BrainSuite Training Workshop

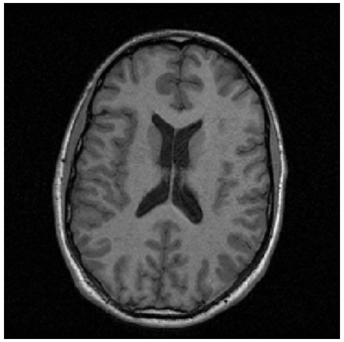
Presented at the USC School of Engineering
28 September 2013

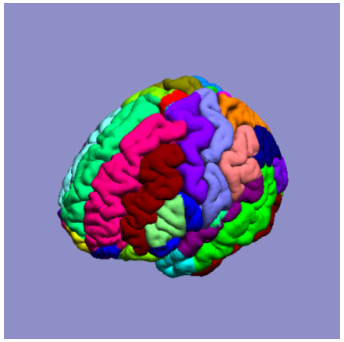
David W. Shattuck, Ph.D.
Anand A. Joshi, Ph.D.
Justin P. Haldar, Ph.D.
Chitresh Bhushan

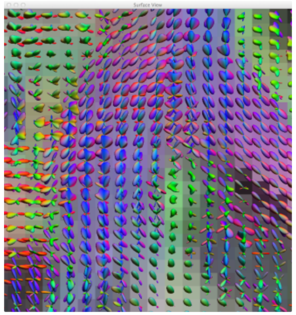
http://brainsuite.org

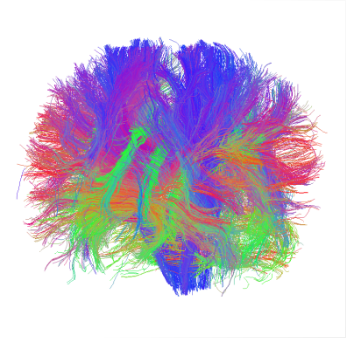
Schedule

10.00-10.45am	David Shattuck: *Cortical Extraction + Demo*
10.45-11.15am	Anand Joshi: *Atlas-Based Registration and Labeling*
11.15-11.45am	Hands-on Training: *Structural Labeling and Analysis*
11.45-12.15pm	Short lunch break (Tutor Hall Café will be open)
12.15-12.45pm	Justin Haldar: *Tractography and connectivity modeling*
12.45-1.15pm	Chitresh Bhushan: *Processing of Diffusion Data*
1.15-2.00pm	Hands-on Training: *Diffusion and Connectivity Analysis*



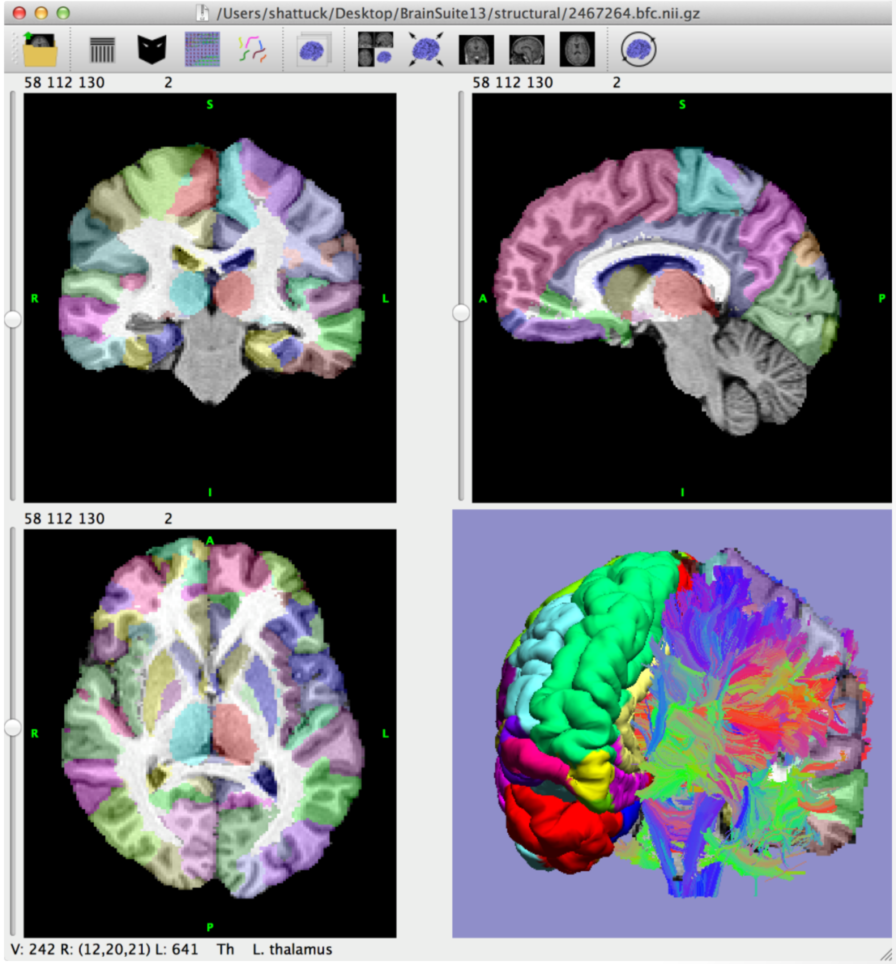






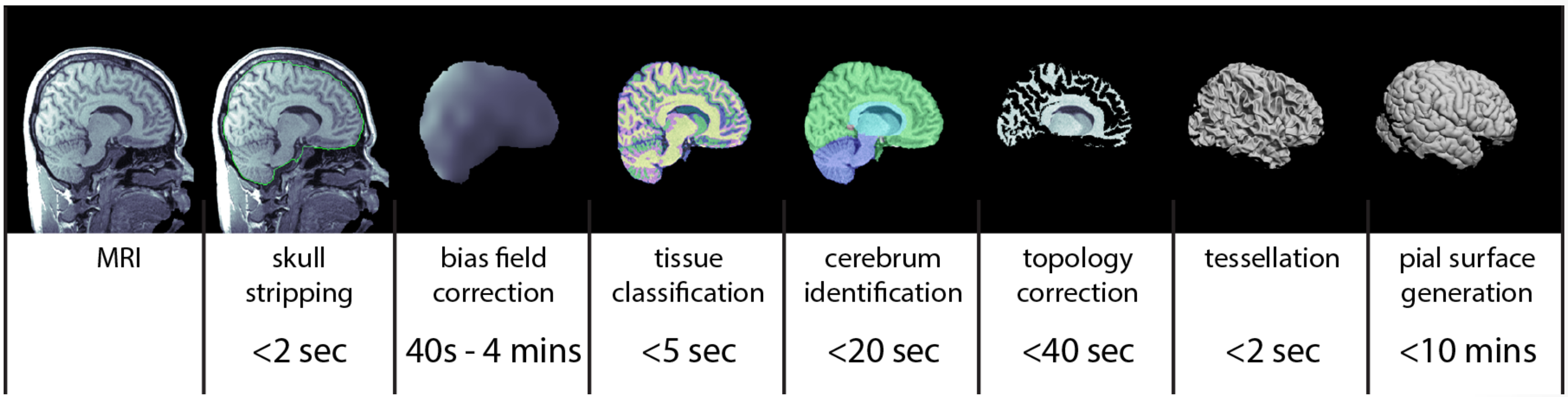
What is BrainSuite?

