a bit about
brain labeling

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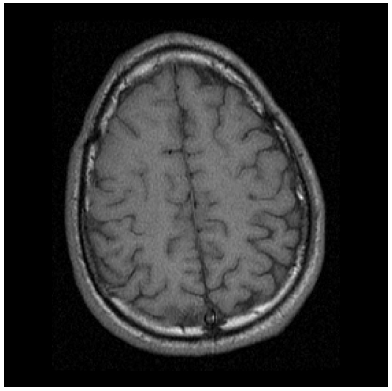
The New School

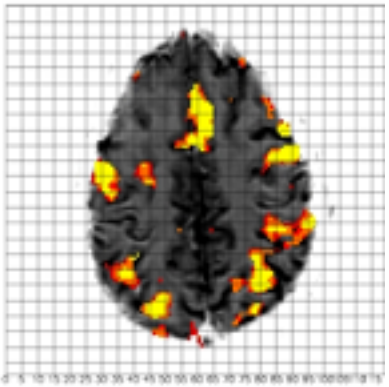
Image data

MRI



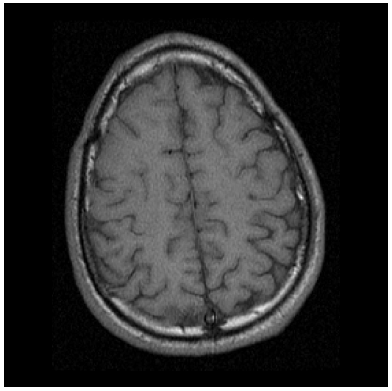
Structural

Functional



Manual labels

MRI



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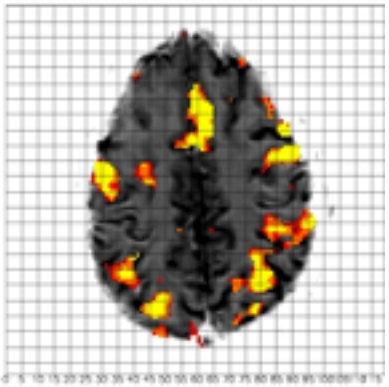

Manual labels

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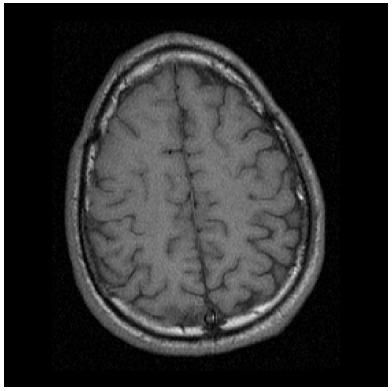

Structural

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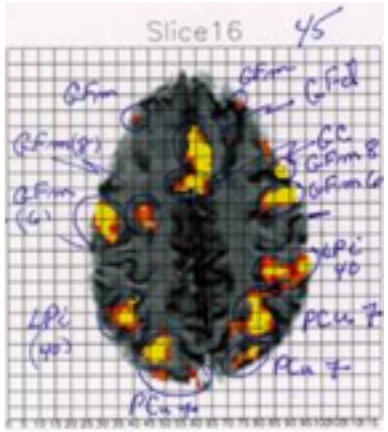
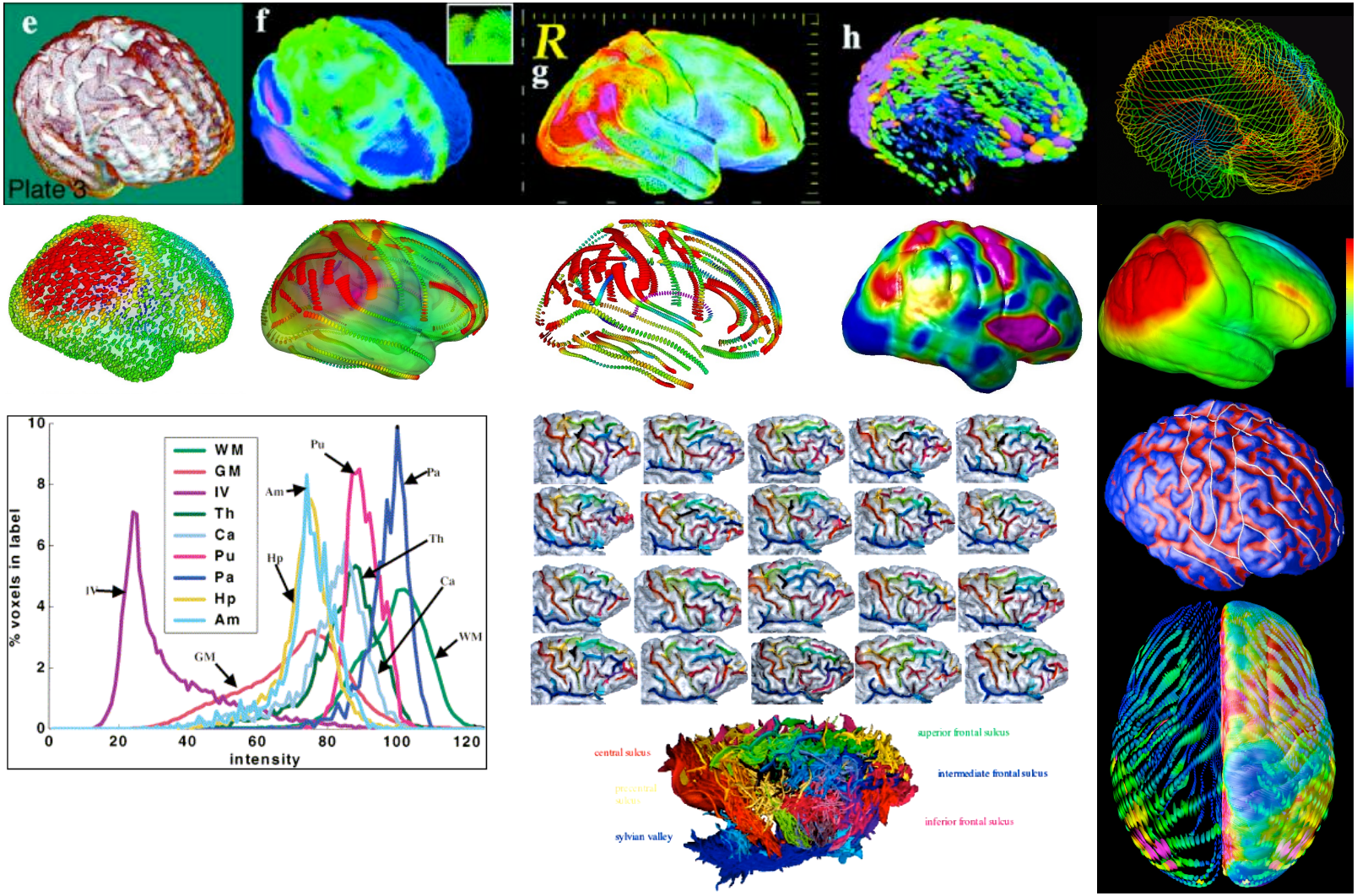
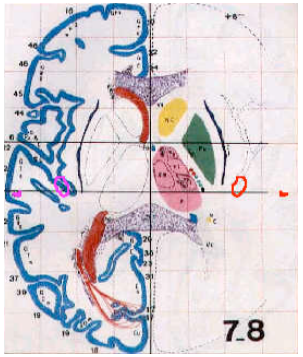


