Establishing correspondences across brain images: surface- vs. volume-based registration and a new way to manually label brains

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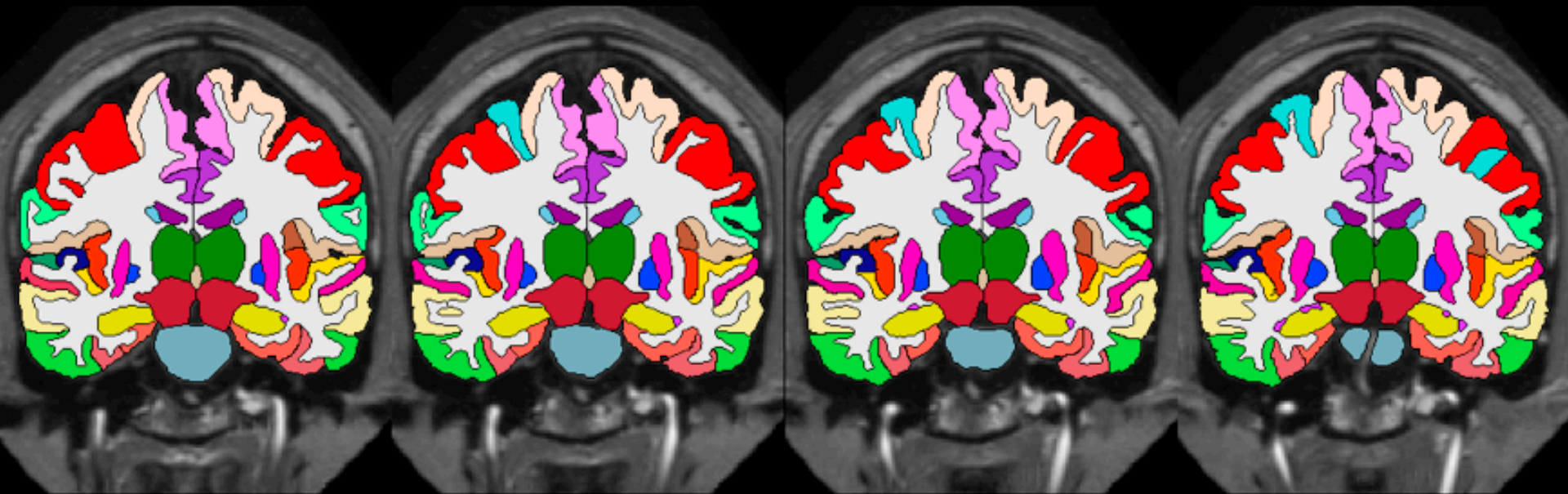
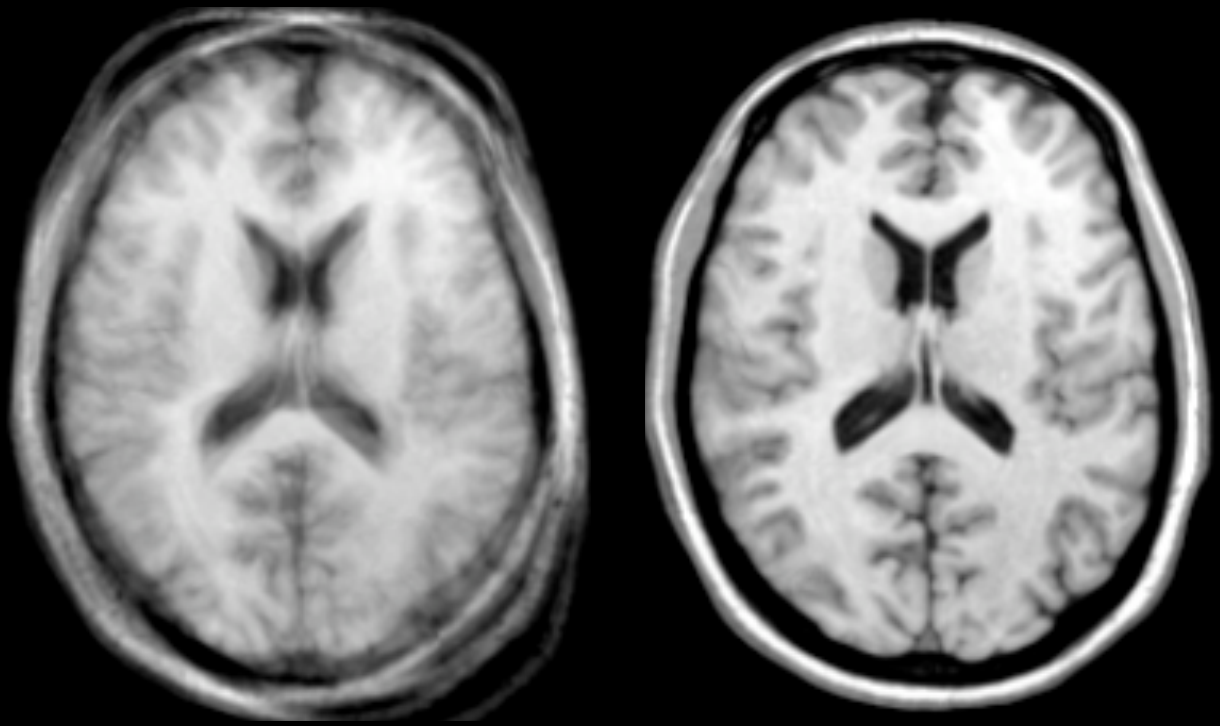
http://www.mindboggle.info/lectures

Yale University (3/25/2010)



Establishing correspondences across brain images: surface- vs. volume-based registration

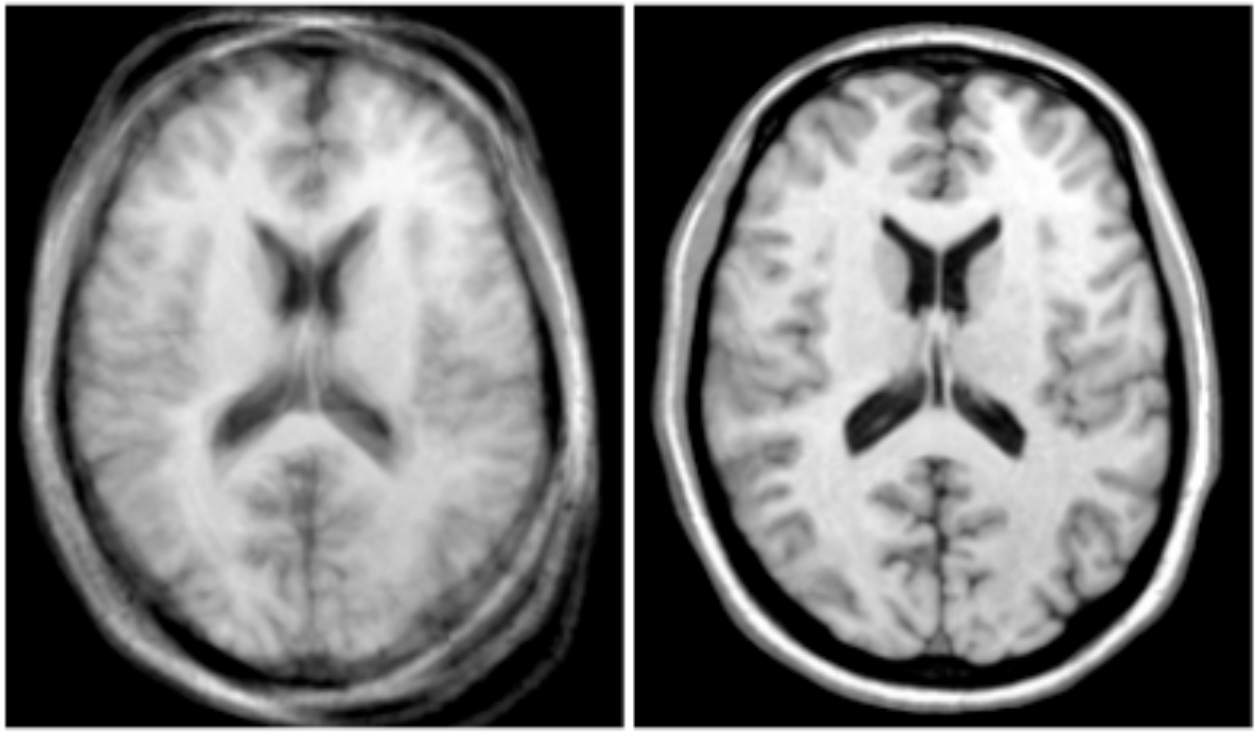
What types of registration are there?



Classify by...

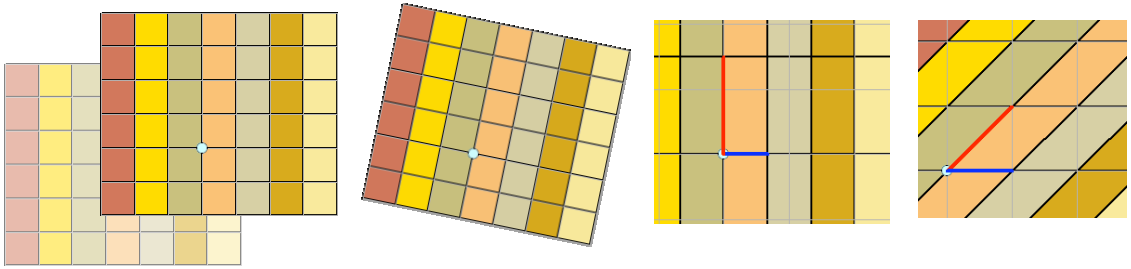
http://dx.doi.org/10.1002/hbm.460030304

...number of degrees of freedom (dof)



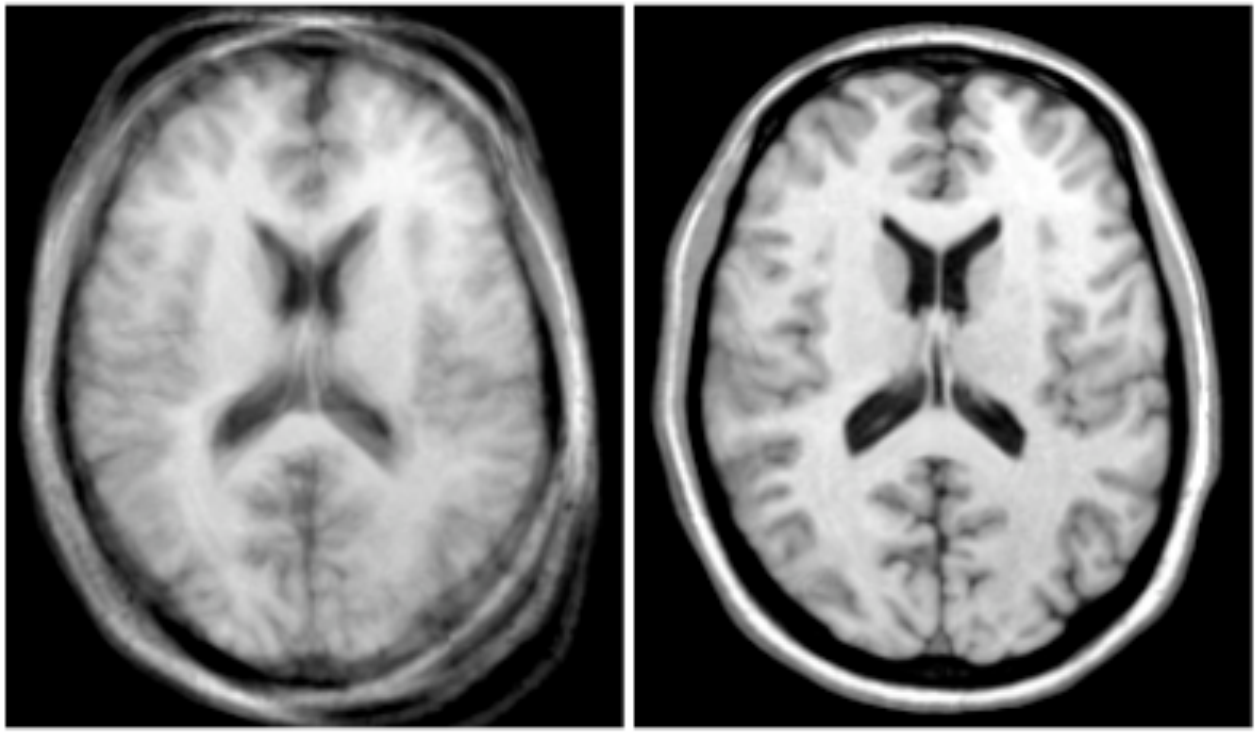
affine (12 dof) nonlinear (>12 dof)

12 dof: 3 translations, 3 rotations, 3 scales, 3 shears



http://dx.doi.org/10.1002/hbm.460030304

...registration steps

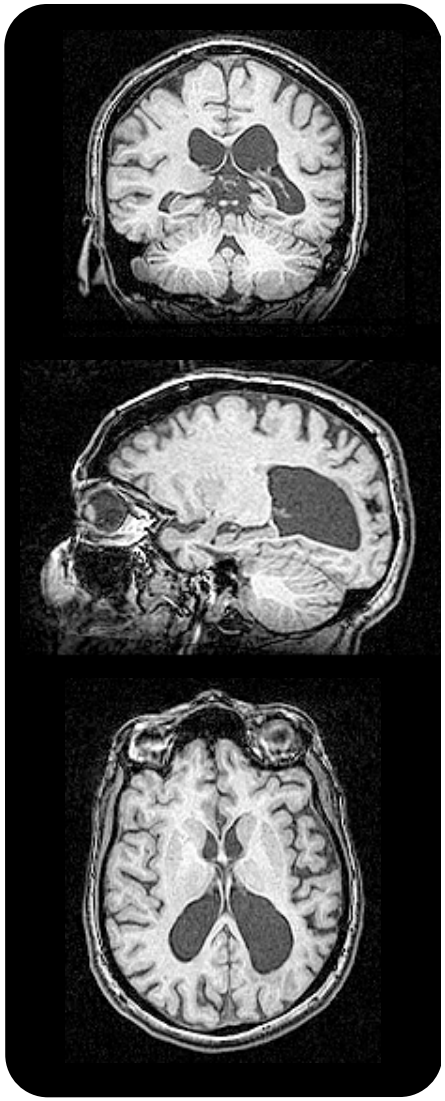


1. Similarity metric: (n)CR, SSD, MSD, (n)CC, MI,...
2. Transformation model: affine, piecewise linear, nonlinear,...
3. Regularization method: multi-resolution/scale, Gaussian blur,...
4. Optimization strategy: simplex, gradient descent,...
5. Interpolation type: nearest-neighbor, trilinear, cubic, sinc,...

