Surface-constrained Volumetric Registration (SVReg)

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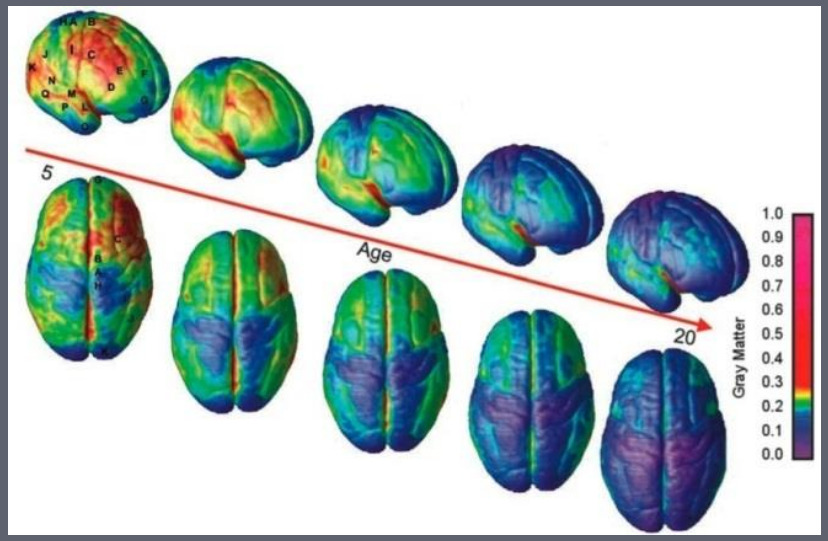
http://brainsuite.org/processing/svreg/

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

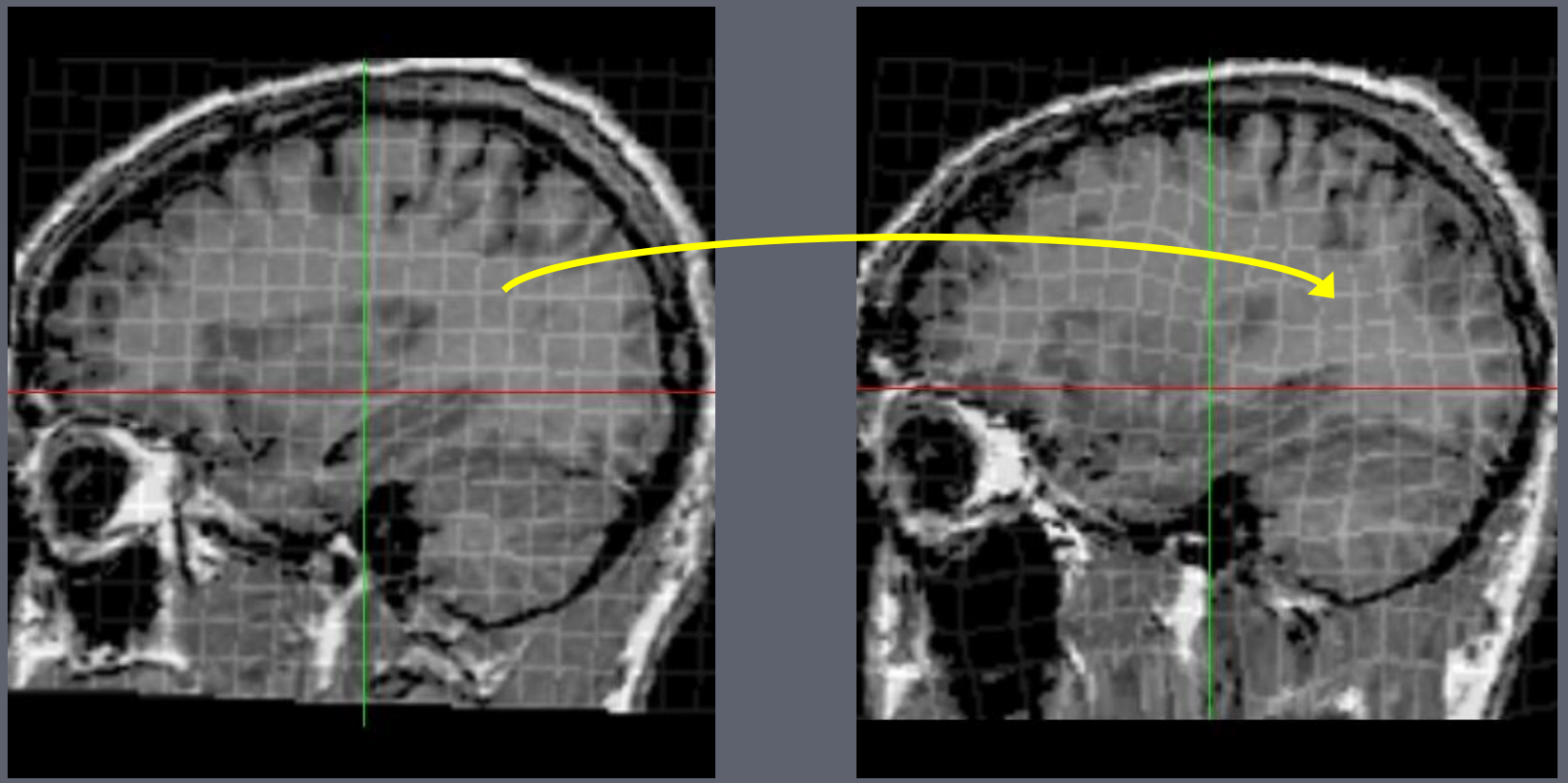


Brain development, N. Gogtay (PNAS'04)

- 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.

What is Image Registration?

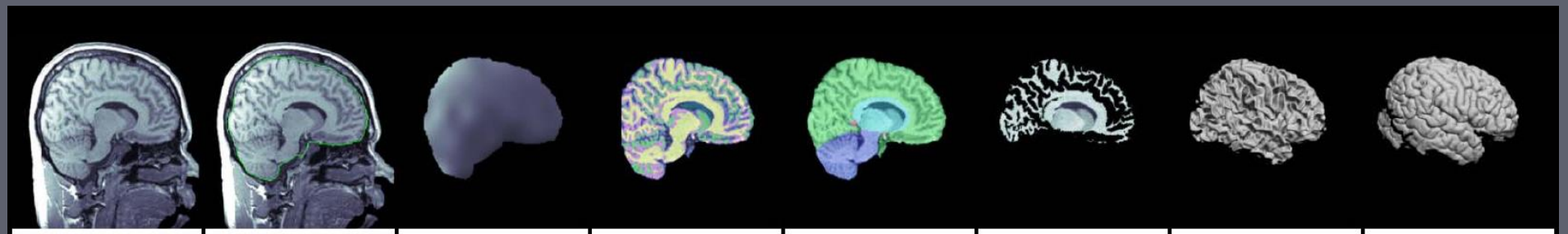
Mapping from point **x** of template brain image **T,** to match to a point **y** of target brain image **S** by a transformation **y=h(x)=x+u(x)**



