Surface-Based MRI Anatomical Analyses

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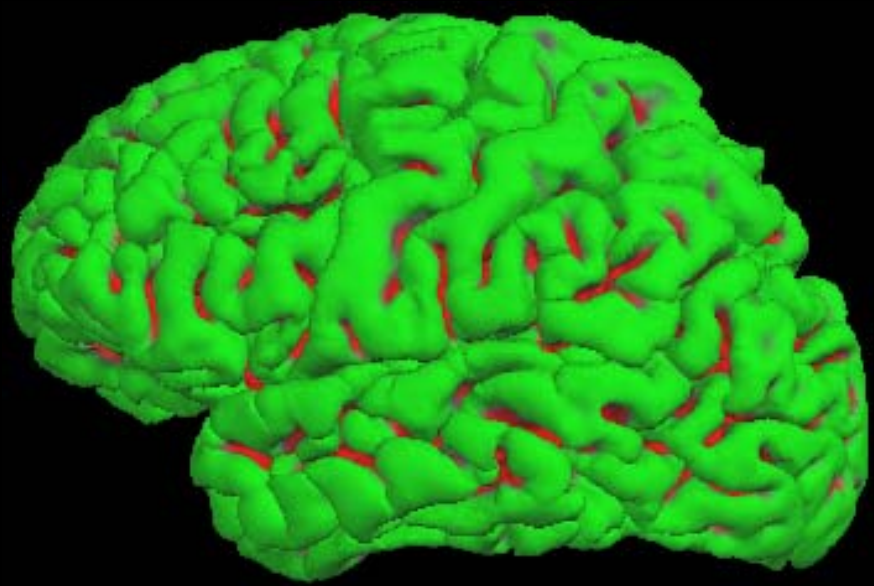


Goals

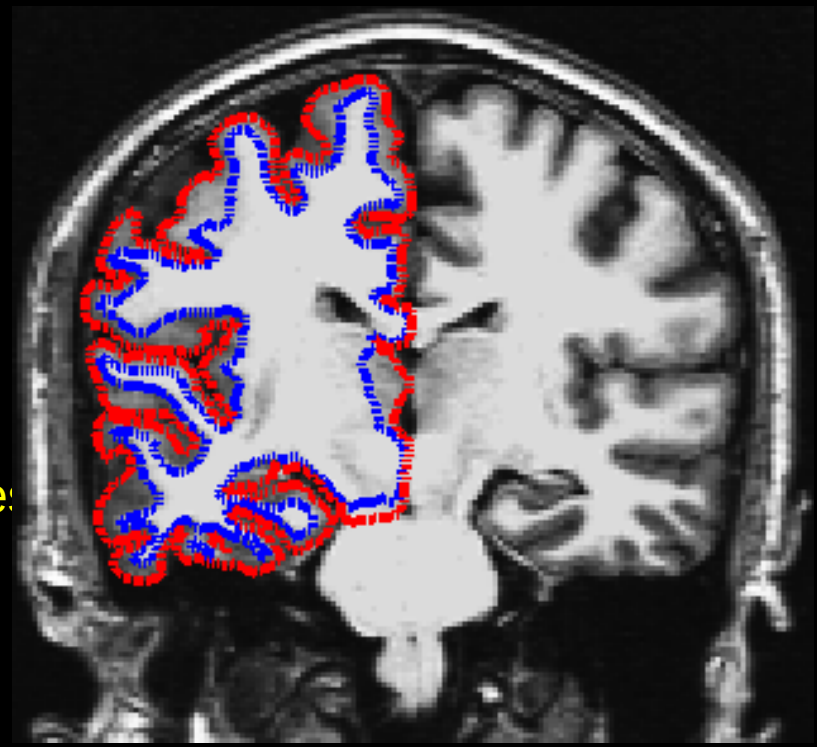
1. Describe surface-based analysis procedures
2. Describe work applying these techniques to the study of age and Alzheimer associated brain alterations
3. Describe some of the caveats associated with MR studies of neurodegeneration

Why use MRI?

- Non invasive technique to obtain indirect measures of neural anatomy and integrity
- Multiple contrast mechanisms allow for obtaining measures that are differentially sensitive to a variety of anatomic and pathologic properties
- Image analysis procedures to obtain numerous measures from a single image

FreeSurfer: MR Image Analysis Software

- Freely Distributed Tools
  - fMRI Analysis
  - Morphometry:
    - Cortical Thickness
    - Cortical Volume
    - Cortical Surface Area
    - Subcortical structural volumes
- Tools on the Horizon
  - Diffusion tensor analysis
  - Callosal morphometry
  - Diffusion informed segmentation
  - Whole brain white matter parcellation (from T1 images)



FreeSurfer Resources

- Most items can be found on the FreeSurfer webpage:
  - http://surfer.nmr.mgh.harvard.edu
- Journal Articles- Dale, FIschl, Sereno
  - Surface reconstruction
  - Coordinate system
  - Thickness
  - Applications
- Documentation: Freesurfer Wiki
  - Manuals
  - Tutorials
  - Downloads
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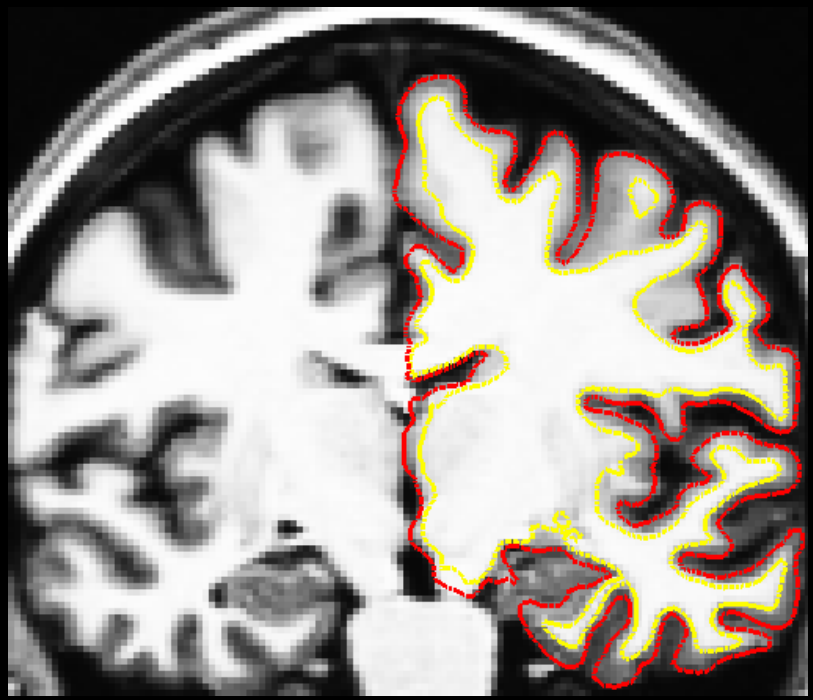
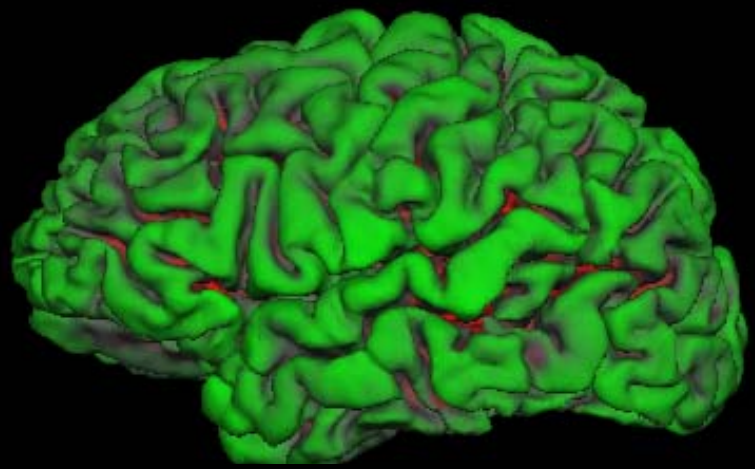
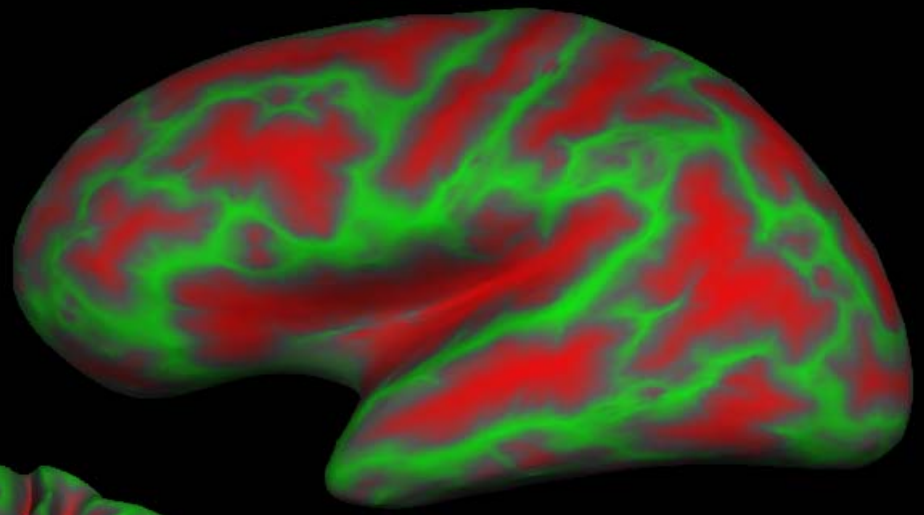
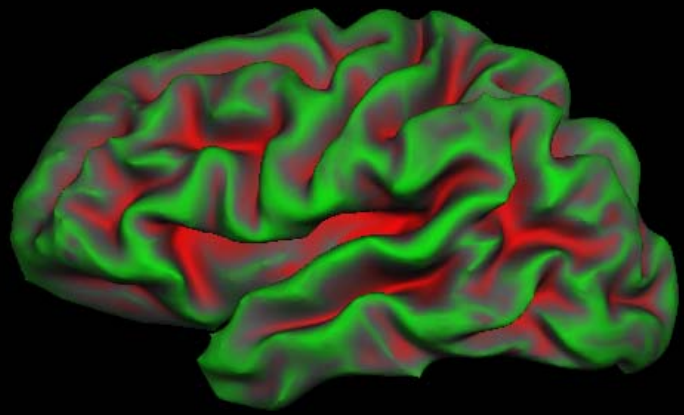
  - Majordomo@surfer.nmr.mgh.harvard.edu subscribe freesurfer in body

Surface Studies of Aging and AD





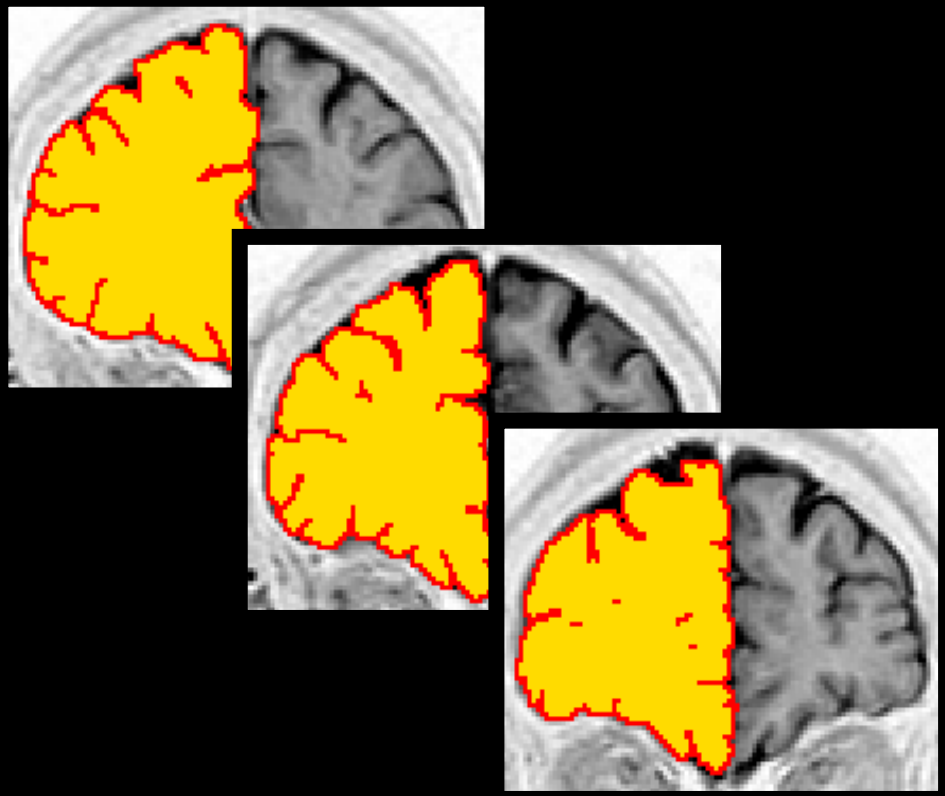


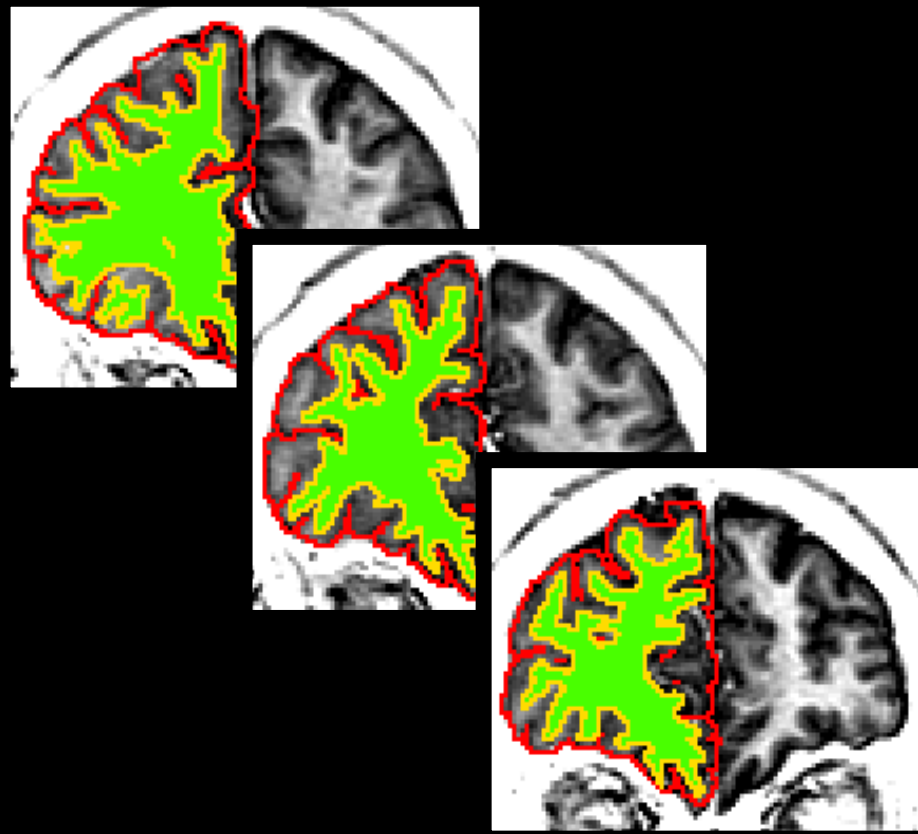


Aging and AD: Global and Regional Degeneration: Prior non-MR Work

- Cortical atrophy is apparent with normal aging and Alzheimer's disease
- *Age-related* global cortical atrophy is minimal early on and accelerated during the sixth and seventh decades, while *early AD* shows cortical atrophy and may accelerate with increasing disease severity
- Greatest and earliest age-related changes suggested to be in association areas (e.g., prefrontal) and later changes in primary sensory regions
- Early and profound degeneration in medial temporal and parietal cortex with AD
- Until recently, there was limited information about regional patterns of atrophy in aging and AD (most studies just examined whole brain)

