Brain labeling, feature identification, and shape analysis

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photo: Bleakley McDowell

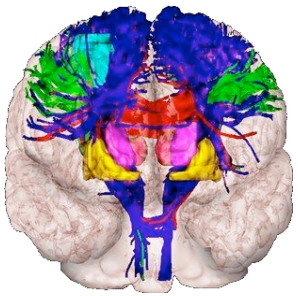
MRI

http://www.coppit.org/brain/

Why label brains?

Labels visually augment anatomy

- teach brain anatomy
- guide neurosurgery



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

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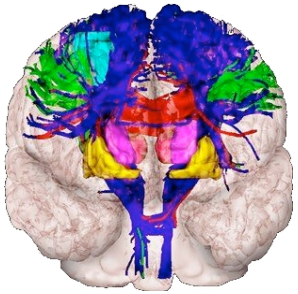
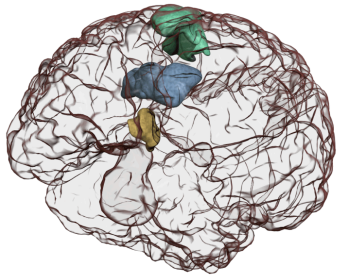


Labels compartmentalize image data

- assign results to brain regions vs. voxels
- quantify data by brain region vs. voxels



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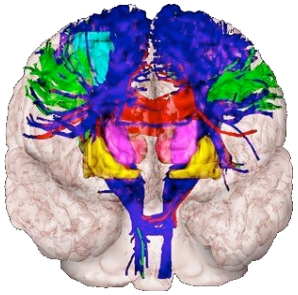

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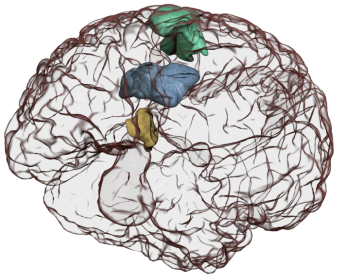
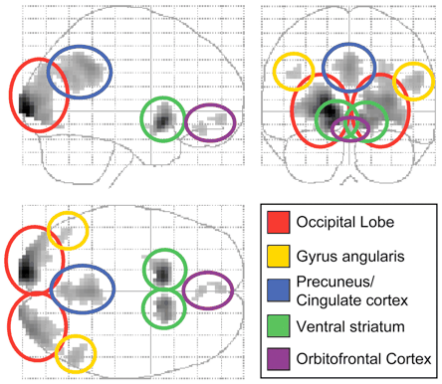


Labels provide a common nomenclature

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



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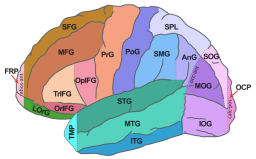
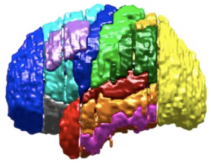
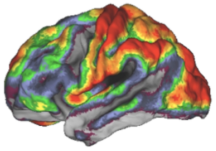
How should we label brain images?



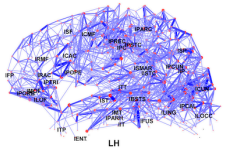
Manual labeling (aMRI)



Atlas registration-based labeling (atlas)

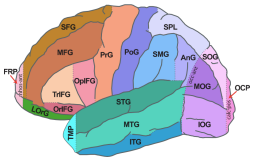


Functional Mapping (fMRI)

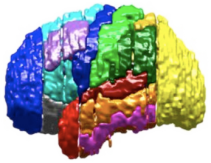


Tractography-based segmentation (dMRI)

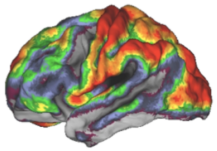
Feature matching (Mindboggle)



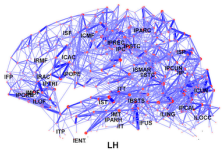
aMRI



atlas

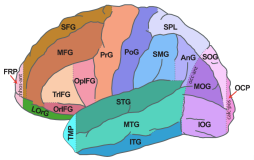


fMRI



dMRI

Mindboggle



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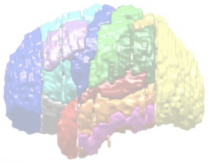

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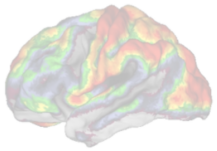

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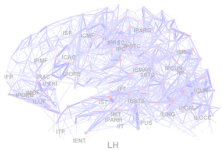

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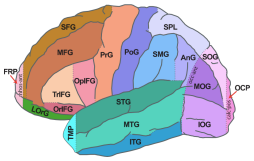

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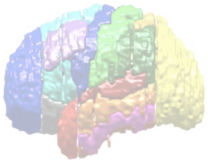

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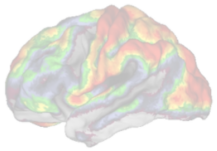

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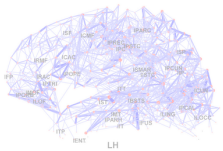

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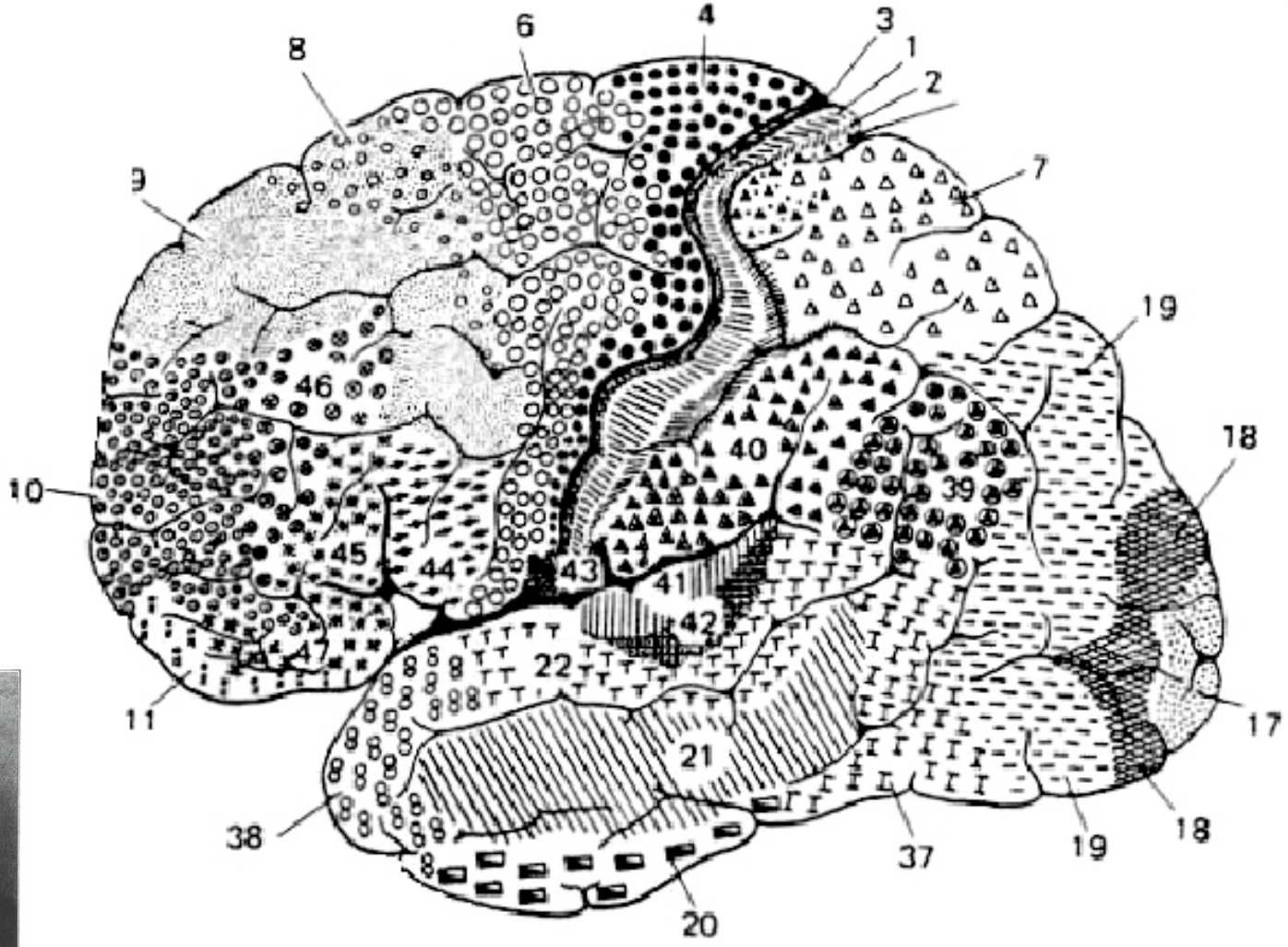
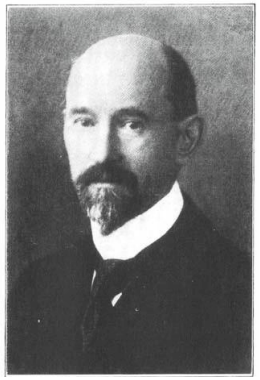
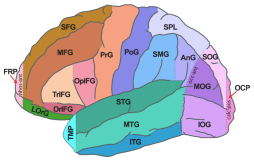


Cytoarchitectonic divisions



Korbinian Brodmann
(1868-1918)



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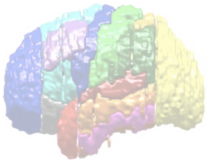

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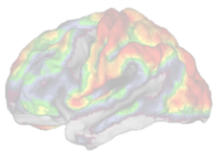

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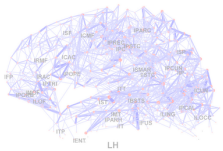

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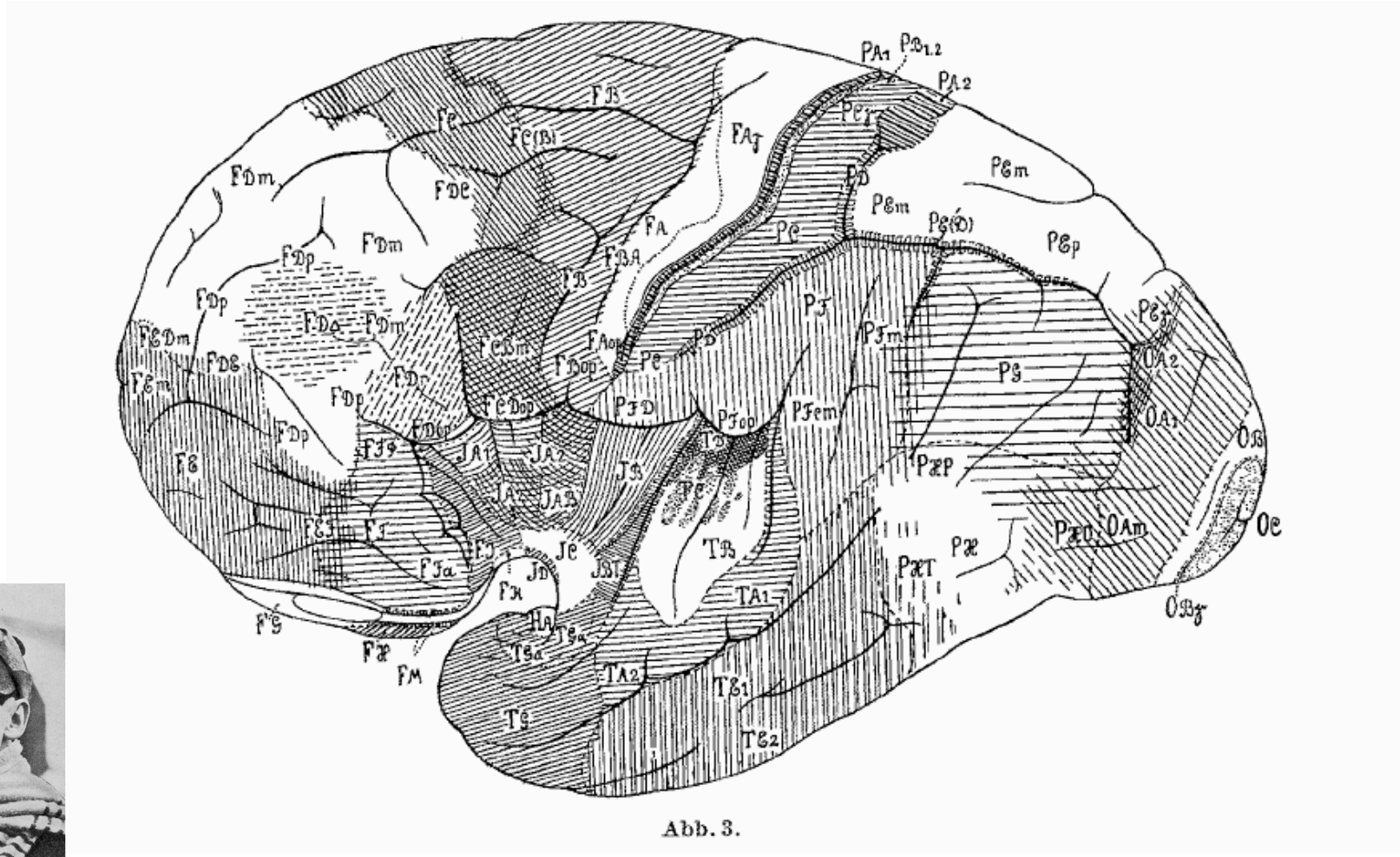
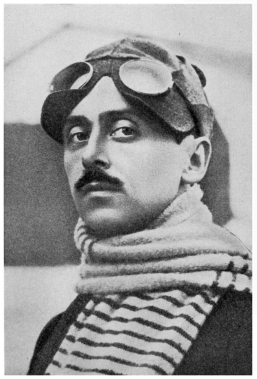
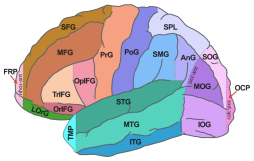




Constantin von Economo
(1876-1931)

Cytoarchitectonic divisions



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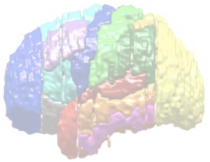

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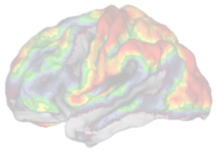

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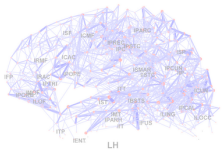

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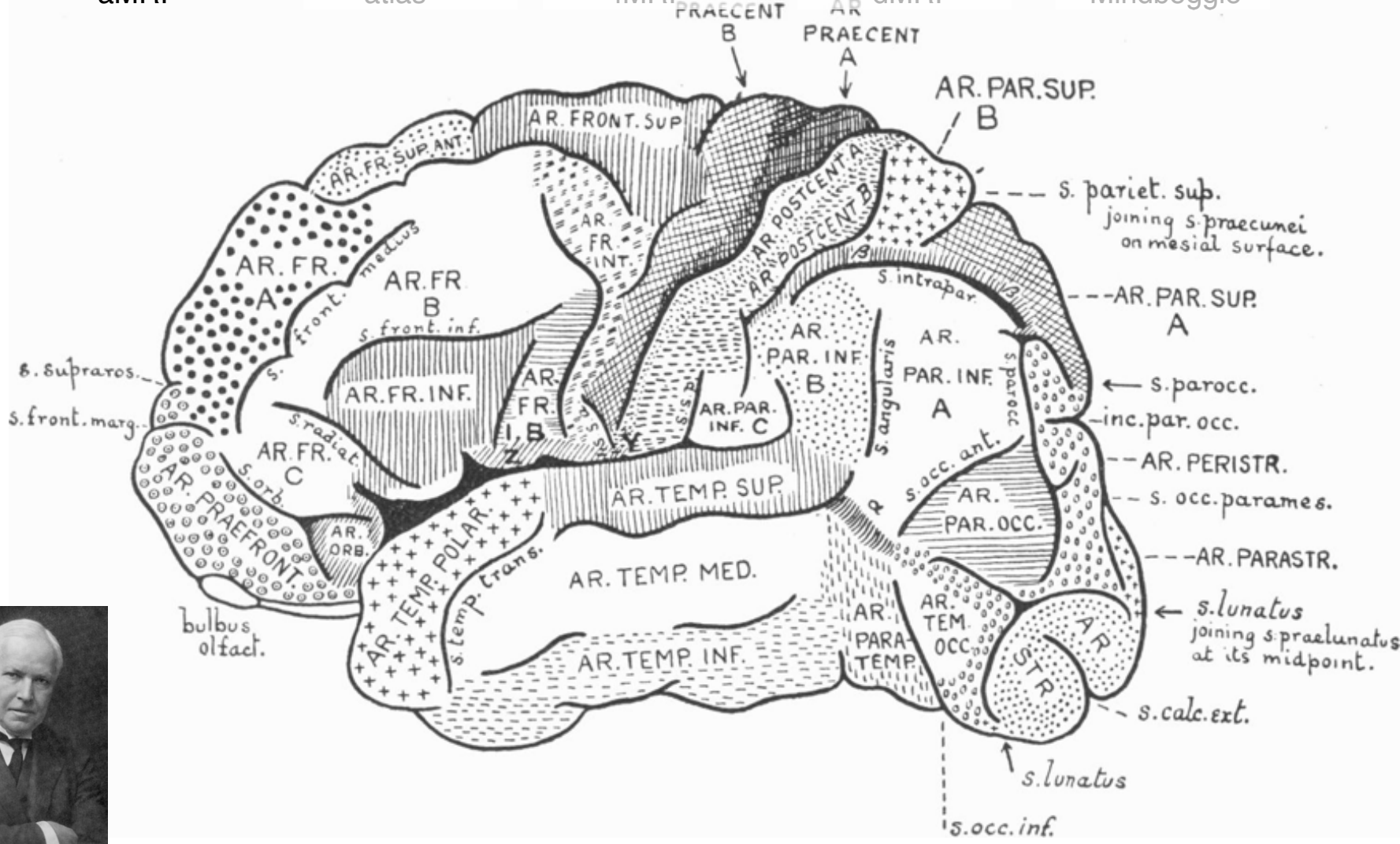
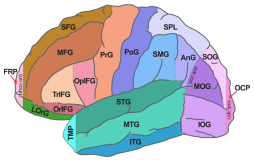