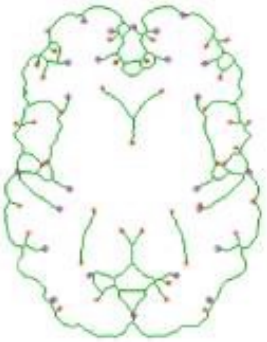
Brain variation

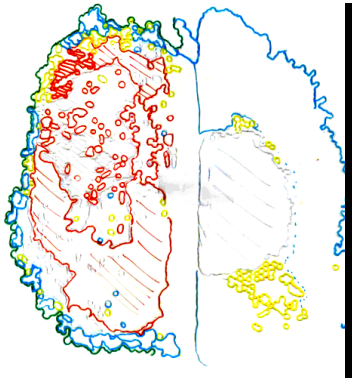


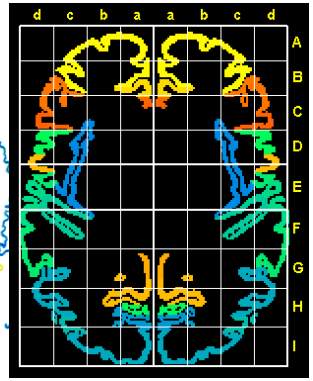
Brain atlases

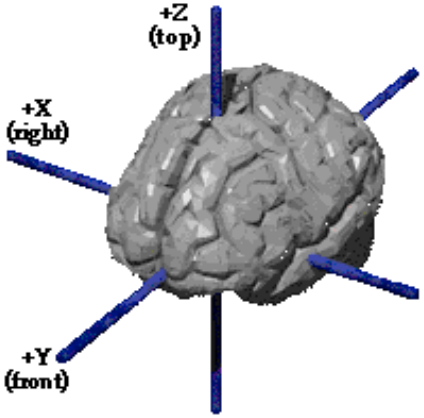
Talairach-Tournoux





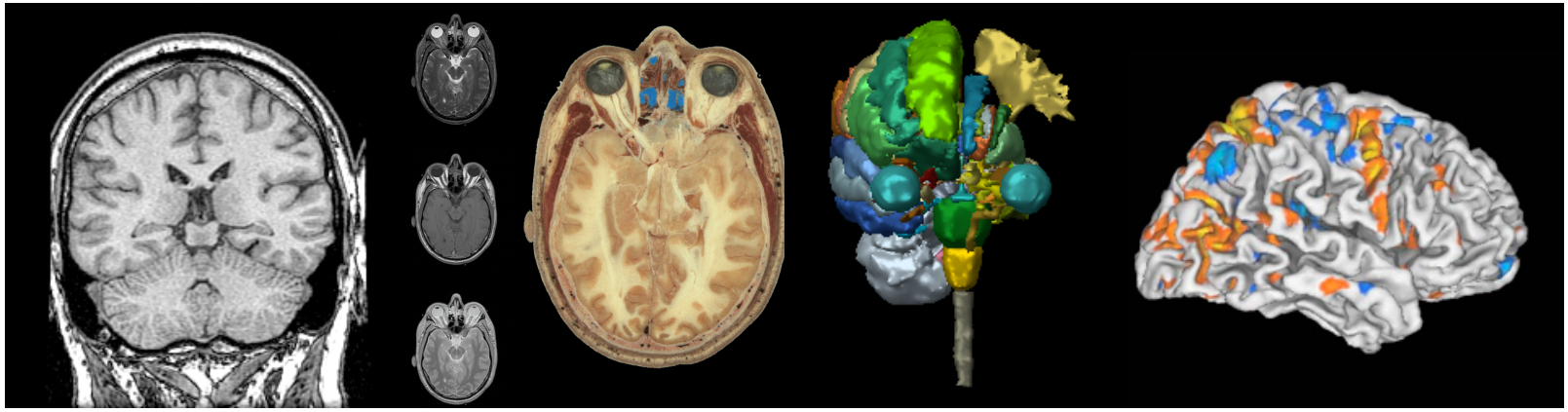




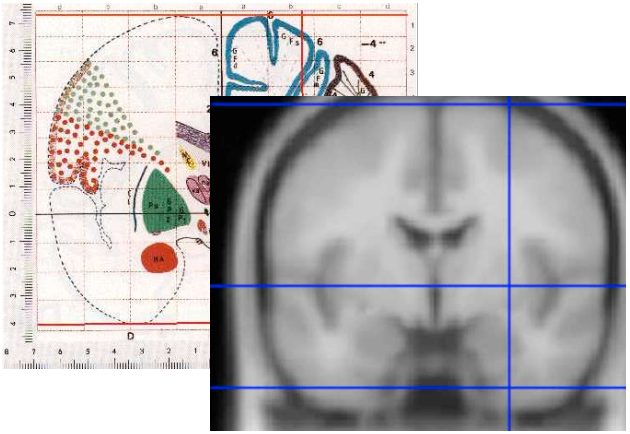


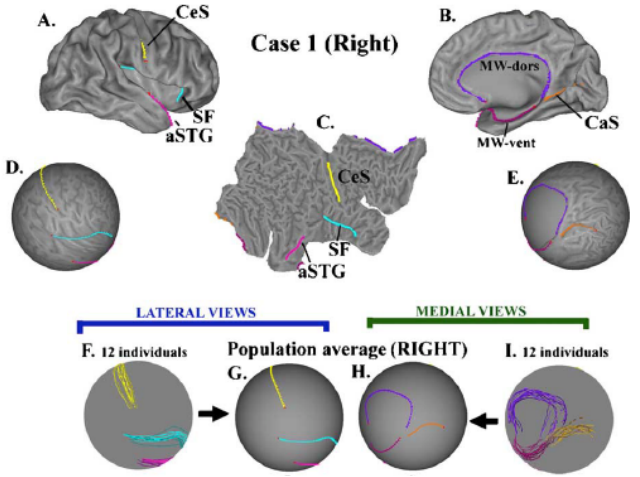
Brain atlases

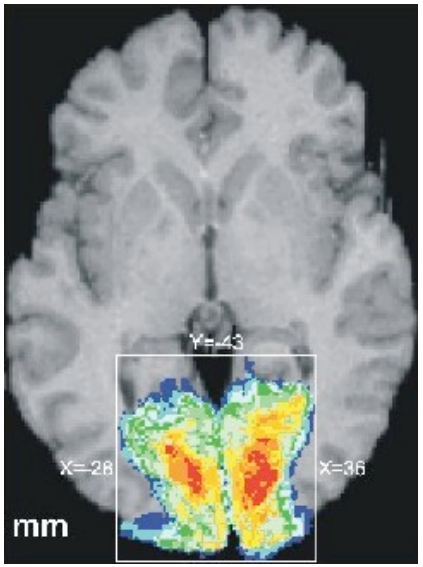
Individuals

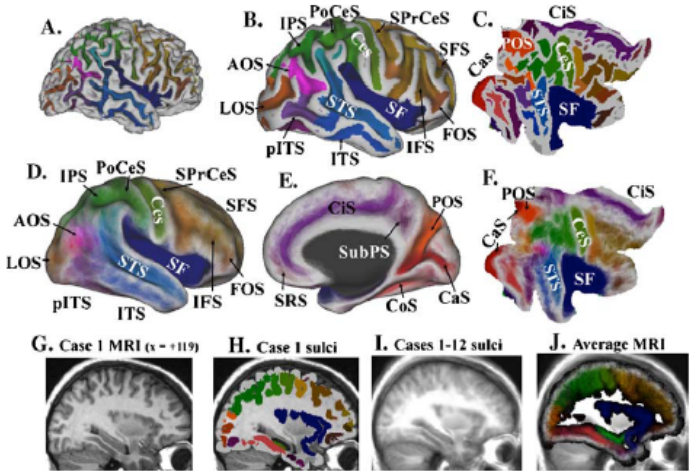


Brain atlases
Multiple



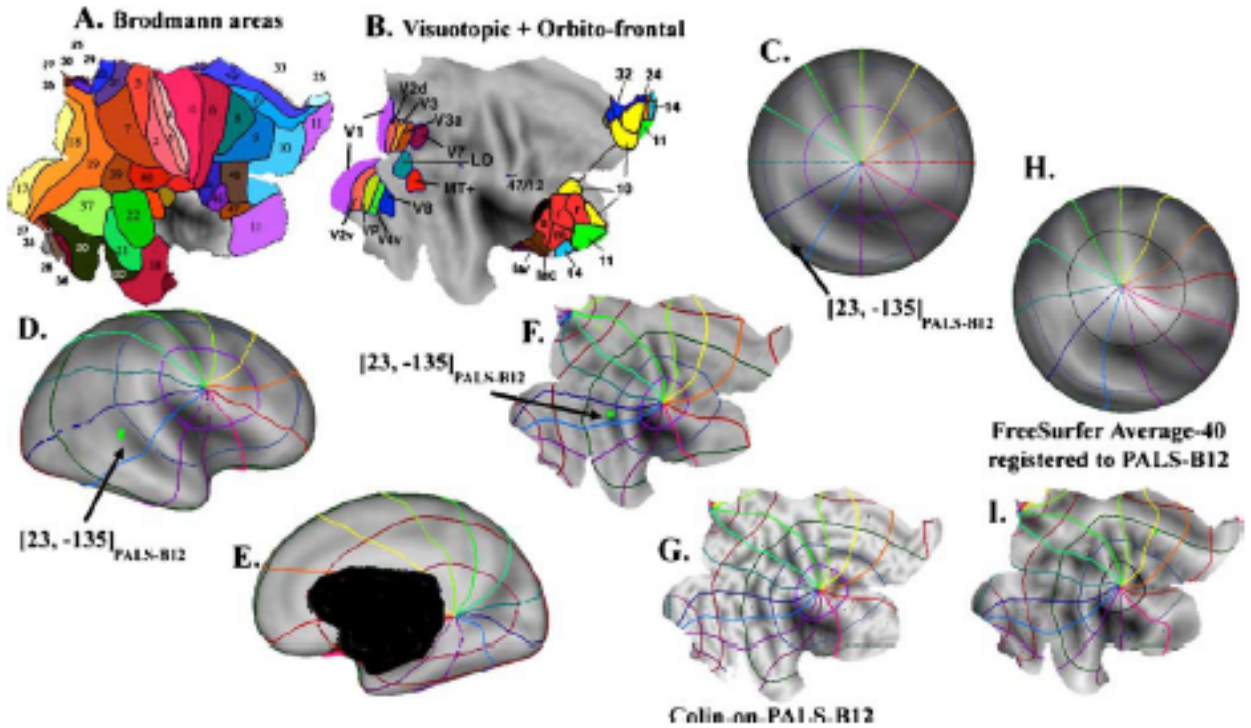






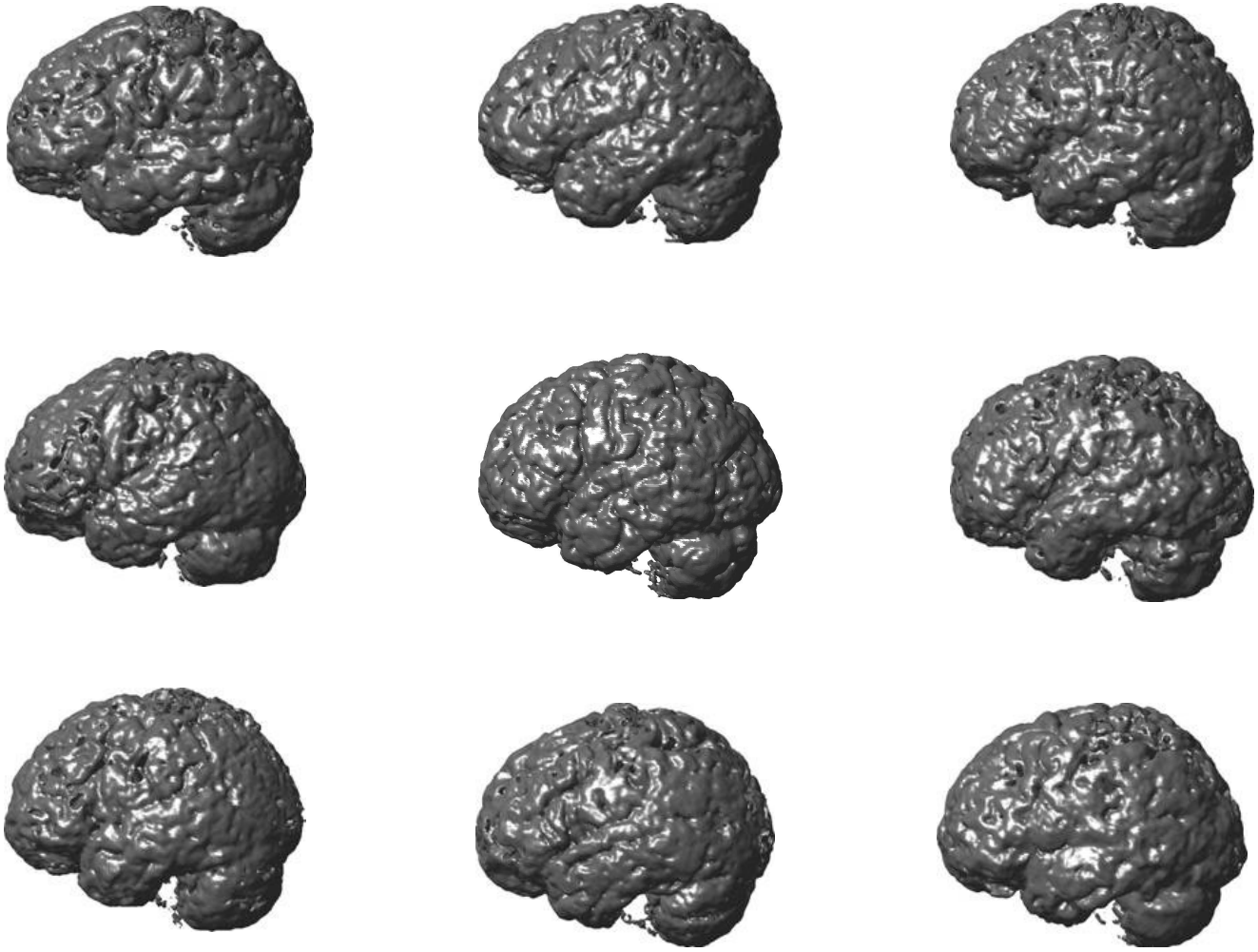
Brain atlases

Hybrids



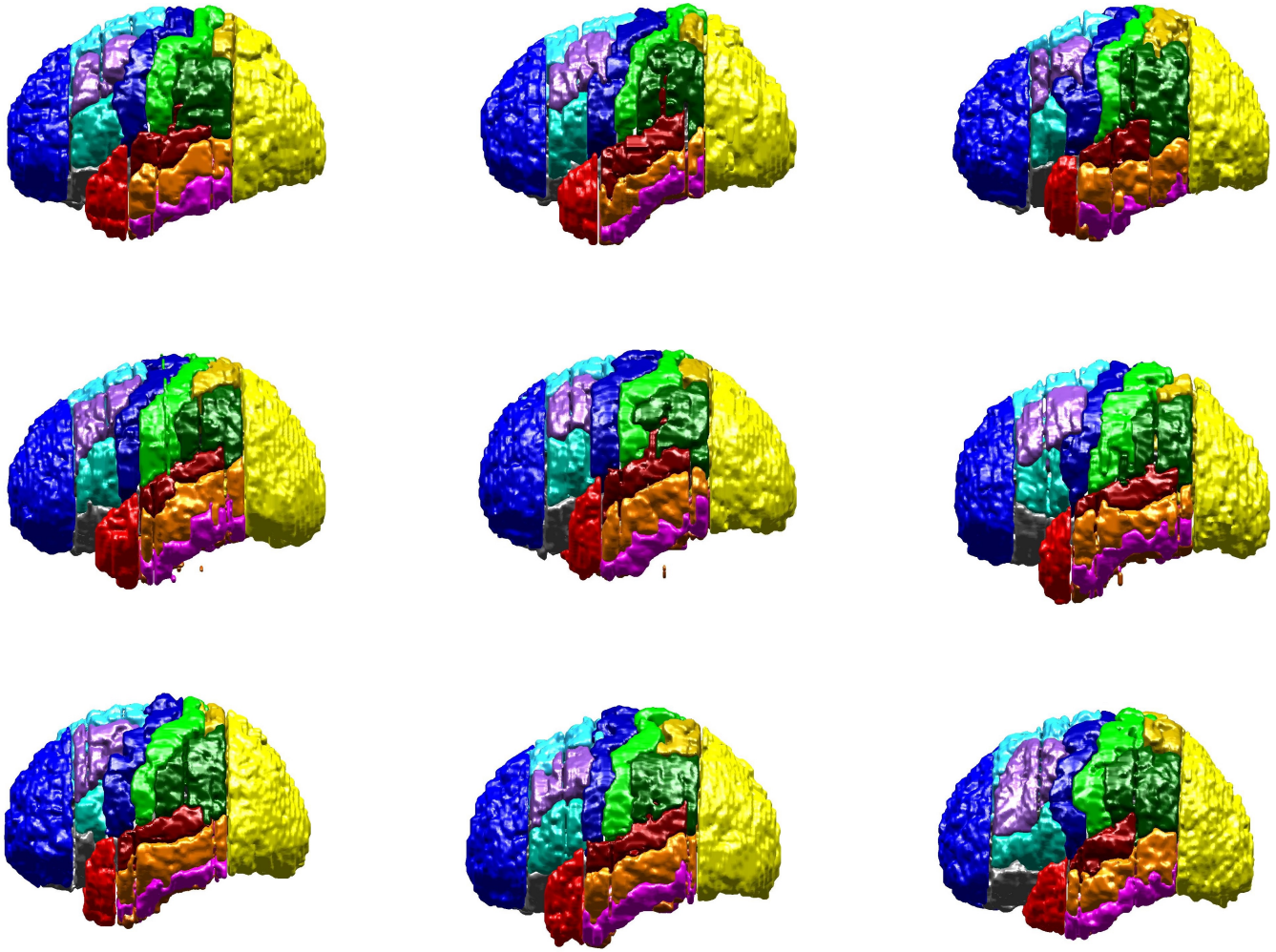
Brain atlases

Build your own!



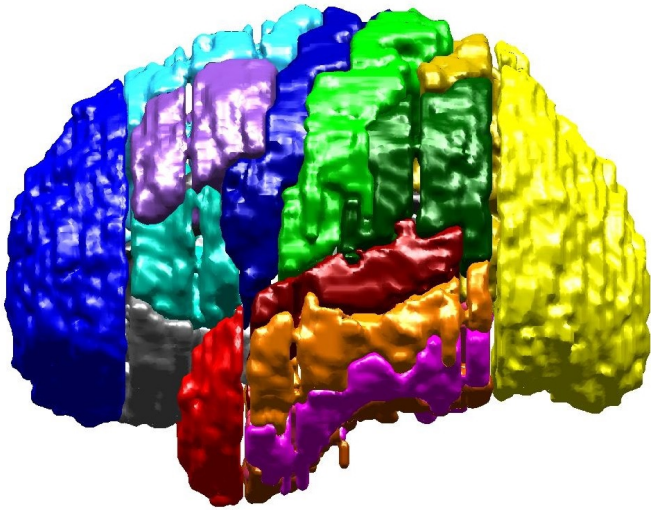
Brain atlases

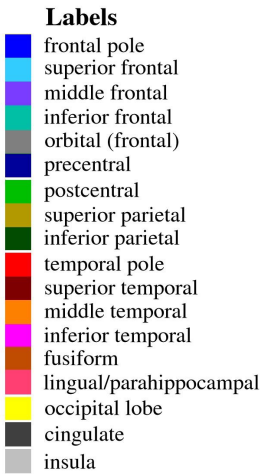
Label them!



The correspondence problem

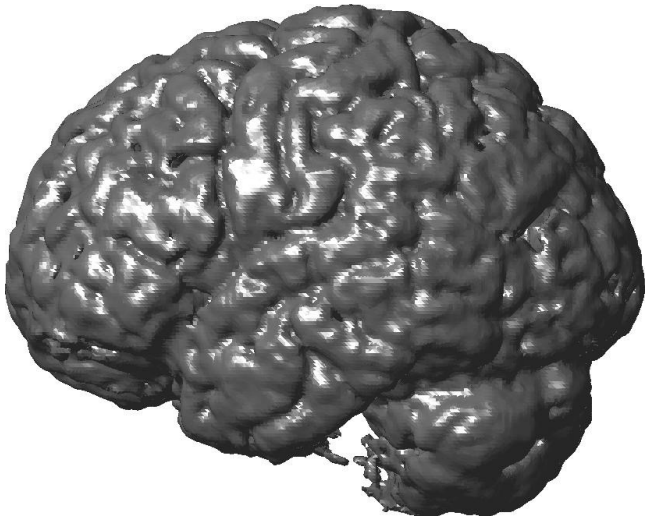
Atlas





?

Subject



Registration

Methods	Examples
Linear registration:	Talairach-type spaces
Piece-wise linear registration:	Talairach (original)
Warping with landmarks:	Thin-plate splines
Unsupervised warping:	SPM, AIR, ANIMAL, ...
Feature matching:	Watershed basins, parametric curves/surfaces

Labeling example

ANIMAL+INSECT

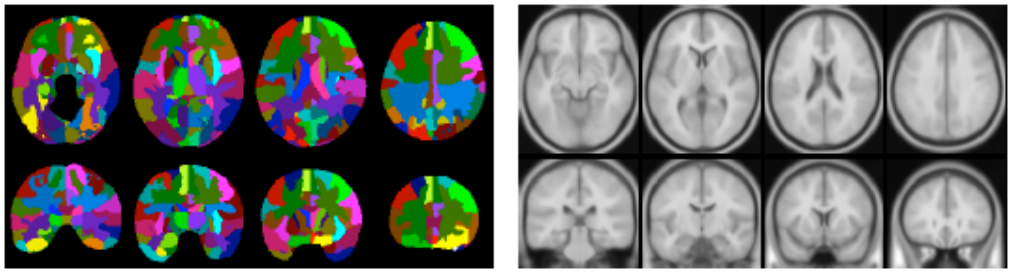


Fig. 2. Max-probability atlas. These images show slices through the maximum probability atlas (left) and the corresponding slices through the ICBM150 T1-weighted average brain (right)

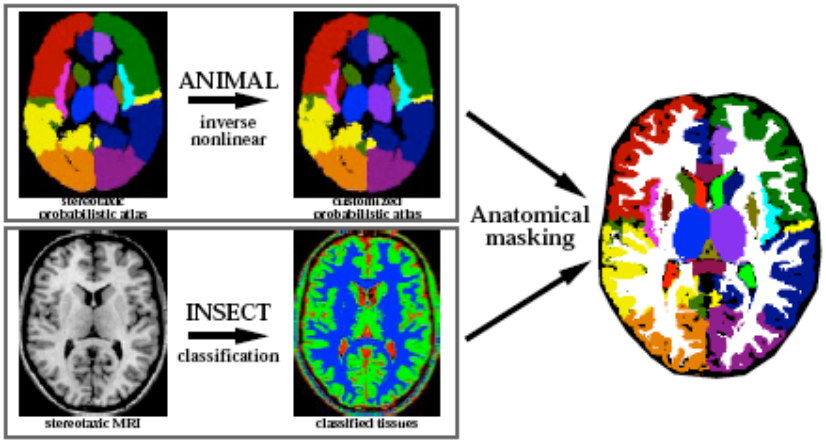


Fig. 3. Schematic of ANIMAL+ INSECT merge. The non-linear transformation required to customized the stereotaxic MPA for the subject is estimated by ANIMAL. The subject's MRI is classified in to WM, GM and CSF classes by INSECT. The classified data are masked by the regions in the c-MPA to segment regions on the subjects MRI volume