- 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*

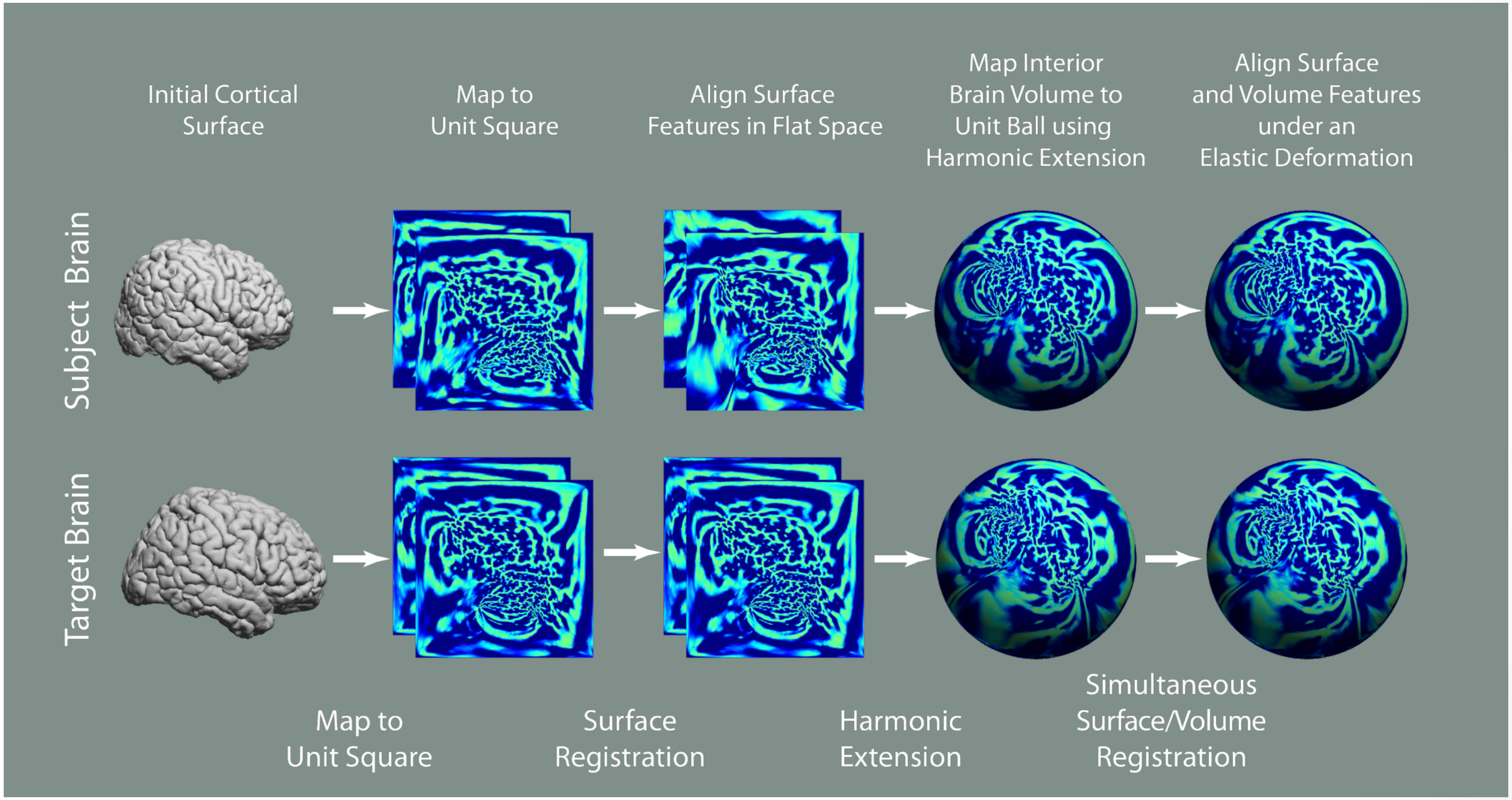


* GUI for Linux version is not yet released

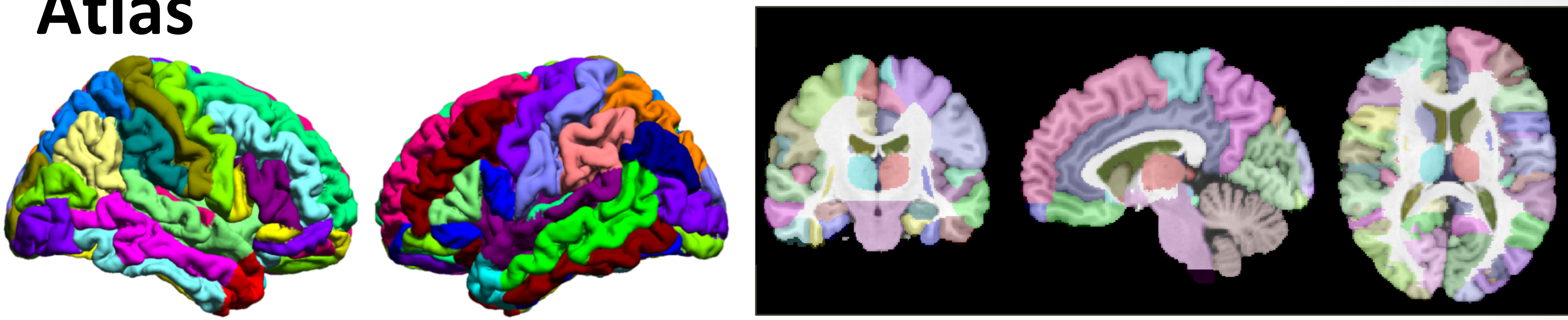
Cortical Surface Extraction



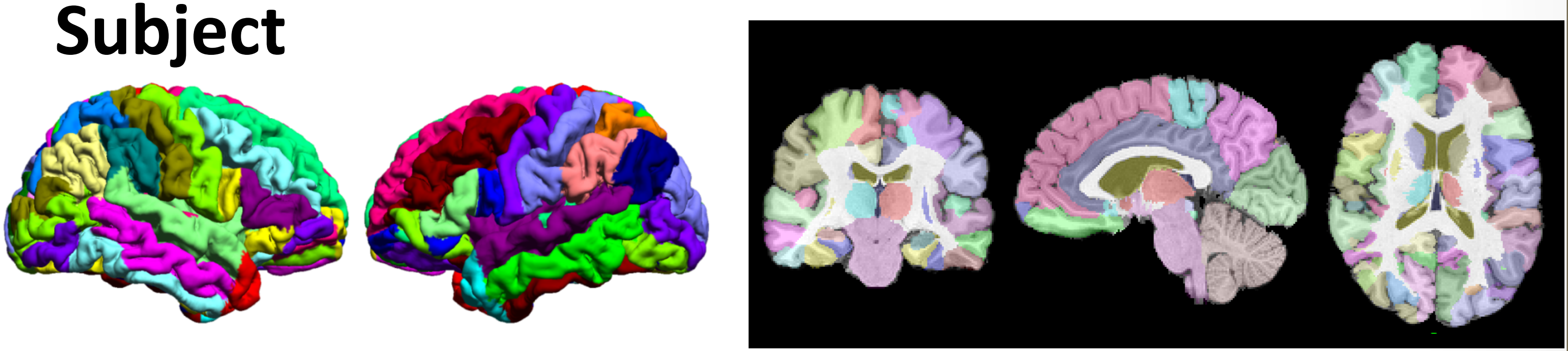
Surface-constrained Volumetric Registration



Atlas



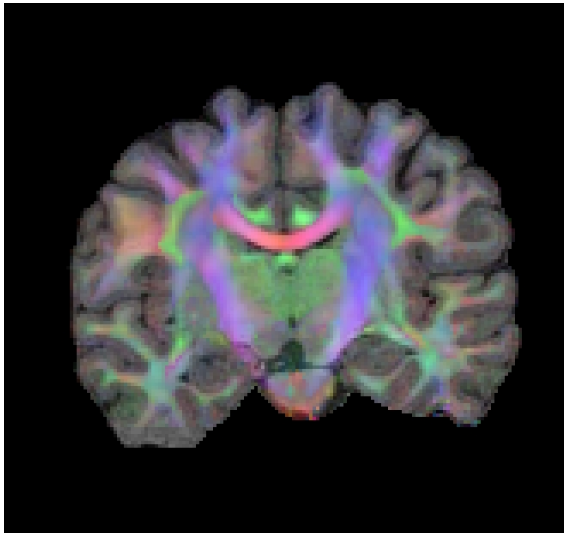
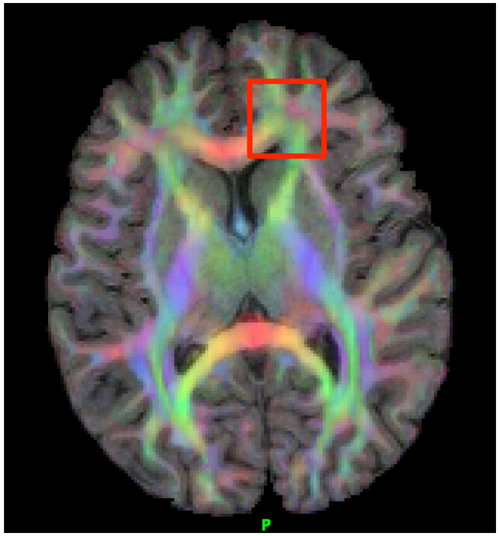
Subject

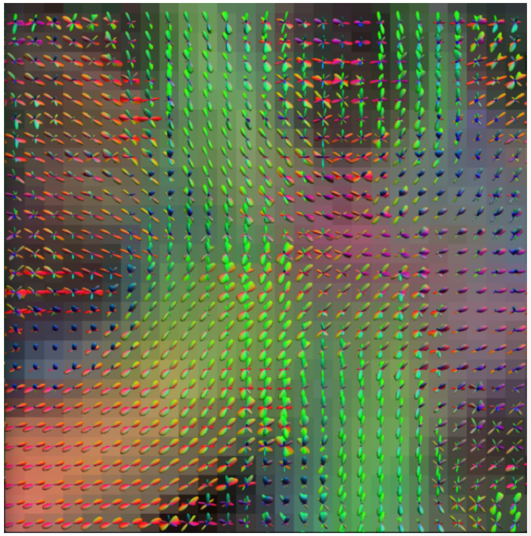


BrainSuite ROI Labeling (top) Surface and volume views of the BrainSuite13 anatomical atlas, delineated into anatomical regions of interest. (bottom) Similar views of an automatically labeled subject dataset.