Sir Grafton Elliot Smith
(1871-1937)

Topographic divisions



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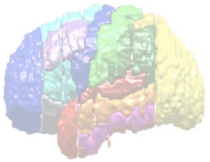

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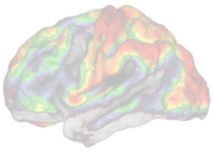

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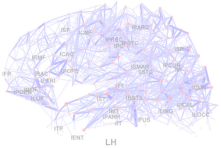

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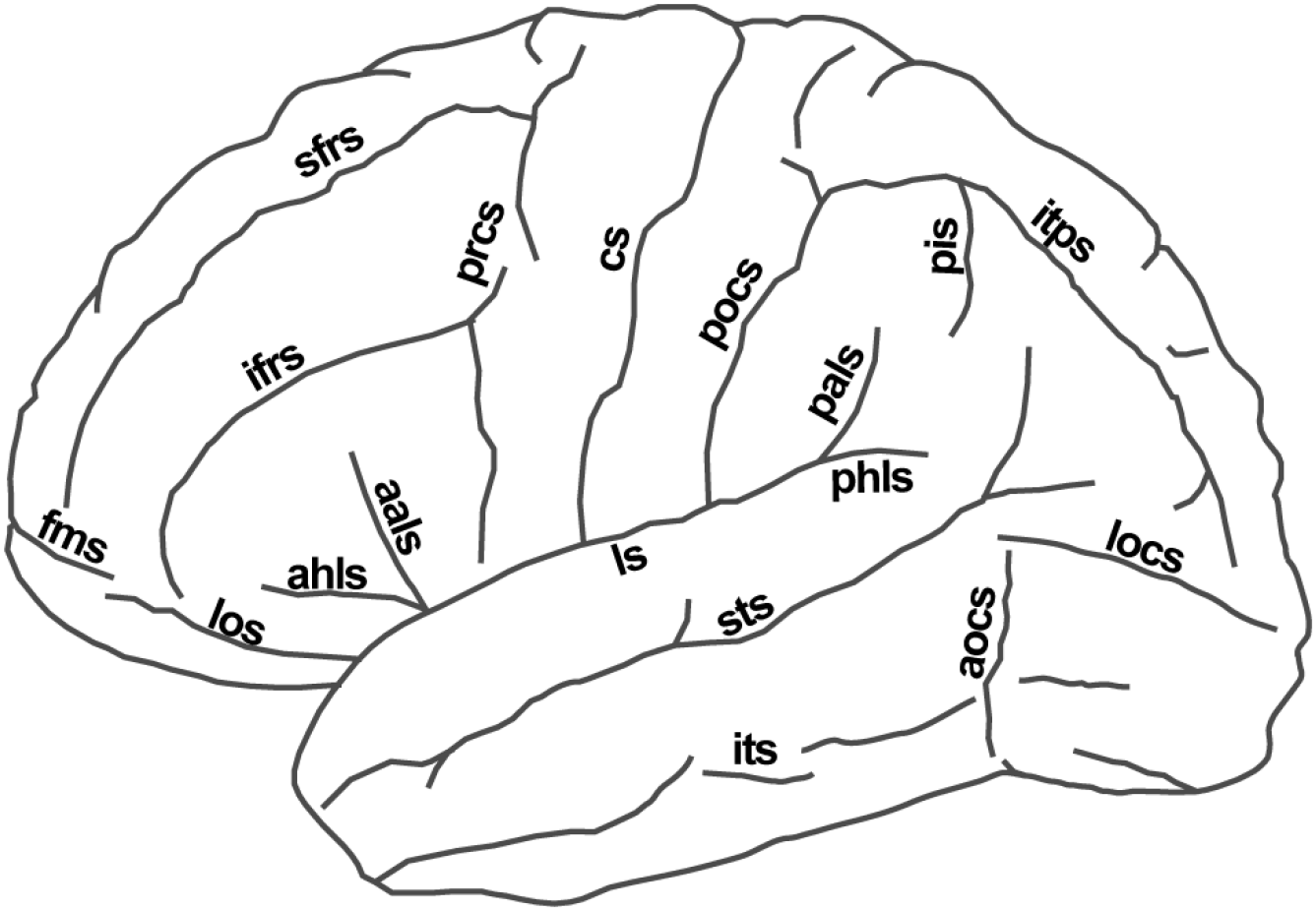
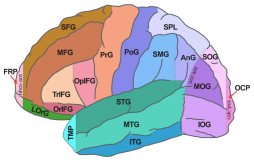
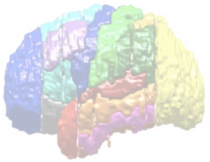


Sulcus definitions



aMRI



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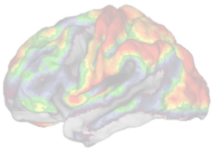

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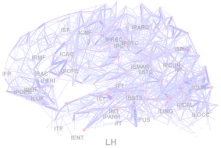

dMRI

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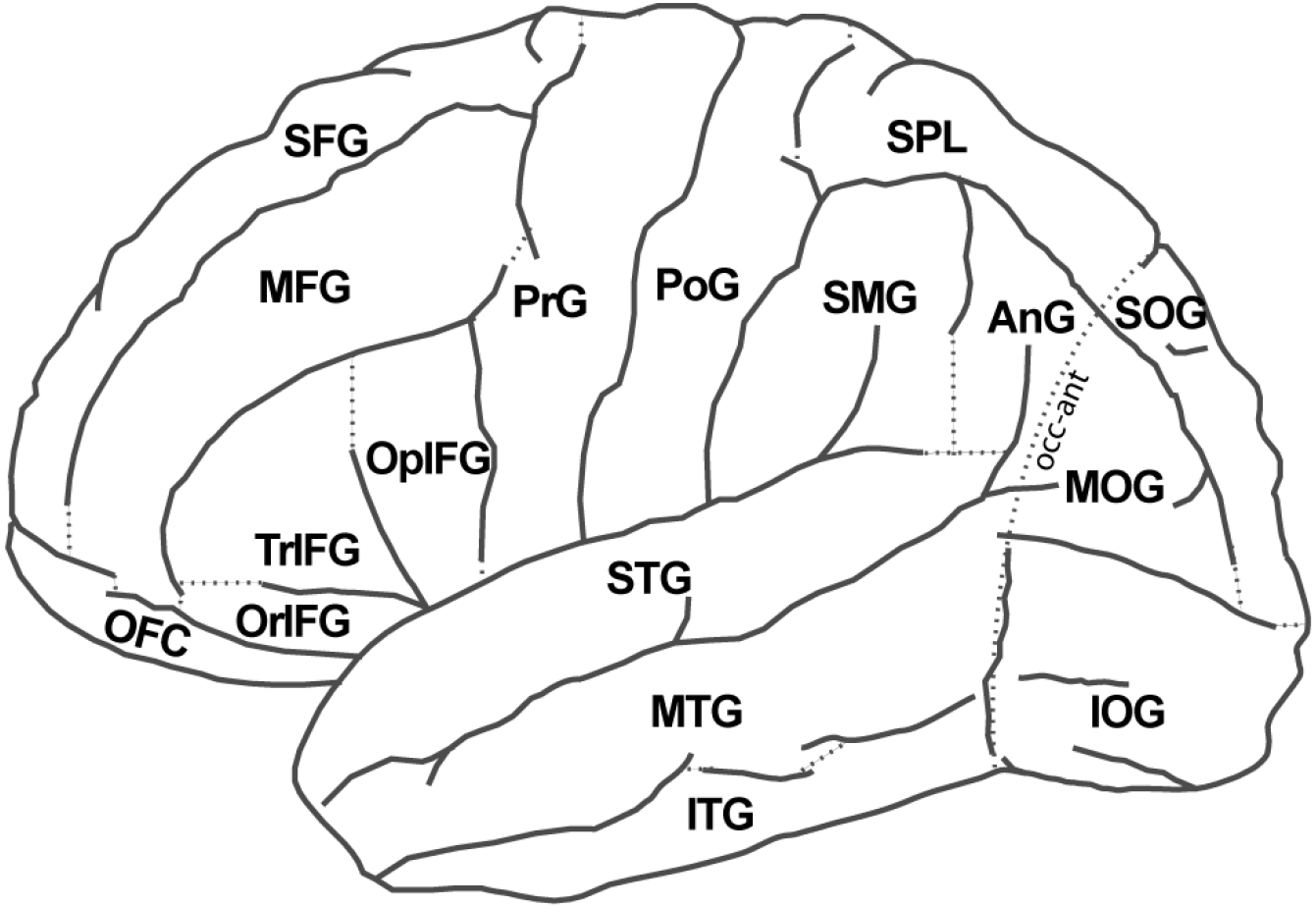
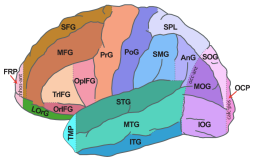


Gyrus definitions



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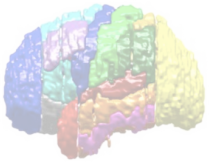

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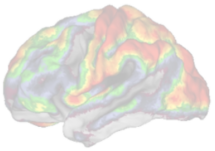

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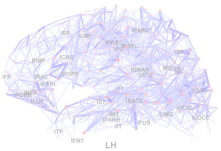

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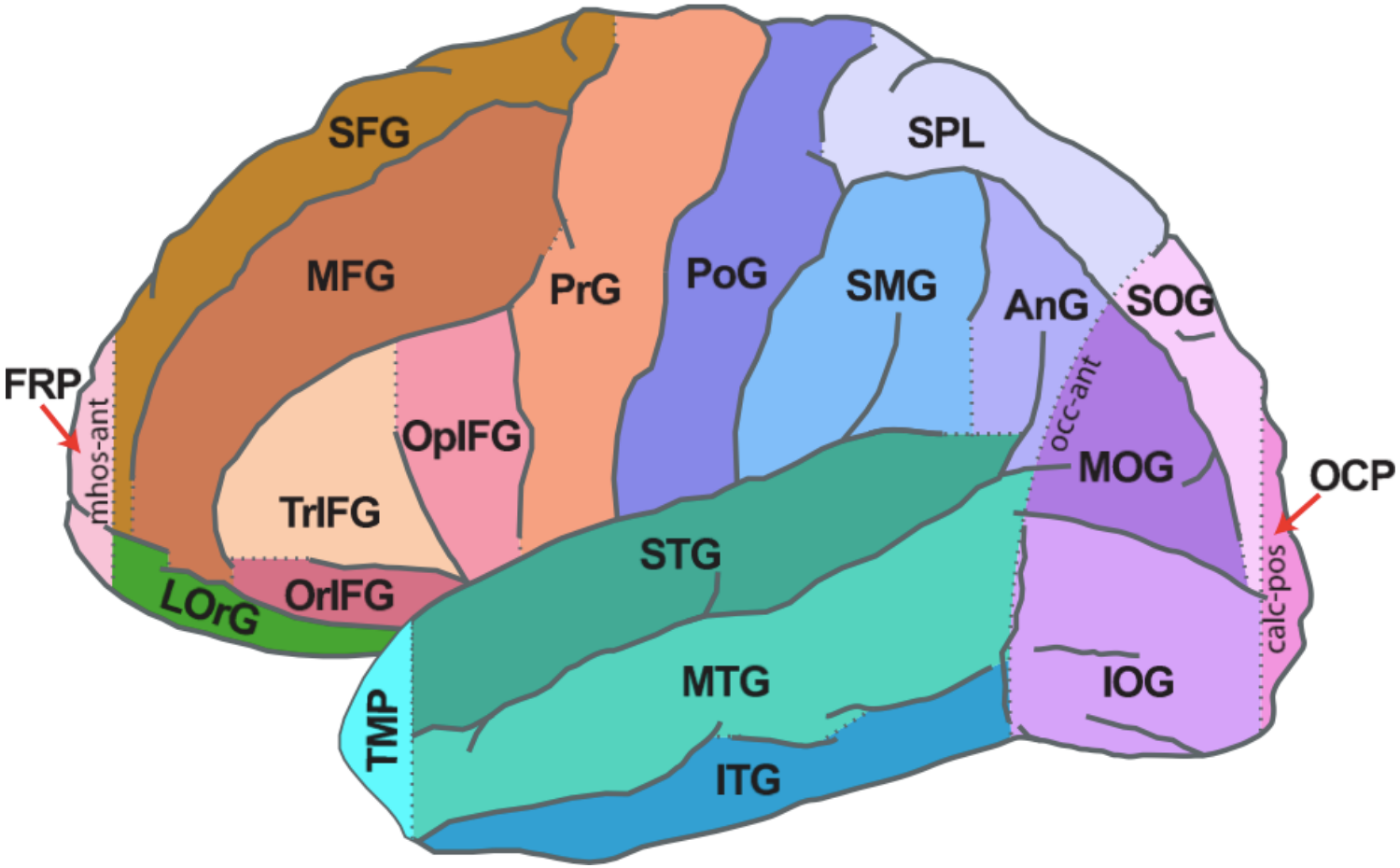

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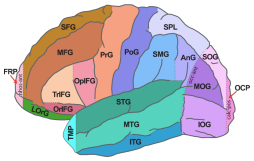

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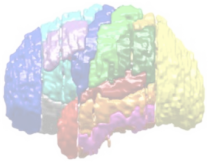
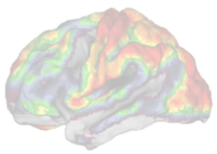


atlas



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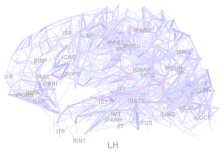
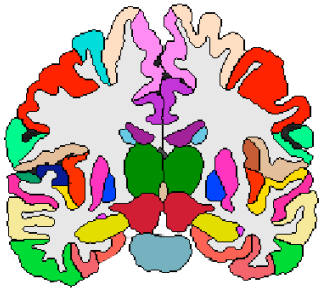
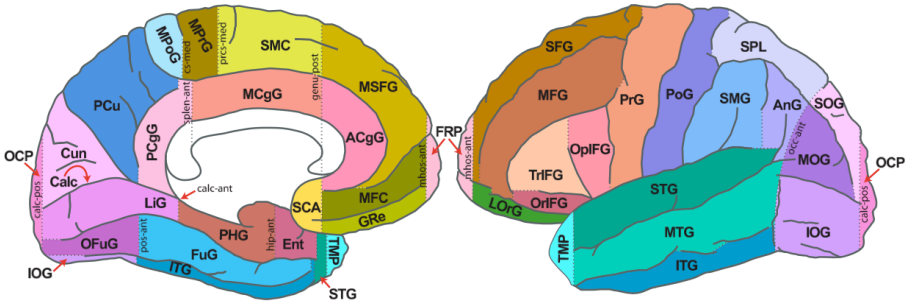
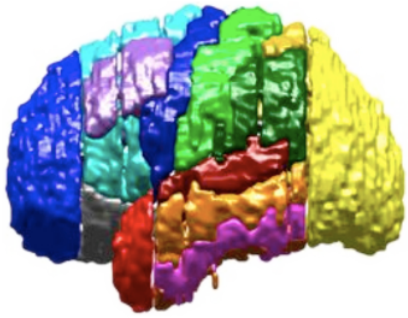


