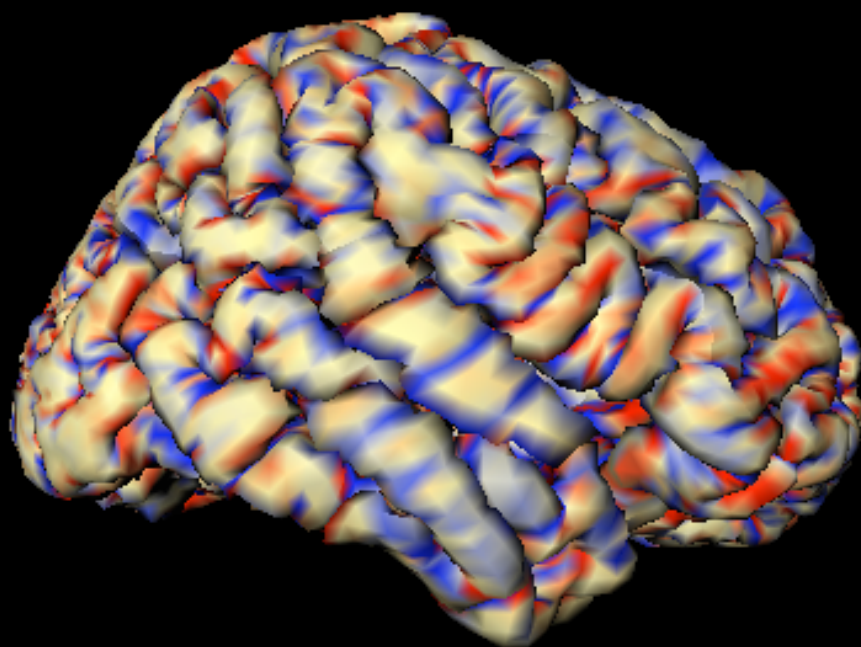


orthogonal projection from B to C

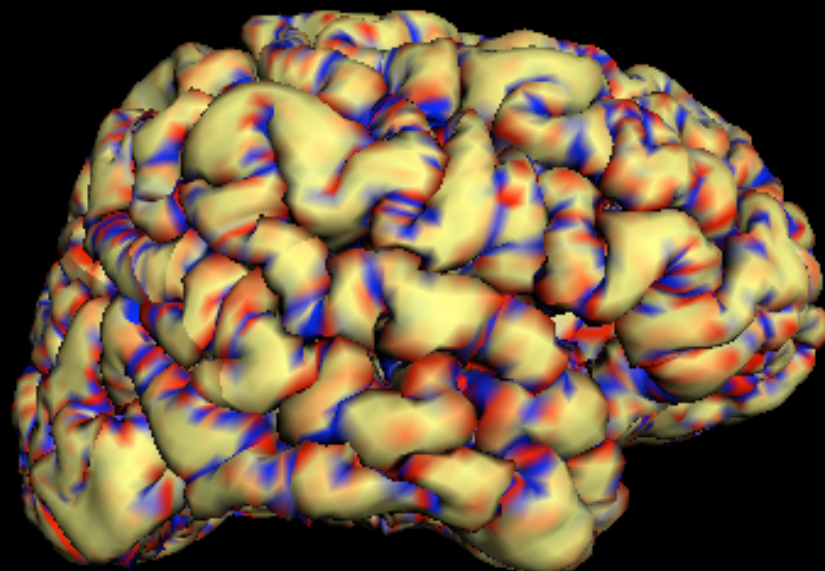
Distance based measurement - cortical thickness



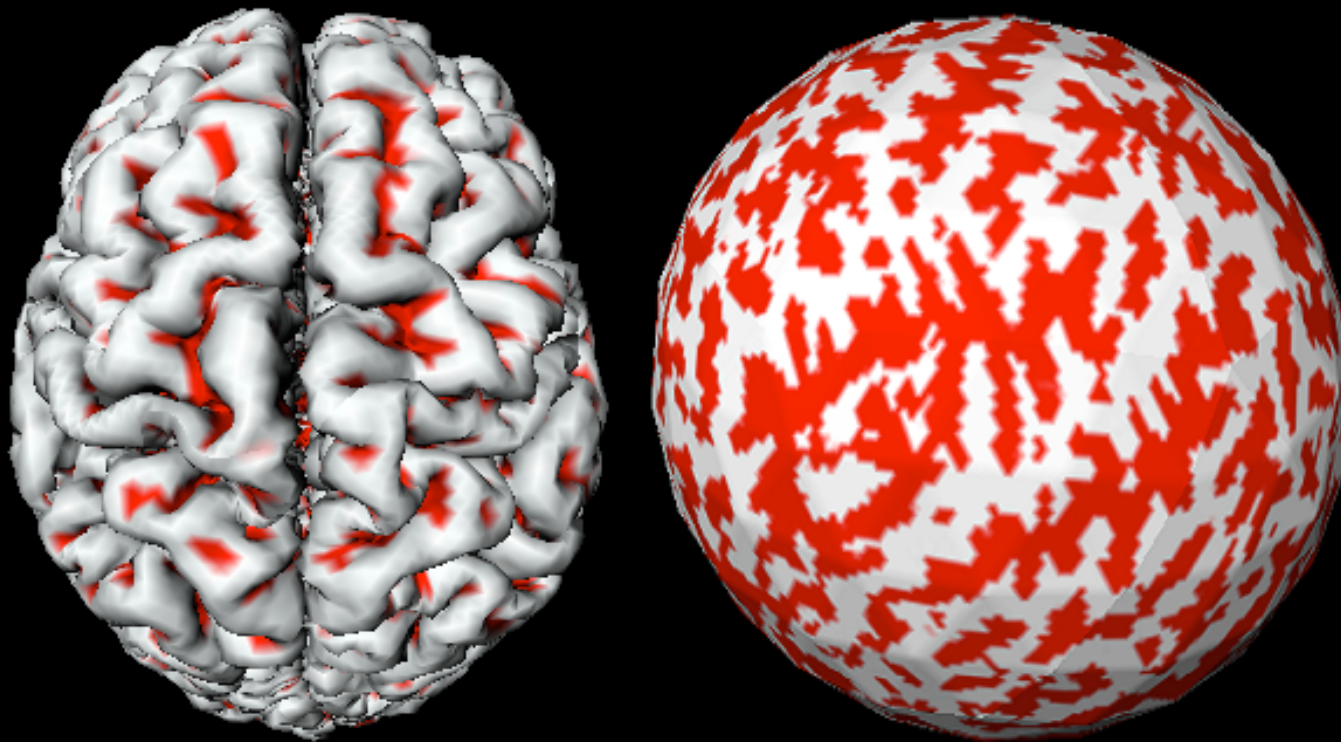
Mean Curvature



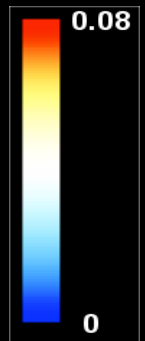
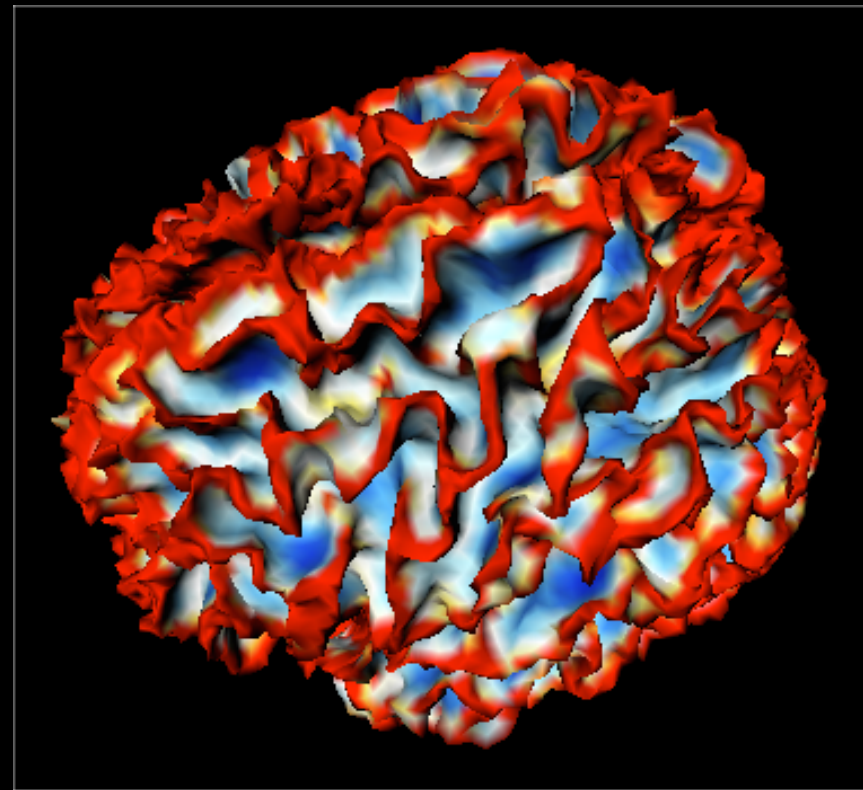
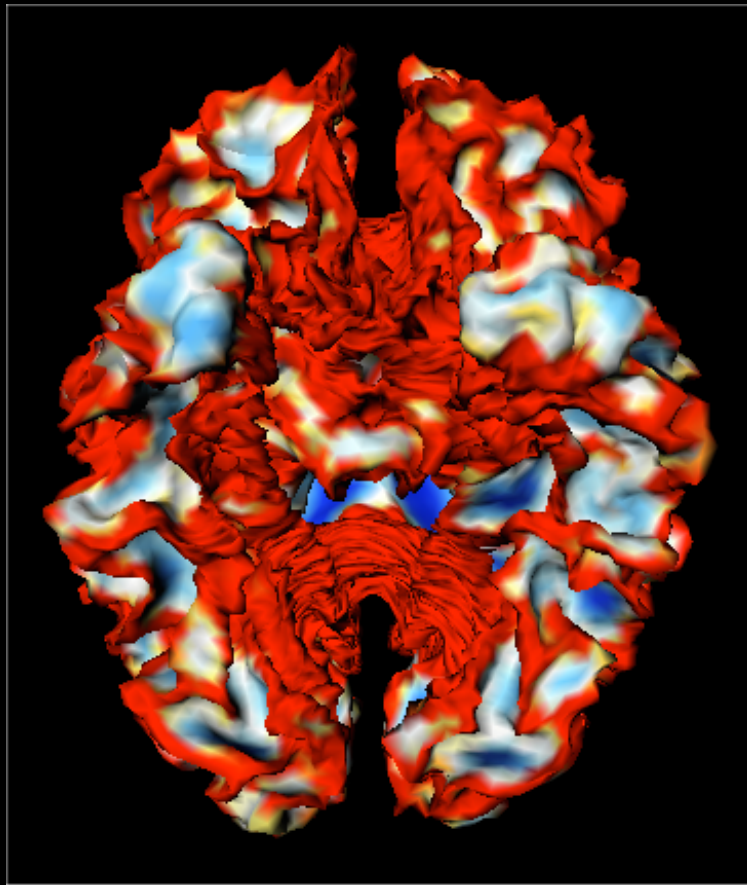
Gaussian Curvature



