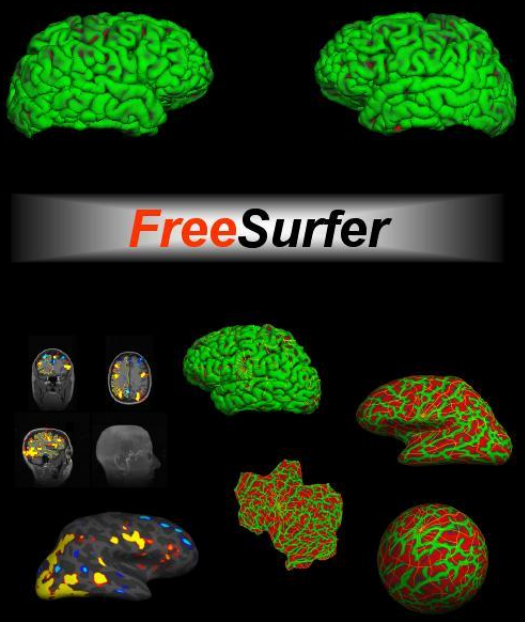
Surface-based Analysis:
Inter-subject Registration and Smoothing



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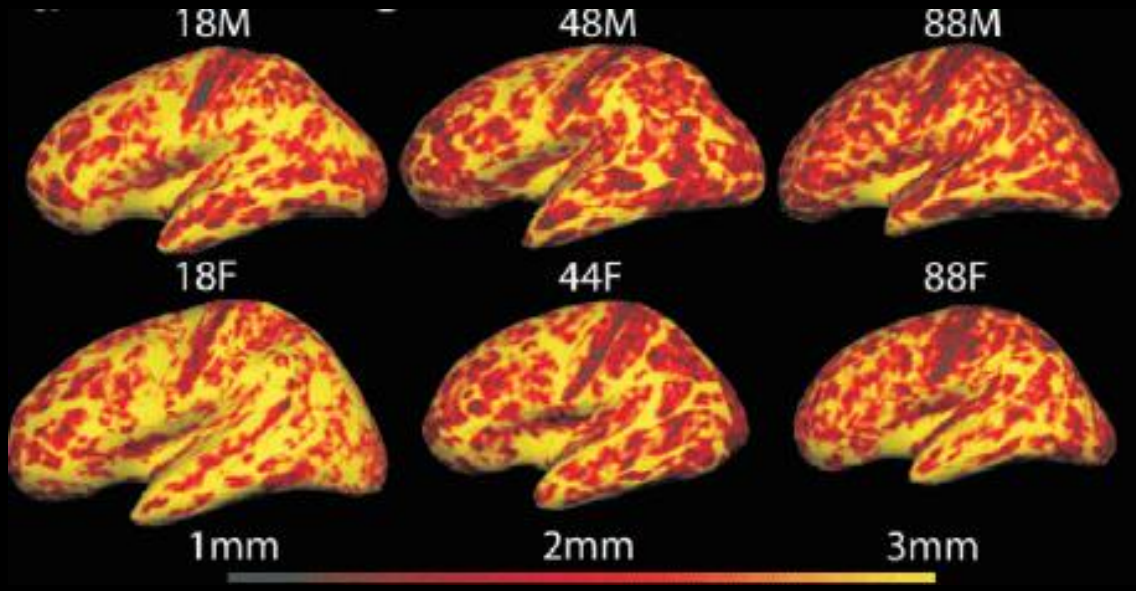
Outline

- 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

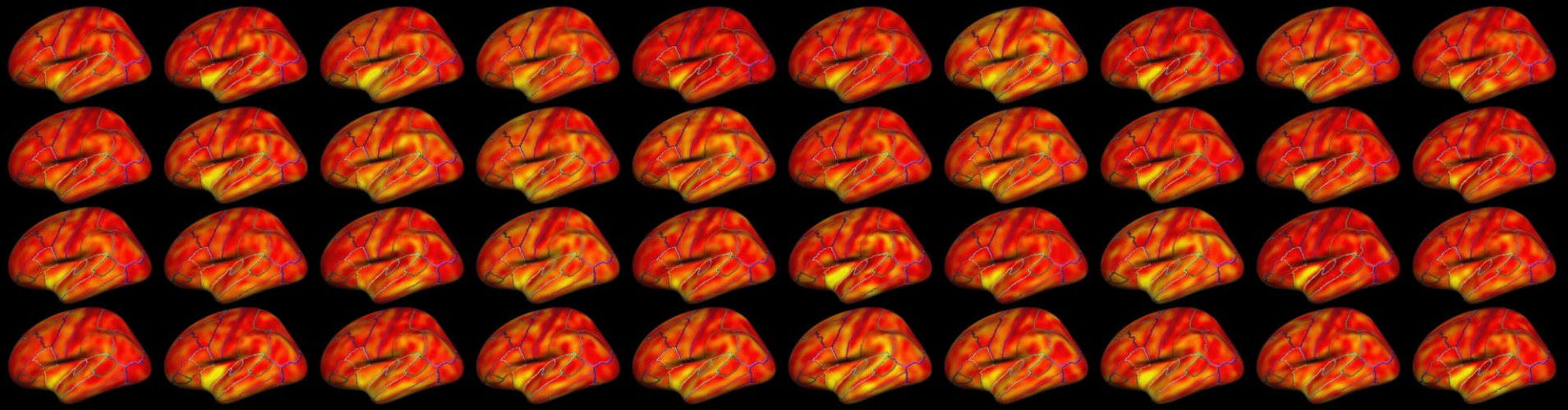
Aging Exploratory Analysis

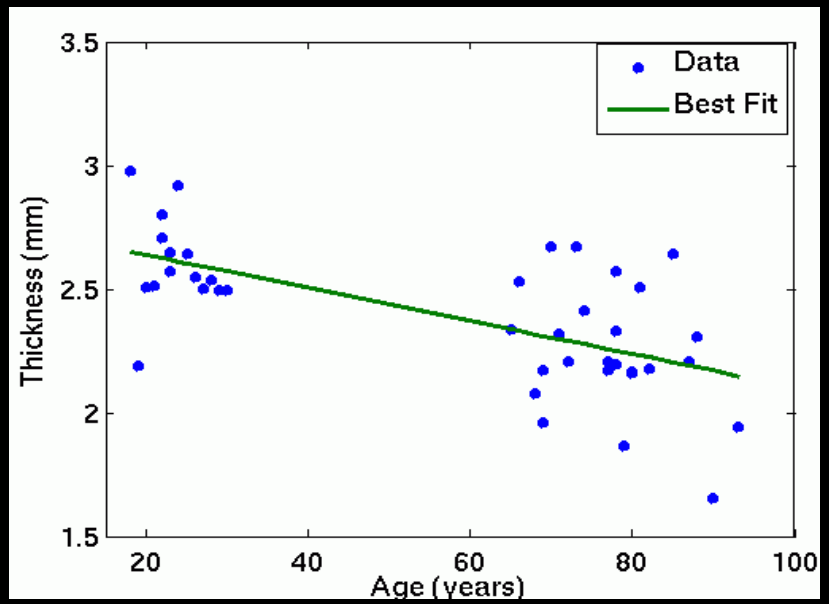


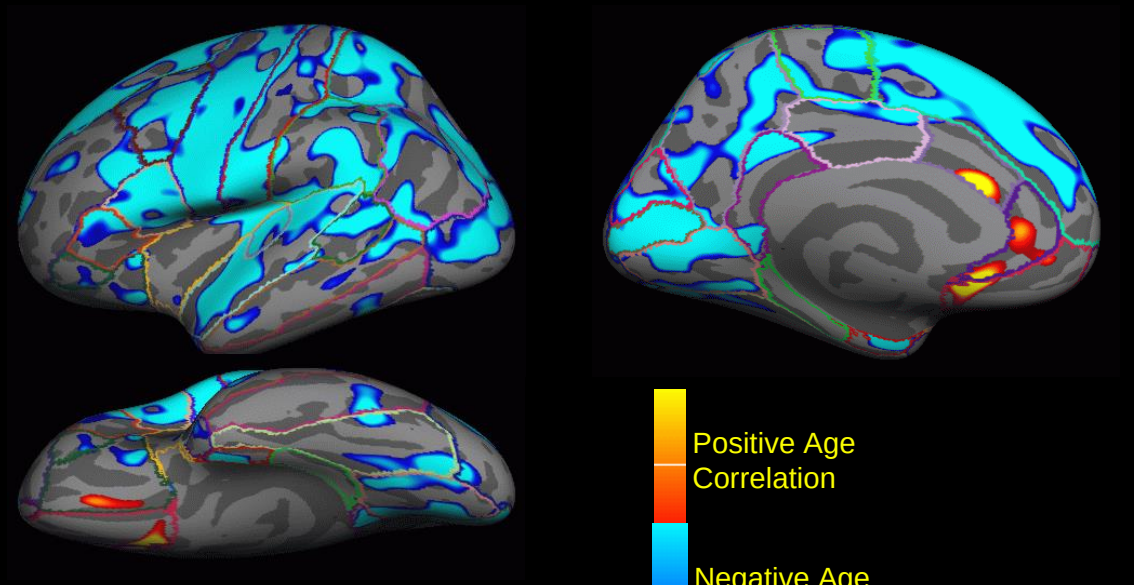
Cortical Thickness vs Aging; Salat, et al, 2004, Cerebral Cortex