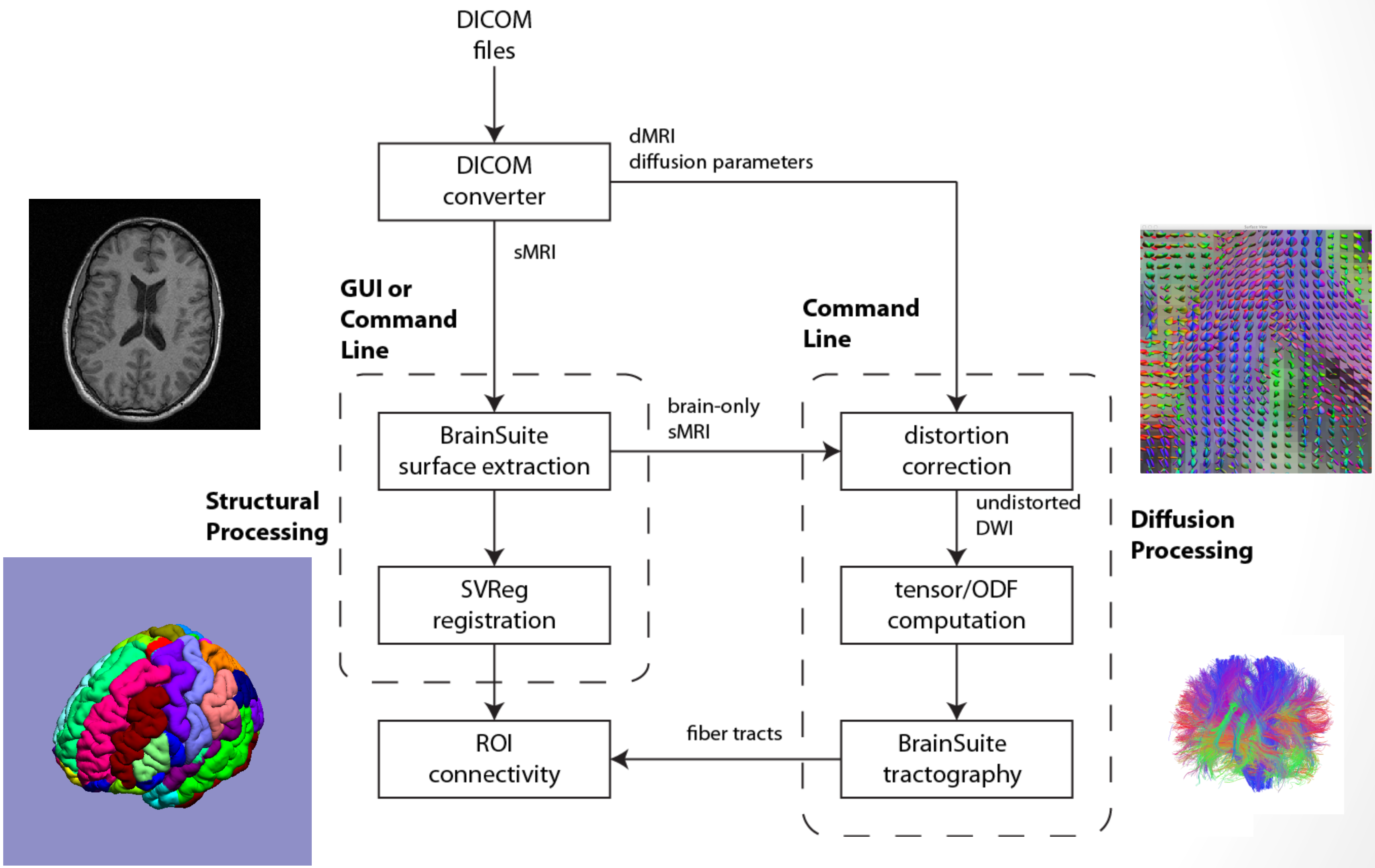
BrainSuite Diffusion Pipeline

- Align diffusion and MPRAGE image
- Correct diffusion data for distortions
- Fit different diffusion models – tensor and ODFs
  - ODFs using FRT and FRACT
  - FRACT (Haldar and Leahy, 2013)
- Compute different quantitative diffusion parameters
- Compute diffusion tracks and connectivity matrix

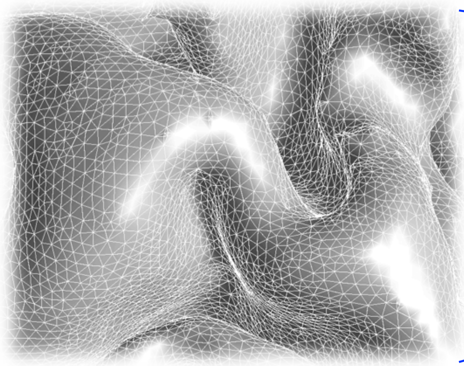





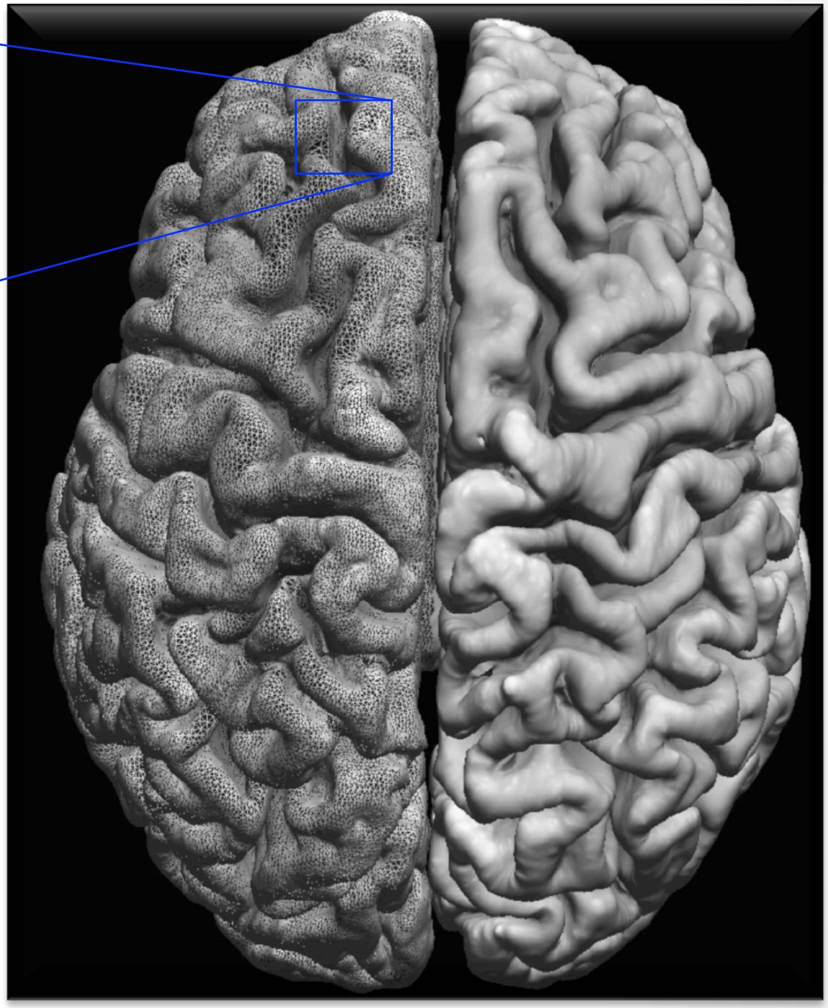
BrainSuite Workflow



Why use surface models?



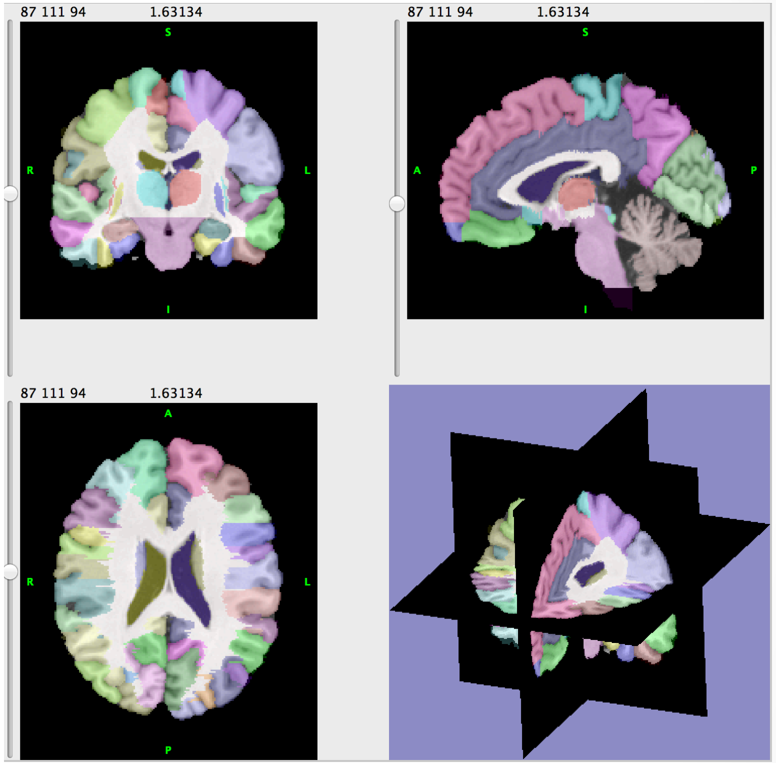
- Cortex is often represented as a high resolution triangulated mesh with ~700,000 triangles
- Many volumetric-based approaches do not align the cortical anatomy well
- We are often interested in functional areas in the cortex
- Surface-based features, e.g., cortical thickness, are of interest in the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



Cortical surface mesh representation

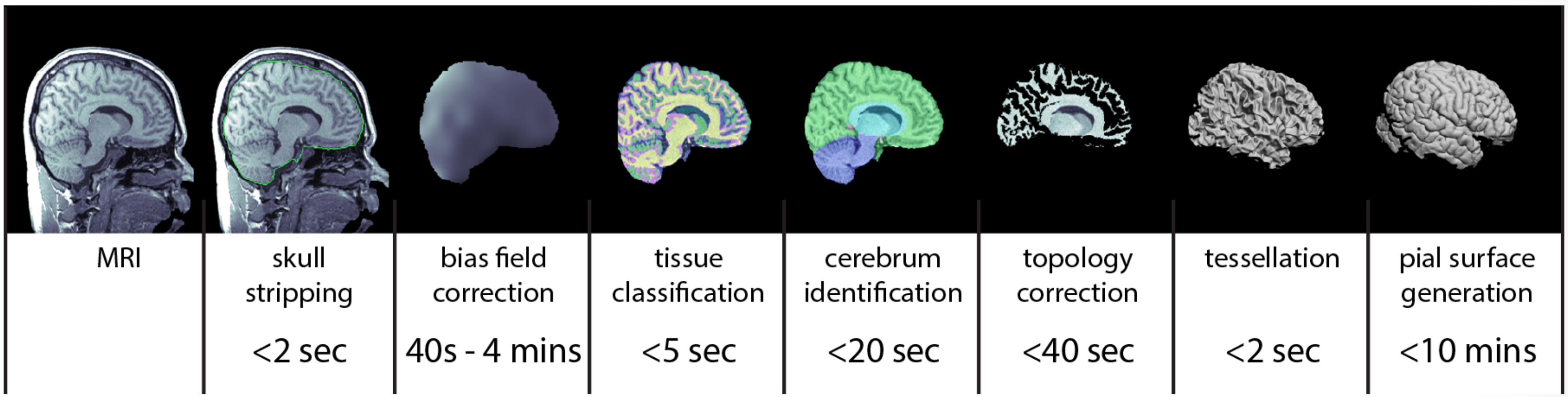
Automation

- One approach to comparative neuroimaging is to manually delineate anatomical structures.
- Drawbacks to manual methods:
  - Raters must be trained to be consistent and to follow a specified protocol
  - Learning effects may bias their processing
  - Raters don't always visualize 3D relationships when viewing slice-based data
- Human raters still constitute the 'gold standard' for many applications
- Automated methods can benefit from the expertise of the rater, which may be superior to an automated algorithm.
- Important to recognize that automated methods may need supervision or correction

