FreeSurfer

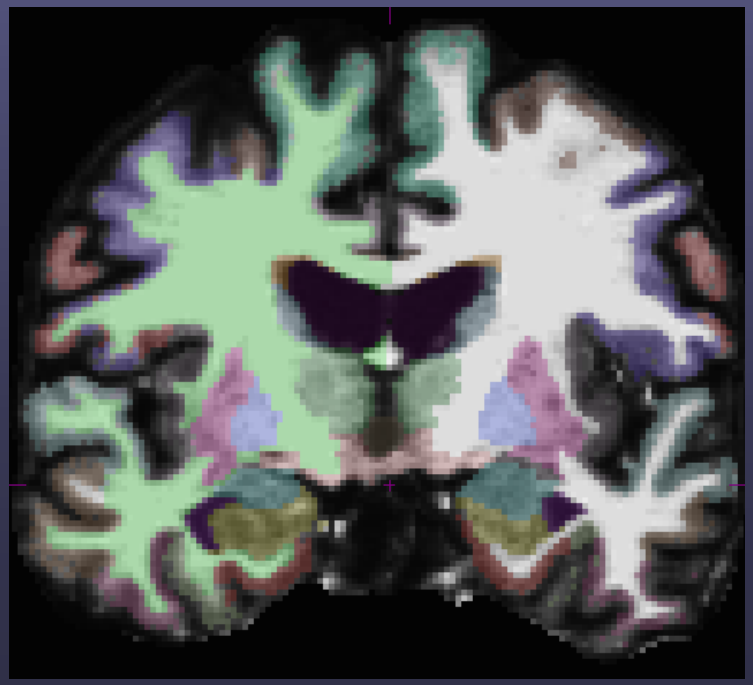
http://surfer.nmr.mgh.harvard.edu

Register

Download

Platforms: Linux, Mac, Windows

freesurfer@nmr.mgh.harvard.edu



Analyzing the Individual Subject in FreeSurfer…

What happens?
How do I do that?
Now What?

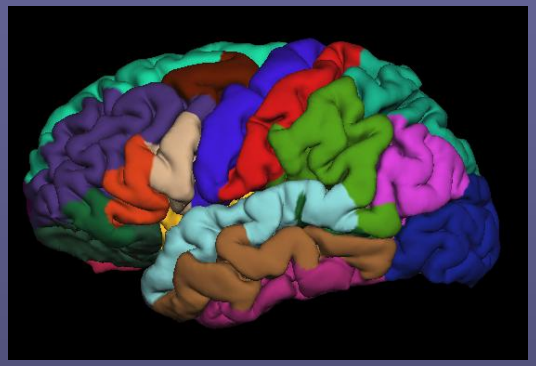
Analyzing the Individual Subject in FreeSurfer…

What happens?

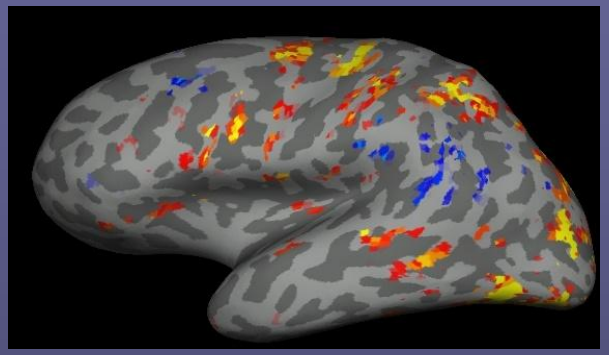
How do I do that?

Now What?

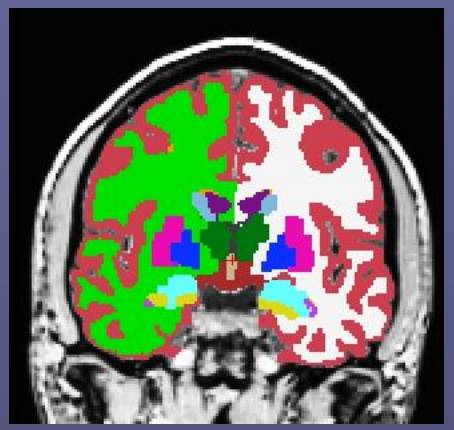
Surface and Volume Analysis



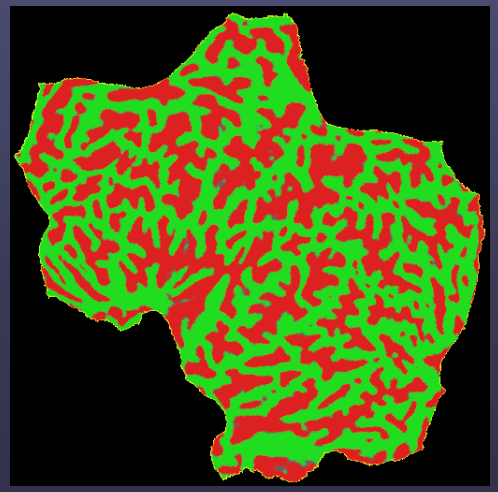
Cortical Reconstruction and Automatic Labeling



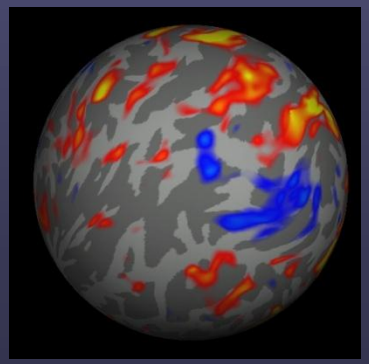
Inflation and Functional Mapping



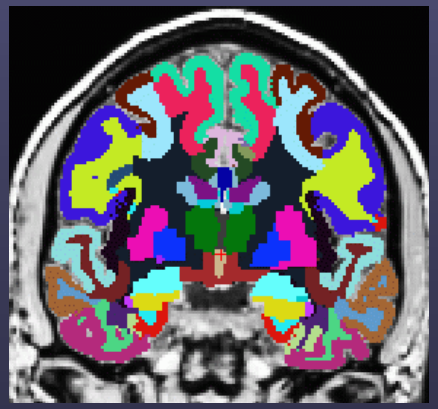
Automatic Subcortical Gray Matter Labeling



Surface Flattening



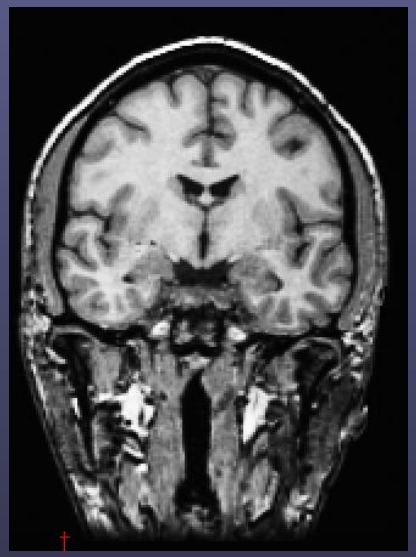
Surface-based Intersubject Alignment and Statistics



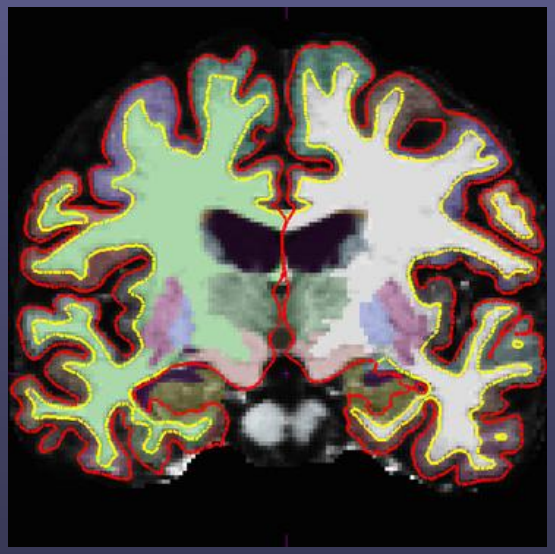
Automatic Gyral White Matter Labeling

Cortical Surface Reconstruction

FreeSurfer creates computerized models of the brain from MRI data.



Input:
T1-weighted (MPRAGE,SPGR)
1mm^3 resolution
(.dcm)



Output:
Segmented & parcellated conformed volume
(.mgz)

MR Anatomy Caveats

Surfaces are only as good as your scan.

- 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 are altered in different populations

Suggested Morphometry Sequences

http://www.nmr.mgh.harvard.edu/~andre/

Analyzing the Individual Subject in FreeSurfer…

Wait…what happens?

How do I do that?

Now What?

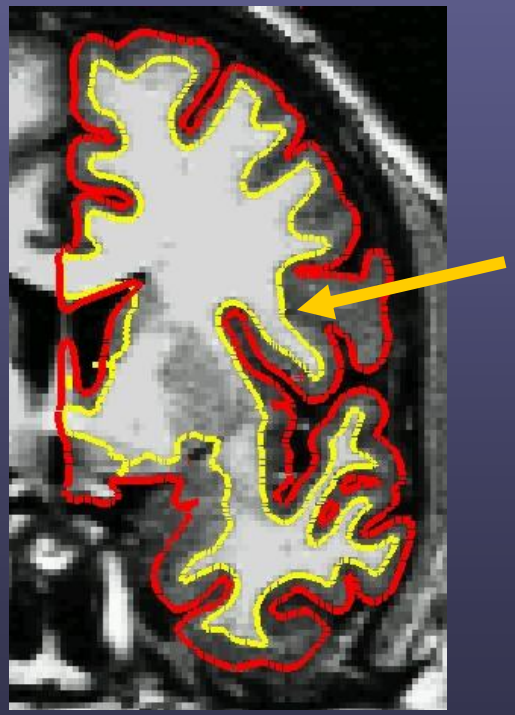
What Happens During Cortical Surface Reconstruction?

- Finds wm/gray boundary – white surface
- Finds gm/CSF boundary – pial surface
- Subcortical Segmentation
- Cortical Parcellation
- Generates surface-based cross-subject registration

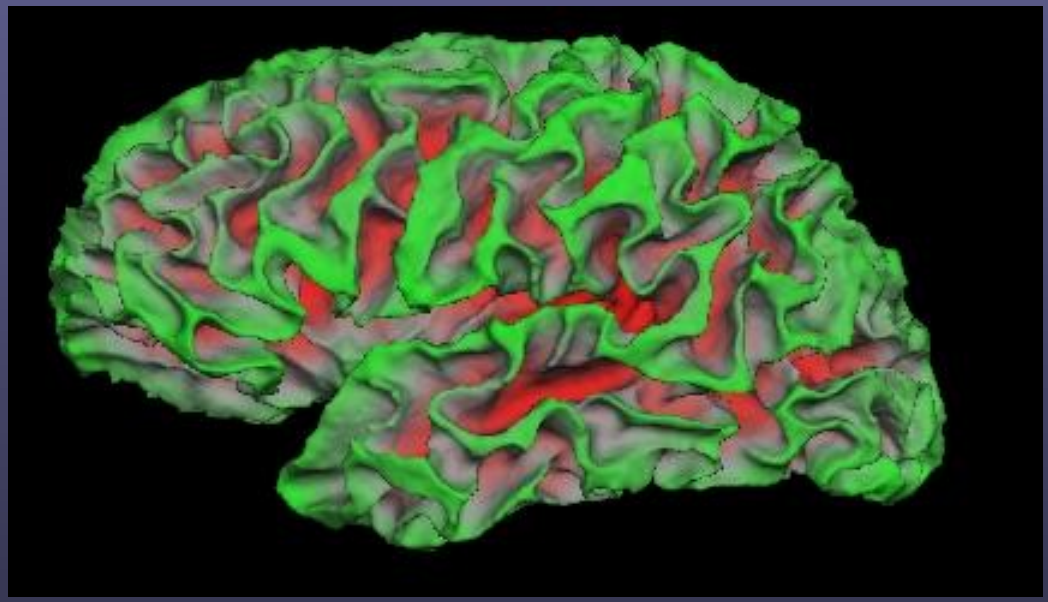
What Happens During Cortical Surface Reconstruction?

- Finds wm/gray boundary – white surface

one slice



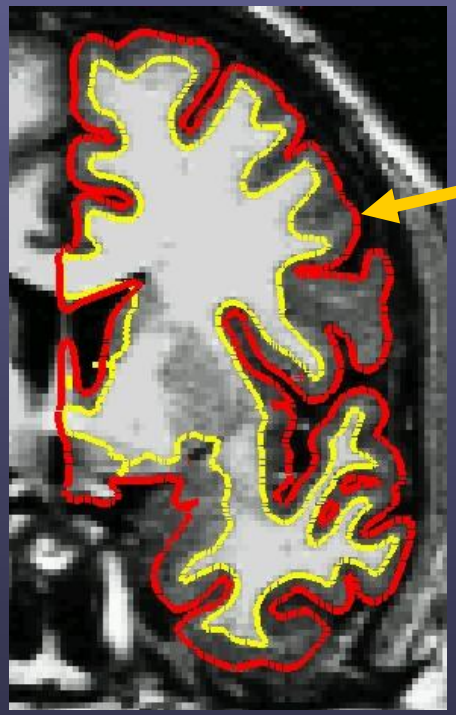
entire brain



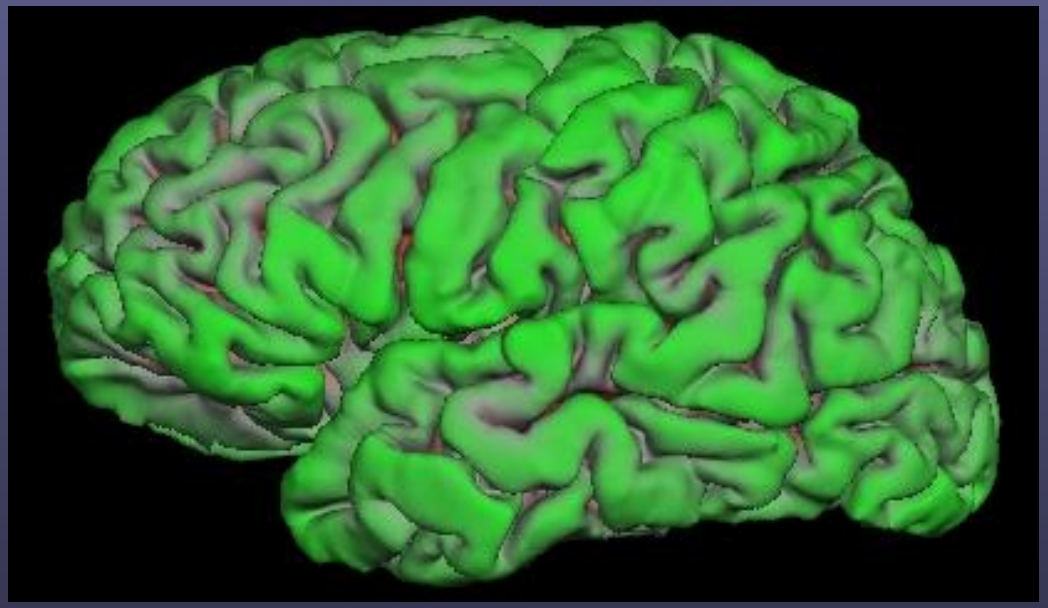
What Happens During Cortical Surface Reconstruction?

- Finds gm/CSF boundary – pial surface

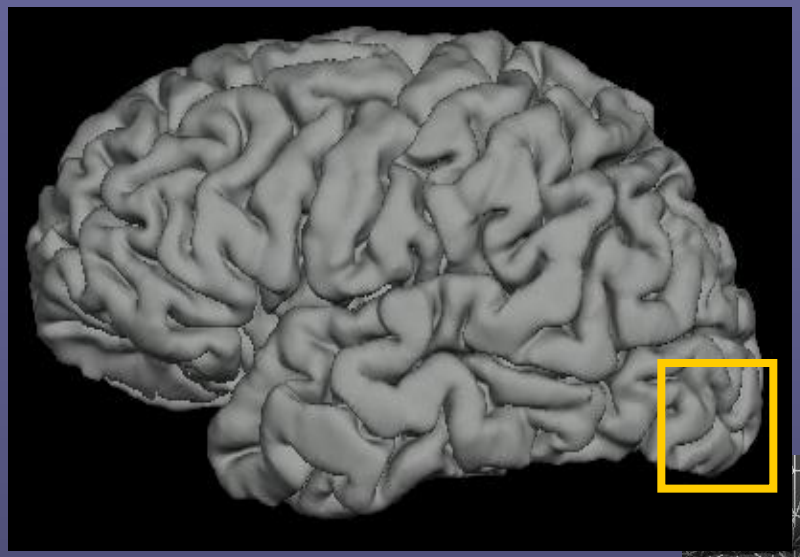
one slice

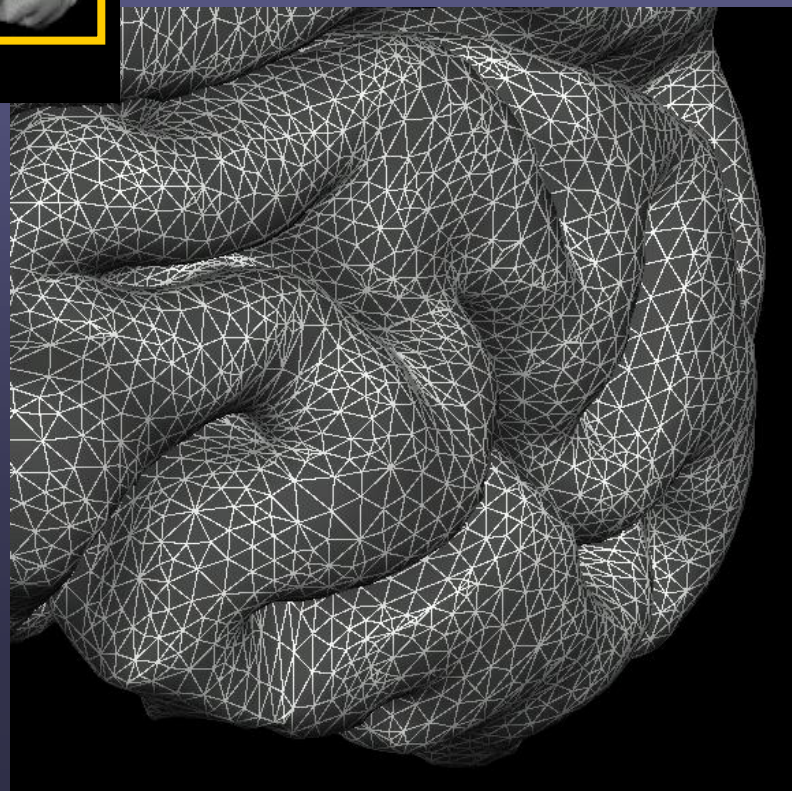


entire brain



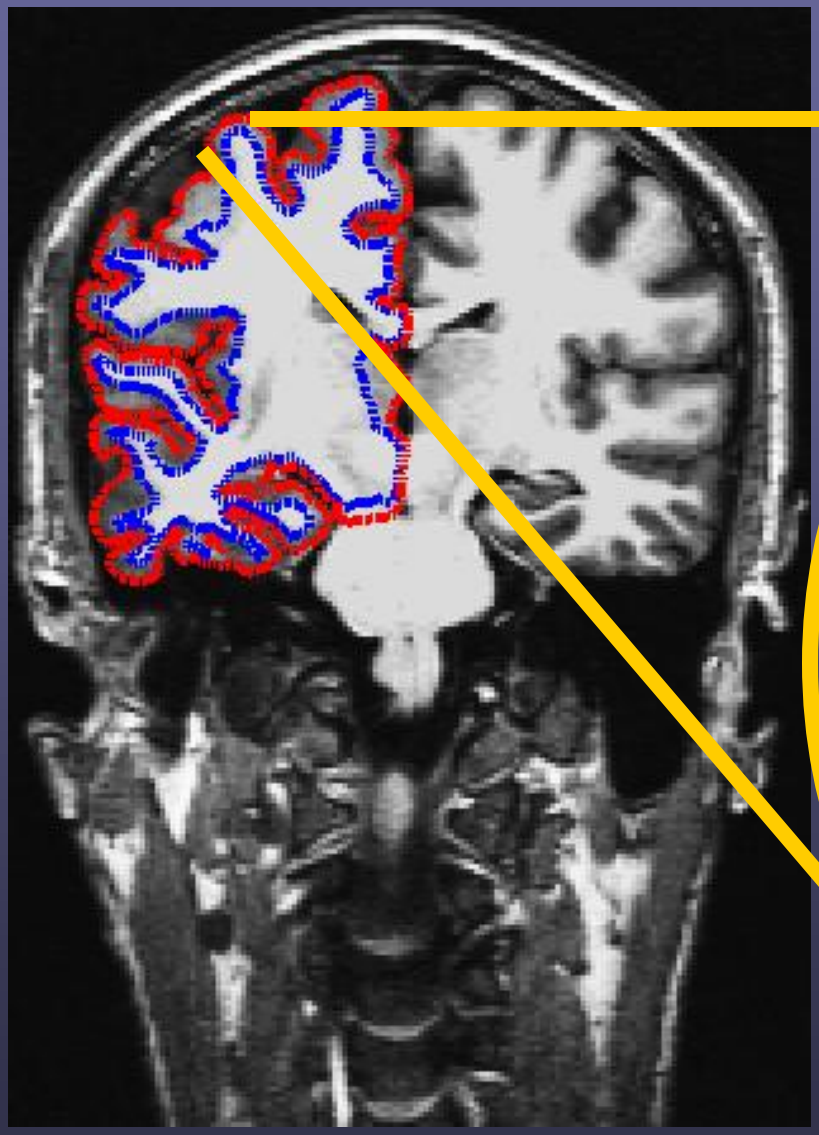
Surface Model





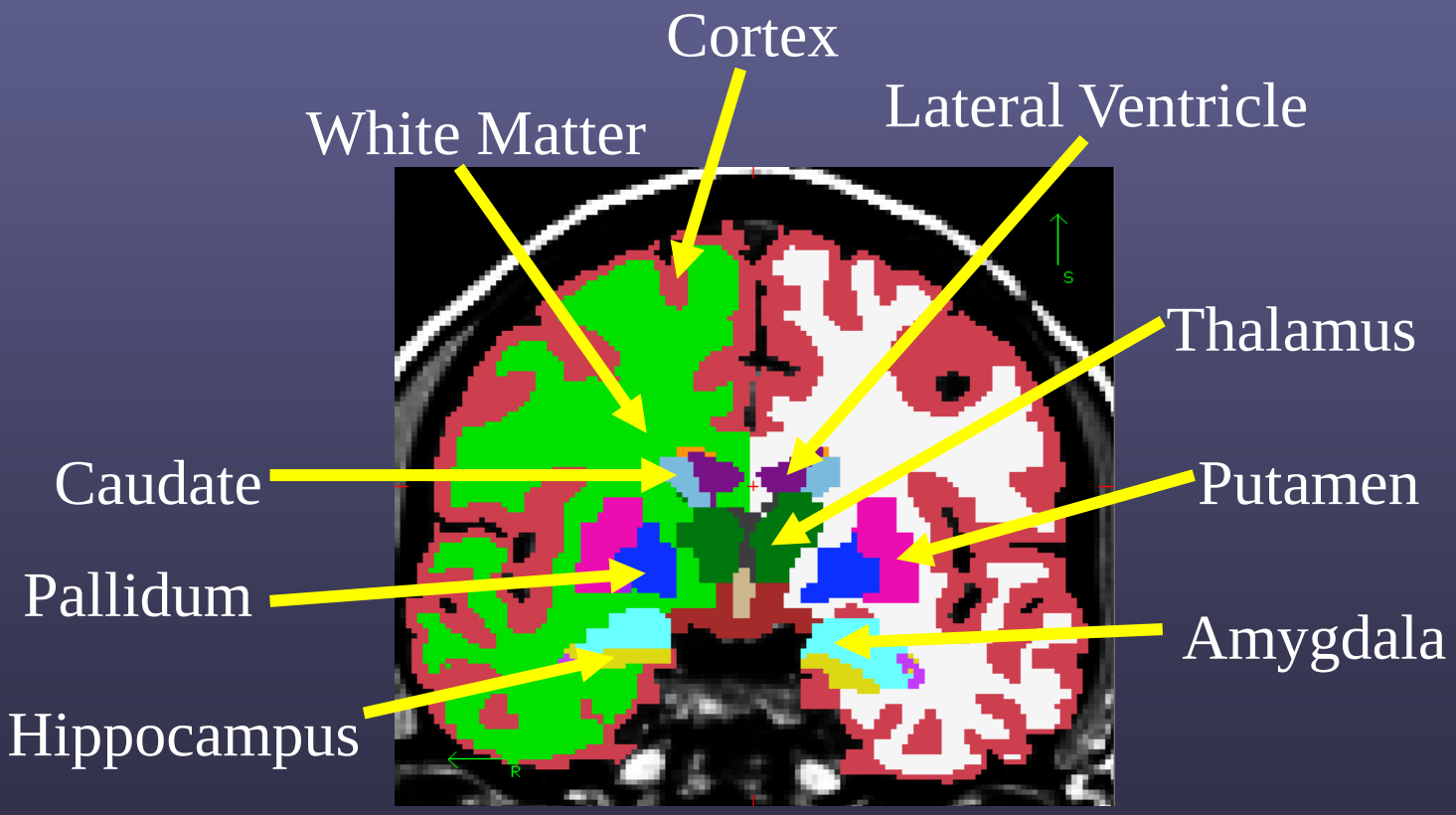
- Mesh of triangles gives a measurable size
- Allows us to measure Area, Curv., Thickness (distance b/w vertices)
- Vertex = point of 6 triangles
- Triangles/Faces ~ 150,000 per hemi
- 1:1 correspondence of vertices
- XYZ at each vertex

Cortical Thickness



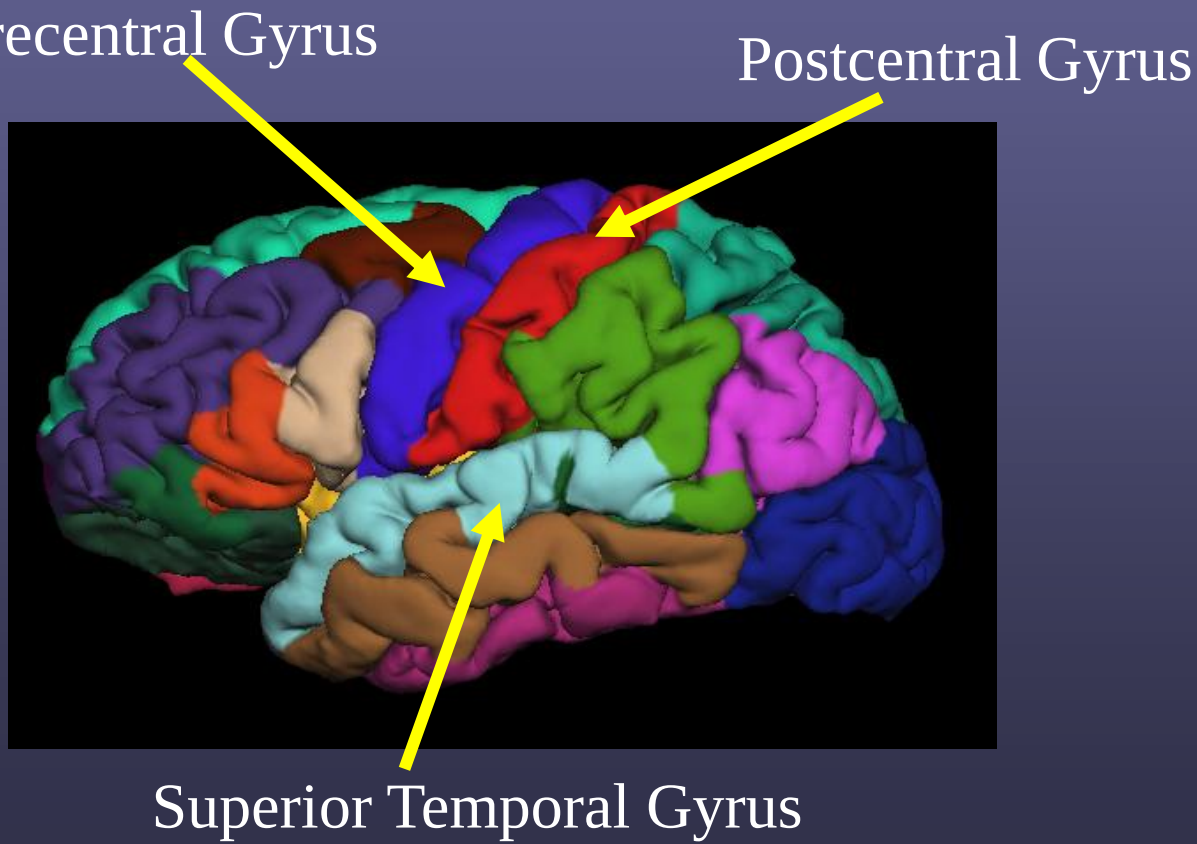
What Happens During Cortical Surface Reconstruction?

