

# BrainSuite13: New Tools for Brain Image Labeling, Connectivity Analysis, and Visualization



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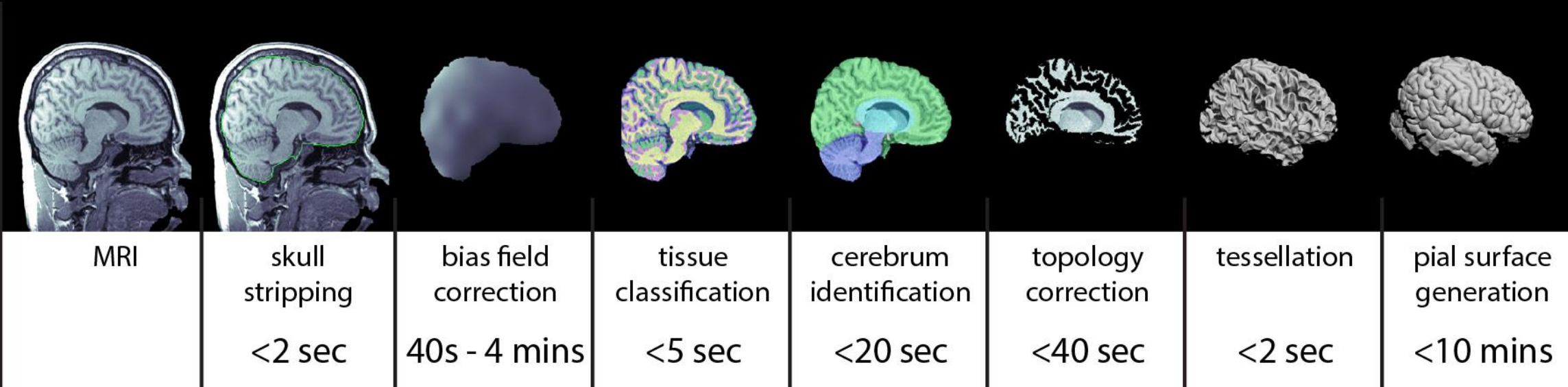
## I. INTRODUCTION

- We describe BrainSuite13, a collection of software tools for jointly processing and visualizing structural and diffusion MRI of the brain.
- BrainSuite13 can combine the results of structural and diffusion processing to generate connectivity maps of the brain based on a set of anatomical ROIs.
- These tools can be applied using scripts or through a graphical user interface (GUI) that provides sophisticated interactive processing and visualization capabilities.
- BrainSuite13 features:
  - Fast processing times – less than 1 hour to extract, register, and label a T1 MRI.
  - Novel methods for correcting distortion in DWI.
  - Visualization capabilities for multiple types of data.
  - Powerful tools for exploring diffusion and connectivity information.
  - Flexibility for performing different types of analysis.

## II. METHODS

### II.a. Software Implementation

- We developed the BrainSuite13 image processing software collection using C++ and compiled MATLAB code.
- The command line tools can be run on Windows, Mac, and Linux
- The graphical user interface is developed using C++, Qt, and OpenGL.
  - Provides interactive tools for displaying image slices, surface models, tensor glyphs, orientation distribution functions (ODFs), and streamline tractography.
  - Provides guided processing through extraction, registration, and labeling steps
  - Includes tools for delineating ROIs interactively.
- The interactive version is available for Windows and Mac (Linux release planned).



**Fig.1. The BrainSuite Cortical Extraction Sequence.** This sequence can extract a set of inner and outer cortical surface meshes for a typical T1-weighted MRI in approximately 10-15 minutes (processed on an Intel 3.5GHz i7-3770).

### II.b. SURFACE EXTRACTION

- Whole-head human T1-weighted anatomical MRIs are processed using BrainSuite's automated cortical surface extraction sequence (see **Fig. 1**) [1].
- Produces inner and outer surface mesh models of the cerebral cortex.
  - The GUI enables manual corrections to be applied at several stages if automated processing does not achieve sufficient quality for segmenting structures.

### II.c. AUTOMATED LABELING OF NEUROANATOMICAL ROIS

The cortical mesh models are registered spatially to a labeled single subject anatomical brain atlas.