Labeling example

Markov Random Field model

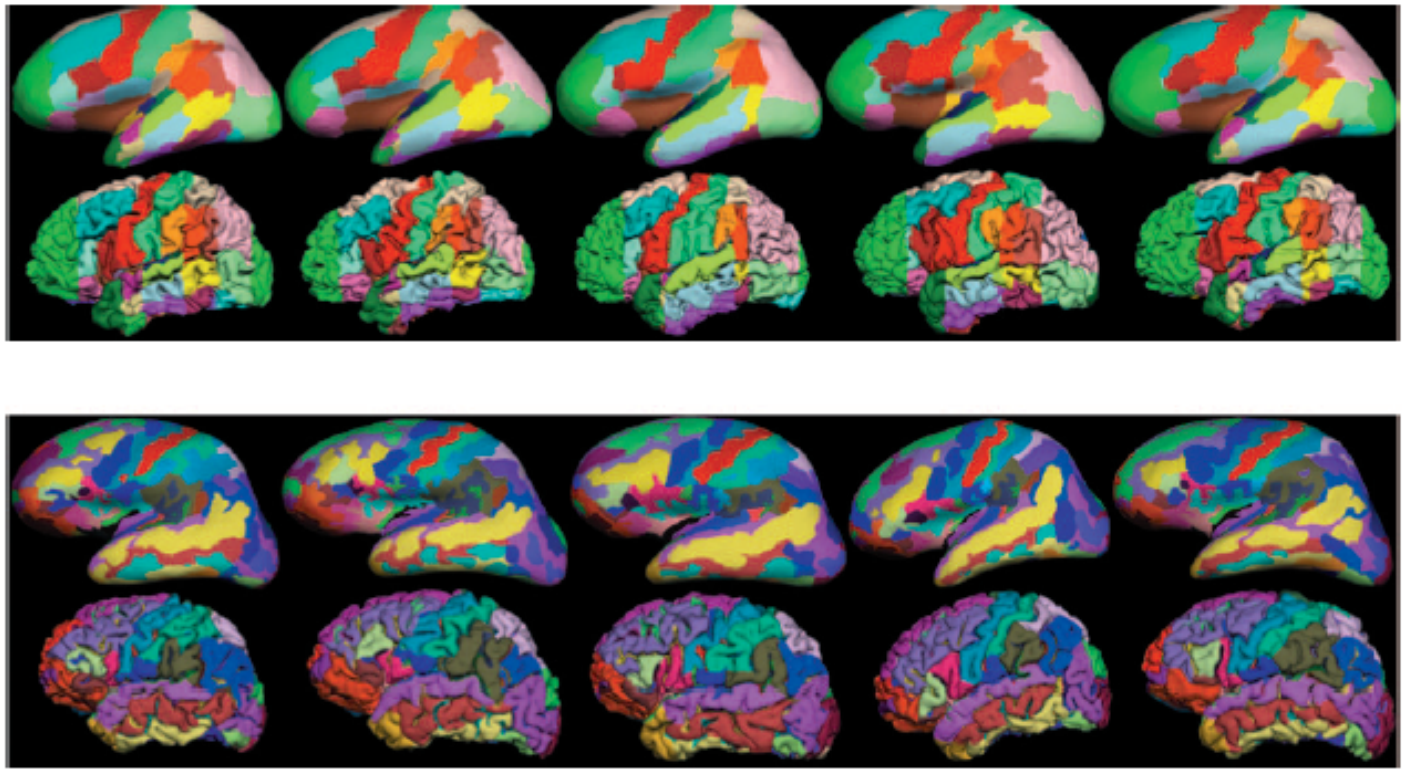
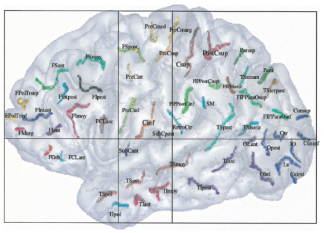
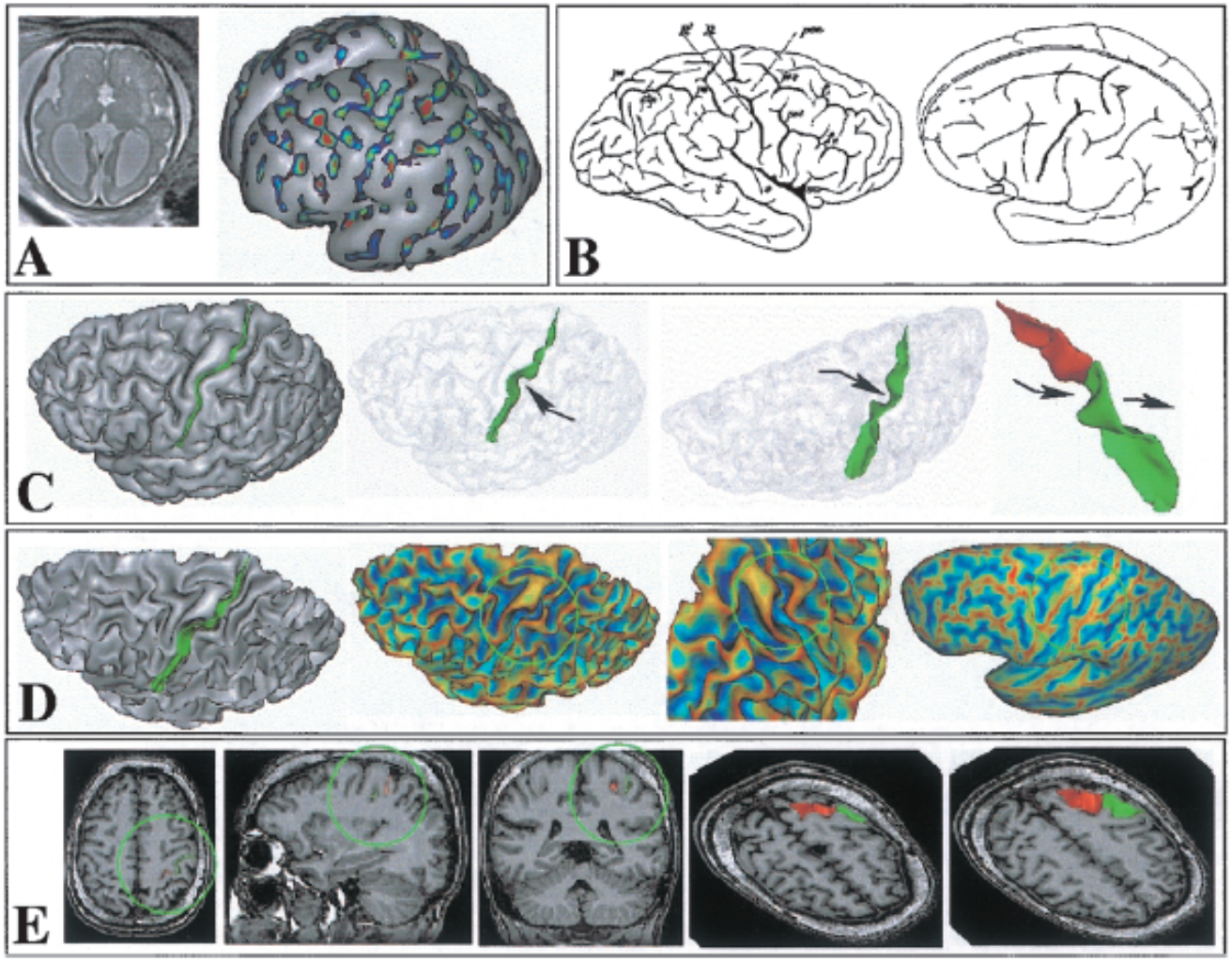


Figure 1. Lateral views of five left hemisphere examples of the CMA (top two rows) and SB (bottom two rows). Each pair of inflated (above) and pial (below) surface representations is from the subject.

Labeling in the future

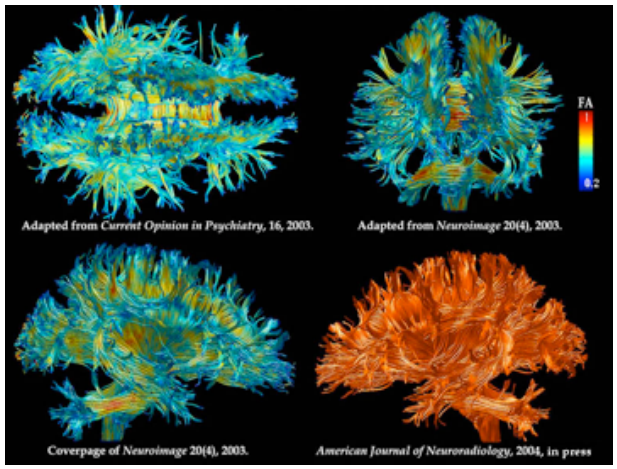
Sulcal roots

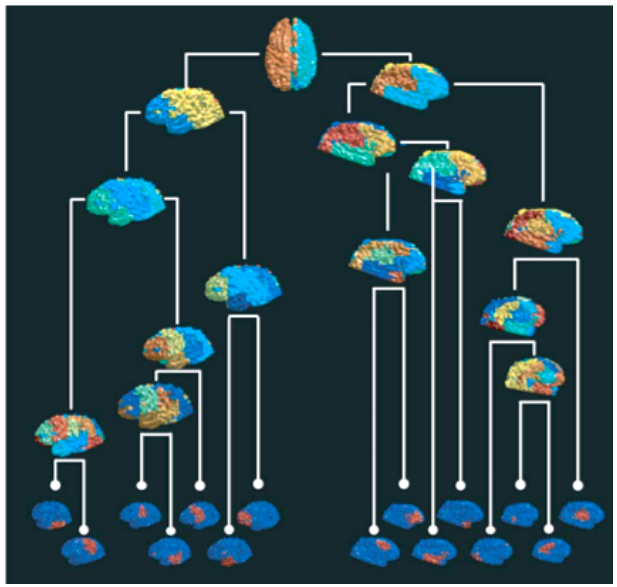


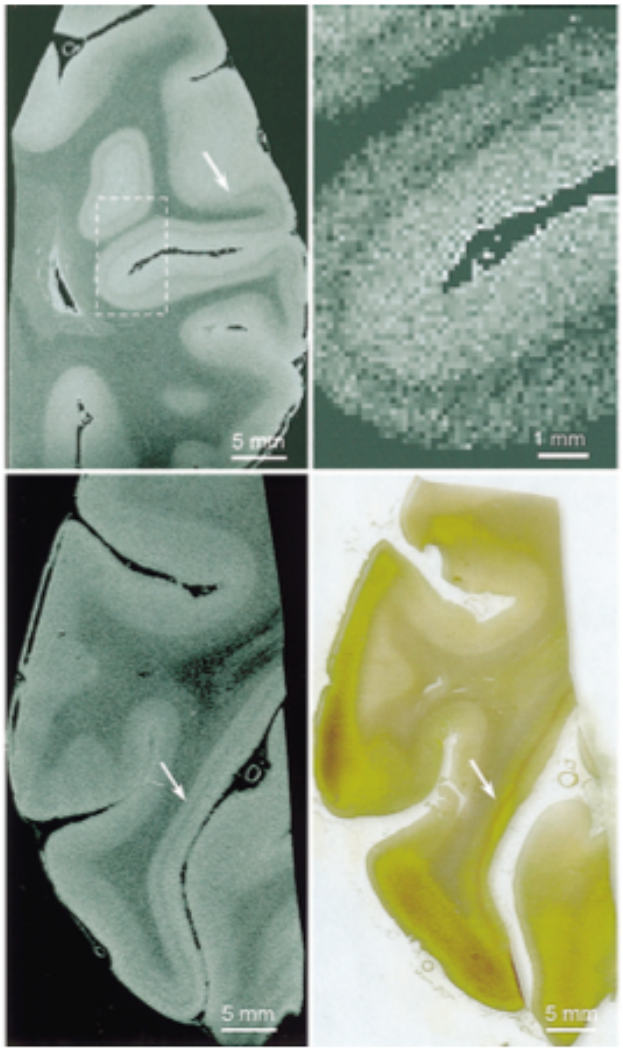


Labeling in the future

Tractography and architectonics







Mindboggle

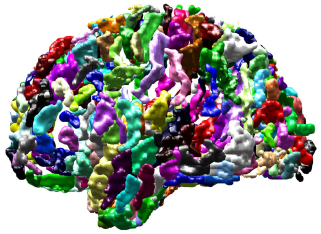
Extract pieces

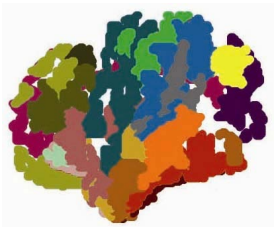
Match pieces

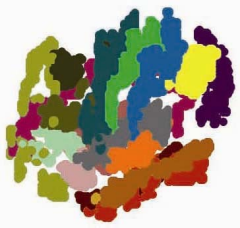
Transform boundaries

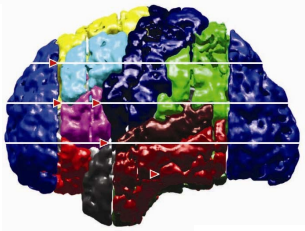
Warp labels

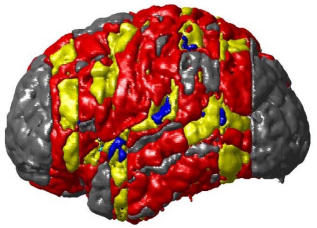
Use multiple atlases











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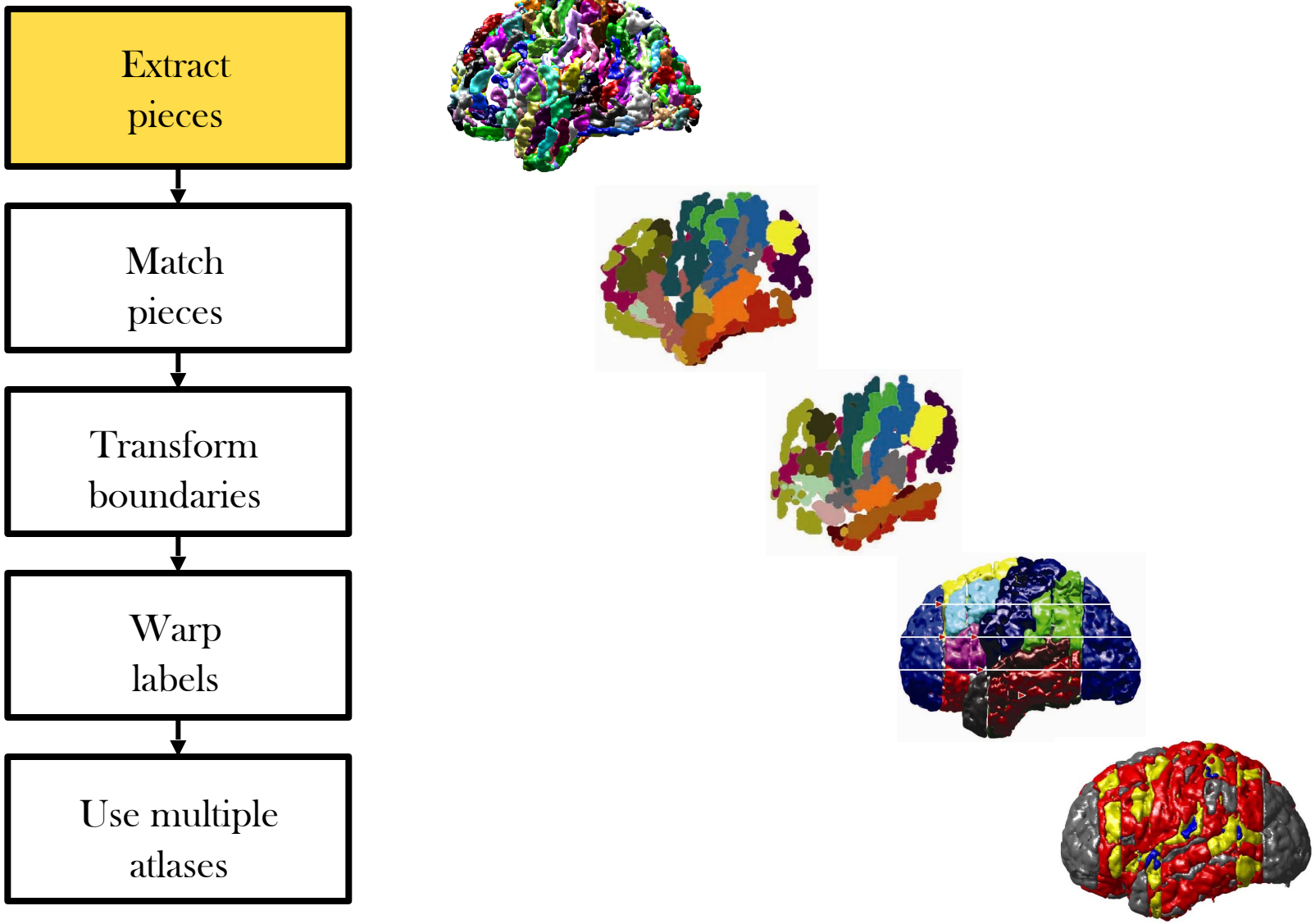
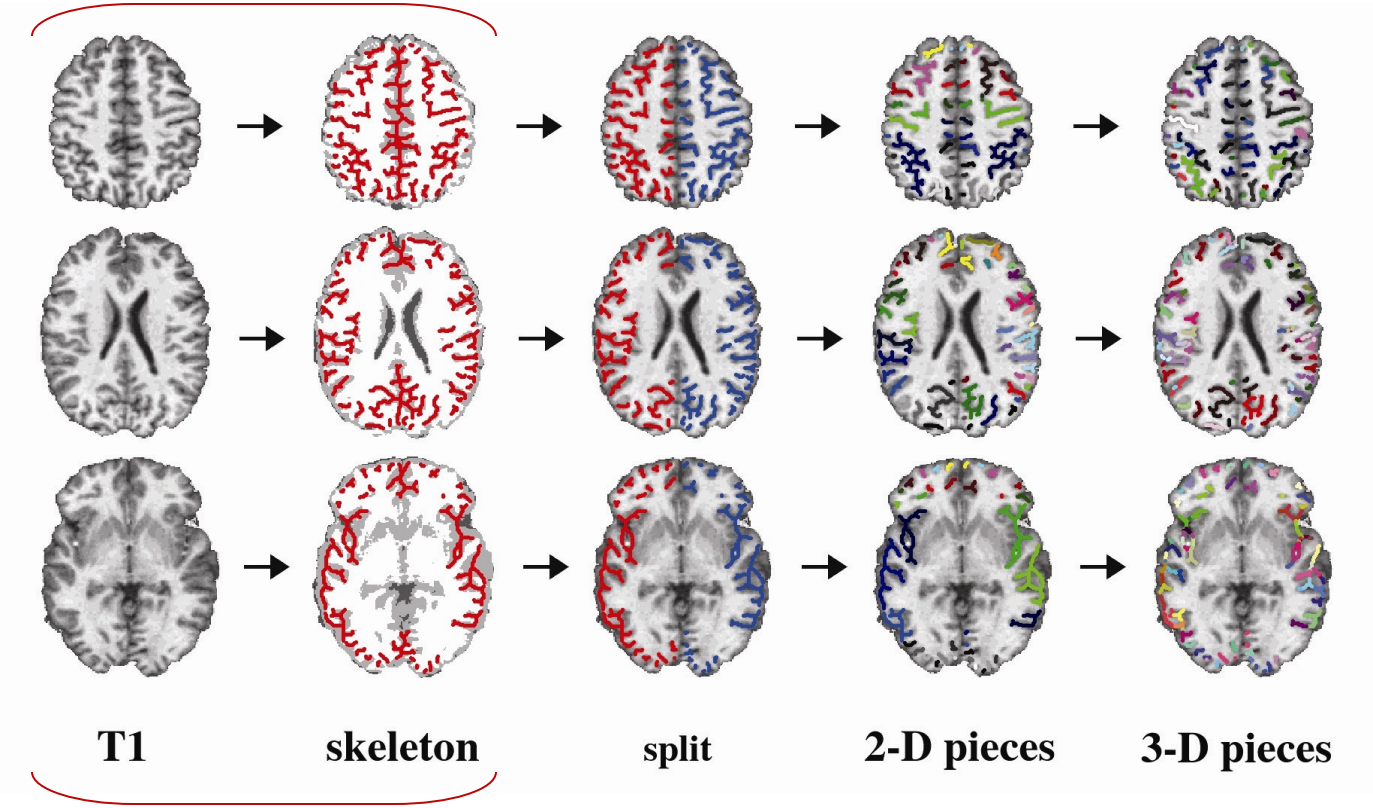
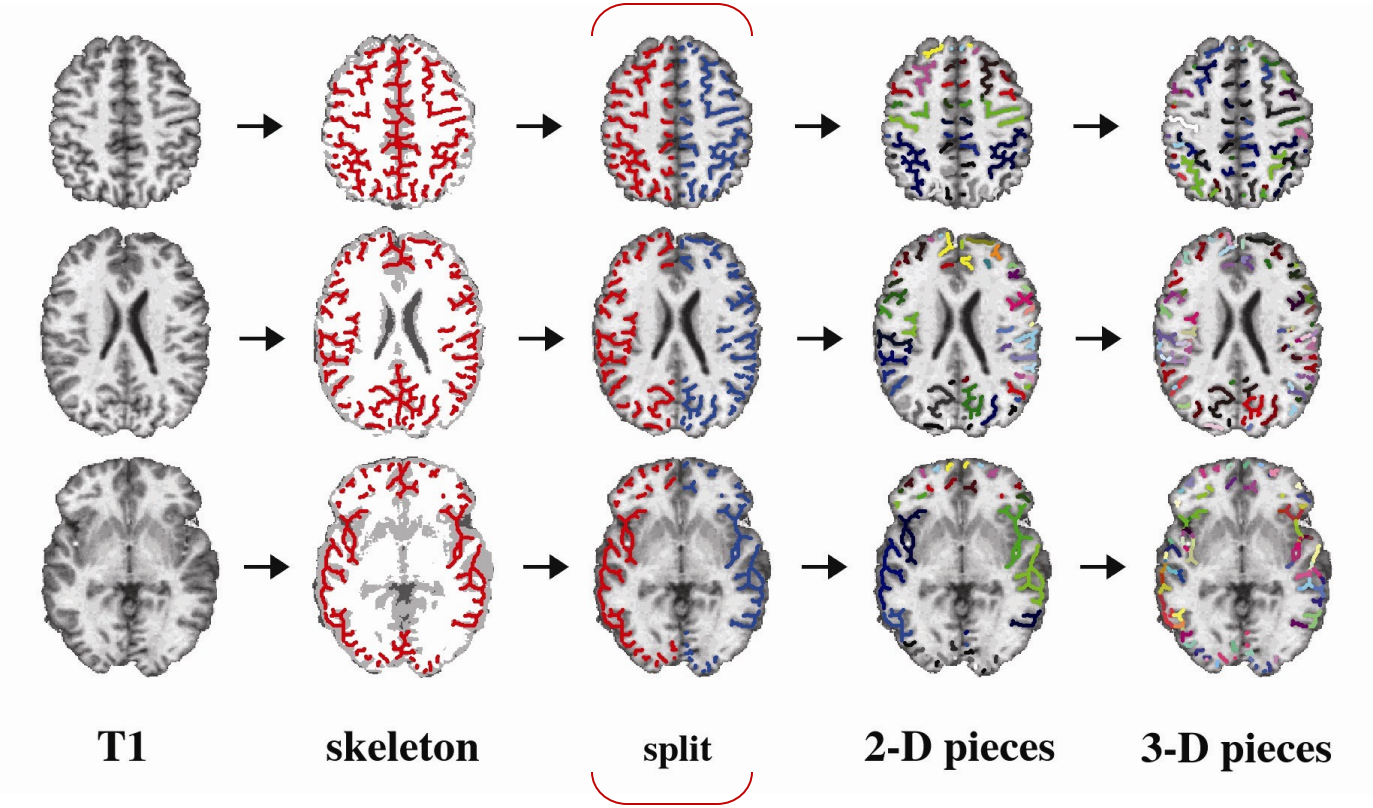

