Activity patterns in the brain: breaking up the problem into pieces

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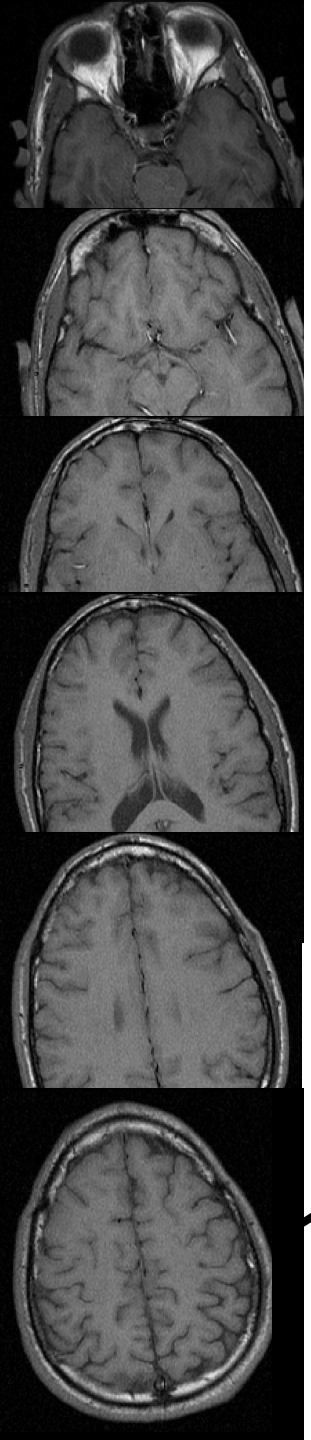
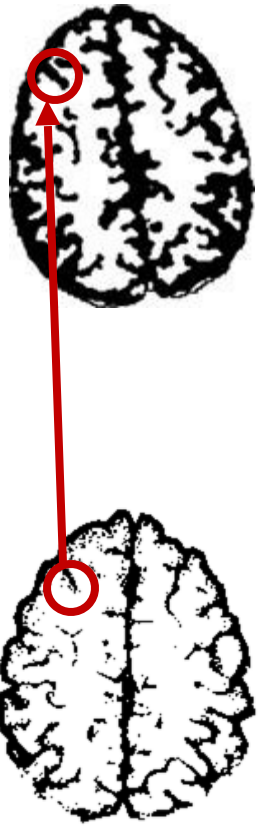
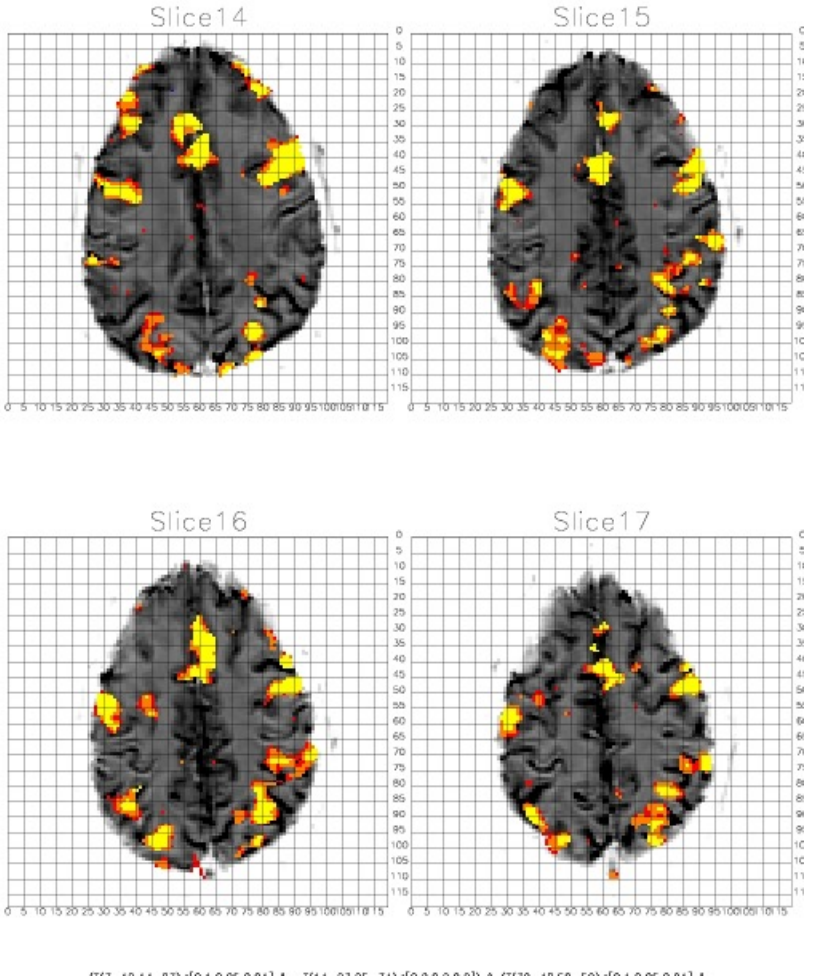
Unlabeled brain image data



