SVReg: Surface-constrained Volumetric Registration

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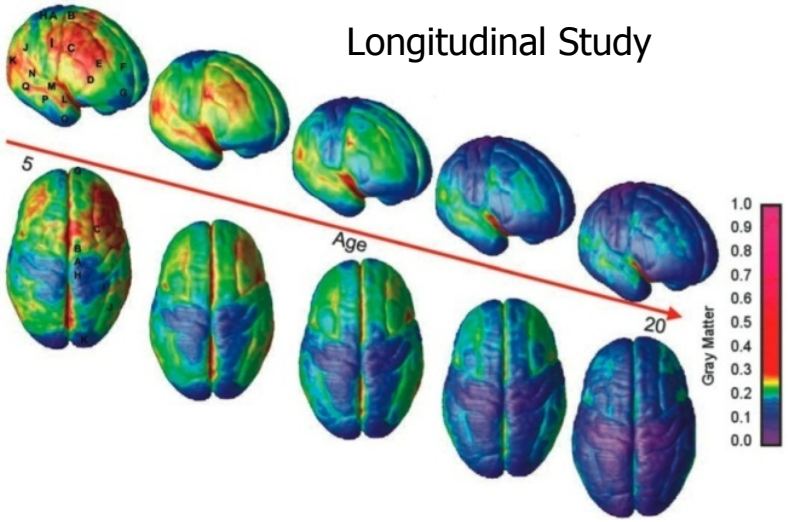
http://brainsuite.bmap.ucla.edu/processing/svreg/

Motivation for Brain Image Registration

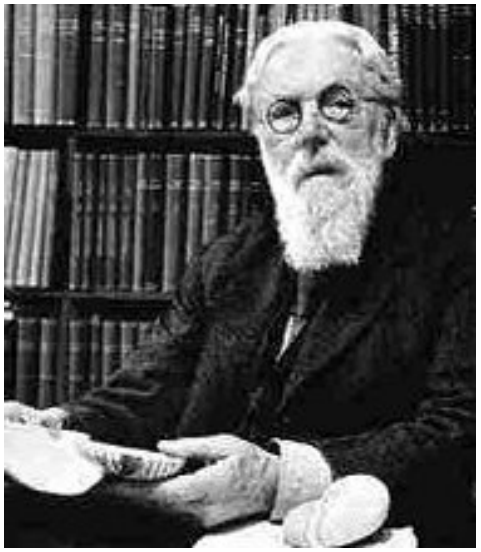
- Analysis of morphometric changes
  - Progression of disease
  - Brain development over time
  - Group differences
  - Lesions, Tumors
- Functional studies
  - Intersubject comparisons of fMRI, MEG,
  - Longitudinal studies of same subject over a period of time
- We use image registration for transferring labels from atlas to subject



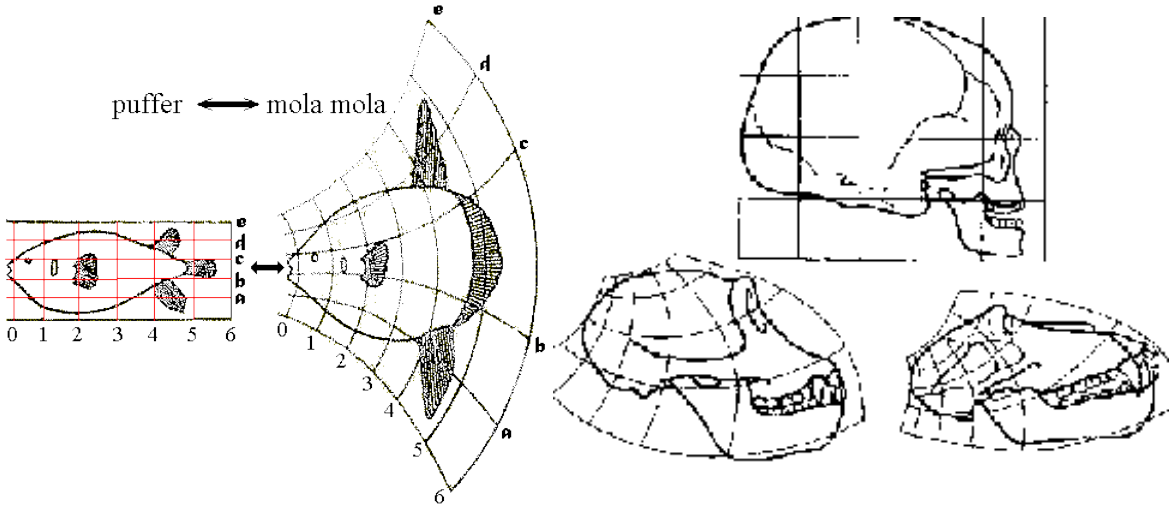
Brain development, N. Gogtay (PNAS'04)

Inter- and intra-subject surface and volume alignment tools are required to integrate neuro-anatomical and functional data.

Image Registration



D'Arcy Thompson (1860-1948)



$$d(F_1(x), F_2(x - h(x))) + |Dh(x)|^2$$

metric

Differential operator

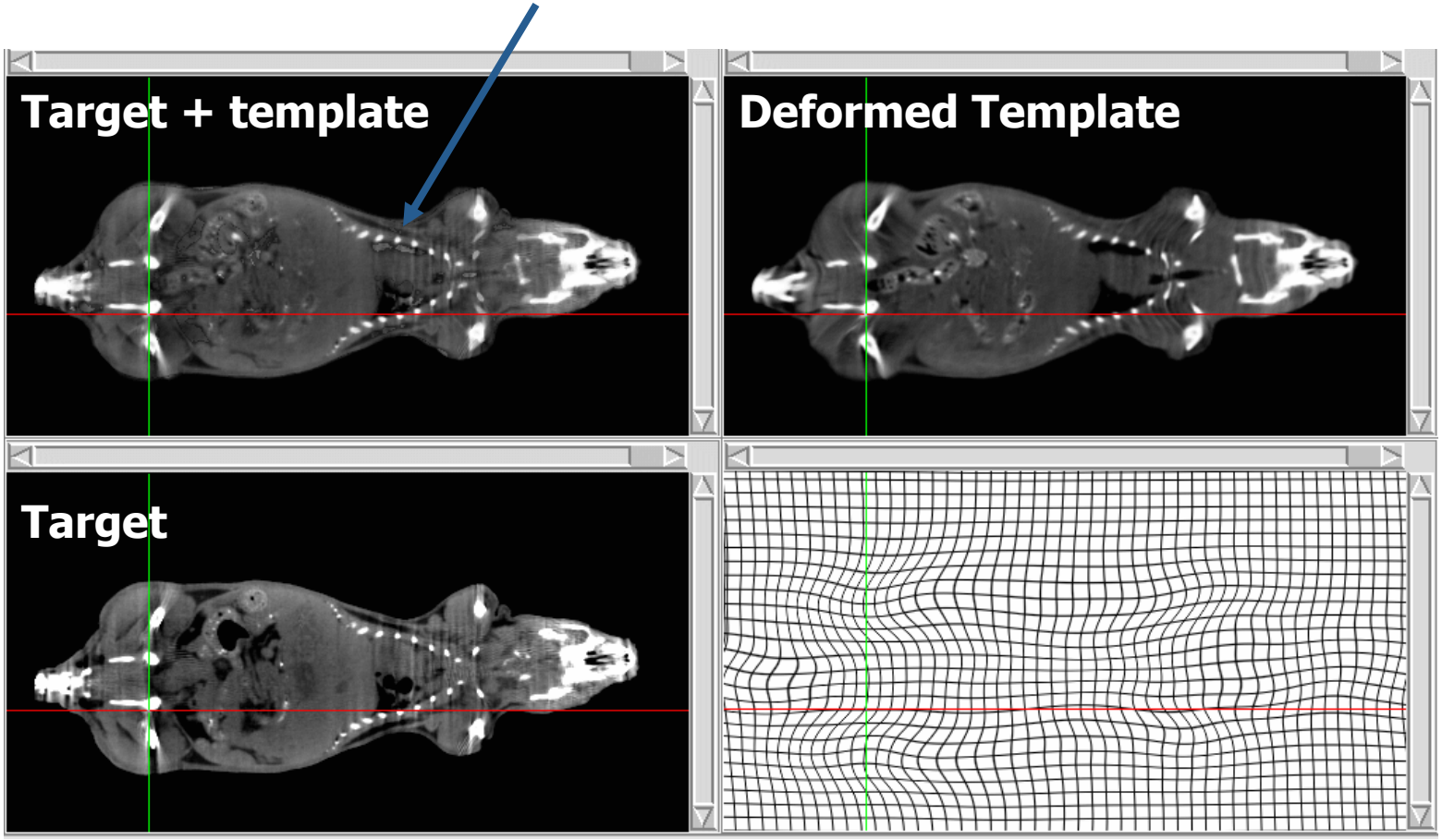
Image Features

Types of Registration Techniques:

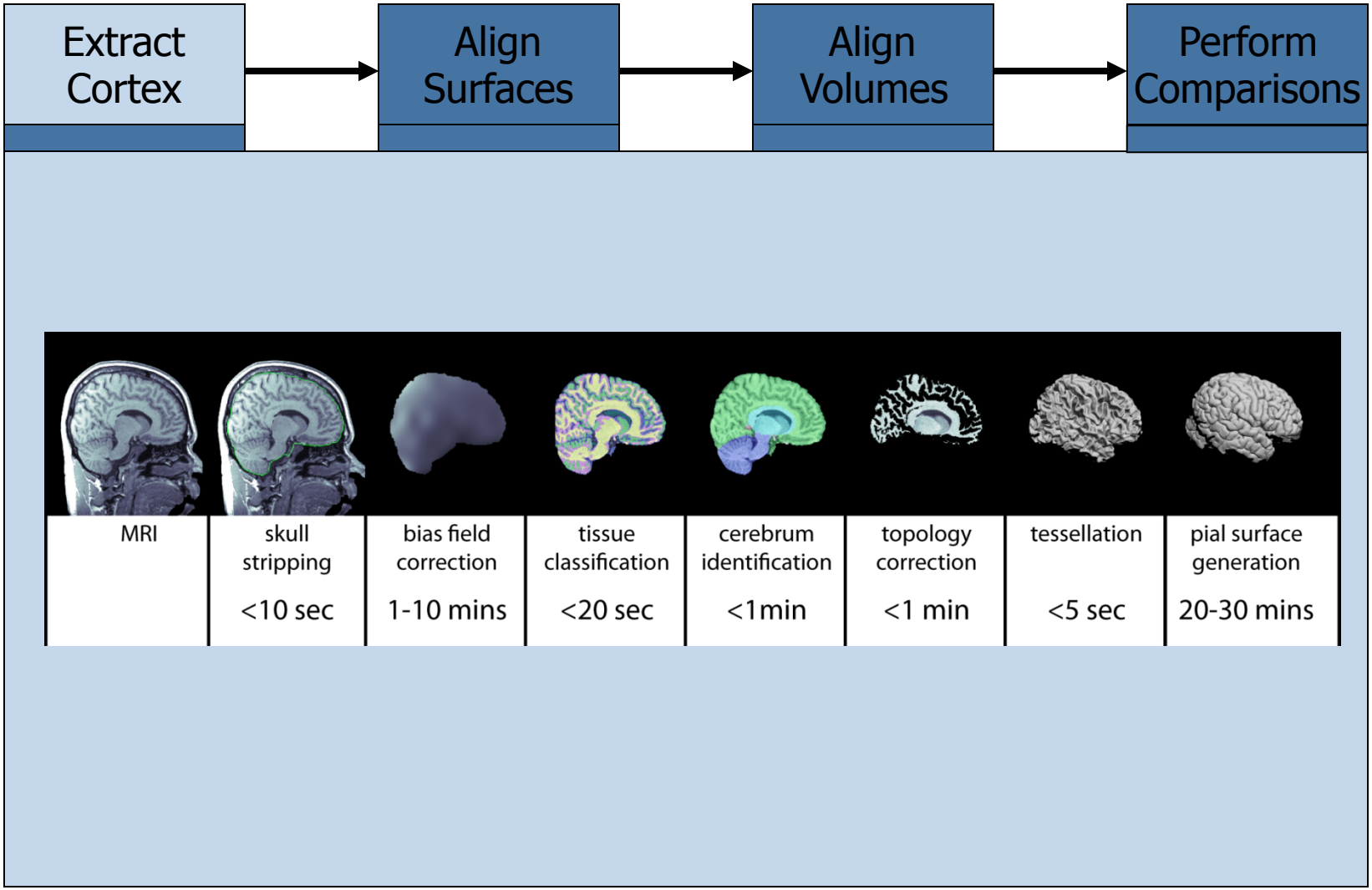
Intensity based or landmark, surface, curves based

What is Image Registration?

Mapping from point **x** of template mouse image **T,** to match to a point **y** of target mouse image **S** by a transformation **y=h(x)=x+u(x)**

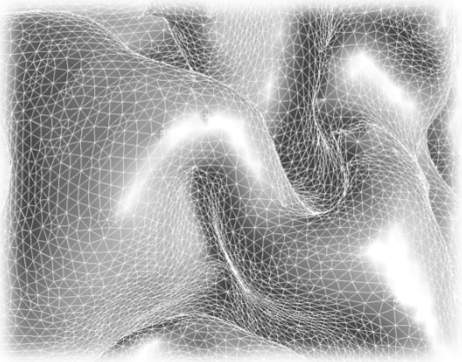


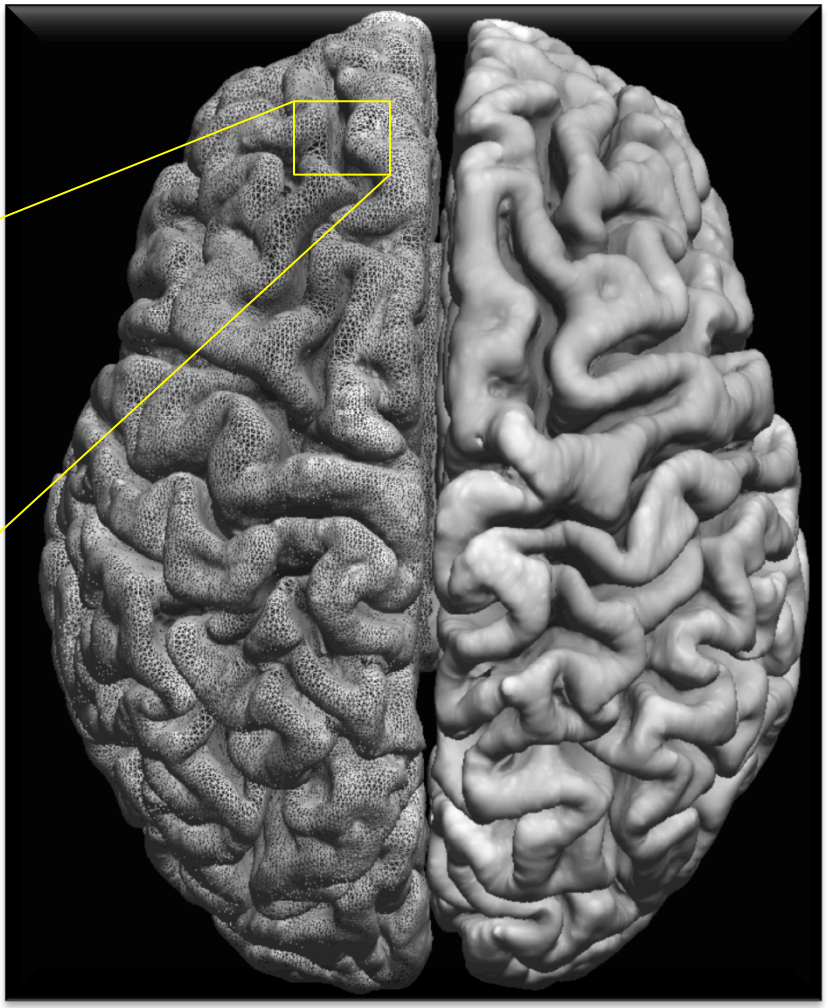
Processing Workflow



Surface Representations

Cortex is often represented as a high resolution triangulated mesh with ~ 700,000 triangles

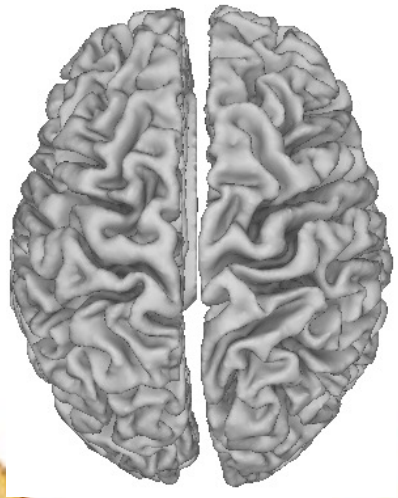




We used this triangulated mesh representation of the surface for performing signal processing and analysis.