Brain image with grid overlay

Warped brain with grid overlay

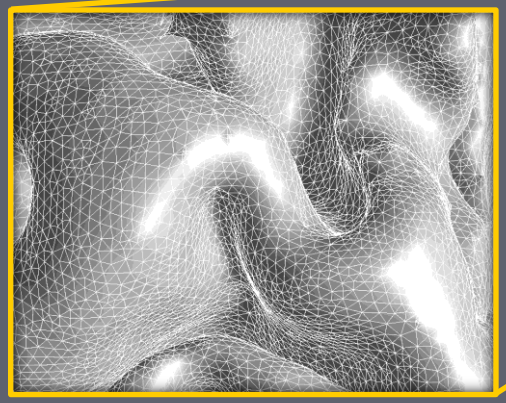
BrainSuite Processing Workflow



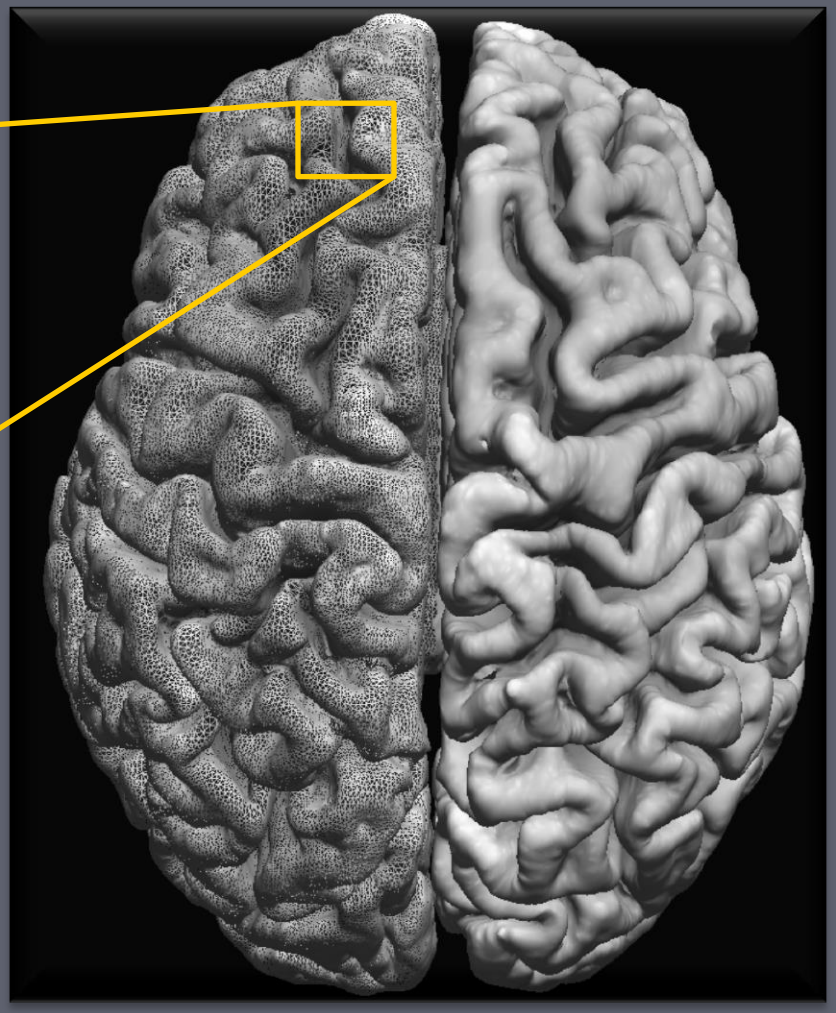
MRI	skull stripping	bias field correction	tissue classification	cerebrum identification	topology correction	tesselation	pial surface generation
	<2 sec	40s - 4 min	<5 sec	<20 sec	<40 sec	<2 sec	<10 min

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.

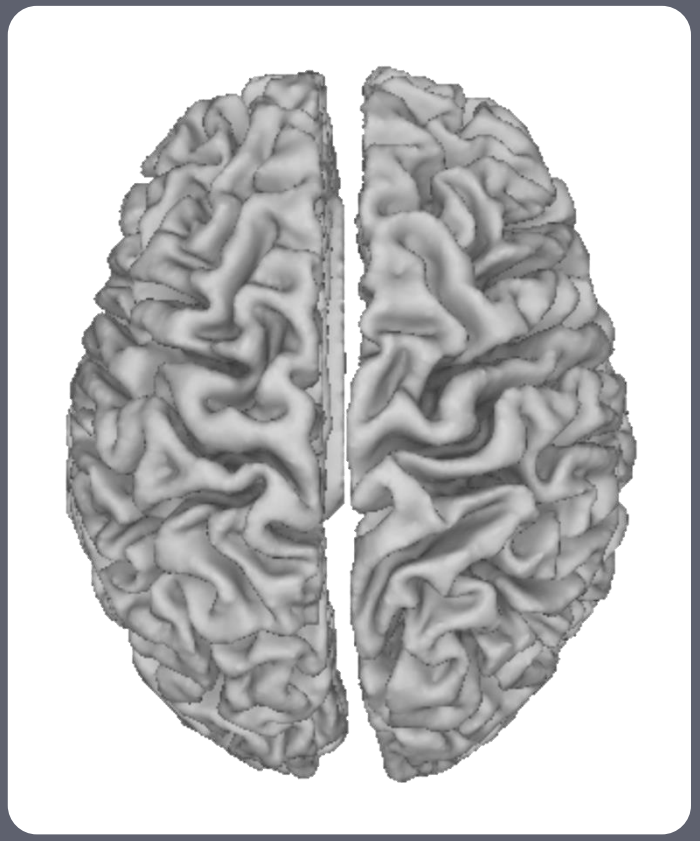


Cortical surface mesh representation

Cortical Surface

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

Equivalent to two 13" pizzas!



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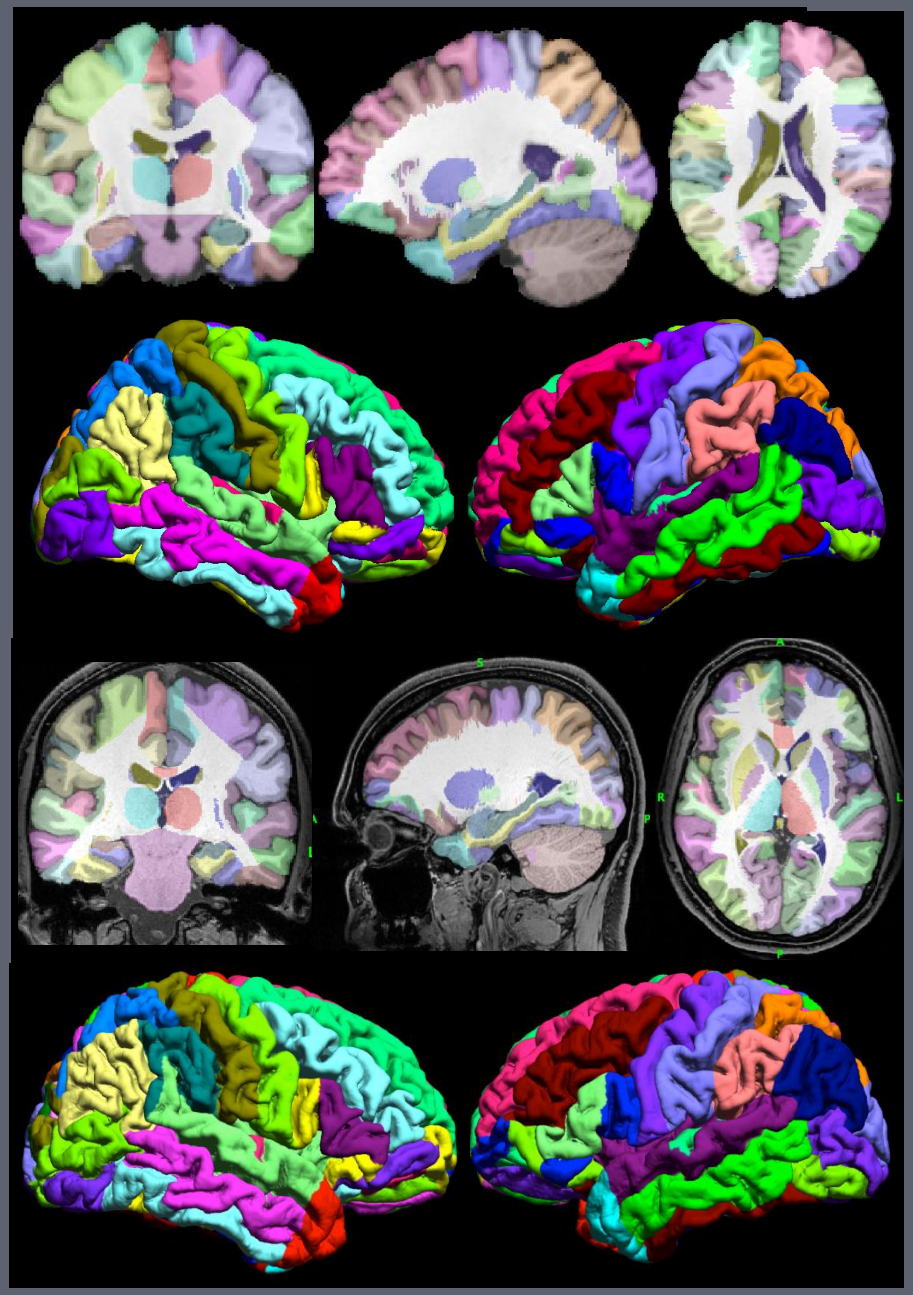
Each cortical area ~ one 3 cm pepperoni!

