# SVReg
## Surface-constrained Volumetric Registration

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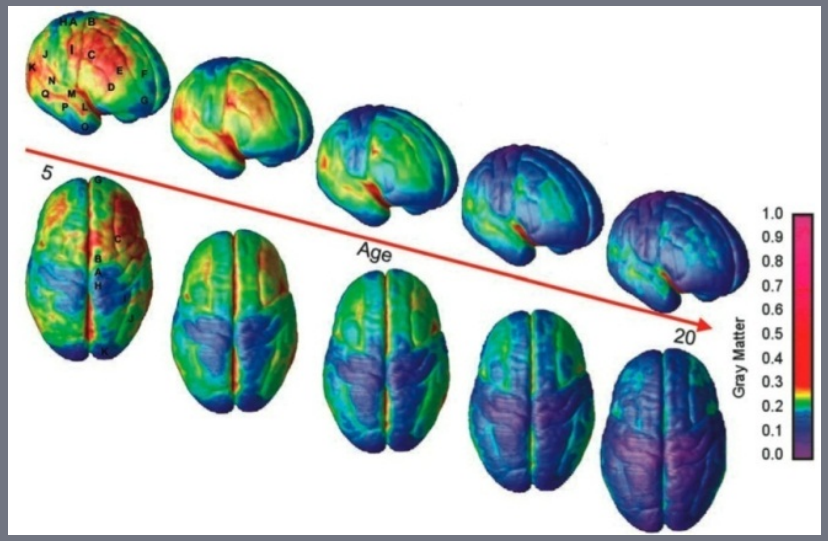
http://brainsuite.bmap.ucla.edu/processing/svreg/

# 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, etc.
  - Longitudinal studies of same subject over a period of time

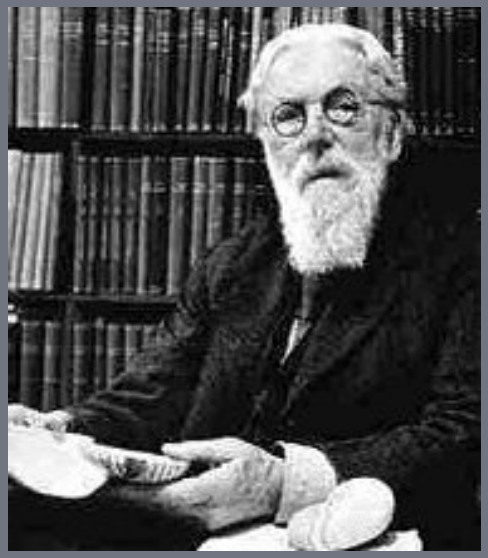
Longitudinal Study



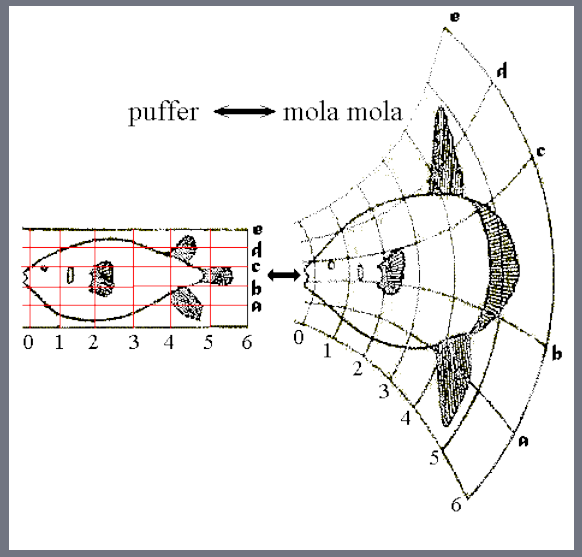

Brain development, N. Gogtay (PNAS'04)

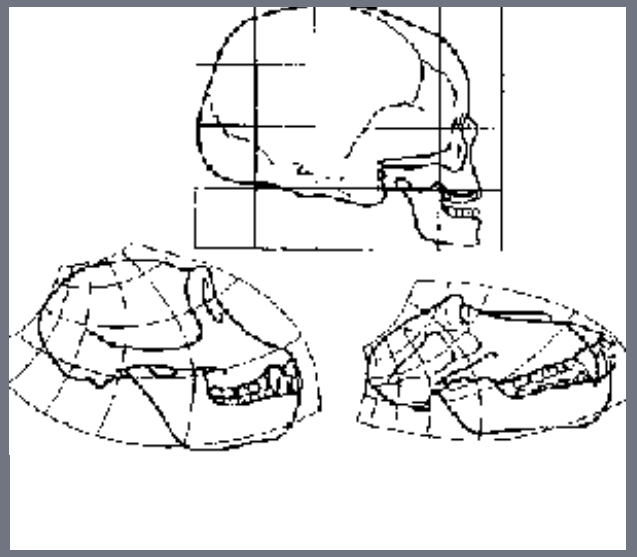
- We use image registration for transferring labels from atlas to subject.
- Inter- and intra-subject surface and volume alignment tools are required to integrate neuro-anatomical and functional data.

# Image Registration



D'Arcy Thompson
(1860-1948)



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

Metric

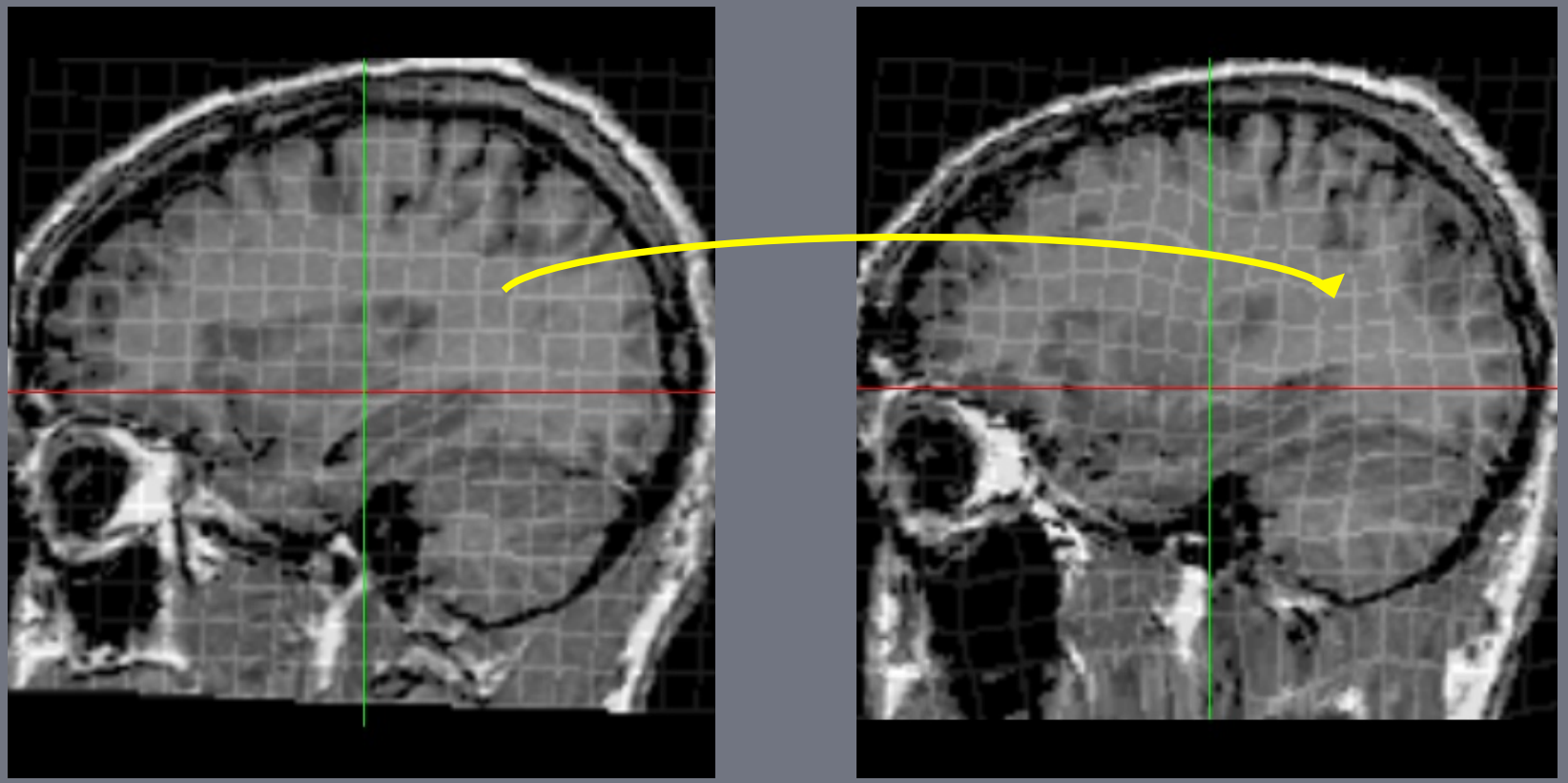
Image Features

Differential Operator

- Types of Registration Techniques:
  intensity based or landmark, surface, curve based