Aging Thickness Study

N=40





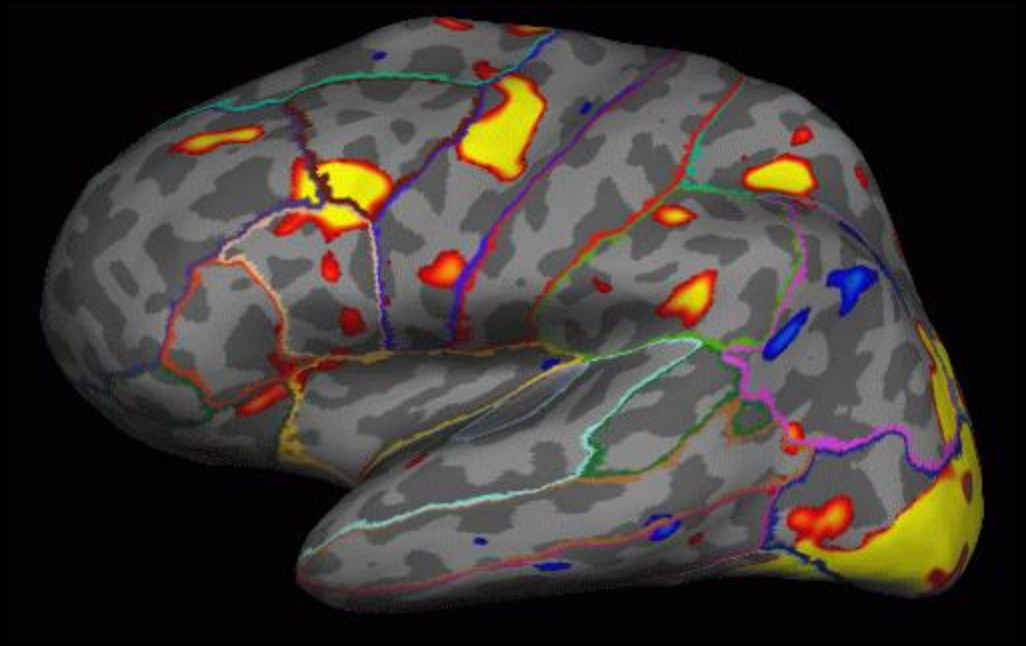


p<.01

Positive Age Correlation

Negative Age Correlation

Individual Exploratory Analysis



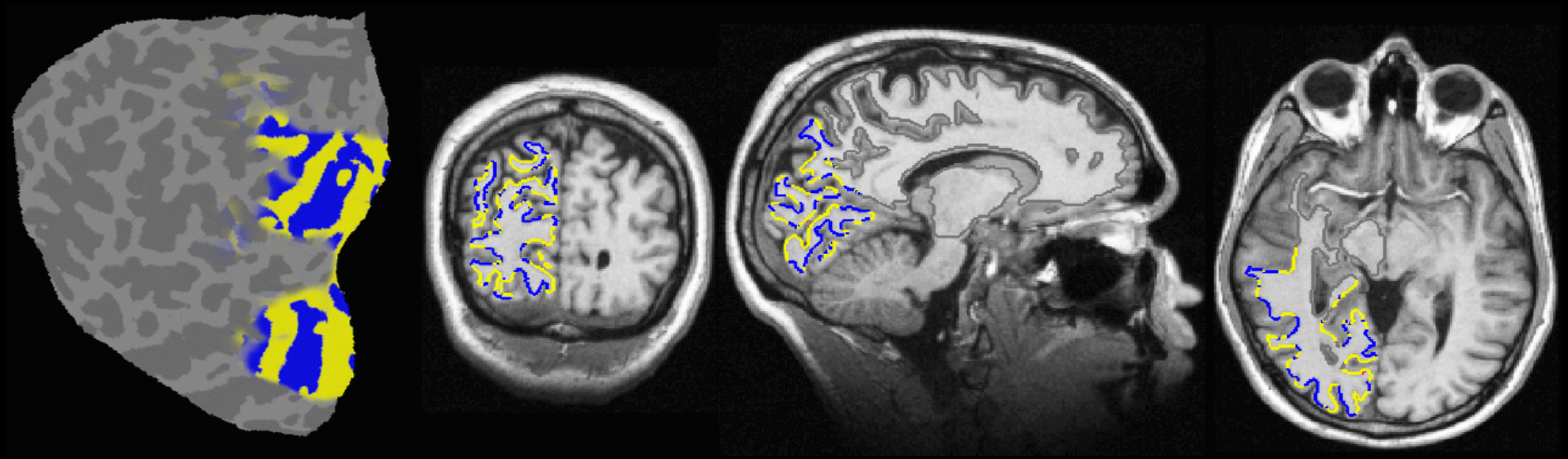
- fMRI Words-vs-Fixation
- Single subject (eg, presurgical planning or functional ROI)
- Outlines are FreeSurfer cortical ROIs
- Yellow and blue blobs are functional activation
- Activation does not lie cleanly within a predefined ROI

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?

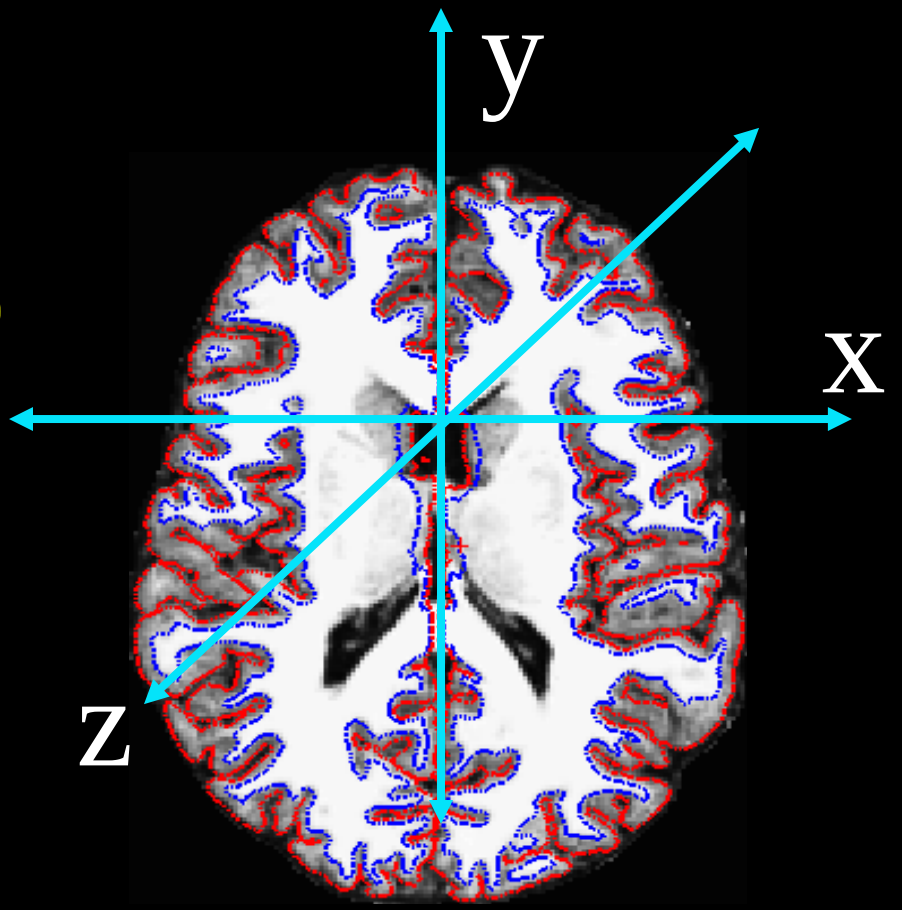
Local functional organization of cortex is largely 2-dimensional! Eg, functional mapping of primary visual areas:



From (Sereno et al, 1995, Science).