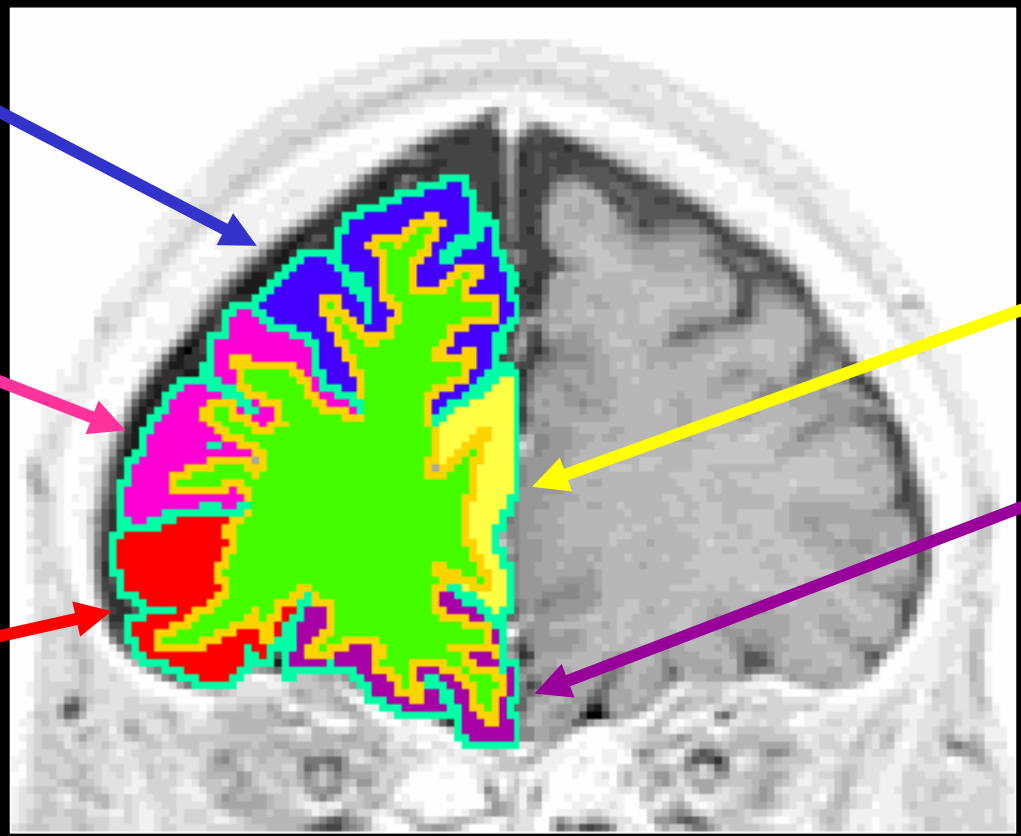
PFC Gray and White Matter Volumes





Manual tracing of each slice

PFC Subregional Measures

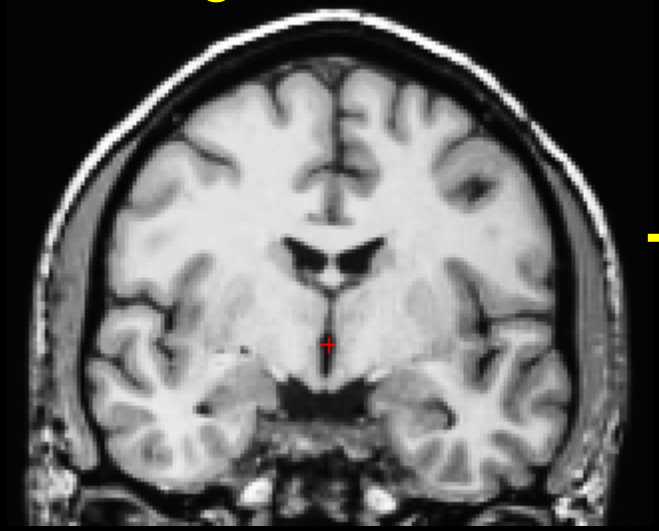


Manually intensive, regionally arbitrary, subjective: Automated measures needed

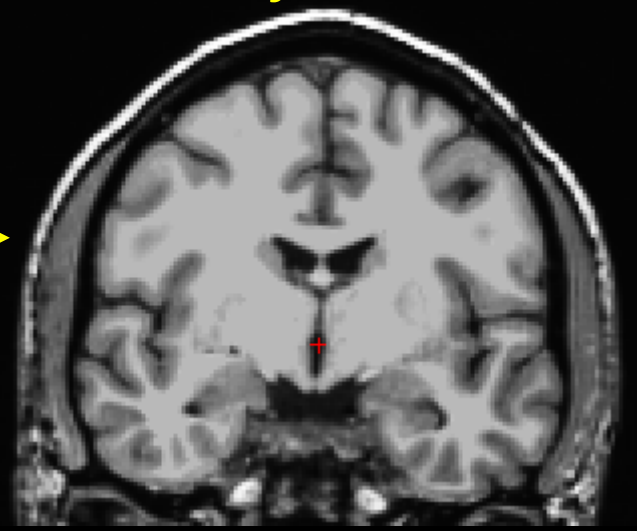
Automated Cortical Reconstruction

Dale, Fischl, Sereno: 1999, 2000

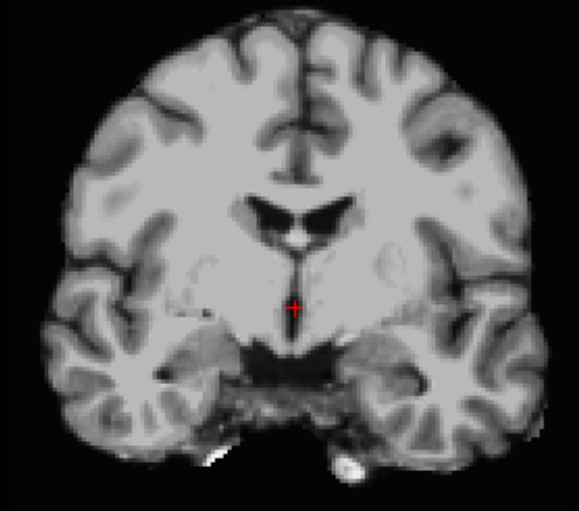
Averaged Hi-Res Scans



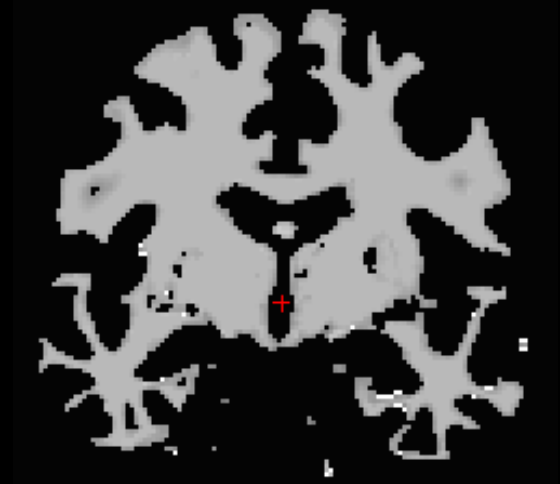
Intensity Normalized



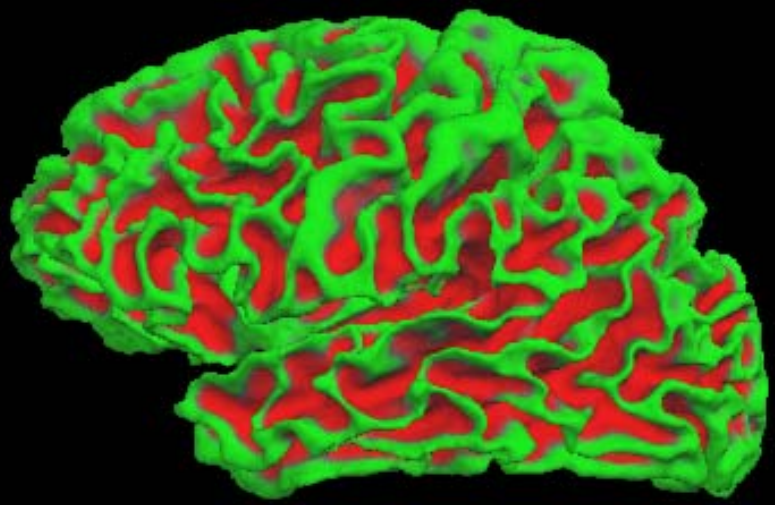
Brain Isolated

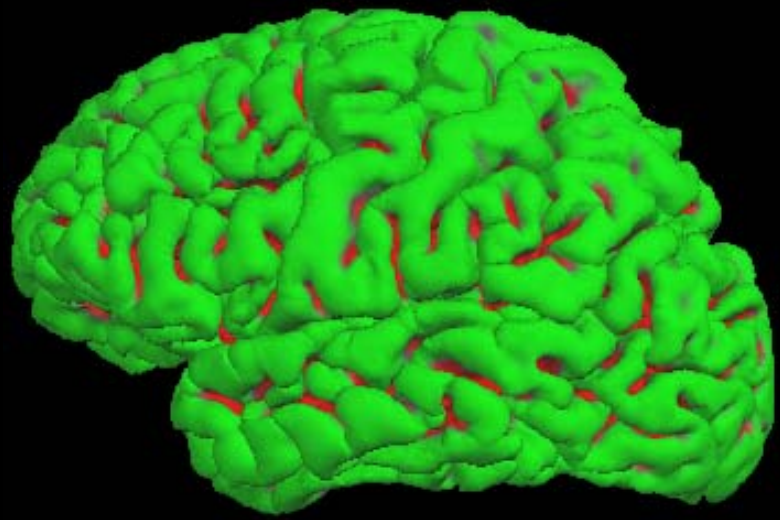


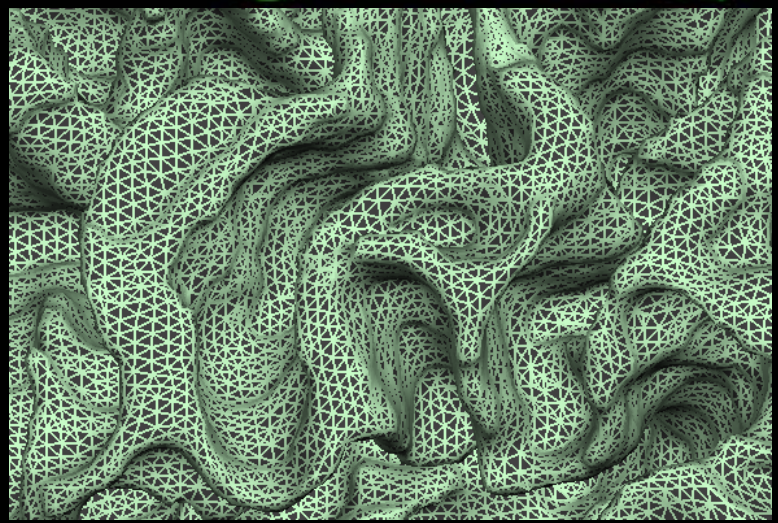
White Matter Isolated



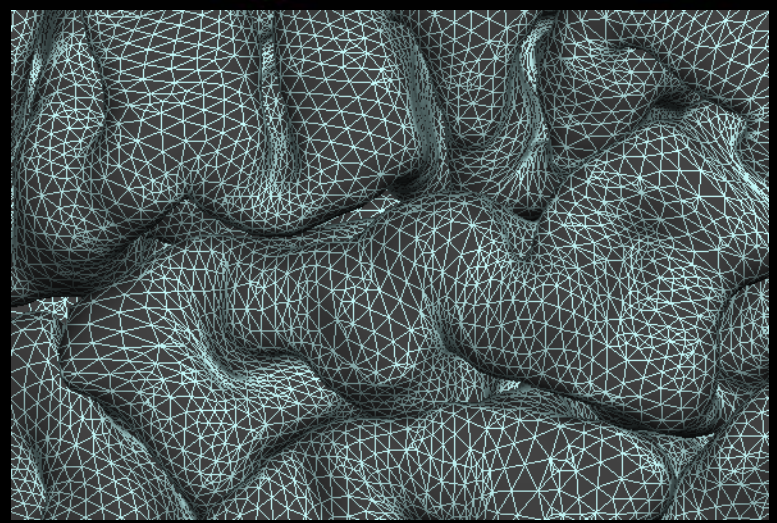
Hemispheres Separated and Tesselated





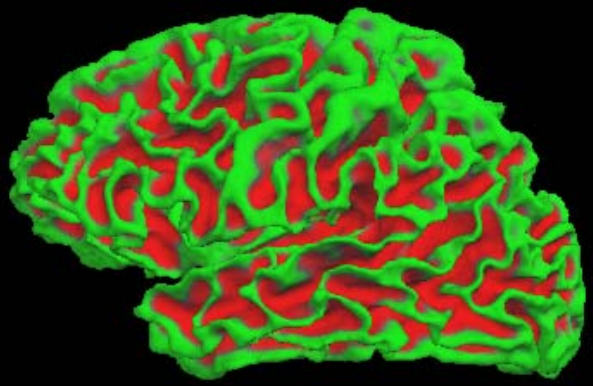


Gray/White Border

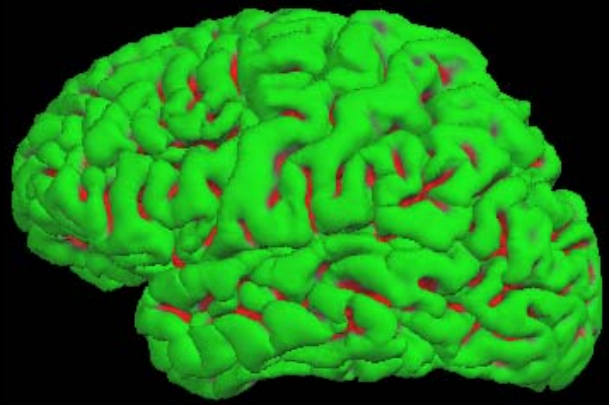


Gray/CSF Border