# What is Image Registration?

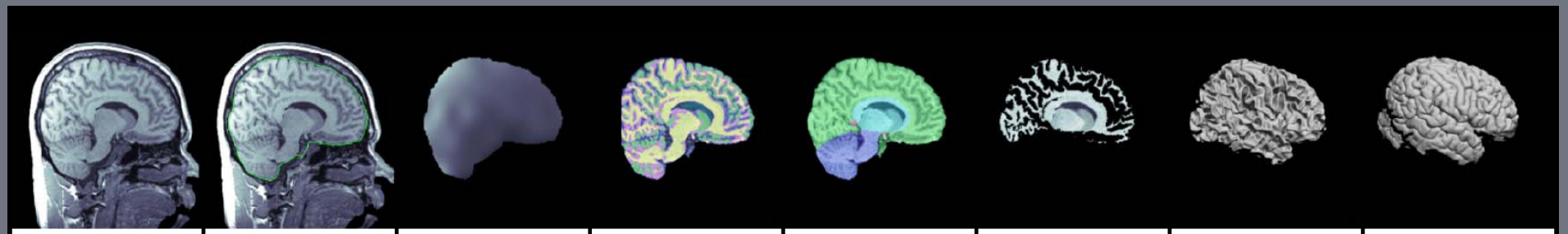
Mapping from point **x** of template brain image **T,** to match to a point **y** of target brain image **S** by a transformation **y=h(x)=x+u(x)**



Brain image with grid overlay

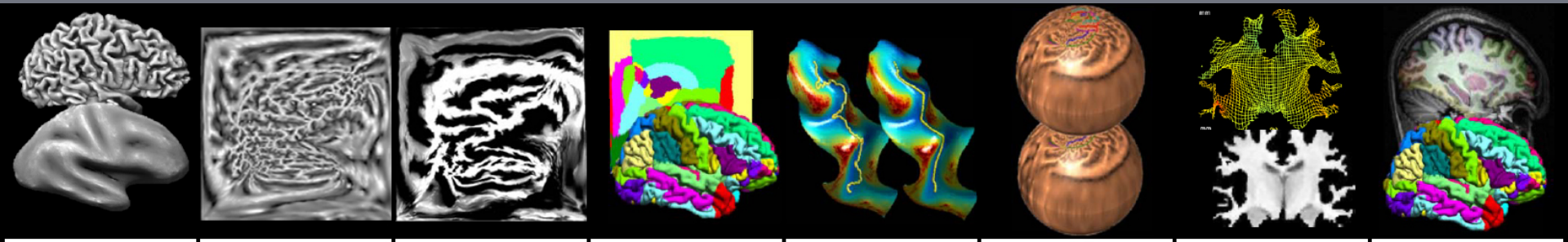
Warped brain with grid overlay

# BrainSuite Processing Workflow



| MRI | skull stripping | bias field correction | tissue classification | cerebrum identification | topology correction | tesselation | pial surface generation |
|---|---|---|---|---|---|---|---|
| | <2 sec | 40s - 4 min | <5 sec | <20 sec | <40 sec | <2 sec | <10 min |

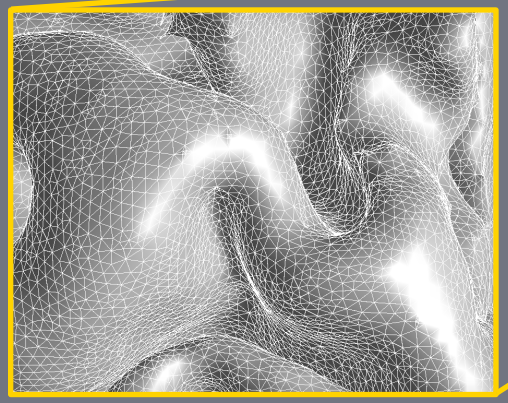
# SVReg Processing Workflow



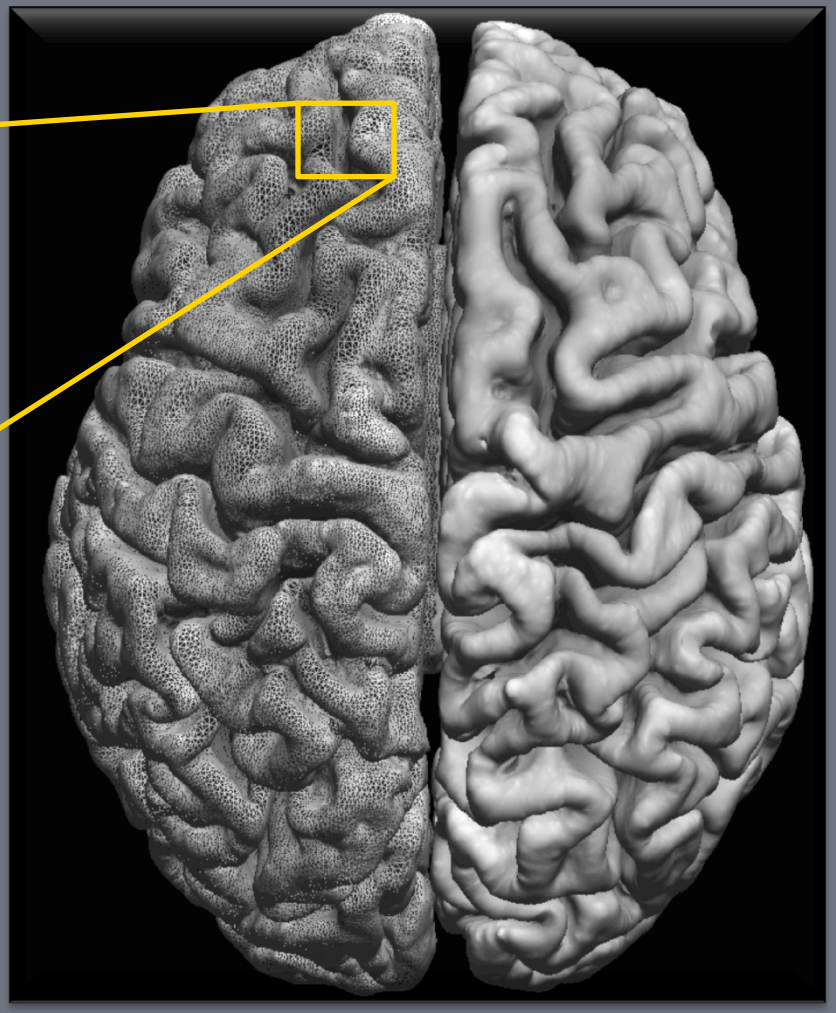
| 3D surface L2 alignment | flat mapping | curvature alignment | transfer of labels | boundary refinement | 3D harmonic mapping | intensity registration | volumetric label transfer |
|---|---|---|---|---|---|---|---|
| ~10 min | ~1 min | ~10 min | <1 min | ~10 min | ~10 min | ~20 min | ~2 min |

# 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.

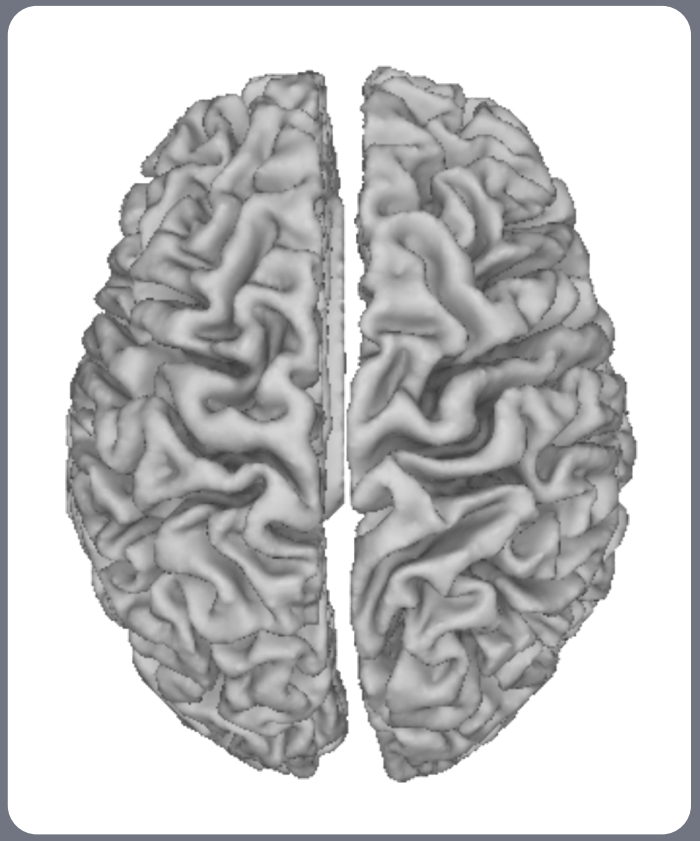


Cortical surface mesh representation

# Cortical Surface

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

Equivalent to two 13" pizzas!



