



UCLA Brain Mapping Center

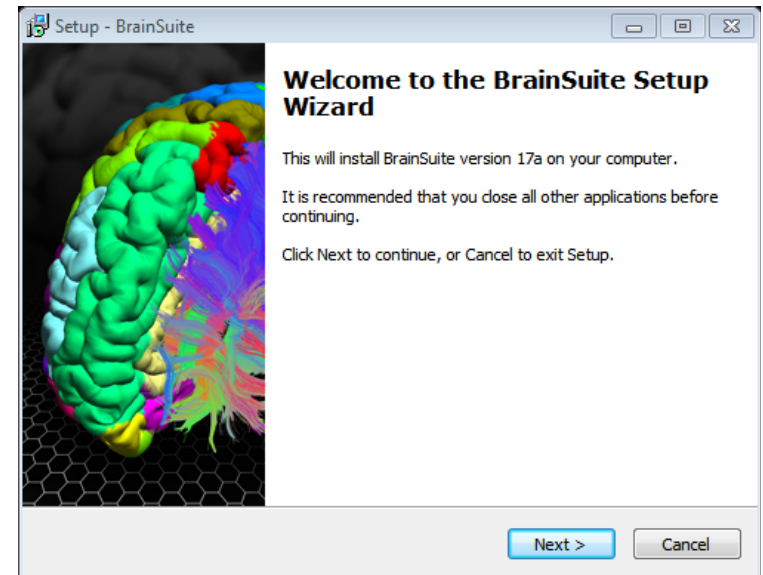
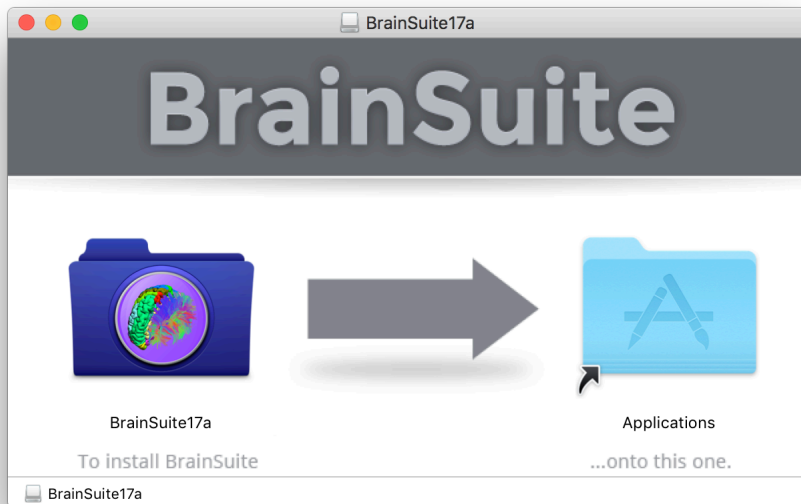
BrainSuite GUI: Surface Extraction and Visualization

Presented at the **2017 BrainSuite Training Workshop, Vancouver**

24 June 2017

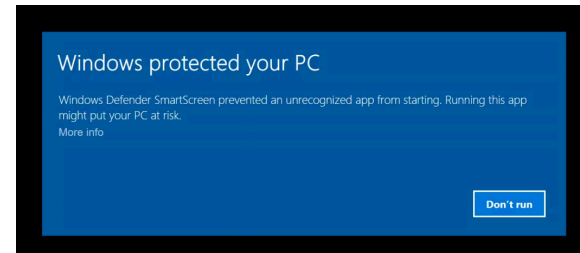
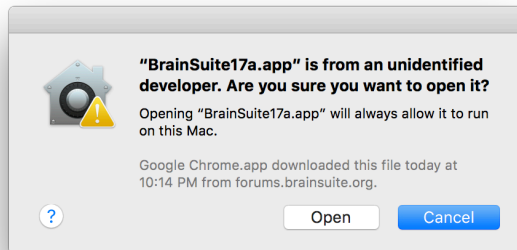
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Installation



- Register and download at <http://brainsuite.org>
- Mac & Windows: open the installer
- Linux : gunzip/untar to your preferred install directory (/opt/)

Installation : Security



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

- Mac
 - Navigate to /Applications/BrainSuite17a/brainsuite17a.app
 - Right-click and select "open".
 - Approve BrainSuite17a to run.
- Windows
 - Win10: select 'more info' and proceed.
 - Win7: approve it through the dialog box.

Installation : MCR

- SVReg and BDP require MATLAB Compiler Runtime (MCR) 2015b
 - **Important: must be the 2015b Version!!!**
 - Included on flash drive.
 - Online: <http://www.mathworks.com/products/compiler/mcr/>

	Windows	Linux	Mac
R2015b (9.00)	64-bit	64-bit	Intel 64-bit

- Links are also on the BrainSuite website.

BrainSuite Filetypes

Orthogonal Views	
File extension	Action
.nii, .nii.gz	3D images in NIFTI format
.odf	List of image files use 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	Colormaps (plain text)
.bst	BrainSuite Study File

Sample Data

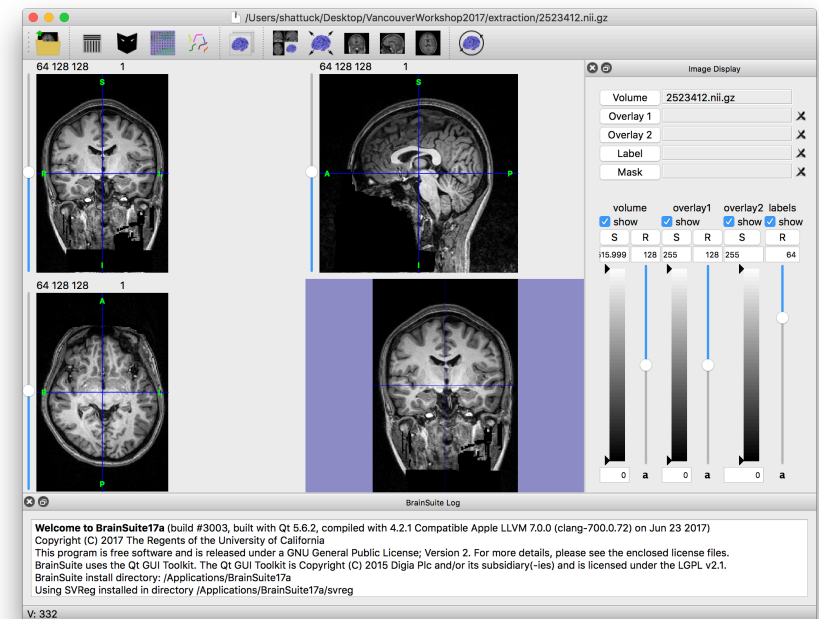
VancouverWorkshop2017

- contains several .bst files for running the examples in this tutorial.
- **extraction** : MRI file for cortical surface extraction
- **structural**: contains SVReg outputs
- **diffusion**: contains output of the BDP commands
- **commandline** : scripts and data to run command line tools
- **BCI-DNI_atlas**: loads the BCI-DNI atlas

Parts of this dataset were produced from the Beijing Enhanced data, Beijing Normal University, State Key Laboratory of Cognitive Neuroscience and Learning Enhanced Sample, which is available under a Creative Commons Attribution - Non-Commercial license (CC-BY). For more details please see: http://fcon_1000.projects.nitrc.org/indi/retro/BeijingEnhanced.html

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 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 can 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 z-plane clipping (off, positive, negative)
Z	Cycle z-plane clipping (off, positive, negative)
H	Reset clipping mode and position

BrainSuite Keyboard Shortcuts

Toolboxes	
Key	Action
I	Show Image Display Toolbox
S	Show Surface Display Toolbox
M	Show Mask Tool (Delineation Toolbox)
P	Show Label Tool (Delineation Toolbox)
C	Show Curve Toolbox
D	Show Diffusion Toolbox

BrainSuite Keyboard Shortcuts

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

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 yz 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)

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

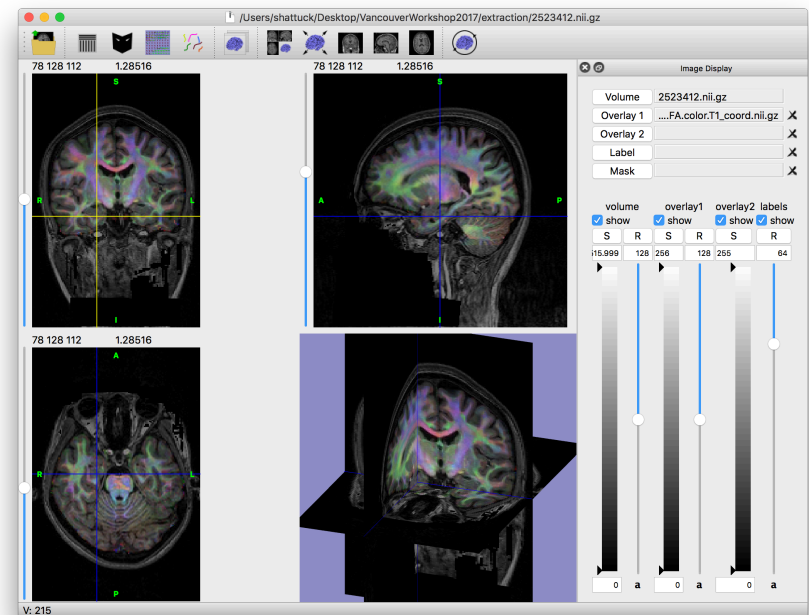
Opening an Overlay

Load an overlay image

- Press the Overlay1 button
- Select the color FA file:

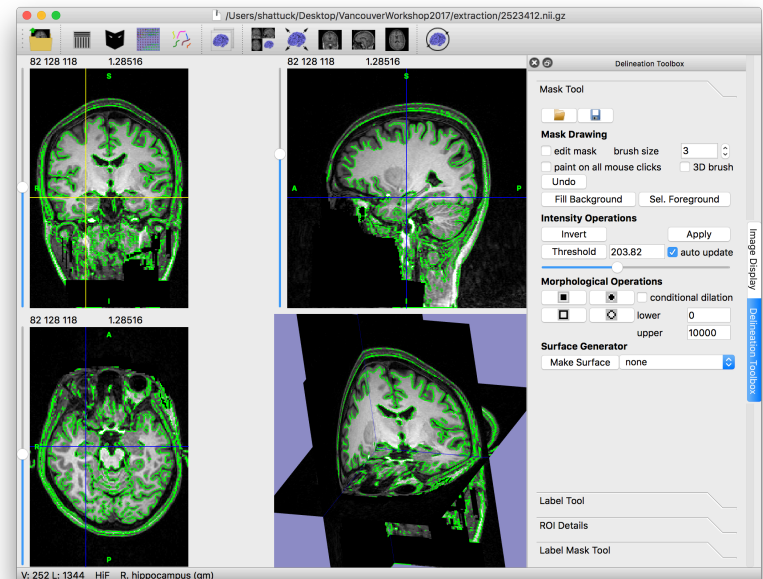
2523412.dwi.RAS.correct.FA.color.T1_coord.nii.gz

Adjust the first alpha slider to change the blending of the two images



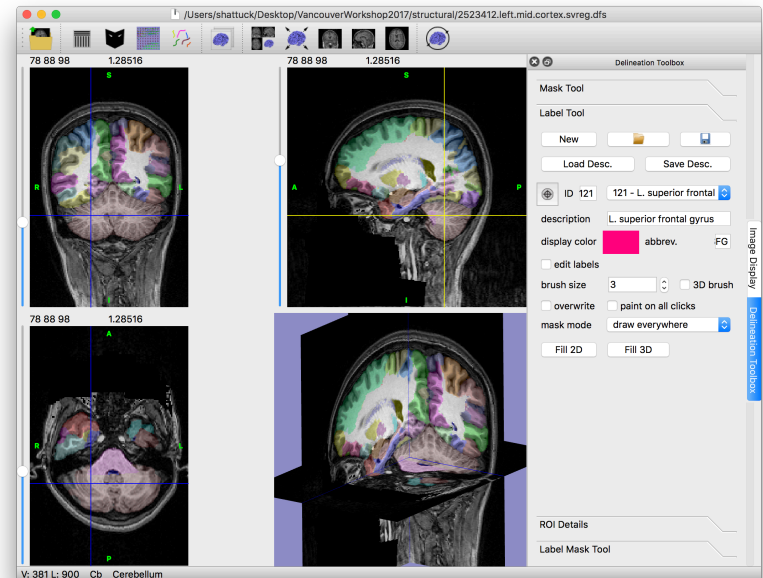
Mask Tool

- 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.