- Subcortical Segmentation



What Happens During Cortical Surface Reconstruction?

- Cortical Parcellation



What Happens During Cortical Surface Reconstruction?

- Finds white/gray boundary – wm surface
- Finds pial/CSF boundary – pial surface
- Subcortical Segmentation
- Cortical Parcellation
- Generates surface-based cross-subject registration

Analyzing the Individual Subject in FreeSurfer…

Wait…what really happens?

How do I do that?

Now What?

Individual Steps

Volumetric Processing Stages (subjid/mri):

1. Motion Cor, Avg, Conform (orig.mgz)
2. Talairach transform computation (transforms/talairach.xfm)
3. Non-uniform inorm (nu.mgz)
4. Intensity Normalization 1 (T1.mgz)
5. Skull Strip (brainmask.mgz)

6. EM Register (linear volumetric registration)
7. CA Intensity Normalization (norm.mgz)
8. CA Non-linear Volumetric Registration
9. CA Label (Volumetric Labeling) (aseg.mgz)

10. Intensity Normalization 2 (T1.mgz)
11. White matter segmentation (wm.mgz)
12. Edit WM With ASeg
13. Fill and cut (filled.mgz)

Surface Processing Stages (subjid/surf):

14. Tessellate (?h.orig.nofix)
15. Smooth1
16. Inflate1
17. QSphere (?h.qsqhere)
18. Automatic Topology Fixer (?h.orig)
19. Final Surfs (?h.white ?h.pial ?.thickness)
20. Smooth2 (?h.smoothwm)
21. Inflate2 (?h.inflated)
22. Aseg Statistics (stats/aseg.stats)
23. Cortical Ribbon Mask (?h.ribbon.mgz)

24. Spherical Morph
25. Spherical Registration (?h.sphere.reg)
26. Map average curvature to subject
27. Cortical Parcellation (Labeling)
28. Cortical Parcellation Statistics
29. Cortical Parcellation mapped to Aseg
30. White Matter Parcellation (wmparc.mgz)

recon-all -help

Note: ?h.orig means lh.orig or rh.orig

Processing Stream Order

NMR FSdev:
http://surfer.nmr.mgh.harvard.edu/fswiki/ReconAllDevTable

FSv5.1:
http://surfer.nmr.mgh.harvard.edu/fswiki/ReconAllTableStableV5.1

FSv4.5:
http://surfer.nmr.mgh.harvard.edu/fswiki/ReconAllTableStablev4

How to Get Started

Use dicoms from scanner as input to Cortical Reconstruction command:

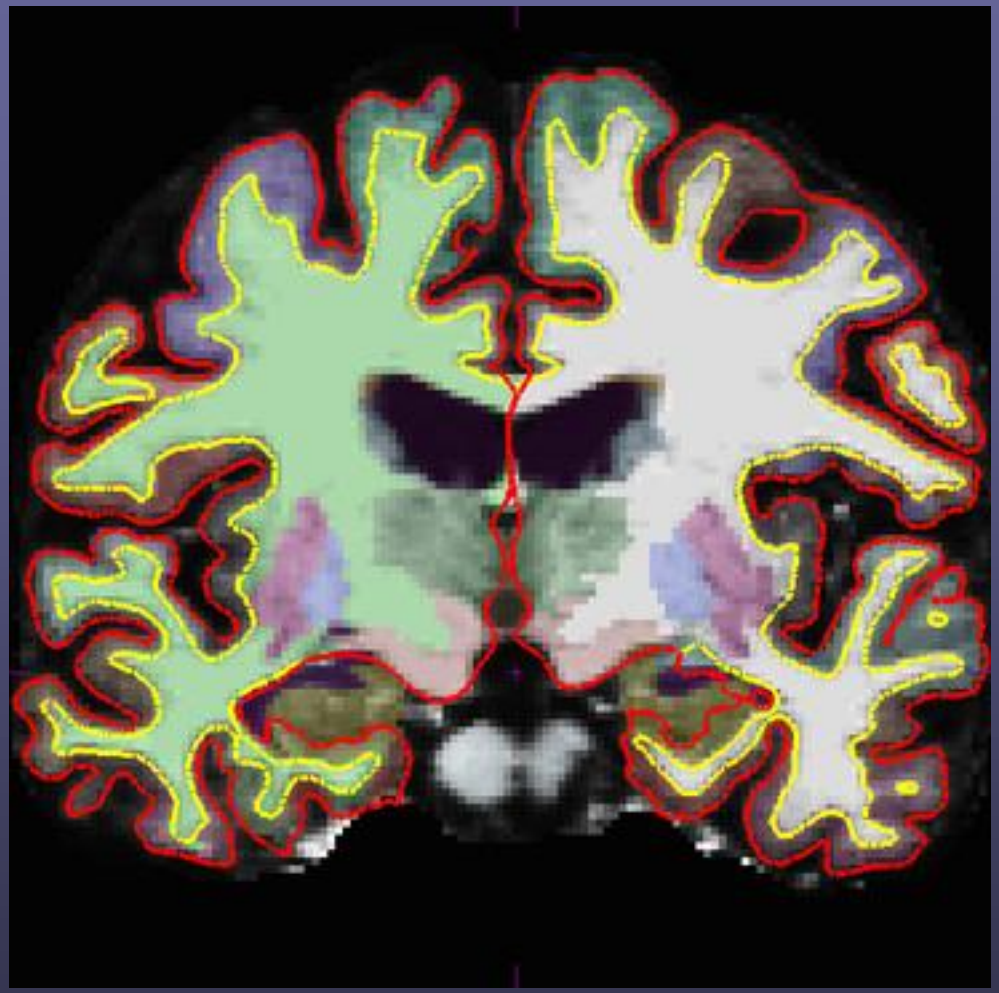
recon-all -all -i <input> -s <subject>

must do for each subject.

Come back in 15-20 hours …

Check your results – accurate to the tissue boundaries?

Output of Cortical Surface Reconstruction



Reconstruction Stages

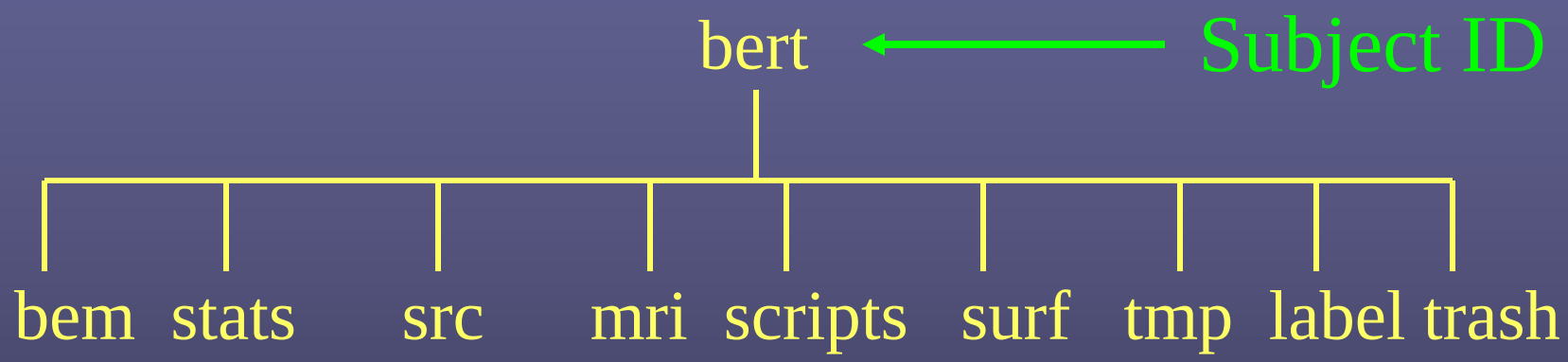
recon-all is broken into three stages

- autorecon1
- autorecon2
- autorecon3

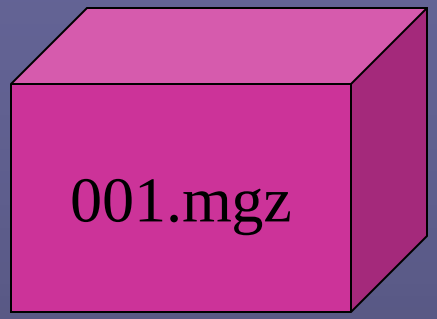
these 3 stages are equivalent to -all

FreeSurfer Directory Tree

Each data set has its own unique SubjectId (eg, bert)



MGZ File Format



- mgz = compressed MGH file
- Can store 4D (like NIFTI)
- cols, rows, slices, frames
- Generic: volumes and surfaces

- Eg, Typical Anatomical Scan Volume: 256 x 256 x 128 x 1

- *FreeSurfer can read/write:*
  NIFTI, Analyze, MINC
  Careful with NIFTI! (has 32k column limit; surfaces could be more)

- *FreeSurfer can read:*
  DICOM, Siemens IMA, AFNI

-autorecon1

Volumetric Processing Stages (subjid/mri):

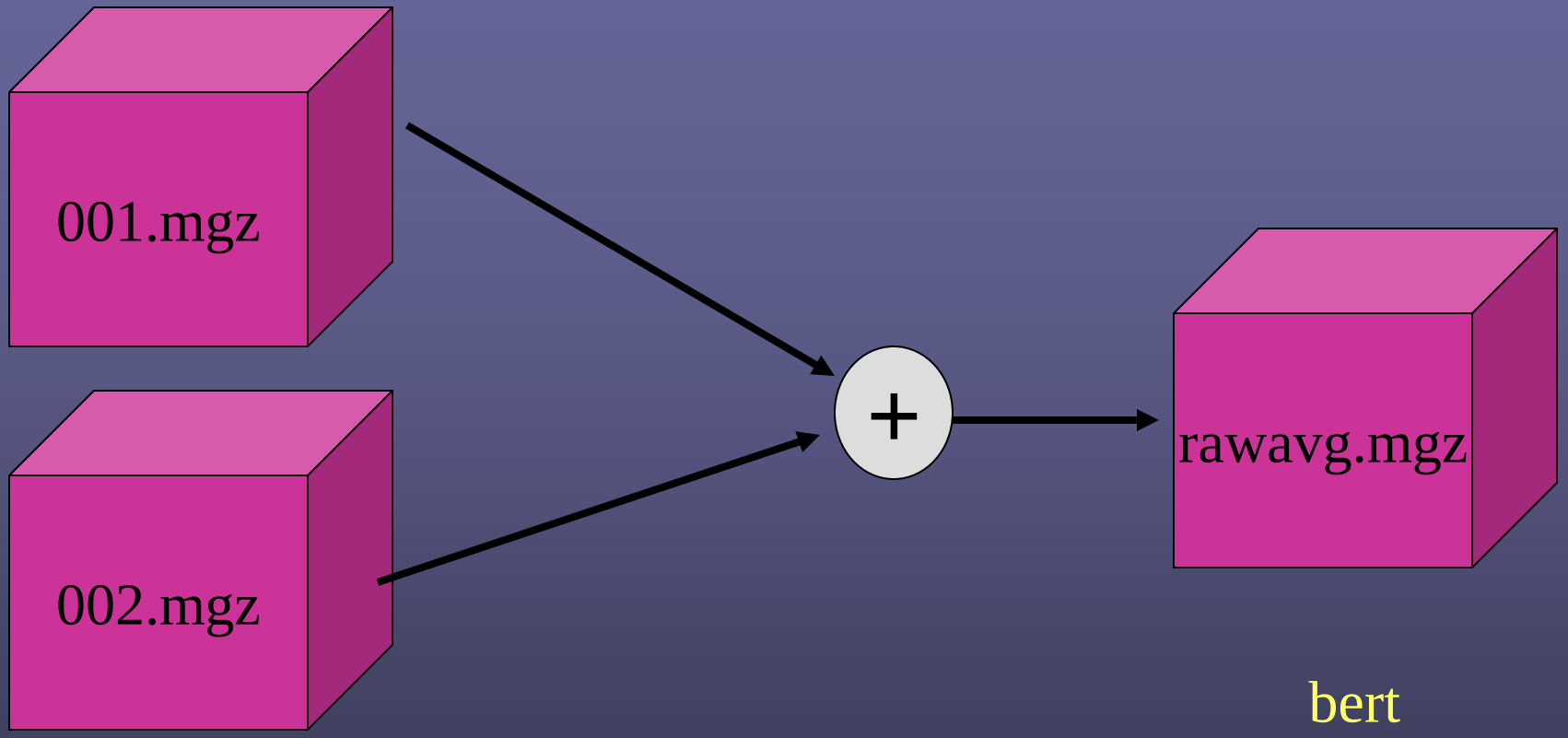
1. Motion Cor, Avg, Conform (orig.mgz)
2. Talairach transform computation (transforms/talairach.xfm)
3. Non-uniform inorm (nu.mgz)
4. Intensity Normalization 1 (T1.mgz)
5. Skull Strip (brainmask.mgz)
6. EM Register (linear volumetric registration)
7. CA Intensity Normalization (norm.mgz)
8. CA Non-linear Volumetric Registration
9. CA Label (Volumetric Labeling) (aseg.mgz)
10. Intensity Normalization 2 (T1.mgz)
11. White matter segmentation (wm.mgz)
12. Edit WM With ASeg
13. Fill and cut (filled.mgz)

Surface Processing Stages (subjid/surf):

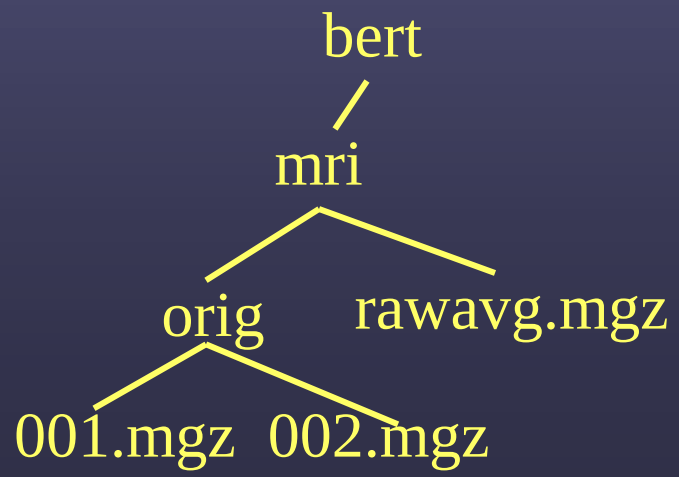
14. Tessellate (?h.orig.nofix)
15. Smooth1
16. Inflate1
17. QSphere (?h.qsqhere)
18. Automatic Topology Fixer (?h.orig)
19. Final Surfs (?h.white ?h.pial ?.thickness)
20. Smooth2 (?h.smoothwm)
21. Inflate2 (?h.inflated)
22. Aseg Statistics (stats/aseg.stats)
23. Cortical Ribbon Mask (?h.ribbon.mgz)
24. Spherical Morph
25. Spherical Registration (?h.sphere.reg)
26. Map average curvature to subject
27. Cortical Parcellation (Labeling)
28. Cortical Parcellation Statistics
29. Cortical Parcellation mapped to Aseg
30. White Matter Parcellation (wmparc.mgz)

recon-all -help

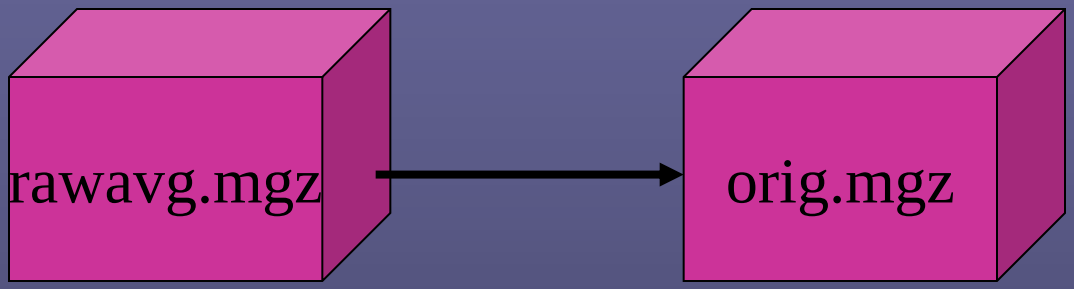
Motion Correction and Averaging



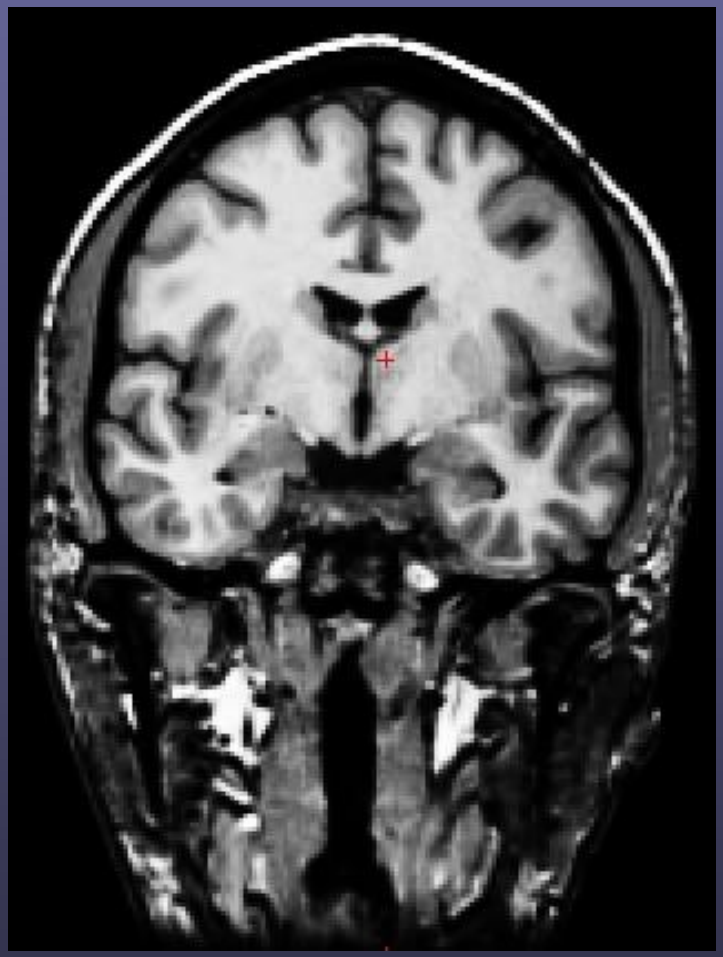
Does not change native resolution.



Conform



Changes to 256^3, 1mm^3
All volumes will be conformed to "anatomical space".



orig Volume

bert
mri
orig.mgz

mri_convert -conform

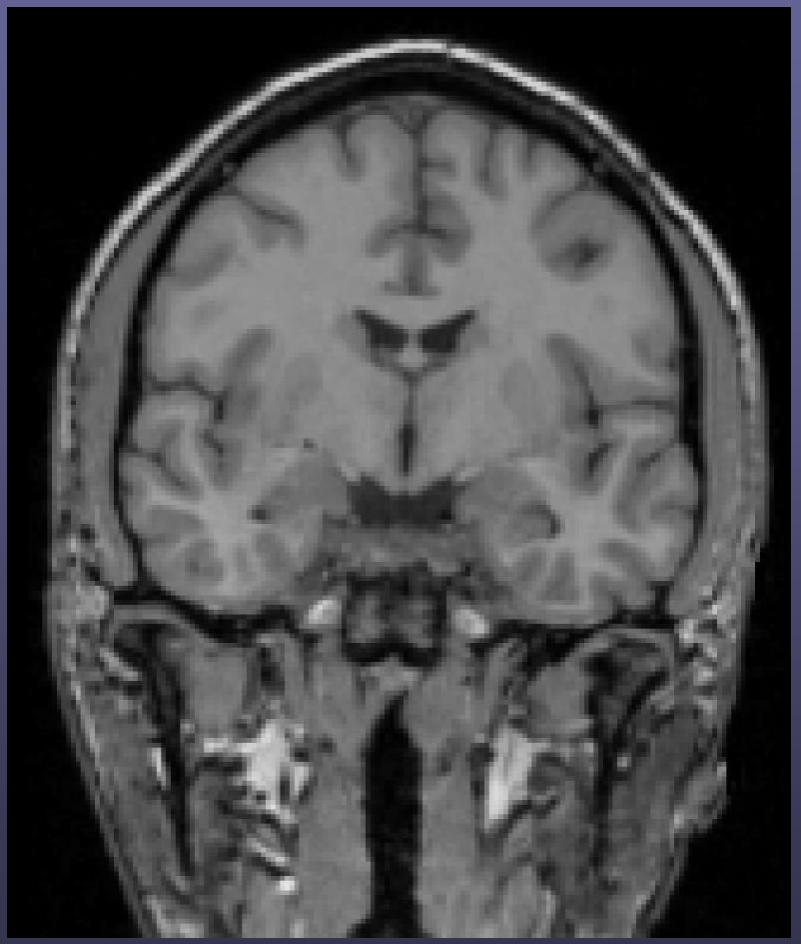
Talairach Transform

- Computes 12 DOF transform matrix
- Does NOT resample
- MNI305 template (compute talairach from this)
- Used to report Talairach coords in papers
- helps with skull strip

talairach_avi, talairach_afd (tal_check)

Non-Uniform Intensity Correction

- Uses MNI tool
  - nu_correct
- Corrects intensity non-uniformity (bias fields)

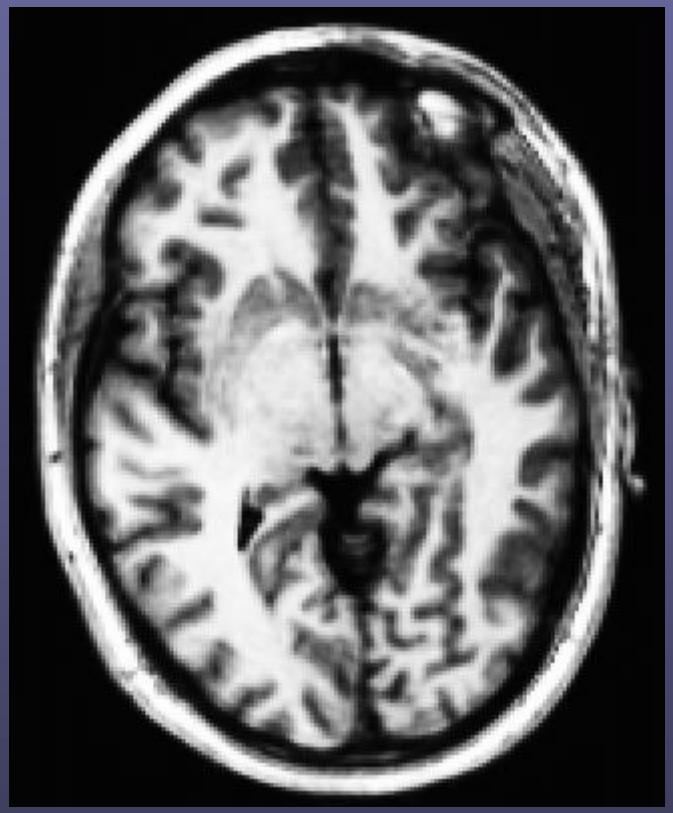


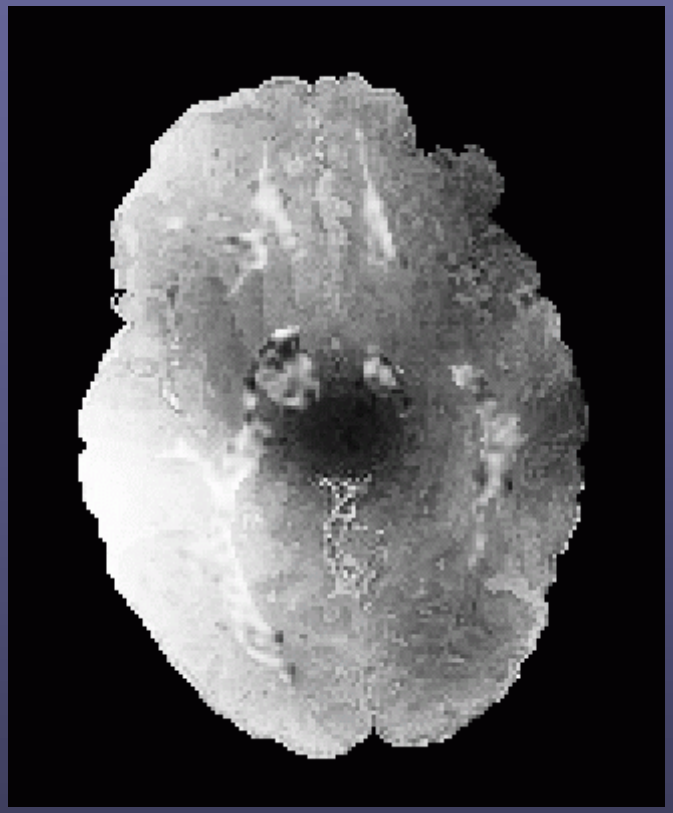
nu Volume

bert
mri
nu.mgz

mri_nu_correct.mni

Intensity Bias



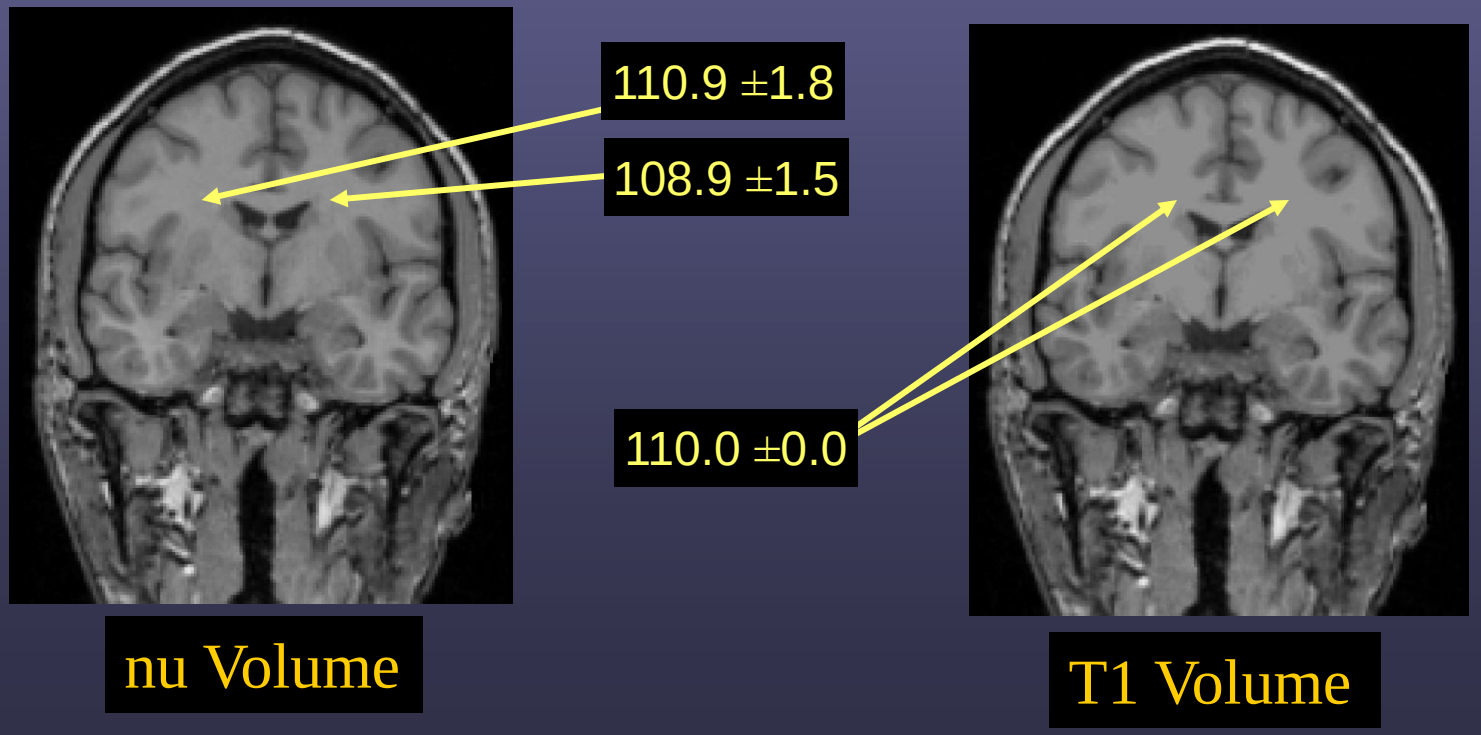


- Left side of the image much brighter than right side
- Worse with many coil elements
- Makes gray/white segmentation difficult