http://dx.doi.org/10.1002/hbm.460030304

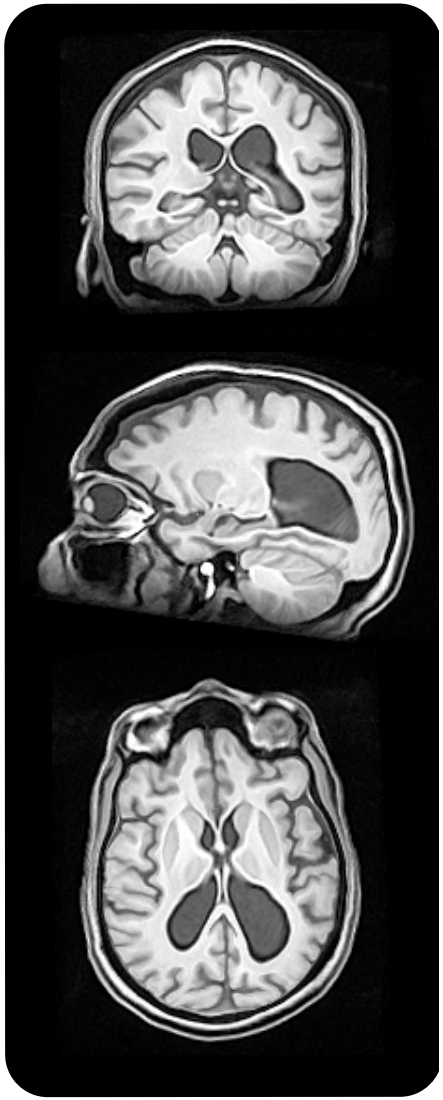
Challenging example

template

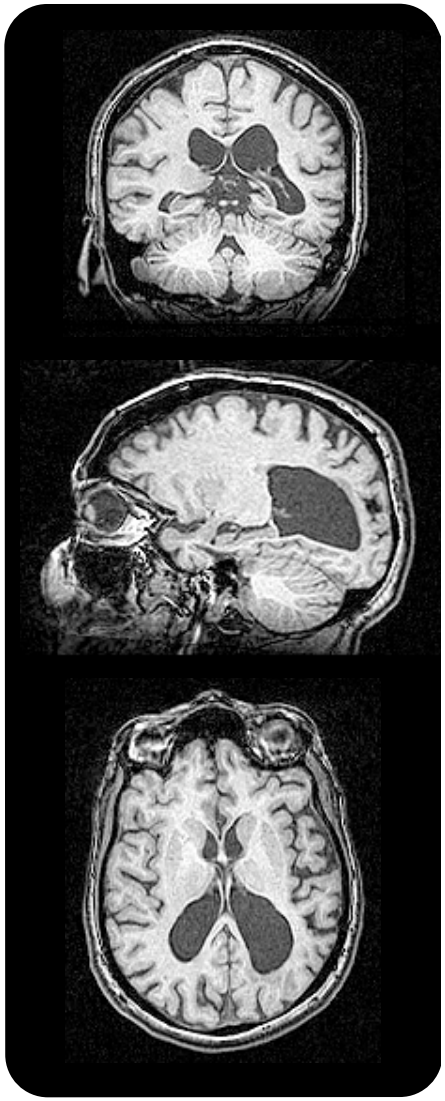


target

What are some applications?

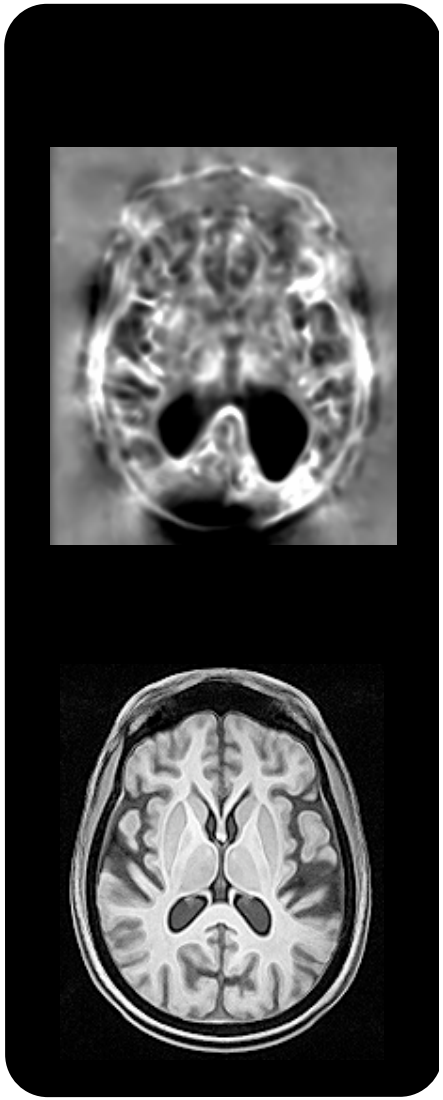


template
to target

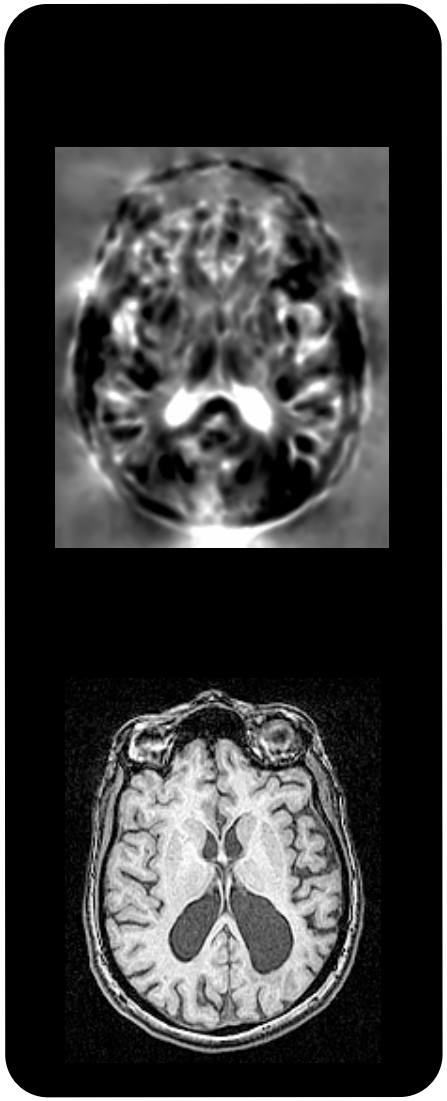


target

1. morphometry

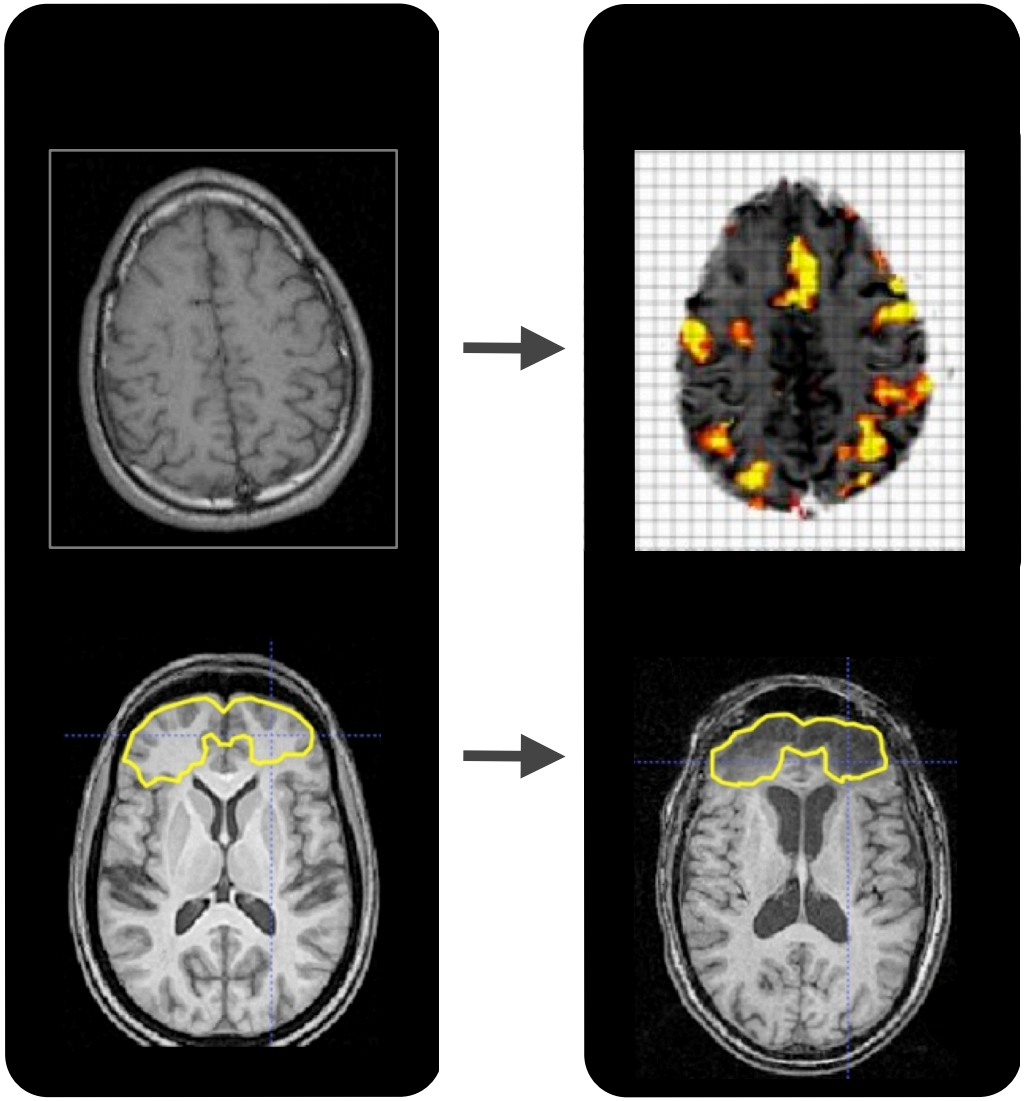


template

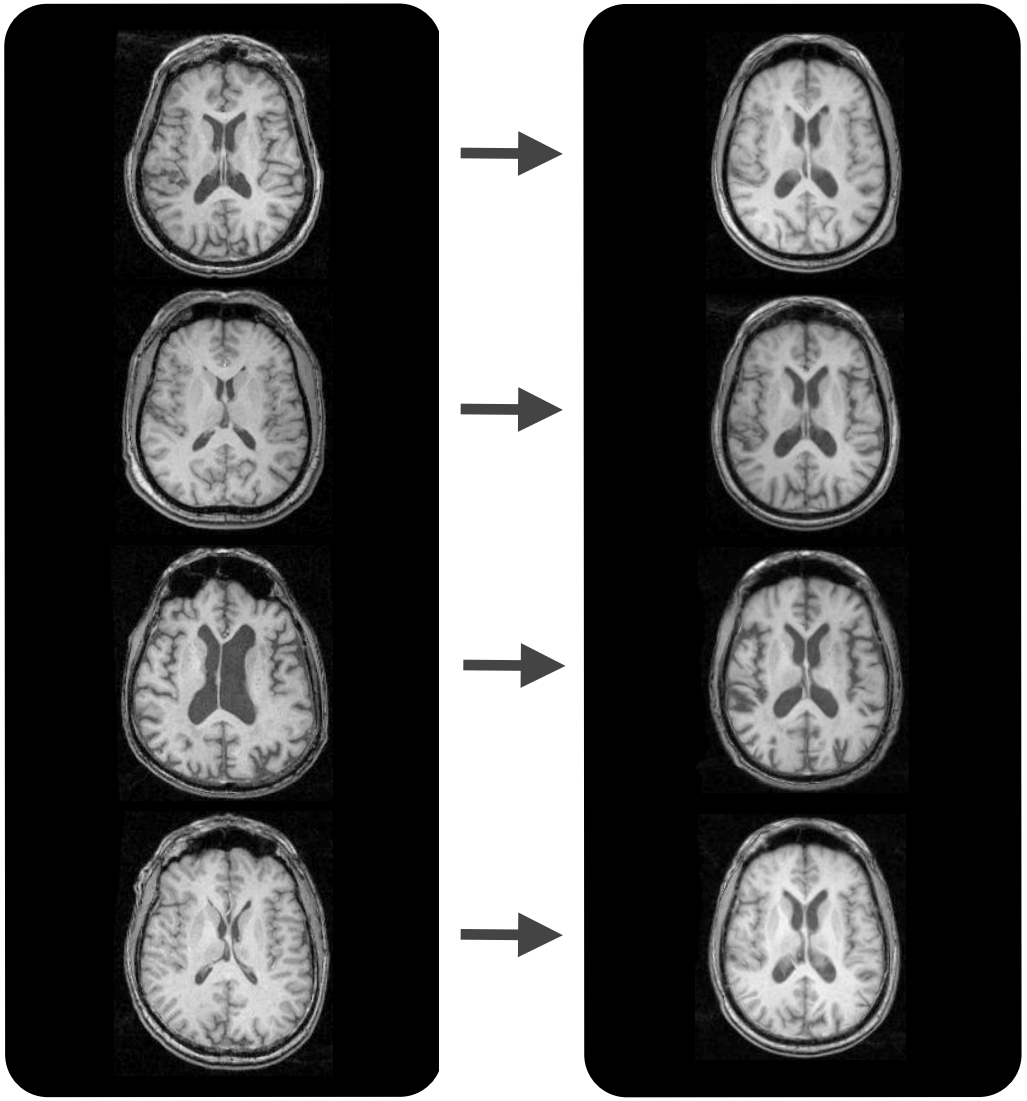


target

2. anatomical localization



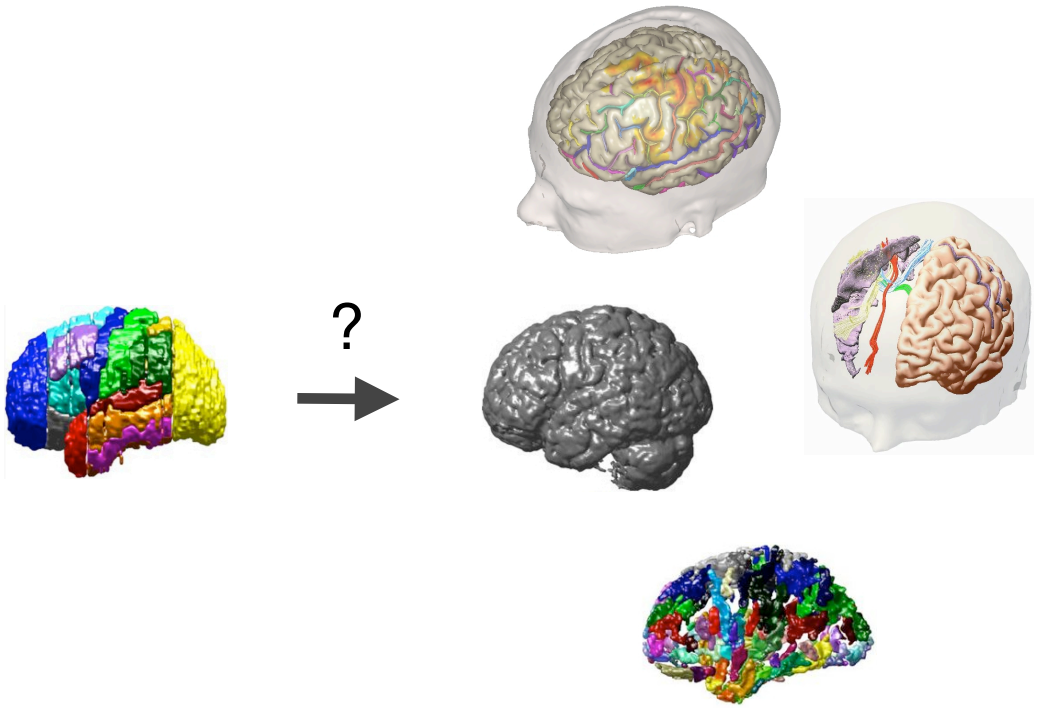
3. “spatial normalization” for group analysis



