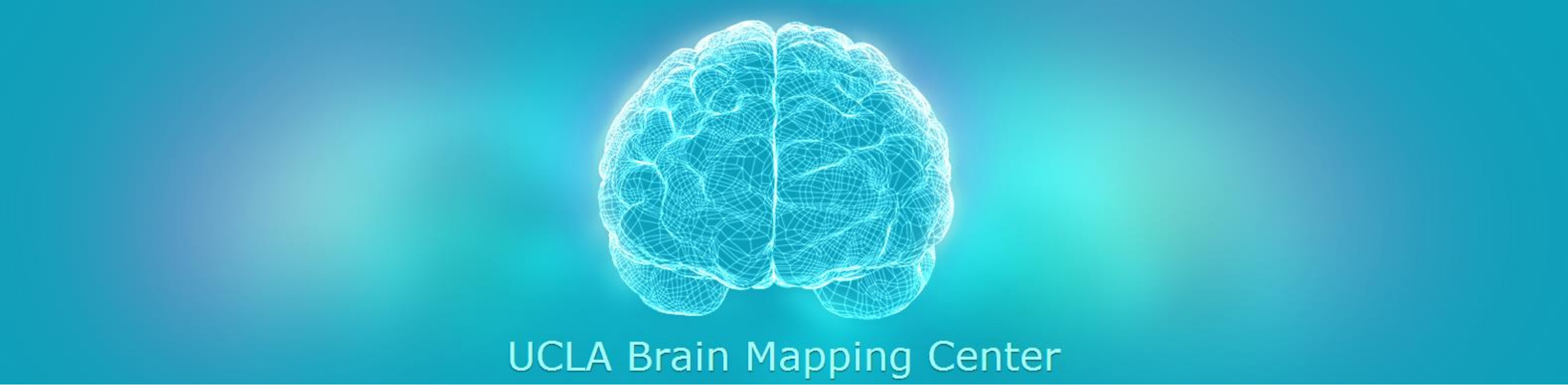


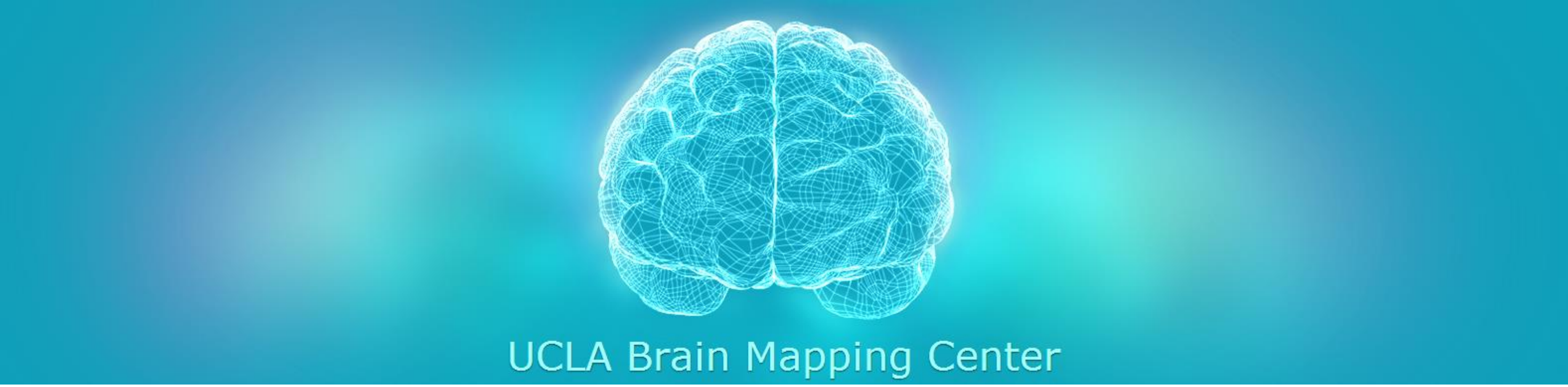
BrainSuite Workshop

Presented at the joint **BrainSuite/Brainstorm workshop**
26 October 2015

David Shattuck
Ahmanson-Lovelace Brain Mapping Center
Department of Neurology
David Geffen School of Medicine at UCLA
http://shattuck.bmap.ucla.edu

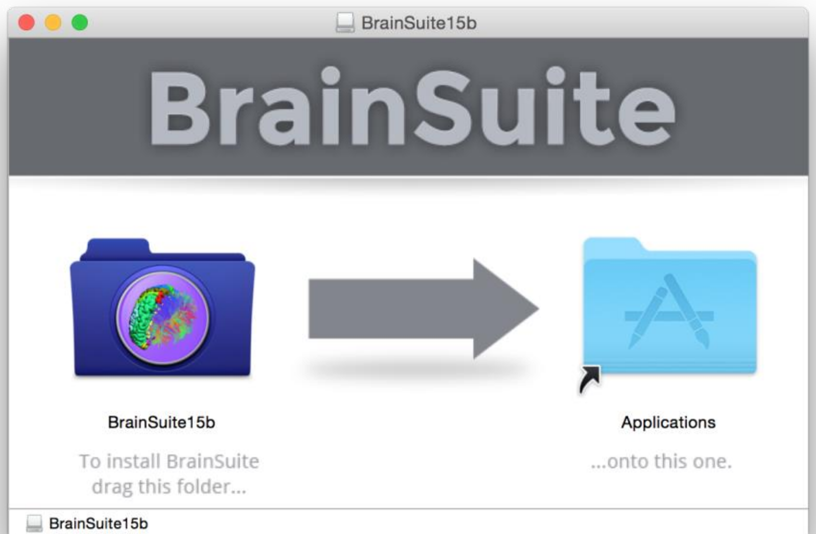
BrainSuite Resources

- e-mail support@brainsuite.org
- Main site http://brainsuite.org
- Registration (forum/download) http://brainsuite.org/register
- Download http://brainsuite.org/download
- User forums http://forums.brainsuite.org
- Tutorials http://brainsuite.org/tutorials
- Additional utilities
  http://brainsuite.org/processing/additional-tools



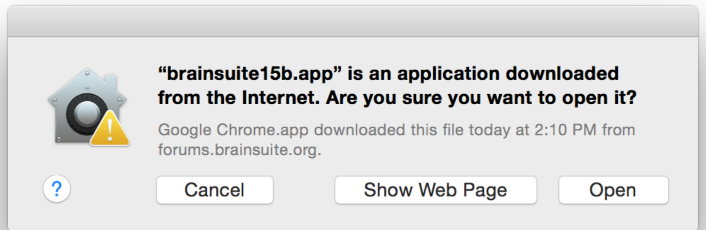
BrainSuite Installation & GUI

Installation



- Register and download at http://brainsuite.org
- Mac & Windows: open the installer
- Linux : gunzip/untar to your preferred install directory
- Note: today you are working with a pre-release version of the software (BrainSuite15c**b10** – beta version of BrainSuite15c)

Installation : Security



You may need to tell your OS that you trust BrainSuite.

- Mac
  - Navigate to /Applications/BrainSuite15cb10/brainsuite15cb10.app
  - Right-click and select "open".
  - Approve BrainSuite15cb10 to run.
- Windows
  - Win7: approve it through the dialog box as above.
  - Other Windows versions may have different security procedures.

Installation : MCR

- SVReg and BDP require MATLAB Compiler Runtime (MCR) 2012a
  - **Important: must be the 2012a Version!!!**
  - http://www.mathworks.com/products/compiler/mcr/

	Windows	Linux	Mac
R2012a (7.17)	64-bit	64-bit	Intel 64-bit

  - Links are also on the BrainSuite website.
- To use MCR 2012a on Mac OS X 10.10 (Yosemite) or 10.11 (El Capitan, you will need to also follow the instructions here:
  http://brainsuite.org/quickstart/installation/mac/yosemite/

Yosemite and El Capitan

The latest versions of OS X, Yosemite and El Capitan, may cause the SVReg and BDP programs, which are compiled MATLAB R2012a code, to stop working.

There is a simple 3-step fix for this:

1. Update XQuartz to 2.7.8
You can do this by either launching XQuartz (it will give you the opportunity to update) or go directly tohttp://xquartz.macosforge.org/landing/ to download the update.

2. link X11 from /opt to /usr
Note: This step may no longer be necessary.
The MATLAB Runtime Compiler library looks for X11 in a different location than OSX 10.10 (Yosemite) installs it. Open a terminal window (to do this, open Finder and type terminal) and run this command to link the X11 libraries to the location that MATLAB expects (you will need sudo privileges):

```
sudo ln -s /opt/X11/ /usr/X11
```

3. install the legacy version of Java 6
See http://support.apple.com/kb/DL1572 to download this update.

More details on OS X 10.10 and MATLAB can be found on these pages from Mathworks:
http://www.mathworks.com/matlabcentral/answers/158895-when-will-matlab-be-updated-for-os-x-yosemite
http://www.mathworks.com/matlabcentral/answers/159016-is-matlab-compatible-with-mac-os-x-10-10-yosemite

Sample Data

USC2015_BrainSuite_Tutorial

- contains several .bst files for running the examples in this tutorial.
- **extraction** : MRI file for cortical surface extraction
- **structural, structural_cropped** : contains SVReg outputs
- **diffusion, diffusion_cropped**: contains output of the BDP commands
- **commandline** : scripts and data to run command line tools
- **Atlases_workshop2015**
- **ICBM25** : sample data for BSS
- **ICBM25_outputs** : sample output data for BSS

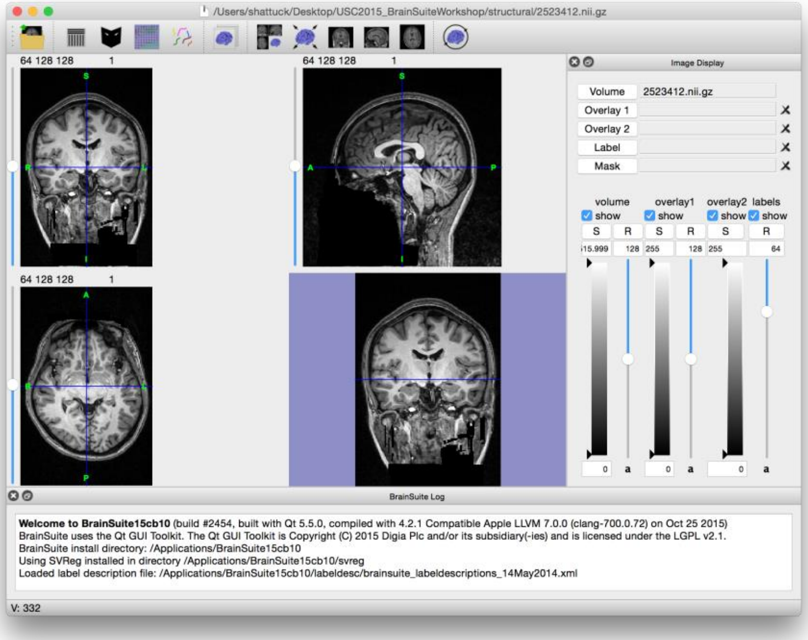
Note: _cropped versions use less memory and will be used for most tutorials

ICBM data are derived from data distributed by the International Consortium for Brain Mapping.

Opening and Displaying an MRI

- Start BrainSuite
- Drag and drop the T1 image from the native space folder onto the interface

  structural/2523412.nii.gz
- Navigation:
  - Scrolling the sliders or click in the image windows
  - Click and drag the mouse in the 3D view to rotate the display
  - Ctrl+click/⌘+click to zoom*
- Press the ‘I’ key to open the Image Display Properties controller
  - Adjust the intensity ranges
  - Right-click to change colormaps



*ctrl for Windows, ⌘ for Mac

BrainSuite Filetypes

Orthogonal Views	
File extension	**Action**
.nii, .nii.gz	3D images in NIFTI format
.odf	List of image files used in ODF representation
.dfs	BrainSuite surface format
.dft	BrainSuite track format (diffusion tractography)
.dfc	BrainSuite curve format (for landmark delineation)
.xml	Label descriptions Spherical ROIs
.lut	colormap lookup table (plain text)
.bst	BrainSuite Study File

http://brainsuite.org/keyboard-shortcuts/

BrainSuite Keyboard Shortcuts

Main Window	
Ctrl Key Combos	**Action**
Ctrl + A	Autoscale images
Ctrl + B	Show previous surface (back)
Ctrl + F	Show next surface (forward)
Ctrl + L [upper case L]	Toggle ROI Labels
Ctrl + l [lower case L]	Toggle ROI Label Outlines
Ctrl + R	Toggle first overlay volume on/off
Ctrl + M [case sensitive]	Cycle mask mode
Ctrl + m [case sensitive]	Toggle Mask on/off
Ctrl + S	Toggle show surfaces
Ctrl + V	Toggle show volume slices in 3D view
Ctrl + X	Toggle show cursors
Ctrl + Z	Undo last paint action

Note that on a Mac you use the ⌘ key instead of Ctrl   http://brainsuite.org/keyboard-shortcuts/

BrainSuite Keyboard Shortcuts

Surface Display	
Key	**Action**
L	Toggle lighting for 3D view
G	Toggle tensor glyphs on/off
O	Toggle ODF glyphs on/off
F	Toggle fibers on/off
W	Toggle wire frame mode for surfaces
X	Cycle X-plane clipping (off, positive, negative)
Y	Cycle Y-plane clipping (off, positive, negative)
Z	Cycle Z-plane clipping (off, positive, negative)
h [case sensitive]	Reset clipping mode and position

http://brainsuite.org/keyboard-shortcuts/

BrainSuite Keyboard Shortcuts

Toolboxes	
Key	**Action**
I	Show Image Display Toolbox
S	Show Surface Display Toolbox
M	Show masking tool (Delineation Toolbox)
P	Show painter tool (Delineation Toolbox)
C	Show Curve Toolbox
D	Show Diffusion Toolbox

http://brainsuite.org/keyboard-shortcuts/

BrainSuite Keyboard Shortcuts

Image Display	
Key	**Action**
+	Zoom In
-	Zoom Out
*	Zoom Best Fit
/	Zoom to 1:1 (in smallest pixel dimension)

http://brainsuite.org/keyboard-shortcuts/

BrainSuite Keyboard Shortcuts

Orthogonal Views	
Alt Key Combos	**Action**
Alt + 1	Rotate 3D view to xy view (axial, from superior)
Alt + 2	Rotate 3D view to xy view (axial, from inferior)
Alt + 3	Rotate 3D view to xz view (coronal, from posterior
Alt + 4	Rotate 3D view to xz view (coronal, from anterior)
Alt + 5	Rotate 3D view to yz view (sagittal, from right)
Alt + 6	Rotate 3D view to yz view (sagittal, from left)

http://brainsuite.org/keyboard-shortcuts/

BrainSuite Keyboard Shortcuts

Connectivity Viewer	
Key	**Action**
1	Show Connectivity for Cortical Areas
2	Show Connectivity for Frontal Lobe
3	Show Connectivity for Parietal Lobe
4	Show Connectivity for Temporal Lobe
5	Show Connectivity for Occipital Lobe
6	Show Connectivity for Subcortical Areas
7	Show Connectivity for Brain Areas
8	Show Connectivity for All Labeled Regions (includes white matter, ventricles, etc).

http://brainsuite.org/keyboard-shortcuts/

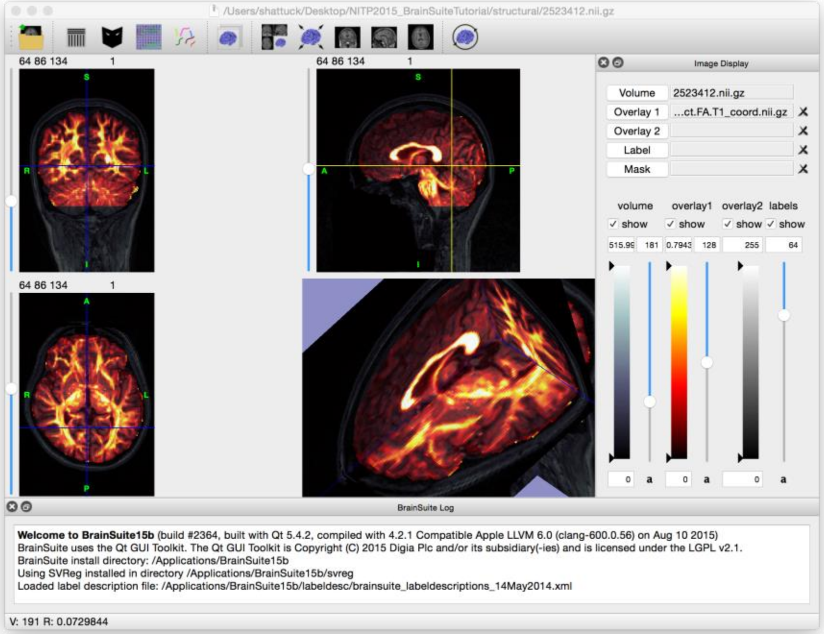
Opening an Overlay

Load an overlay image

- Press the Overlay1 button
- Select the FA file:

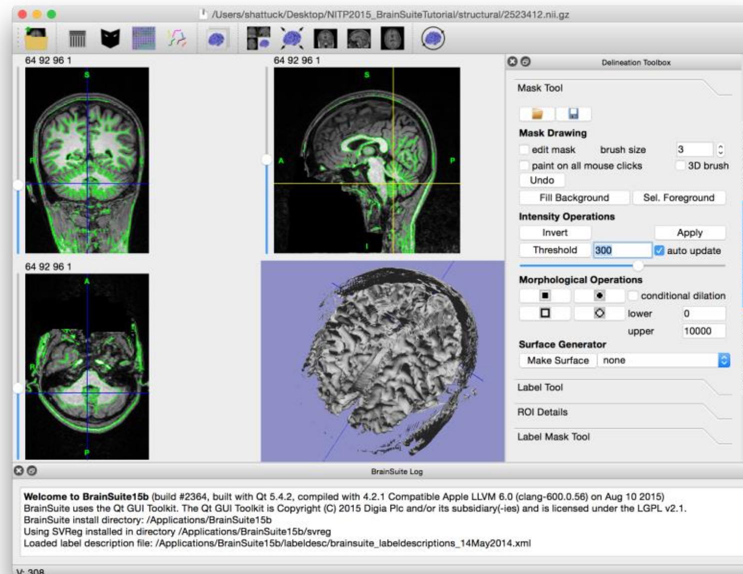
diffusion/DTI/2523412.dwi.RAS.correct.FA.T1_coord.nii.gz

- Adjust the first alpha slider to change the blending of the two images
- Change the colormap of the overlay

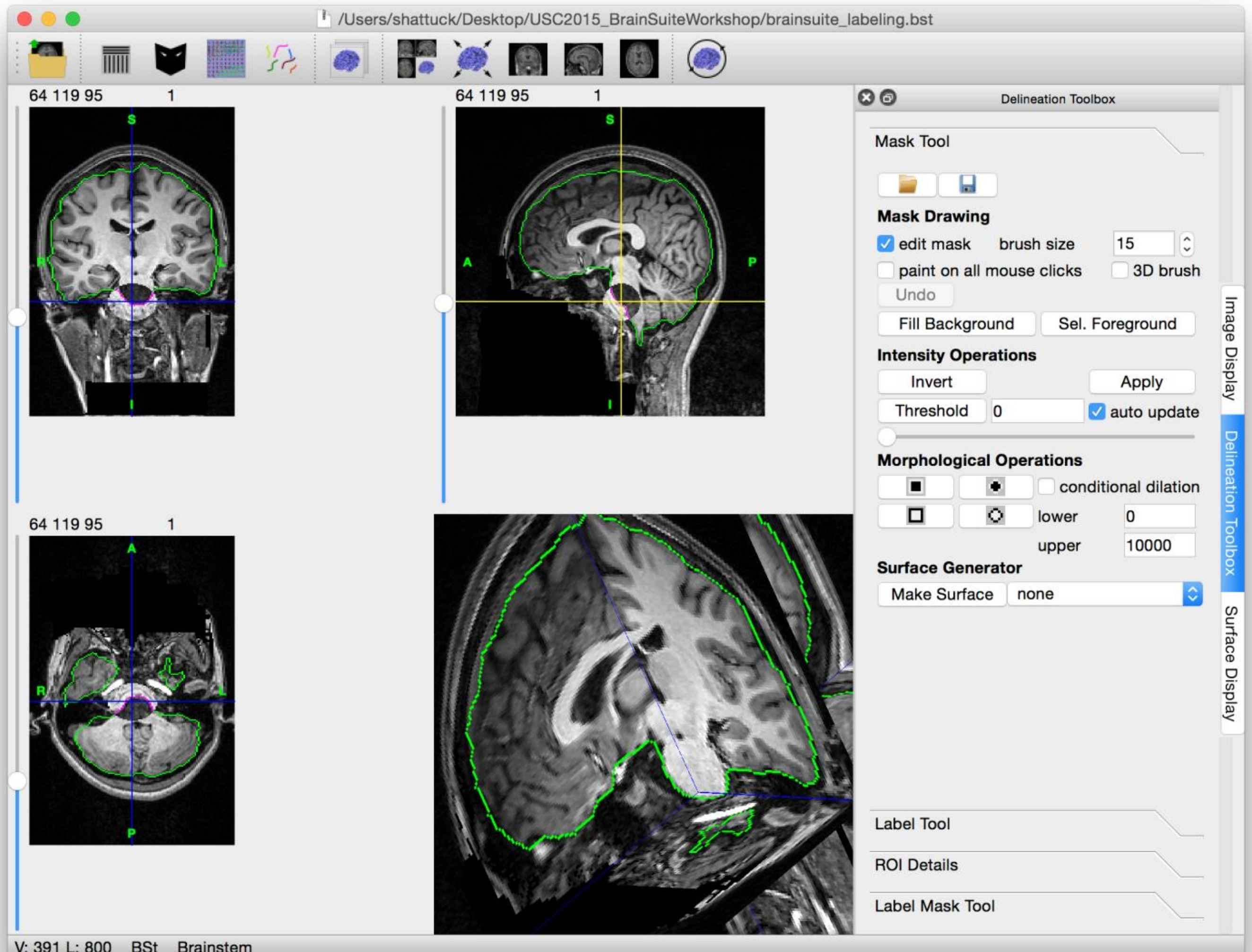


Mask and Surface Tools

- Open the T1 image as the primary volume
- Open the display properties and adjust the lower intensity range
- Press ‘M’ to open the mask tool
- Adjust the slider under Threshold, and see the mask boundary change.
- This will create a new mask as the slider moves.
- Set the value to 256.
- Press the ‘Make Surface’ button (you may need to enlarge the BrainSuite window to see this button)
- Press ctrl+V/⌘+V to hide the slices in the 3D view