=

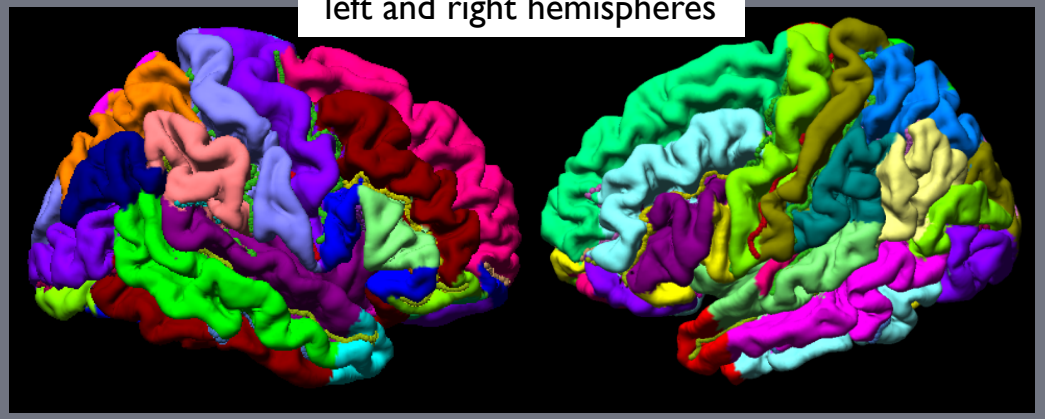
Each cortical area ~ one 3 cm pepperoni!

# BrainSuiteAtlas I

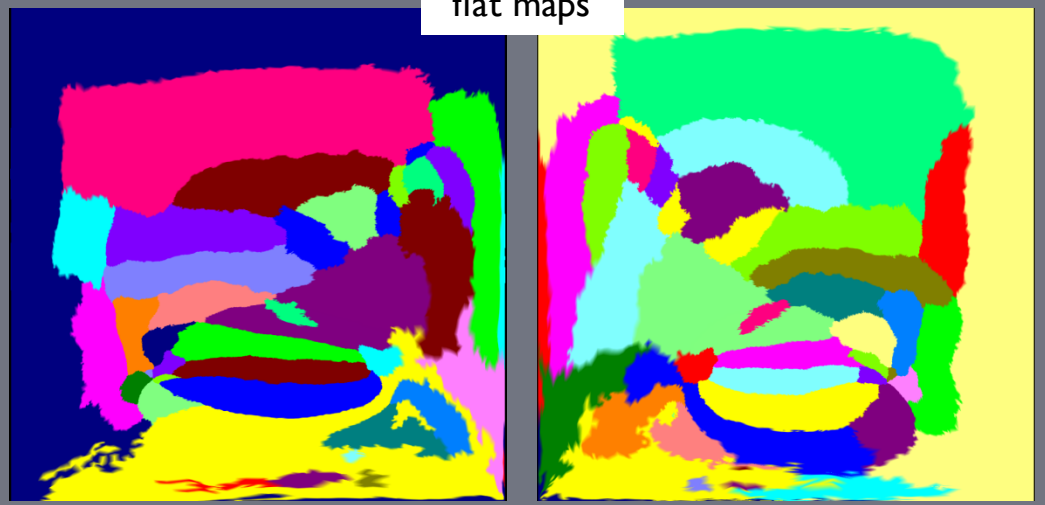
- Single subject atlas labeled at USC by expert neuroanatomist
- 26 sulcal curves per hemisphere
- 98 volumetric regions of interest (ROIs), 35*2=70 cortical ROIs