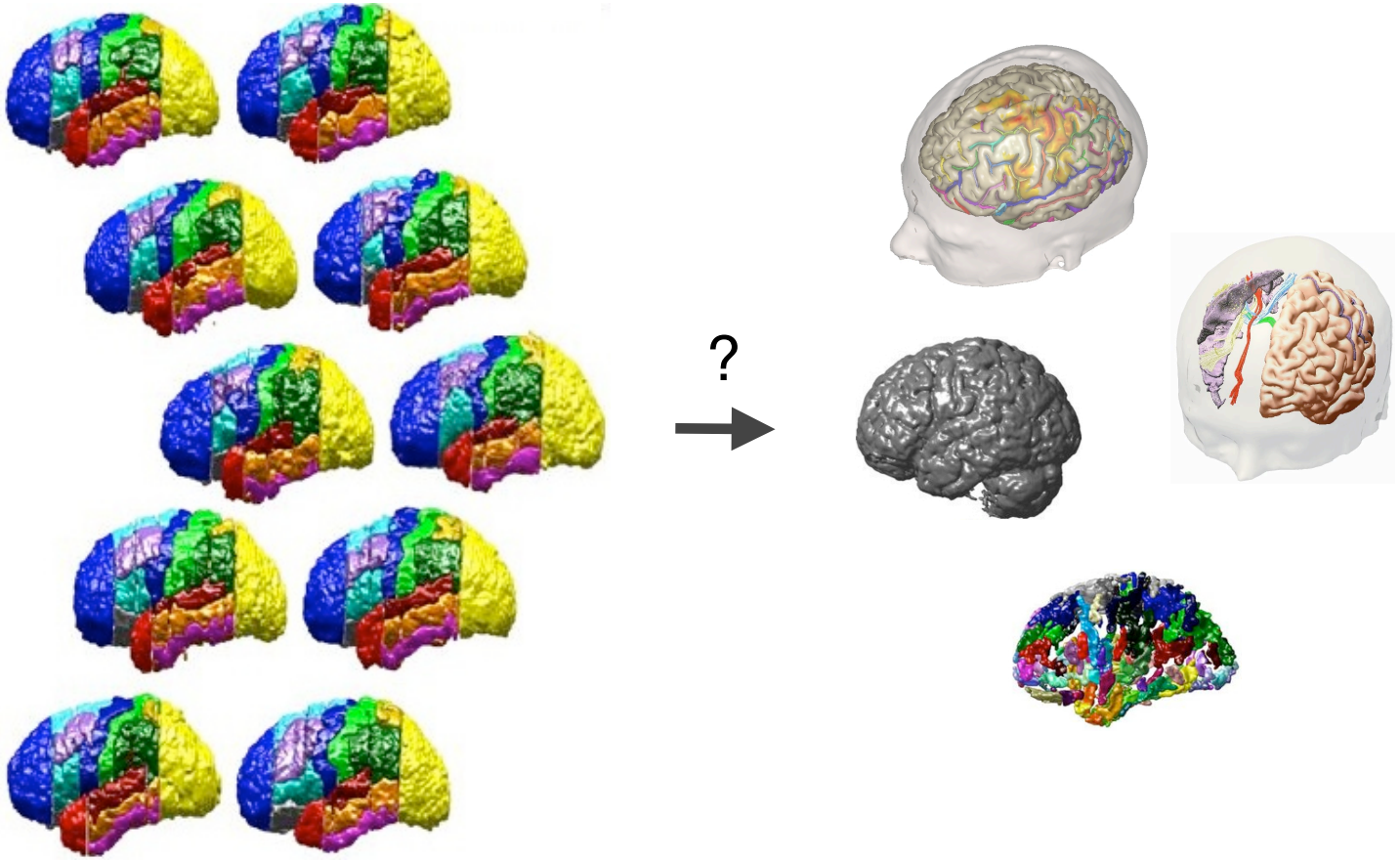
targets

template space

4a. atlas-based labeling

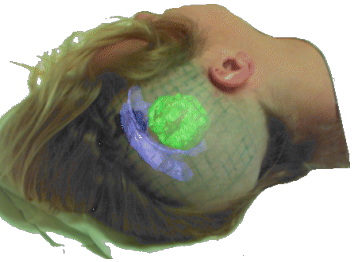


4b. multi-atlas labeling

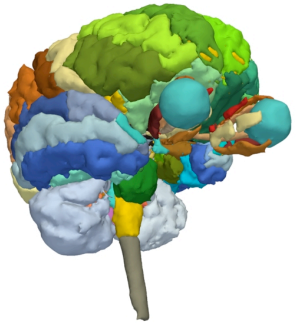


Why label brains?

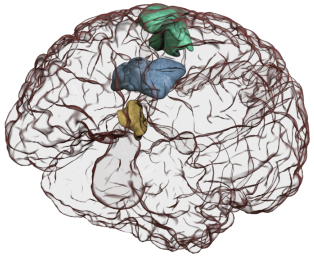
(1) labels serve as a visual guide and teaching tool



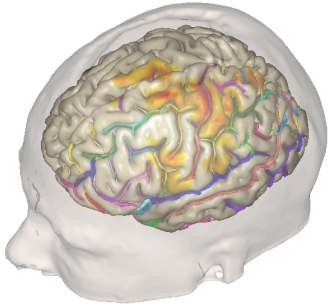
- guide neurosurgery
- teach brain anatomy



(2) labels break up data within a brain

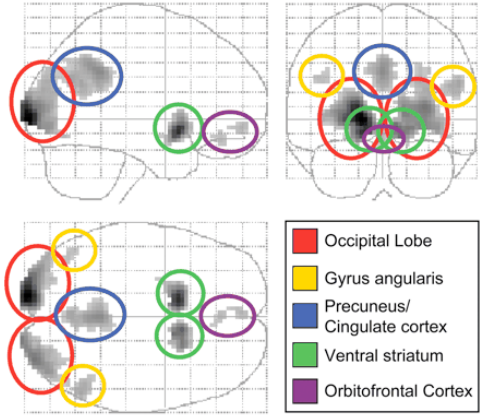


- quantify data by brain region
- assign results to brain regions



(3) labels establish correspondences across brains

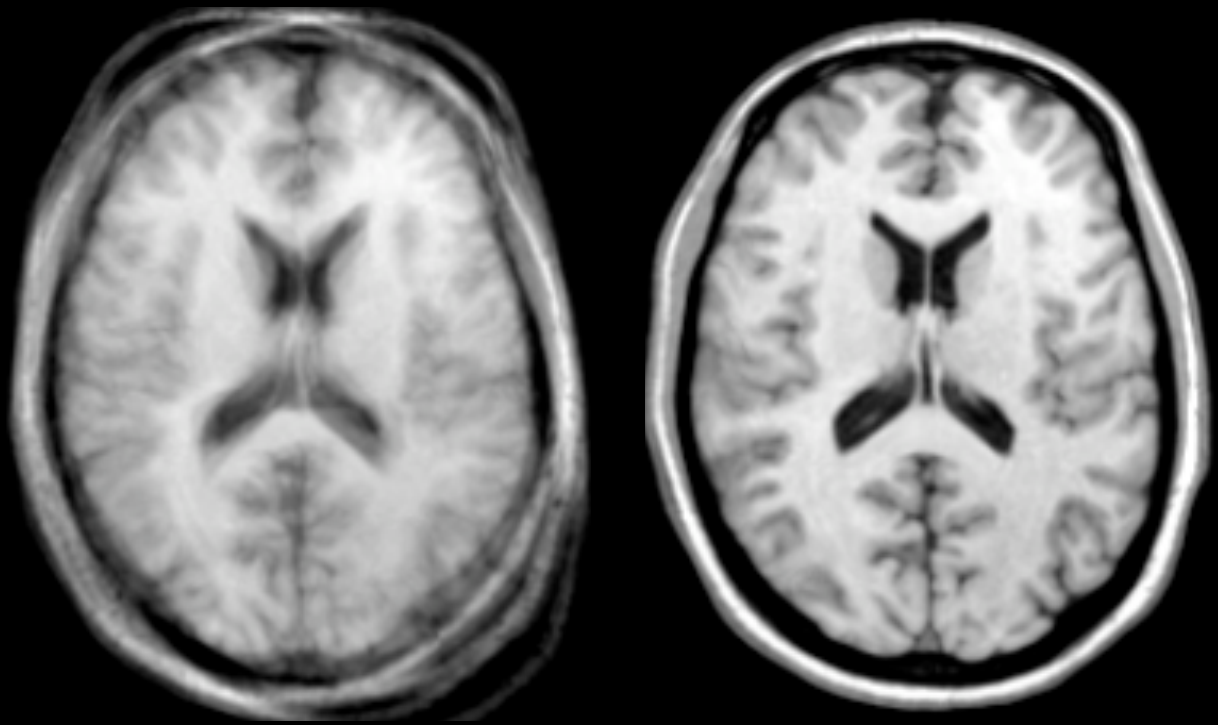
- compare individuals within a study
- compare results across studies
- communicate results with a common language



http://www.cbd.ucla.edu/bios/iacoboni.html, http://brainvisa.info/, http://dx.doi.org/10.1126/science.1145876
http://groups.csail.mit.edu/vision/medical-vision/past-projects.html, http://www.spl.harvard.edu/publications/item/view/1265

How accurate is a registration?

How accurate is the *anatomical* correspondence?



http://dx.doi.org/10.1002/hbm.460030304

"Evaluation of 14 nonlinear deformation algorithms applied to human brain MRI registration"

NeuroImage (2009)
http://www.mindboggle.info/papers/

Software	Similarity metric	Transformation
SyN	CC	bi-directional diffeomorphism (D)
ART	nCC	FFD based on cubic splines (H, np)
IRTK	nMI	cubic B-splines
SPM5 DARTEL	multinomial model: congealing	FDM of viscosity field (Dc)
JRD-fluid	Jensen-Rényi divergence	viscous fluid; variational calculus (D)
Diffeomorphic Demons	SSD	displacement field (D, np)
FNIRT	SSD	cubic B-splines
ROMEO	displaced frame difference	local affine
ANIMAL	CC	local translations
SICLE	SSD	3-D Fourier series (D)
SPM5 Unified Segment	generative segmentation	discrete cosine transforms
SPM5 "SPM2-type"	MSD	discrete cosine transforms
SPM5 Normalize	MSD	discrete cosine transforms
AIR	MSD	5th-order polynomial warps
FLIRT (linear)	nCR	linear, rigid-body

n = normalized
CC = cross-correlation
CR = correlation ratio
MI = mutual information
MSD = mean of squared differences
SSD = sum of squared differences

D = diffeomorphic
Dc = diffeomorphic, constant over time
FDM = finite difference model
FFD = free-form deformation
H = homeomorphic
np = nonparametric

“Evaluation of volume-based and surface-based brain image registration methods”

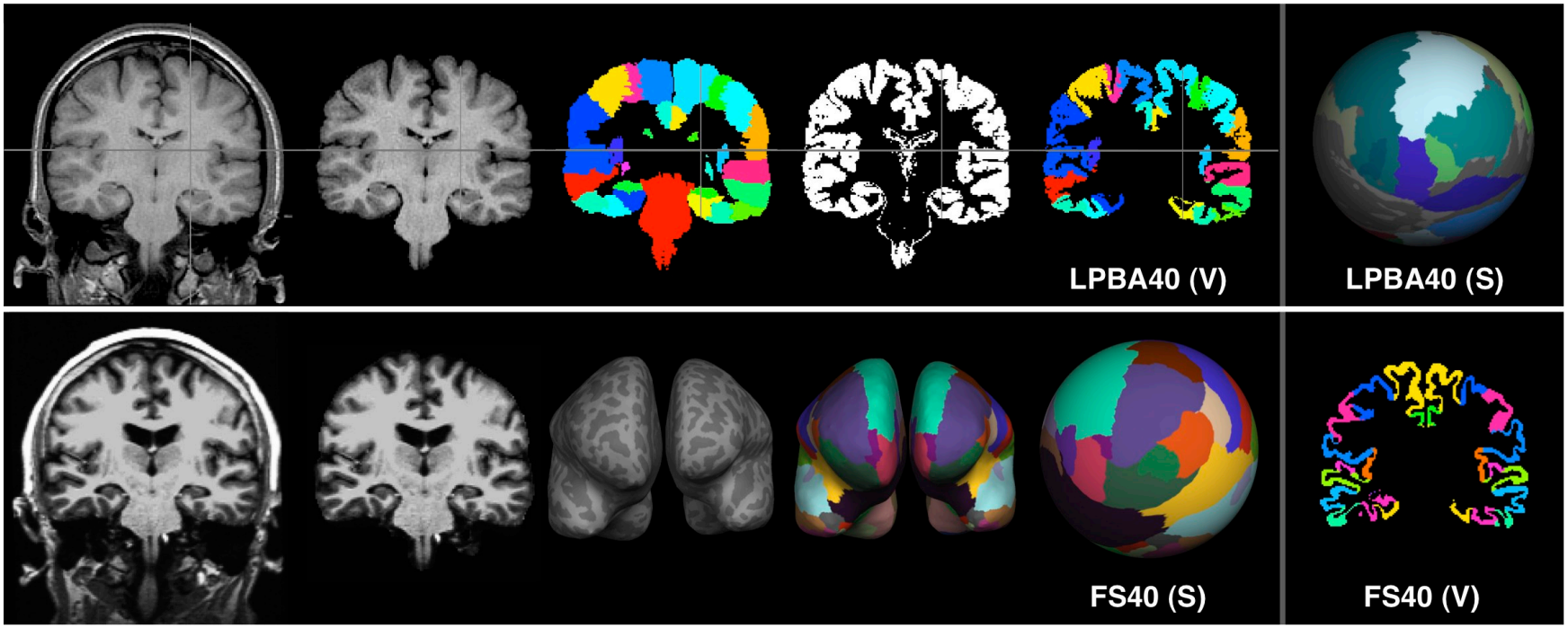
NeuroImage (2010)
http://www.mindboggle.info/papers/

Collaborators:	Software:	Space:
Satrajit S. Ghosh		
Brian Avants, James C. Gee	ANTS (SyN)	volume
Babak Ardekani	ART	volume
Bruce Fischl	FreeSurfer	surface
B.T.T. Yeo	Spherical Demons	surface