Mask Editing



Shift-Ctrl-Click to edit mask

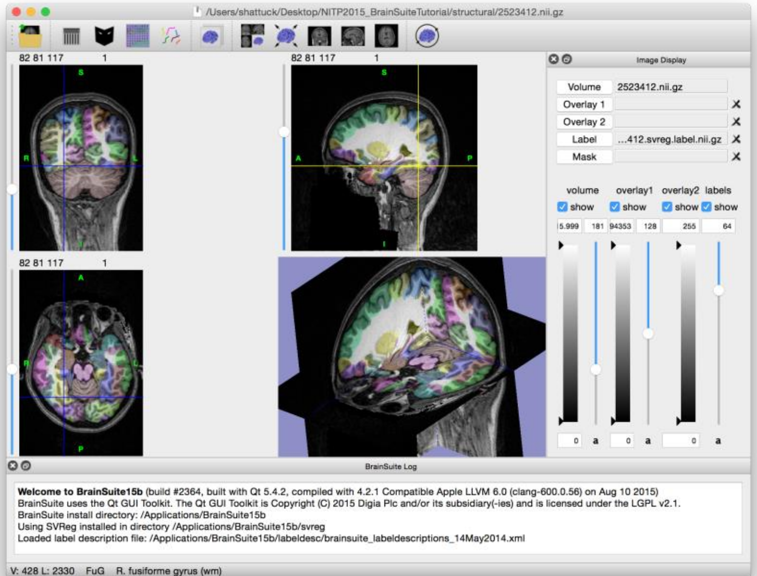
Right Click: erase

Left Click: paint

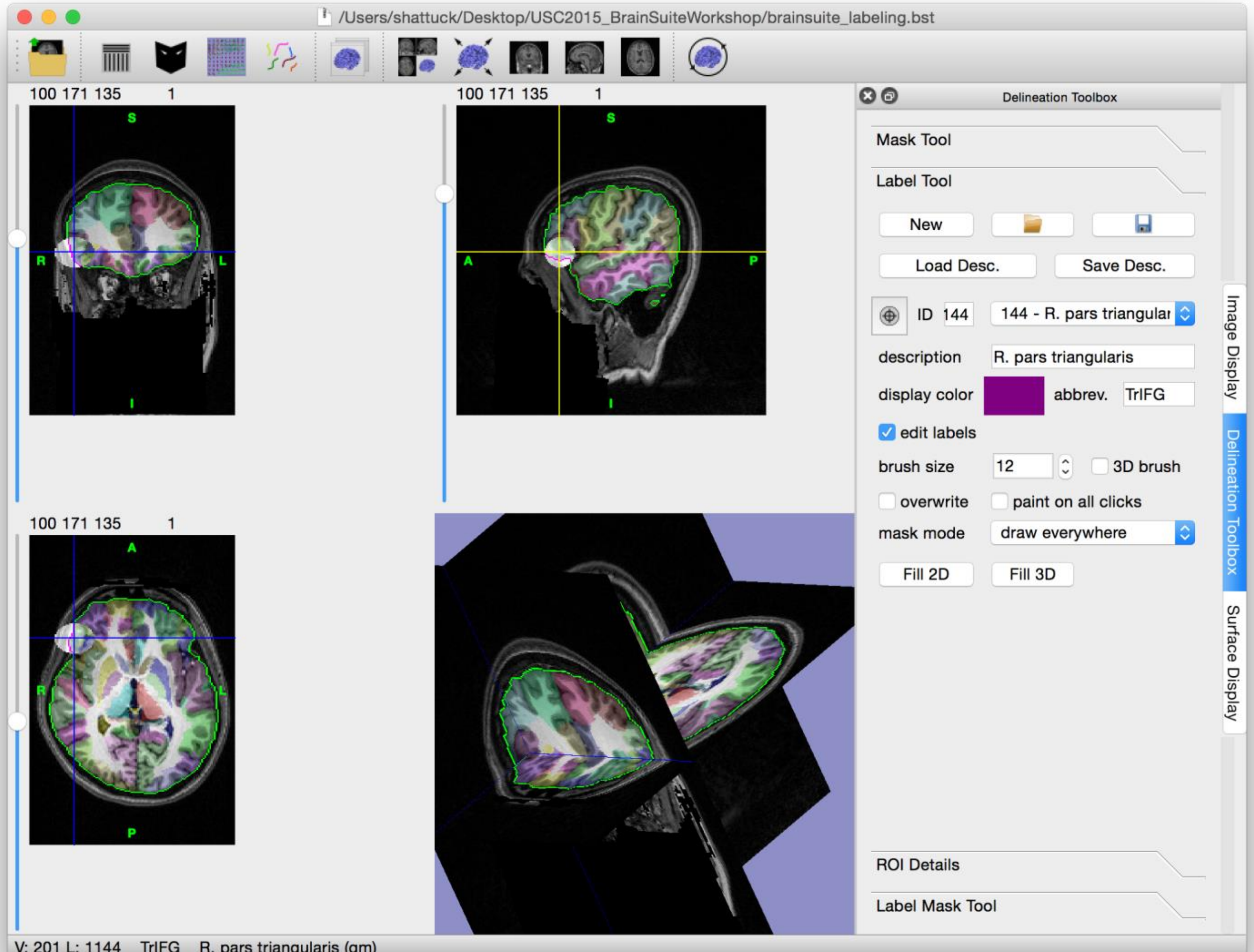
Can be difficult with a track pad!

Working with Labels

- Load data from the structural directory
  - Load 2523412.nii.gz
  - Load 2523412.svreg.label.nii.gz as a Label image
- Each color corresponds to a different anatomical area as defined by BrainSuite
- Click the mouse on a labeled area, and the label is shown in the status bar.



Label Editing



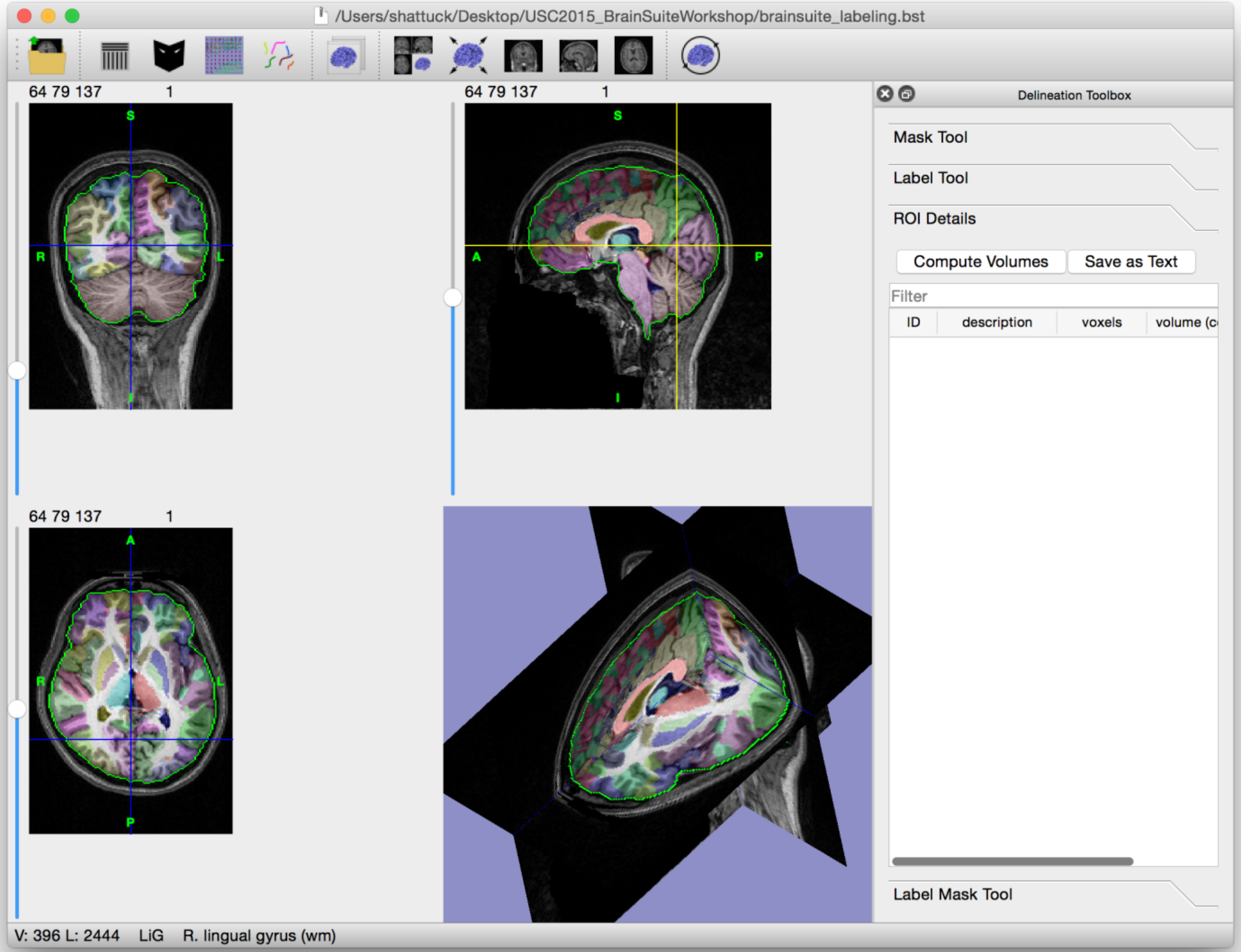
Shift-Ctrl-Click to edit mask

Right Click: erase

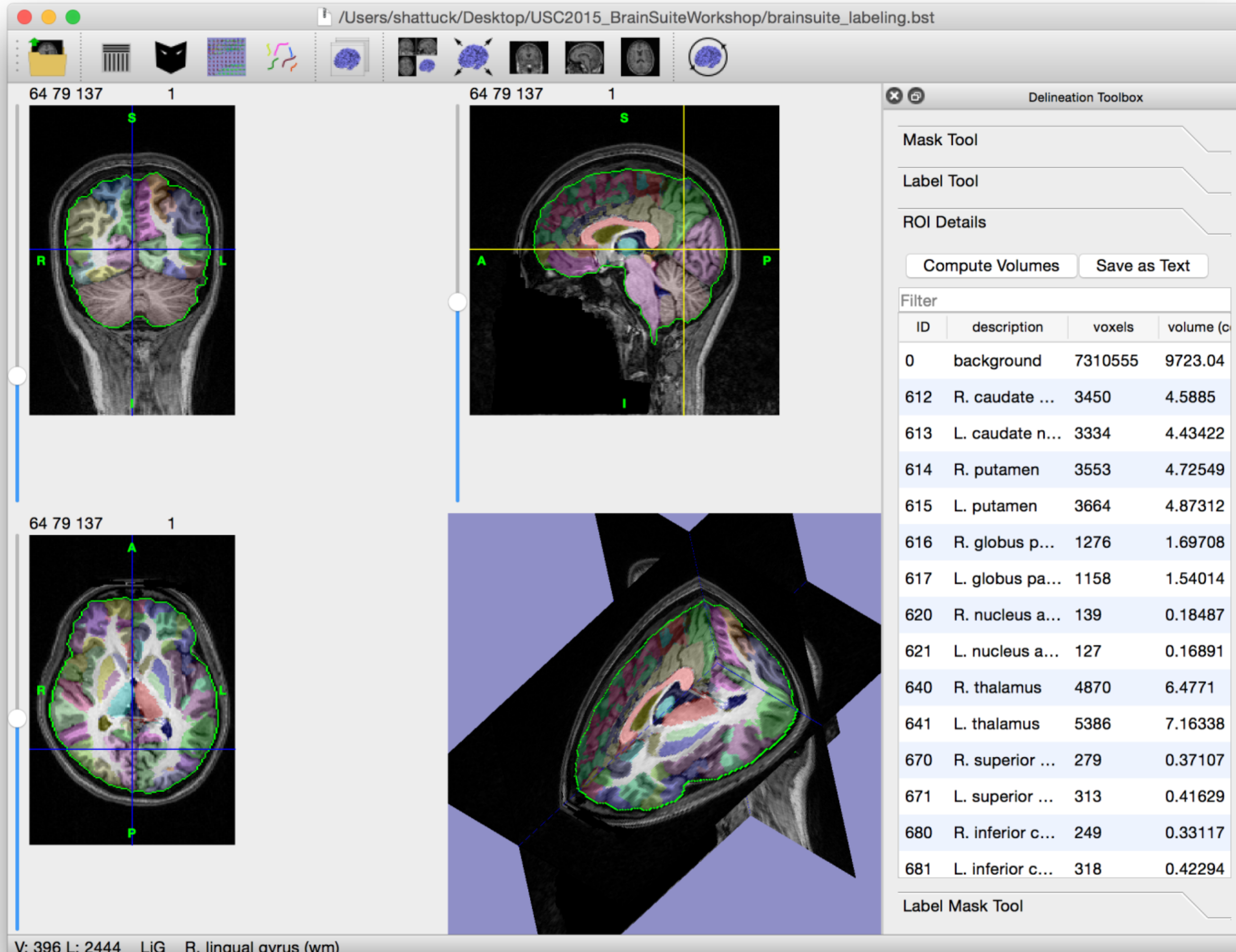
Left Click: paint

Can be difficult with a track pad!

ROI Details

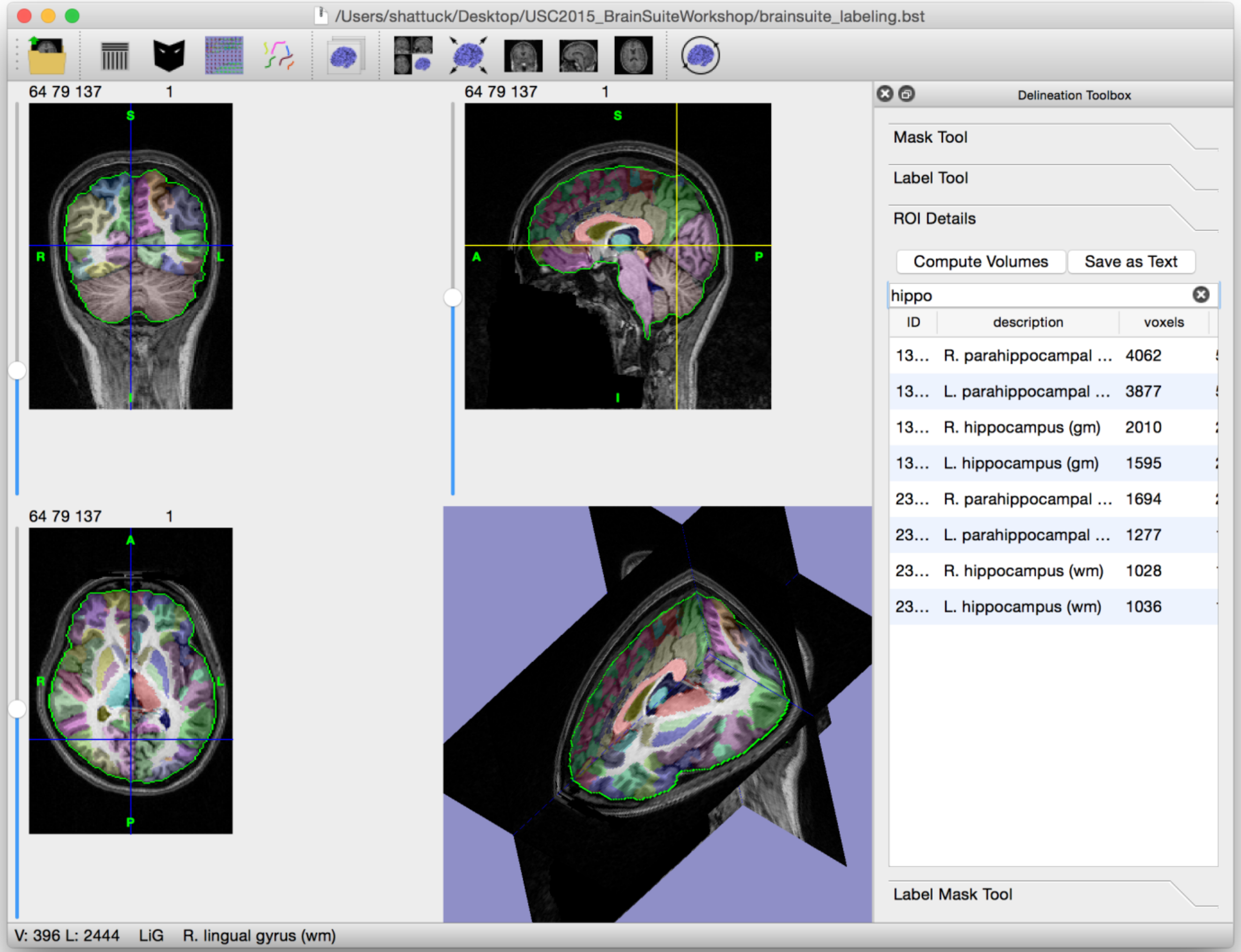

/Users/shattuck/Desktop/USC2015_BrainSuiteWorkshop/brainsuite_labeling.bst
64 79 137 1
64 79 137 1
64 79 137 1
Delineation Toolbox
Mask Tool
Label Tool
ROI Details
Compute Volumes
Save as Text
Filter
ID
description
voxels
volume (c
Label Mask Tool
V: 396 L: 2444 LiG R. lingual gyrus (wm)

ROI Details



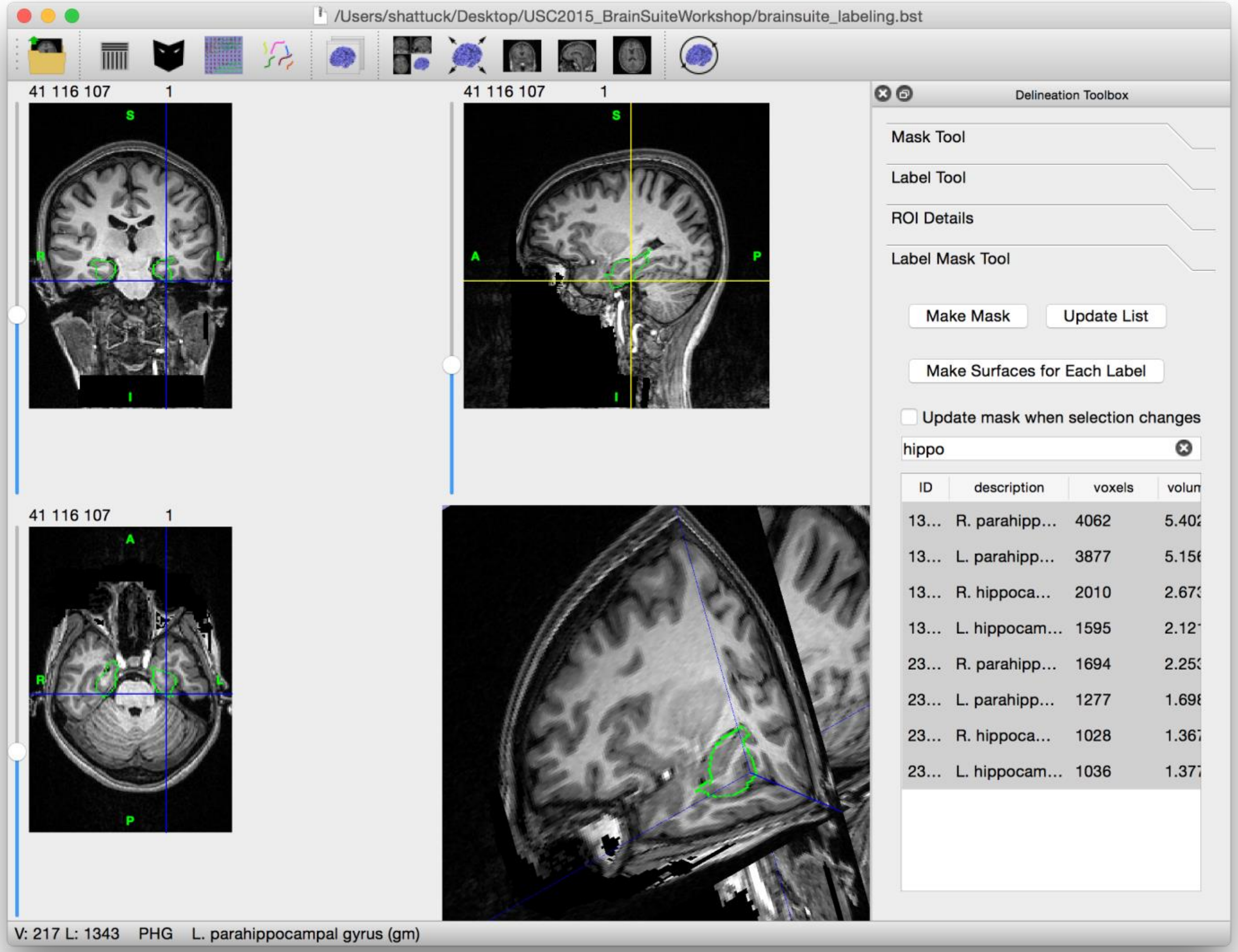
/Users/shattuck/Desktop/USC2015_BrainSuiteWorkshop/brainsuite_labeling.bst
Delineation Toolbox
Mask Tool
Label Tool
ROI Details
Compute Volumes
Save as Text
Filter
ID description voxels volume (c
0 background 7310555 9723.04
612 R. caudate ... 3450 4.5885
613 L. caudate n... 3334 4.43422
614 R. putamen 3553 4.72549
615 L. putamen 3664 4.87312
616 R. globus p... 1276 1.69708
617 L. globus pa... 1158 1.54014
620 R. nucleus a... 139 0.18487
621 L. nucleus a... 127 0.16891
640 R. thalamus 4870 6.4771
641 L. thalamus 5386 7.16338
670 R. superior ... 279 0.37107
671 L. superior ... 313 0.41629
680 R. inferior c... 249 0.33117
681 L. inferior c... 318 0.42294
Label Mask Tool
64 79 137 1
V: 396 L: 2444 LiG R. lingual gyrus (wm)