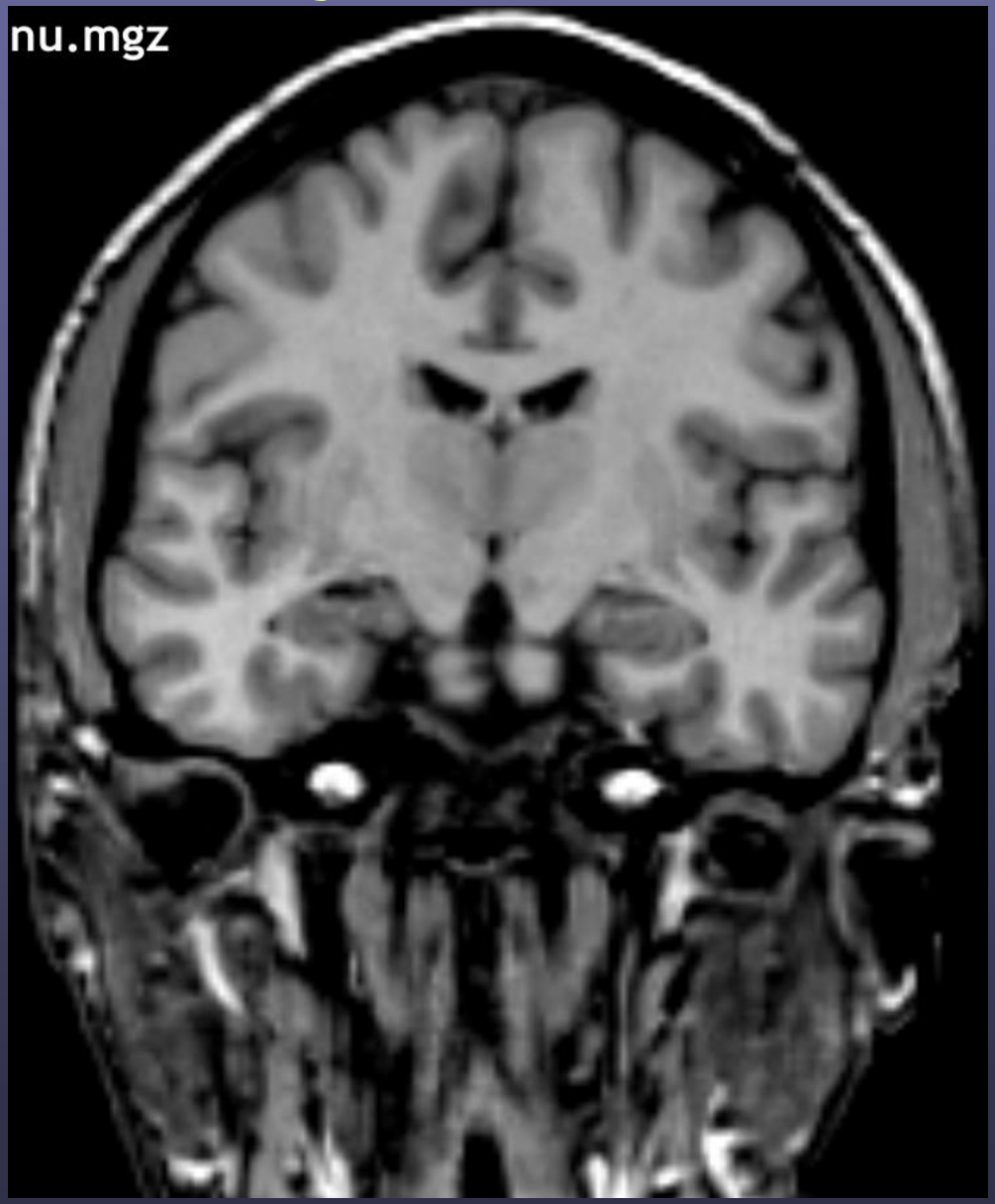
Intensity Normalization

- Presegmentation (T1.mgz)
  - Most WM = 110 intensity
  - Pre- and Post-Skull Strip

bert
mri
T1.mgz



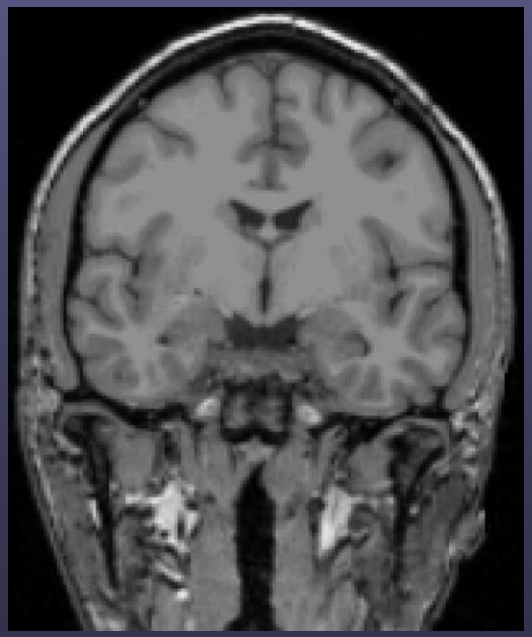
Intensity Normalization



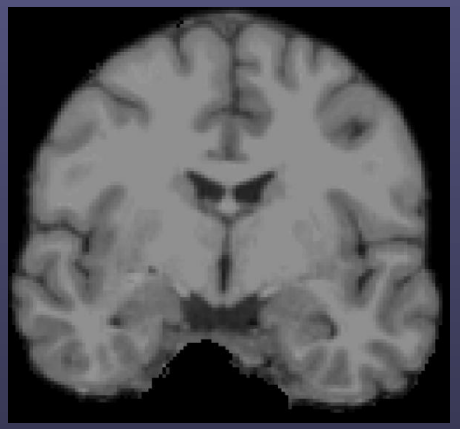
Skull Strip

- Removes all non-brain
  - Skull, Eyes, Neck, Dura
- brainmask.mgz

bert
mri
brainmask.mgz



T1 Volume



Brainmask Volume

mri_watershed, mri_gcut

FreeSurfer Directory Tree

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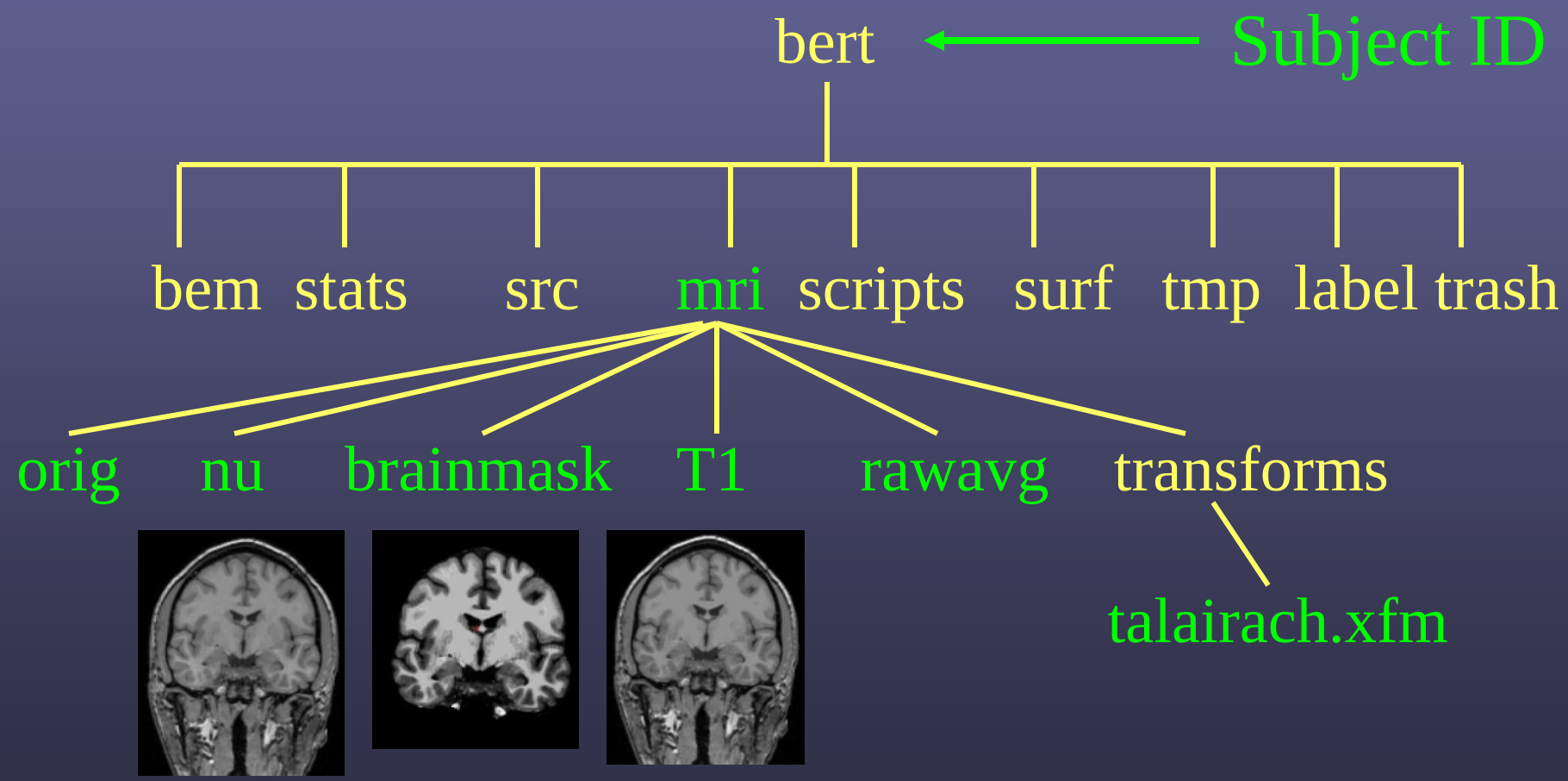


-autorecon2

Volumetric Processing Stages (subjid/mri):

1. Motion Cor, Avg, Conform (orig.mgz)
2. Talairach transform computation (transforms/talairach.xfm)
3. Non-uniform inorm (nu.mgz)
4. Intensity Normalization 1 (T1.mgz)
5. Skull Strip (brainmask.mgz)
6. EM Register (linear volumetric registration)
7. CA Intensity Normalization (norm.mgz)
8. CA Non-linear Volumetric Registration
9. CA Label (Volumetric Labeling) (aseg.mgz)
10. Intensity Normalization 2 (T1.mgz)
11. White matter segmentation (wm.mgz)
12. Edit WM With ASeg
13. Fill and cut (filled.mgz)

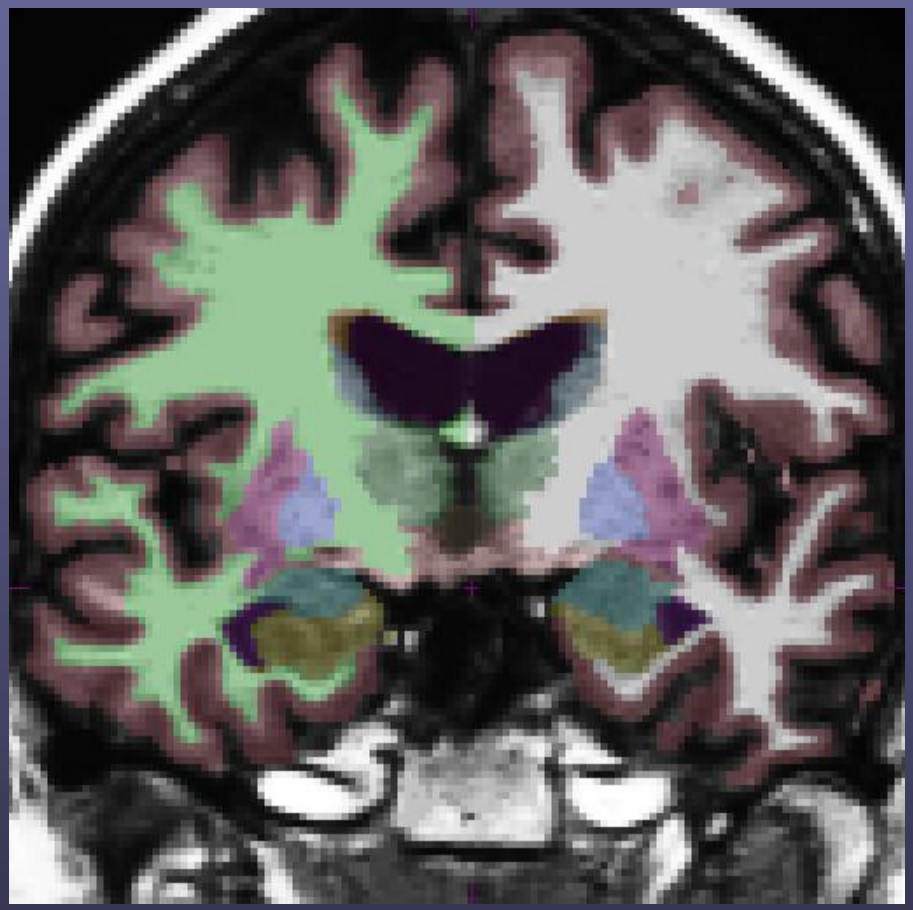
Surface Processing Stages (subjid/surf):

14. Tessellate (?h.orig.nofix)
15. Smooth1
16. Inflate1
17. QSphere (?h.qsqhere)
18. Automatic Topology Fixer (?h.orig)
19. Final Surfs (?h.white ?h.pial ?.thickness)
20. Smooth2 (?h.smoothwm)
21. Inflate2 (?h.inflated)
22. Aseg Statistics (stats/aseg.stats)
23. Cortical Ribbon Mask (?h.ribbon.mgz)
24. Spherical Morph
25. Spherical Registration (?h.sphere.reg)
26. Map average curvature to subject
27. Cortical Parcellation (Labeling)
28. Cortical Parcellation Statistics
29. Cortical Parcellation mapped to Aseg
30. White Matter Parcellation (wmparc.mgz)

recon-all -help

Note: lh processed completely first, then rh.

Automatic Volume Labeling



aseg.mgz

- Label subcortical structures and wm/gm
- Determine volumes of subcortical structures
- Used to fill in subcortical structures for later steps

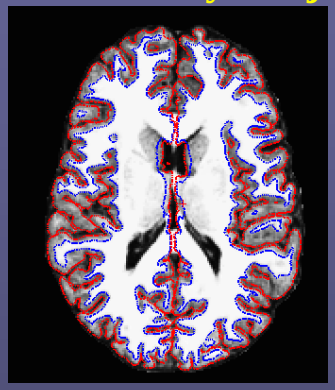
bert
mri
aseg.mgz

steps 6-9, 22

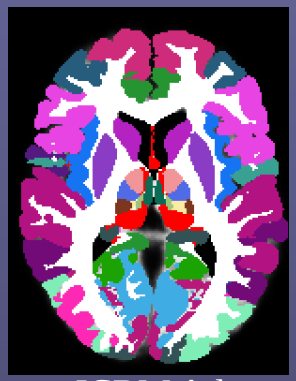
(best viewed on norm.mgz)

We use atlas + intensity + spatial location + geometric info + neighboring voxels + other info…

Why not just register to an ROI Atlas?



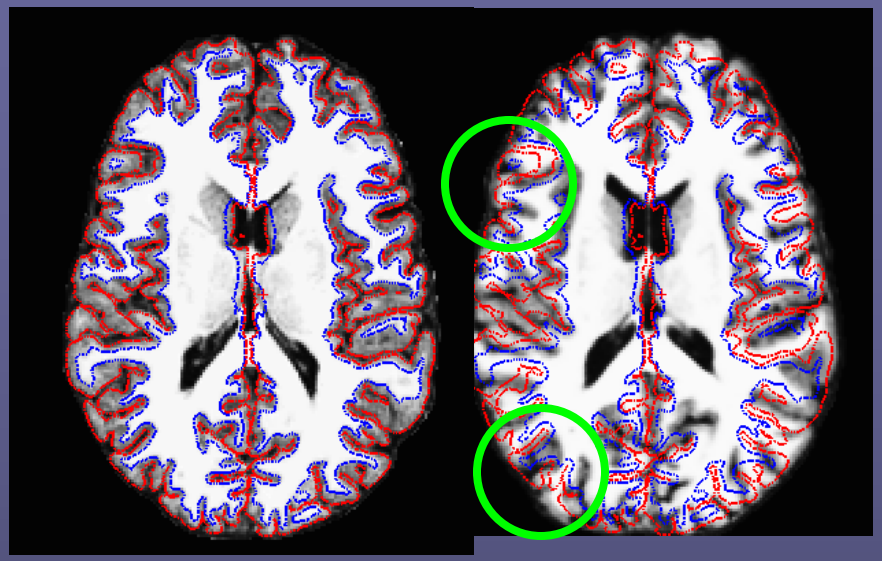
12 DOF (Affine)



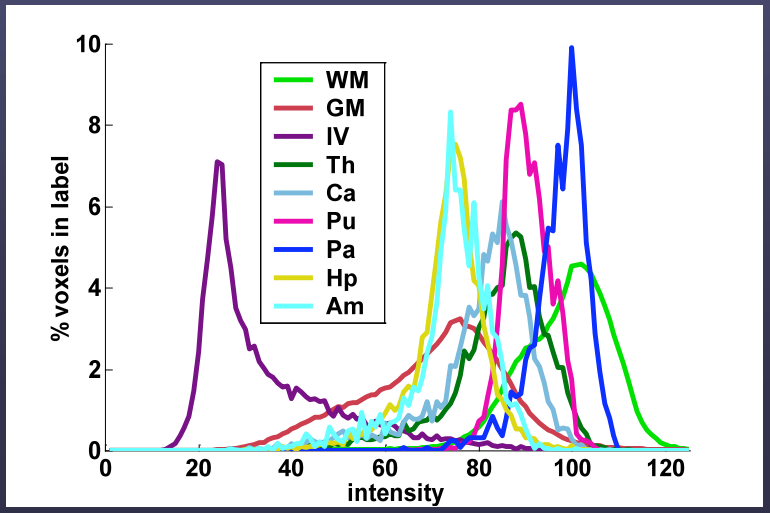
ICBM Atlas

Problems with Affine (12 DOF) Registration

• ROIs need to be individualized.



Can't segment on intensity alone

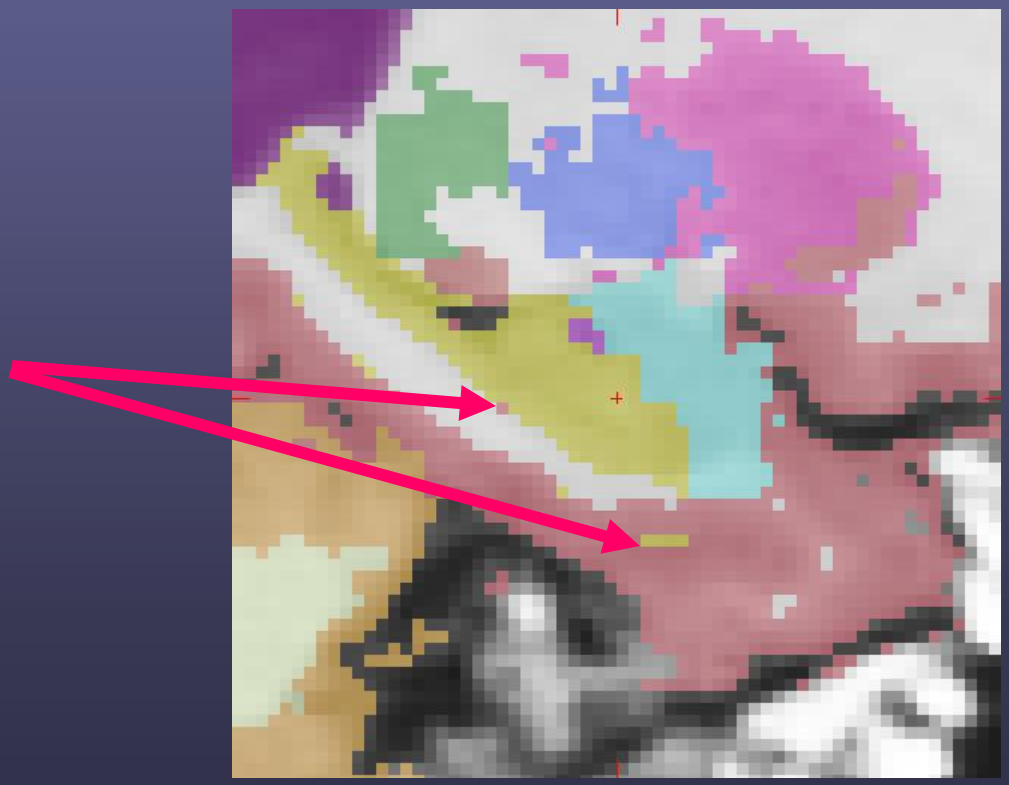


Gaussian classifier array atlas

$FREESURFER_HOME/average/RB_all_2008-03-26

Markov Random Field: Motivation

What is the probability that cortical gray matter occurs inferior to hippocampus?



-subcortseg

-autorecon2

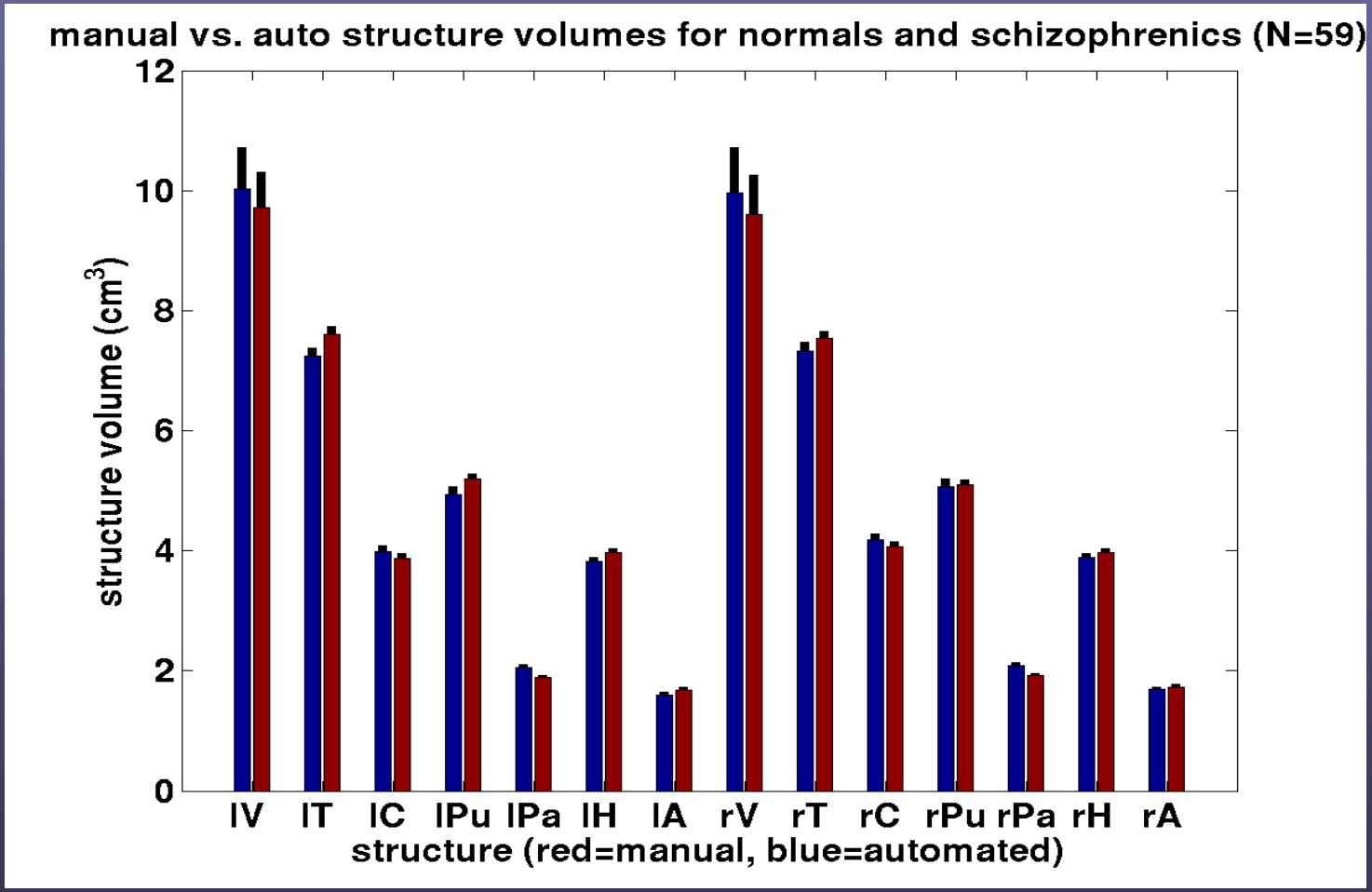
Segmentation: MRF

Preliminary Segmentation

Final Segmentation

steps 6-9, 22

Validation of Volume Labeling *



Manual labeling done by Center for Morphometric Analysis (CMA)

*Thanks to Drs Larry Seidman and Jill Goldstein for providing this data.