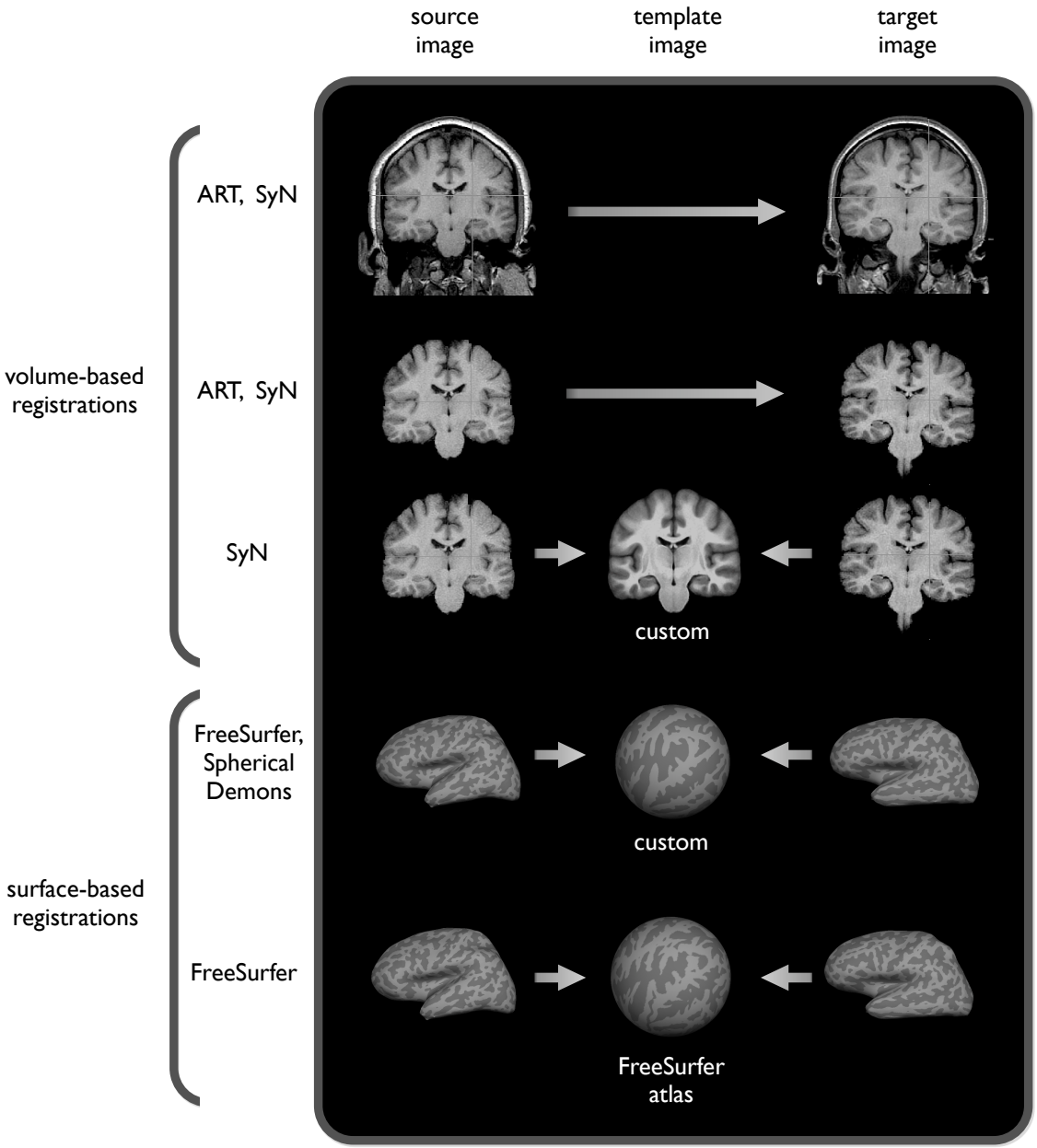
- first study to compare volume and surface registration methods
- first study to compare whole-head and brain-only image registrations
- compares registration accuracy with and without custom templates
- >16,000 registrations
- 80 manually labeled brain images for evaluation
- 2 different brain labeling protocols

Volume and Surface data

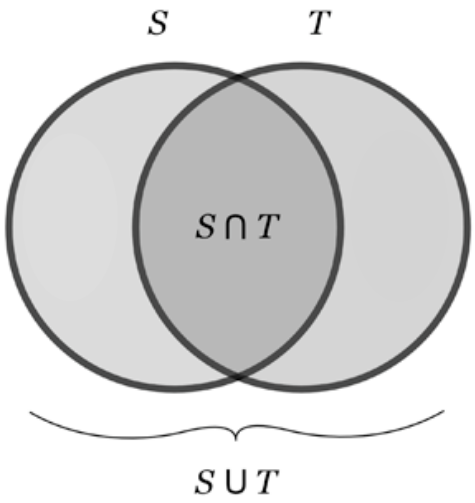
(labeled in volumes **and** surfaces)



Registrations



Evaluation measures



Target overlap: $TO = \frac{\sum_r |S_r \cap T_r|}{\sum_r |T_r|}$

Union overlap: $UO = \frac{\sum_r |S_r \cap T_r|}{\sum_r |S_r \cup T_r|}$

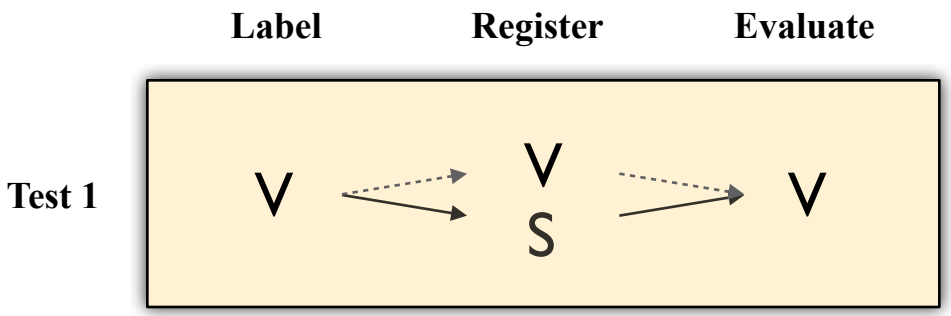
Mean overlap: $MO = 2\frac{\sum_r |S_r \cap T_r|}{\sum_r (|S_r| + |T_r|)}$

Volume similarity: $VS = 2\frac{\sum_r (|S_r| - |T_r|)}{\sum_r (|S_r| + |T_r|)}$

Hausdorff Distance Error:

$$DE(S,T) = \sum_r mean(mean_{s \epsilon S_r}(inf_{t \epsilon T_r}(d(s,t))), mean_{t \epsilon T_r}(inf_{s \epsilon S_r}(d(s,t))))$$

Test 1: Volume labels and evaluation



V: LPBA40
S: FS40

V: ART, SyN
S: FreeSurfer, Spherical Demons

V: overlap
S: overlap, distance

Test 1 results

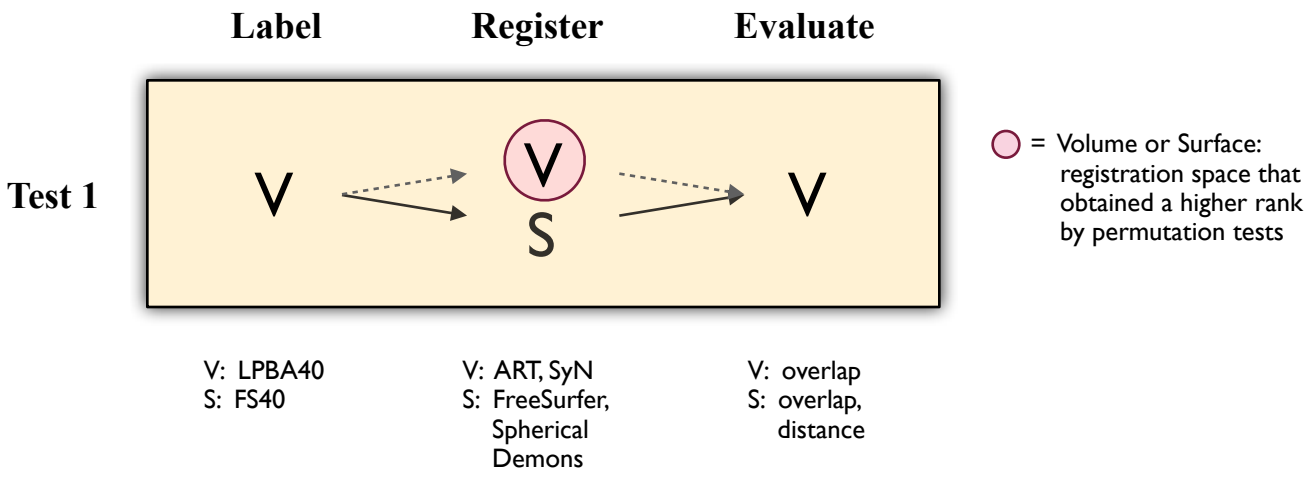
Permutation test

Volume registration methods	
Rank 1	SyN with custom templates
Rank 2	SyN ART

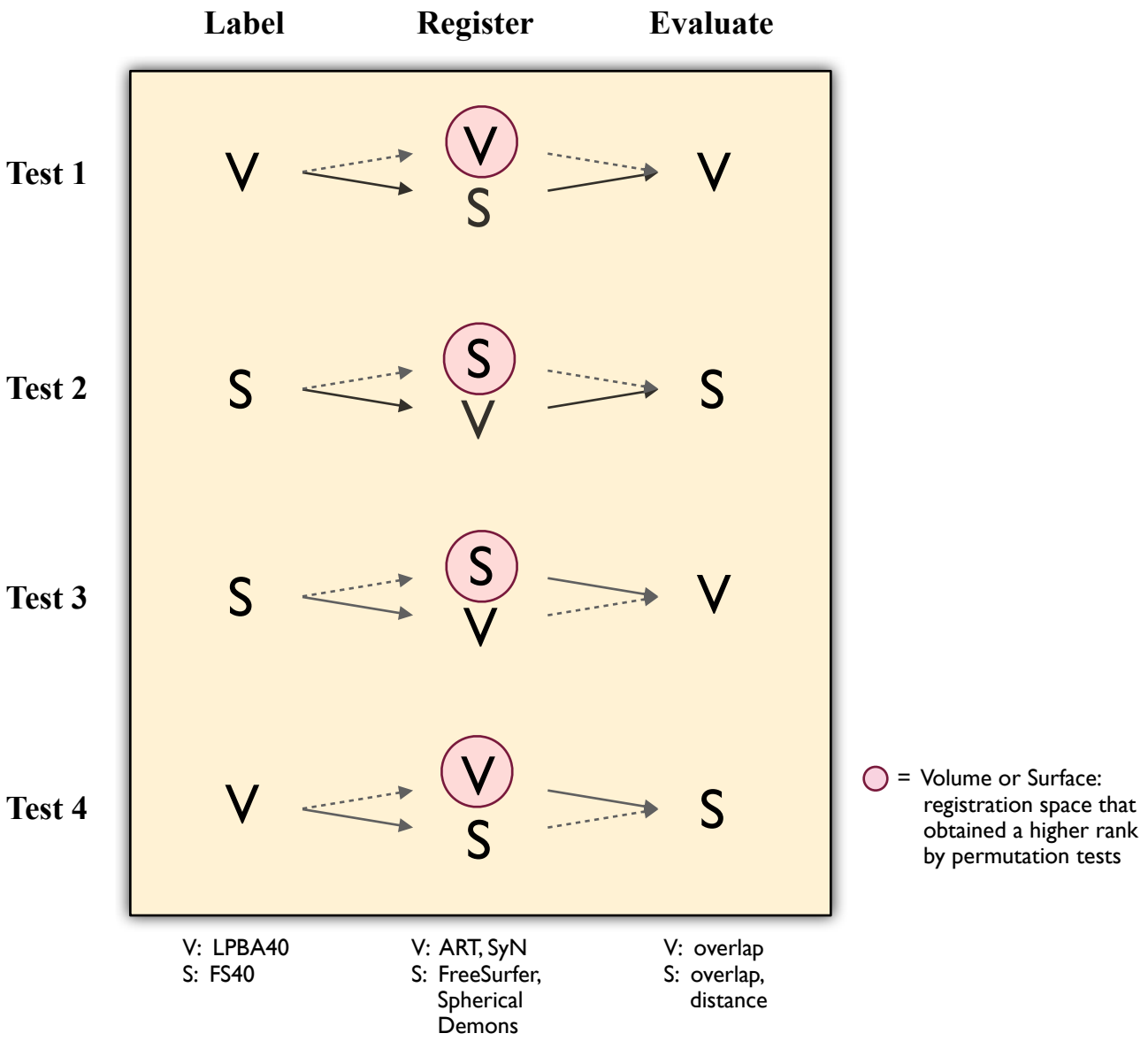
Permutation test

Surface registration methods	
Rank 1	FreeSurfer with custom templates Spherical Demons with custom templates
Rank 2	FreeSurfer with default atlas