BrainSuiteAtlas I

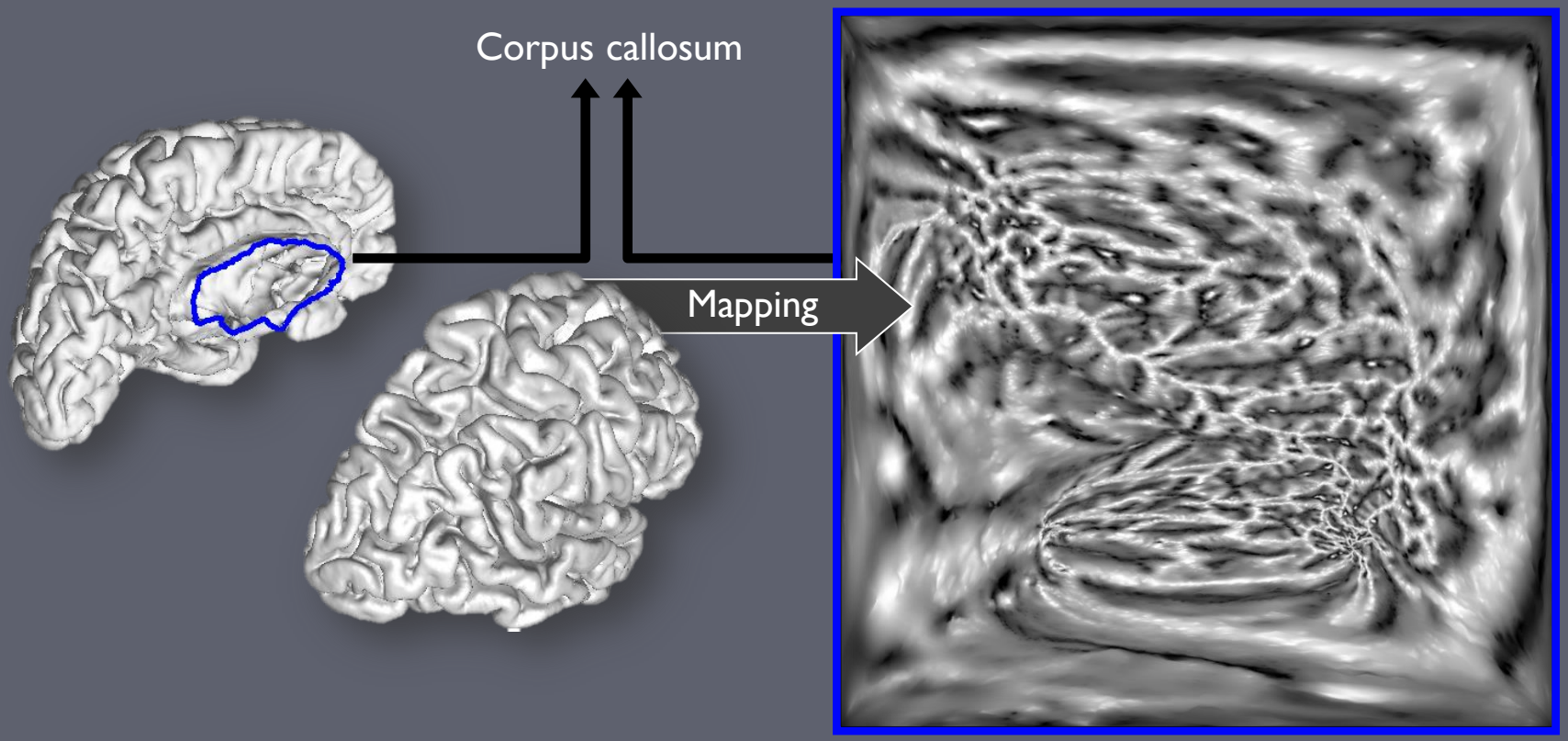
- Single subject atlas labeled at USC by expert neuroanatomist
- 26 sulcal curves per hemisphere
- 98 volumetric regions of interest (ROIs), 35*2=70 cortical ROIs

BCI-DNI Atlas

- Single subject atlas labeled at USC by expert neuroanatomist
- high-resolution (0.5 mm × 0.5 mm × 0.8 mm) 3D MPRAGE, 3T scan
- 26 sulcal curves per hemisphere
- 95 volumetric regions of interest (ROIs), 33*2=66 cortical ROIs



Cortical Surface Parameterization

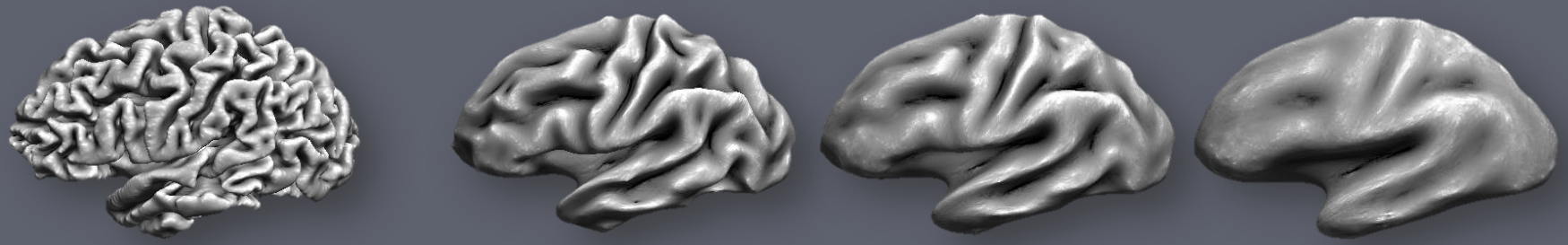


Flat-map color coded by curvature

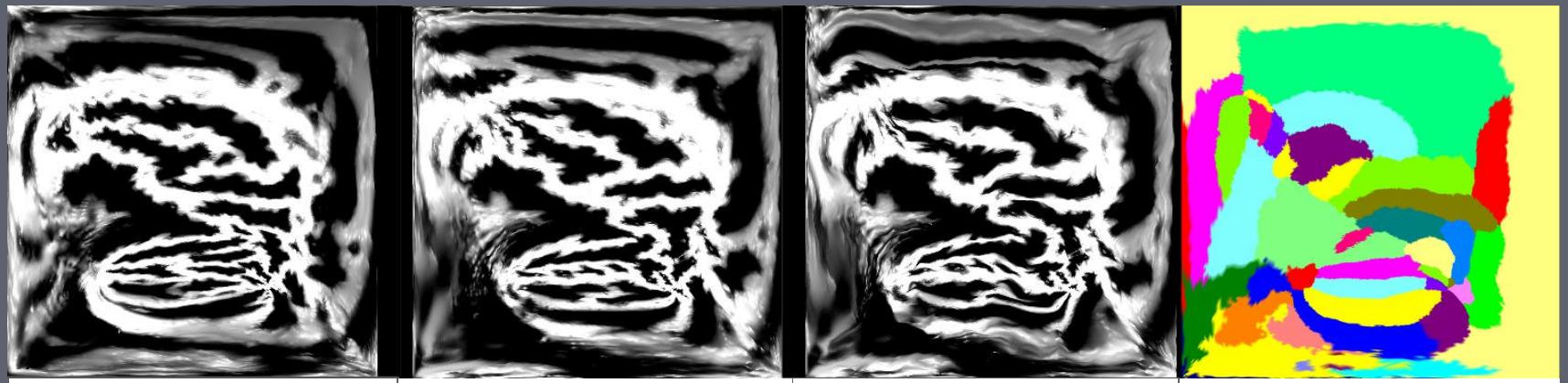
Extensions to Automatic Registration Without Sulcal Curves