Extract pieces
Match pieces
Transform boundaries
Warp labels
Use multiple atlases

Extract pieces



- Skeletonize each slice of segmented non-white matter (only step in 2-D).
- Split the resulting sulcus skeleton into left and right hemispheres.
- 2-D pieces in adjacent slices are grouped to make 3-D pieces.

Extract pieces



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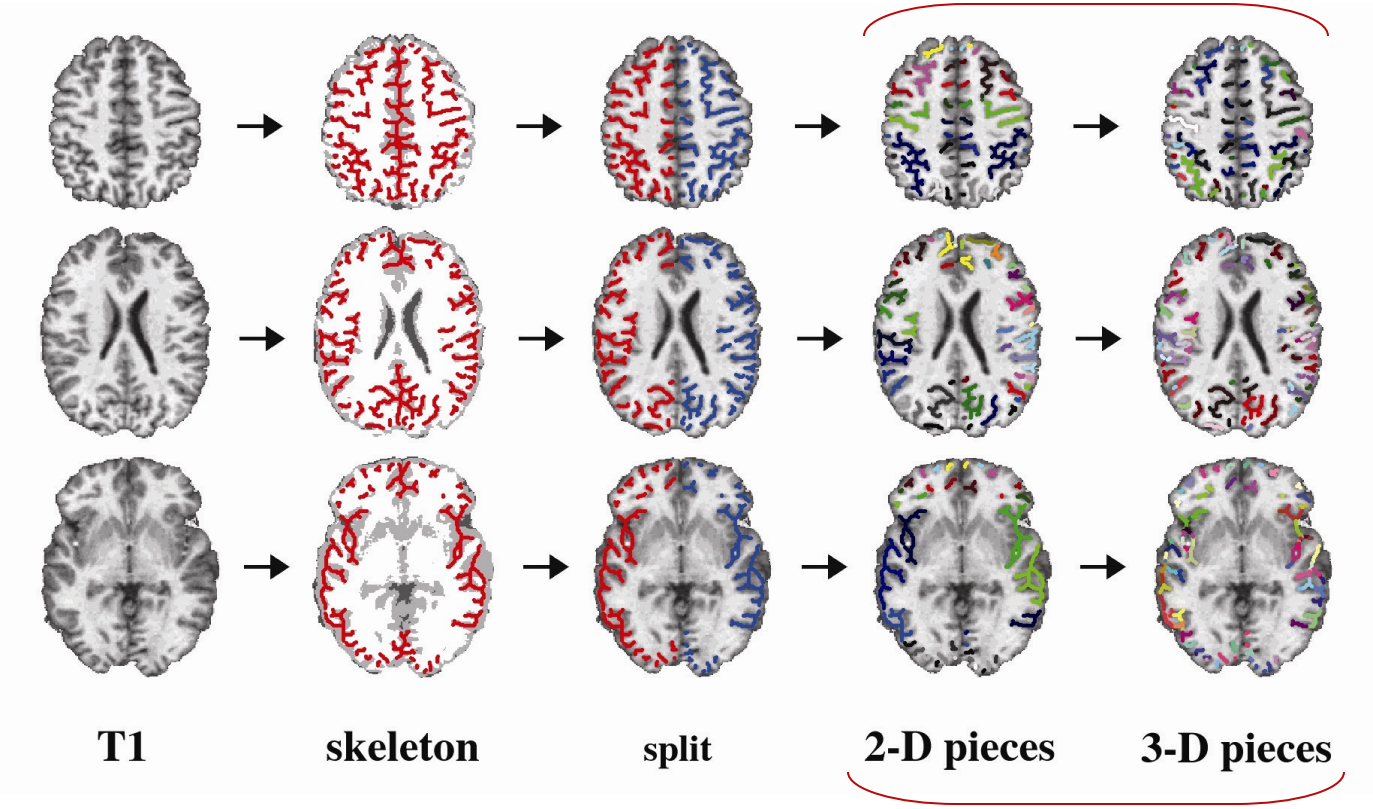

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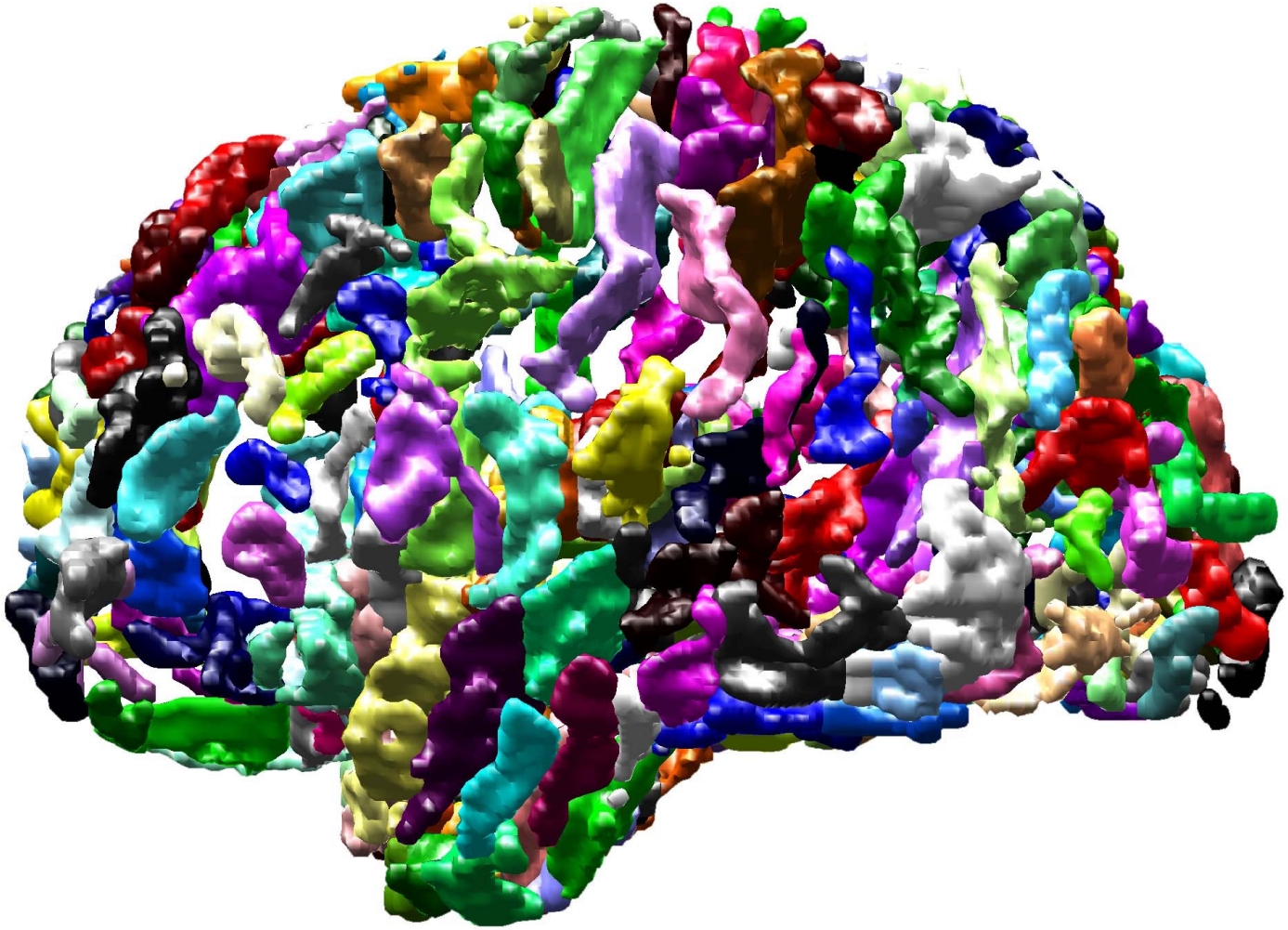
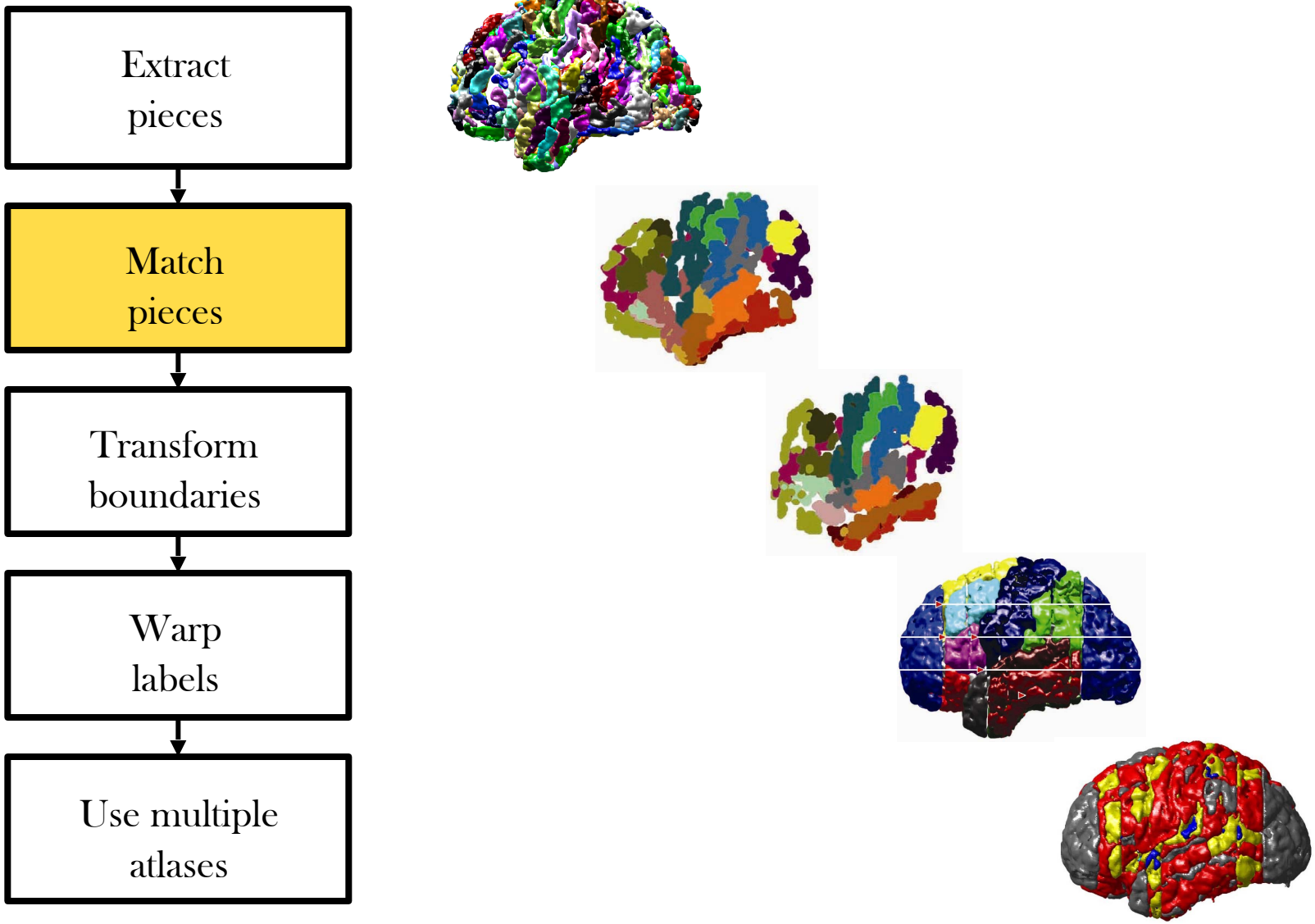


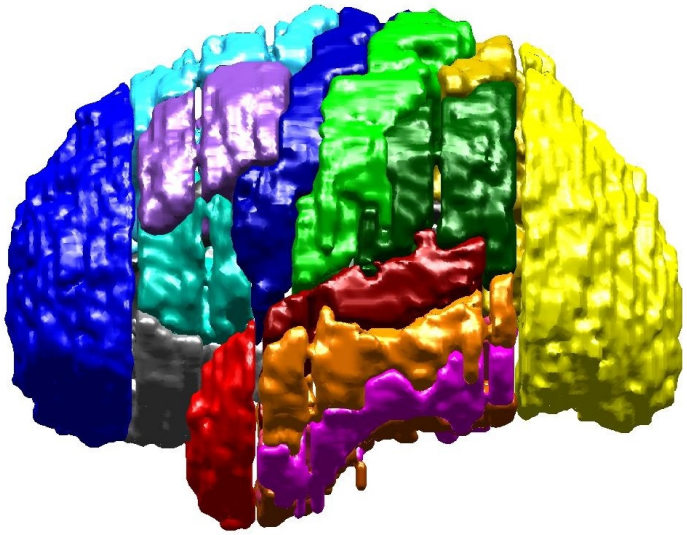
Mindboggle


Extract pieces
Match pieces
Transform boundaries
Warp labels
Use multiple atlases

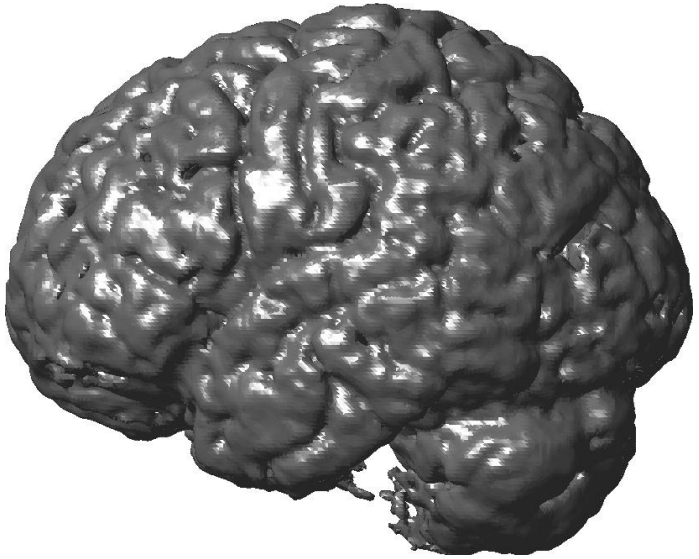
Match pieces

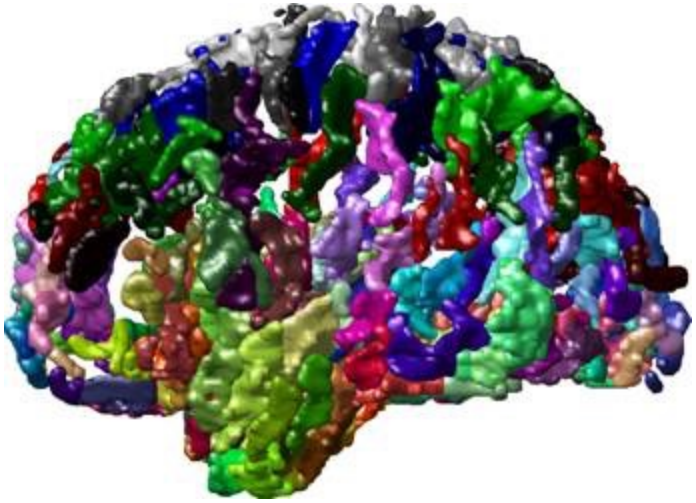
Atlas

Subject



?