ROI Details

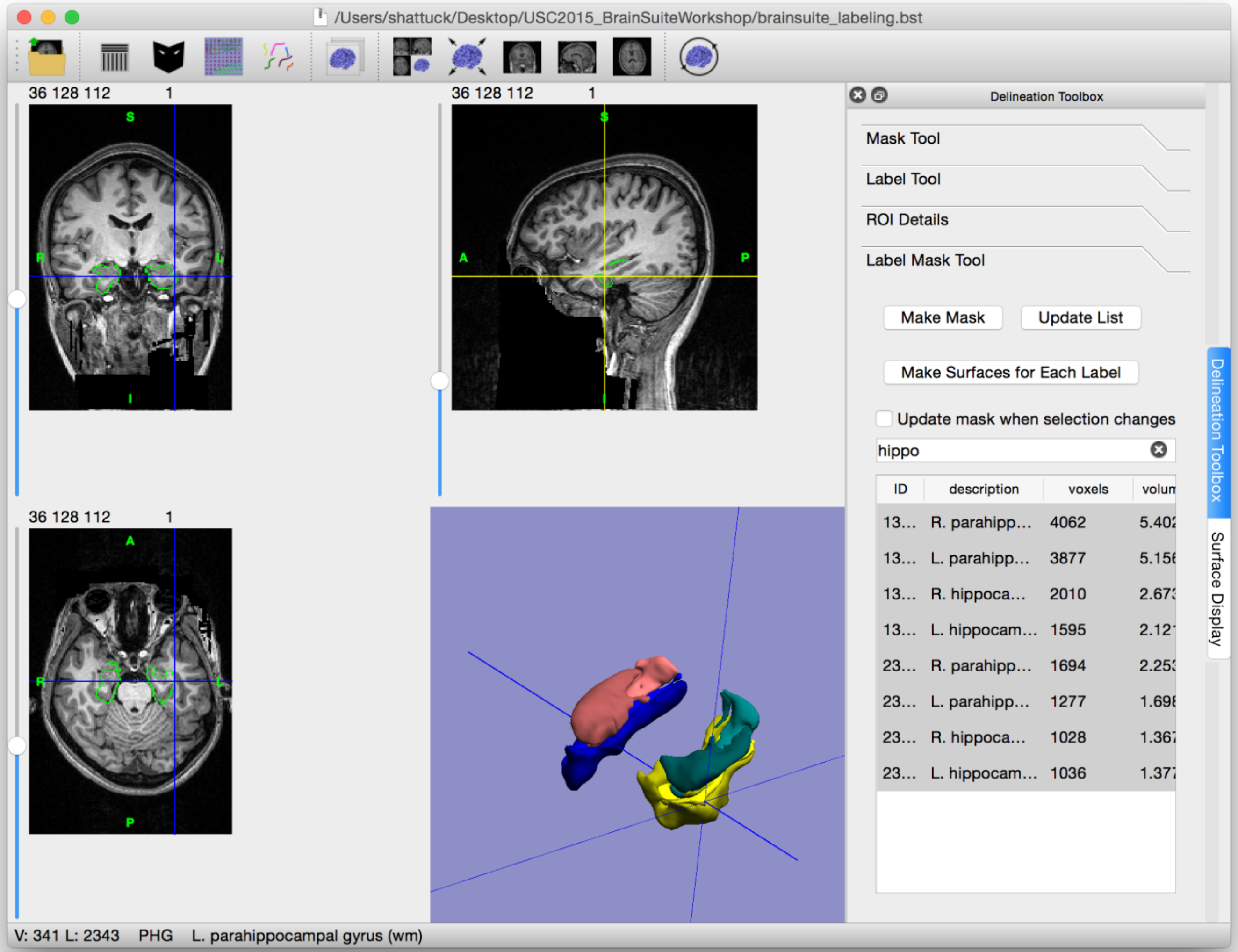


/Users/shattuck/Desktop/USC2015_BrainSuiteWorkshop/brainsuite_labeling.bst
64 79 137 1
Delineation Toolbox
Mask Tool
Label Tool
ROI Details
Compute Volumes
Save as Text
hippo
ID description voxels
13… R. parahippocampal … 4062
13… L. parahippocampal … 3877
13… R. hippocampus (gm) 2010
13… L. hippocampus (gm) 1595
23… R. parahippocampal … 1694
23… L. parahippocampal … 1277
23… R. hippocampus (wm) 1028
23… L. hippocampus (wm) 1036
Label Mask Tool
V: 396 L: 2444 LiG R. lingual gyrus (wm)

Label Mask Tool

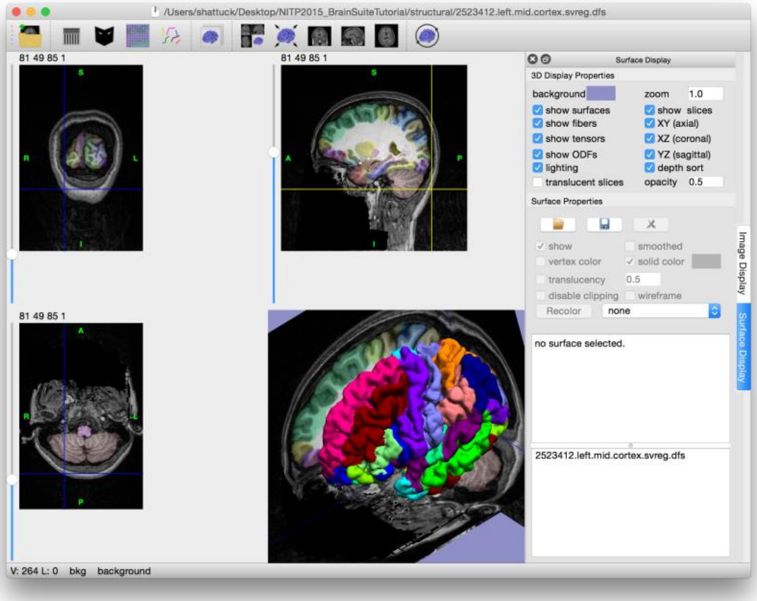


Label Mask Tool : Surfaces

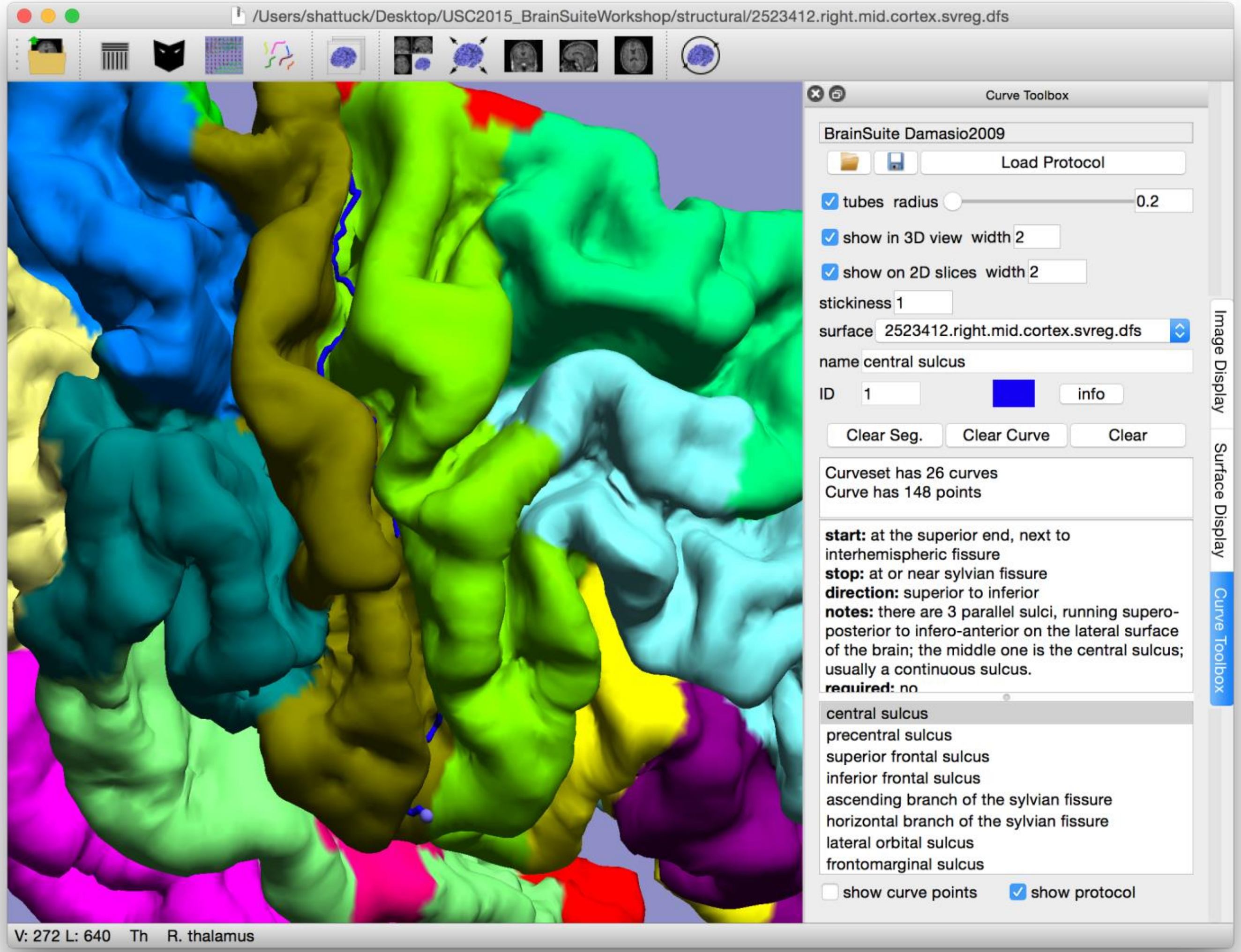


Working with Surfaces

- From the structural folder, drag and drop the file 2523412.left.mid.cortex.svreg.dfs onto BrainSuite
- Properties of the different surfaces can be adjusted
  - Show or hide
  - Wireframe mode
  - Translucency
- Recolor based on different properties
  - Volumetric labeling
  - Curvature



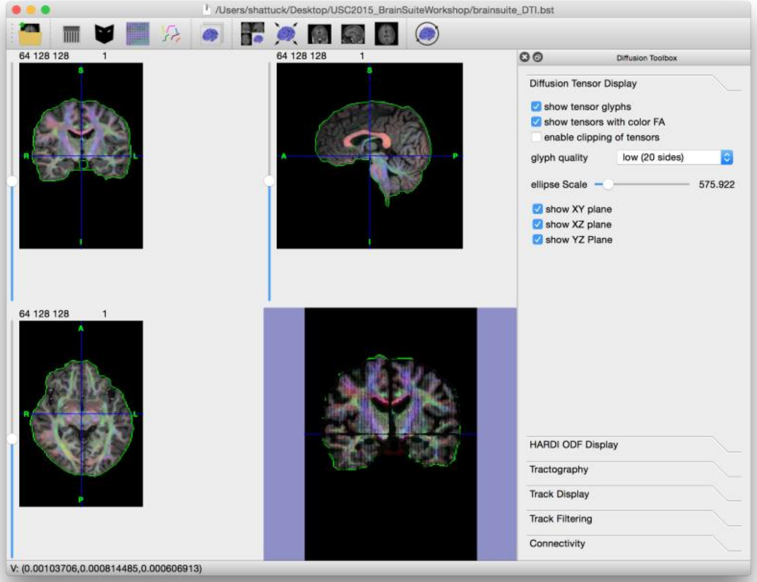
Delineation Tools



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

DTI Data

- **Drop brainsuite_DTI.bst onto BrainSuite**
- Adjust the image display parameters (‘I’) to increase the brightness.
- Scroll through the volume and observe some of the structure that is made visible by the DTI
  - Hide the volume slices (ctrl+V/⌘+V)
  - Make the surface display full view
  - Zoom into the image
  - In the diffusion toolbox (‘D’), adjust the size of the diffusion glyphs
- You can also load the structural scan as an overlay to observe the different modalities.



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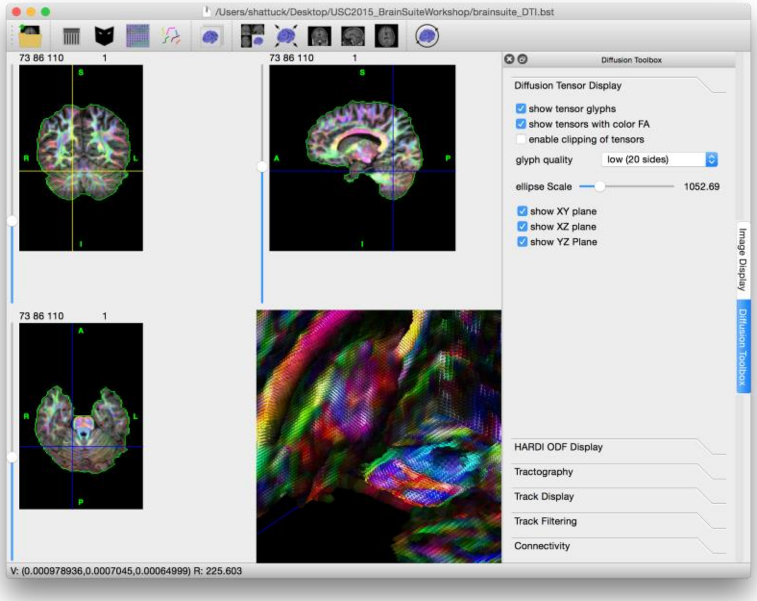

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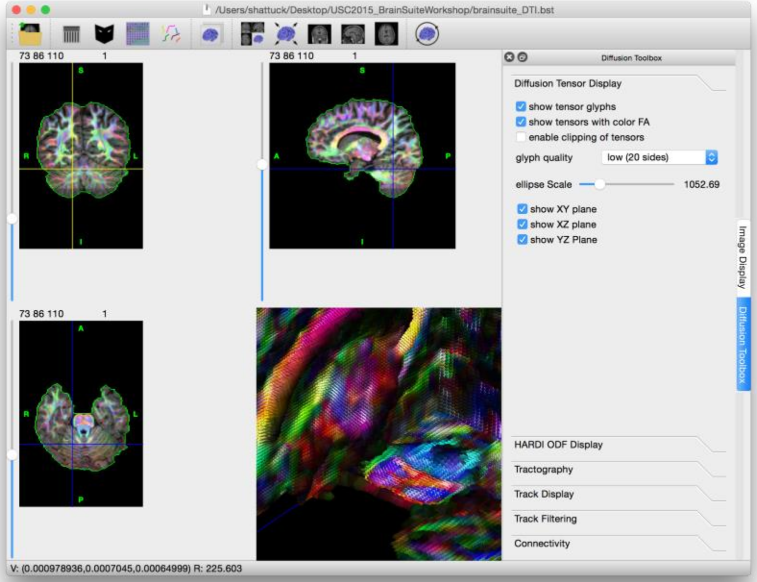

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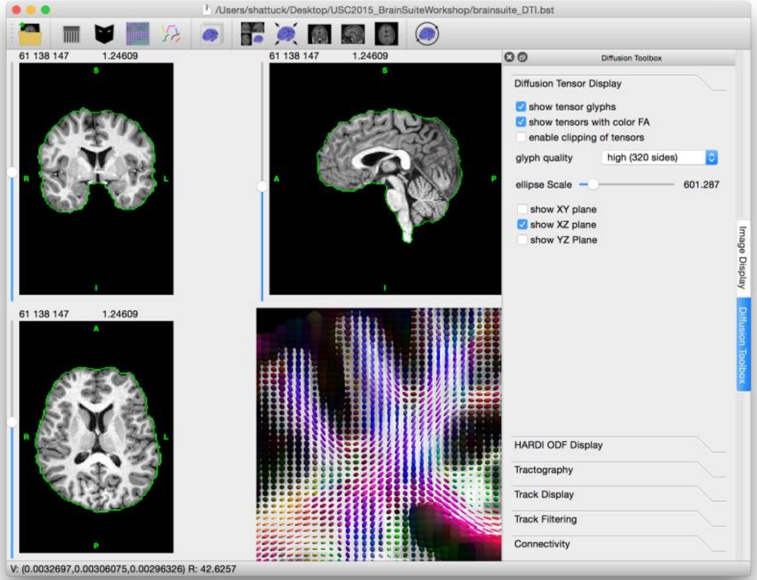
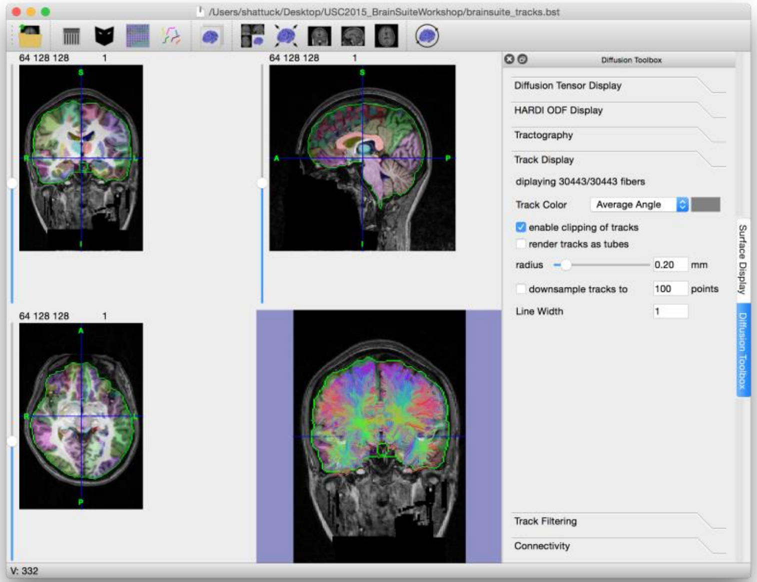
- **You can also load the structural scan as an overlay to observe the different modalities.**



Tractography

- **Drop brainsuite_tracks.bst onto BrainSuite**
- Explore the tracks using the interface
  - Surfaces off (‘S’)
  - Cut planes (x/y/z keys)
  - Fibers on/off (‘F’)



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  - Cut planes (x/y/z keys)
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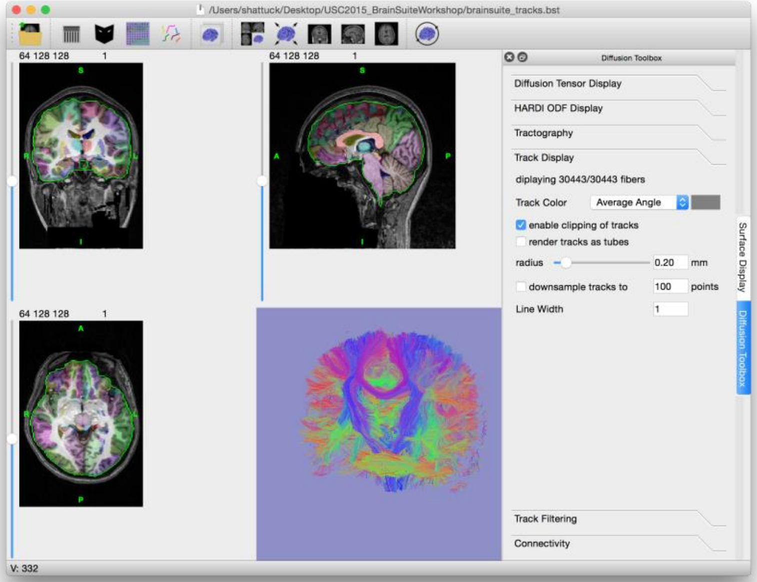
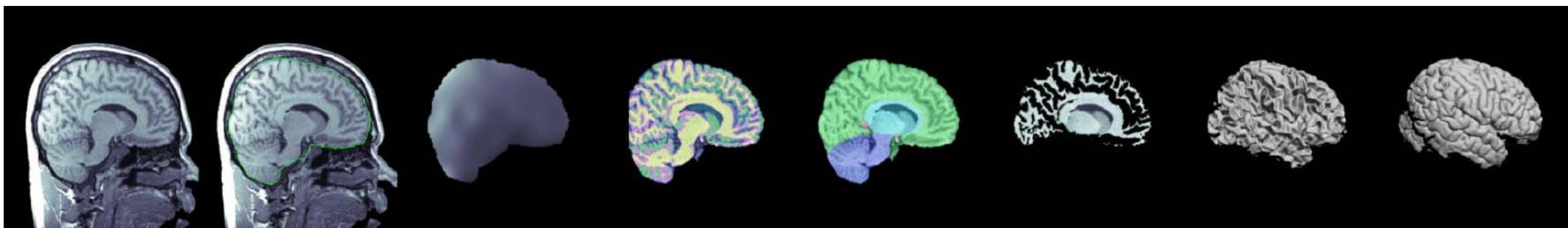