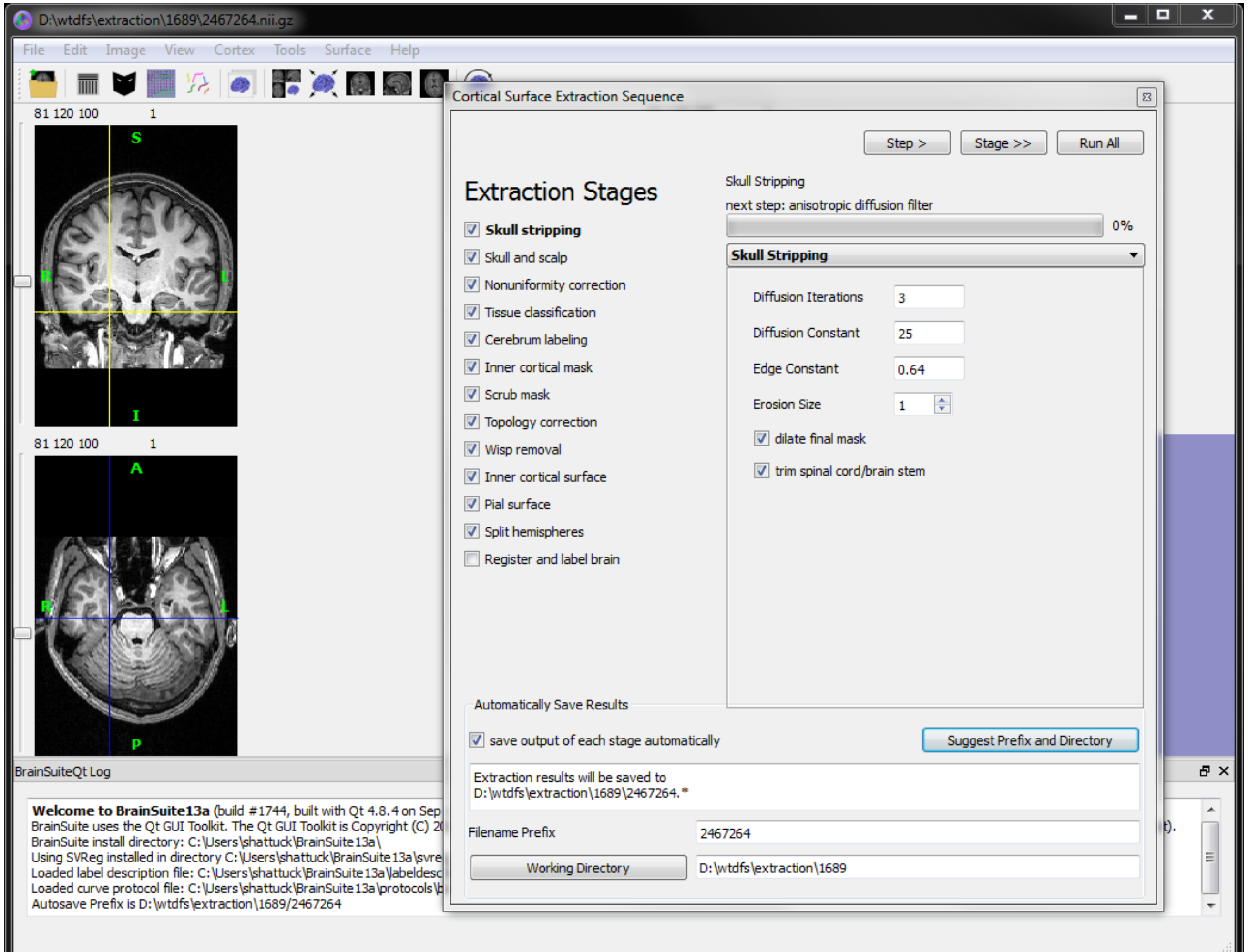


A manually delineated brain atlas (BrainSuiteAtlas1)

Cortical Surface Extraction



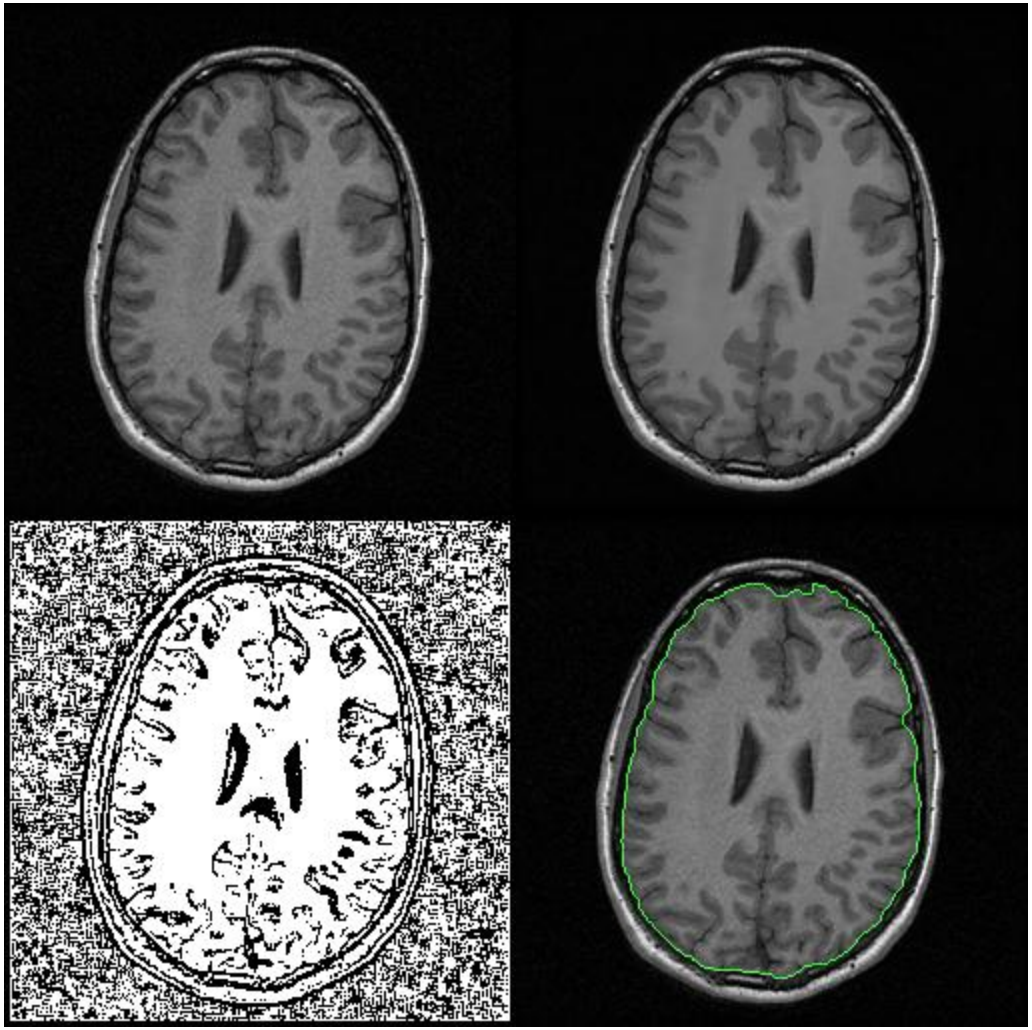
Cortical Surface Extraction GUI



Menu Item: Cortex -> Cortical Surface Extraction Sequence

Skull Stripping

MRI Filtered MRI

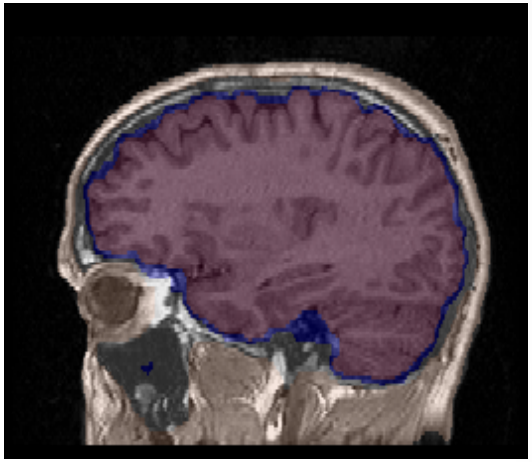


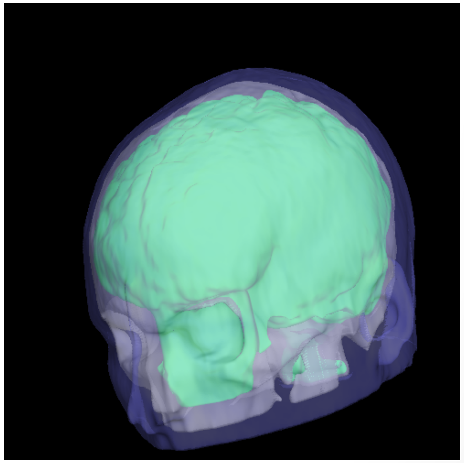
Edge Mask Brain Boundary (green)

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

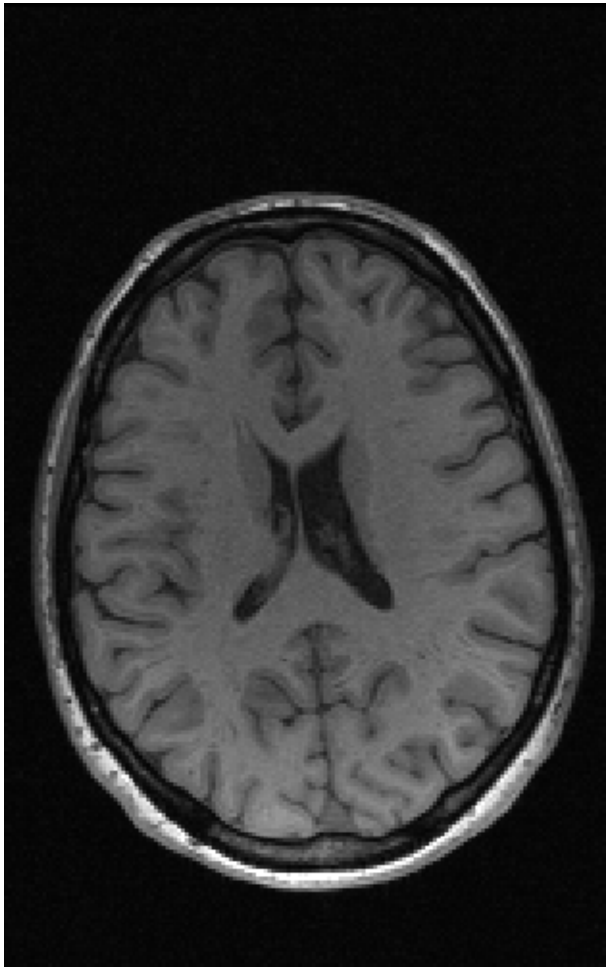
Skull and Scalp

- 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.