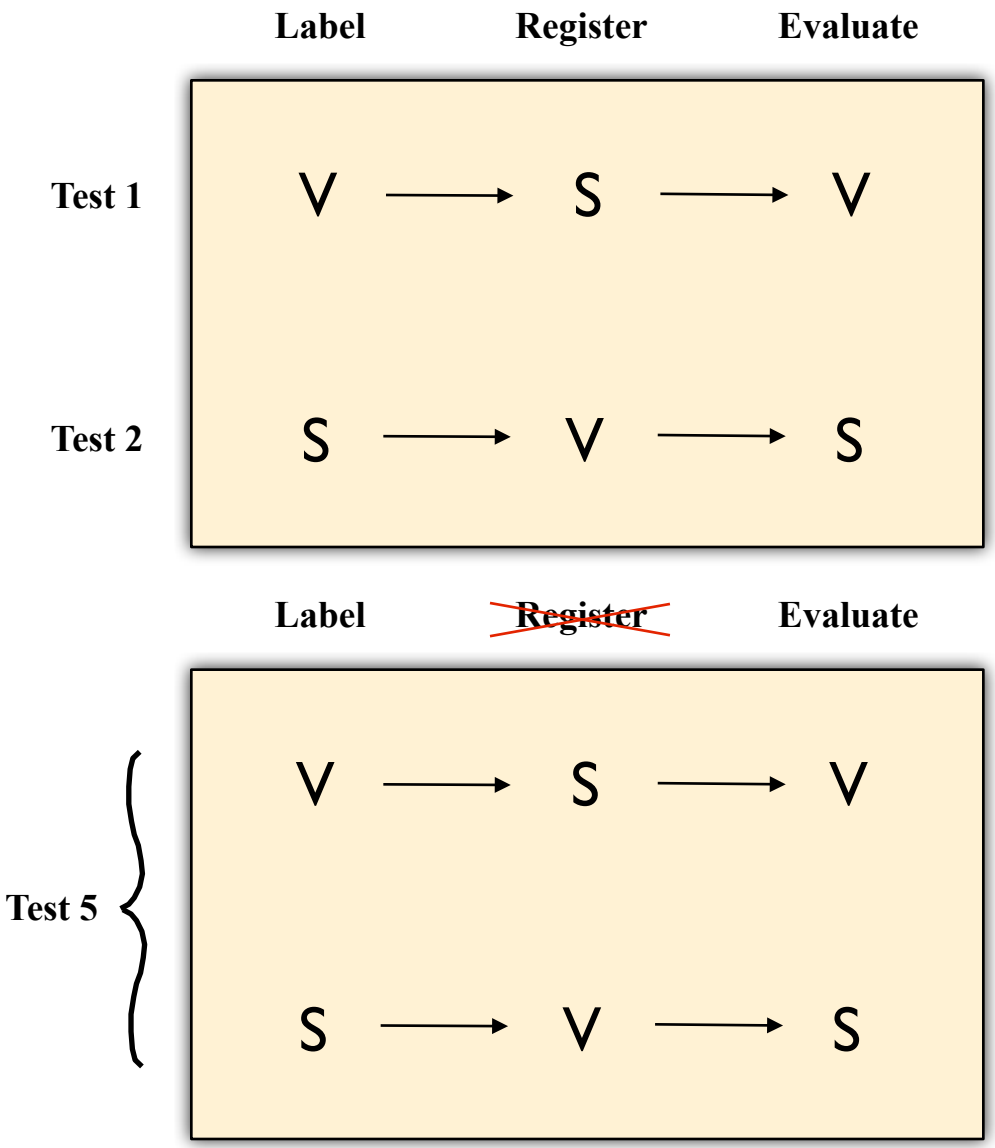
Test 1 results



Tests 1-4 results



Tests 5: resampling error



Conclusions

1. Brain extraction aids volume registration.

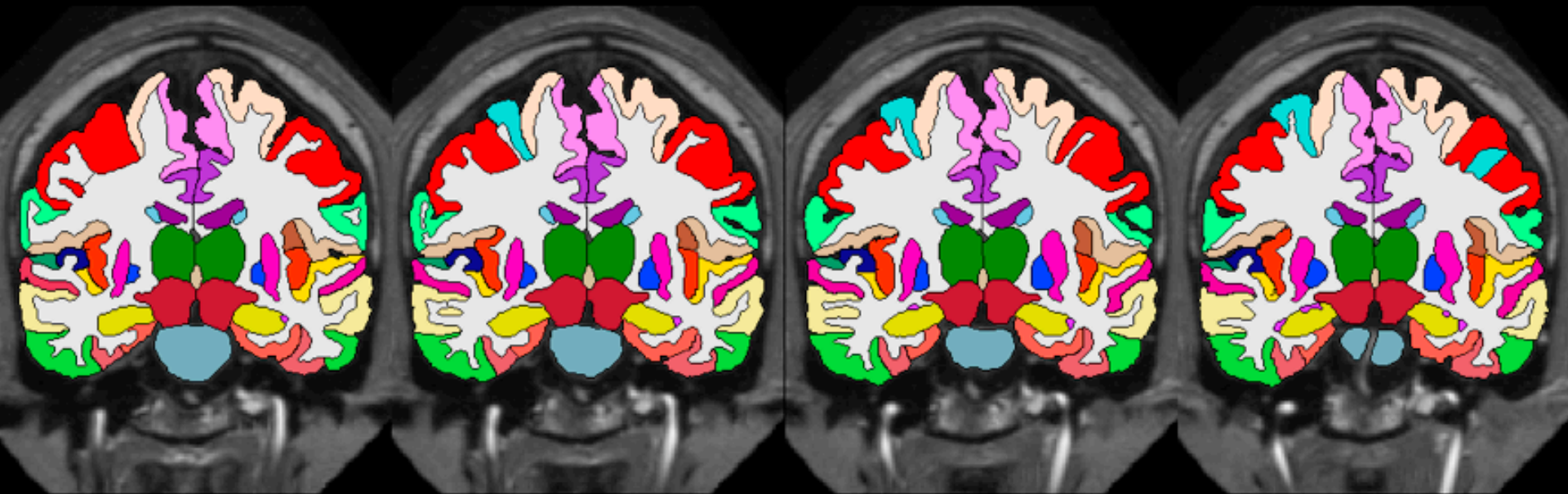
2. Custom templates improve registration over direct pairwise registration.

3. Resampling volume labels on surfaces or surface labels on volumes precludes a fair comparison between surface and volume registration methods.

Recommendation

Construct a custom template from a limited sample drawn from the same or a similar representative population, using the same algorithm used for registering brains to the template.

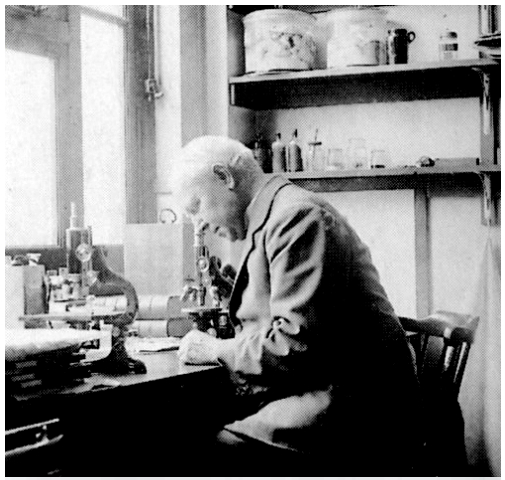
Establishing correspondences across brain images: surface- vs. volume-based registration and a new way to manually label brains

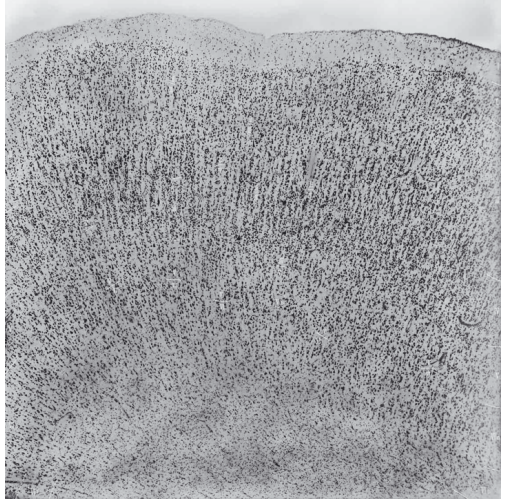


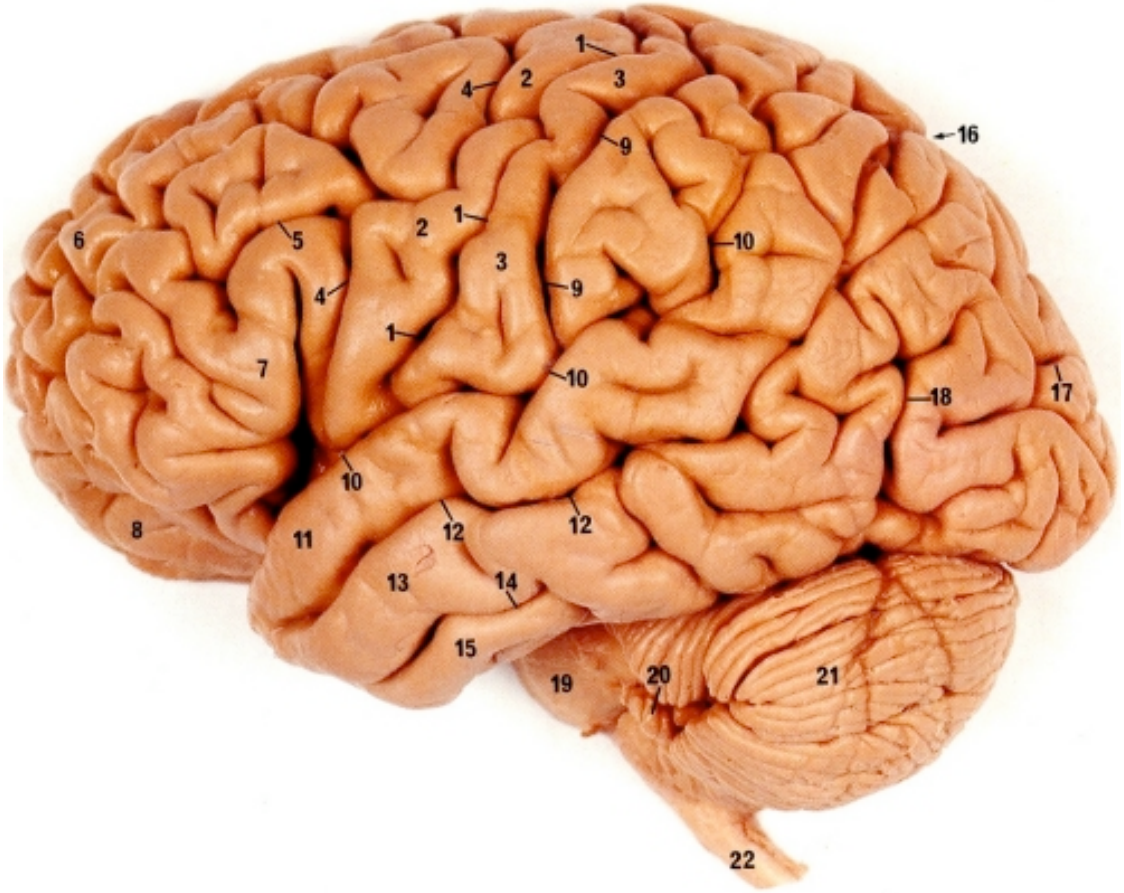
http://www.wired.com/medtech/health/magazine/17-04/ff_brainatlas

brain anatomy

histology (microscopic)
gross anatomy (macroscopic)



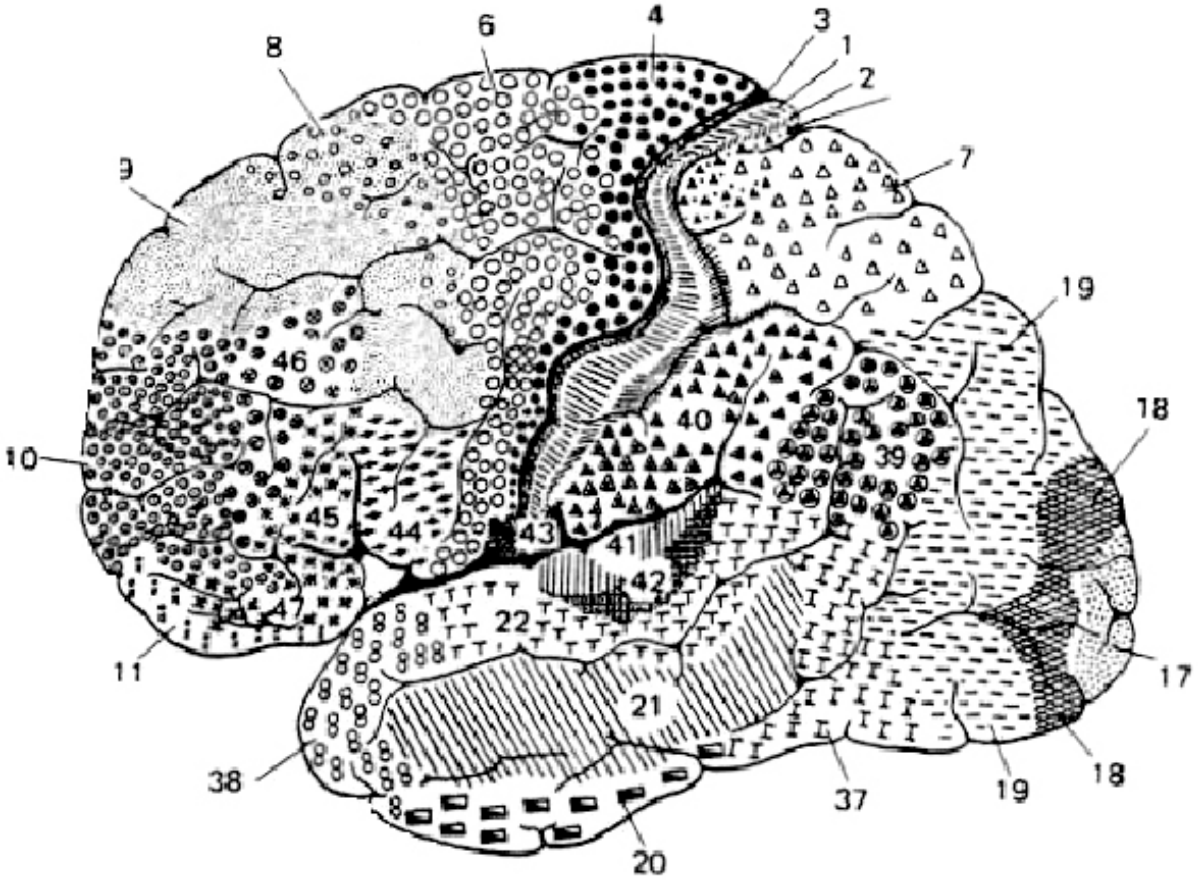




brain anatomy

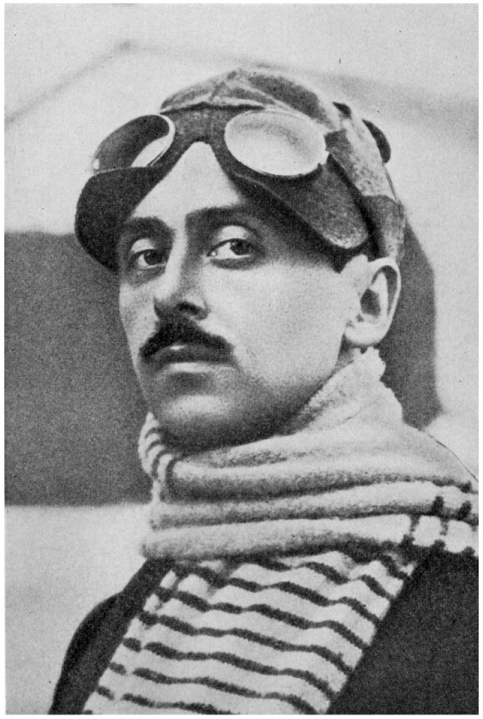
histology (microscopic)

Korbinian Brodmann
(1868-1918)



brain anatomy

histology (microscopic)



Constantin von Economo
(1876-1931)