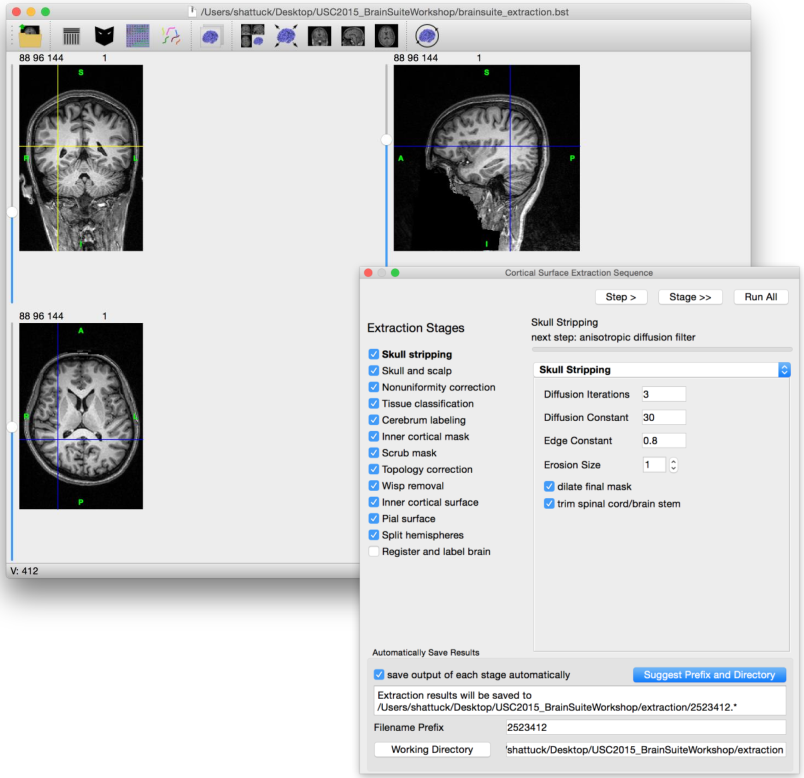
Cortical Surface Extraction



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

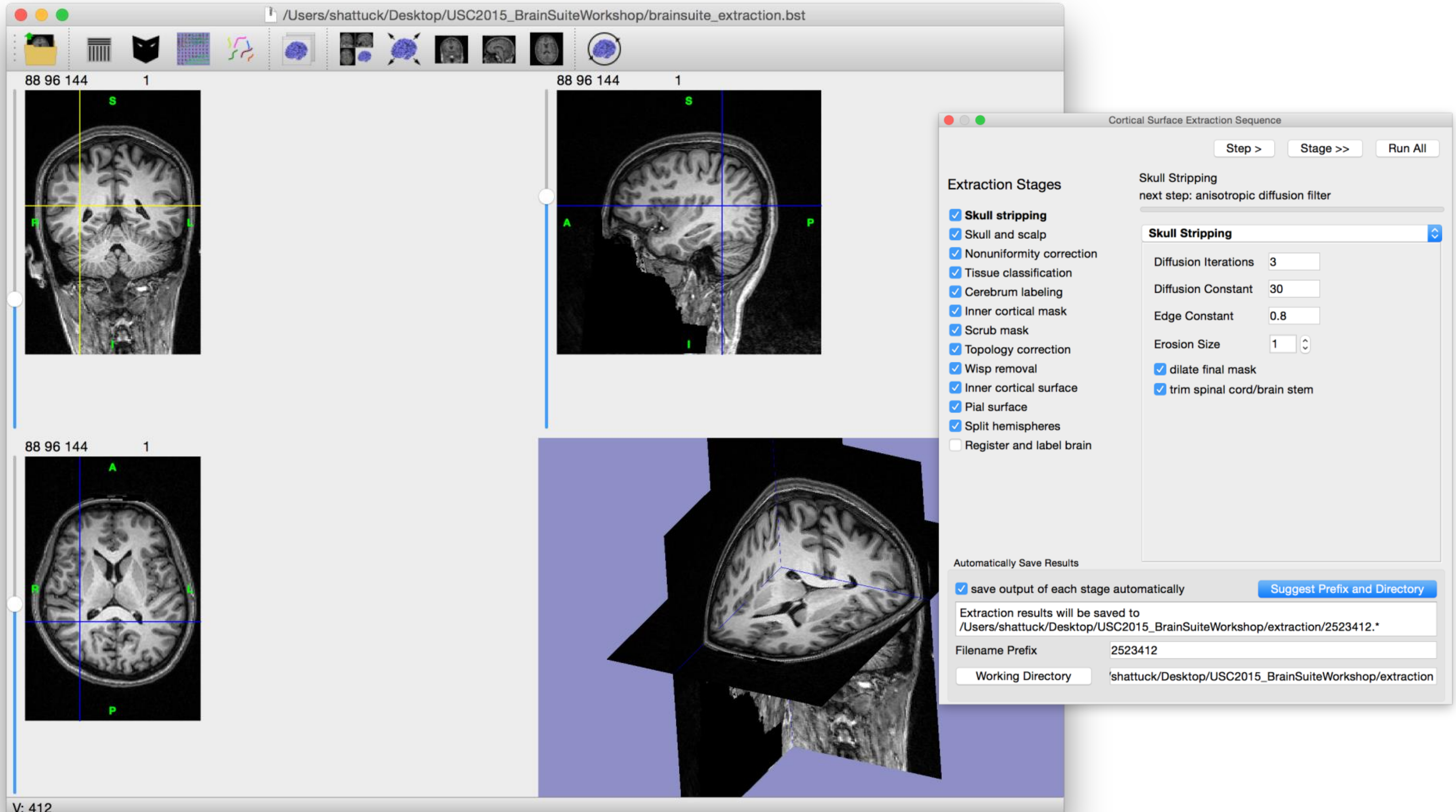
Extracting a Brain Surface

- Load the T1 image from the **extraction** folder* or drag brainsuite_extraction.bst onto BrainSuite.
- Open “Cortex -> Cortical Surface Extraction Sequence”
- Change the Skull Stripping parameters as follows:
  - Diffusion constant: 30
  - Edge constant: 0.80
  - These values will be automatically loaded if you use the .bst file

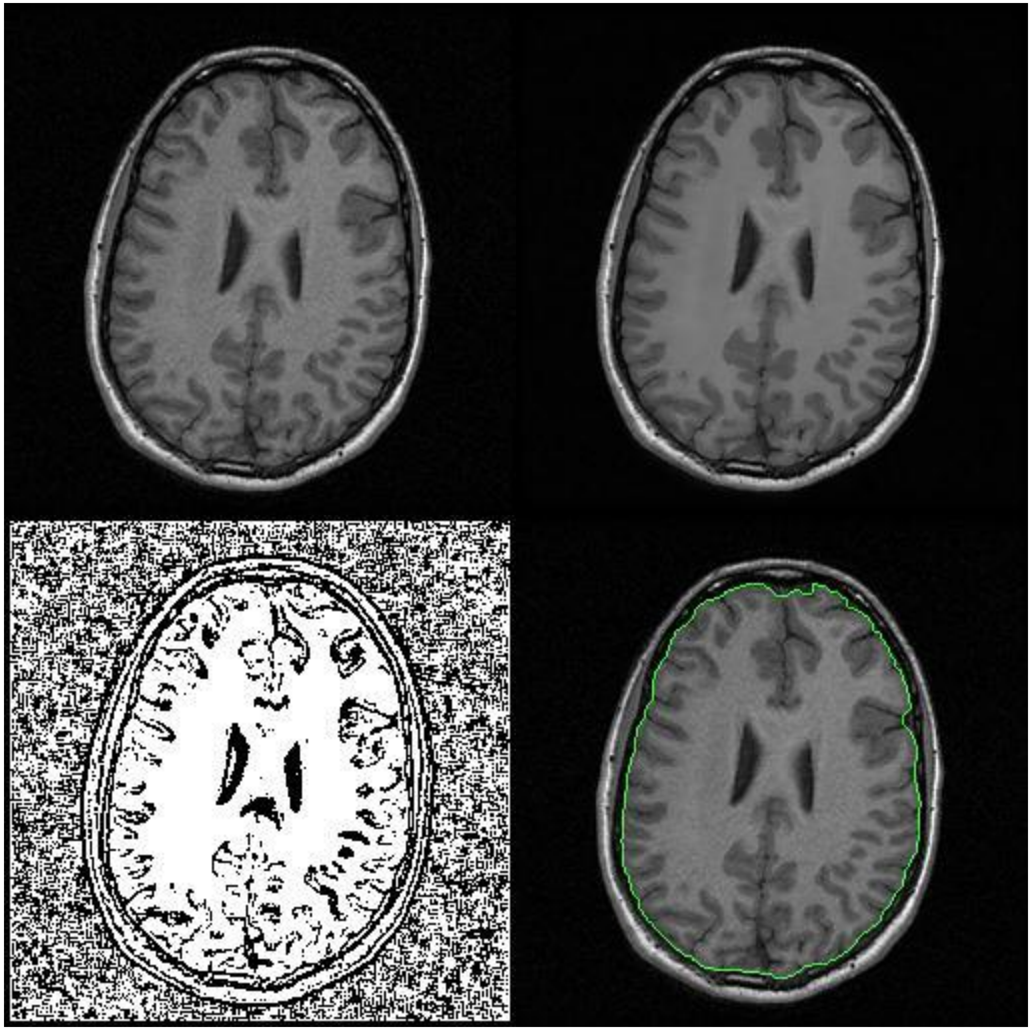


*By default, BrainSuite’s extraction dialog will write files to the same directory as the input image, so be sure to use the extraction folder rather than the structural folder, which contains pre-processed data.

Cortical Surface Extraction Dialog

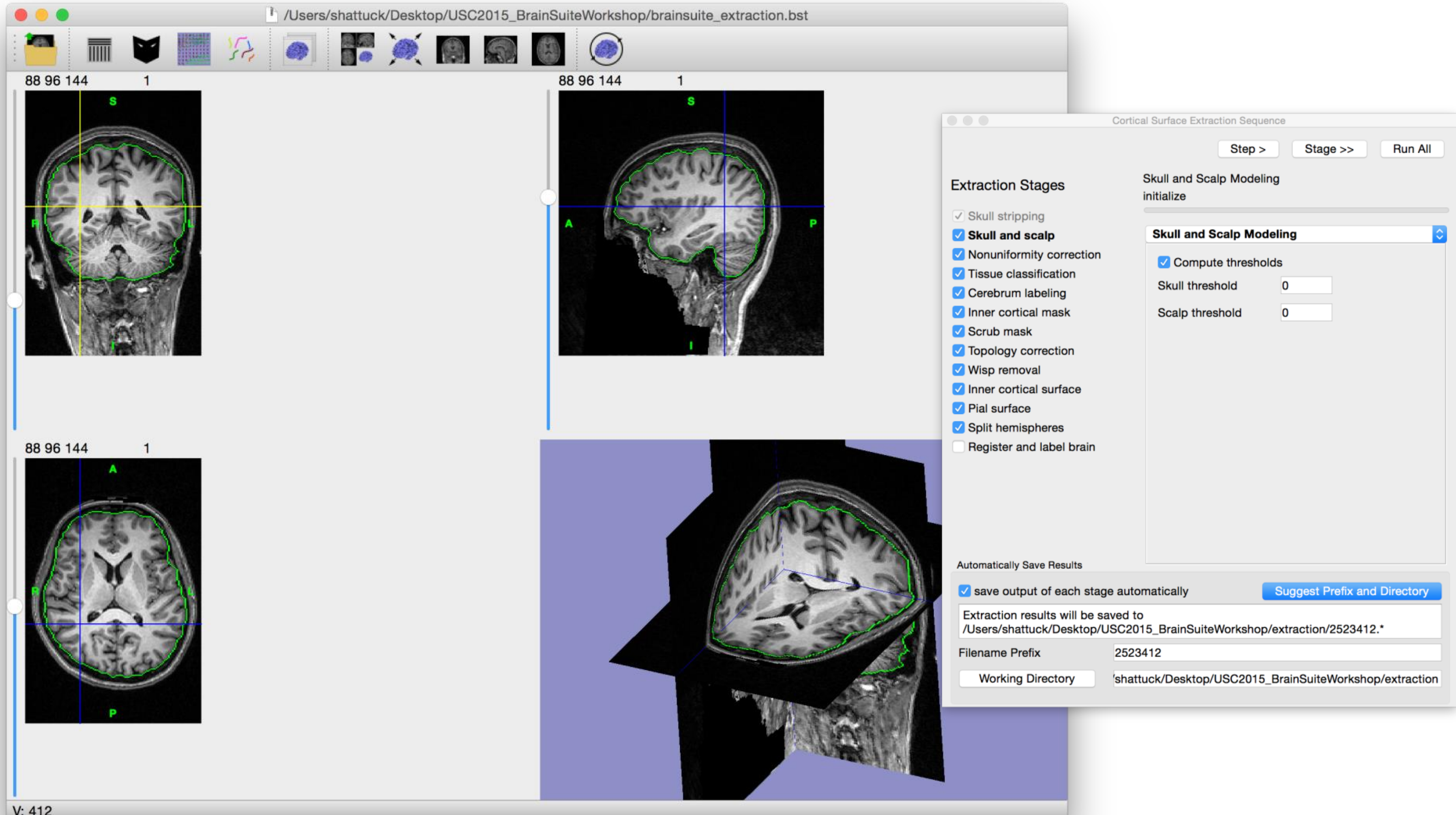


Skull Stripping



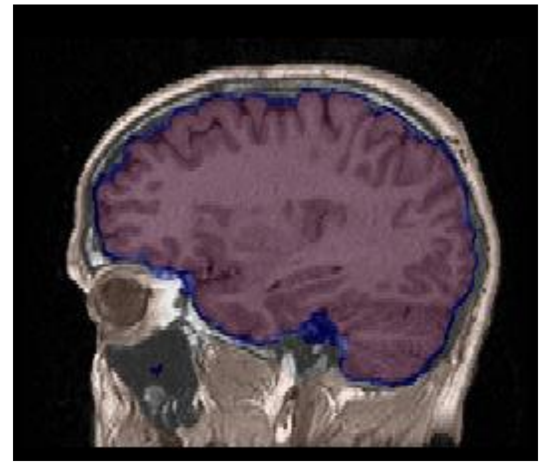
- Brain Surface Extractor (BSE) extracts the brain from non-brain tissue using a combination of:
  - anisotropic diffusion filtering
  - edge detection
  - mathematical morphological operators
- This method can rapidly identify the brain within the MRI

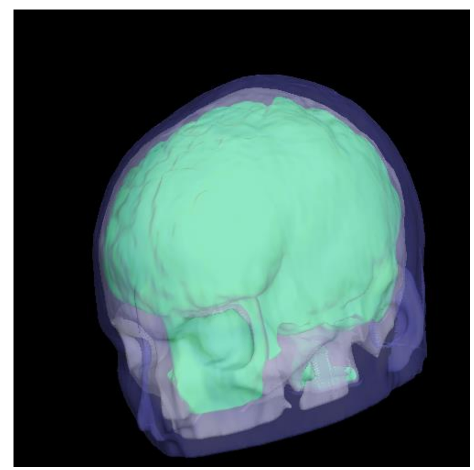
Skull-stripped Brain



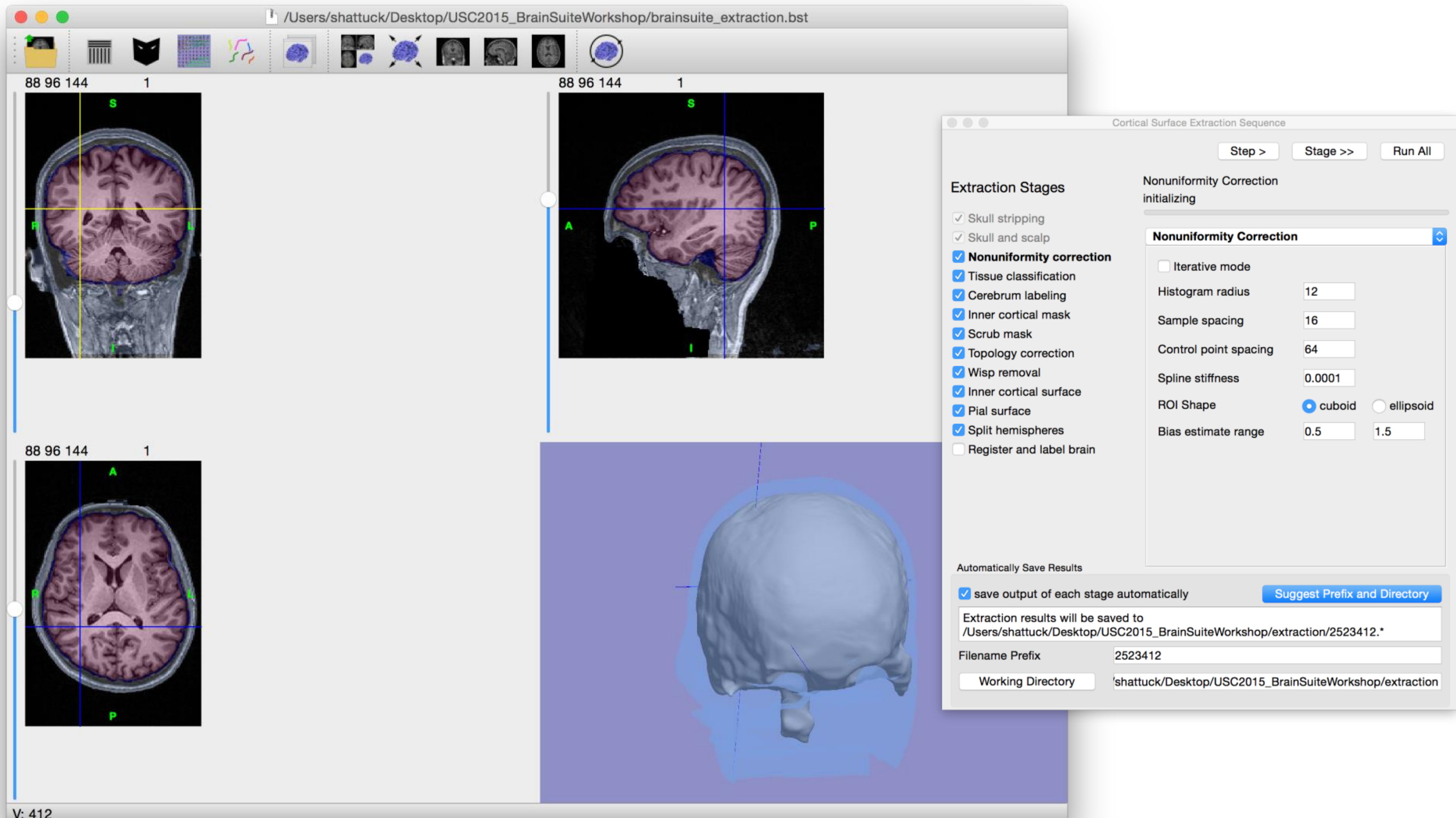
Skull and Scalp Modeling

- 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.