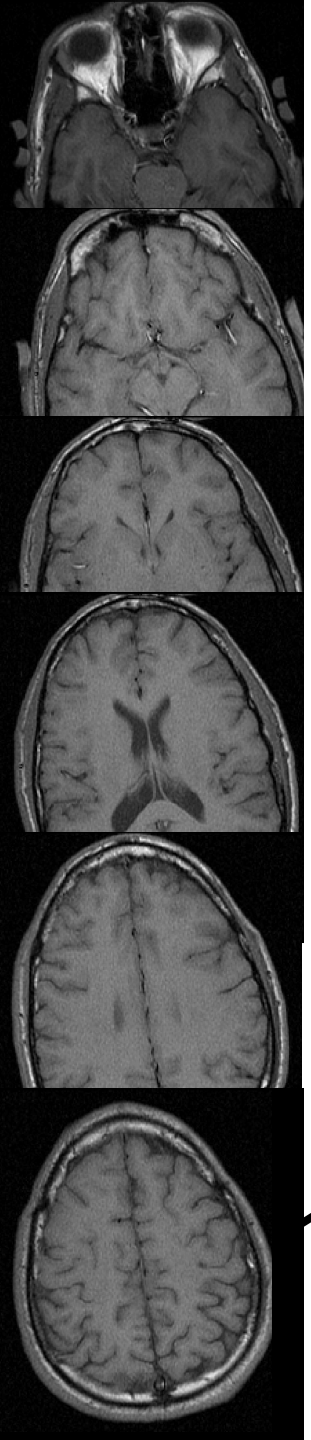
Morphometric data



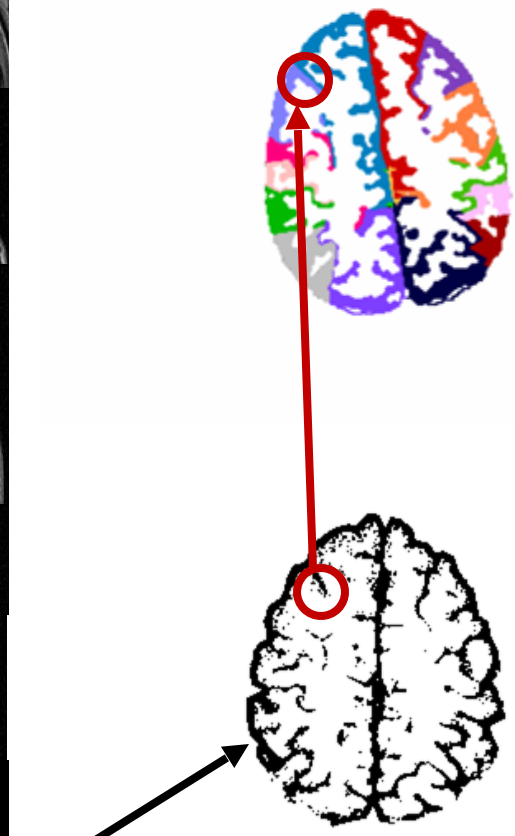
fMRI BOLD data



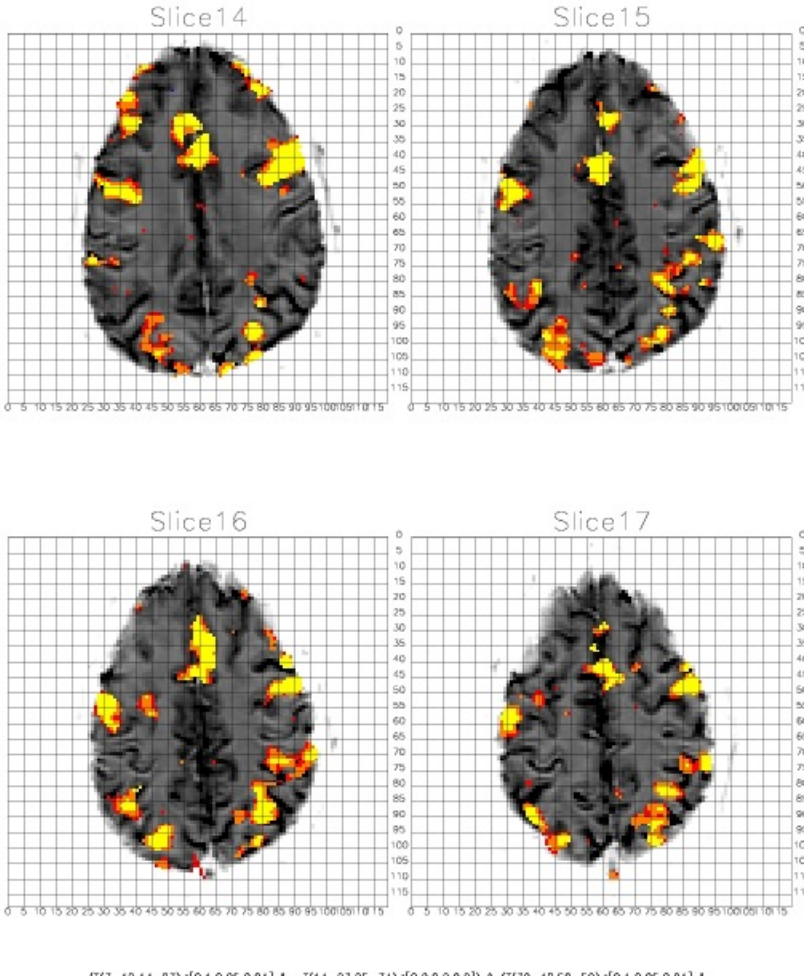
Manually labeled structural data



Morphometric data

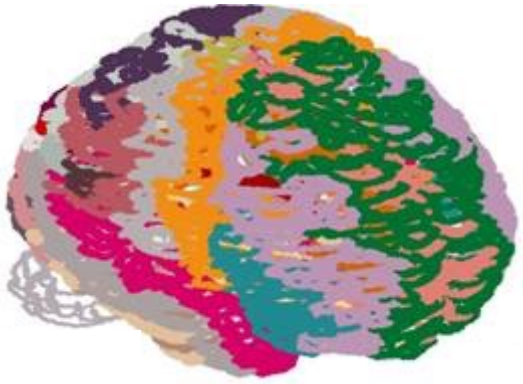


fMRI BOLD data

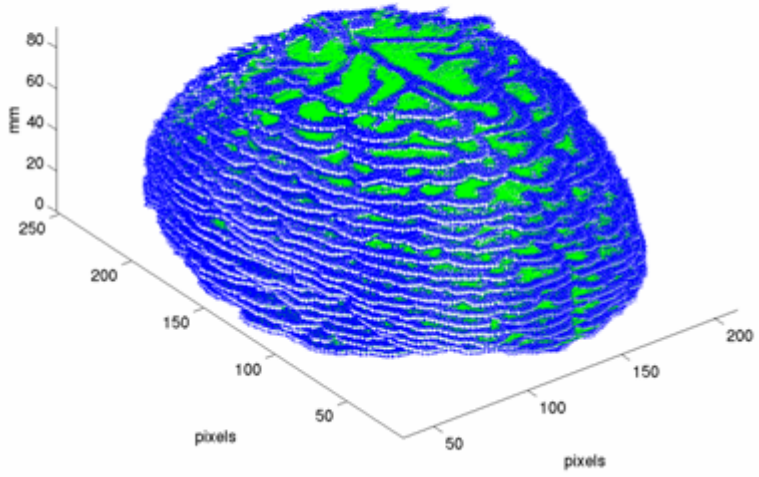


Manually labeled activity data

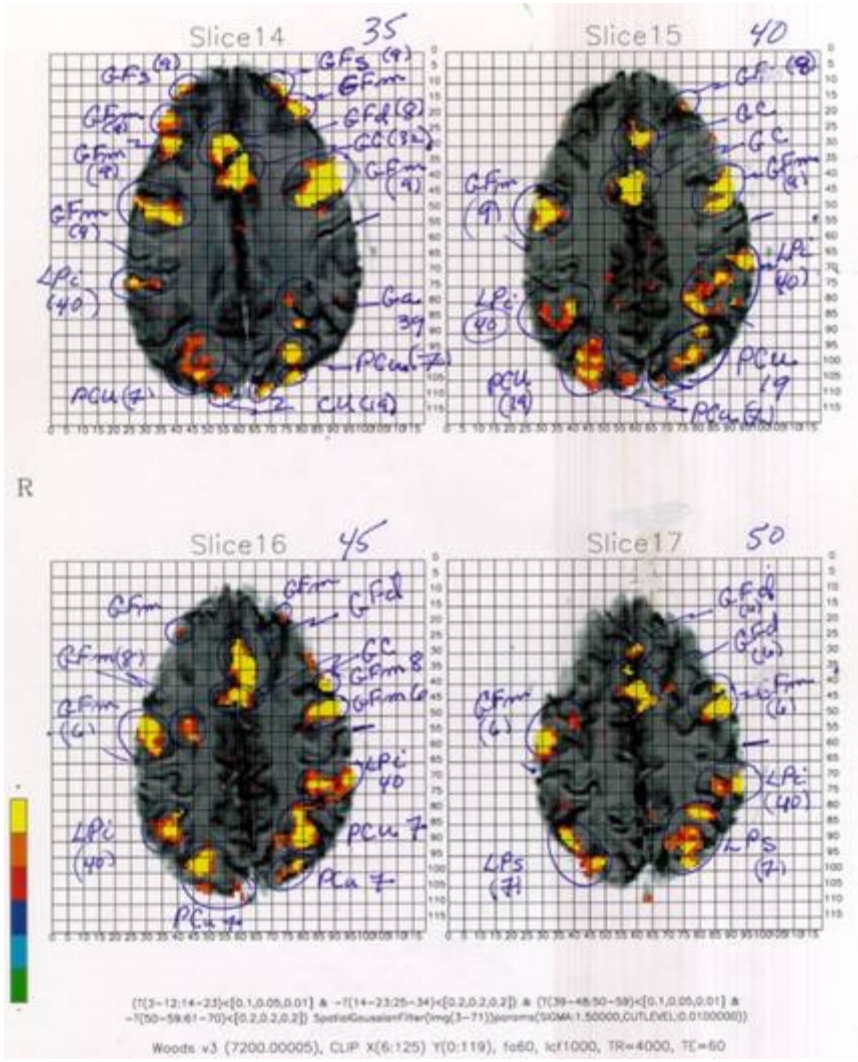
Talairach Atlas



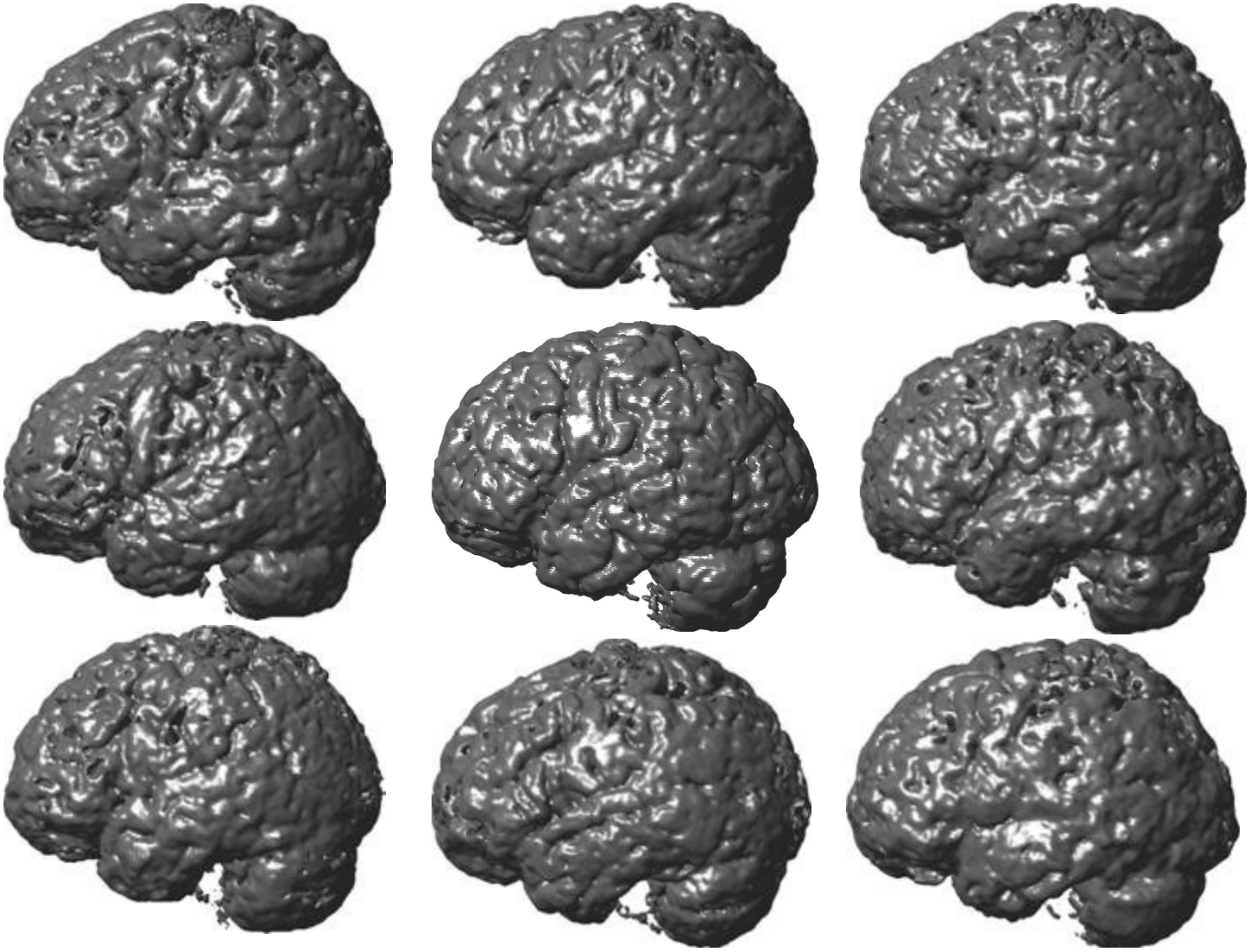
Corresponding subject slices



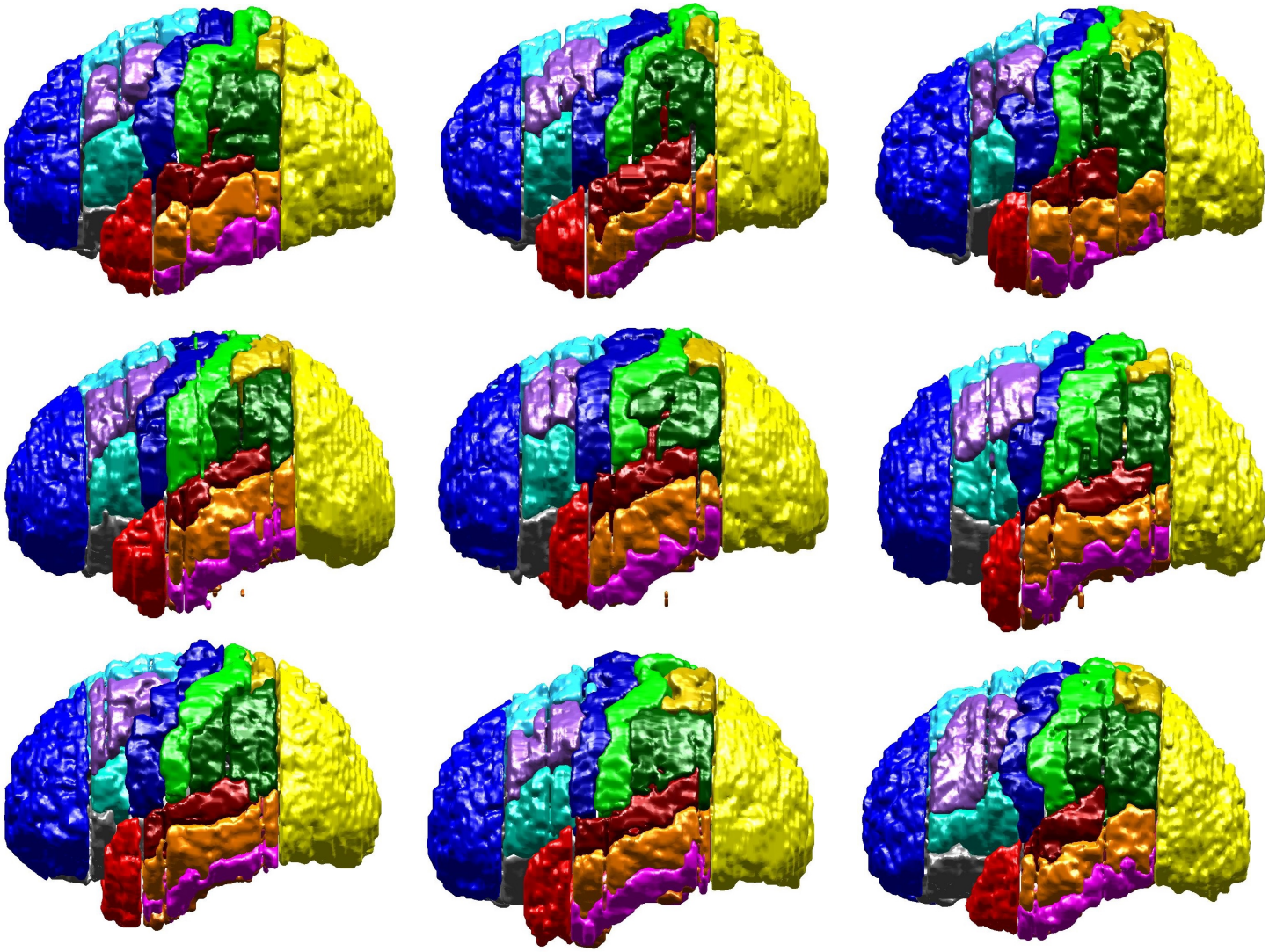
fMRI BOLD data



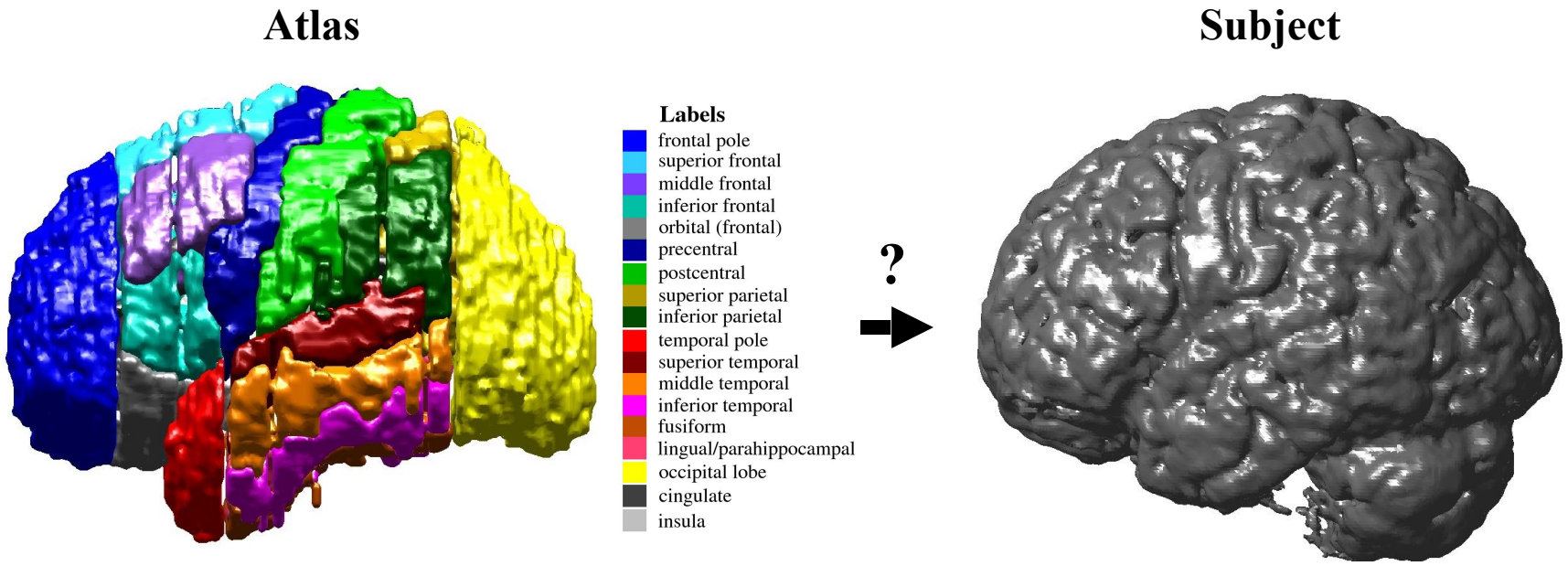
Unlabeled brains



Atlases (manually labeled brains)



The correspondence problem

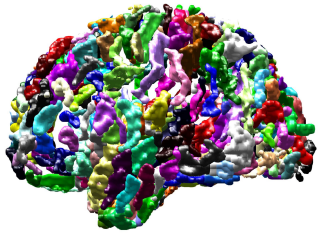


Standard approaches

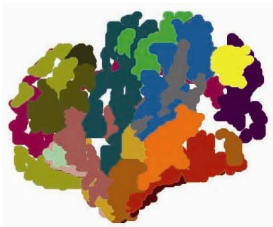
Methods	**Examples**
Linear registration:	Talairach-type spaces
Piece-wise linear registration:	Talairach (original)
Warping with landmarks:	Thin-plate splines
Unsupervised warping:	SPM, AIR, ANIMAL
Feature matching:	Watershed basins, parametric curves/surfaces