T1 MRI and label overlay

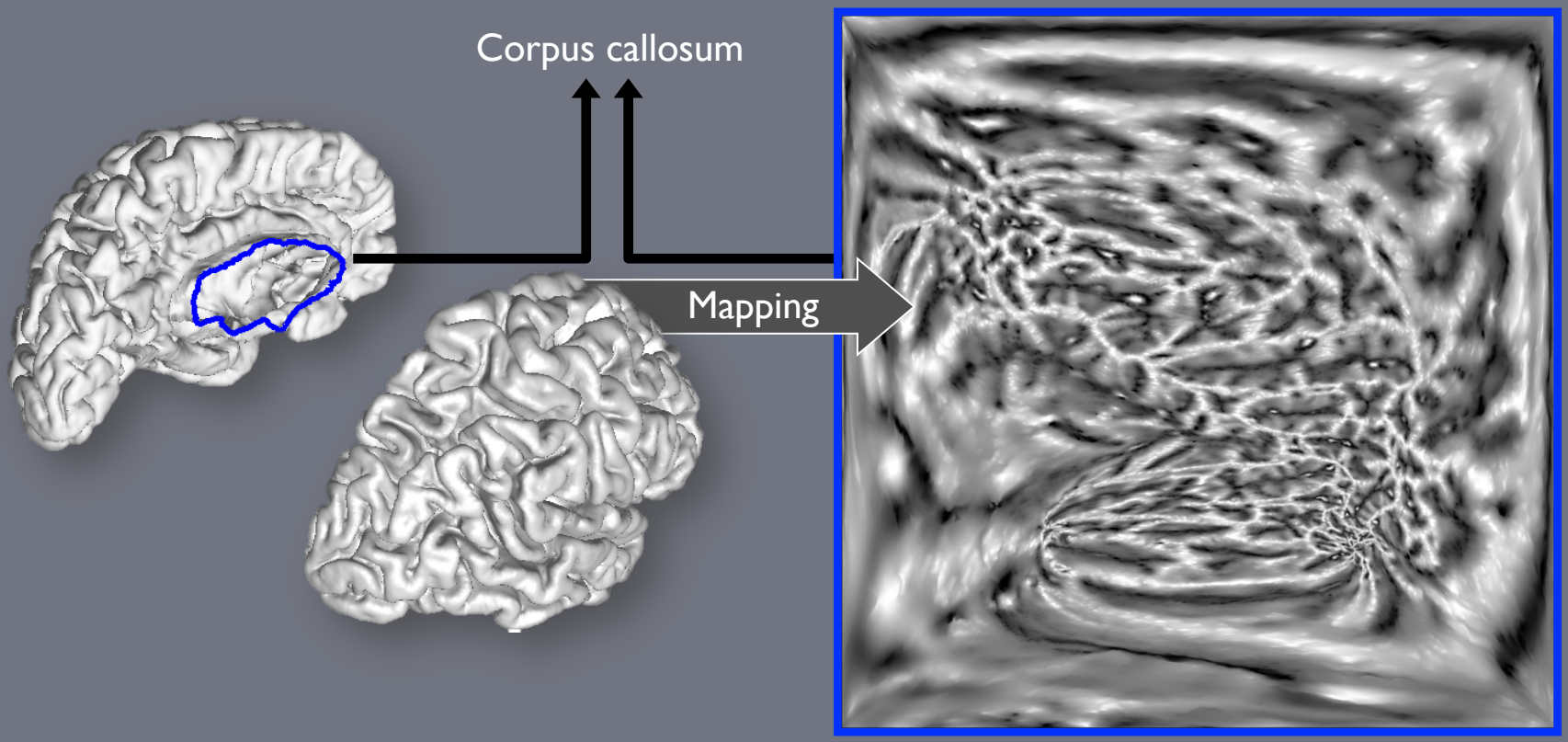
left and right hemispheres



flat maps



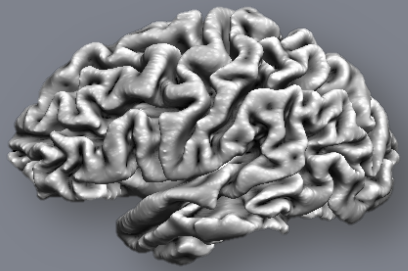
# Cortical Surface Parameterization



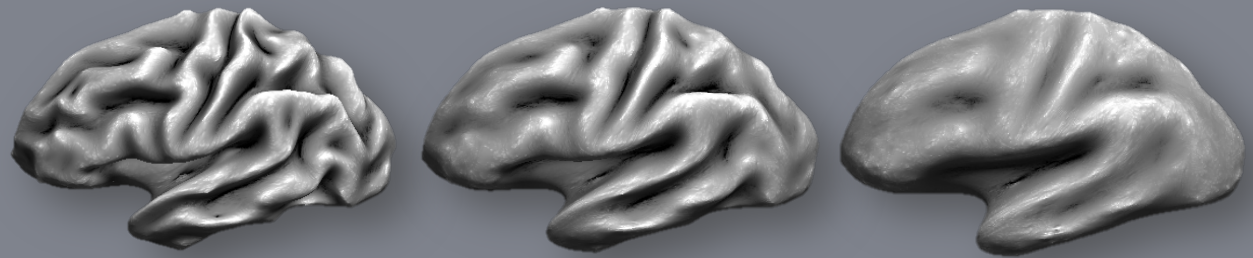

Flat-map color coded by curvature

# Extensions to Automatic Registration Without Sulcal Curves

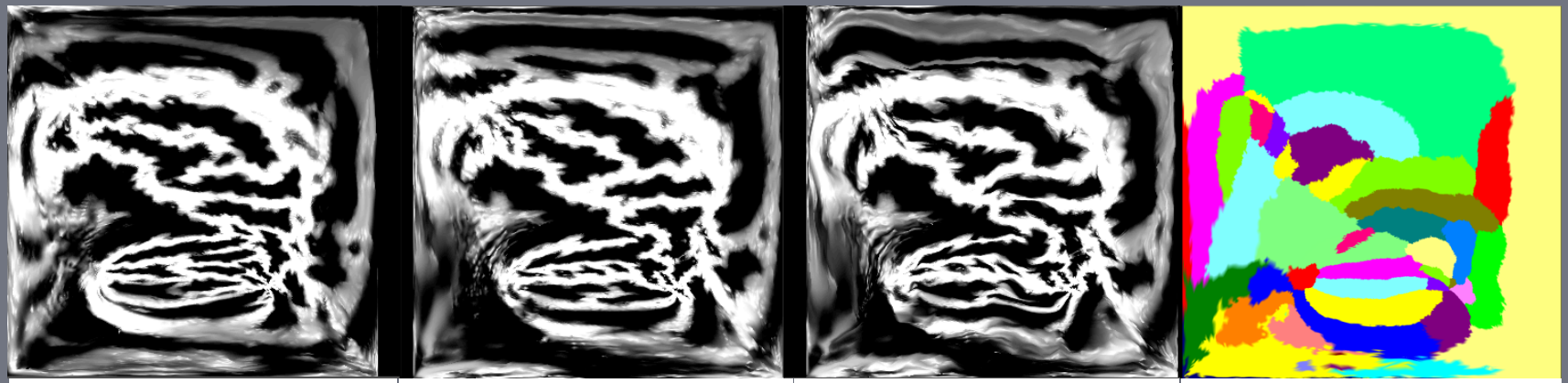
Input mid surface



Smoothed surfaces



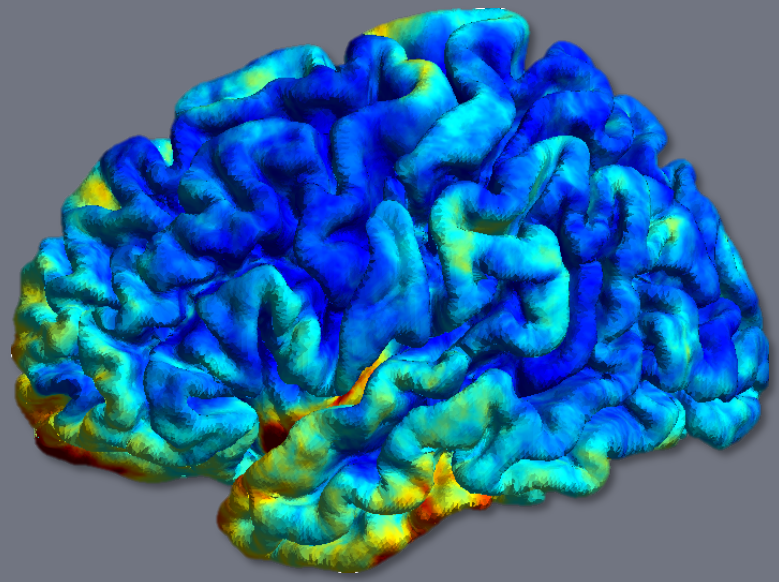
Cumulative curvature computation for multiresolution representation



| atlas | subject | warped subject | color-coded labels |
|---|---|---|---|

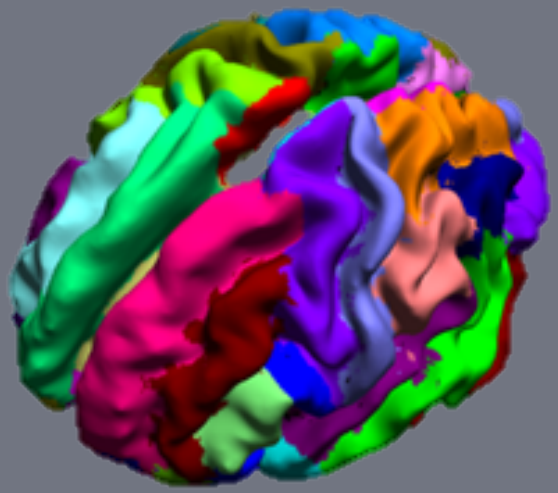
Elastic matching for atlas and subject flat maps

# Curvature Weighting

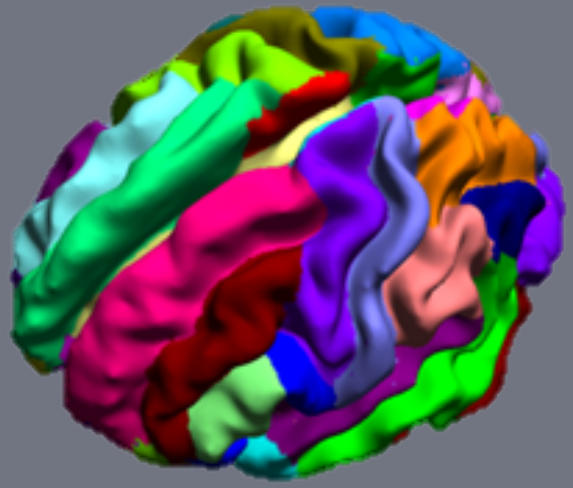


- Color coded curvature variance is shown in the figure.
- Computed by aligning 100 brains. Inverse of curvature variance is used as a weighting on the curvature cost function.

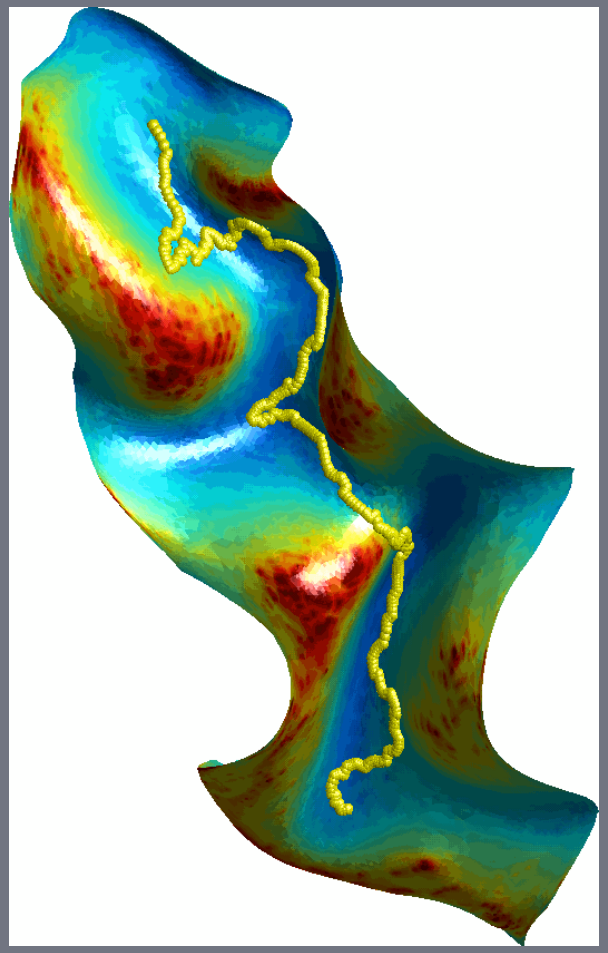
# Refinement of Labels and Sulci



Original labels plotted on a smoothened representation of a cortical surface.