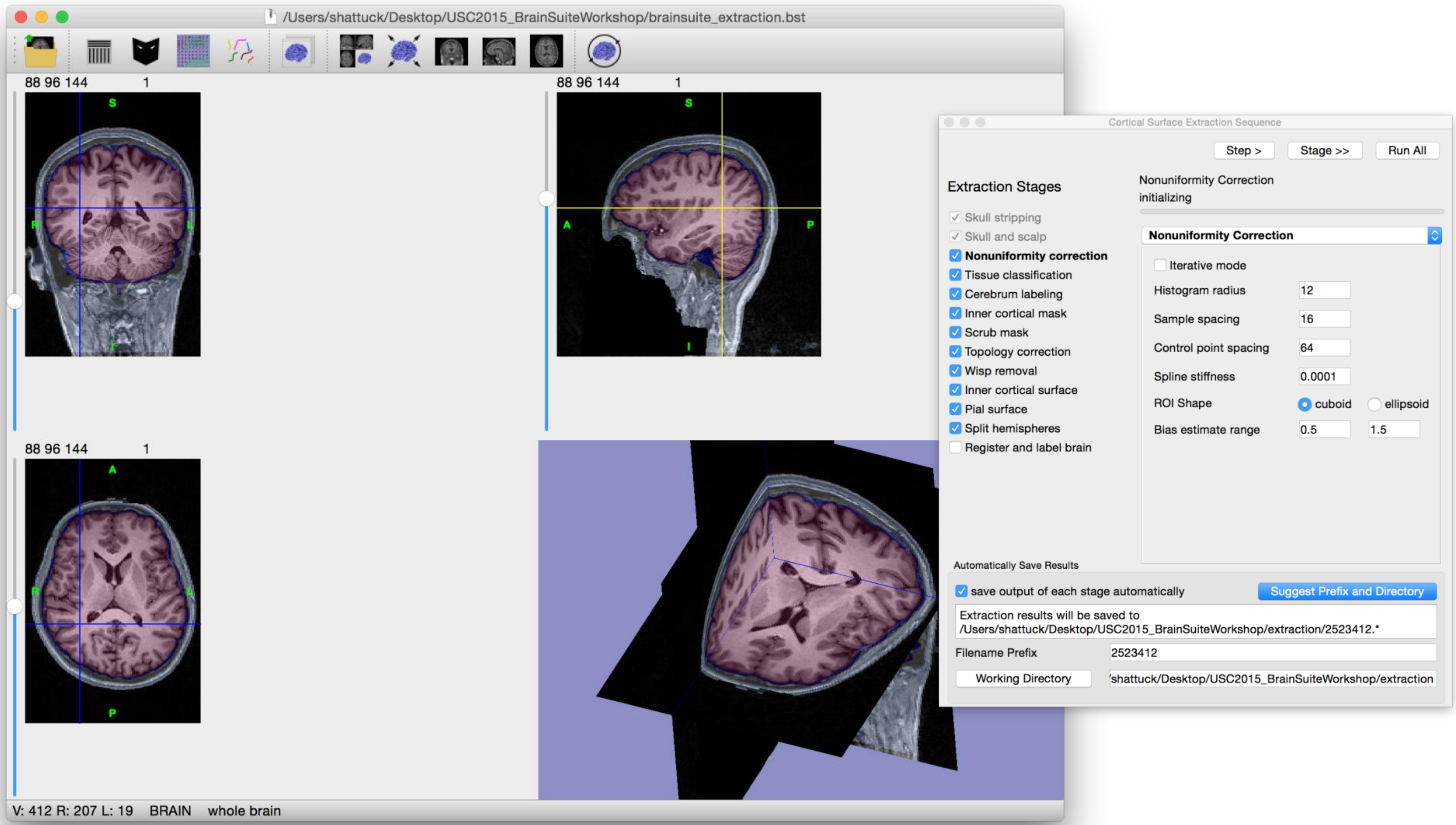




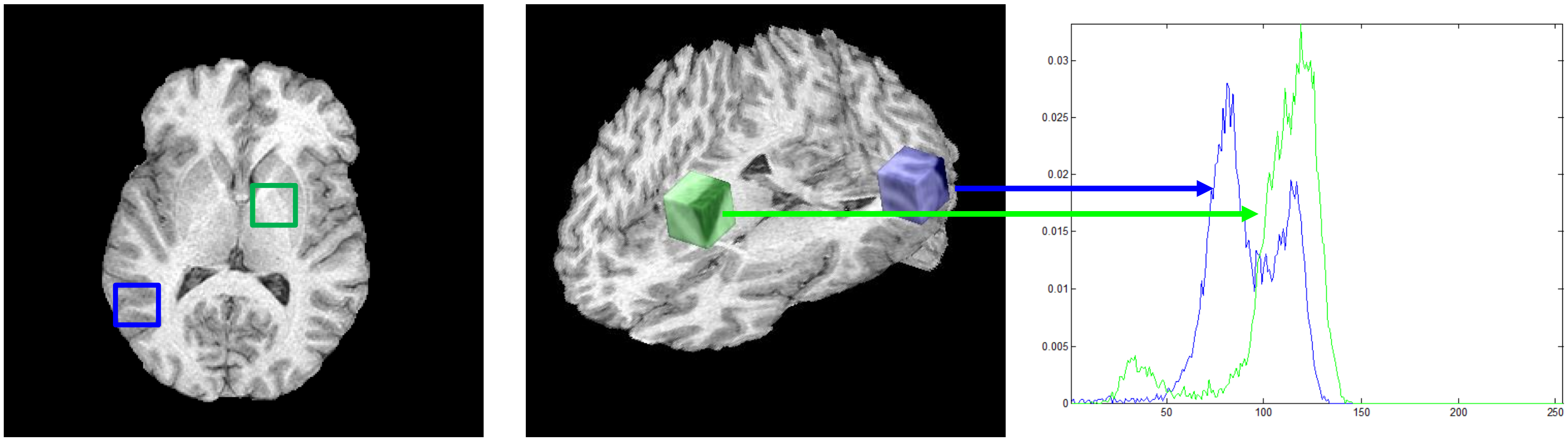
Skull & Scalp Models



Skull & Scalp Labels



Nonuniformity Correction



Two cubic regions ROIs

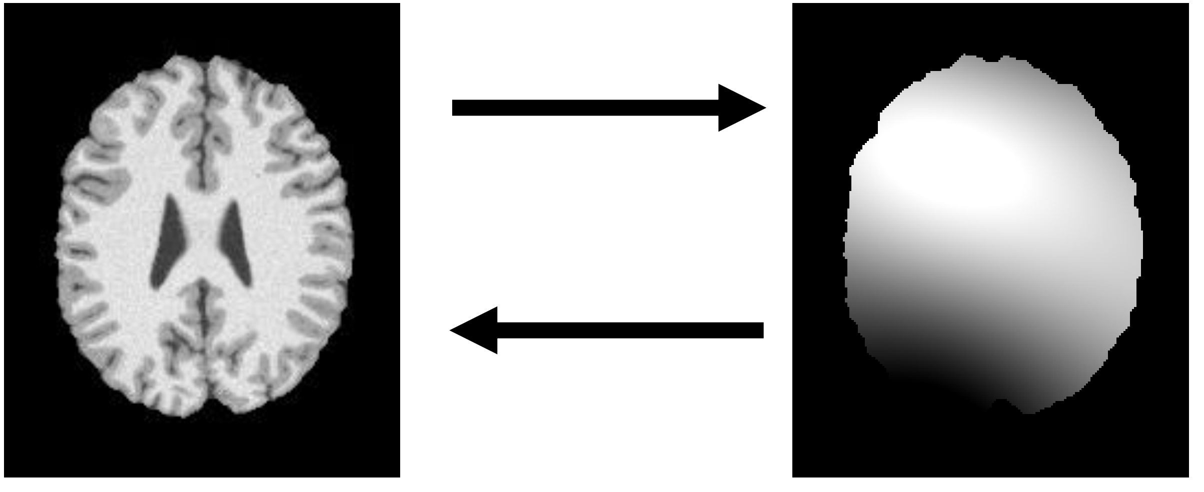
3D rendering of the ROIs

Histograms of the two ROIs

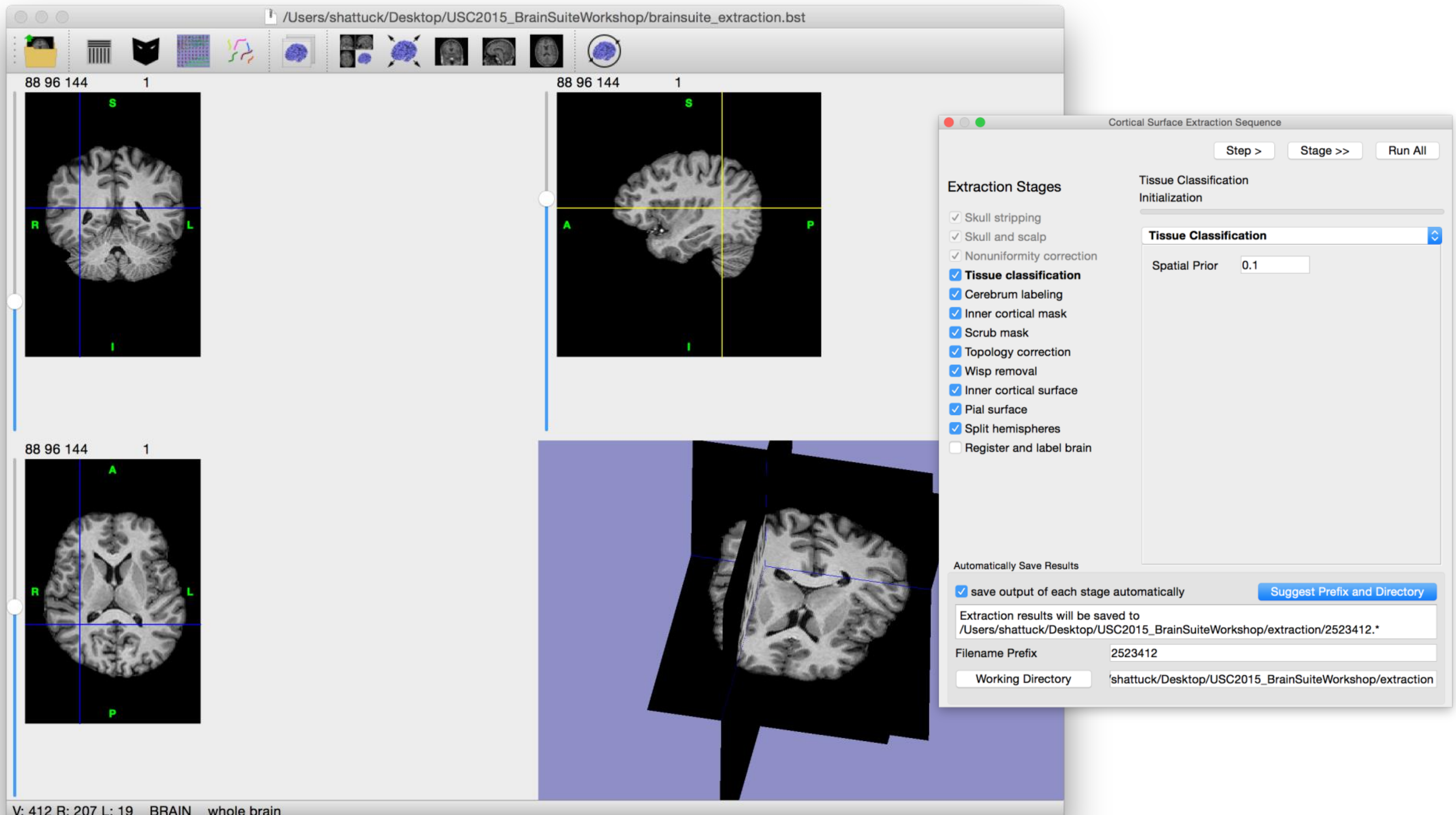
- Nonuniform signal gain can confound tissue classification techniques
- Bias Field Corrector (BFC) performs nonuniformity correction by analyzing the intensity profiles of regions of interest (ROIs)
- We can fit a histogram model to these ROIs and estimate the local gain variation

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.

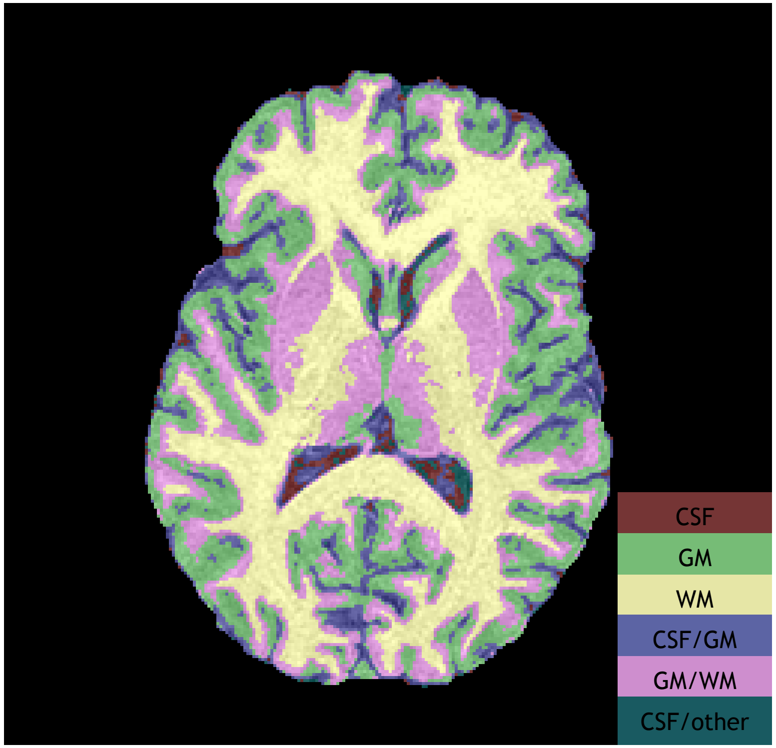


Bias-corrected Image

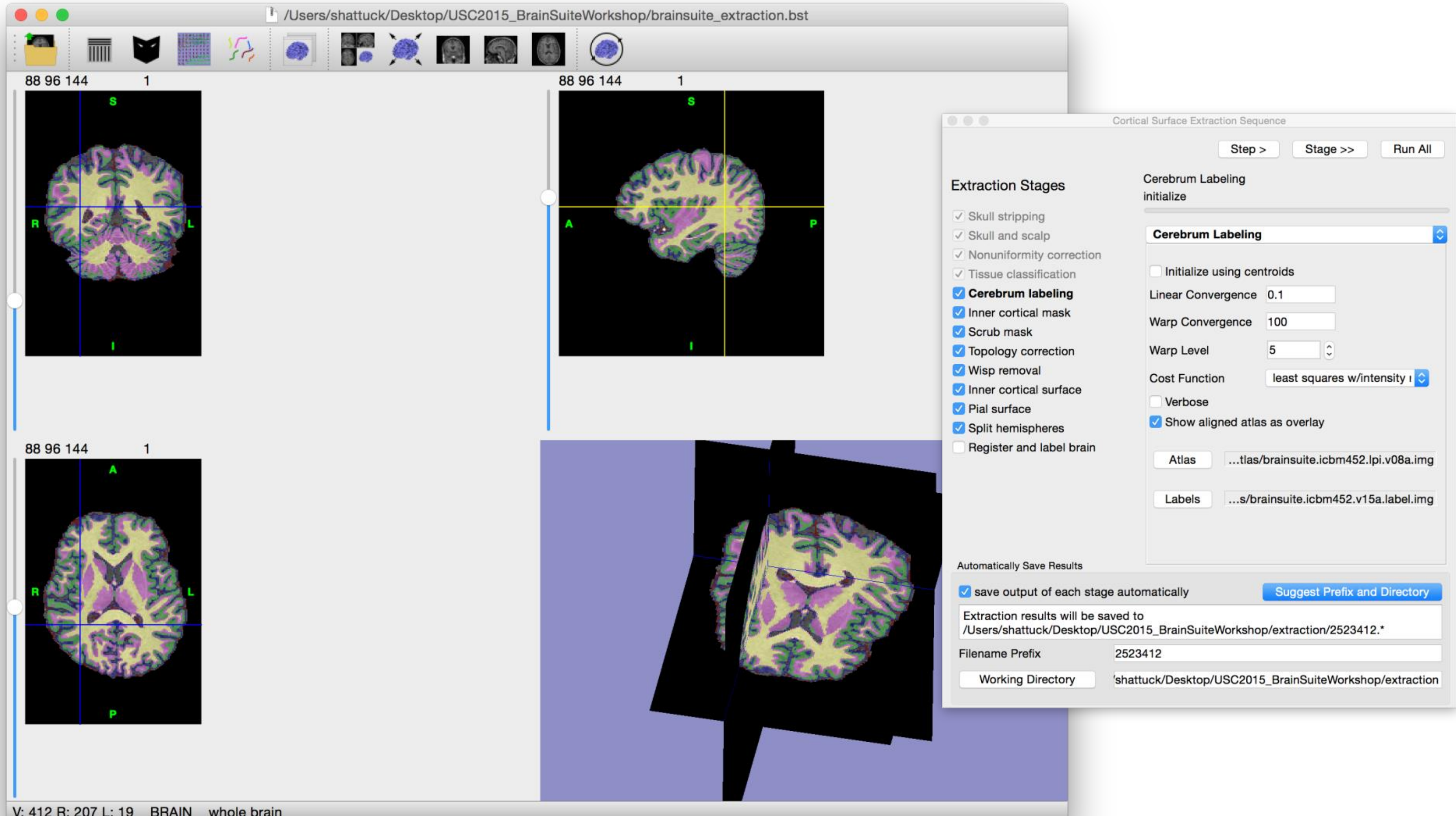


Tissue Classification

- 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



Tissue Class Labeling

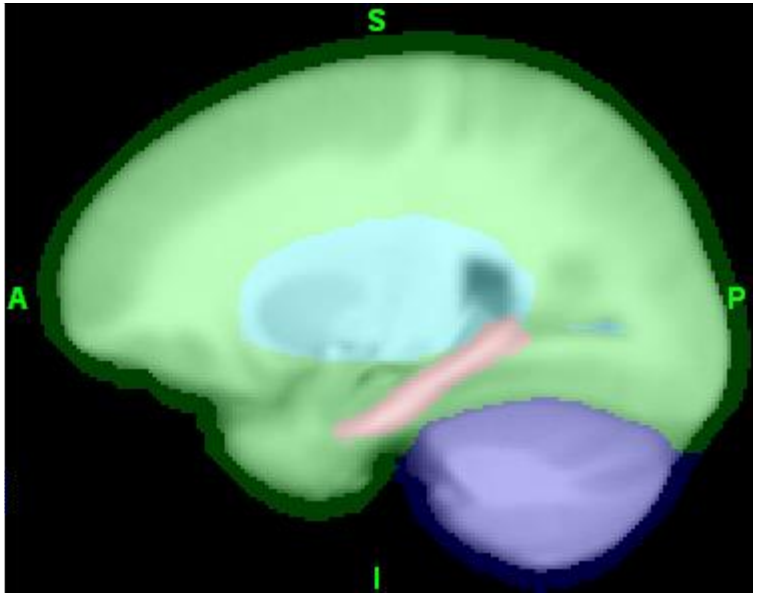


Cerebrum Labeling

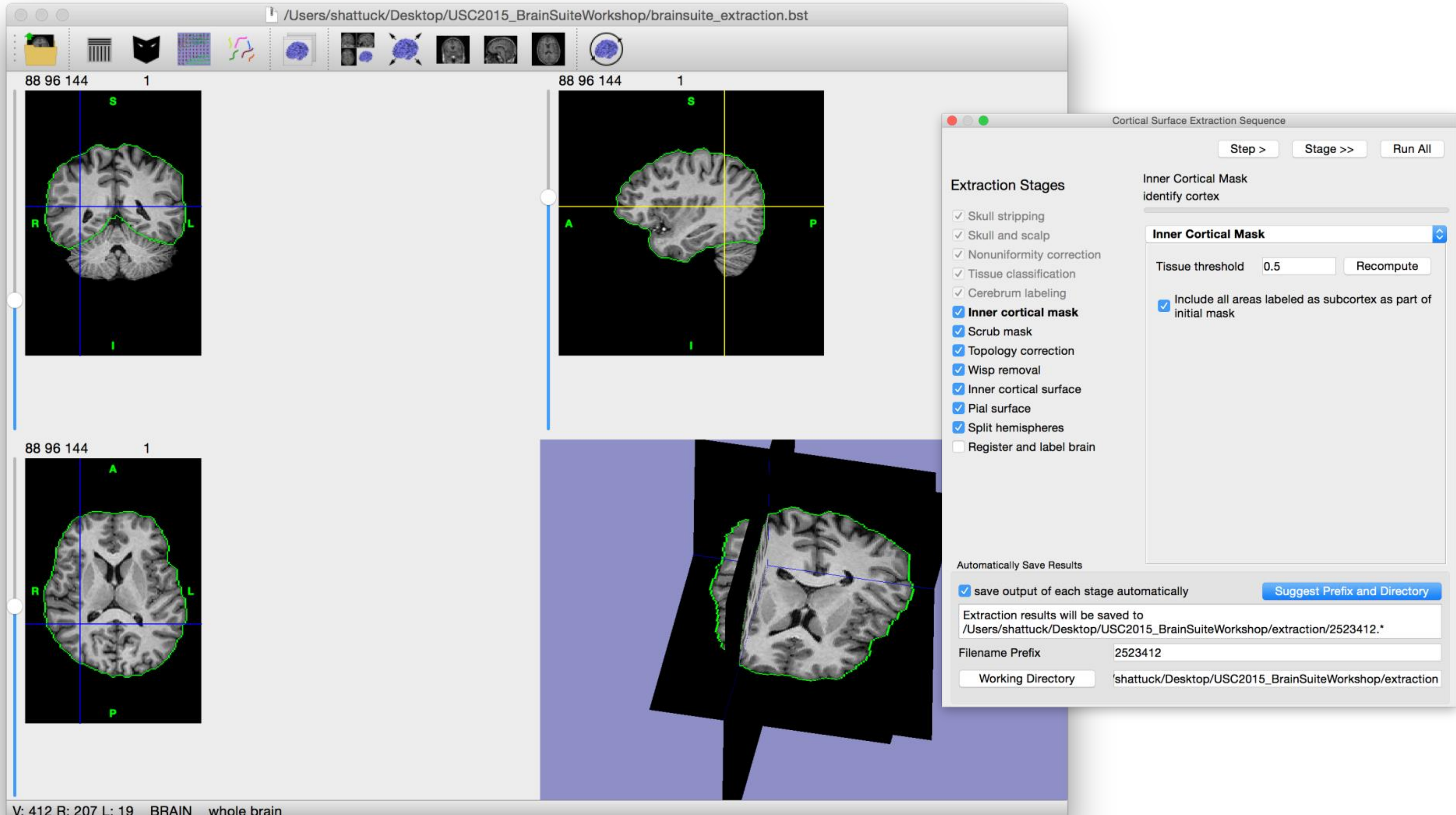
- For the cortical surface, we are interested in the cerebrum, which we separate from the rest of the brain.

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

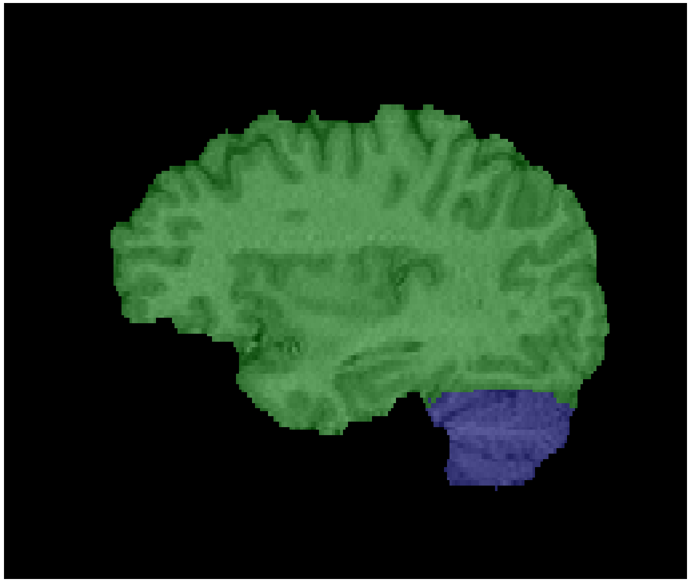
- We have labeled this atlas:
  - cerebrum / cerebellum
  - subcortical regions
  - left / right hemispheres