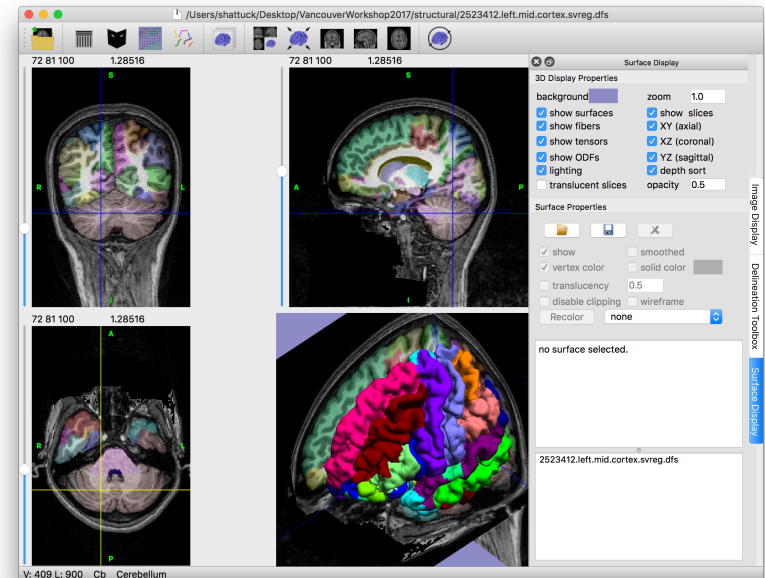
Working with Labels

- Load data from the structural directory
 - Load 2523412.nii.gz
 - Load 2523412.svreg.label.nii.gz as a Label image
- Press 'P' to open the Label Tool
- 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.

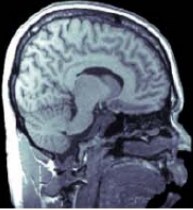
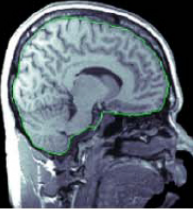

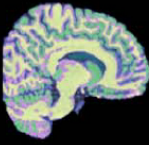
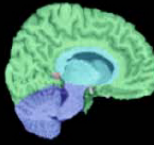





Working with Surfaces

- 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

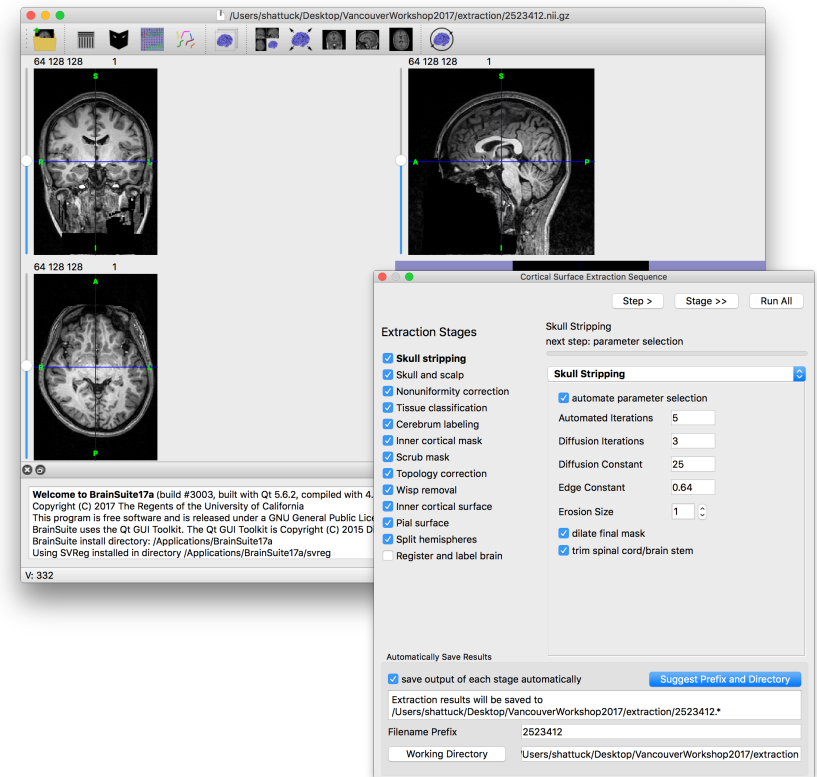


Cortical Surface Extraction

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

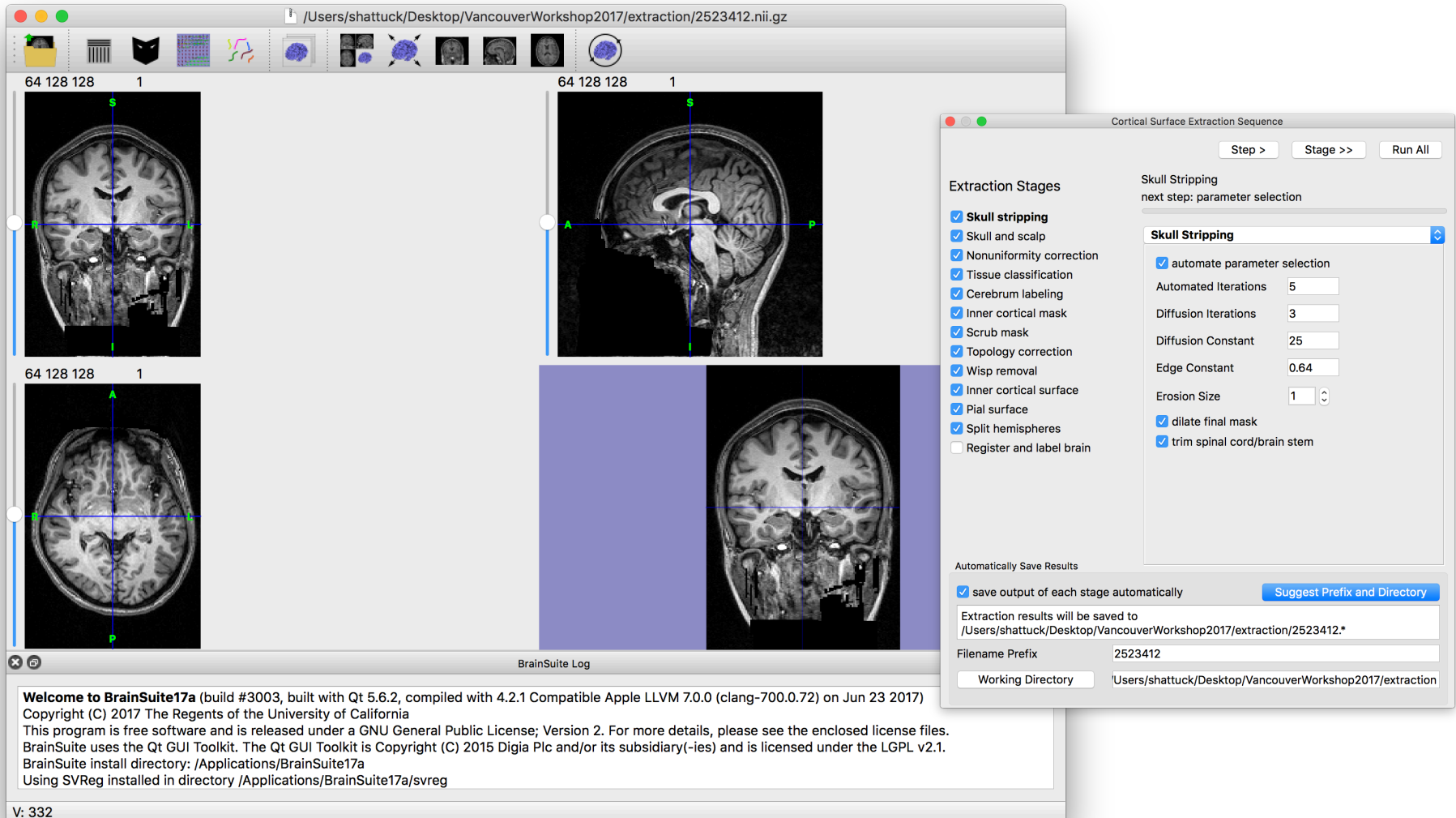
Extracting a Brain Surface

- Load the T1 image from the **extraction** folder* or drag brainsuite_extraction.bst onto BrainSuite.
- Open “Cortex -> Cortical Surface Extraction Sequence”
- By default, BrainSuite will use automated parameter selection for skull stripping



*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.

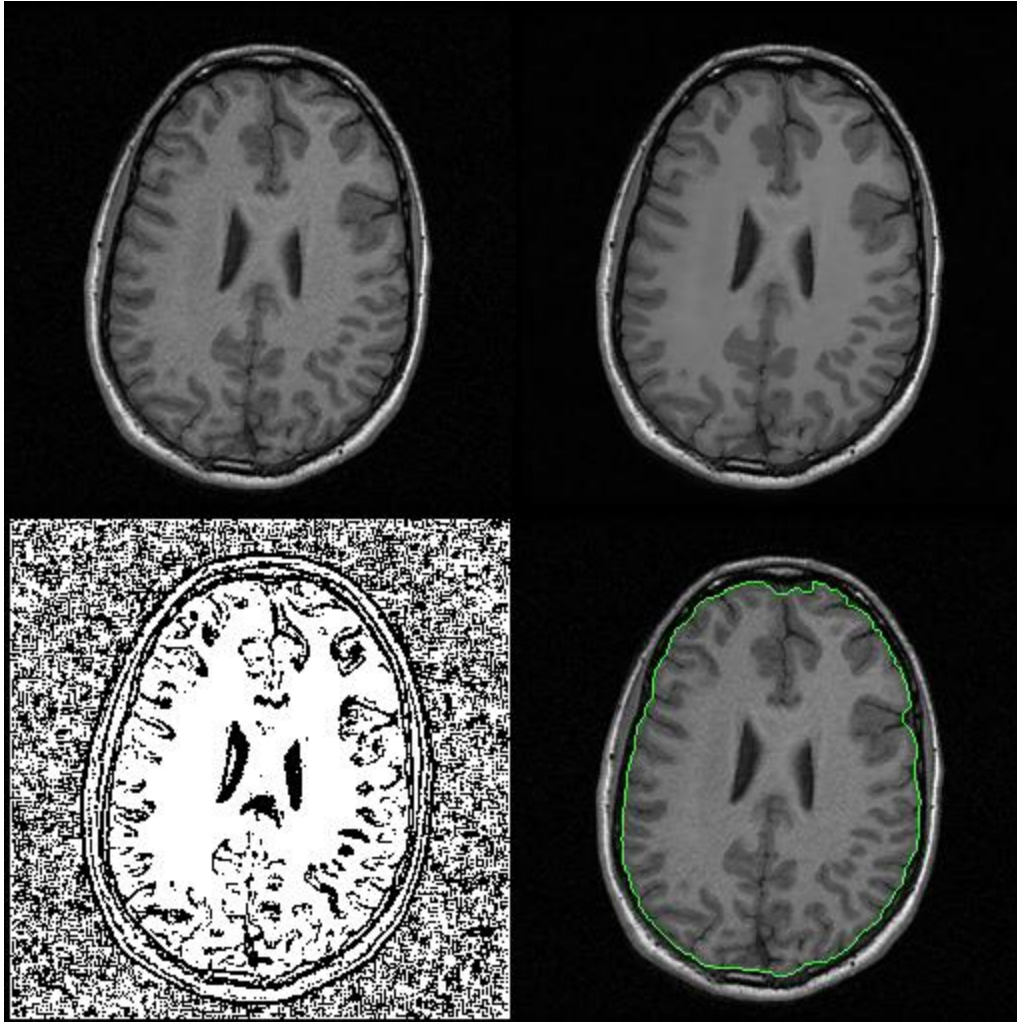
Cortical Surface Extraction Dialog



Skull Stripping

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-stripped Brain

The screenshot displays the BrainSuite software interface. The main window shows three brain slices: a coronal view (top left), a sagittal view (top right), and an axial view (bottom left). Each slice has a green outline representing the skull-stripped brain. A 3D rendering of the brain is shown in the bottom right. The bottom of the window features a log window with the following text:

```
4. cost(3,28.125,0.544,2)=17.1824
4. cost(3,26.875,0.576,1)=16.6966
lowest cost(3,26.875,0.576,1)=16.6966
saved /Users/shattuck/Desktop/VancouverWorkshop2017/extraction/2523412.mask.nii.gz
saved /Users/shattuck/Desktop/VancouverWorkshop2017/extraction/2523412.bse.nii.gz
Skull Stripping took 0:17.802
```

At the bottom left, the text "V: 326 R: 161" is visible. Overlaid on the right is the "Cortical Surface Extraction Sequence" dialog box. It includes a "Step >" button, a "Stage >>" button, and a "Run All" button. The "Extraction Stages" section lists the following steps, all of which are checked:

- Skull stripping
- Skull and scalp
- Nonuniformity correction
- Tissue classification
- Cerebrum labeling
- Inner cortical mask
- Scrub mask
- Topology correction
- Wisp removal
- Inner cortical surface
- Pial surface
- Split hemispheres
- Register and label brain

The "Skull and Scalp Modeling" section includes the following options:

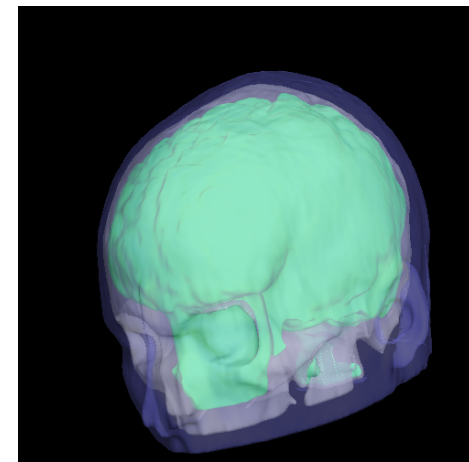
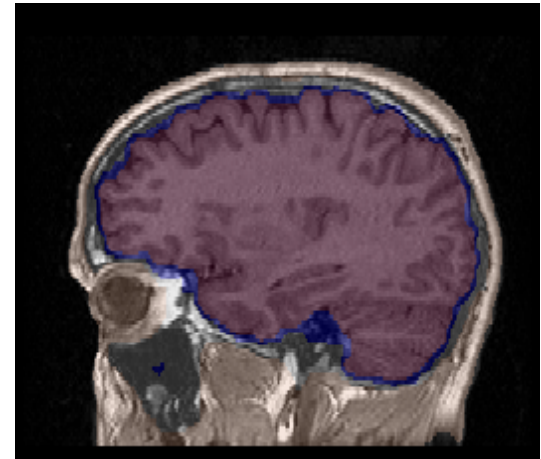
- Compute thresholds (checked)
- Skull threshold: 0
- Scalp threshold: 0

At the bottom of the dialog, there is a section for "Automatically Save Results" with the following options:

- save output of each stage automatically (checked)
- Suggest Prefix and Directory (button)
- Extraction results will be saved to: /Users/shattuck/Desktop/VancouverWorkshop2017/extraction/2523412.*
- Filename Prefix: 2523412
- Working Directory: /Users/shattuck/Desktop/VancouverWorkshop2017/extraction

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

The screenshot displays the BrainSuite software interface. The main window shows three views of a brain scan: a coronal slice (top left), a sagittal slice (top right), and an axial slice (bottom left). A 3D model of the skull and scalp is shown in the bottom right. The status bar at the bottom indicates 'V: 326 R: 161'.

The 'Cortical Surface Extraction Sequence' dialog box is open, showing the following settings:

- Extraction Stages:**
 - ☒ Skull stripping
 - ☒ Skull and scalp
 - ☒ Nonuniformity correction
 - ☒ Tissue classification
 - ☒ Cerebrum labeling
 - ☒ Inner cortical mask
 - ☒ Scrub mask
 - ☒ Topology correction
 - ☒ Wisp removal
 - ☒ Inner cortical surface
 - ☒ Pial surface
 - ☒ Split hemispheres
 - ☐ Register and label brain
- Nonuniformity Correction:**
 - ☐ Iterative mode
 - Histogram radius: 12
 - Sample spacing: 16
 - Control point spacing: 64
 - Spline stiffness: 0.0001
 - ROI Shape: ☒ cuboid ☐ ellipsoid
 - Bias estimate range: 0.5 1.5
- Automatically Save Results:**
 - ☒ save output of each stage automatically
- Extraction results will be saved to:** /Users/shattuck/Desktop/VancouverWorkshop2017/extraction/2523412.*
- Filename Prefix:** 2523412
- Working Directory:** /Users/shattuck/Desktop/VancouverWorkshop2017/extraction

The BrainSuite Log at the bottom shows the following commands and timing:

```
wrote /Users/shattuck/Desktop/VancouverWorkshop2017/extraction/2523412.skull.label.nii.gz
wrote /Users/shattuck/Desktop/VancouverWorkshop2017/extraction/2523412.brain.dfs
wrote /Users/shattuck/Desktop/VancouverWorkshop2017/extraction/2523412.inner_skull.dfs
wrote /Users/shattuck/Desktop/VancouverWorkshop2017/extraction/2523412.outer_skull.dfs
wrote /Users/shattuck/Desktop/VancouverWorkshop2017/extraction/2523412.scalp.dfs
Skull and Scalp Modeling took 0:02.685
```

Nonuniformity Correction

The screenshot displays the BrainSuite software interface. The main window shows four brain MRI slices: three axial views and one sagittal view. The top-left slice is labeled 'S' for superior, 'I' for inferior, 'A' for anterior, and 'P' for posterior. The top-right slice is labeled 'S', 'I', 'A', and 'P'. The bottom-left slice is labeled 'A', 'P', 'I', and 'S'. The bottom-right slice is a sagittal view. The top of the window shows the file path: `/Users/shattuck/Desktop/VancouverWorkshop2017/extraction/2523412.nii.gz`. The bottom of the window shows the BrainSuite Log with the following text:

```
wrote /Users/shattuck/Desktop/VancouverWorkshop2017/extraction/2523412.skull.label.nii.gz
wrote /Users/shattuck/Desktop/VancouverWorkshop2017/extraction/2523412.brain.dfs
wrote /Users/shattuck/Desktop/VancouverWorkshop2017/extraction/2523412.inner_skull.dfs
wrote /Users/shattuck/Desktop/VancouverWorkshop2017/extraction/2523412.outer_skull.dfs
wrote /Users/shattuck/Desktop/VancouverWorkshop2017/extraction/2523412.scalp.dfs
Skull and Scalp Modeling took 0:02.685
```

The status bar at the bottom left shows 'V: 326 R: 161'. A dialog box titled 'Cortical Surface Extraction Sequence' is open on the right. It has buttons for 'Step >', 'Stage >>', and 'Run All'. The 'Extraction Stages' section lists the following stages with checkboxes:

- ☒ Skull stripping
- ☒ Skull and scalp
- ☒ **Nonuniformity correction**
- ☒ Tissue classification
- ☒ Cerebrum labeling
- ☒ Inner cortical mask
- ☒ Scrub mask
- ☒ Topology correction
- ☒ Wisp removal
- ☒ Inner cortical surface
- ☒ Pial surface
- ☒ Split hemispheres
- ☐ Register and label brain

The 'Nonuniformity Correction' section is expanded, showing the following options:

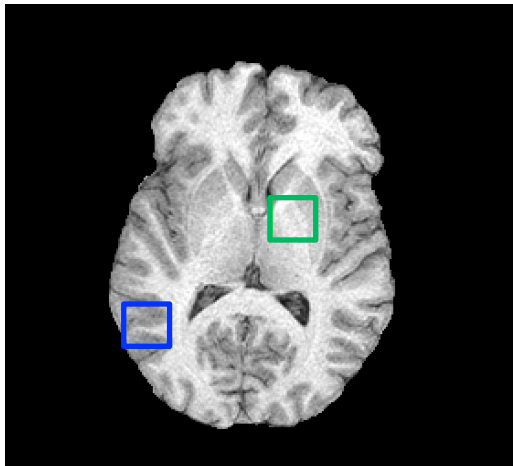
- ☐ Iterative mode
- Histogram radius: 12
- Sample spacing: 16
- Control point spacing: 64
- Spline stiffness: 0.0001
- ROI Shape: ☒ cuboid ☐ ellipsoid
- Bias estimate range: 0.5 1.5

The 'Automatically Save Results' section has the following options:

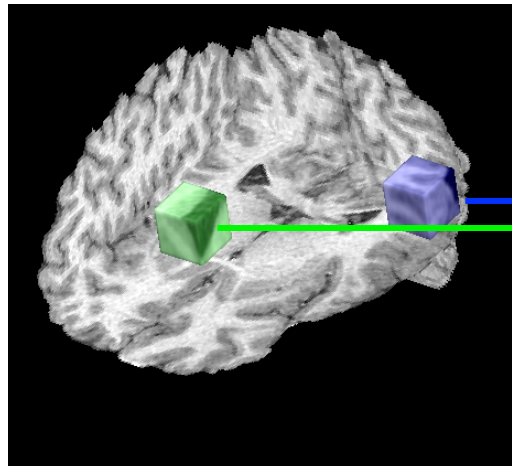
- ☒ save output of each stage automatically
- Suggest Prefix and Directory

The 'Extraction results will be saved to' field shows the path: `/Users/shattuck/Desktop/VancouverWorkshop2017/extraction/2523412.*`. The 'Filename Prefix' field shows '2523412'. The 'Working Directory' field shows `/Users/shattuck/Desktop/VancouverWorkshop2017/extraction`.

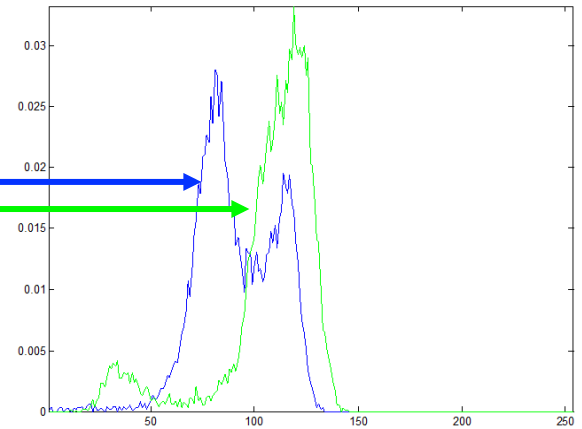
Nonuniformity Correction



Two cubic regions ROIs



3D rendering of the ROIs

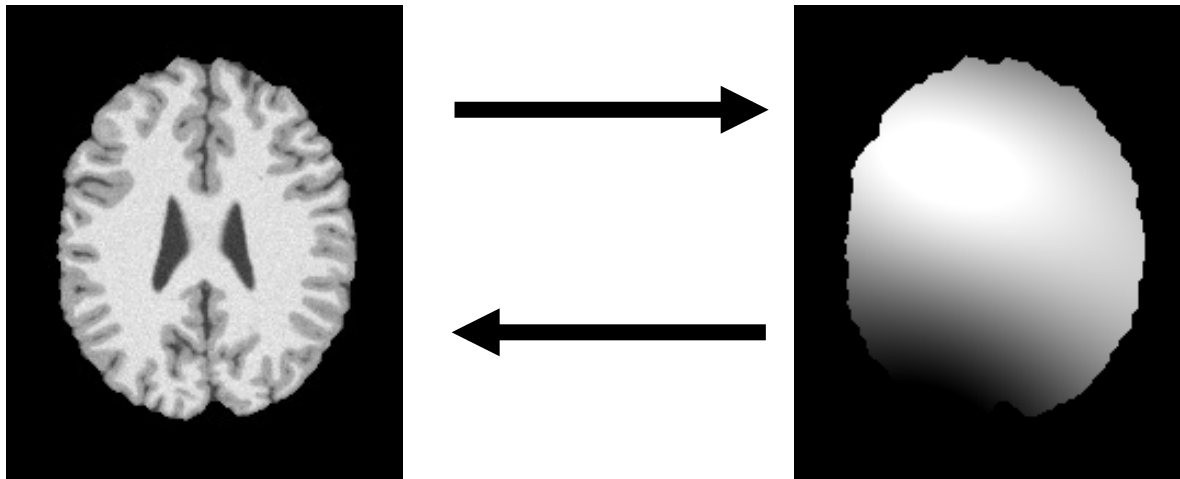


Histograms of the two ROIs

- 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

The screenshot displays the BrainSuite software interface. The main window shows a 3D rendering of a brain with a bias-corrected image. The image is displayed in three orthogonal views: axial, sagittal, and coronal. The axial view is at the top left, the sagittal view is at the top right, and the coronal view is at the bottom left. The 3D rendering is at the bottom right. The interface includes a toolbar at the top with various icons for file operations and image manipulation. The status bar at the bottom shows the coordinates V: 326 R: 161.

