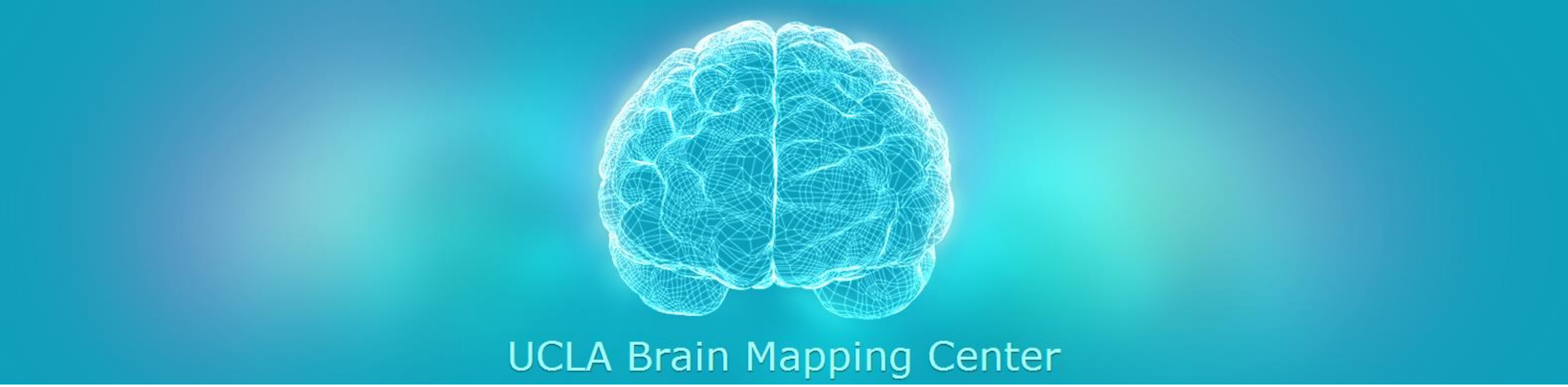

BrainSuite

Presented at the **UCLA Advanced Neuroimaging Summer Program**
12 August 2015

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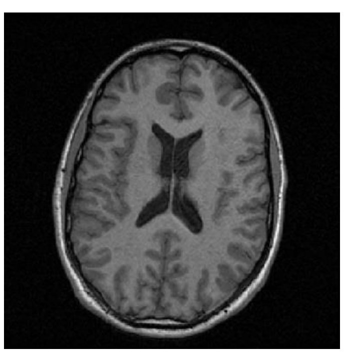
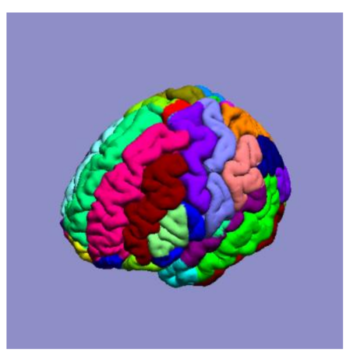
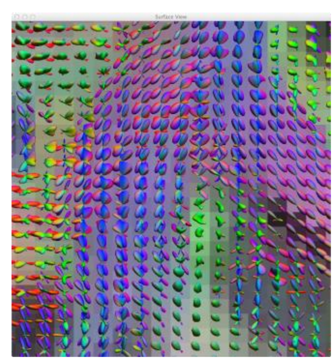
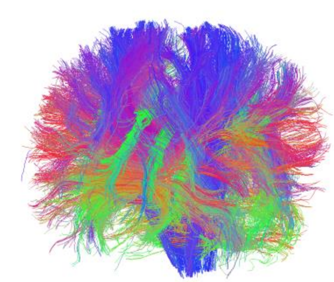
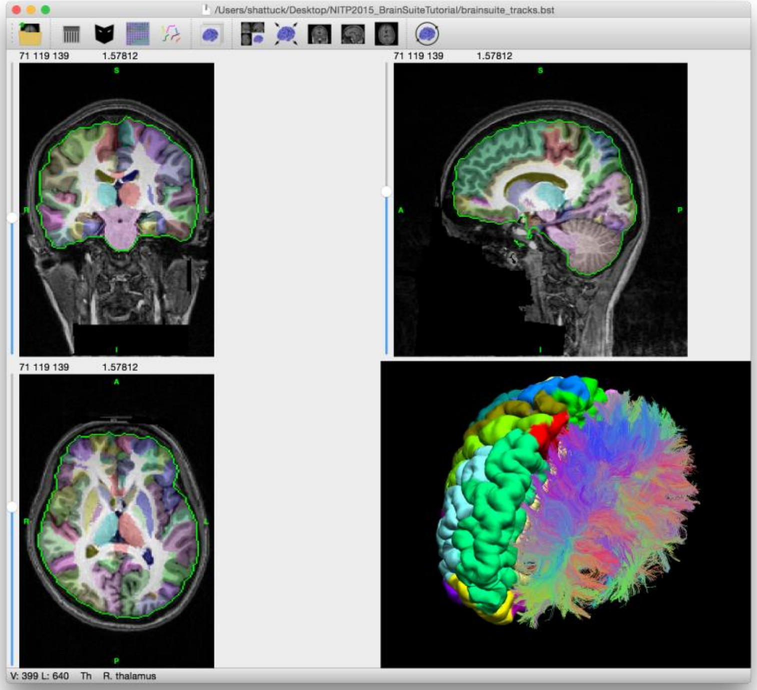
Objectives

- Introduce you to the BrainSuite software tools
- Overviews of the major components of the software
- Hands-on training with assistance from experienced users
  - Sample data sets
  - Your own data
- Provide assistance with how to integrate the software into your research approach.

BrainSuite

- Collection of image analysis tools designed to process structural and diffusion MRI
  - Automated sequence to extract cortical surface models from T1-MRI
  - Tools to register surface and volume data to an atlas to define anatomical ROIs
  - Tools for processing diffusion imaging data, including coregistration to anatomical T1 image, ODF and tensor fitting, and tractography.
  - Visualization tools for exploring these data.
- Runs on Windows, Mac, and Linux*



* GUI for Linux version is not yet released

BrainSuite Team

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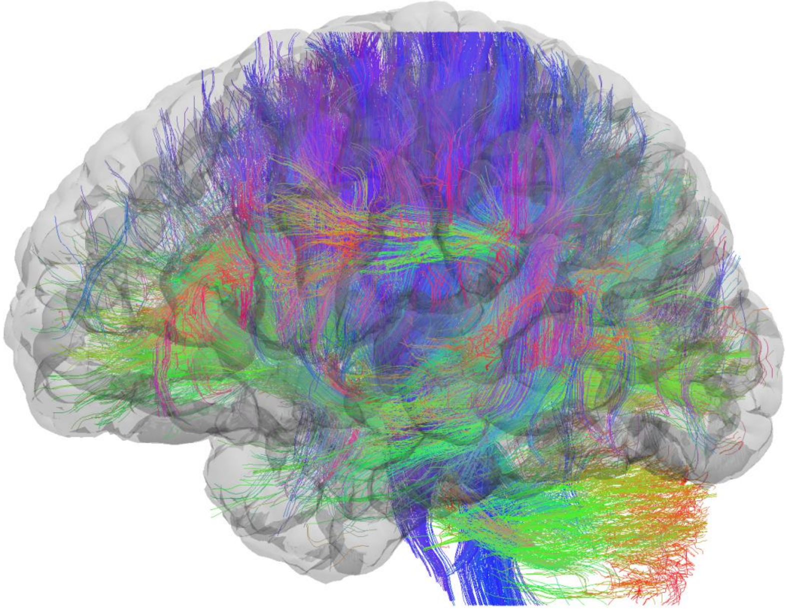
BrainSuite Highlights

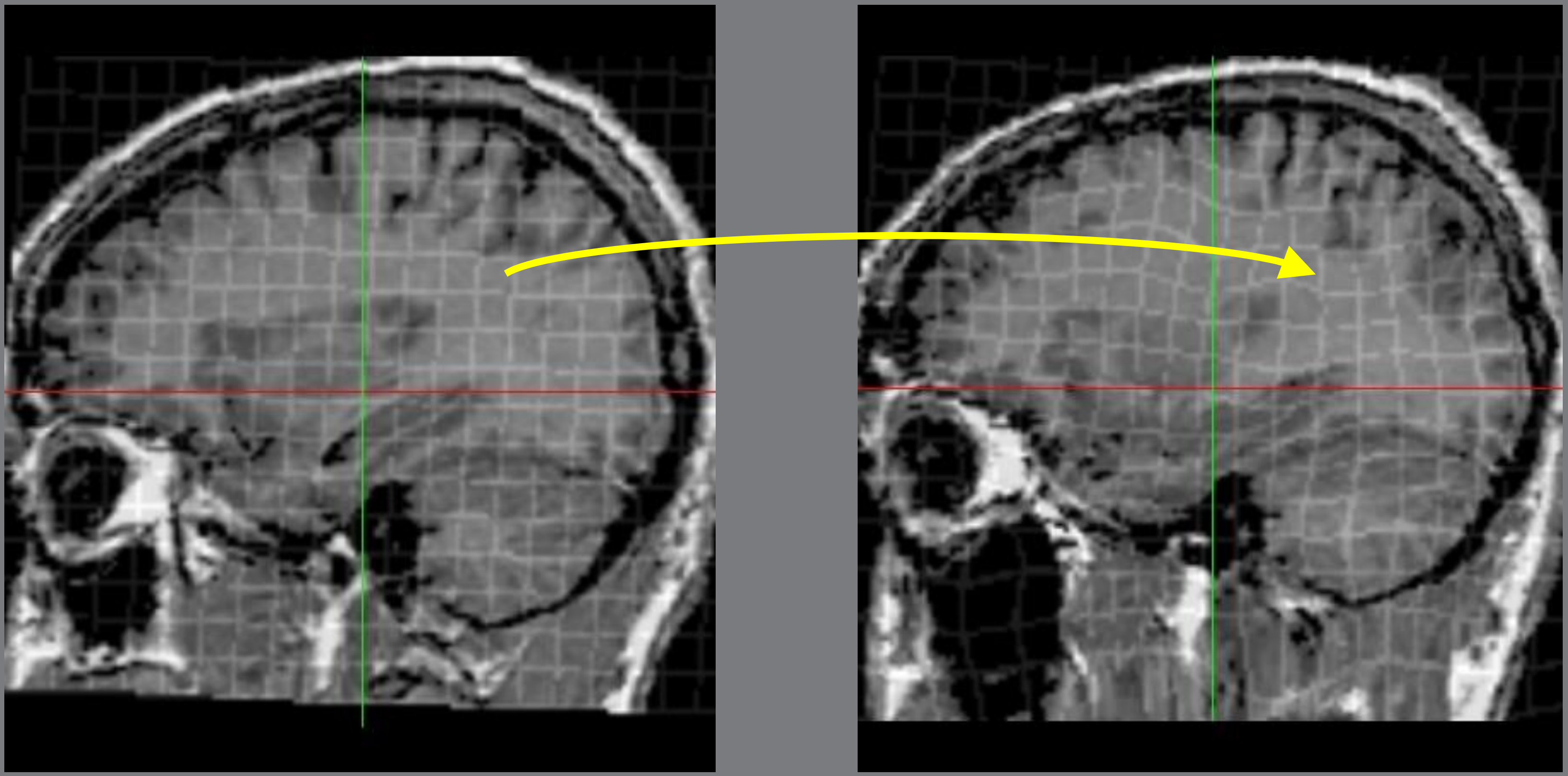
- Interactive processing
- Visualization capabilities
- Joint surface/volume registration
- New BCI-DNI brain atlas
- Customizable atlases
- Unique diffusion modeling (FRACT)
- Multiple methods for B0-distortion correction
- Atlas-based connectivity analysis
- GUI and command-line versions with cross-platform consistency



Motivation

- We are typically interested in performing comparisons across different brains or brains at different points in time.
- For these comparisons to be meaningful, we must be able to establish spatial anatomical correspondence across the data
- Once correspondence is established, we can study various neuroanatomical features in the data.
  - Size of structures, cortical thickness, cortical complexity
  - White matter architecture, connectivity relationships
  - How these change over time or in the presence of disease or trauma
- BrainSuite software goals
  - Address these challenges with automated processing where possible
  - Provide facilities to intervene when necessary
  - Provide tools to streamline the tasks of performing analysis

Image Registration

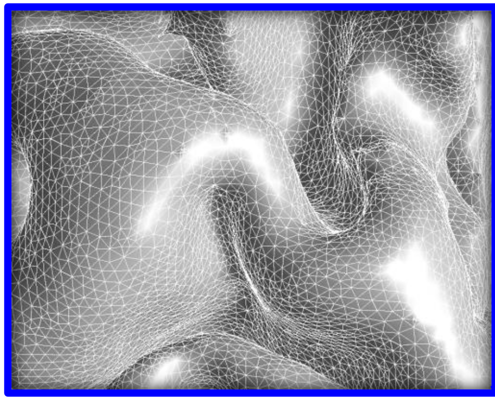


Brain image with grid overlay

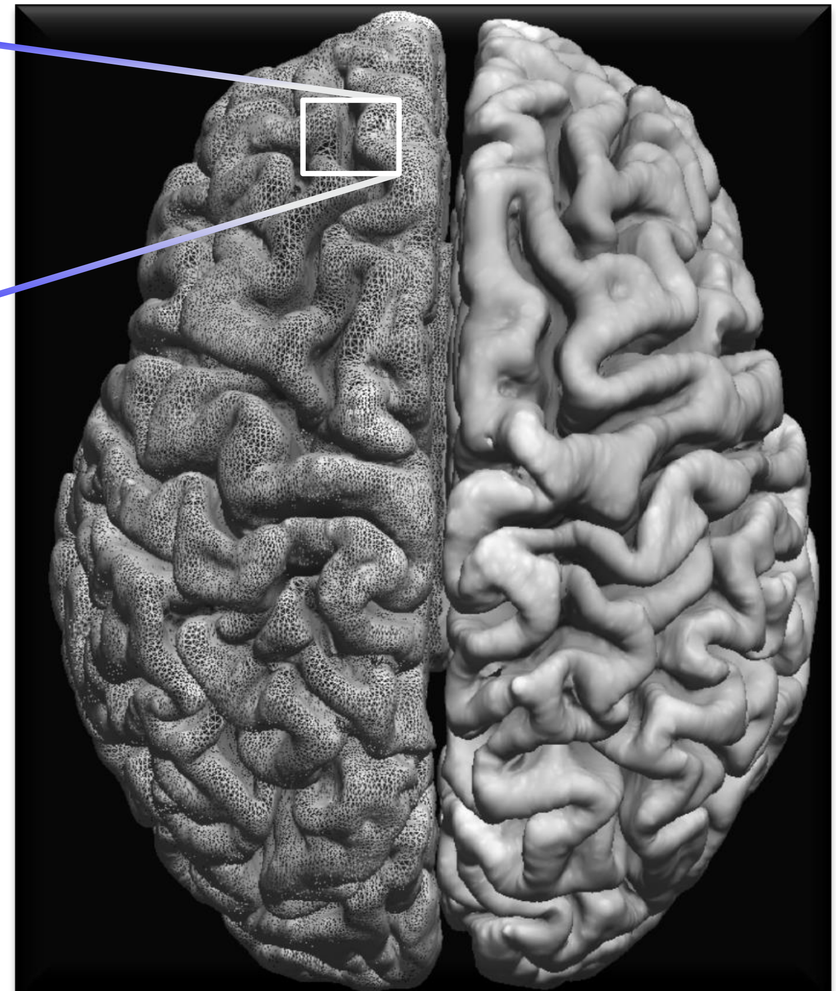
Warped brain with grid overlay

- Mapping from points in a template brain image to matching points in a target brain image.

Surface Models

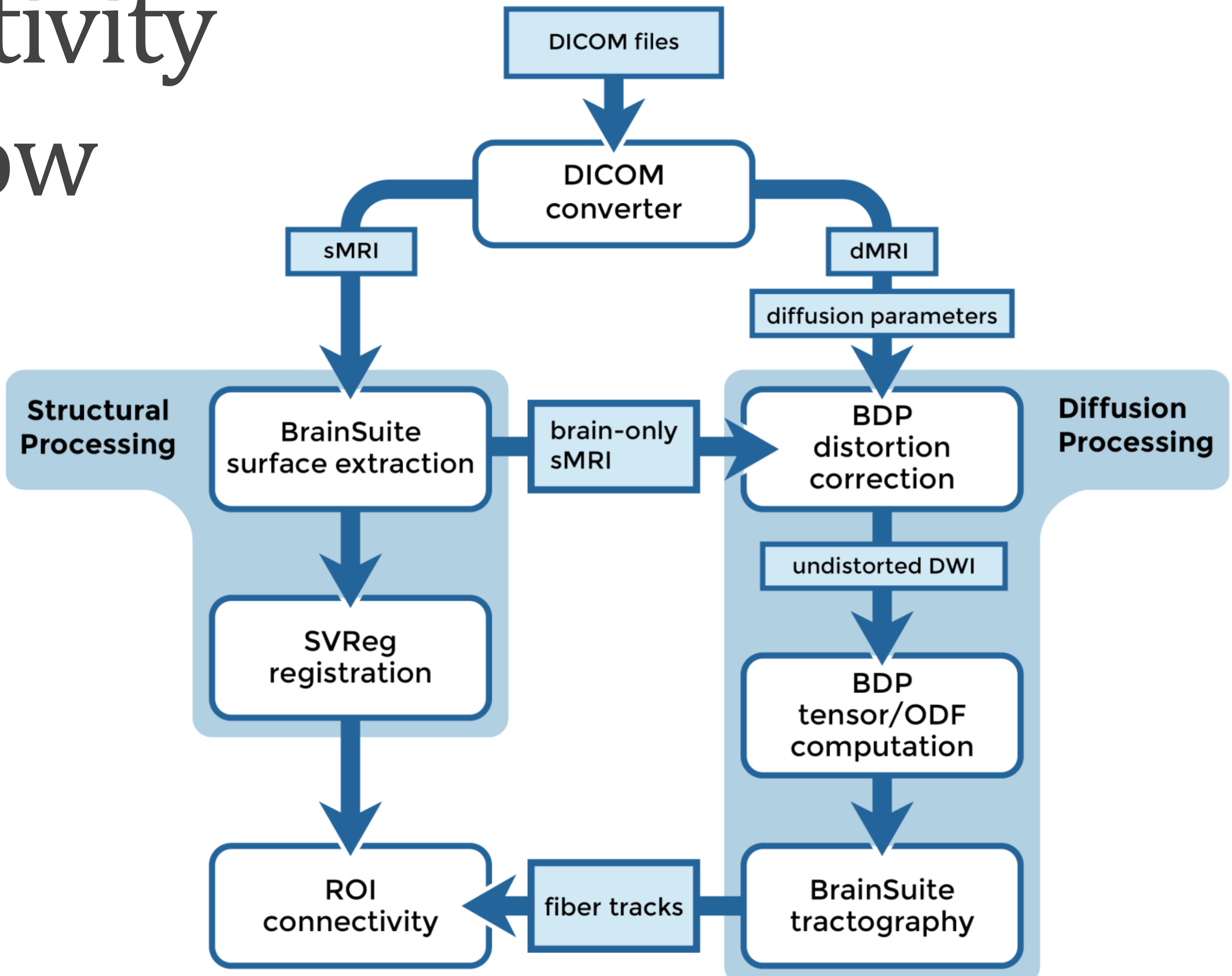


- We are often interested in functional areas in the cortex
- Surface-based features are of interest in the study of development or disease processes
- Many volumetric-based approaches do not align the cortical anatomy well
- EEG/MEG source localization: the location and orientation of the cortical surface can provide additional information
- Cortex can be represented as a high resolution triangulated mesh with ~700,000 triangles