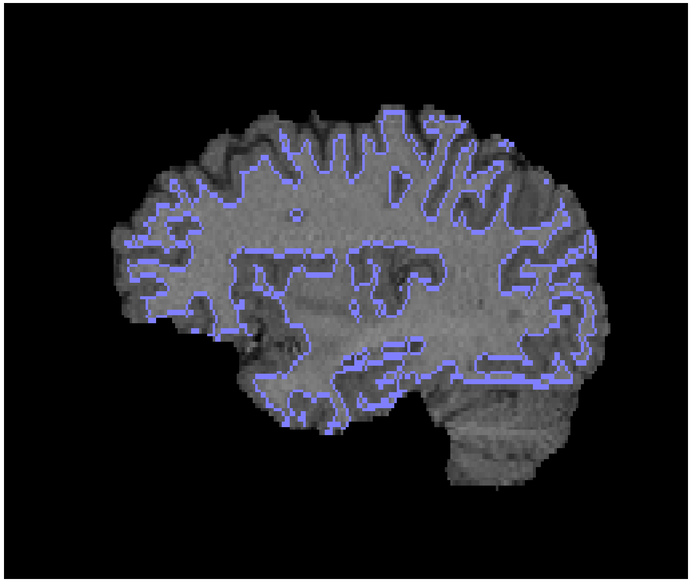


Inner Cortical Mask



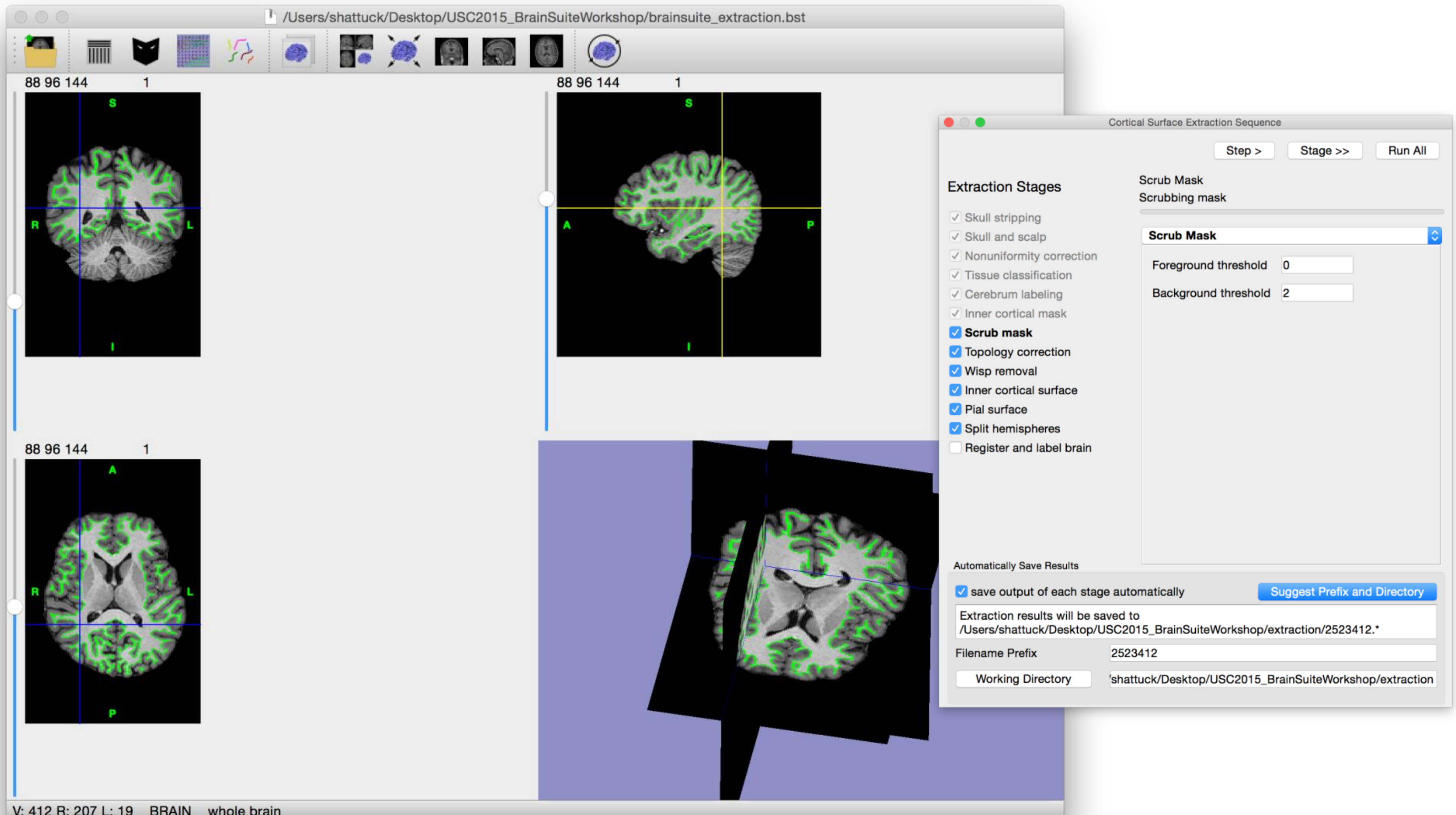
Inner Cortical Mask





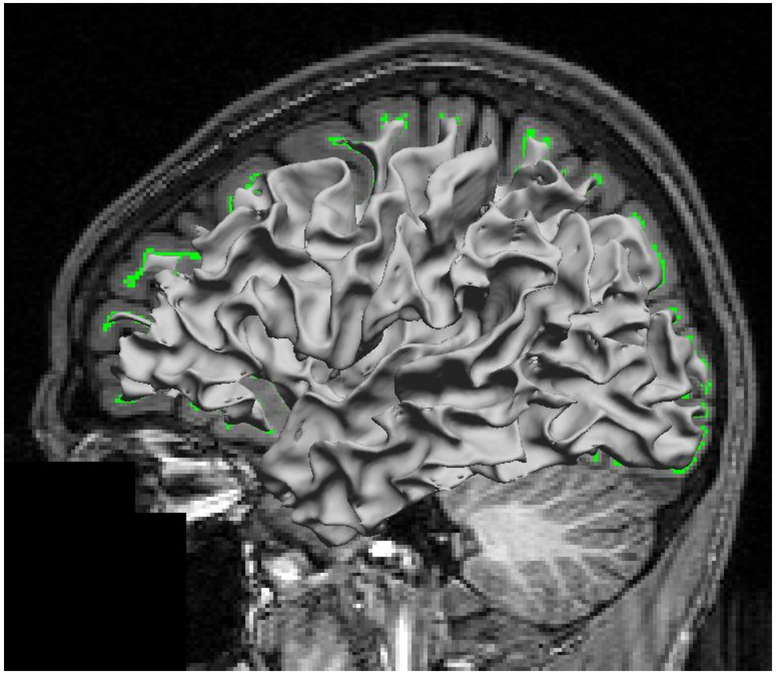
- We combine our registered brain atlas with our tissue map
  - Retain subcortical structures, including nuclei
  - Identify the inner boundary of the cerebral cortex

Inner Cortical Mask



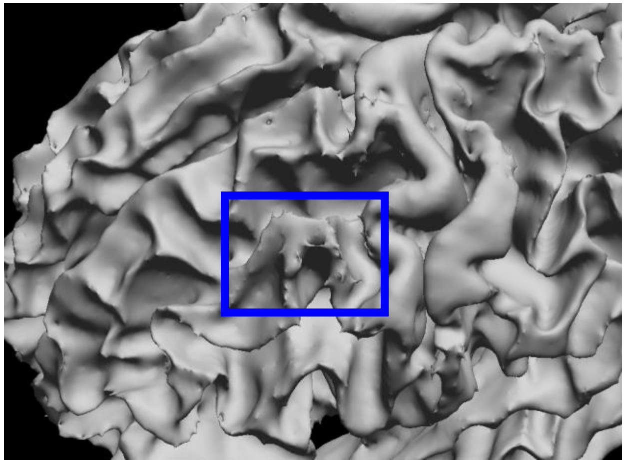
Surface Generation

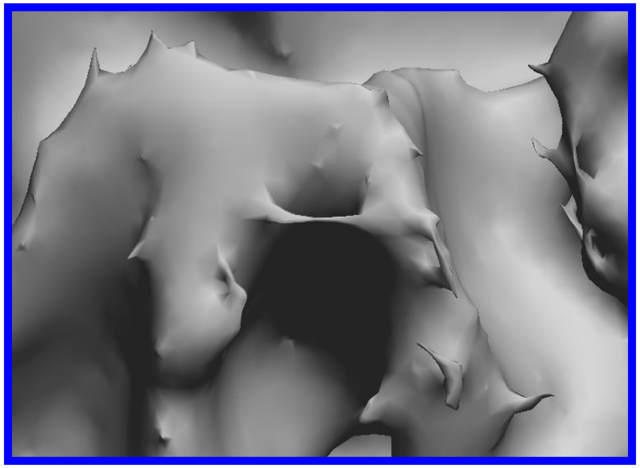
By applying a tessellation algorithm, we can generate a surface mesh from a 3D volume.



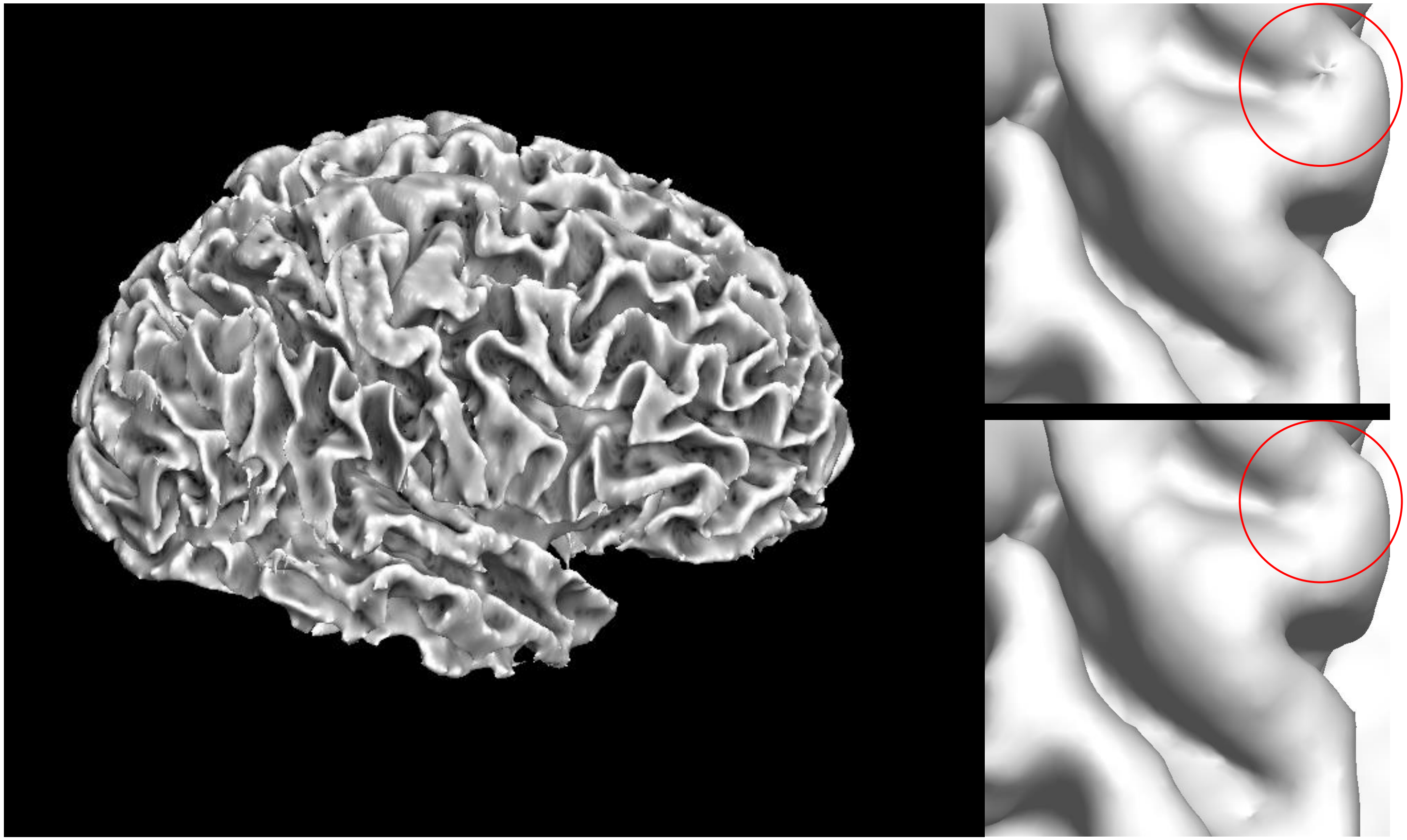
Topological Errors

- 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

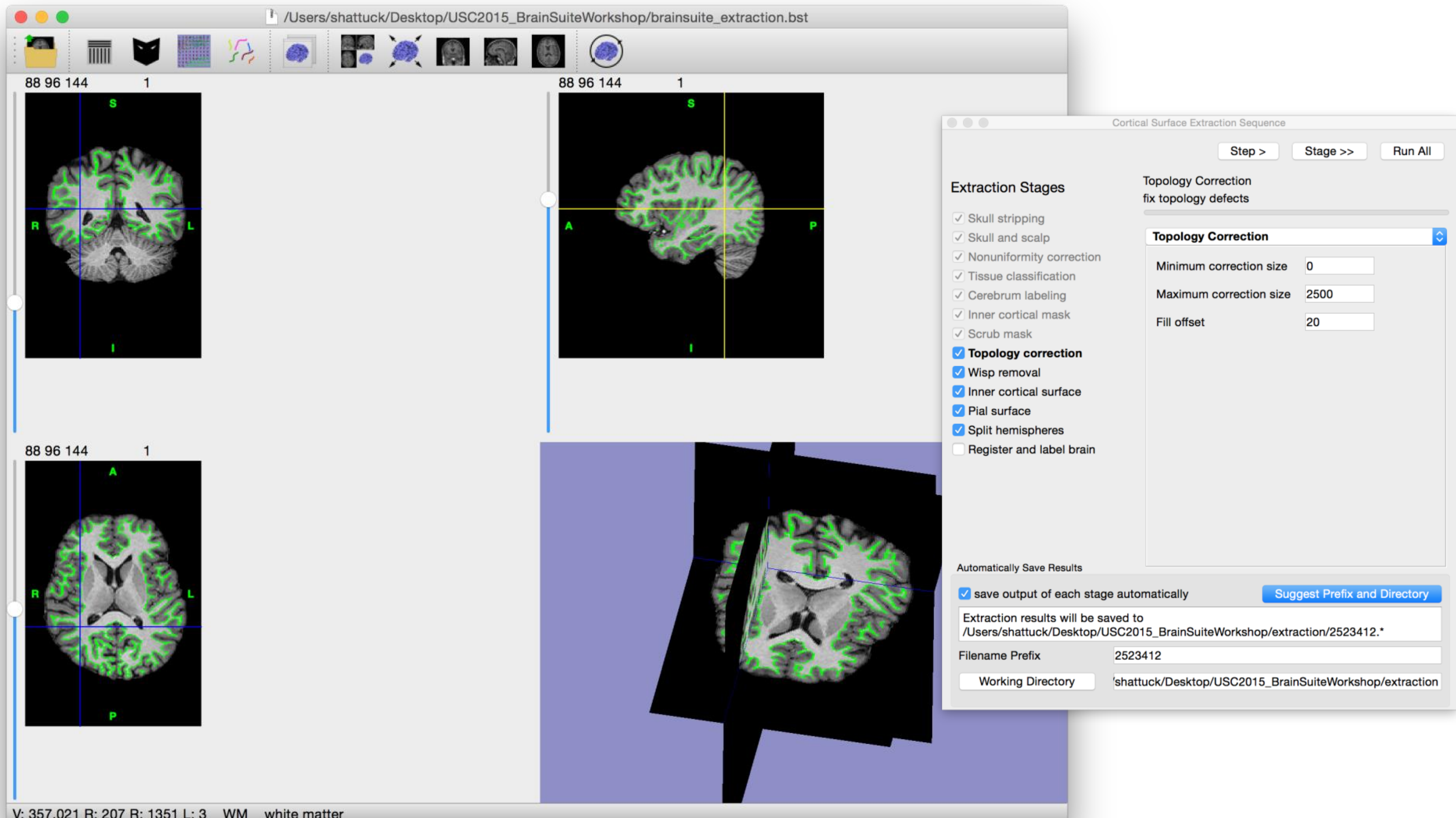


(left) cortical surface model produced from binary masks

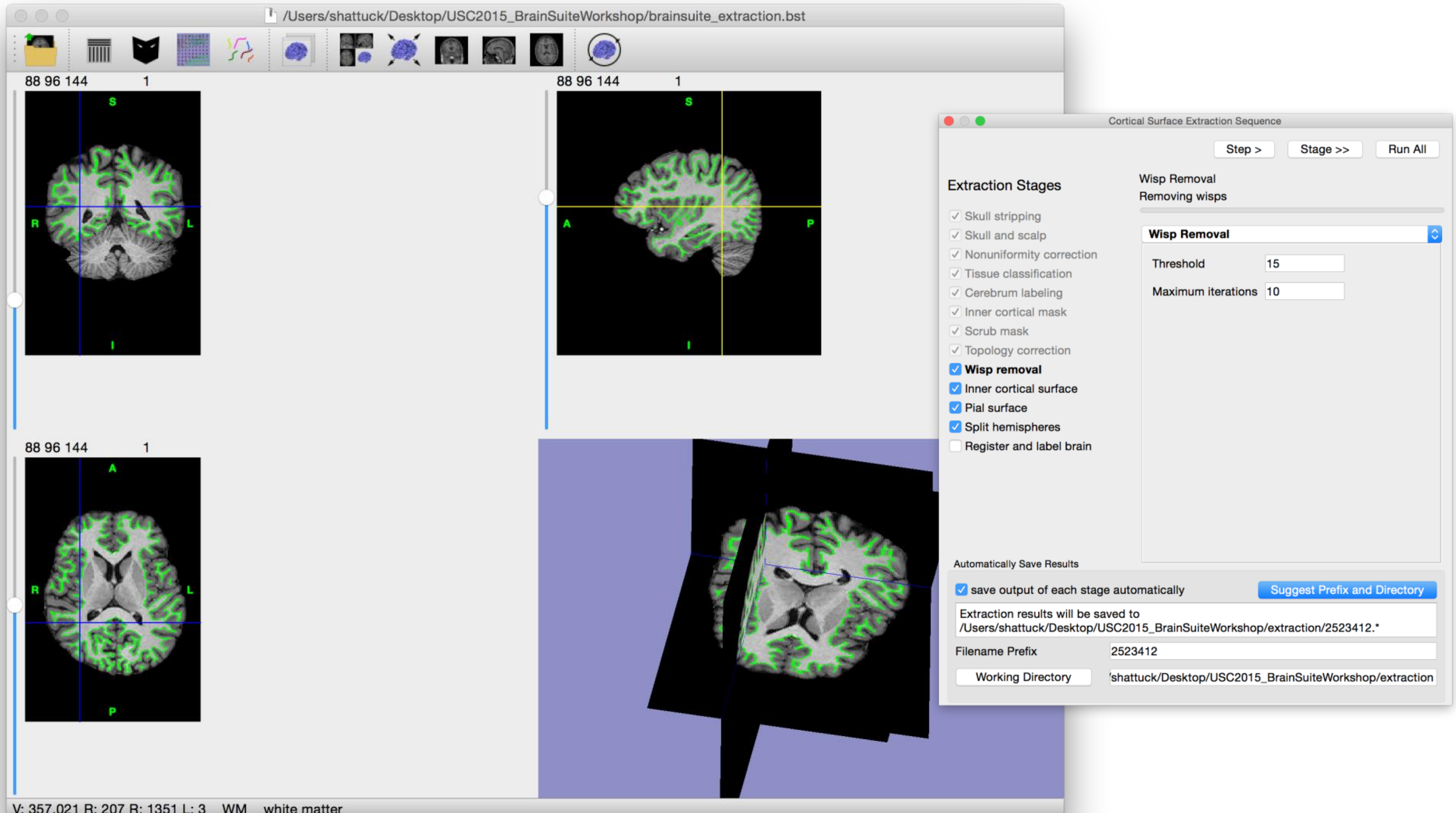
(top right) close-up view of a handle on the surface generated from the volume before topological correction