The **Cortical Surface Extraction Sequence** dialog is open, showing the following settings:

- Extraction Stages:**
 - ☒ Skull stripping
 - ☒ Skull and scalp
 - ☒ Nonuniformity correction
 - ☒ **Tissue classification**
 - ☒ Cerebrum labeling
 - ☒ Inner cortical mask
 - ☒ Scrub mask
 - ☒ Topology correction
 - ☒ Wisp removal
 - ☒ Inner cortical surface
 - ☒ Pial surface
 - ☒ Split hemispheres
 - ☐ Register and label brain
- Tissue Classification Initialization:**
 - Tissue Classification:** [Dropdown menu]
 - Spatial Prior:** 0.1
- Automatically Save Results:**
 - ☒ save output of each stage automatically
 - Suggest Prefix and Directory:** [Button]
- Extraction results will be saved to:** /Users/shattuck/Desktop/VancouverWorkshop2017/extraction/2523412.*
- Filename Prefix:** 2523412
- Working Directory:** /Users/shattuck/Desktop/VancouverWorkshop2017/extraction

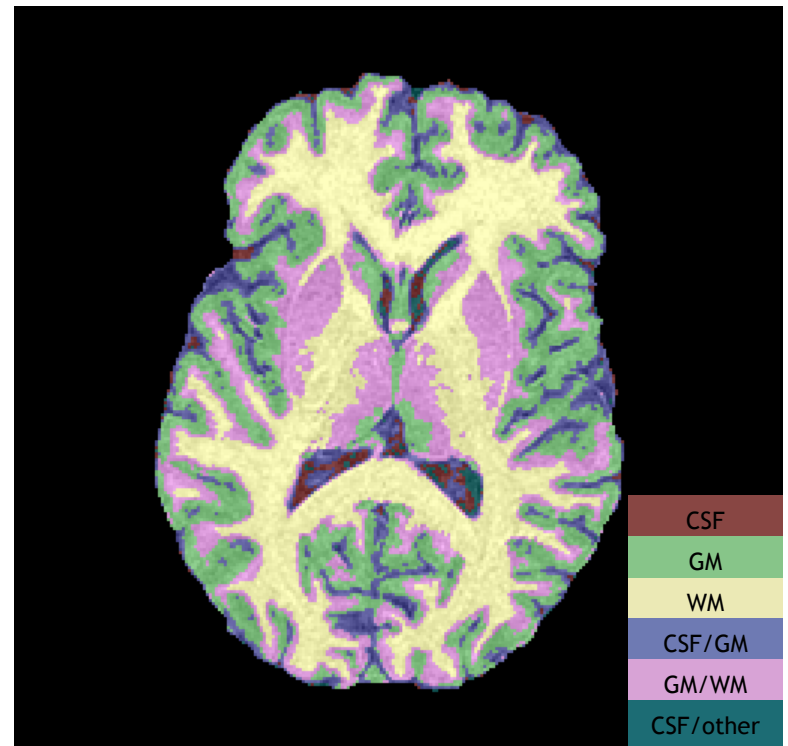
BrainSuite Log:

```
wrote /Users/shattuck/Desktop/VancouverWorkshop2017/extraction/2523412.inner_skull.dfs
wrote /Users/shattuck/Desktop/VancouverWorkshop2017/extraction/2523412.outer_skull.dfs
wrote /Users/shattuck/Desktop/VancouverWorkshop2017/extraction/2523412.scalp.dfs
Skull and Scalp Modeling took 0:02.685
wrote /Users/shattuck/Desktop/VancouverWorkshop2017/extraction/2523412.bfc.nii.gz
Nonuniformity Correction took 0:13.017
```

V: 326 R: 161

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

The screenshot displays the BrainSuite software interface. The main window shows four brain slices: three axial slices (top-left, bottom-left, and top-right) and one sagittal slice (middle-right). Each slice is color-coded to represent different tissue classes: yellow for grey matter, green for white matter, and purple for cerebrospinal fluid. The slices are labeled with 'S' for superior, 'I' for inferior, 'R' for right, and 'L' for left. The top-right slice is also labeled with 'A' for anterior and 'P' for posterior. The bottom-right slice shows a 3D reconstruction of the brain surface.

The BrainSuite Log at the bottom left shows the following output:

```
Skull and Scalp Modeling took 0:02.685
wrote /Users/shattuck/Desktop/VancouverWorkshop2017/extraction/2523412.bfc.nii.gz
Nonuniformity Correction took 0:13.017
wrote /Users/shattuck/Desktop/VancouverWorkshop2017/extraction/2523412.pvc.label.nii.gz
wrote /Users/shattuck/Desktop/VancouverWorkshop2017/extraction/2523412.pvc.frac.nii.gz
Tissue Classification took 0:02.363
```

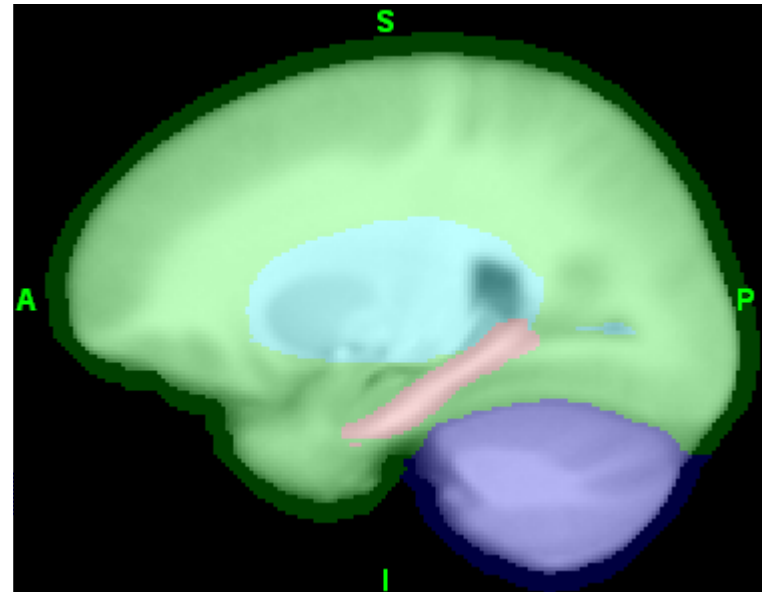
The status bar at the bottom left indicates: V: 324.968 R: 184 L: 5 GW grey matter/white matter

The Cortical Surface Extraction Sequence dialog box is open on the right. It shows the following settings:

- Extraction Stages:**
 - ☒ Skull stripping
 - ☒ Skull and scalp
 - ☒ Nonuniformity correction
 - ☒ Tissue classification
 - ☒ **Cerebrum labeling**
 - ☒ Inner cortical mask
 - ☒ Scrub mask
 - ☒ Topology correction
 - ☒ Wisp removal
 - ☒ Inner cortical surface
 - ☒ Pial surface
 - ☒ Split hemispheres
 - ☐ Register and label brain
- Cerebrum Labeling initialize:**
 - ☐ Initialize using centroids
 - Linear Convergence: 0.1
 - Warp Convergence: 100
 - Warp Level: 5
 - Cost Function: least squares w/intensity
 - ☐ Verbose
 - ☒ Show aligned atlas as overlay
- Atlas:** ...tlas/brainsuite.icbm452.lpi.v08a.img
- Labels:** ...as/brainsuite.icbm452.v15a.label.img
- Automatically Save Results:**
 - ☒ save output of each stage automatically
 - Suggest Prefix and Directory
- Extraction results will be saved to:** /Users/shattuck/Desktop/VancouverWorkshop2017/extraction/2523412.*
- Filename Prefix:** 2523412
- Working Directory:** /Users/shattuck/Desktop/VancouverWorkshop2017/extraction

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

The screenshot displays the BrainSuite software interface. The main window shows four brain MRI slices: three axial slices (top-left, bottom-left, and top-right) and one sagittal slice (middle-right). Each slice is overlaid with a green cortical mask. The bottom-right panel shows a 3D rendering of the brain surface with the inner cortical mask highlighted in green. The top of the window shows a file path: `/Users/shattuck/Desktop/VancouverWorkshop2017/extraction/2523412.nii.gz`. The bottom of the window shows a console log with the following text:

```
alignwarp.c: 262: WARNING: Registration terminated due to a Hessian matrix that was not positive definite
Inspection of results is advised
finished align warp 0:05
wrote /Users/shattuck/Desktop/VancouverWorkshop2017/extraction/2523412.hemi.label.nii.gz
wrote /Users/shattuck/Desktop/VancouverWorkshop2017/extraction/2523412.cerebrum.mask.nii.gz
Cerebrum Labeling took 0:11.479
```

The console also displays coordinates: `V: 294.884 R: 175 R: 1230 L: 5 GW grey matter/white matter`.

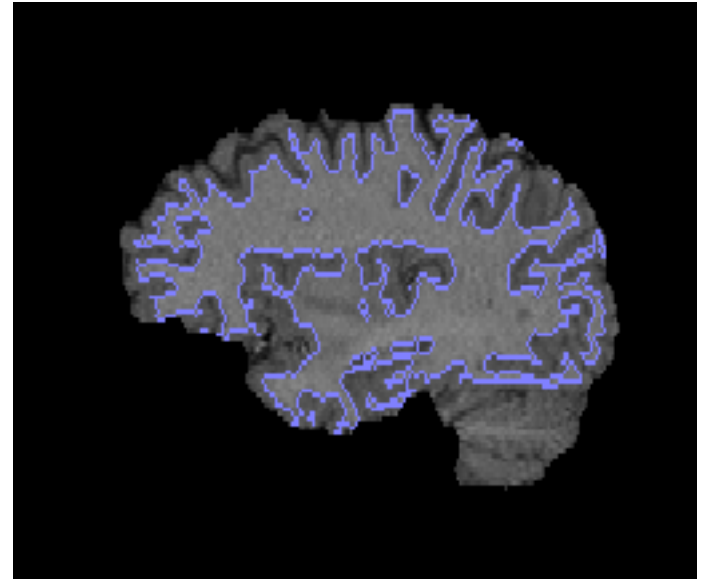
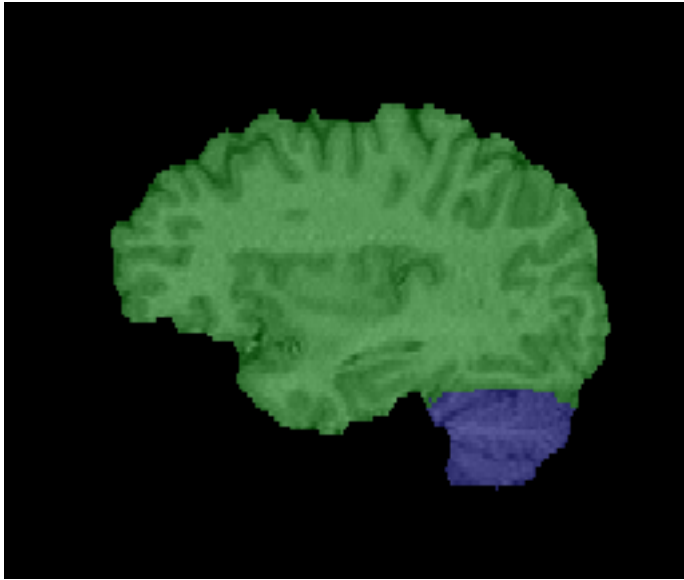
Overlaid on the right is the "Cortical Surface Extraction Sequence" dialog box. It features a "Step >" button, a "Stage >>" button, and a "Run All" button. The "Extraction Stages" section lists the following steps:

- ☒ Skull stripping
- ☒ Skull and scalp
- ☒ Nonuniformity correction
- ☒ Tissue classification
- ☒ Cerebrum labeling
- ☒ **Inner cortical mask**
- ☒ Scrub mask
- ☒ Topology correction
- ☒ Wisp removal
- ☒ Inner cortical surface
- ☒ Pial surface
- ☒ Split hemispheres
- ☐ Register and label brain

The "Inner Cortical Mask" section is expanded, showing a "Tissue threshold" of 0.5 and a "Recompute" button. Below this, there is a checkbox labeled "Include all areas labeled as subcortex as part of initial mask" which is checked.

The "Automatically Save Results" section has a checkbox labeled "save output of each stage automatically" which is checked. A "Suggest Prefix and Directory" button is also present. Below this, the "Extraction results will be saved to" field shows the path: `/Users/shattuck/Desktop/VancouverWorkshop2017/extraction/2523412.*`. The "Filename Prefix" field contains `2523412`. The "Working Directory" field contains `/Users/shattuck/Desktop/VancouverWorkshop2017/extraction`.

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

The screenshot displays the BrainSuite software interface. The main window shows four brain MRI slices: two axial views (top-left and bottom-left) and two sagittal views (top-right and bottom-right). The slices are labeled with 'S' (Superior), 'I' (Inferior), 'R' (Right), 'L' (Left), 'A' (Anterior), and 'P' (Posterior). The bottom-right slice shows a 3D reconstruction of the brain surface. The top of the window shows a file path: `/Users/shattuck/Desktop/VancouverWorkshop2017/extraction/2523412.nii.gz`. The bottom of the window shows a log of operations:

```
Inspection of results is advised
finished align warp 0:05
wrote /Users/shattuck/Desktop/VancouverWorkshop2017/extraction/2523412.hemi.label.nii.gz
wrote /Users/shattuck/Desktop/VancouverWorkshop2017/extraction/2523412.cerebrum.mask.nii.gz
Cerebrum Labeling took 0:11.479
Inner Cortical Mask took 0:00.608
```

At the bottom of the window, a status bar displays: `V: 286.755 R: 165 R: 1324 L: 5 GW grey matter/white matter`.