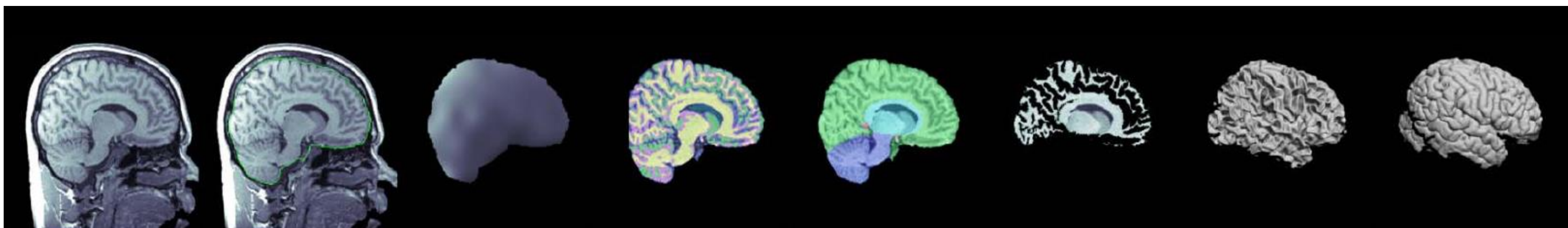


Cortical surface mesh representation

BrainSuite Connectivity Workflow

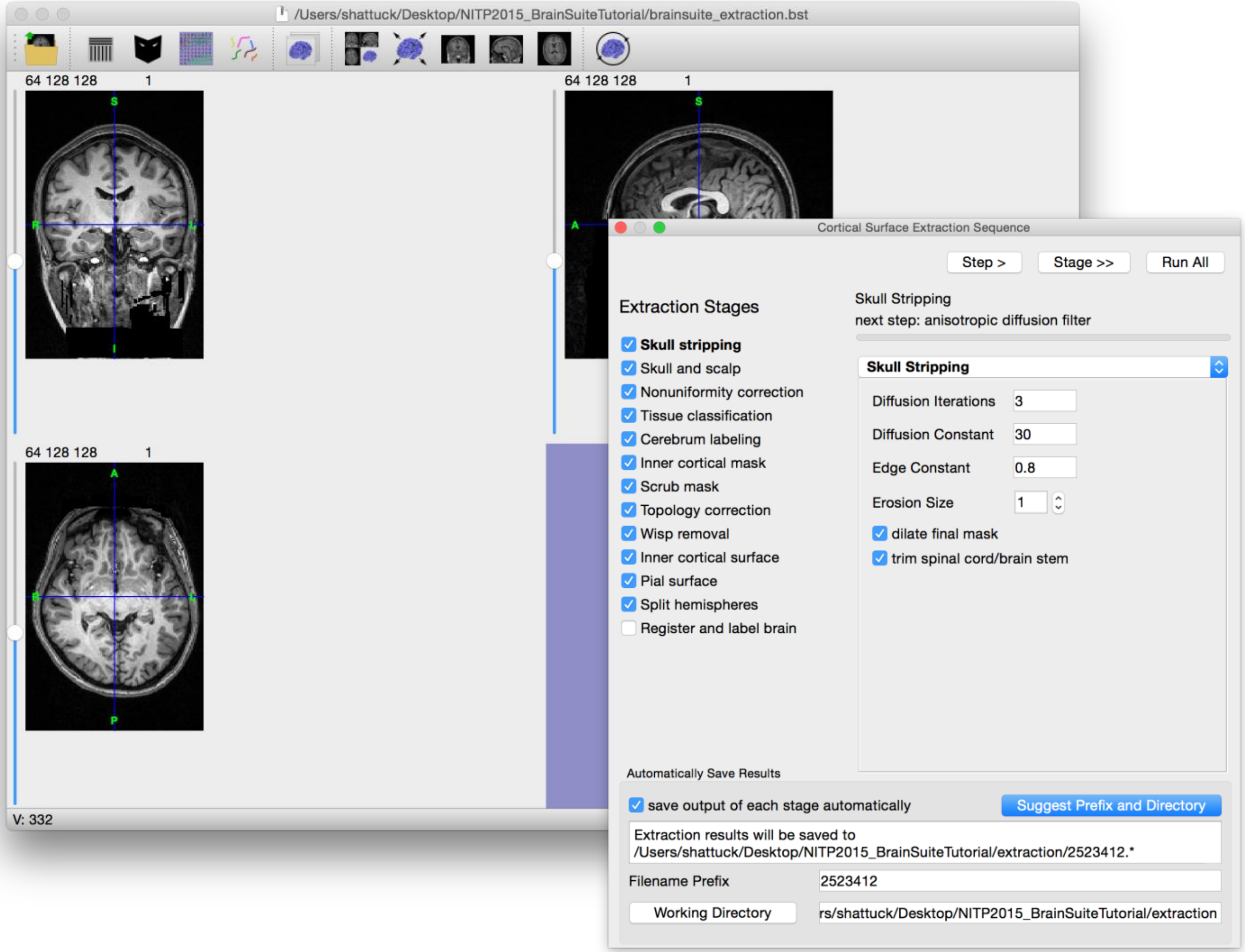


Cortical Surface Extraction



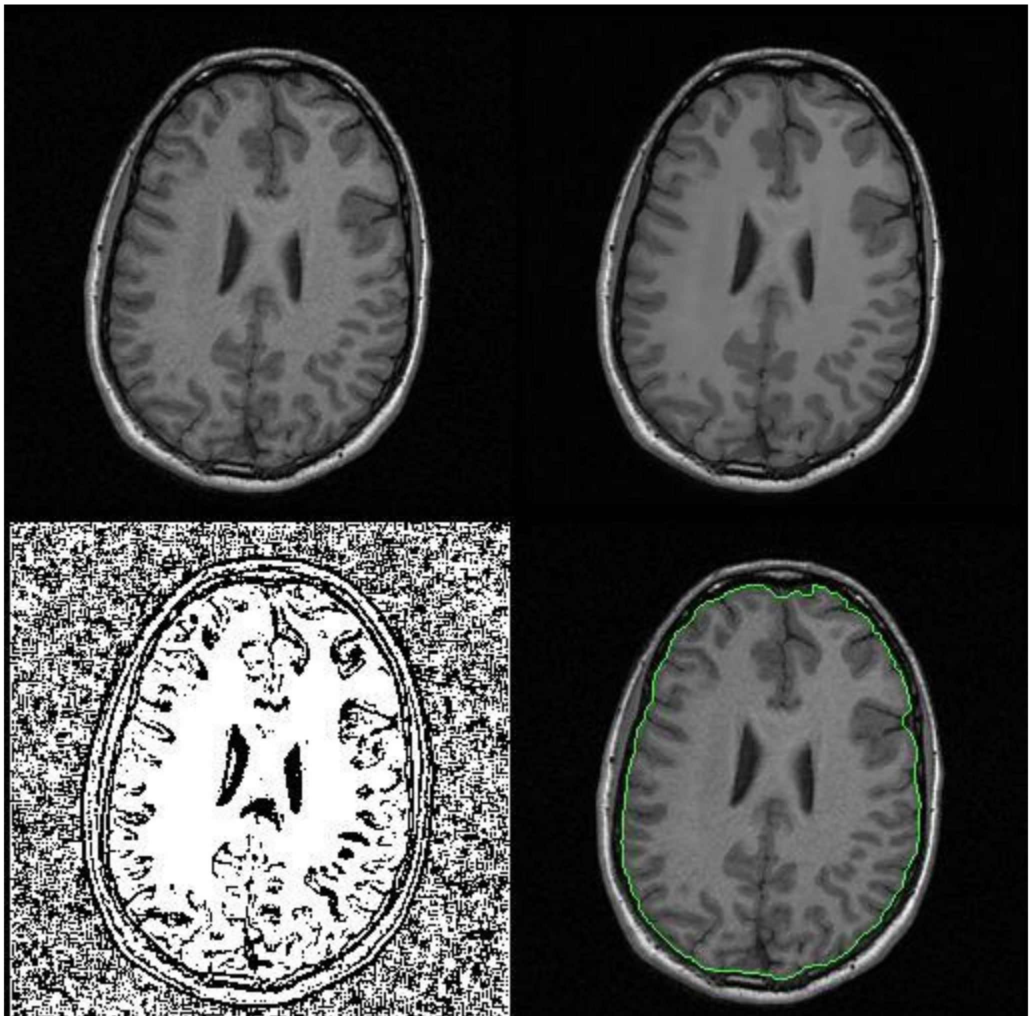
MRI	skull stripping	nonuniformity correction	tissue classification	cerebrum labeling	topology correction	inner cortical surface generation	pial surface generation
	<2 sec	40s - 4 min	<5 sec	<20 sec	<40 sec	<2 sec	<10 min

Cortical Extraction Sequence



Skull Stripping

MRI Filtered MRI

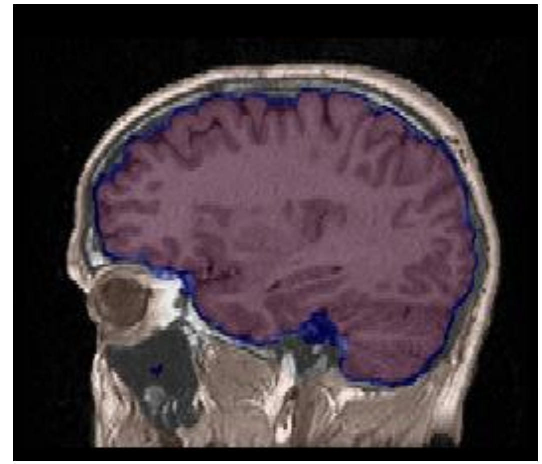


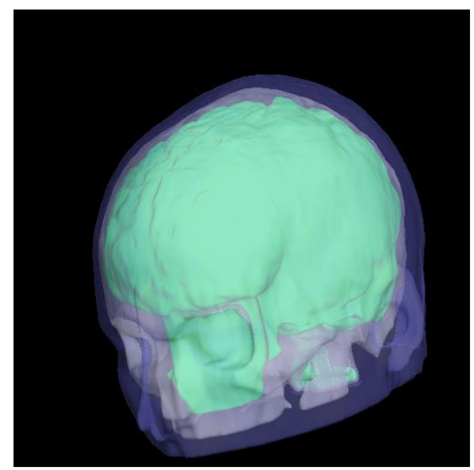
Edge Mask Brain Boundary (green)

- Brain Surface Extractor (BSE) extracts the brain from non-brain tissue using a combination of:
  - anisotropic diffusion filtering
  - edge detection
  - mathematical morphological operators
- This method can rapidly identify the brain within the MRI

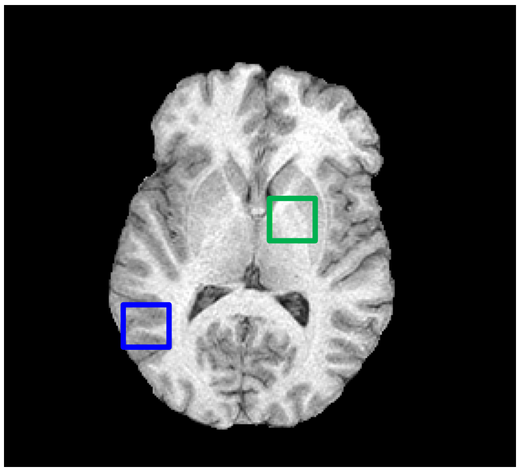
Skull and Scalp Modeling

- We can apply thresholding, mathematical morphology, and connected component labeling to MRI to identify skull and scalp regions.
- The method builds upon the BSE skull stripping result.
- The volumes produced by this algorithm will not intersect.
- We can produce surface meshes from the label volume.
- The results are suitable for use in MEG/EEG source localization.

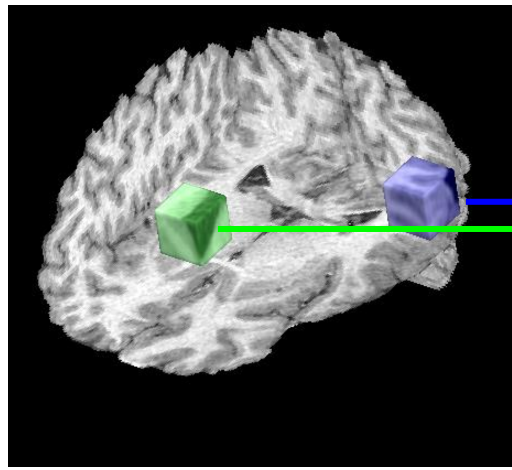




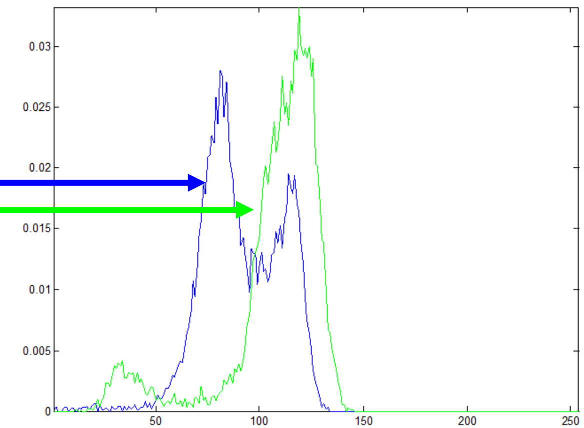
Nonuniformity Correction



Two cubic regions ROIs



3D rendering of the ROIs

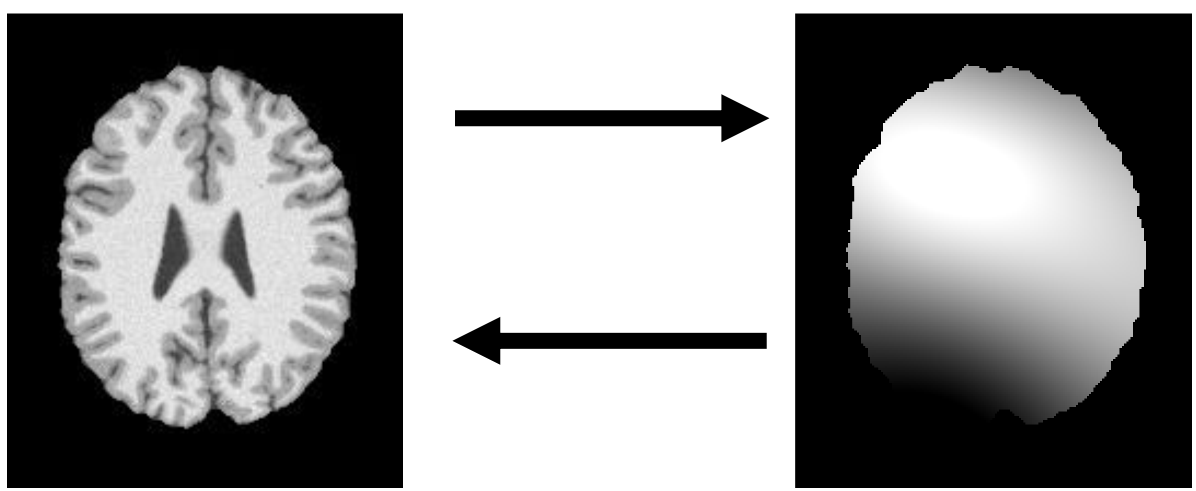


Histograms of the two ROIs

- Nonuniform signal gain can confound tissue classification techniques
- Bias Field Corrector (BFC) performs nonuniformity correction by analyzing the intensity profiles of regions of interest (ROIs)
- We can fit a histogram model to these ROIs and estimate the local gain variation

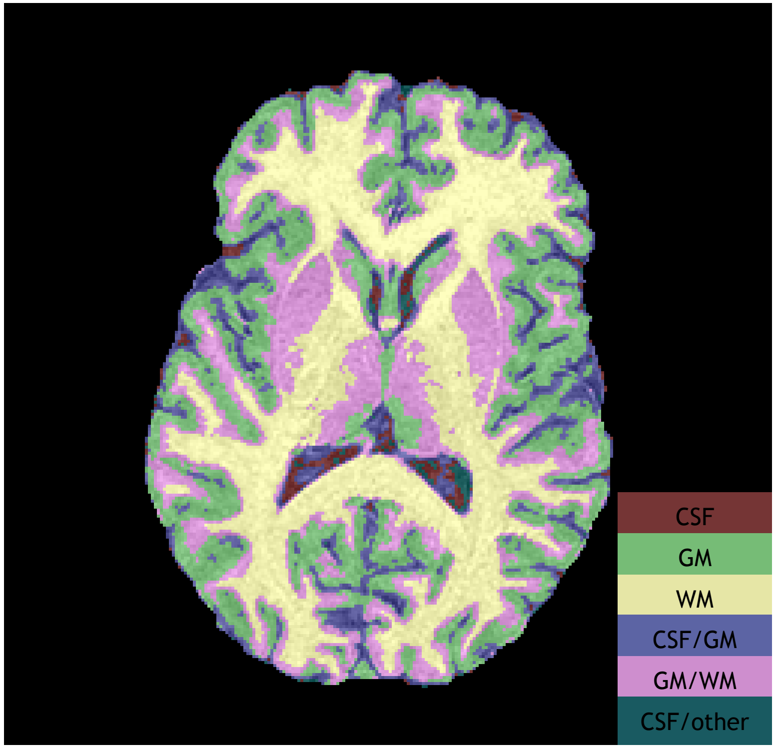
Nonuniformity Correction

- Estimate bias parameter at several points throughout the image.
- Remove outliers from our collection of estimates.
- Fit a tri-cubic B-spline to the estimate points.
- Divide the image by the B-spline to make the correction.



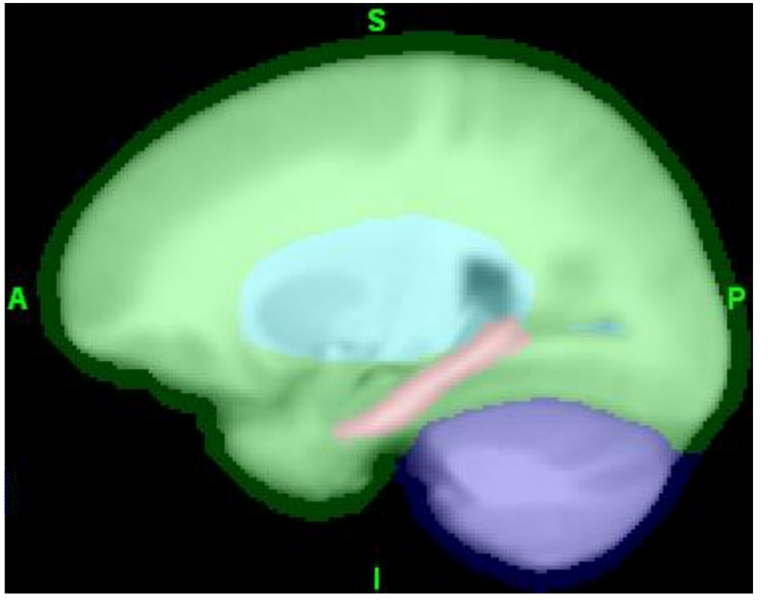
Tissue Classification

- We use a statistical tissue classifier to label each voxel according to tissue type.
  - Initialize with a maximum likelihood classification
  - Refine with a maximum a posteriori (MAP) classifier that produces more contiguous regions of tissue
- Tissue categories are
  - Pure: GM, WM, CSF
  - Mixed: GM/CSF, GM/WM, CSF/Other
- Also estimate tissue fractions at each voxel

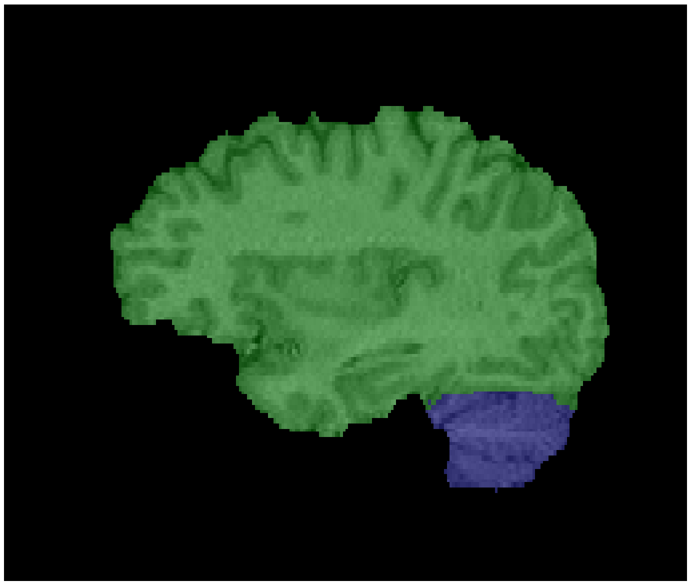


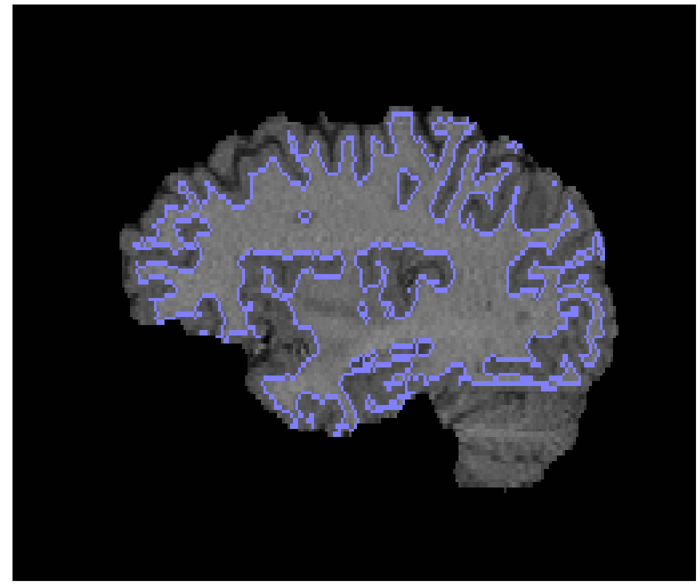
Cerebrum Labeling

- For the cortical surface, we are interested in the cerebrum, which we separate from the rest of the brain.
- We achieve this by registering a multi-subject average brain (ICBM452) to the individual brain using AIR (R. Woods)
- We have labeled this atlas:
  - cerebrum / cerebellum
  - subcortical regions
  - left / right hemispheres



Inner Cortical Mask

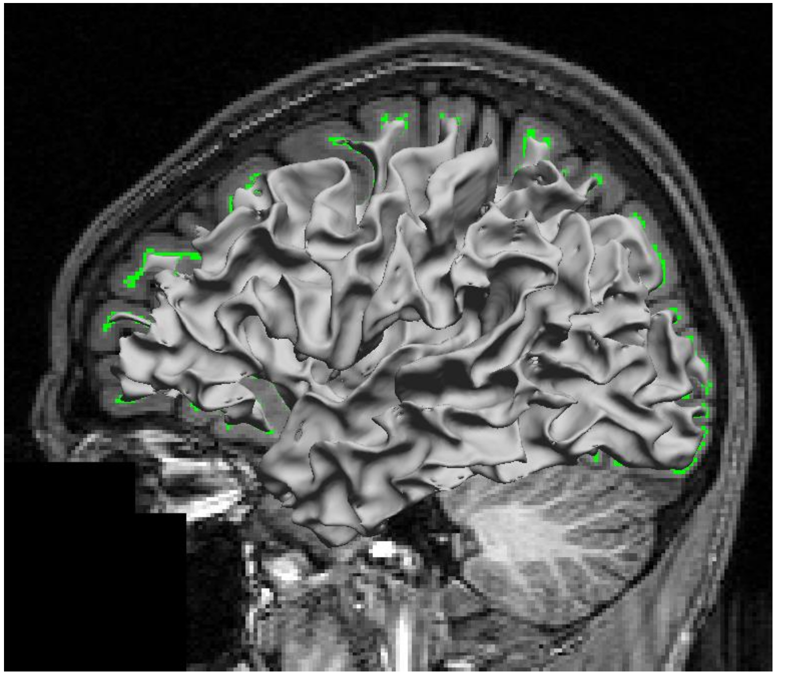




- We combine our registered brain atlas with our tissue map
  - Retain subcortical structures, including nuclei
  - Identify the inner boundary of the cerebral cortex

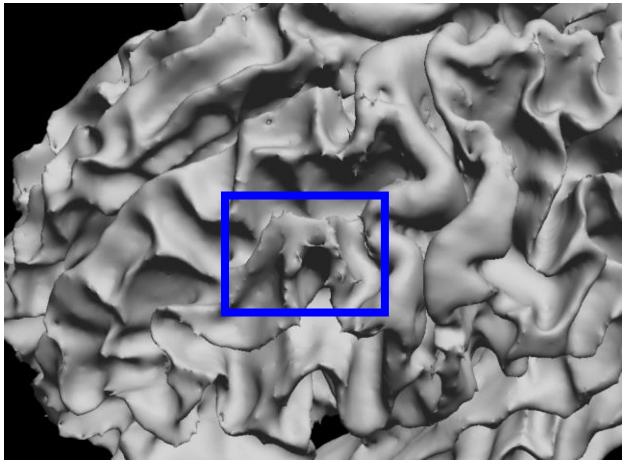
Surface Generation

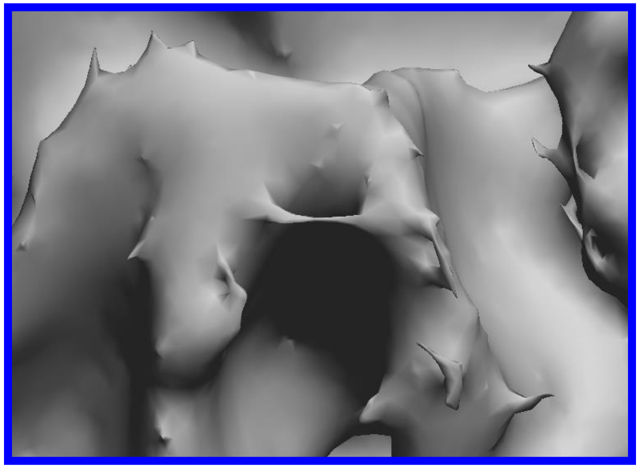
By applying a tessellation algorithm, we can generate a surface mesh from a 3D volume.