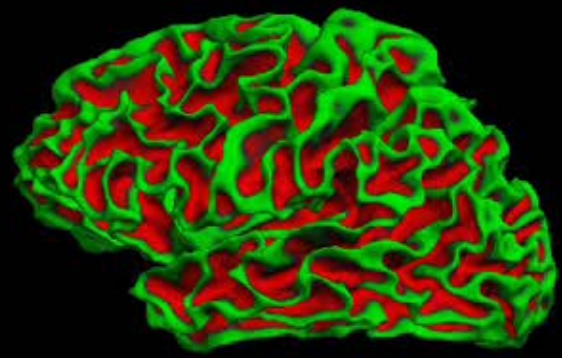
Gray/CSF Deformation



Gray-White Boundary

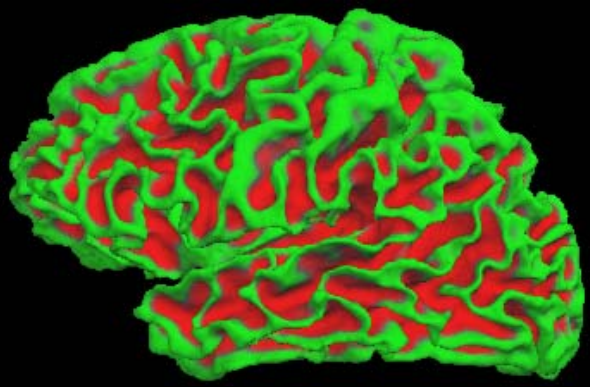


Outer Cortical Surface

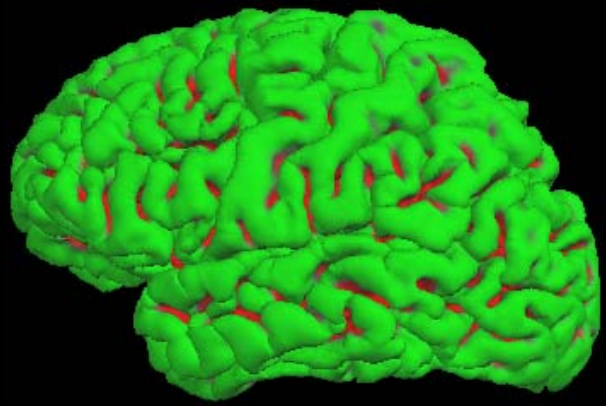


Dale and Sereno, 1993; Dale et al., Dale et al., 1999; Fischl et al., 1999; Fischl et al., 2000; Fischl et al., 2001

Optimal Surface Placement

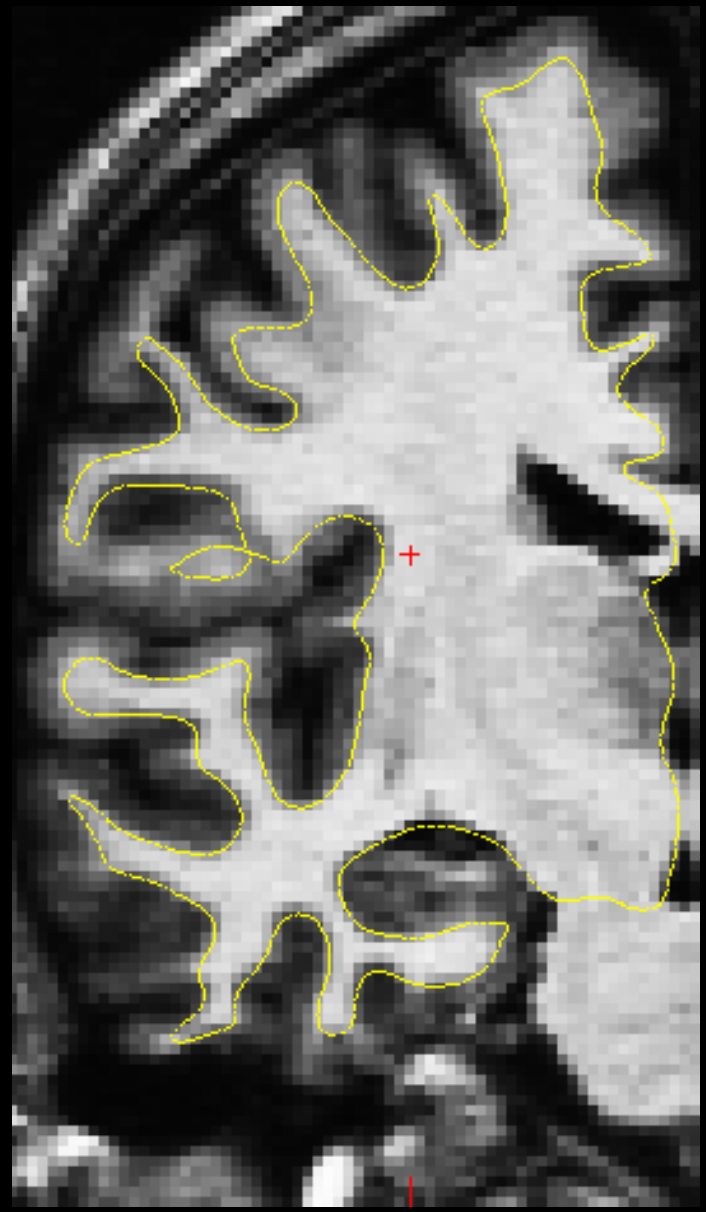


Gray-White Boundary

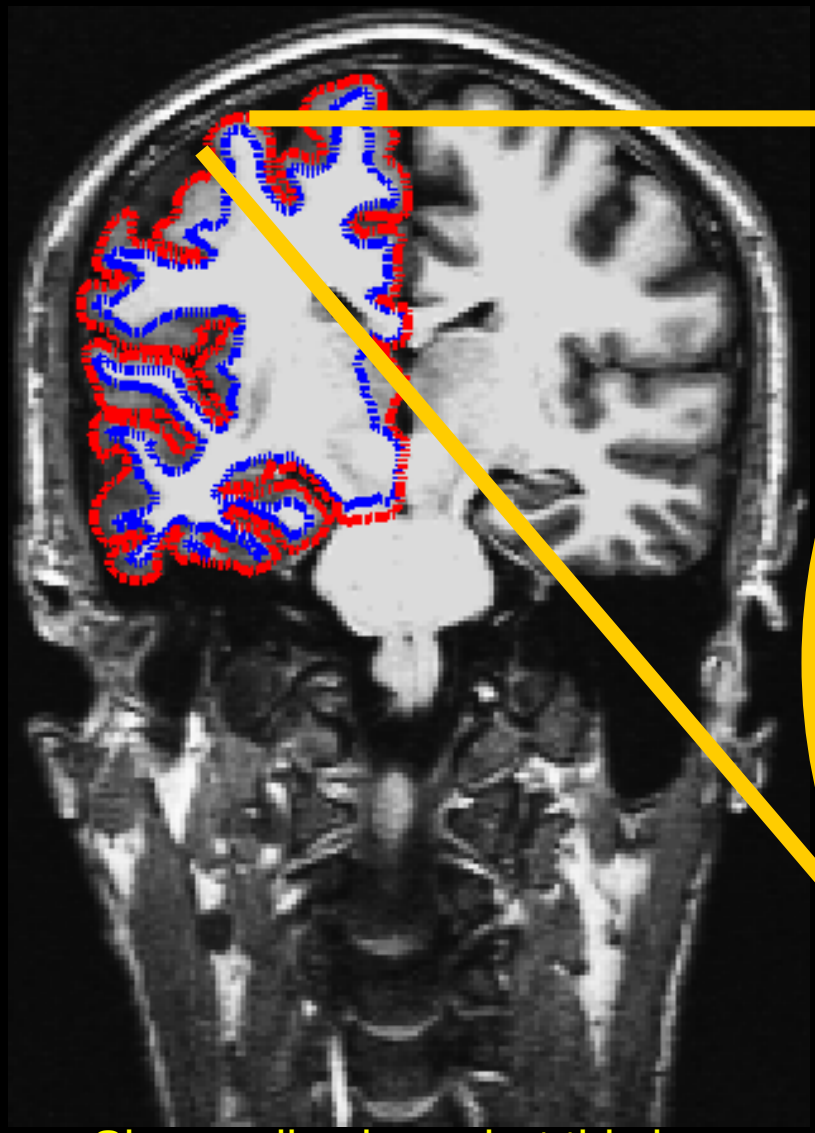


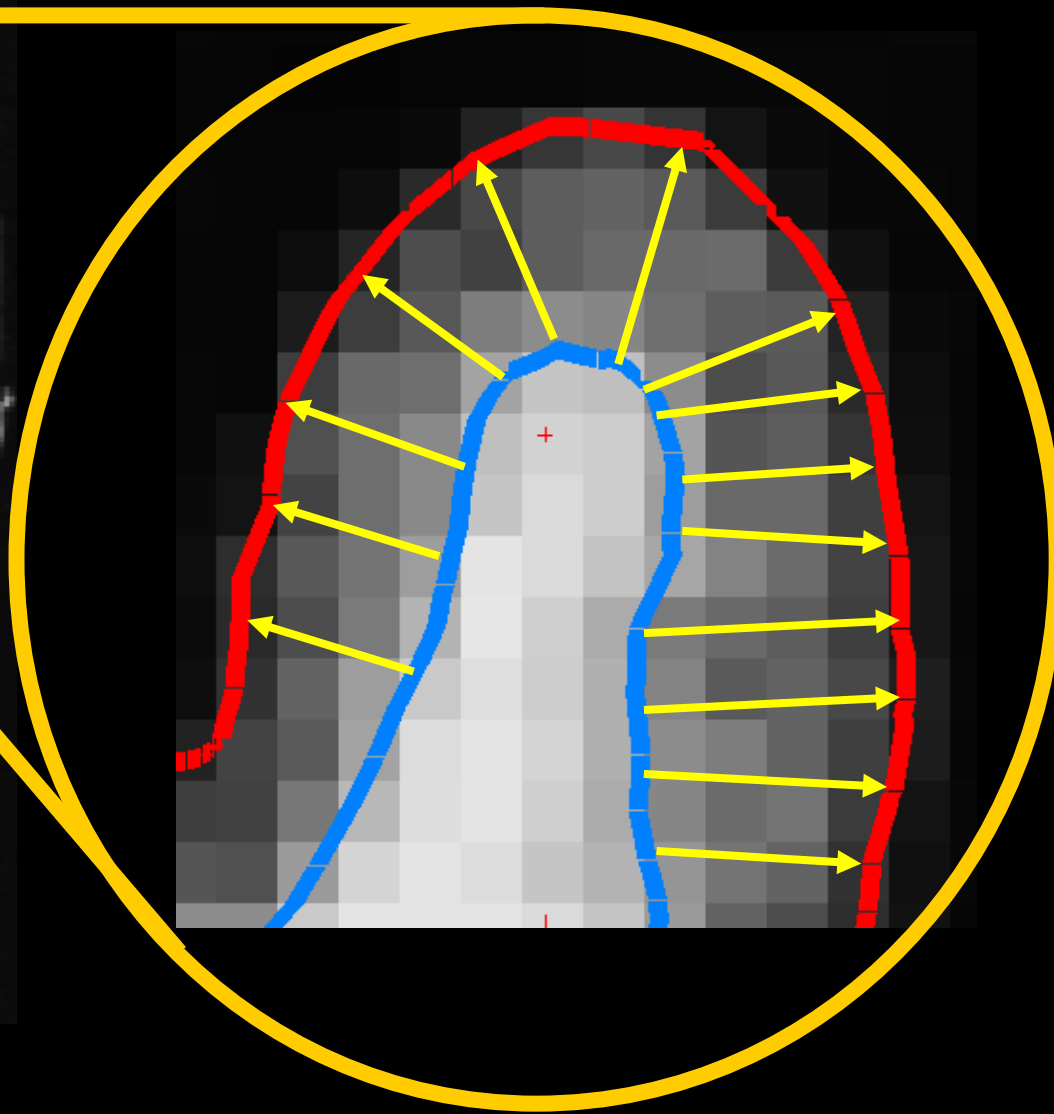
Outer Cortical Surface

Uses information about WM curvature and surrounding tissue



Cortical Thickness

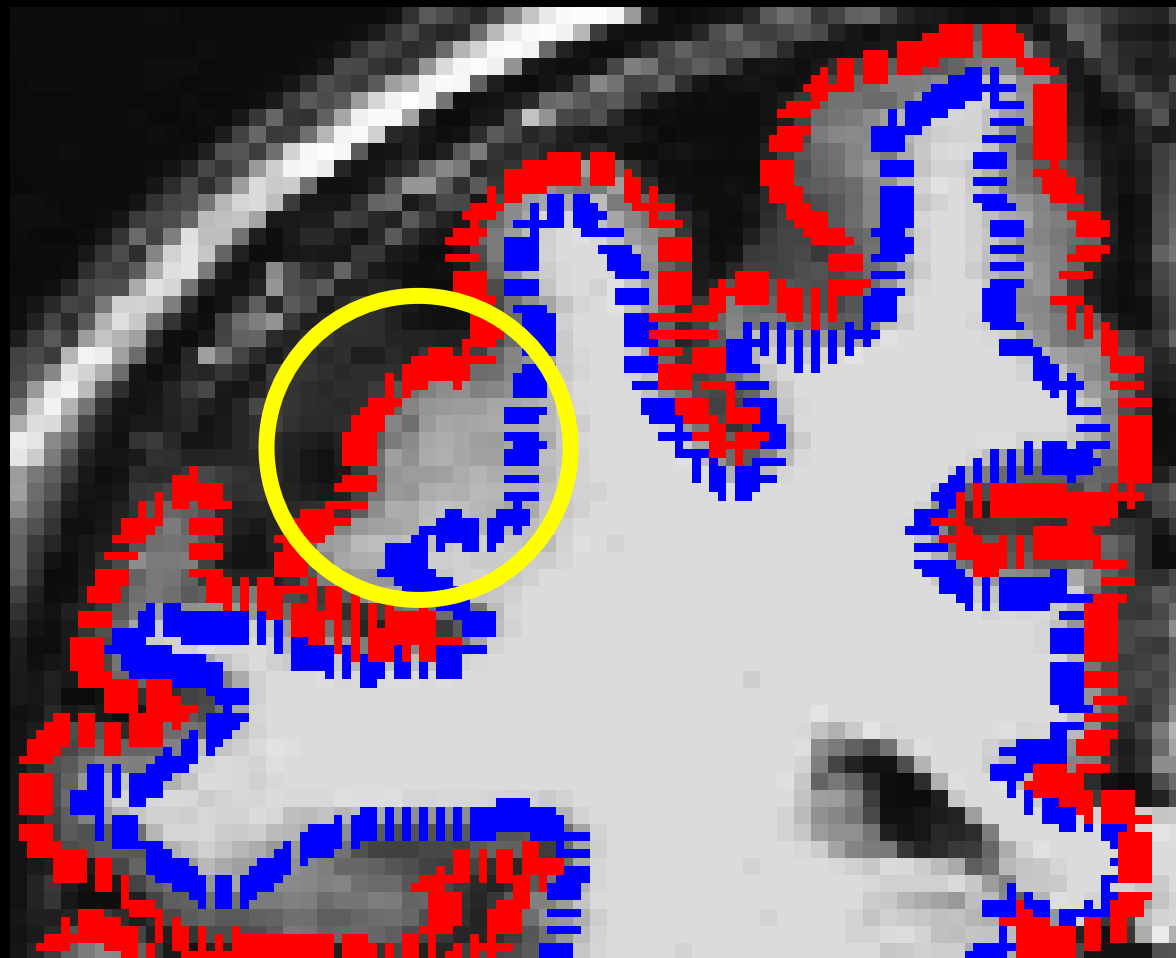




Shown slice here, but this is a whole ribbon process

Thickness must consider entire ribbon

Cortex is not 10 mm thick



Cortical thinning in aging and AD Questions:

How early can age-related cortical atrophy be detected?