Cortical surface mesh representation

Average surface area = 960 cm sq. (~1900 cm sq. for two hemispheres)



= two 13” pizzas!

Each cortical area ~ one 3 cm pepperoni!

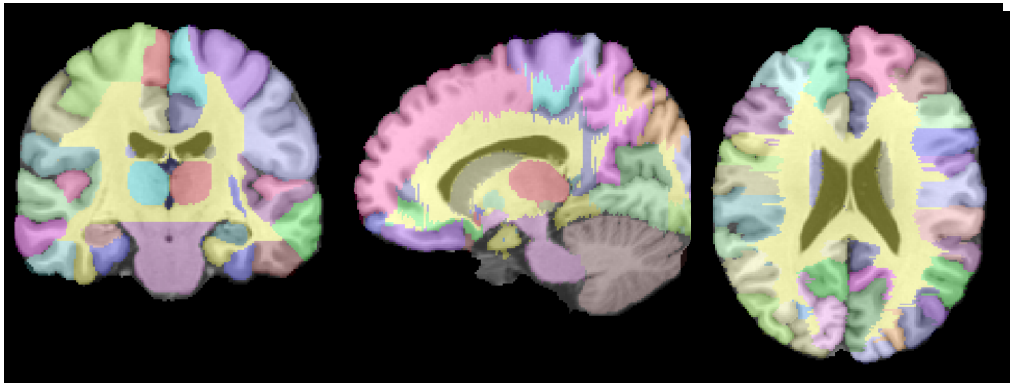
Atlas

Single subject atlas labeled at USC by expert neuroanatomist

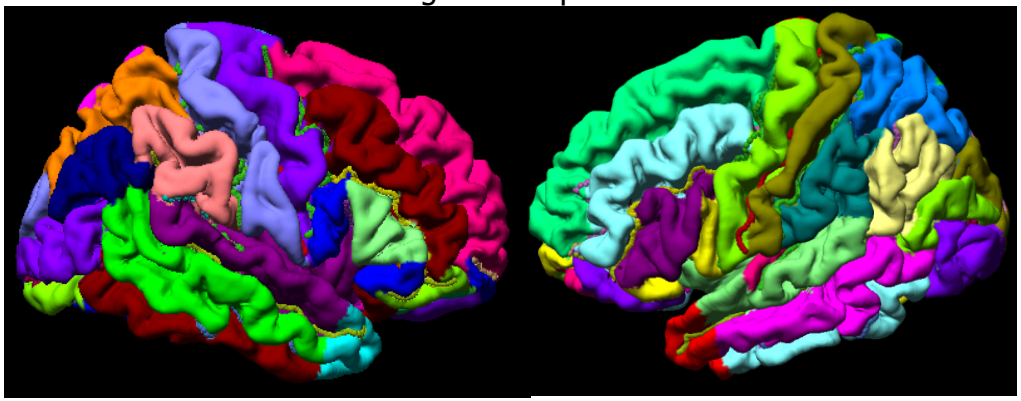
26 sulcal curves per hemisphere

98 volumetric regions of interest (ROIs), 35*2=70 cortical ROIs

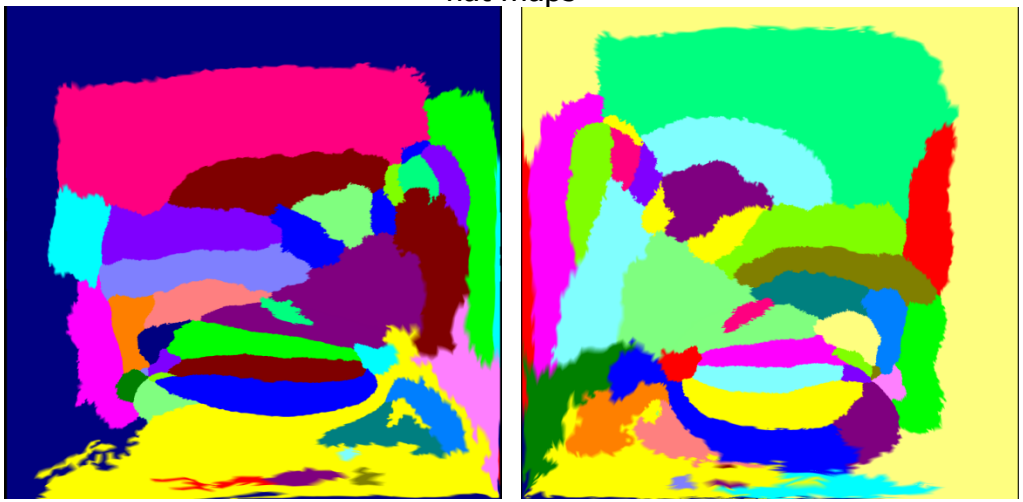
T1 MRI and label overlay



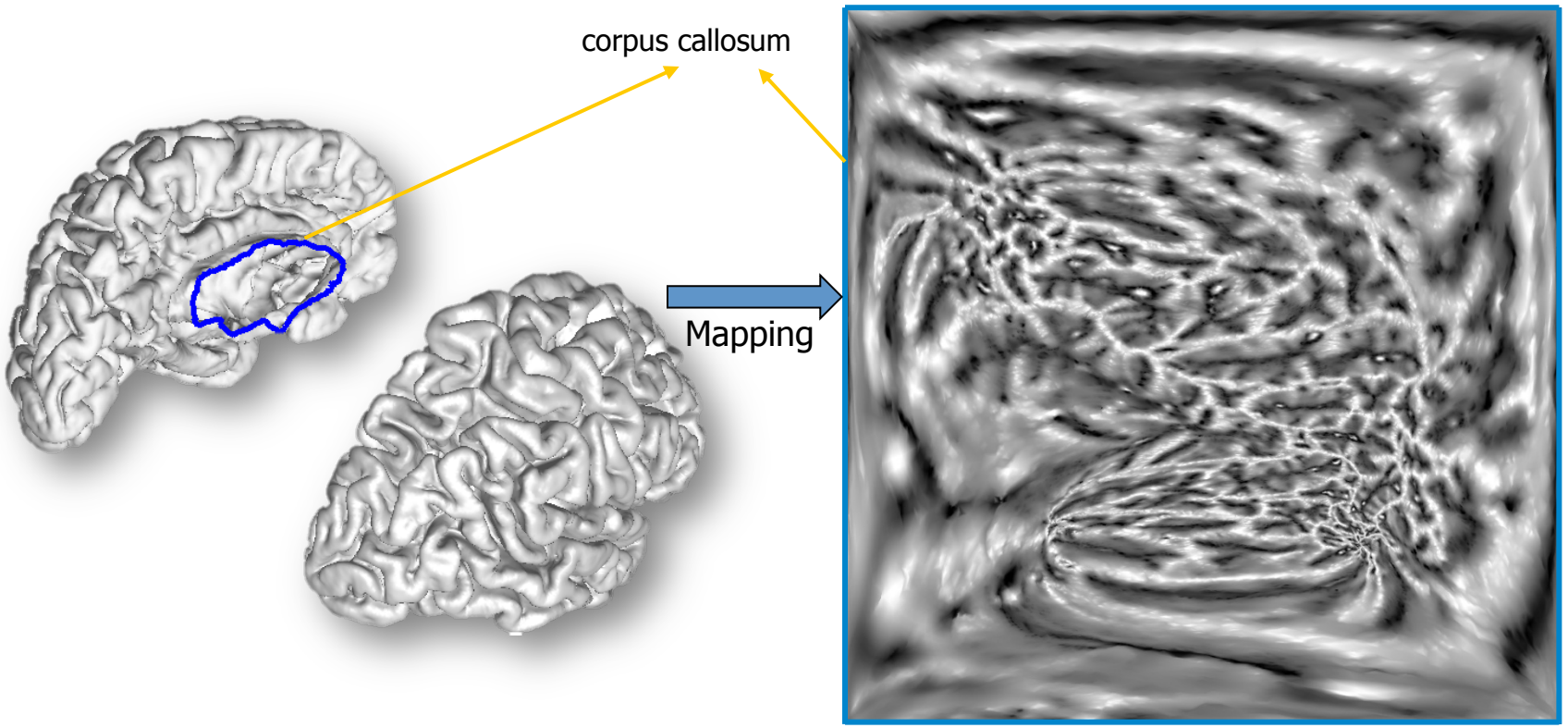
left and right hemispheres



flat maps



Cortical Surface Parameterization



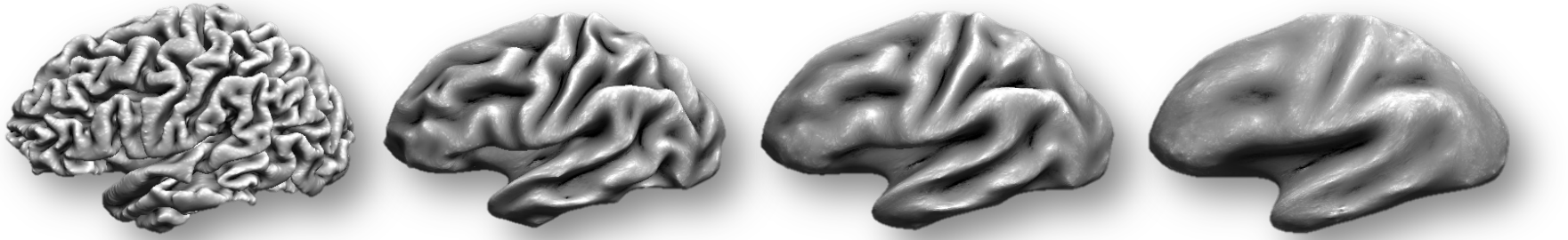