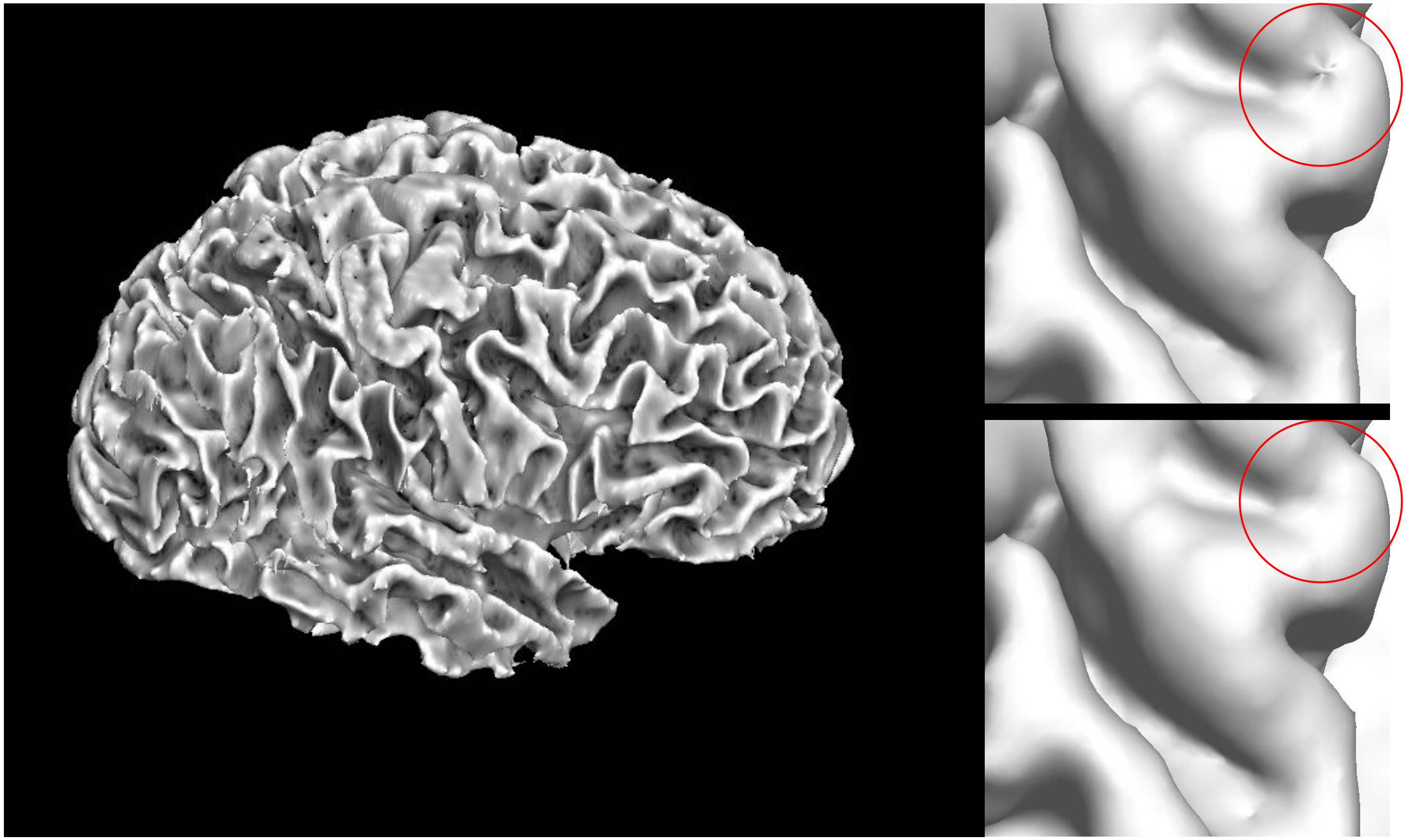
Topological Errors

- In normal human brains, the cortical surface can be considered as a single sheet of grey matter.
- Closing this sheet at the brainstem, we can assume that the topology of the cortical surface is equivalent to a sphere, i.e., it should have no holes or handles.
- This allows us to represent the cortical surface using a 2D coordinate system.
- Unfortunately, our segmentation result will produce a surface with many topological defects.





Topology Correction

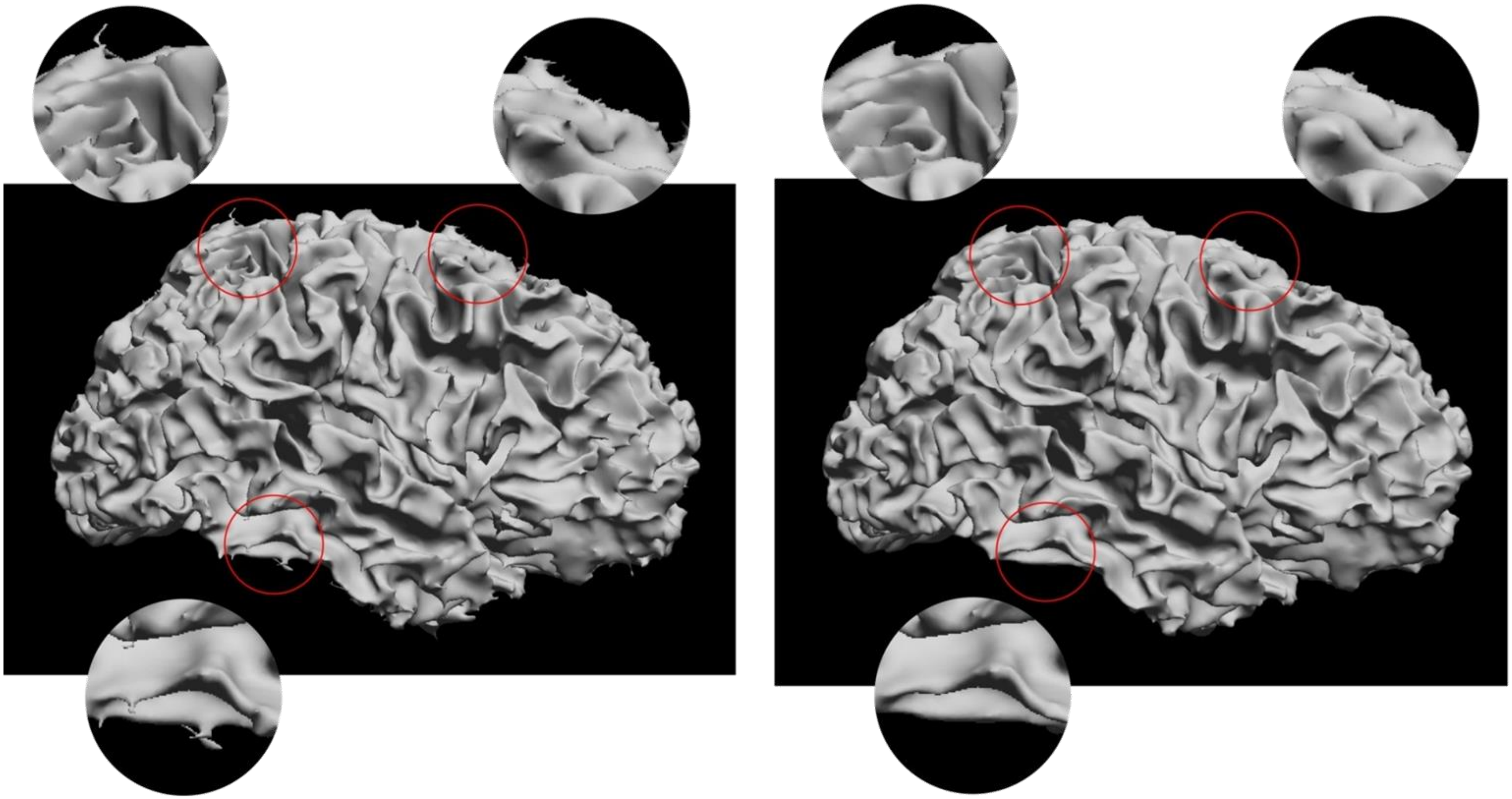


(left) cortical surface model produced from binary masks

(top right) close-up view of a handle on the surface generated from the volume before topological correction

(bottom right) close-up view of the same region on the surface generated from the same volume after topology correction.

Wisp Removal



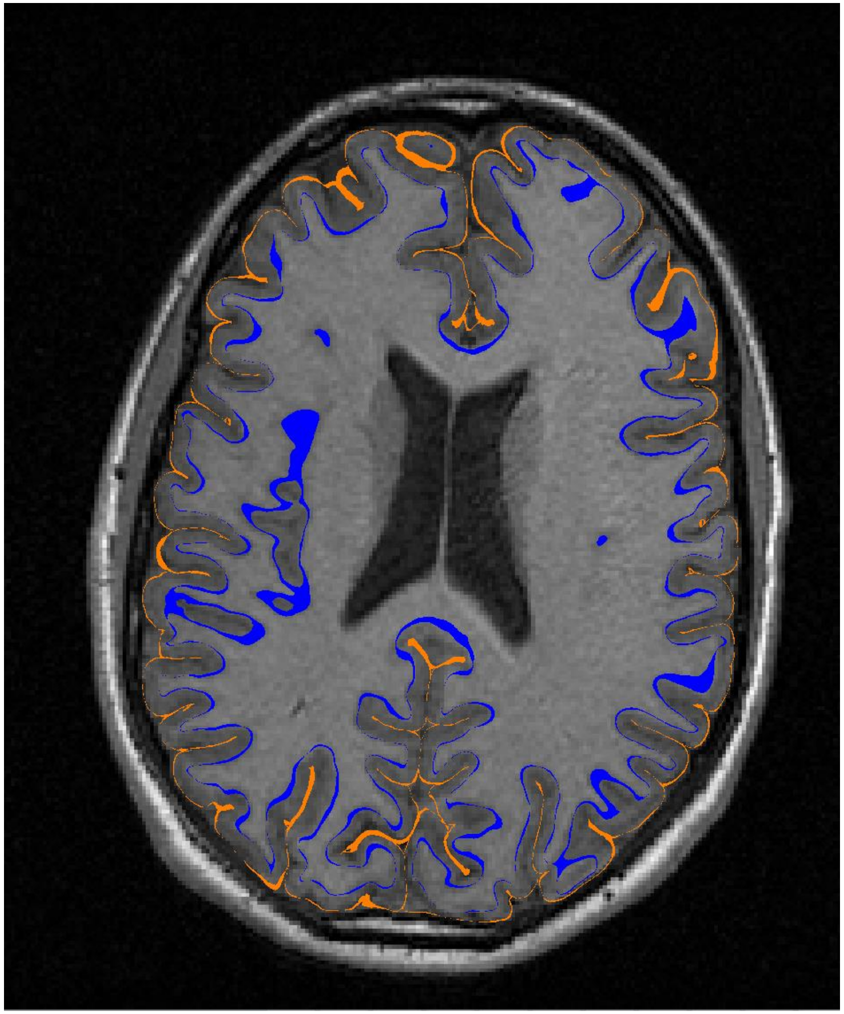
Inner Cortical Surface

After applying the topology correction and dewisp filters, we apply marching cubes to generate a representation of the inner cortical boundary.

Pial Surface

- Expand inner cortex to outer boundary
- Produces a surface with 1-1 vertex correspondence from GM/WM to GM/CSF
  - Preserves the surface topology
  - Provides direct thickness computation
  - Data from each surface maps directly to the other

Pial Surface

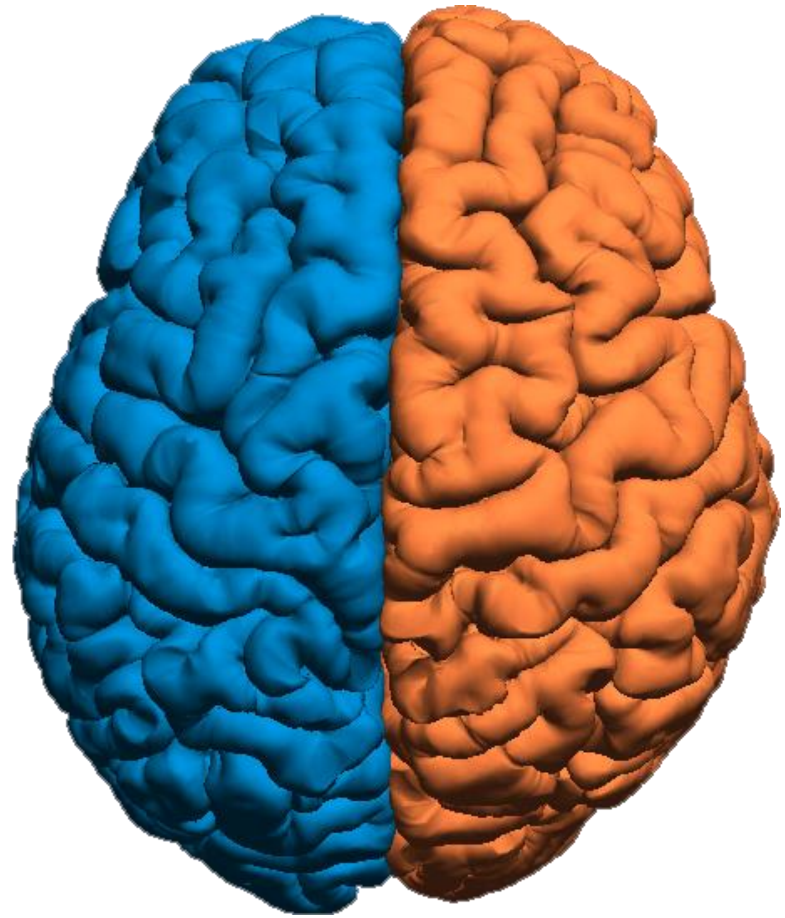


Contour view showing the inner (blue) and outer (orange) boundaries of the cortex.

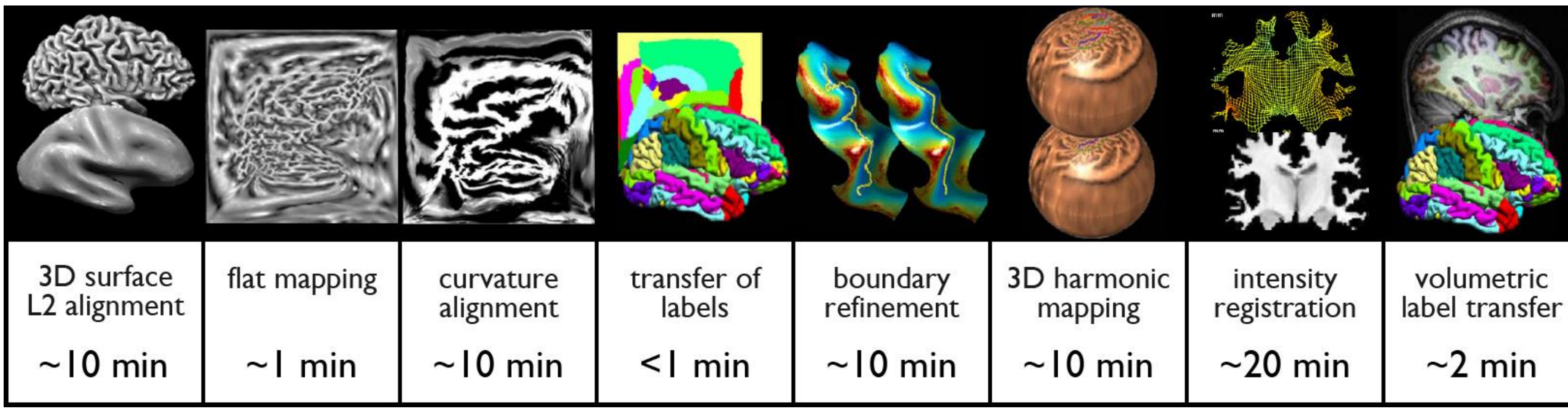
Split Hemispheres

We can separate the meshes into left and right hemispheres based on hour cerebrum labeling

These surface models are then used by the surface/volume registration and labeling routine (SVReg)

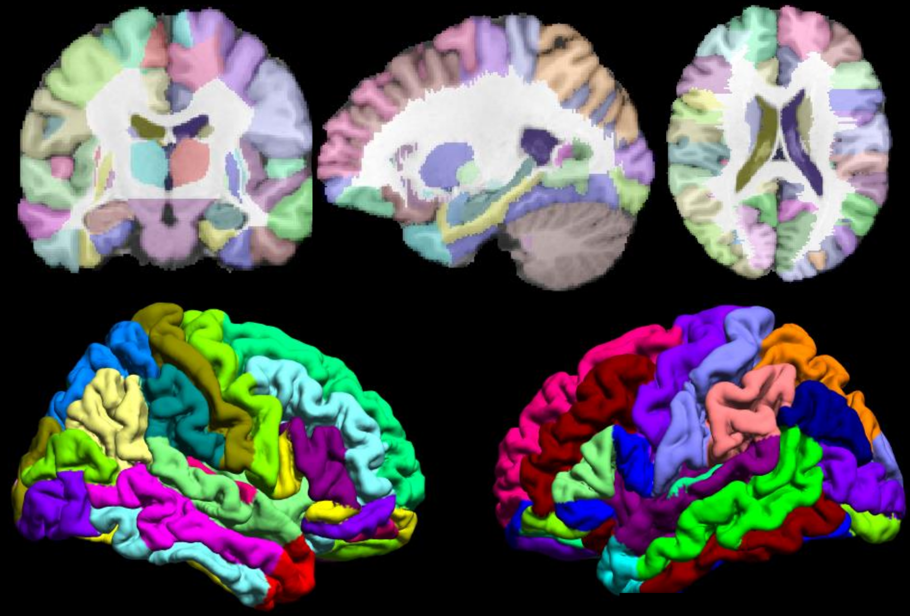


Surface-constrained Volumetric Registration



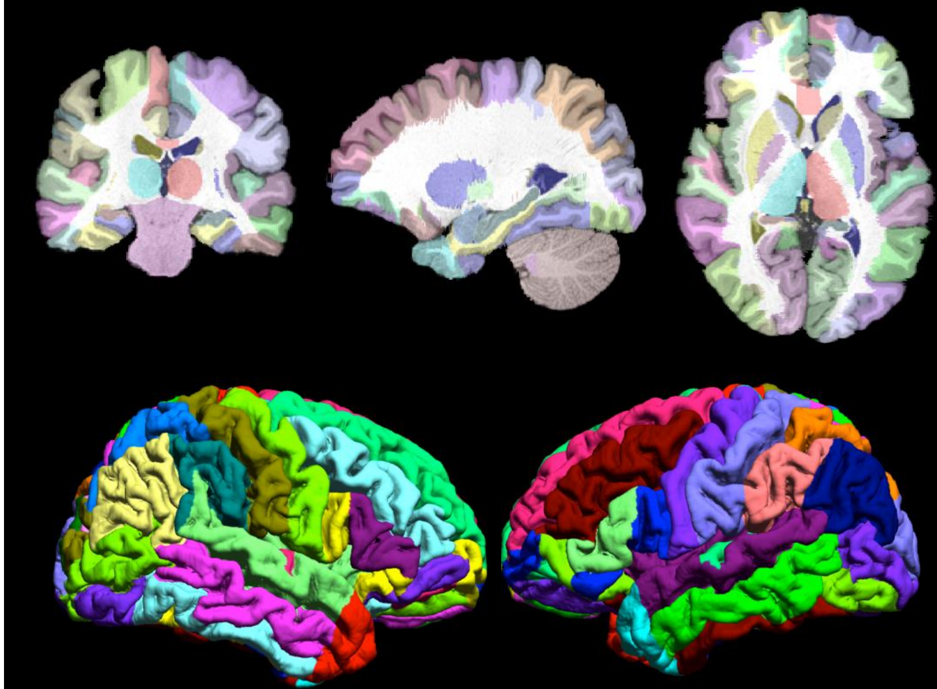
BrainSuite Atlas1

- Single subject atlas labeled at USC by an expert neuroanatomist
- 26 sulcal curves per hemisphere
- 98 volumetric regions of interest (ROIs), 35*2=70 cortical ROIs

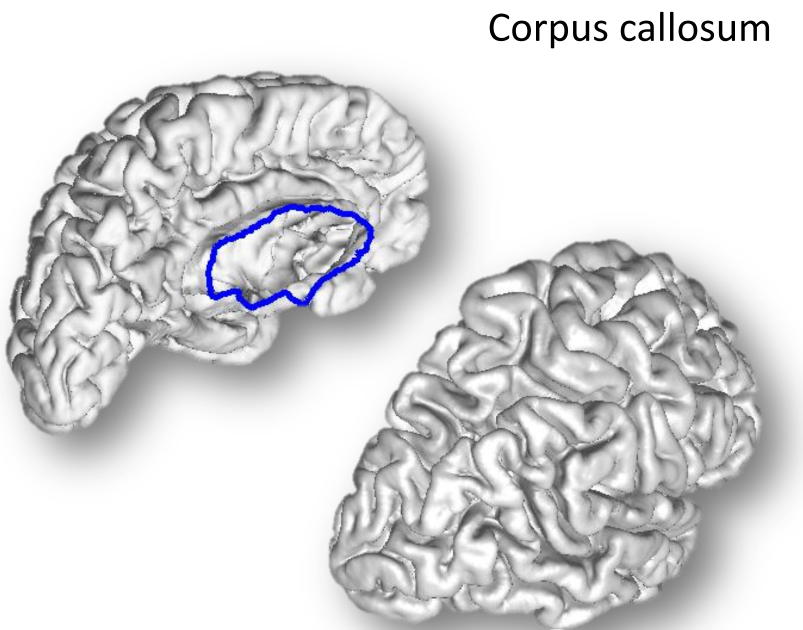


BCI-DNI Atlas

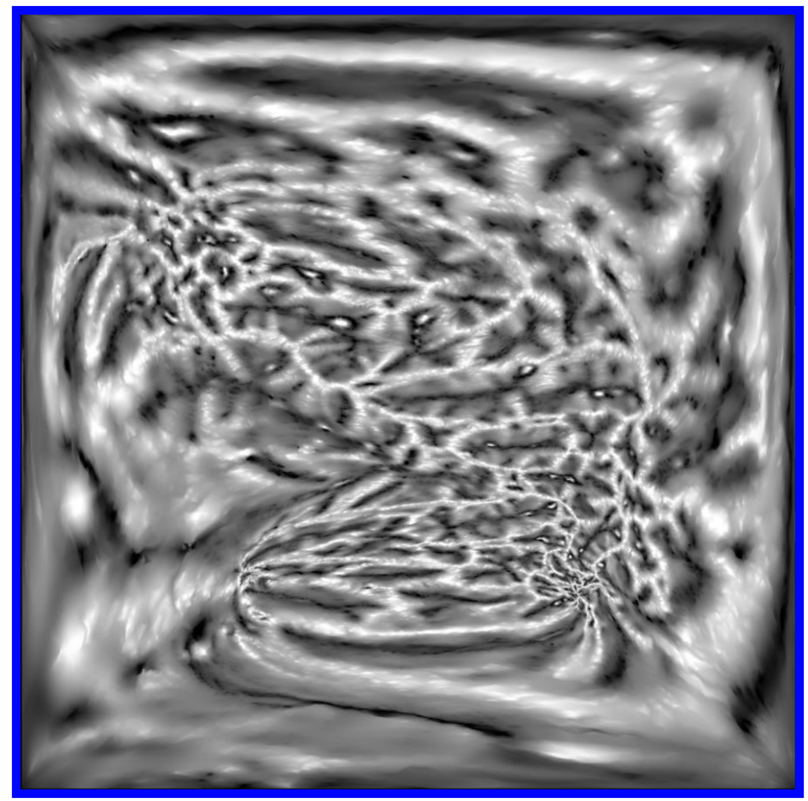
- Single subject atlas labeled at USC by an expert neuroanatomist
- high-resolution (0.5 mm × 0.5 mm × 0.8 mm) 3D MPRAGE, 3T scan
- 26 sulcal curves per hemisphere
- 95 volumetric regions of interest (ROIs), 33*2=66 cortical ROIs