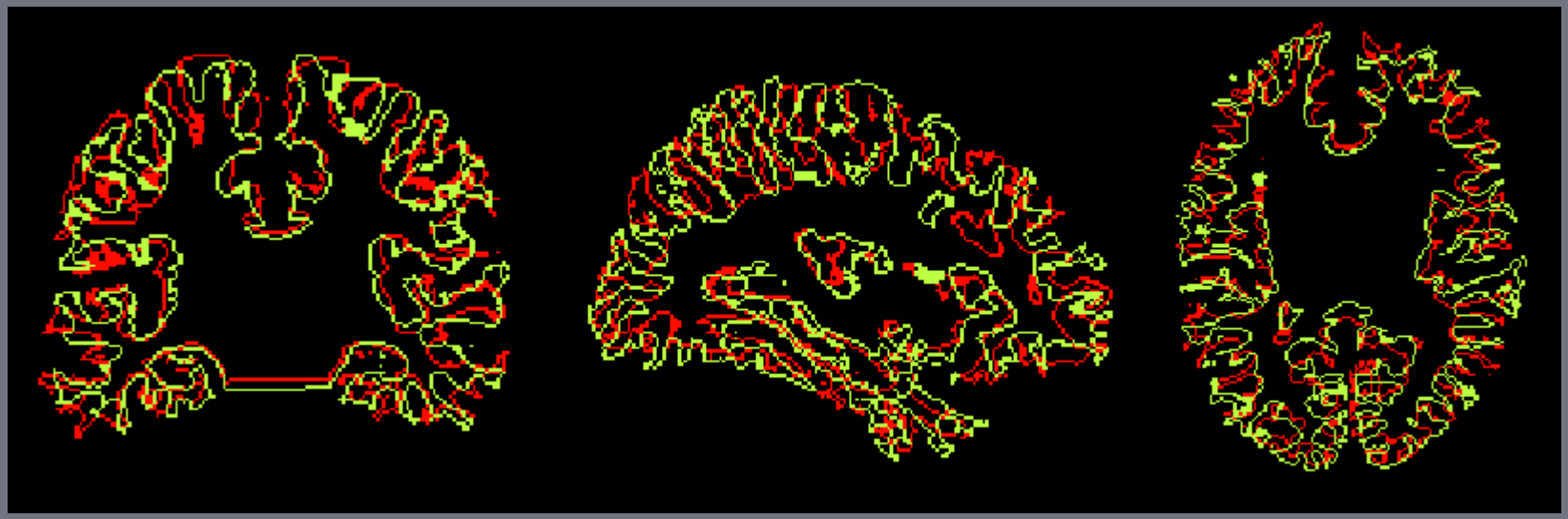
Labels after geodesic curvature. Flow plotted on a smoothened representation of a cortical surface.



Animation of the geodesic curvature flow for sulcal refinement.

# Motivation for Surface-Constrained Volumetric Registration

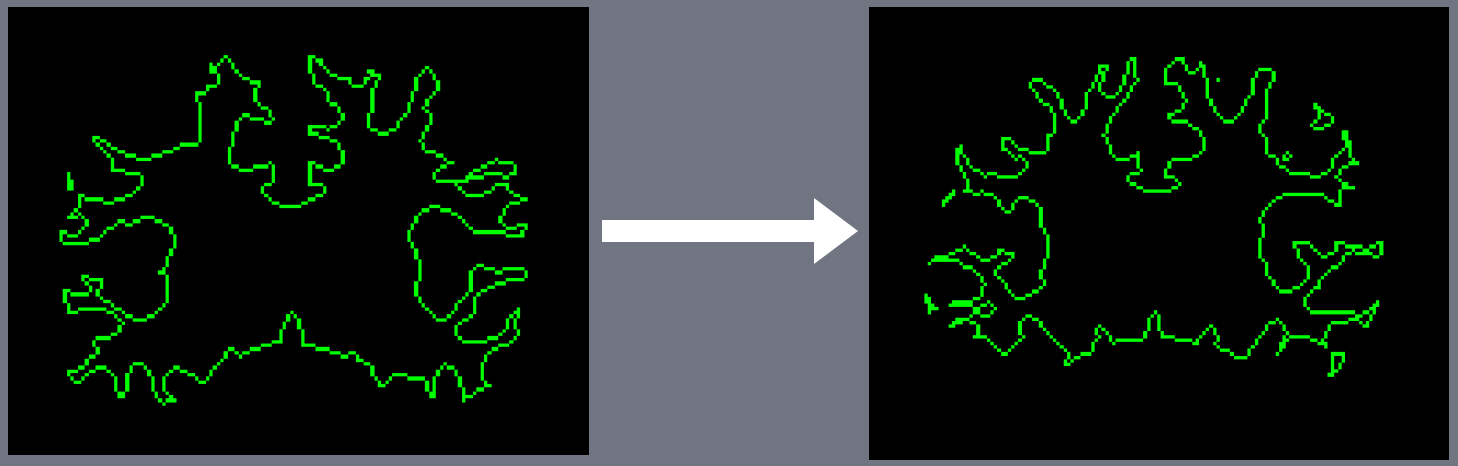
Alignment of 2 brains by AIR ($5^{th}$ order)