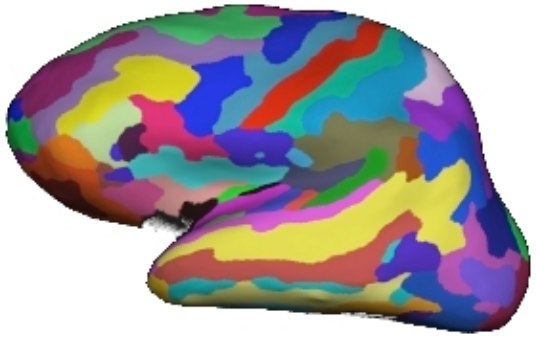
dMRI

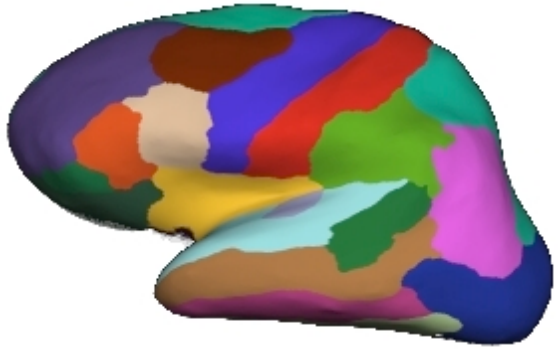
Mindboggle

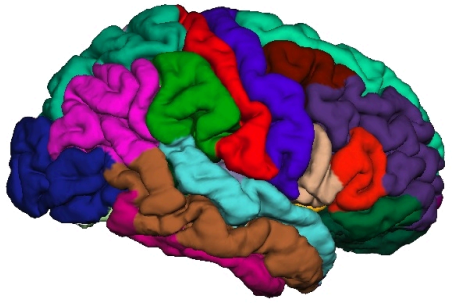




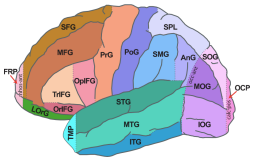




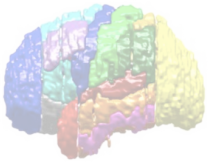




Volume vs. surface label definitions



aMRI



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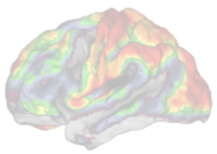

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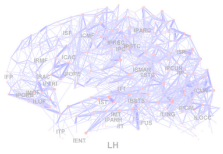
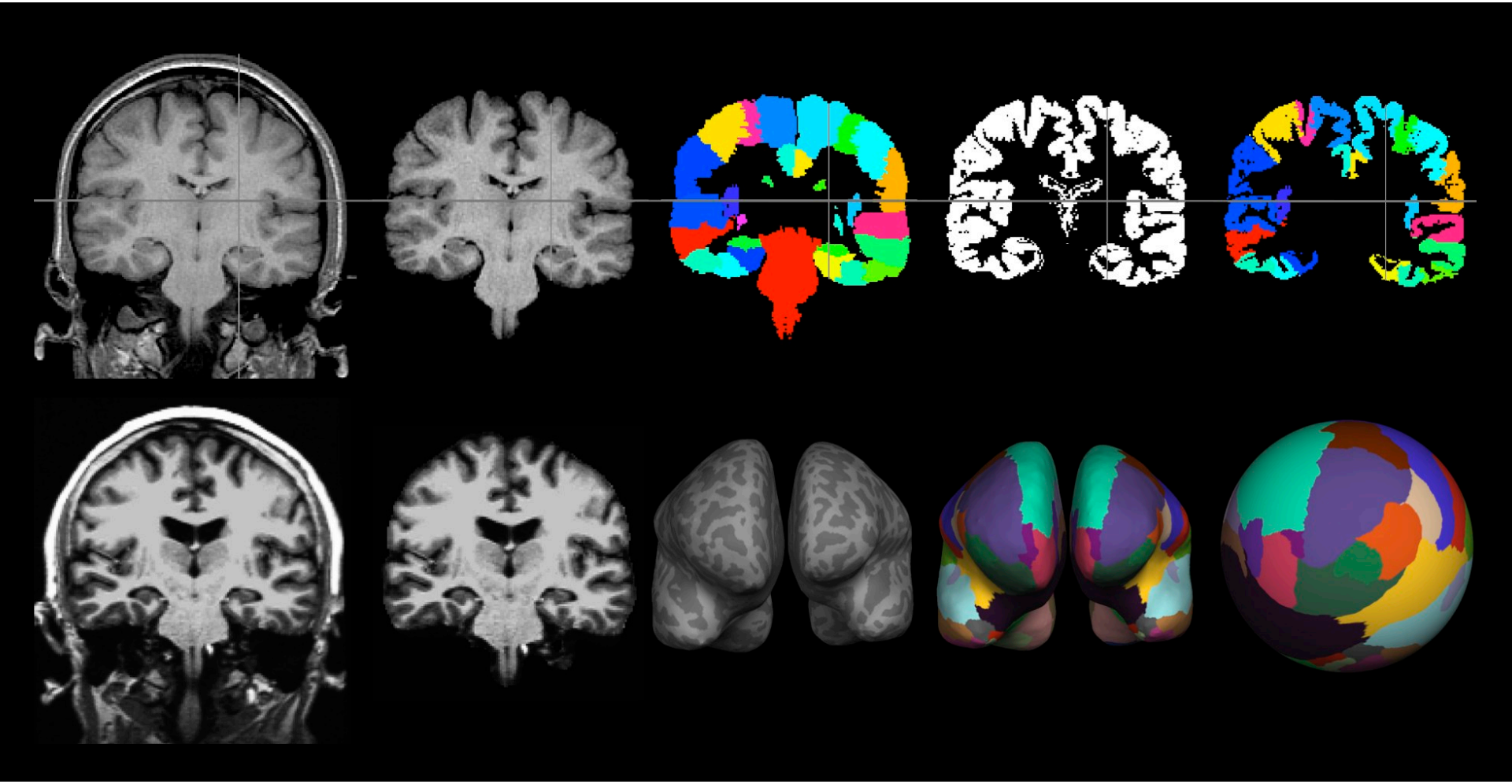
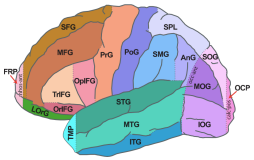


dMRI

Mindboggle



Volume vs. surface label definitions



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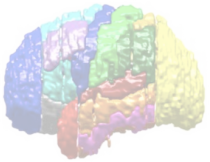

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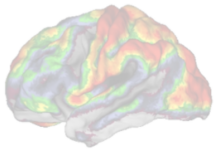

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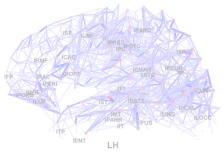

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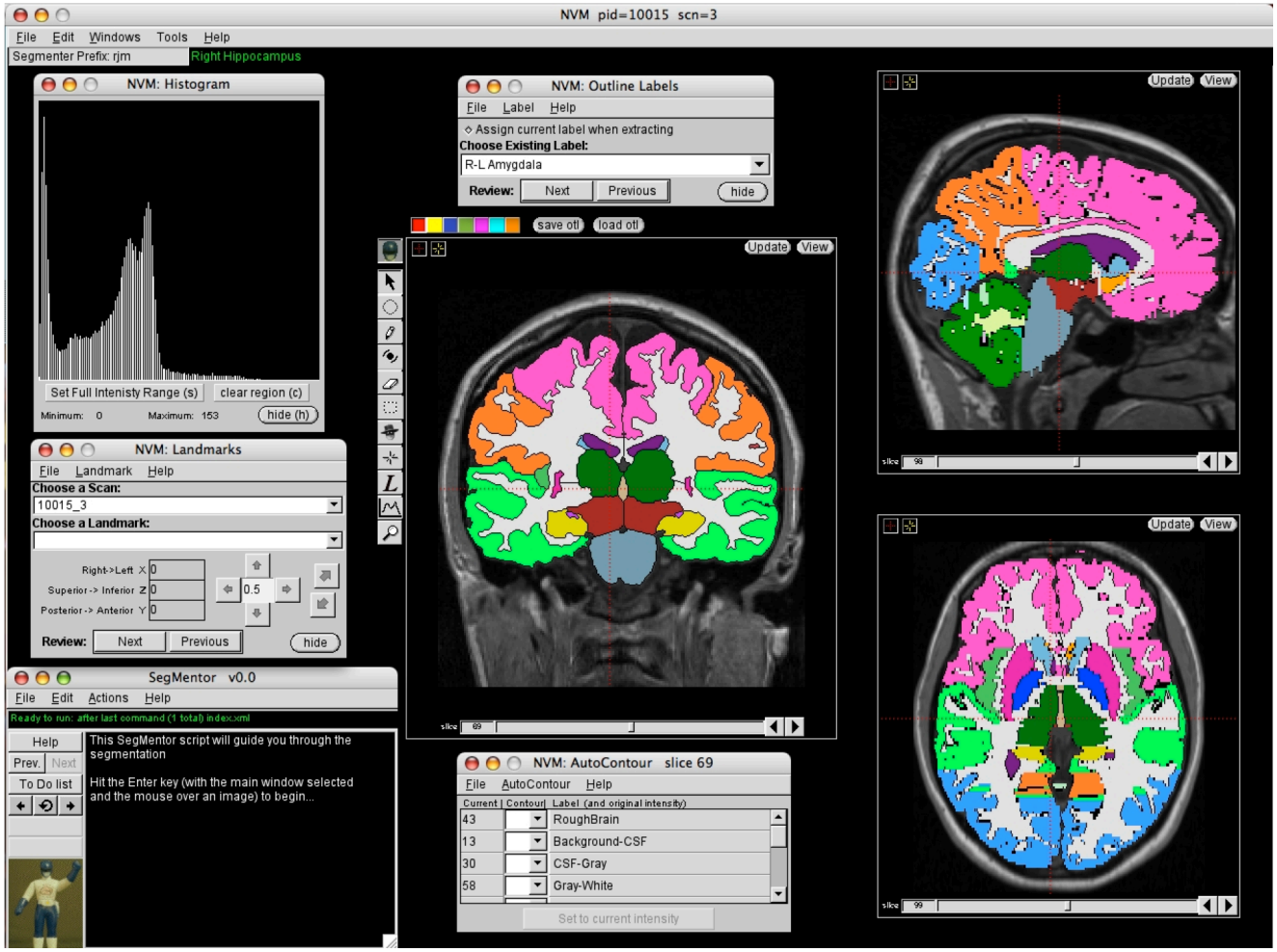
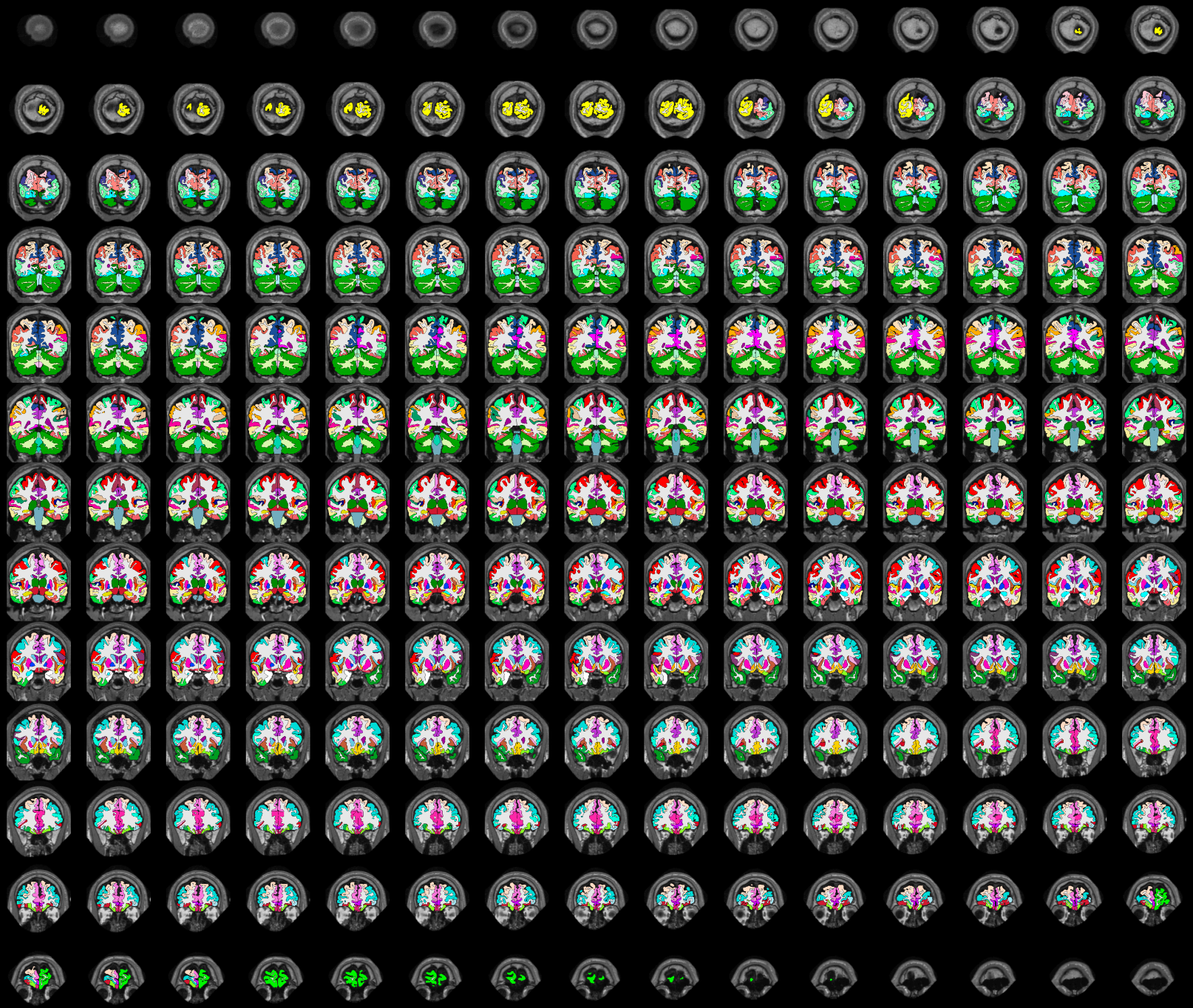
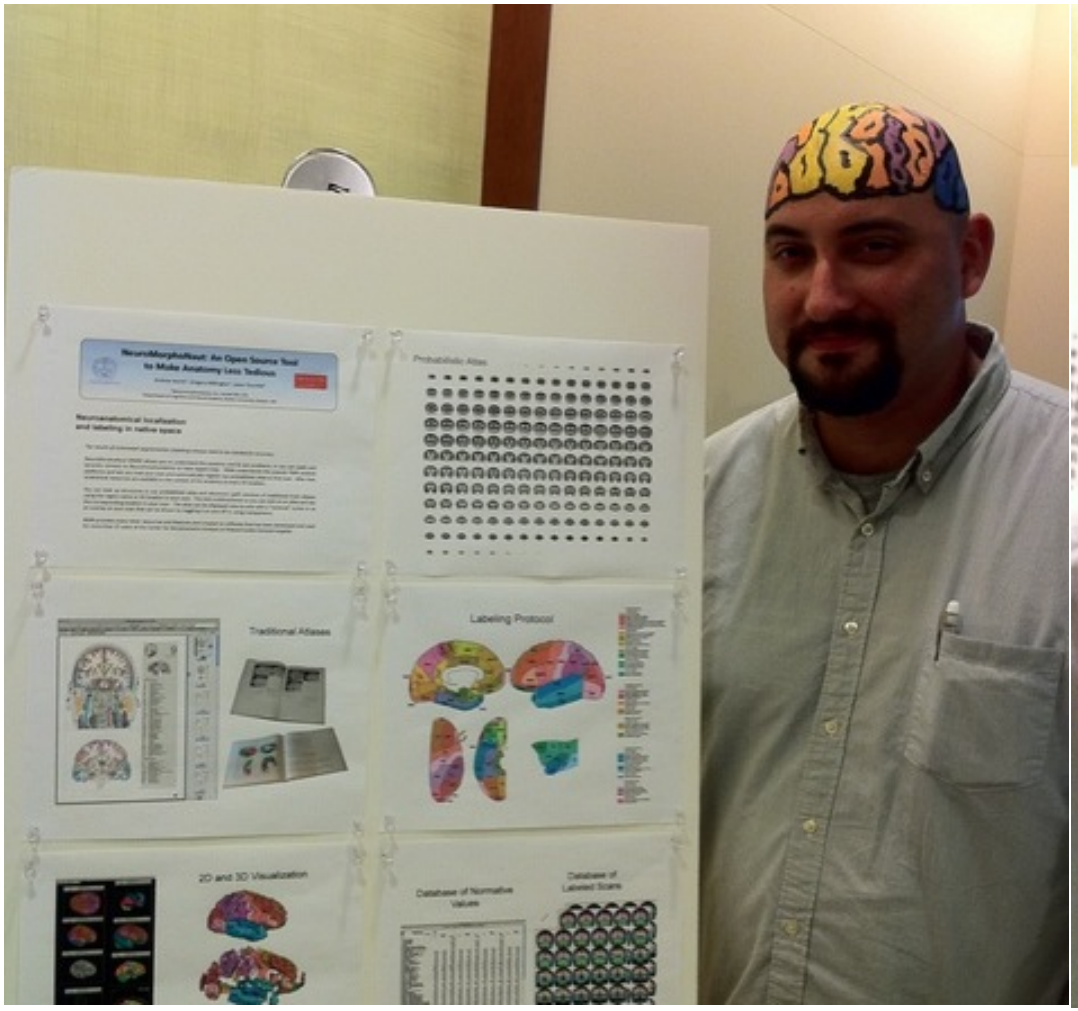
Mindboggle