Flat Mapping

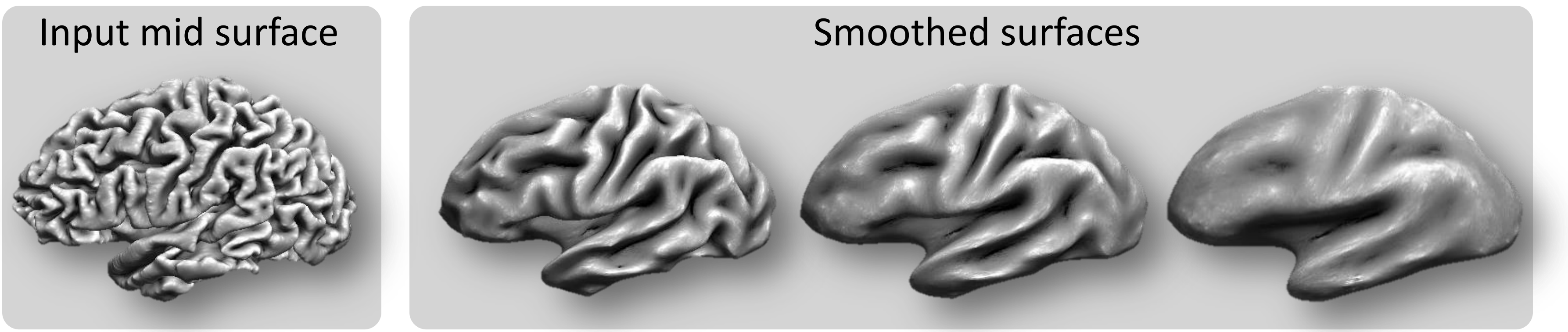


Cortical Surface Parameterization

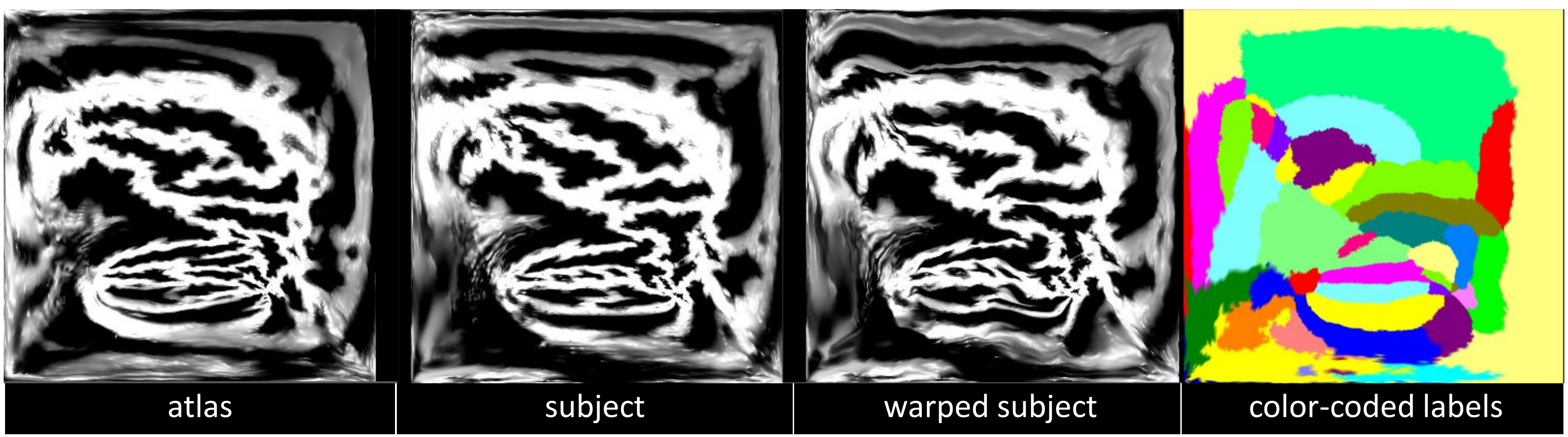


Flat-map color coded by curvature

Curvature Alignment

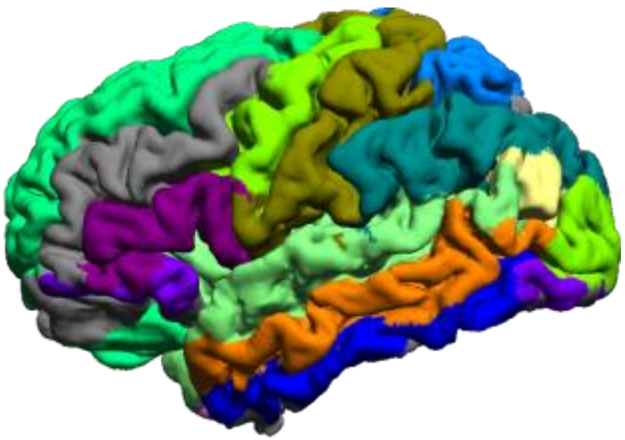


Cumulative curvature computation for multiresolution representation

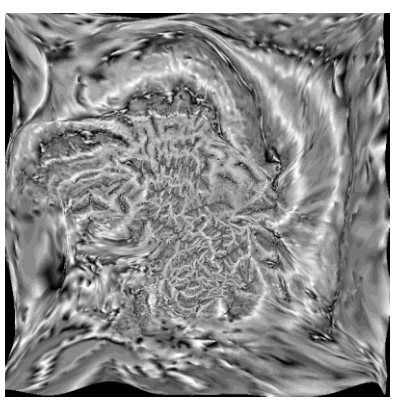


Elastic matching for atlas and subject flat maps

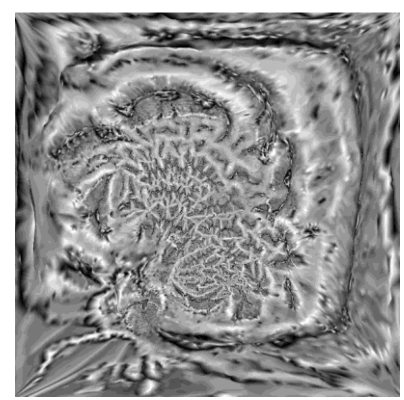
Transfer of Labels



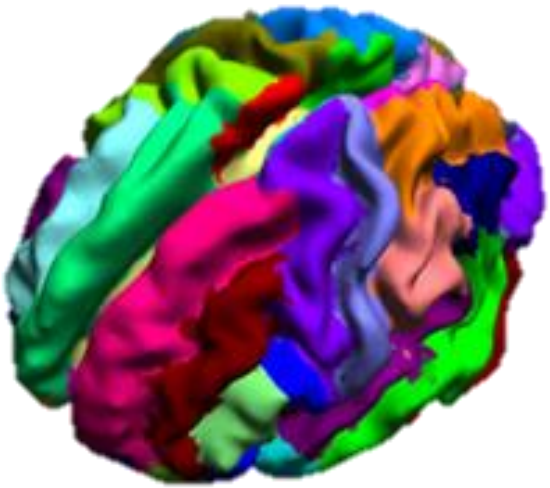
subject



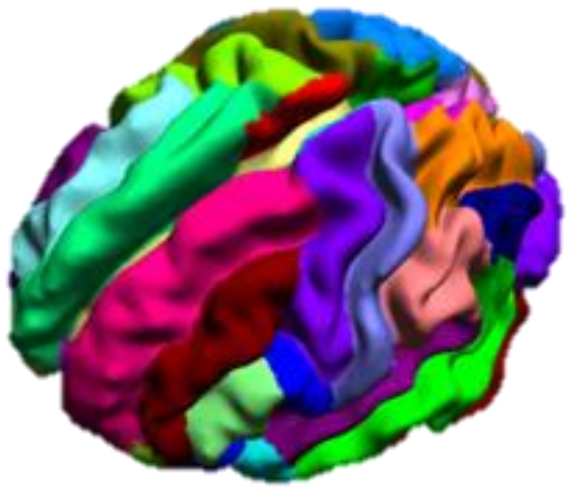
atlas



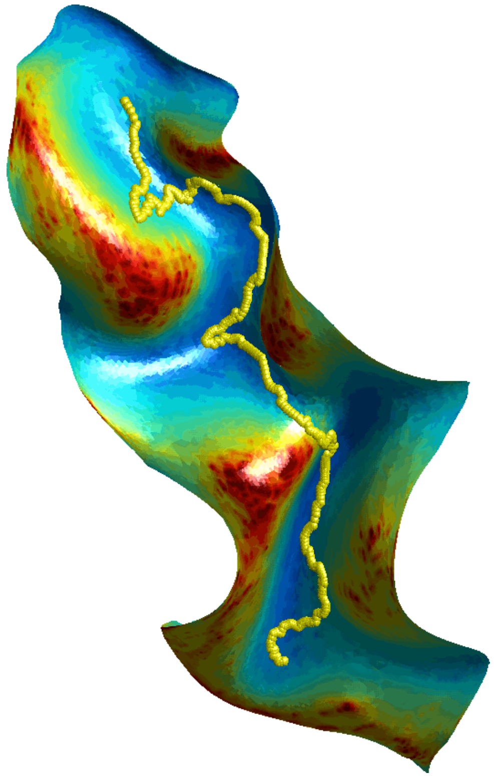
Boundary Refinement



Original labels plotted on a smoothed representation of a cortical surface.

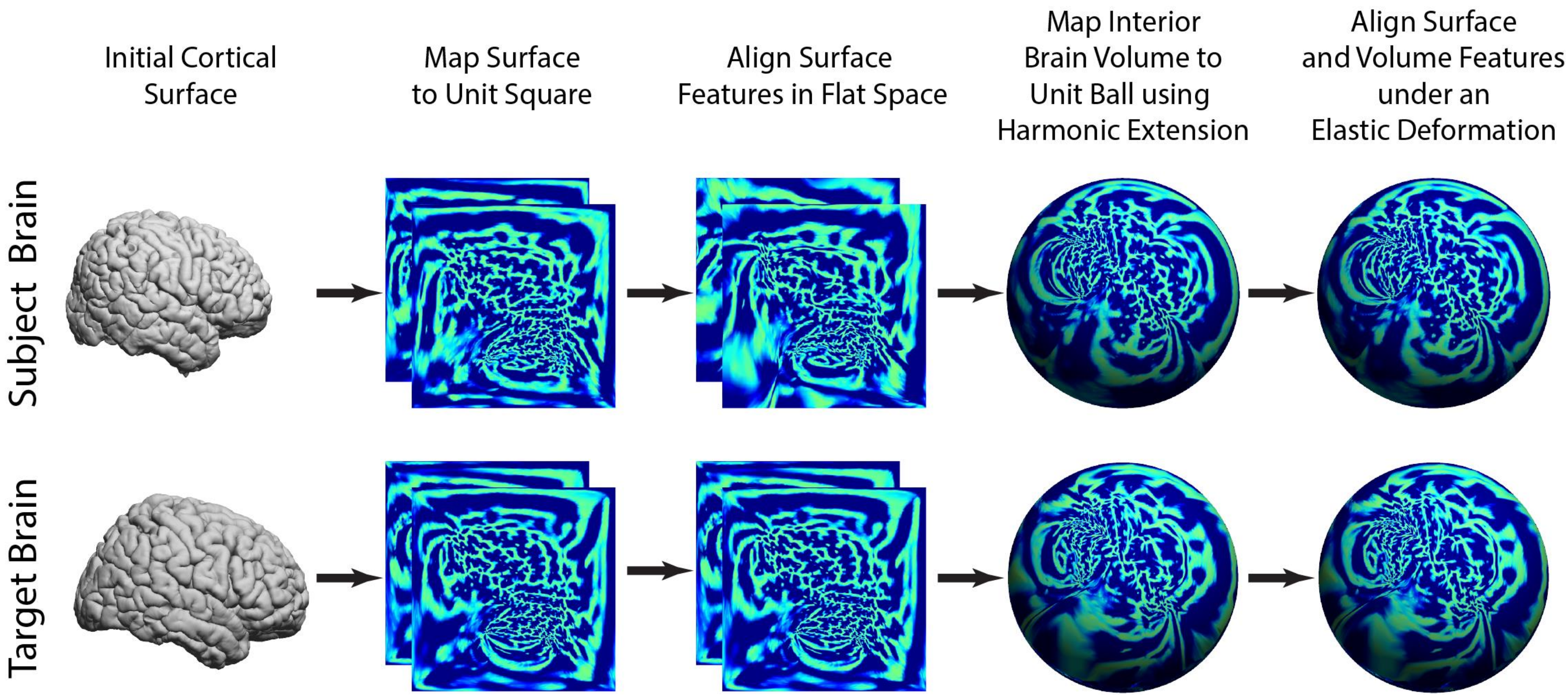


Labels after geodesic curvature flow plotted on a smoothed representation of a cortical surface.



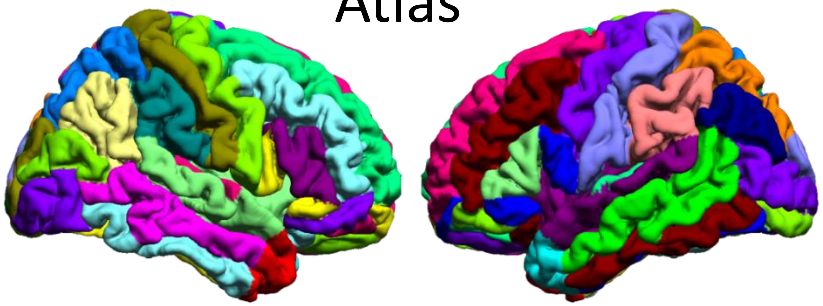
Animation of the geodesic curvature flow for sulcal refinement.

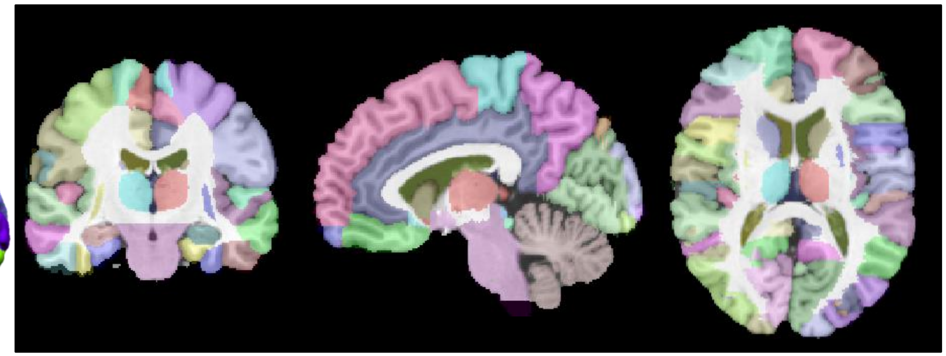
3D Harmonic Mapping & Intensity Registration



Volumetric Label Transfer

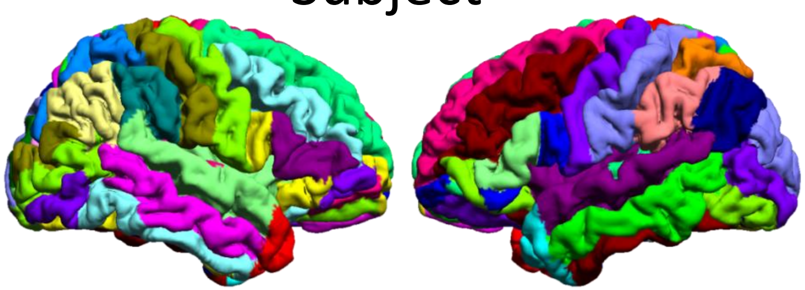
Atlas

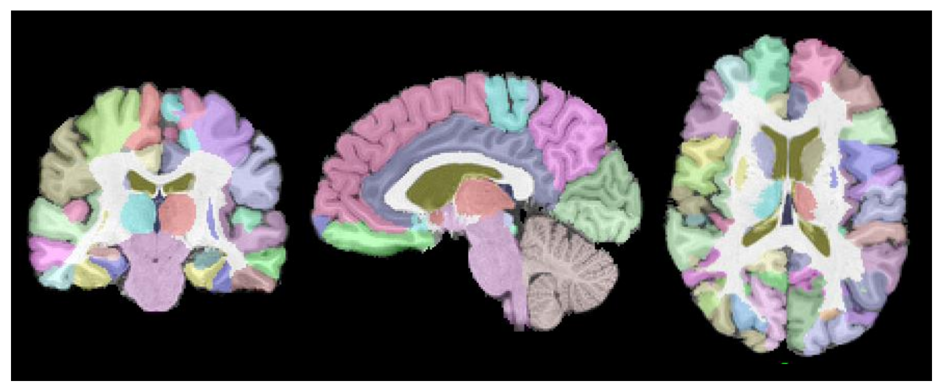




Views of the BrainSuite anatomical atlas, delineated into anatomical ROIs.

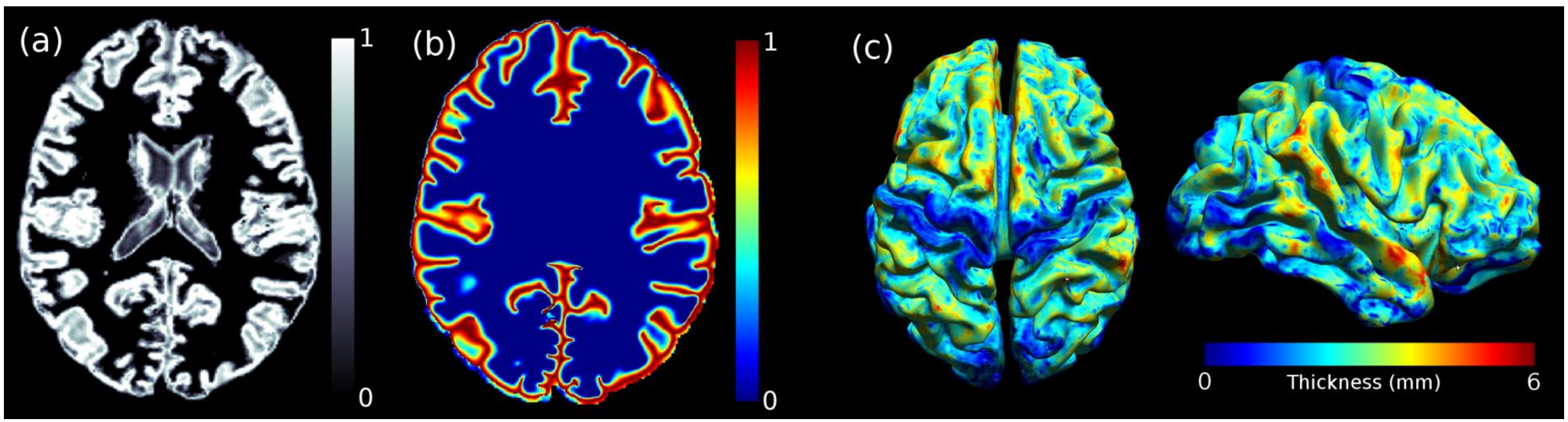
Subject





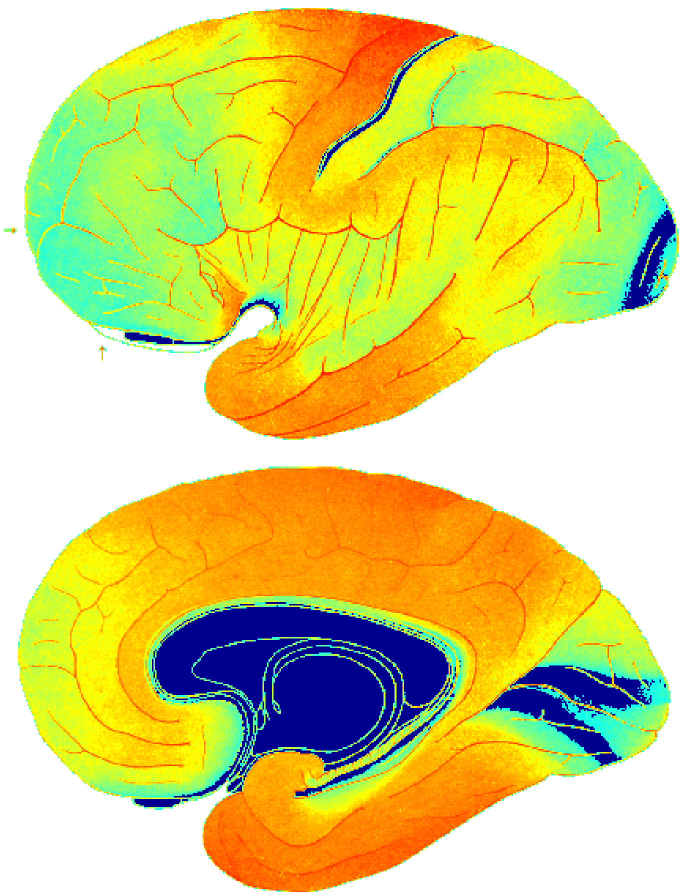
Similar views of an automatically labeled subject dataset.

Cortical Thickness using Partial Tissue Fraction Estimates

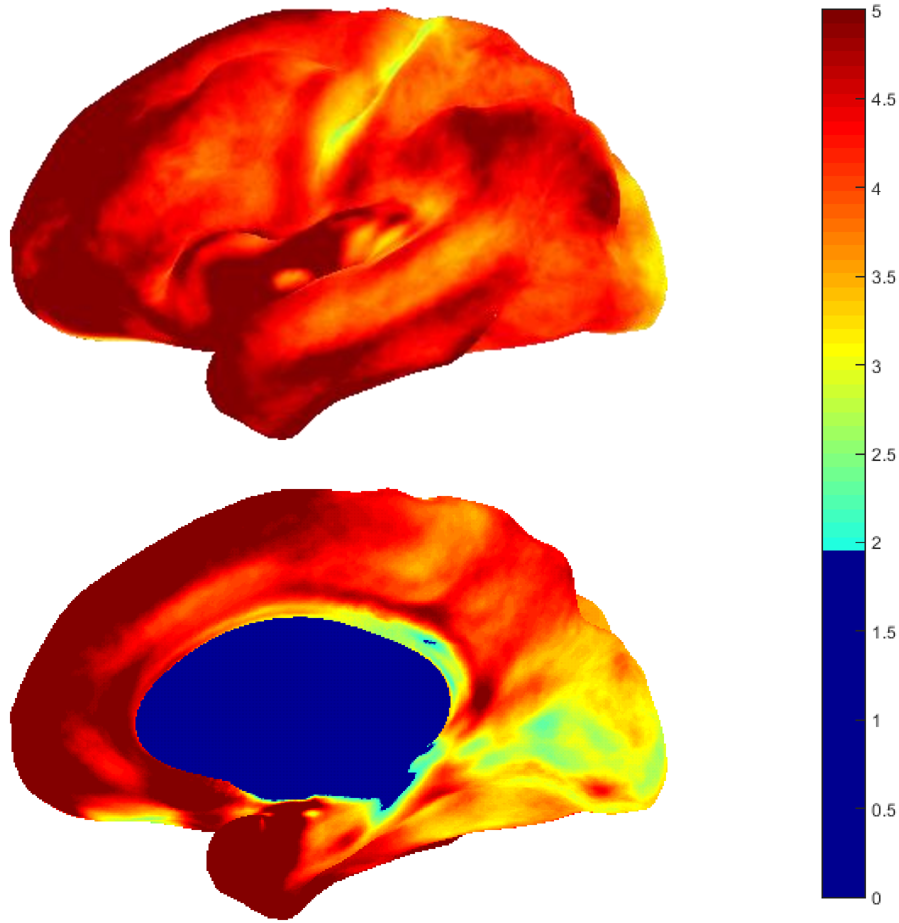


(a) Gray-matter fraction estimated using a partial volume model;
(b) Temperature map obtained using the proposed ALE method; and
(c) Thickness estimate using the ALE method shown on the estimated mid-cortical surface.