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

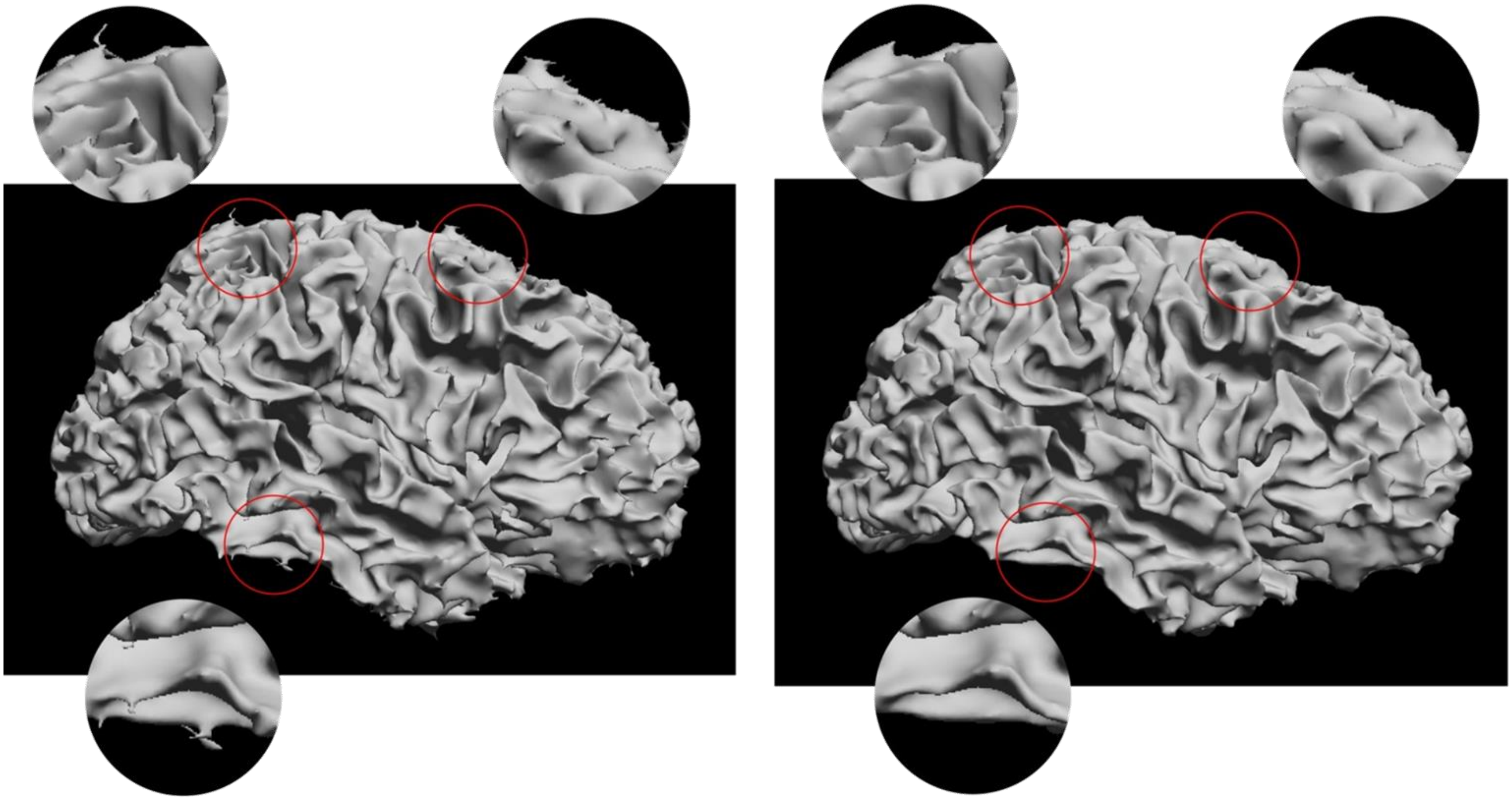
Scrubbed Mask



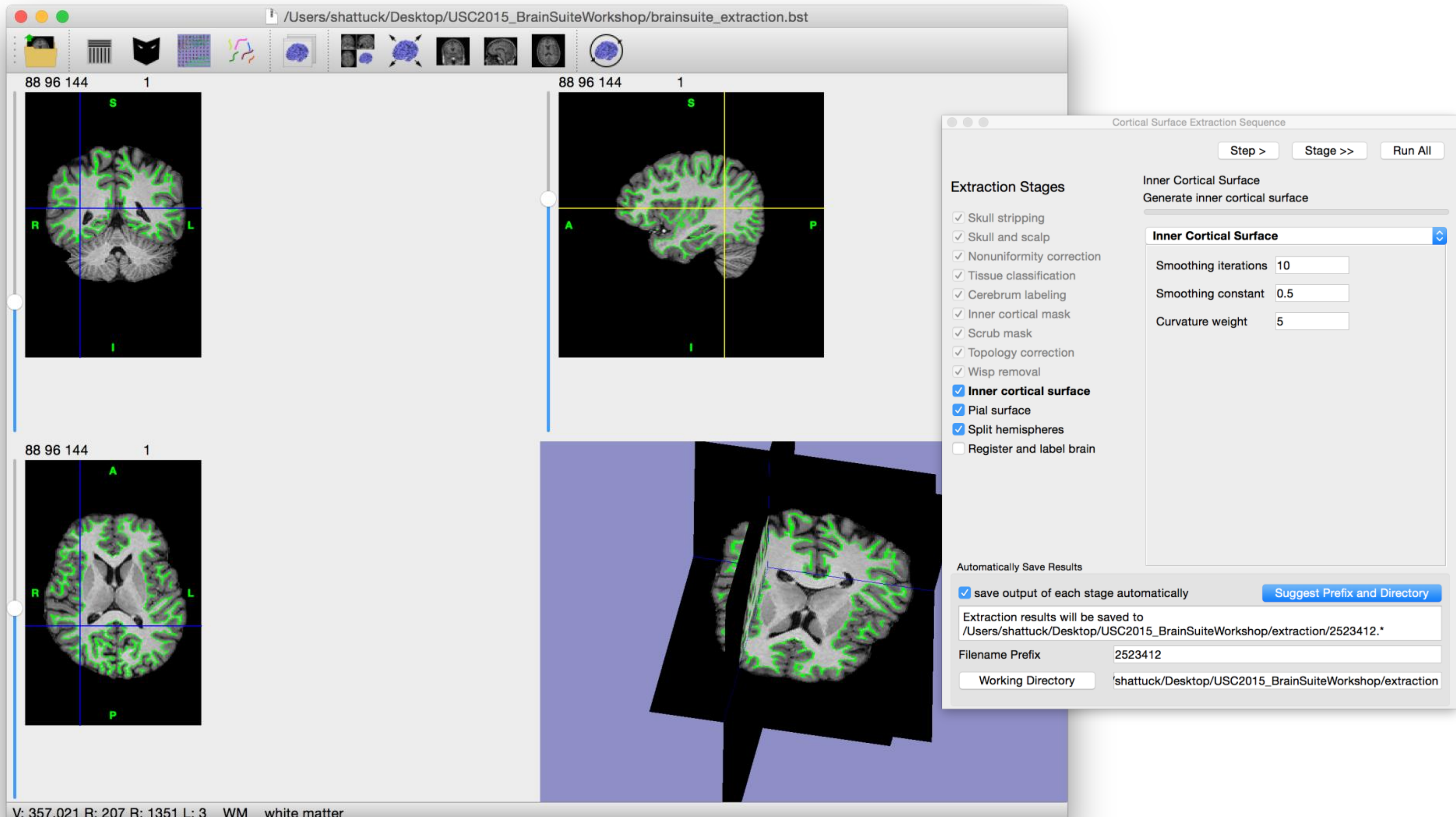
Topology-corrected Mask



Wisp Removal

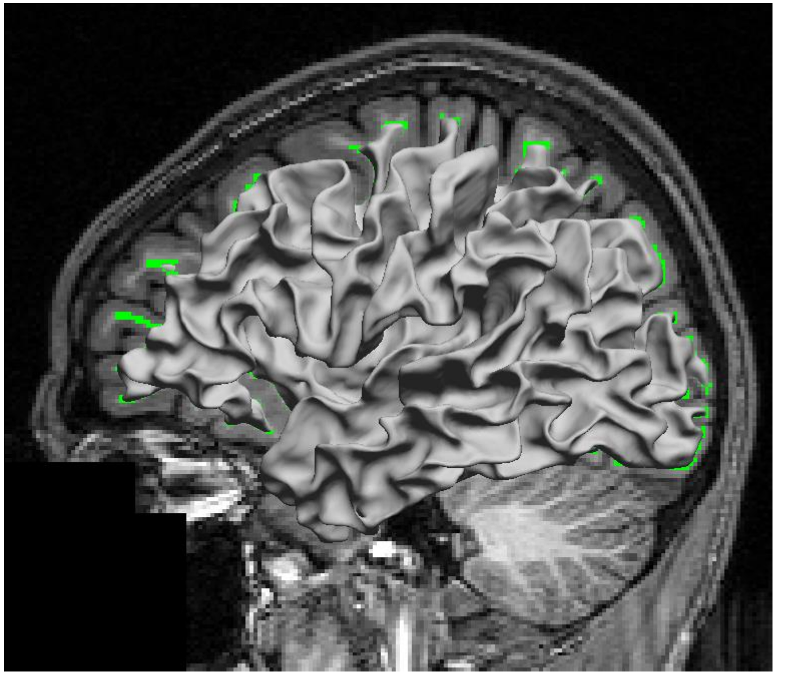


Final Inner Cortex Mask

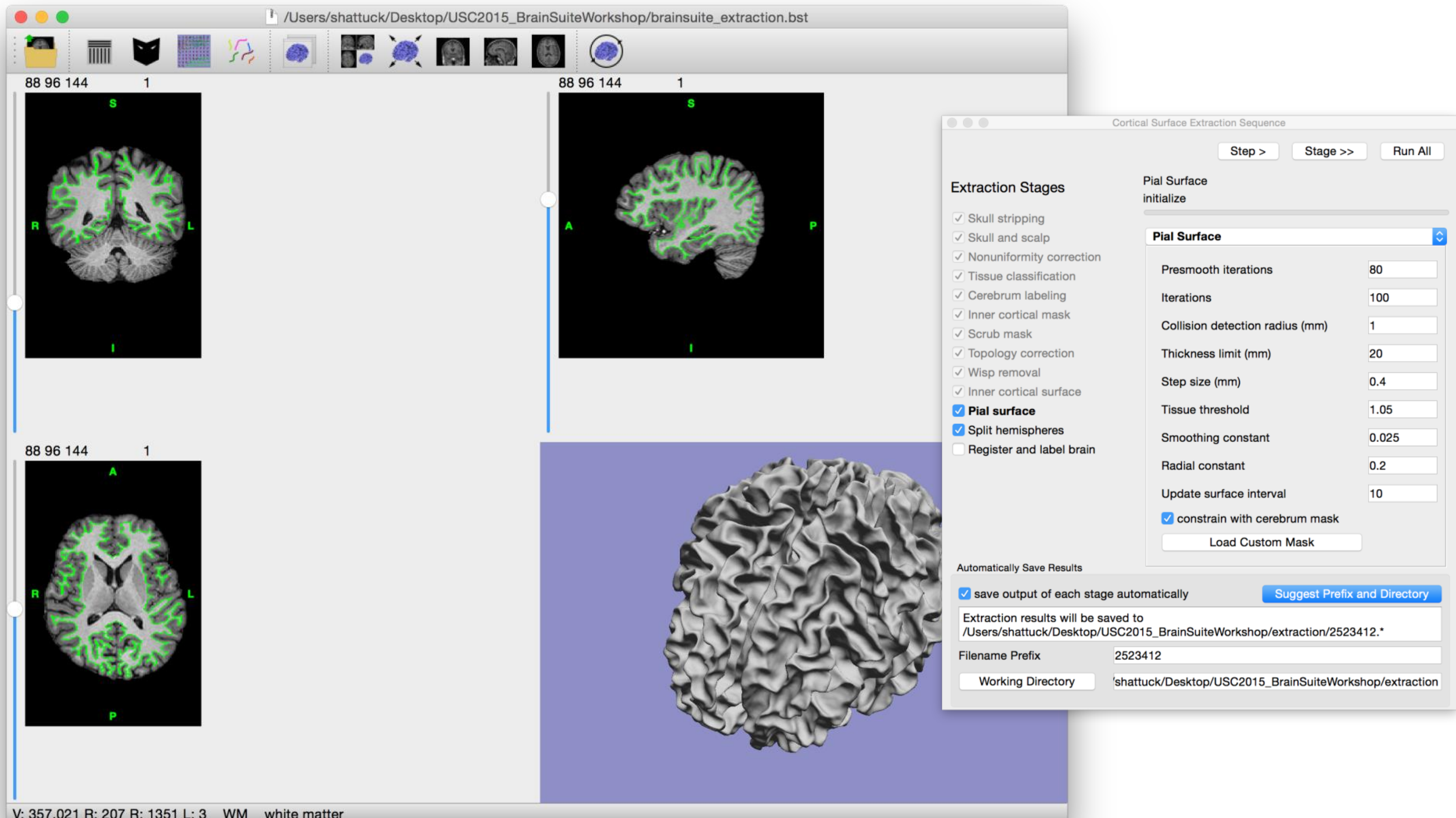


Inner Cortical Surface

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



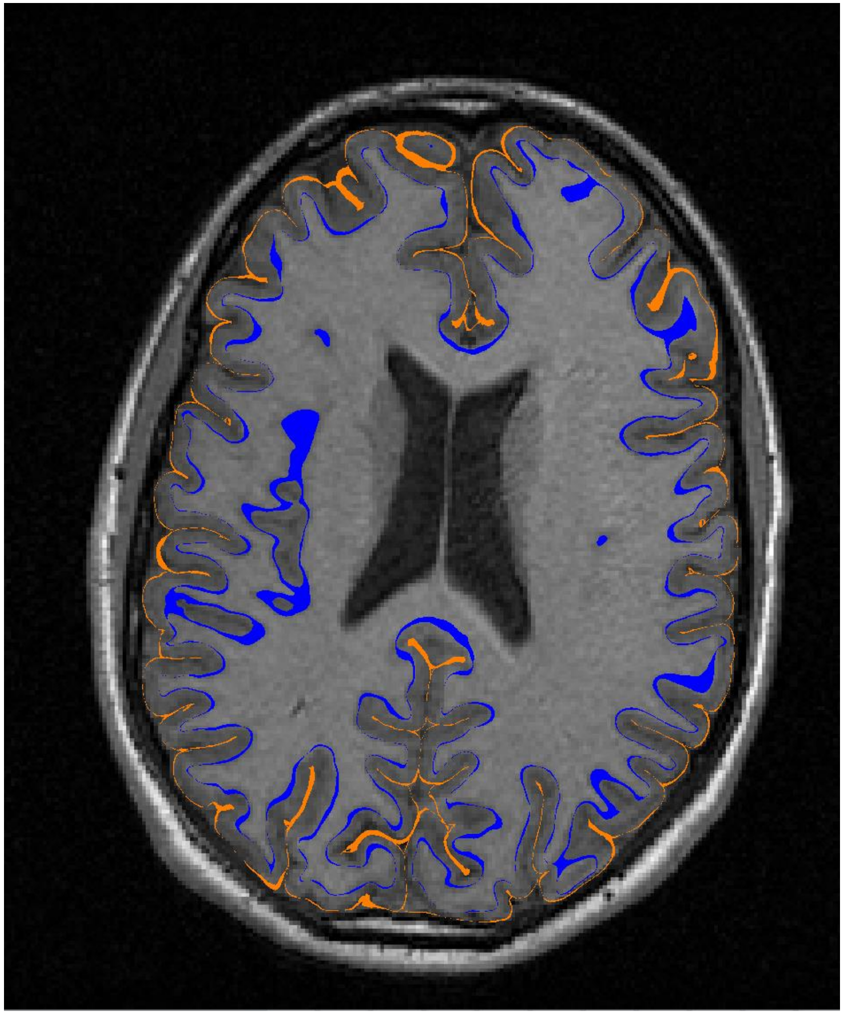
Inner Cortical Surface



Pial Surface

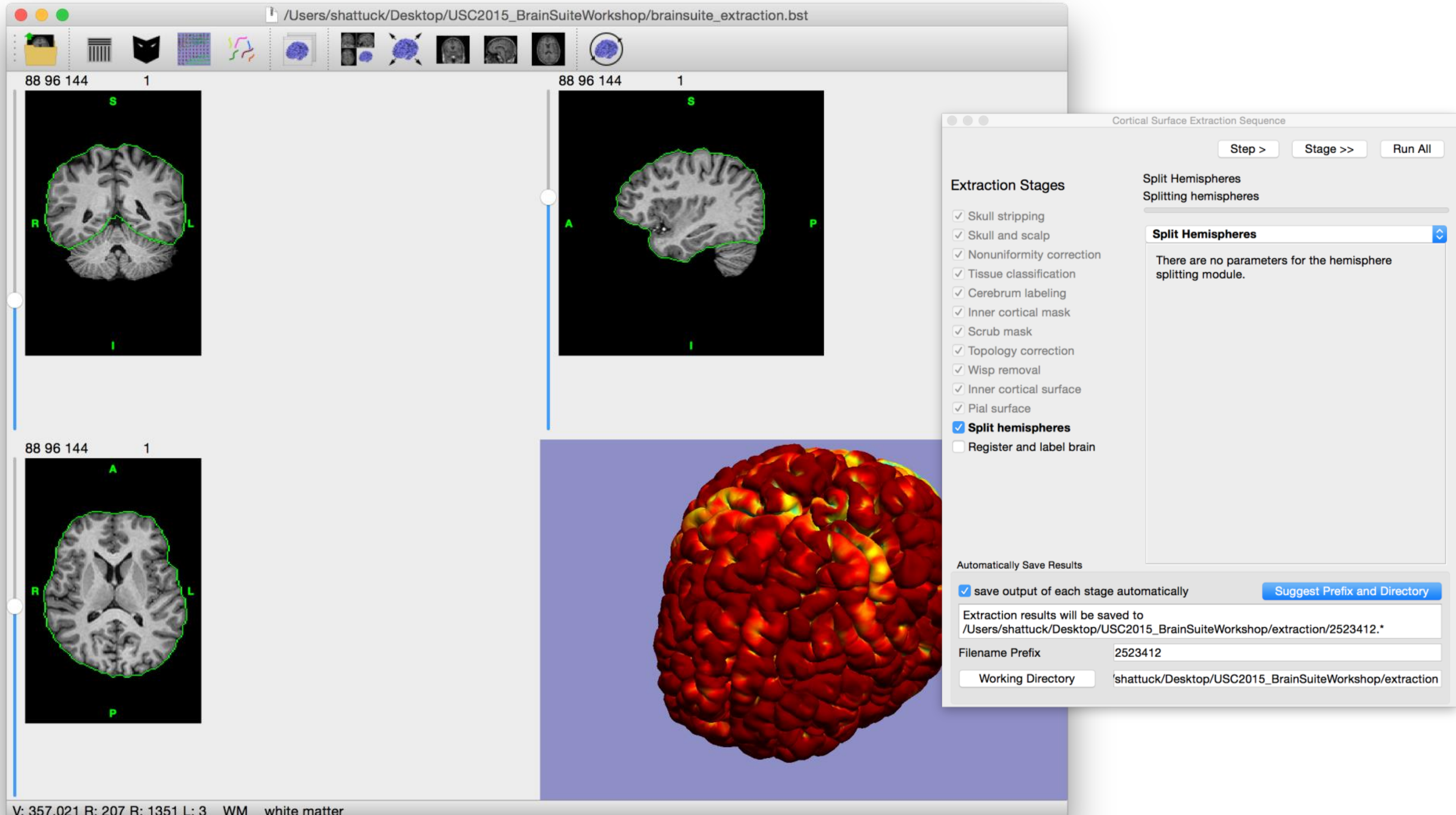
- Expand inner cortex to outer boundary
- Produces a surface with 1-1 vertex correspondence from GM/WM to GM/CSF
  - Preserves the surface topology
  - Provides direct thickness computation
  - Data from each surface maps directly to the other