White Matter Segmentation

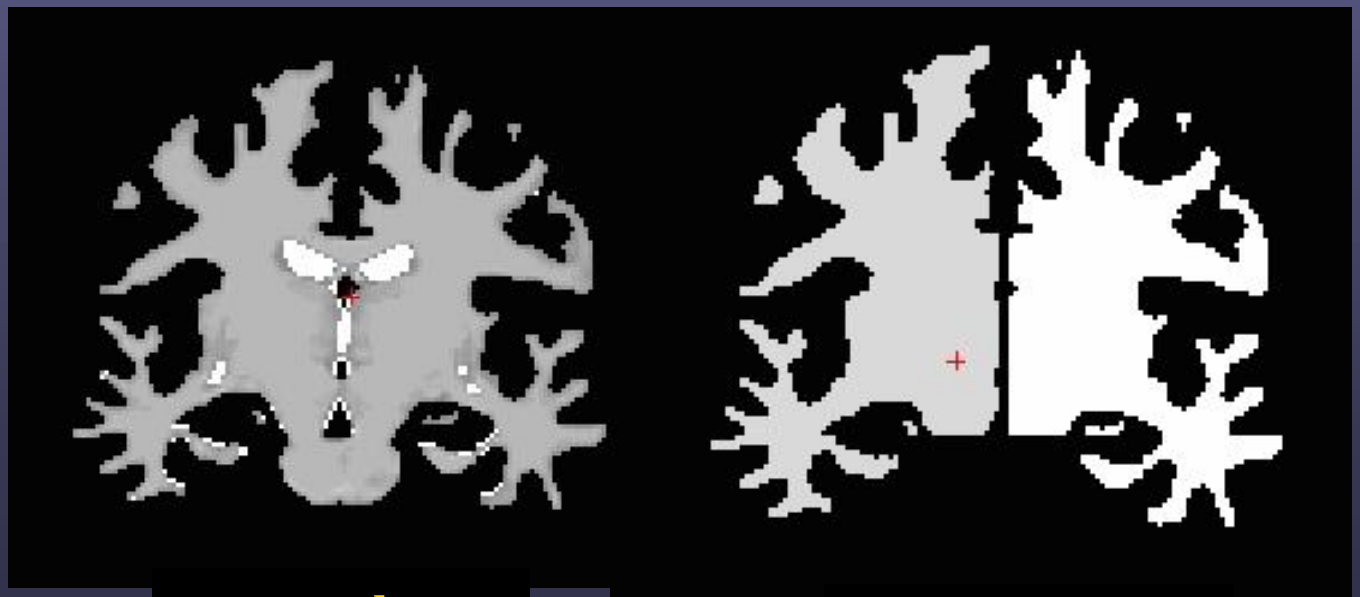
- Separates white matter from everything else
- “Fills in” subcortical structures
- Cerebellum removed, brain stem still there

bert
\
mri
/
wm.mgz

mri_segment, mri_edit_wm_with_aseg, mri_pretess

Fill and Cut (Subcortical Mass)

- Fills in any voids
- Removes any islands
- Removes brain stem
- Separates hemispheres (each hemi has different value)
- filled.mgz = “Subcortical Mass”



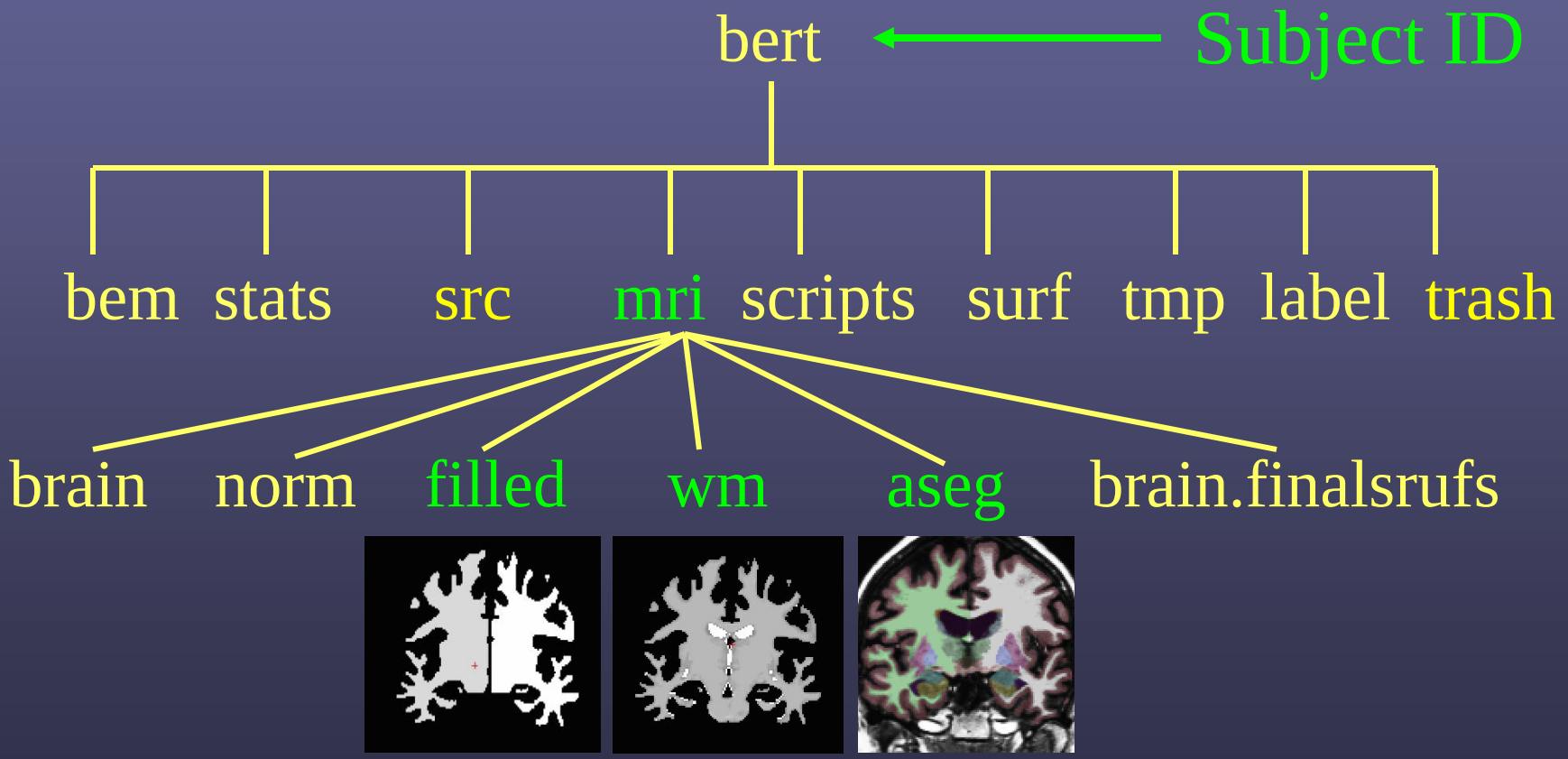
WM Volume

Filled Volume

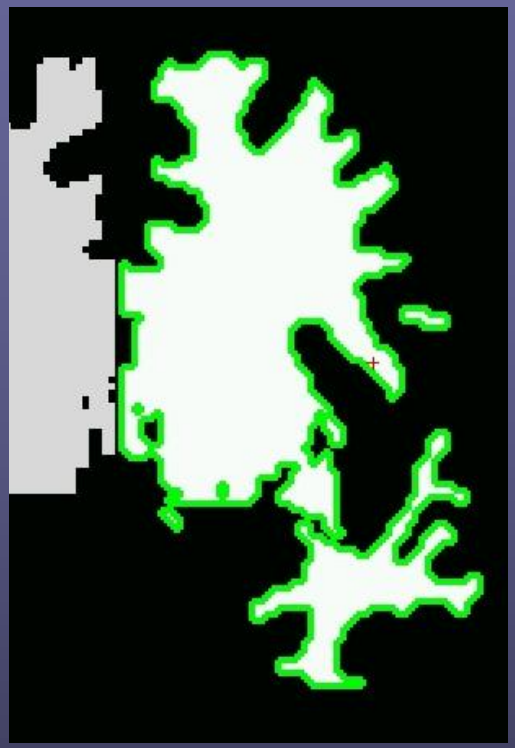
bert
\
mri
/
filled.mgz

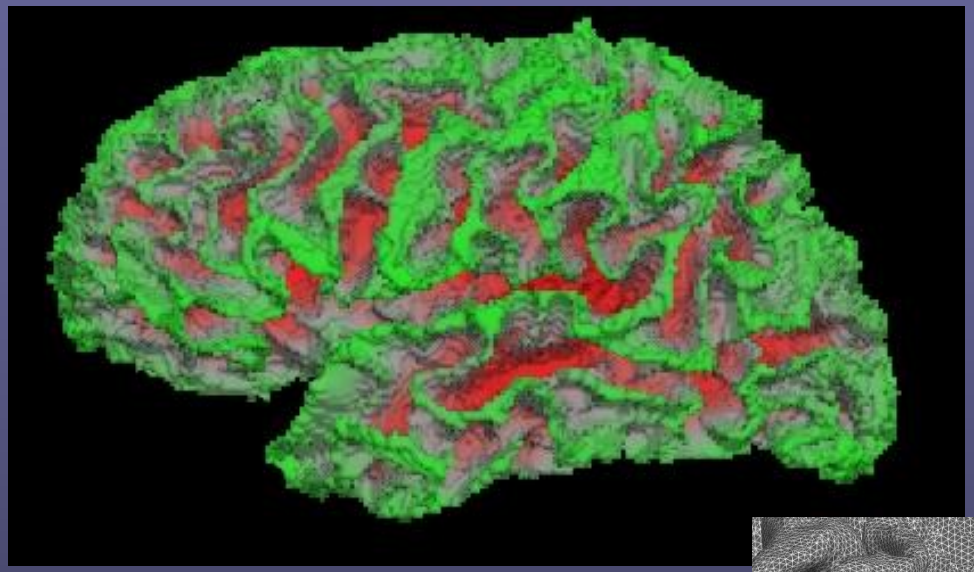
FreeSurfer Directory Tree

Each data set has its own unique SubjectId (eg, bert)



Tessellation





bert
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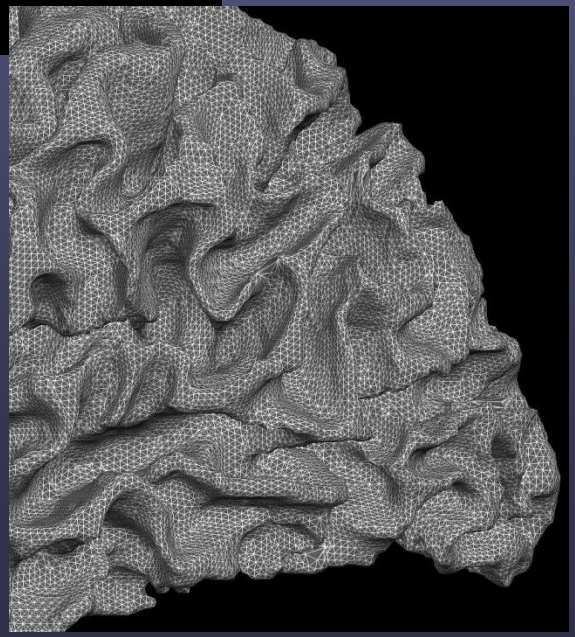
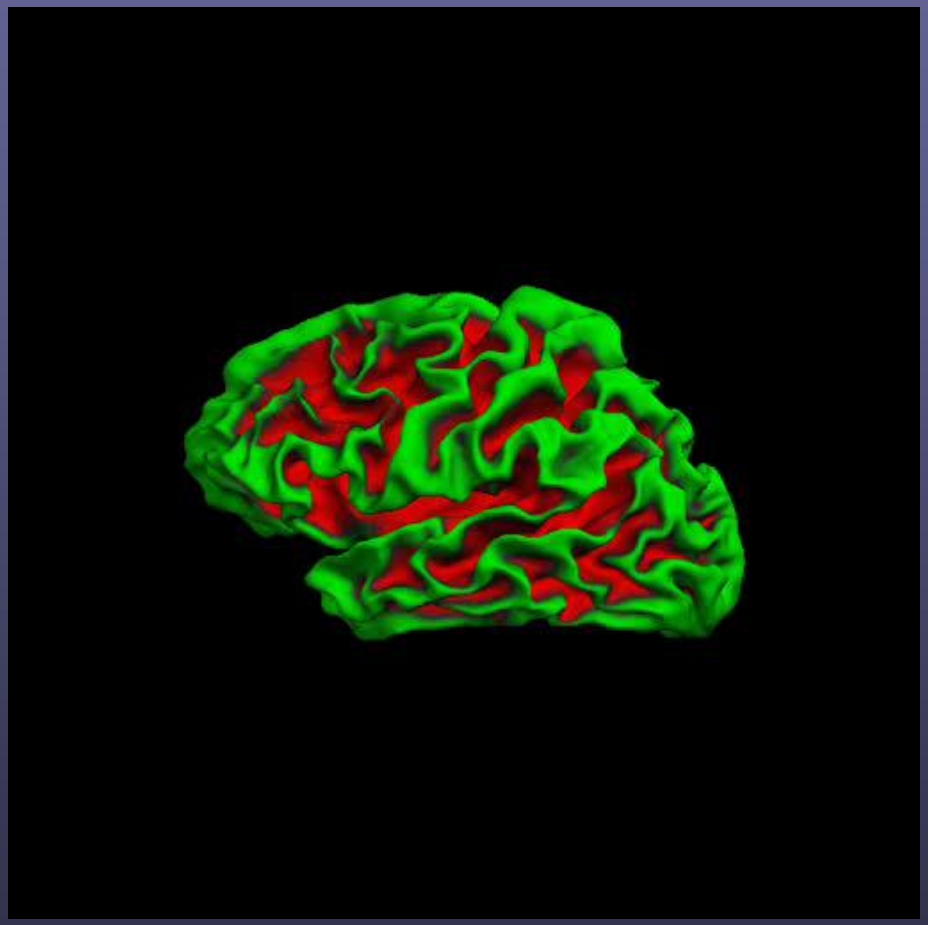
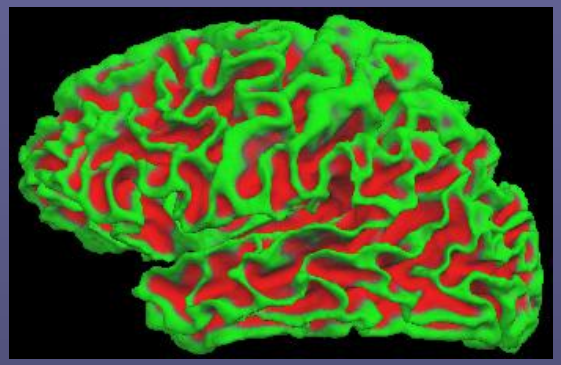
surf
/
?h.orig.nofix

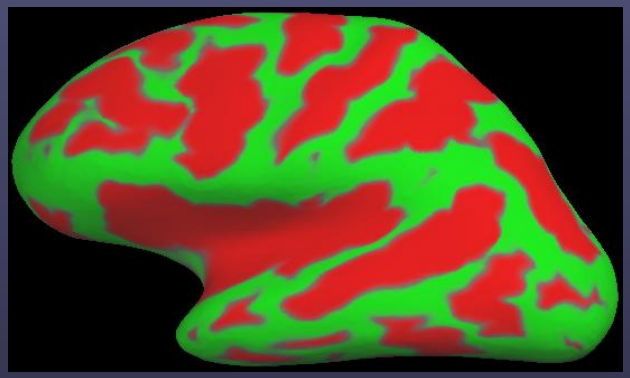


- Mosaic of triangles (“tessellation”)
- Errors: Donut holes, handles
  - Subsequently fixed by the automatic topology fixer

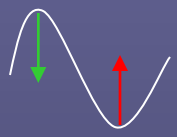
Inflation: Visualization







Gyri



Sulci

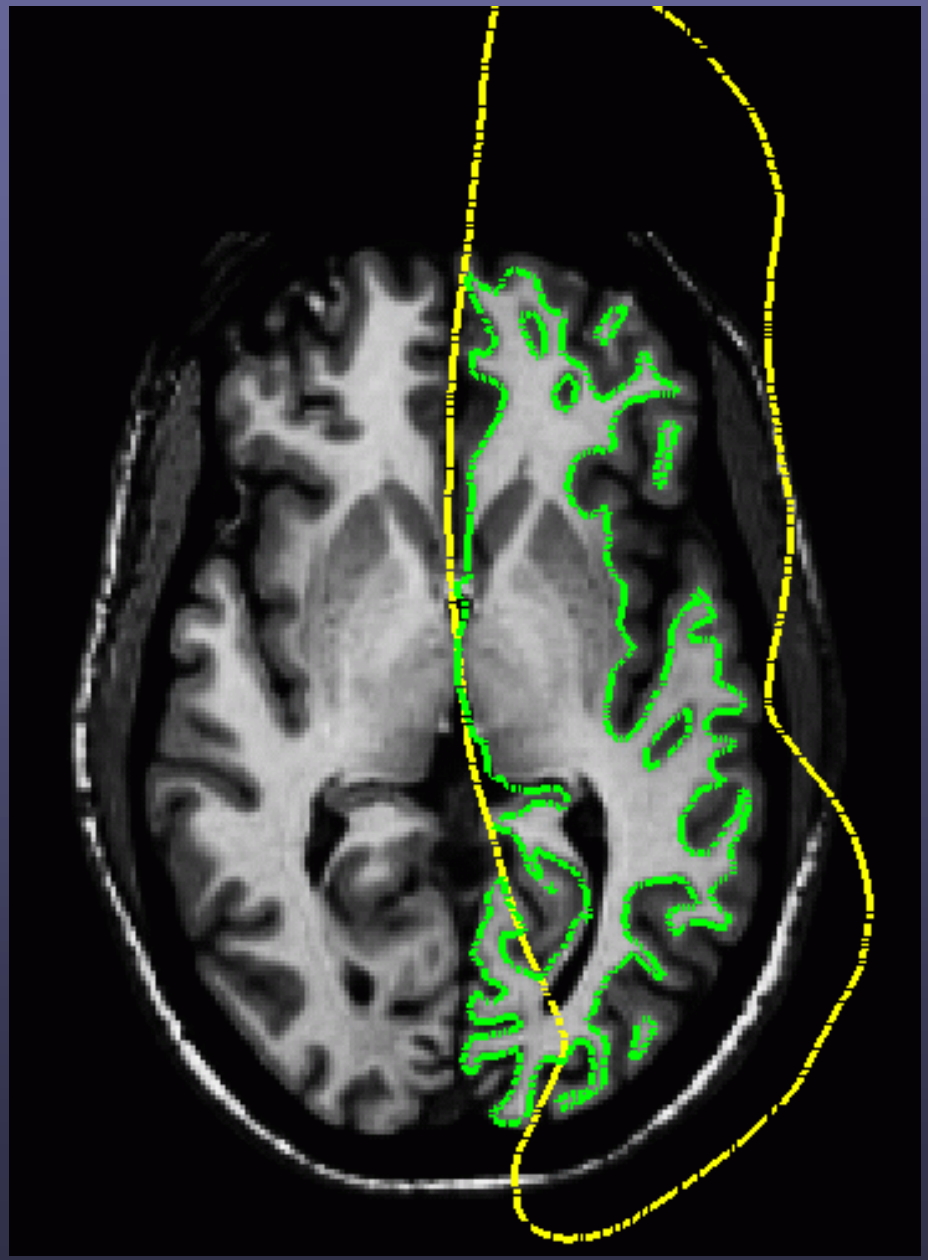
bert

surf

?h.inflated.nofix

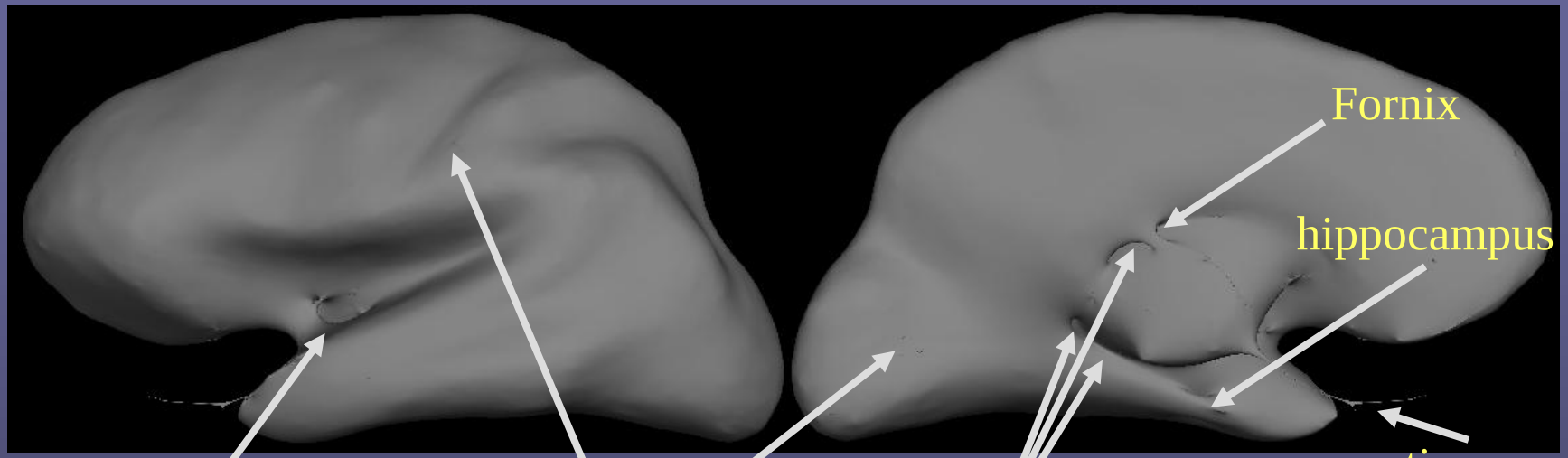
Dale and Sereno, 1993; Dale et al., Dale et al., 1999; Fischl et al., 1999; Fischl et al., 2000; Fischl et al., 2001

Surface Inflation



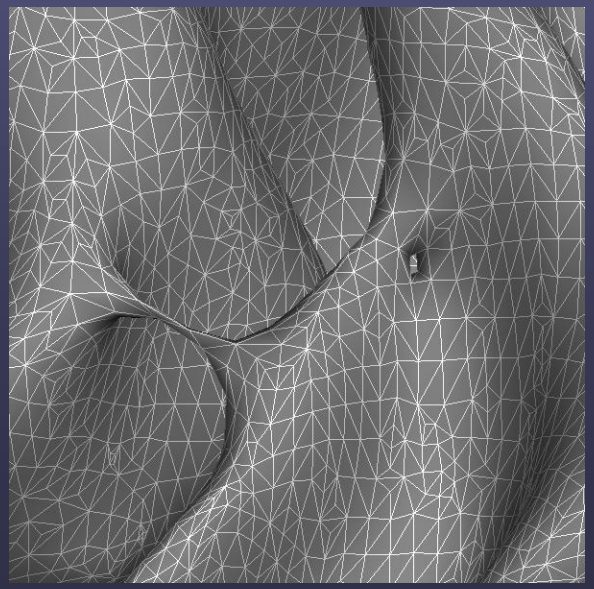
- Nudge vertices
- No intensity constraint
- See inside sulci
- Used for sphere