Mean curvature can be used to quantify sulcal pattern



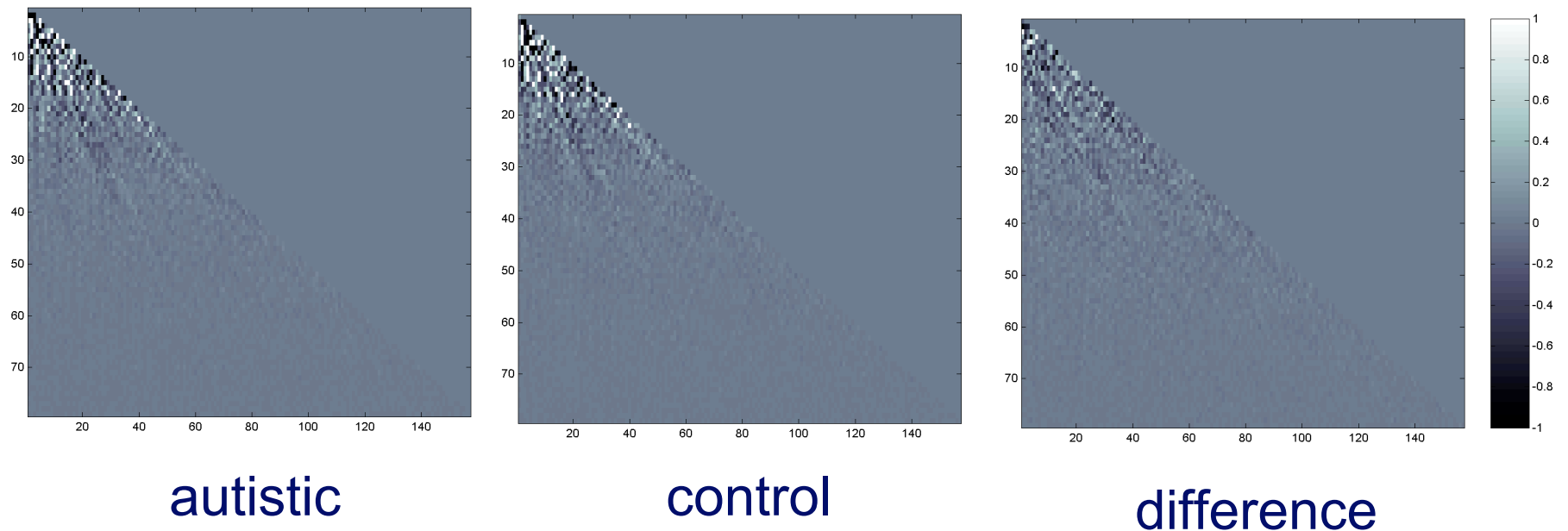
Application of curvature measure: Tensor-based morphometry (TBM)



Thin-plate spline energy can be used to measure the curvature of the surface. Between ages 12 and 16, it increases both locally and globally.

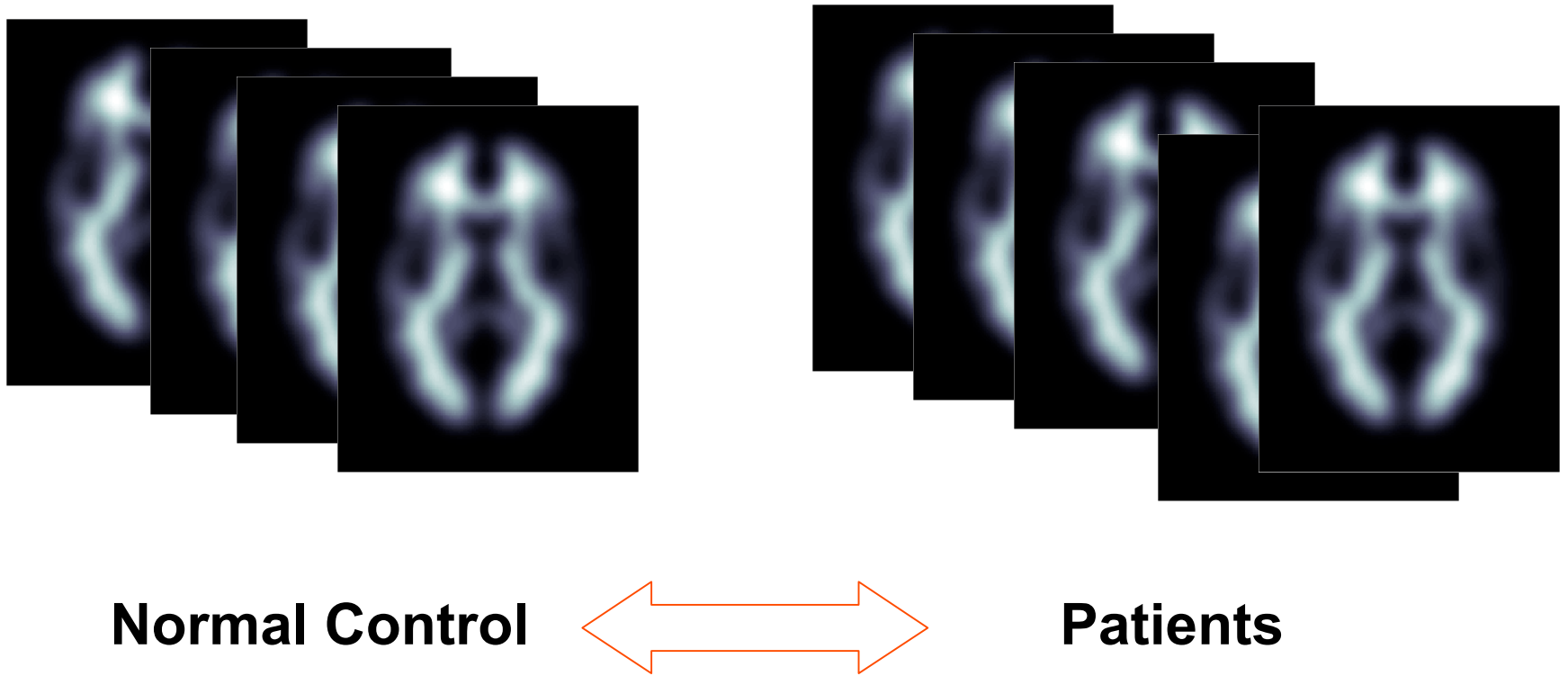
6241 Fourier coefficients can be used to quantify individual anatomical shape