What are the regional patterns of age-related cortical atrophy?

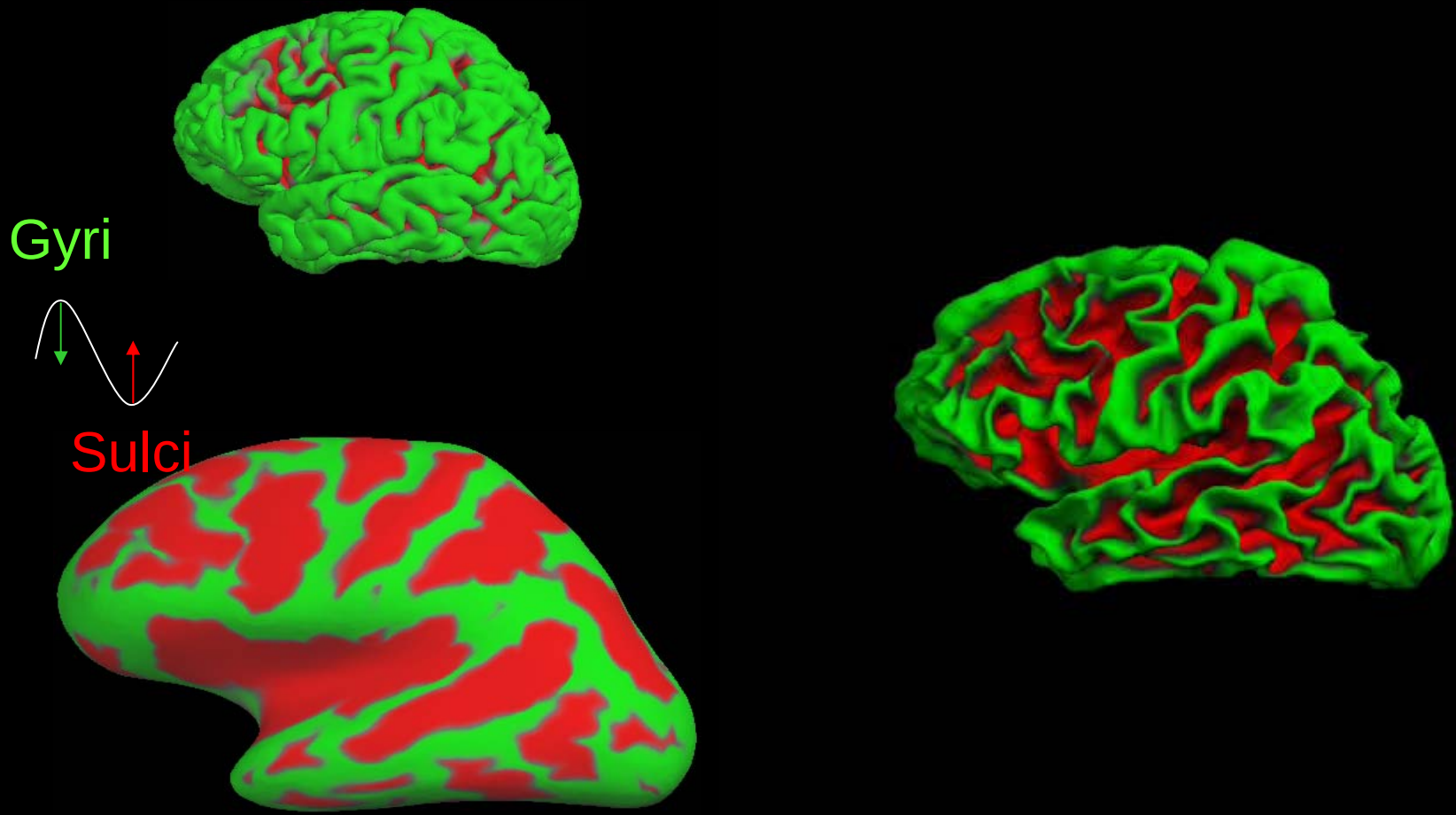
Do patterns of cortical atrophy differ in AD compared to healthy aging?

Participants

- Younger Participants (YP; n = 31; mean age 22.8)
- Middle-aged Participants (MP; n = 18; mean age 49.4)
- Older Participants (OP; n = 58; mean age 77.1)
- Patients with Alzheimer's disease (AD; n = 57; matched to OP)

- Scans collected through WUSTL ADRC in collaboration with Drs. Randy Buckner and John Morris

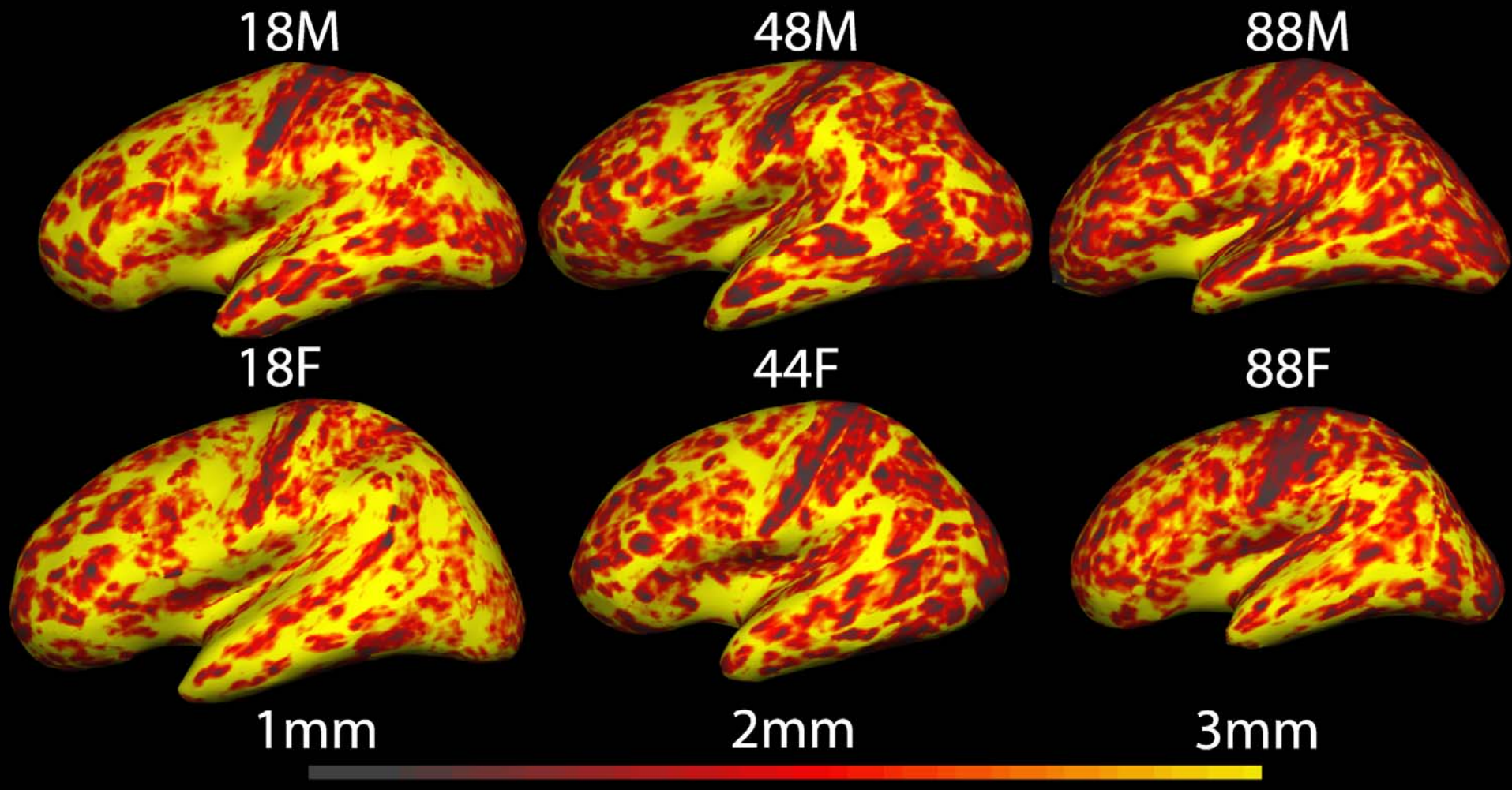
Visualization: Surface Inflation



Dale and Sereno, 1993; Dale et al., Dale et al., 1999; Fischl et al., 1999; Fischl et al., 2000; Fischl et al., 2001

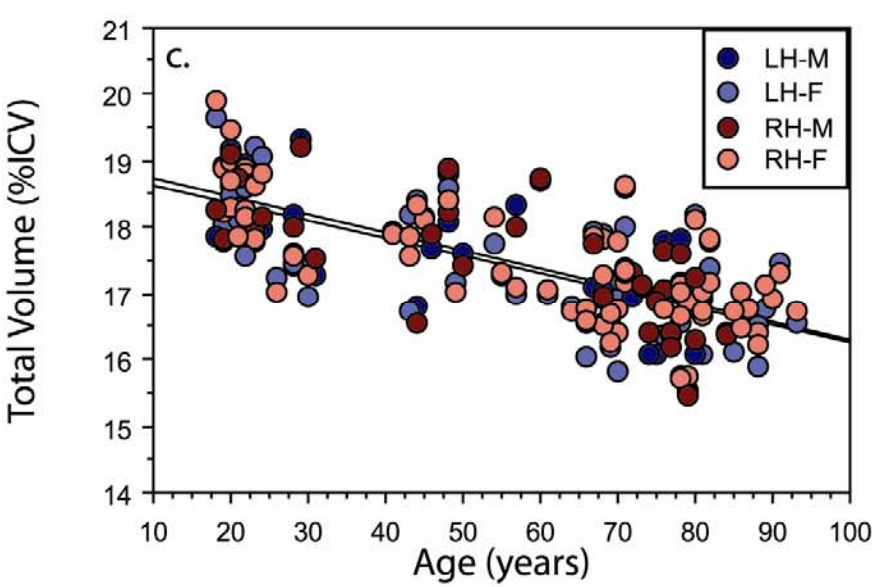
Thickness Maps

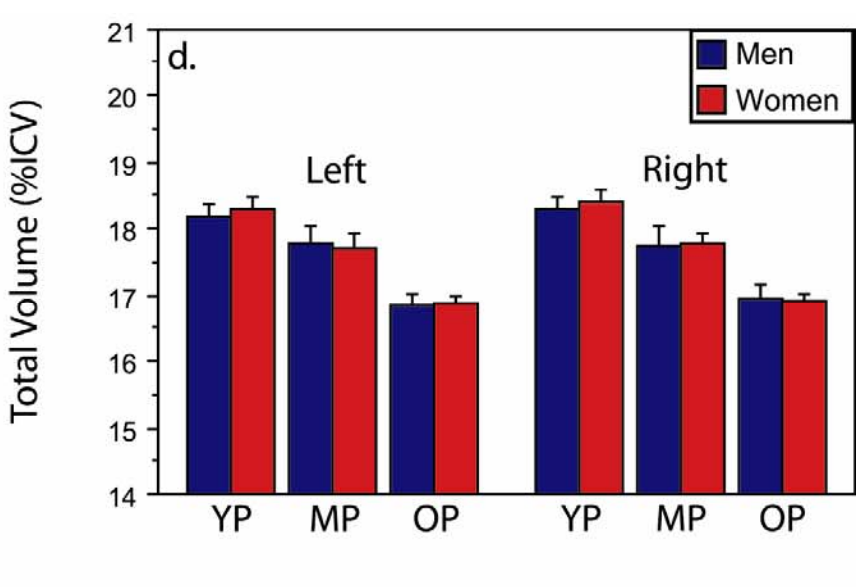
- Thinning (shift from yellow to red) apparent in individual participants with increasing age



Aging: Global Volume

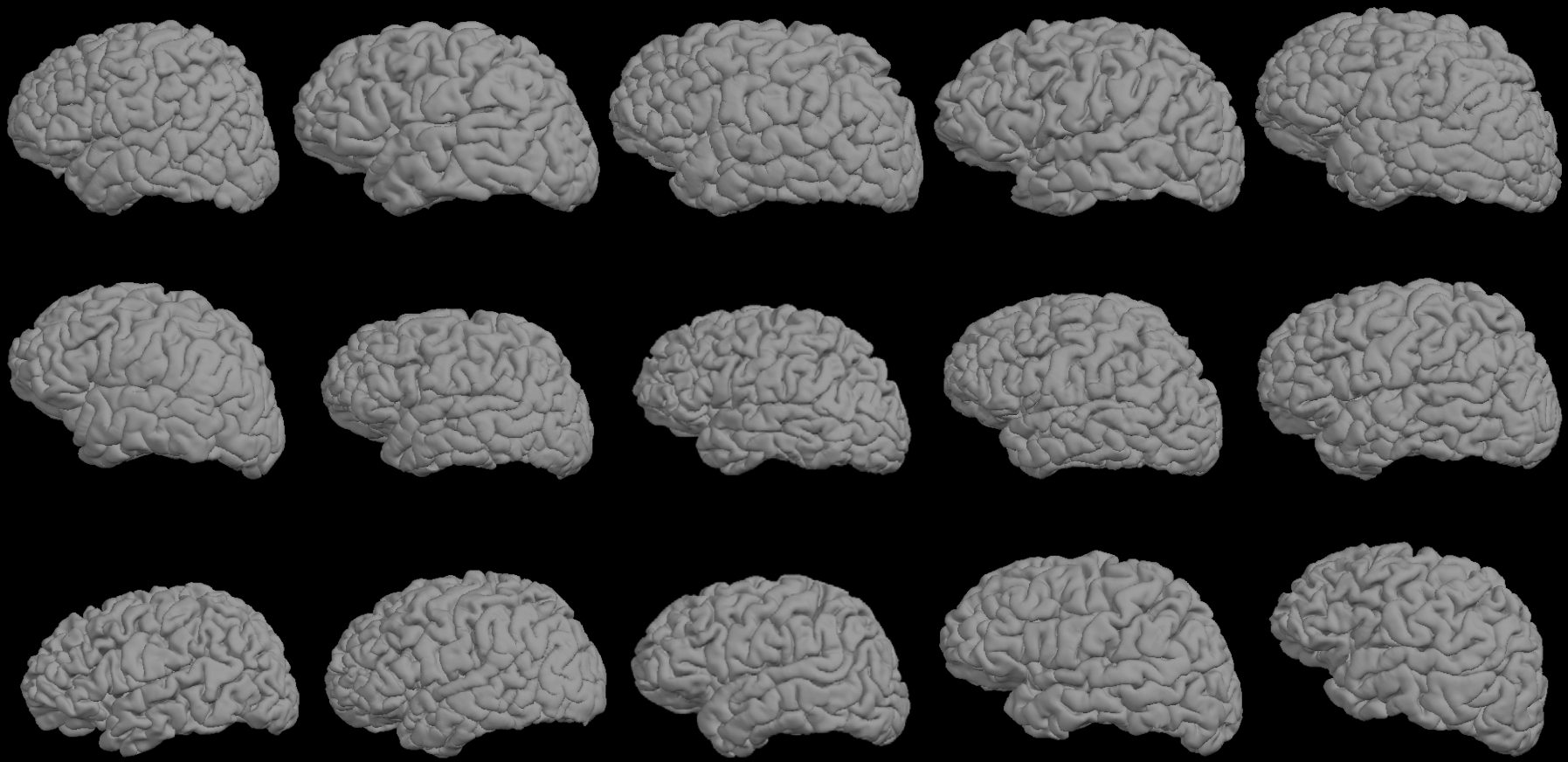
- Total volume correlated with age across all participants
- Total volume reduced in MP and OP compared to YP, and OP compared to MP
- No sex differences when volumes corrected for head size