Automatic Topology Fixer

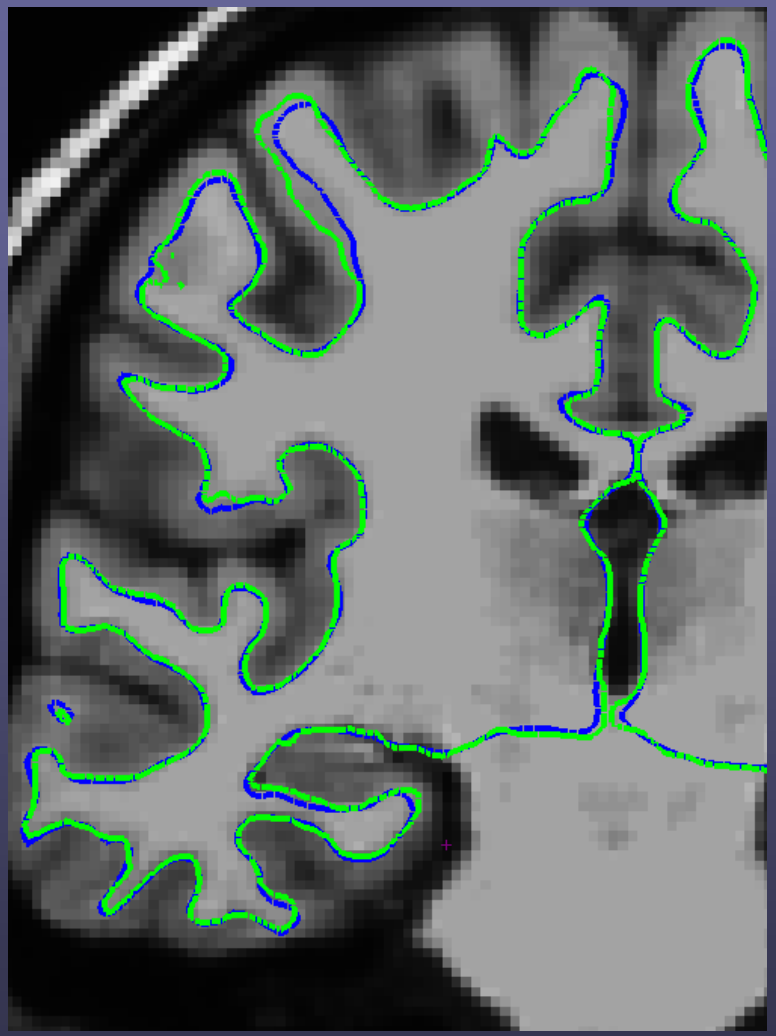


- Holes
- Handles
- Automatically Fixed

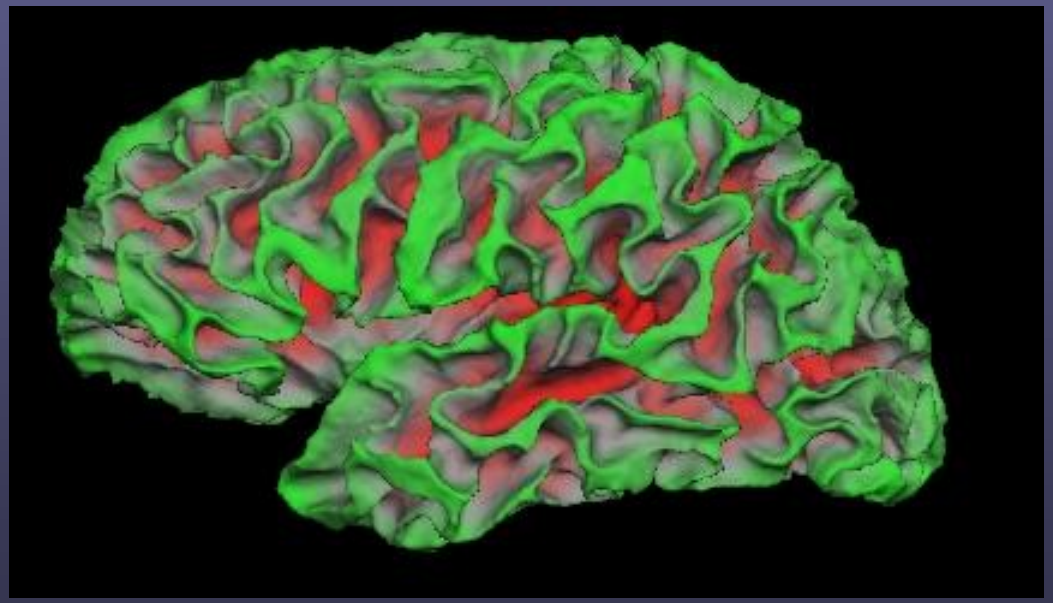
bert
surf
?h.inflated ?h.orig



White Matter Surface



- Nudge orig surface
- Follow T1 intensity gradients
- Smoothness constraint
- Vertex Identity stays constant

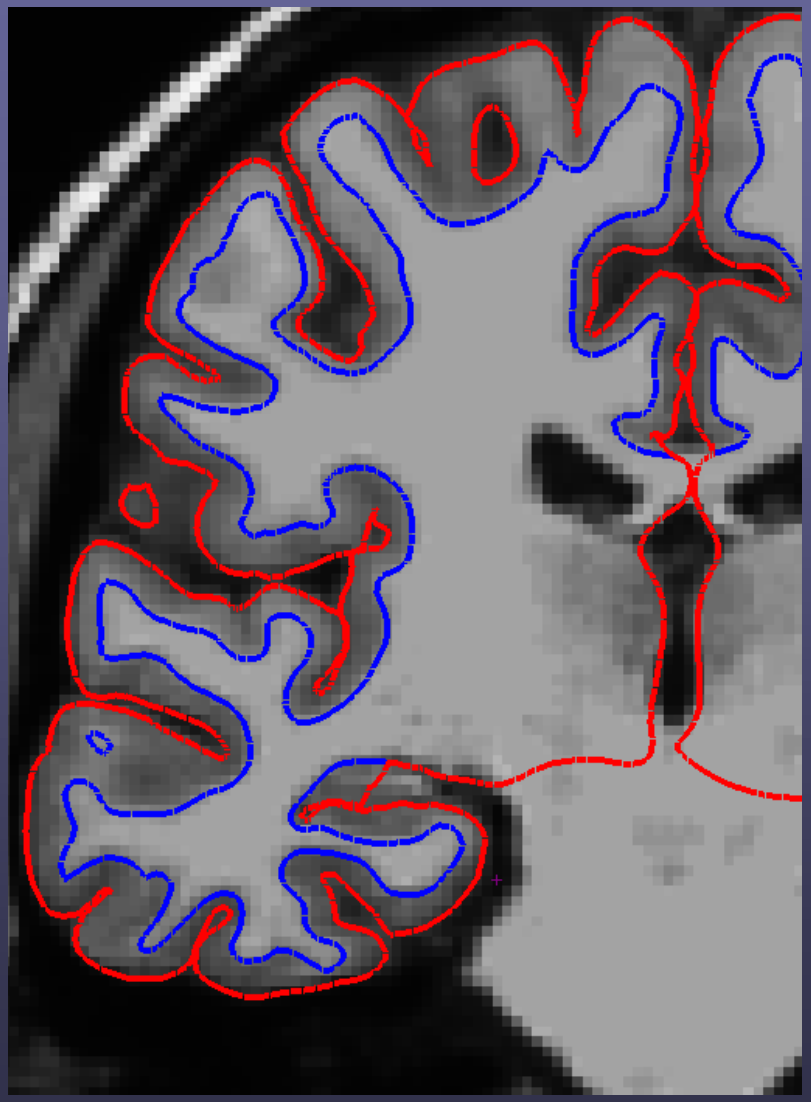


bert

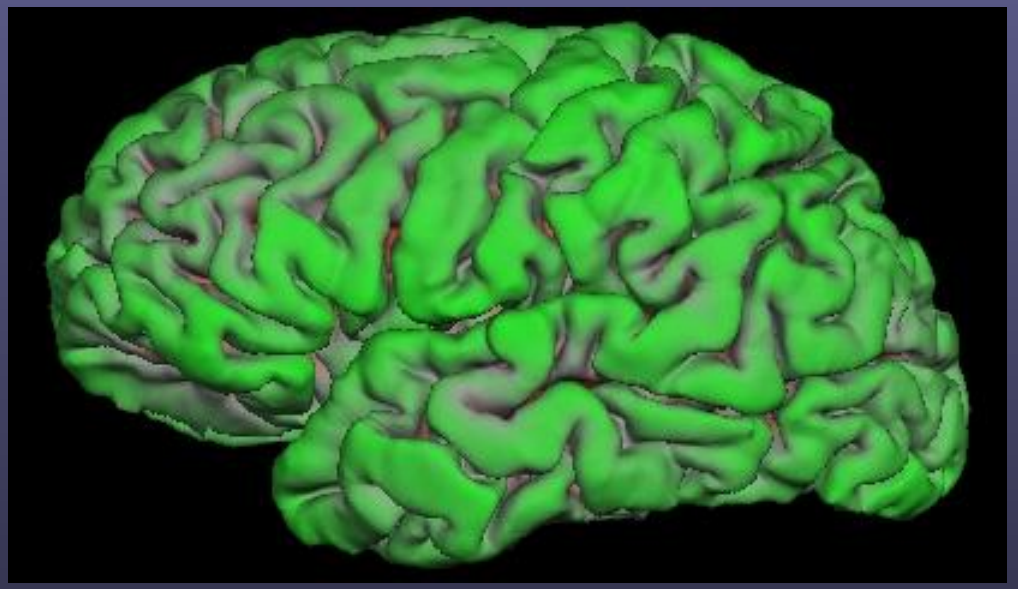
surf

?h.white

Pial Surface

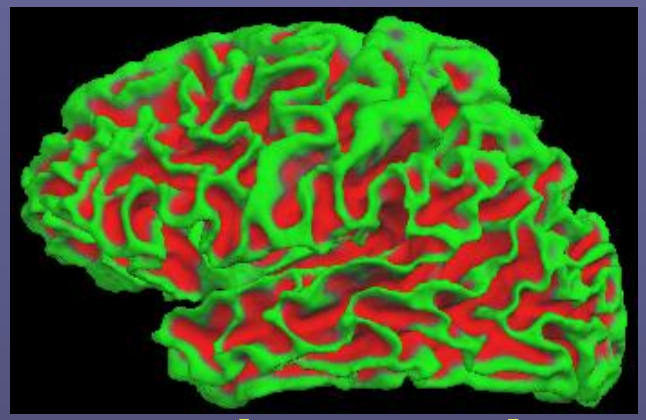


- Nudge white surface
- Follow T1 intensity gradients
- Vertex Identity Stays

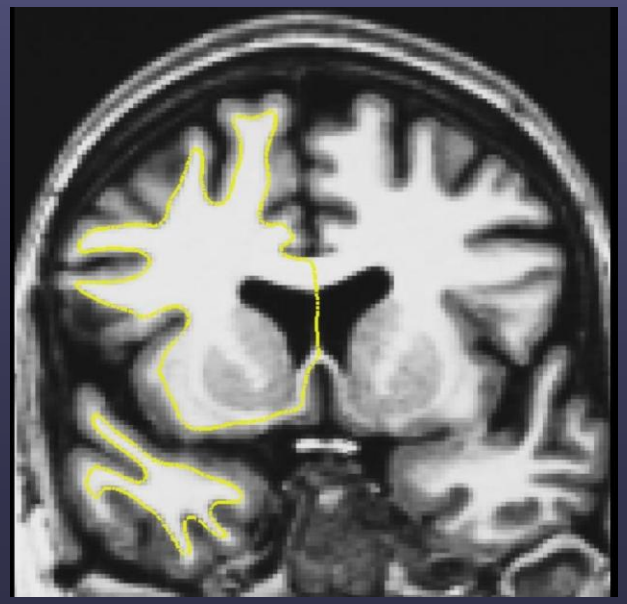


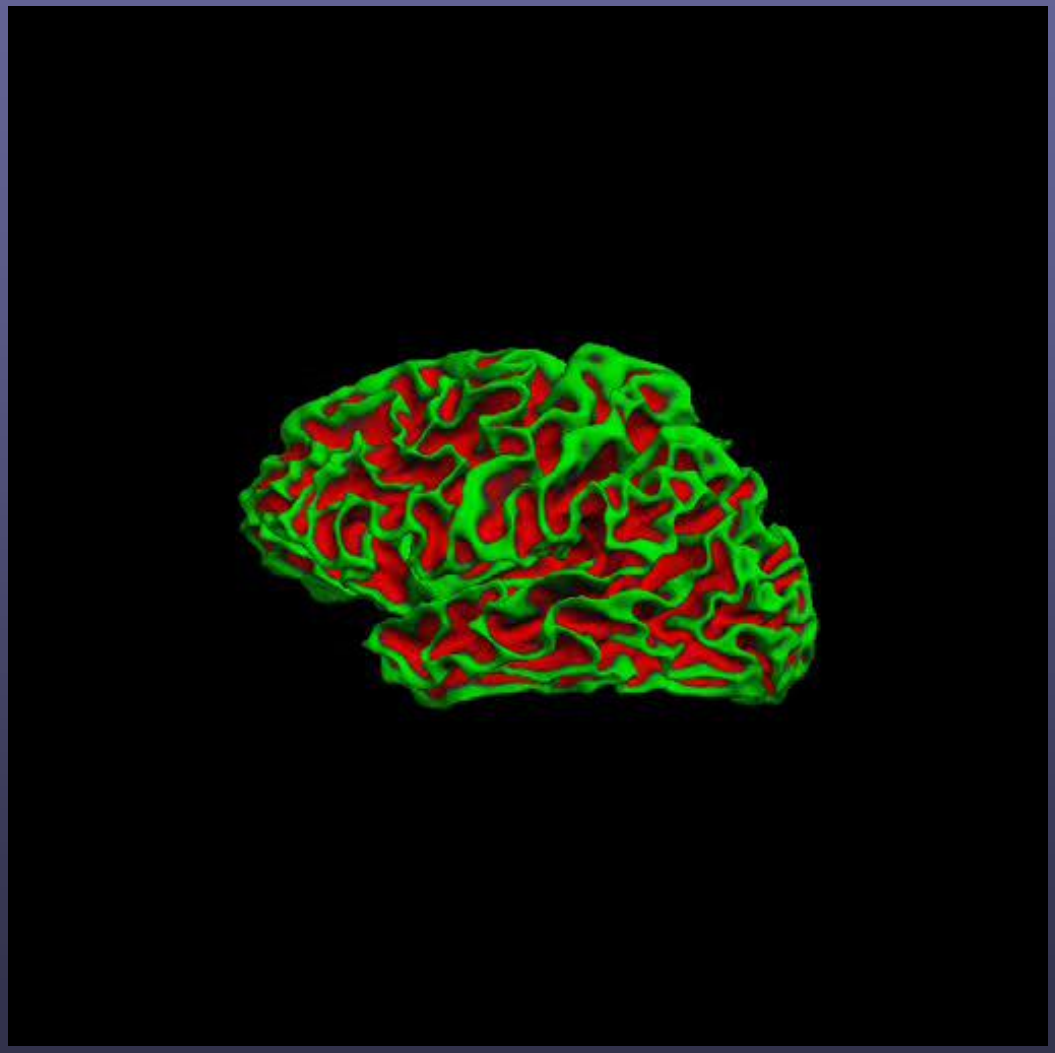
bert \ surf \ ?h.pial

Optimal Surface Placement



Gray-White Boundary

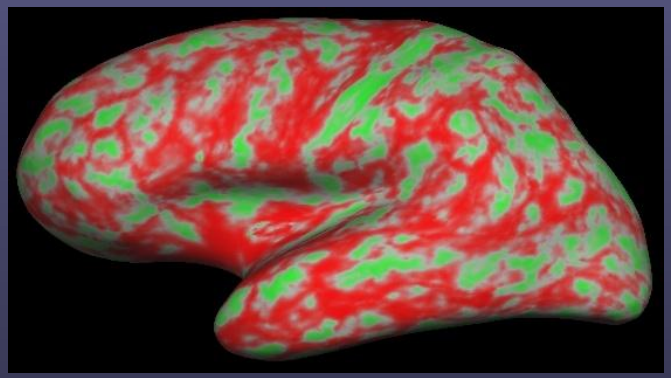




Outer Cortical Surface

Cortical Thickness

- Distance between white and pial surfaces
- One value per vertex
- Surface-based more accurate than volume-based

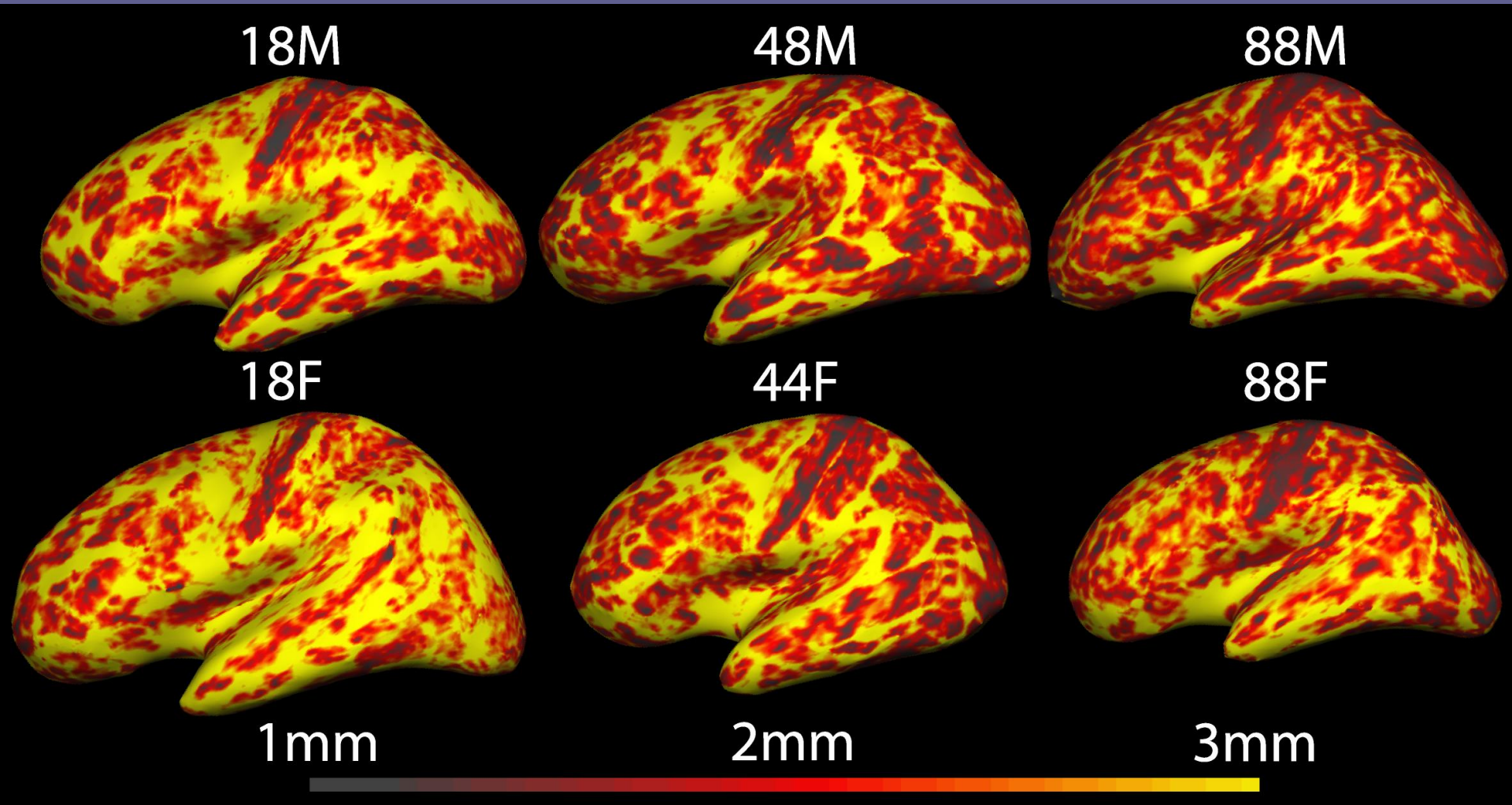


white surface

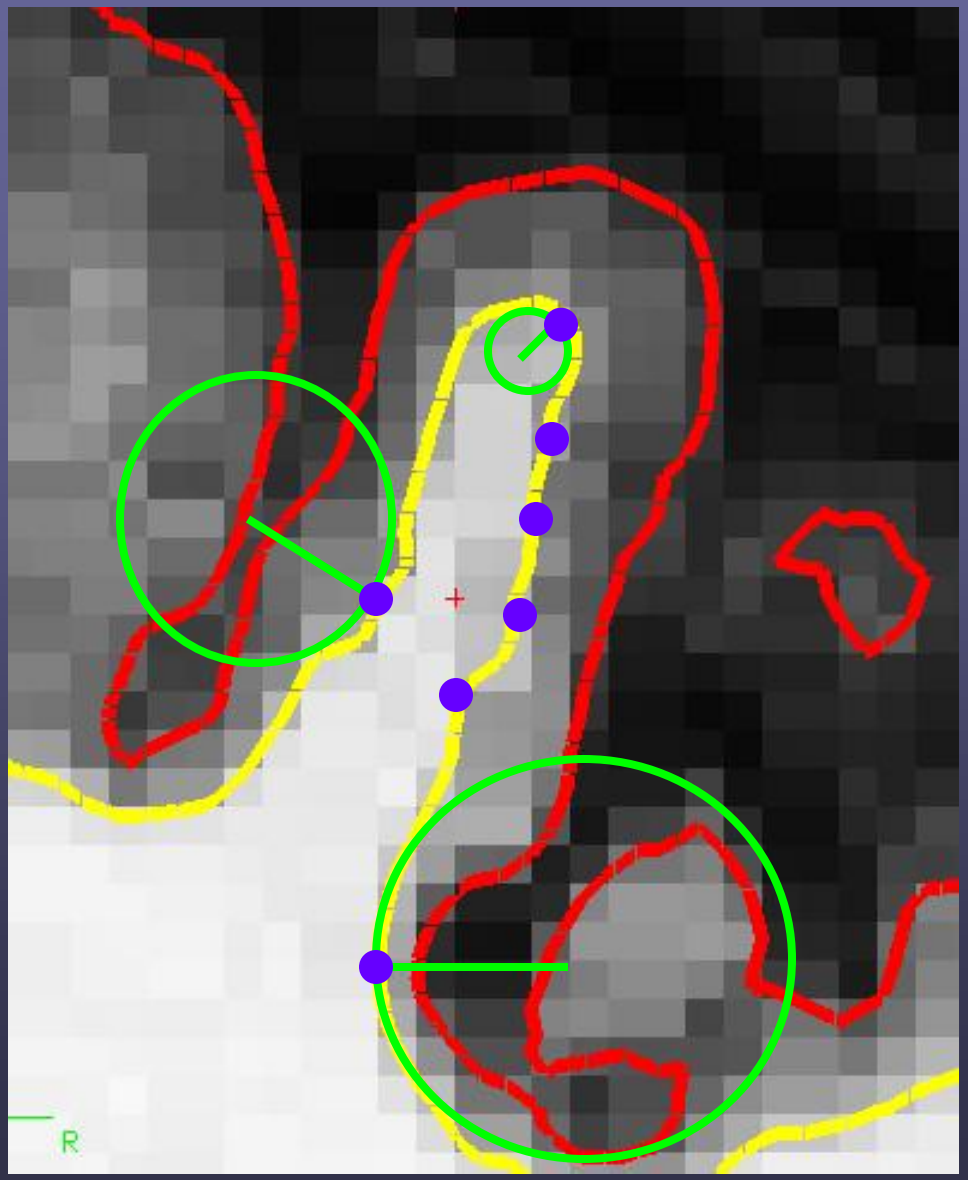
lh.thickness, rh.thickness

Thickness Maps

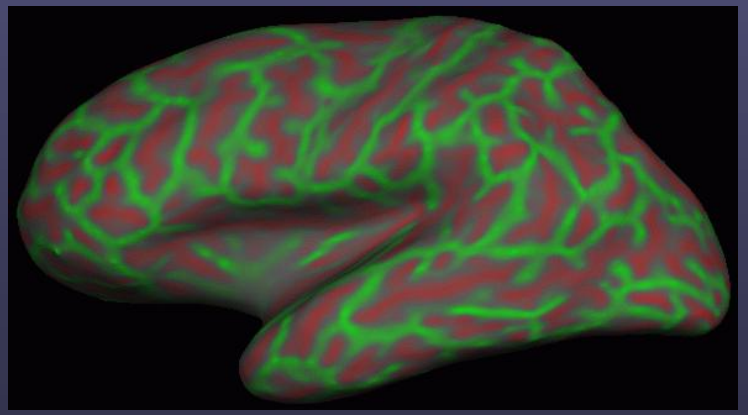
- Red regions are thinner
- Yellow regions are thicker



Curvature (Radial)

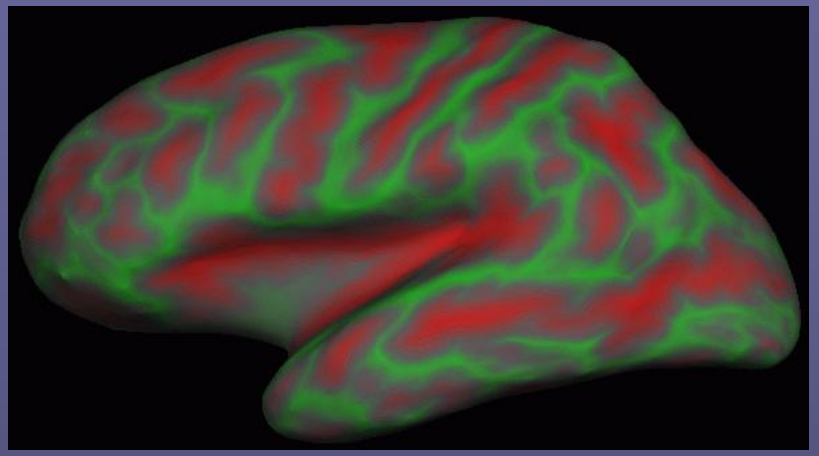


- Circle tangent to surface at each vertex
- Curvature measure is 1/radius of circle
- One value per vertex
- Signed (sulcus/gyrus)
- Actually use gaussian curvature