Flat-map color coded by curvature

p-harmonic maps are critical points of harmonic energy given by

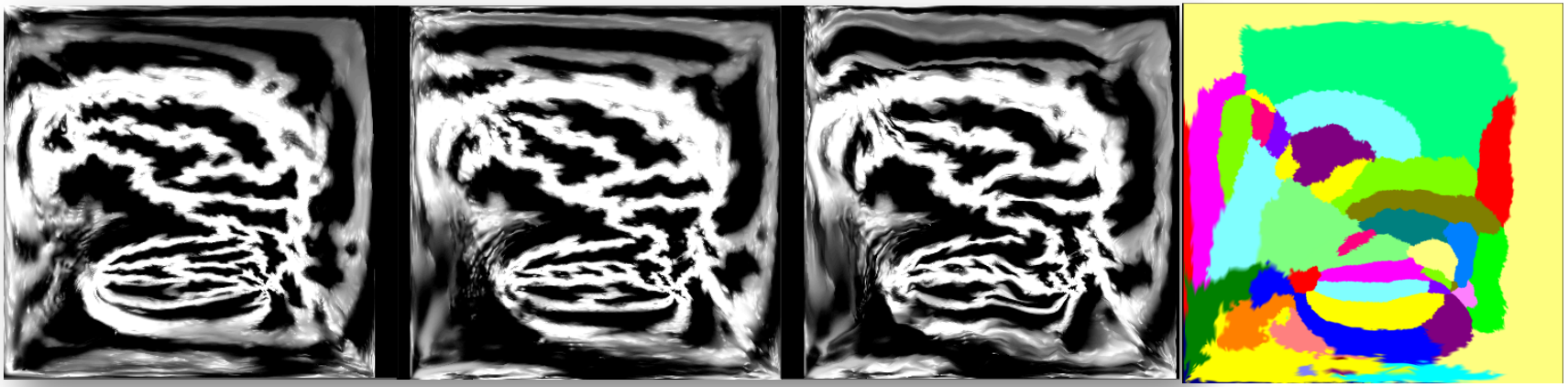
Extensions to automatic registration without sulcal curves

Input mid surface

Smoothed surfaces

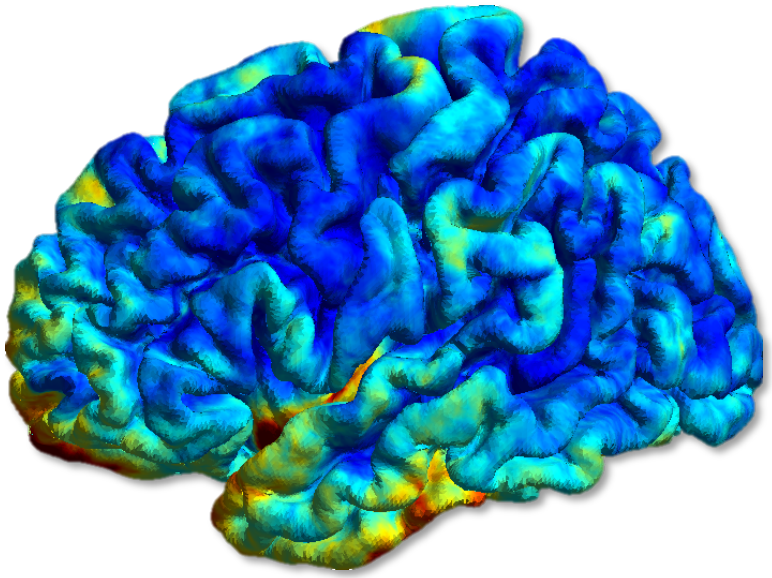


Cumulative curvature computation for multiresolution representation



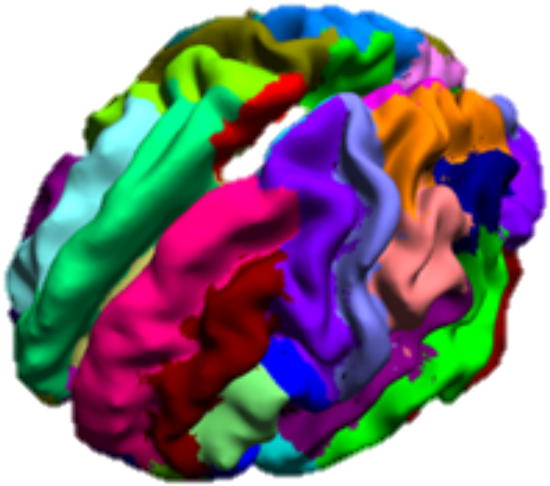
Elastic matching for atlas and subject flat maps

Curvature Weighting

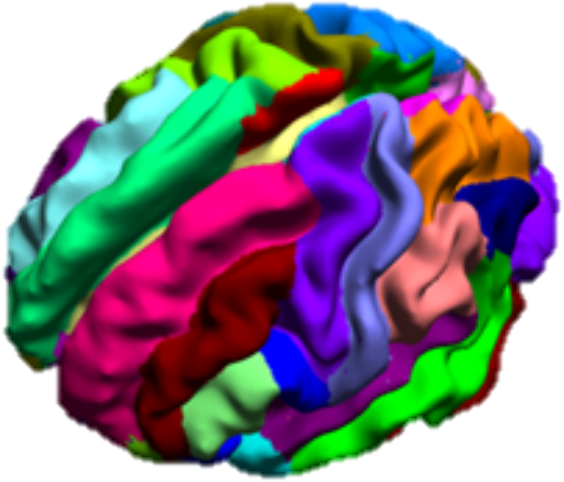


Color coded curvature Variance is shown in the figure
Computed by aligning 100 brains. Inverse of curvature variance is used as a weighting on the curvature cost function