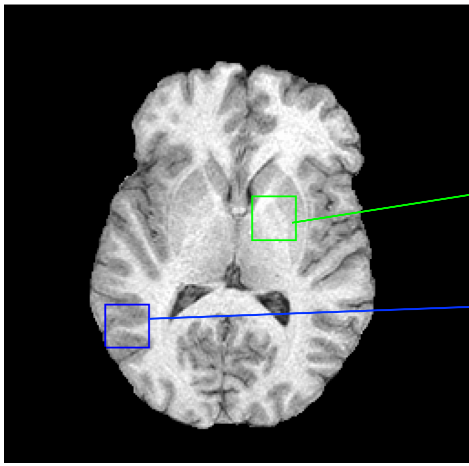


Nonuniformity Artifacts

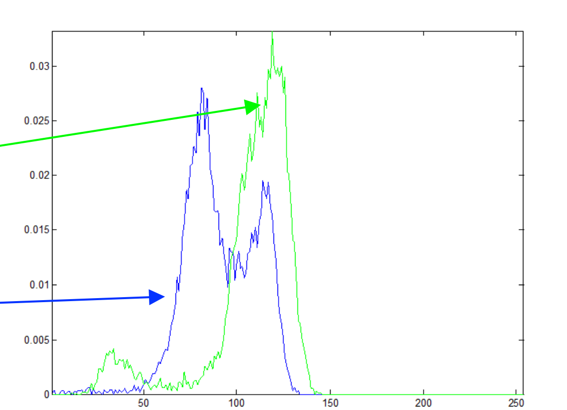


- Imperfections in the scanner hardware as well as subject anatomy introduce magnetic field artifacts that produce shading in the image.
- This can confound tissue classification and other analysis

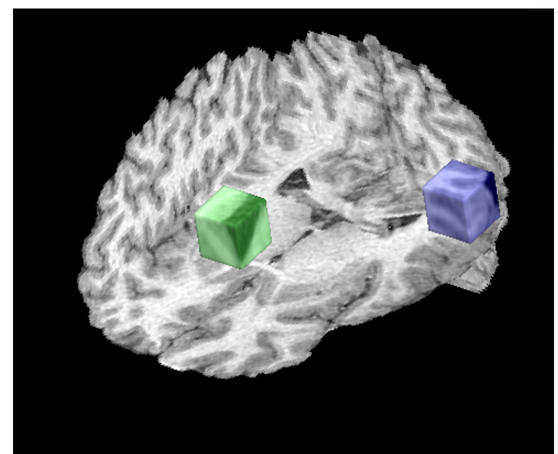
Nonuniformity Correction



Two cubic regions of interest (ROIs)



Histograms of the two ROIs

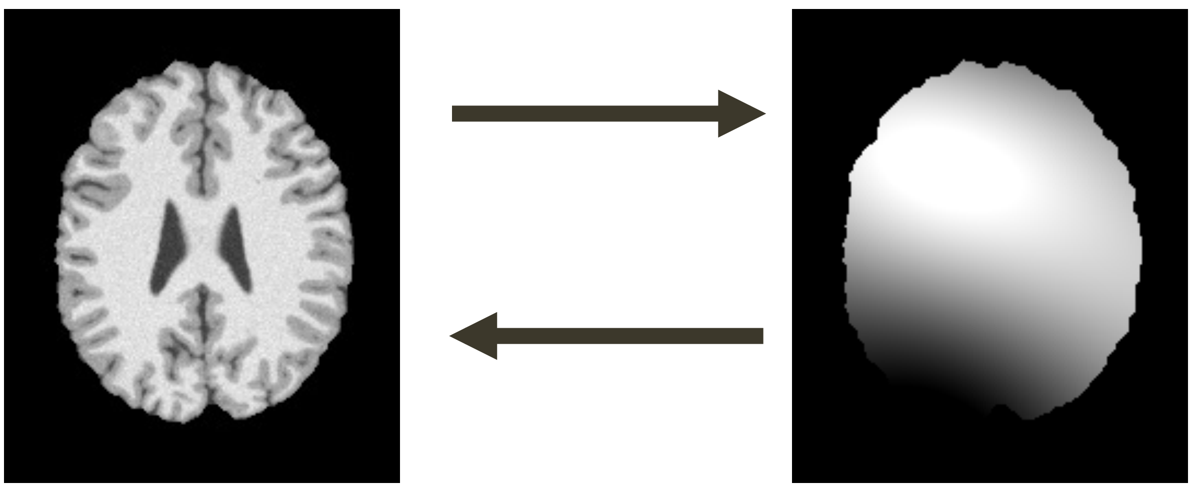


3D rendering of the ROIs

- Bias Field Corrector (BFC) performs non-uniformity correction by analyzing regional histograms
- Sub-volumes have dramatically different profiles.
- Regional histograms reflect this.

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.

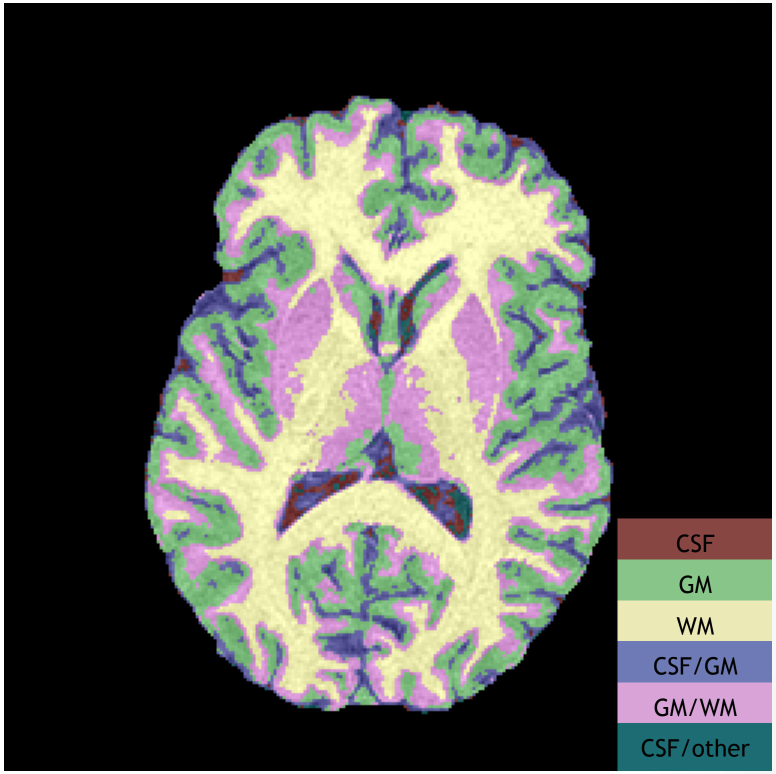


Manual Bias Correction Tool

http://neuroimage.usc.edu/neuro/Resources/bfc_correction_tool

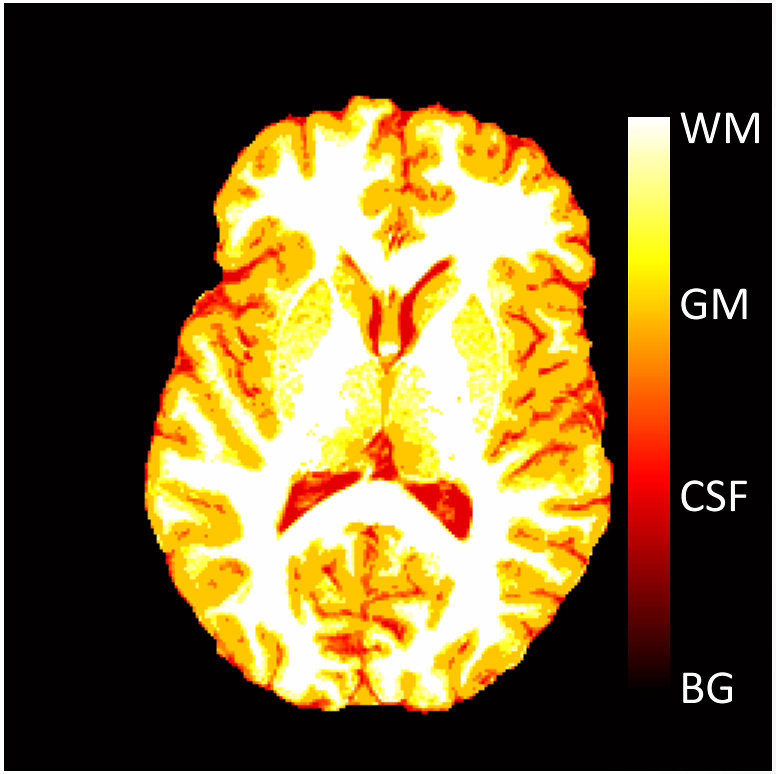
Tissue Classification

- 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, Other



Tissue Classification

- For each brain voxel, we estimate the tissue fraction as follows:
  - Pure voxels are 100%.
    - CSF=1
    - GM=2
    - WM=3
  - Each mixed tissue voxel is assigned a fractional value based on where its signal intensity falls between the class means.
    - E.g., 1.25 represents 75% CSF and 25% GM