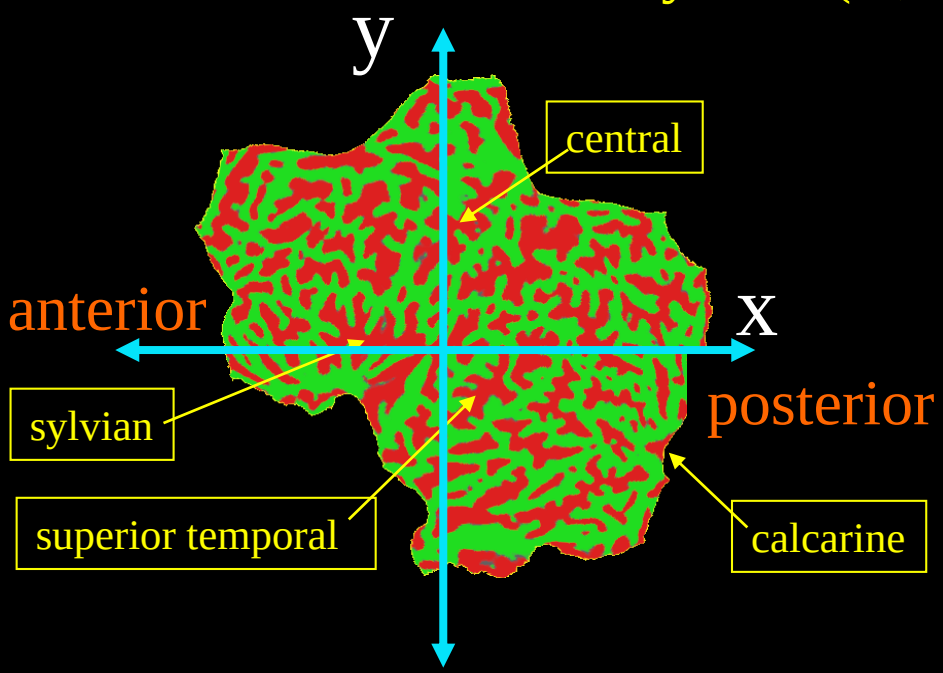
Coordinate Systems: 3D (Volumetric)

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



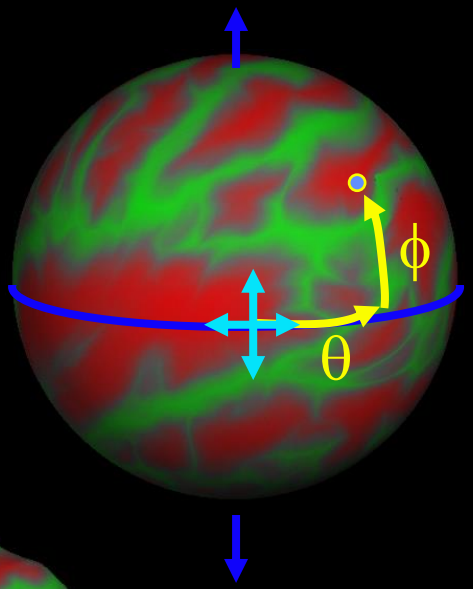
Coordinate Systems: 2D (Surface)

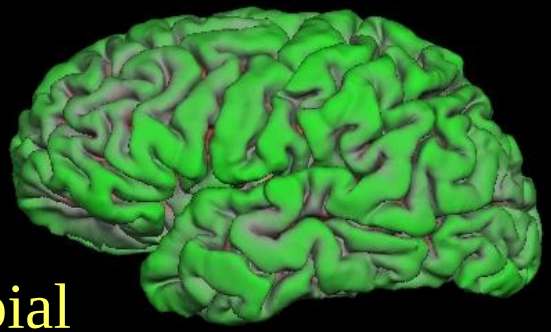
Sheet: 2D Coordinate System (X,Y)



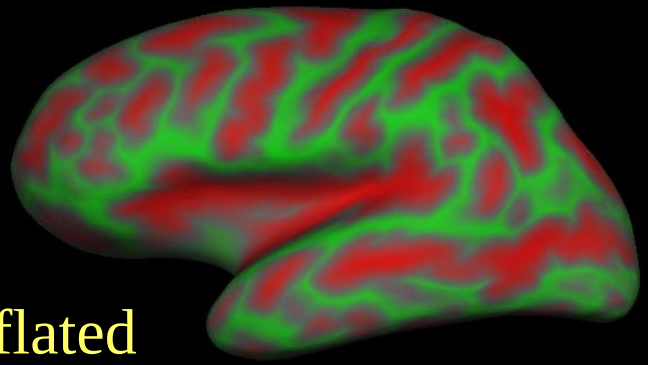
Sphere: 2D Coordinate System

- Latitude and Longitude (θ, ϕ)
- Continuous, no cuts
- Value at each point (eg, thickness)





pial



inflated

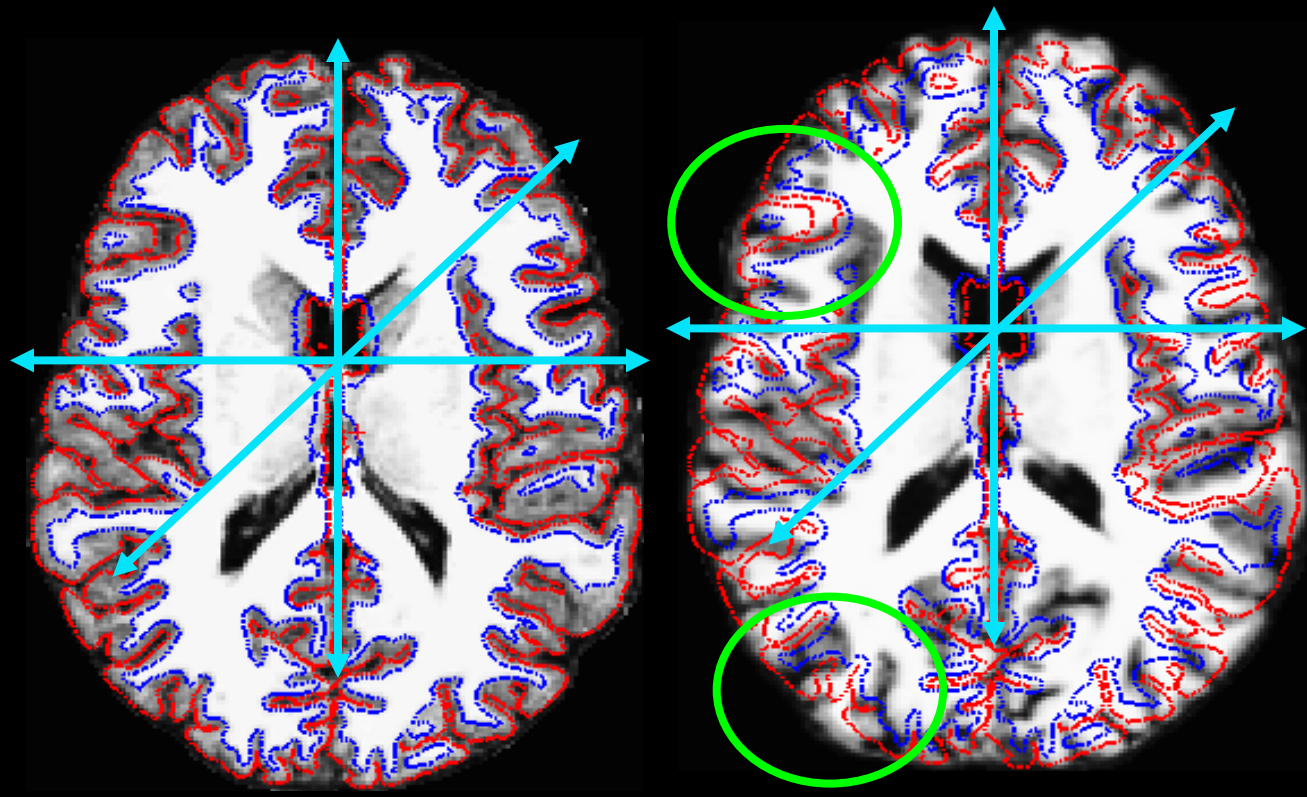
Curvature

- SULCUS (+)
- GYRUS (-)