Mindboggle

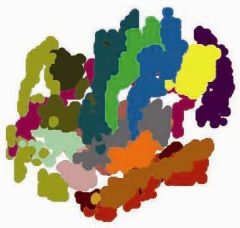
Extract pieces



Match pieces

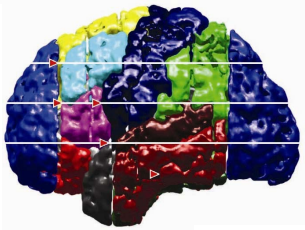


Transform boundaries



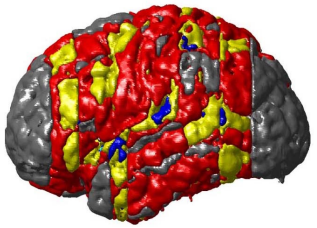
Warp labels

Evaluate



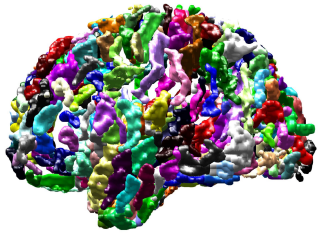
Use multiple atlases

Evaluate



Mindboggle

Extract pieces



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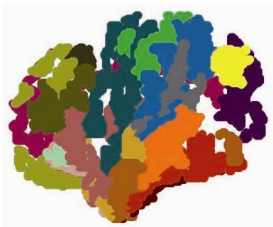

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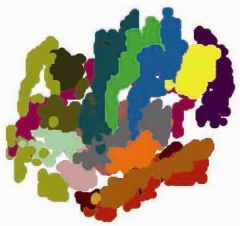

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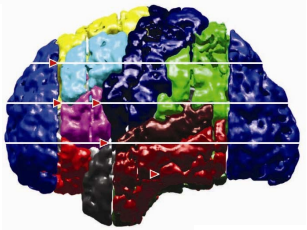

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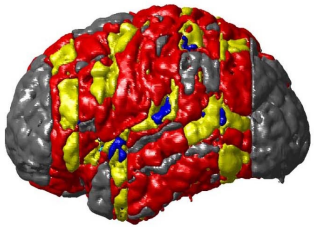
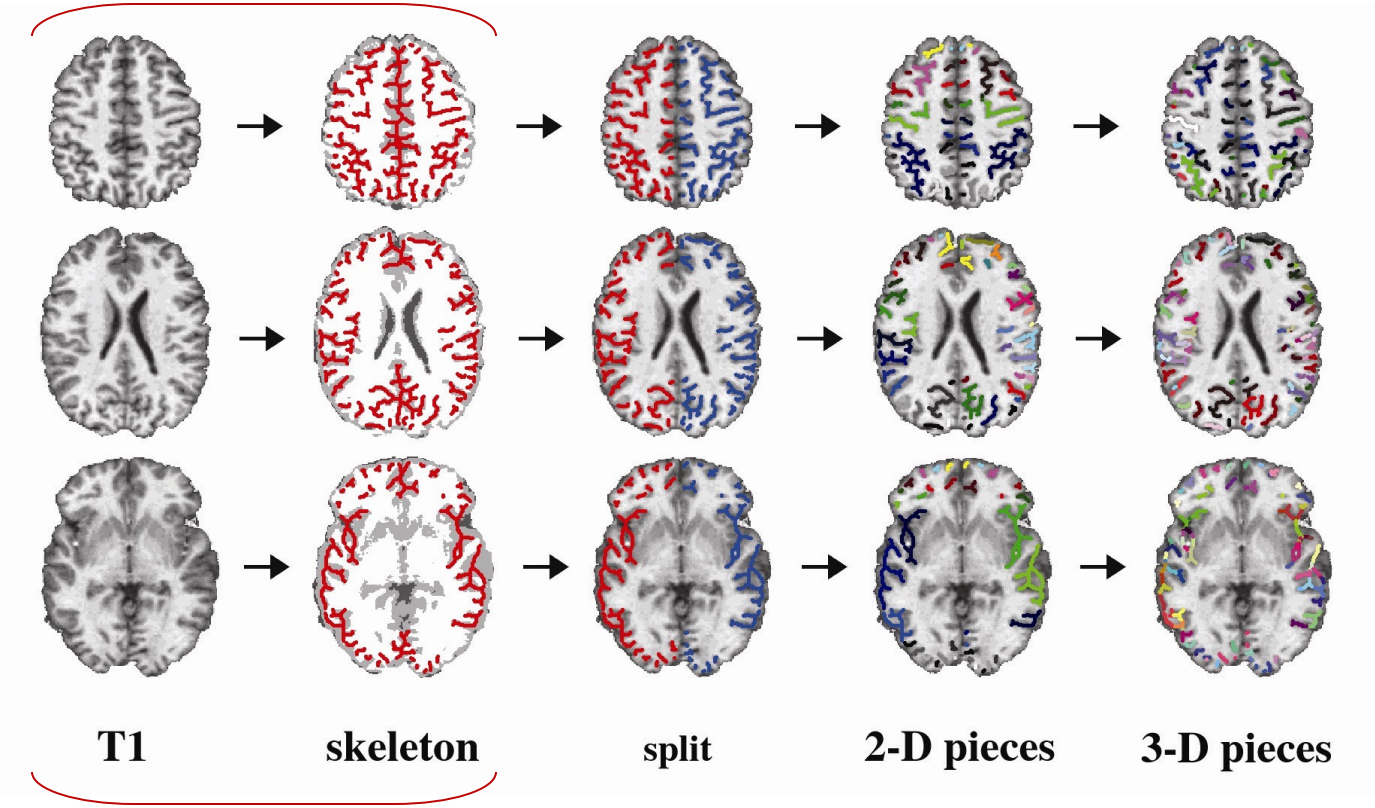
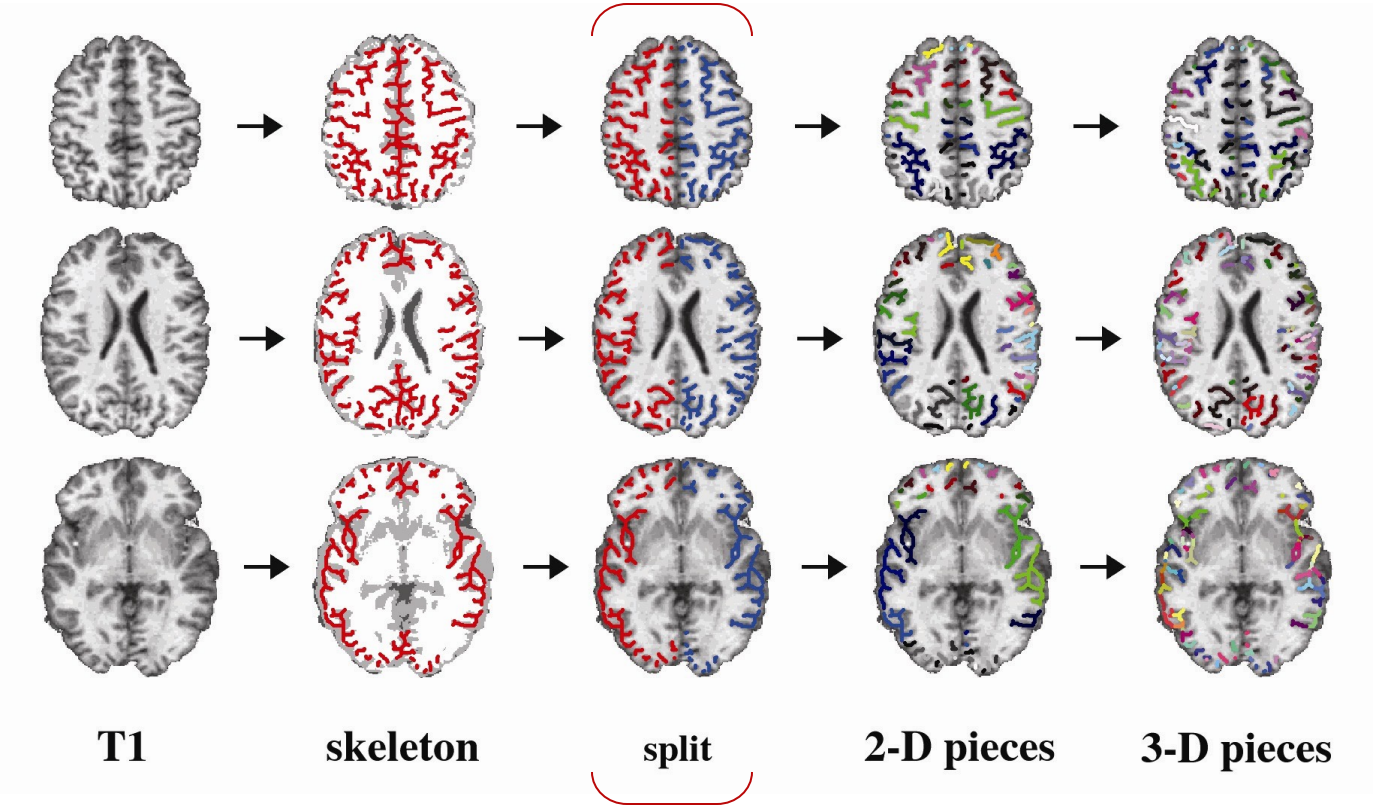


Extract pieces



- **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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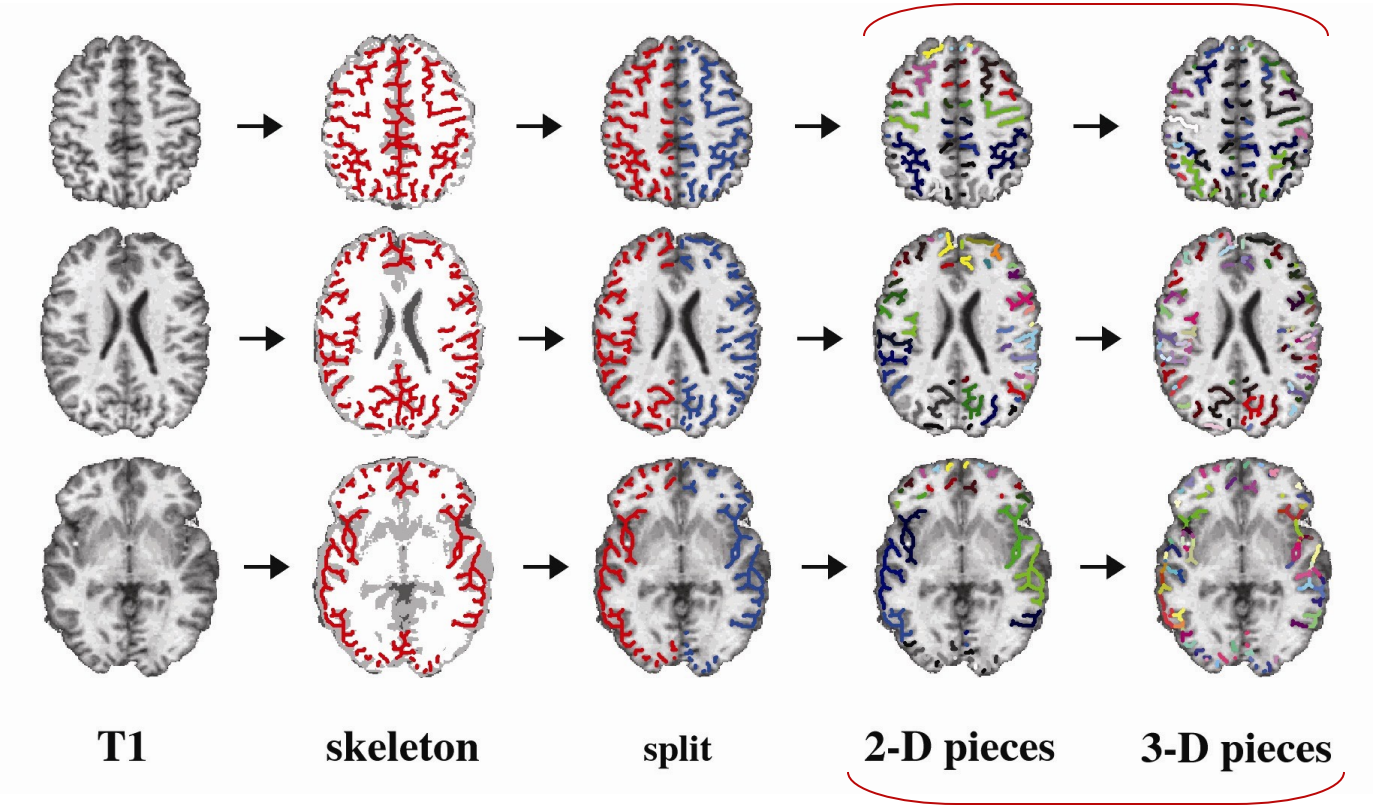