Pial Surface



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

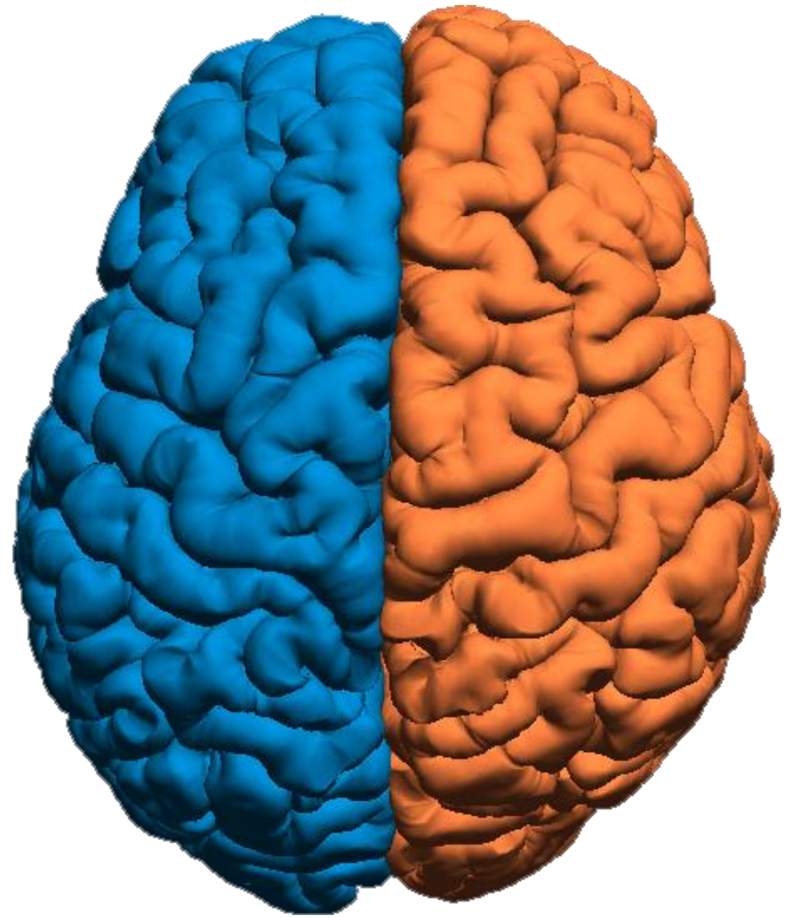
Pial Surface



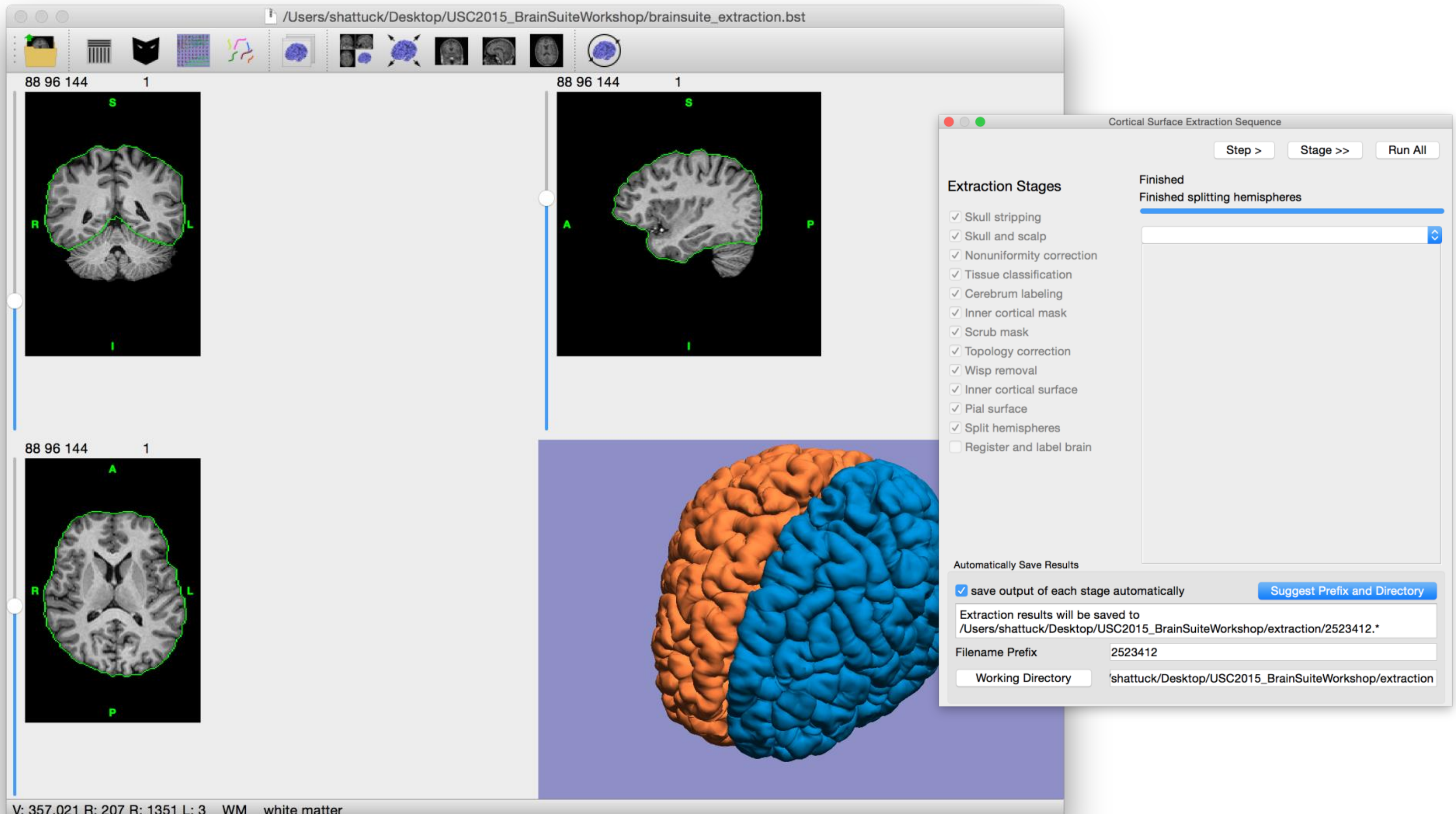
Split Hemispheres

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

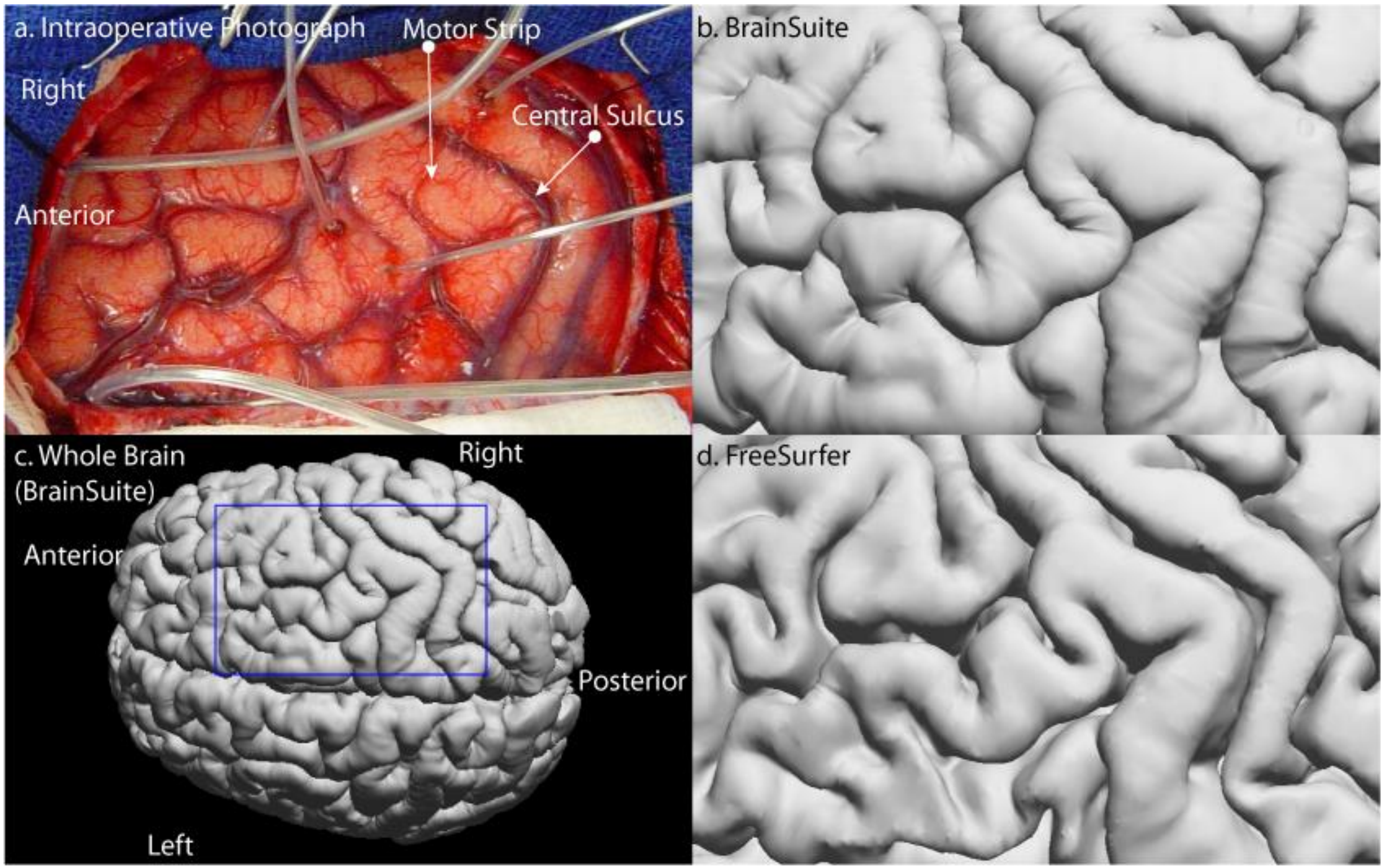
These surface models are then used by the surface/volume registration and labeling routine (SVReg)



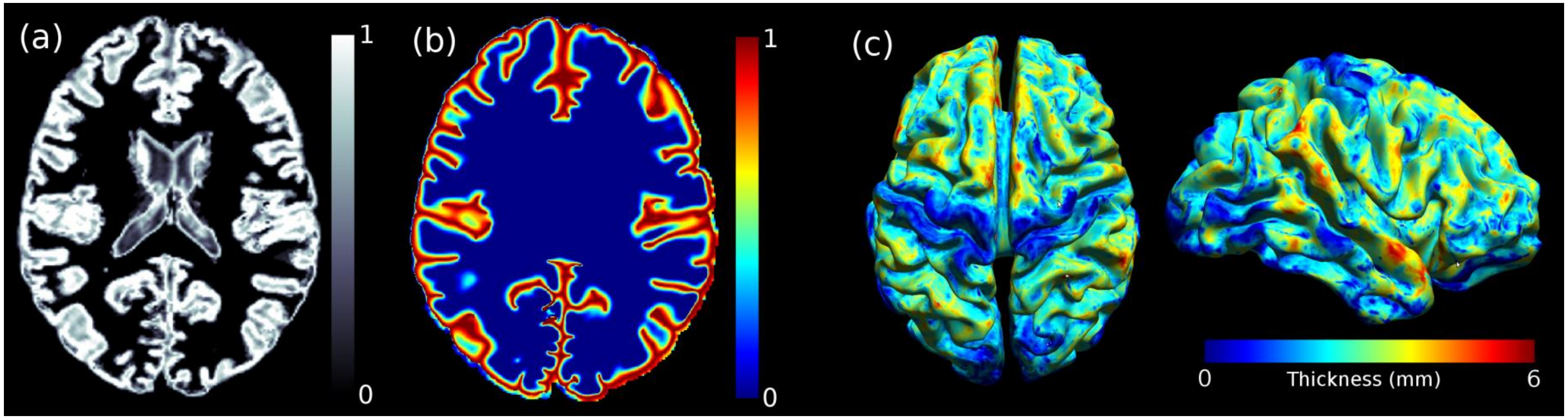
Split Hemispheres



Automated Surfaces vs Intraoperative Photograph

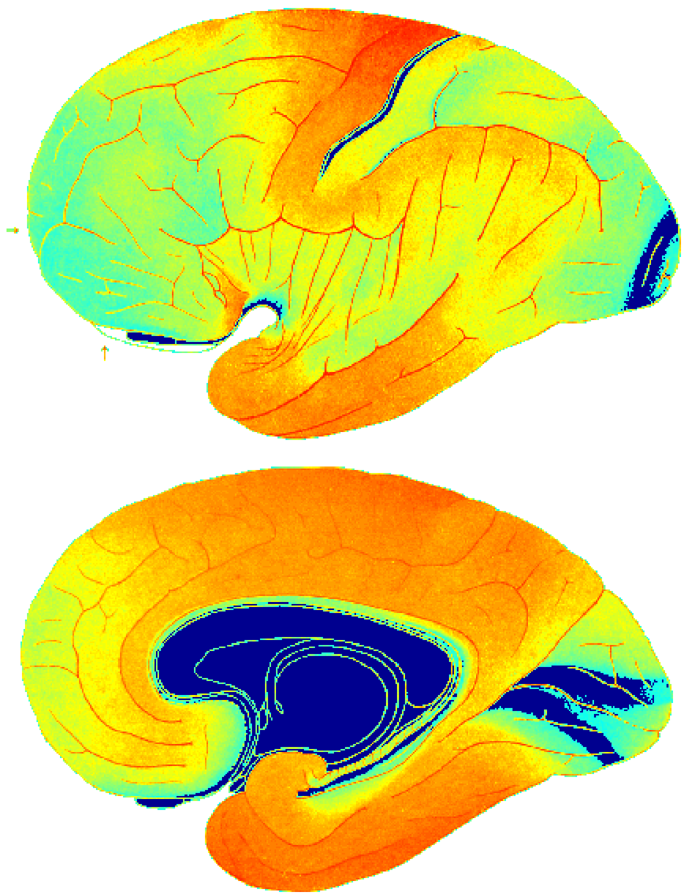


Cortical Thickness using Partial Tissue Fraction Estimates

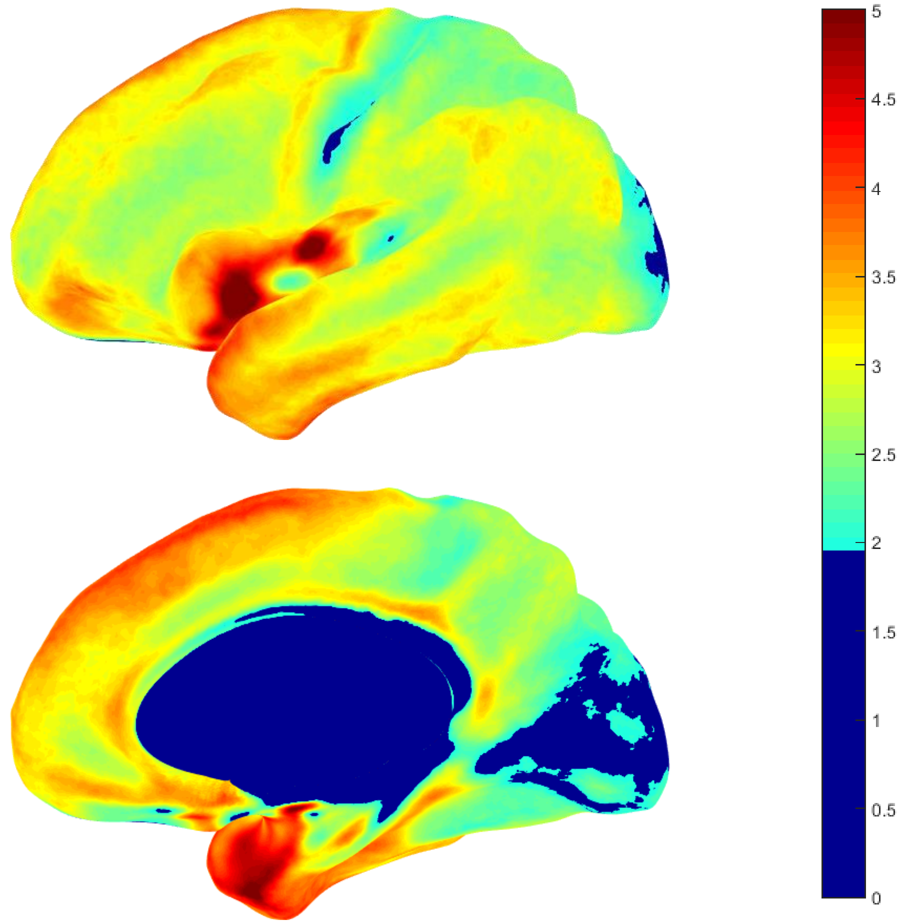


(a) Gray-matter fraction estimated using a partial volume model;
(b) Temperature map obtained using the proposed ALE method; and
(c) Thickness estimate using the ALE method shown on the estimated mid-cortical surface.

Comparisons

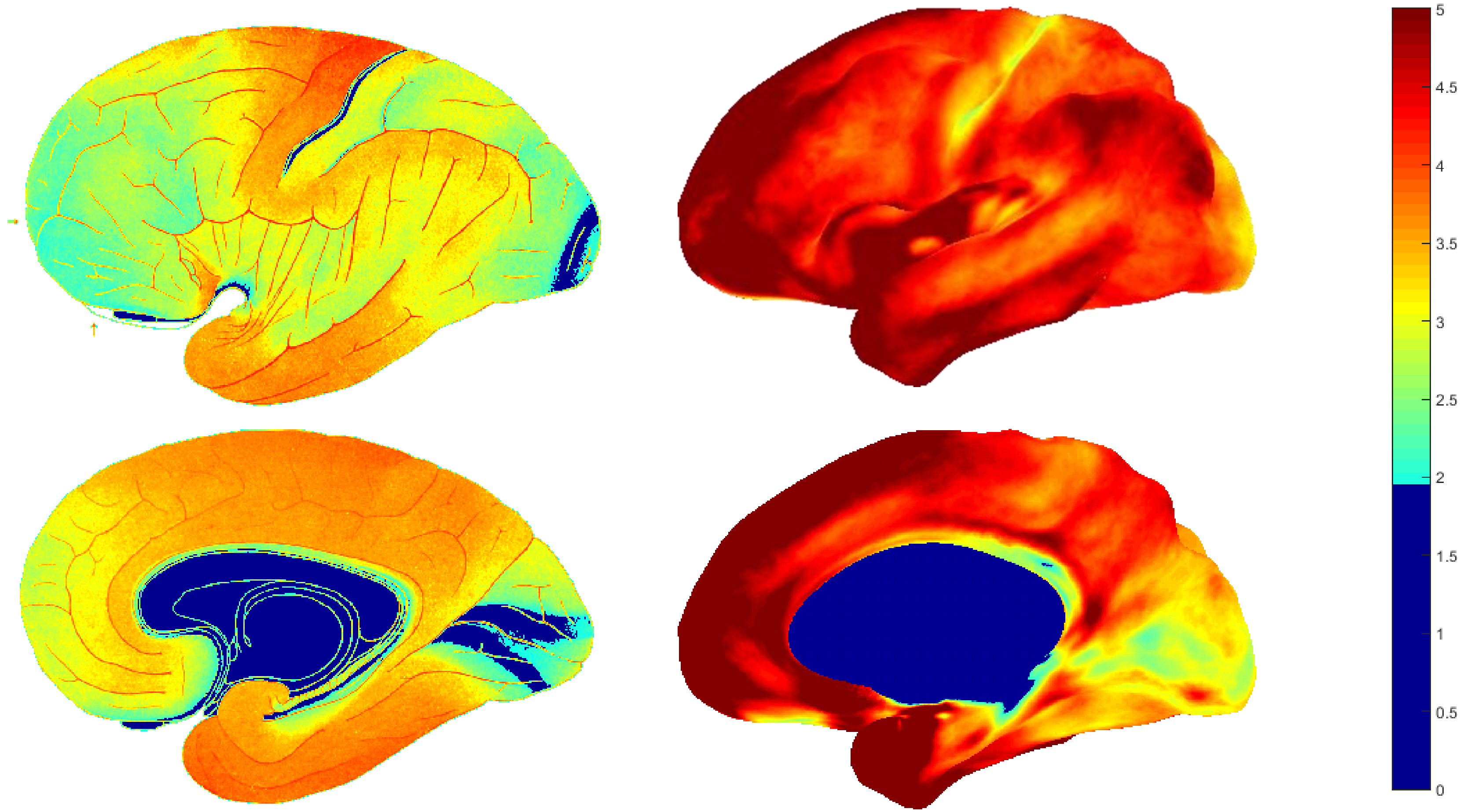


Von Economo and Koskinas (1925)



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

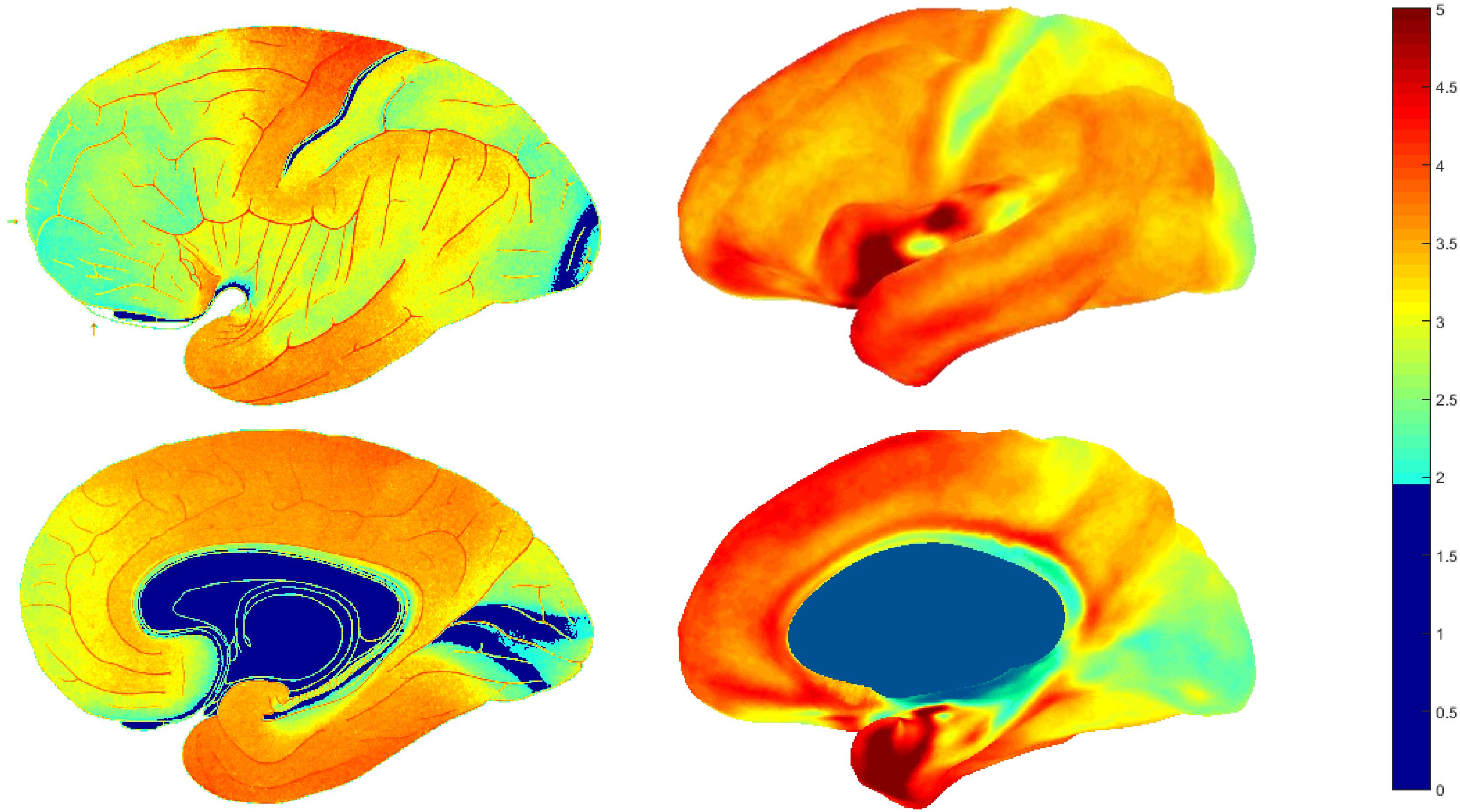
Comparisons



Von Economo and Koskinas (1925)

From MRI using linked distance (averaged over 186 subjects)

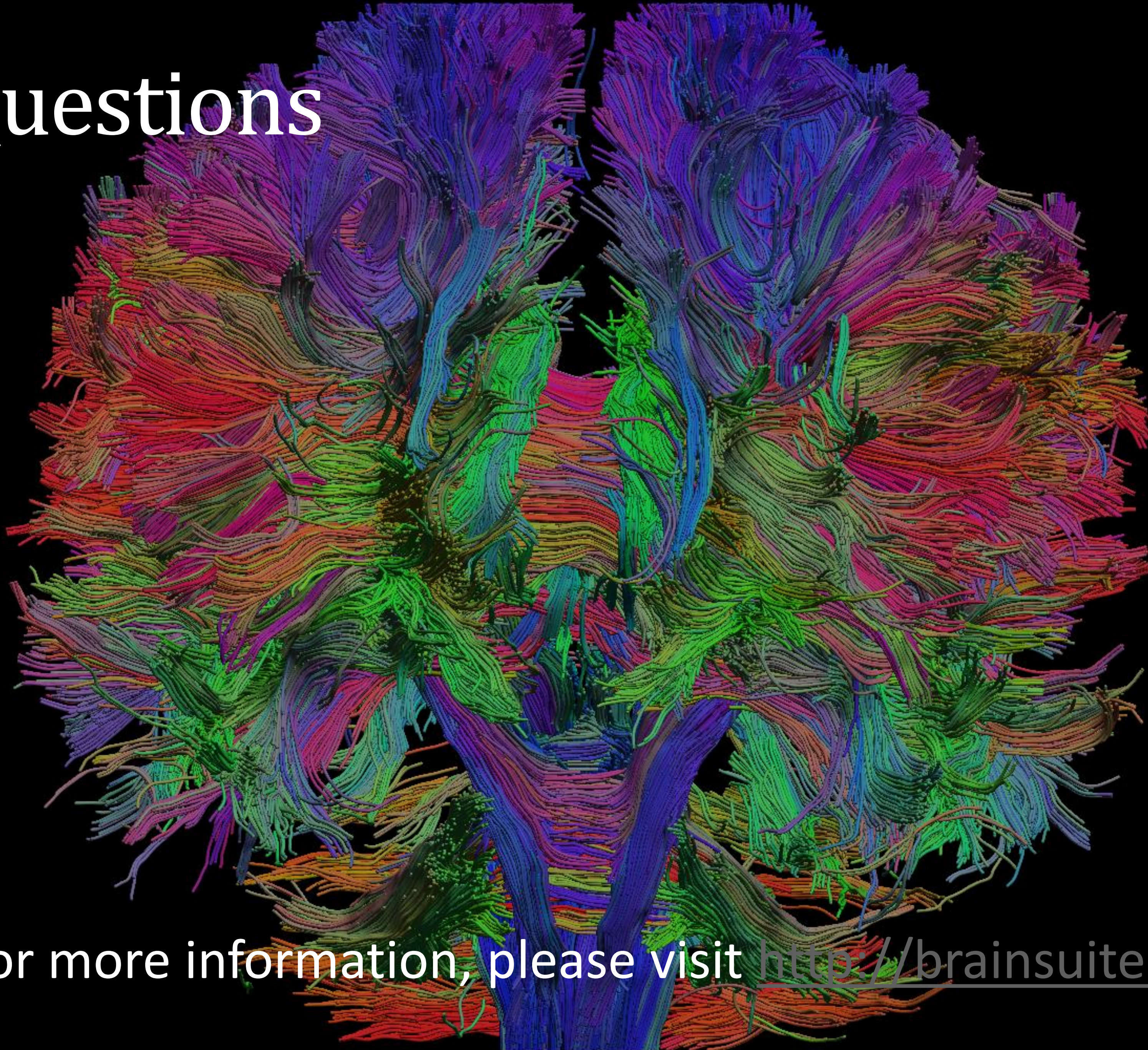
Comparisons



Von Economo and Koskinas (1925)

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

Questions



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