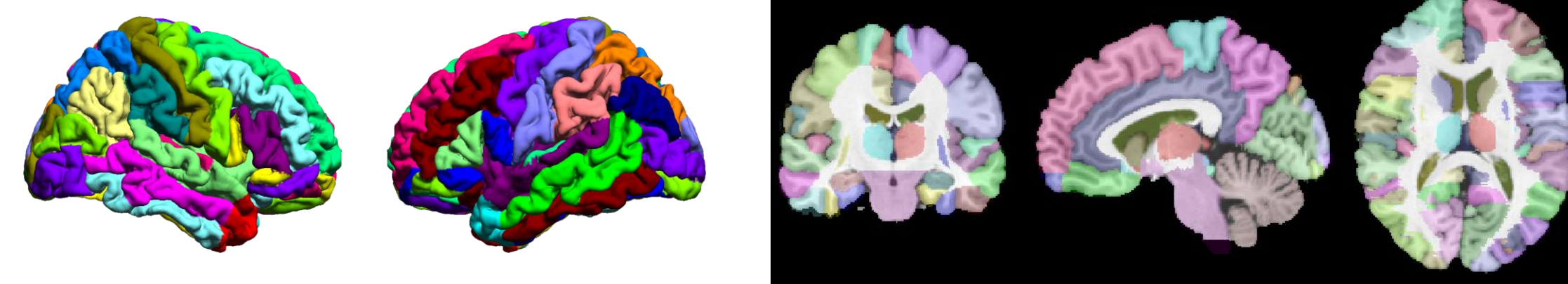
#### Neuroanatomical Atlas

- Based on a T1-weighted MRI with corresponding cortical surface mesh representations generated using the BrainSuite software.
- The atlas comprises surface and volume data that were delineated manually by an expert neuroanatomist into 98 anatomical ROIs (see **Fig. 2**).

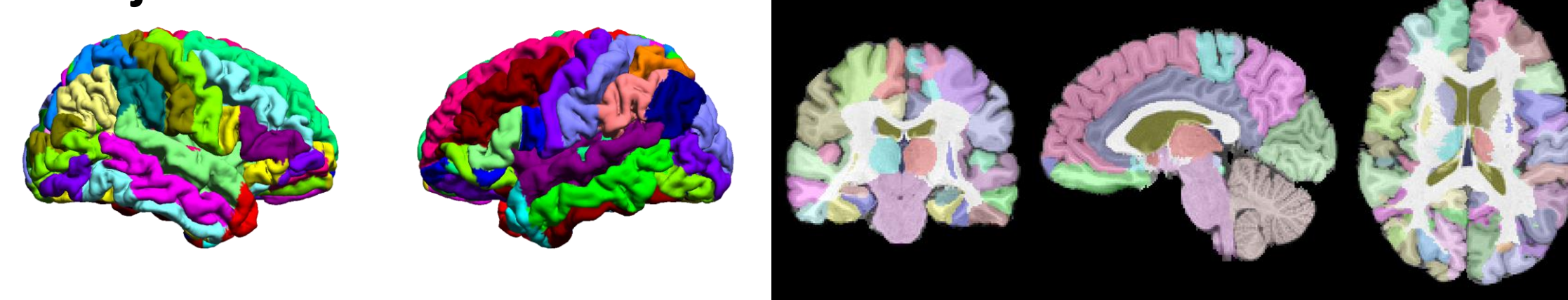
#### Surface/Volume Registration (SVReg)

- Registration is performed using a combined surface/volume procedure [2].
  - First employs a curvature-based surface registration process to align the cortical surface features of the subject and the atlas.
  - Surface registration is used to initialize a volumetric alignment.
  - Volumetric alignment is refined using elastic image registration.
  - Produces an alignment of the cortical features in the surface space, with a corresponding alignment of the volumetric data.
- The labels from the atlas are transferred to the surface and volume of the subject data, producing a segmentation of the subject MRI into the delineated ROIs.
- The ROI boundaries on the cortical surfaces are refined locally at the mid-cortical surface using geodesic curvature flow [3], such that the boundaries conform to the bottoms of the sulcal valleys.
- The structural image processing modules enable various attributes to be measured and compared, e.g., cortical thickness and ROI volumes.
- The surface and volume labels are useful for analysis of functional, structural, and parametric images.
- Registration, labeling, and refinement stages can be performed in ~40 minutes for a typical MRI (processed on an Intel 3.5GHz i7-3770).