Input mid surface

Smoothed surfaces

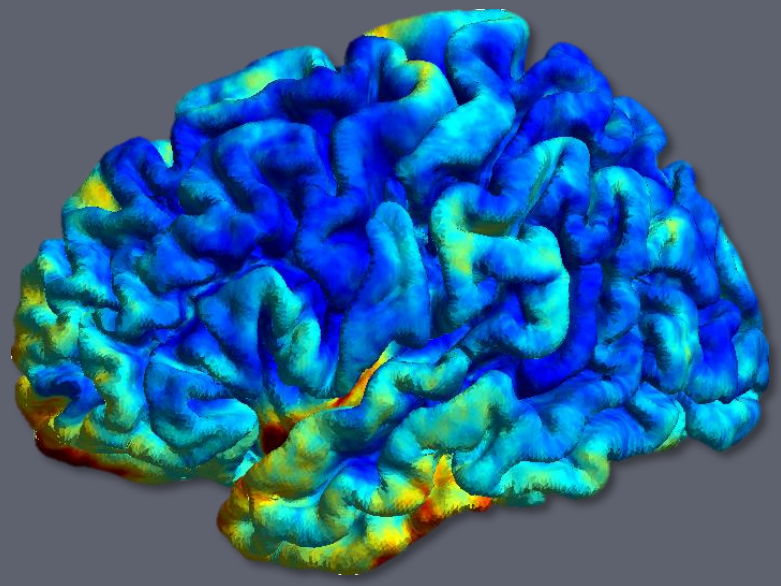


Cumulative curvature computation for multiresolution representation



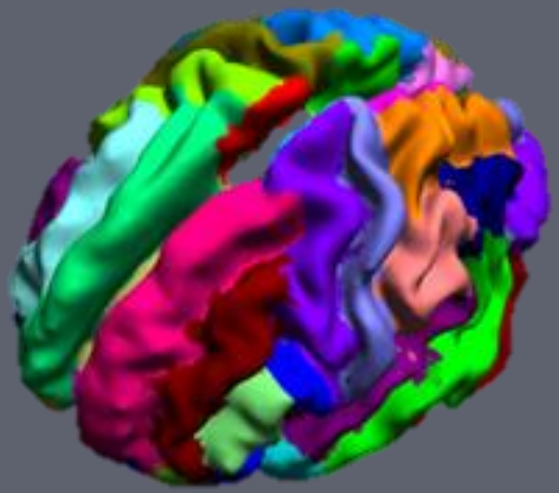
Elastic matching for atlas and subject flat maps

Curvature Weighting

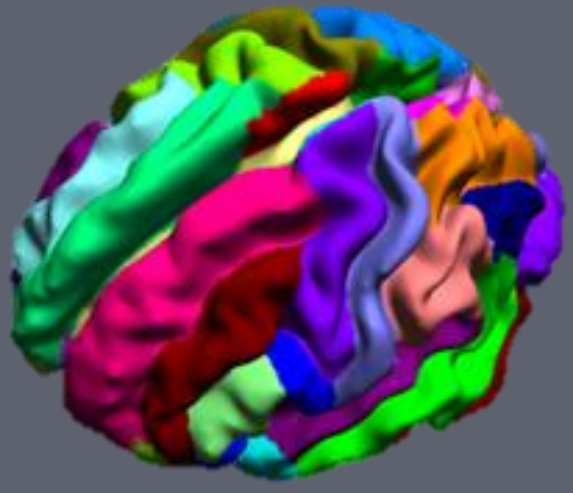


- Color coded curvature variance is shown in the figure.
- Computed by aligning 100 brains. Inverse of curvature variance is used as a weighting on the curvature cost function.

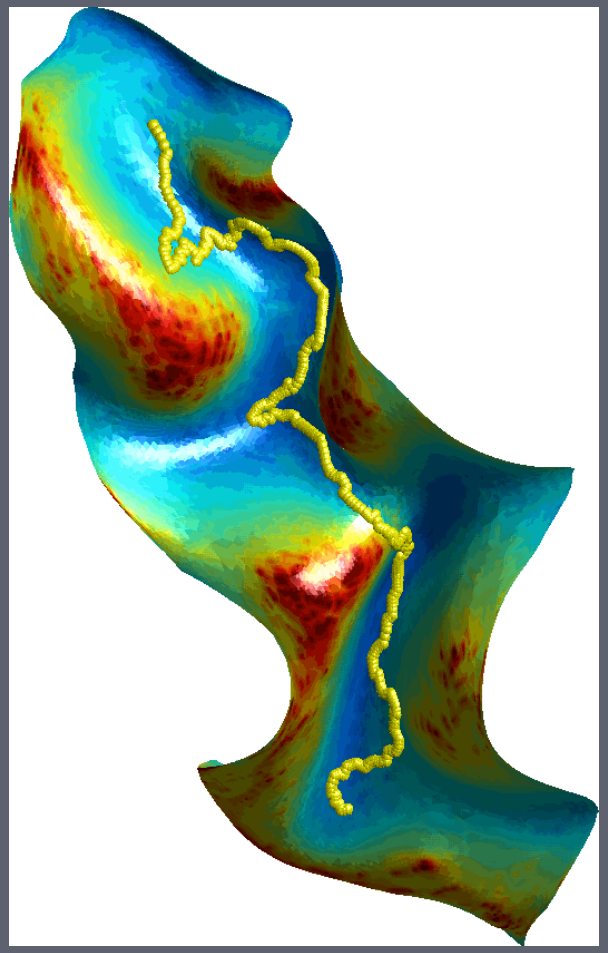
Refinement of Labels and Sulci



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

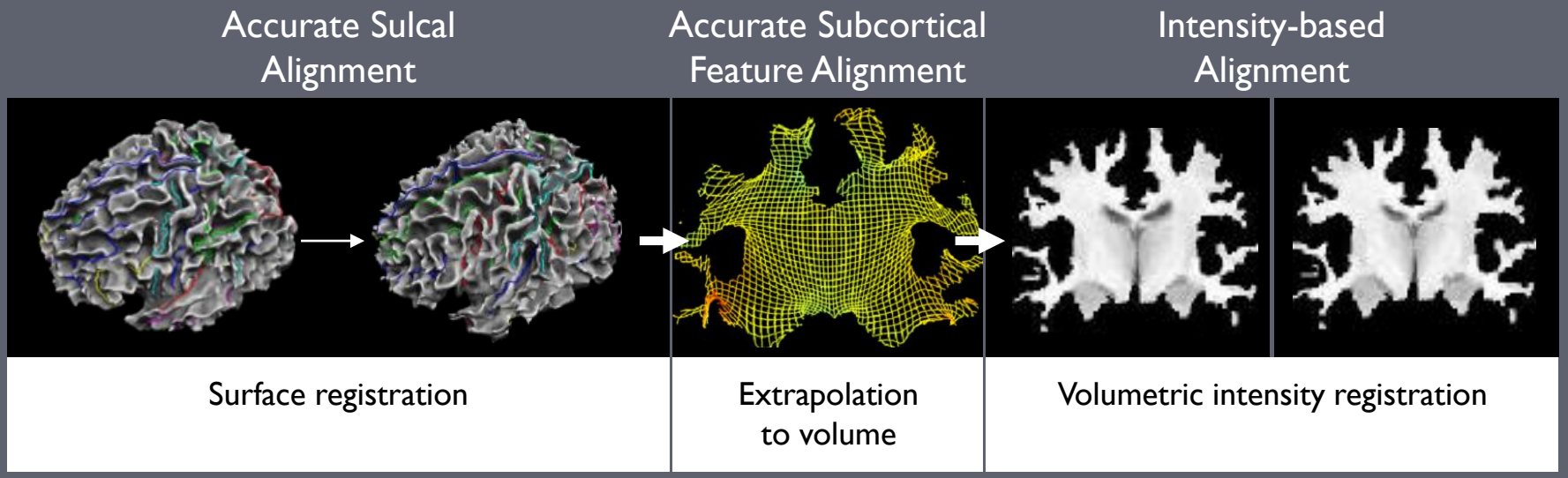


Labels after geodesic curvature. Flow plotted on a smoothened representation of a cortical surface.