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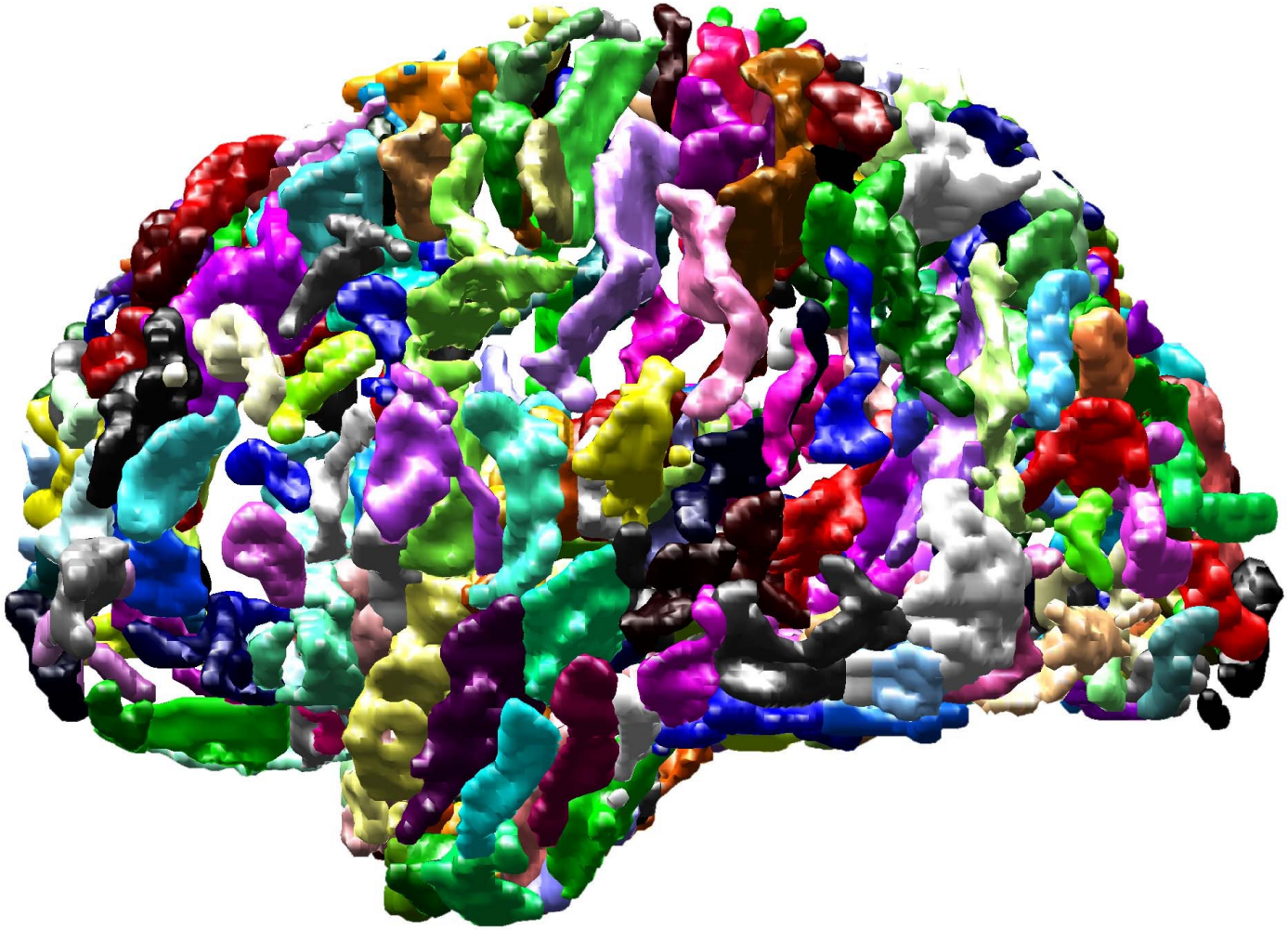
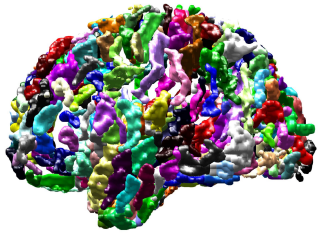
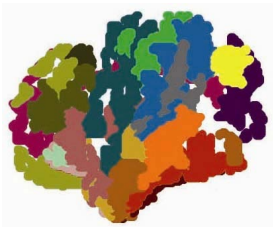


Mindboggle

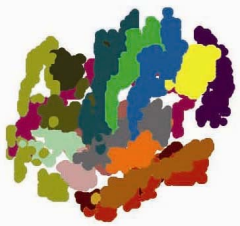
Extract pieces



Match pieces

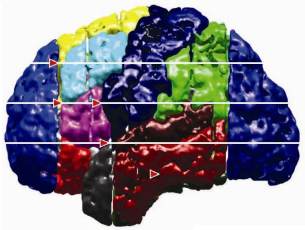


Transform boundaries



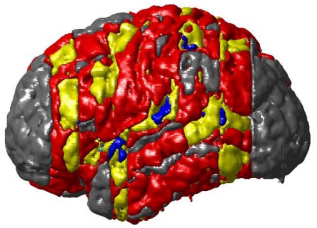
Warp labels

Evaluate

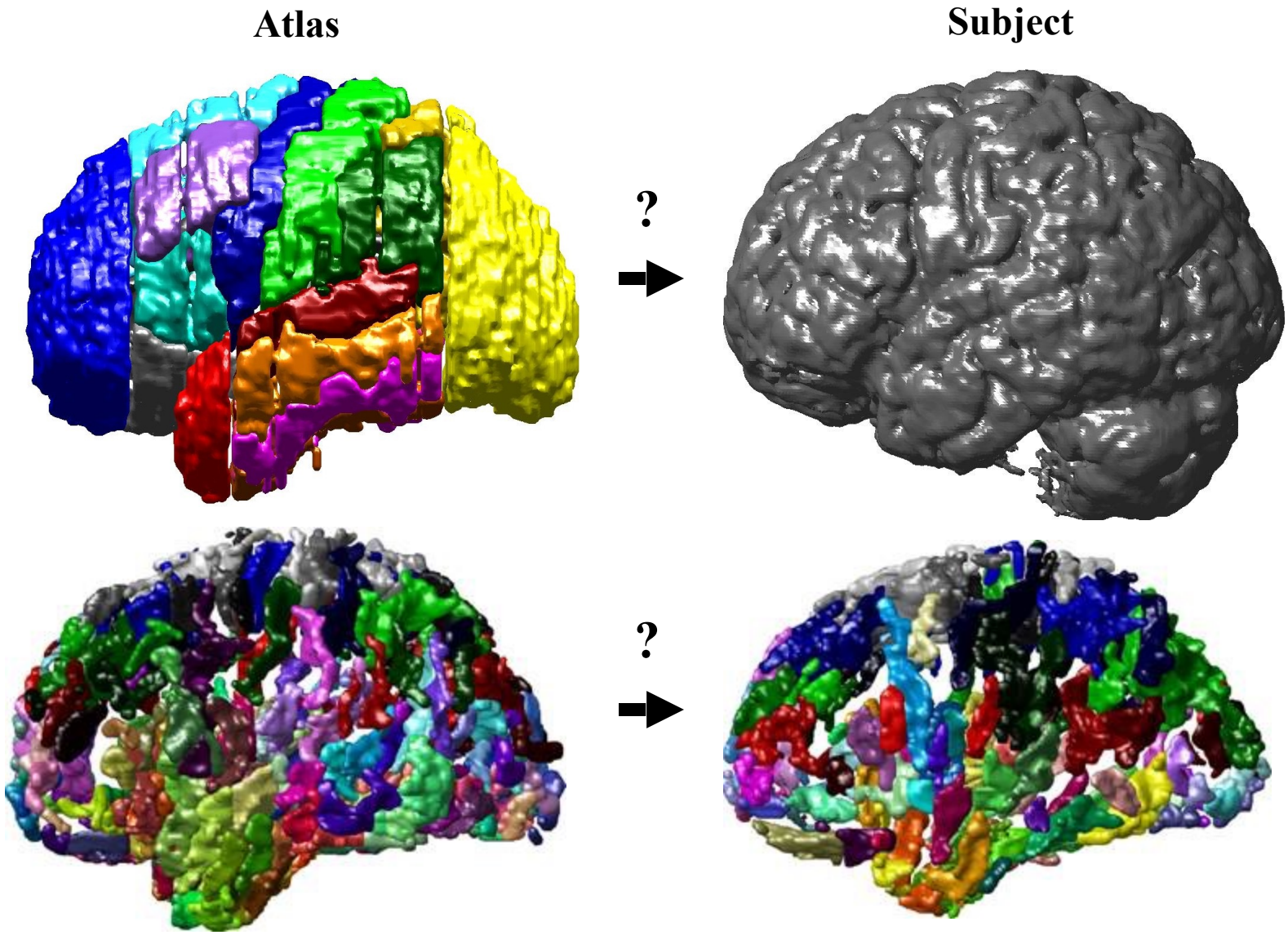


Use multiple atlases

Evaluate



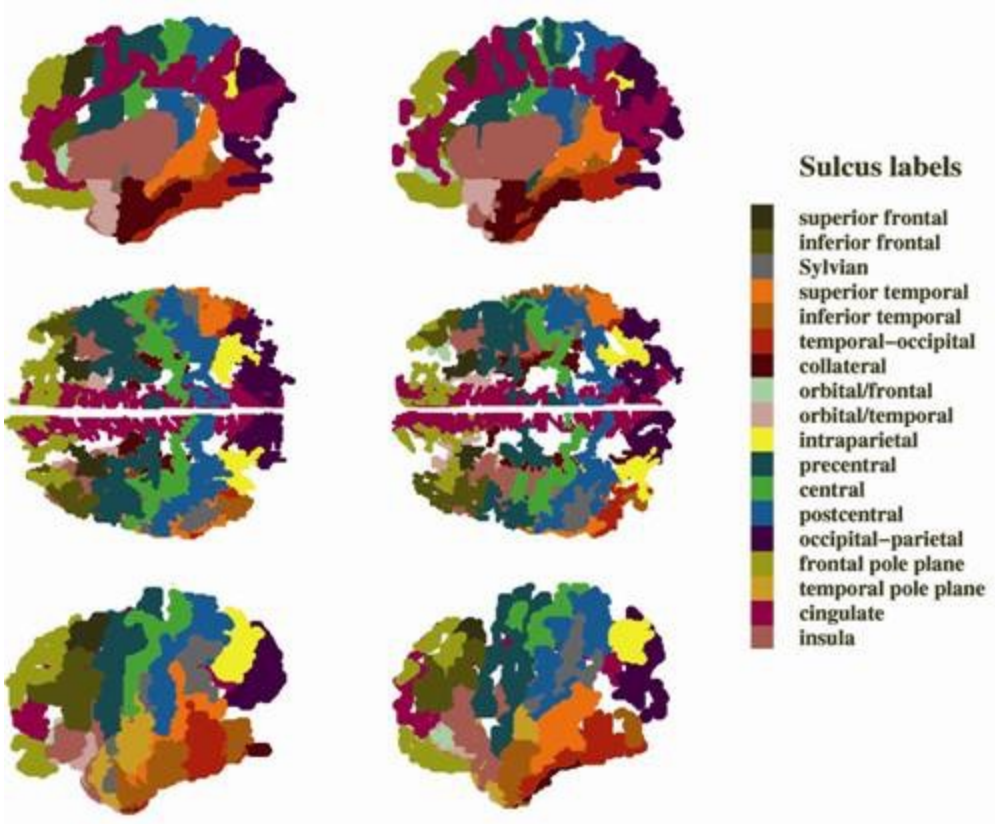
Match pieces



Match pieces

Atlas pieces
(grouped by sulci)

Subject pieces
(matches)

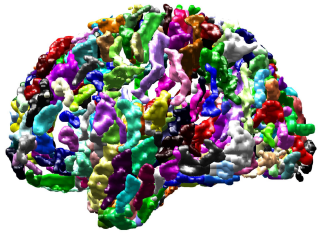


- Order matches by a **cost function**: $\mathbf{Cost = w_N N + w_V V + w_P P + w_O O}$

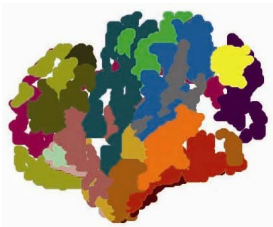
N = Δ # voxels **P** = Δ mean position
V = Δ # subvolumes **O** = non-overlap