### Atlas



### Subject



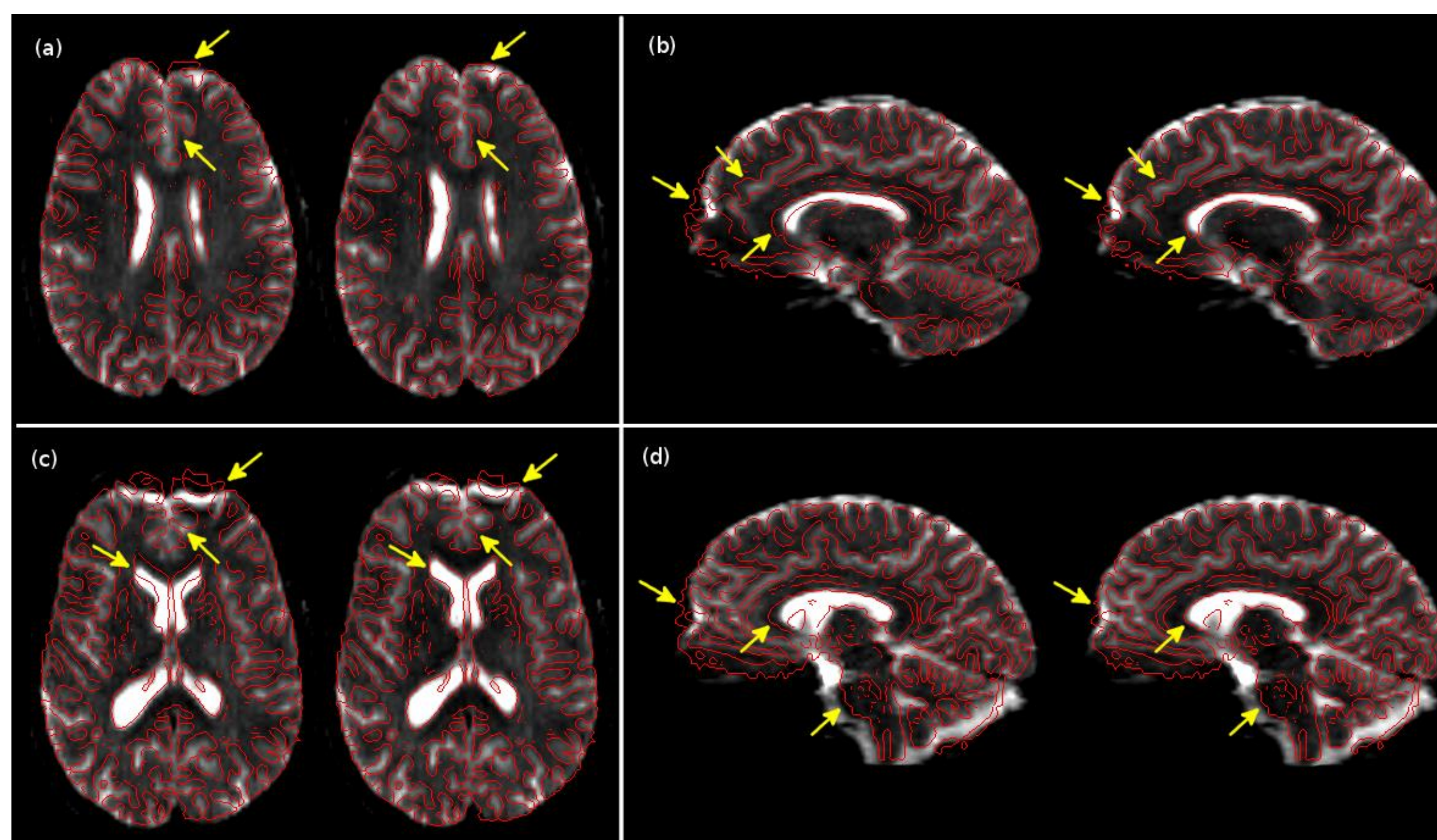
**Fig.2. BrainSuite13 ROI Labeling** (top) Surface and volume views of the BrainSuite13 anatomical atlas, delineated into anatomical regions of interest. (bottom) Similar views of an automatically labeled subject dataset.