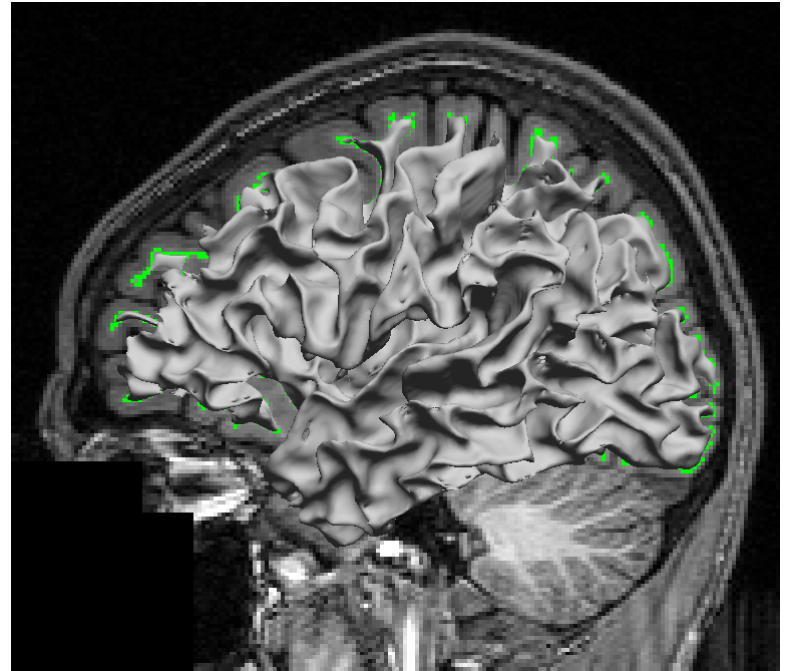
Overlaid on the right is the 'Cortical Surface Extraction Sequence' dialog box. It features a 'Step >' button, a 'Stage >>' button, and a 'Run All' button. The 'Extraction Stages' section lists the following steps with checkboxes:

- ☒ Skull stripping
- ☒ Skull and scalp
- ☒ Nonuniformity correction
- ☒ Tissue classification
- ☒ Cerebrum labeling
- ☒ Inner cortical mask
- ☒ **Scrub mask**
- ☒ Topology correction
- ☒ Wisp removal
- ☒ Inner cortical surface
- ☒ Pial surface
- ☒ Split hemispheres
- ☐ Register and label brain

The 'Scrub Mask' section includes a 'Scrubbing mask' dropdown menu and two input fields: 'Foreground threshold' set to 0 and 'Background threshold' set to 2. Below this, the 'Automatically Save Results' section has a checked checkbox for 'save output of each stage automatically' and a 'Suggest Prefix and Directory' button. The 'Extraction results will be saved to' field shows the path: `/Users/shattuck/Desktop/VancouverWorkshop2017/extraction/2523412.*`. The 'Filename Prefix' field is set to '2523412'. The 'Working Directory' field is set to `/Users/shattuck/Desktop/VancouverWorkshop2017/extraction`.

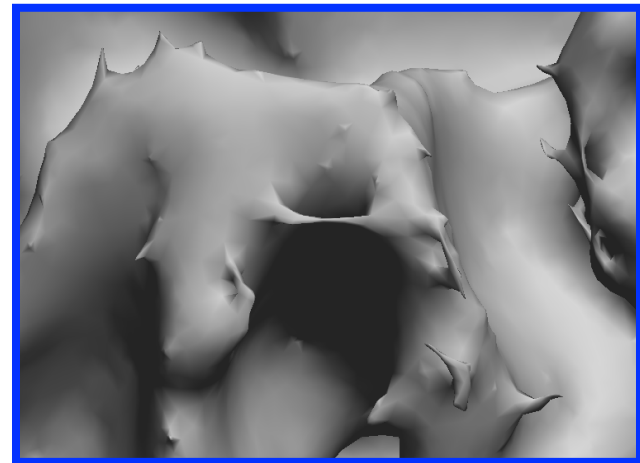
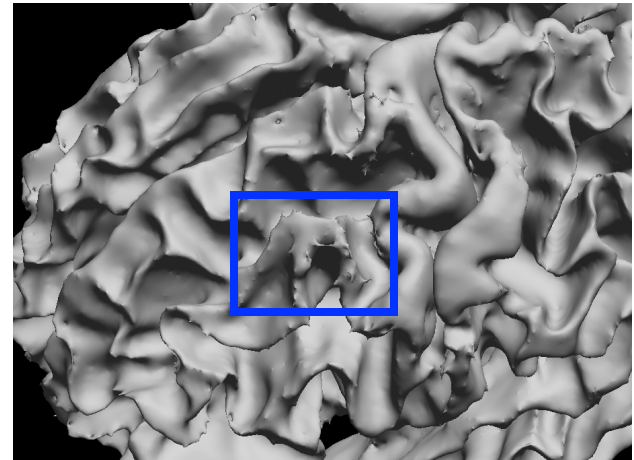
Surface Generation

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

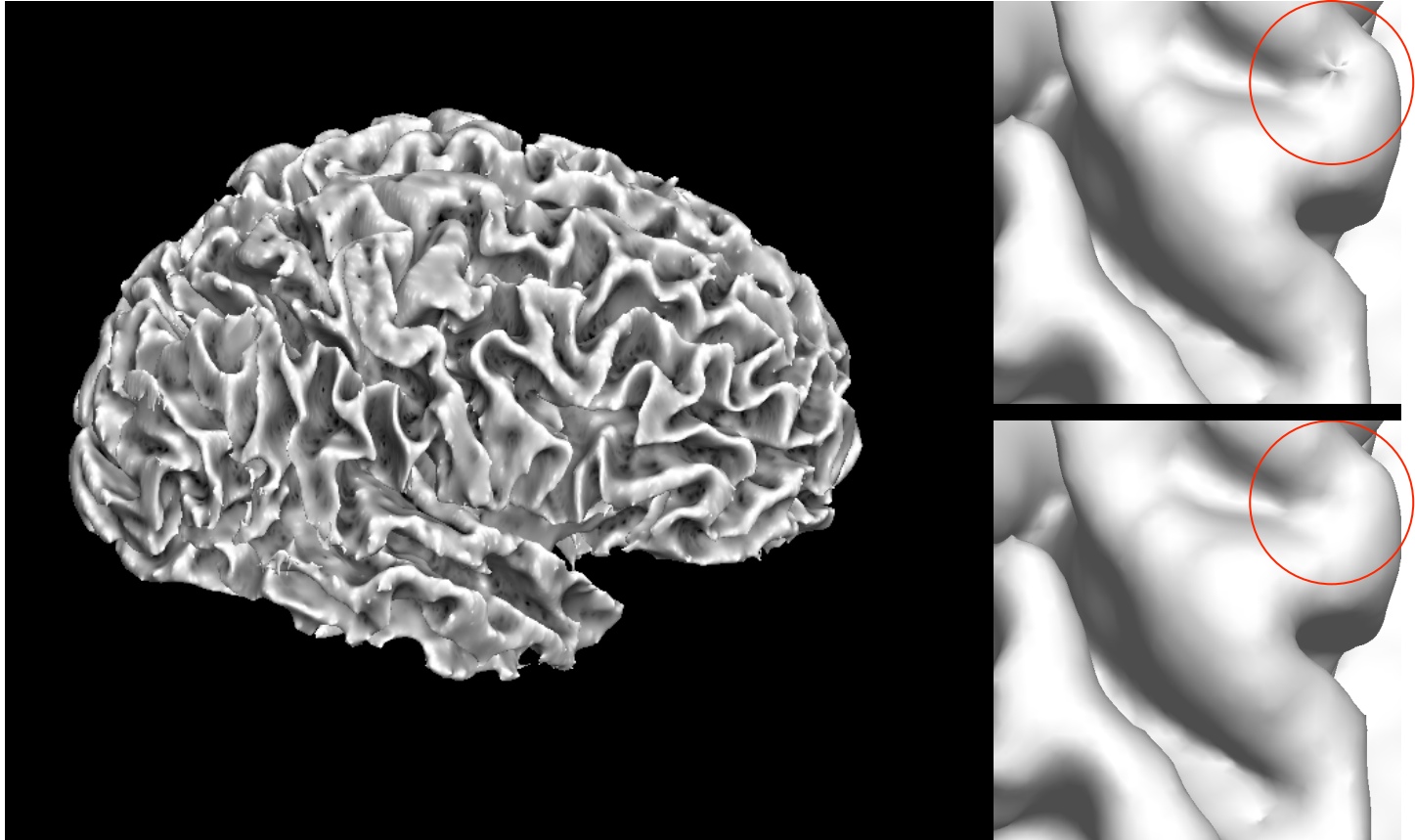


Topological Errors

- 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

The screenshot displays the BrainSuite software interface. The main window shows four brain slices: three axial views (top-left, bottom-left, and top-right) and one sagittal view (bottom-right). Each slice has green outlines representing the extracted cortical surfaces. The top-left and bottom-left slices are labeled with 'S', 'R', 'L', and 'I' for Superior, Right, Left, and Inferior. The top-right slice is labeled with 'S', 'A', 'P', and 'I' for Superior, Anterior, Posterior, and Inferior. The bottom-right slice is a sagittal view. A 'BrainSuite Log' window at the bottom left shows the following text:

```
wrote /Users/shattuck/Desktop/VancouverWorkshop2017/extraction/2523412.hemi.label.nii.gz
wrote /Users/shattuck/Desktop/VancouverWorkshop2017/extraction/2523412.cerebrum.mask.nii.gz
Cerebrum Labeling took 0:11.479
Inner Cortical Mask took 0:00.608
wrote /Users/shattuck/Desktop/VancouverWorkshop2017/extraction/2523412.cortex.scrubbed.mask.nii.gz
Scrub Mask took 0:00.545
```

A 'Cortical Surface Extraction Sequence' dialog box is open on the right. It contains the following settings:

- Extraction Stages:**
 - ☒ Skull stripping
 - ☒ Skull and scalp
 - ☒ Nonuniformity correction
 - ☒ Tissue classification
 - ☒ Cerebrum labeling
 - ☒ Inner cortical mask
 - ☒ Scrub mask
 - ☒ **Topology correction**
 - ☒ Wisp removal
 - ☒ Inner cortical surface
 - ☒ Pial surface
 - ☒ Split hemispheres
 - ☐ Register and label brain
- Topology Correction:**
 - fix topology defects
 - Minimum correction size: 0
 - Maximum correction size: 2500
 - Fill offset: 20
- Automatically Save Results:**
 - ☒ save output of each stage automatically
- Extraction results will be saved to:** /Users/shattuck/Desktop/VancouverWorkshop2017/extraction/2523412.*
- Filename Prefix:** 2523412
- Working Directory:** /Users/shattuck/Desktop/VancouverWorkshop2017/extraction

Buttons at the top of the dialog include 'Step >', 'Stage >>', and 'Run All'. A 'Suggest Prefix and Directory' button is also present.

At the bottom of the BrainSuite window, the status bar reads: V: 286.755 R: 165 R: 1324 L: 5 GW grey matter/white matter

Topology-corrected Mask

The screenshot displays the BrainSuite software interface. The main window shows four brain slices (axial, sagittal, and two coronal) with green outlines representing the cortical surface. The top-left slice is labeled 'S' (Superior), 'R' (Right), 'L' (Left), and 'I' (Inferior). The top-right slice is labeled 'S' (Superior), 'A' (Anterior), 'P' (Posterior), and 'I' (Inferior). The bottom-left slice is labeled 'A' (Anterior), 'R' (Right), 'L' (Left), and 'P' (Posterior). The bottom-right slice is a 3D view of the brain with green outlines. The top bar shows the file path: `/Users/shattuck/Desktop/VancouverWorkshop2017/extraction/2523412.nii.gz`. The bottom bar shows the file name: `BrainSuite Log`.

The **Cortical Surface Extraction Sequence** dialog box is open, showing the following settings:

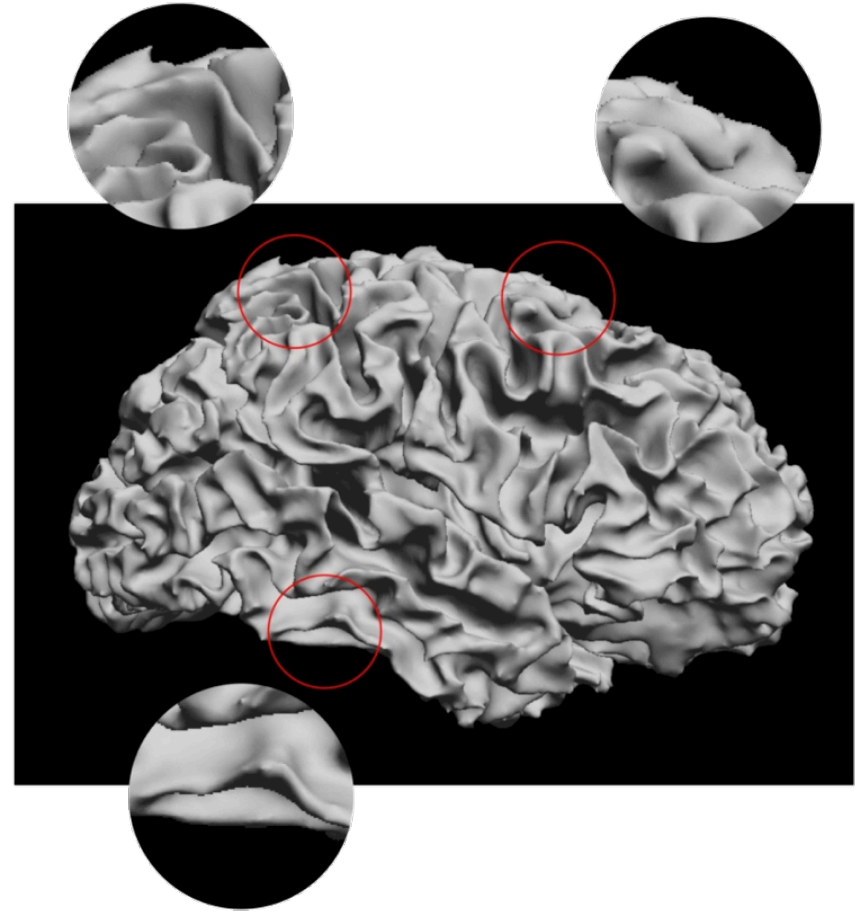
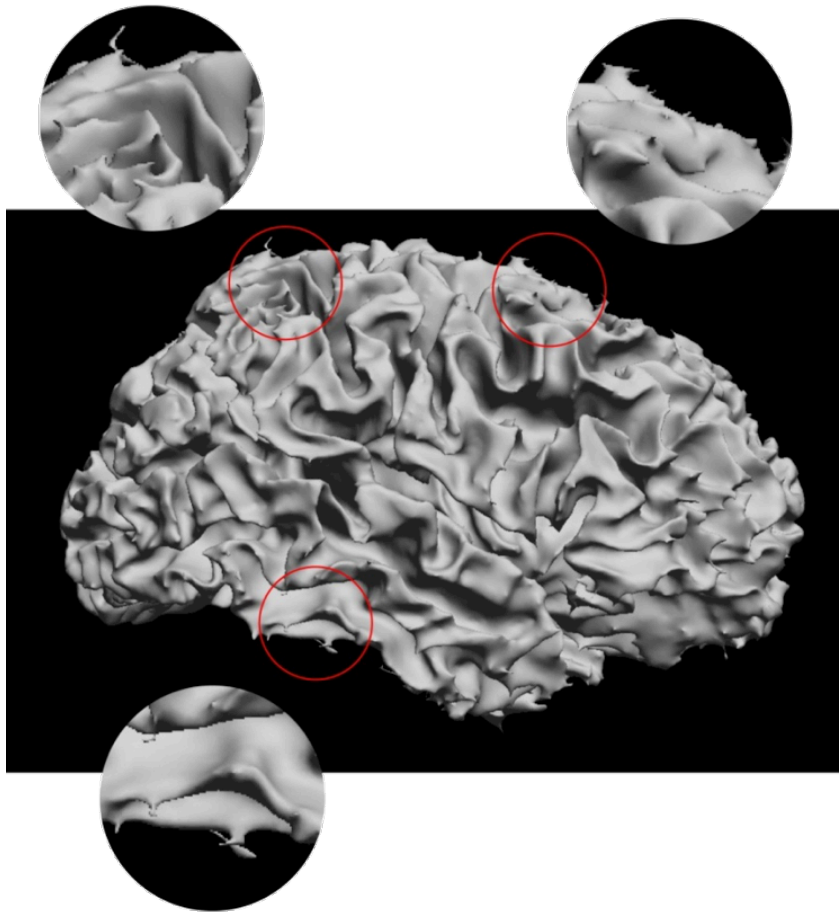
- Extraction Stages:**
 - ☒ Skull stripping
 - ☒ Skull and scalp
 - ☒ Nonuniformity correction
 - ☒ Tissue classification
 - ☒ Cerebrum labeling
 - ☒ Inner cortical mask
 - ☒ Scrub mask
 - ☒ Topology correction
 - ☒ **Wisp removal**
 - ☒ Inner cortical surface
 - ☒ Pial surface
 - ☒ Split hemispheres
 - ☐ Register and label brain
- Wisp Removal:**
 - Threshold: 15
 - Maximum iterations: 10
- Automatically Save Results:**
 - ☒ save output of each stage automatically
- Extraction results will be saved to:** `/Users/shattuck/Desktop/VancouverWorkshop2017/extraction/2523412.*`
- Filename Prefix:** 2523412
- Working Directory:** `/Users/shattuck/Desktop/VancouverWorkshop2017/extraction`

The **BrainSuite Log** window at the bottom shows the following output:

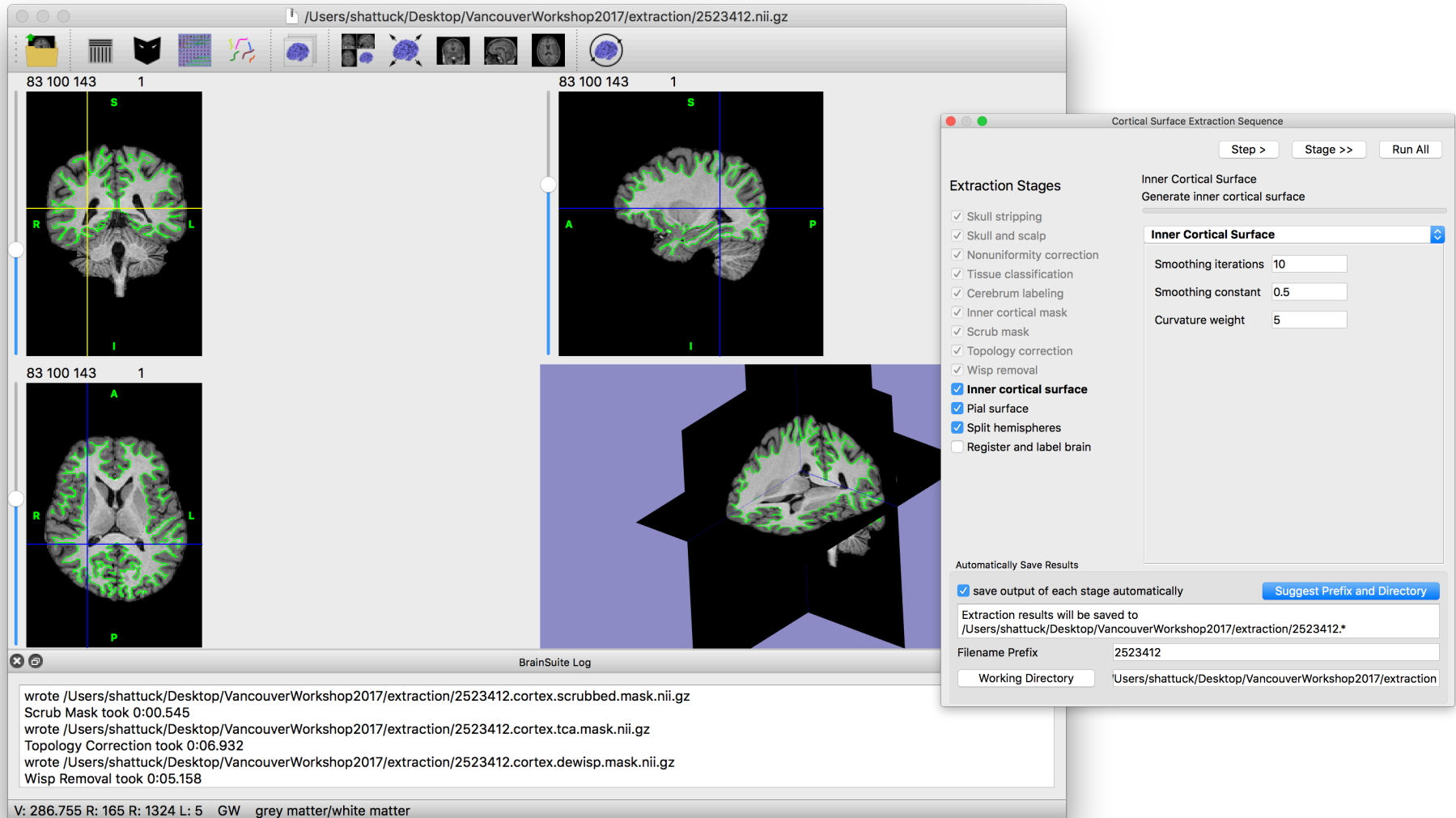
```
Cerebrum Labeling took 0:11.479
Inner Cortical Mask took 0:00.608
wrote /Users/shattuck/Desktop/VancouverWorkshop2017/extraction/2523412.cortex.scrubbed.mask.nii.gz
Scrub Mask took 0:00.545
wrote /Users/shattuck/Desktop/VancouverWorkshop2017/extraction/2523412.cortex.tca.mask.nii.gz
Topology Correction took 0:06.932
```

The status bar at the bottom indicates: `V: 286.755 R: 165 R: 1324 L: 5 GW grey matter/white matter`

Wisp Removal



Final Inner Cortex Mask



BrainSuite Log

```
wrote /Users/shattuck/Desktop/VancouverWorkshop2017/extraction/2523412.cortex.scrubbed.mask.nii.gz
Scrub Mask took 0:00.545
wrote /Users/shattuck/Desktop/VancouverWorkshop2017/extraction/2523412.cortex.tca.mask.nii.gz
Topology Correction took 0:06.932
wrote /Users/shattuck/Desktop/VancouverWorkshop2017/extraction/2523412.cortex.dewisp.mask.nii.gz
Wisp Removal took 0:05.158
```

V: 286.755 R: 165 R: 1324 L: 5 GW grey matter/white matter

Cortical Surface Extraction Sequence

Step > Stage >> Run All

Extraction Stages

- ☒ Skull stripping
- ☒ Skull and scalp
- ☒ Nonuniformity correction
- ☒ Tissue classification
- ☒ Cerebrum labeling
- ☒ Inner cortical mask
- ☒ Scrub mask
- ☒ Topology correction
- ☒ Wisp removal
- ☒ **Inner cortical surface**
- ☒ Pial surface
- ☒ Split hemispheres
- ☐ Register and label brain

Inner Cortical Surface

Generate inner cortical surface

Inner Cortical Surface

Smoothing iterations 10

Smoothing constant 0.5

Curvature weight 5

Automatically Save Results

☒ save output of each stage automatically

Suggest Prefix and Directory

Extraction results will be saved to
/Users/shattuck/Desktop/VancouverWorkshop2017/extraction/2523412.*

Filename Prefix 2523412

Working Directory /Users/shattuck/Desktop/VancouverWorkshop2017/extraction

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

The screenshot displays the BrainSuite software interface. The main window shows three axial brain slices with green outlines representing the inner cortical surface. A 3D rendering of the brain surface is visible in the bottom right. A configuration window titled 'Cortical Surface Extraction Sequence' is open on the right, showing various extraction stages and parameters.

BrainSuite Log

```
wrote /Users/shattuck/Desktop/VancouverWorkshop2017/extraction/2523412.cortex.tca.mask.nii.gz
Topology Correction took 0:06.932
wrote /Users/shattuck/Desktop/VancouverWorkshop2017/extraction/2523412.cortex.dewisp.mask.nii.gz
Wisp Removal took 0:05.158
wrote /Users/shattuck/Desktop/VancouverWorkshop2017/extraction/2523412.inner.cortex.dfs
Inner Cortical Surface took 0:00.603
```

Cortical Surface Extraction Sequence

Step > Stage >> Run All

Extraction Stages

- ☒ Skull stripping
- ☒ Skull and scalp
- ☒ Nonuniformity correction
- ☒ Tissue classification
- ☒ Cerebrum labeling
- ☒ Inner cortical mask
- ☒ Scrub mask
- ☒ Topology correction
- ☒ Wisp removal
- ☒ Inner cortical surface
- ☒ **Pial surface**
- ☒ Split hemispheres
- ☐ Register and label brain

Pial Surface

Presmooth iterations: 80

Iterations: 100

Collision detection radius (mm): 1

Thickness limit (mm): 20

Step size (mm): 0.4

Tissue threshold: 1.05

Smoothing constant: 0.025

Radial constant: 0.2

Update surface interval: 10

☒ constrain with cerebrum mask

Load Custom Mask

Automatically Save Results

☒ save output of each stage automatically

Suggest Prefix and Directory

Extraction results will be saved to
/Users/shattuck/Desktop/VancouverWorkshop2017/extraction/2523412.*