Mindboggle

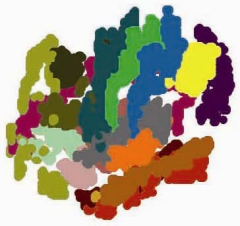
Extract pieces



Match pieces

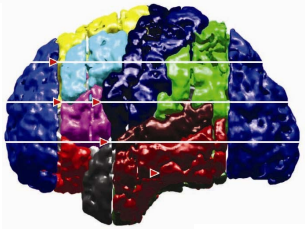


Transform boundaries



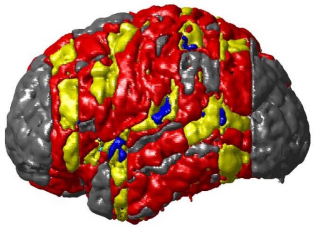
Warp labels

Evaluate



Use multiple atlases

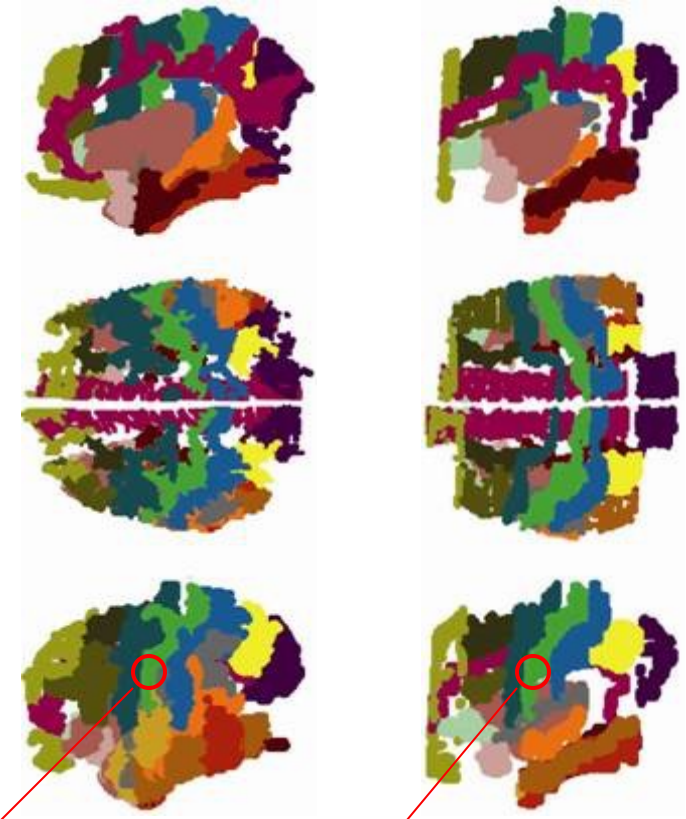
Evaluate

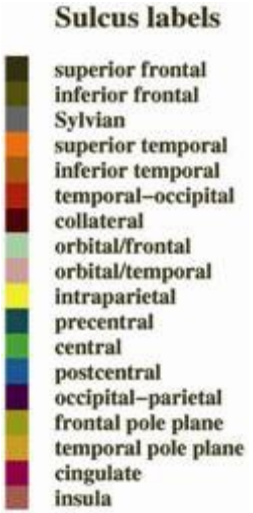


Transform boundaries

Atlas pieces
(grouped by sulci)

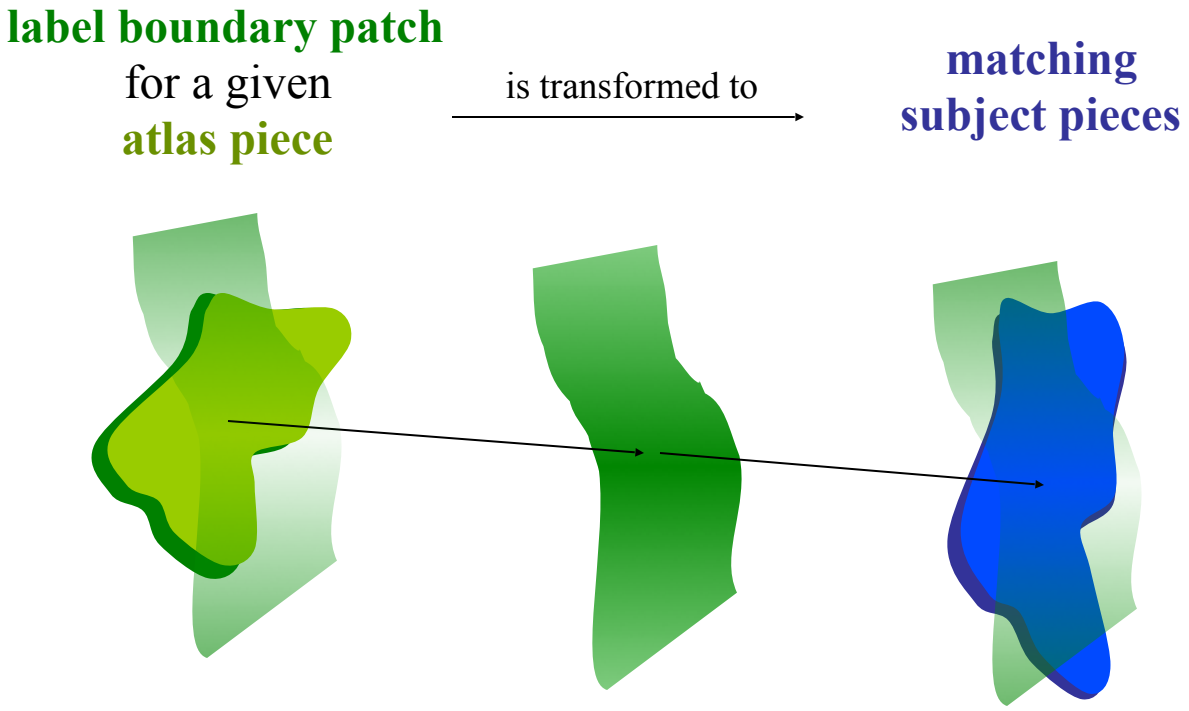
Label boundaries
(grouped by sulci)





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

Transform boundaries

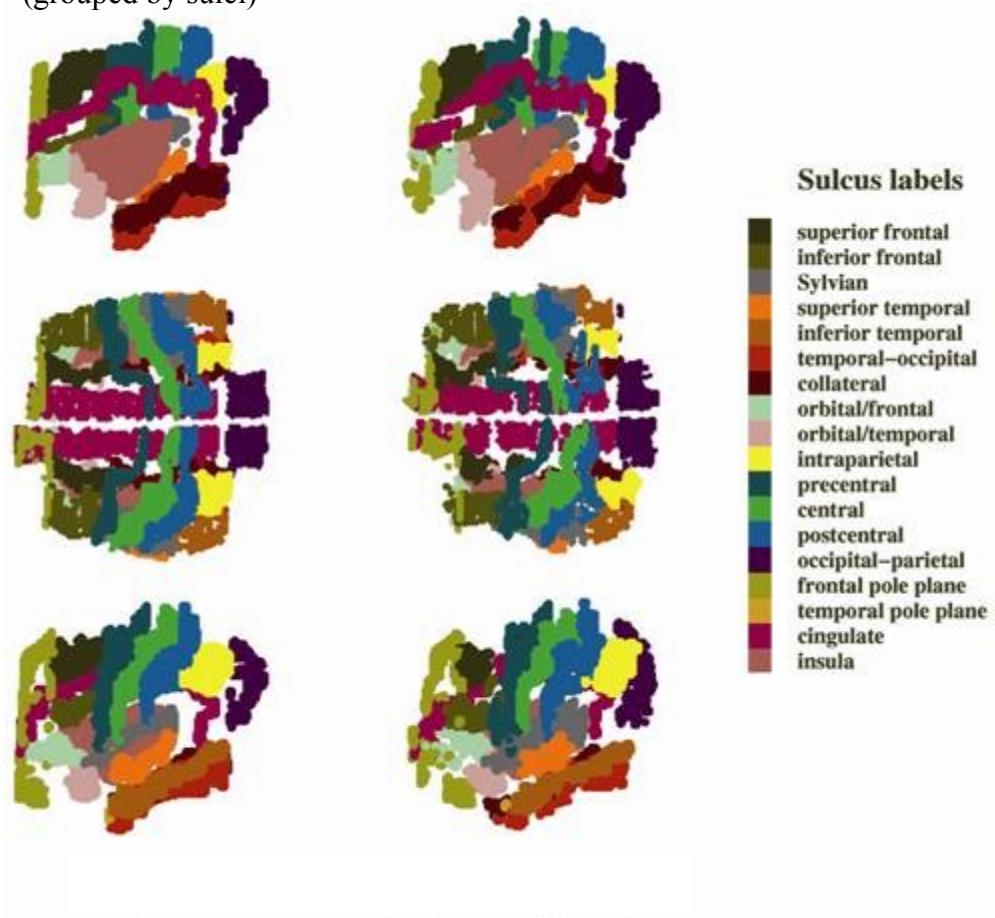


- Translate atlas label boundaries to the subject brain, patch by patch.
  Translation: mean (subject pieces) - mean (matching atlas piece).

Transform boundaries

Atlas boundaries → **Subject**

(grouped by sulci)



Mindboggle

Extract pieces

Match pieces

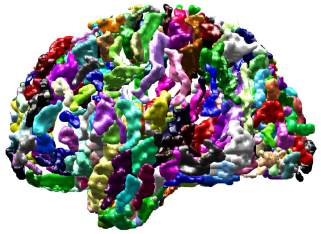
Transform boundaries

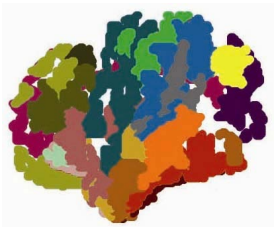
Warp labels

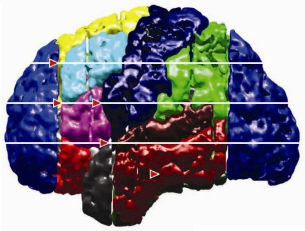
Evaluate

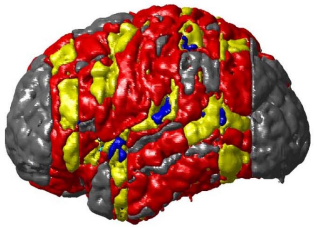
Use multiple atlases

Evaluate

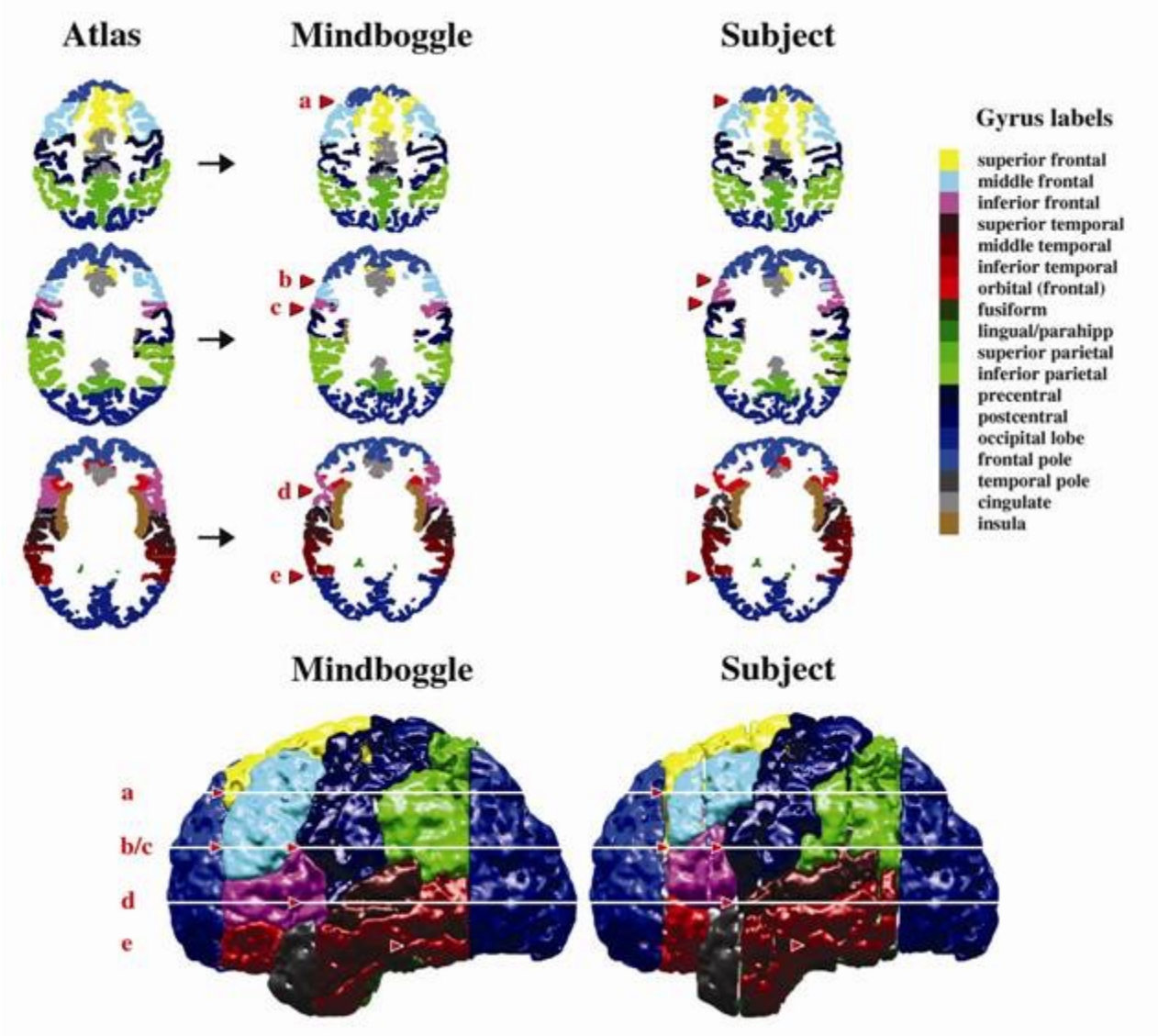




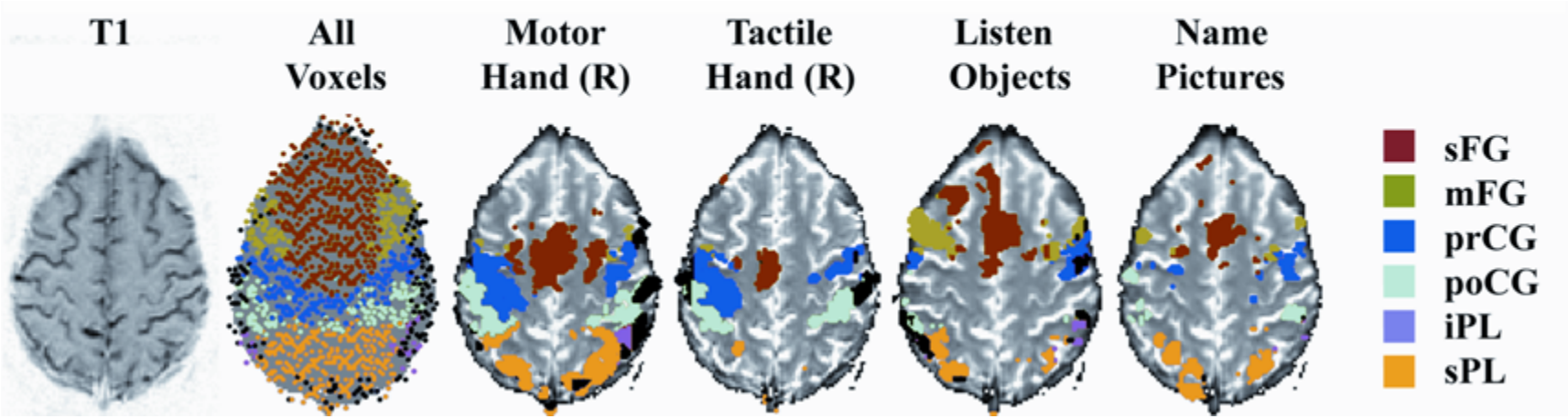




Warp labels


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

Functional mapping tests

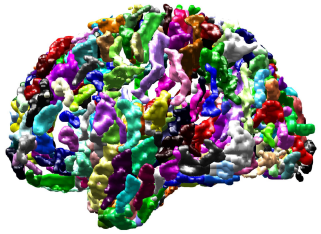


The resulting labels may be transferred to a coregistered volume of activity data.