Comparisons

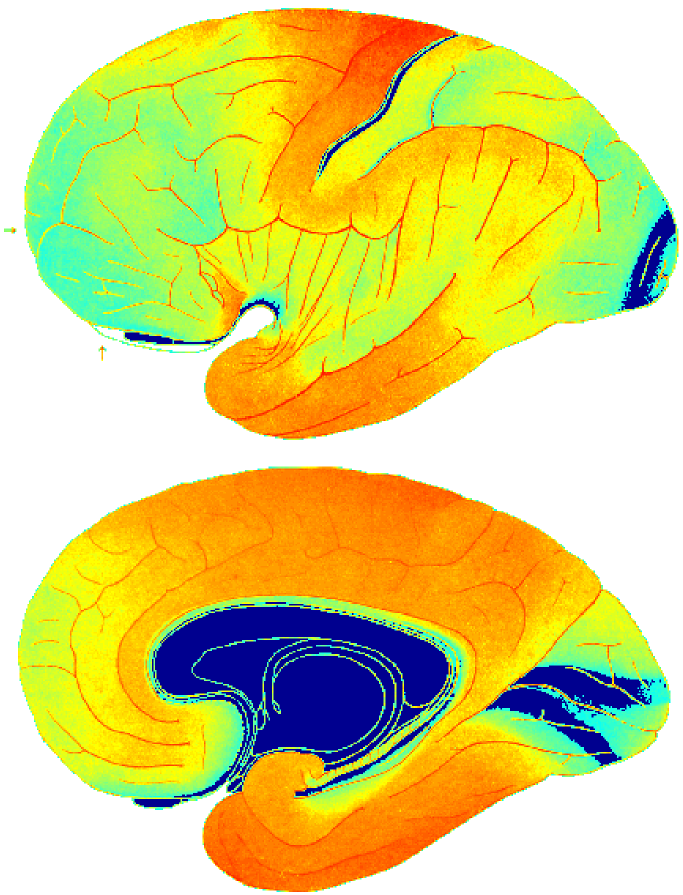


Von Economo and Koskinas (1925)



From MRI using linked distance (averaged over 186 subjects)

Comparisons



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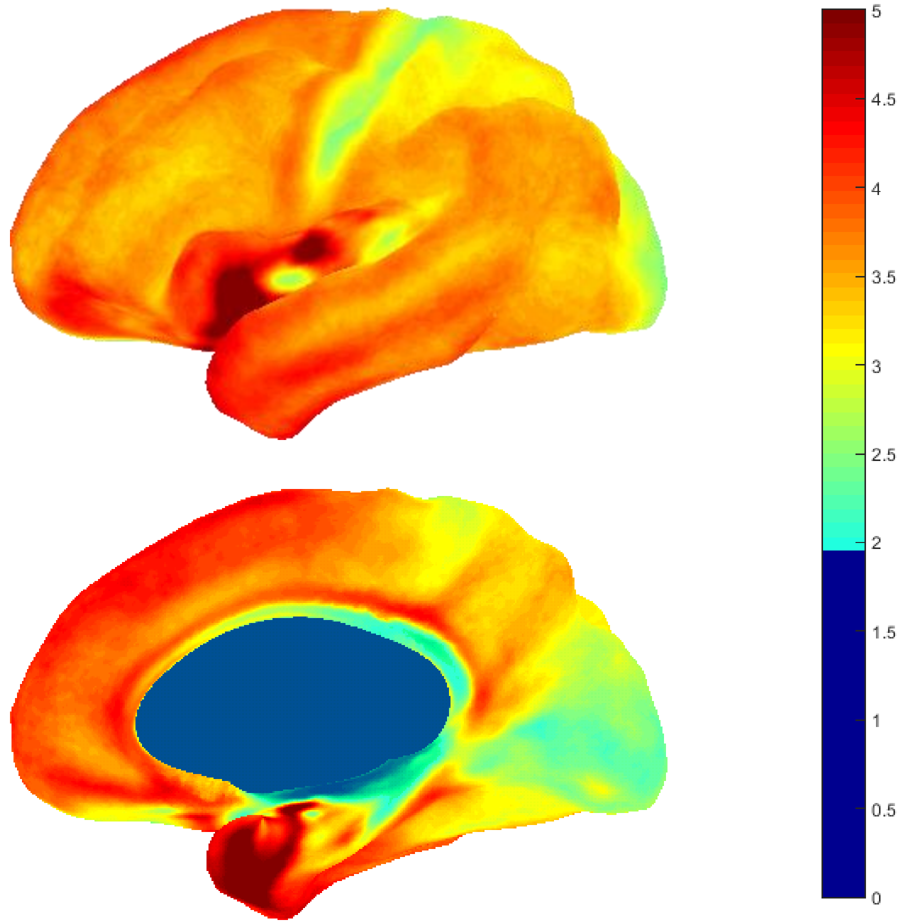
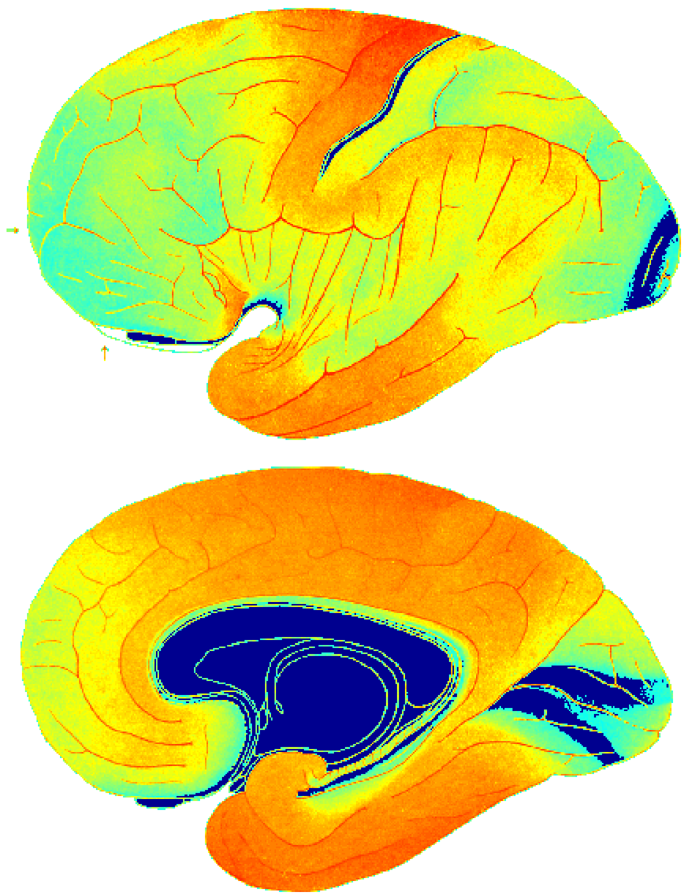
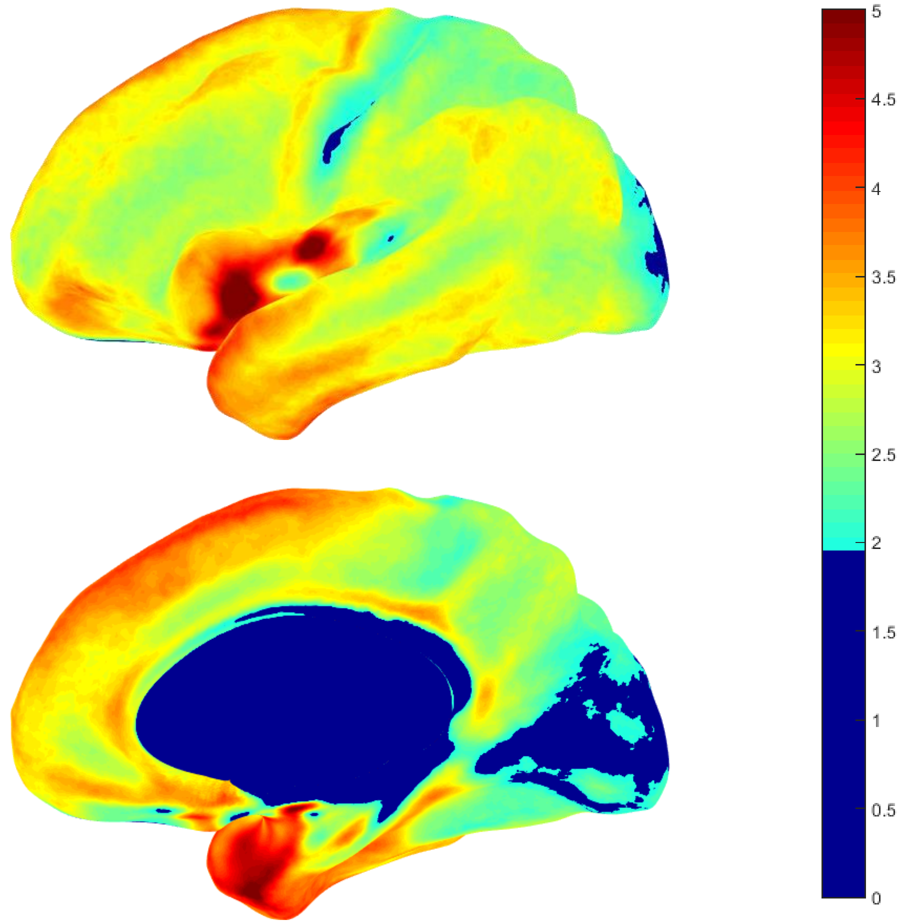


From MRI: isotropic heat equations (averaged over 186 subjects)

Comparisons



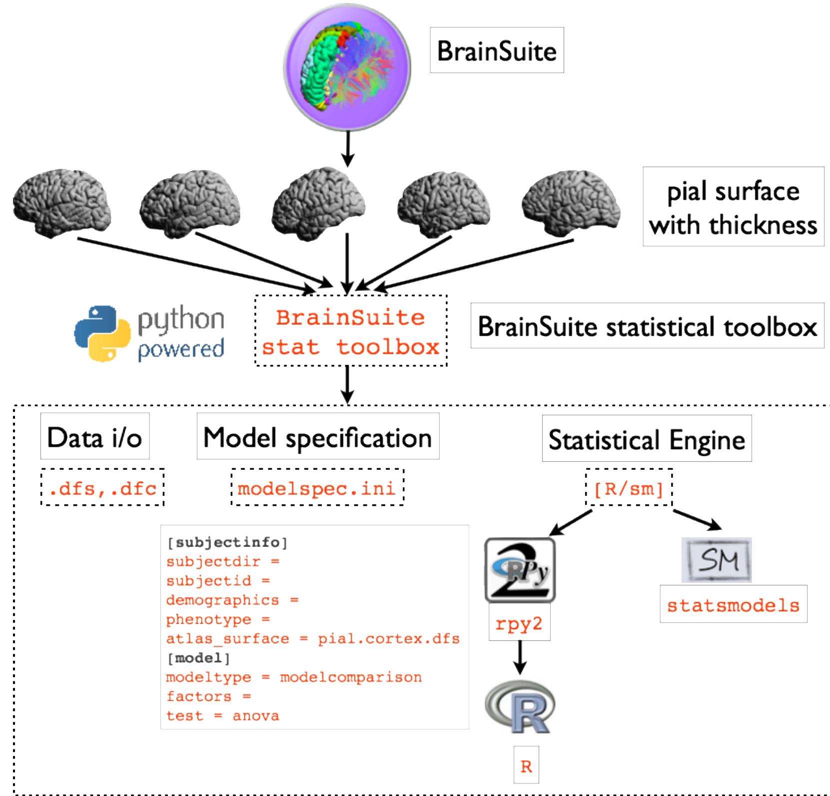
Von Economo and Koskinas (1925)

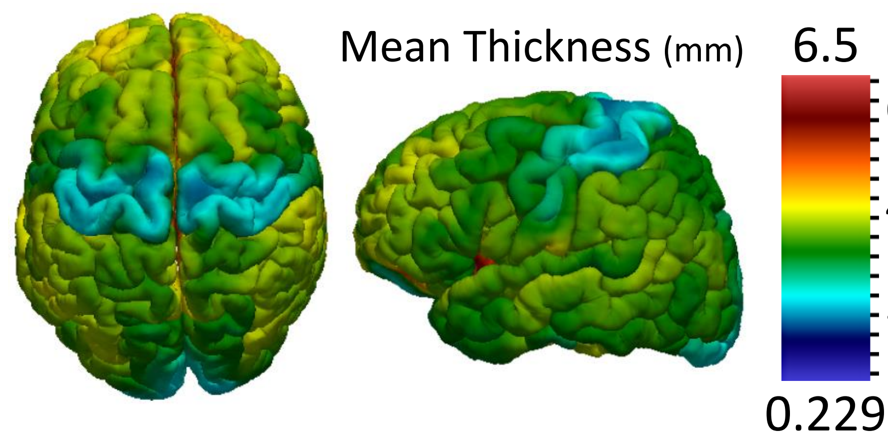


From MRI: anisotropic heat equation (averaged over 186 subjects)

BrainSuite Statistical Toolbox

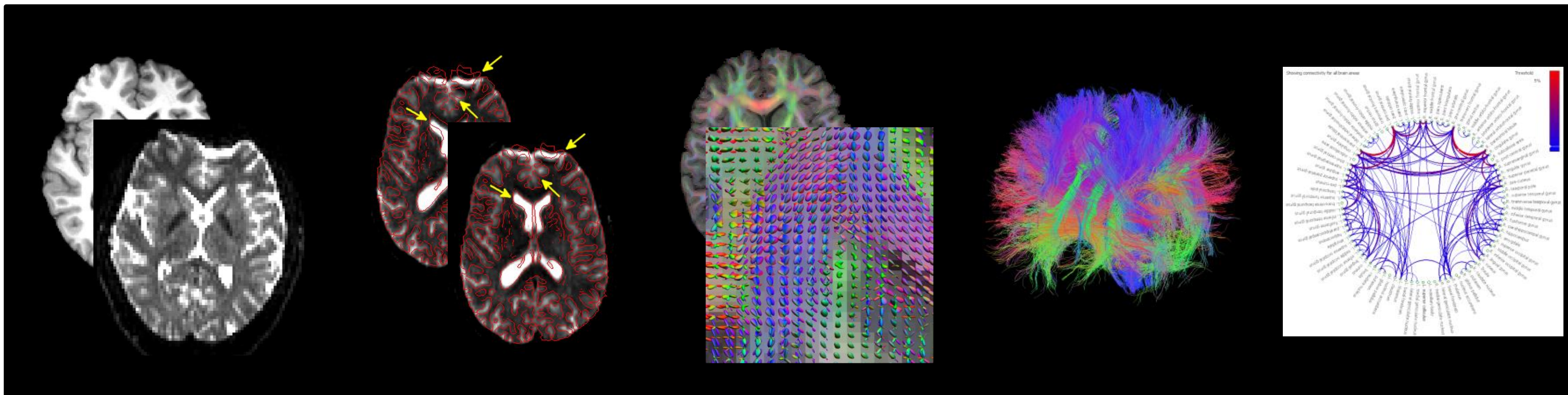
- Performs structural group analysis for cortical surfaces
- Encapsulates data representation, the model specification, and the statistical computation process.
- Implemented in Python with rpy2.
- Cross-platform - Win, Mac, Linux
- Offers statistical methods:
  - ANOVA, GLM, correlation
  - Provision for Multiple testing - FDR
  - Uses R data.table to efficiently vectorize operations
- Available at brainsuite.org/bss





S. Joshi et al., OHBM2014

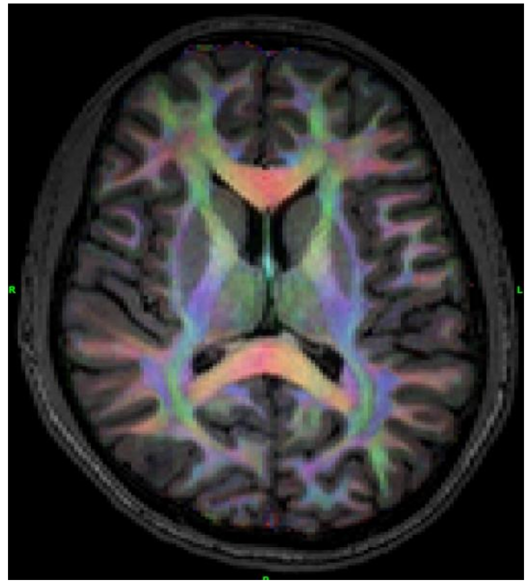
BrainSuite Diffusion Pipeline



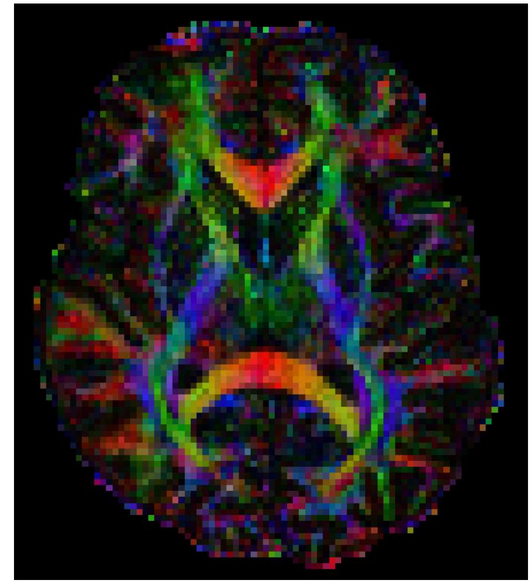
T1/DWI coregistration	distortion correction	diffusion modeling	whole-brain tractography	connectivity analysis

T1 / Diffusion Registration

T1 Coordinates
(Surfaces, Labels)



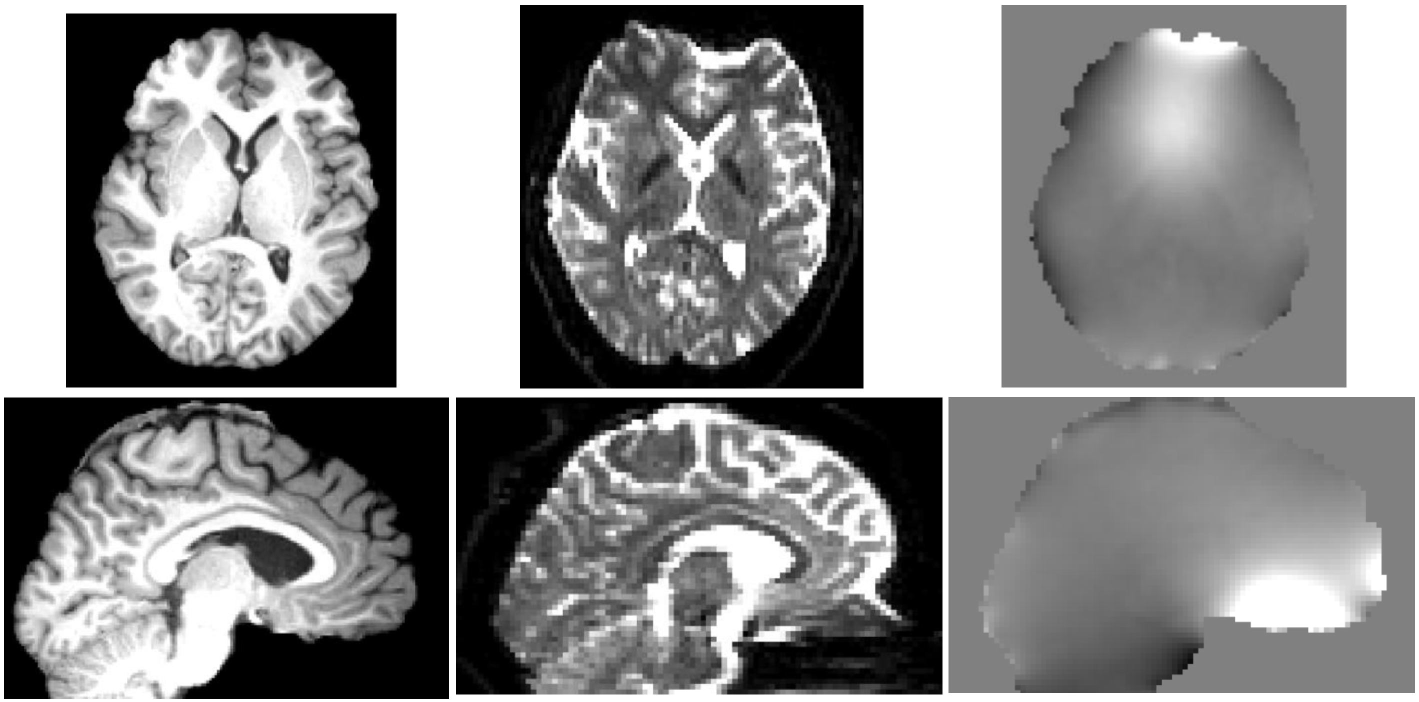
T1/Color-FA
Overlay



Diffusion Coordinates

- If we want to fuse information from diffusion and structural MRI, we need to co-register them.
- However, rigid registration is not enough.

EPI Distortion

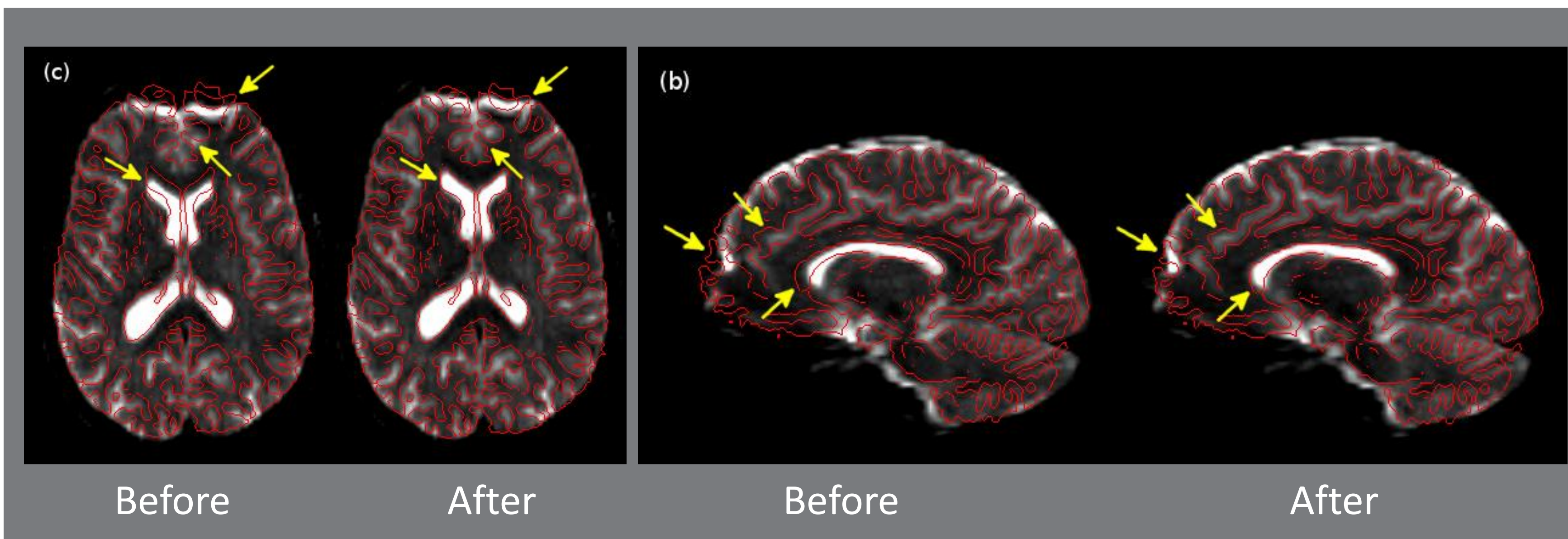


MPRAGE image | b=0 image (EPI) | Field inhomogeneity map

- Diffusion MRI uses fast acquisition – echo planar imaging (EPI)
- Susceptibility differences ➔ magnetic field (B0) inhomogeneity
- EPI is sensitive to B0 inhomogeneity ➔ localized geometric distortion

