Brain Image Registration Using Cortically Constrained Harmonic Mappings
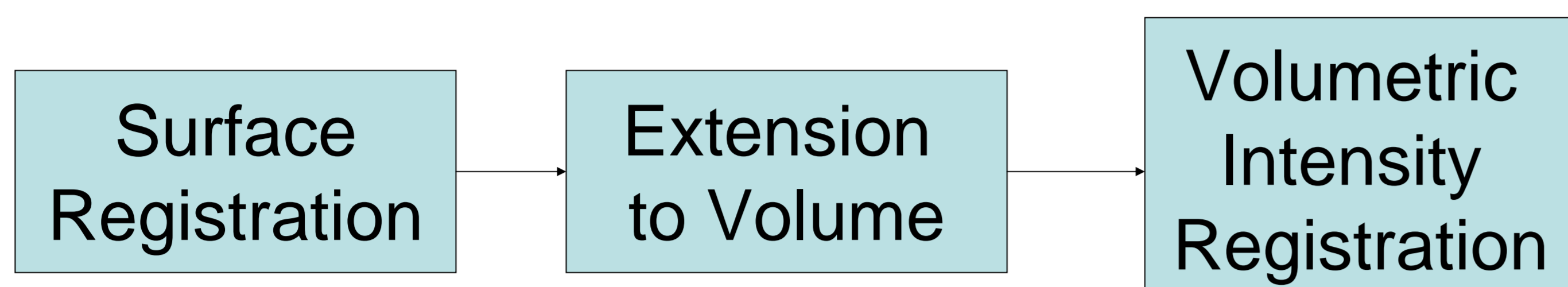
Anand A Joshi[1], David W Shattuck[2], Paul M Thompson[2] and Richard M Leahy[1]

[1]Signal and Image Processing Institute, University of Southern California, Los Angeles, USA
[2]Laboratory of Neuro Imaging, University of California, Los Angeles, USA

Surface Registration → Extension to Volume → Volumetric Intensity Registration

Problem Statement

1. Surface matching which computes maps between surface pairs – the cortical surfaces and the grey matter/csf surfaces of the two brains, with sulcal alignment constraints.
2. Extrapolation of the surface map to the entire cortical volume by a harmonic map.
3. Refinement of the harmonic map on the interior volumes to improve intensity alignment of subcortical structures.