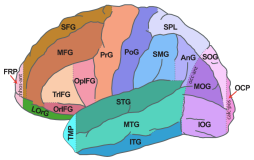


Manual labeling software

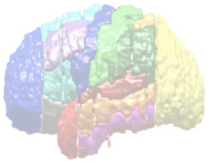




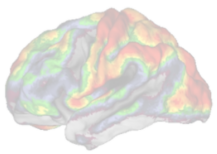
Greg Millington
Neuromorphometrics



aMRI



atlas



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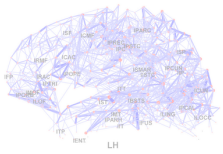
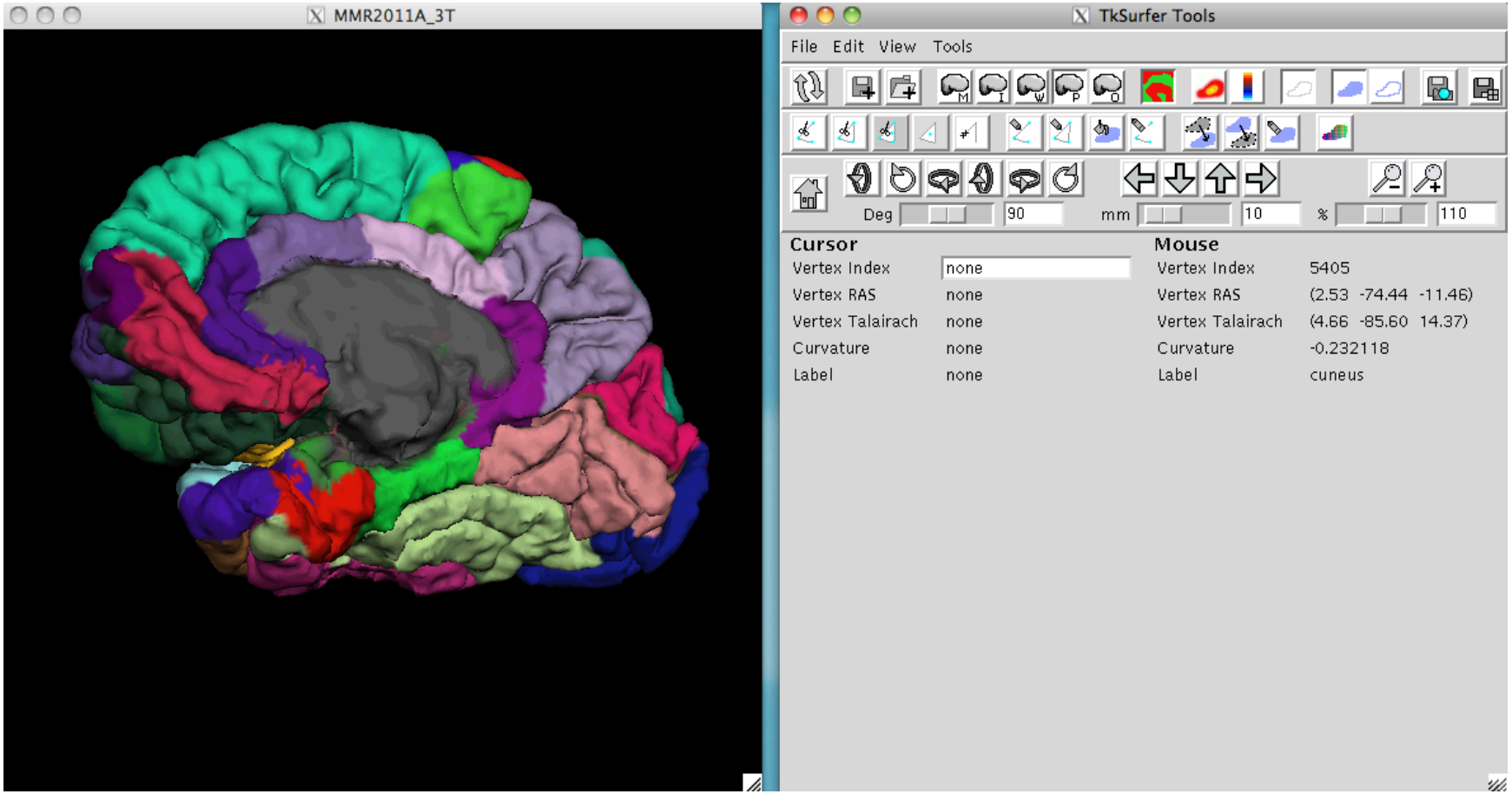
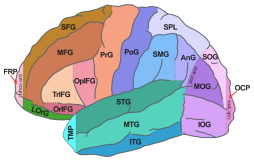


dMRI

Mindboggle



Manual editing of cortical surface labels



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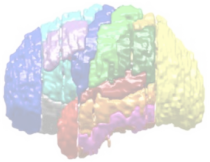

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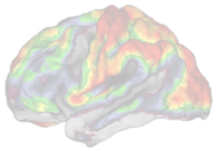

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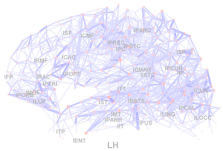
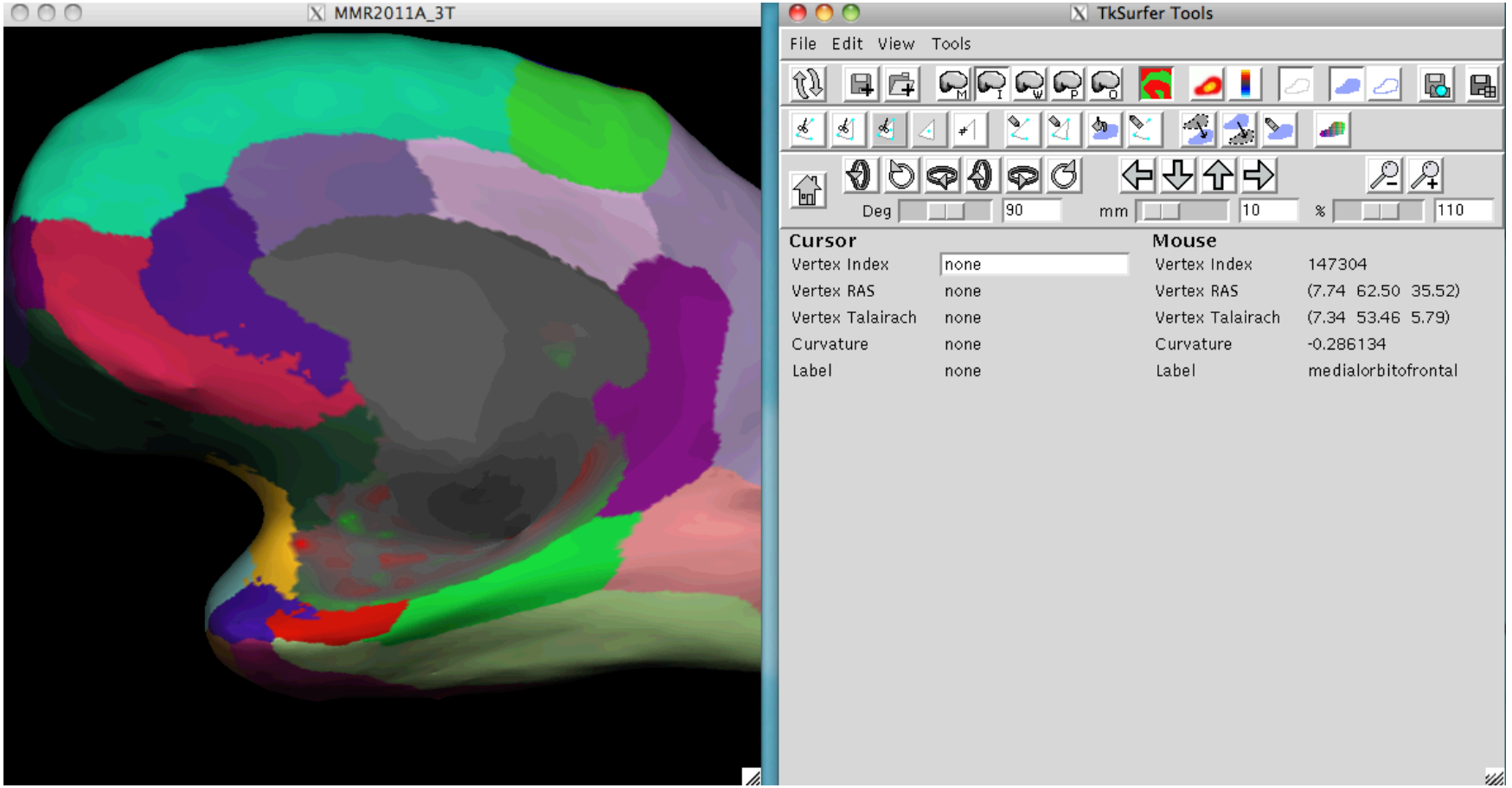
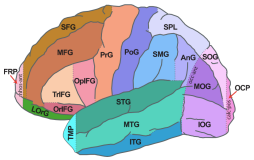


dMRI

Mindboggle



Manual editing of cortical surface labels



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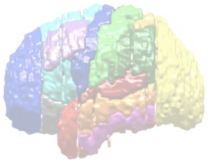

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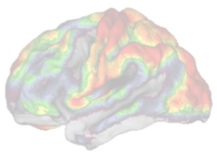

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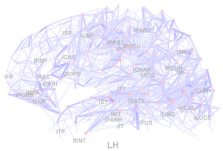
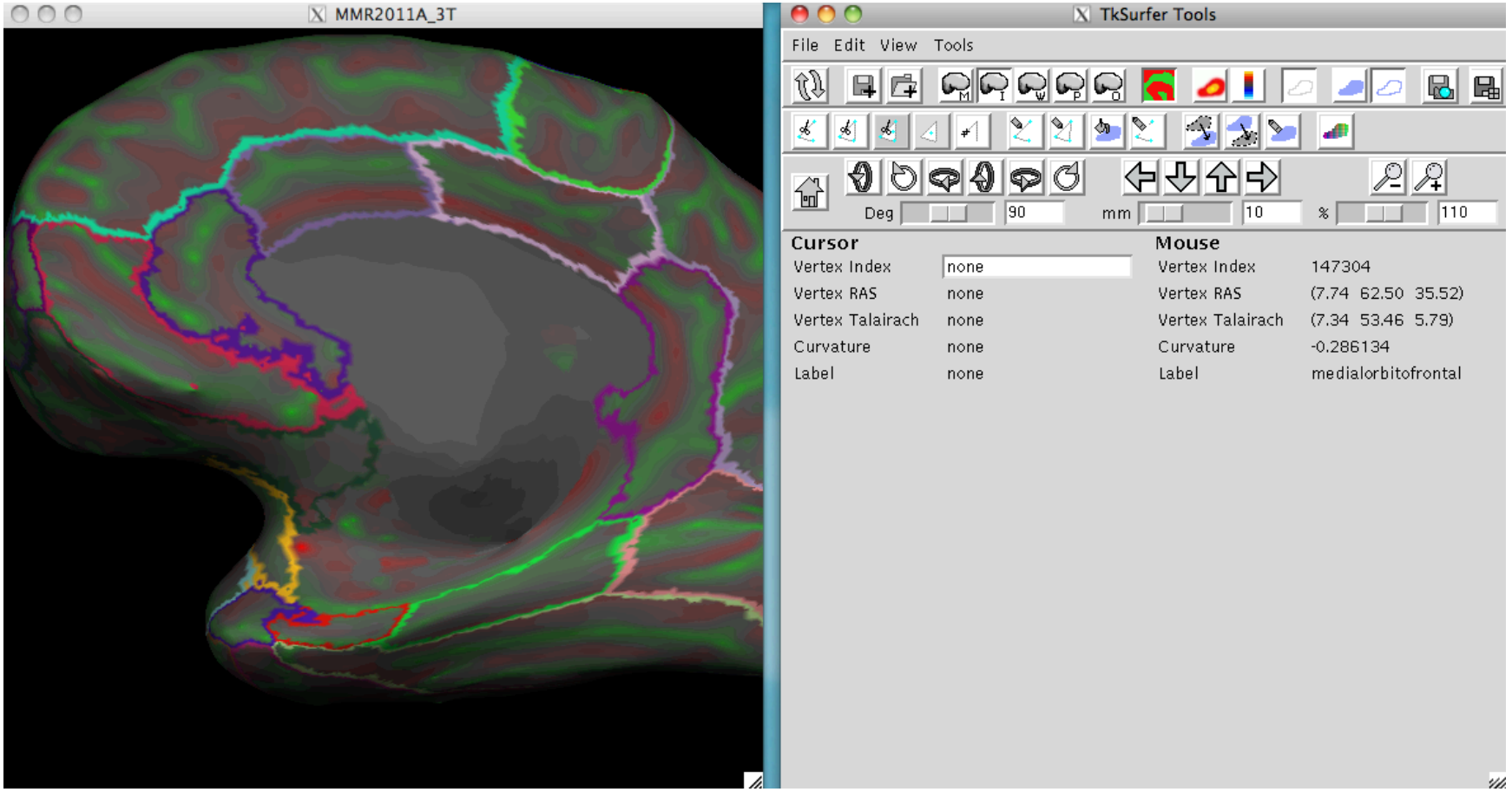
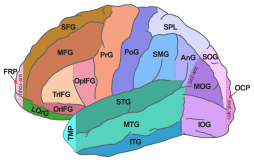


dMRI

Mindboggle



Manual editing of cortical surface labels



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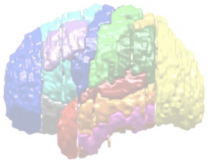

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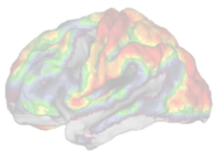

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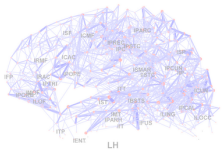
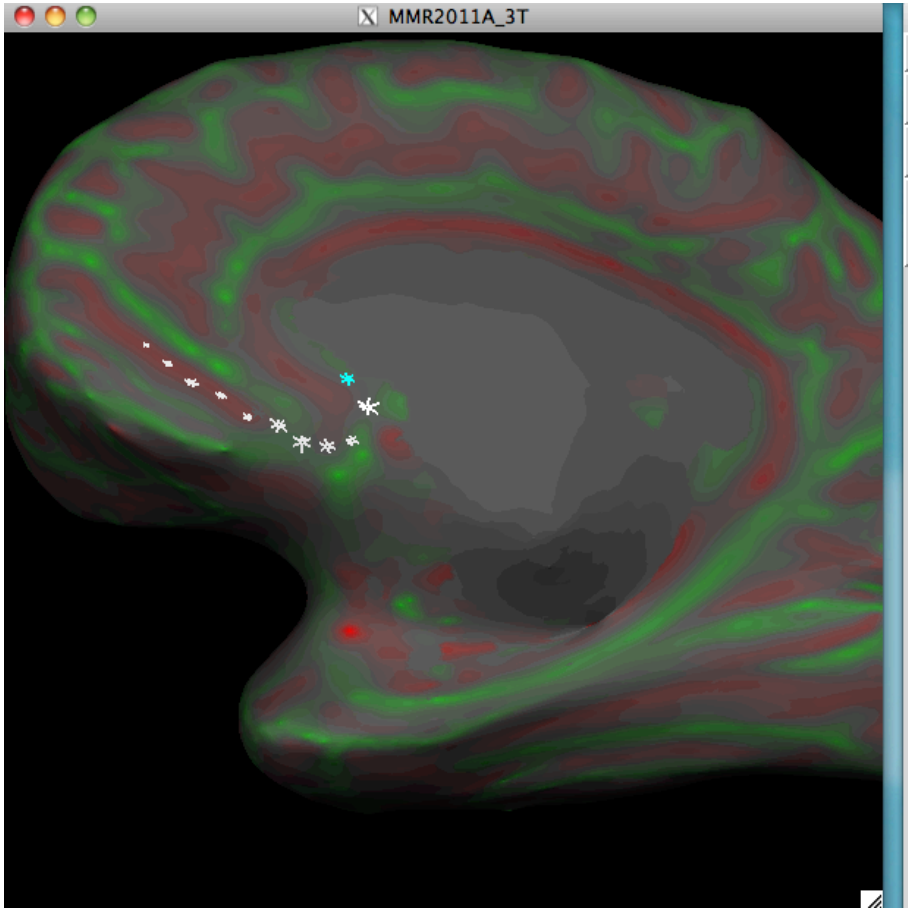
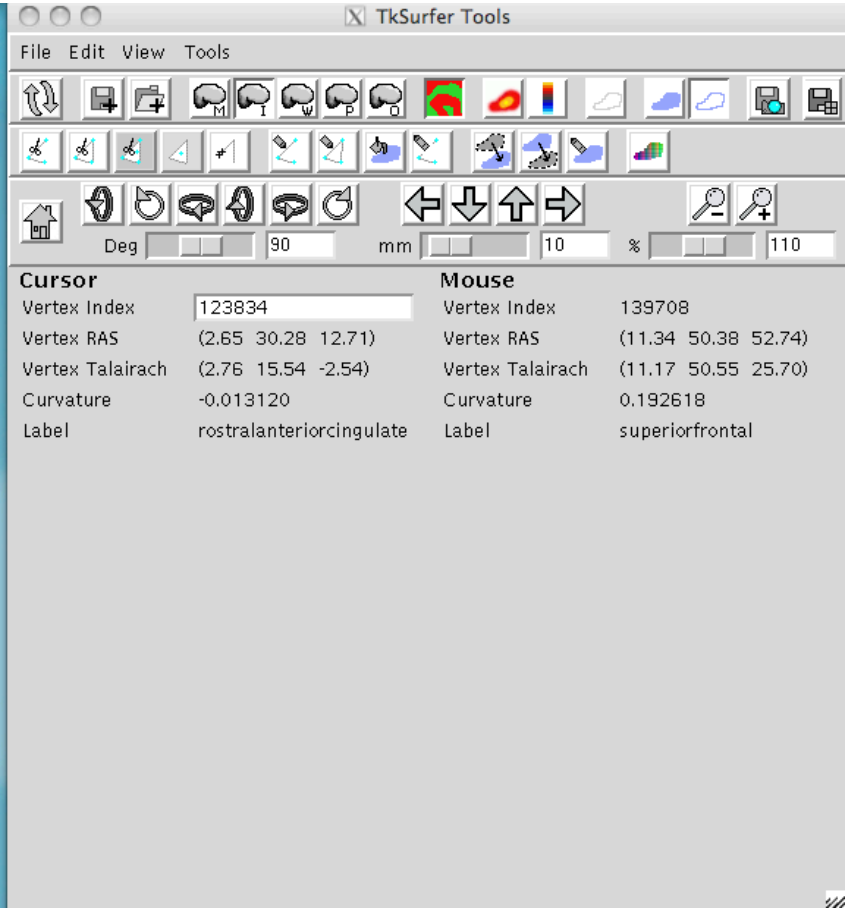