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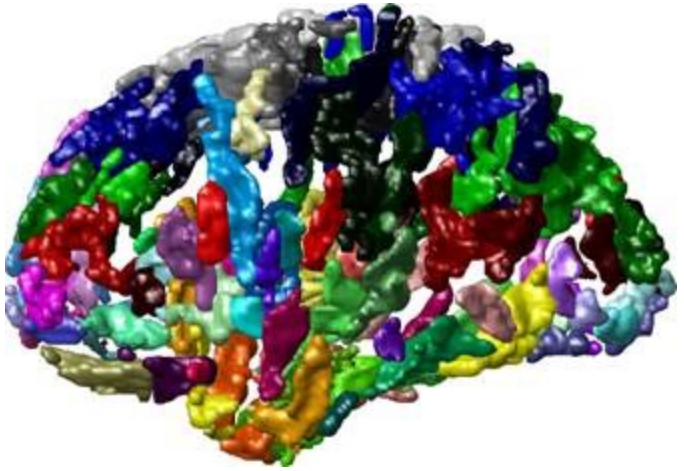
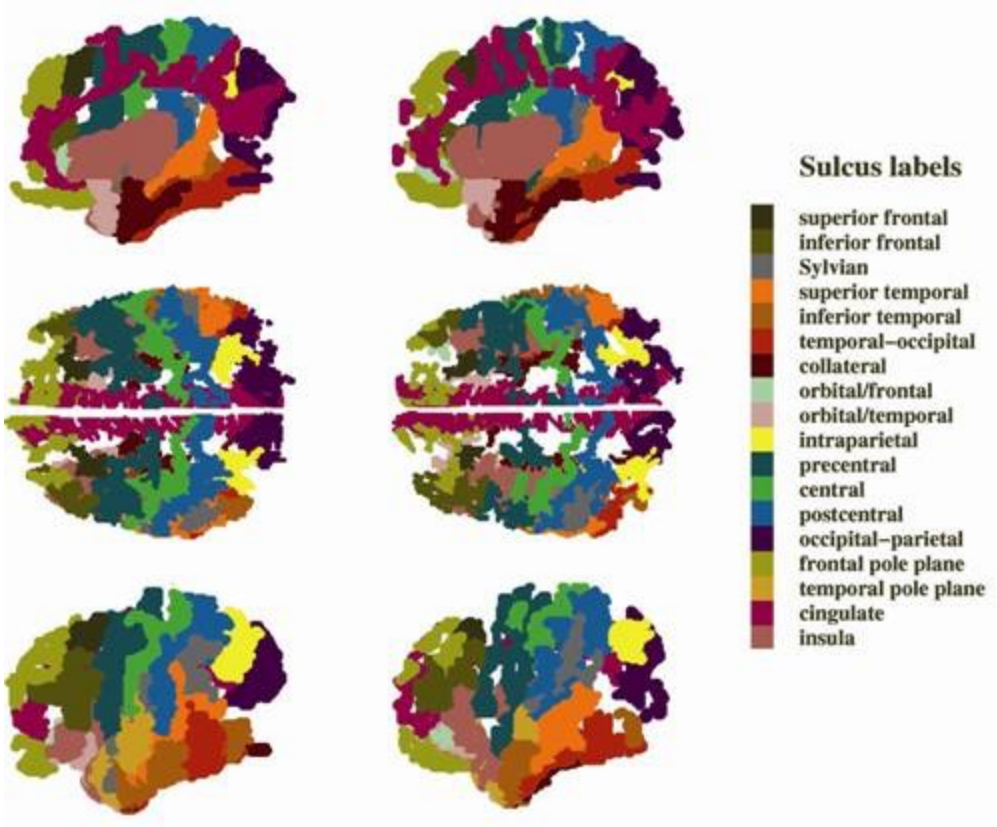


Match pieces

Atlas pieces
(grouped by sulci)

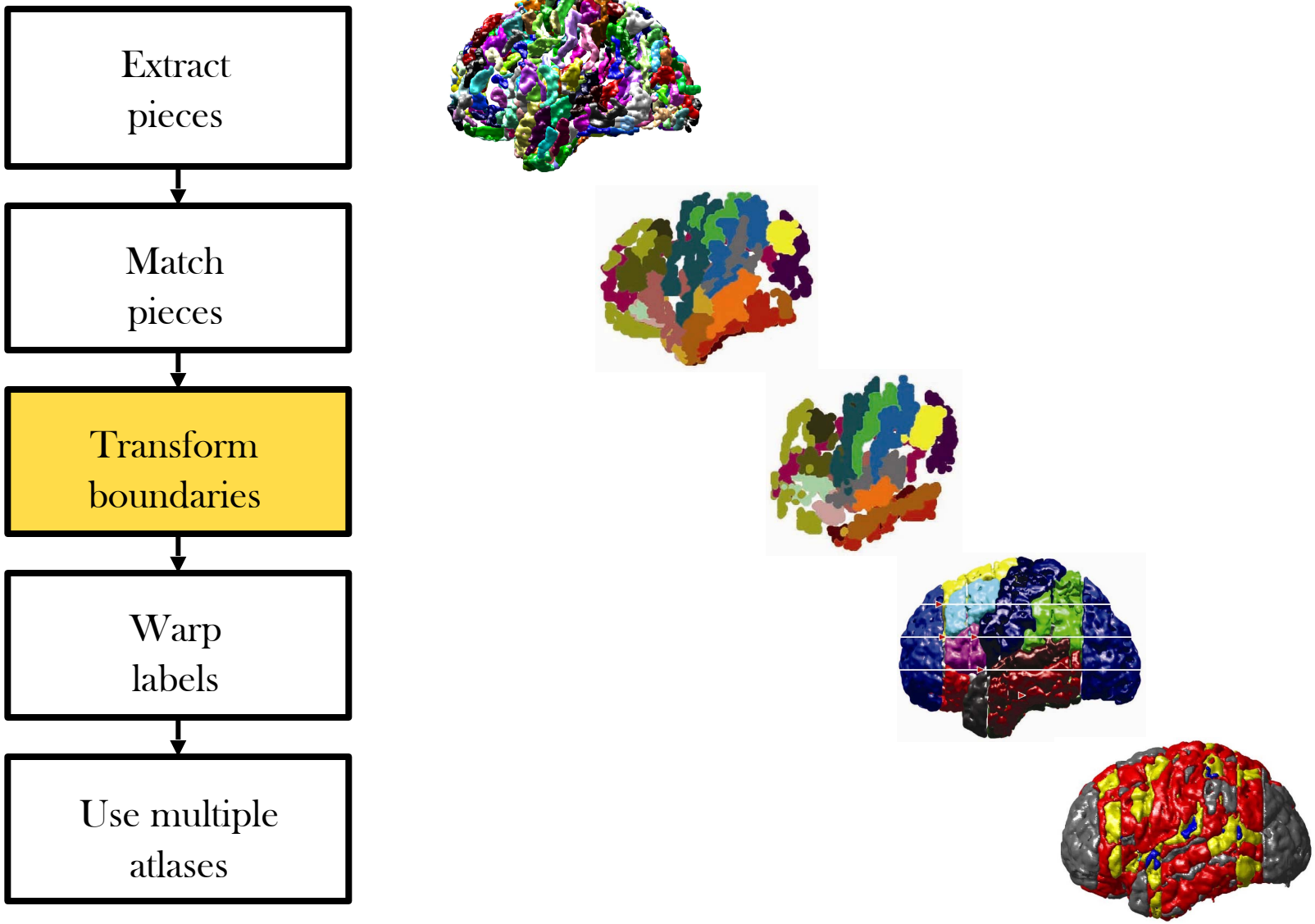
Subject pieces
(matches)



- Order matches by a cost function: $\text{Cost} = w_N N + w_V V + w_P P + w_O O$

$N = \Delta$ # voxels $P = \Delta$ mean position
$V = \Delta$ # subvolumes O = non-overlap

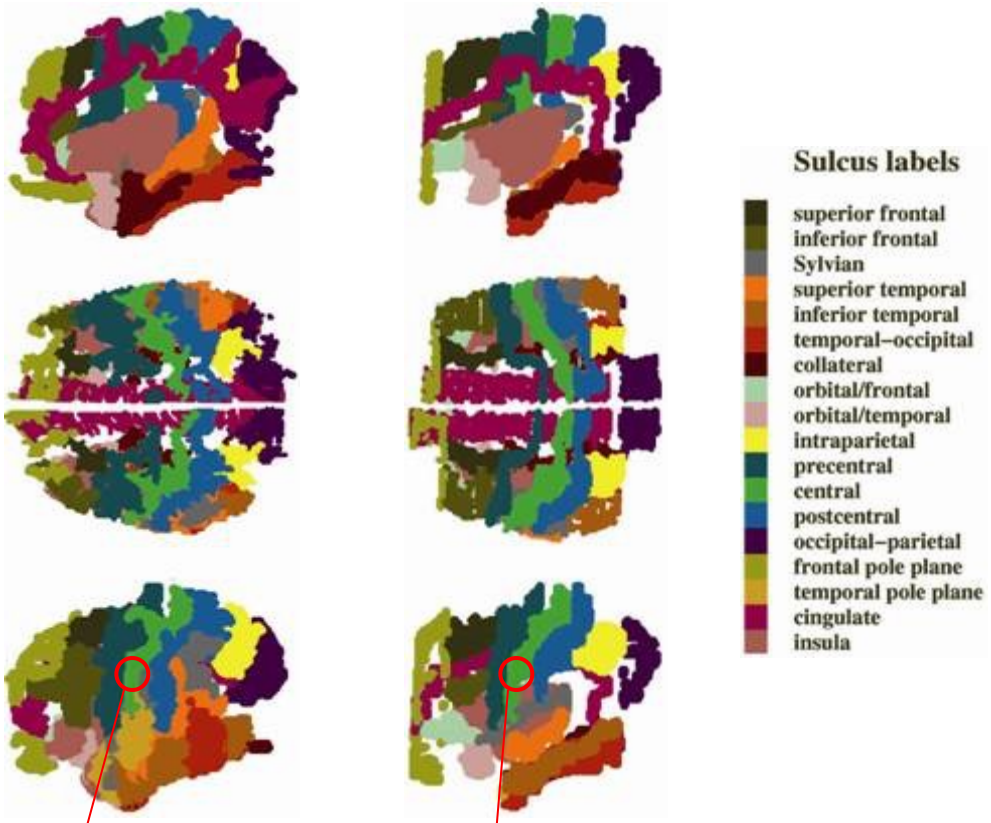
Mindboggle


Extract pieces
Match pieces
Transform boundaries
Warp labels
Use multiple atlases

Transform boundaries

Atlas pieces
(grouped by sulci)

Label boundaries
(grouped by sulci)



- Each atlas piece is paired with a patch of nearest label boundary points.

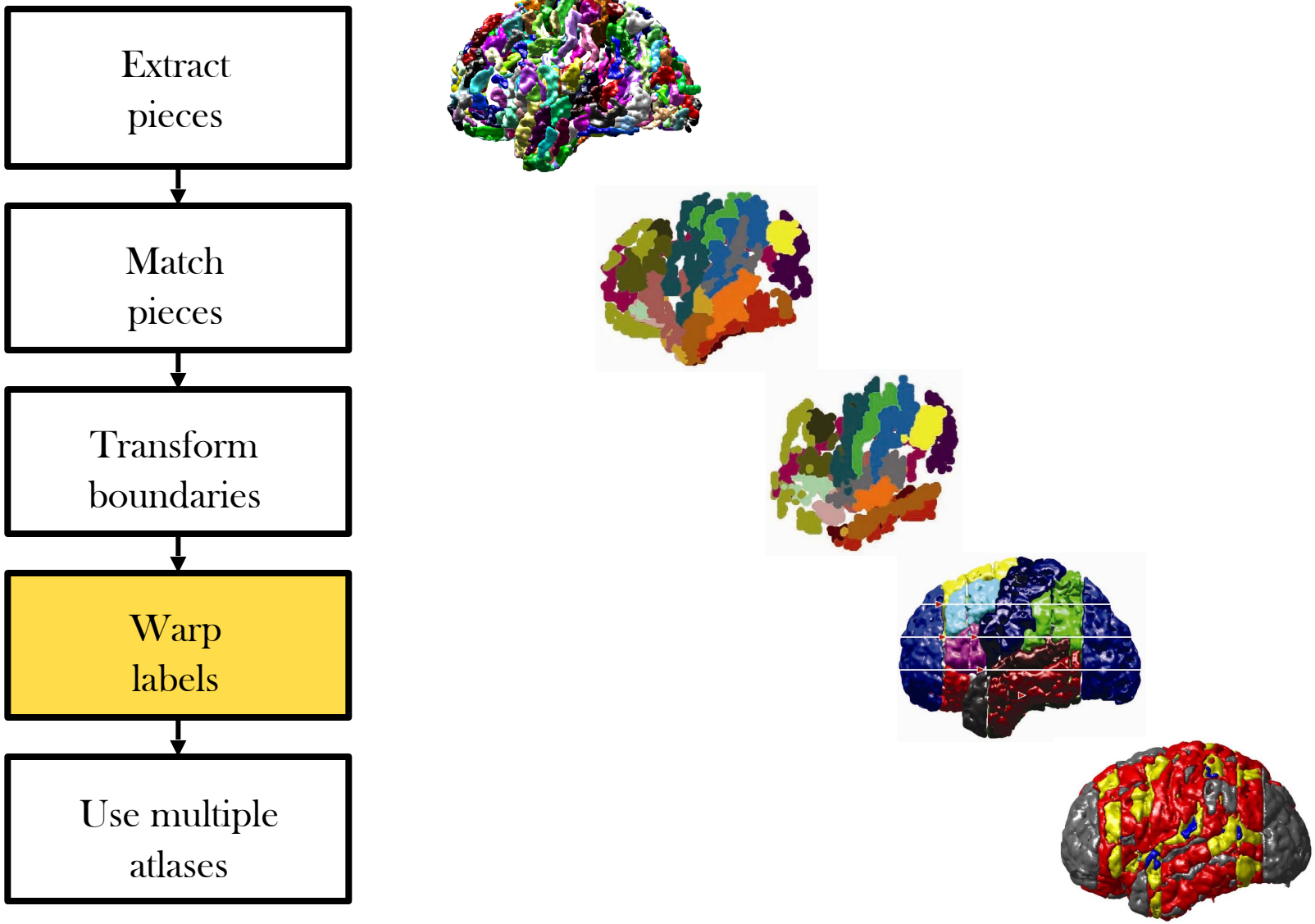
Transform boundaries

Atlas pieces
(grouped by sulci)

Label boundaries
(grouped by sulci)