Animation of the geodesic curvature flow for sulcal refinement.

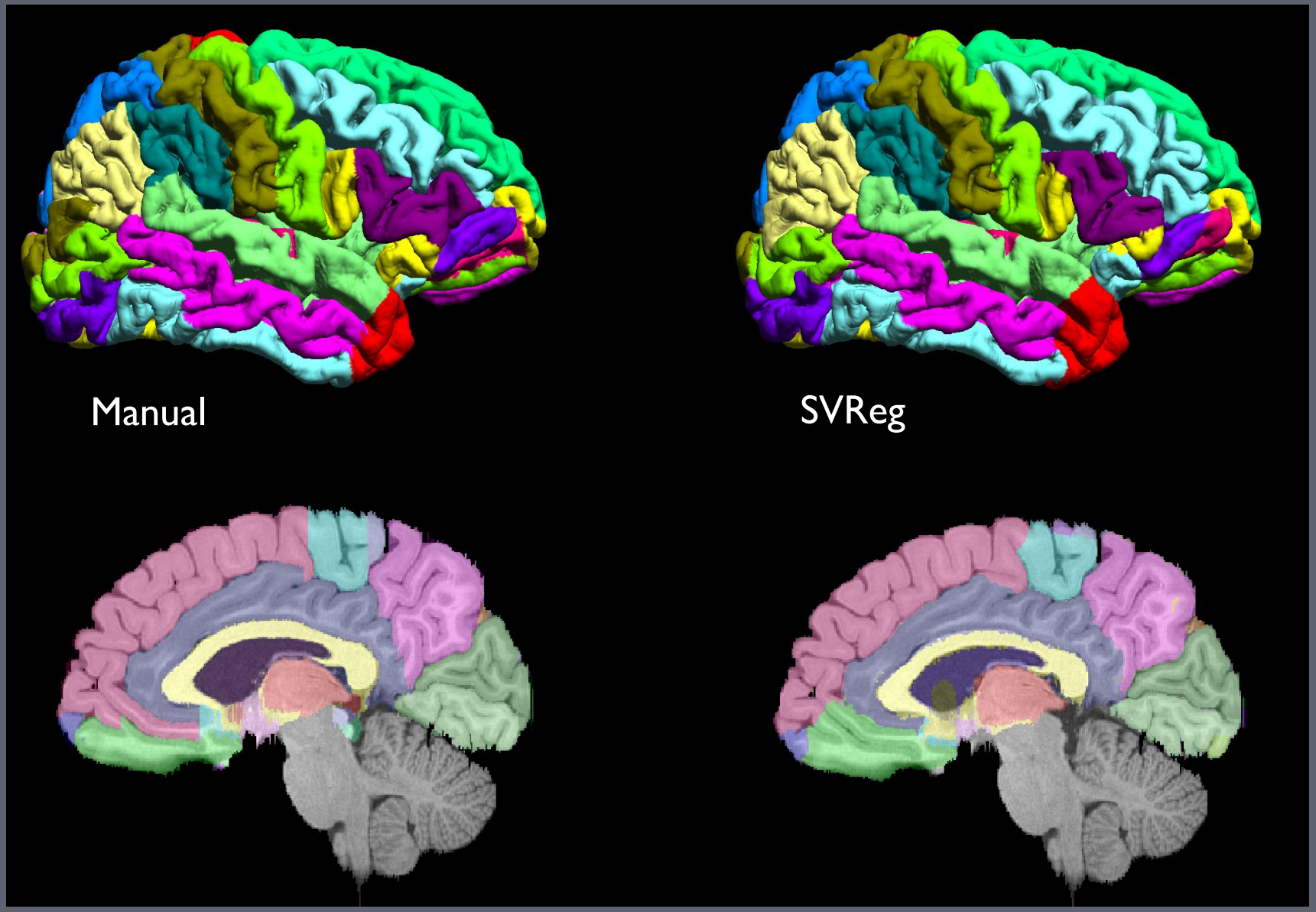
Extension to Volumetric Registration



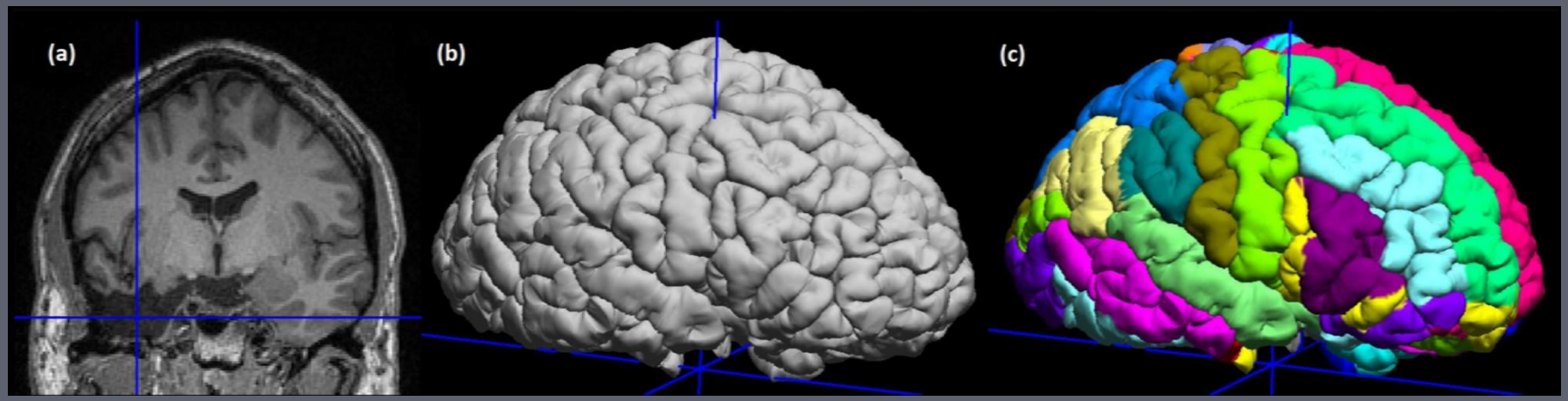
- Solves the difficult problem of surface/sulcal registration in 3D volume.
- Surface and Volume Registration (SVReg) method performs accurate alignment of both cortical surfaces as well as subcortical volumes.