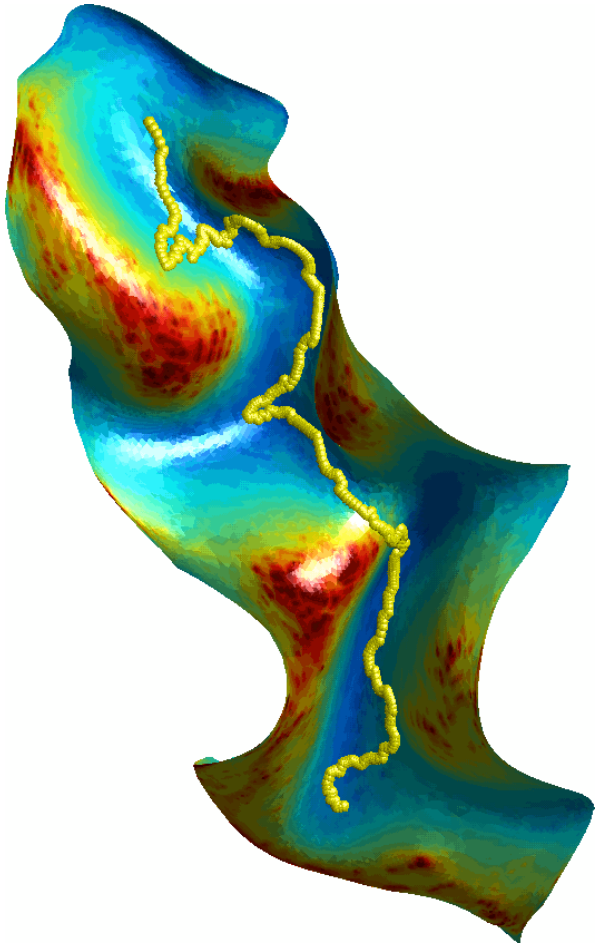
Refinement of labels and sulci



Original labels plotted on a smoothened representation of a cortical surface



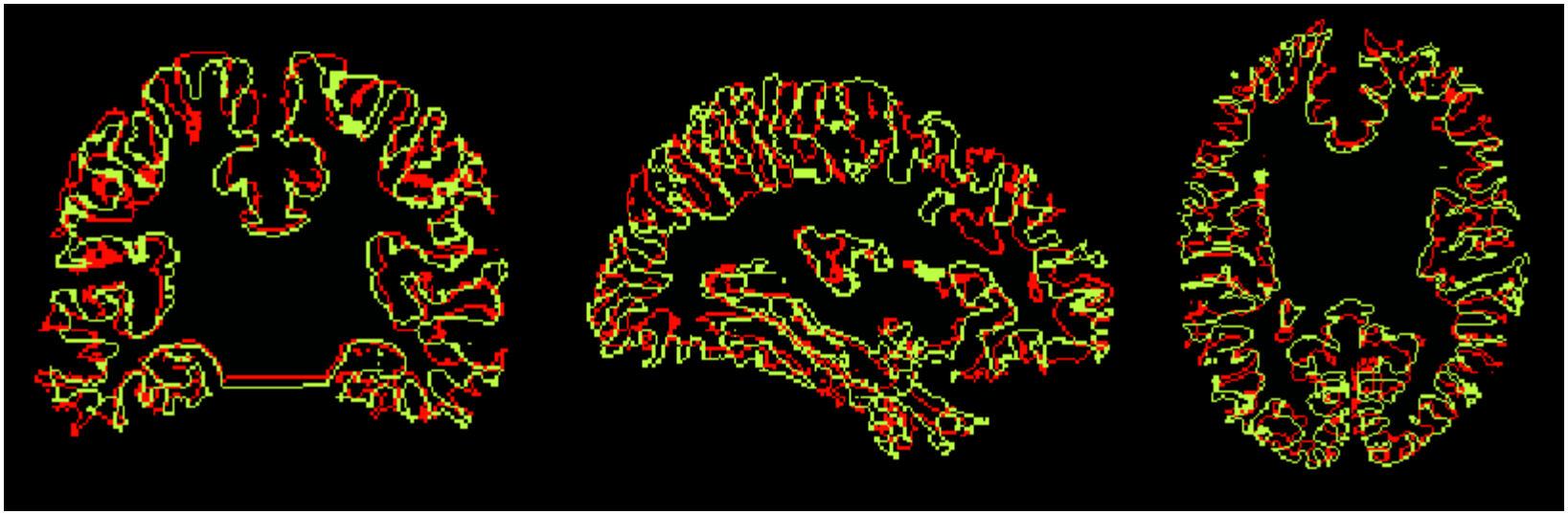
Labels after geodesic curvature Flow plotted on a smoothened representation of a cortical surface



Animation of the geodesic curvature flow for sulcal refinement

Motivation for Surface-constrained Volumetric Registration

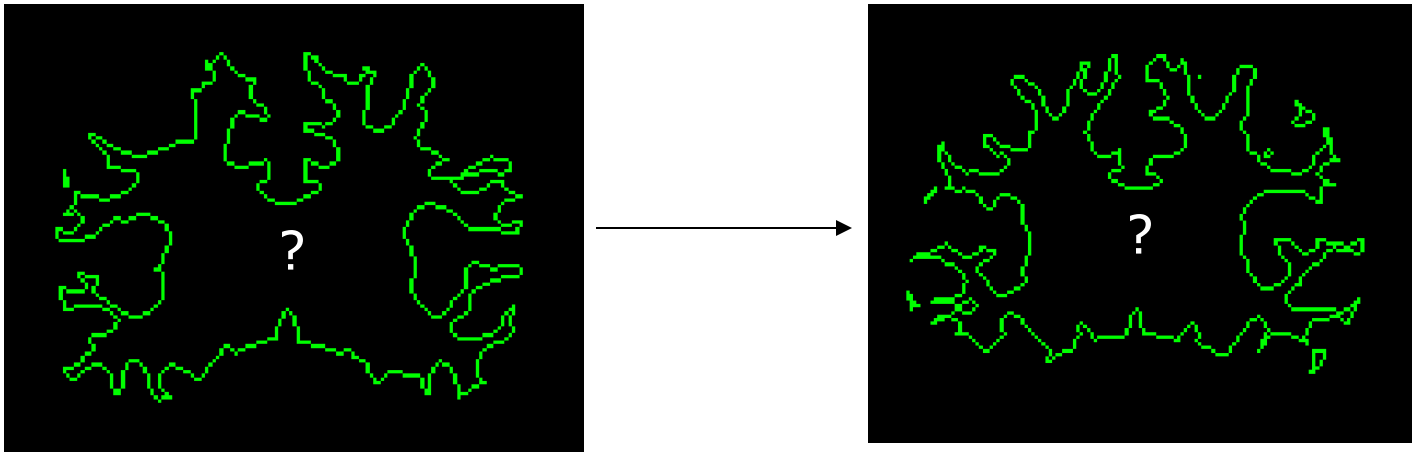
Alignment of 2 brains by AIR (5^{th} order)