→ Subject

Mindboggle


Extract pieces
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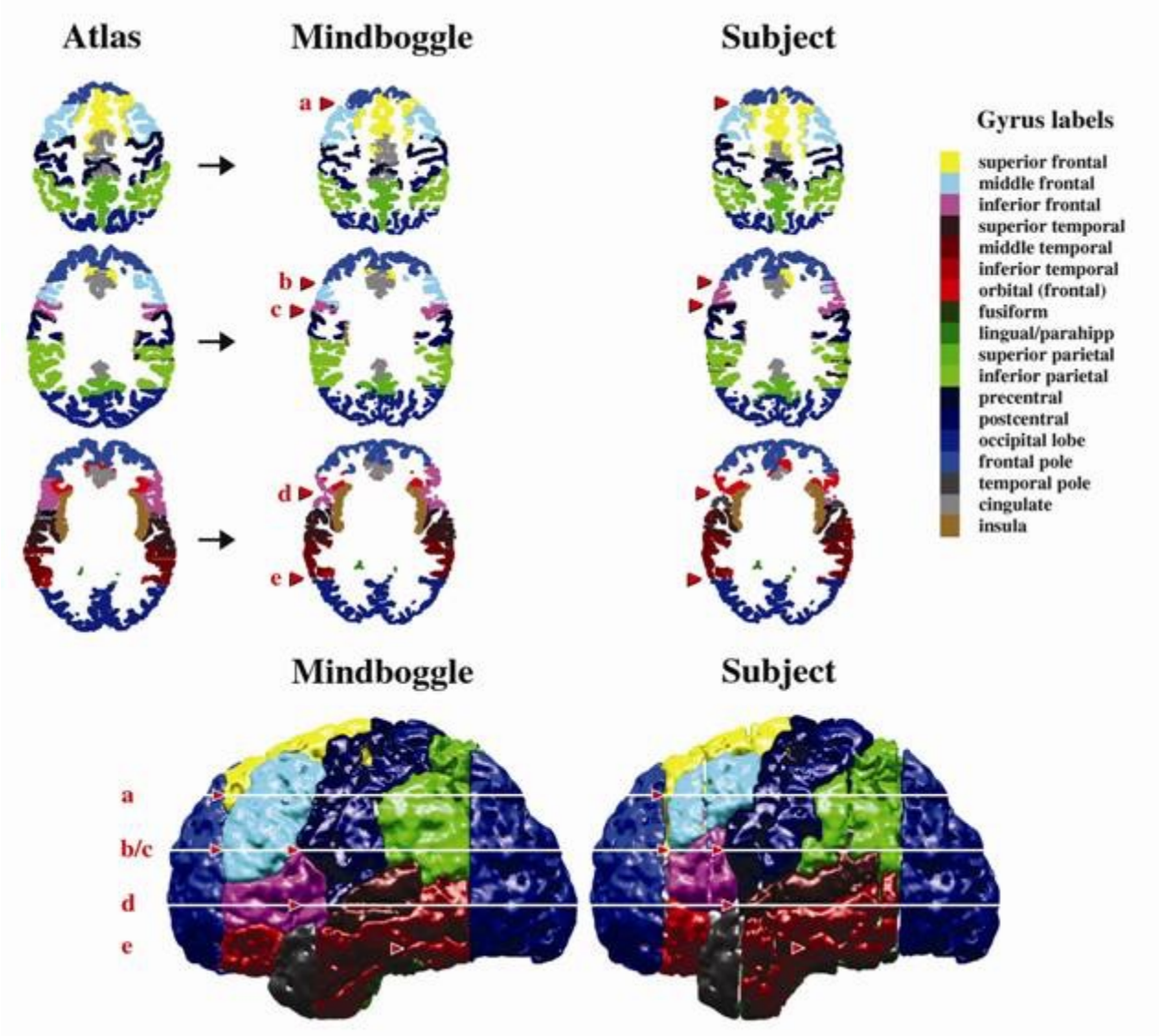
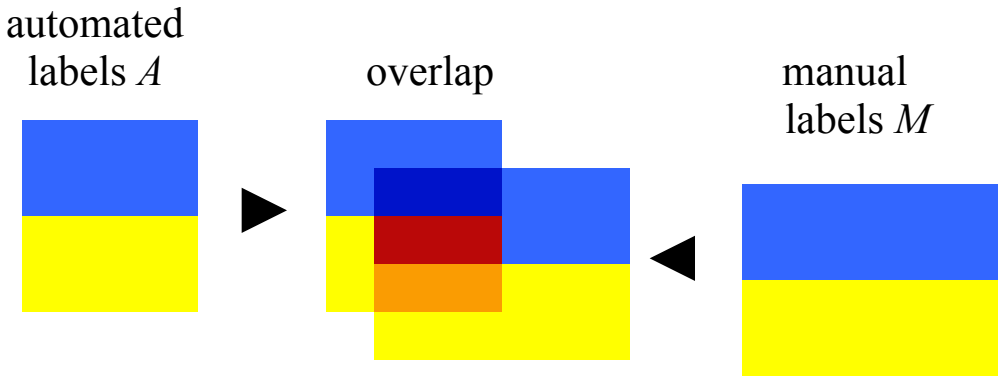
Warp labels


Atlas
Mindboggle
Subject
a
b
c
d
e
Gyrus labels
superior frontal
middle frontal
inferior frontal
superior temporal
middle temporal
inferior temporal
orbital (frontal)
fusiform
lingual/parahipp
superior parietal
inferior parietal
precentral
postcentral
occipital lobe
frontal pole
temporal pole
cingulate
insula
Mindboggle
Subject
a
b/c
d
e

Evaluation



Label agreement metrics:

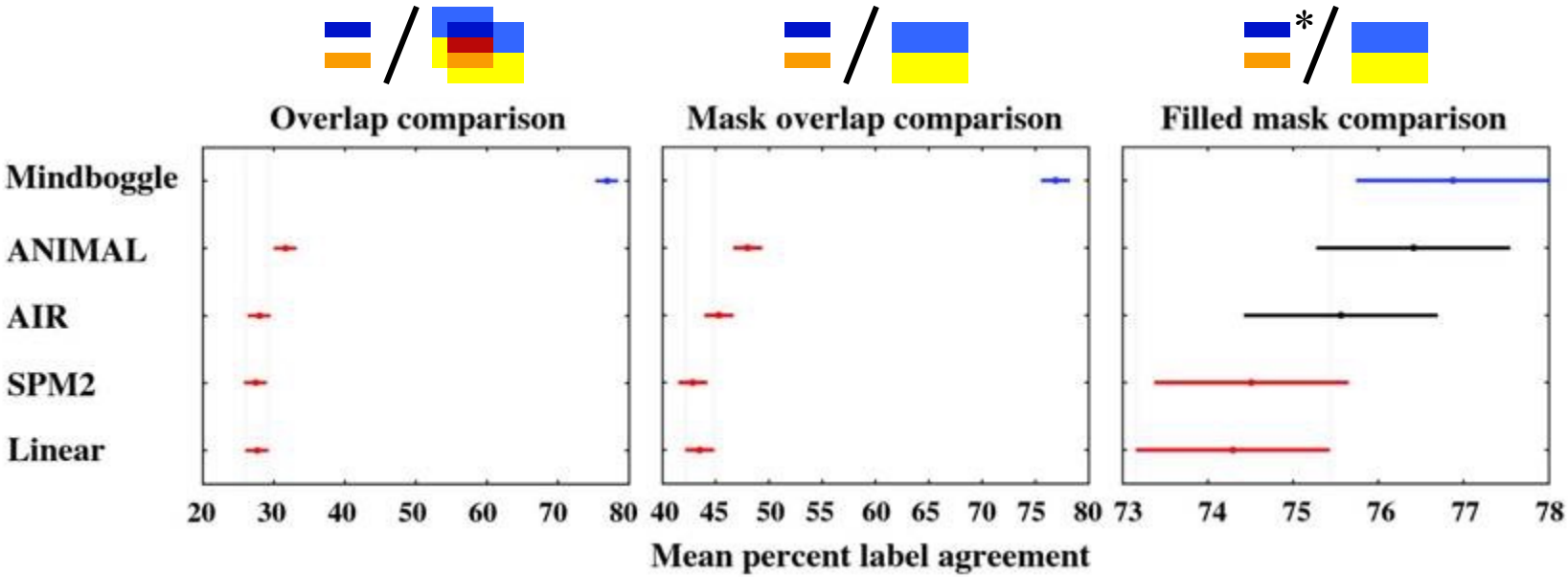
$$V_a = \frac{\text{intersection with the same label}}{V_c = \text{comparison volume}} = \frac{\blacksquare}{?}$$

intersection $= V_a /$ intersection of atlas and subject $= \blacksquare / \blacksquare = \frac{\sum|A_i \cap M_i|}{\sum|A \cap M_i|}$

overlap $= V_a /$ union of atlas and subject $= \blacksquare / \blacksquare = \frac{\sum|A_i \cap M_j|}{\sum|A_i \cup M_i|}$

mask overlap, filled mask overlap $= V_a /$ subject $= \blacksquare / \blacksquare = \frac{\sum|A_i \cap M_i|}{\sum|M_i|}$

Evaluation

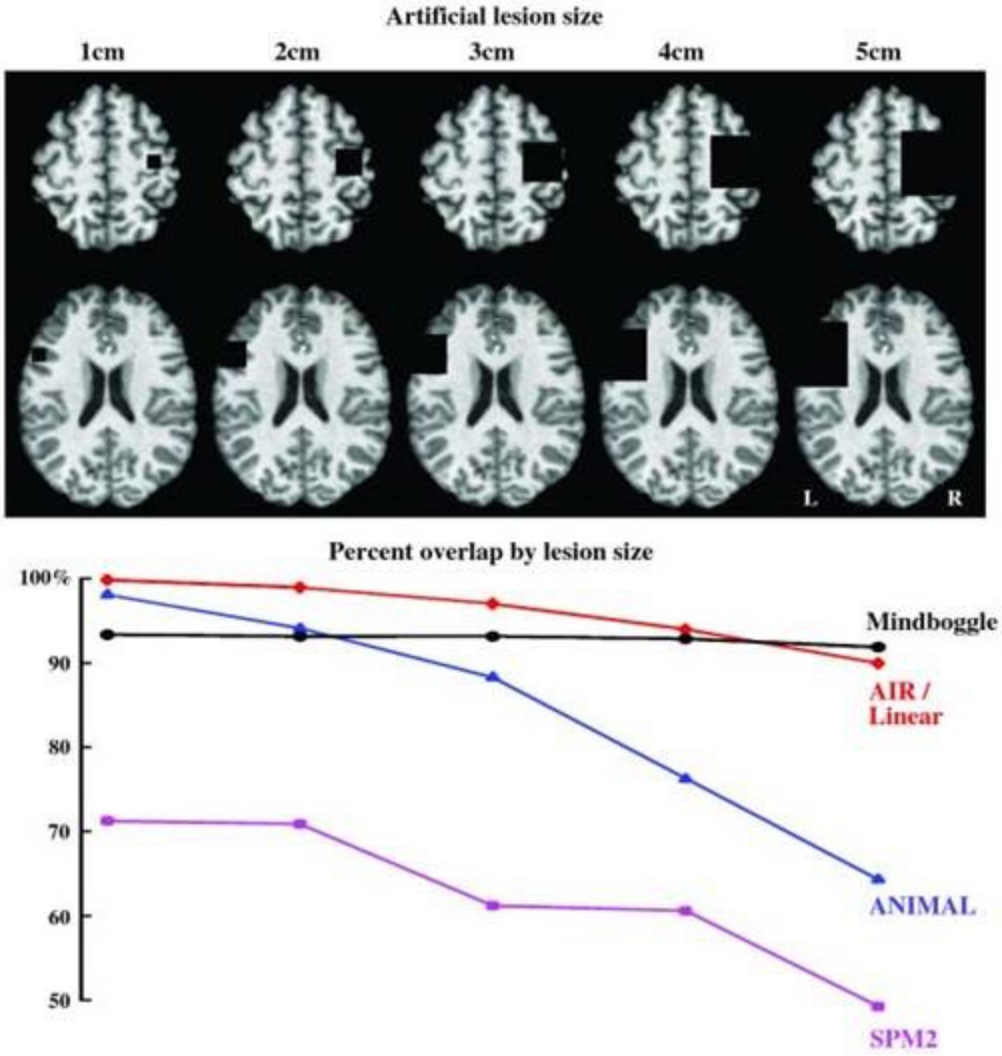


- A one-way ANOVA was performed to test if the means are the same for the label agreements obtained by each of the methods.

- A multiple comparison test was then performed to determine which pair of means are significantly different (95% confidence interval around the mean, based on the Studentized range distribution).

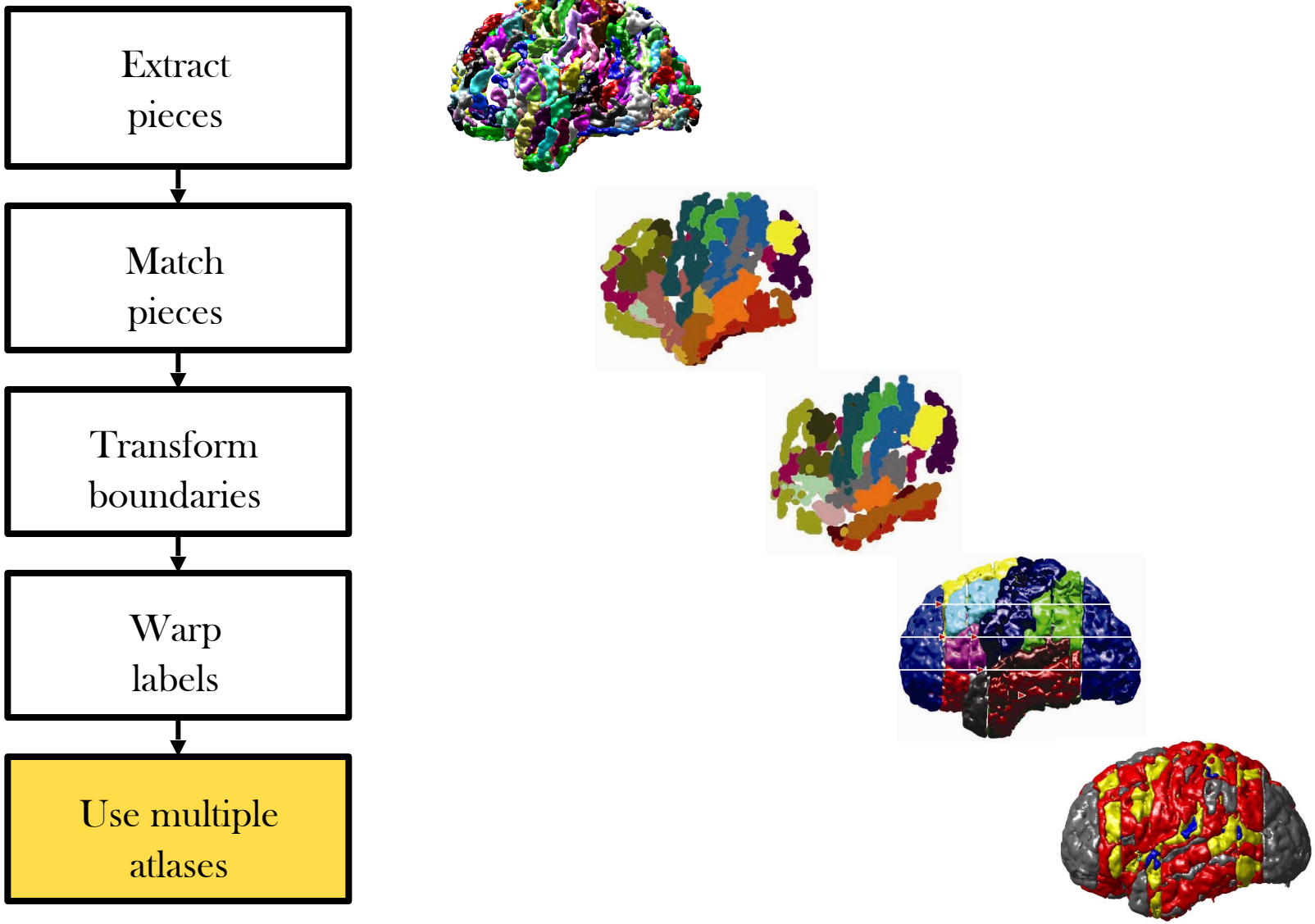
- Mindboggle obtained a significantly higher mean filled mask label agreement than did linear registration or SPM2 ($p < 0.05$).

Evaluation



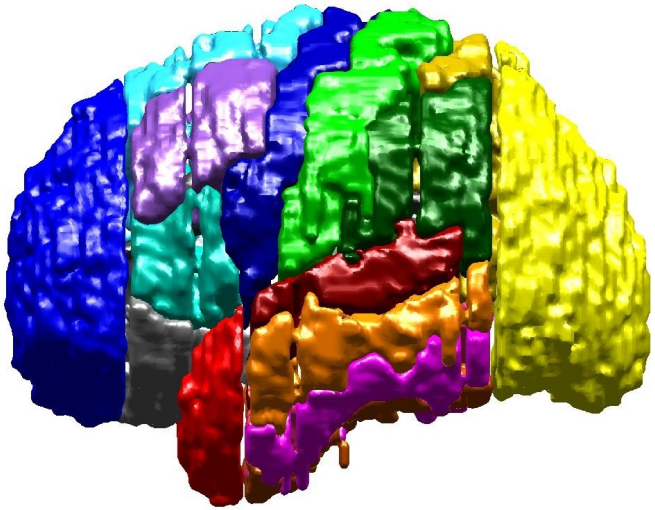
- The atlas was used to label an artificially lesioned version of itself.