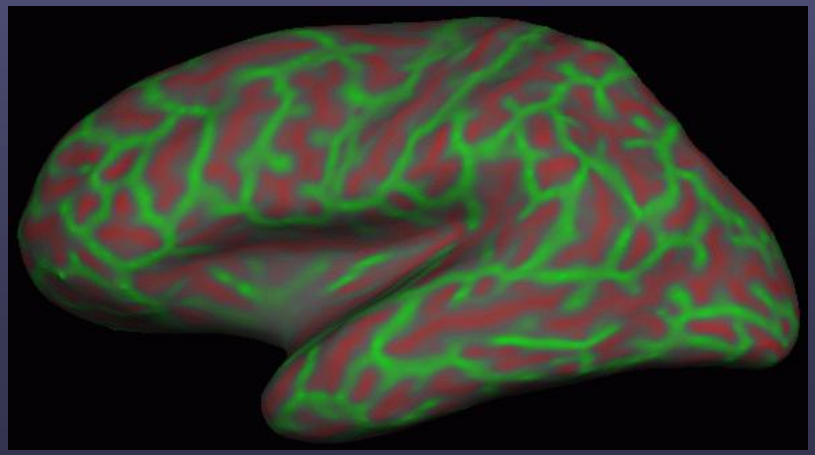


lh.curv, rh.curv

Sulcal Depth



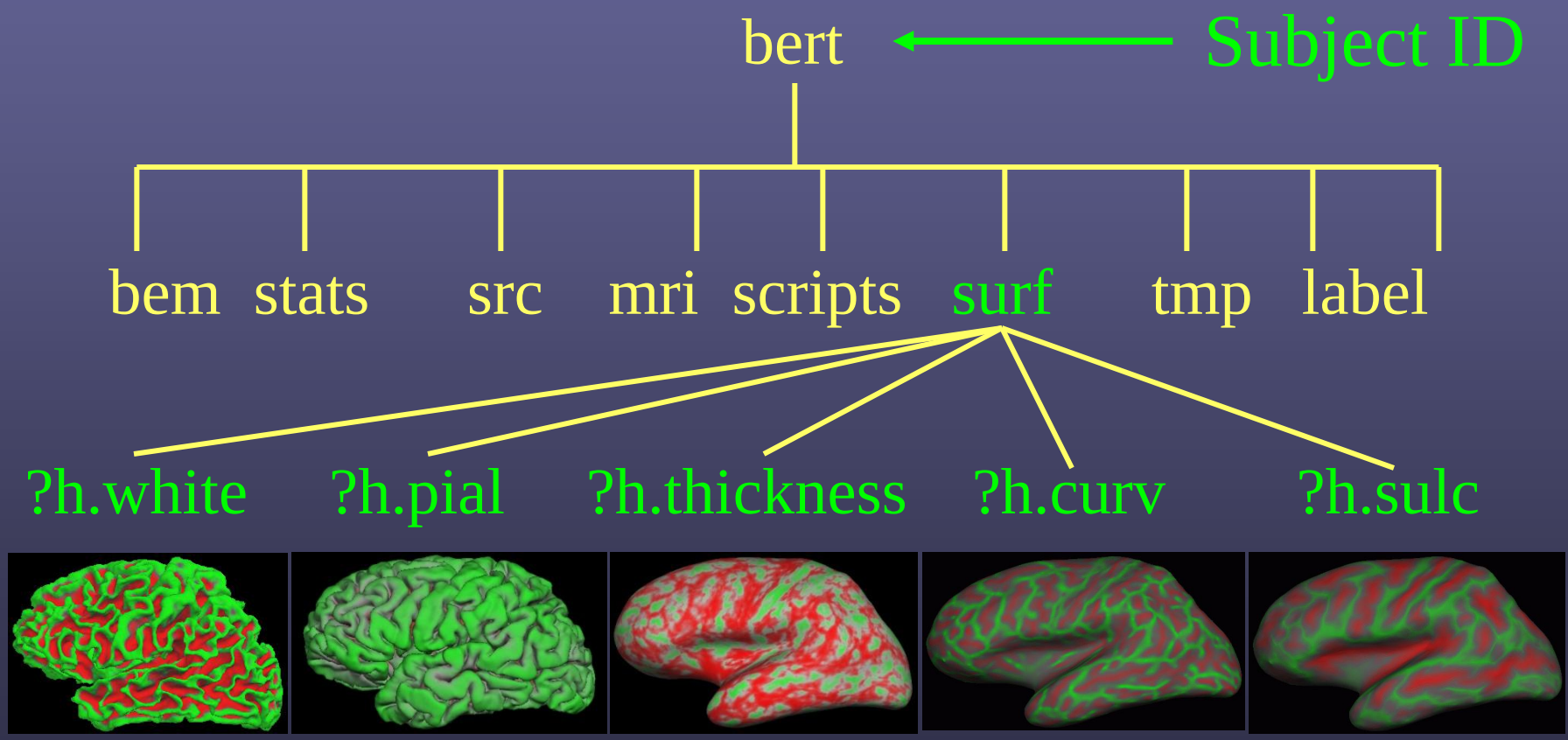
lh.sulc, rh.sulc



lh.curv, rh.curv

FreeSurfer Directory Tree

Each data set has its own unique SubjectId (eg, bert)



-autorecon3

Volumetric Processing Stages (subjid/mri):

1. Motion Cor, Avg, Conform (orig.mgz)
2. Talairach transform computation (transforms/talairach.xfm)
3. Non-uniform inorm (nu.mgz)
4. Intensity Normalization 1 (T1.mgz)
5. Skull Strip (brainmask.mgz)
6. EM Register (linear volumetric registration)
7. CA Intensity Normalization (norm.mgz)
8. CA Non-linear Volumetric Registration
9. CA Label (Volumetric Labeling) (aseg.mgz)
10. Intensity Normalization 2 (T1.mgz)
11. White matter segmentation (wm.mgz)
12. Edit WM With ASeg
13. Fill and cut (filled.mgz)

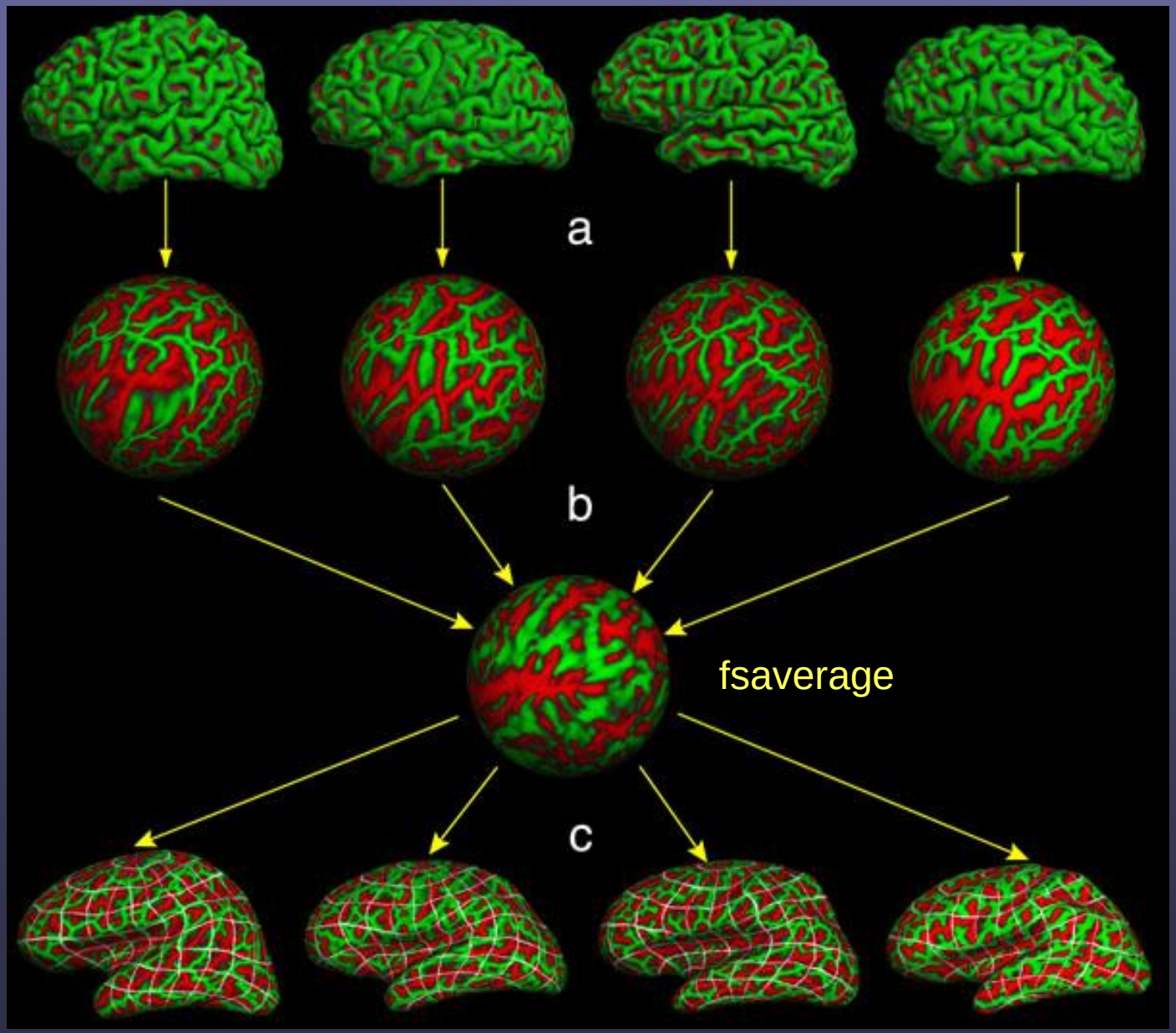
Surface Processing Stages (subjid/surf):

14. Tessellate (?h.orig.nofix)
15. Smooth1
16. Inflate1
17. QSphere (?h.qsqhere)
18. Automatic Topology Fixer (?h.orig)
19. Final Surfs (?h.white ?h.pial ?.thickness)
20. Smooth2 (?h.smoothwm)
21. Inflate2 (?h.inflated)
22. Aseg Statistics (stats/aseg.stats)
23. Cortical Ribbon Mask (?h.ribbon.mgz)
24. Spherical Morph
25. Spherical Registration (?h.sphere.reg)
26. Map average curvature to subject
27. Cortical Parcellation (Labeling)
28. Cortical Parcellation Statistics
29. Cortical Parcellation mapped to Aseg
30. White Matter Parcellation (wmparc.mgz)

recon-all -help

Note: lh processed completely first, then rh.

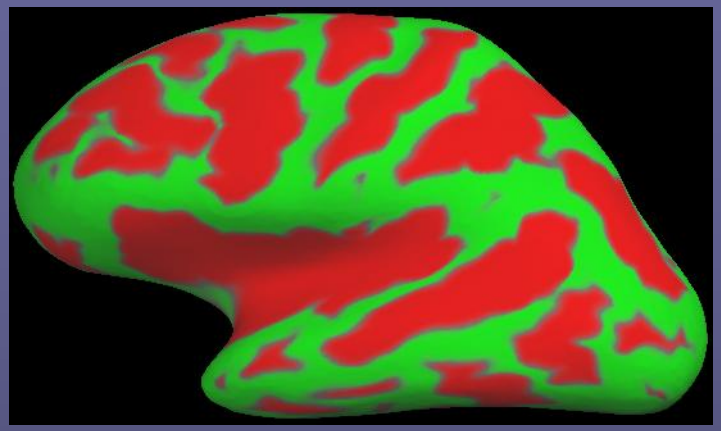
Surface-Based Spherical Coord System



-sphere
-surfreg

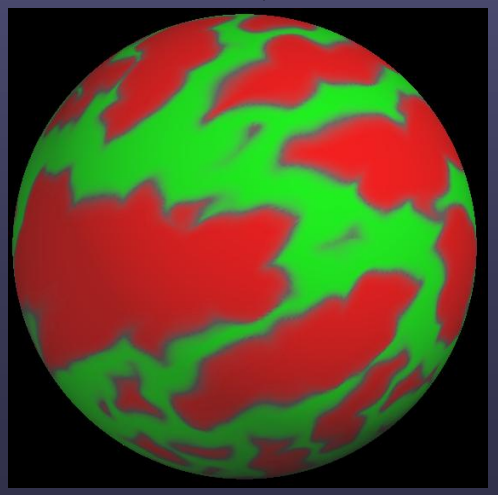
-autorecon3

“Spherical” Registration

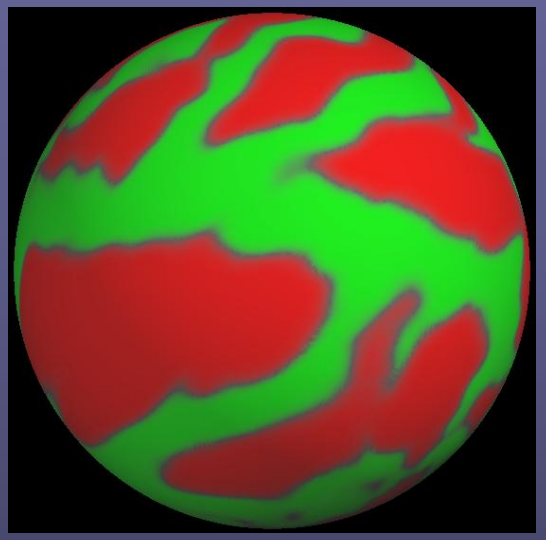


Inflated Surface (Sulcal Map)

Spherical Inflation



Individual Subject



Atlas (Target)

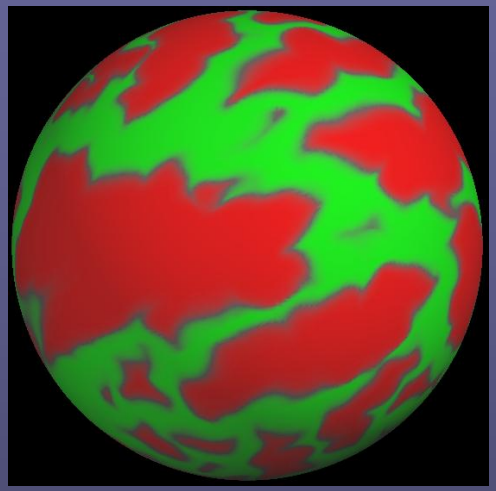
High-Dimensional Registration
to Spherical Template

bert
surf
?h.sphere

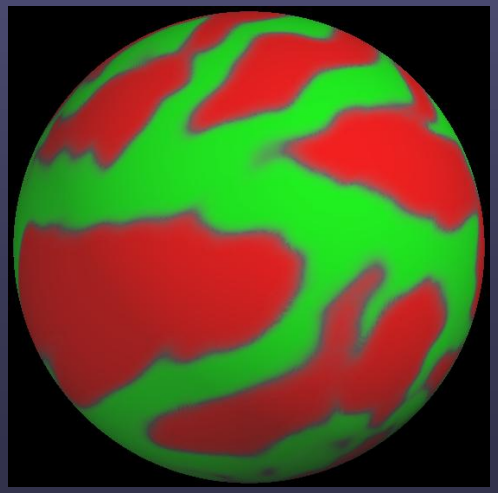
-sphere
-surfreg

-autorecon3

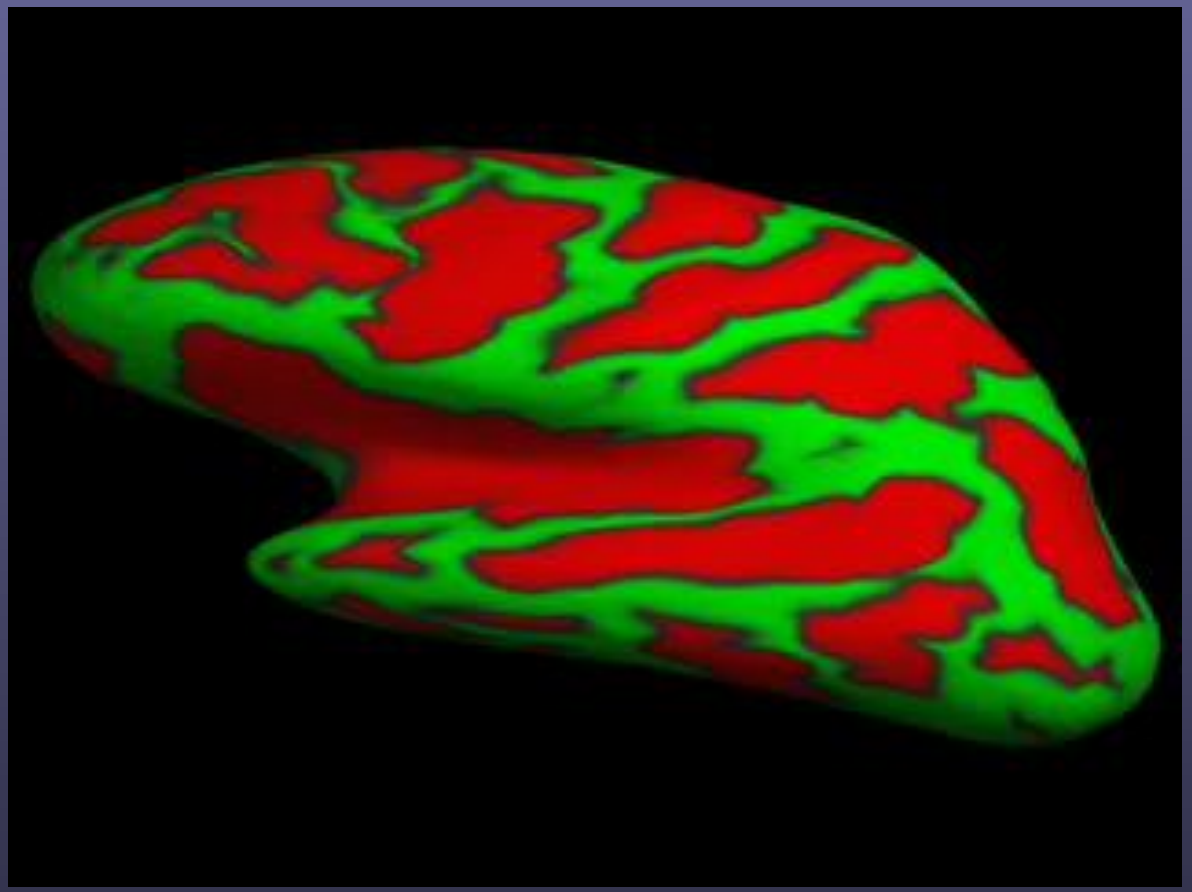
Spherical Inflation Registration to Atlas



Individual Subject



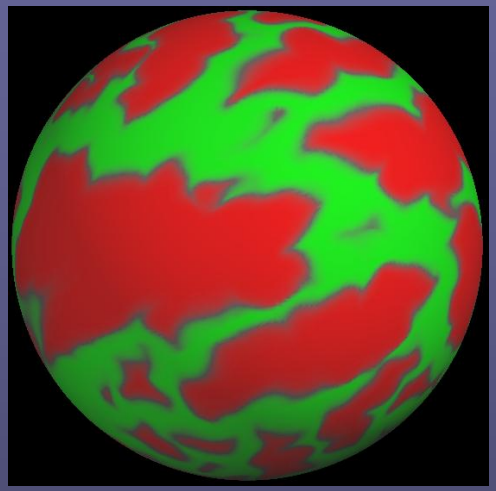
Atlas (Target)



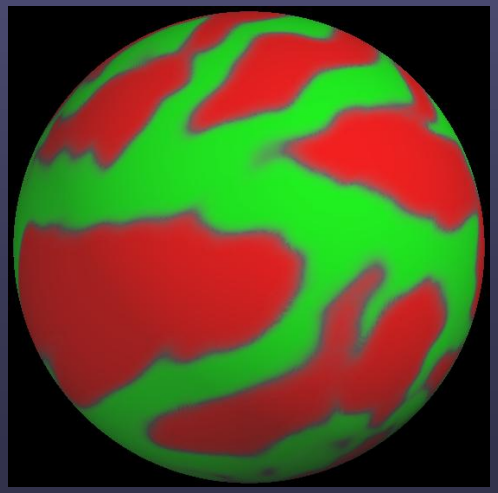
-sphere
-surfreg

-autorecon3

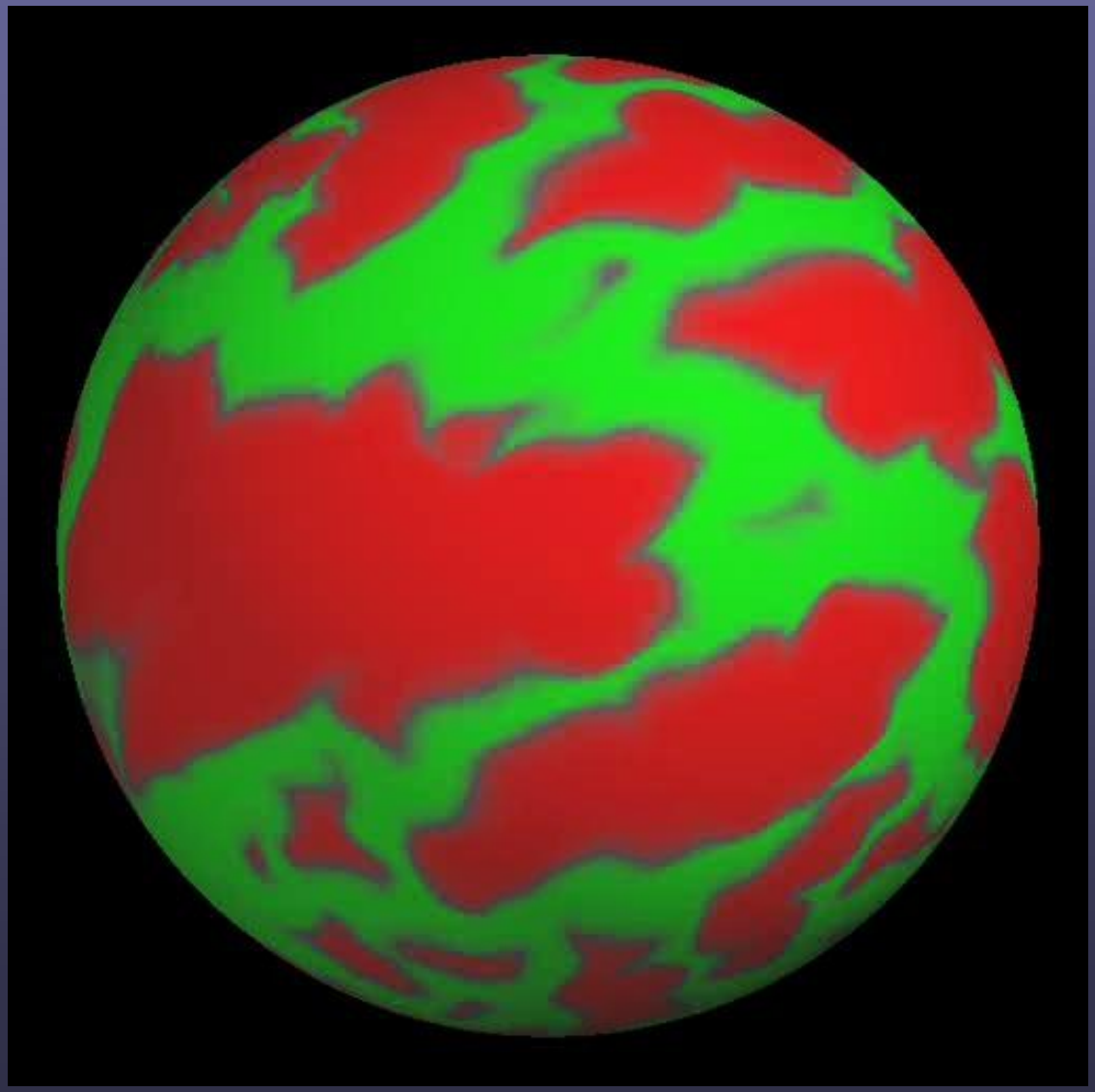
Spherical Inflation Registration to Atlas



Individual Subject



Atlas (Target)