Inter-subject Registration

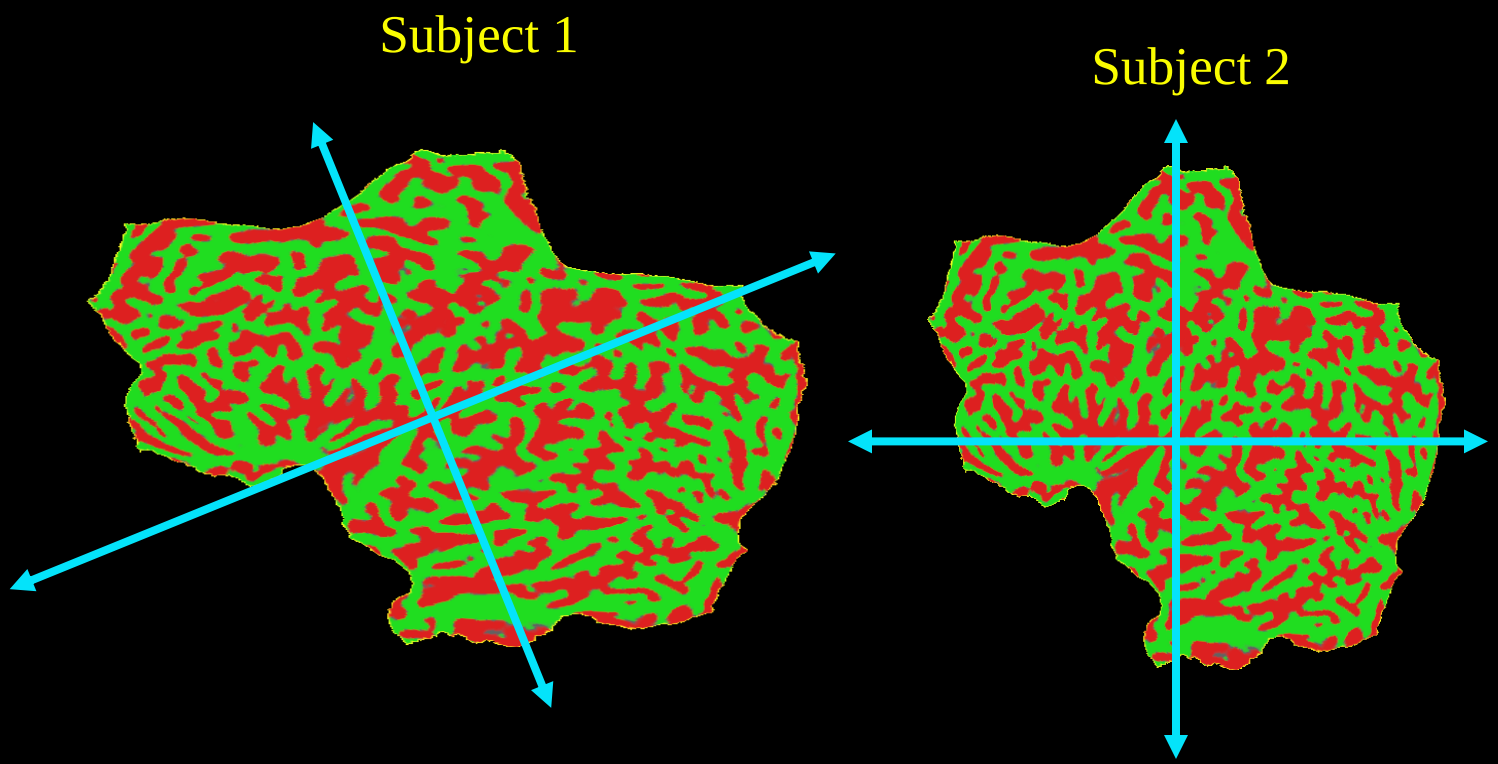
Volumetric Inter-subject Registration

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



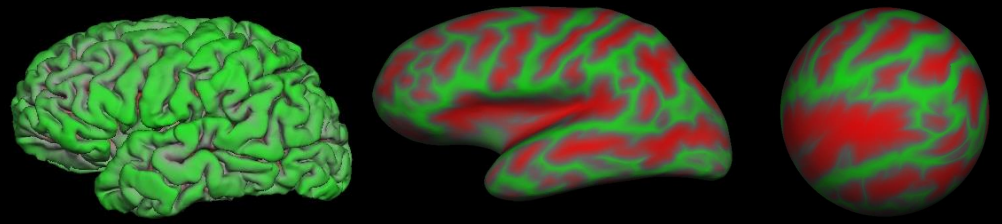
- Match Intensity, Voxel-by-Voxel
- Problems
- Can use non-linear volumetric (cf CVS)