+ Good alignment of subcortical structures

- Sulcal alignment inaccurate

Surface Registration Methods



- Doesn’t define volumetric correspondence

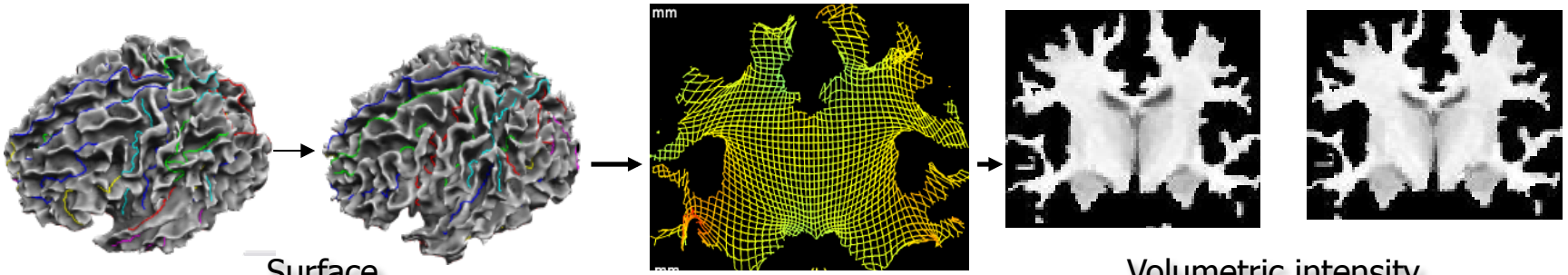
+ Accurate sulcal alignment

Extension to Volumetric Registration

Accurate Sulcal Alignment

Accurate Subcortical Feature Alignment

Intensity-based Alignment



Surface registration

Extrapolation to volume

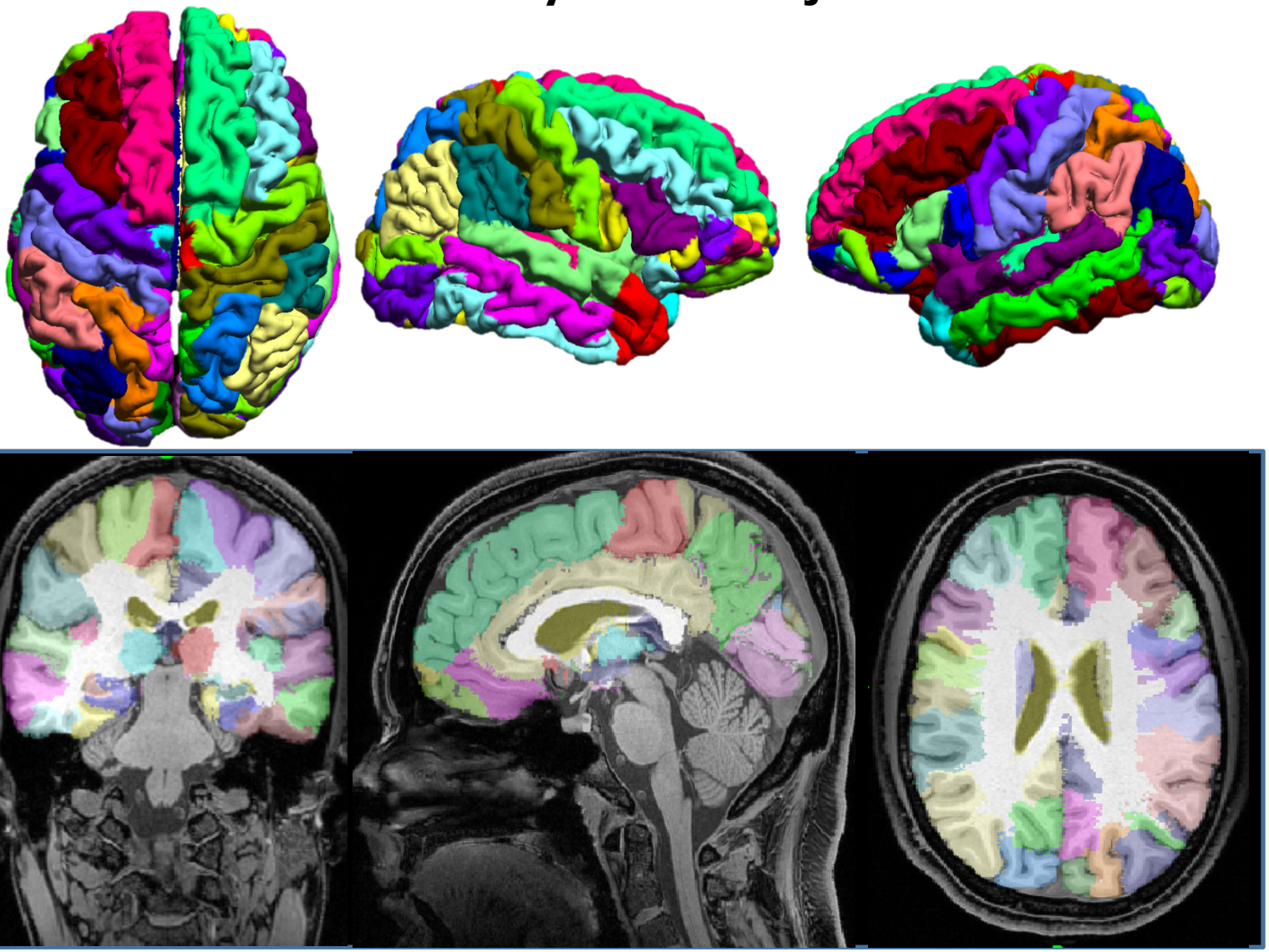
Volumetric intensity registration

Solves the difficult problem of surface/sulcal Registration in 3D volume

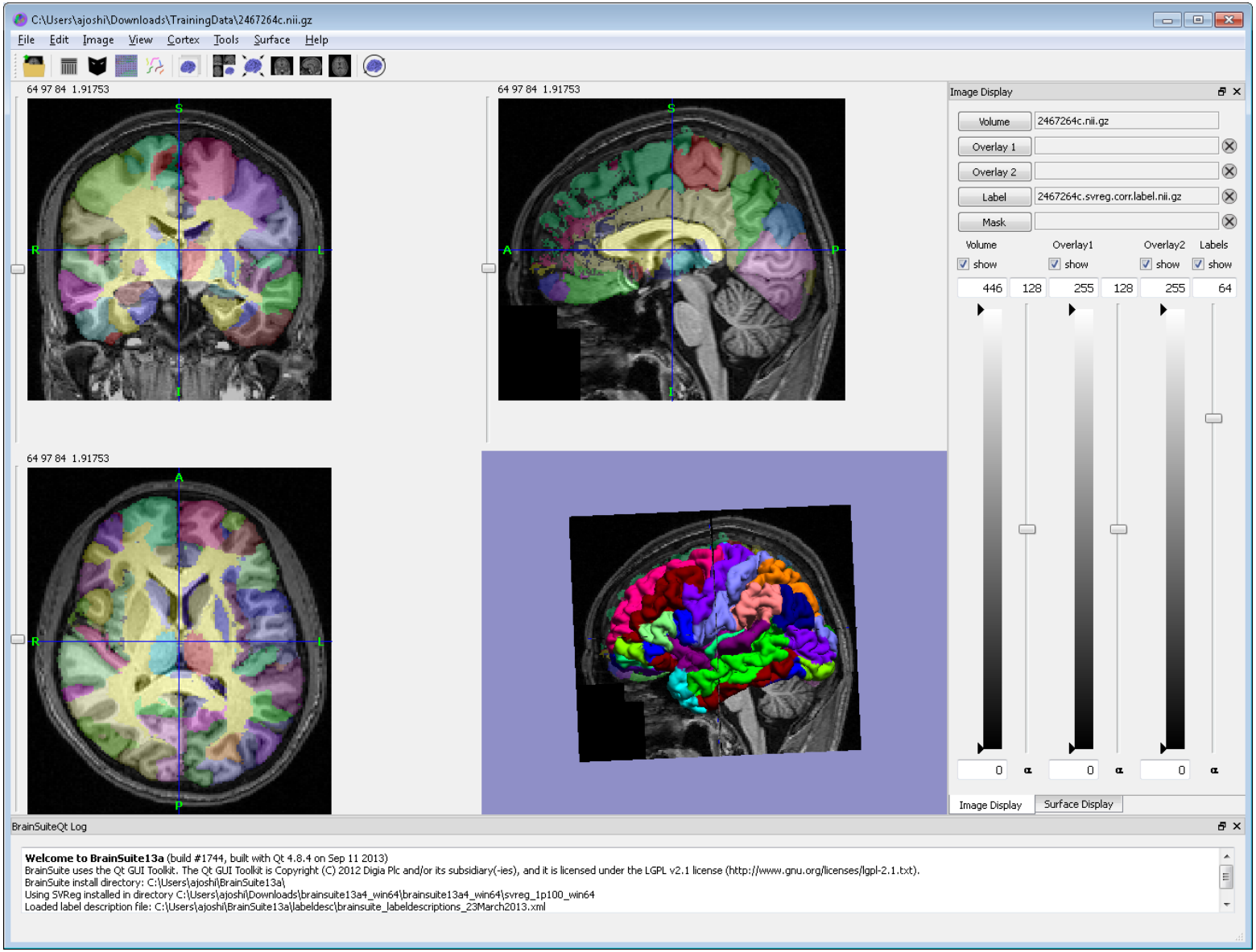
Surface and Volume Registration (SVReg) method performs accurate alignment of both cortical surfaces as well as subcortical volumes.