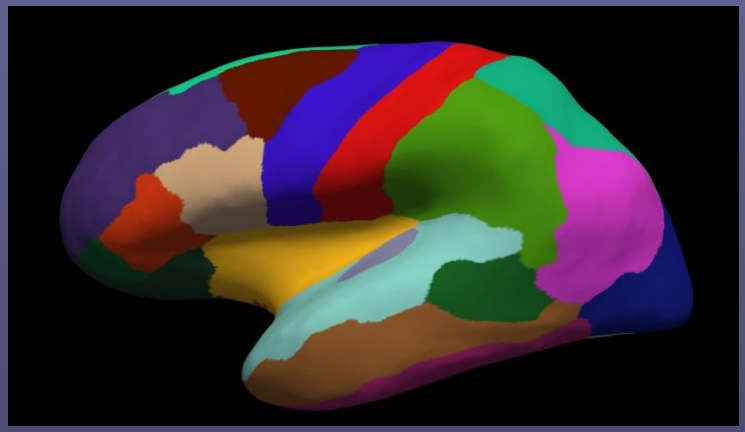


-cortparc

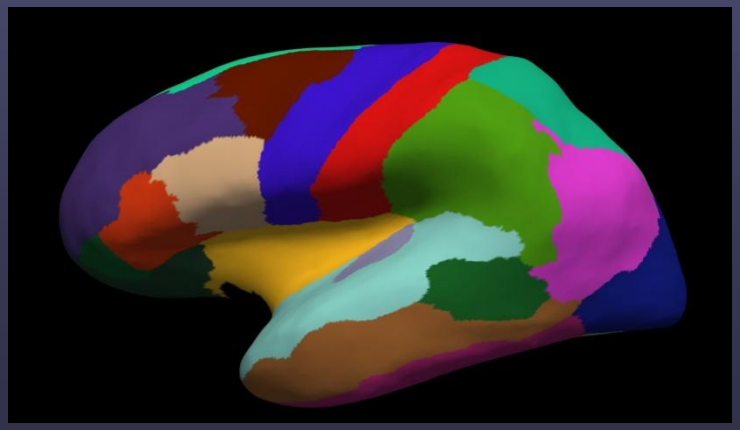
-autorecon3

Cortical Parcellation

Spherical Template based
on Manual Parcellation



Map to Individual
Thru Spherical Reg



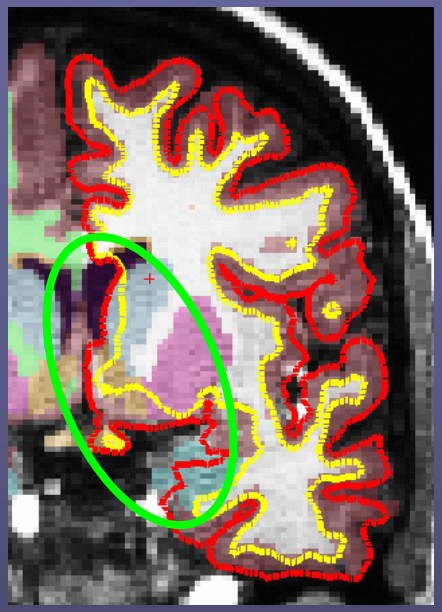
Fine-tune based on
individual anatomy

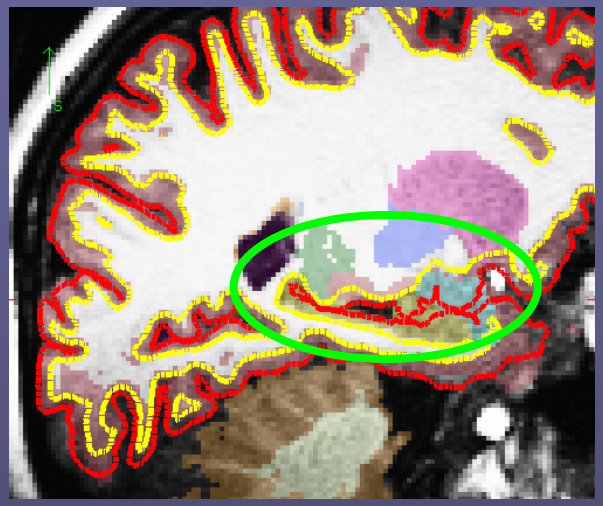
bert

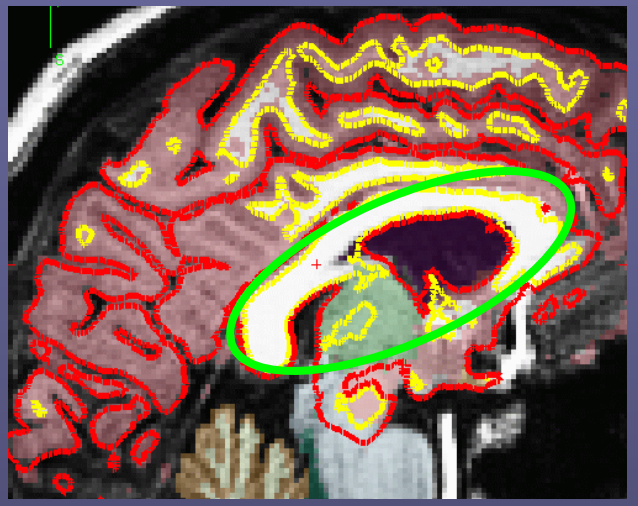
label

?h.aparc.annot

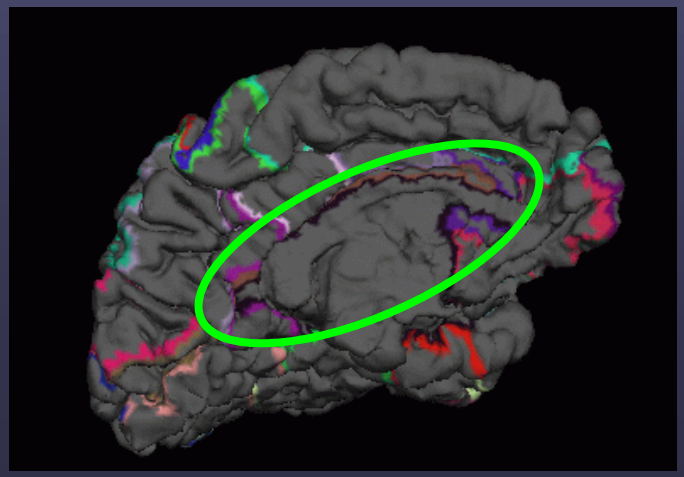
Non-Cortical Areas of Surface

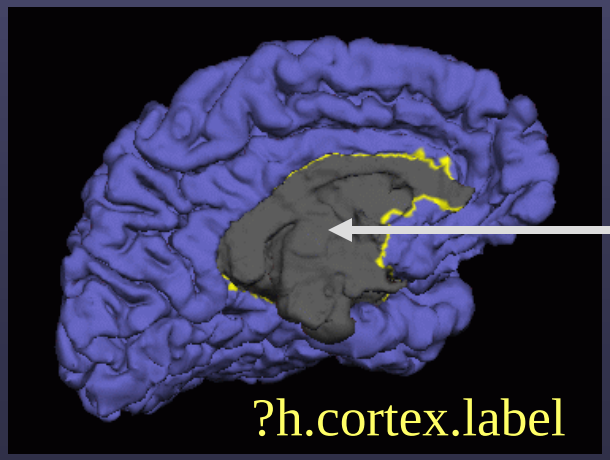






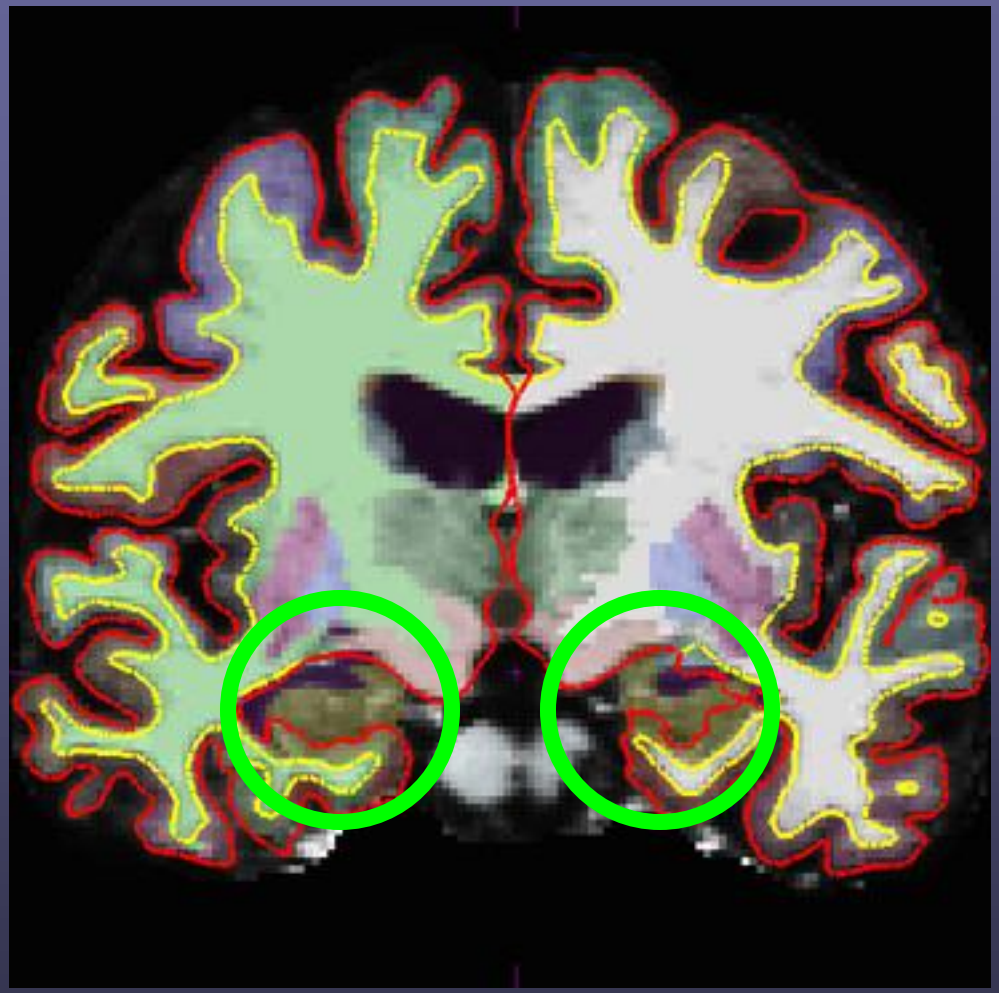
Amygdala, Putamen, Hippocampus, Caudate, Ventricles, CC





"unknown" region

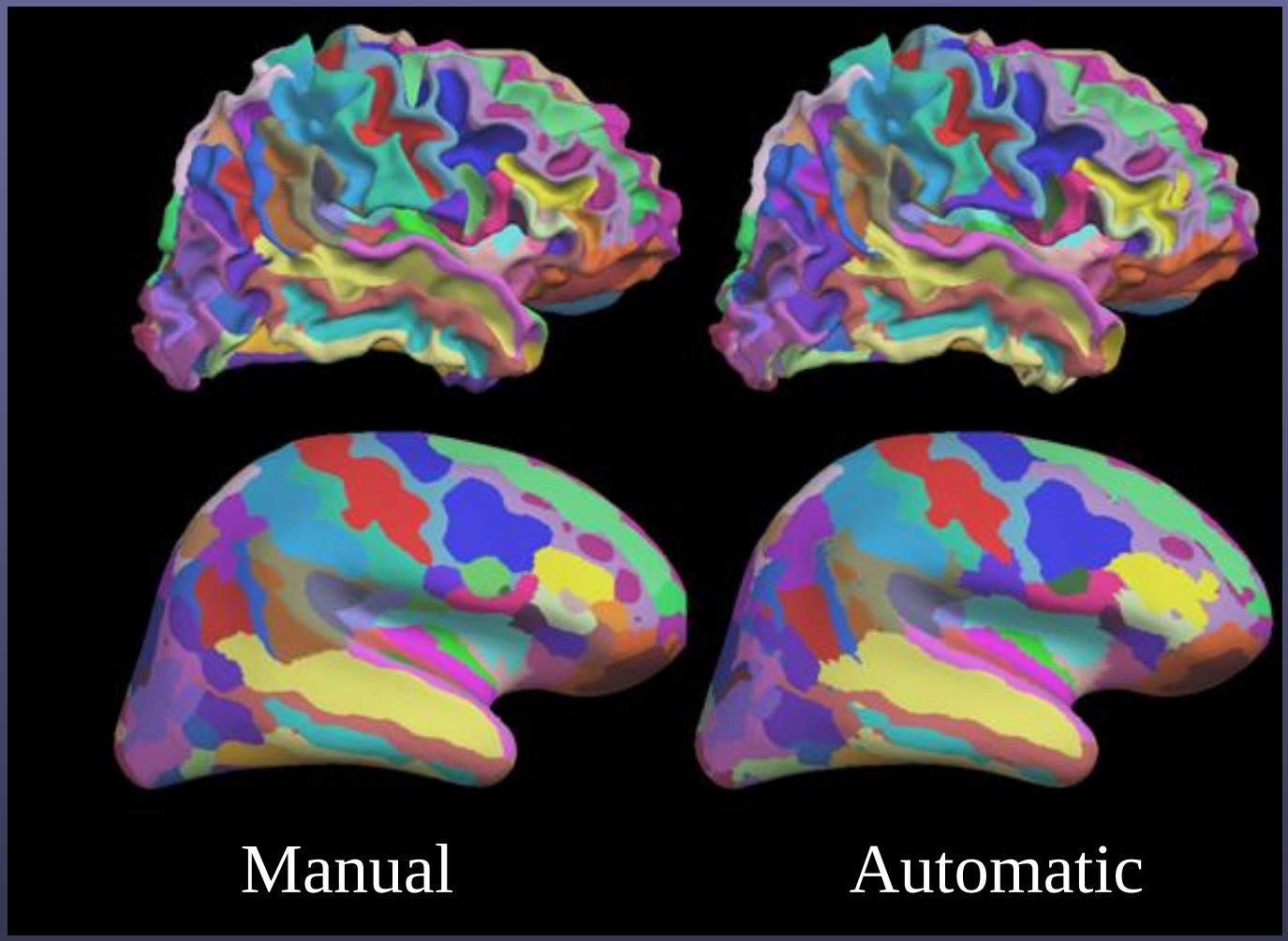
Output of Cortical Surface Reconstruction



Amygdala, Hippocampus

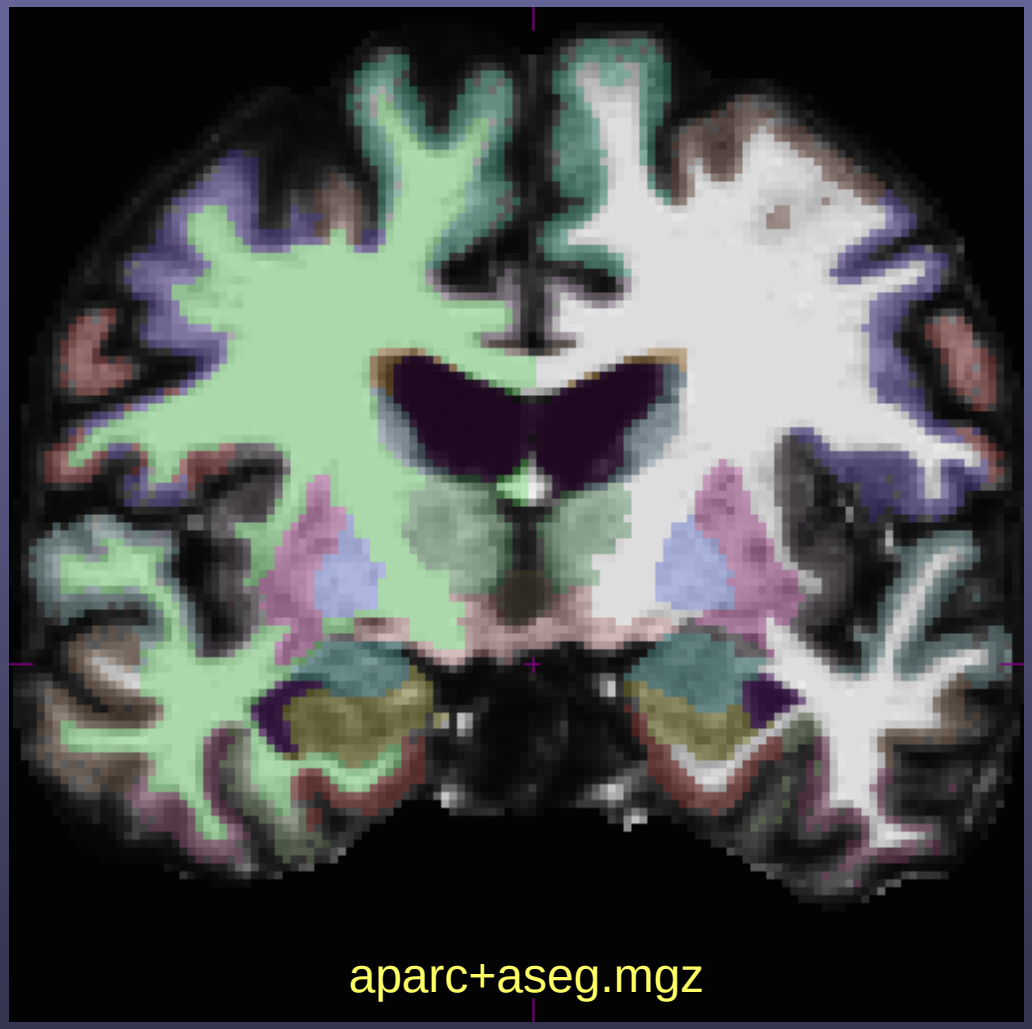
-cortparc2 -autorecon3

Cortical Parcellation: 2



Thanks to Christophe Destrieux for this slide.

Aparc+Aseg



bert

label

aparc+aseg.mgz

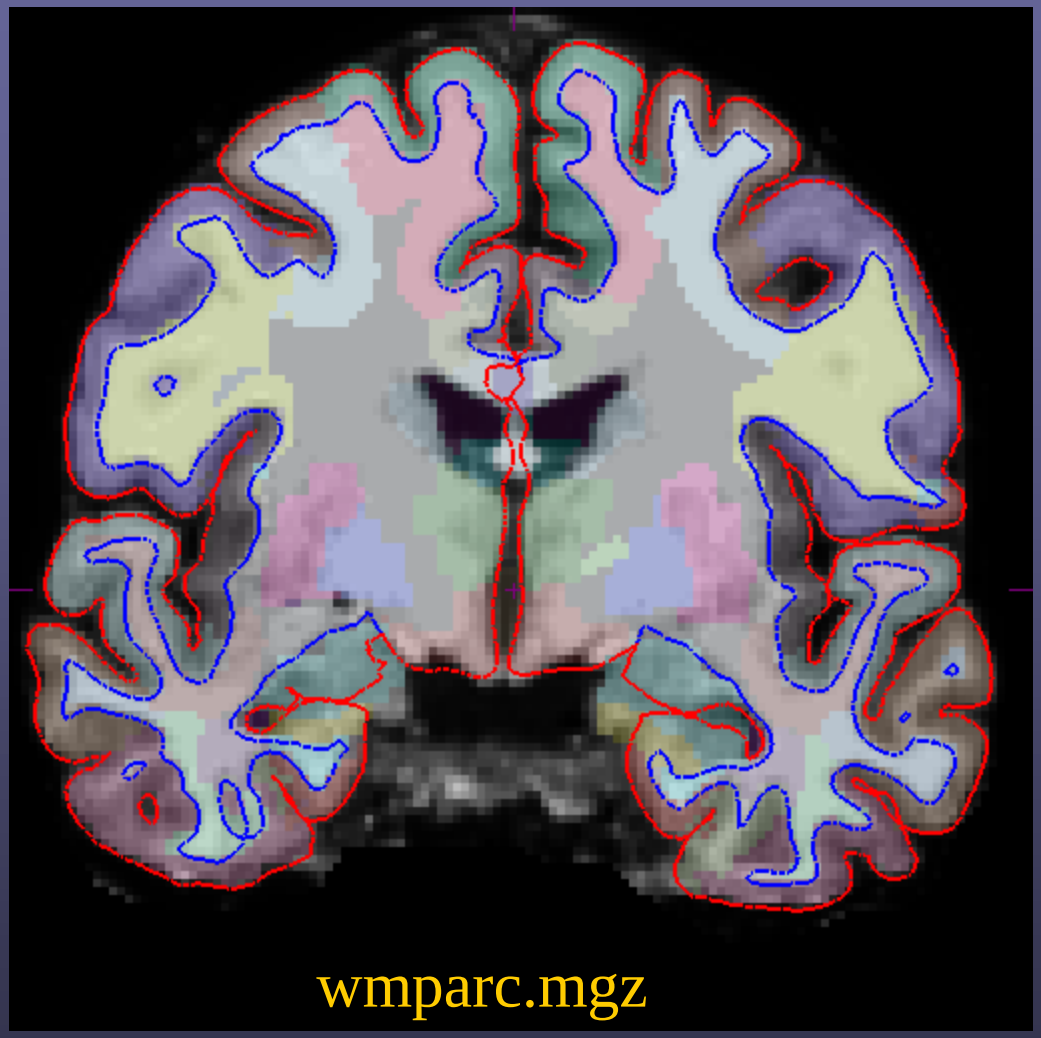
There is also aparc.a2009s+aseg.mgz for Destrieux atlas

-wmparc

-autorecon3

White Matter Parcellation

Nearest Cortical Label to point in White Matter



bert

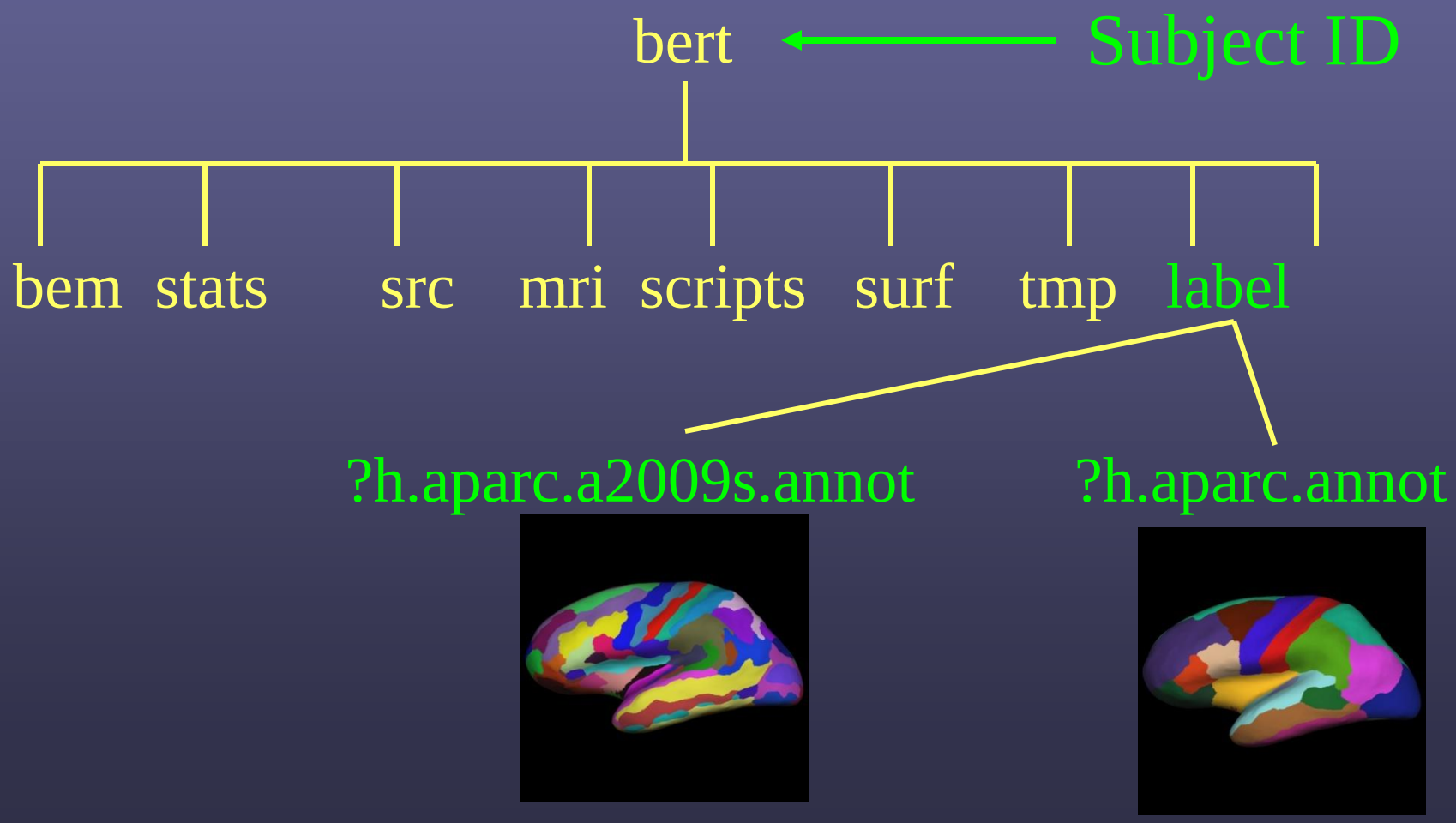
label

wmparc.mgz

Salat DH, Greve DN, Pacheco JL, Quinn BT, Helmer KG, Buckner RL, Fischl B. Regional white matter volume differences in nondemented aging and Alzheimer's disease. Neuroimage. 2008 Nov 5.

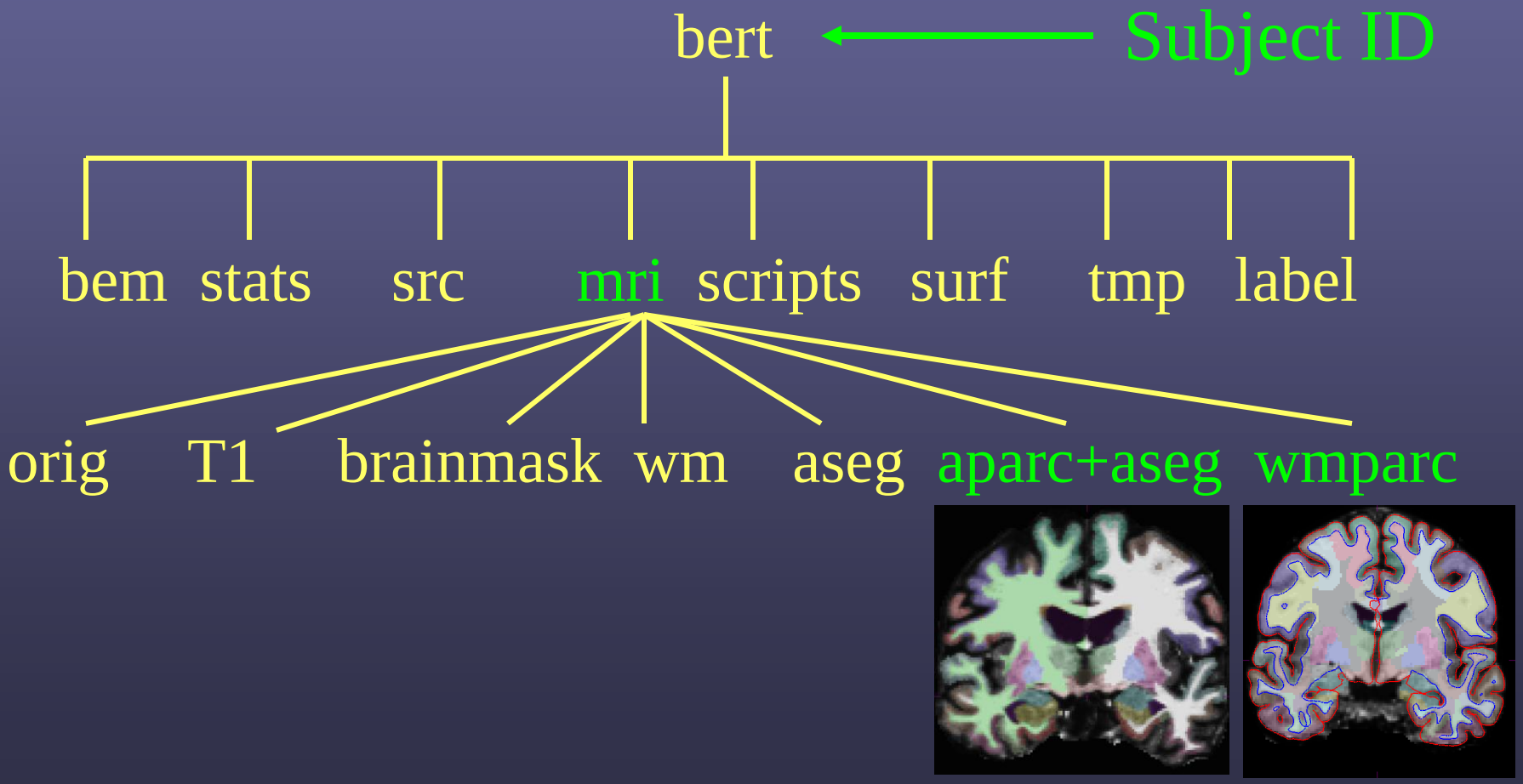
FreeSurfer Directory Tree

Each data set has its own unique SubjectId (eg, bert)



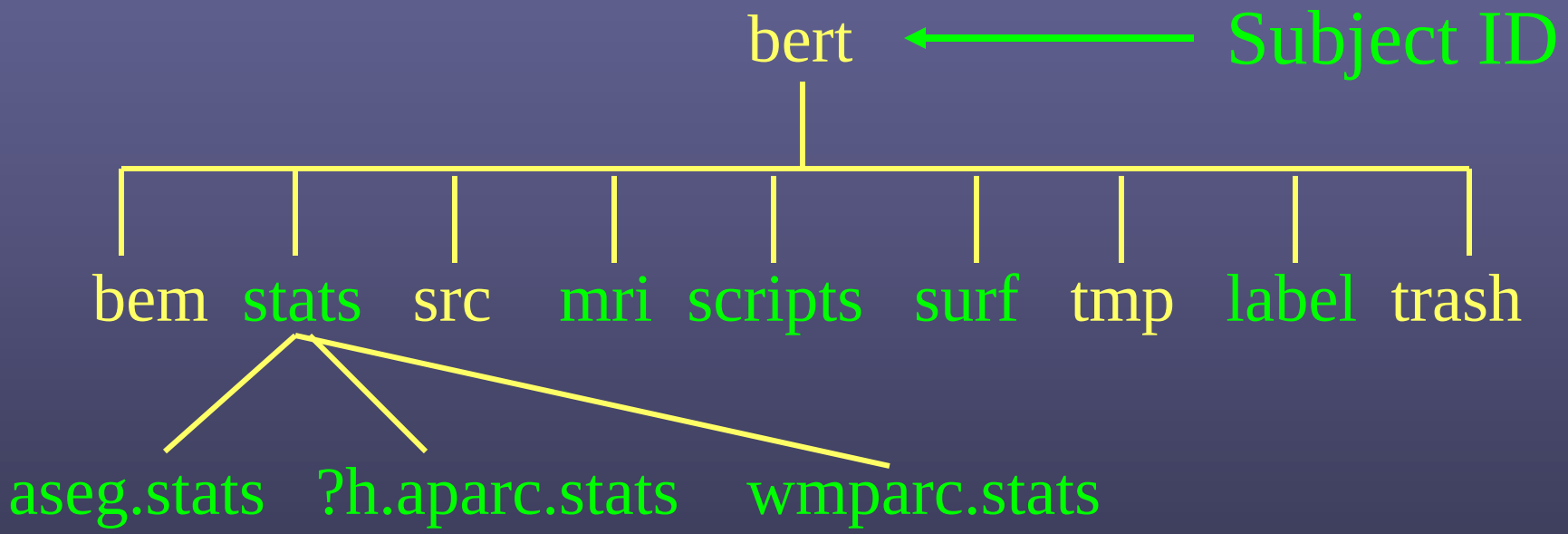
FreeSurfer Directory Tree

Each data set has its own unique SubjectId (eg, bert)



FreeSurfer Directory Tree

Directories used often are in green.