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

Automated vs Manual Labeling



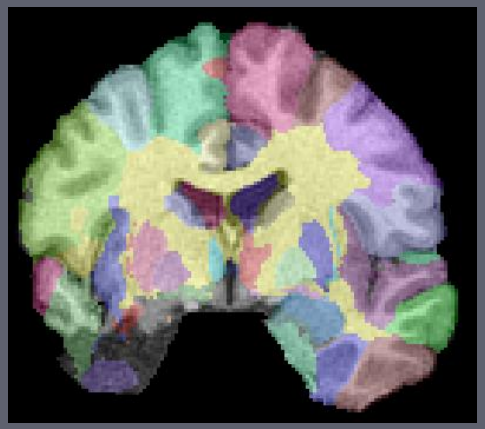
Lesion Brains

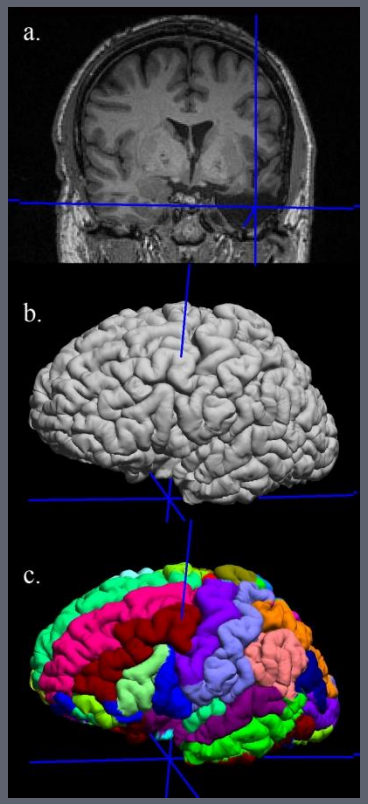


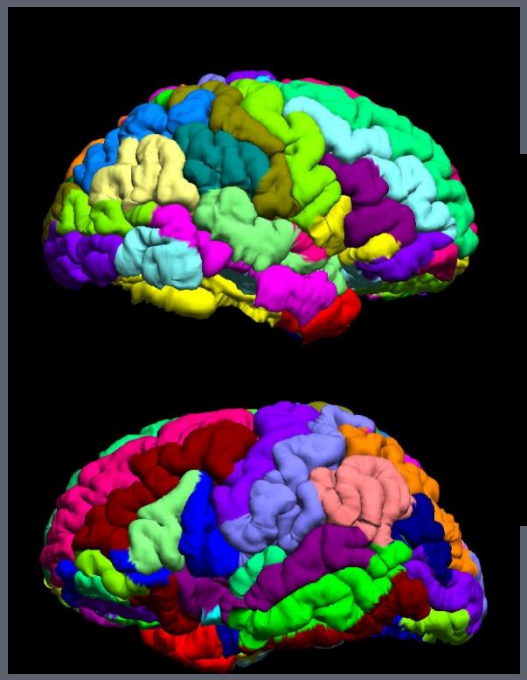
- SVReg may work with brains with lesions or other abnormalities

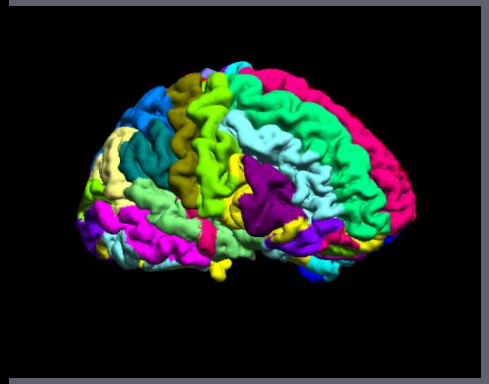
  * The results might show varying degree of accuracy depending on how severe the abnormality in the brain is

More Examples of Lesion Brains

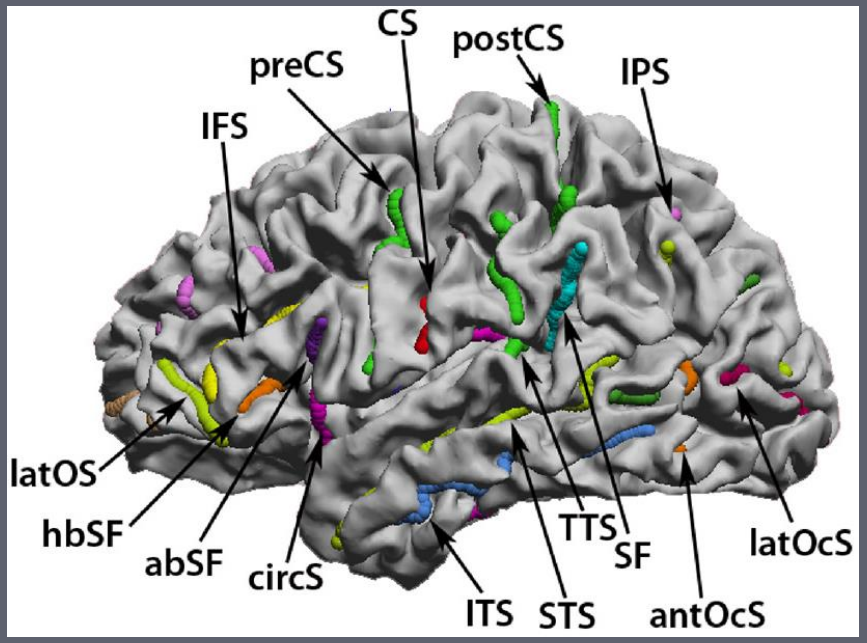




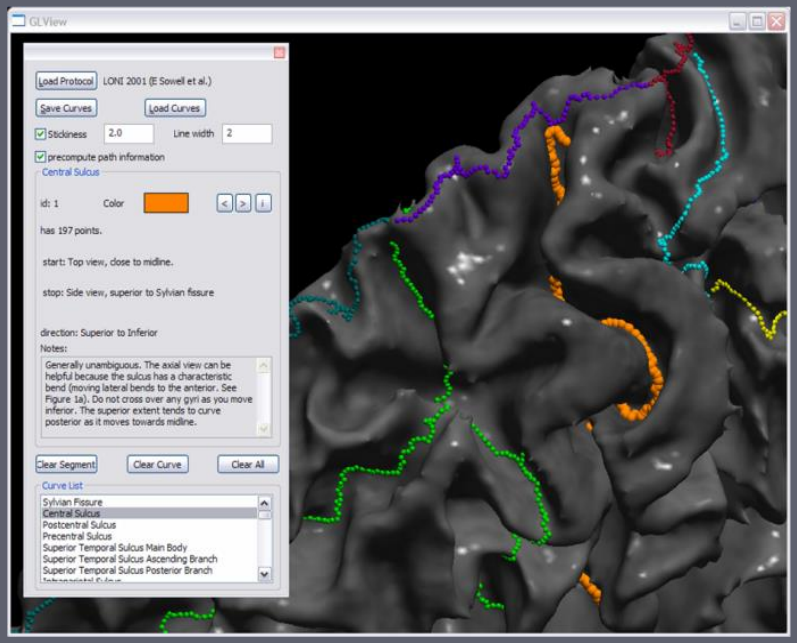




Cortical Surface Registration Based on Manually Traced Sulcal Curves (future release)



Sulcal delineation protocol in BrainSuite

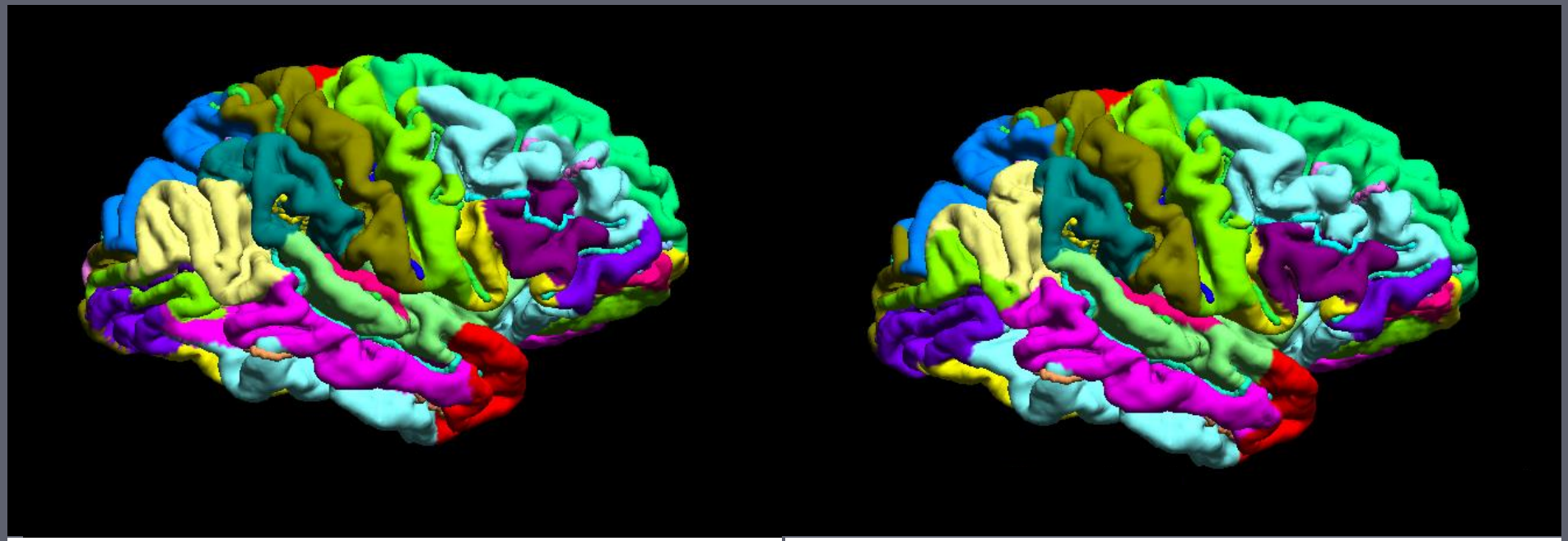


Sulcal curve delineation tool in BrainSuite

- 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.