Filename Prefix: 2523412

Working Directory: /Users/shattuck/Desktop/VancouverWorkshop2017/extraction

BrainSuite Log

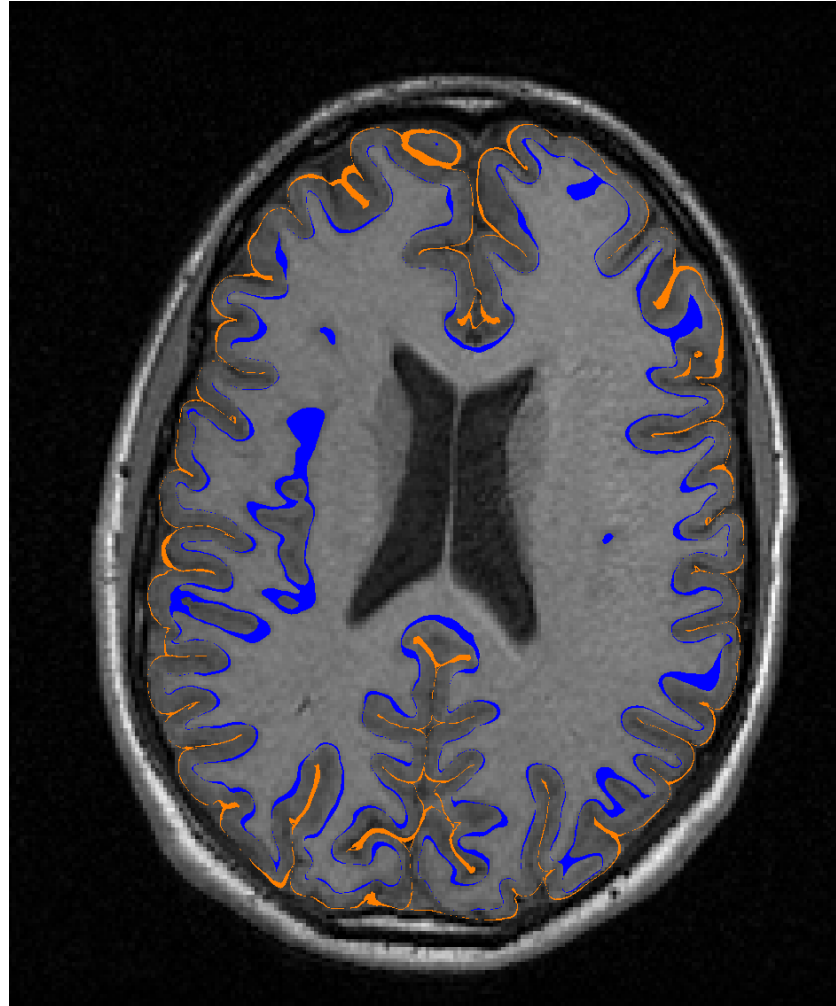
V: 265.85 R: 145 R: 1164 L: 5 GW grey matter/white matter

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

The image displays the BrainSuite software interface for brain surface extraction. The main window shows four views of a brain: three axial slices (top-left, bottom-left, and top-right) and a 3D surface reconstruction (bottom-right). The slices are labeled with 'S' for superior, 'I' for inferior, 'R' for right, and 'L' for left. The 3D surface is colored with a gradient from red to yellow. A 'Cortical Surface Extraction Sequence' dialog box is open on the right, showing a list of extraction stages with checkboxes. The 'Split hemispheres' stage is checked. Below the list, there is a section for 'Split Hemispheres' with a dropdown menu and a message: 'There are no parameters for the hemisphere splitting module.' At the bottom of the dialog, there is a section for 'Automatically Save Results' with a checked box for 'save output of each stage automatically' and a 'Suggest Prefix and Directory' button. The 'Filename Prefix' is set to '2523412' and the 'Working Directory' is set to '/Users/shattuck/Desktop/VancouverWorkshop2017/extraction'. A log window at the bottom left shows the following text:

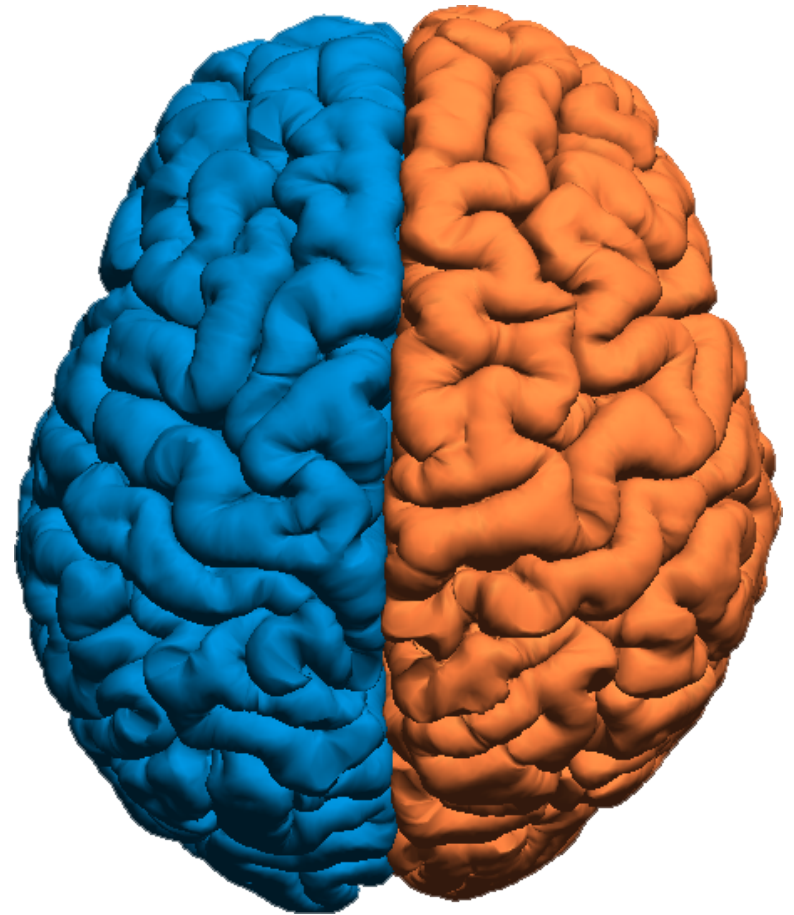
```
Inner Cortical Surface took 0:00.603
copied cerebrum mask to displayed mask
using cerebrum mask to constrain surface expansion.
Completed pial surface generation.
wrote /Users/shattuck/Desktop/VancouverWorkshop2017/extraction/2523412.pial.cortex.dfs
Pial Surface took 9:37.386
```

At the bottom of the main window, the coordinates and tissue type are displayed: V: 265.85 R: 145 R: 1164 L: 5 GW grey matter/white matter

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

The image displays the BrainSuite software interface for brain image processing. The main window shows four panels: three axial/sagittal views of a brain slice with green outlines and one 3D rendering of a brain hemisphere. The 3D rendering is colored with a gradient from red to yellow. The interface includes a top toolbar with various icons and a bottom status bar.

BrainSuite Log

Inner Cortical Surface took 0:00.603
copied cerebrum mask to displayed mask
using cerebrum mask to constrain surface expansion.
Completed pial surface generation.
wrote /Users/shattuck/Desktop/VancouverWorkshop2017/extraction/2523412.pial.cortex.dfs
Pial Surface took 9:37.386

V: 265.85 R: 145 R: 1164 L: 5 GW grey matter/white matter

Cortical Surface Extraction Sequence

Step > Stage >> Run All

Extraction Stages

- ☒ Skull stripping
- ☒ Skull and scalp
- ☒ Nonuniformity correction
- ☒ Tissue classification
- ☒ Cerebrum labeling
- ☒ Inner cortical mask
- ☒ Scrub mask
- ☒ Topology correction
- ☒ Wisp removal
- ☒ Inner cortical surface
- ☒ Pial surface
- ☒ Split hemispheres
- ☐ Register and label brain

Finished
Finished splitting hemispheres

Automatically Save Results

☒ save output of each stage automatically

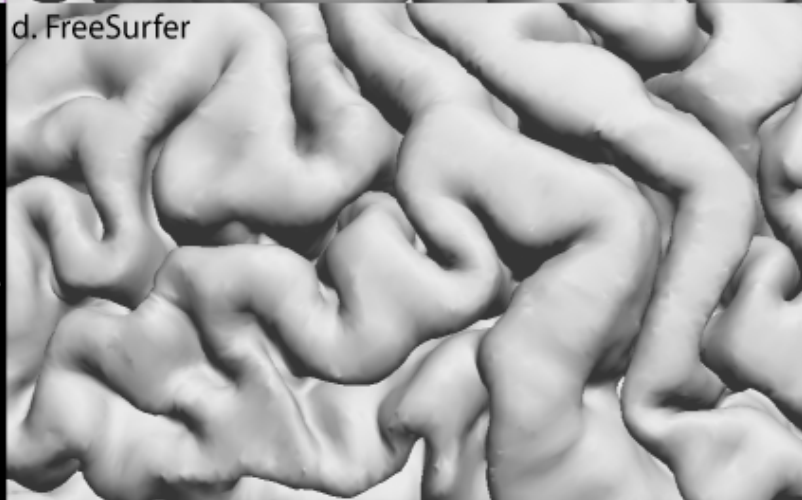
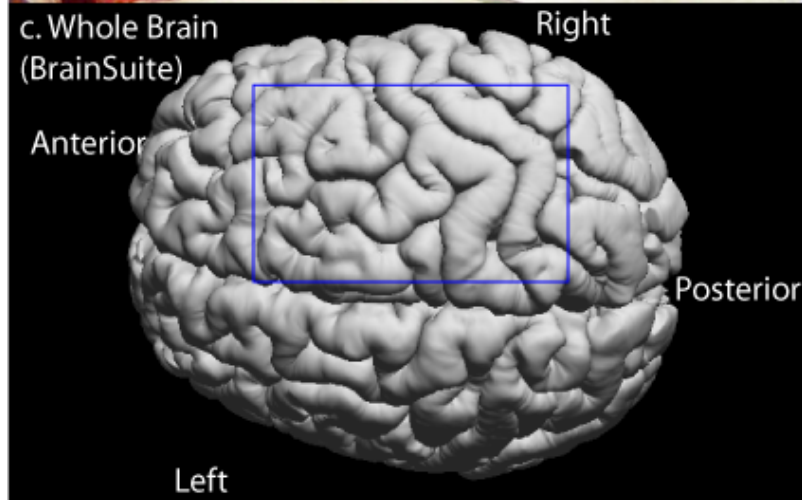
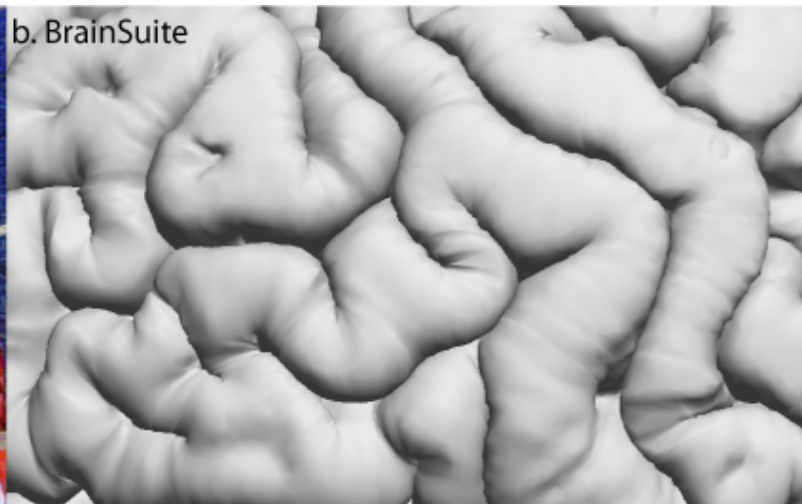
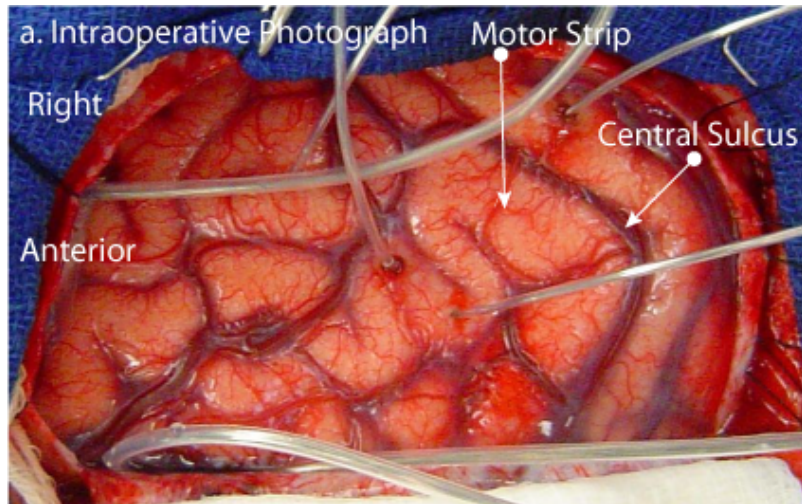
Suggest Prefix and Directory

Extraction results will be saved to
/Users/shattuck/Desktop/VancouverWorkshop2017/extraction/2523412.*