Why use FreeSurfer?
What happens?
How do I do that?
Now What?

Using FreeSurfer

With FreeSurfer, certain variables must be set in order to use it correctly:

FREESURFER_HOME

tell Operating System where FreeSurfer is

SUBJECTS_DIR

tell FreeSurfer where data is

Within NMR/Martinos

Stable version:

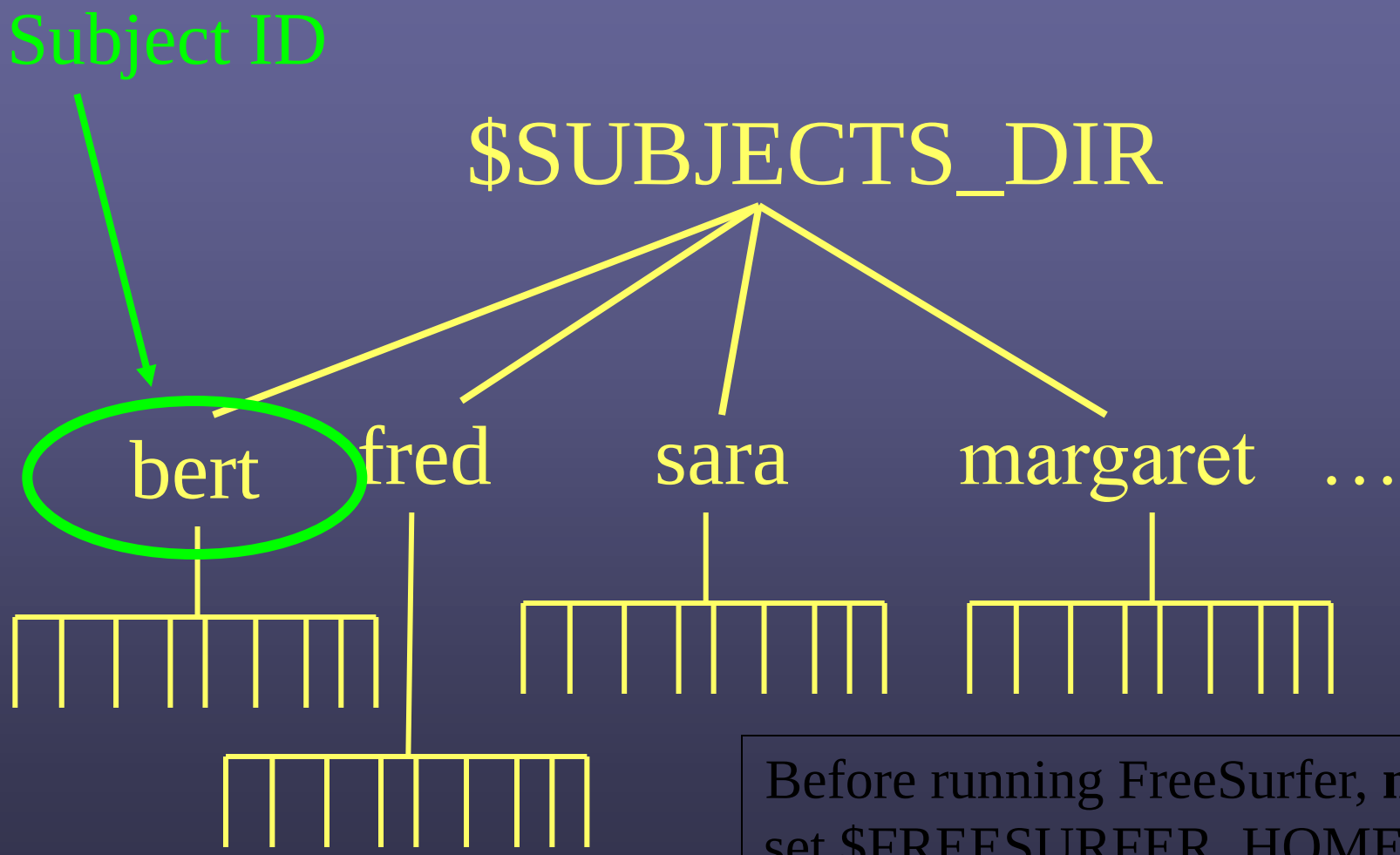
source /usr/local/freesurfer/nmr-stable-env

Development version:

source /usr/local/freesurfer/nmr-dev-env

http://surfer.nmr.mgh.harvard.edu/fswiki/InternalFreeSurferDistributions

Set-up Environmental Variables



Before running FreeSurfer, **must** set $FREESURFER_HOME and $SUBJECTS_DIR

Starting the Reconstruction Process

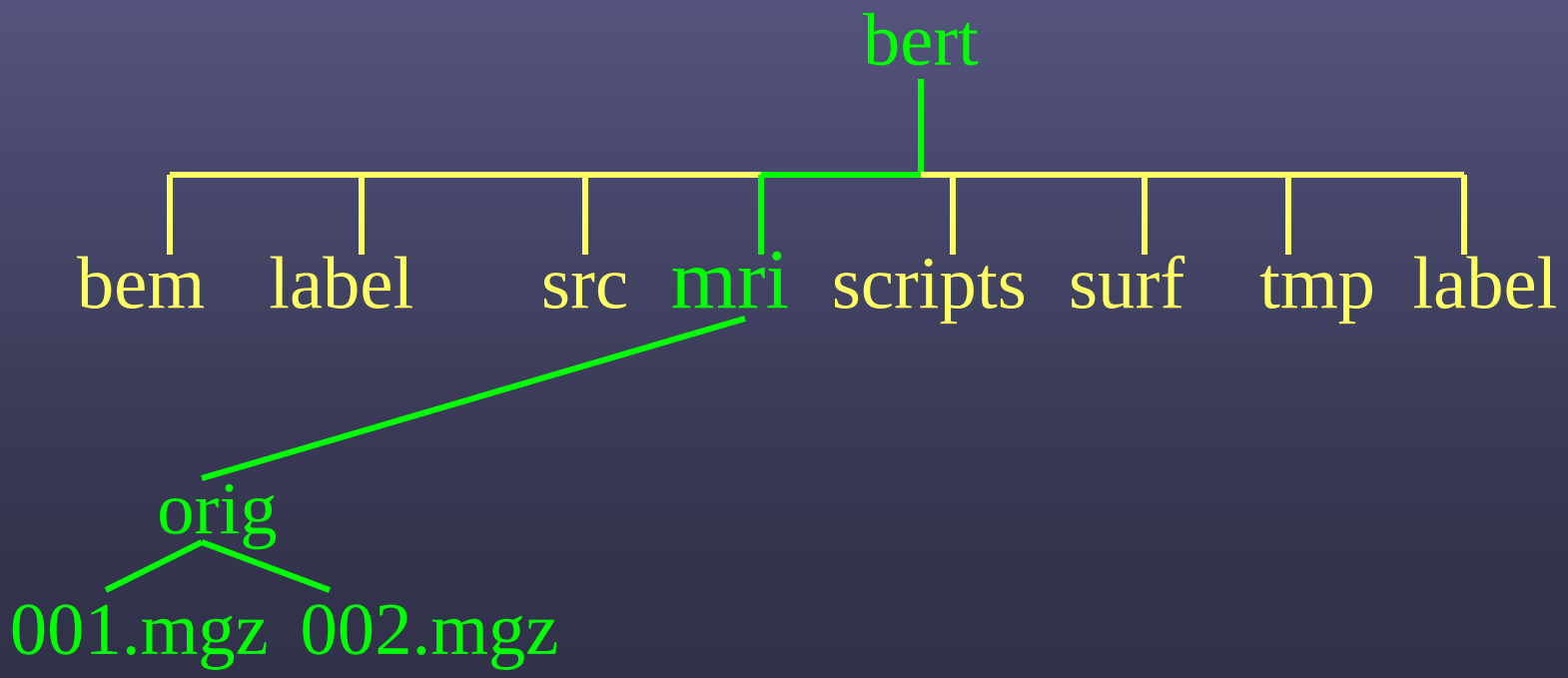
Before running FreeSurfer, **must** set $FREESURFER_HOME and $SUBJECTS_DIR

recon-all \
-i /path/to/your/raw/data1 \
-i /path/to/your/raw/data2 \
-all -s subject_id

- This will create the subject directory ‘subject_id’ in your $SUBJECTS_DIR and convert your 2 raw acquisitions to mgz and use them as input for the ‘-all’ command.

Alternative: Add Your Data

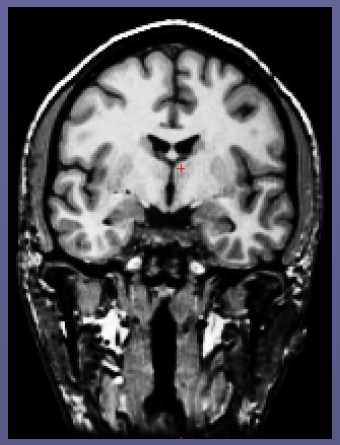
- cd $SUBJECTS_DIR
- mkdir –p bert/mri/orig
- mri_convert rawdata.nii bert/mri/orig/001.mgz
- mri_convert rawdata.nii bert/mri/orig/002.mgz
- recon-all –all –s bert

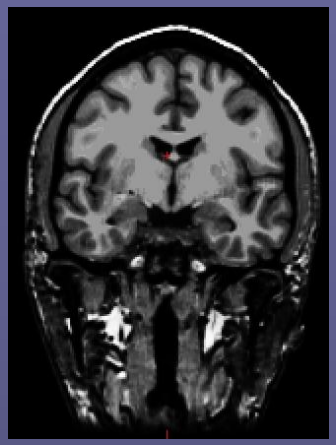


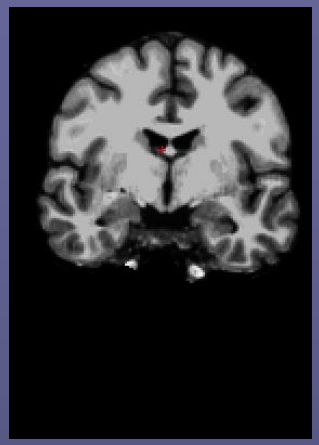
FreeSurfer Output

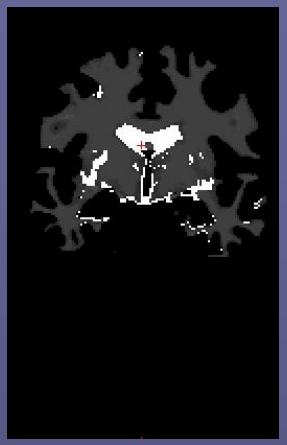
- Volumes
- Surfaces
- Surface Overlays
- ROI Summaries

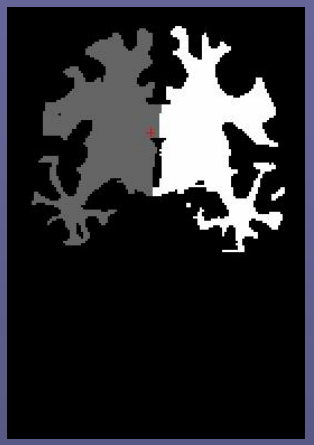
Volumes

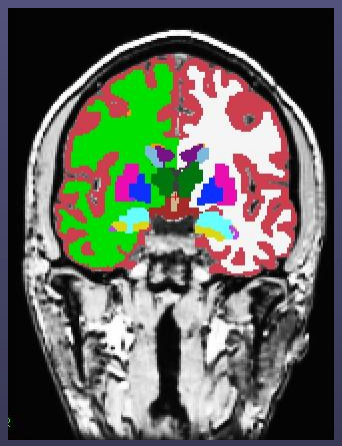

orig.mgz

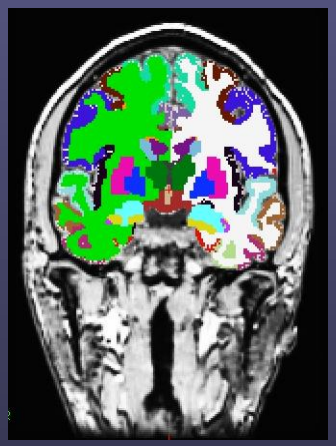

T1.mgz


brainmask.mgz


wm.mgz


filled.mgz
Subcortical Mass

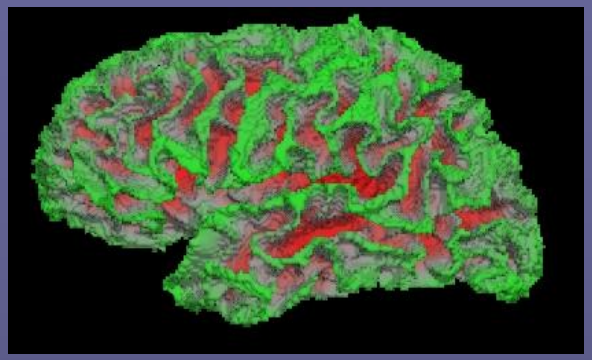

aseg.mgz


aparc+aseg.mgz

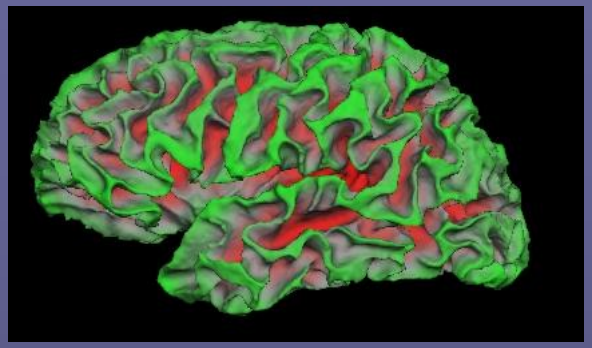
- $SUBJECTS_DIR/bert/mri
- All “Conformed” 256^3, 1mm
- File format: .mgz

Volume Viewer:
tkmedit

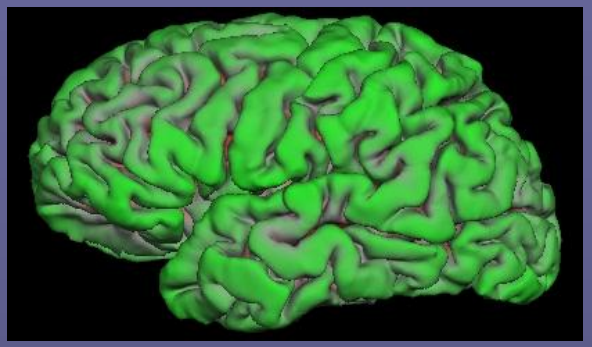
Surfaces



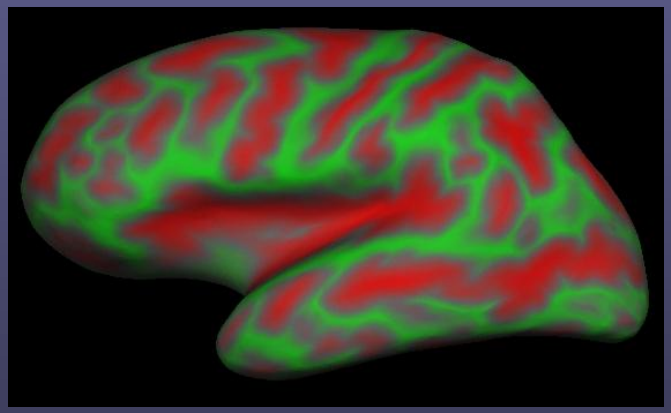
.orig



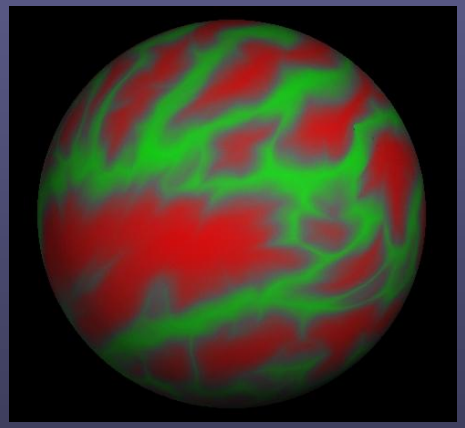
.white



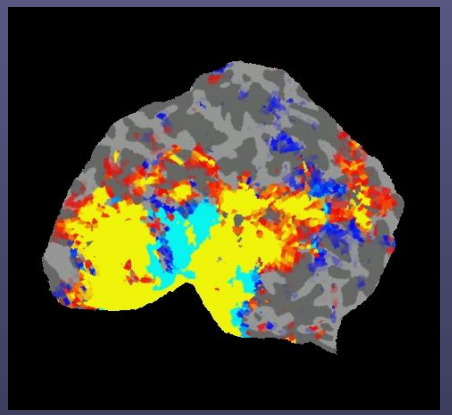
.pial



.inflated



sphere, sphere.reg

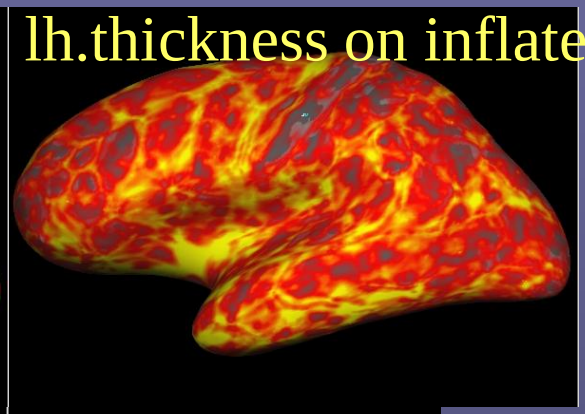


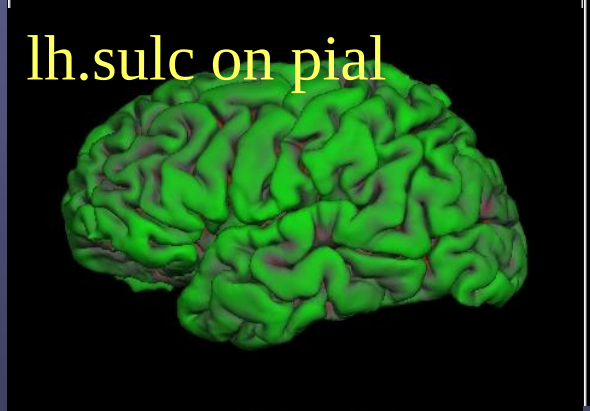
flat

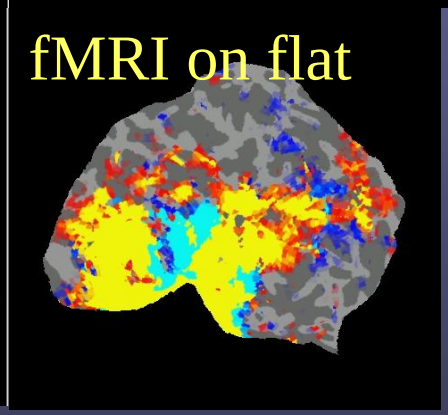
- $SUBJECTS_DIR/bert/surf
- Number/Identity of vertices stays the same (except flat)
- XYZ Location Changes
- Flattening not done as part of standard reconstruction

Surface Viewer: tksurfer

Surface Overlays







- Value for each vertex
- Color indicates value
- Color: gray,red/green, heat, color table
- Rendered on any surface
- fMRI/Stat Maps too

Other FreeSurfer File Formats

Unique to FreeSurfer

- Surface: lh.white, lh.pial, lh.orig
- Curv: lh.curv, lh.sulc, lh.thickness
- Annotation: lh.aparc.annot
- Label: lh.pericalcarine.label

Why use FreeSurfer?
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Quality Check Your Recon

- Do your surfaces follow gm/wm borders?

- Does the subcortical segmentation follow intensity boundaries?

Troubleshooting

recon-all fails

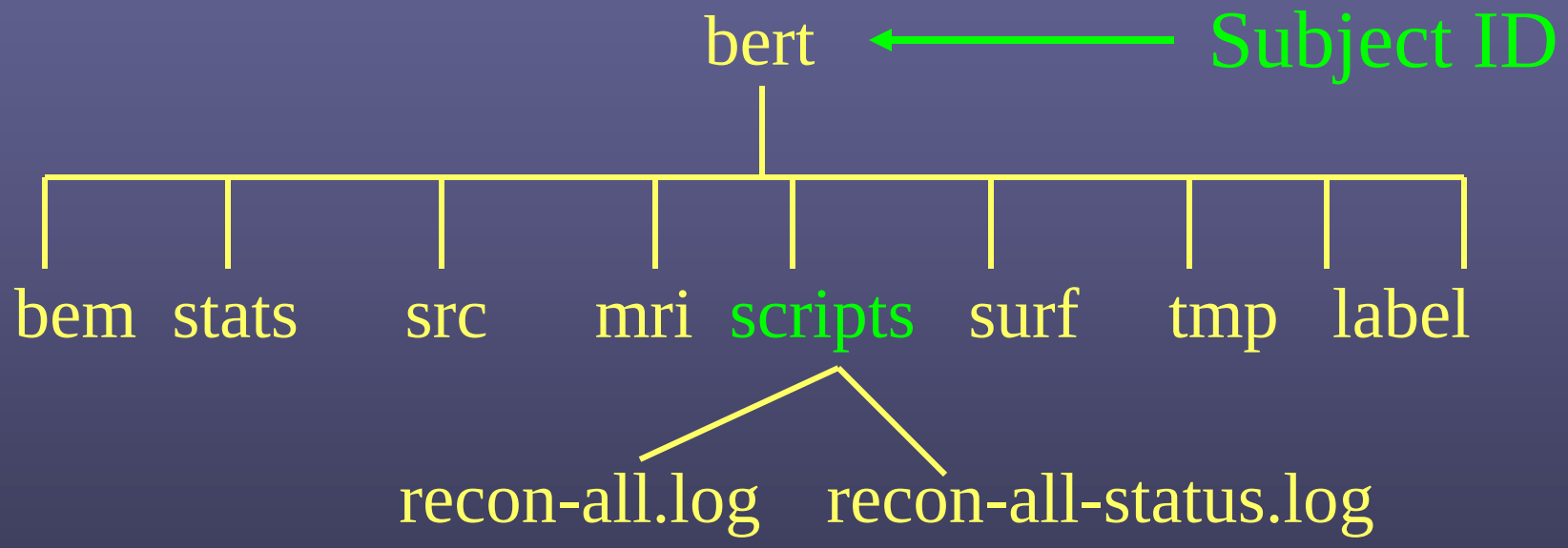
- check recon-all.log
- try to rerun step that failed
- look at volume from last successful step
- examine data quality to see what might cause error
- if it fails again, attempt to run modified version of command if possible
- search FreeSurfer mailing list for other instances of this problem:

http://www.mail-archive.com/freesurfer@nmr.mgh.harvard.edu/

- email the mailing list if still need help

FreeSurfer Directory Tree

Each data set has its own unique SubjectId (eg, bert)



Bug Reporting

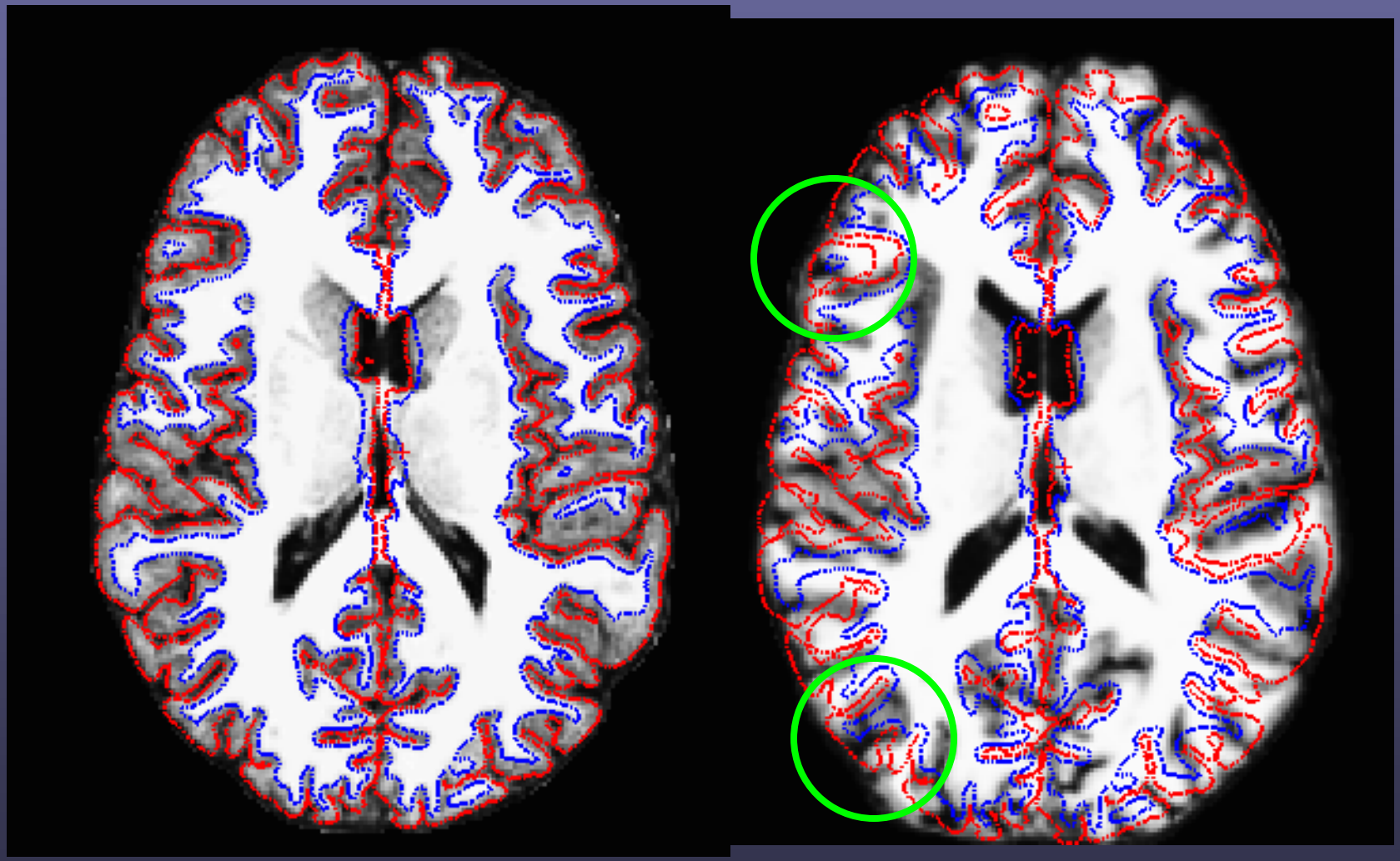
- Report version currently using
  - see top of recon-all.log
  - more $FREESURFER_HOME/build-stamp.txt
- command line tried to run
- attach recon-all.log
- Output in terminal window if appropriate
- Operating System

The End

Manifold Surgery

BEFORE

AFTER

Problems with Affine (12 DOF) Registration

- ROIs need to be individualized.