Mindboggle labeled activity from 5 subjects undergoing 4 standard tasks that are known to elicit activity in specific regions (Hirsch, 2000). We determined whether Mindboggle's labels included those regions. According to Mindboggle, of the 45 gyrii expected to be activated (9 gyrii distributed across 4 tasks performed by 5 subjects), 44 were activated, well within expected variance of the subject pool.

Mindboggle

Extract pieces



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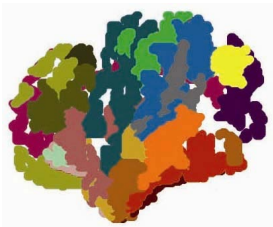

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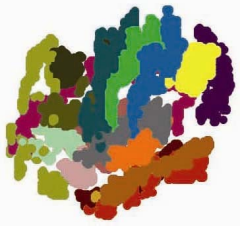
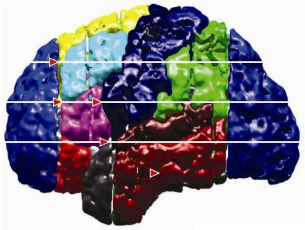


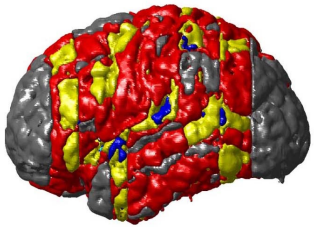
Warp labels

Evaluate

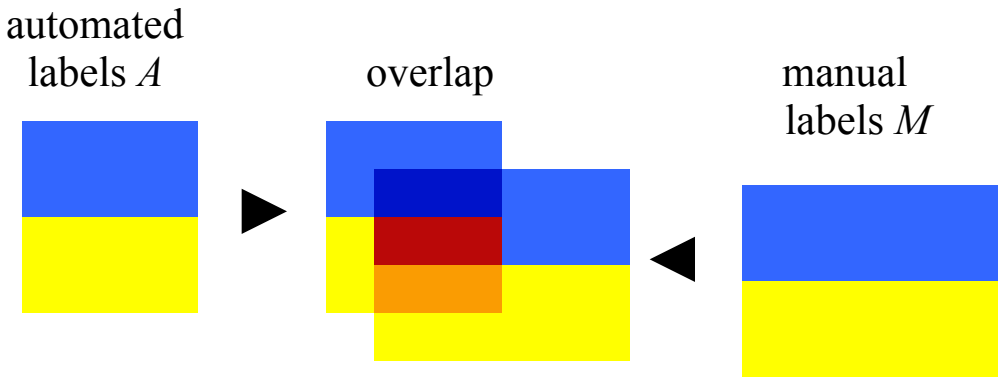


Use multiple atlases

Evaluate



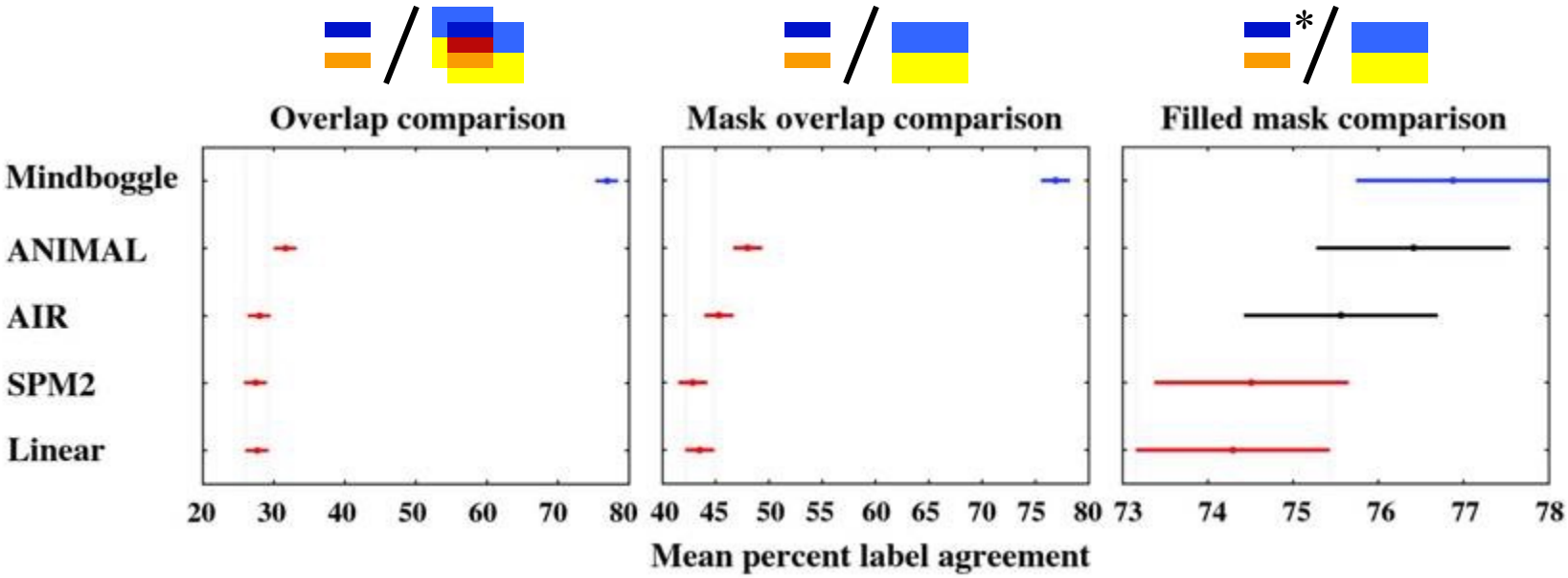
Evaluation



Label agreement metric:

$$\frac{\mathbf{V_a}}{\mathbf{V_c}} = \frac{\text{intersection with the same label}}{\text{subject volume}} = \frac{\text{}}{\text{}} = \frac{\sum|\boldsymbol{A_i}\cap\boldsymbol{M_i}|}{\sum|\boldsymbol{M_i}|}$$

Evaluation

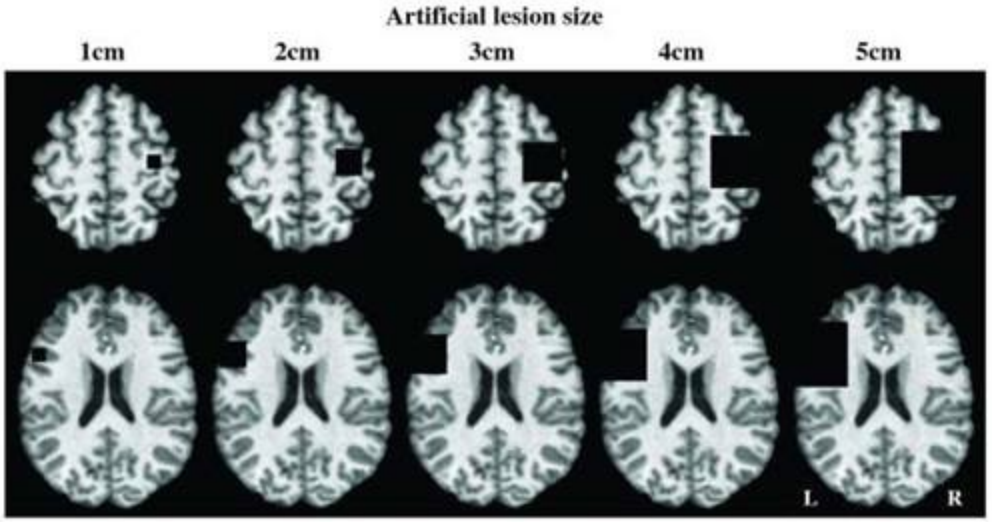


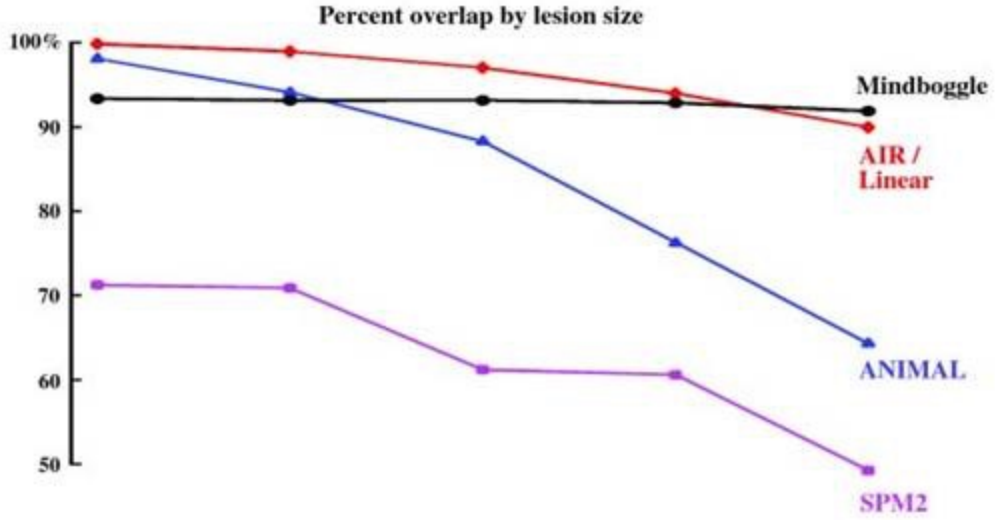
- A **one-way ANOVA** was performed to test if the means are the same for the label agreements obtained by each of the methods.

- 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

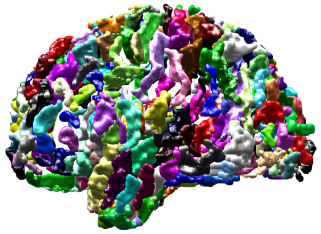




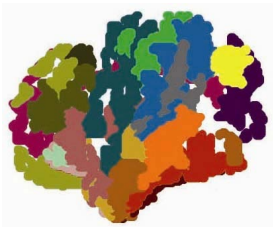
- The atlas was used to label an artificially lesioned version of itself.