Average SPHARM coefficients



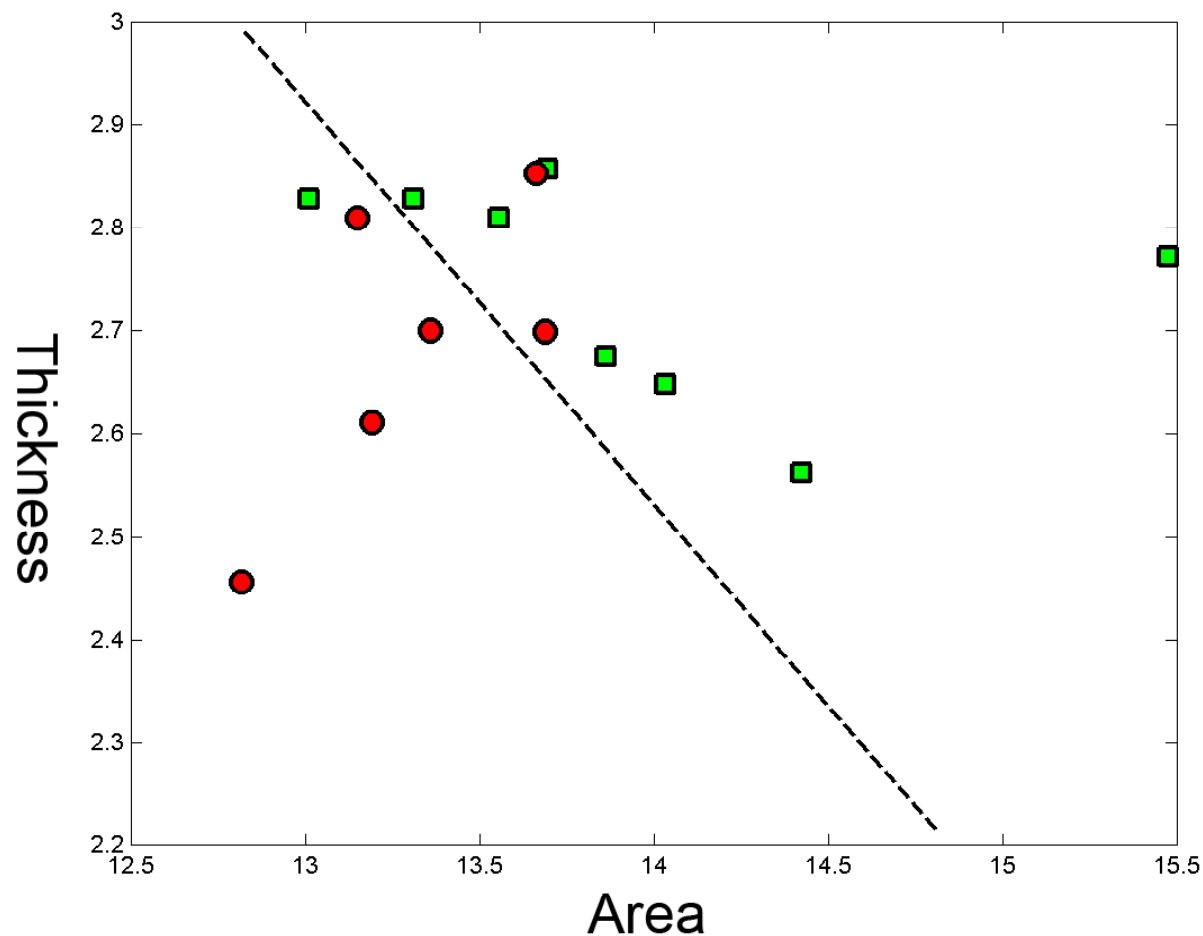
78th degree Weighted-SPHARM

5. Statistical Analyses on Medical Images



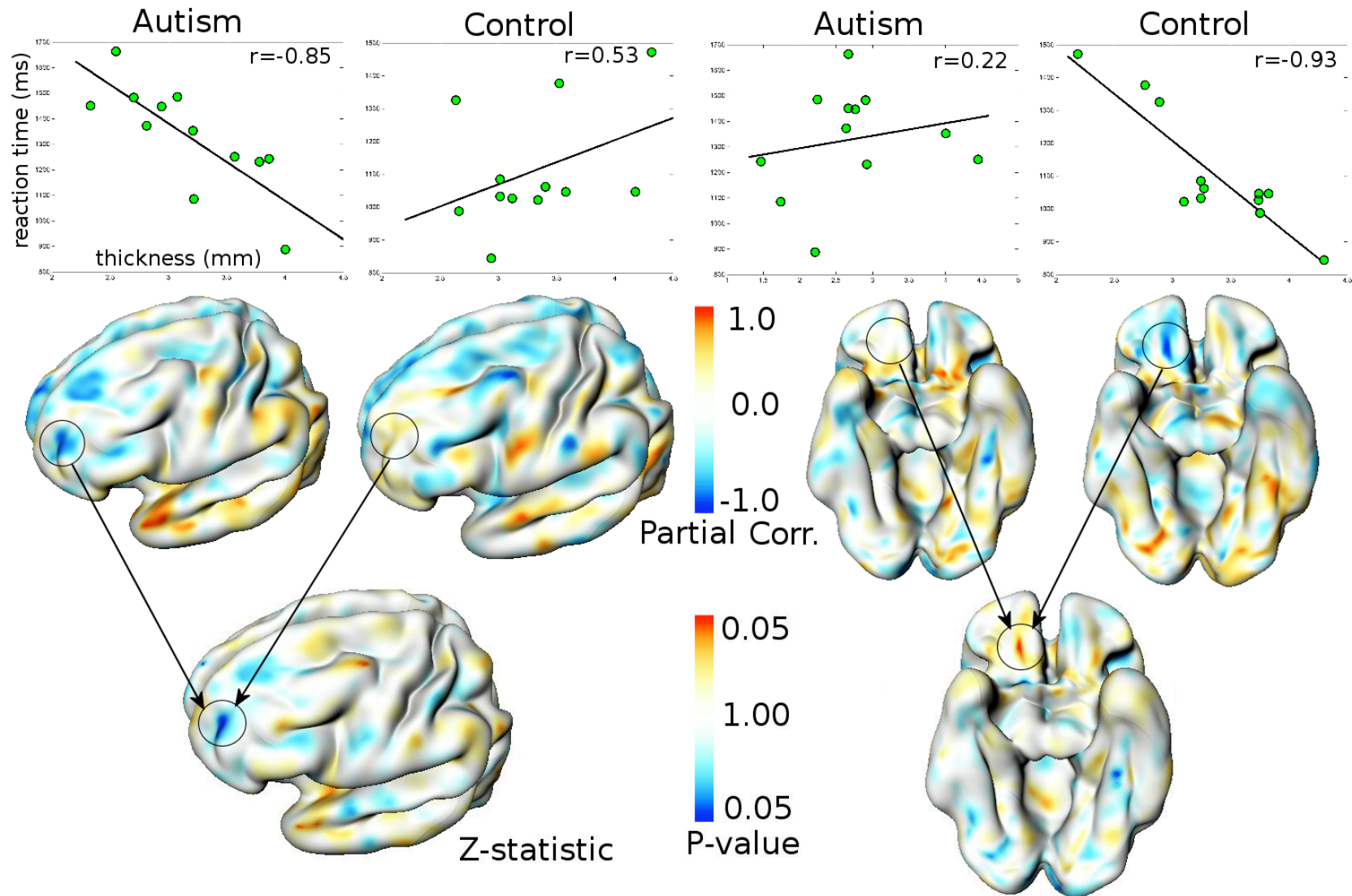
Main issue: are these images different between groups ?

Classification for imaging biomarkers via logistic regression



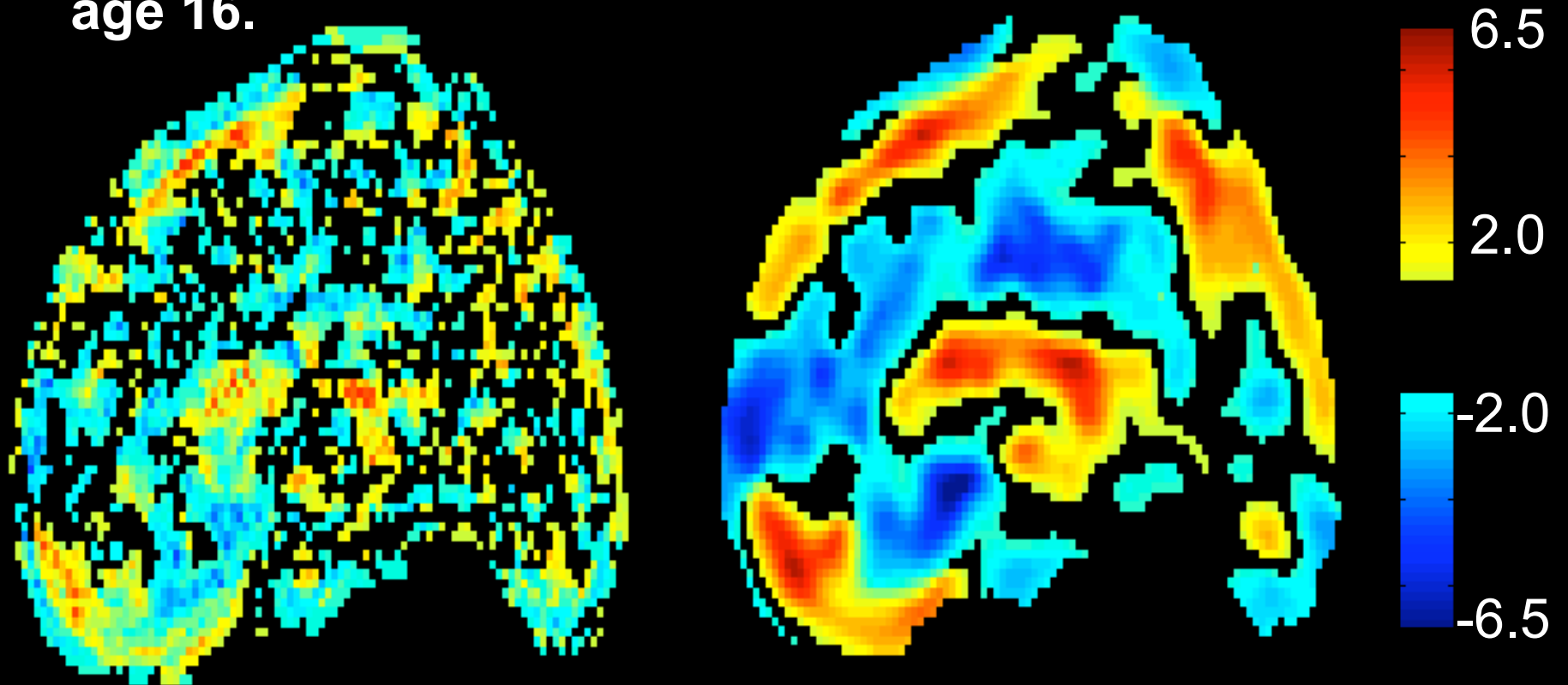
Red: mild cognition impairment (MCI)
Green: elderly normal controls

Correlating behavioral and imaging measures



How to increase statistical sensitivity ?

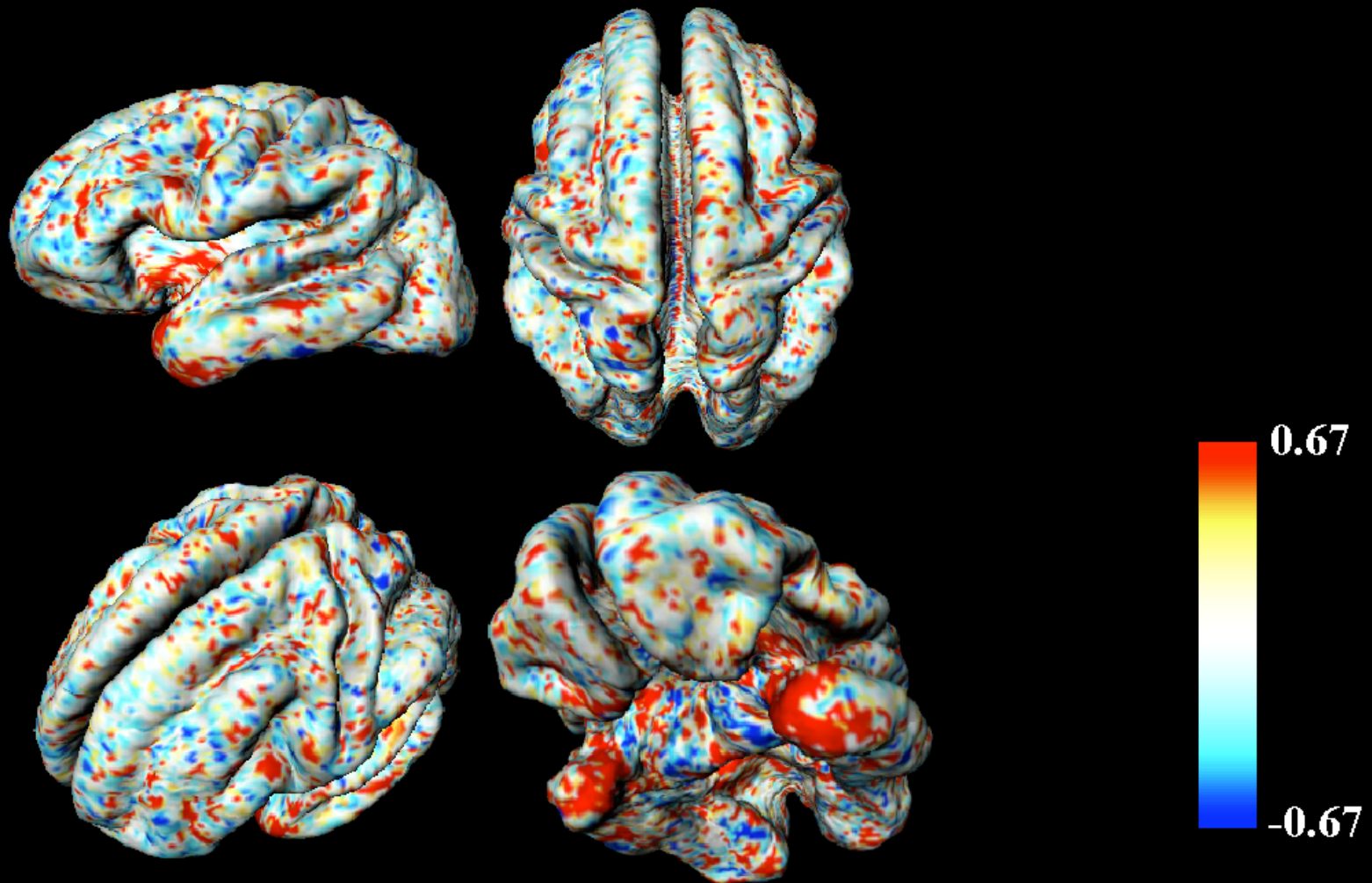
***t*-statistic map** of Jacobian determinant (volume measurement) for 28 normal subjects from age 12 to age 16.