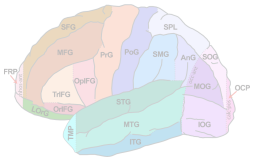
dMRI

Mindboggle





Manual editing of cortical surface labels



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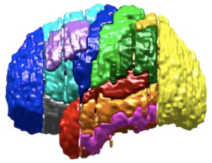

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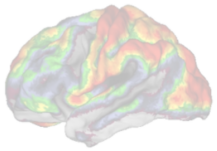

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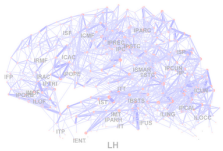
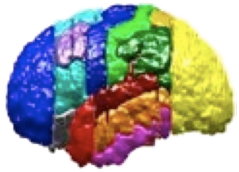
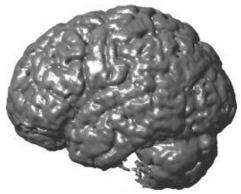


dMRI

Mindboggle

atlas





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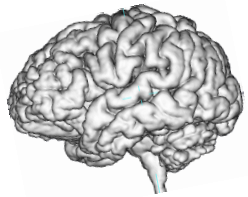
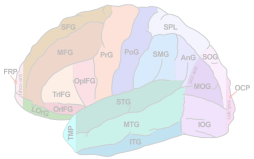


Atlas registration-based labeling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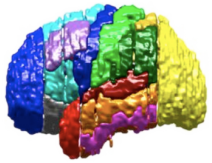
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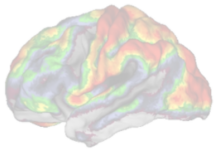
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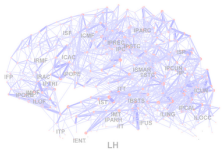
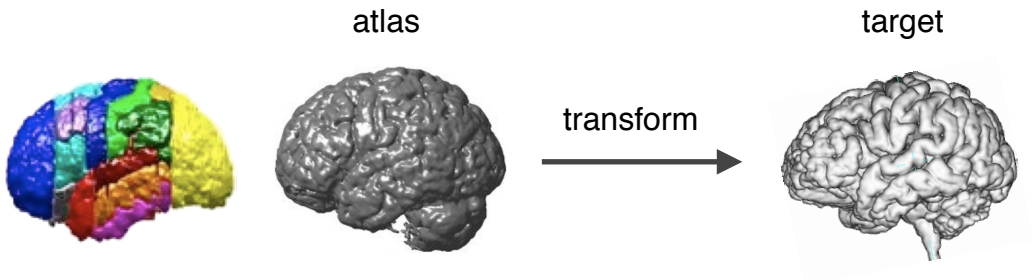
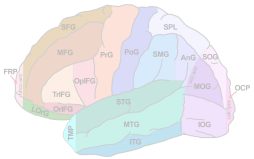

dMRI

Mindboggle



Atlas registration-based labeling:

Step 1: compute the registration transform from the atlas to the target



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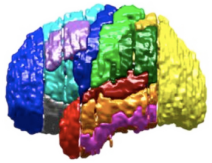
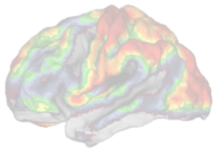
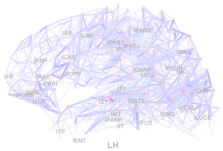


atlas

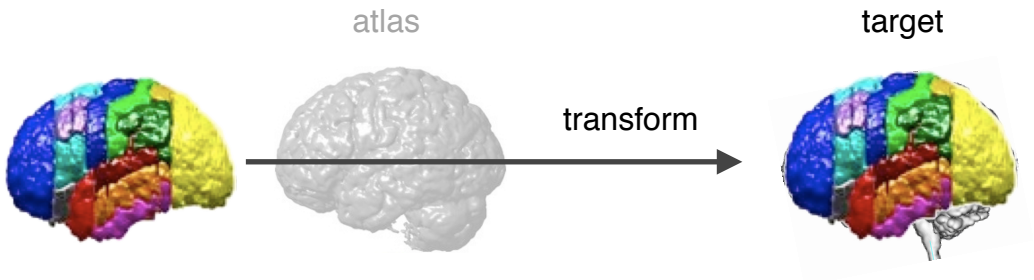


fMRI



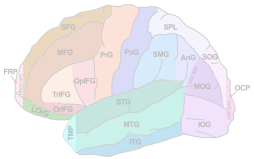
dMRI

Mindboggle

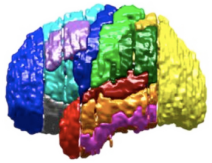


Atlas registration-based labeling:

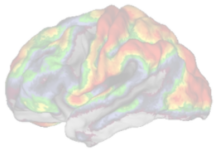
Step 2: apply the transform to the atlas labels



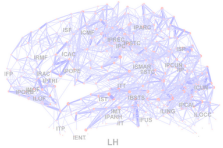
aMRI



atlas

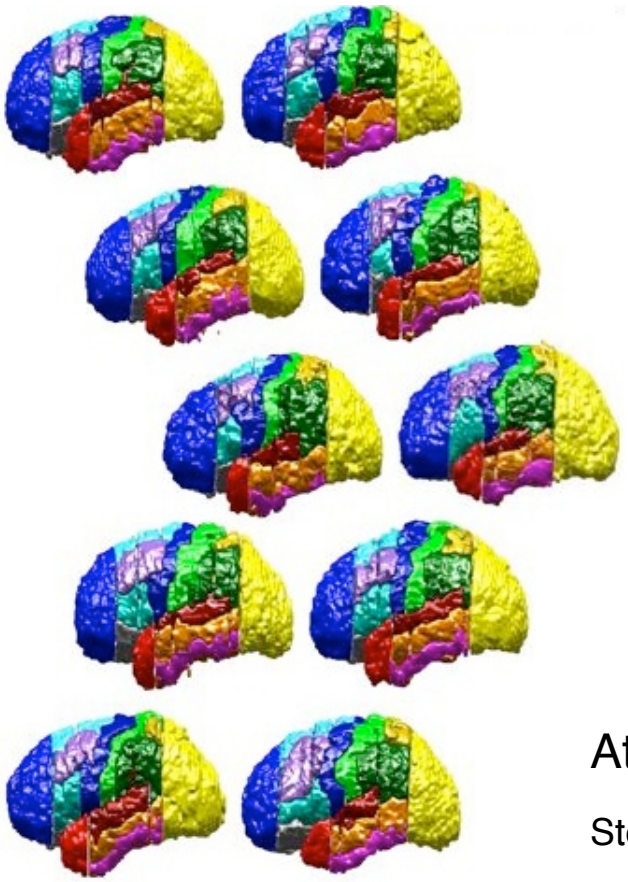


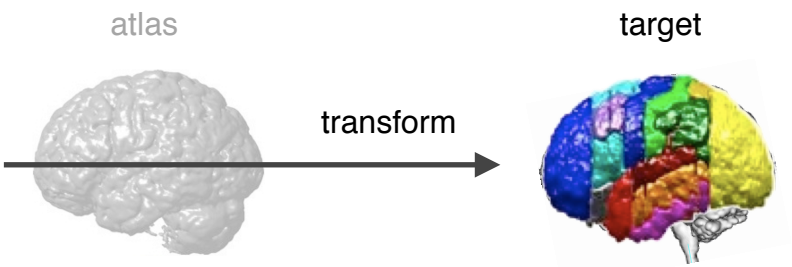
fMRI



dMRI

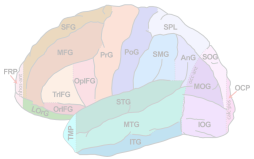
Mindboggle



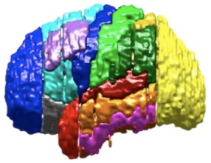


Atlas registration-based labeling:

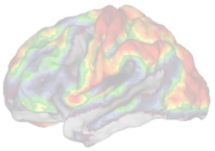
Step N: compute and apply transforms for multiple atlases



aMRI



atlas



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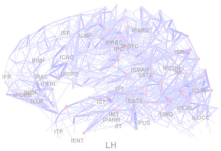
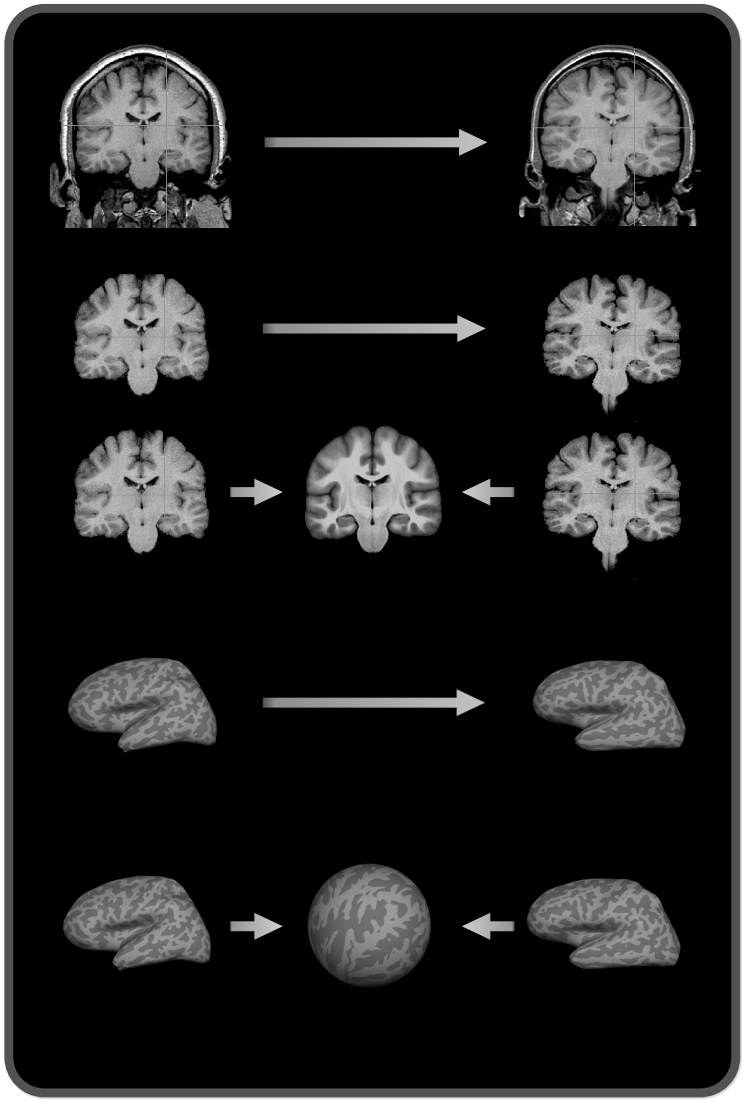
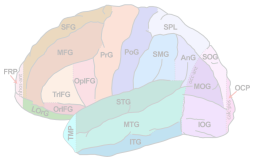


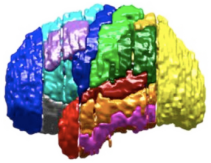
dMRI

Mindboggle





aMRI



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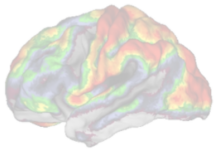

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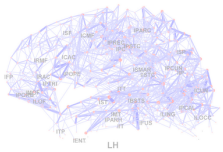

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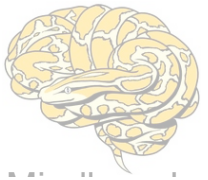
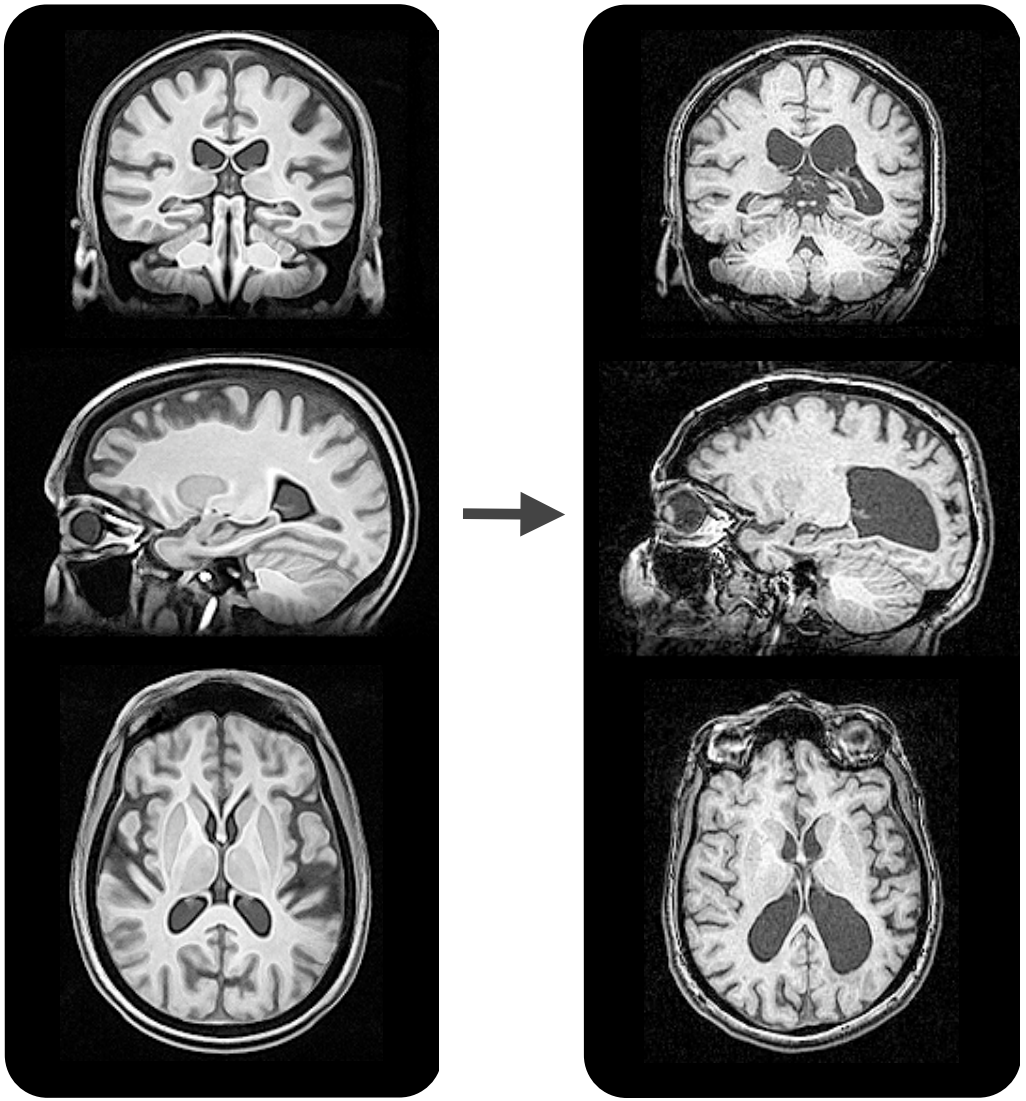
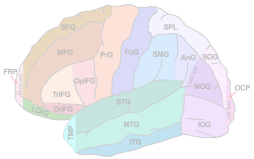




after Avants, et al. 2008



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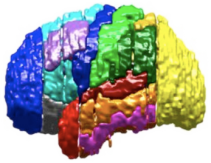
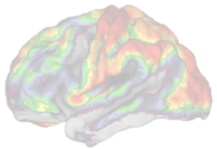


