Standard meshes for inter- and intra-subject surface-based analysis with minimal interpolation

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Introduction

Data from Functional Magnetic Resonance Imaging (FMRI) are increasingly being mapped to 3D models of the cortical surface.

Such maps reveal the topology of activation that is often obscured in volumetric data and offer enhanced visualization of cortical function.

Currently, surface mapping of functional activity involves interpolation of the functional data.

Unnecessary interpolations, especially in the volumetric space, can strongly affect the topology of activation.

We present a general framework for greatly simplifying inter- and intra- subject analyses while eliminating all interpolation steps.

Volumetric Grid and Surface Topology

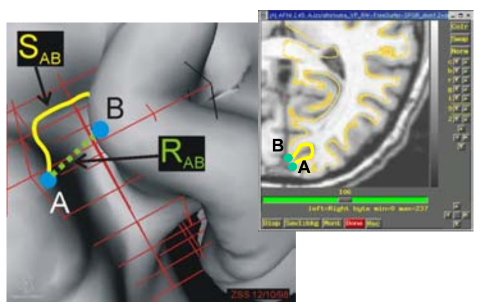


Figure 1: Volumetric sampling obscures the topology of activation. The two points A and B, though distant on the cortical surface, are juxtaposed in the FMRI grid (4mm voxel size). Volume-based interpolation will disproportionately alter the topography of activation at points such as A and B from the topology at other points at less crucial locations.

Methods & Results

Surface Creation and Inter-subject Mapping Without Interpolation

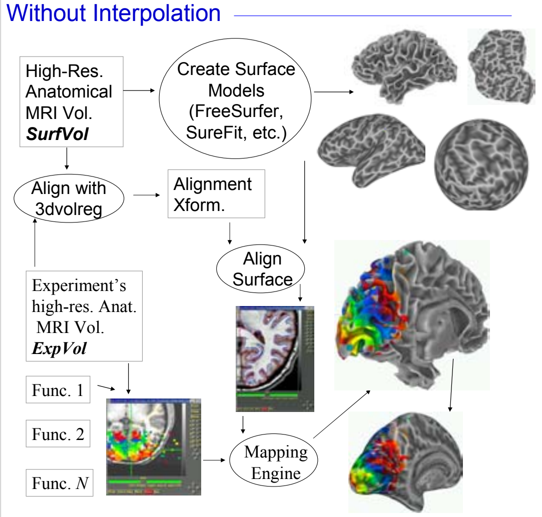


Figure 2 illustrates how surface models are brought into alignment with experimental functional data without interpolation of the latter. The transform for aligning the surface with the functional data is the one required to align *SurfVol* with *ExpVol.*

Methods & Results

Warping to Spherical Template

To compare data across subjects, individual surface models are warped (registered) to a common template [2,3].

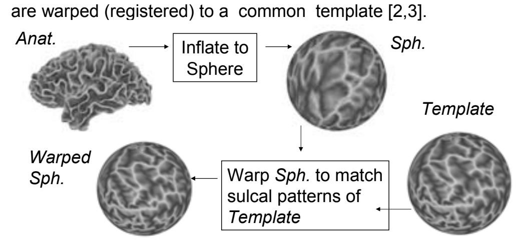
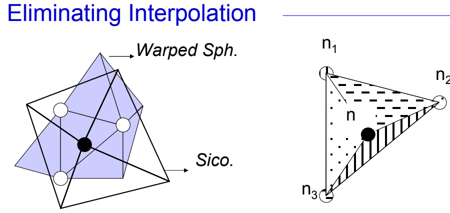


Figure 3: An individual subject's surface model (*Anat*) is inflated to a sphere (*Sph*) and then warped so that sulcal patterns match those of the spherical surface template (*Template*).

For cross-subject analysis, combining data across surfaces requires cumbersome interpolation on the warped spherical surfaces because they are not homologous.

Standard Meshes: Eliminating Interpolation



Interpolation can be eliminated if we create homologous surfaces that are also in register with *Template*.

- Create a tessellated icosahedron (*Sico*) with a certain node density
- Map each node *n* in *Sico* to the triangle *T:(n1, n2, n3)* in *Warped Sph.* that contains *n*'s radial projection
- This allows the representation of any node property, *P(n)*, as a function of the properties of *n1, n2, n3*:

$P(n) = a1\ P(n1) + a2\ P(n2) + a3\ P(n3)$

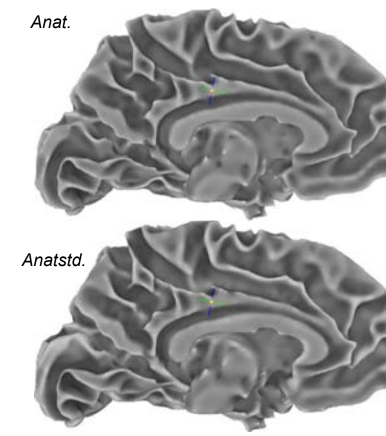
where *a* represents the interpolation weights based on the area coordinates of *n* in *T*.

- Create a standard mesh model of *Anat* by substituting for *P(.)*, the *X,Y* and *Z* coordinates of the nodes in *Anat*.

The result is *Anatstd*, a surface virtually identical in shape to *Anat.* but with a mesh that is identical across subjects.