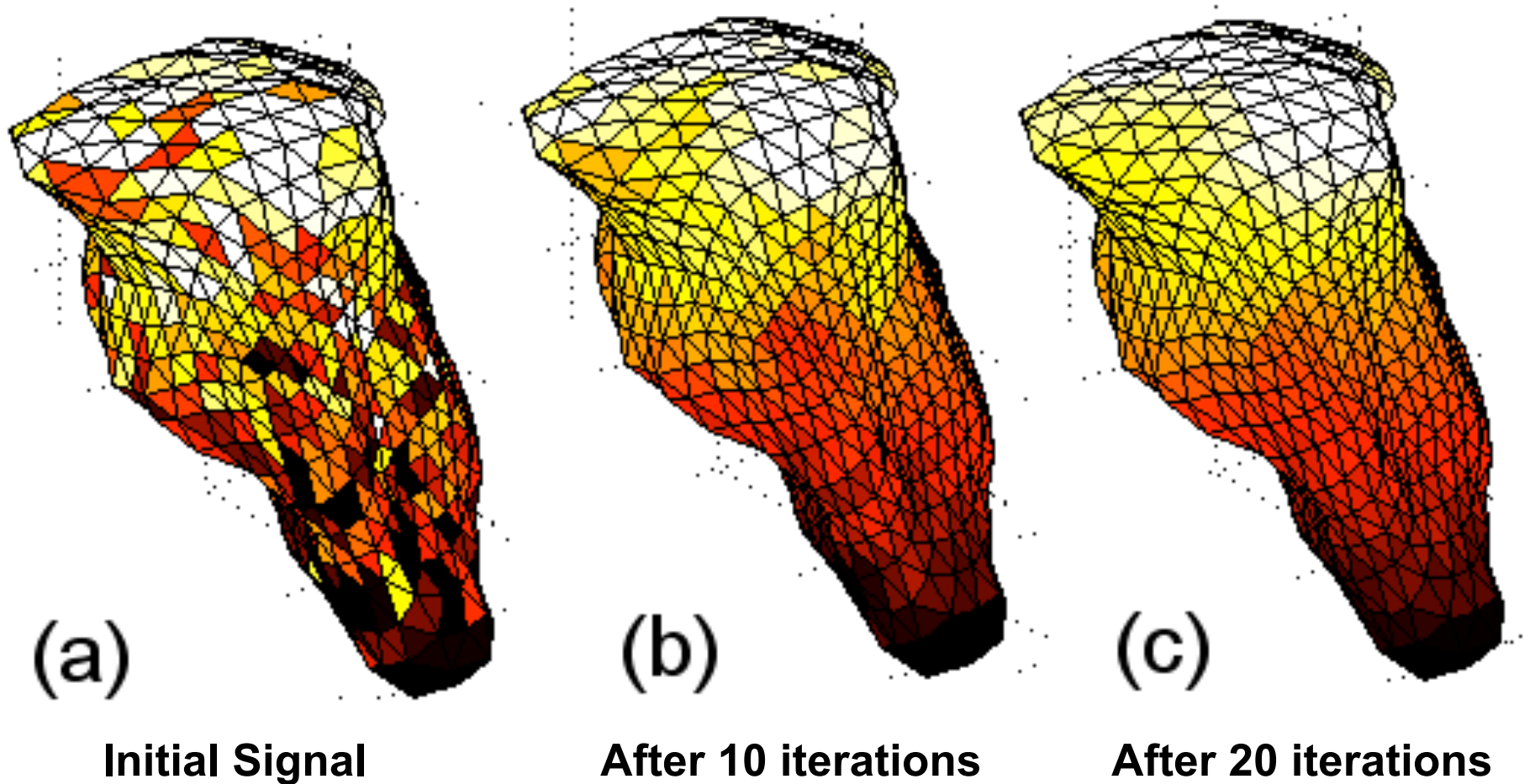
10mm FWHM Gaussian kernel smoothing

**Most imaging measurements are noisy.
Increasing signal-to-noise (SNR) ratio is necessary.**

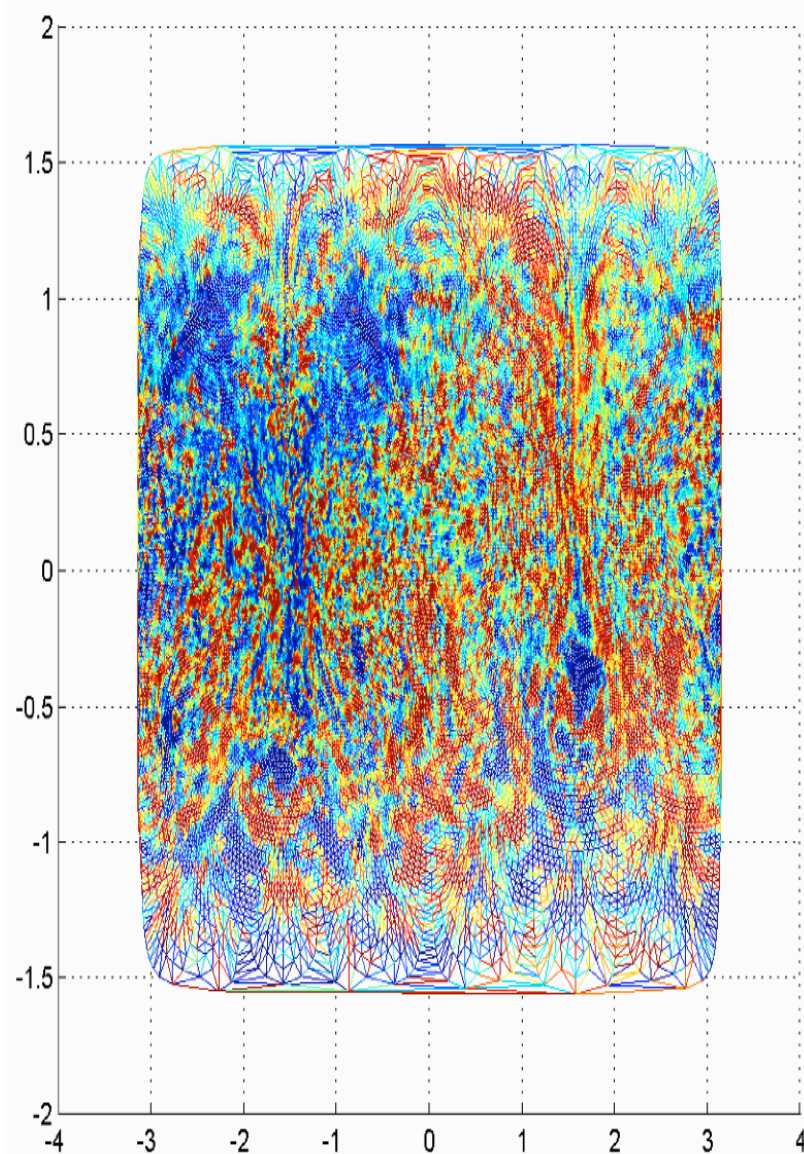
Cortical thickness dilatation (single subject, age = 14)



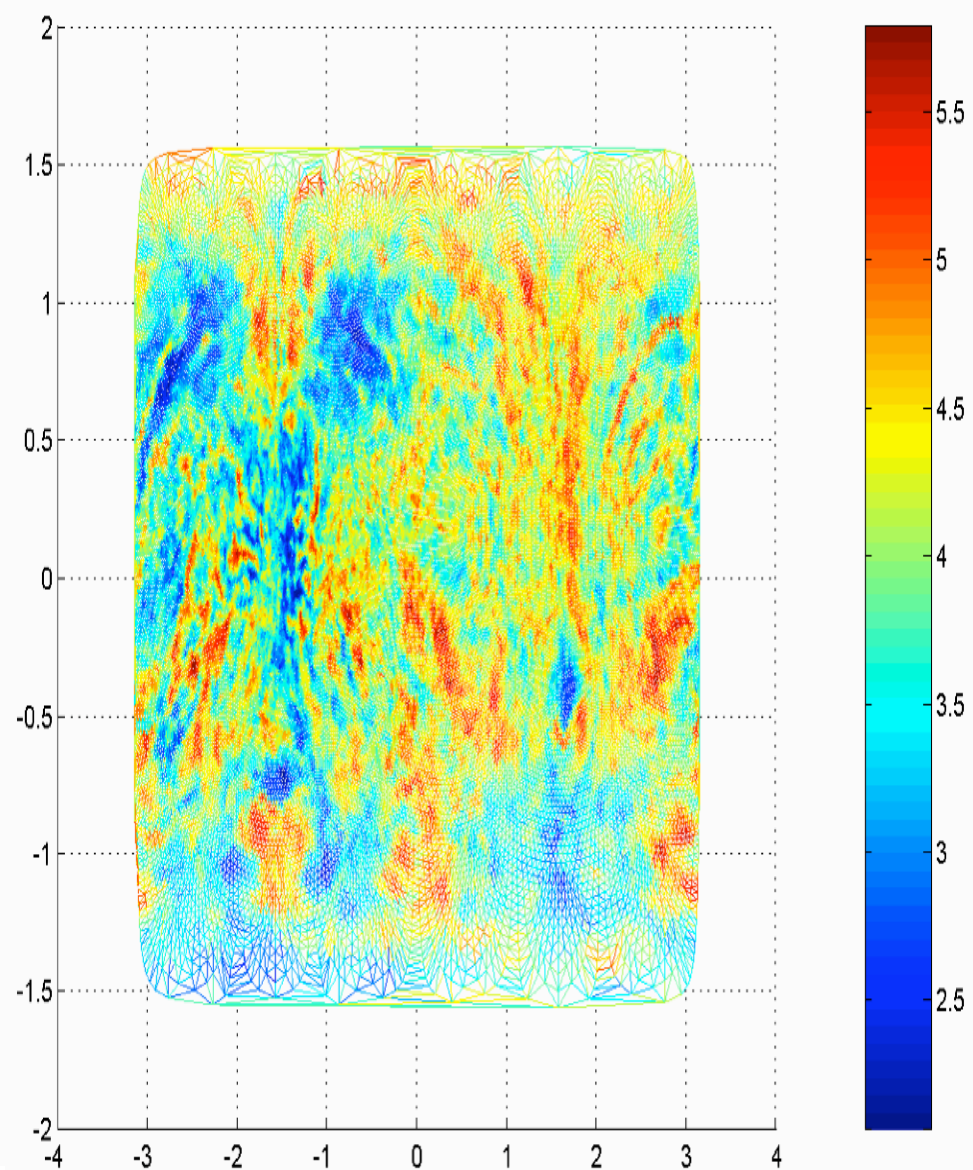
Smoothing along anatomical tissue boundary to increase SNR