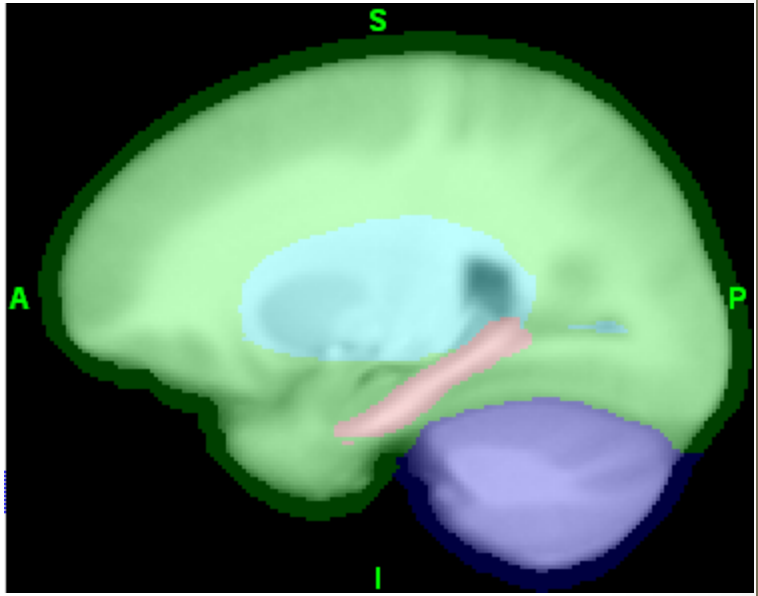


Cerebrum Labeling

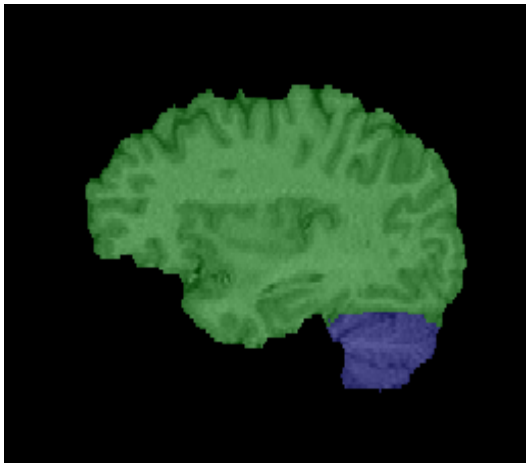
- For the cortical surface, we are interested in the cerebrum, which we separate from the rest of the brain.

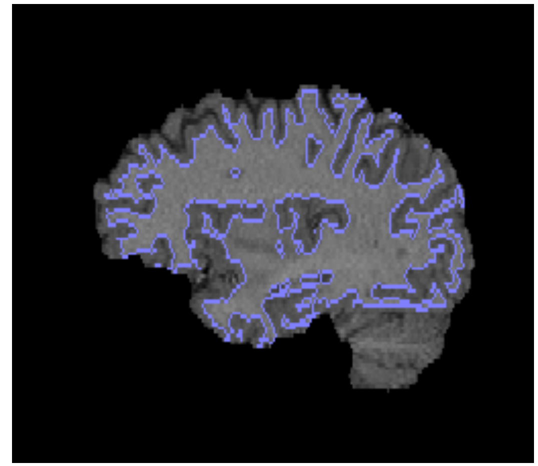
- We achieve this by registering a multi-subject average brain (ICBM452) to the individual brain using AIR (R. Woods)

- We have labeled this atlas:
  - cerebrum / cerebellum
  - subcortical regions
  - left / right



Inner Cortical Mask

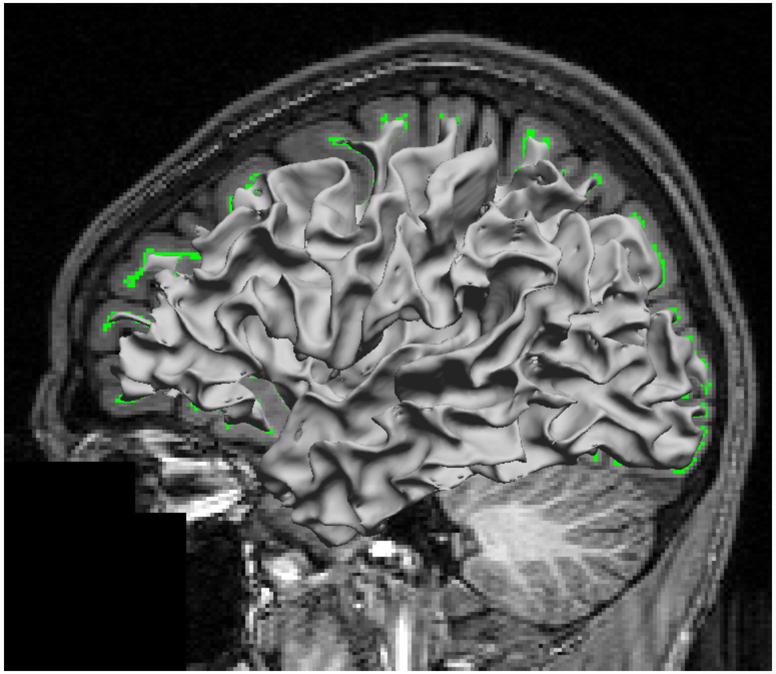




- We combine our registered brain atlas with our tissue map
  - retain subcortical structures, including nuclei
  - identify the inner boundary of the cerebral cortex

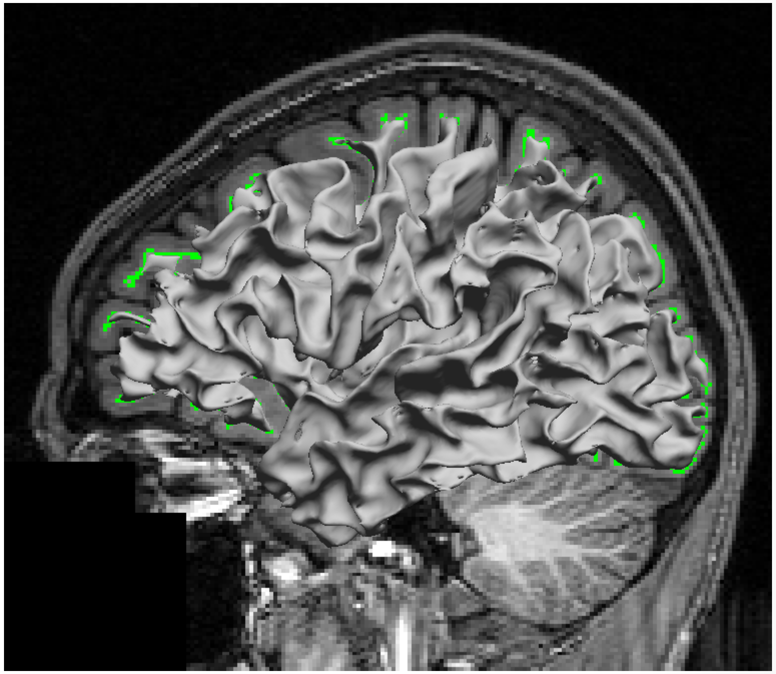
Surface Generation

- By applying a tessellation algorithm (Marching Cubes), we can generate a surface mesh from a 3D volume



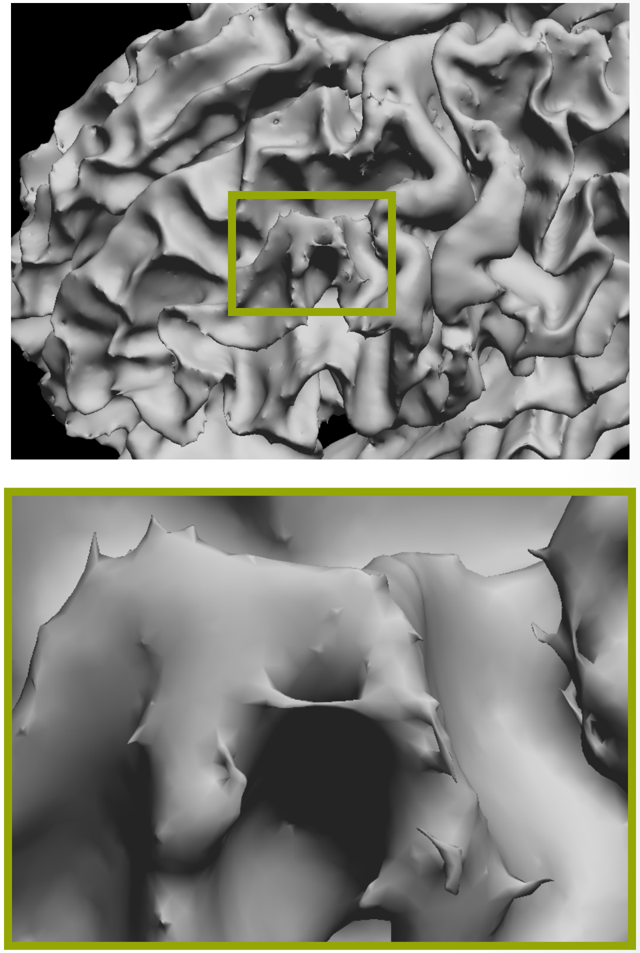
Scrub Mask

- We can remove small divets and bumps in the surface prior to tessellation by looking at local voxel configurations on the boundary of the binary mask.