### II.d. DIFFUSION IMAGE PROCESSING

#### Distortion Correction

BrainSuite13 provides two methods for correcting distortion induced by B0 inhomogeneity in diffusion weighted images (either can be used for correction):

- Registration-based: uses a constrained non-rigid registration (see **Fig. 3**) to the undistorted T1-weighted anatomical image [4] (does not require fieldmap).
- Fieldmap-based: uses a fieldmap collected during the diffusion MRI session to correct for distortion.



**Fig. 3. Registration based distortion correction (without fieldmap) via the BrainSuite Diffusion Pipeline (BDP).** Each sub-figure shows (left) distorted and (right) corrected b=0 image, overlaid with the edge-map (red outline) generated from the T1-weighted image. Arrows indicate areas of significant correction.

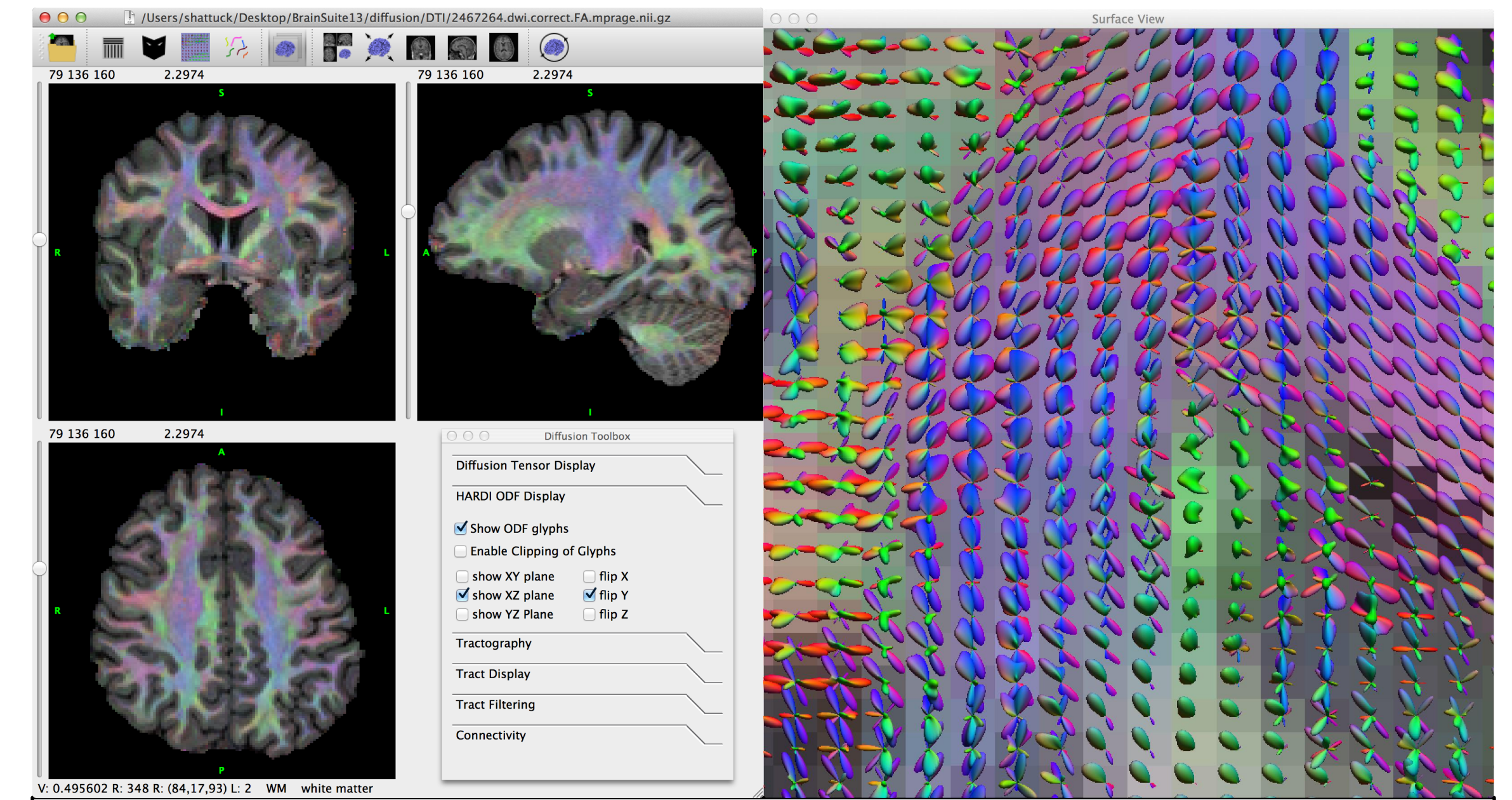