Joshi et al. (2007) IEEE Trans. Med. Imag.

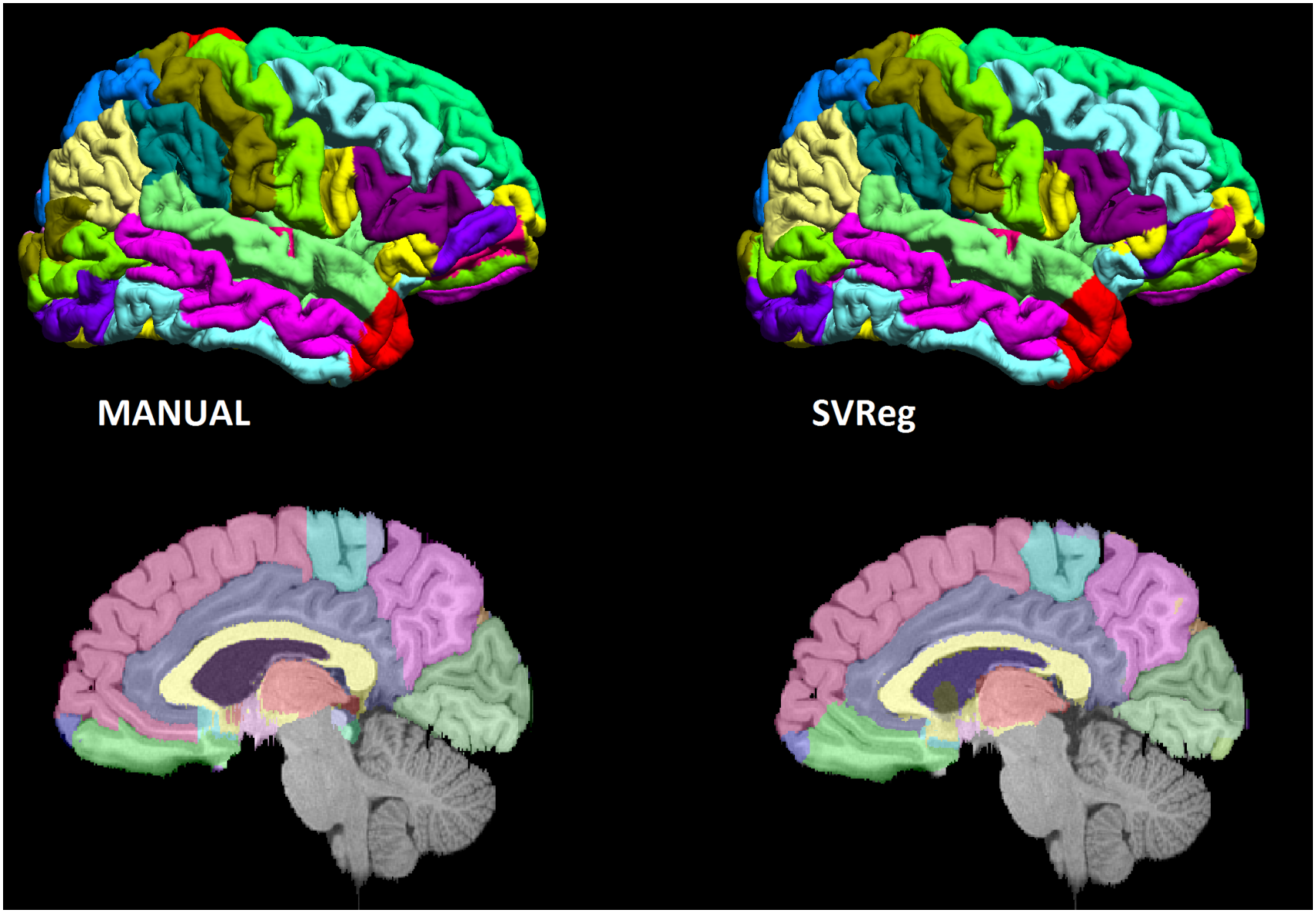
Automatically labeled subject brain



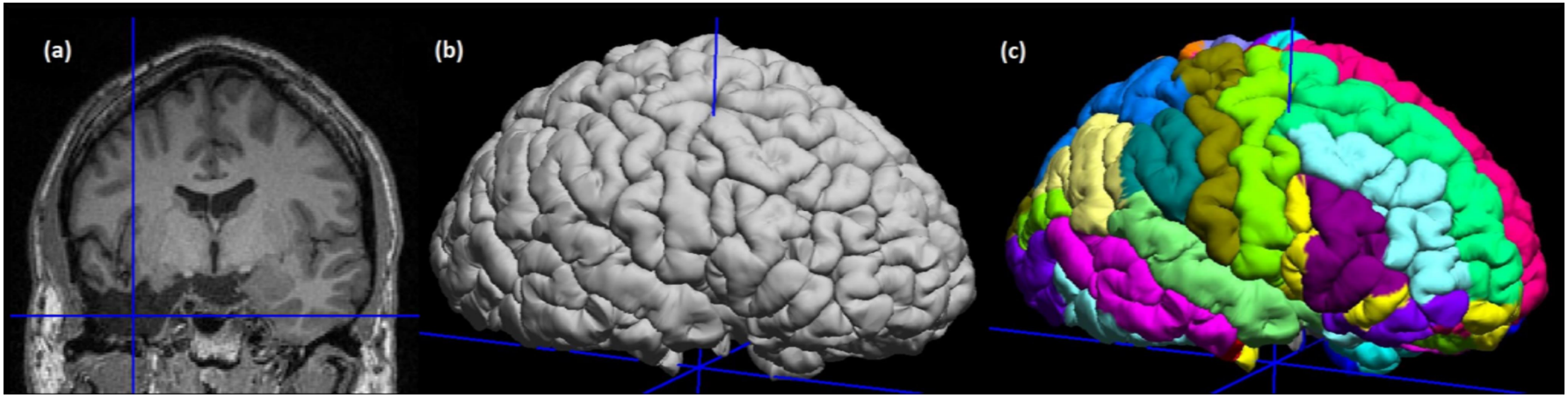
Automatically generated surface (above) and volume labels (below)