Surface Registration

grey/csf surface

grey/white surface

M N

ϕ_M ϕ_N
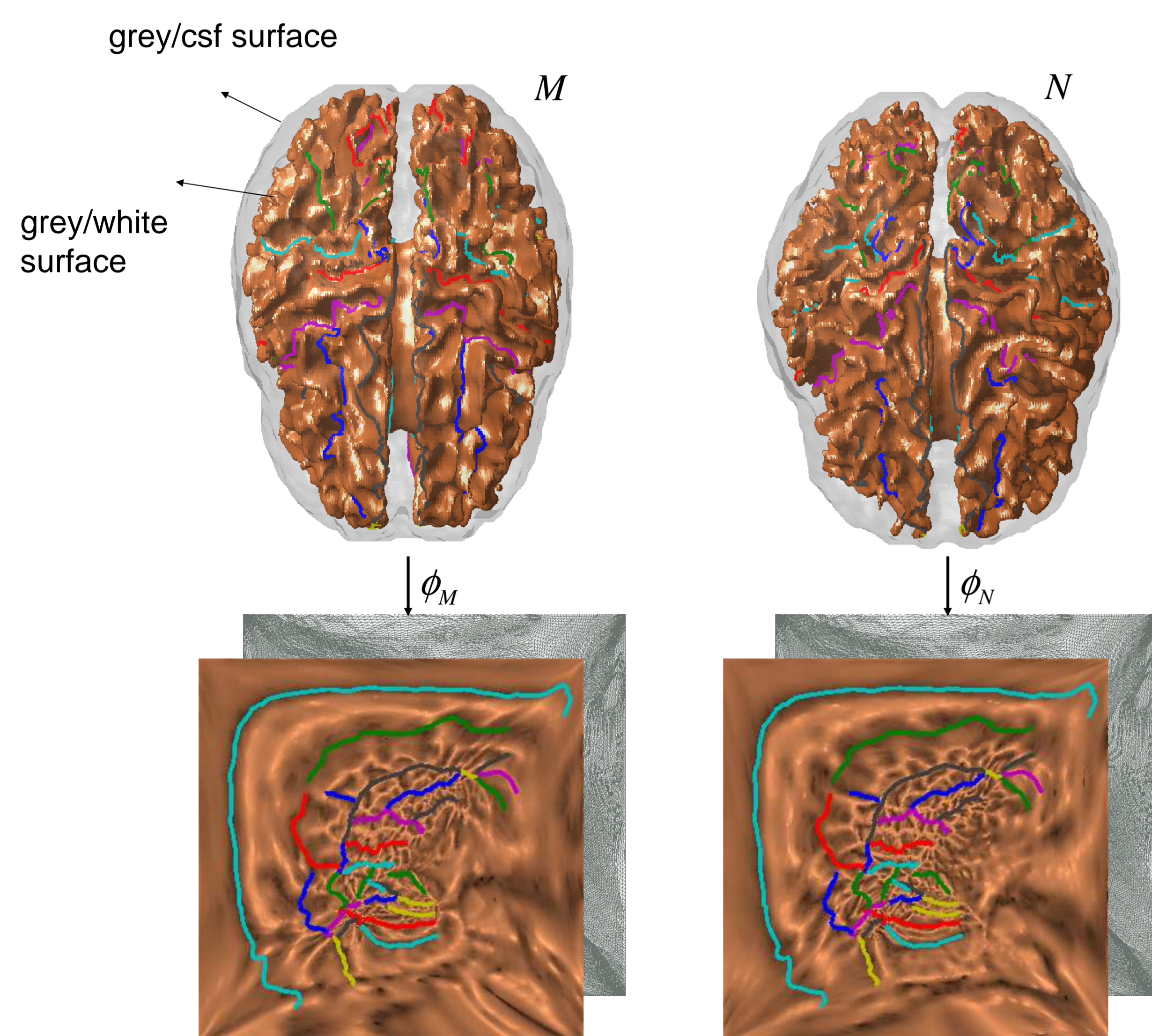
We model the cortical surface as an elastic sheet by solving the linear elastic equilibrium equation in the geometry of the cortical surface by minimizing the energy integral

$$C(\phi_M, \phi_N) = E(\phi_M) + E(\phi_N) + \sigma^2 \sum_{k=1}^{K} \left(\phi_M(x_k) - \phi_N(y_k) \right)^2$$

where $\phi_M(x_k)$ and $\phi_N(x_k)$ denote the coordinates assigned to the set of K sulcal landmarks and

$$E(\phi_M) = \int_M \frac{\lambda}{4} \left(\mathrm{Tr}((D\phi)^T + D\phi) \right)^2 + \frac{\mu}{2} \left(\mathrm{Tr}((D\phi)^T + D\phi)^2 \right) dS.$$