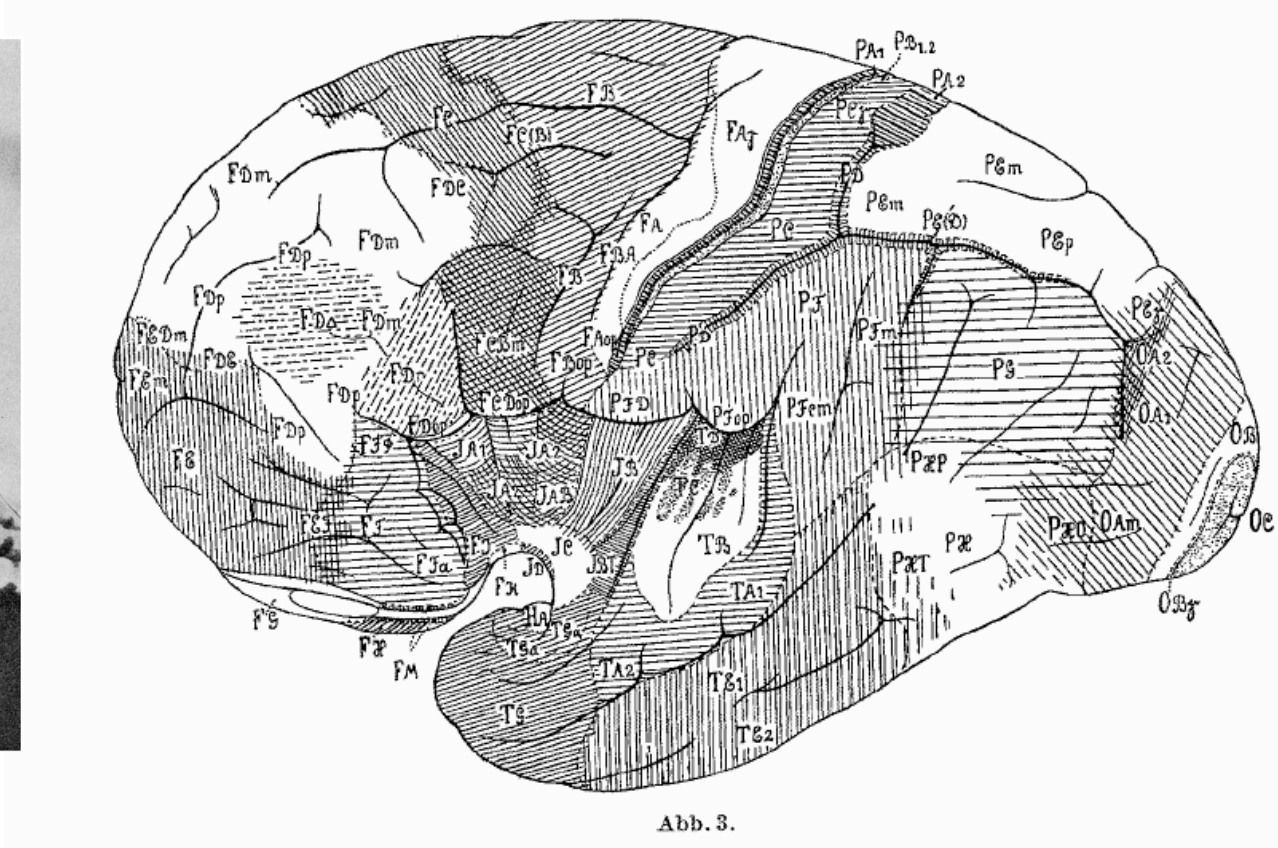
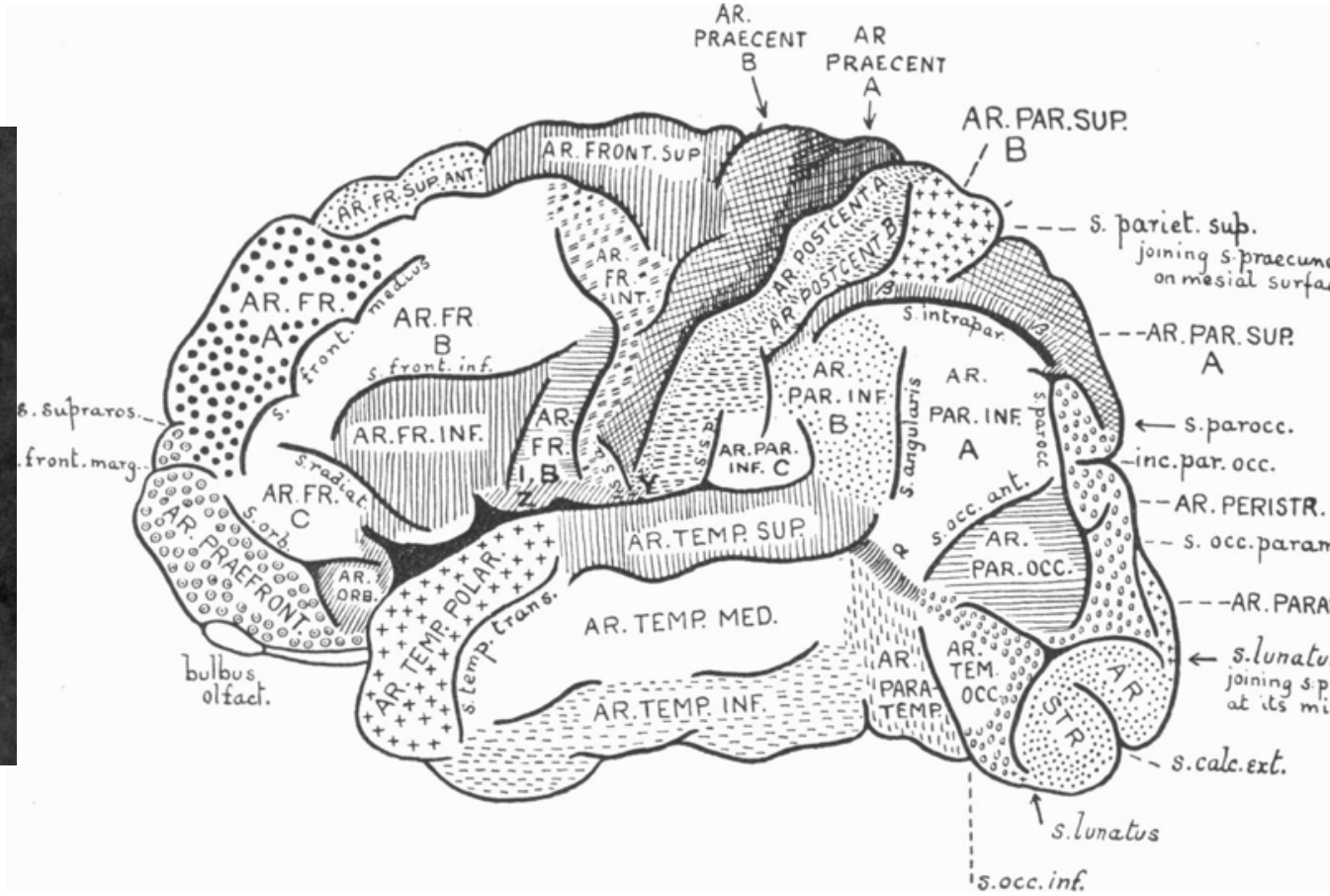


Abb. 3.

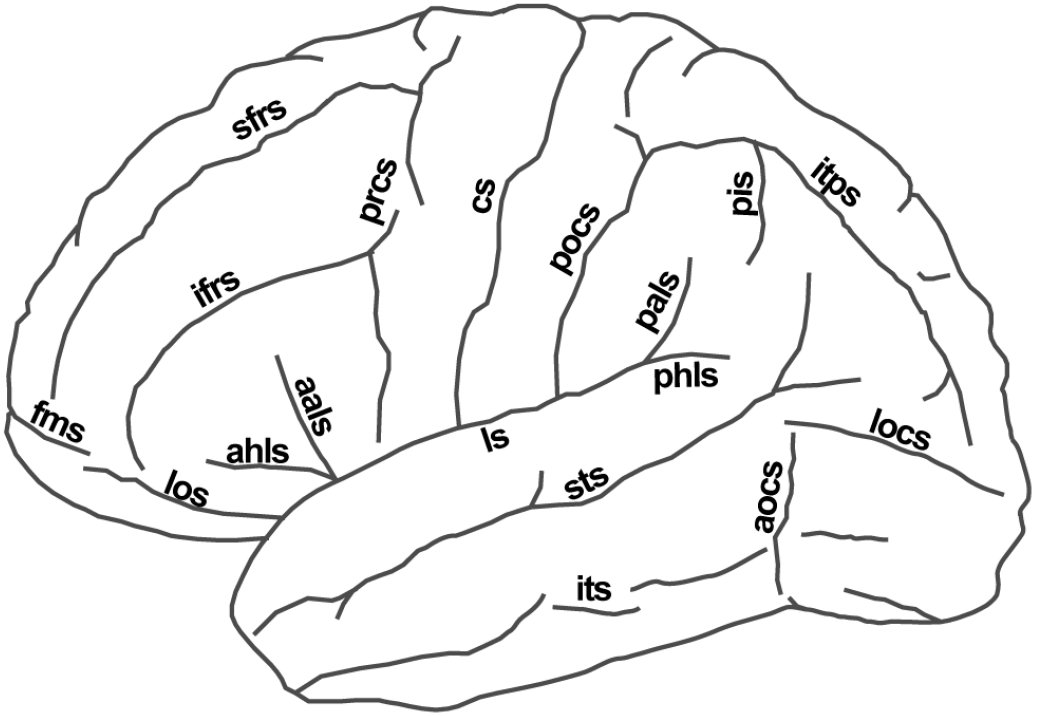
brain anatomy

gross anatomy (macroscopic)

Sir Grafton Elliot Smith
(1871-1937)



1
2
3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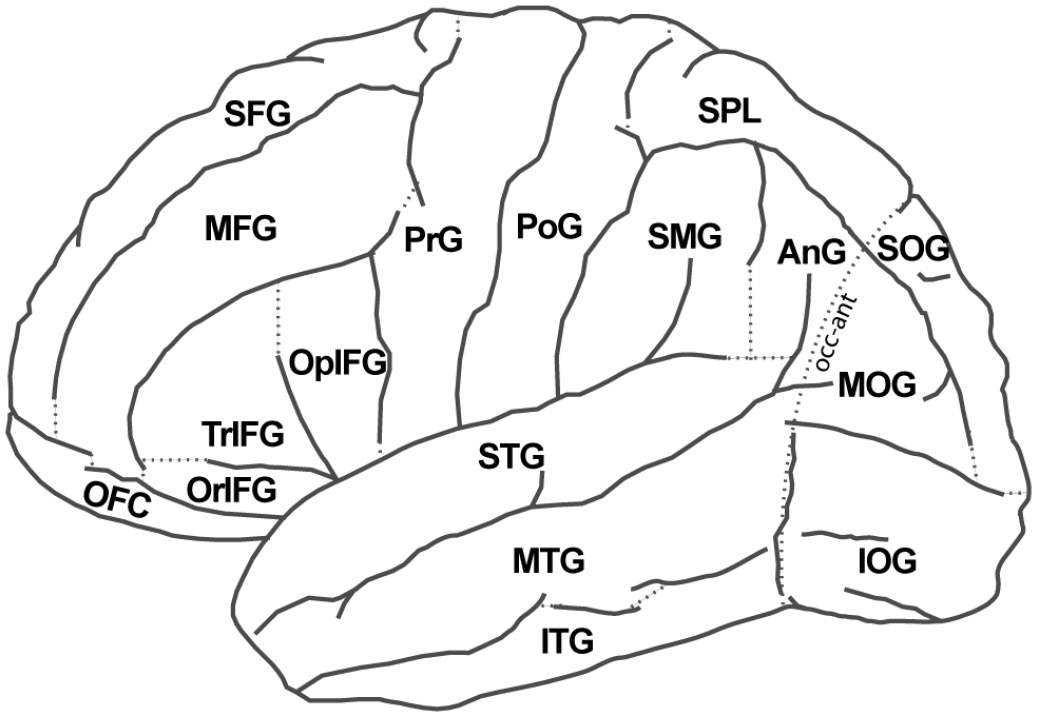
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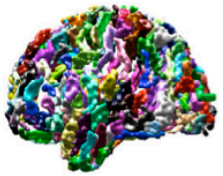


brainCOLOR Collaborative Open Labeling Online Resource

Proposed Cortical Parcellation Protocol: SURVEY 1 SURVEY 2

Neuromorphometrics has developed a cortical parcellation (anatomical labeling) protocol that will be used by trained personnel to manually label an initial set of at least 800 to 1,000 T1-weighted MRI brain volumes as part of three different NIH-funded grants (find out more).

This protocol is derived from some of the best and most frequently used parcellation methods established by other research groups. From a detailed review of these methods, including their anatomic validity and consistency across brains, Jason Tourville and Ruth Carper have extracted the best approaches from each of these research groups and consolidated them into a single parcellation protocol.

The anatomically labeled brain images will be made publicly available online as a free, downloadable resource. In order to ensure that these anatomical labels are meaningful and useful to the neuroscientific community, we urge you to take the following two surveys.

SURVEY 1, below, collects your comments regarding the protocol.
SURVEY 2 takes recommendations for additional datasets you wish to have us manually label.

Instructions
For each survey, please fill in your name and email address, fill in the survey and click the Submit button at the bottom of the survey.

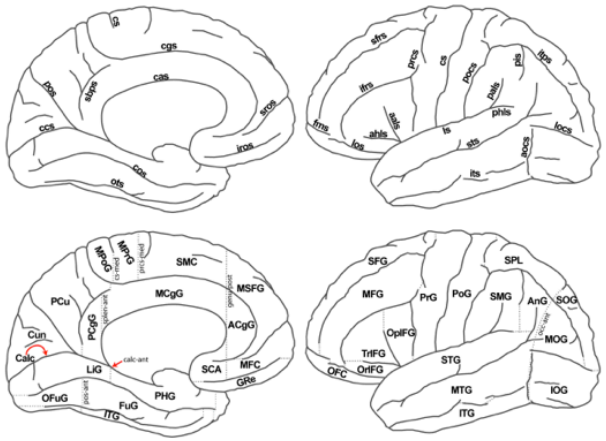


Figure 2. Region-delimiting sulci (top) and proposed regions of interest (bottom) of the medial (left) and lateral (right) cortical surfaces are schematized (see lists above for abbreviation definitions). All regions, including optional regions are shown with the exception of entorhinal cortex. Boundaries not formed by sulci are indicated by dotted lines. Dividing planes are labeled (all lower case; dotted lines that are not labeled represent simple extensions of sulci). The curved arrow from the Calcarine Cortex ROI (Calc) to the calcarine sulcus indicates that the ROI lies within the sulcus.

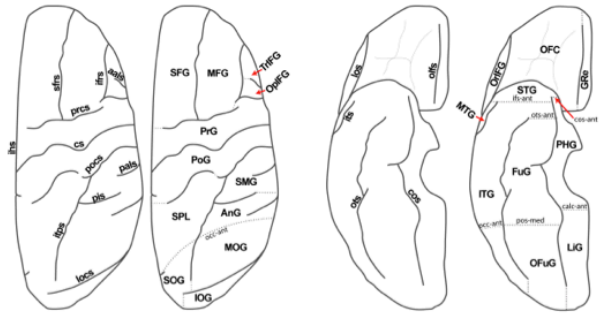
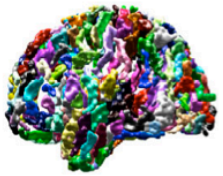


Figure 3. Sulci and ROIs are shown on the dorsal (left group) and ventral (right group) surfaces. Boundaries not formed by sulci are indicated by dotted lines. Dividing planes are labeled (all lower case; dotted lines that are not labeled represent simple extensions of sulci).