#### Tensor and ODF Estimation

- After coregistering the diffusion weighted images and the T1-weighted image, tensors and ODFs are estimated in the structural T1 image space (see **Fig. 4**).
- The BrainSuite Diffusion Pipeline can quantify the diffusion signal in three ways:
  - Fitting a diffusion tensor imaging (DTI) model.
  - Applying the Funk-Radon Transform (FRT) [5].
  - Applying the Funk-Radon and Cosine Transform (FRCT) [6-7].
- The Funk-Radon and Cosine Transform is a new linear transform-based ODF estimation method that generalizes the FRT.
- FRCT can provide higher angular resolution and/or robustness to noise and modeling errors than existing state-of-the-art ODF estimation methods.



#### SOFTWARE DOWNLOAD

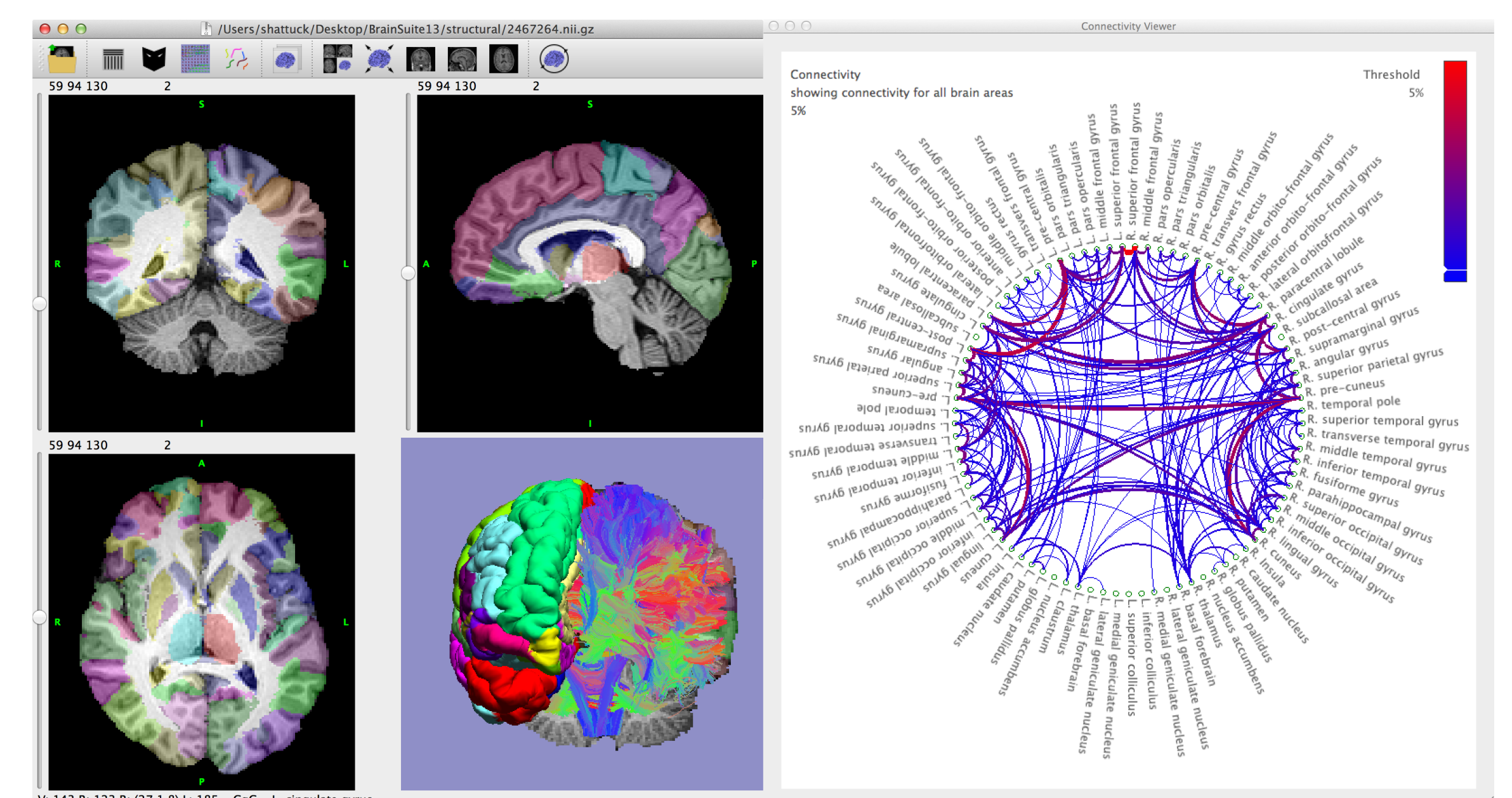
For more information or to download the software, please visit the BrainSuite website: <http://brainsuite.loni.ucla.edu>. Tutorials and sample data are also available on our website.