Registration-based Correction

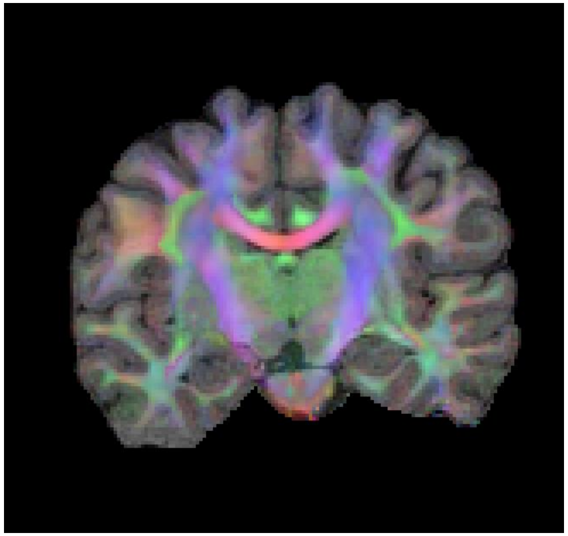
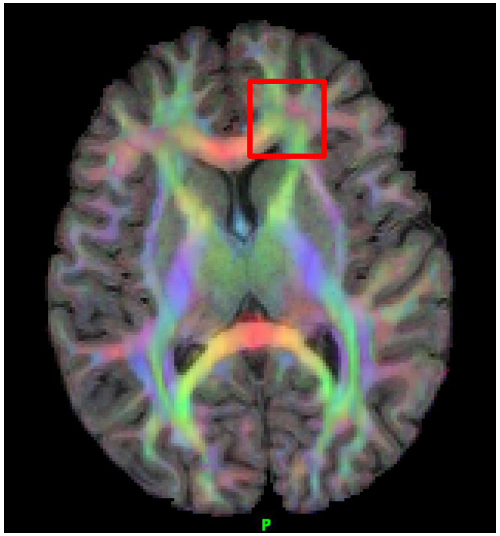
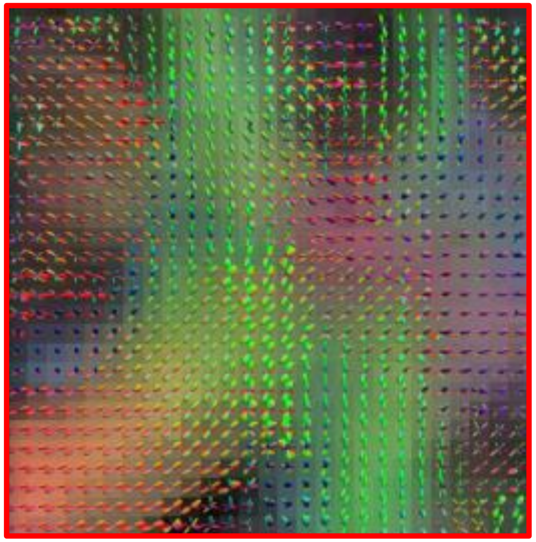
- Corrects the distortion in diffusion (EPI) images using non-rigid registration
- No fieldmap is required
- Similar performance to fieldmap method



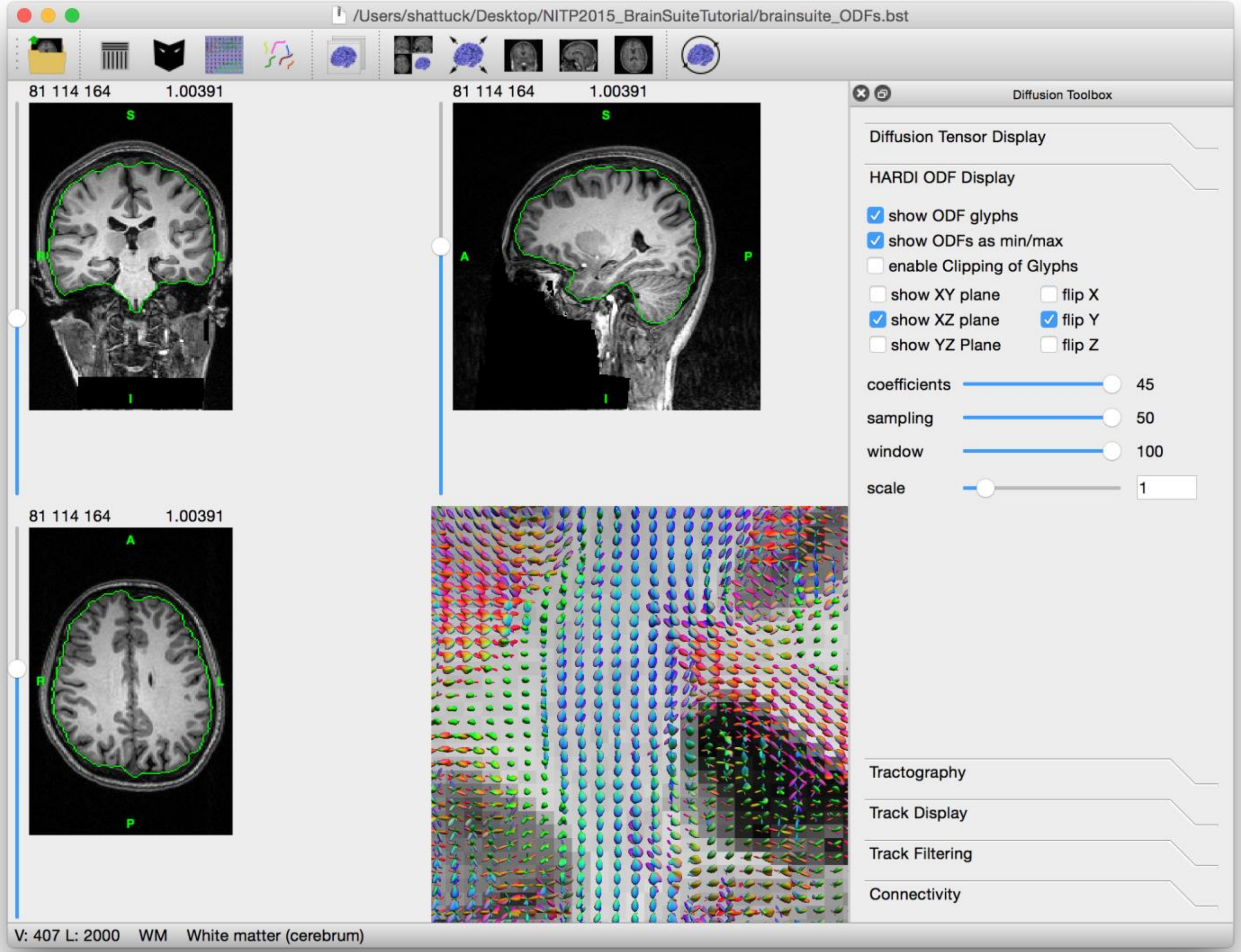
C. Bhushan et al., NeuroImage 2015

Tensor and ODF Estimation

- Estimate diffusion tensors
  - FA, MD, color-FA
- Axial, Radial diffusivity
- ODFs using FRT (Tuch, 2004)
- ODFs using FRACT (Haldar and Leahy, 2013)
  - improved accuracy
  - higher angular resolution

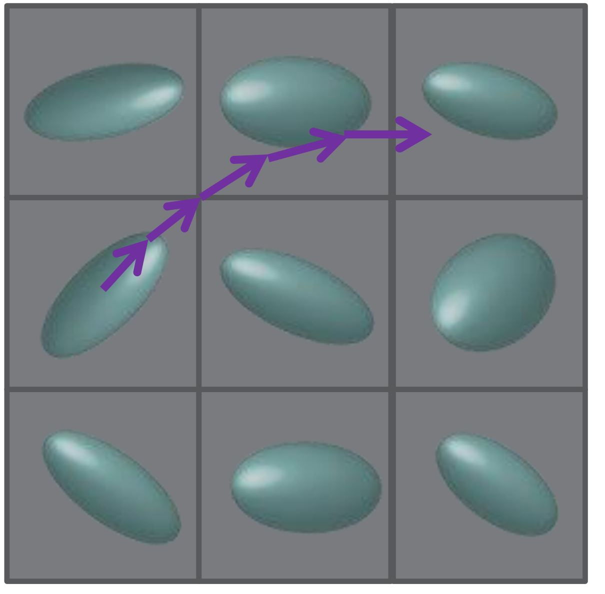




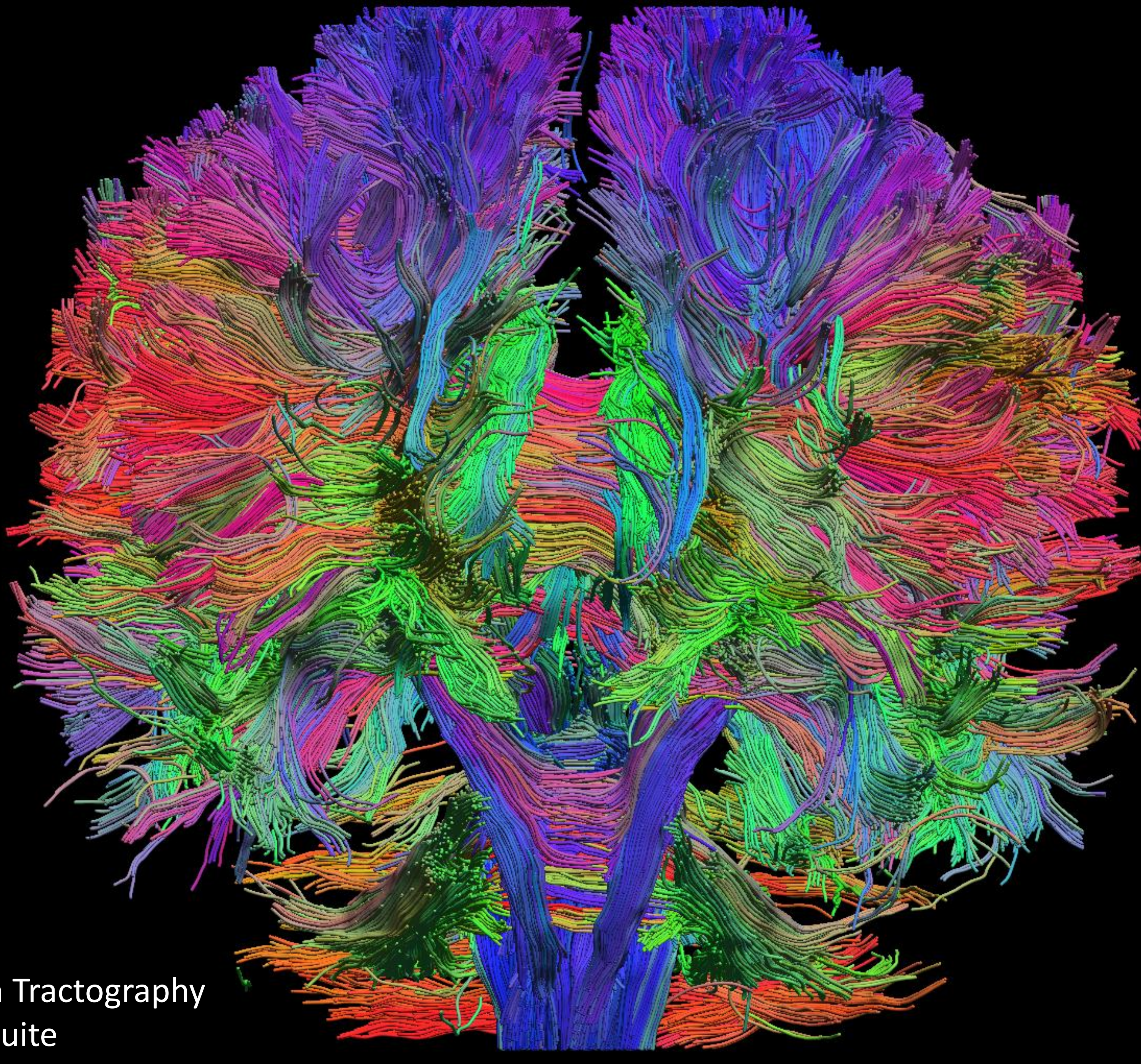
Visualization of Diffusion Data



Fiber Tracking

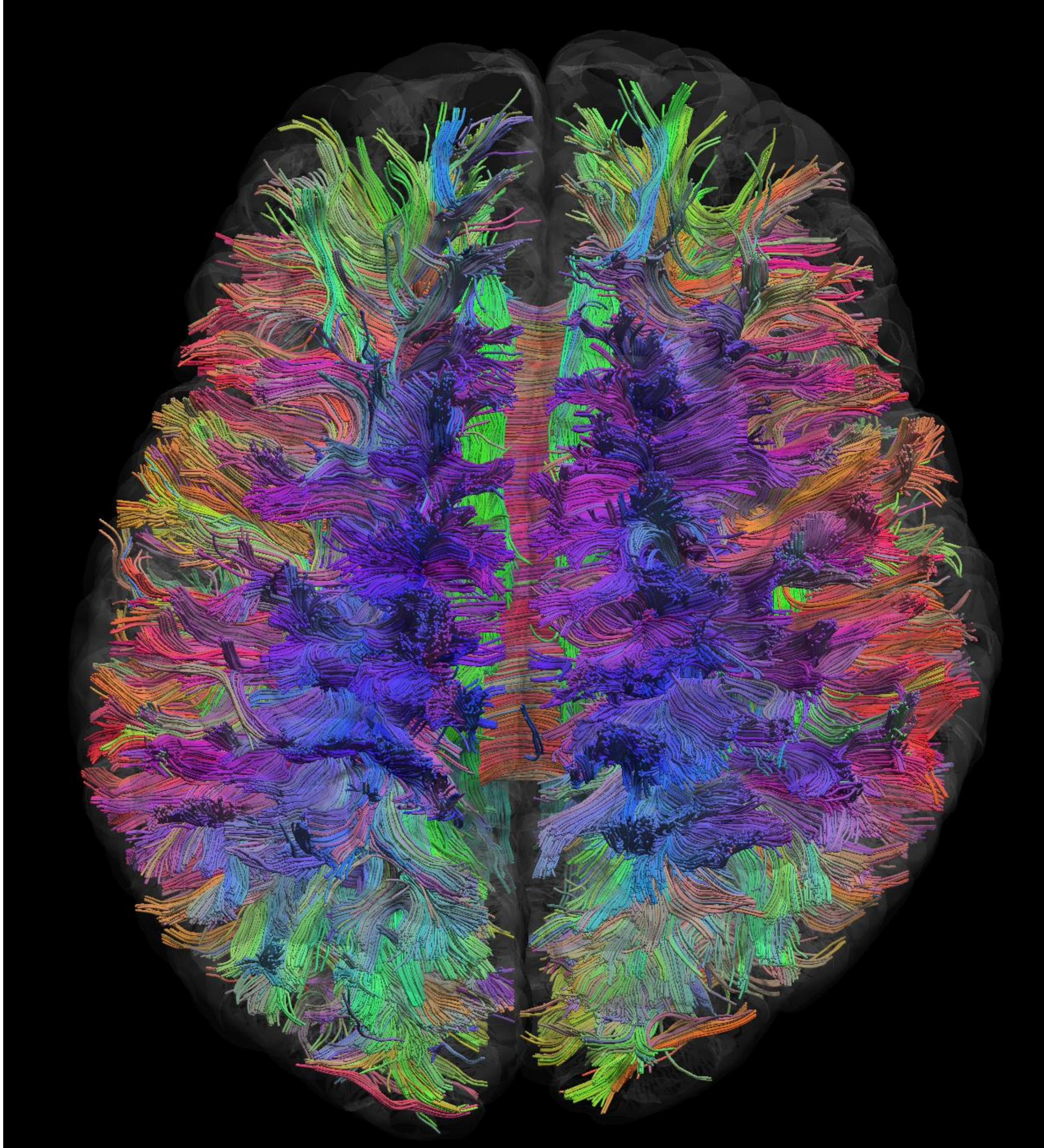
- We can trace out fiber tracks in the data using direction vectors determined from DTI ellipses or by analyzing ODFs.
- Essentially, we step through each voxel, reorienting the direction based on the estimated diffusion pattern.
- Various criteria can be used to determine when to start or stop the tracking.
- We can seed at numerous points throughout the image to get a picture of whole brain tractography.





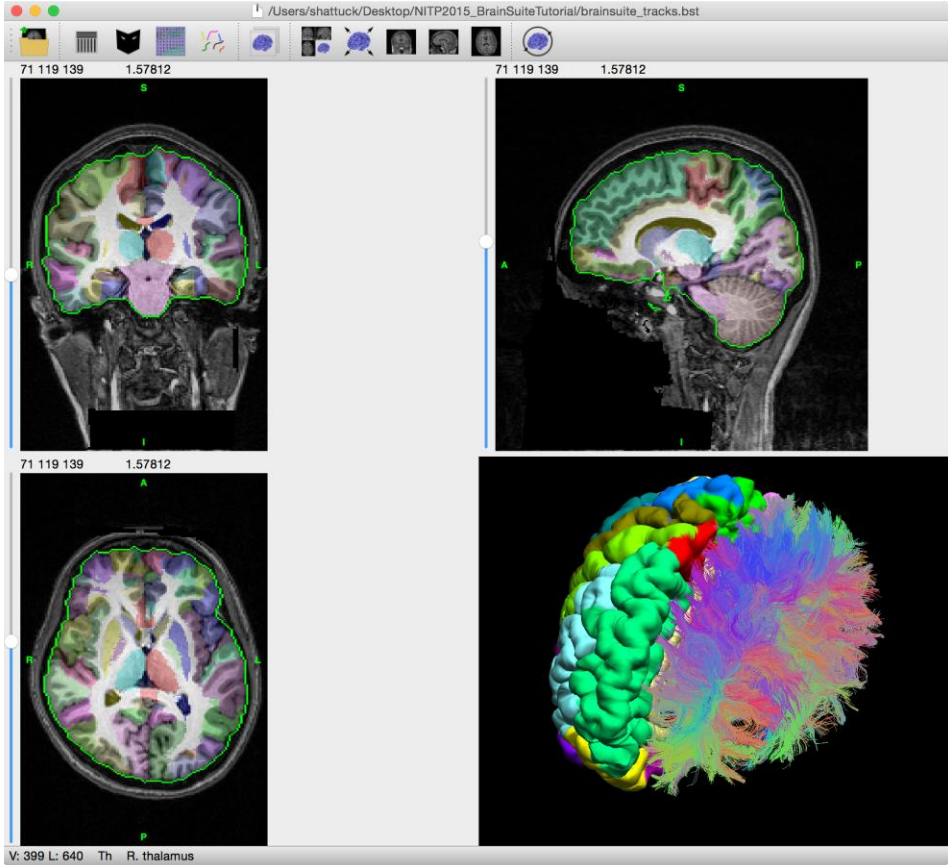
Diffusion Tractography
in BrainSuite

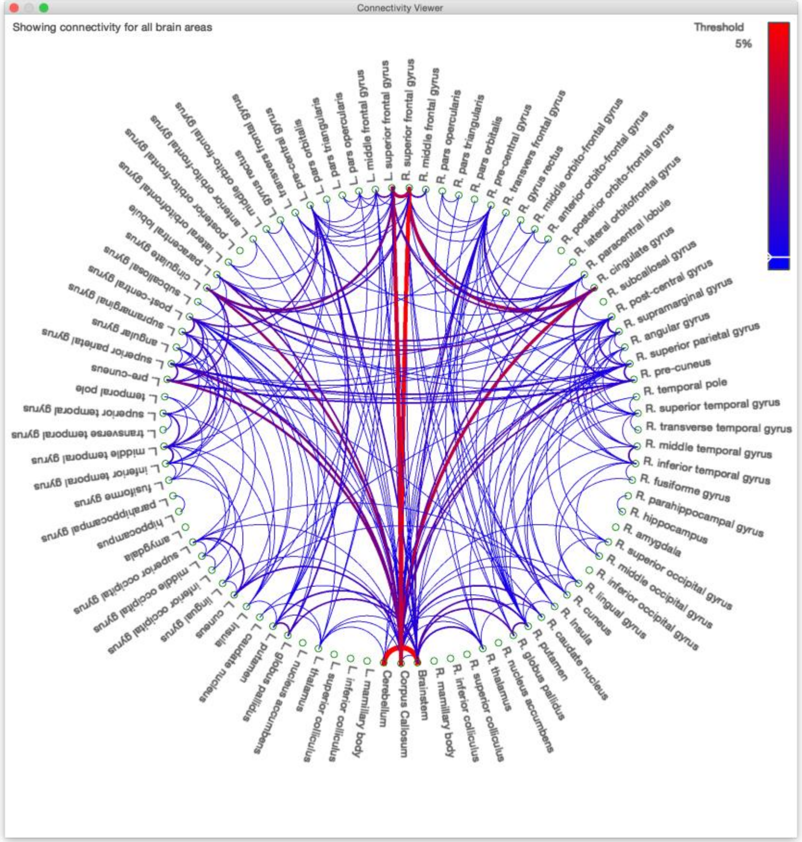
Axial View of Fiber Tracking



Diffusion Tractography
in BrainSuite

BrainSuite Connectivity

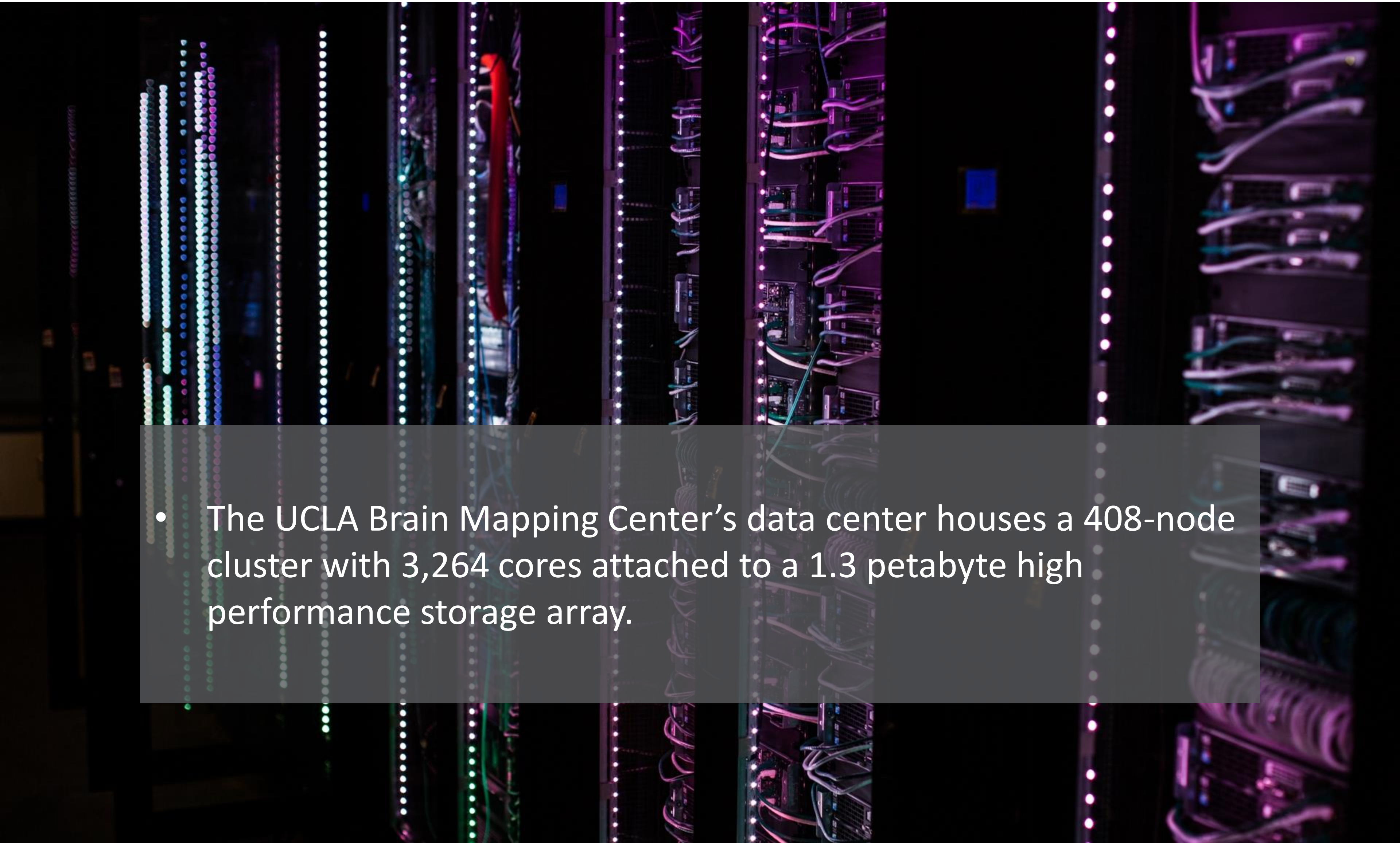




- Fiber tracking in the same space as the labeled MRI
- ROI connectivity analysis