Surface-based Inter-subject Registration

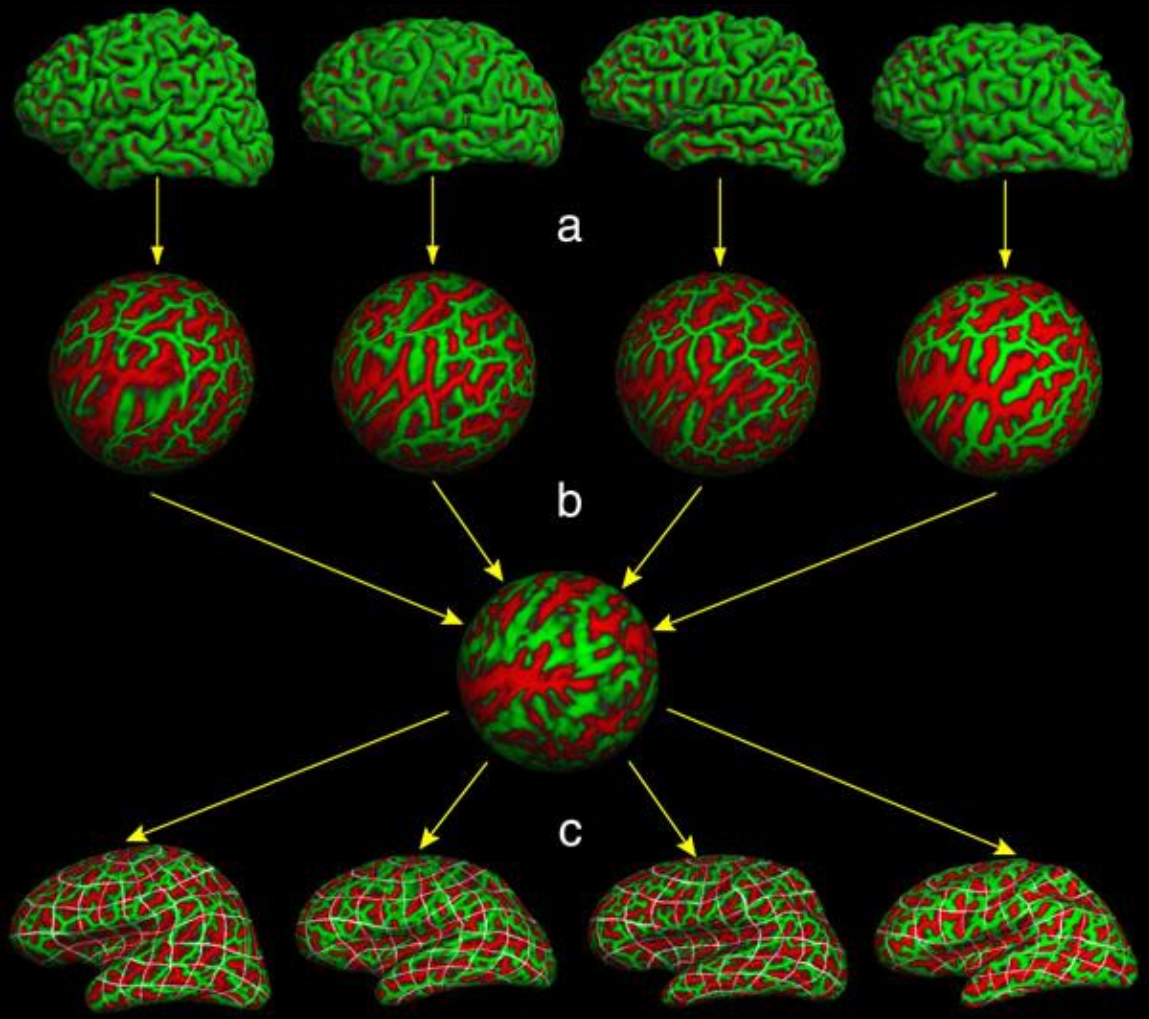


Curvature "Intensity"
- SULCUS (+)
- GYRUS (-)
- Codes folding pattern

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

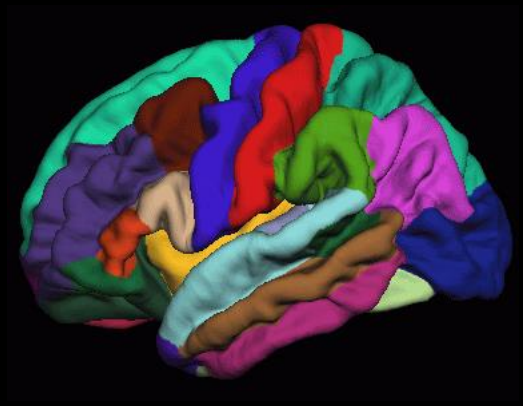


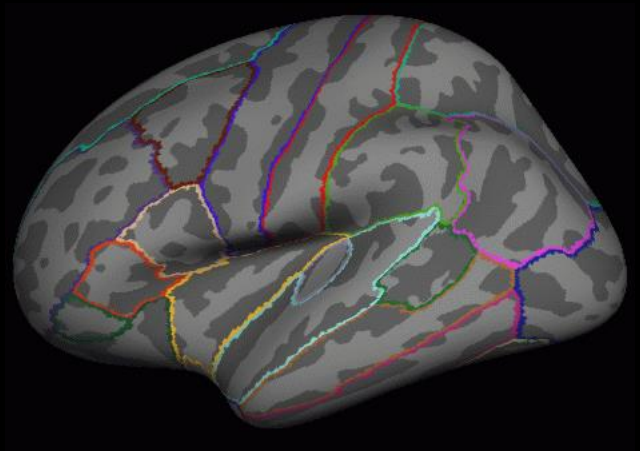
A Surface-Based Coordinate System

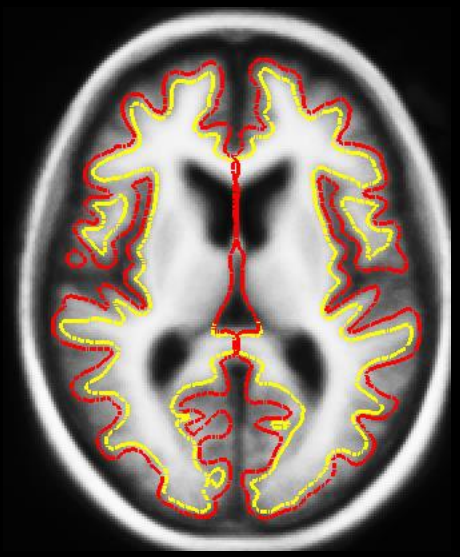


Common space for group analysis (like Talairach)

fsaverage







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

?h.average.curvature.filled.buckner40.tif

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

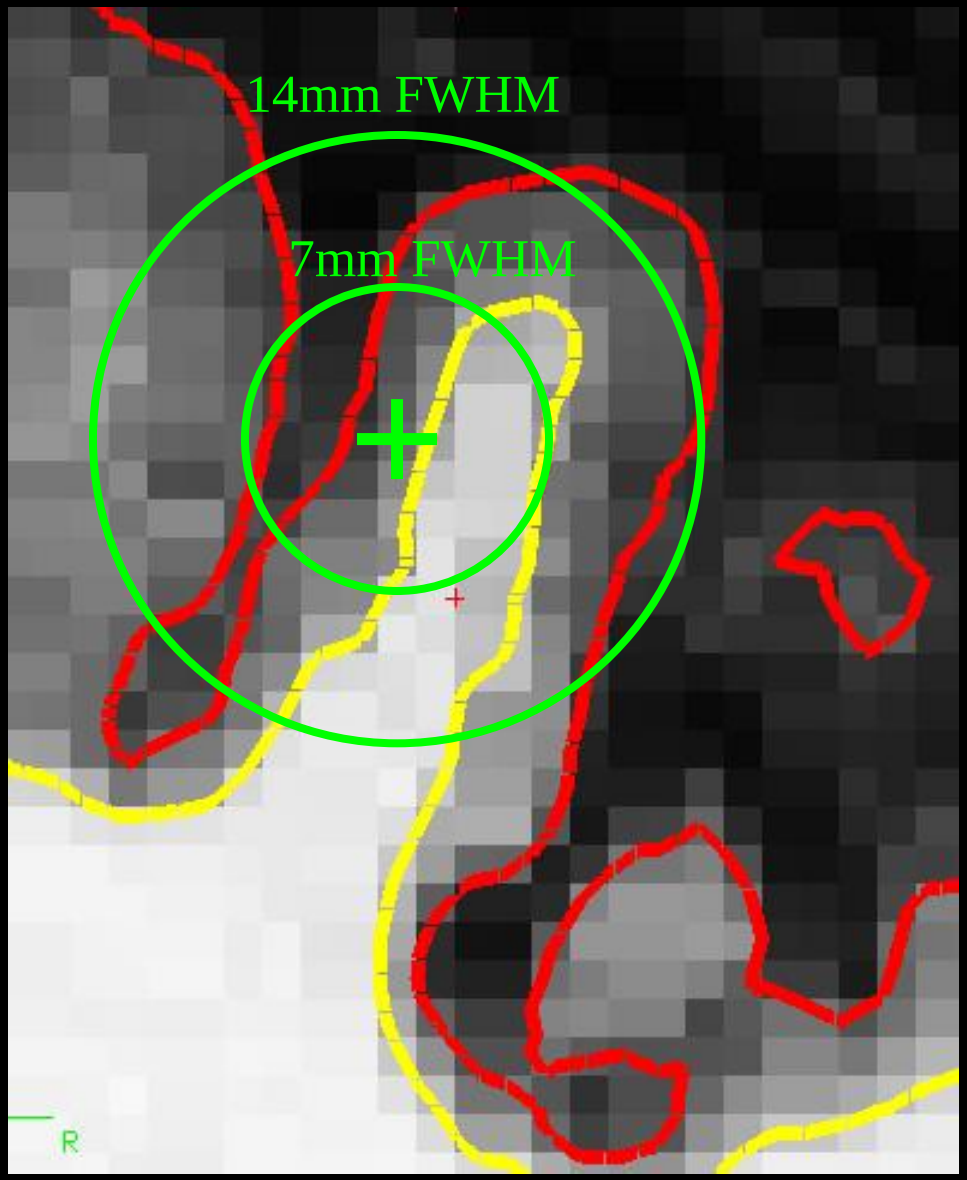
Why should you smooth?

- Might Improve CNR/SNR
- Improve inter-subject registration

How much smoothing?