+ Good alignment of subcortical structures

- Sulcal alignment inaccurate

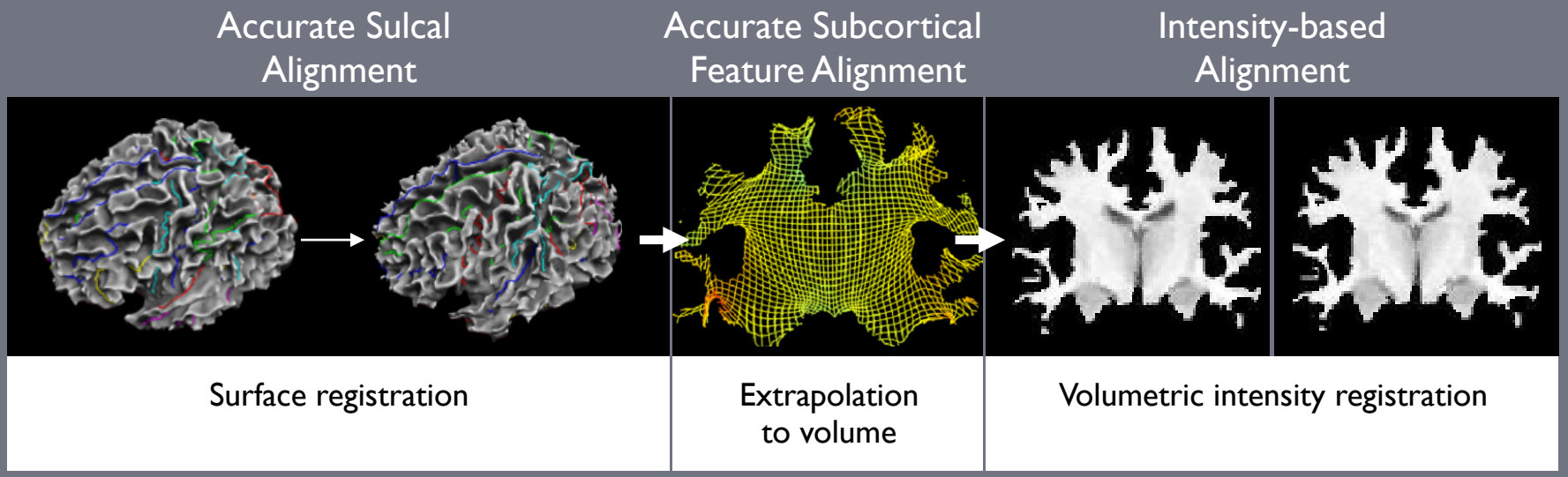
# Surface Registration Methods



- Doesn't define volumetric correspondence

+ Accurate sulcal alignment

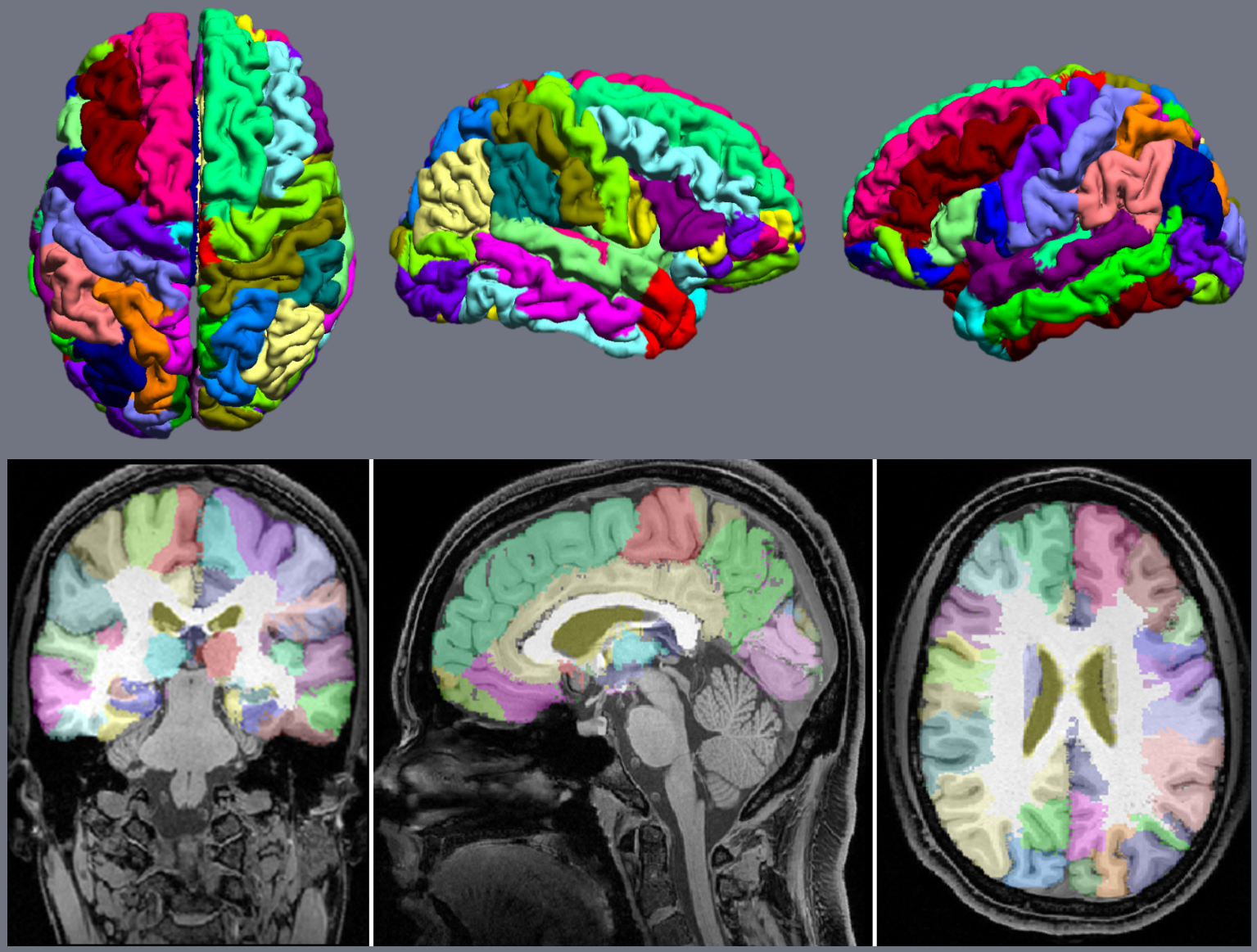
# Extension to Volumetric Registration



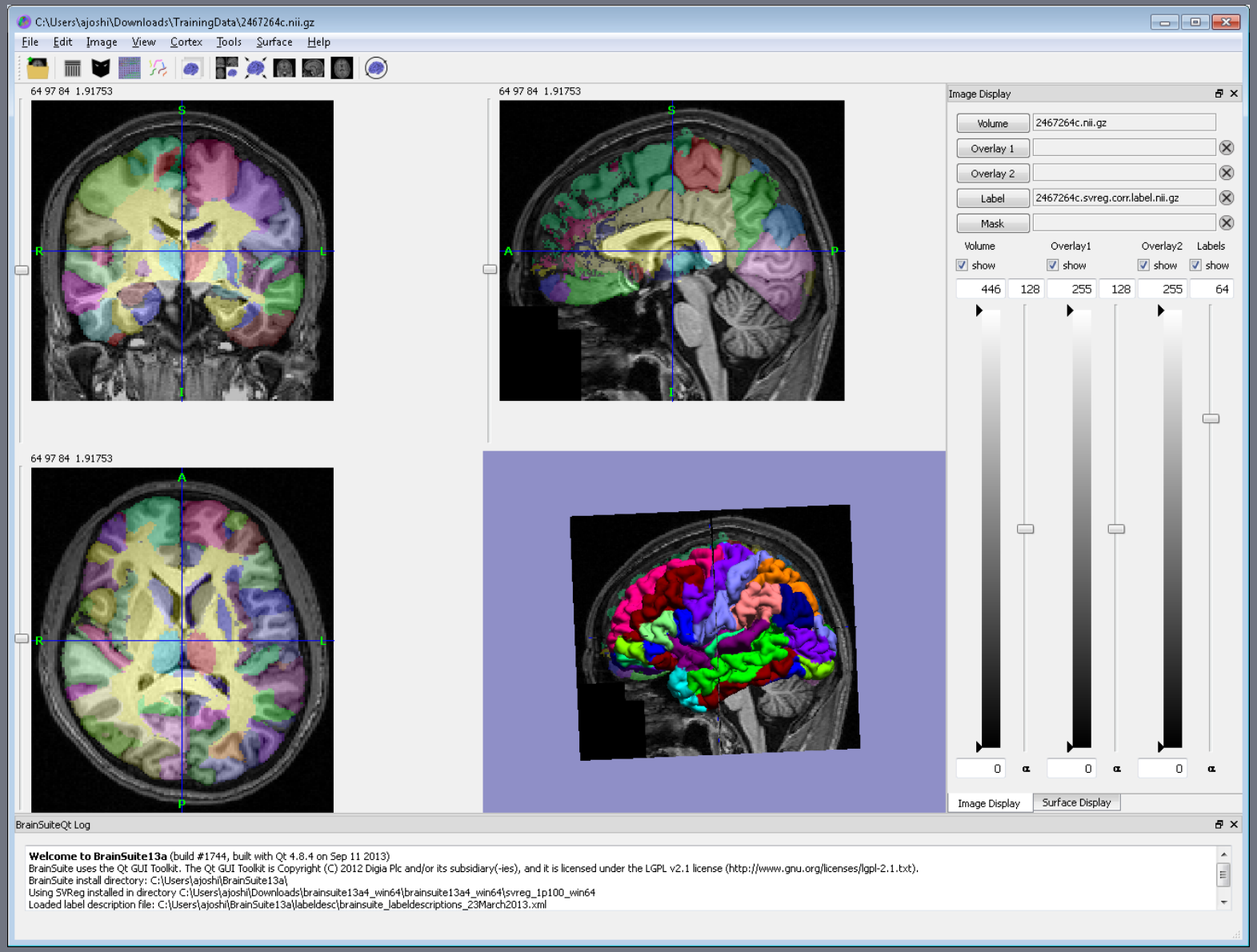

- Solves the difficult problem of surface/sulcal registration in 3D volume.
- Surface and Volume Registration (SVReg) method performs accurate alignment of both cortical surfaces as well as subcortical volumes.