The same nodes on standard surface models of different subjects now refer to a similar anatomical location (within the variability of the warping process).

Original and Standard-Mesh Surfaces are Virtually Identical



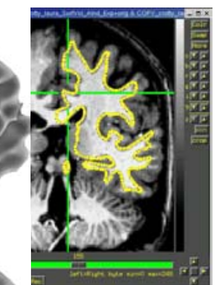


Figure 4: Original (top) and standard-mesh surface models and their intersection with the anatomical volume. Surfaces are virtually identical.

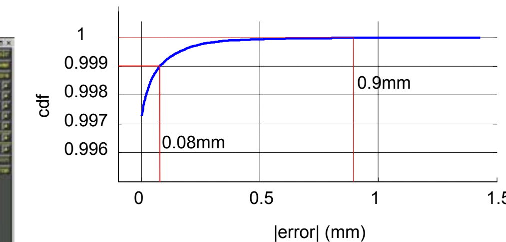


Figure 5: Cumulative Distribution Function of error between original and standard-mesh surfaces. Mean error was 2×10^{-5} mm with a standard deviation of 9×10^{-3} mm. 99.9% of nodes had an error less than 0.08 mm and 99.999% under 0.9mm. These errors are due to interpolation artifacts and can be reduced with appropriate smoothing. Errors were measured by the distance along the normal at each node from one surface to the next. Graph shows results combined across 6 surfaces.

Correspondence of node id across subjects

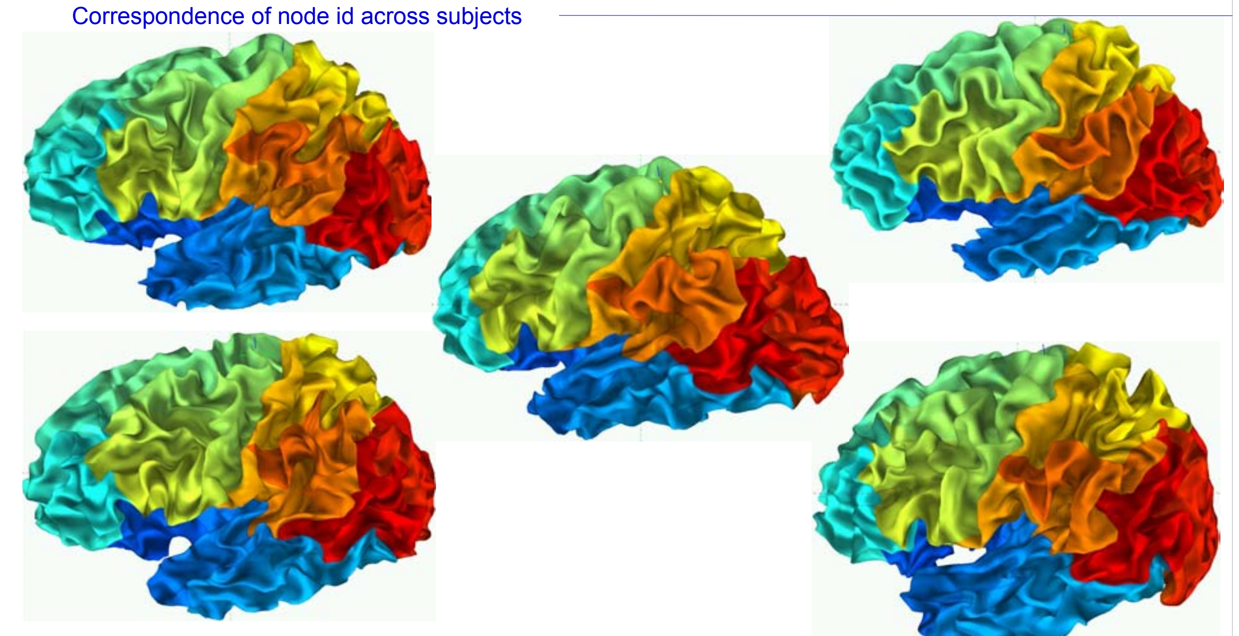


Figure 6: Set of 5 standard mesh surface models. Node colors encode for node indices. Note how nodes with the same indices correspond to comparable sulcal landmarks despite the marked anatomical variability across subjects.

Conclusions

We propose a topology-based frame of reference for cross-subject analysis instead of a coordinate-based one.

Topology-based reference provides all the functionality of the coordinate-based counterpart while greatly simplifying cross-subject analysis and without interpolating functional data.

The proposed method is independent of surface creation methods and preserves the morphology of the original surface.

With the adoption of a common template, surface data is directly exchangeable across subjects and surface mapping software.

References

Van Essen, D., H. Drury, et al. (1998). "Functional and structural mapping of human cerebral cortex: solutions are in the surfaces." PNAS. 95(3): 788-95.

Fischl, B., M.I. Sereno, and A.M. Dale, *Cortical surface-based analysis. II: Inflation, flattening, and a surface-based coordinate system.* Neuroimage, 1999. **9**(2): p. 195-207.

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Software Implementation

The proposed algorithm has been implemented and included with the distribution of AFNI http://afni.nimh.nih.gov and SUMA http://afni.nimh.nih.gov/ssc/ziad/SUMA .

<u>See also:</u> Poster # 809 by R.W. Cox et al.

Poster # 805 by P.C. Christidis et al.