Diffusion smoothing: isotropic diffusion equation

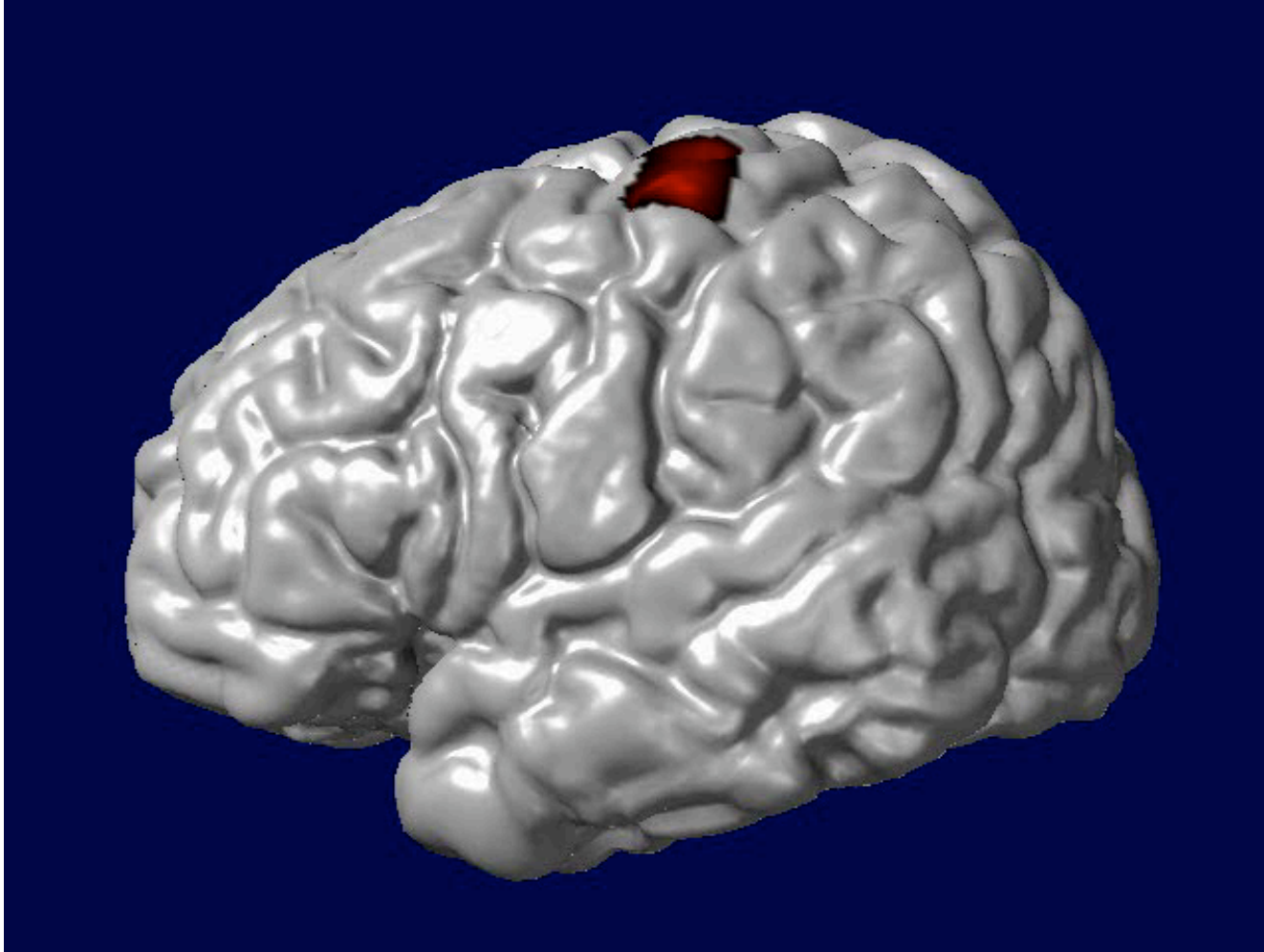


Thickness measure

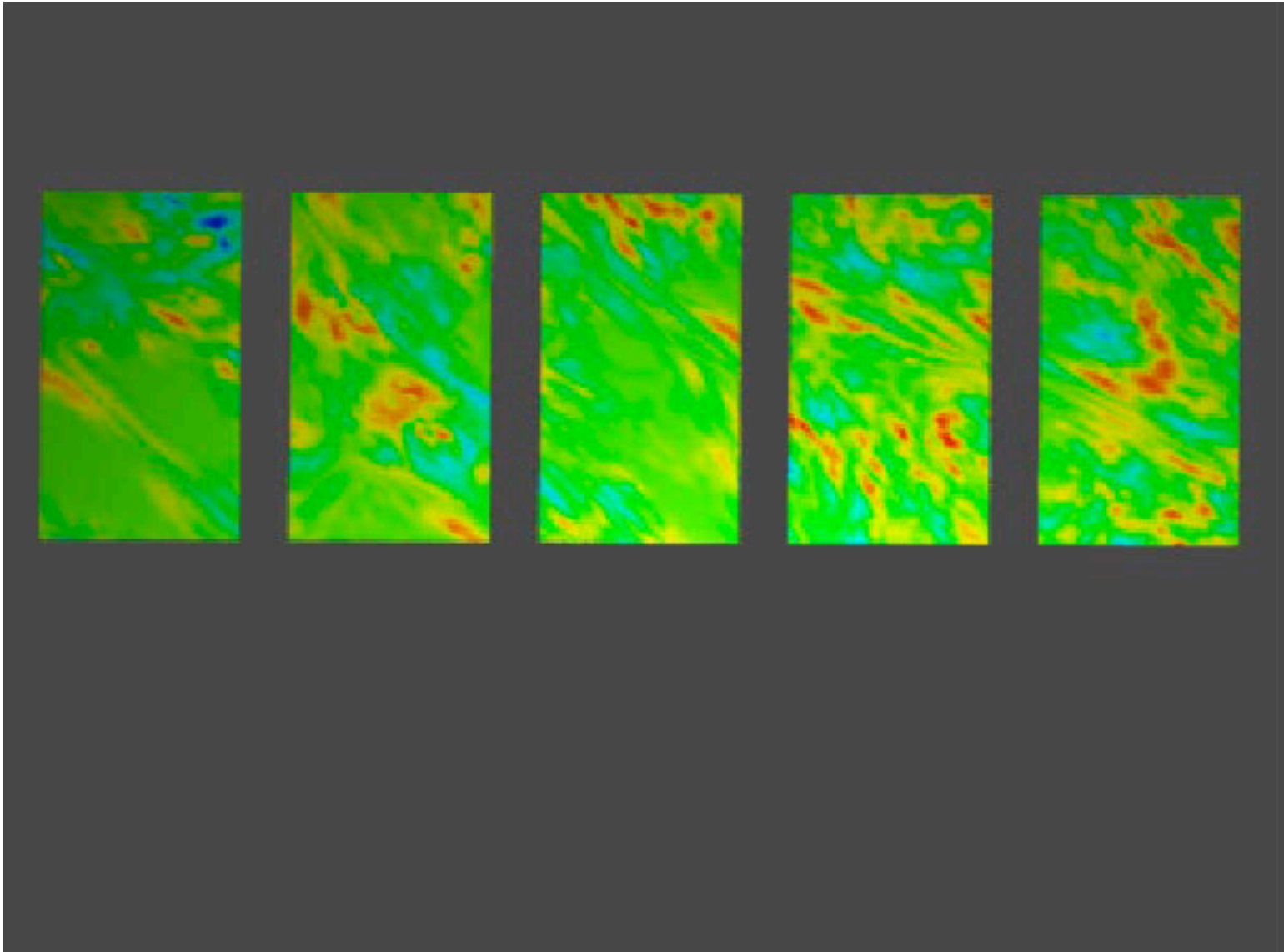


Signal enhancement

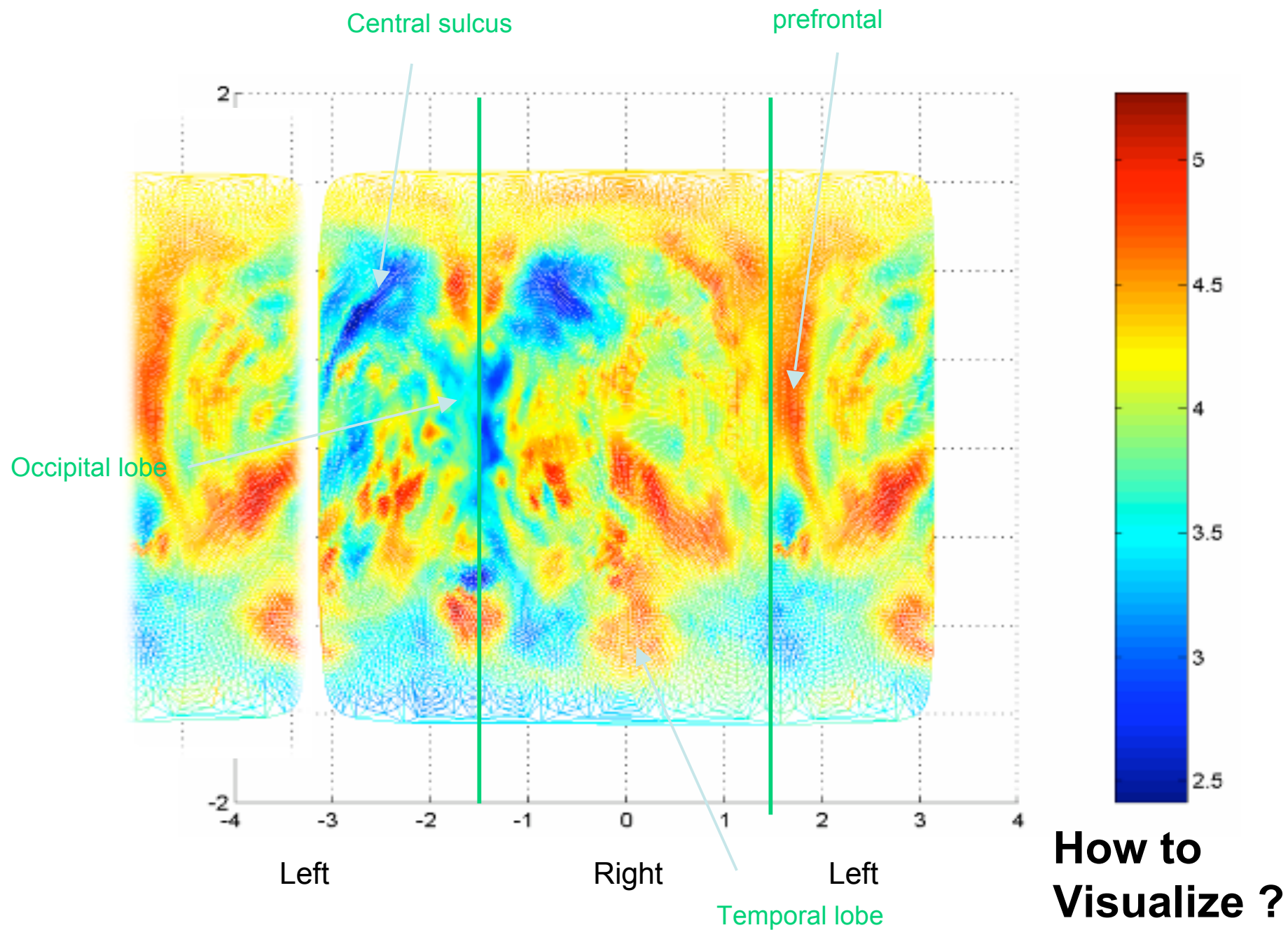
Issue of image parameterization



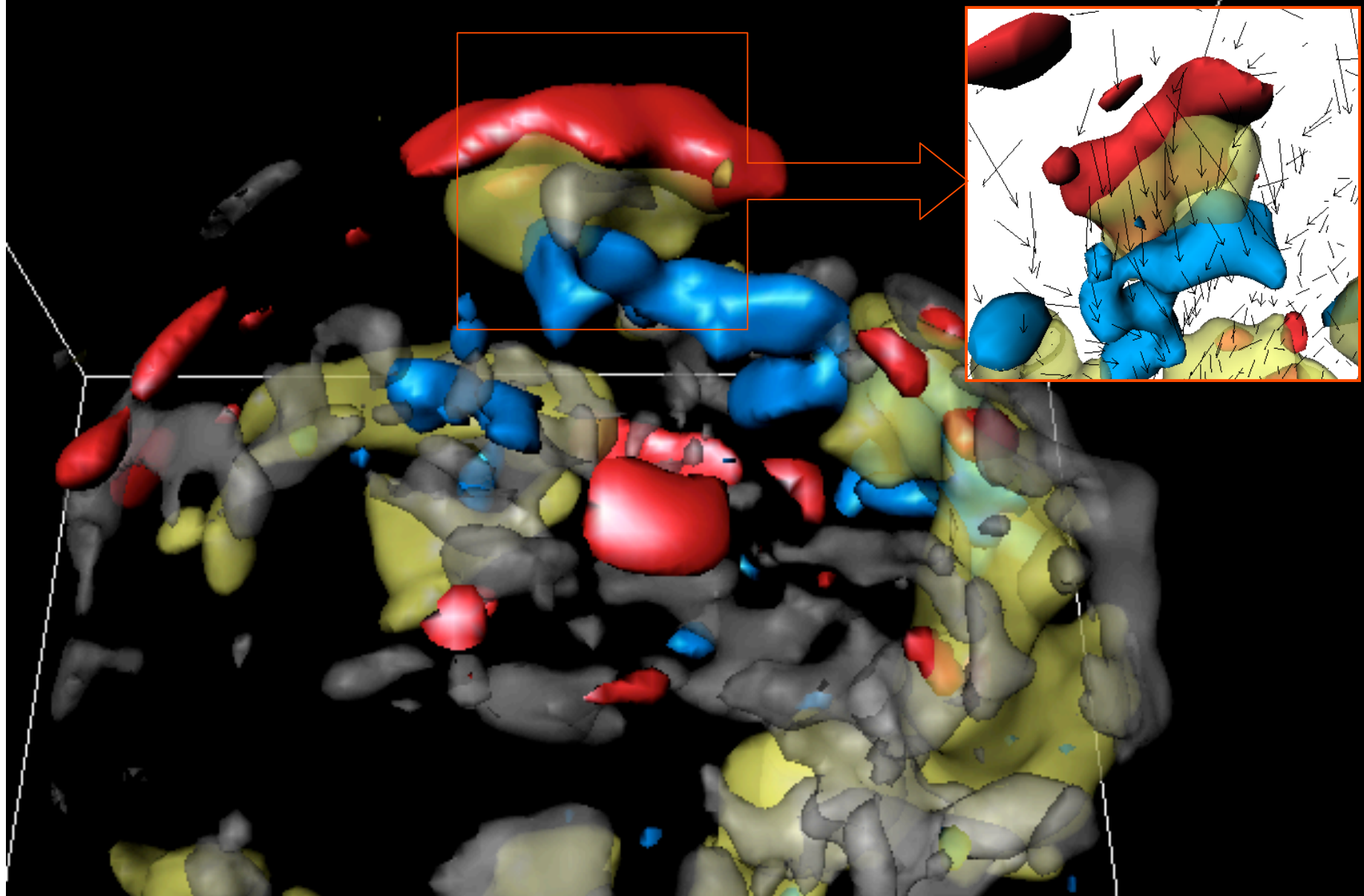
Source: Montreal Neurological Institute



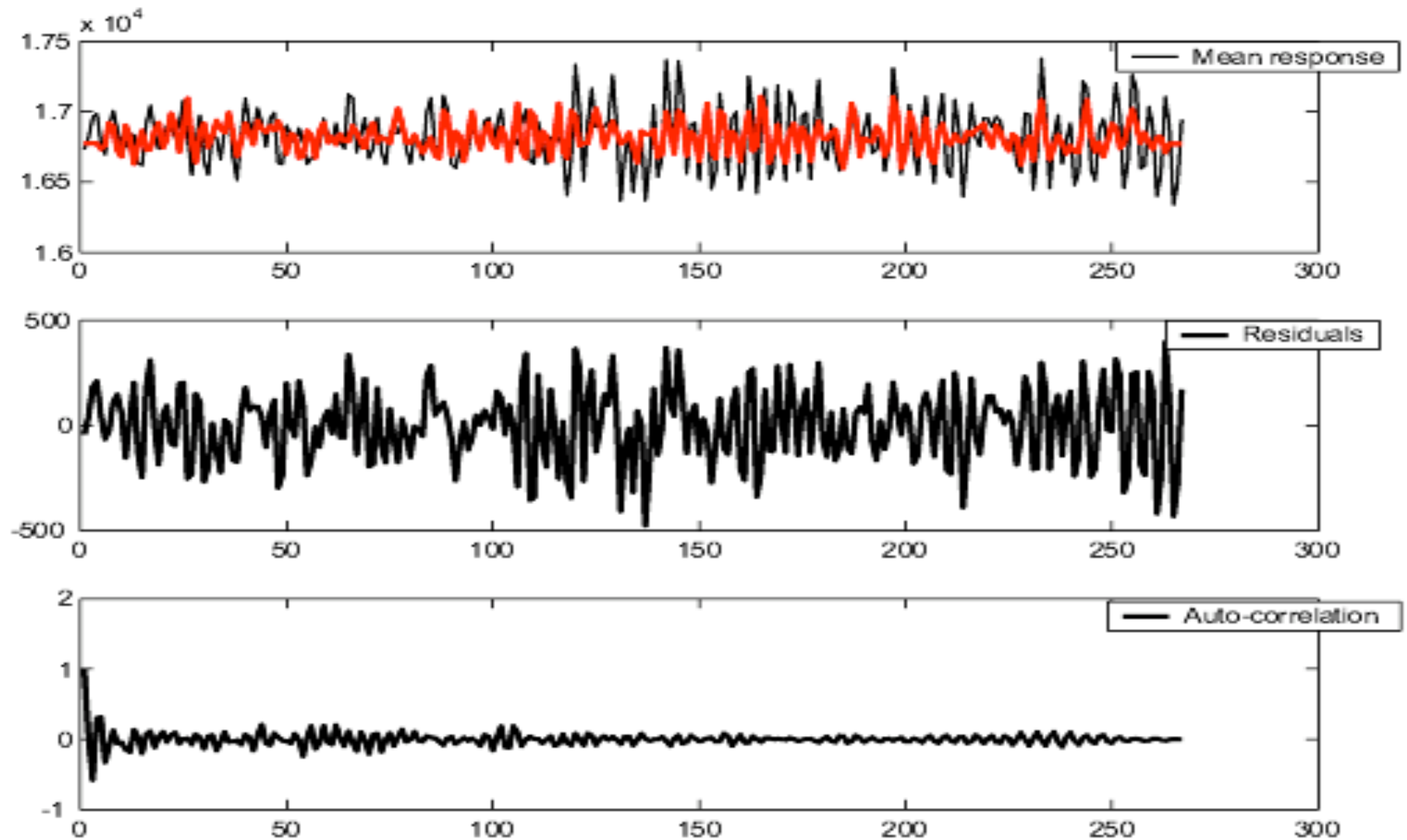