subject to the sulcal matching constraints and the constraint that the corpus callosum is mapped to the boundary of the unit square. We use 21 sulcal landmarks traced using the sulcal anatomy protocol defined at LONI (http://www.loni.ucla.edu/NCRR/protocols.aspx).
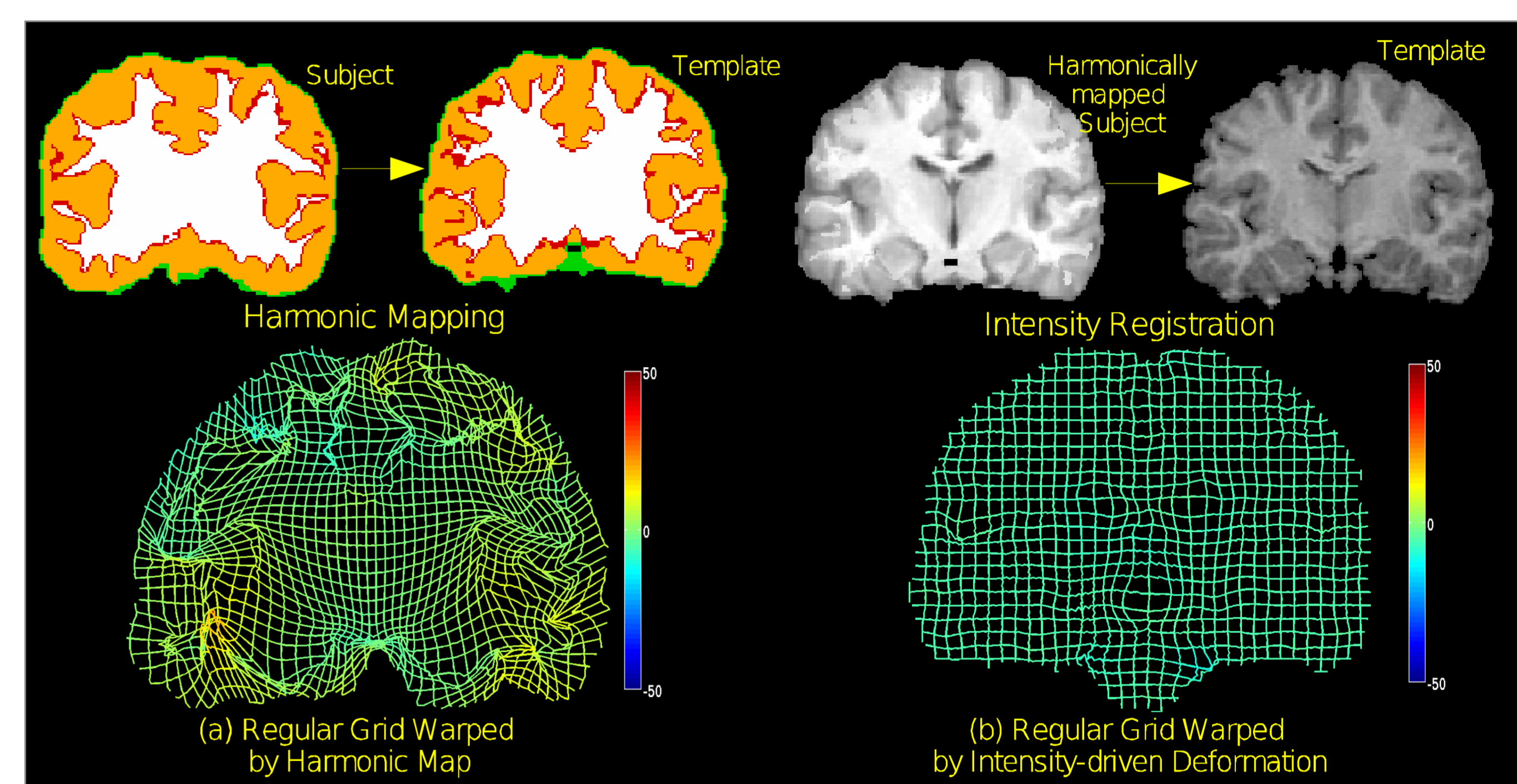
The MRI and segmentation data sets are made available at (http://www.cma.mgh.harvard.edu).