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

# Automatically Labeled Subject Brain

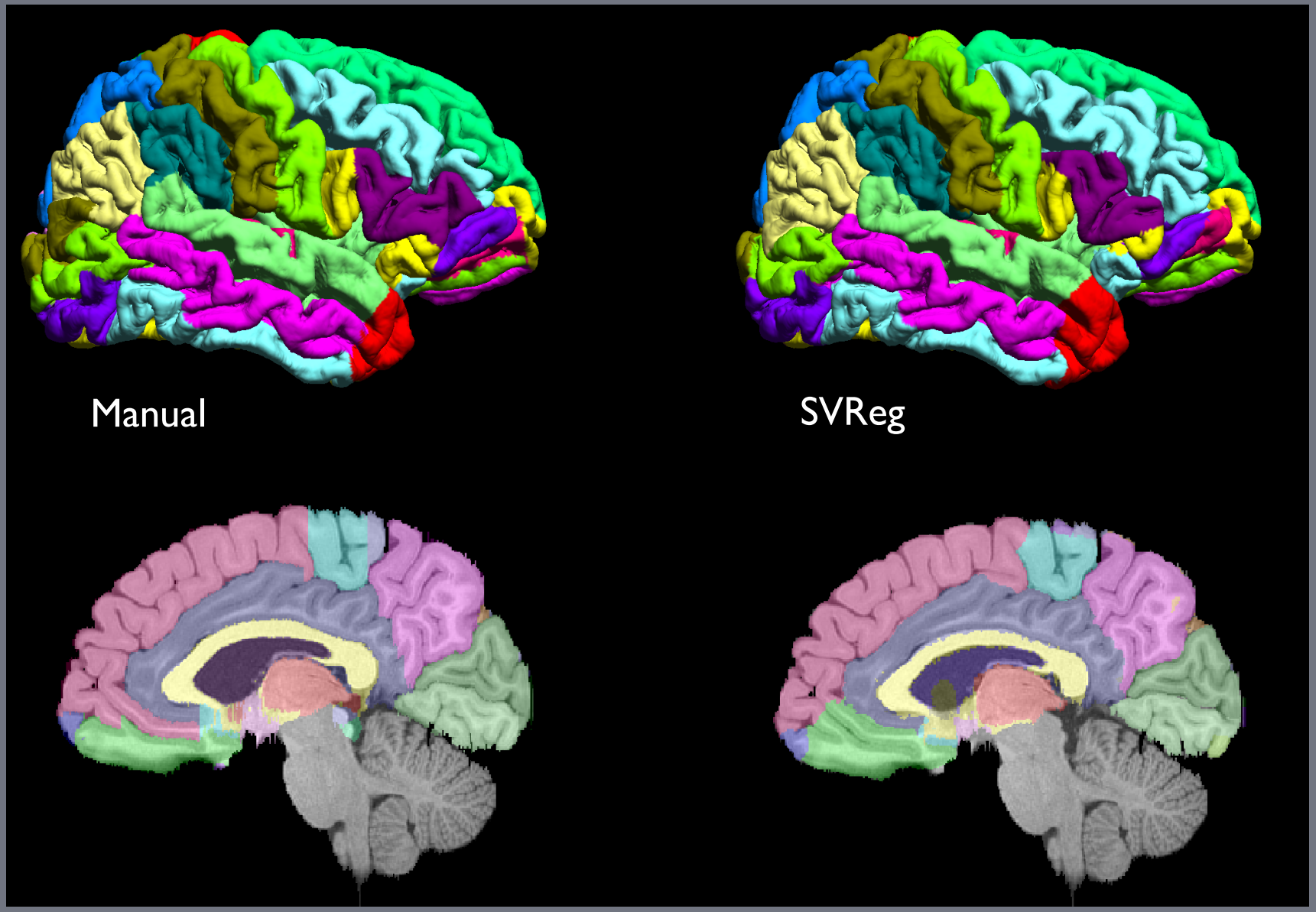


Automatically generated surface (above) and volume labels (below)

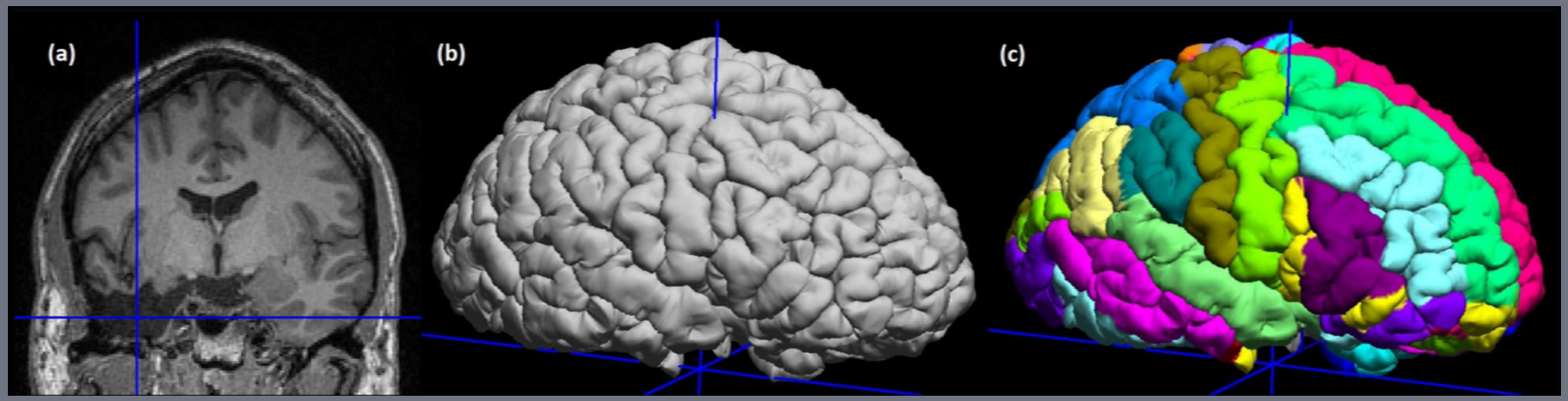



Generated surface and volume labels in the BrainSuite GUI

# Automated vs Manual Labeling



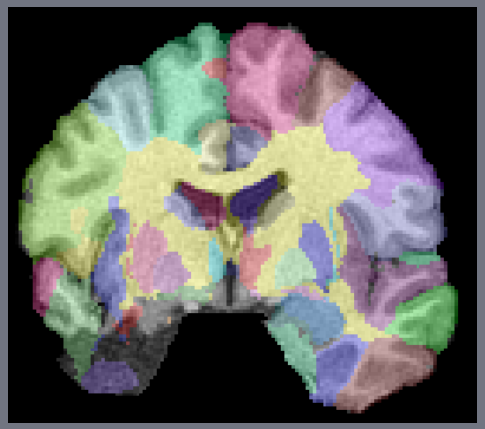
# Lesion Brains

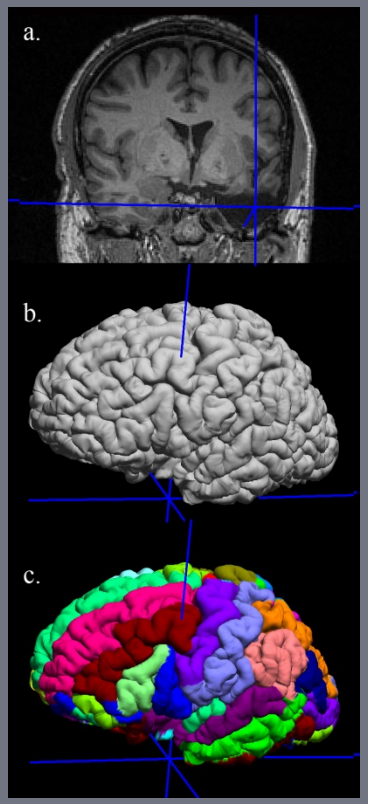


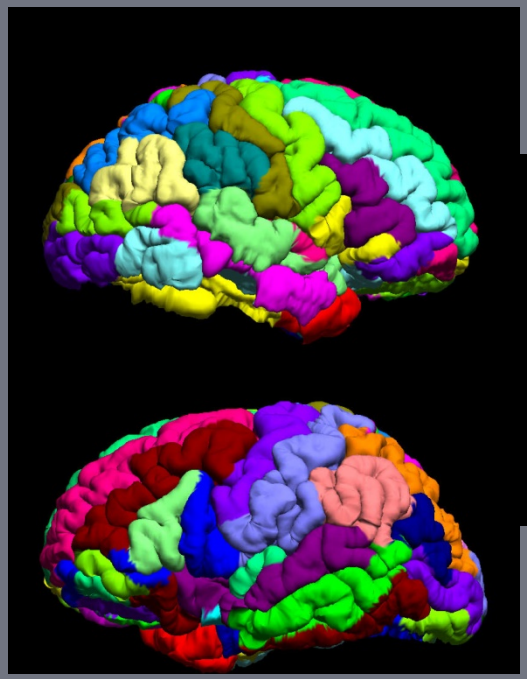

- SVReg may work with brains with lesions or other abnormalities

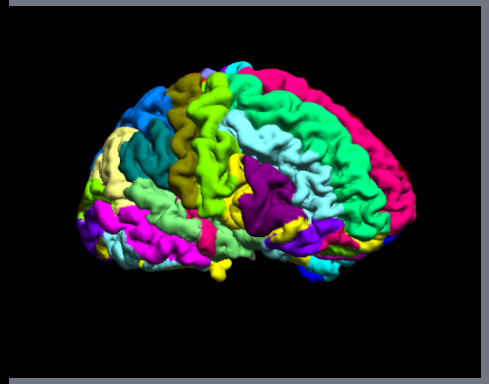
  * The results might show varying degree of accuracy depending on how severe the abnormality in the brain is