Source: Jonathan Taylor
Stanford University



Visualization of statistical significant regions



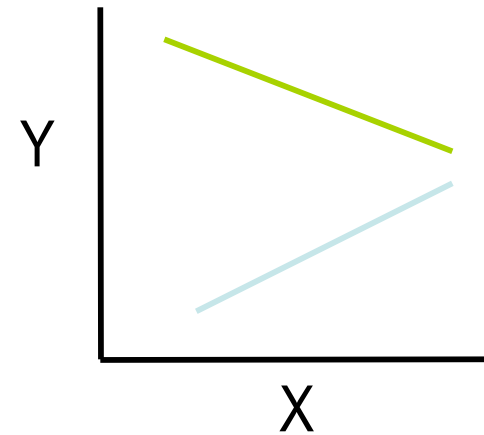
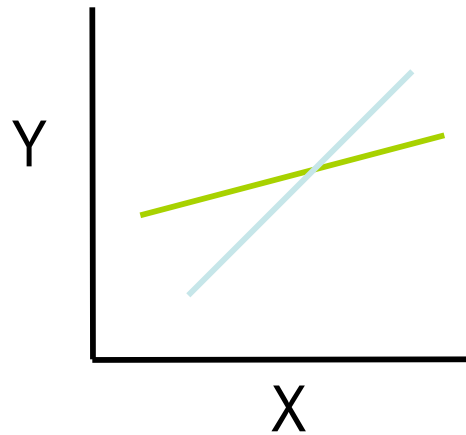
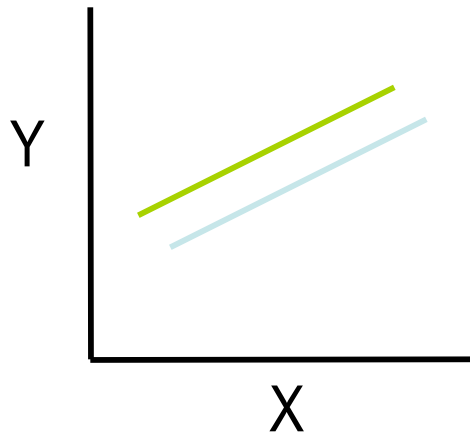
Time series analysis of fMRI signal in the left amygdala



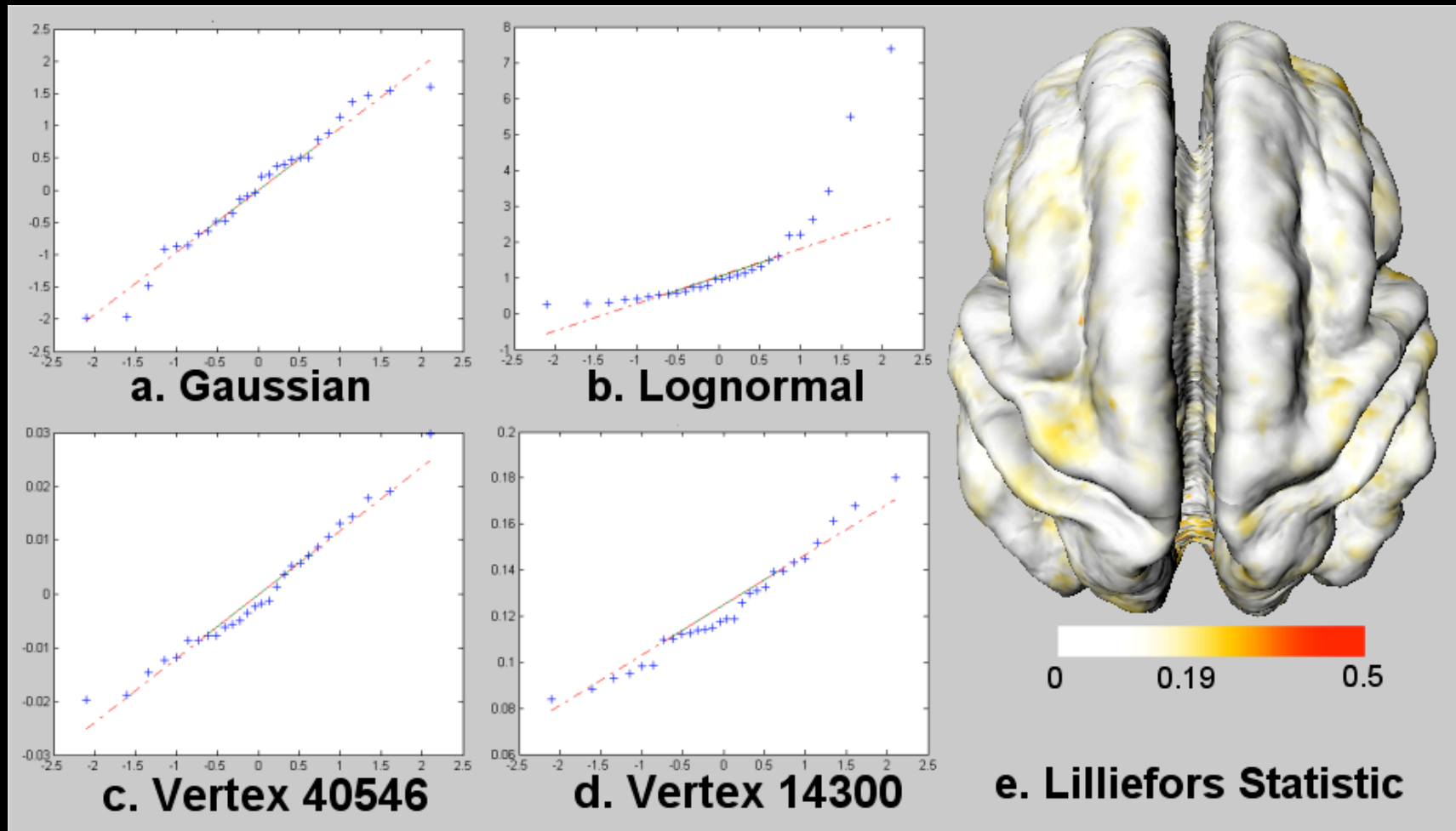
Comparing rate of biological change between groups