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Proposed Cortical Parcellation Protocol: SURVEY 1 SURVEY 2

Frontal Lobe (FL): Lateral Surface

Precentral Gyrus (PrG)

Anterior: precentral sulcus --- Posterior: central sulcus --- Superior: superior margin of the interhemispheric fissure --- Inferior: lateral margin of the dorsal bank of the lateral fissure

Superior Frontal Gyrus (SFG)

Anterior: frontomarginal sulcus --- Posterior: precentral sulcus / plane prcs-med --- Medial: superior margin of interhemispheric fissure --- Inferior: anteriorly: lateral orbital sulcus; posteriorly: middle frontal sulcus

Middle Frontal Gyrus (MFG)

Posterior: precentral sulcus --- Superior: superior frontal sulcus --- Inferior: anteriorly: lateral orbital sulcus; posteriorly: inferior frontal sulcus

Inferior Frontal Gyrus (IFG)

Posterior: precentral sulcus --- Superior/anterior: anteriorly: lateral orbital sulcus; posteriorly: inferior frontal sulcus --- Inferior: anteriorly: lateral orbital sulcus; posteriorly: lateral orbital sulcus / posterior projection from the posterior limit of the lateral orbital sulcus to the lateral sulcus

Regions of interest included in the protocol

ACgG	anterior cingulate gyrus
AIns*	anterior insula
AnG	angular gyrus
Calc*	calcarine cortex
CgG	cingulate gyrus
CO	central operculum
Cun	cuneus
Ent	entorhinal area
FO	frontal operculum
FuG	fusiform gyrus
GRe	gyrus rectus
IFG	inferior frontal gyrus
IOG	inferior occipital gyrus
ITG	inferior temporal gyrus
LiG	lingual gyrus
MCgG*	middle cingulate gyrus
MFC*	medial frontal cortex
MFG	middle frontal gyrus
MOG*	middle occipital gyrus
MPoG	postcentral gyrus, medial segment
MPrG	precentral gyrus, medial segment
MSFG	superior frontal gyrus, medial segment
MTG	middle temporal gyrus
OFC*	orbitofrontal cortex
OFuG*	occipital fusiform gyrus
OpIFG	opercular part of the inferior frontal gyrus
OrIFG	orbital part of the inferior frontal gyrus
PCgG	posterior cingulate gyrus
PCu	precuneus
PHG	parahippocampal gyrus
PIns*	posterior insula
PO	parietal operculum
PoG	postcentral gyrus
PP*	planum polare
PrG	precentral gyrus
PT*	planum temporale
SCA	subcallosal area
SFG	supereior frontal gyrus
SMC*	supplementary motor cortex
SMG	supramarginal gyrus
SOG	superior occipital gyrus
SPL	superior parietal lobule
STG	superior temporal gyrus
TriFG	triangular part of the inferior frontal gyrus
TTG	transverse temporal gyrus

* not included in the NeuroNames database

Sulci included in the protocol and their abbreviations

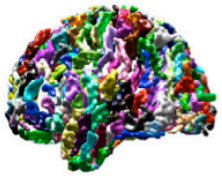
aals	anterior ascending ramus of the lateral sulcus
ahls	anterior horizontal ramus of the lateral sulcus
aocs	anterior occipital sulcus
cas	callosal sulcus
ccs	calcarine sulcus
cgs	cingulate sulcus
cis	central insular sulcus
cos	collateral sulcus
crs	circular insular sulcus
cs	central sulcus
fms*	frontomarginal sulcus
ftts*	first transverse temporal sulcus
hs*	Heschl's sulcus
ifrs	inferior frontal sulcus
ihs*	interhemispheric sulcus
ltts*	intermediate transverse temporal sulcus
iros	inferior rostral sulcus
itps	intraparietal sulcus
its	inferior temporal sulcus
locs	lateral occipital sulcus
los	lateral orbital sulcus
ls	lateral sulcus
olfs	olfactory sulcus
ots	occipitotemporal sulcus
pals	posterior ascending ramus of the lateral sulcus
phls	posterior horizontal ramus of the lateral sulcus
pis*	primary intermediate sulcus
pocs	postcentral sulcus
pos	parietooccipital sulcus
prcs*	precentral sulcus
sbps	subparietal sulcus
sfrs	superior frontal sulcus
sros	superior rostral sulcus
sts	superior temporal sulcus

* not included in the NeuroNames database

Dividing planes included in the protocol and their abbreviations

The following dividing planes are used in the protocol.
Planes are coronal unless specified otherwise:

calc-ant	anterior limit of the calcarine sulcus
cos-ant	anterior limit of the collateral sulcus
cs-med	dorsomedial limit of the central sulcus;
genu-post	marked by the posterior limit of the genu of the corpus callosum
ifs-ant	anterior limit of the inferior temporal sulcus
occ-ant	oblique medial-lateral plane given by a line drawn through points at (i) ventrolateral limit of the anterior occipital sulcus, (ii) jnct of the lateral occipital sulcus and the anterior occipital sulcus, and (iii) the dorsomedial limit of the parietooccipital sulcus
ots-ant	anterior limit of the occipitotemporal sulcus
prcs-med	dorsomedial limit of the precentral sulcus
prcs-lat	ventrolateral limit of the precentral sulcus
pocs-lat	ventrolateral limit of the postcentral sulcus
pos-ant	anterior limit of the ventral bank of the parietooccipital sulcus
tf-jnct	junction of the temporal and frontal lobes
splen-ant	anterior limit of the splenium of the corpus callosum



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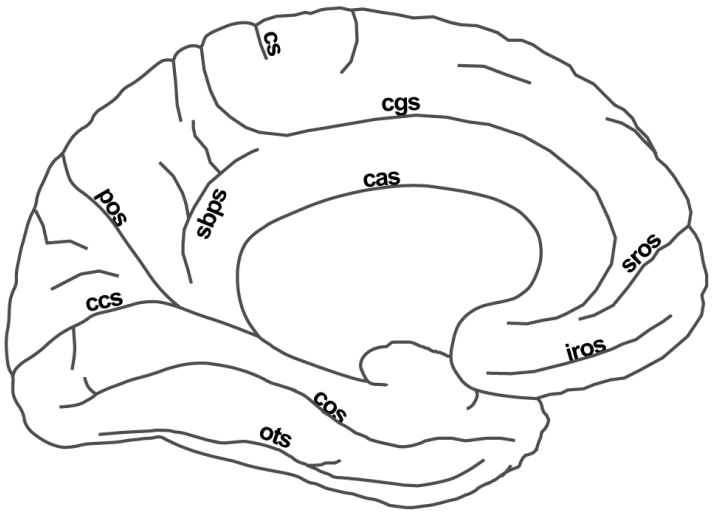

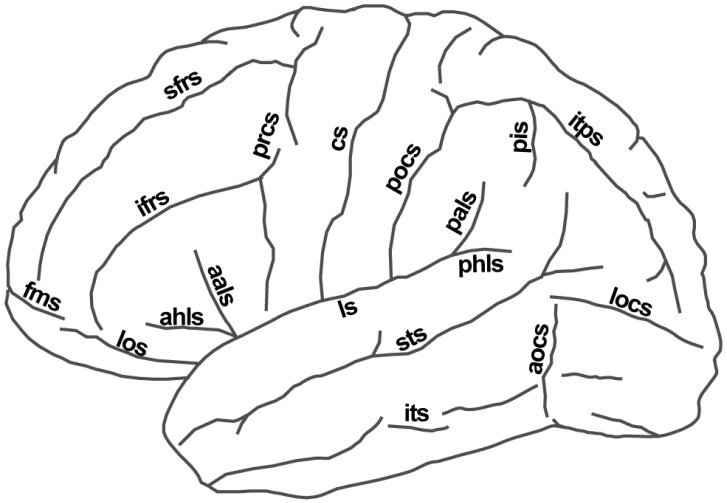

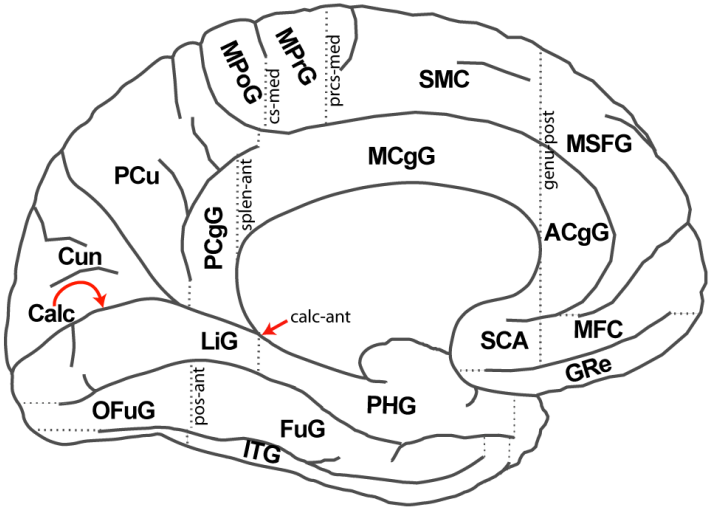

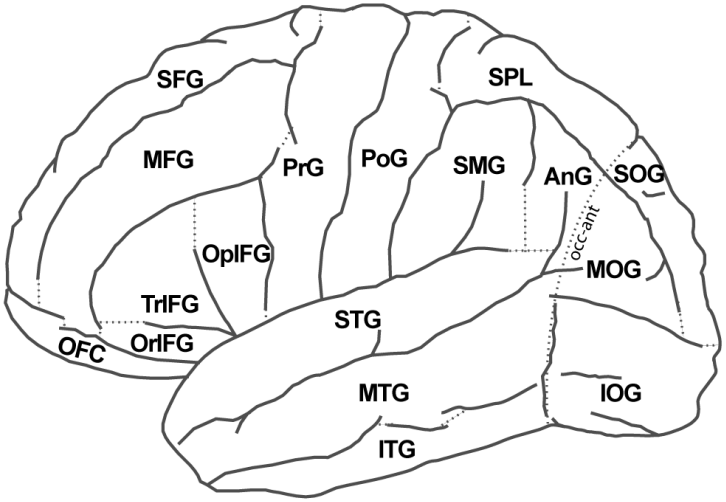

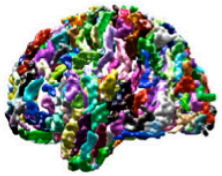

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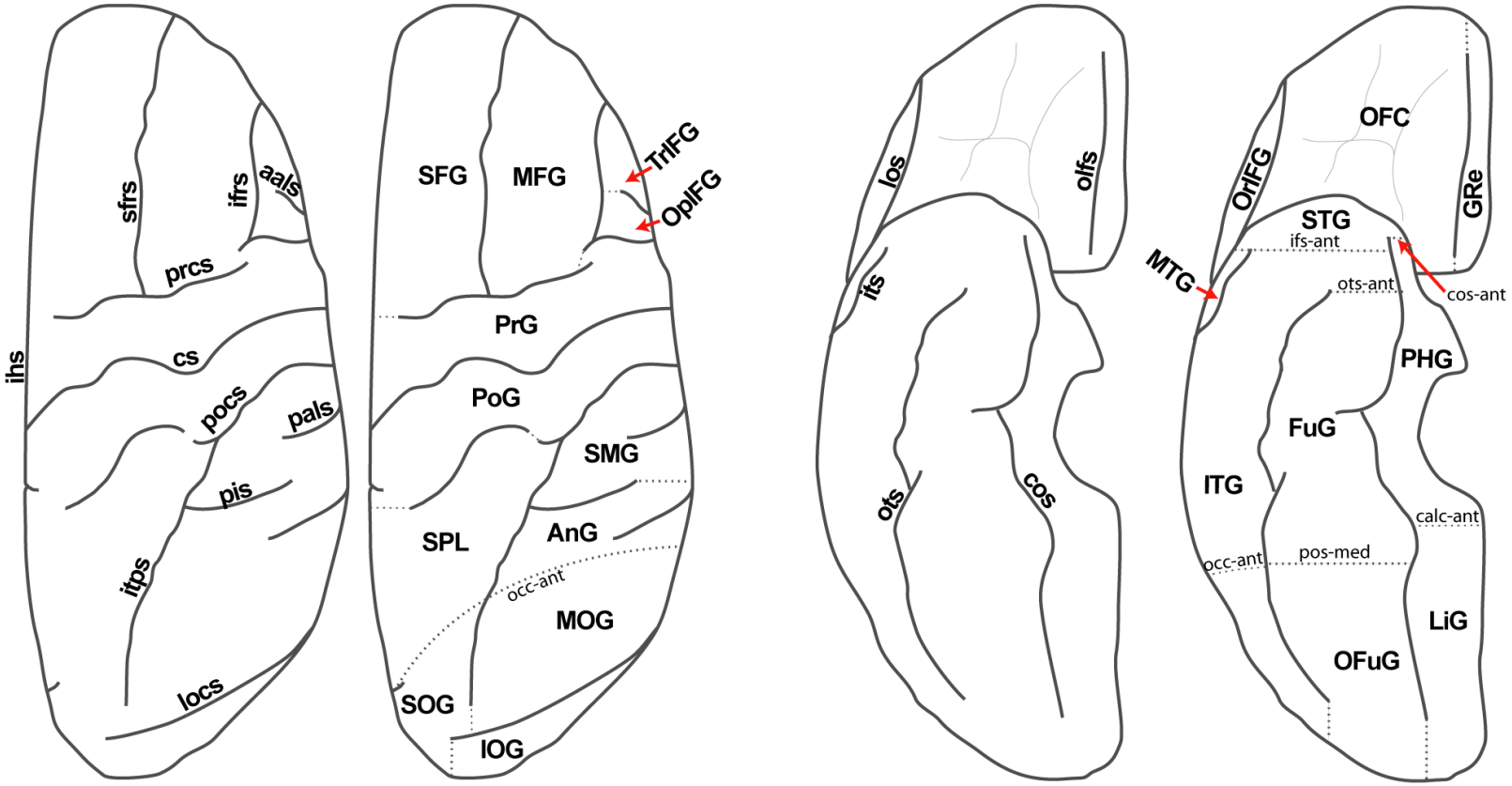