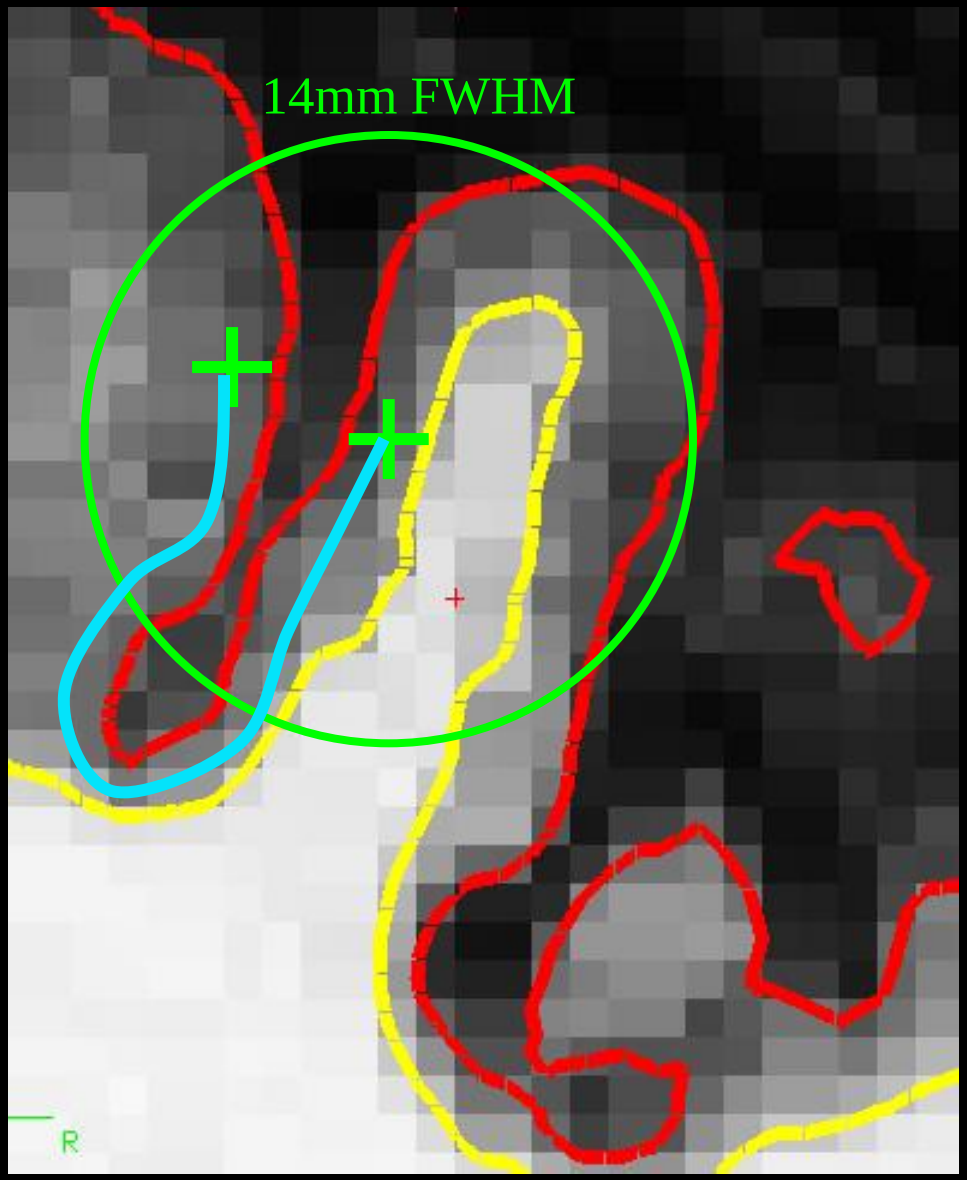
- Blob-size
- Typically 5-20 mm FWHM
- Surface smoothing more forgiving than volume-based

Volume-based Smoothing



- Smoothing is averaging of "nearby" voxels

Volume-based Smoothing



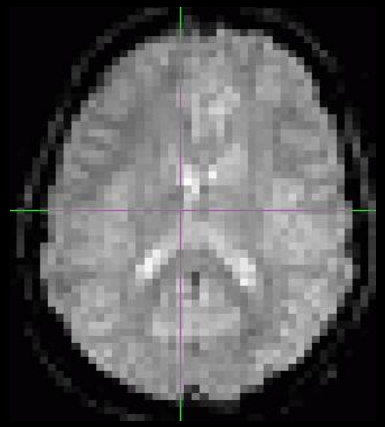
- 5 mm apart in 3D
- 25 mm apart on surface!
- Kernel much larger
- Averaging with other tissue types (WM, CSF)
- Averaging with other functional areas

Spatial Smoothing

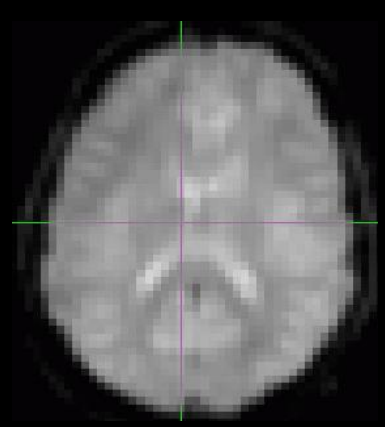
- Spatially convolve image with Gaussian kernel.
- Kernel sums to 1
- Full-Width/Half-max: FWHM = σ/sqrt(log(256))