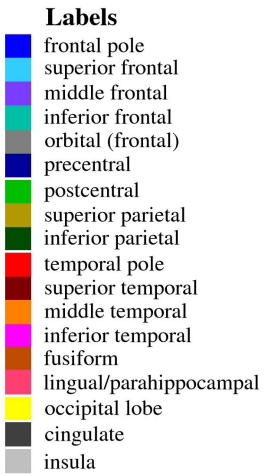
Mindboggle


Extract pieces
Match pieces
Transform boundaries
Warp labels
Use multiple atlases

Single atlas

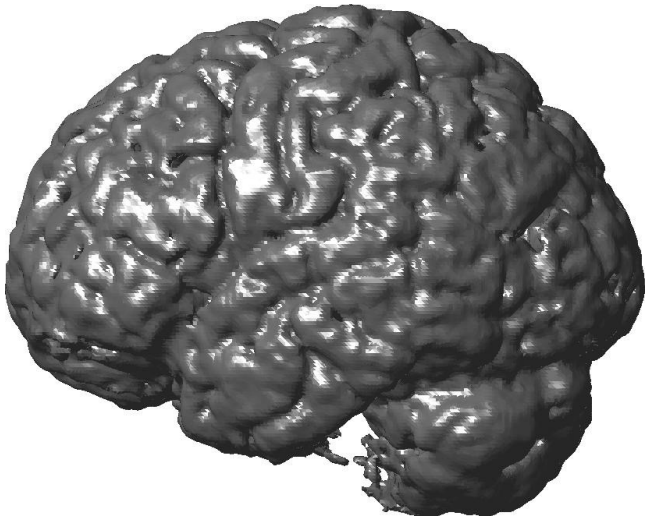
Atlas



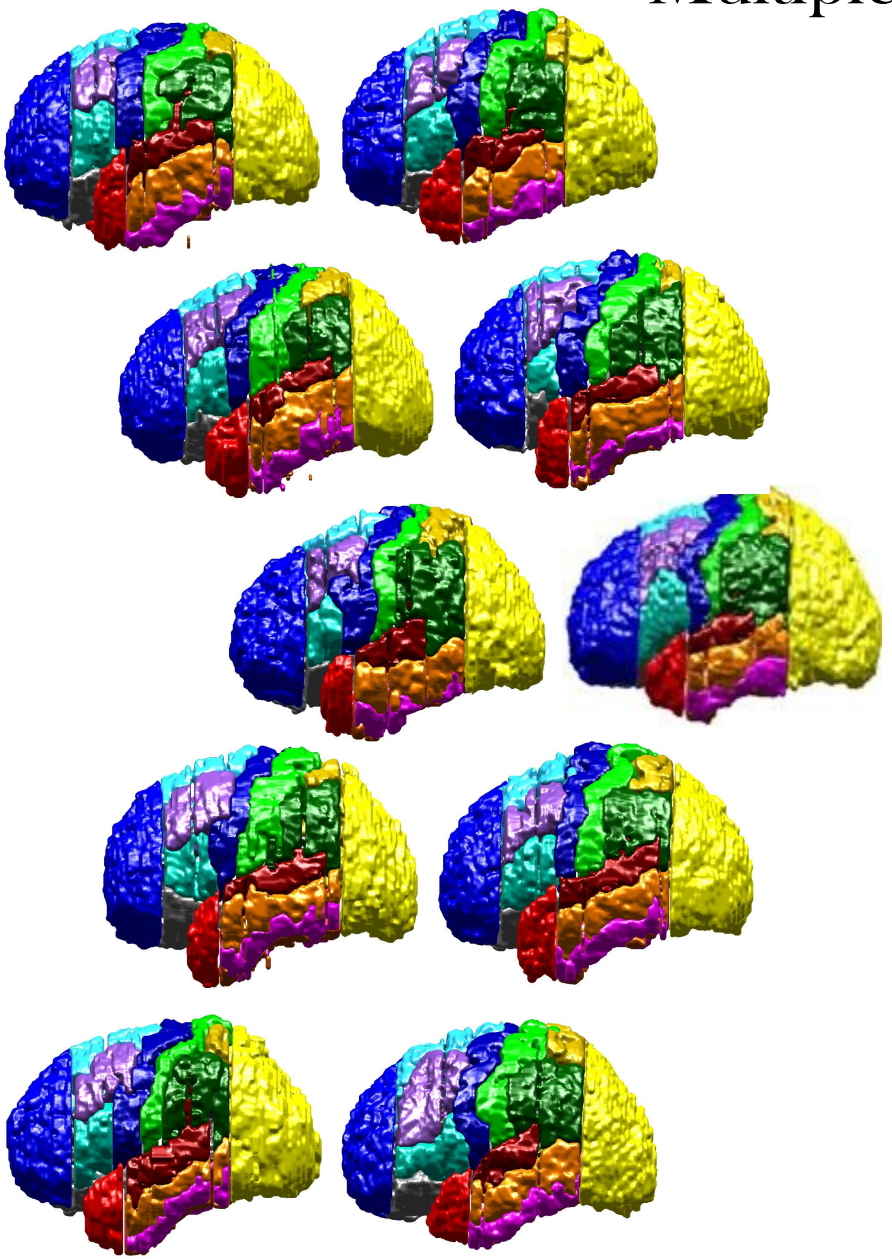


?

Subject

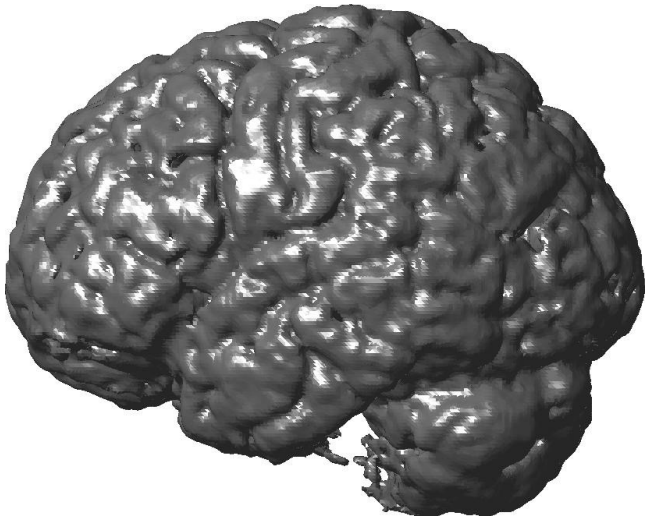


Multiple atlases



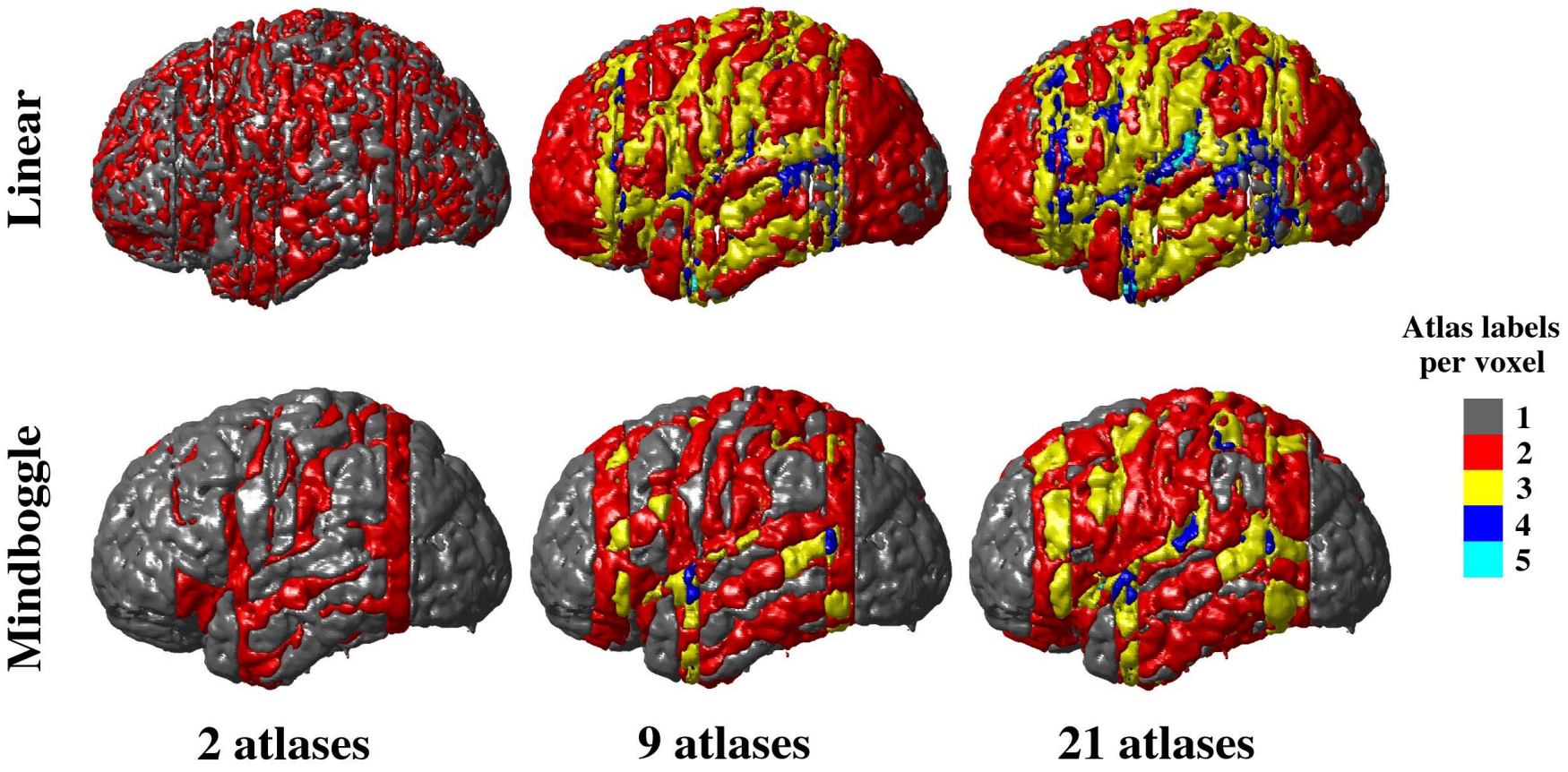
?