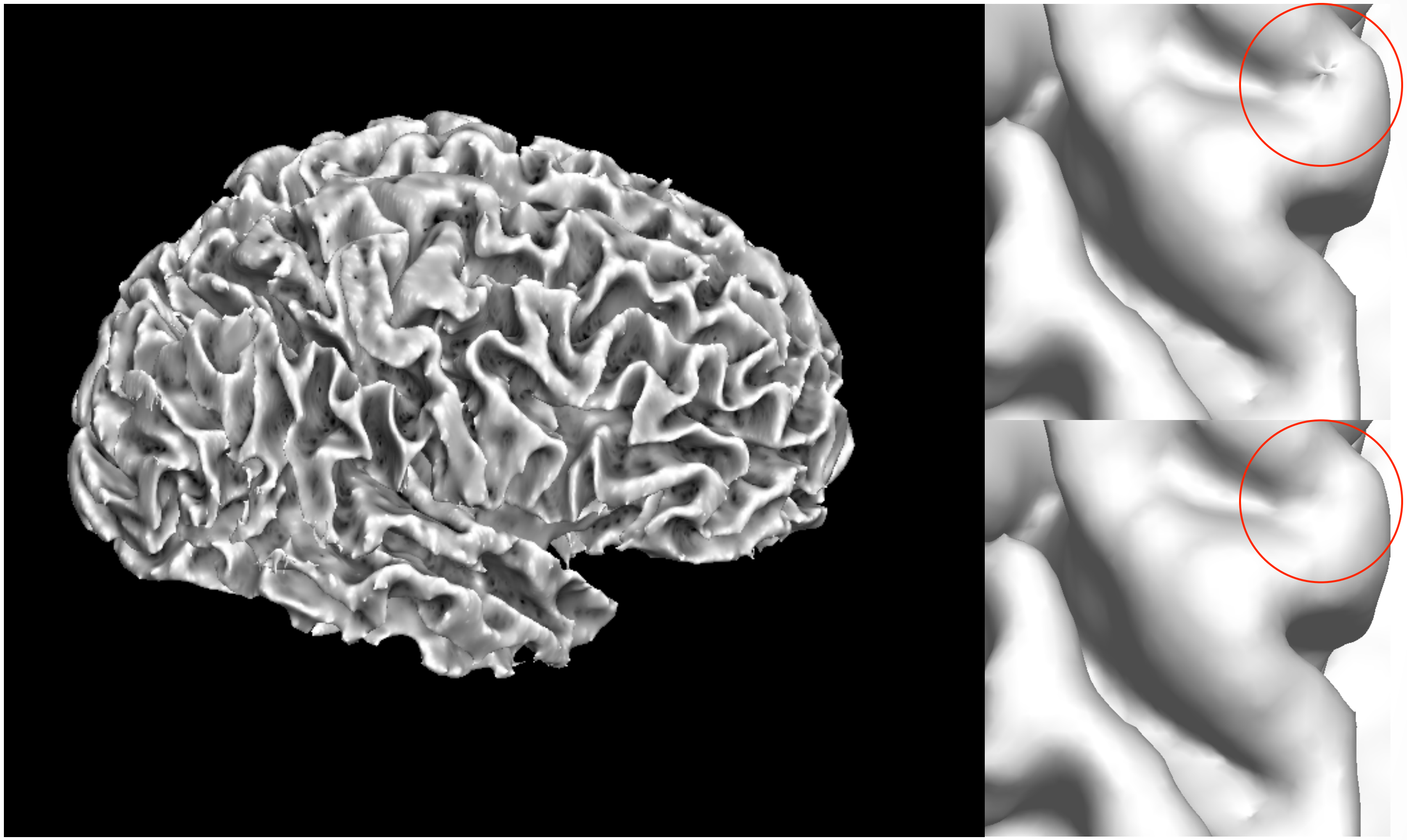


Topological Errors

- 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.