σ = standard deviation of the Gaussian

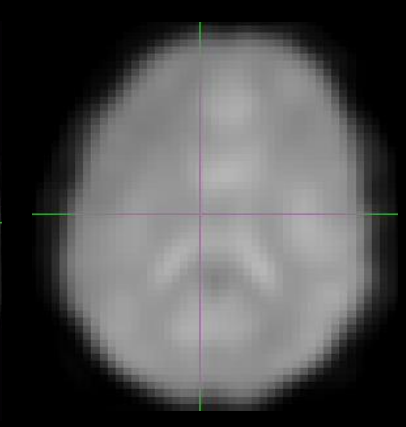
0 FWHM



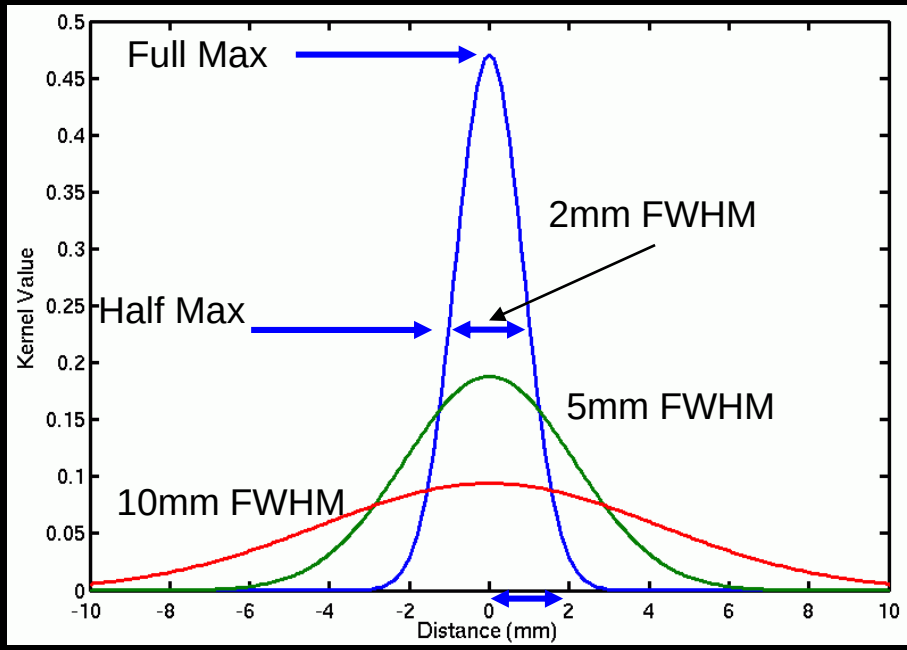
5 FWHM



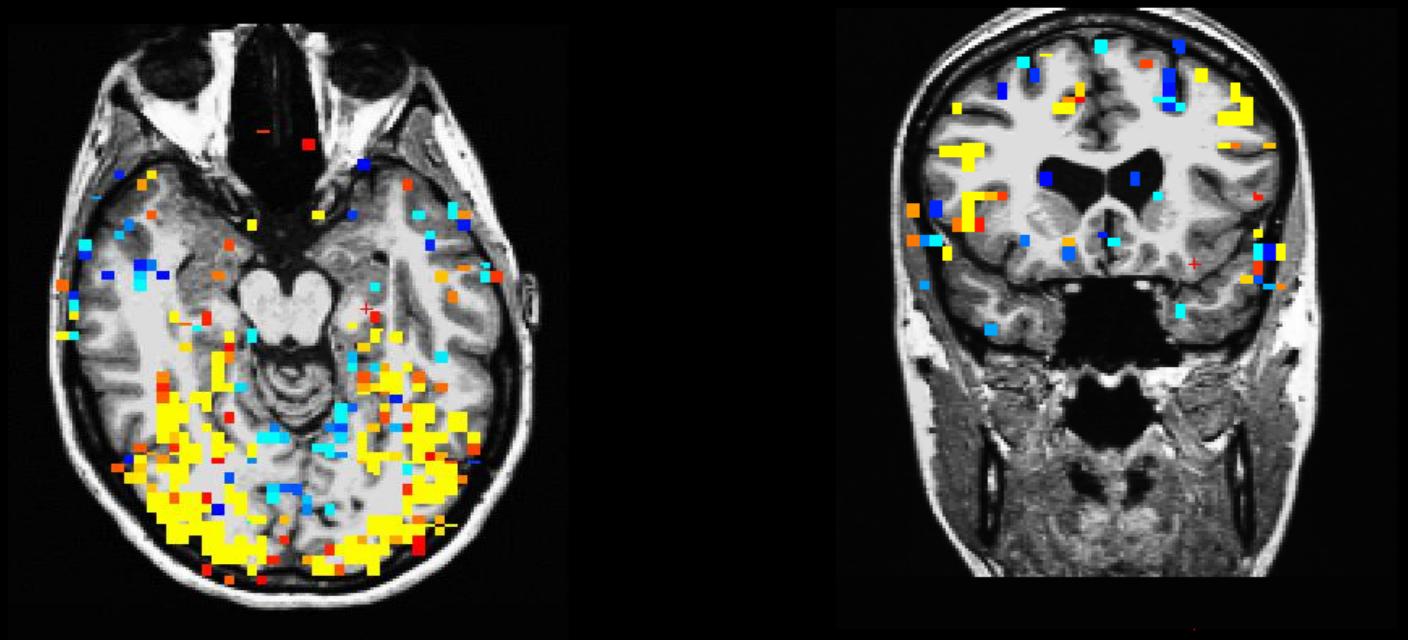
10 FWHM



Full-Width/Half-max



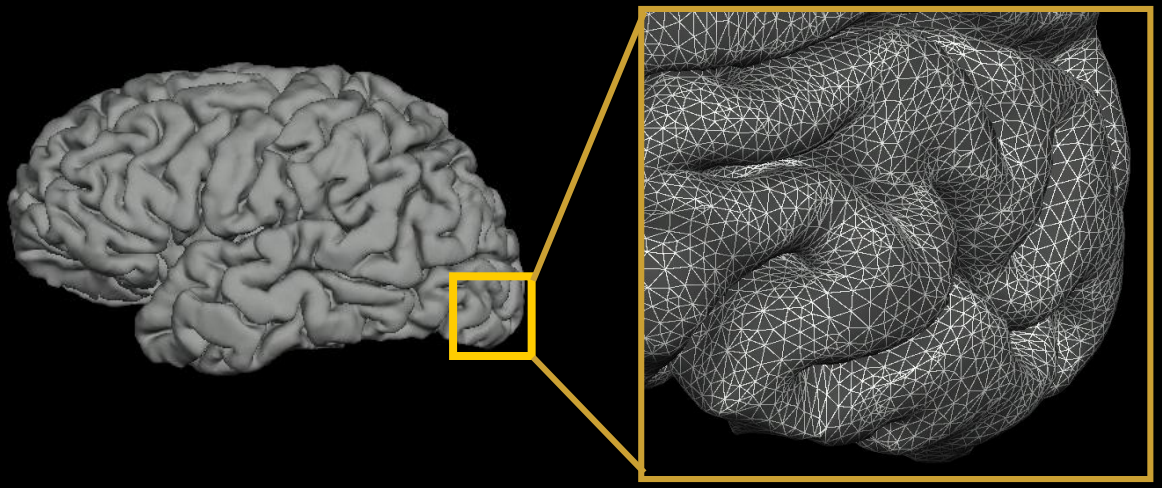
Effect of Smoothing on Activation



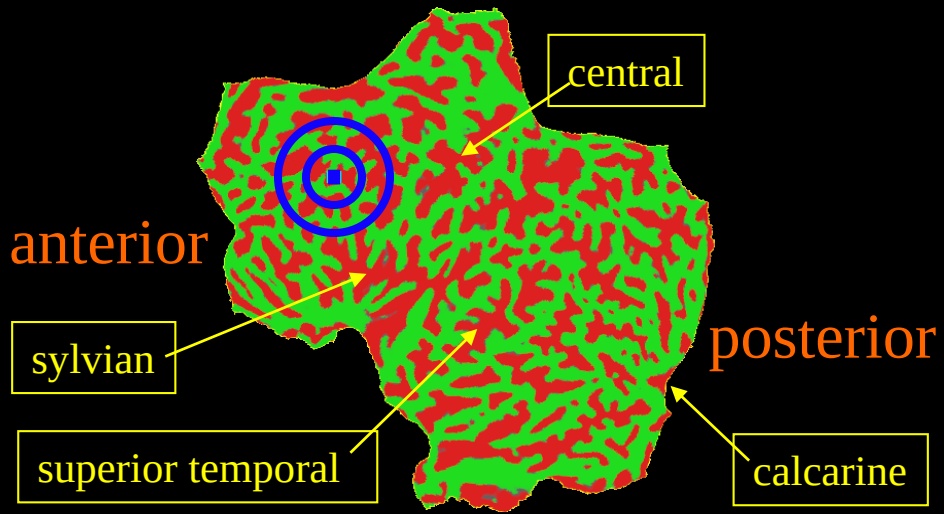
- Working memory paradigm
- FWHM: 0, 2, 4, 6, 8, 10, 12, 14, 16, 18, 20

Surface-based Smoothing

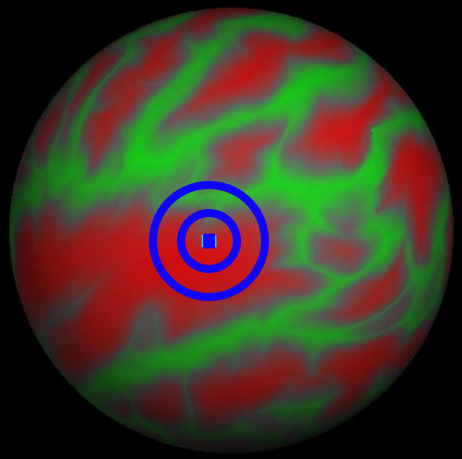
- Smoothing is averaging of nearby vertices



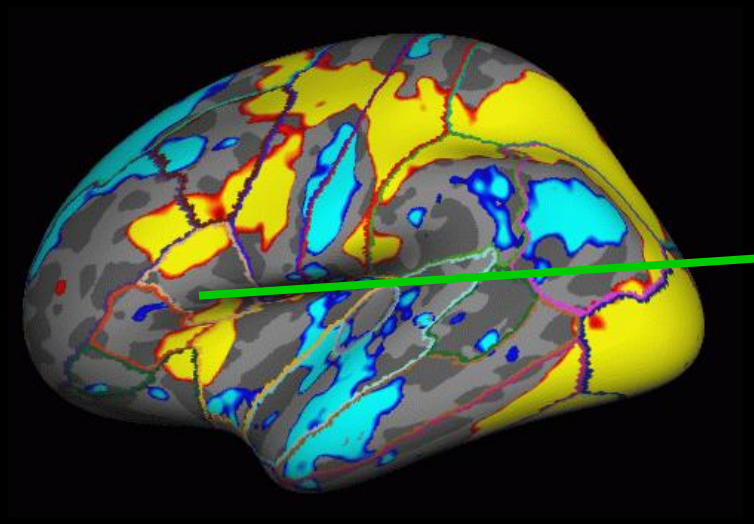
Sheet: 2D Coordinate System (X,Y)



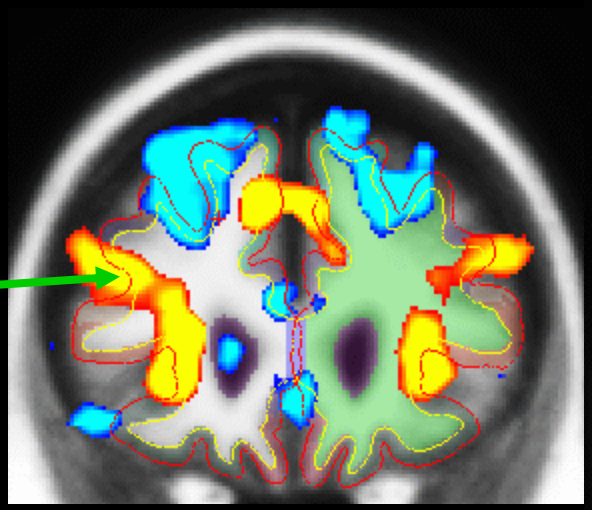
Sphere: 2D Coordinate System (θ,ϕ)