atlas



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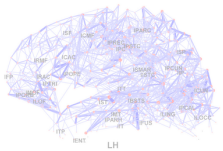
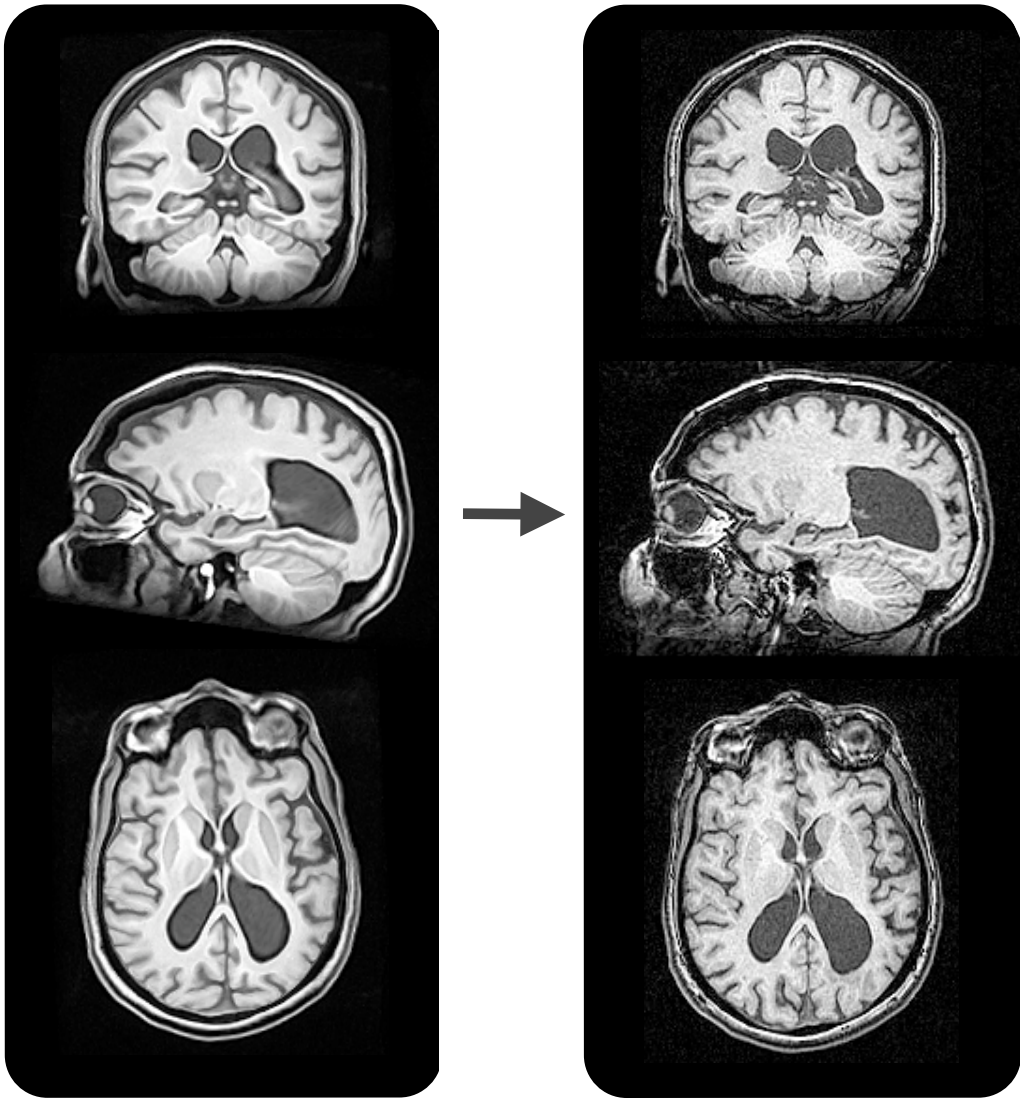
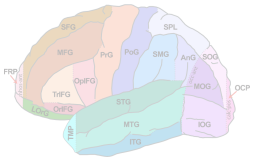


dMRI



after Avants, et al. 2008



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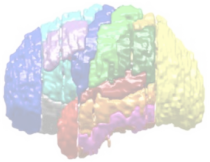

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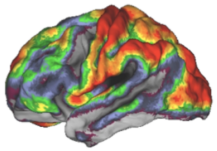

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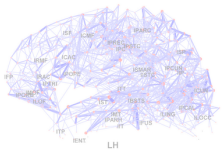
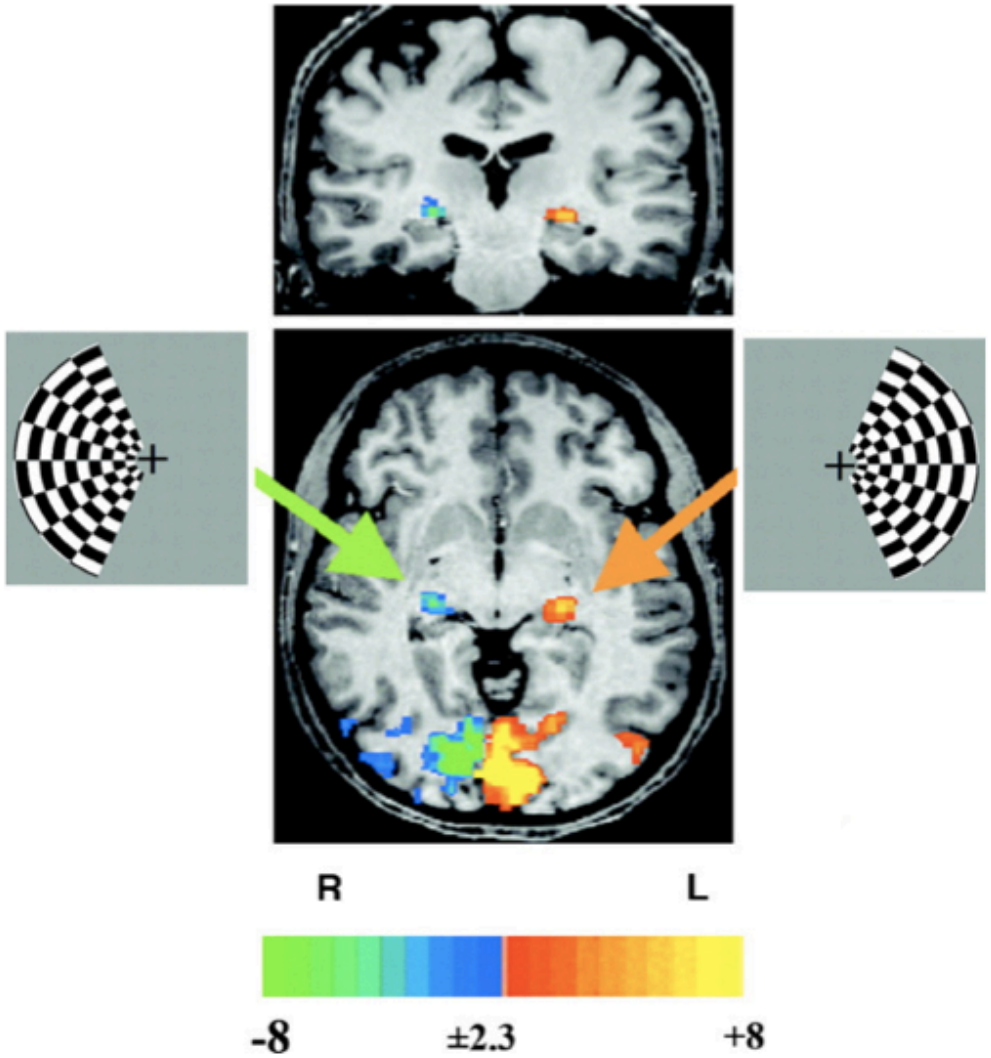
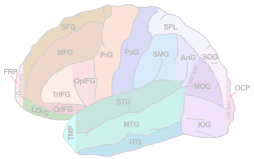


dMRI

Mindboggle



Kastner, et al., 2004



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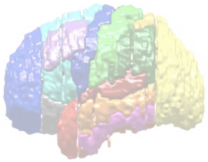

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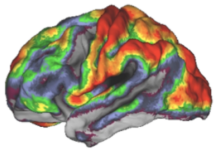

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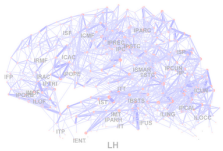
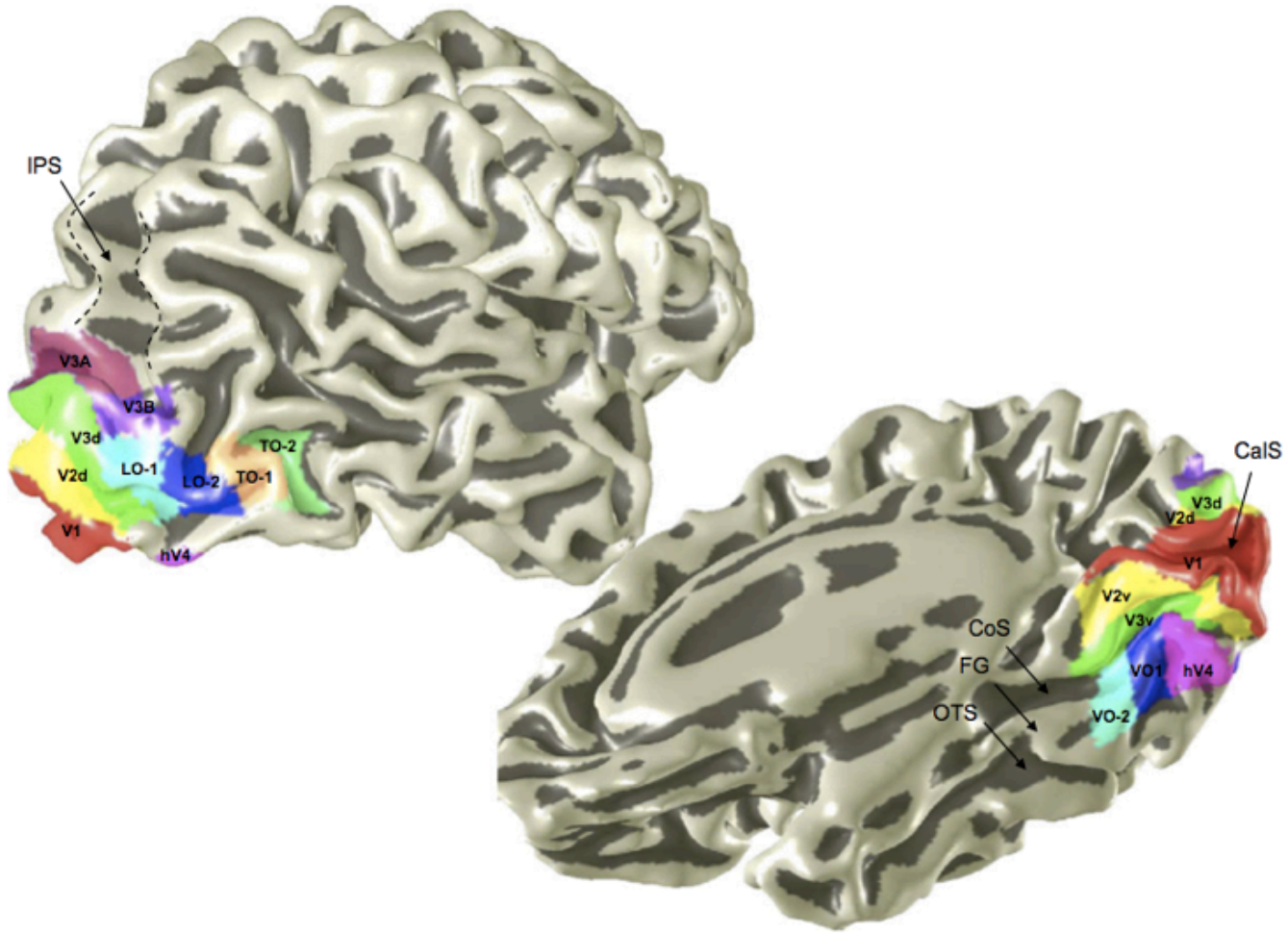


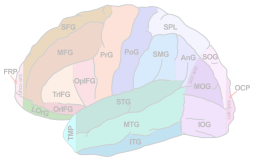
dMRI

Mindboggle



Visuotopic mapping

Wandell and Winawer, 2011



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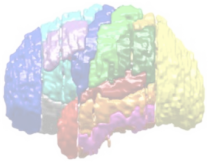

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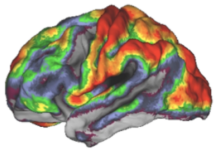
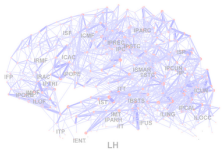
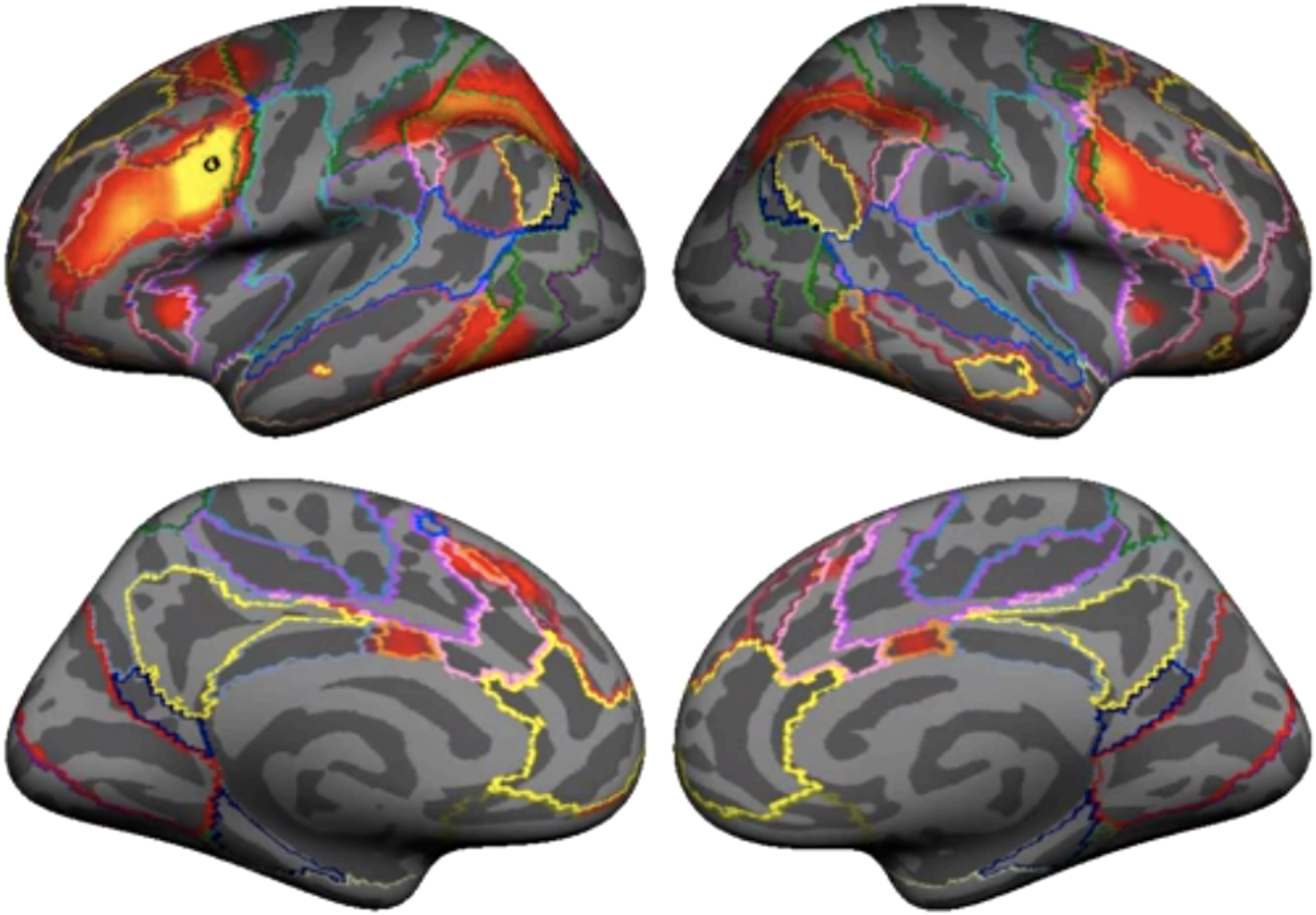


fMRI



dMRI

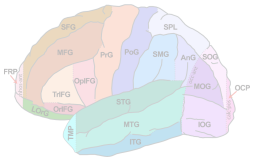
Mindboggle



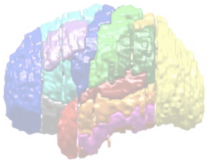
Functional “connectivity”

7-network (N=1000)

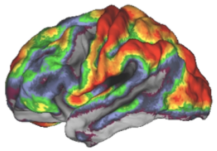
http://www.youtube.com/watch?v=05j-TvKnFaA&feature=player_detailpage