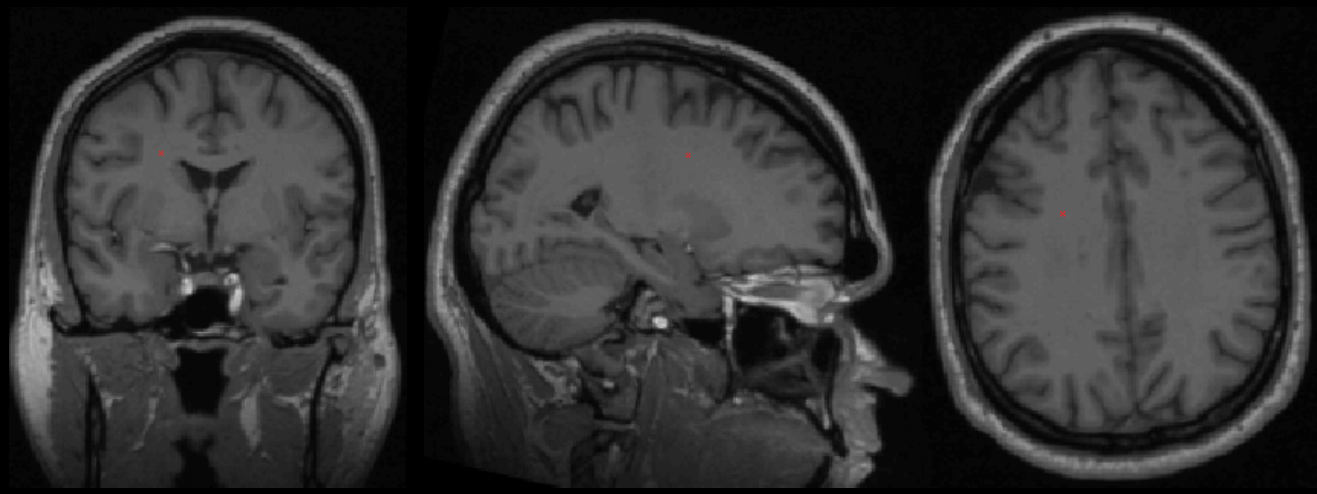
Volume is calculated from thickness by surface area: Can be decomposed

How to align different cortical surfaces?

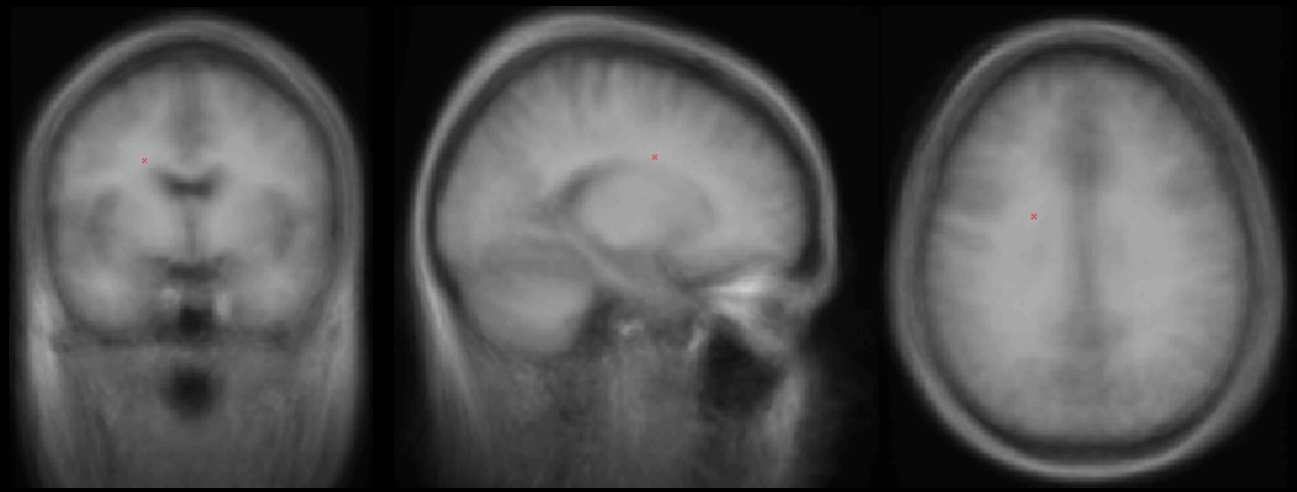


Talairach averaging

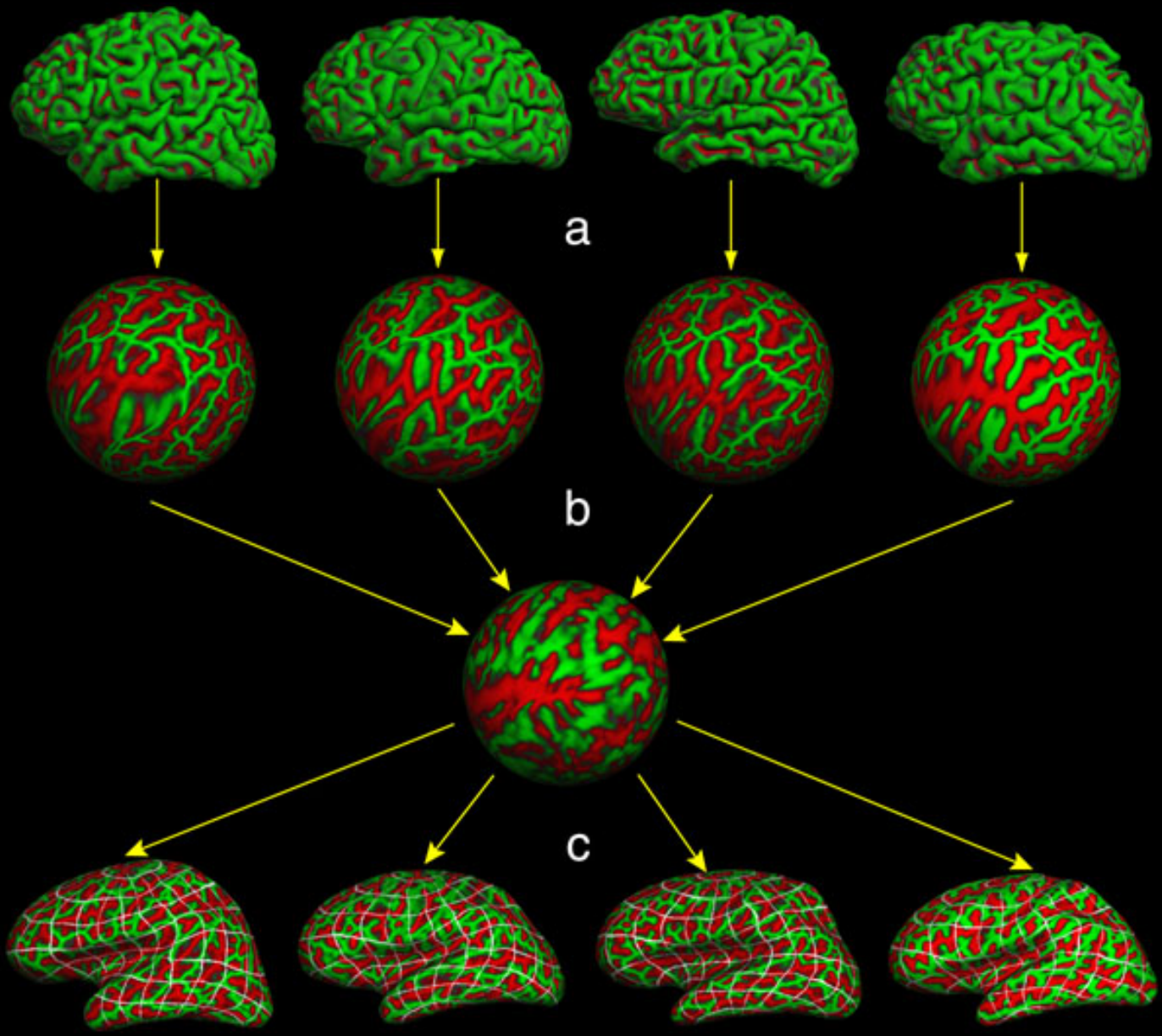
Single subject



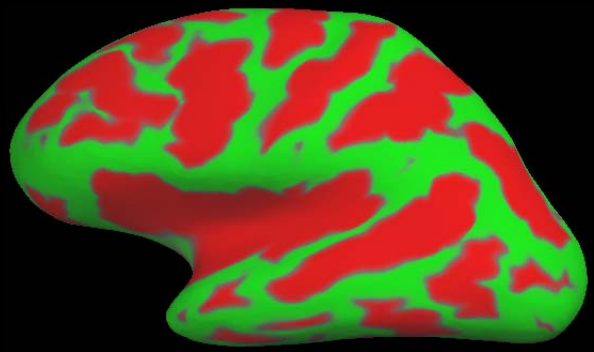
Average of 40



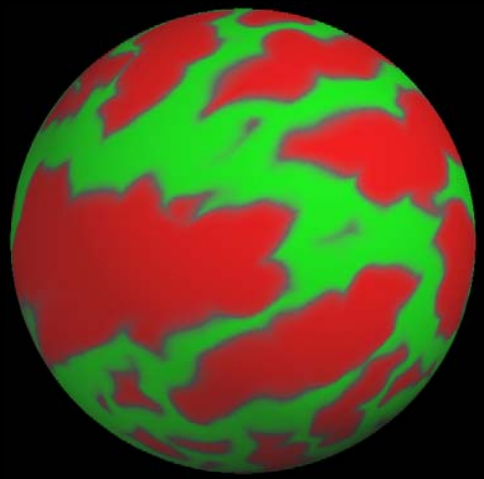
Surface-Based Spherical Coordinate System