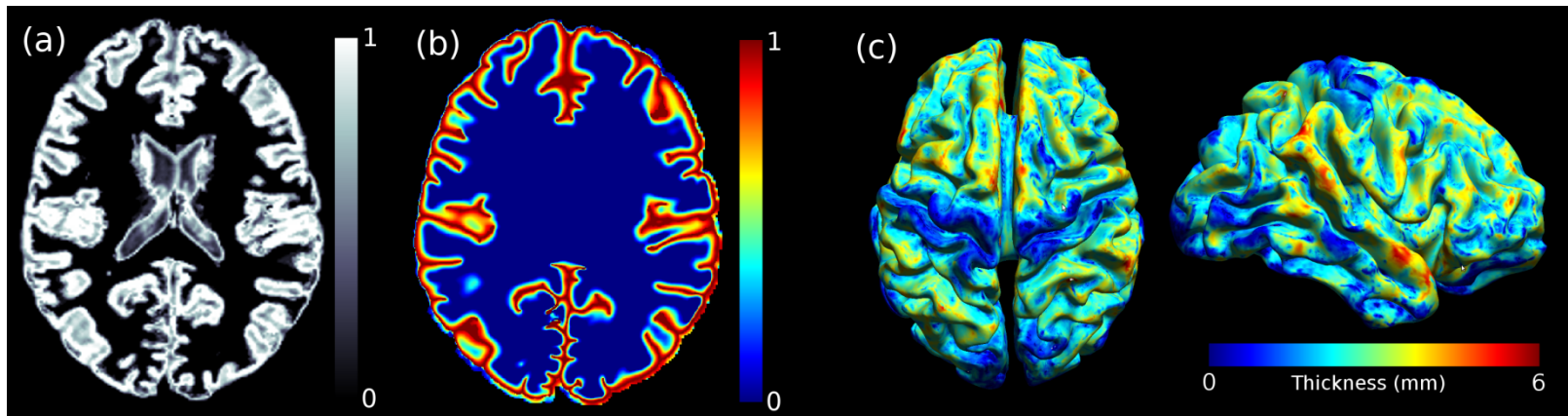
Filename Prefix: 2523412

Working Directory: /Users/shattuck/Desktop/VancouverWorkshop2017/extraction

Automated Surfaces vs Intraoperative Photograph

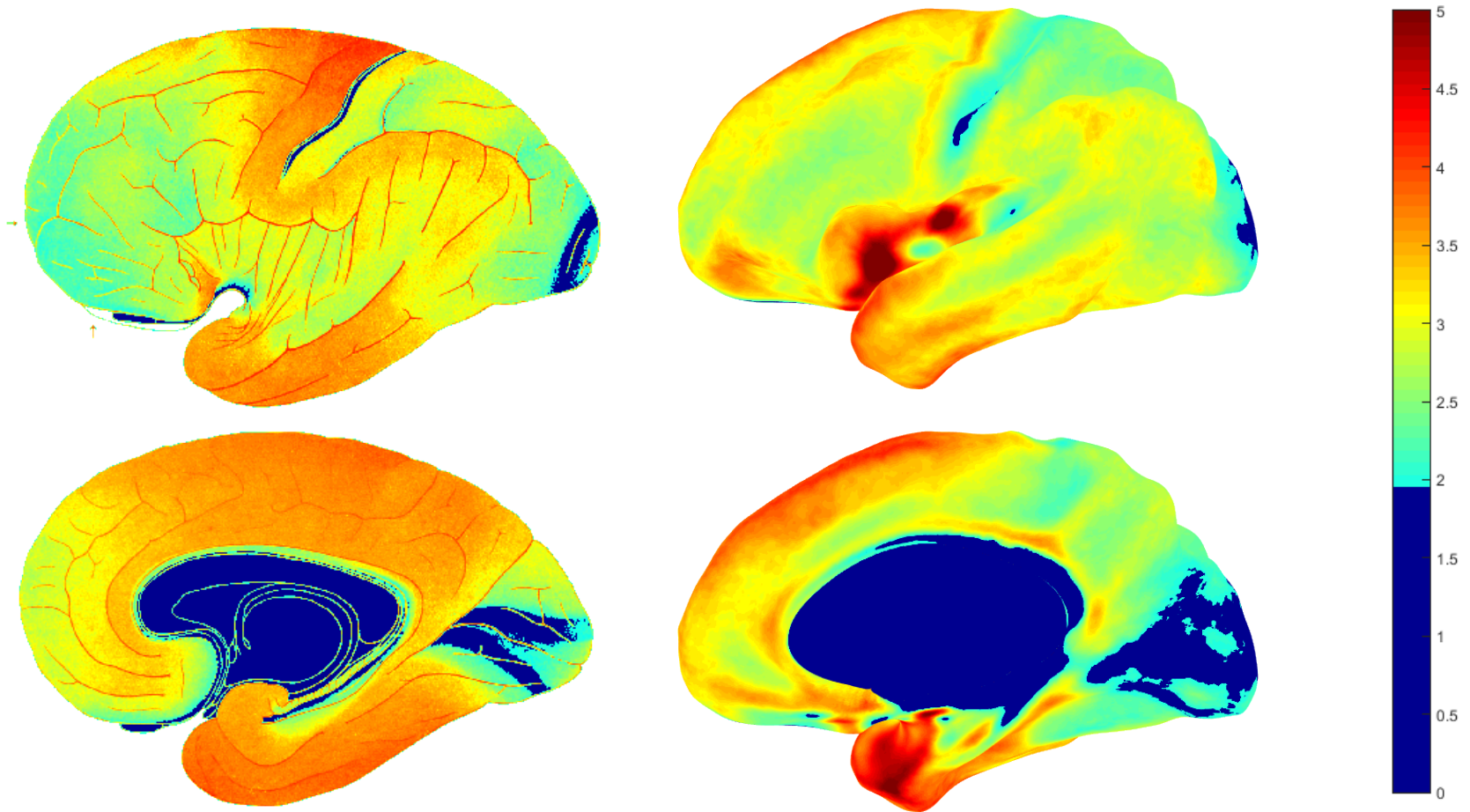


Cortical Thickness using Partial Tissue Fraction Estimates



- (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.

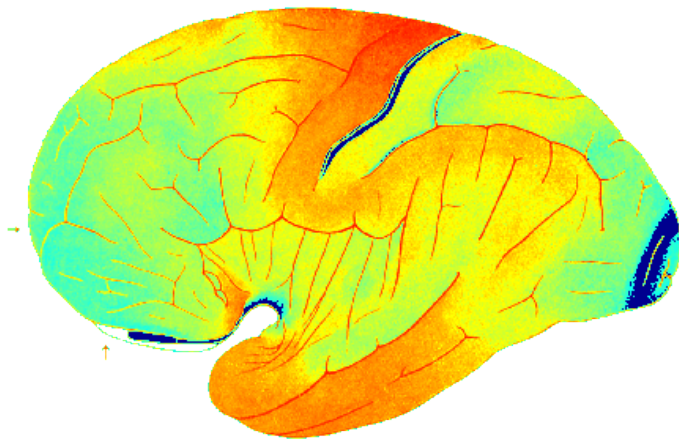
Comparisons



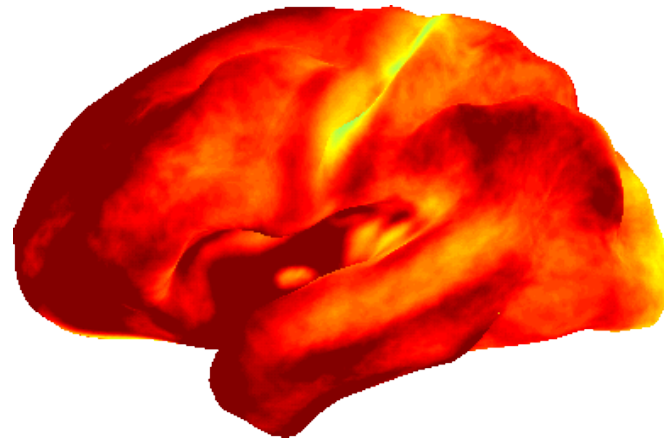
Von Economo and Koskinas (1925)

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

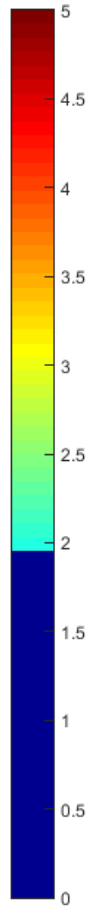
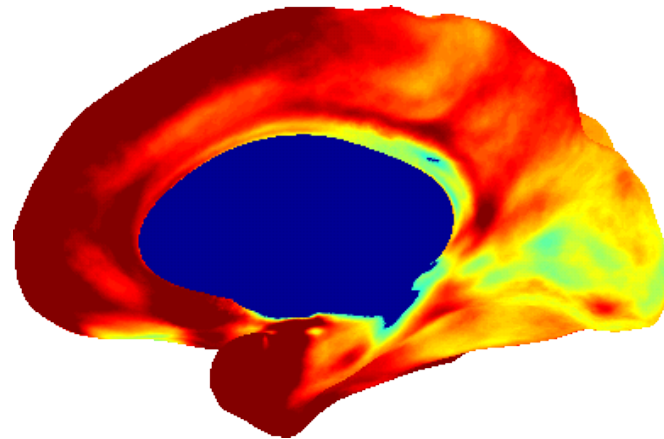
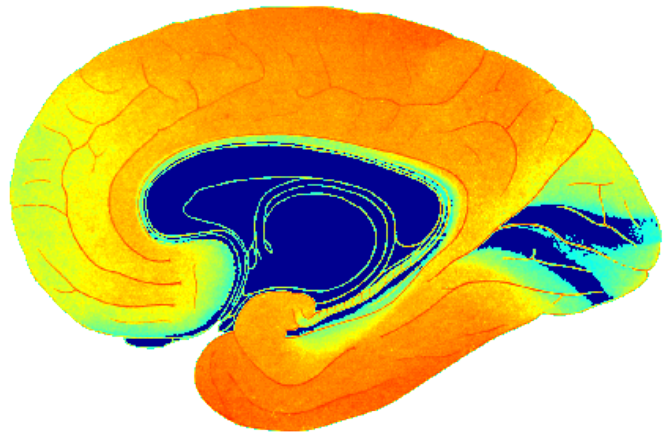
Comparisons



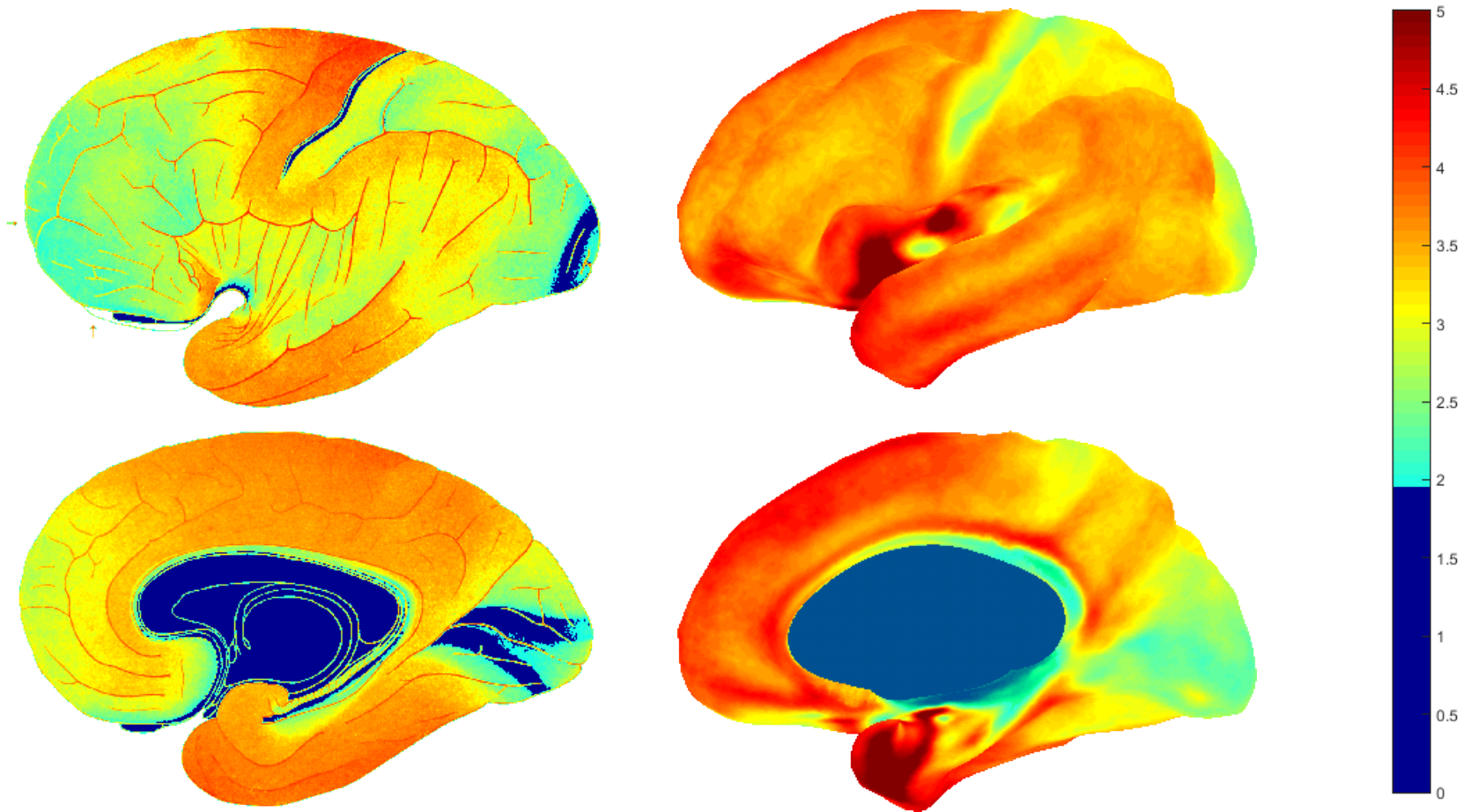
Von Economo and Koskinas (1925)



From MRI using linked distance
(averaged over 186 subjects)



Comparisons



Von Economo and Koskinas (1925)

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