Surface-based Analysis: Inter-subject Registration and Smoothing
Outline

- Exploratory Spatial Analysis
- Coordinate Systems
  - 3D (Volumetric)
  - 2D (Surface-based)
- Inter-subject registration
  - Volume-based
  - Surface-based
- Surface-based smoothing
- Surface-based clustering
Exploratory Spatial Analysis

• Don’t know where effect is going to be
• vs ROI analysis
• Analyze each voxel separately
• Create a map
• Find clusters
Aging Exploratory Analysis

Cortical Thickness vs Aging; Salat, et al, 2004, Cerebral Cortex
Aging Thickness Study

N=40

Positive Age Correlation

Negative Age Correlation

p<.01
Individual Exploratory Analysis

- fMRI Words-vs-Fixation
- Single subject (e.g., presurgical planning or functional ROI)
- Outlines are FreeSurfer cortical ROIs
- Yellow and blue blobs are functional activation
- Activation does not lie cleanly within a predefined ROI
Exploratory Spatial Analysis

- Generally requires spatial smoothing of data to increase SNR
- For group analysis, requires that subjects’ brains be aligned to each other on a voxel-wise basis
- Neither needed for an ROI analysis
- Smoothing and inter-subject registration can be performed in the volume or on the surface
Why Is a Model of the Cortical Surface Useful?

Local functional organization of cortex is largely 2-dimensional! Eg, functional mapping of primary visual areas:

From (Sereno et al, 1995, Science).
Coordinate Systems: 3D (Volumetric)

- 3D Coordinate System
  - XYZ
  - RAS (Right-Anterior-Superior)
  - CRS (Column-Row-Slice)
  - Origin (XYZ=0, eg, AC)
  - MR Intensity at each XYZ
Coordinate Systems: 2D (Surface)

Sheet: 2D Coordinate System (X,Y)
- **central**
- **anterior**
- **posterior**
- **superior temporal**
- **calcarine**

Sphere: 2D Coordinate System
- Latitude and Longitude ($\theta$, $\phi$)
- Continuous, no cuts
- Value at each point (eg, thickness)

Curvature
- **SULCUS** (+)
- **GYRUS** (-)
Inter-subject Registration
Volumetric Inter-subject Registration

- Affine/Linear
  - Translate
  - Rotate
  - Stretch
  - Shear
  - (12 DOF)

- Match Intensity, Voxel-by-Voxel
- Problems
- Can use non-linear volumetric (cf CVS)
Surface-based Inter-subject Registration

- Translate, Rotate, Stretch, Shear (12 DOF)
- Match Curvature, Vertex-by-Vertex
- Nonlinear Stretching (“Morphing”) allowed (area regularization)
- Actually done on sphere
- “Spherical Morph”

Curvature “Intensity”
- SULCUS (+)
- GYRUS (-)
- Codes folding pattern
A Surface-Based Coordinate System

Common space for group analysis (like Talairach)
fsaverage

- Has “subject” folder like individual FS subjects
- “Buckner 40” subjects
- Default registration space
- MNI305 coordinates
Surface-based Inter-subject Registration

• Gray Matter-to-Gray Matter (it’s all gray matter!)
• Gyrus-to-Gyrus and Sulcus-to-Sulcus
• Some minor folding patterns won’t line up
• Fully automated, no landmarking needed
• Atlas registration is probabilistic, most variable regions get less weight
• Done automatically in recon-all
• fsaverage
Spatial Smoothing

Why should you smooth?
• Might Improve CNR/SNR
• Improve inter-subject registration

How much smoothing?
• Blob-size
• Typically 5-20 mm FWHM
• Surface smoothing more forgiving than volume-based
Volume-based Smoothing

- Smoothing is averaging of “nearby” voxels.
Volume-based Smoothing

- 5 mm apart in 3D
- 25 mm apart on surface!
- Kernel much larger
- Averaging with other tissue types (WM, CSF)
- Averaging with other functional areas

14mm FWHM
Spatial Smoothing

• Spatially convolve image with Gaussian kernel.
• Kernel sums to 1
• Full-Width/Half-max: $\text{FWHM} = \frac{\sigma}{\sqrt{\log(256)}}$

$\sigma =$ standard deviation of the Gaussian
Effect of Smoothing on Activation

- Working memory paradigm
- FWHM: 0, 2, 4, 6, 8, 10, 12, 14, 16, 18, 20
Surface-based Smoothing

- Smoothing is averaging of nearby vertices

Sheet: 2D Coordinate System (X,Y)  
Sphere: 2D Coordinate System (θ,φ)

- anterior
- sylvian
- superior temporal
- central
- posterior
- calcarine
Group fMRI Analysis: Volume vs Surface

Surface-based Registration and smoothing

Affine registration to MNI305 with volume smoothing

Probe-vs-Fixation. Data from Functional Biomedical Informatics Research Network (fBIRN)
5HT₄ BP Asymmetry Study (N=16)

Surface Smoothing

Volume Smoothing

Left > Right

Right > Left
Surface-based Clustering

- A cluster is a group of connected (neighboring) vertices above threshold
- Neighborhood is 2D, not 3D
- Cluster has a size (area in mm$^2$)
- Reduced search space (corrections for multiple comparisons)
Summary

• Why Surface-based Analysis?
  – Function has surface-based organization
  – Inter-subject registration: anatomy, not intensity
  – Smoothing
  – Clustering
  – Like 3D, but 2D

Use FreeSurfer

Be Happy