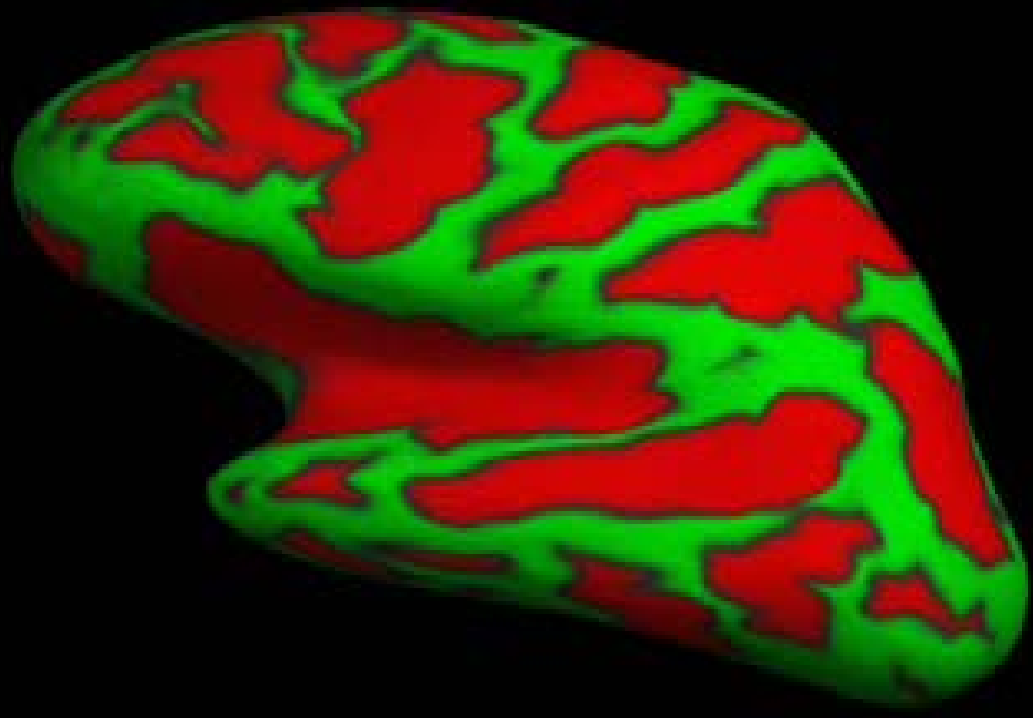
Spherical Averaging



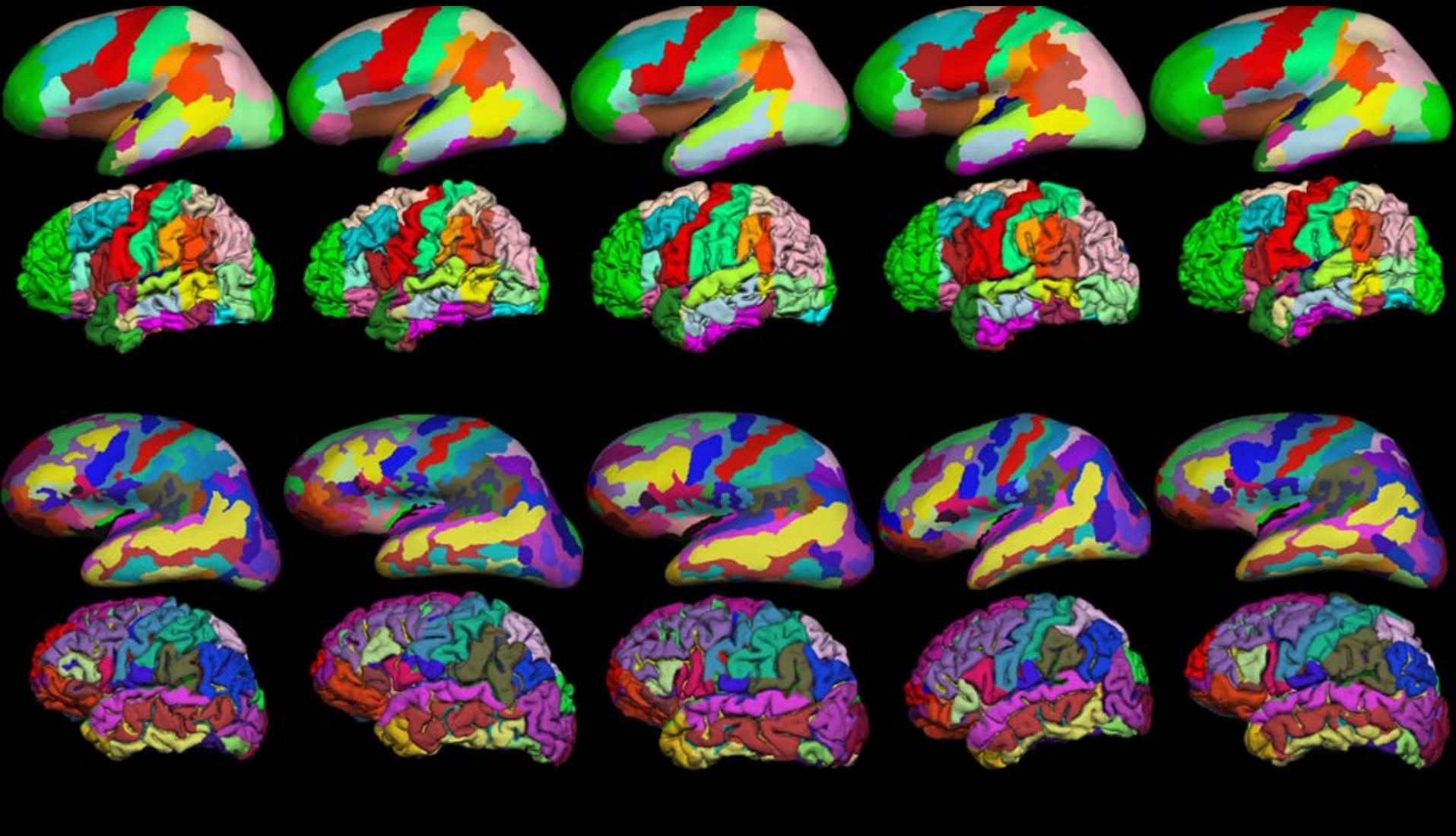
Inflated Surface



Transformed Surface

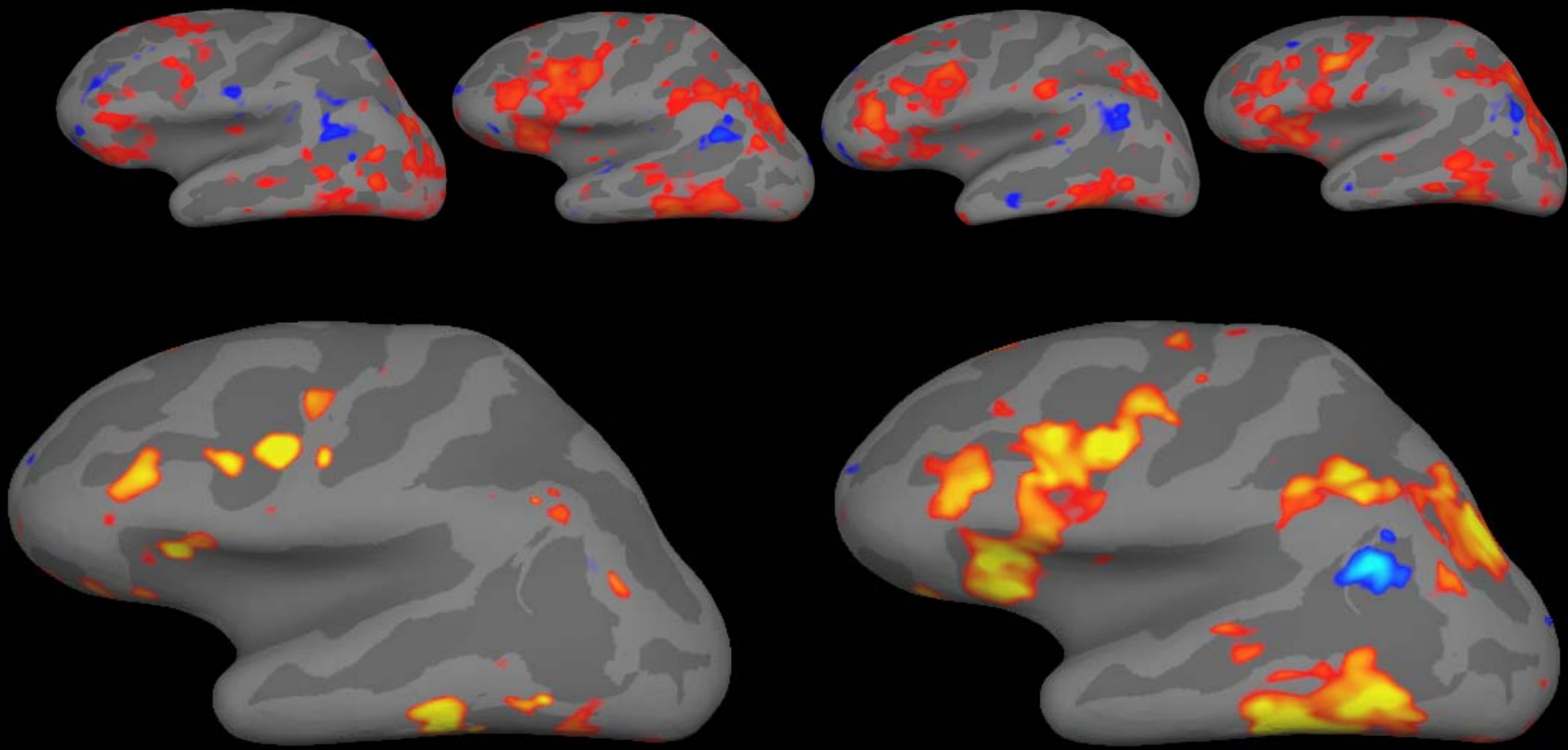


Automated Cortical Labeling Demonstrates the Power of Spherical Averaging



Effect of Speherical Averaging

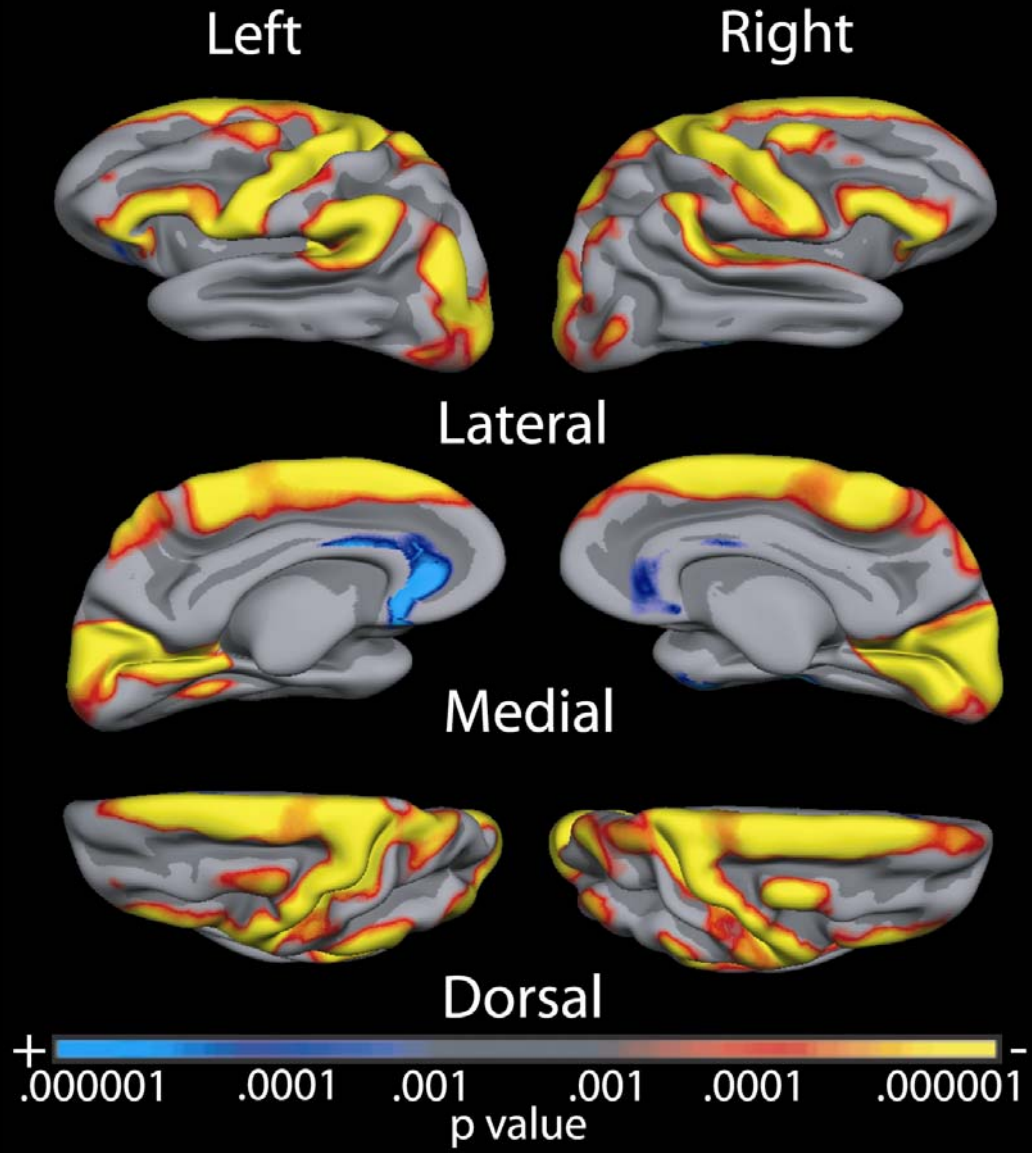
Repetition Effect (Novel vs. Repeated Words)



Talairach Average **Spherical Average**

Thinning from Young to Old Age

- Thinning in primary as well as association areas

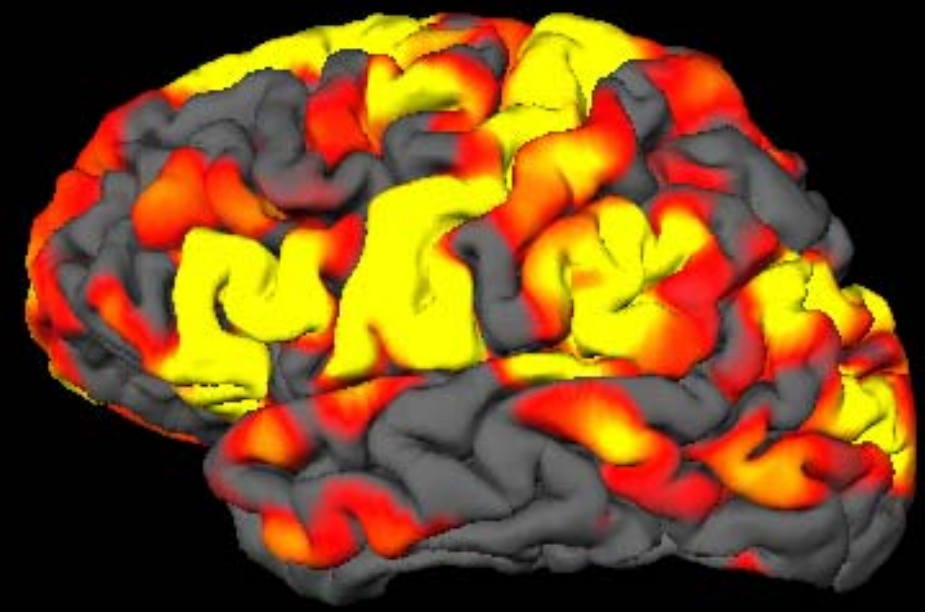


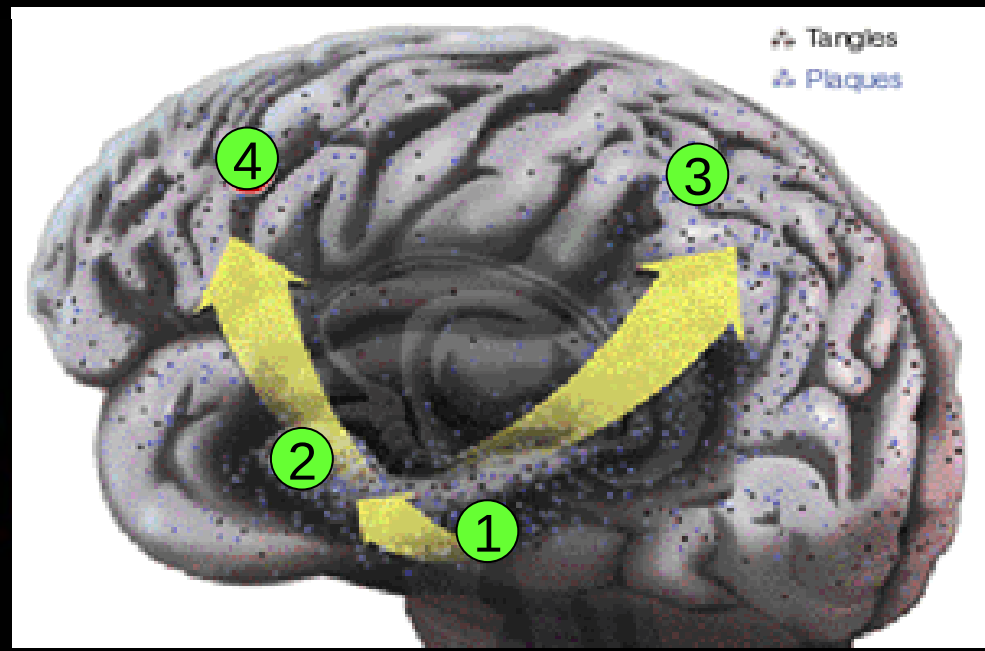
Aging v AD Brain

Do patterns of cortical atrophy differ in AD compared to healthy aging?