# More Examples of Lesion Brains

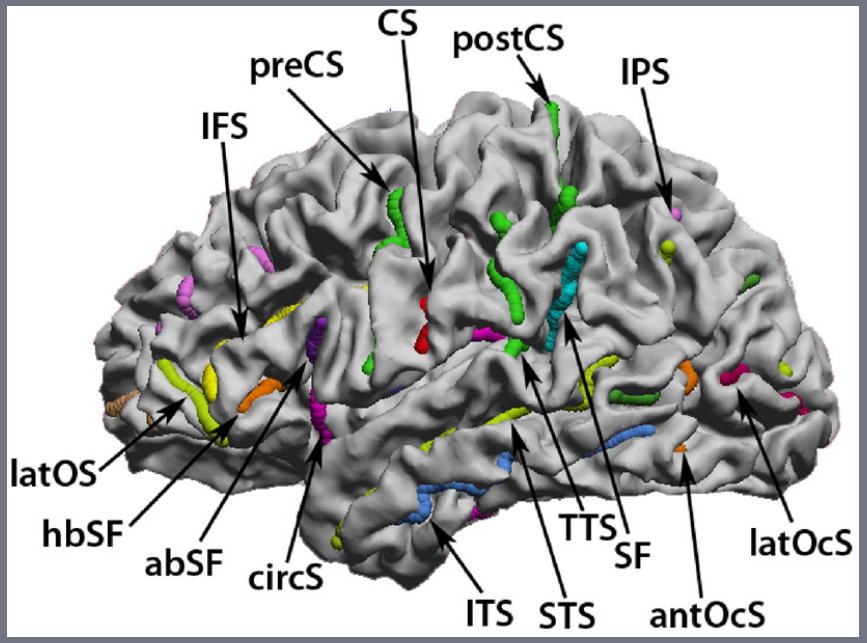




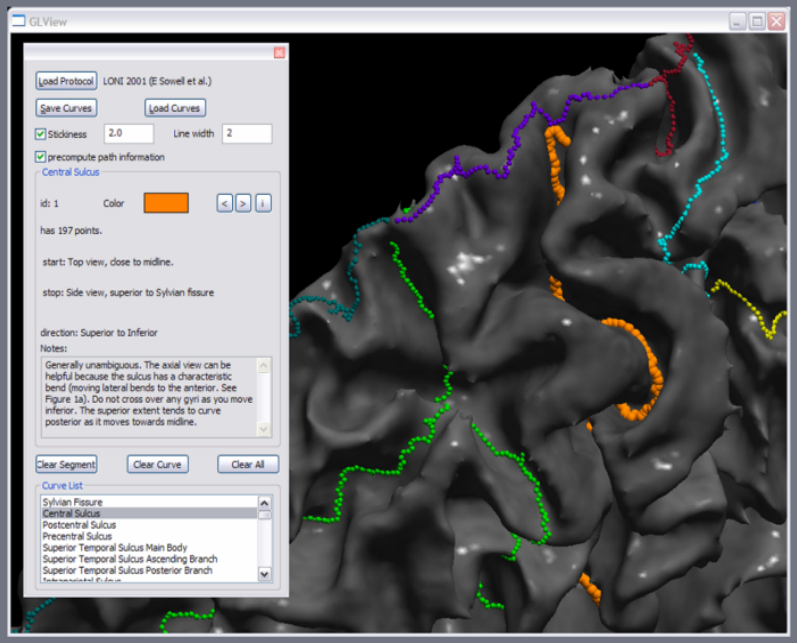





# Cortical Surface Registration Based on Manually Traced Sulcal Curves (future release)




Sulcal delineation protocol in BrainSuite

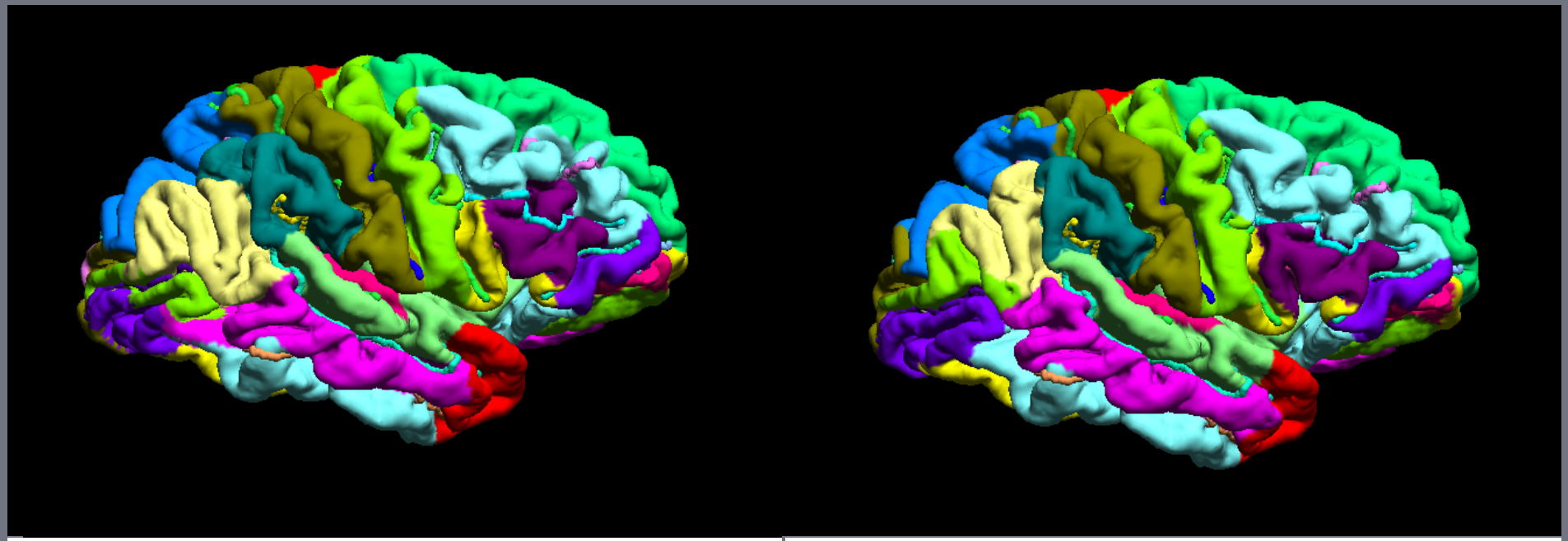



Sulcal curve delineation tool in BrainSuite

- Delineation protocol includes 26 sulcal curves per hemisphere
- Can trace all 26 or a subset of these curves to use as constraints

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

# Sulcal-Constrained Registration (future release)



| Fully automated | With sulcal curve protocol |
| --- | --- |

# SVReg Program and Interface

- 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.
  - Point-wise cortical thickness, on subject and mapped to atlas.
  - ROI-wise cortical thickness, curvature, cortical areas of ROIs, gray matter, white matter and CSF volumes.
  - Spreadsheet of statistics.
  - Sulcal curves transferred from atlas to subject.

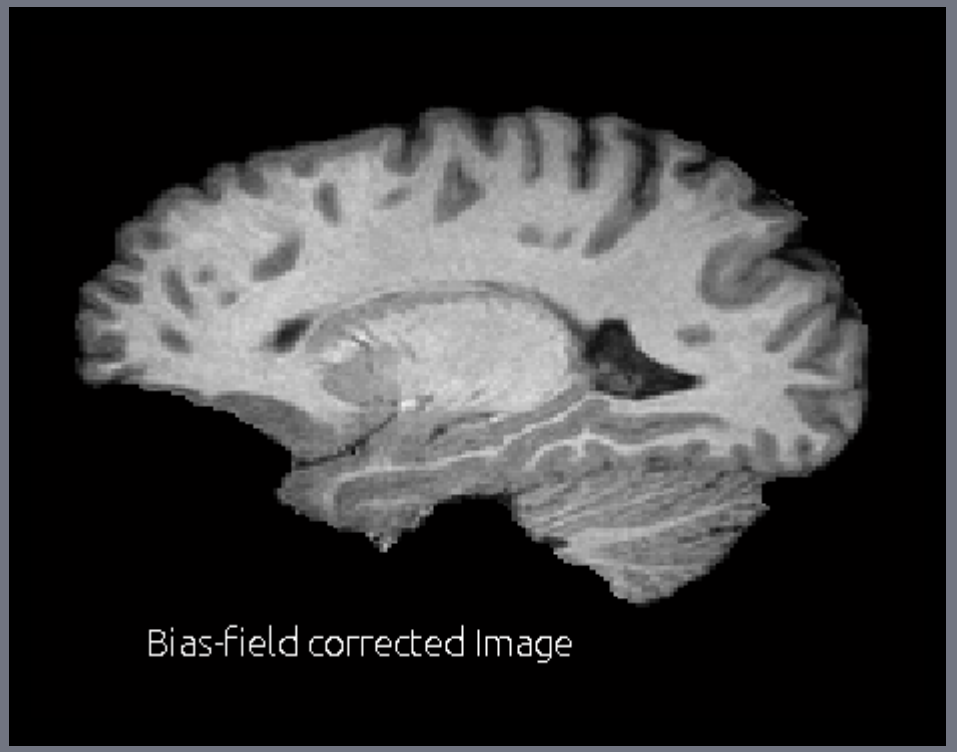
# Demo of SVReg

# Utilities for Data Processing

- Smoothing functions on surfaces.
- Group differences: ROI-wise and Point-wise.
- Inverting the volumetric map.
- Regenerating stats file after manual corrections to the label file.
- Labeling of surfaces and volumes based on manually drawn cortical ROIs.
- Computing surface and volume stats for arbitrary ROIs.
- Create a new atlas for using with SVReg.

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*, 26(12):1657-1669.

**Joshi AA,** Shattuck DW & Leahy RM (2012) A Fast and Accurate Method for Automated Cortical Surface Registration and Labeling, *Proc. WBIR*, LNCS 7359, Springer 2012, 180-189.

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