Test null hypothesis

Ho: slopes in linear models are identical

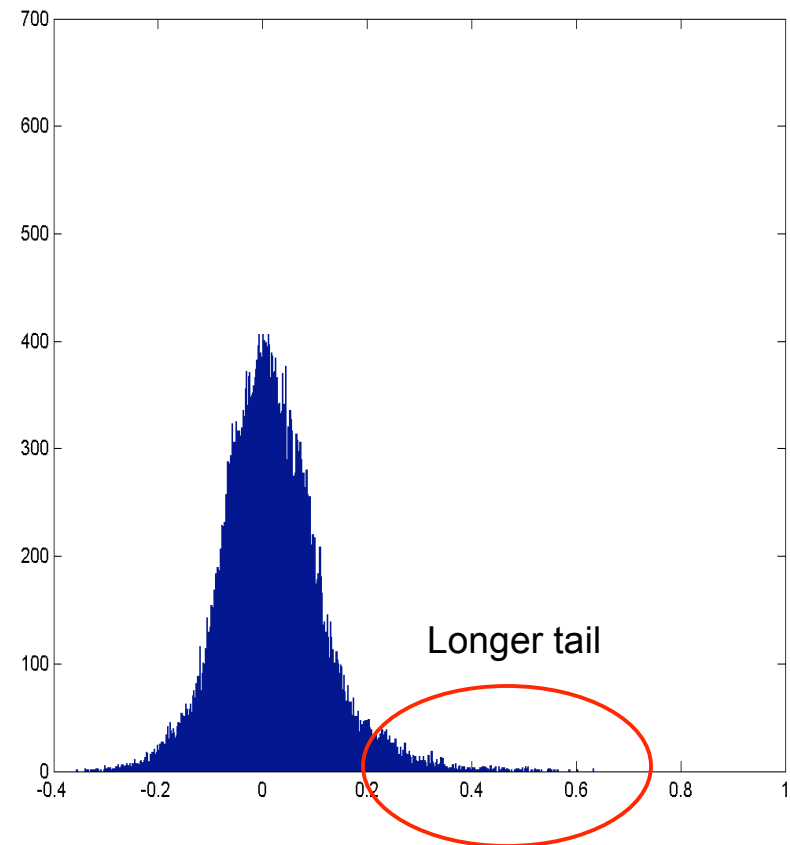
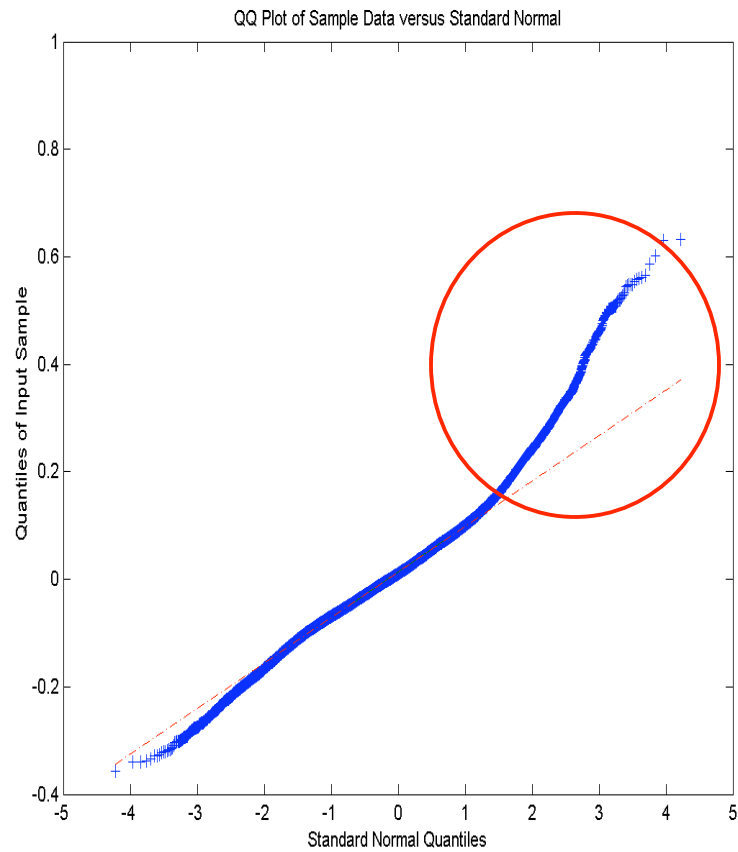


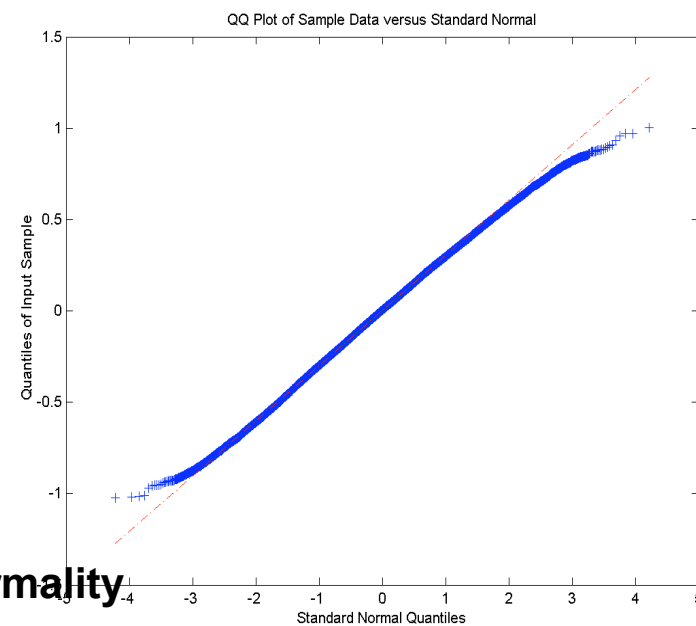
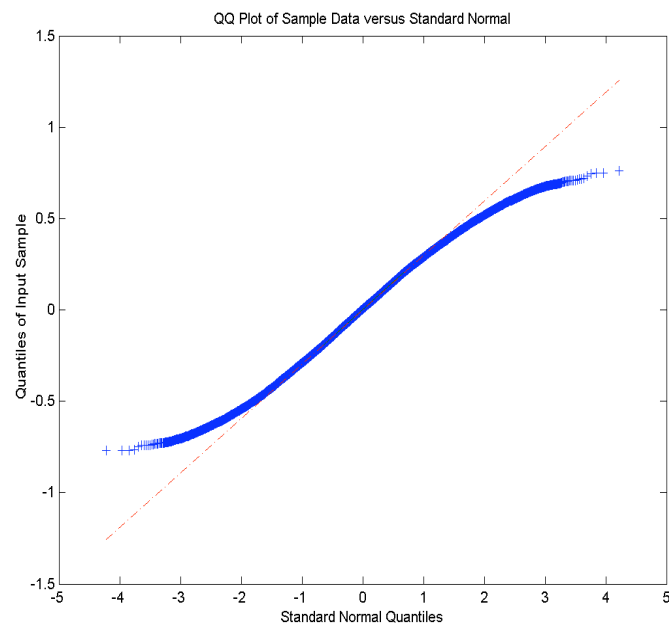
5. Validation- on statistical model & assumptions