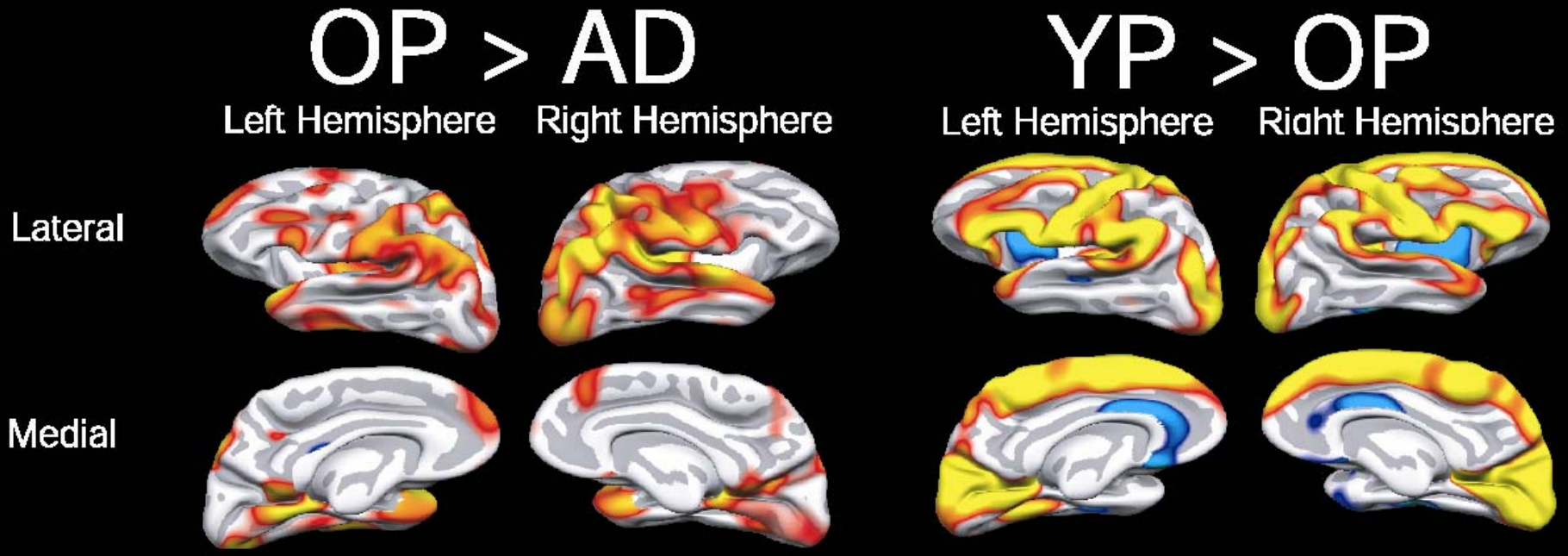
Alois Alzheimer described in 1906

Staging: Ball, Braak, Hyman





Regional Thinning: Aging v AD



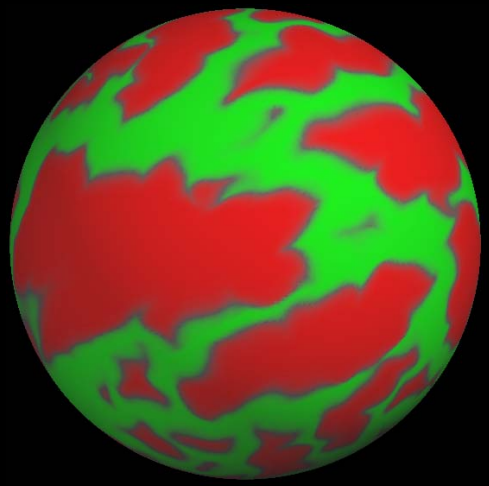
*Cortical loss in AD seems to be primarily thickness, not surface area

Thickness Summary

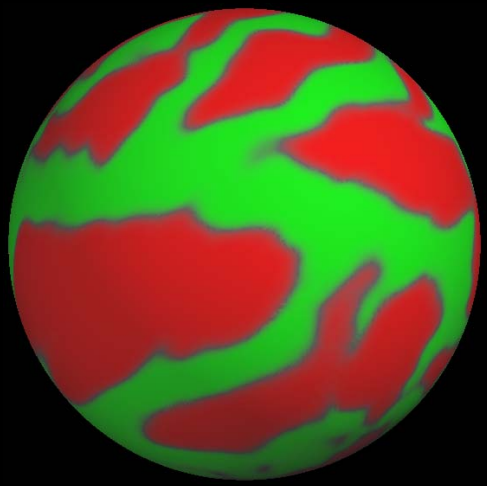
- Global thinning is apparent with early aging (earlier than we expected)
- Age-related thinning is regionally widespread including association cortex as well as primary sensory/motor regions (more widespread than we expected)
- Regional thinning differs in AD compared to healthy aging with greater thinning in medial temporal and parietal cortex in AD, consistent with pathology studies
- Thickness measures may be useful clinically (e.g., diagnostically)

What else can we do with surfaces?

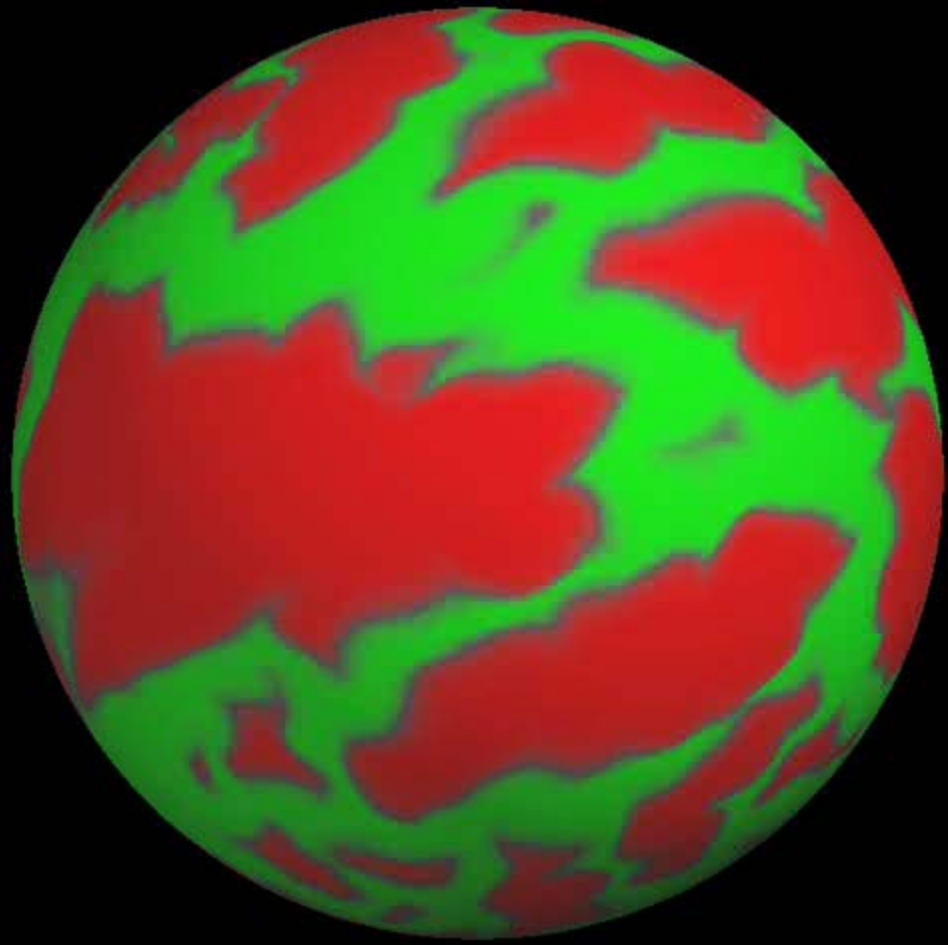
Additional Properties of Interest: Amount of ‘Stretching’ to Match Atlas

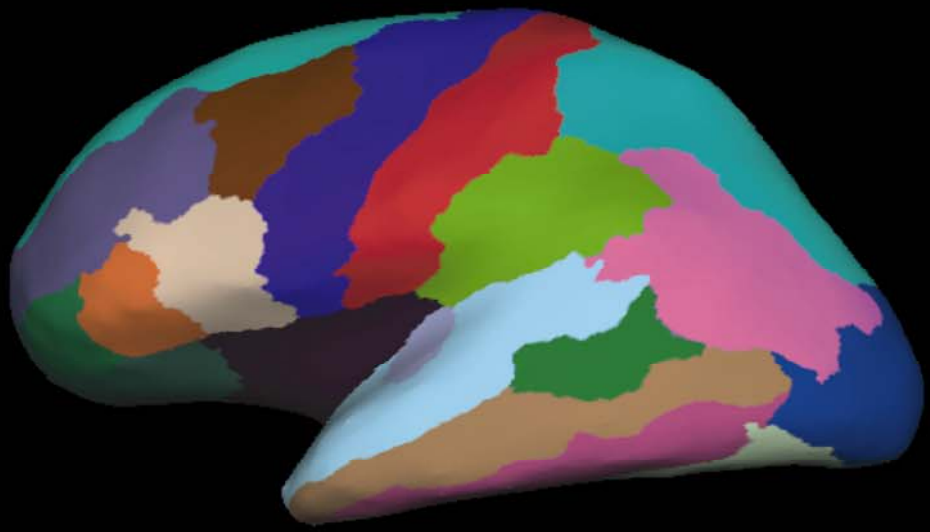


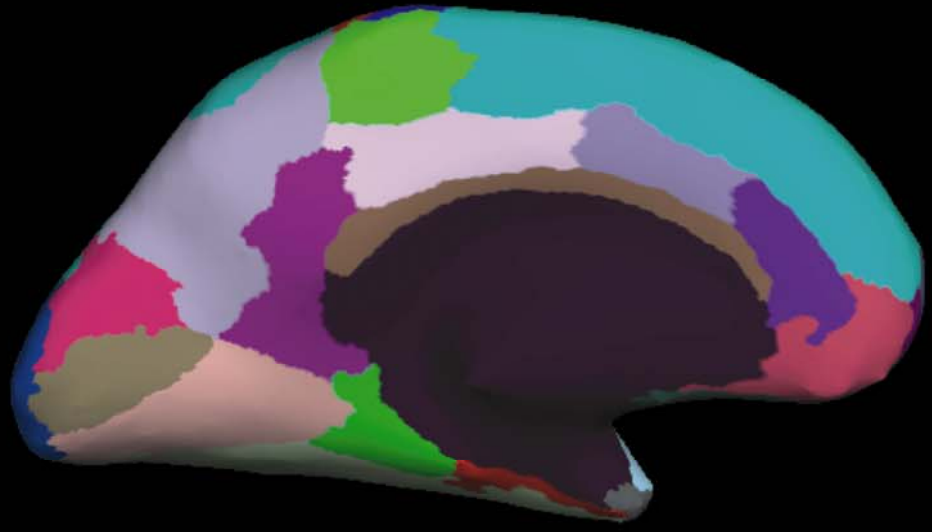
Individual Subject



Average (Target)



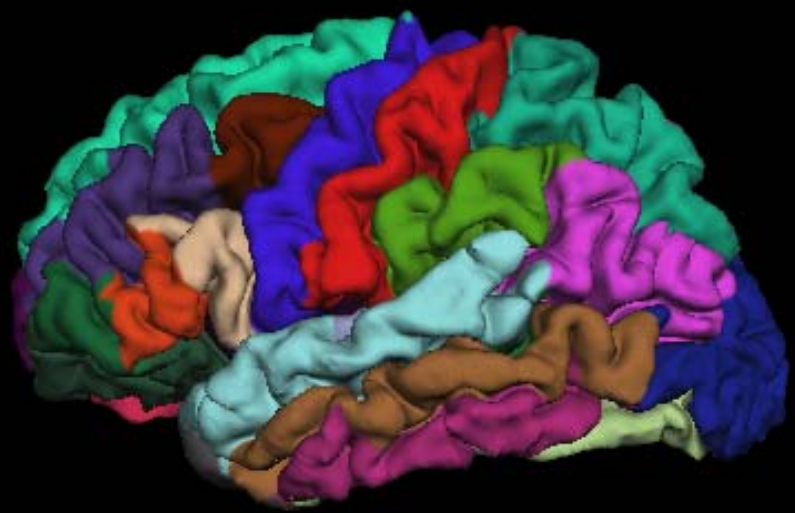




Cortex → white matter

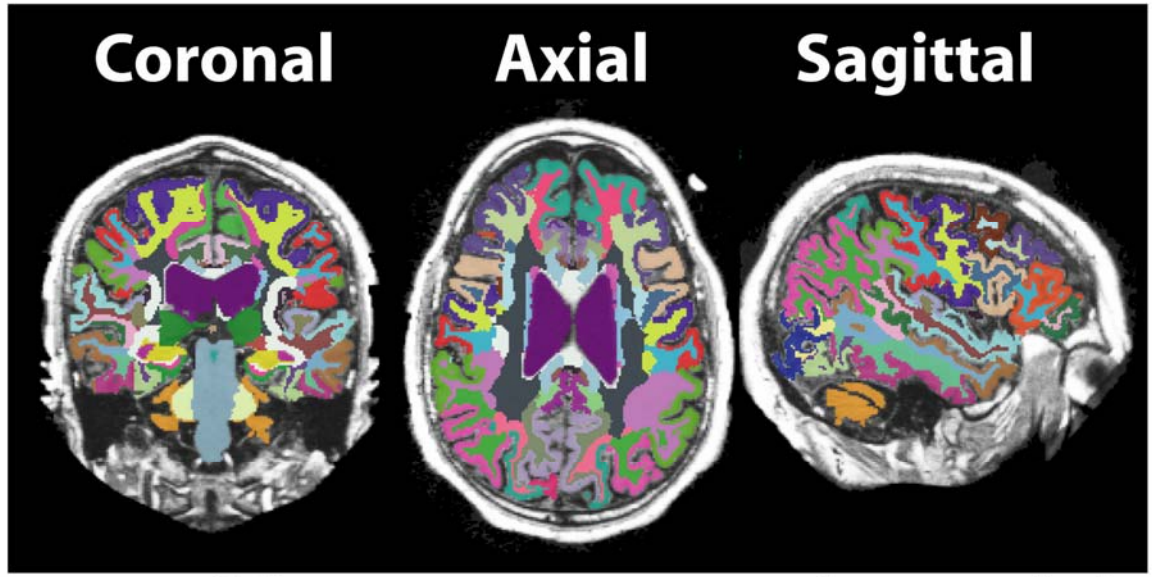
Can be used to inform subcortical labeling