Subject



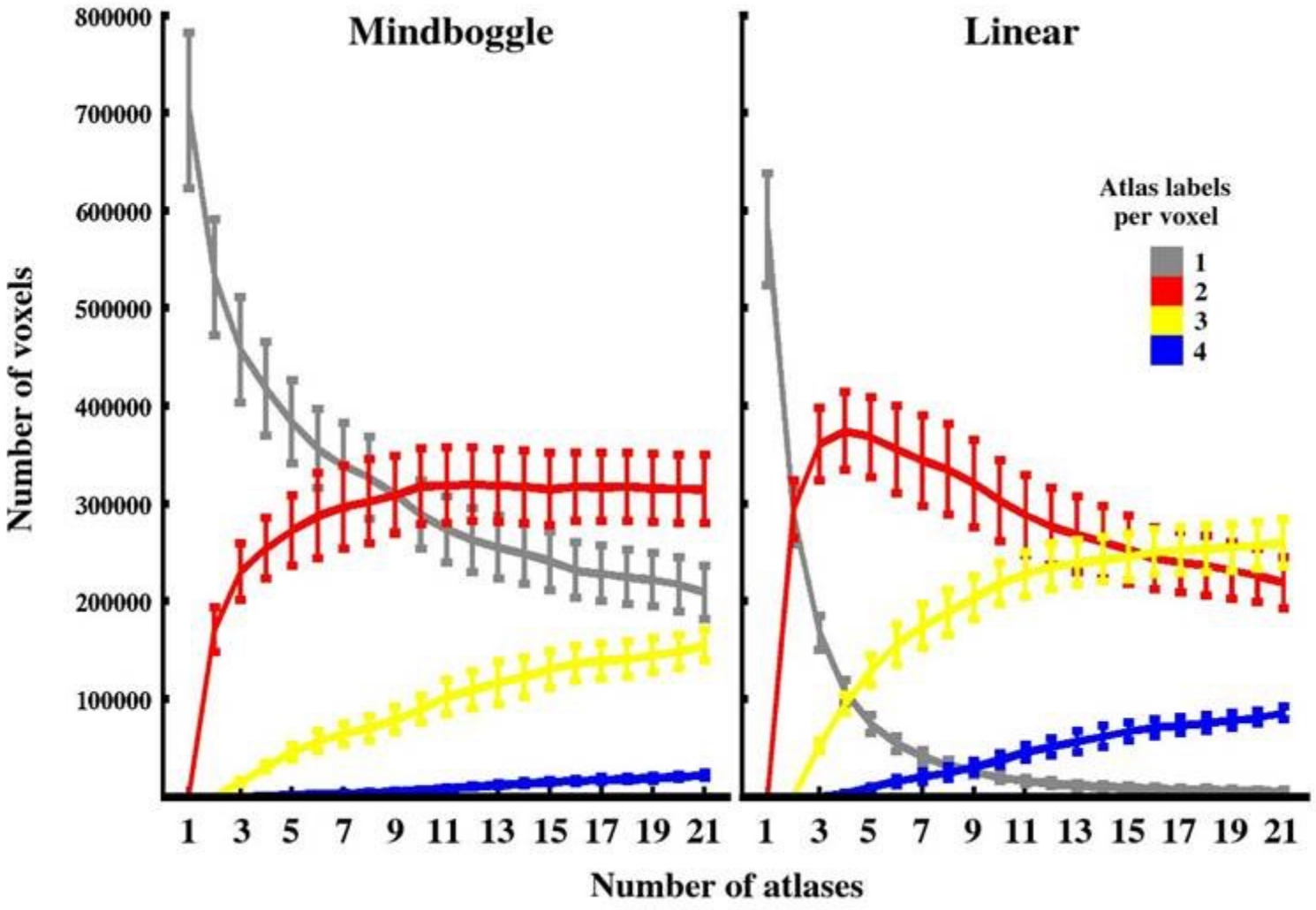
Multiple atlases

Number of labels per voxel



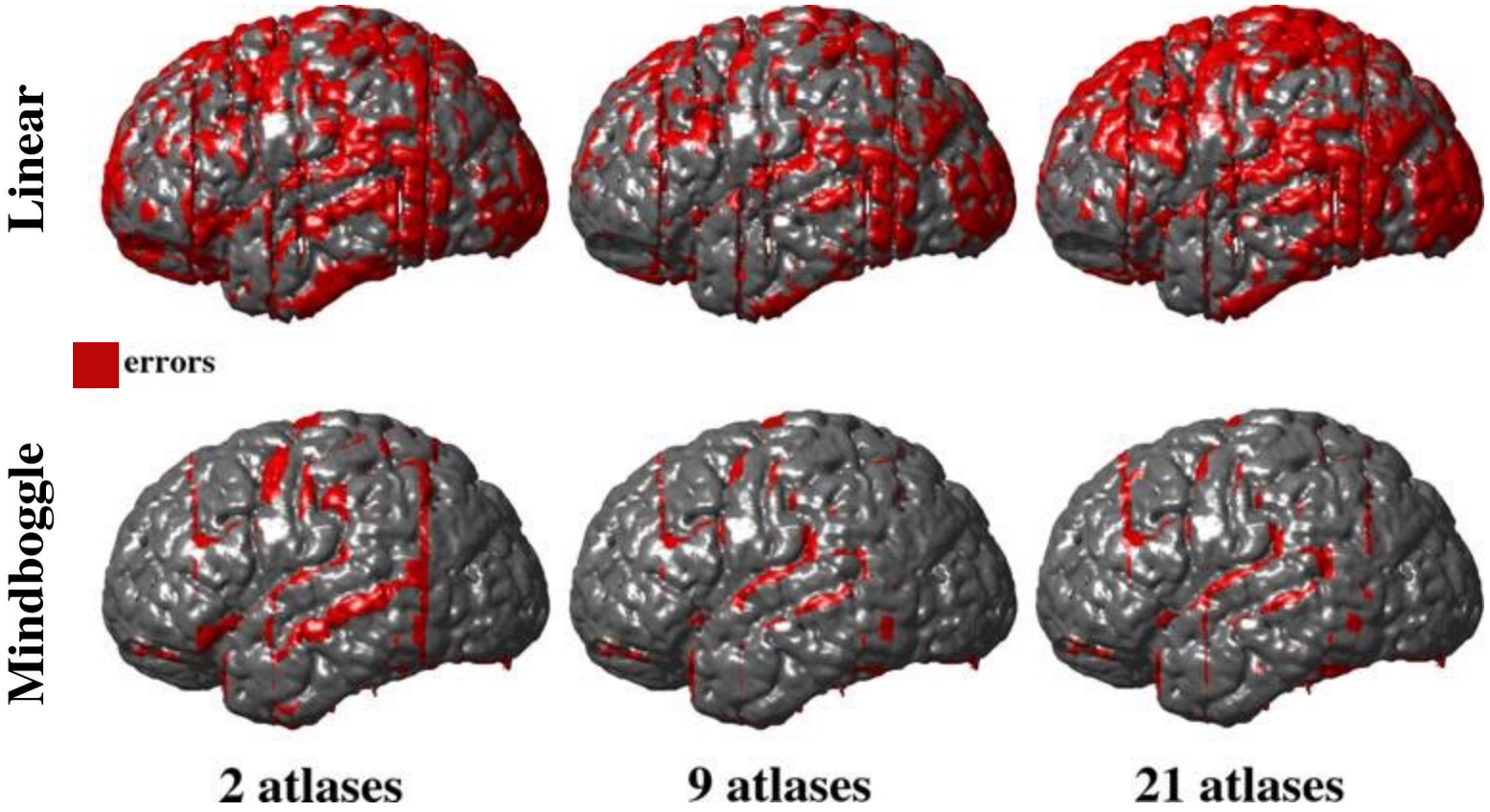
Multiple atlases

Number of labels per voxel: voxel counts



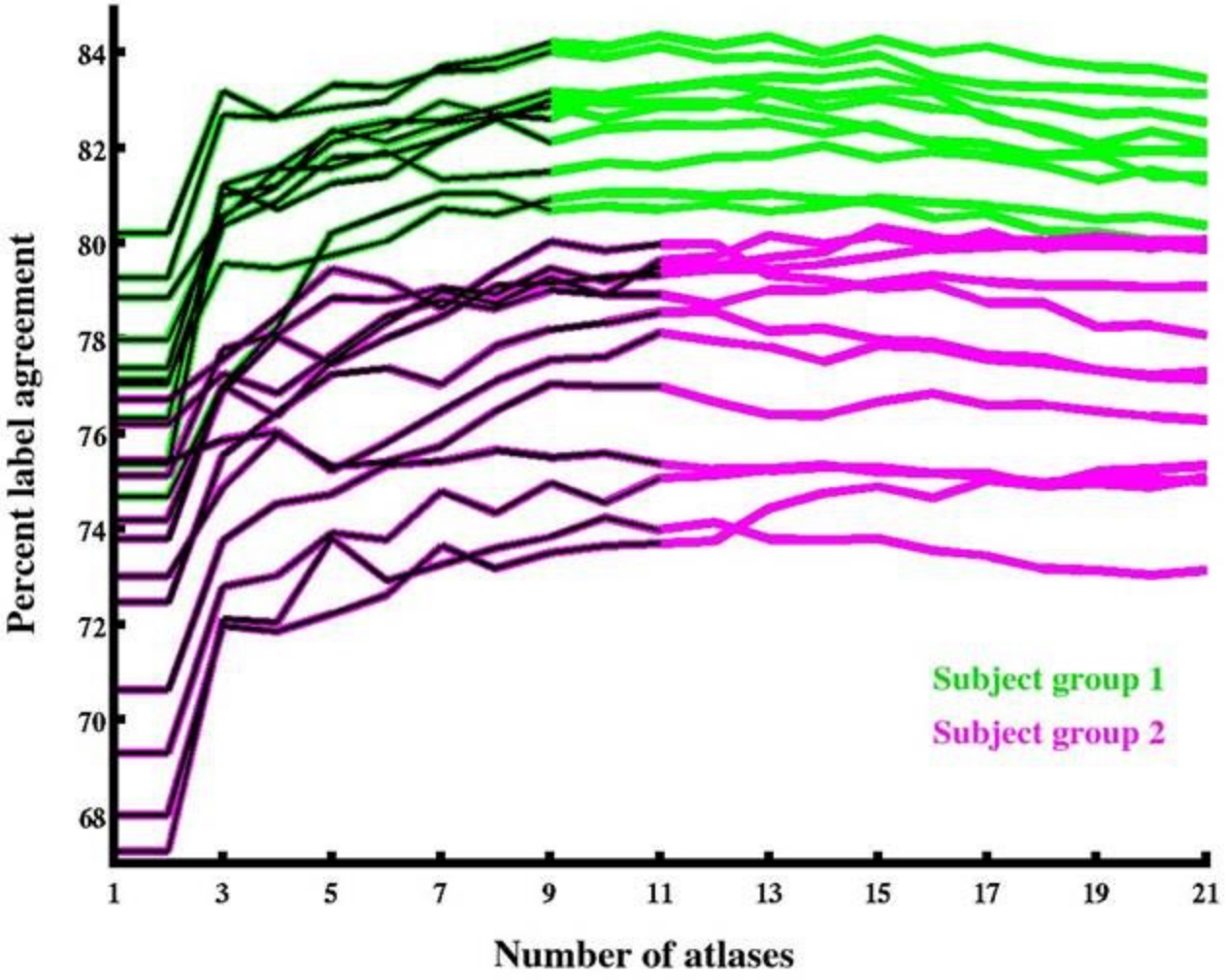
Evaluation

Errors: automated labels ≠ manual labels



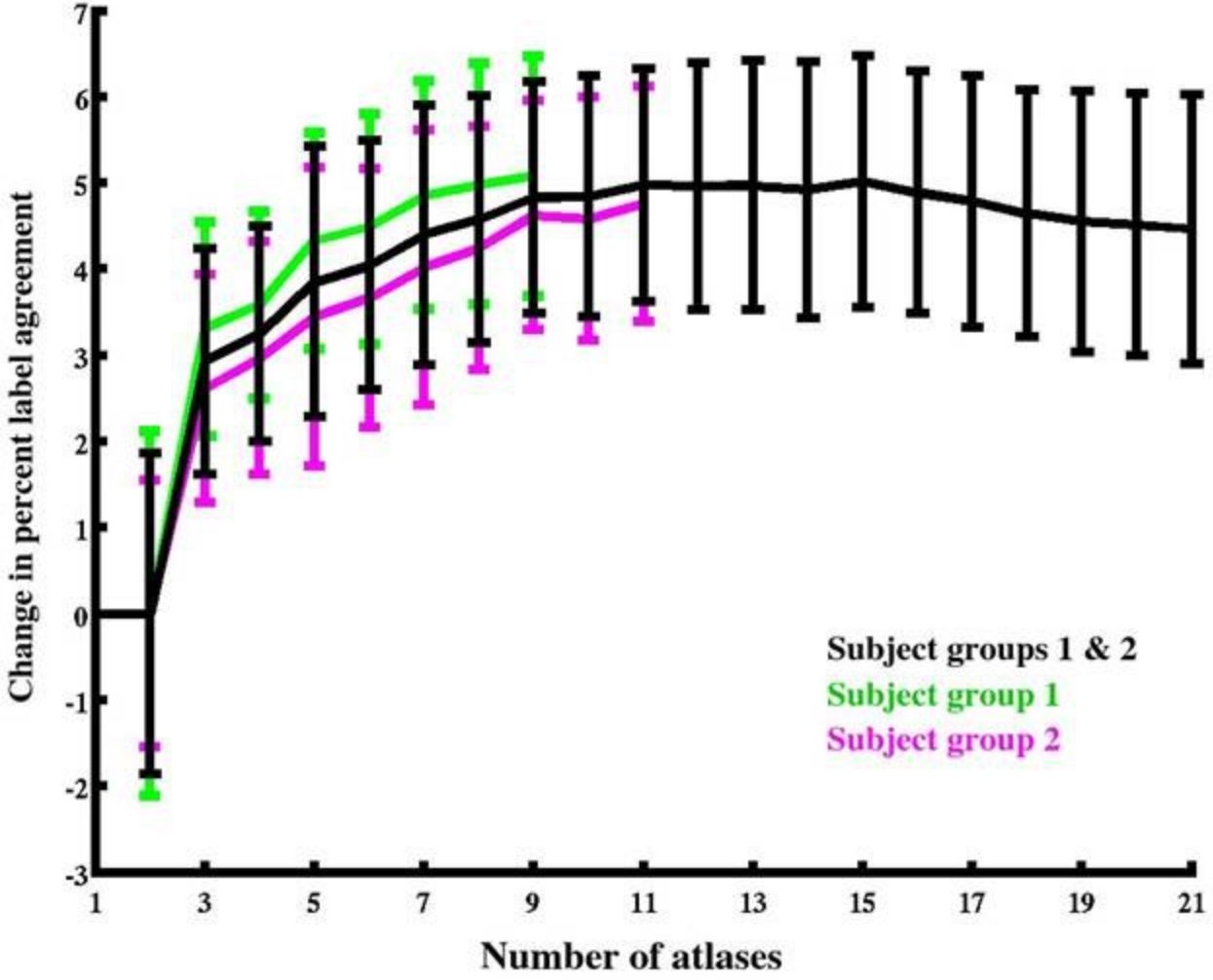
Evaluation

Percent label agreement
by subject, number of atlases



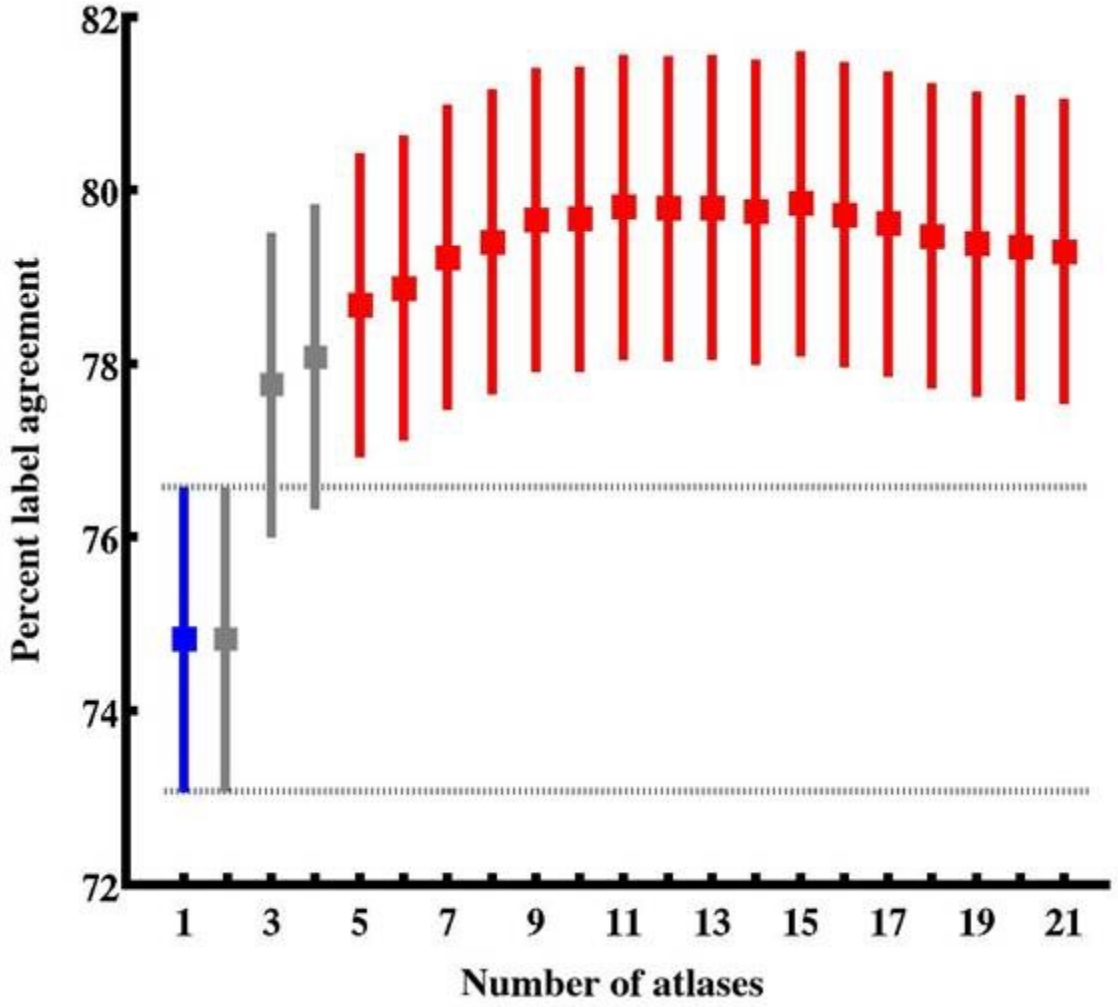
Evaluation

Change in percent label agreement
by subject group, number of atlases



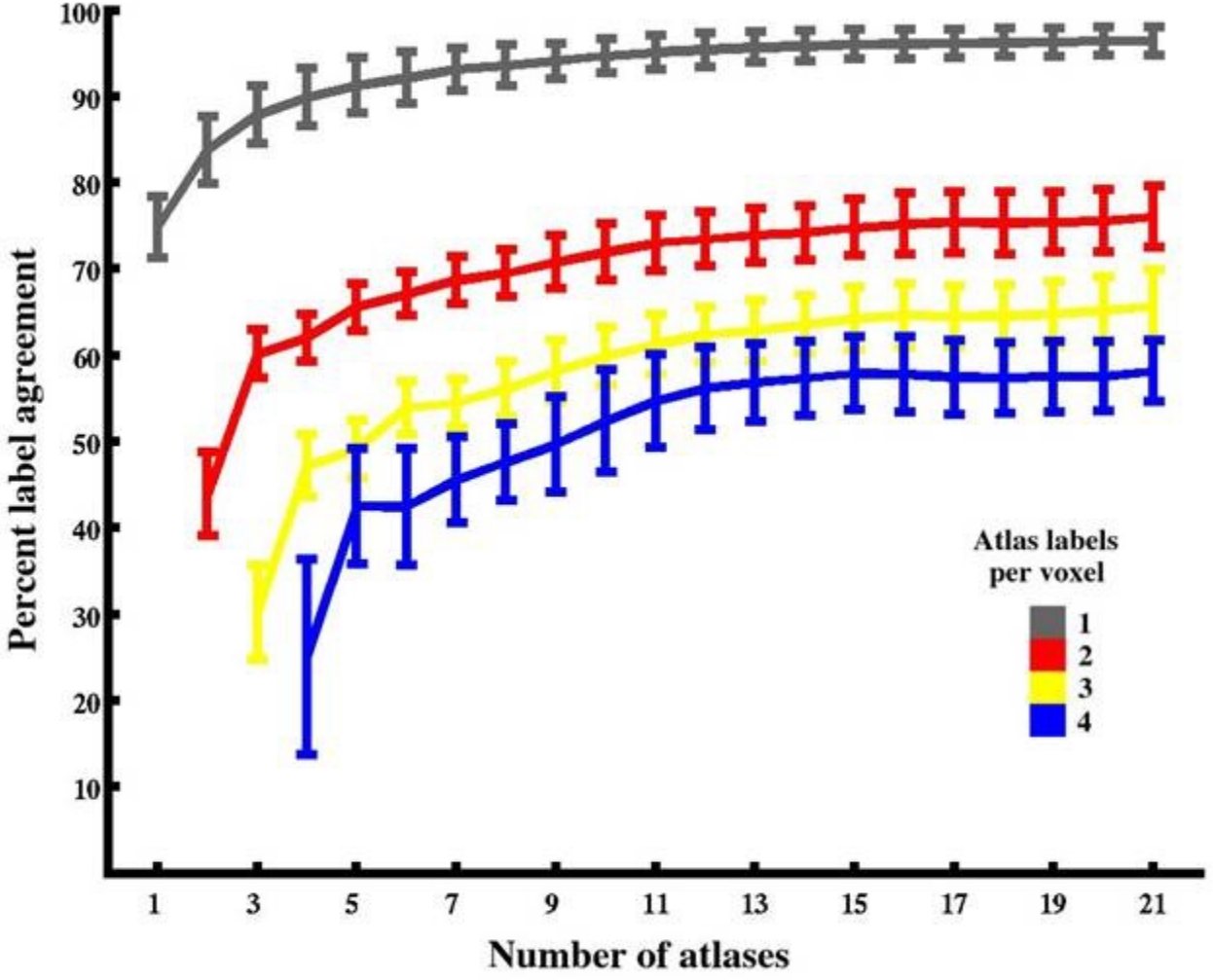
Evaluation

ANOVA, multiple comparison



Evaluation

Percent label agreement
by number of labels per voxel, number of atlases



Conclusions

Mindboggle:

- Fully automated
- Feature-based (vs. intensity-based registration)
- Does not assume that different brains preserve topography
- Robust to reduced and nonuniform image quality
- Competitive with standard techniques
- Performs just as well when parts of brain are removed
- Labels may be transferred to any regions of interest (e.g. structures or activity data)
- Multiple atlases provide independent label sets, confidence measures, higher accuracy

Acknowledgments

Joy Hirsch	fMRI Research Center Columbia University
Brett Mensh	New York State Psychiatric Institute Columbia University
Satrajit Ghosh, Jason Tourville:	Cognitive and Neural Systems Boston University Frank Guenther, PI; supported by NIH grant R01 DC02852
Jack Grinband	Columbia University