**Fig. 4. Diffusion Imaging in BrainSuite13.** (left) T1 image, overlaid with a color FA map computed from the coregistered, distortion-corrected diffusion images; and (right) 3D rendering of FRCT ODFs displayed with blended T1 and color FA image slices. The input imaging data are from the Beijing Enhanced dataset [8].

### II.e. CONNECTIVITY ANALYSIS AND VISUALIZATION

- Diffusion streamlines are tracked using a deterministic method.
- For each pair of ROIs, the number of tracks passing through both ROIs is counted to produce a connectivity matrix, which is normalized by its maximum element.
- This matrix structure is represented visually using a circular plot, in which the connectivity strength is indicated by the weight and color of the arc connecting the ROIs on the plot (see **Fig. 5**).
- The connectivity graph is synchronized with the 3D display, enabling users to select regions of interest and visualize the corresponding connected fiber tracks.



**Fig. 5. Tractography and connectivity in BrainSuite13.** (left) a T1-weighted MRI and extracted hemisphere surface with labeled ROIs, and a set of diffusion fiber tracks; (right) the interactive connectivity diagram, based on the same data shown in Fig. 4.

## III. RESULTS

- Our recently released software, BrainSuite13, provides integrated functionality for processing and visualizing structural and diffusion MRI.
- The results of BrainSuite13's segmentation, labeling, diffusion, and connectivity processing are shown in **Fig. 5**.
- The software is available for download at <http://brainsuite.loni.ucla.edu>.

## IV. REFERENCES

- Shattuck and Leahy, *Medical Image Analysis* 2002; 8(2):129-142.
- Joshi et al., *IEEE TMI* 2007; 26(12):1657-1669.
- Joshi et al., *WBIR 2012*: 180-189.
- Bhushan et al., *APSIPA* 2012.
- Tuch et al., *Magn Reson Med* 2004;52:1358-1372.
- Haldar and Leahy, *NeuroImage* 2013;71:233-247.
- Haldar and Leahy, *Proc IEEE ISBI* 2013; 504-507.
- [http://fcon\\_1000.projects.nitrc.org/indi/retro/BeijingEnhanced.html](http://fcon_1000.projects.nitrc.org/indi/retro/BeijingEnhanced.html)

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