Mindboggle

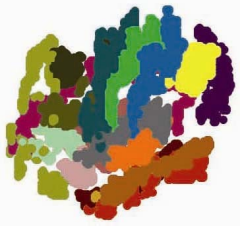
Extract pieces



Match pieces

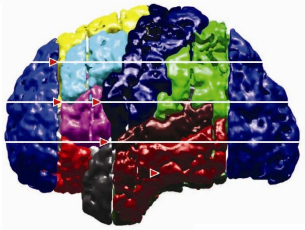


Transform boundaries



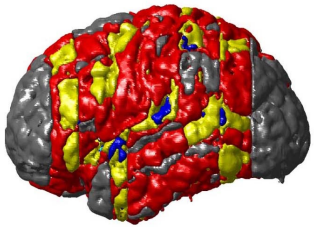
Warp labels

Evaluate



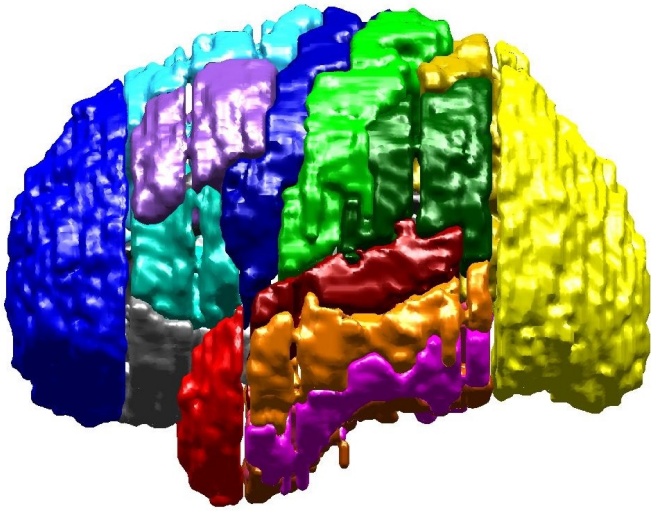
Use multiple atlases

Evaluate



A single atlas

Atlas

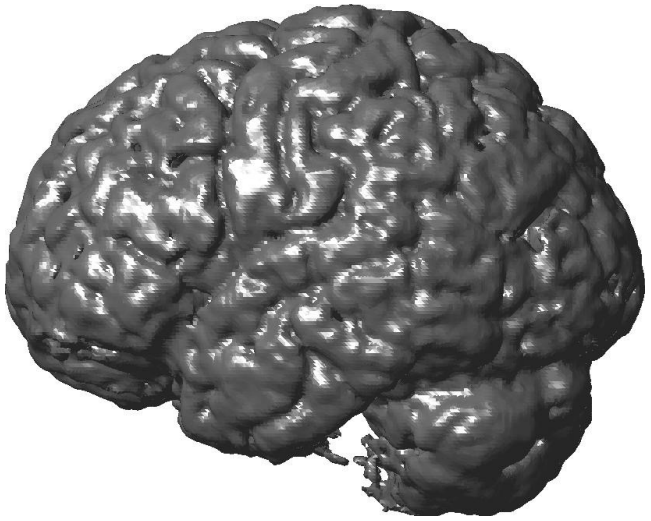


Labels

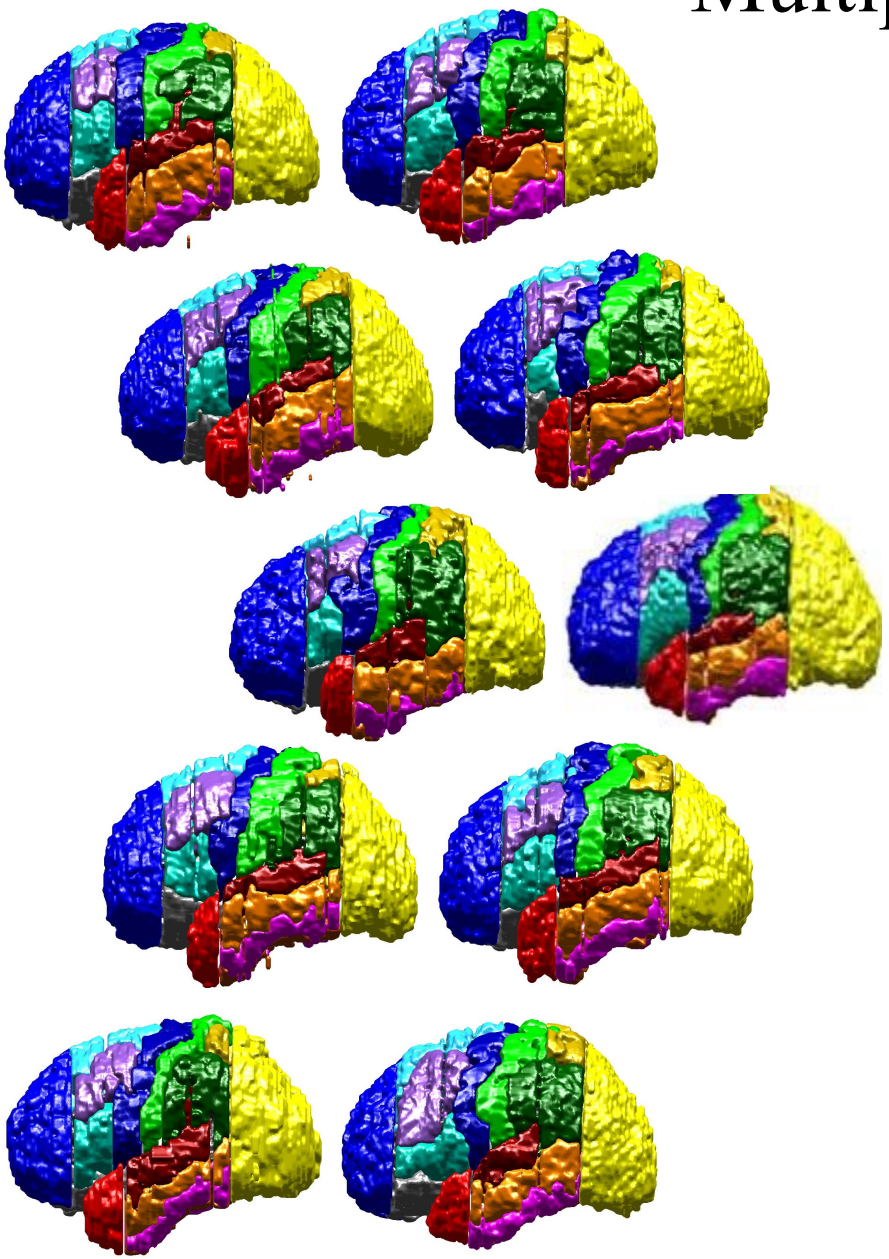
- frontal pole
- superior frontal
- middle frontal
- inferior frontal
- orbital (frontal)
- precentral
- postcentral
- superior parietal
- inferior parietal
- temporal pole
- superior temporal
- middle temporal
- inferior temporal
- fusiform
- lingual/parahippocampal
- occipital lobe
- cingulate
- insula

?

Subject

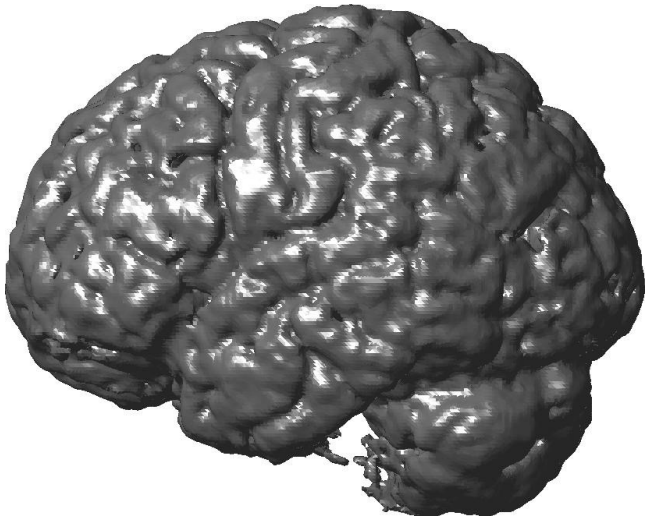


Multiple atlases



?