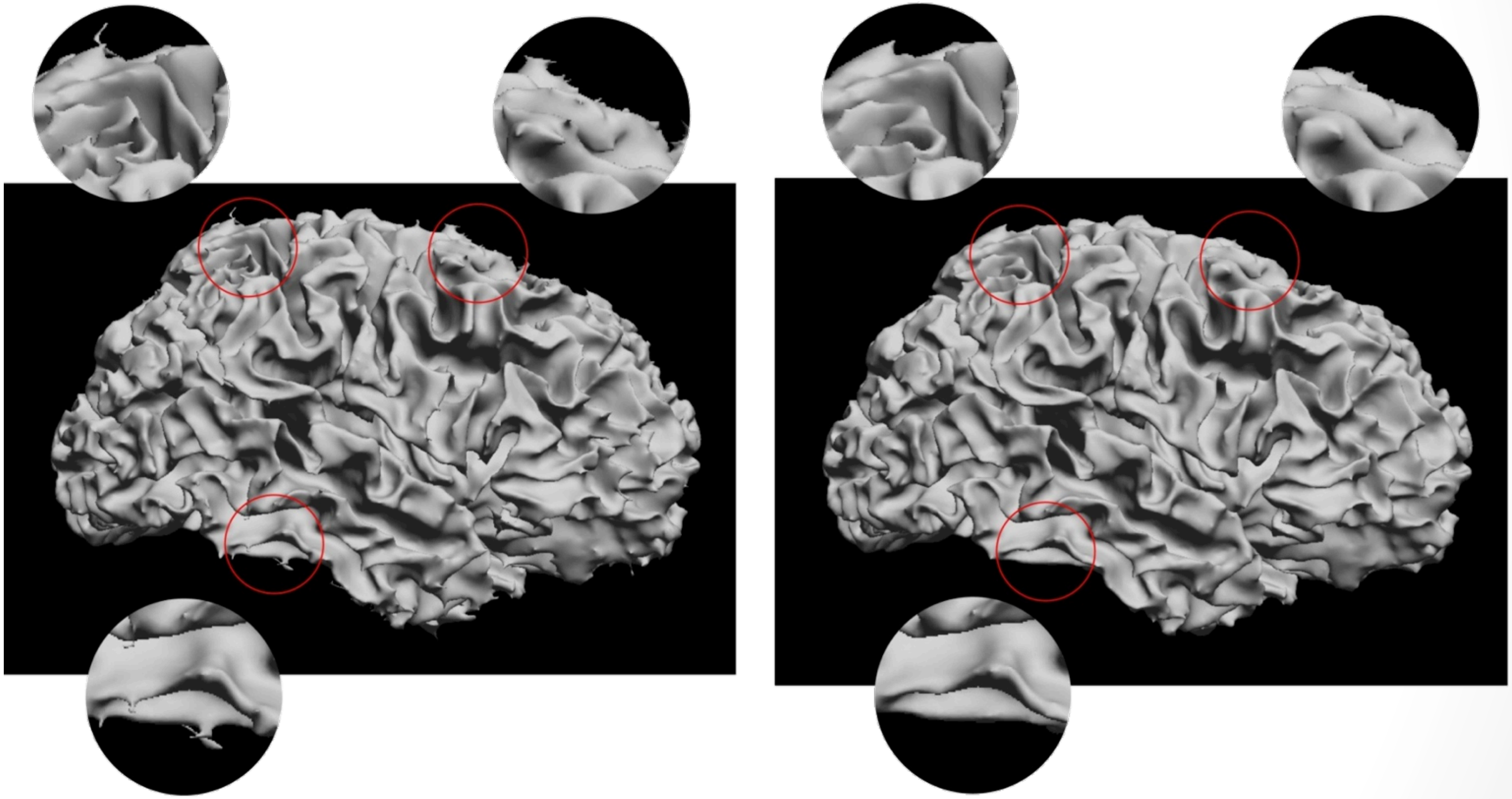
Topology Correction



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

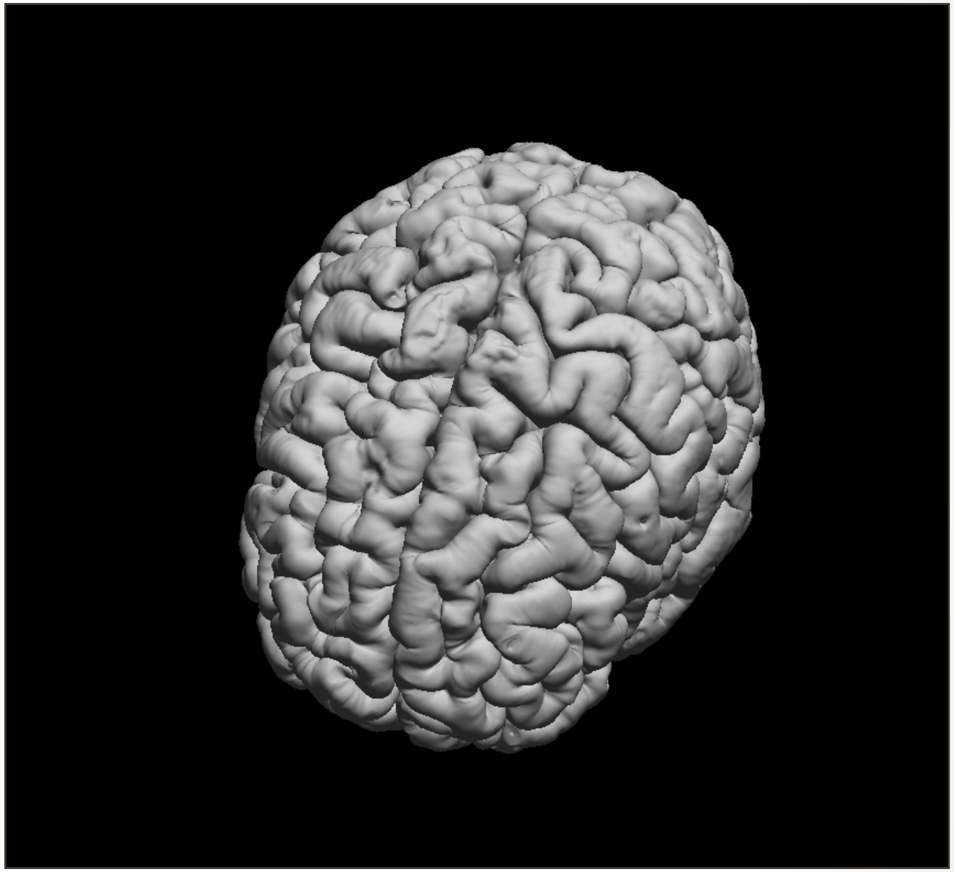


Inner Cortical Surface

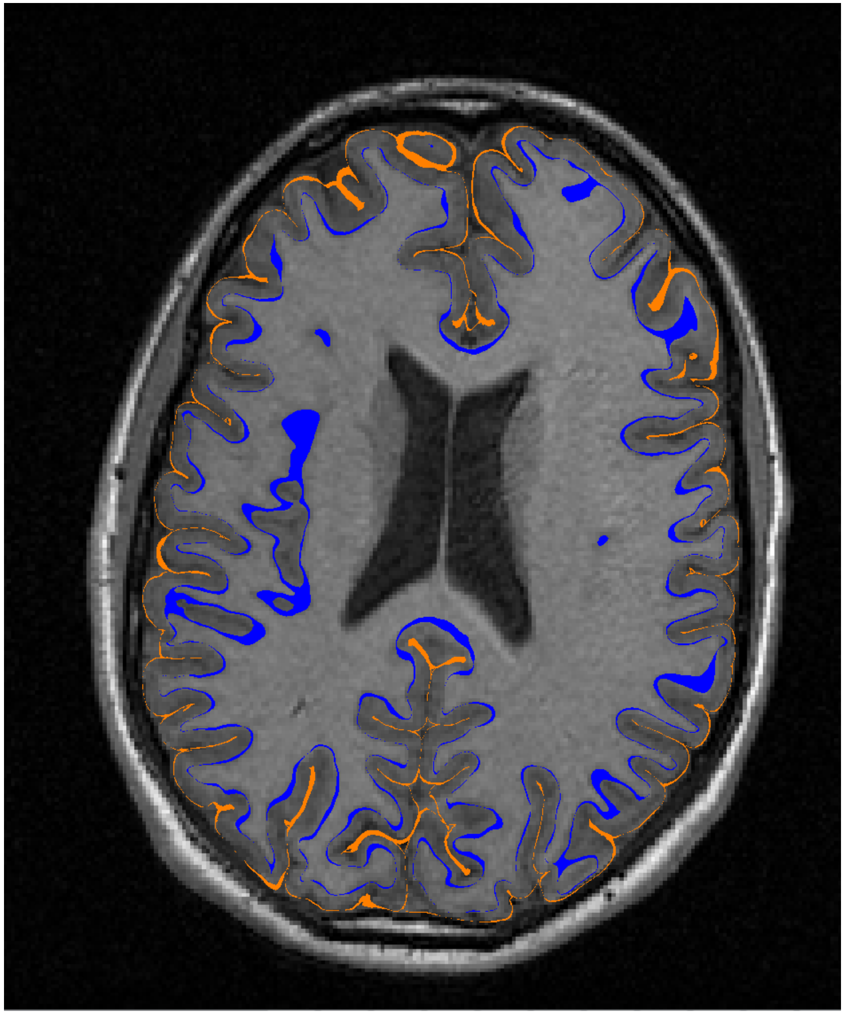
- After applying the scrub mask, topology correction, and dewisping filters, we compute the inner cortical surface mesh model.

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



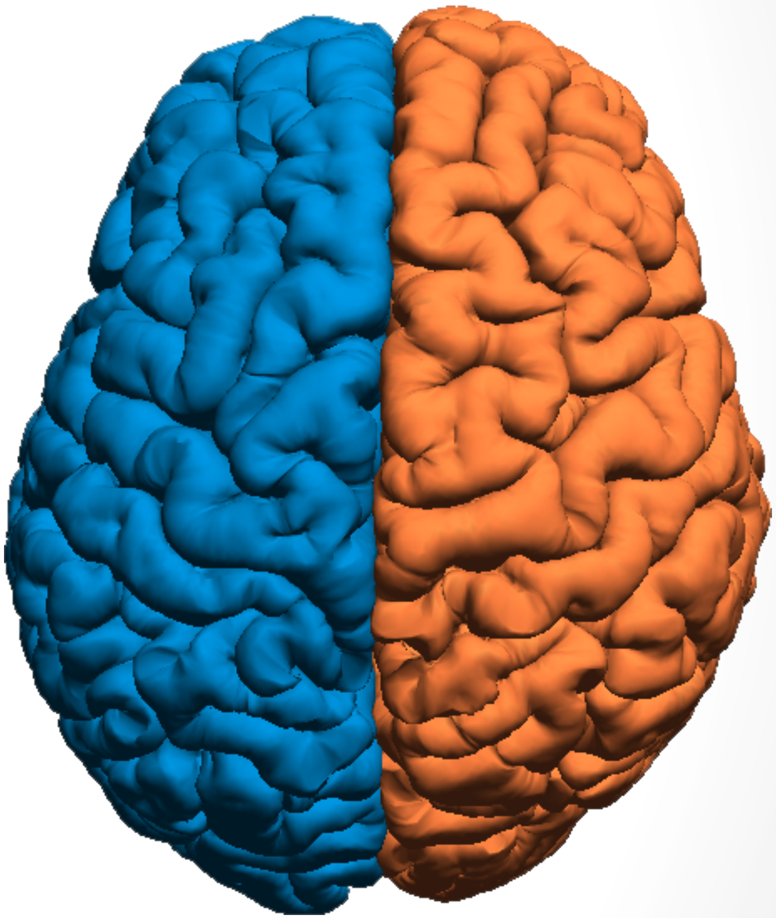
Pial Surface



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

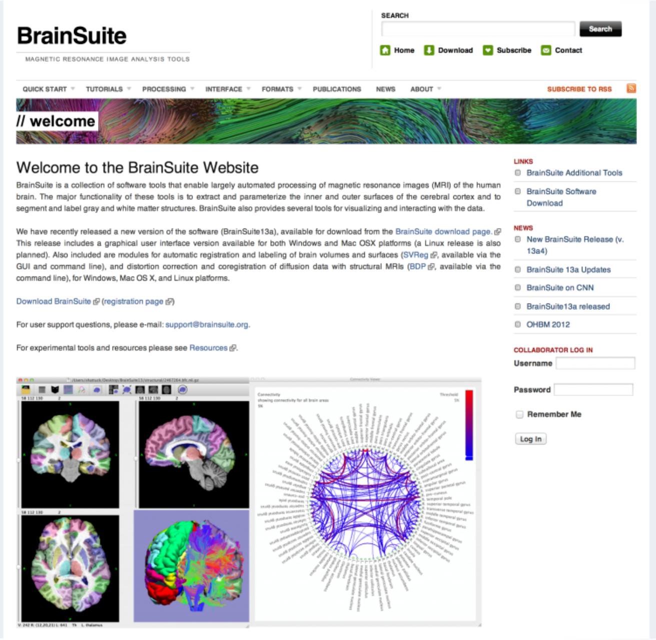
Split Hemispheres

- The **Split Hemispheres** step combines the hemisphere labels (computed during **Cerebrum Labeling**) with the surface models to separate the cerebral hemispheres.
- The meshes are checked to ensure that only a single cut is made in the surface
- These surface models are then used by the surface/ volume registration and labeling routine (SVReg)



For More Information

- Website: http://brainsuite.org
  - Tutorials
  - Videos
  - Slides
  - Downloads
- Questions: support@brainsuite.org
- Forums coming soon on the website
- Additional tools & utilities http://neuroimage.usc.edu/neuro/Resources/



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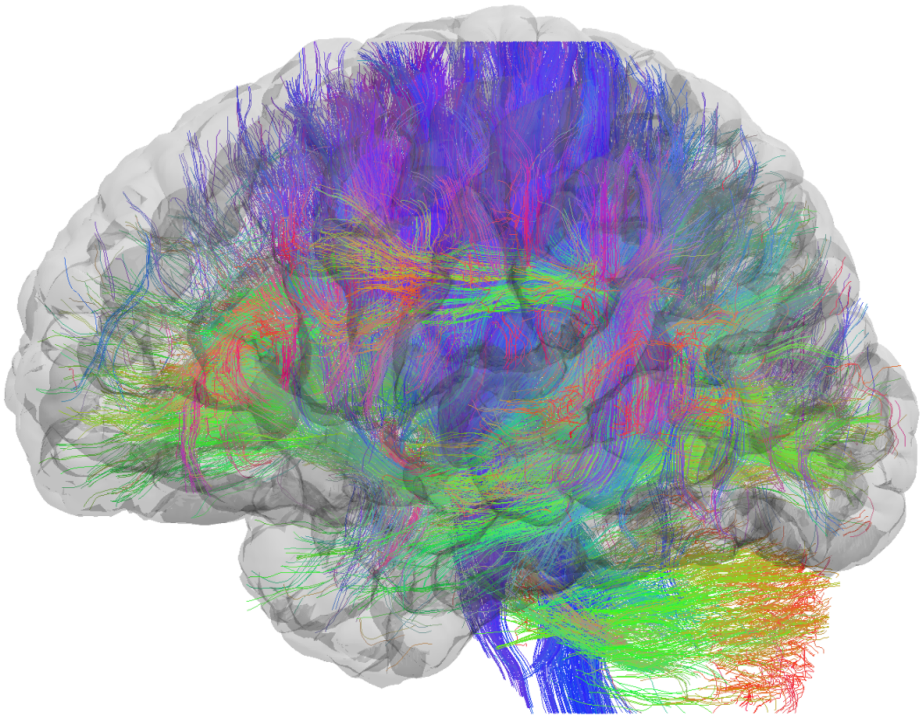

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