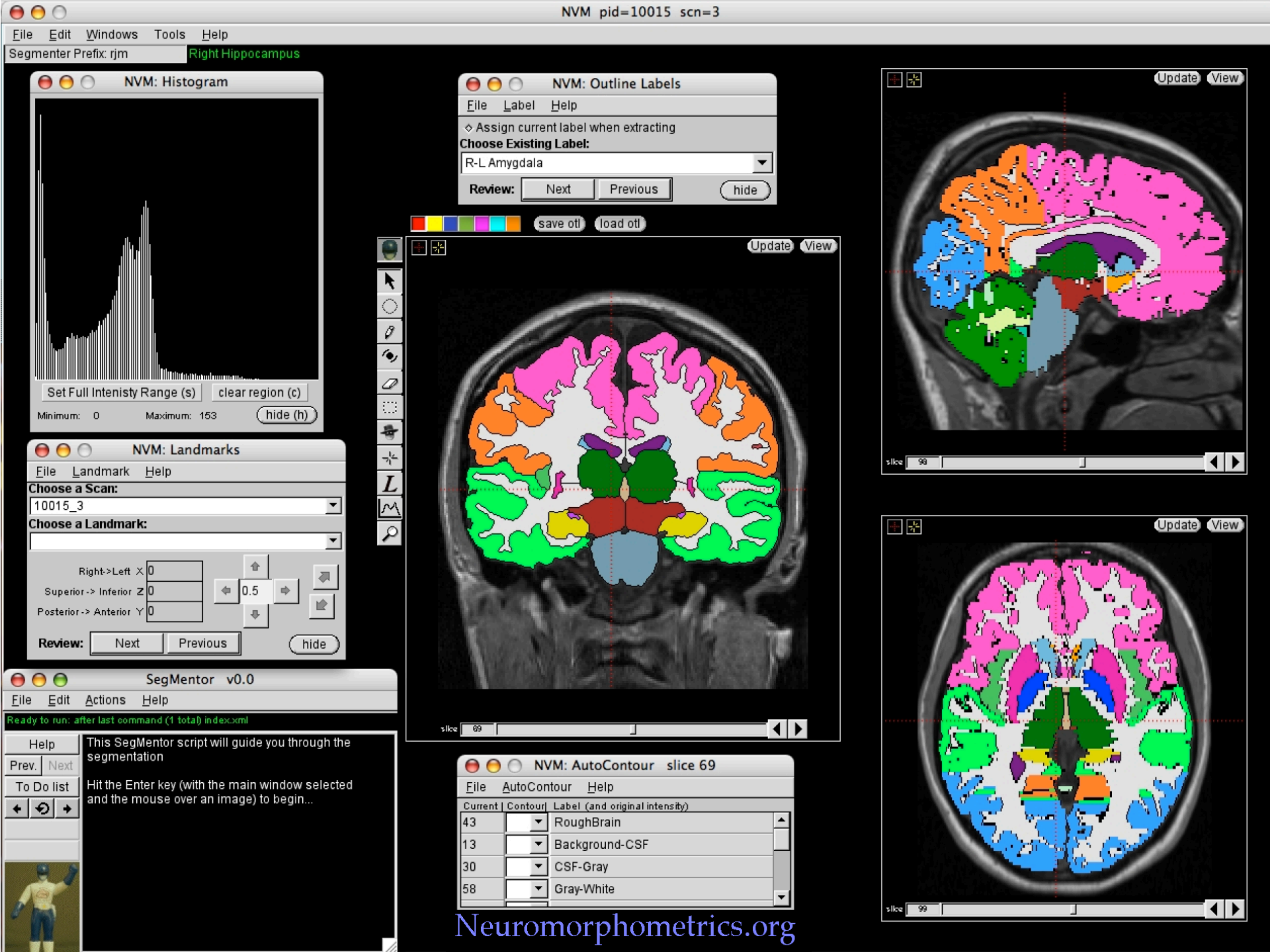
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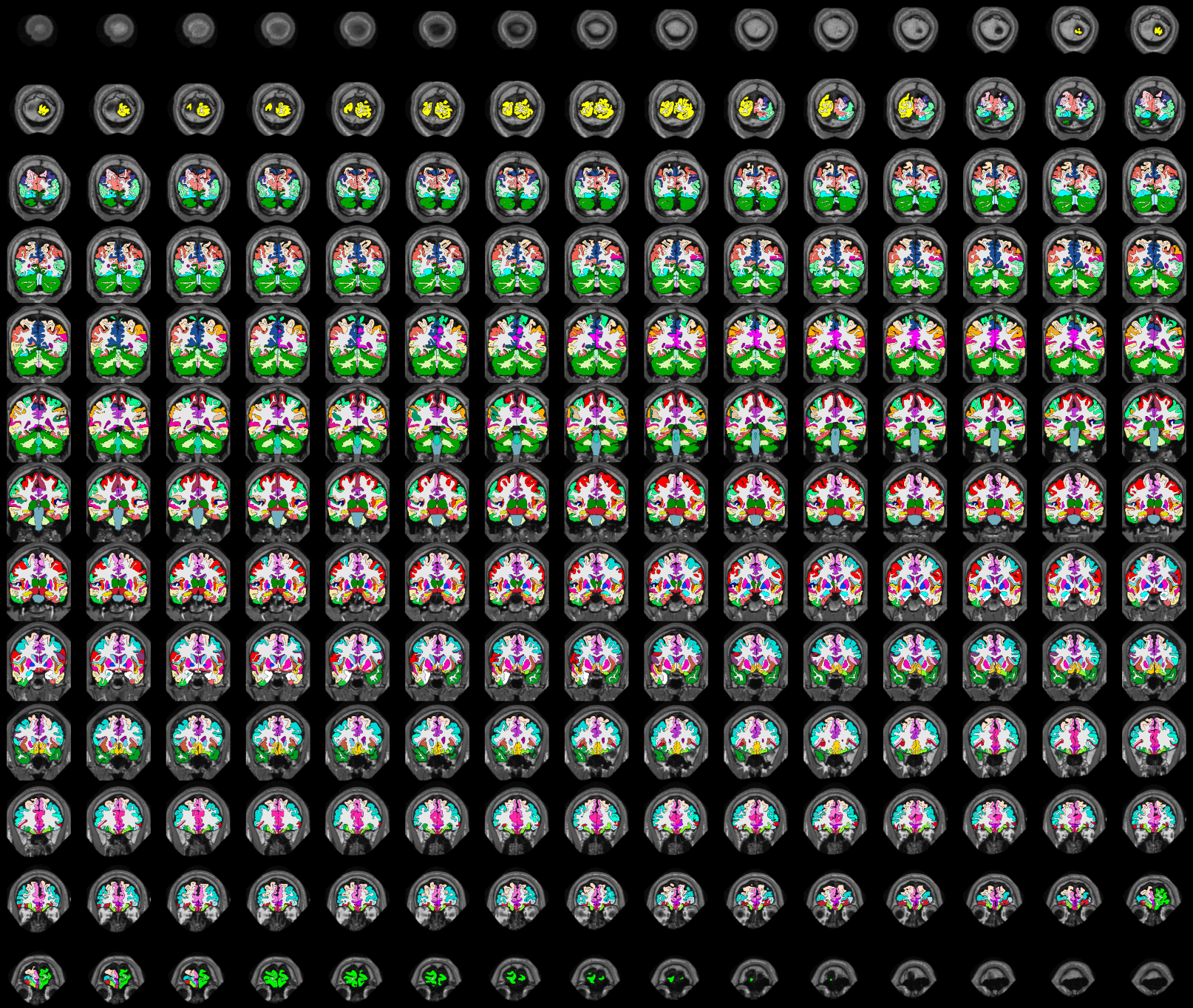
43 RoughBrain
13 Background-CSF
30 CSF-Gray
58 Gray-White
Neuromorphometrics.org



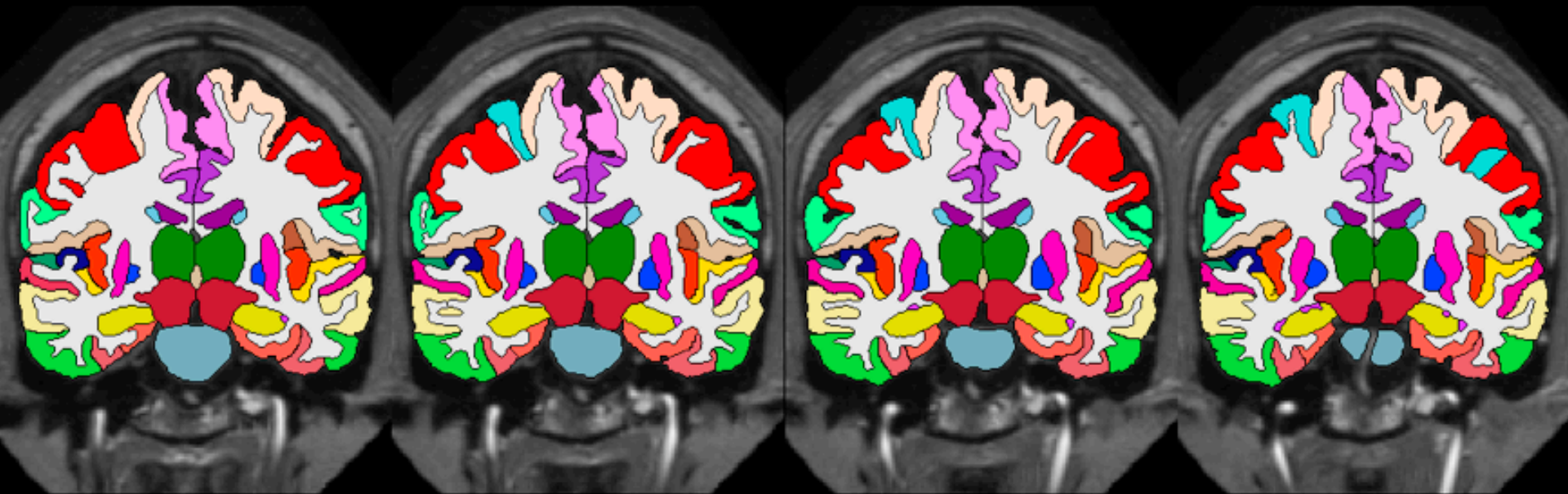
Questions? arno@mindboggle.info

Download this lecture: http://www.mindboggle.info/lectures/

Evaluation study website: http://www.mindboggle.info/papers/

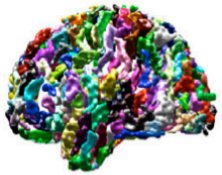
Registration examples used in the slides:
http://www.picsl.upenn.edu/ANTS/ and presentation by Brian Avants

Recent review of brain registration algorithms:
“Brain functional localization: a survey of image registration techniques”
IEEE Trans Med Imaging. 2007. 26(4): 427-451. (330 references!)



Permutation tests

1. Select a subset of P independent brain pairs
2. Select a pair of methods (two vectors of P total overlap values)
3. Subtract the two vectors and compute the mean difference D
4. Select a subset of the elements from one of the vectors
5. Swap this subset across the two vectors
6. Subtract the resulting vectors; compute the mean difference D_p
7. Repeat steps #4-6 N times
8. Count the number of times n where[4] $\text{abs}(D_p) \geq \text{abs}(D)$
9. Compute the exact p-value: $p = \frac{n}{N}$
10. Repeat steps #1-9; compute the fraction of times where $p \leq 0.05$



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Proposed Cortical Parcellation Protocol

Survey information -- back to SURVEY 1 --

For general protocol questions, email Jason Tourville: jtour@cns.bu.edu
For questions about the survey, email Arno Klein: arno@mindboggle.info

People involved

We welcome the participation of others!

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The Online Brain Atlas Reconciliation Tool

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Select atlases to compare

Click on an atlas name to select individual regions from that atlas for comparison.

Click on the **X** at the intersection of two atlases in the table below to compare the two atlases in their entirety.

	AAL	CYTO	H-O	ICBM	LPBA	T&G	TALc	TALg
AAL		X	X	X	X	X	X	X
CYTO	X		X	X	X	X	X	X
H-O	X	X		X	X	X	X	X
ICBM	X	X	X		X	X	X	X
LPBA	X	X	X	X		X	X	X
T&G	X	X	X	X	X		X	X
TALc	X	X	X	X	X	X		X
TALg	X	X	X	X	X	X	X	

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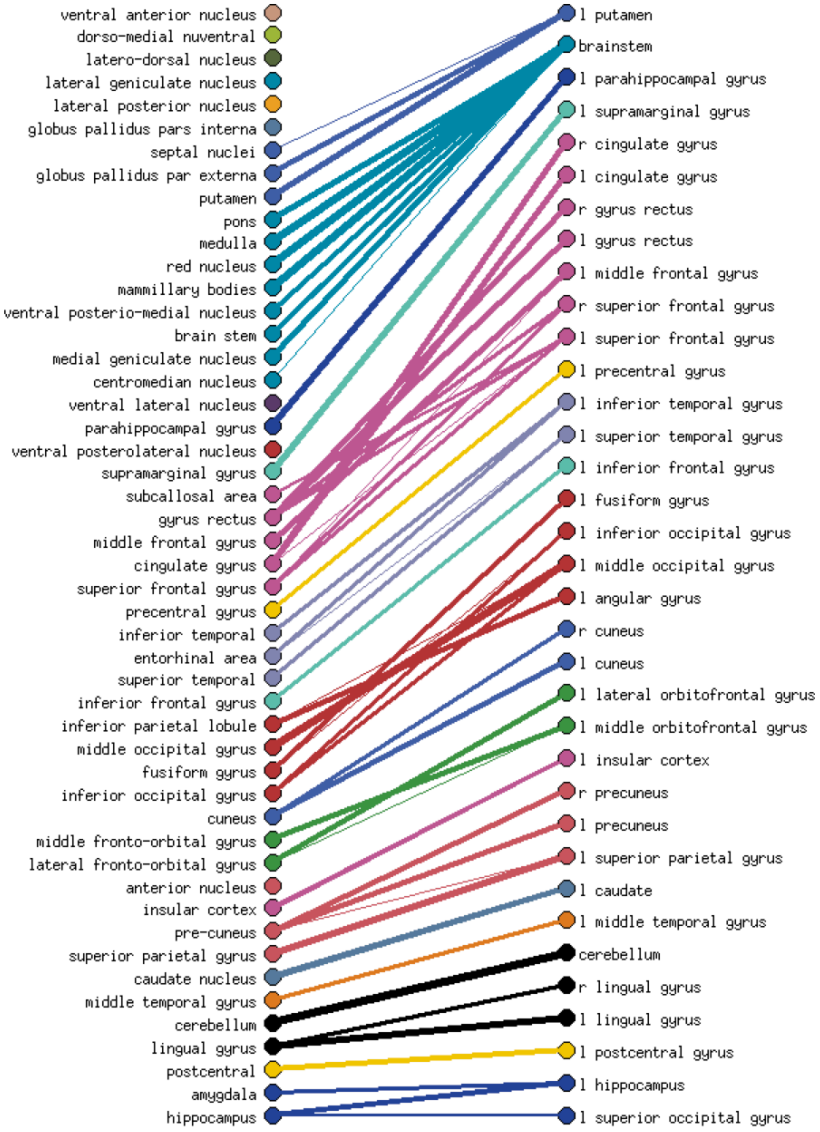
Select atlases to compare

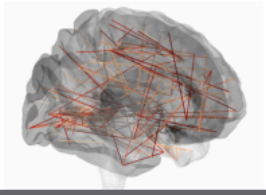
Click on an atlas name to select individual regions from

Click on the **X** at the intersection of two atlases in the ta

	AAL	CYTO	H-O	ICBM	LPBA	T&G
AAL		X	X	X	X	X
CYTO	X		X	X	X	X
H-O	X	X		X	X	X
ICBM	X	X	X		X	X
LPBA	X	X	X	X		X
T&G	X	X	X	X	X	
TALc	X	X	X	X	X	X
TALg	X	X	X	X	X	X



Raw concordance matrix Shows the fraction of the volume of the region on the left from the ICBM atlas which is contained in the region on the top from the LPBA40 atlas.



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Main Page

Connectome Wiki is a knowledge base for macro- and mesoscale brain region and brain structural connectivity information across species. Employing modern semantic wiki technology, it serves as collaborative platform as well.

	What can I get?	What can I contribute?
Brain Regions	Plenty of information, including links to relevant literature and much more.	If you research is in particular brain regions, or model organisms not yet registred, feel free to act as domain expert and add your knowledge.
Brain Connections	Well established neuronal connections based mainly on neuronal tracer studies from the literature.	If you do any tracer studies, add findings with appropriate published papers. Incrementally building a mesoscale skeleton wiring diagram.
Abbreviations	Look up abbreviations and corresponding English and Latin names	Complete any that is missing. See also PapersToAdd.
Partition Schemes	Foundational and more partitions with their corresponding delineation criteria and protocols.	Register your own partition scheme and link it semantically against known schemes.
Species	Information about different species is available, using their binomial name as identifier.	Adding brain region pages for your particular research organisms.
External	Enhance the ConnectomeViewer with Volume-To-Ontology mappings.	Use ConnectomeWiki as knowledge backend for your application concerned with gross neuroanatomy.
Data Source	You can download the raw data in RDF or JSON.	Contact the maintainer if you have data to contribute.
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