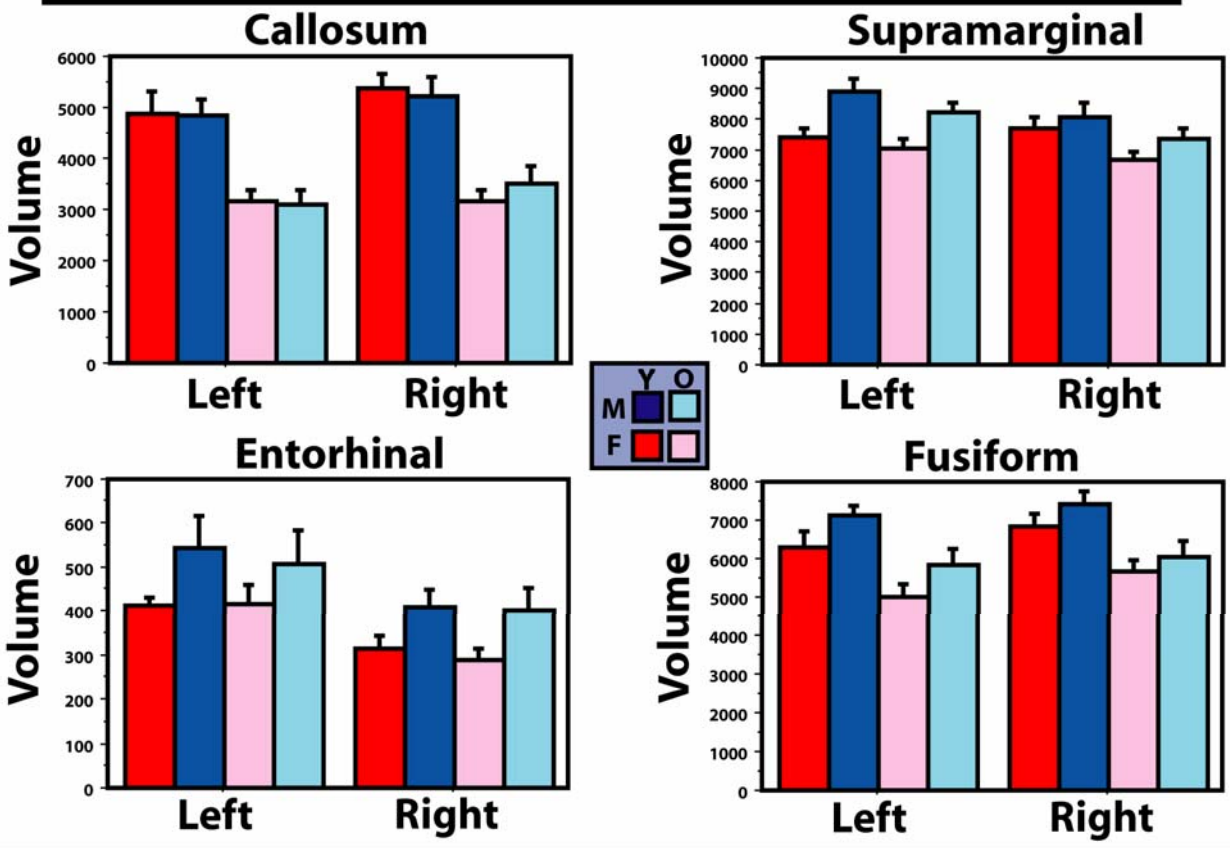
"Twinkie Model"



Why use WM Parcellation?

1. Could provide information about WM associated with specific cortical regions
2. T1 data is far more abundant than DTI data
3. May provide unique information about WM degeneration

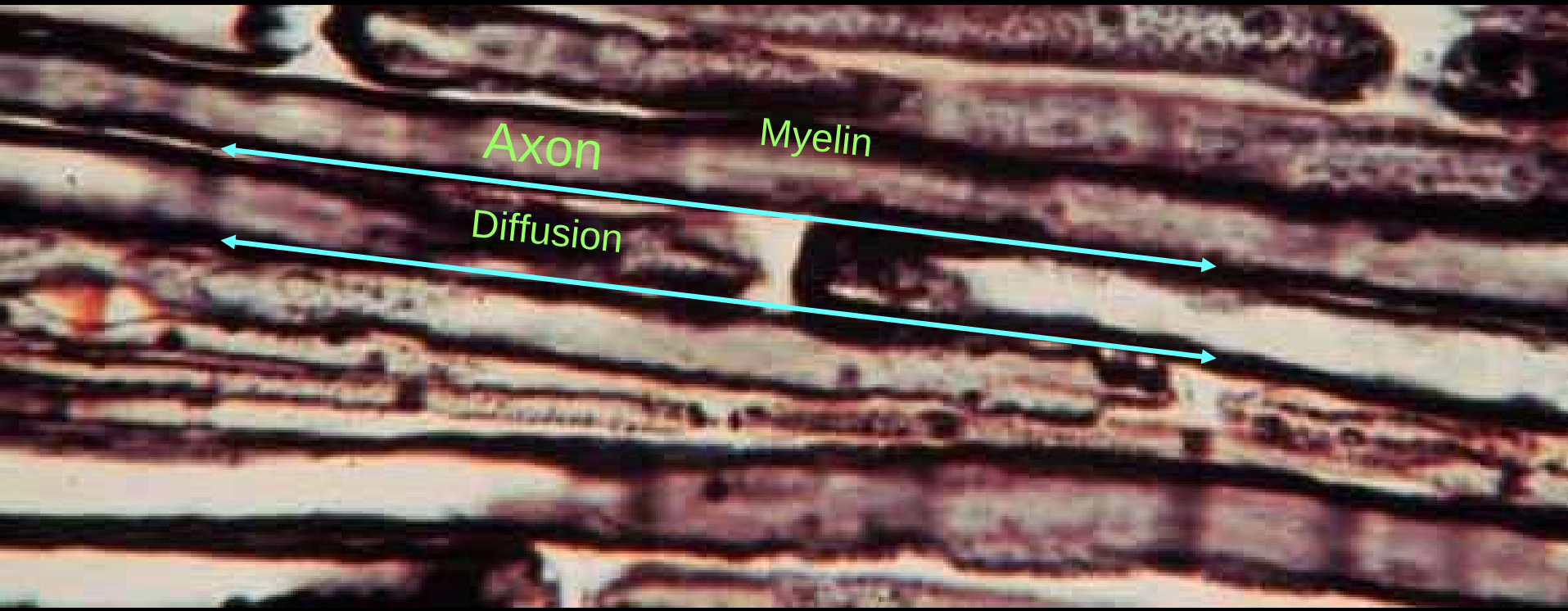




MR Anatomy Caveats

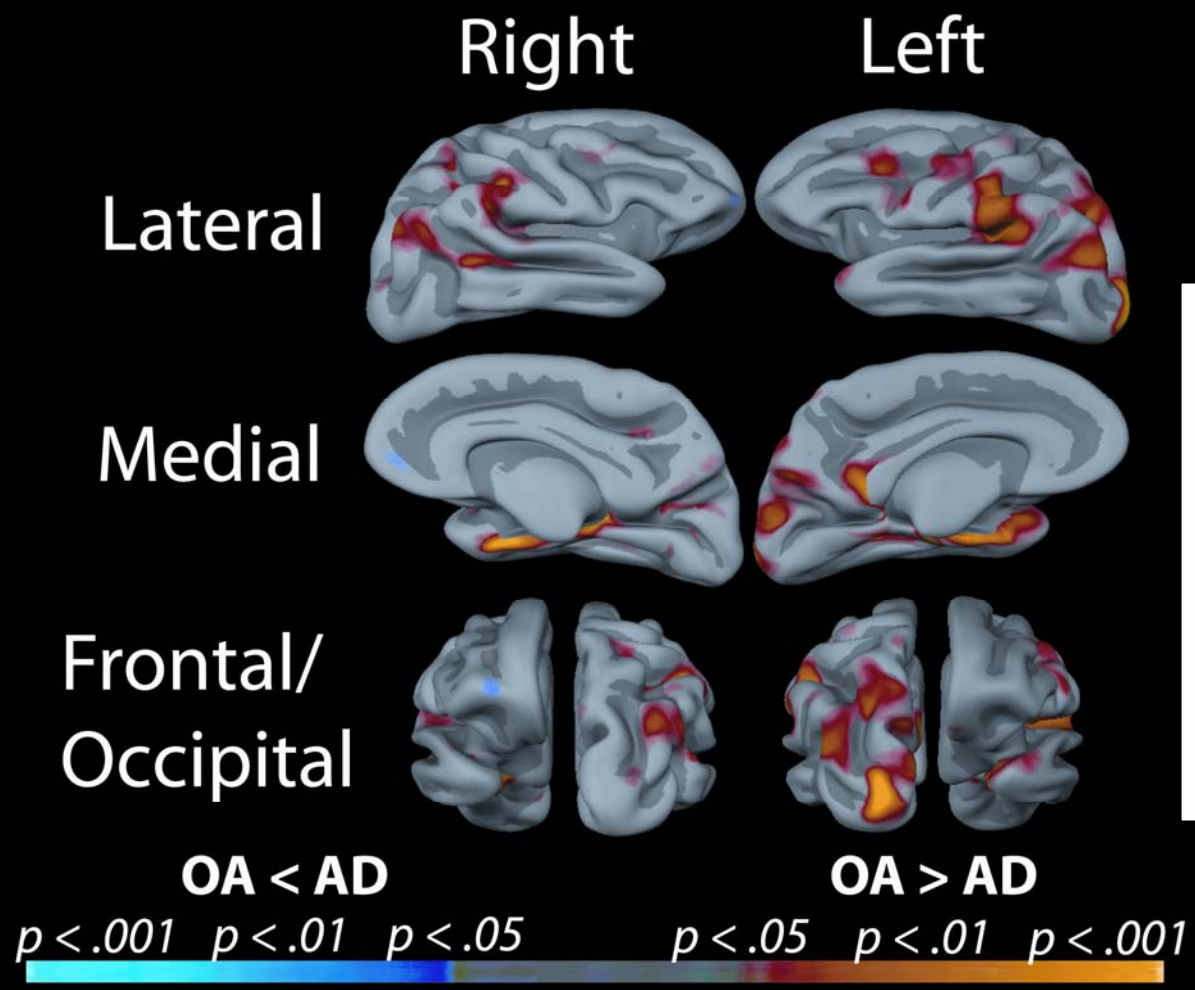
- Dependent on data quality
  - Contrast to noise
  - Signal to noise
  - Voxel resolution
- MR Artifacts
  - MR susceptibility
  - MR distortions
- Variations in MR tissue parameters across regions of the brain and are altered in different populations
- Most problems can be reduced if acknowledged, and potentially be strengths
- What is the biological basis of morphometric changes?

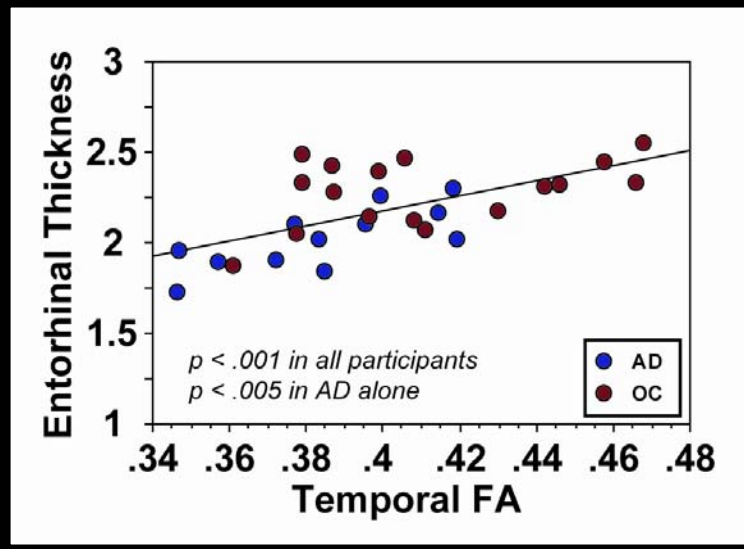
Multimodal 1: Diffusion Tensor Imaging



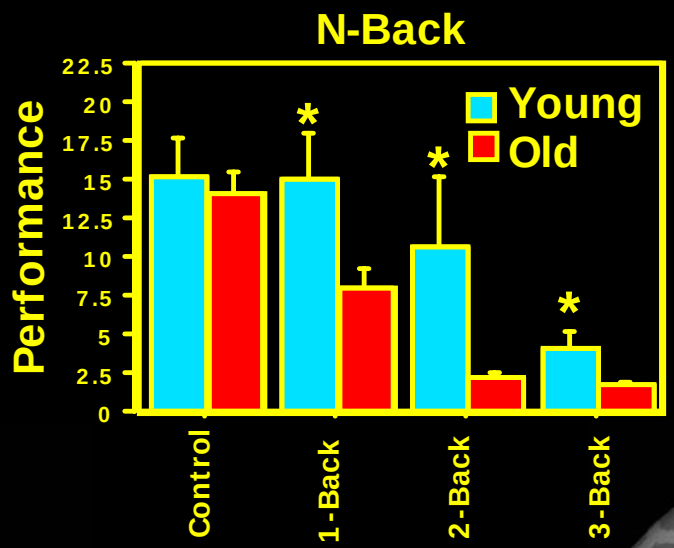
- Contrast dependent on molecular self diffusion of water
- Diffusion highly influenced by myelinated axons
  - Questions about biophysics in health and disease
- Index of various aspects of tissue microstructure
  - Myelination
  - Orientation

Association Between FA and Cortical Thickness



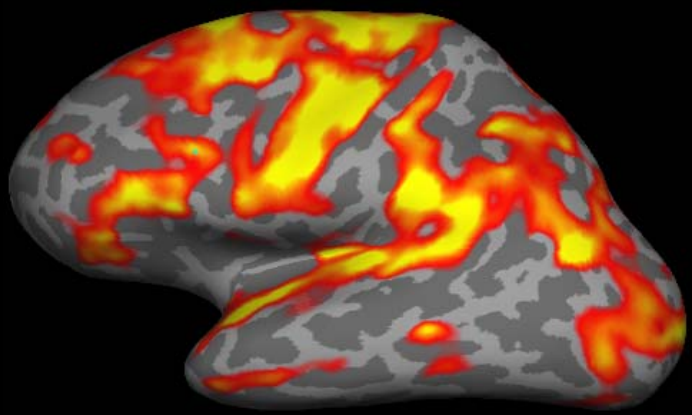


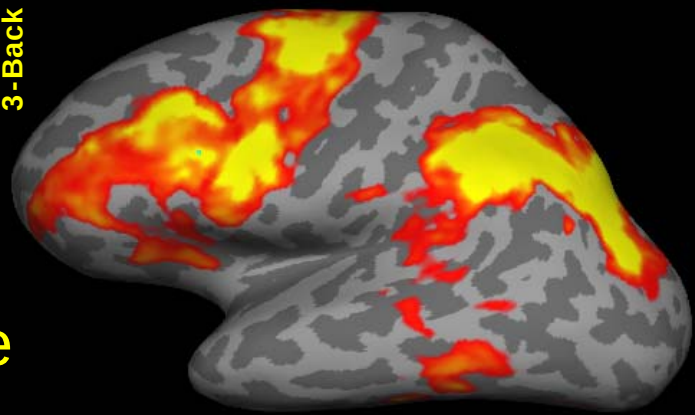
Performance



GM Structure

Brain Function





WM Structure