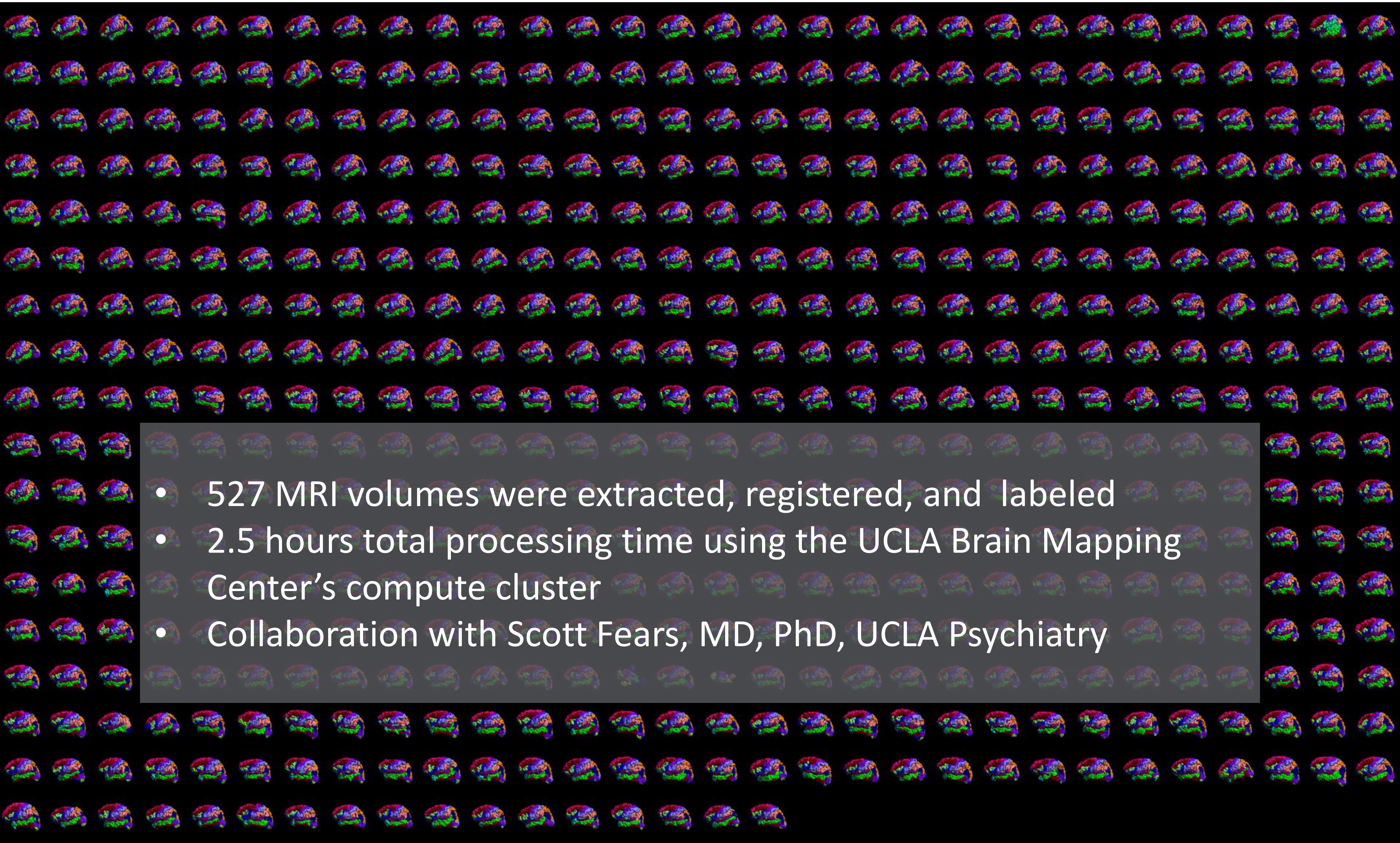
Applications and Ongoing Work

Large Scale Brain Mapping



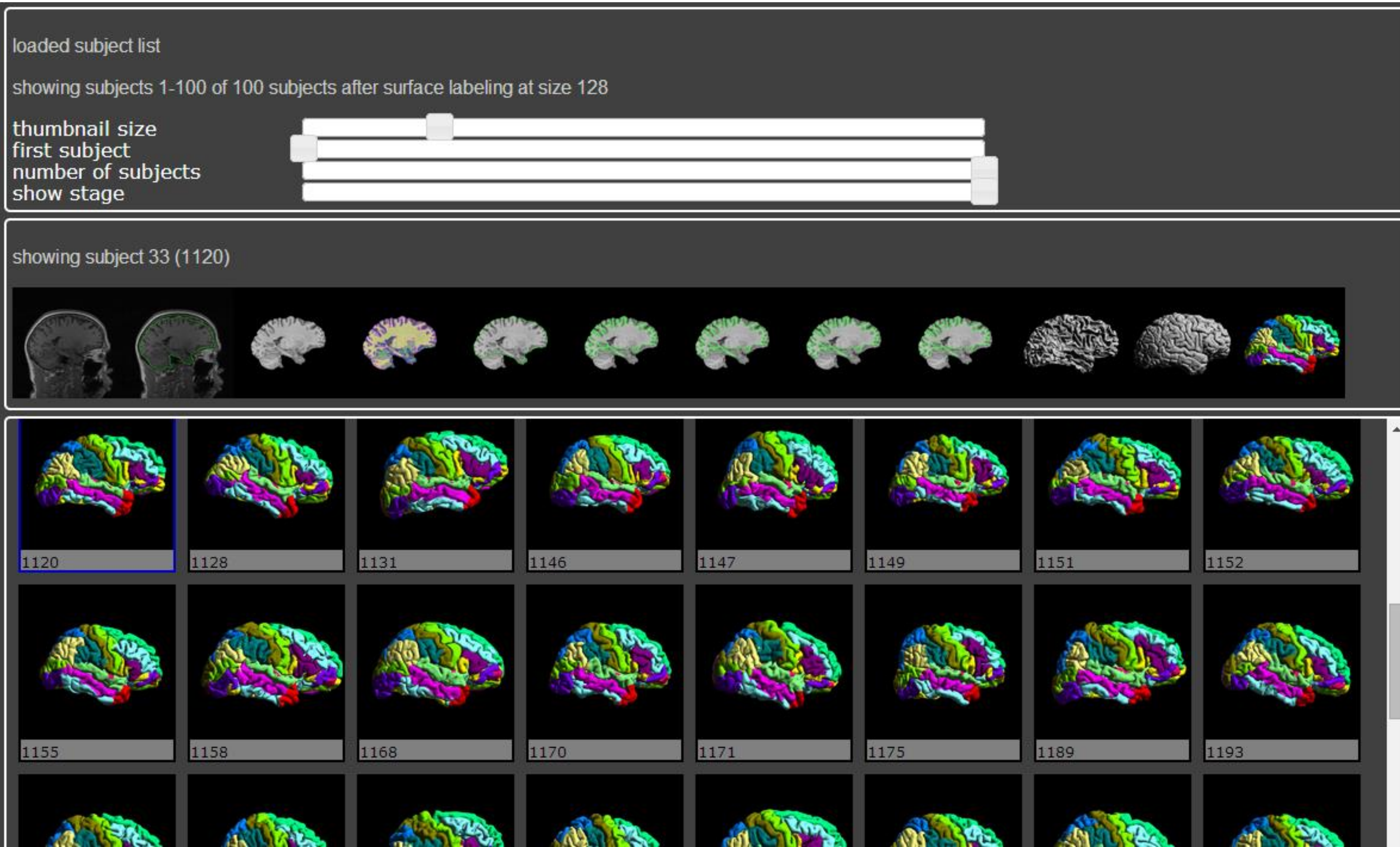
- The UCLA Brain Mapping Center’s data center houses a 408-node cluster with 3,264 cores attached to a 1.3 petabyte high performance storage array.

Large Scale Brain Mapping



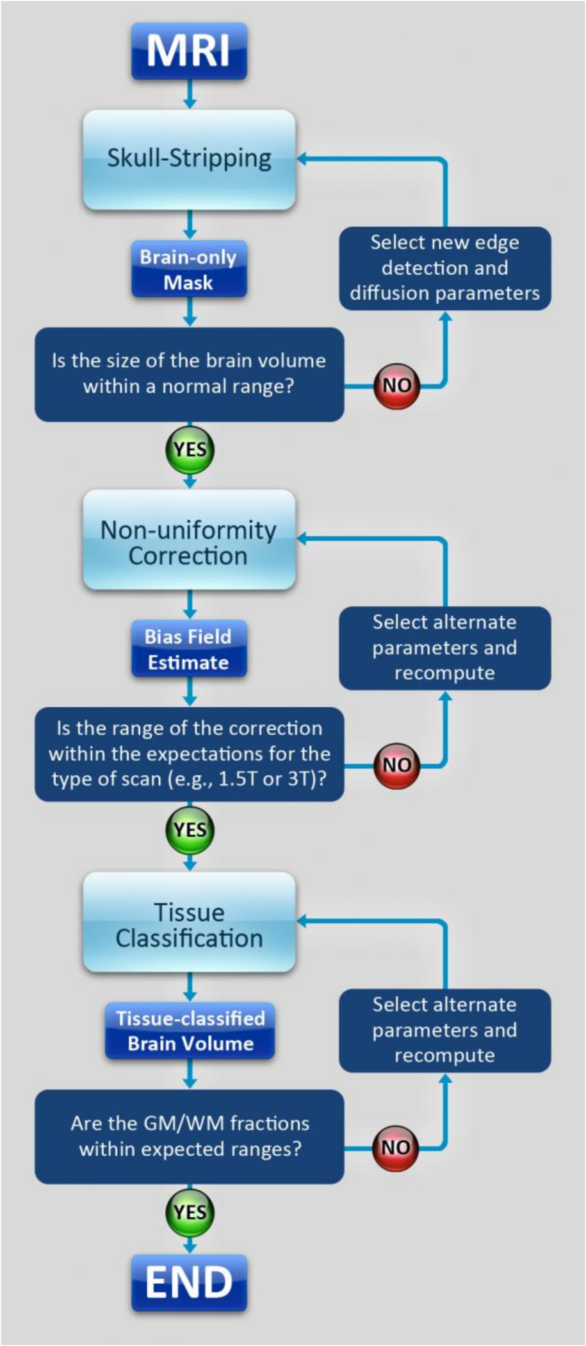
- 527 MRI volumes were extracted, registered, and labeled
- 2.5 hours total processing time using the UCLA Brain Mapping Center's compute cluster
- Collaboration with Scott Fears, MD, PhD, UCLA Psychiatry

Quality Control

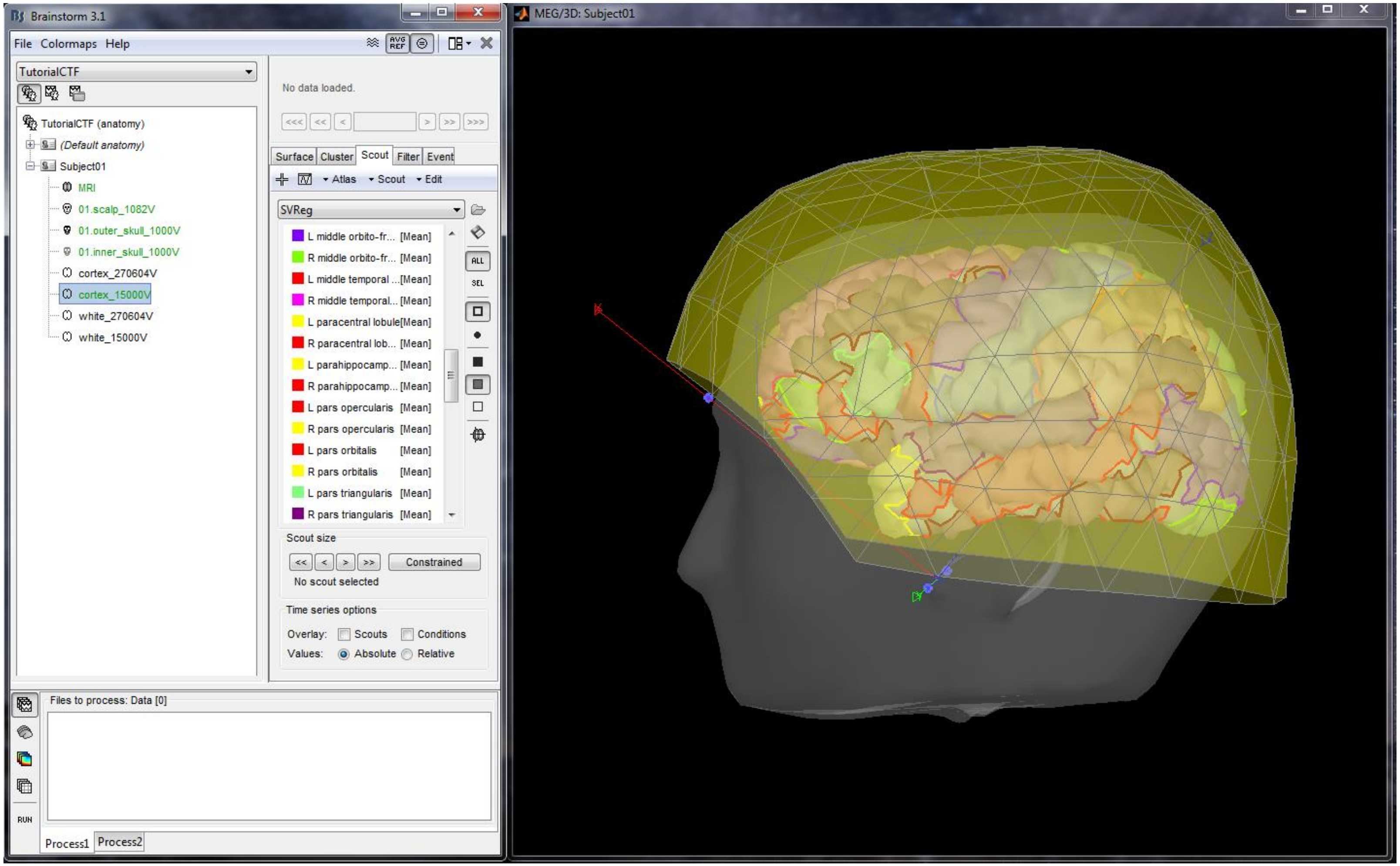


Error Detection

- We plan to develop interfaces that facilitate identification of errors in the processing chain.
  - Web-based reports
  - Software interfaces that allow errors to be corrected and the processing continued
- Quality assurance
  - Automatically identify potential failures based on measures.
  - For example, is the total brain volume within a normal range?



Integration with BrainStorm

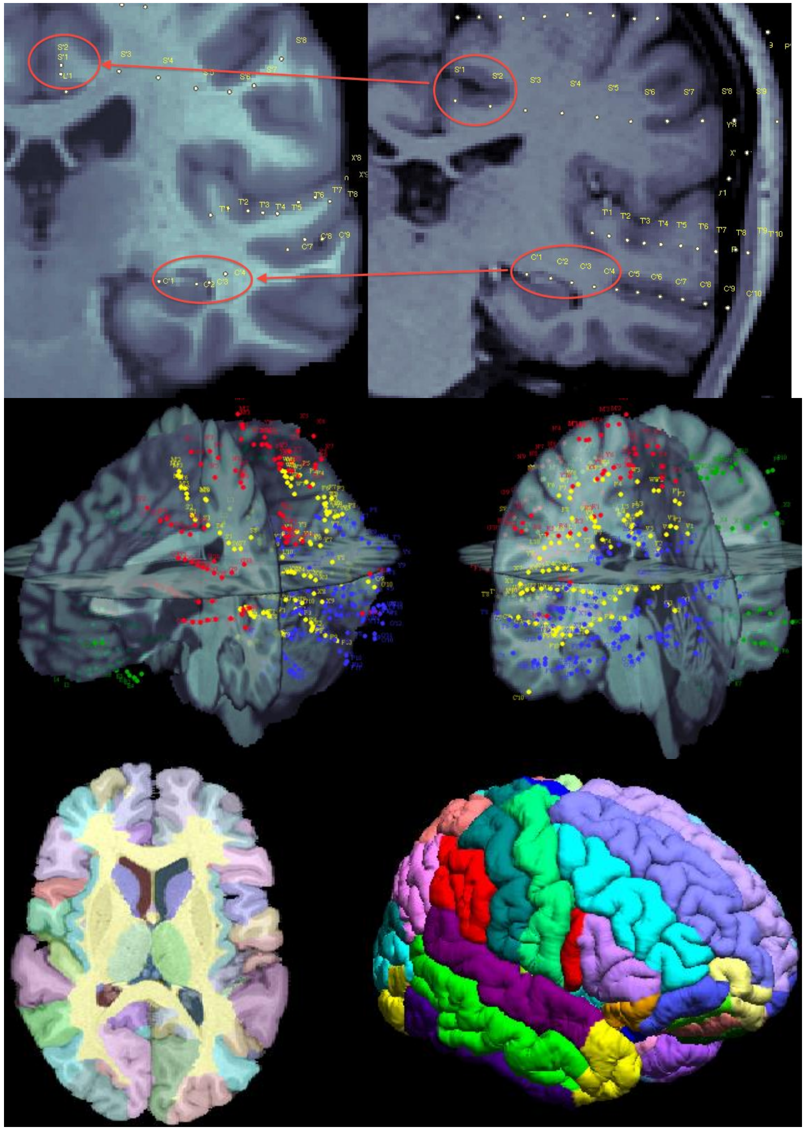


BrainSuite Cortical Surface Model with ROIs Labeling imported into BrainStorm. The BrainSuite parcellation can be directly imported into BrainStorm, where the ROIs are useful for interpreting current sources.

see also: http://neuroimage.usc.edu/brainstorm/Tutorials/SegBrainSuite

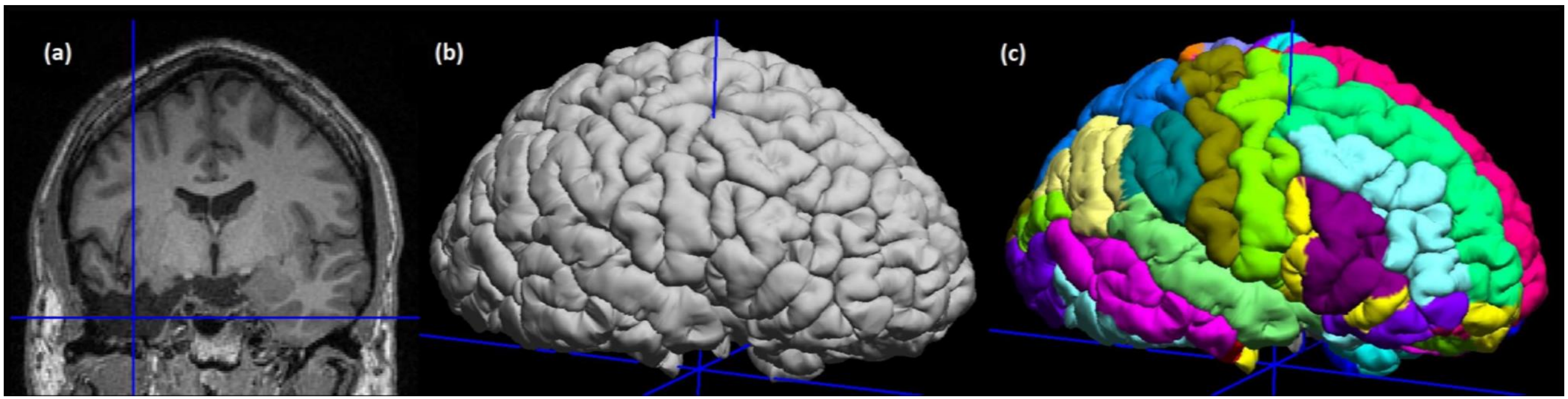
SEEG Mapping

- Stereo-electroencephalography (SEEG) are implanted to localize the source of epilepsy
- Goal: use SVREG to map SEEG electrode data into a common space
- SEEG electrode positions are deformed by the registration



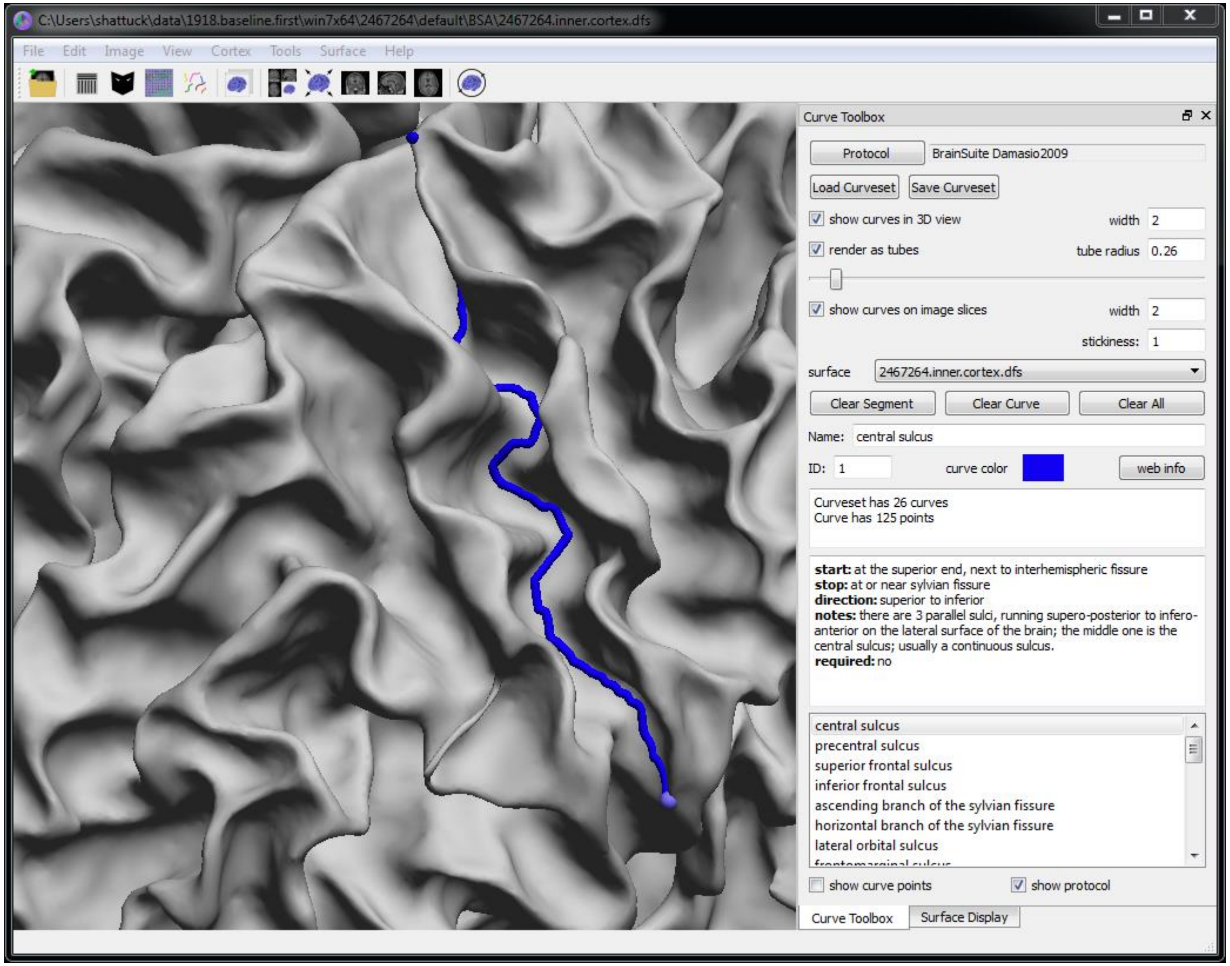
Mapping of SEEG electrodes to atlas space (J. Mosher, A. Joshi, and R. Leahy, unpublished work)