IMPROVED SUBCORTICAL SEGMENTATION

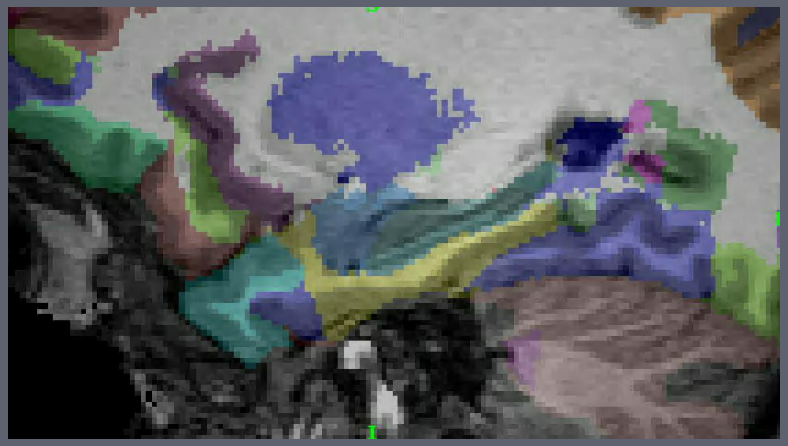
Earlier version

New version

LABELING OF HIPPOCAMPUS AND AMYGDALA

- The surfaces are not reliable near hippocampus and amygdala and therefore these labels tend to be inaccurate.
- The new code ignores surface constraints near these structures and rely only on intensity to get more accurate labeling.

Earlier version



New version

CORTICAL THICKNESS USING PARTIAL TISSUE FRACTION ESTIMATES

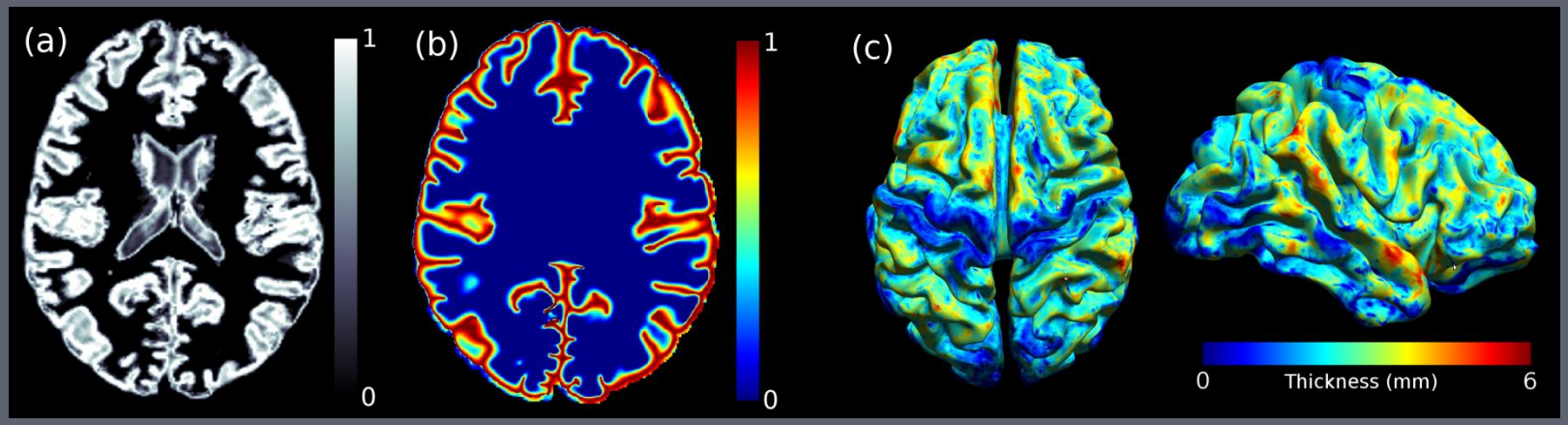
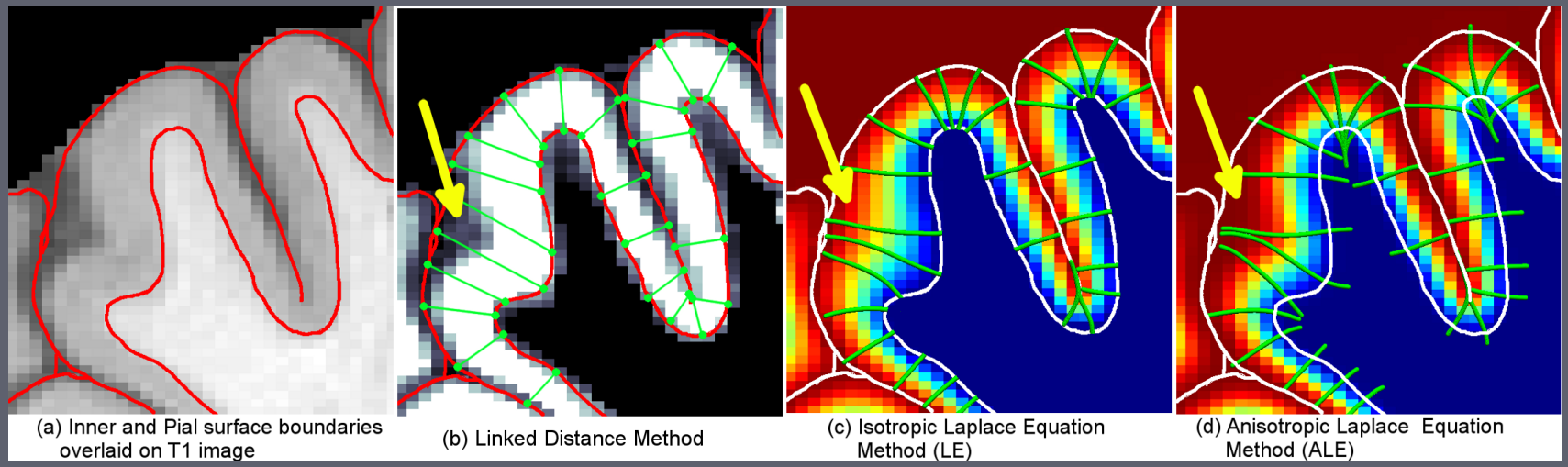


Figure: Thickness estimation procedure. (a) Gray-matter fraction estimated using a partial volume model; (b) Temperature map obtained using the proposed ALE method; and (c) Thickness estimate using the ALE method shown on the estimated mid-cortical surface.