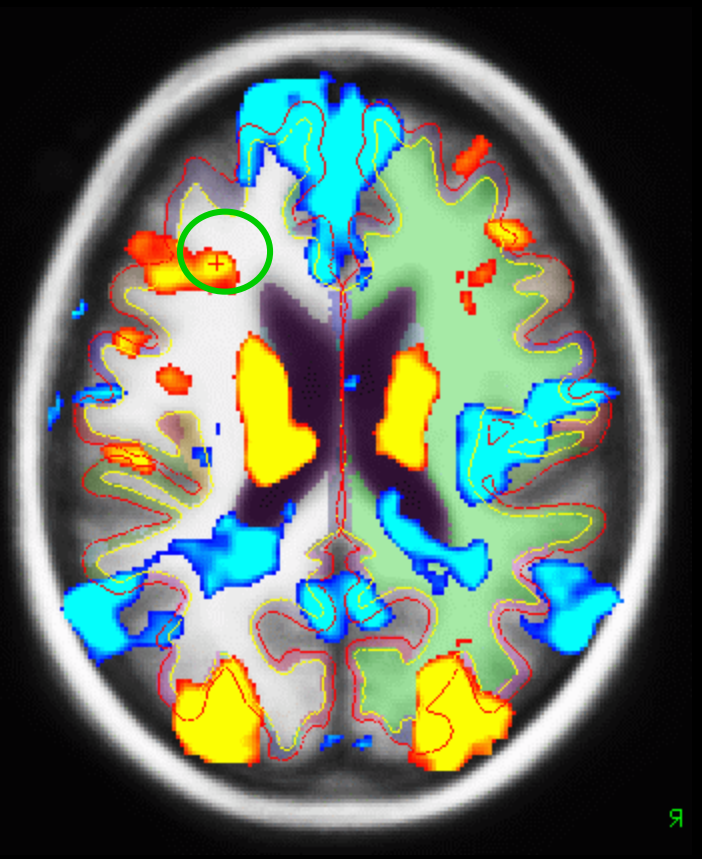


Group fMRI Analysis: Volume vs Surface



Surface-based Registration
and smoothing

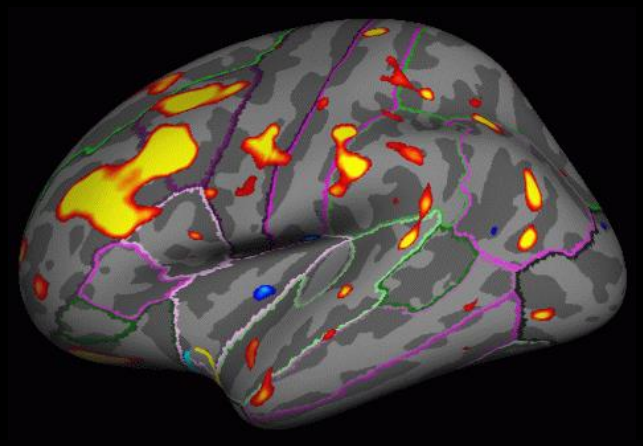


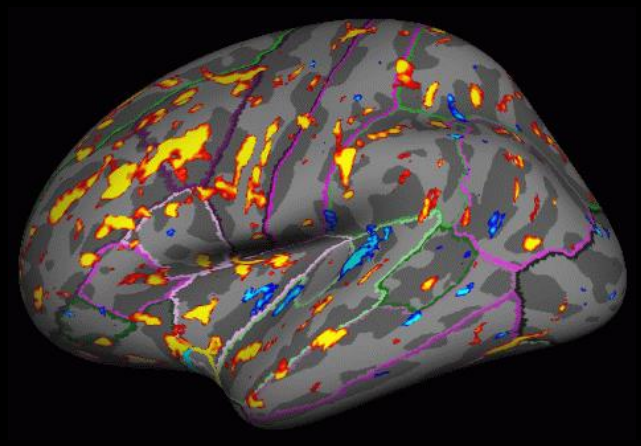


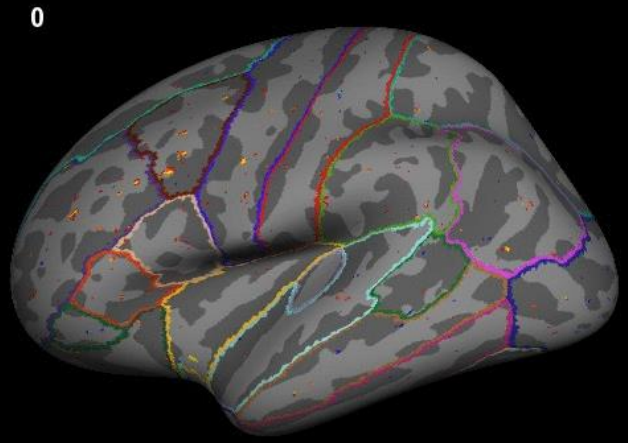
Affine registration to MNI305
with volume smoothing

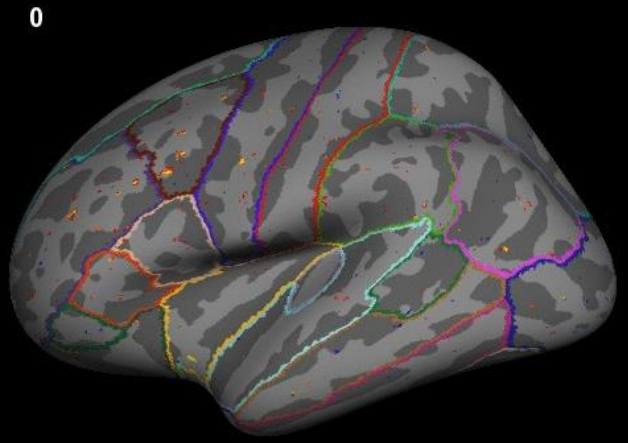
Probe-vs-Fixation. Data from Functional Biomedical Informatics Research Network (fBIRN)

$5HT_4$ BP Asymmetry Study (N=16)









Left > Right

$p<10^{-3}$

$p<10^{-2}$

Right > Left

$p<10^{-2}$

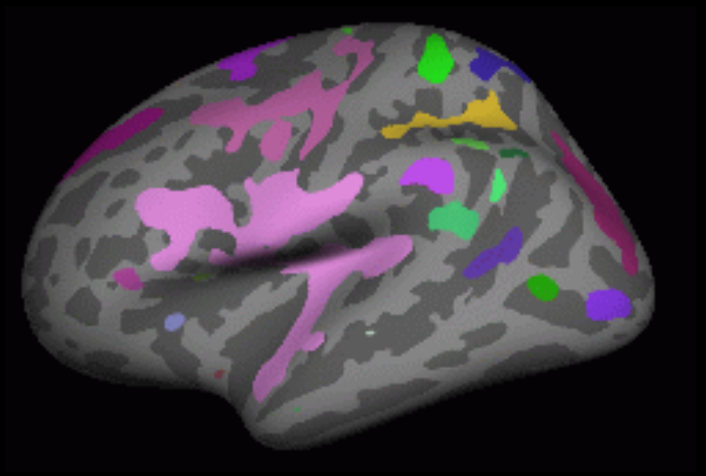
$p<10^{-3}$

Surface Smoothing

Volume Smoothing

Surface-based Clustering

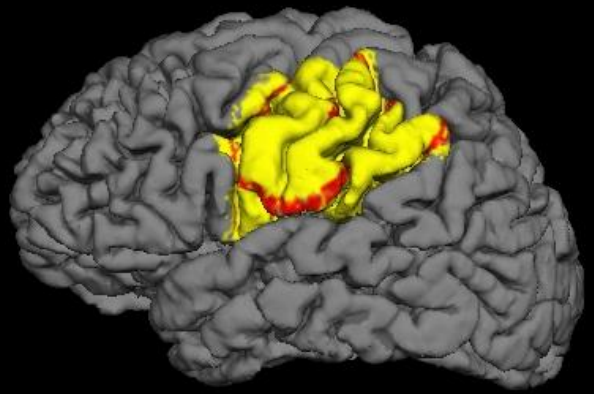
- A cluster is a group of connected (neighboring) vertices above threshold
- Neighborhood is 2D, not 3D
- Cluster has a size (area in mm^2)
- Reduced search space (corrections for multiple comparisons)



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