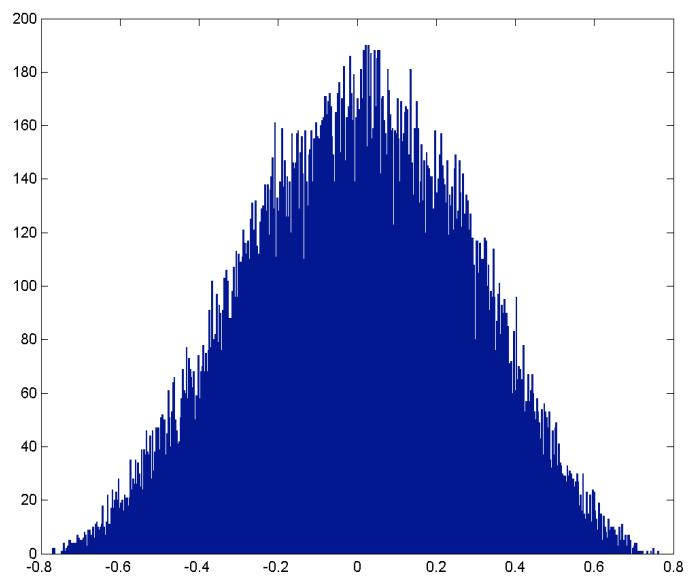
Checking normality of imaging measures

Quantile-Quantile (QQ) plot showing asymmetric distribution

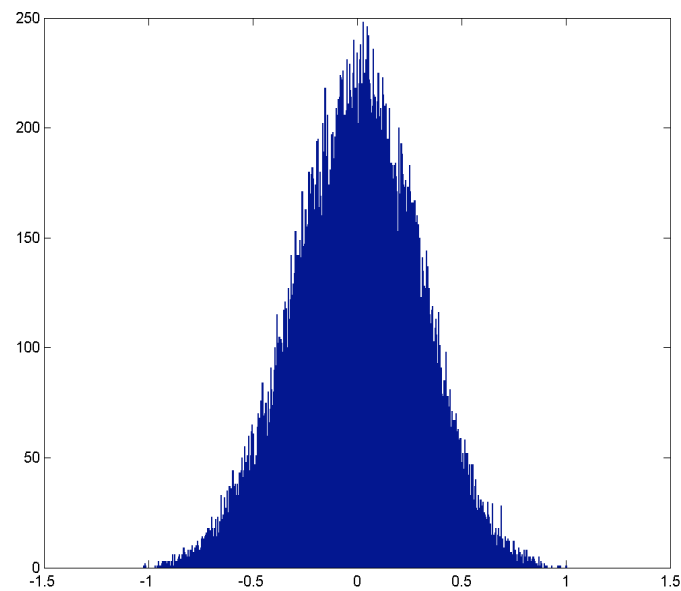




Increasing normality
of data

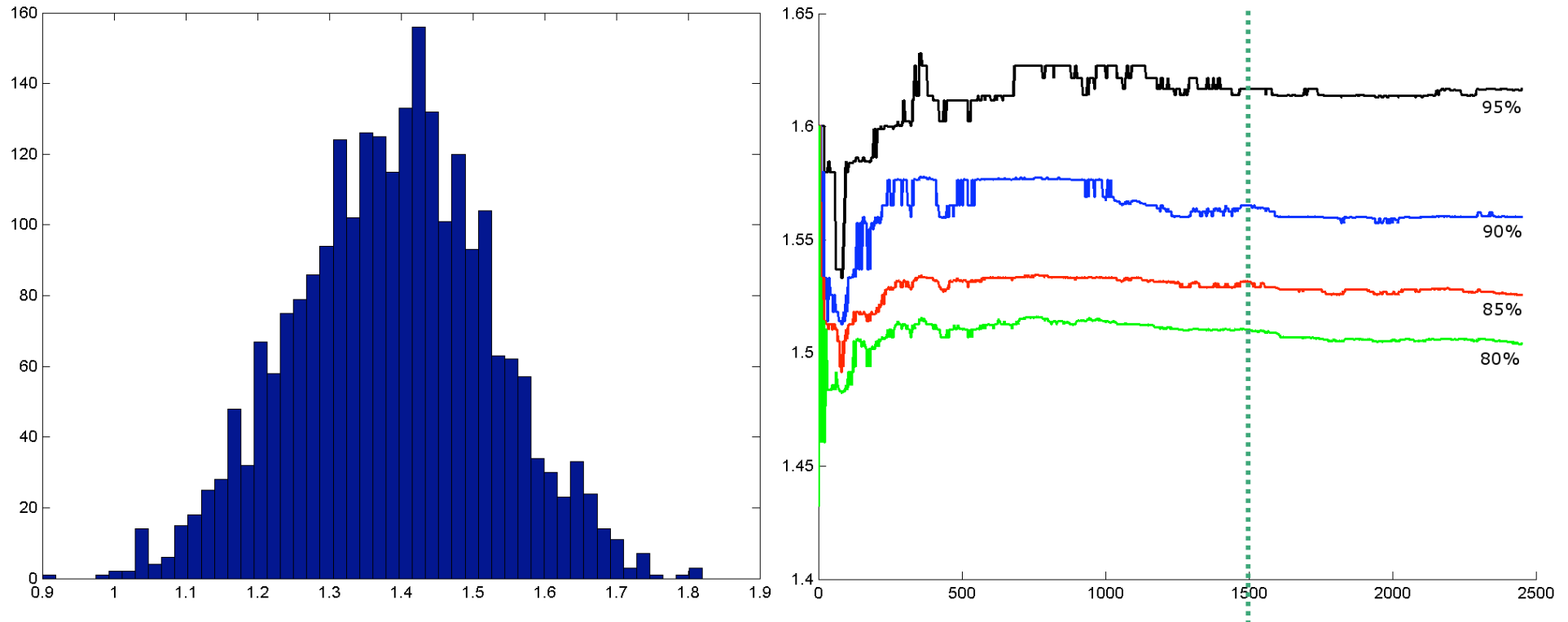


Fisher's
Z transform
on correlation



Permutation test - model free statistical inference

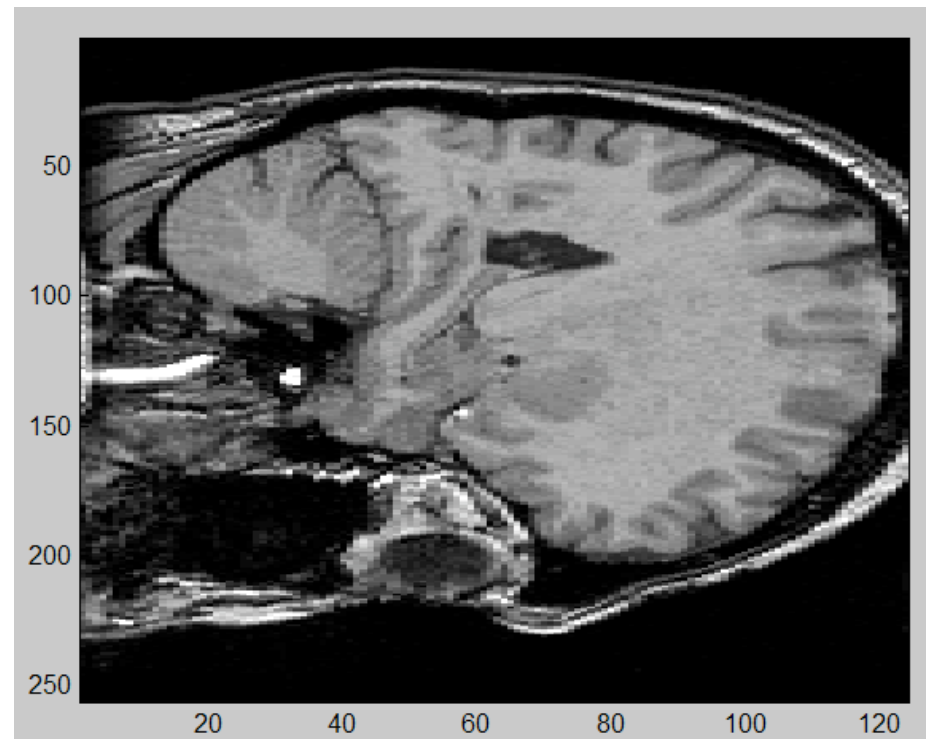
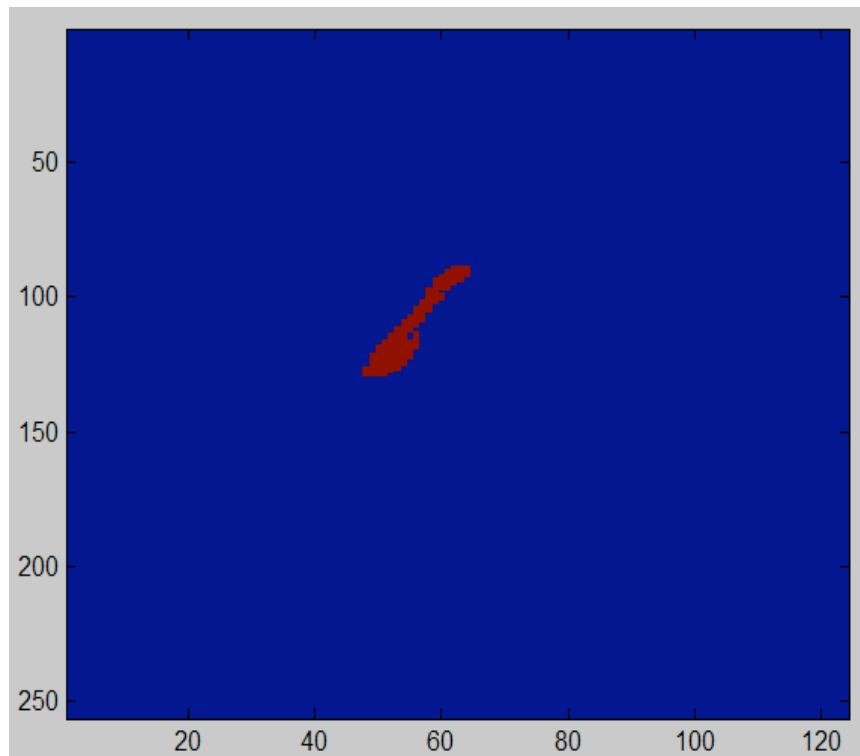
Not recommended for most of studies.



More than 1500 permutations are needed to guarantee the convergence of the thresholding.
8 hours of running time in MATLAB.

5. Validation - on imaging measures

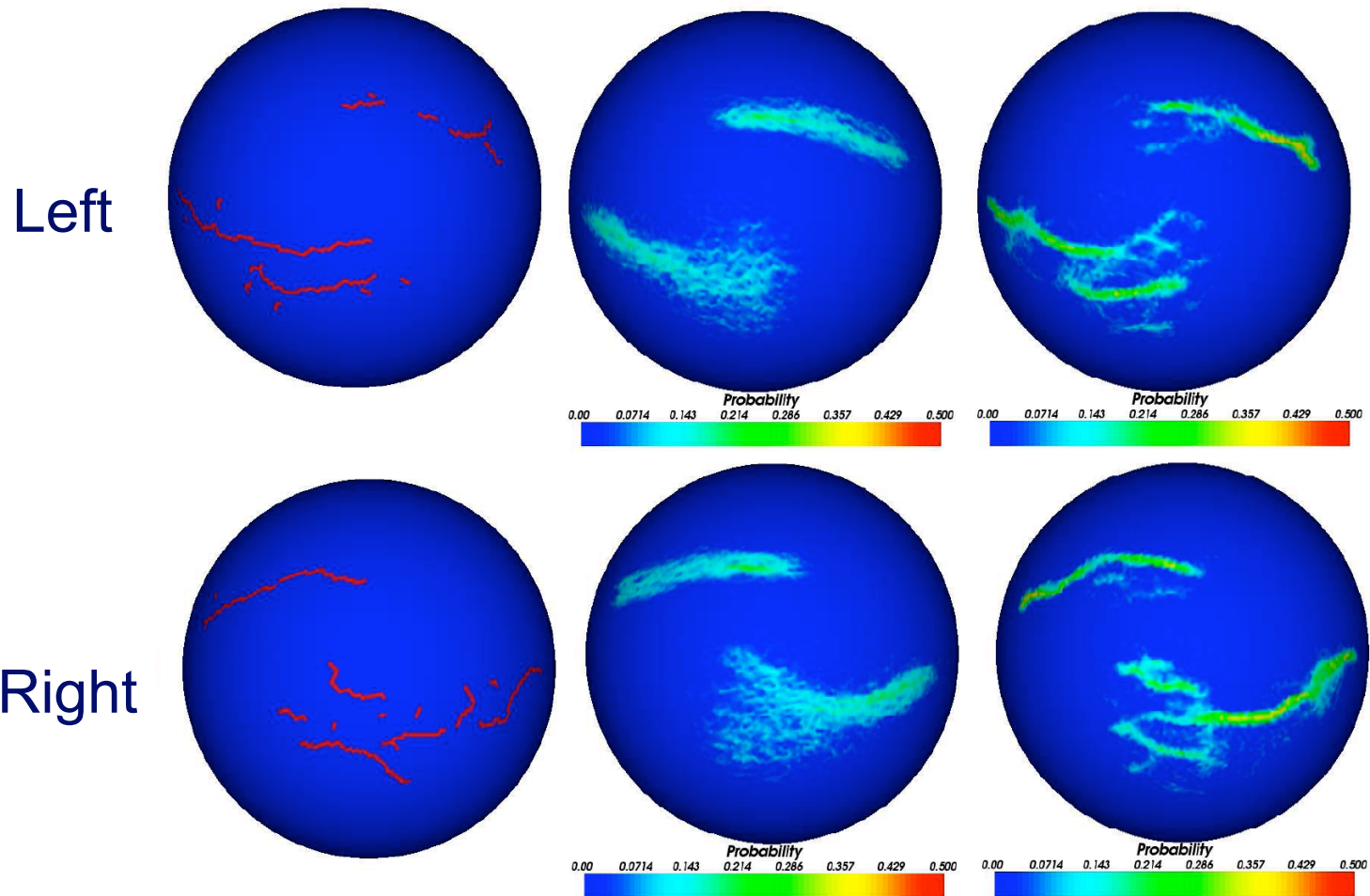
How accurate is manual segmentation ?



For many anatomical areas, possibly due to noise, manual segmentation is still the best approach.

Validation - on image registration based on simulated 149 subjects

NeuroImage (2005)



Central and temporal sulcus

Lecture 2 topics

Voxel-based morphometry

Linear models