Segmentation & Labeling of Abnormal Data



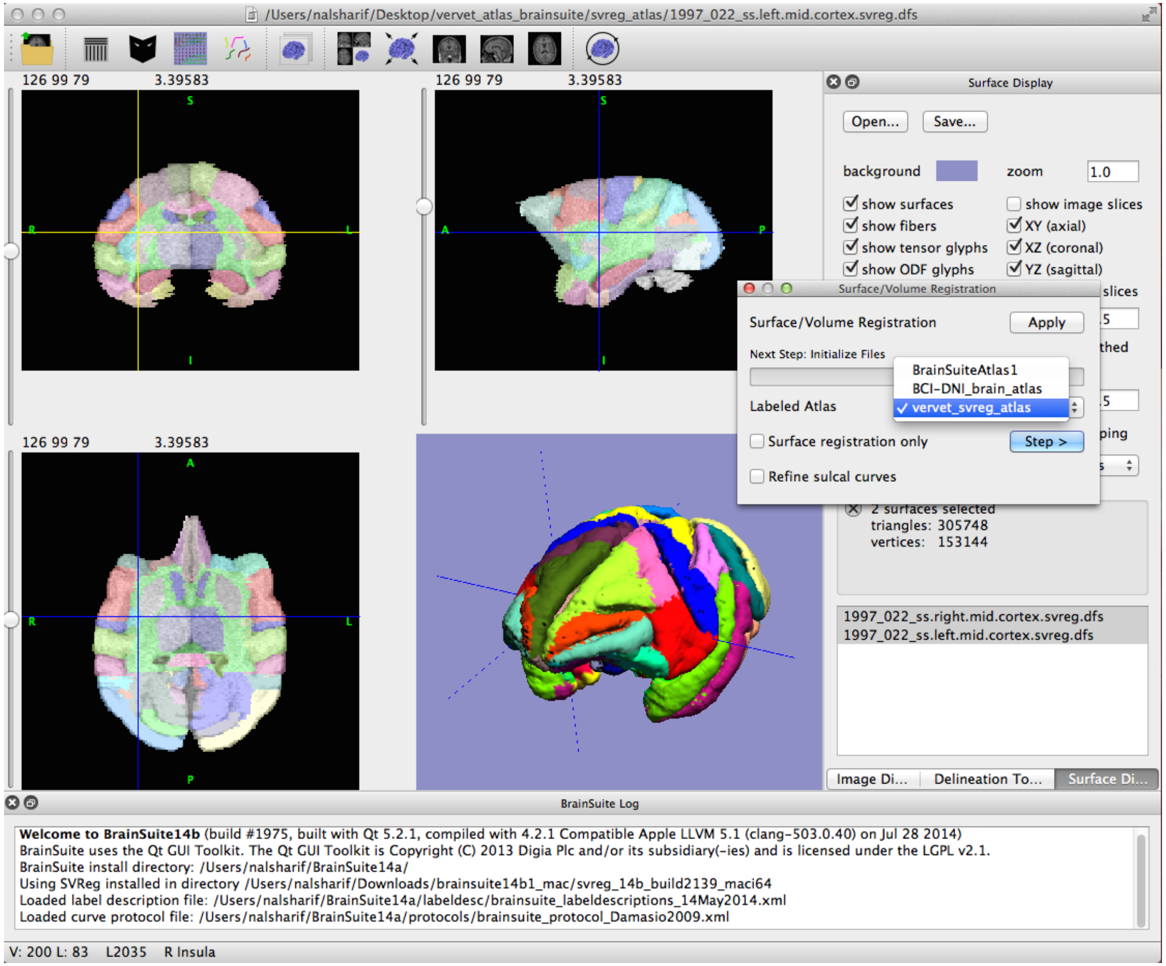
- Develop methodologies to handle lesions, resections, and other pathology
- Manual identification tools
- Segmentation, registration, and labeling tools
- Lesion detection software

Delineation Tools



BrainSuite provides tools for labeling and identifying volumetric and surface-based landmarks.

Custom Atlases



- BrainSuite provides capability to build custom atlases
- Example shown is a vervet atlas

CLARITY Technique for Neuroimaging: Hippocampus

Thy1-GFP endogenous expression

Imaged with confocal microscopy

Visualized in Vaa3D

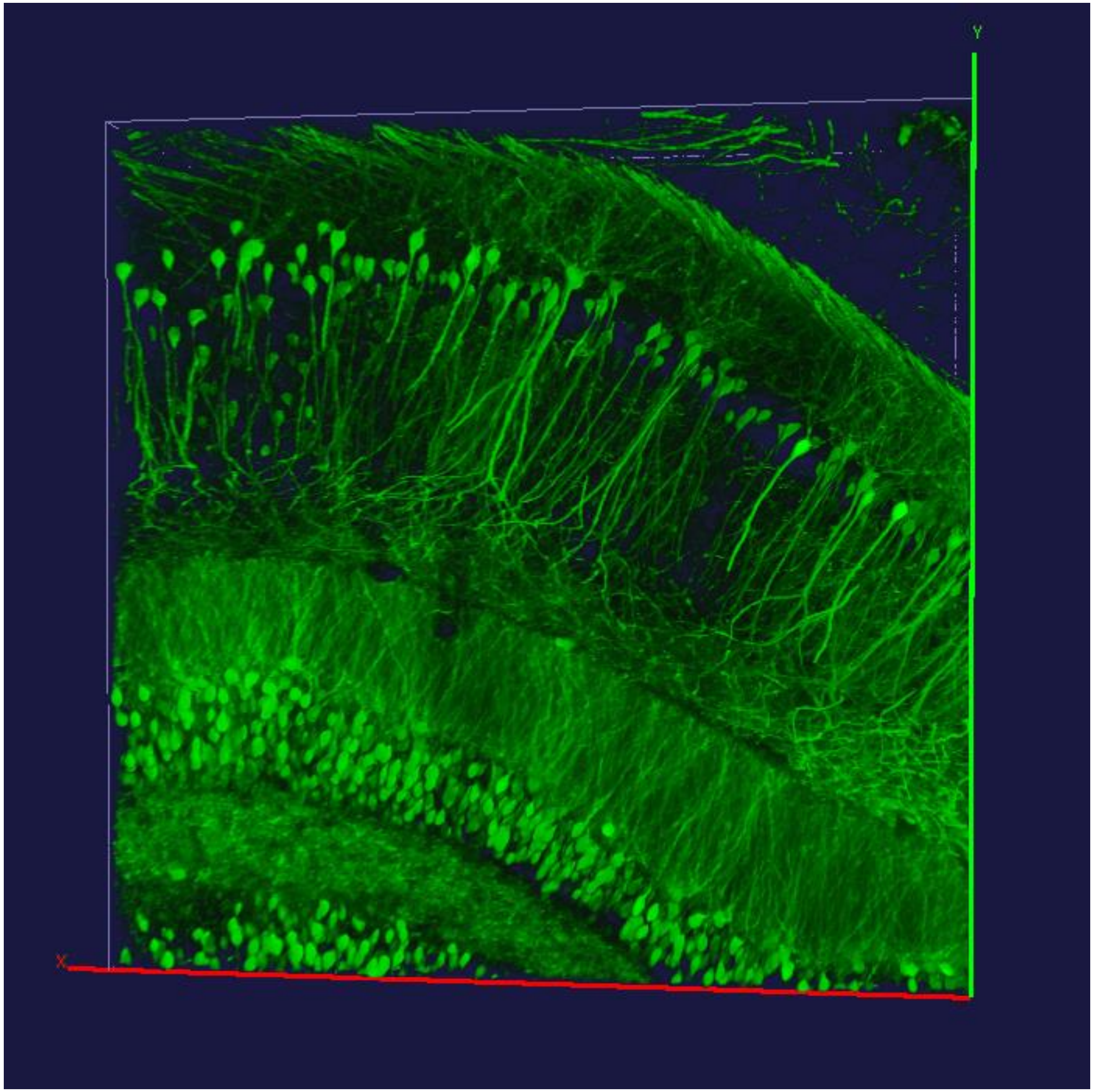


Image provided by Luis de la Torre-Ubieta, PhD, Jason Stein, PhD, and Daniel Geschwind, MD, PhD (UCLA).

CLARITY Technique for Neuroimaging: Cortex

Thy1-GFP mouse cortex

Endogenous GFP (red) and GFP immunostaining (green)

Prepared from 1mm thick coronal slices

Imaged with confocal microscopy

Visualized in Vaa3D

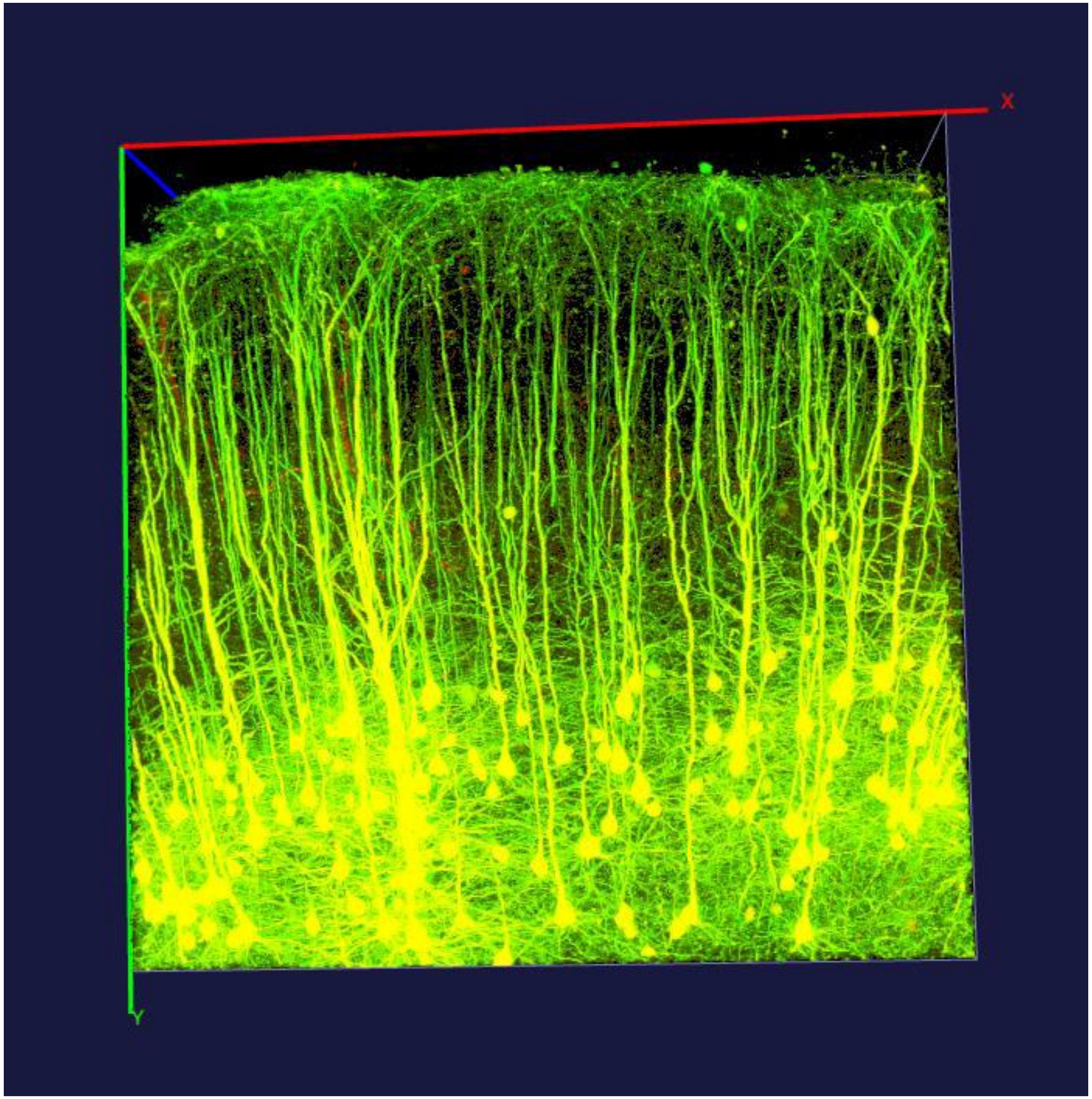
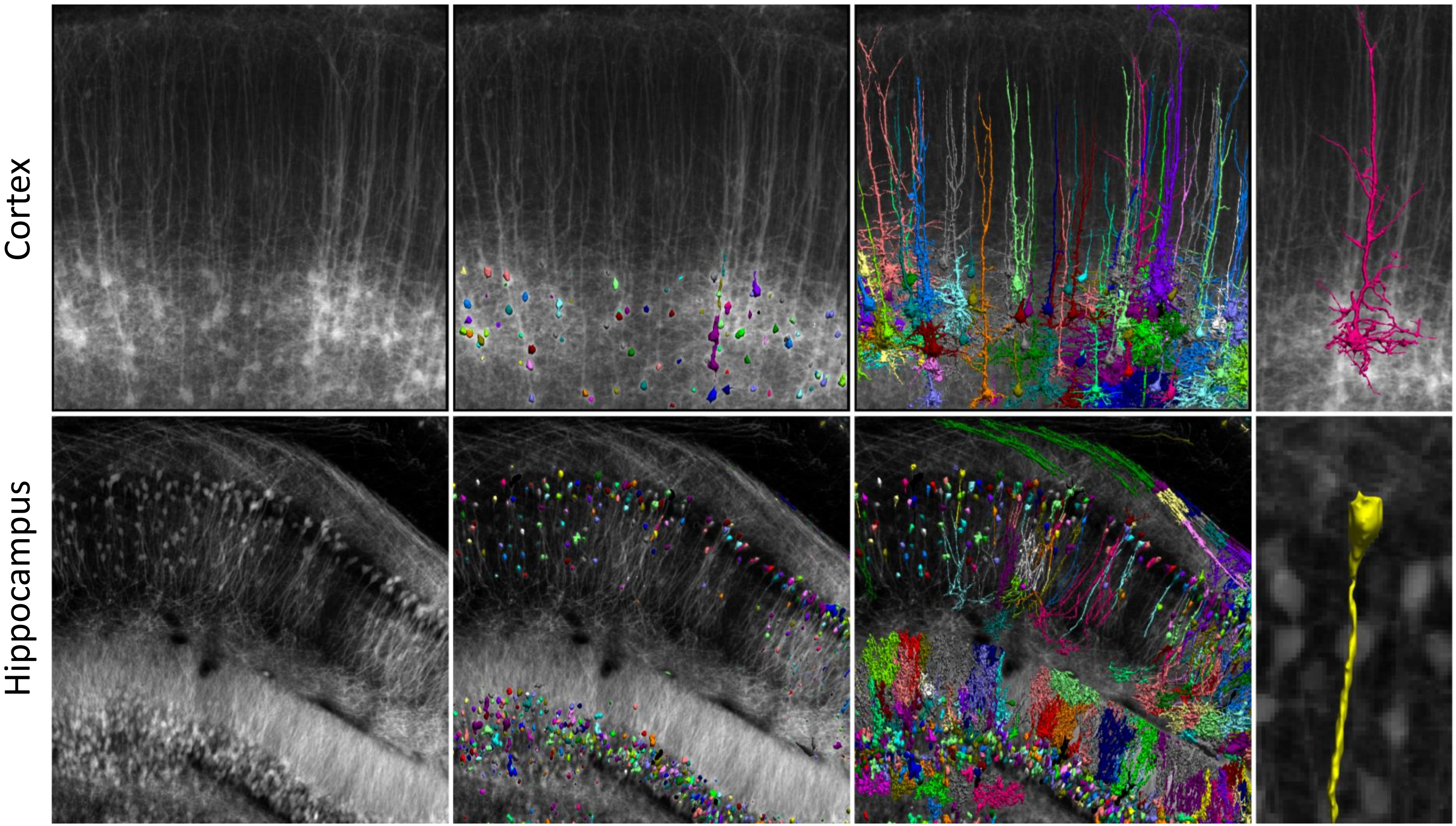
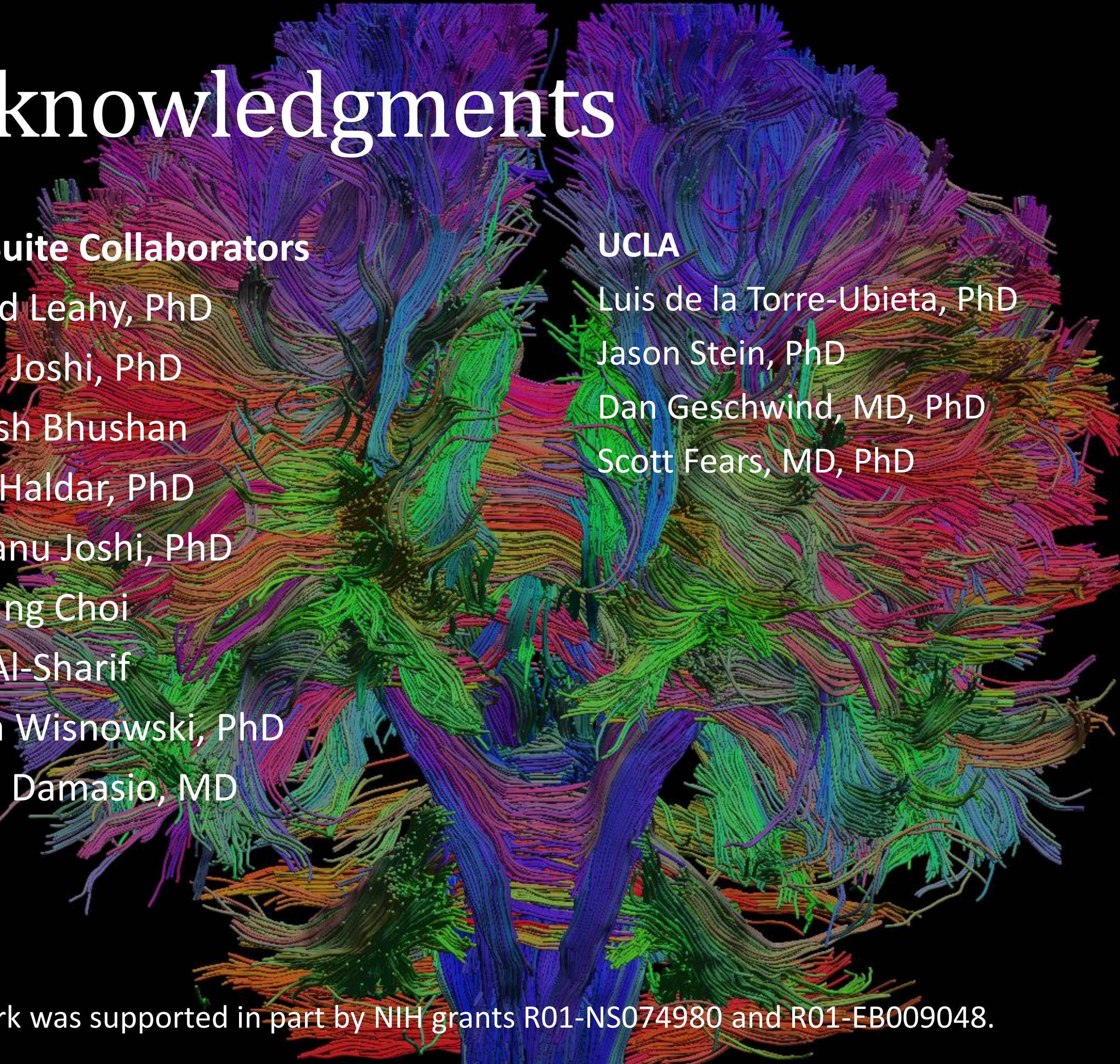


Image provided by Luis de la Torre-Ubieta, PhD, Jason Stein, PhD, and Daniel Geschwind, MD, PhD (UCLA).

CLARITY Image Analysis





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Jason Stein, PhD
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Scott Fears, MD, PhD

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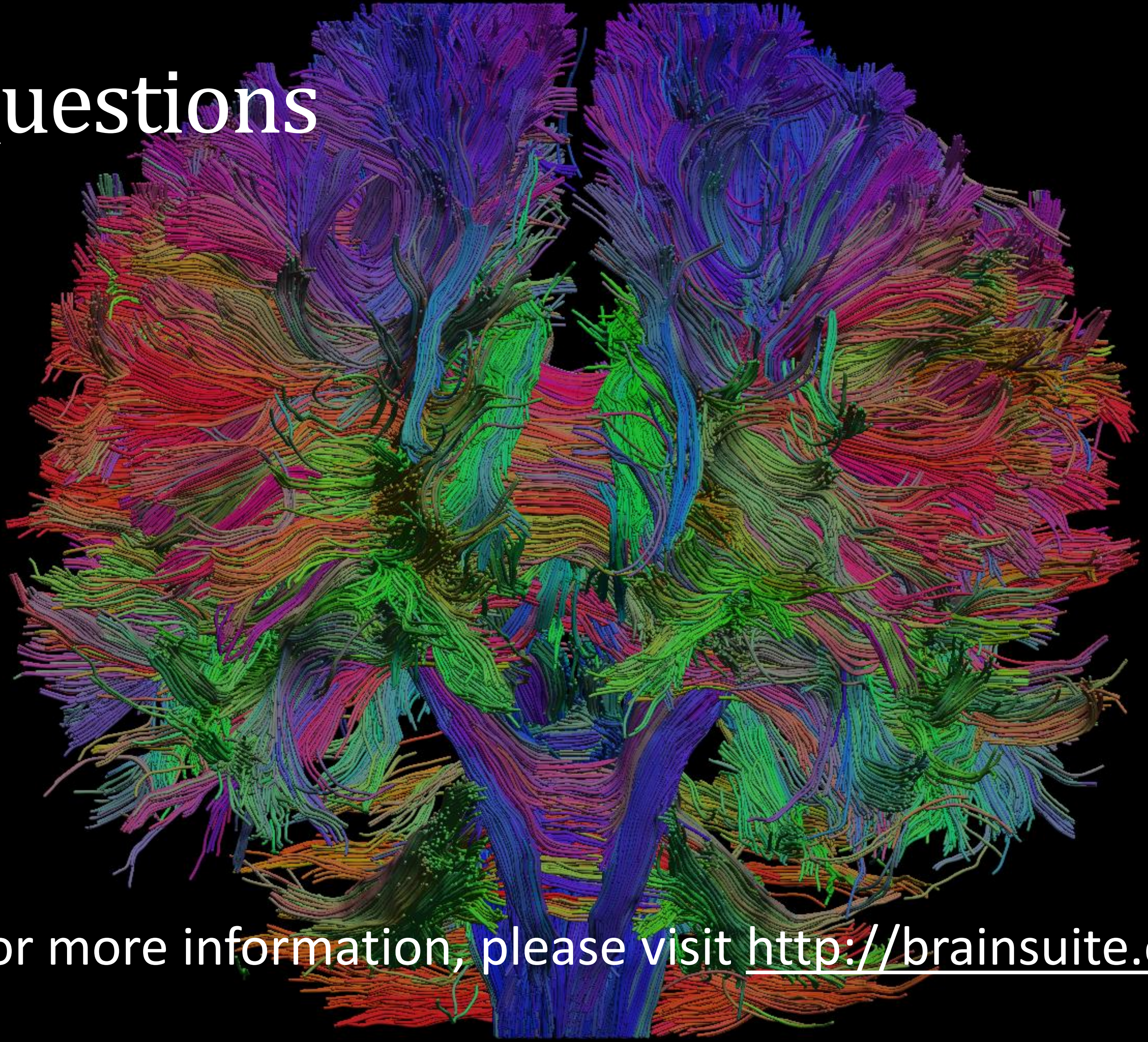
Questions



For more information, please visit http://brainsuite.org