Subject



Mindboggle

Extract pieces

Match pieces

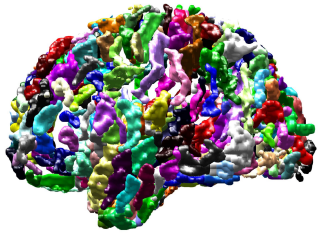
Transform boundaries

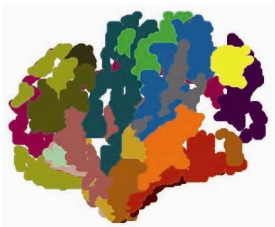
Warp labels

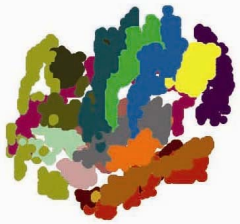
Evaluate

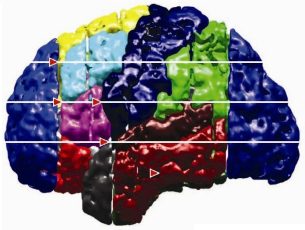
Use multiple atlases

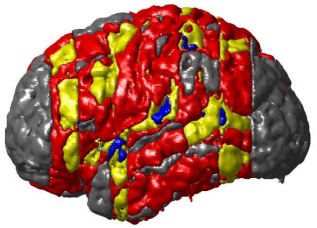
Evaluate





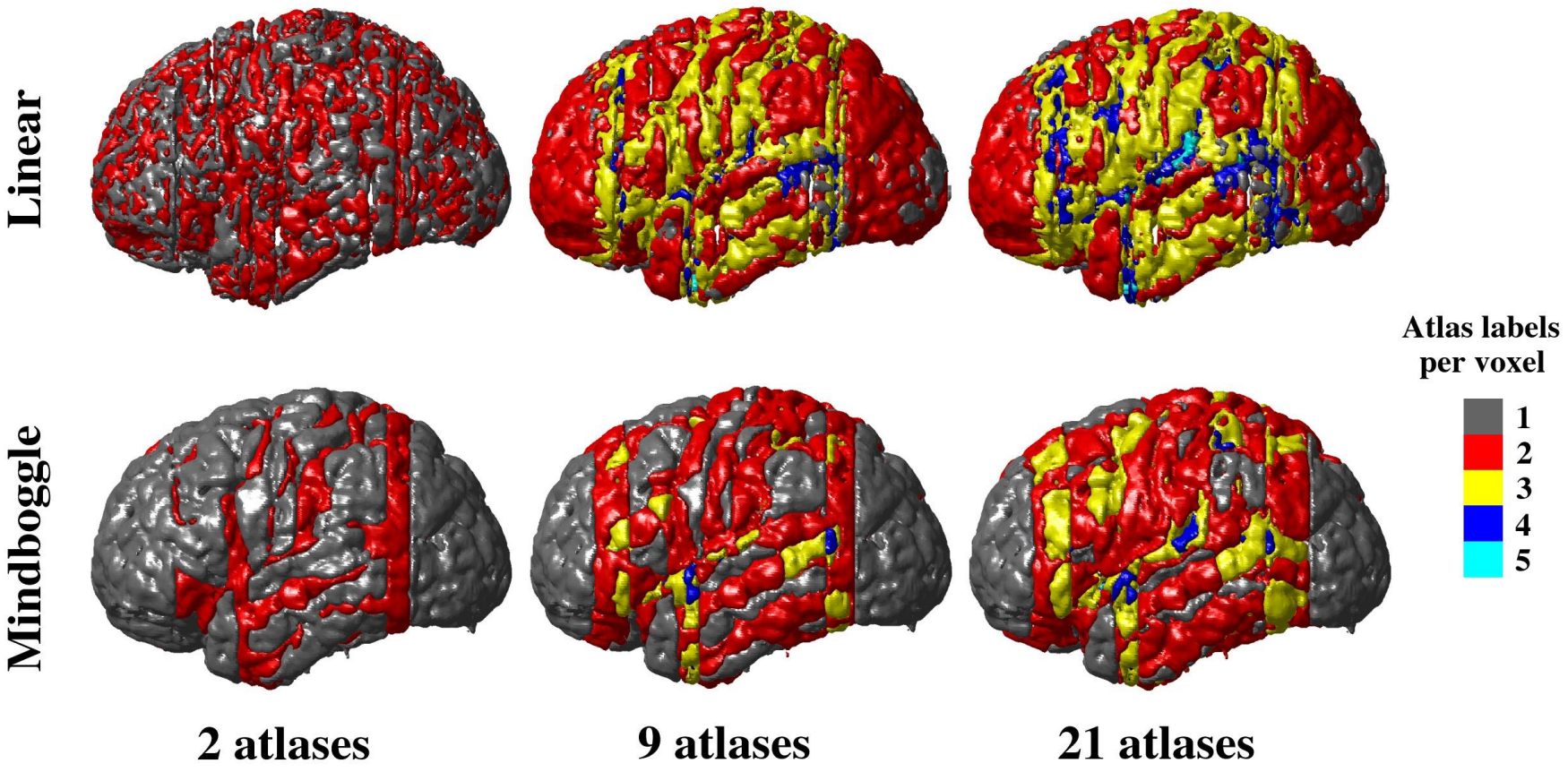






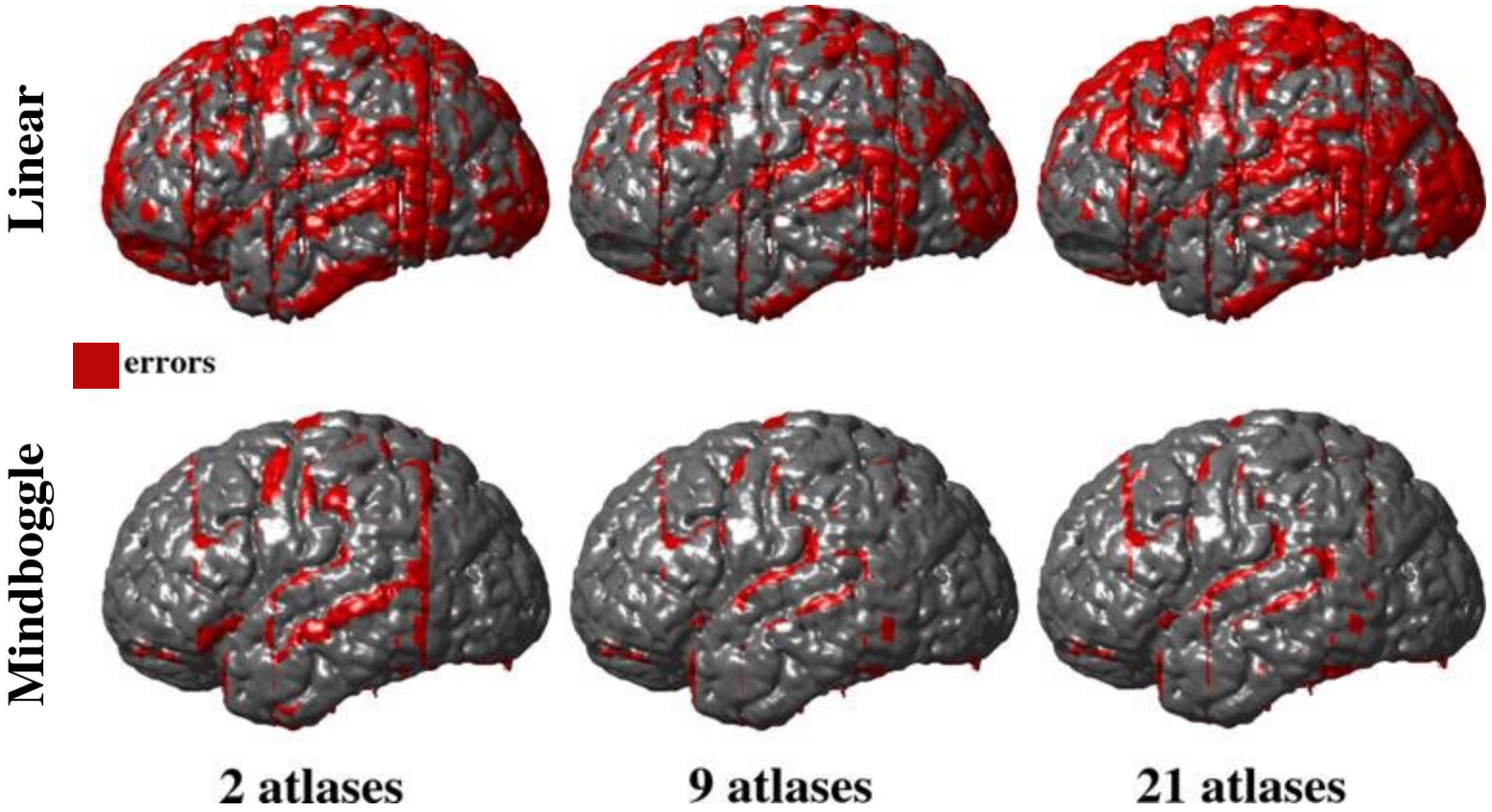
Multiple atlases

Number of labels per voxel



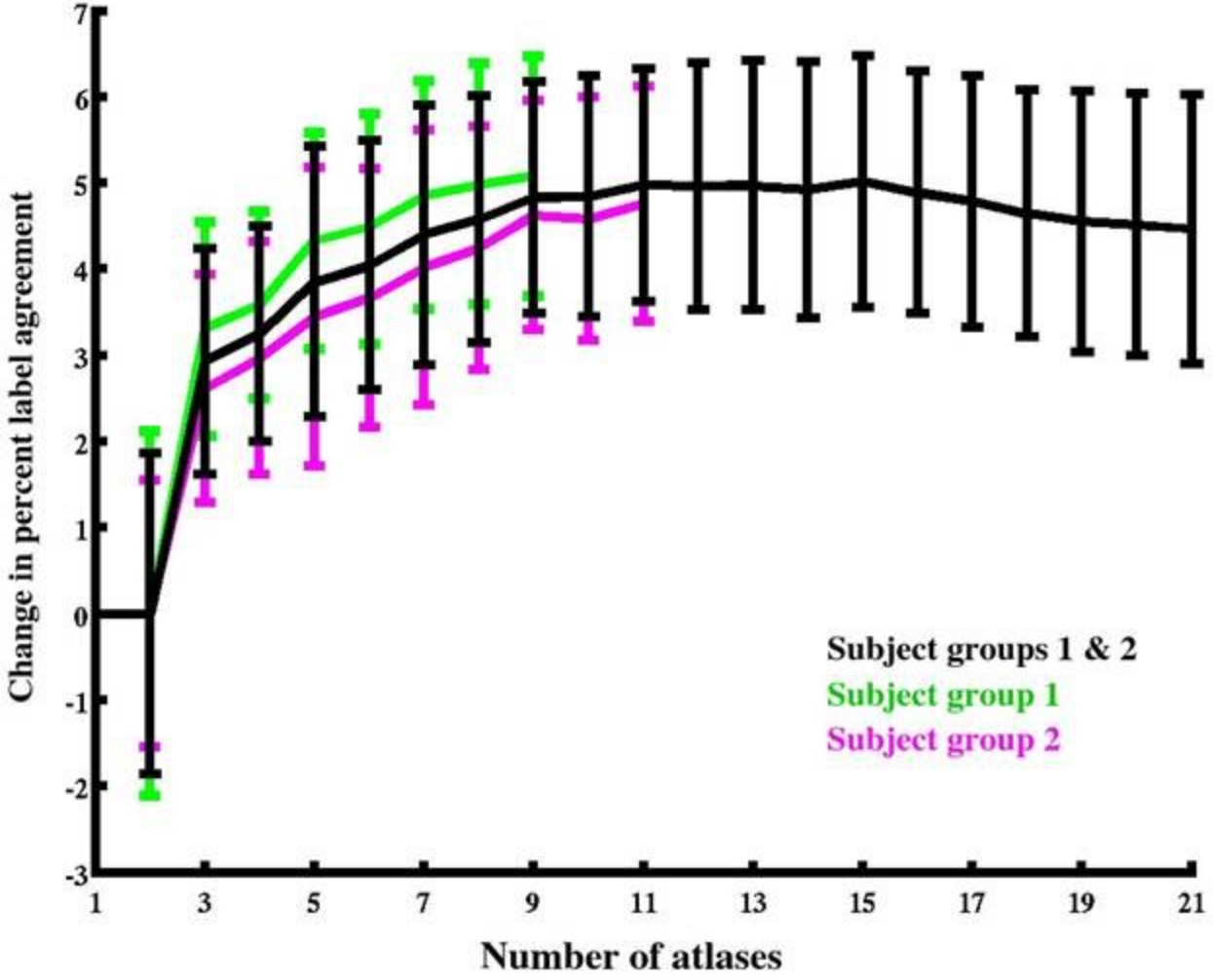
Evaluation

Errors: automated labels ≠ manual labels



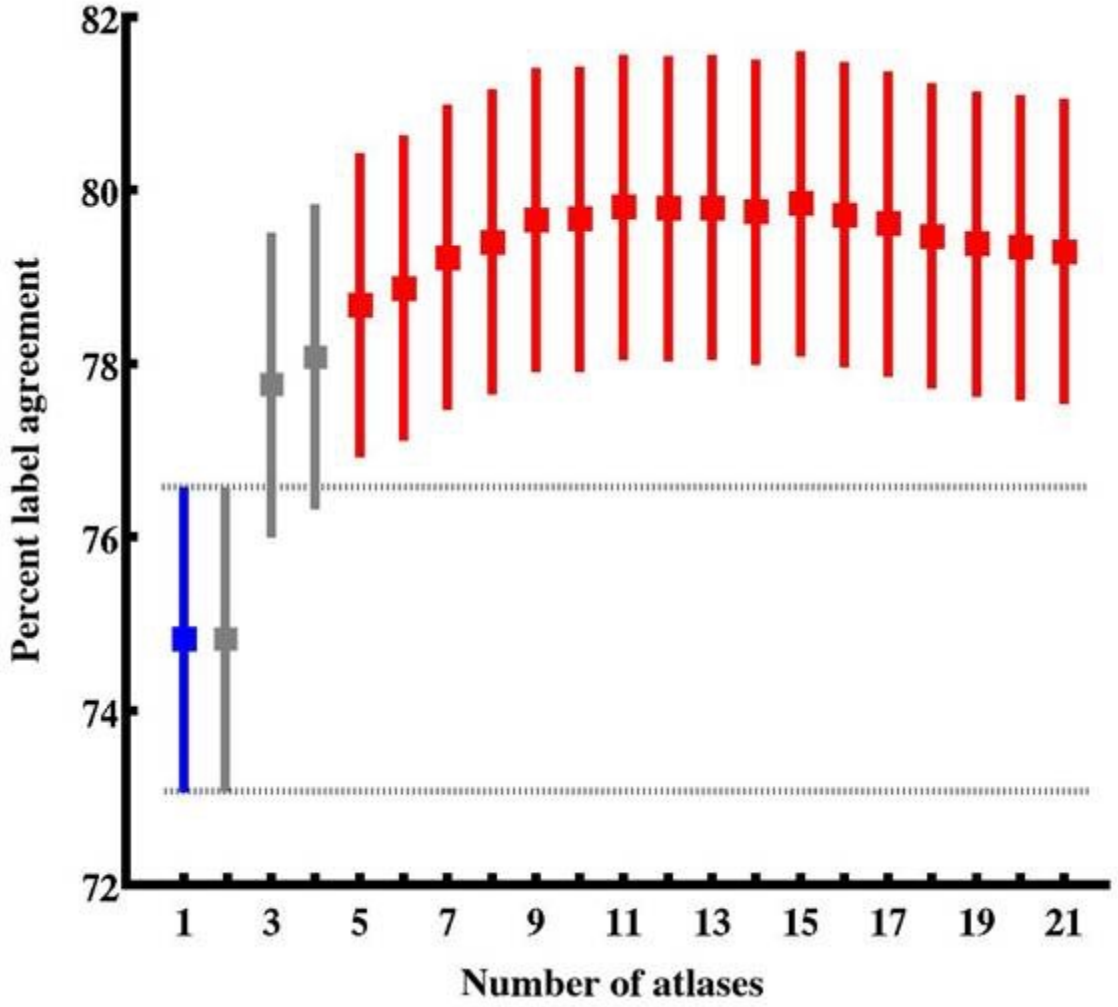
Evaluation

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



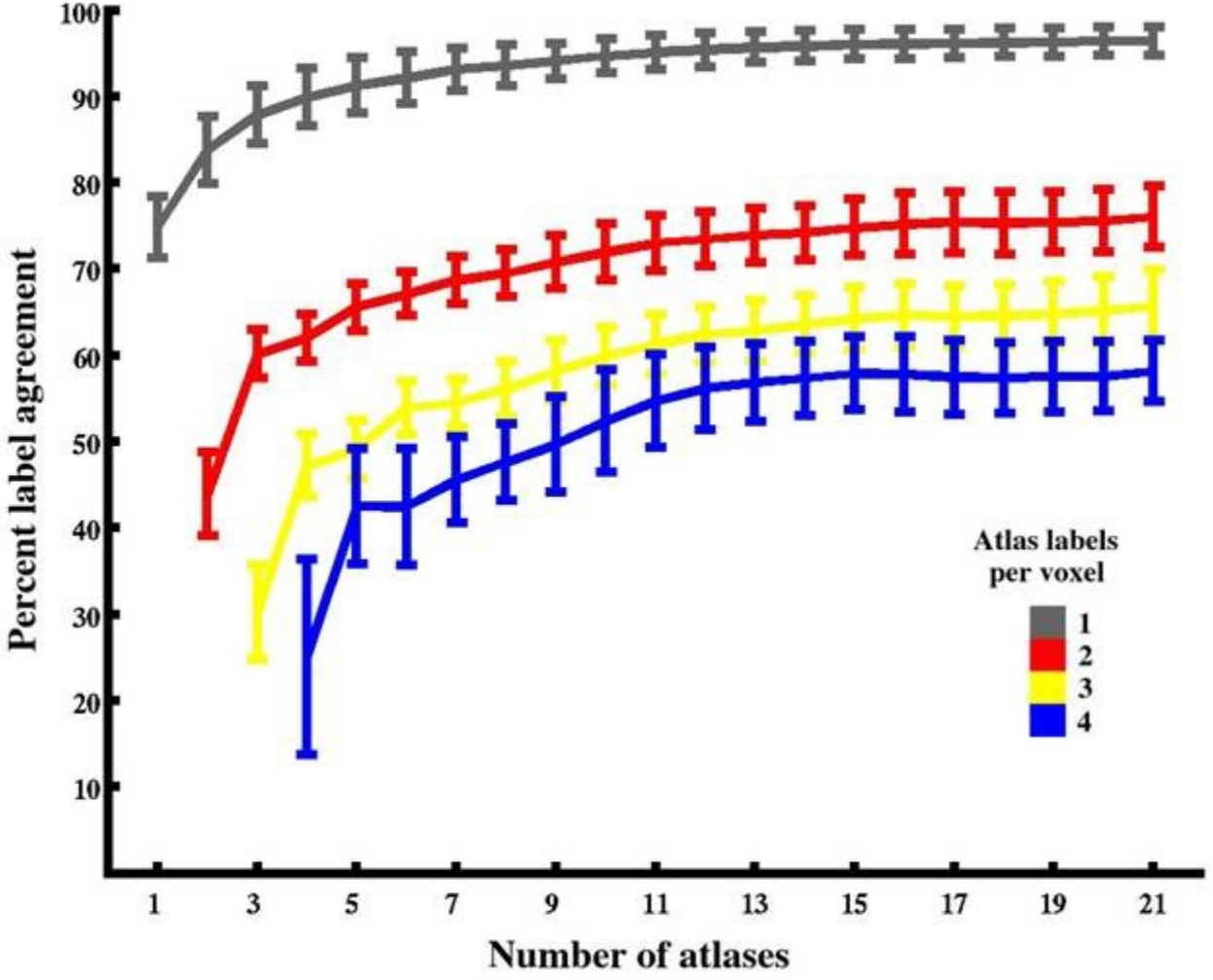
Evaluation

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

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Jack Grinband	Columbia University

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