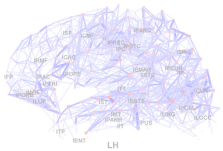
aMRI



atlas

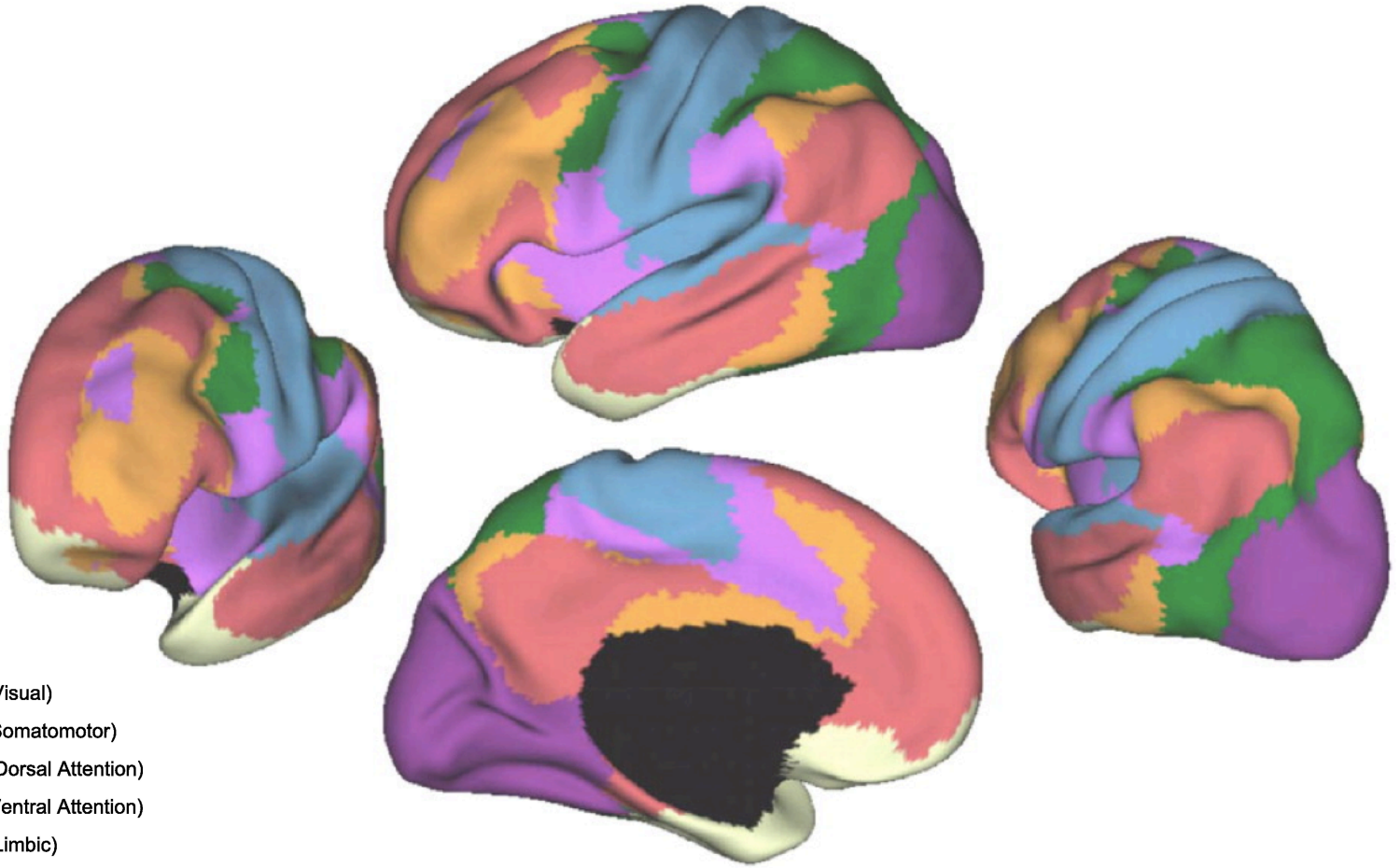


fMRI



dMRI

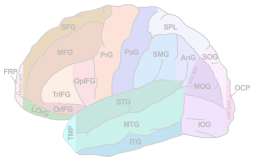
Mindboggle

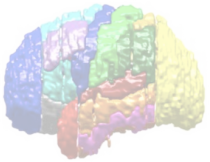


Functional “connectivity”

7-network (N=1000)

Yeo, et al., JNeurophysiology, 2011


aMRI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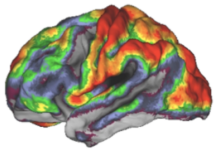
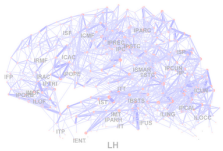
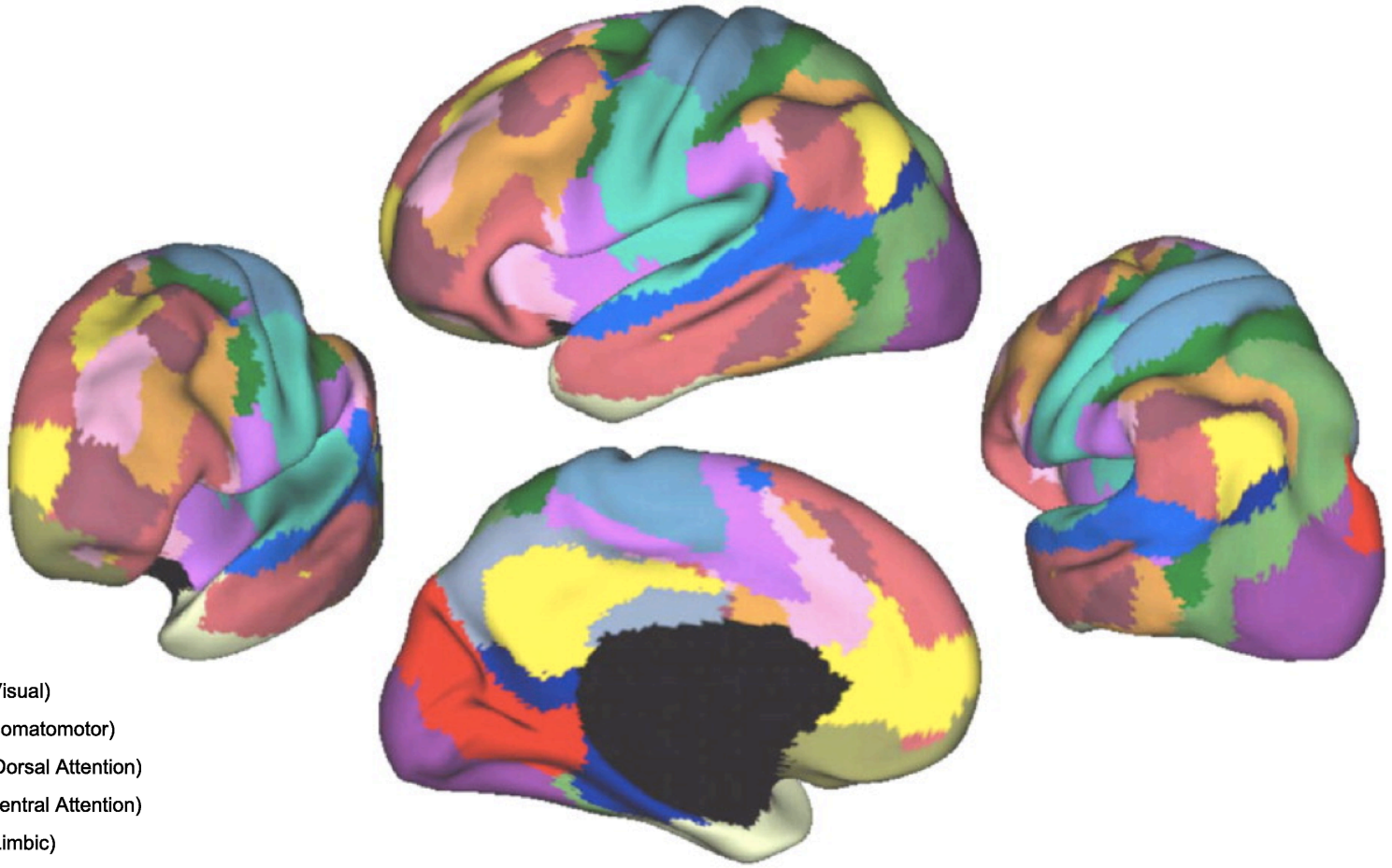

fMRI


dMRI

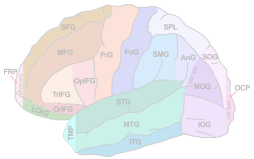
Mindboggle



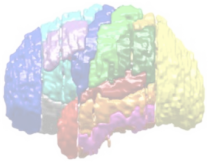
Functional “connectivity”

17-network (N=1000)

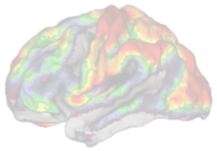
Yeo, et al., JNeurophysiology, 2011



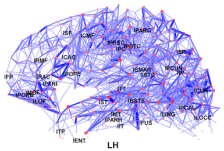
aMRI



atlas

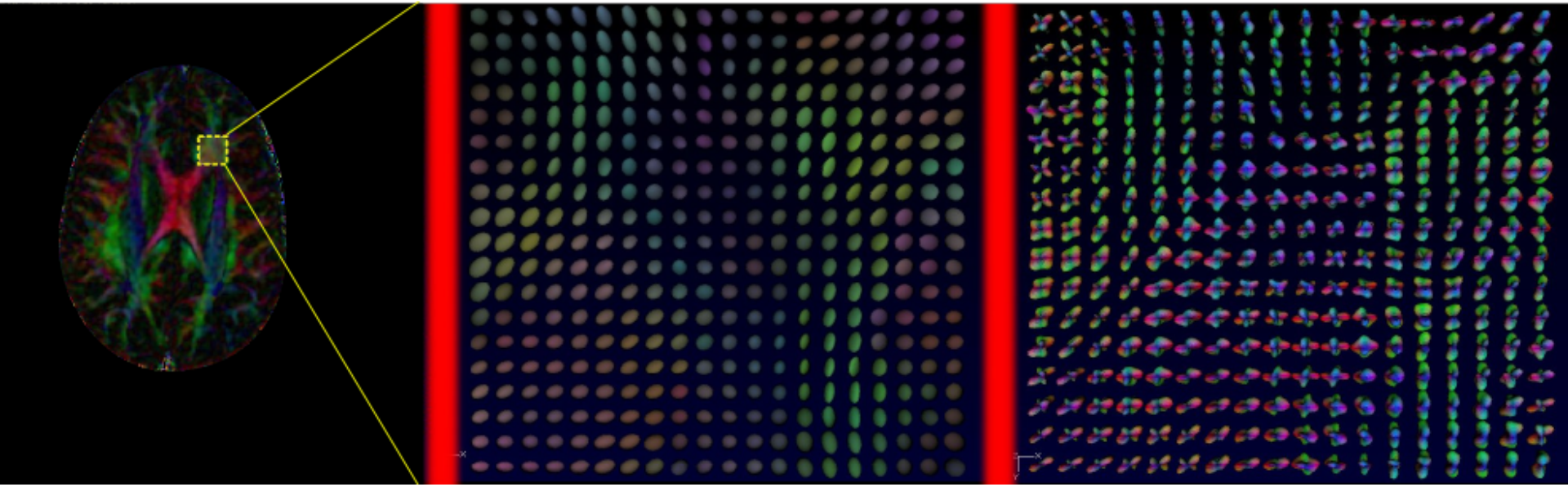


fMRI



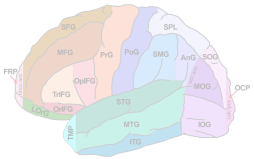
dMRI

Mindboggle

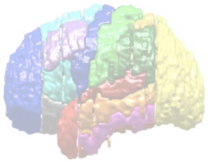


Diffusion MRI

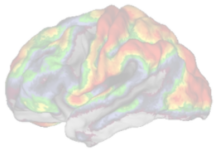
http://www.cim.mcgill.ca/~assemlal/spip.php?



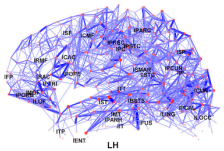
aMRI



atlas

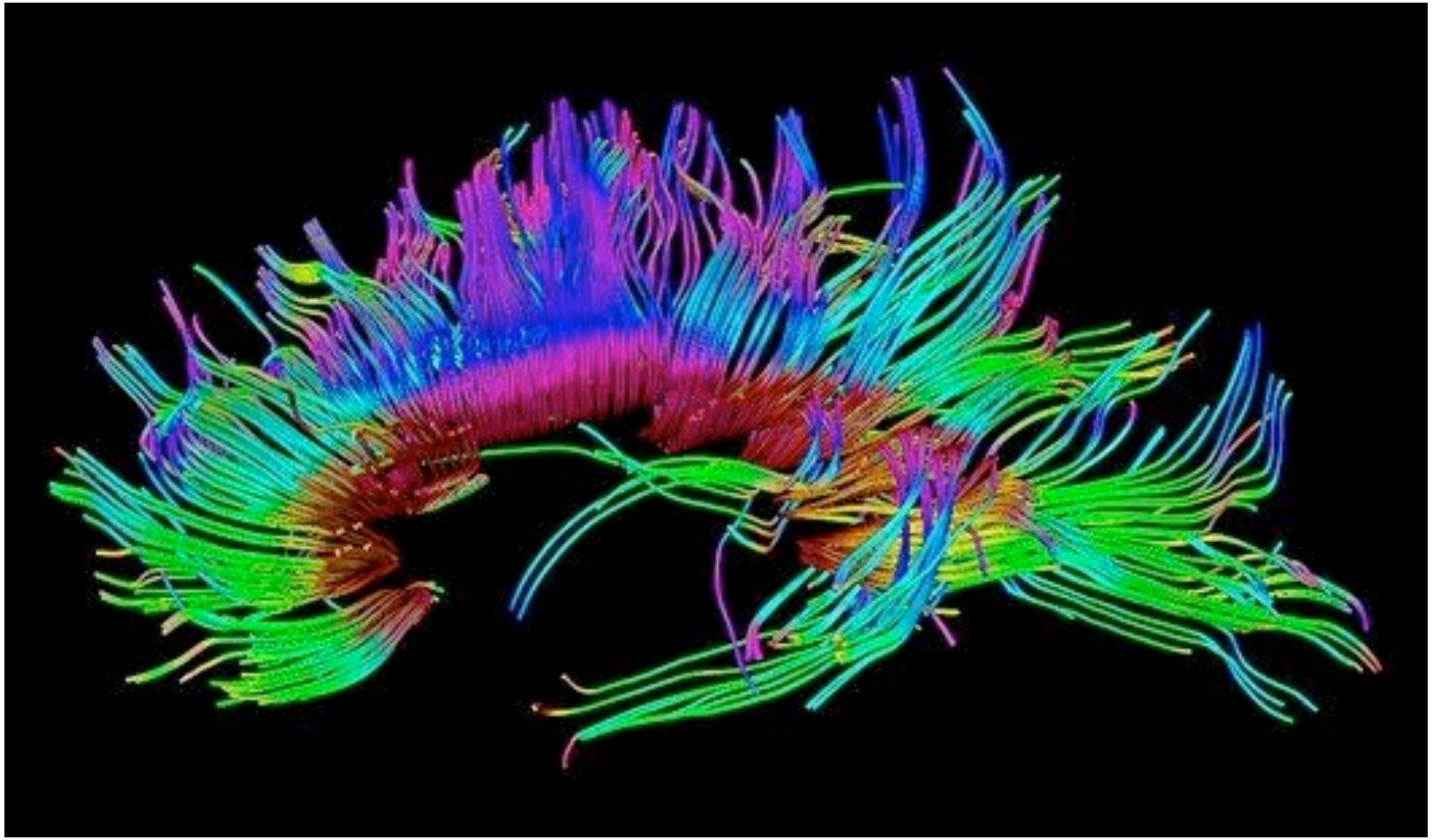


fMRI



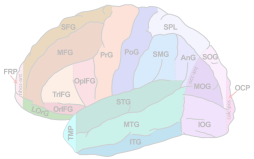
dMRI

Mindboggle



Diffusion tractography

Wiegall et al., 2003, Kirby



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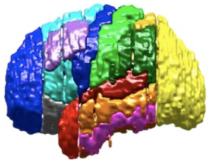

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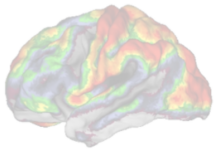

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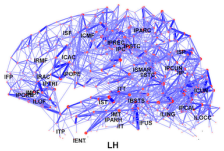