Generated surface and volume labels in BrainSuite interface

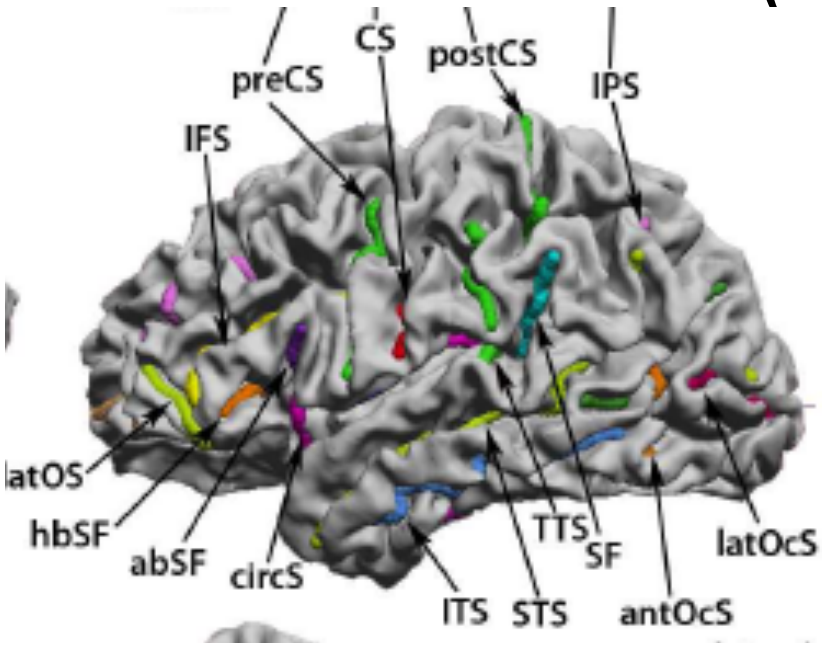

MANUAL
SVReg

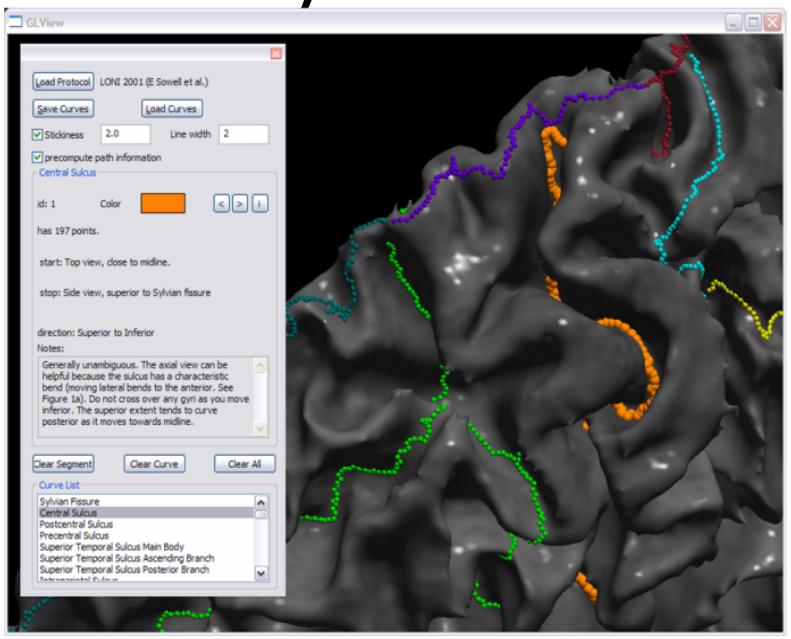
Lesion brains



SVReg works with the lesion brains

Cortical surface registration based on manually traced sulcal curves (future release)





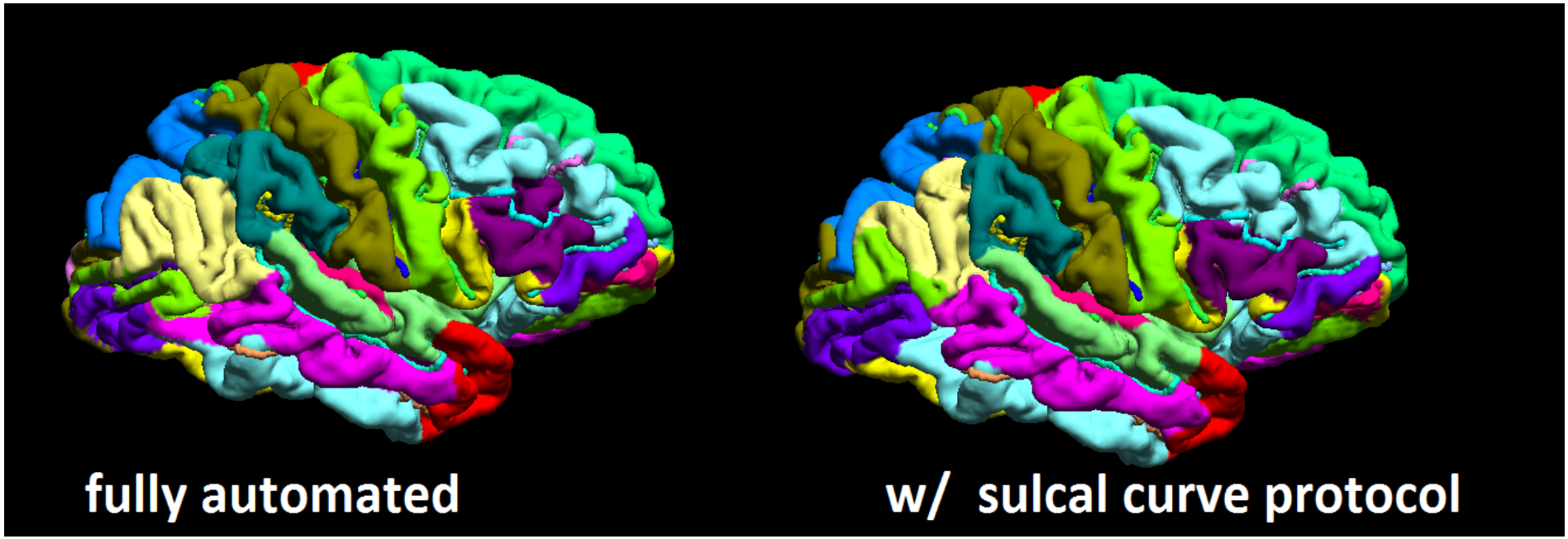
Sulcal curve delineation tool in Brainsuite

Delineation protocol includes 26 sulcal curves per hemisphere

Can traces all 26 or a subset of these curves to use as constraints

Sulcal curve delineation protocol: **http://neuroimage.usc.edu/CurveProtocol_STS.html**

Sulcally constrained registration (in future release)



- Inputs of SVReg
  - Surfaces and volumes generated by BrainSuite

- Outputs of SVReg
  - Labeled inner, pial and mid cortical surfaces
  - Labeled brain volume
  - Map from subject to atlas
  - Pointwise cortical thickness, on subject and mapped to atlas.
  - ROIwise cortical thickness, curvature, cortical areas of ROIs, gray matter, white matter and CSF volumes.
  - Spreadsheet of statistics
  - Sulcal curves transferred from atlas to subject

Demo of SVREG

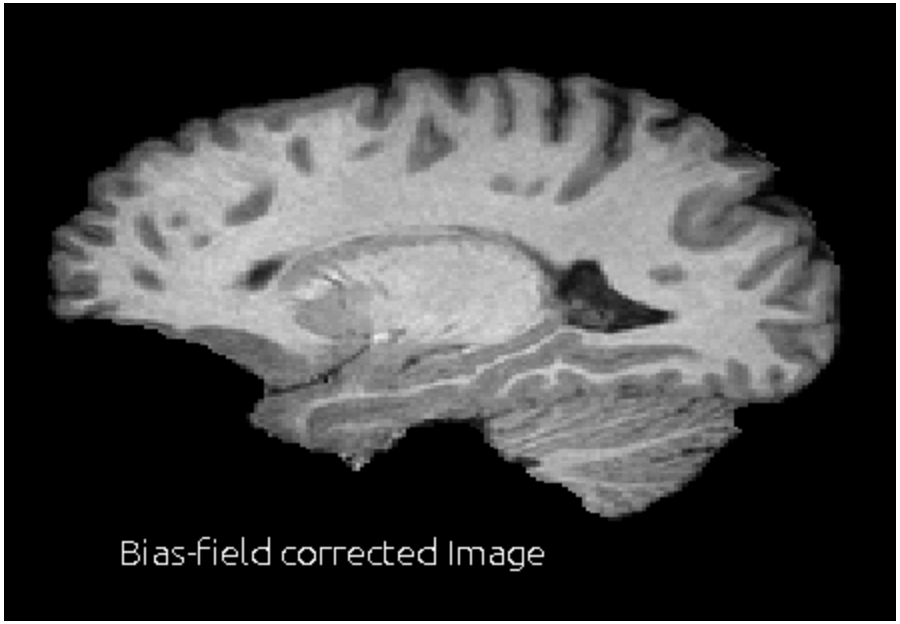
Utilities for Data Processing

- 1. Smoothing functions on surfaces
- 2. Group differences: ROIwise and pointwise
- 3. Inverting the volumetric map
- 4. Regenerating stats file after manual corrections to the label file
- 5. Labeling of surfaces and volumes based on manually drawn cortical ROIs

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

Bias correction tool

Allows manual correction of the bias field



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

References

- **Joshi AA**, Shattuck DW, Thompson PM, and Richard M. Leahy (2007) *Surface Constrained Volumetric Brain Registration Using Harmonic Mappings*, IEEE Transactions on Medical Imaging, Vol. 26 (12), pp. 1657-1669. Dec 2007.

- **Joshi AA,** Shattuck DW and Leahy RM, *A Fast and Accurate Method for Automated Cortical Surface Registration and Labeling*, Proc. WBIR LNCS Springer 2012, 180-189.

- **Joshi AA**, Leahy RM, Thompson PM, Shattuck DW (2004) *Cortical Surface Parameterization by P-Harmonic Energy Minimization*. ISBI 2004: 428-431