Volumetric Registration
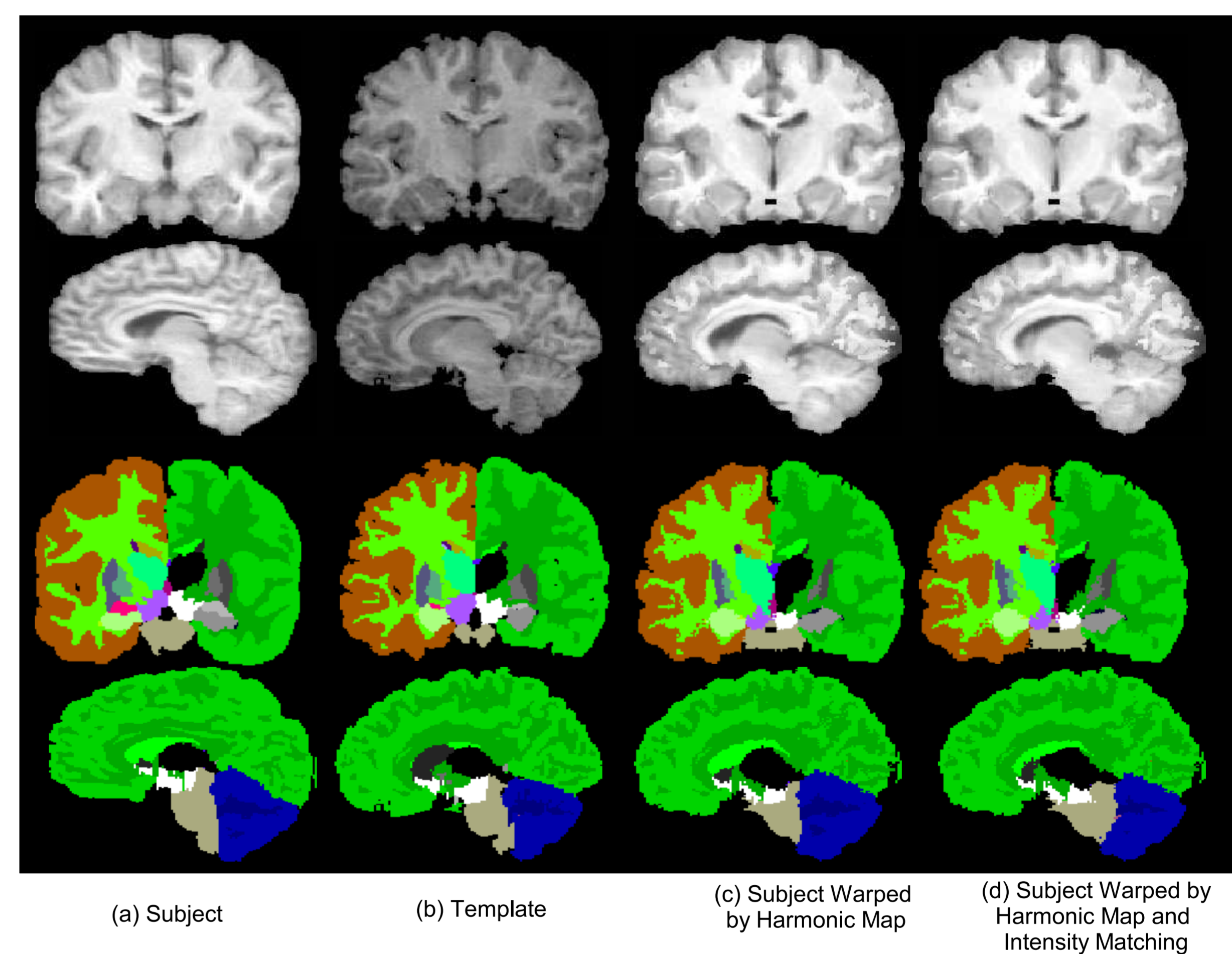
The surface point correspondence is extended to the entire volume using a harmonic map u = (u1,u2,u3) with the boundary mapping constraints defined by the surface matching.

$$E_h(u) = \frac{1}{2} \int_M \sum_{i=1}^{3} \sum_{\alpha=1}^{3} \left(\frac{\partial u^\alpha(x)}{\partial x^i} \right)^2 dV$$

Harmonic mapping is followed by inverse consistent linear elastic intensity registration.

(a) Regular Grid Warped by Harmonic Map
(b) Regular Grid Warped by Intensity-driven Deformation

Results

(a) Subject   (b) Template   (c) Subject Warped by Harmonic Map   (d) Subject Warped by Harmonic Map and Intensity Matching

RMS error in sulcal landmarks is **11mm**, **11.5mm** and **2.4mm** for AIR, HAMMER and our method respectively.

Table of Dice coefficients

Subcortical Structure	AIR	Harmonic	HAMMER	Harmonic +Intensity
Left Thalamus	0.79	0.68	0.73	0.71
Left Caudate	0.31	0.50	0.58	0.62
Left Putamen	0.61	0.40	0.51	0.47
Left Hippocampus	0.30	0.56	0.67	0.59
Right Thalamus	0.77	0.66	0.87	0.72
Right Caudate	0.32	0.46	0.81	0.54
Right Putamen	0.53	0.52	0.67	0.57
Right Hippocampus	0.33	0.58	0.59	0.69

References

[1] Joshi, A et al., "A Finite Element Method for elastic parameterization and alignment of cortical surfaces using sulcal constraints," *ISBI'07*.
[2] Joshi, A et al., "Surface-constrained volumetric brain registration using harmonic mappings," IEEE Trans. on Med. Imag. (To Appear).