THICKNESS COMPUTATION METHOD



(a) Inner and Pial surface boundaries overlaid on T1 image

(b) Linked Distance Method

(c) Isotropic Laplace Equation Method (LE)

(d) Anisotropic Laplace Equation Method (ALE)

Mathematical Formulation

$$\frac{\partial \phi(x,y,z,t)}{\partial t} = div\left(\frac{1}{f(x,y,z)}\nabla\phi(x,y,z,t)\right)$$

$\frac{\partial \phi(x,y,z,t)}{\partial t}$: Temperature

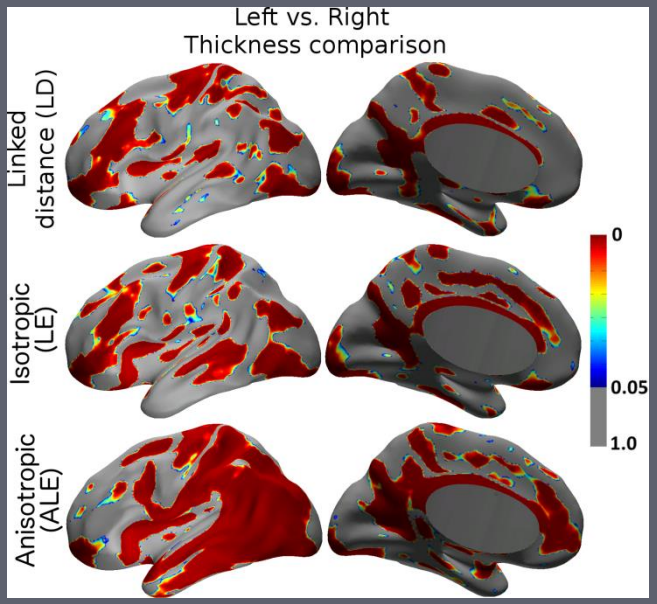
$f(x,y,z)$: Gray matter fraction

$$T(x,y,z) = f(x,y,z)\frac{1}{||\nabla\phi_\infty(x,y,z)||}$$

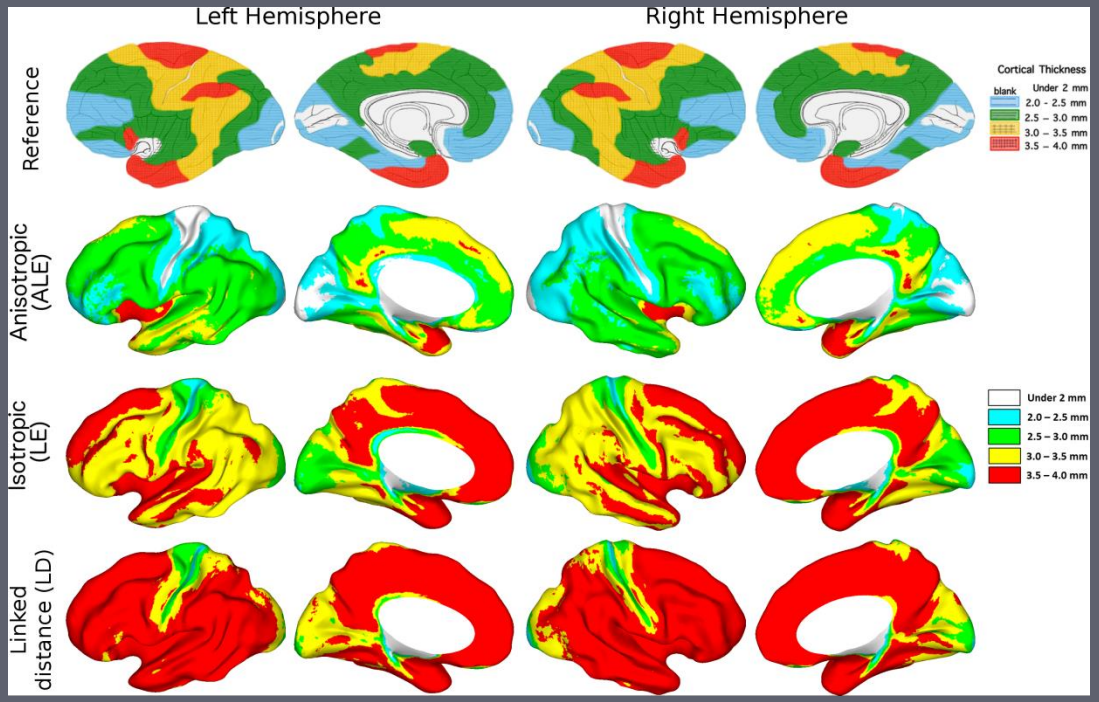
$T(x,y,z)$: Equilibrium Temperature

Features

- invariant to convolution by unit integral kernel
- Avg thickness is more consistent with literature
- Shows higher significance in population studies



The p-value map of significant left-to-right cortical thickness differences estimated using the three different methods (LD, LE, ALE).



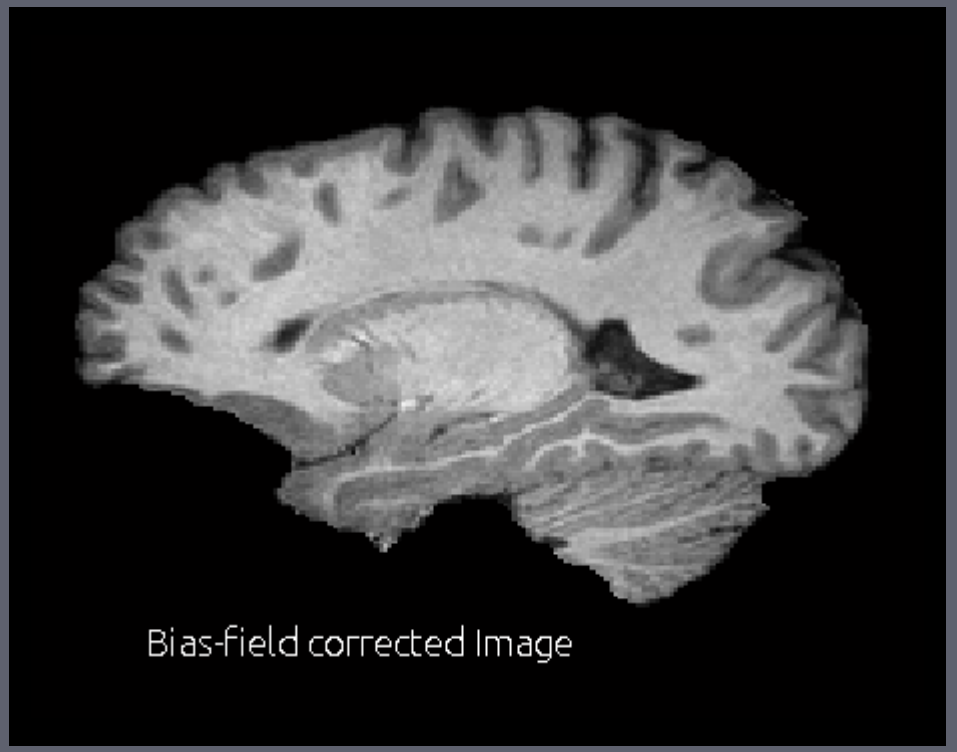
Average cortical thickness map estimated using (row 1) histology (von Economo, 2009), (row 2) Anisotropic Laplace Equation (ALE), (row 3) Isotropic Laplace Equation (LE), and (row 4) Linked Distance (LD) methods.

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

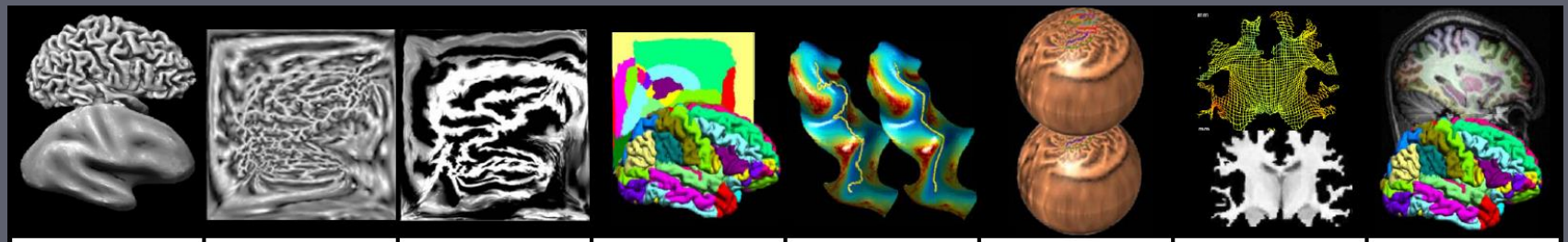
Bias Correction Tool



Allows manual correction of the bias field

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

THANKS!



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

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.