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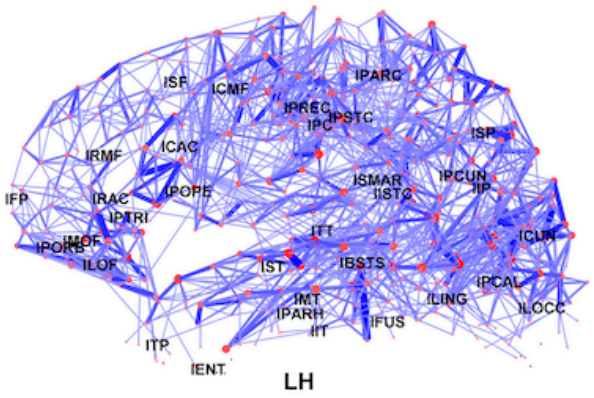
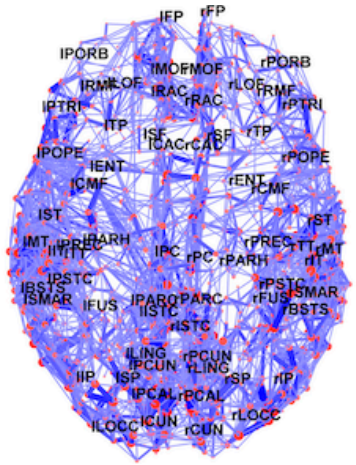
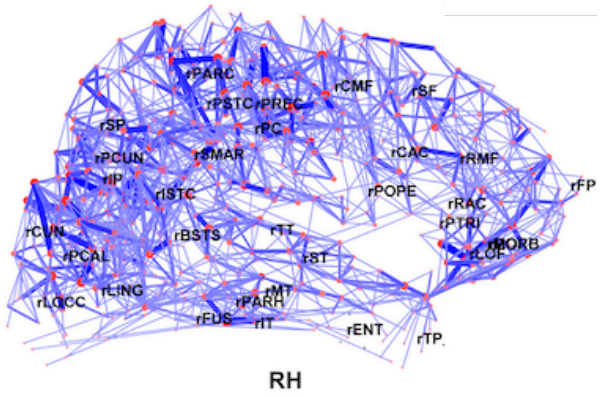
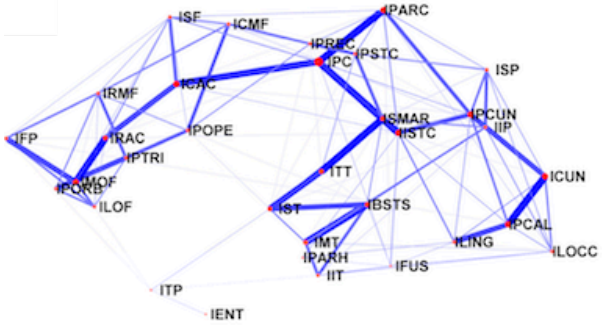
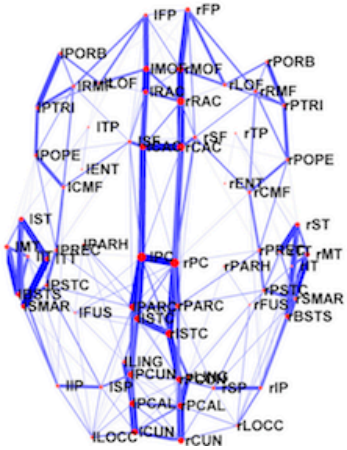
Mindboggle

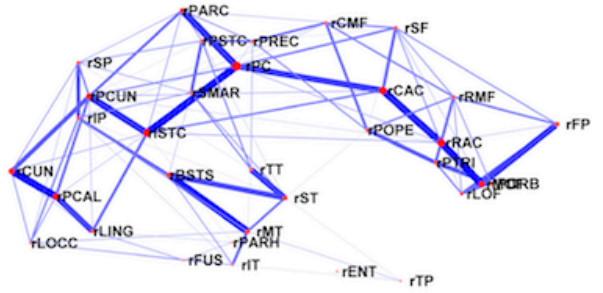








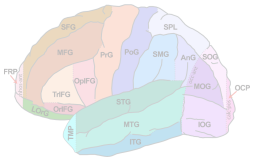




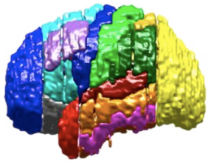
RH

Labeled tractography networks

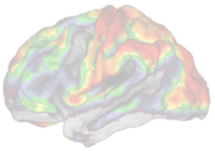
Hagmann, et al., 2008



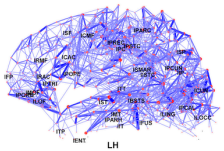
aMRI



atlas

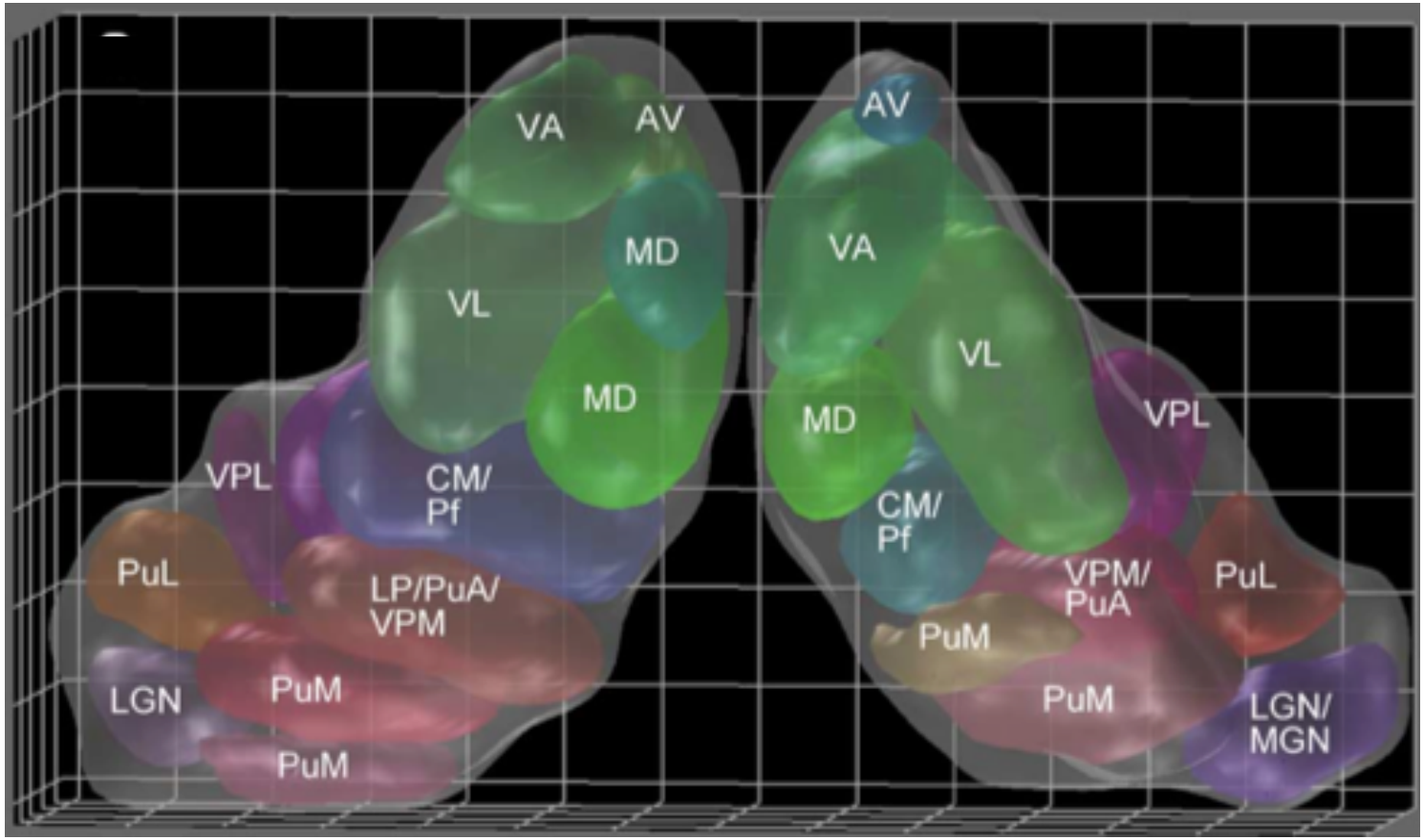


fMRI



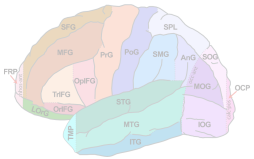
dMRI

Mindboggle



Tractography + atlas-based labeling

Wiegall et al., 2003



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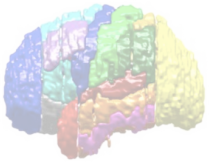

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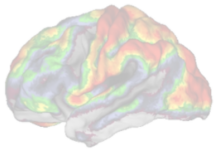

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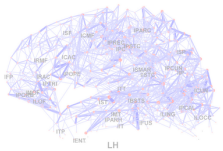
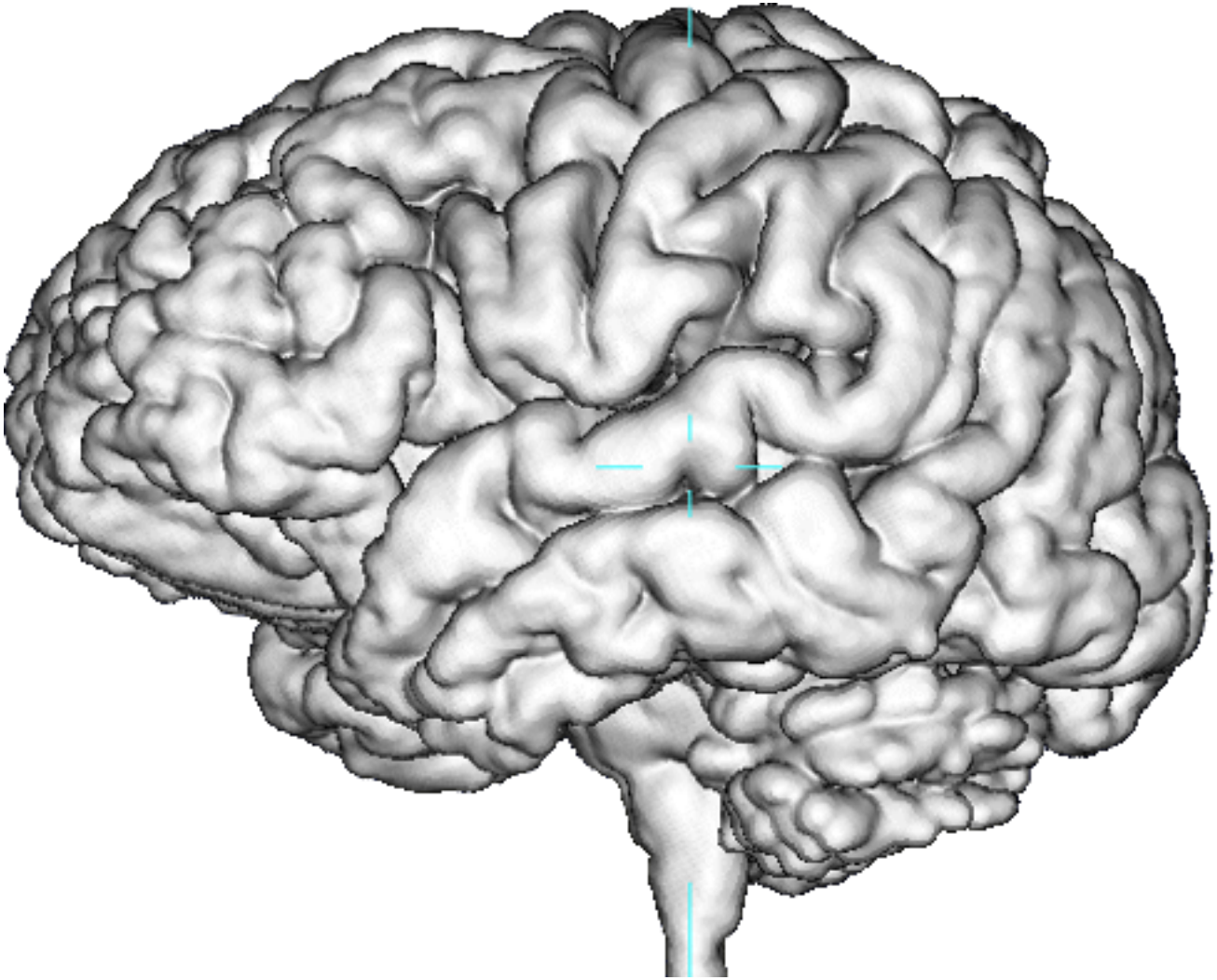
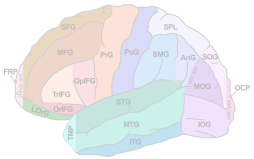


dMRI

Mindboggle





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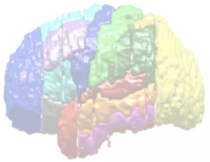

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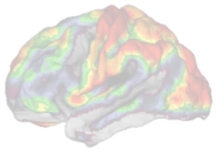

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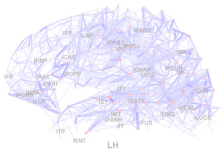

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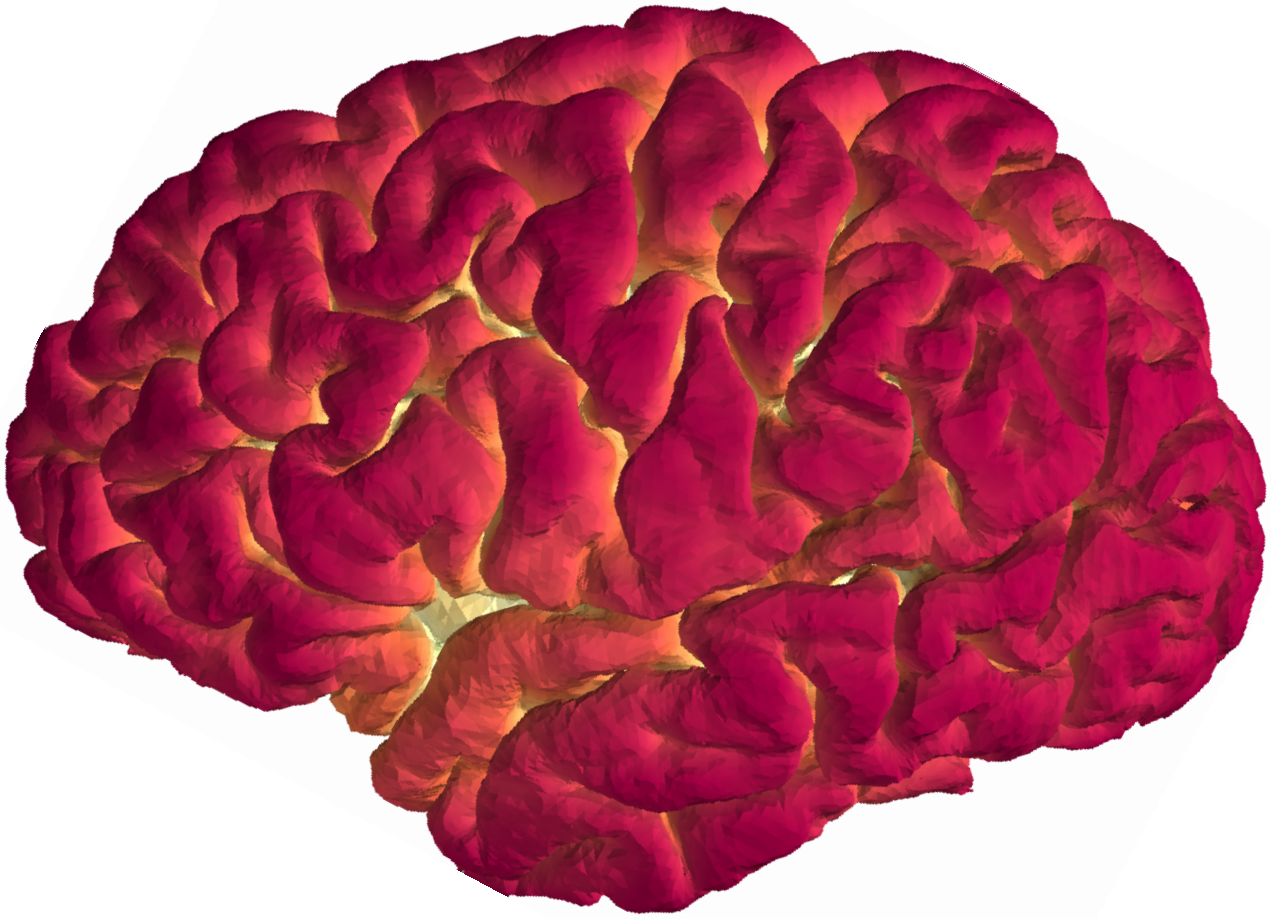
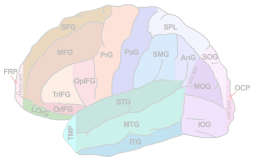
Mindboggle



Depth map



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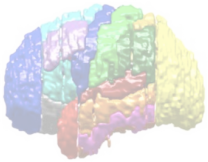

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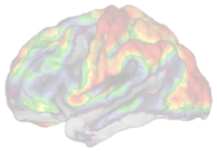

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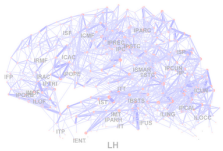
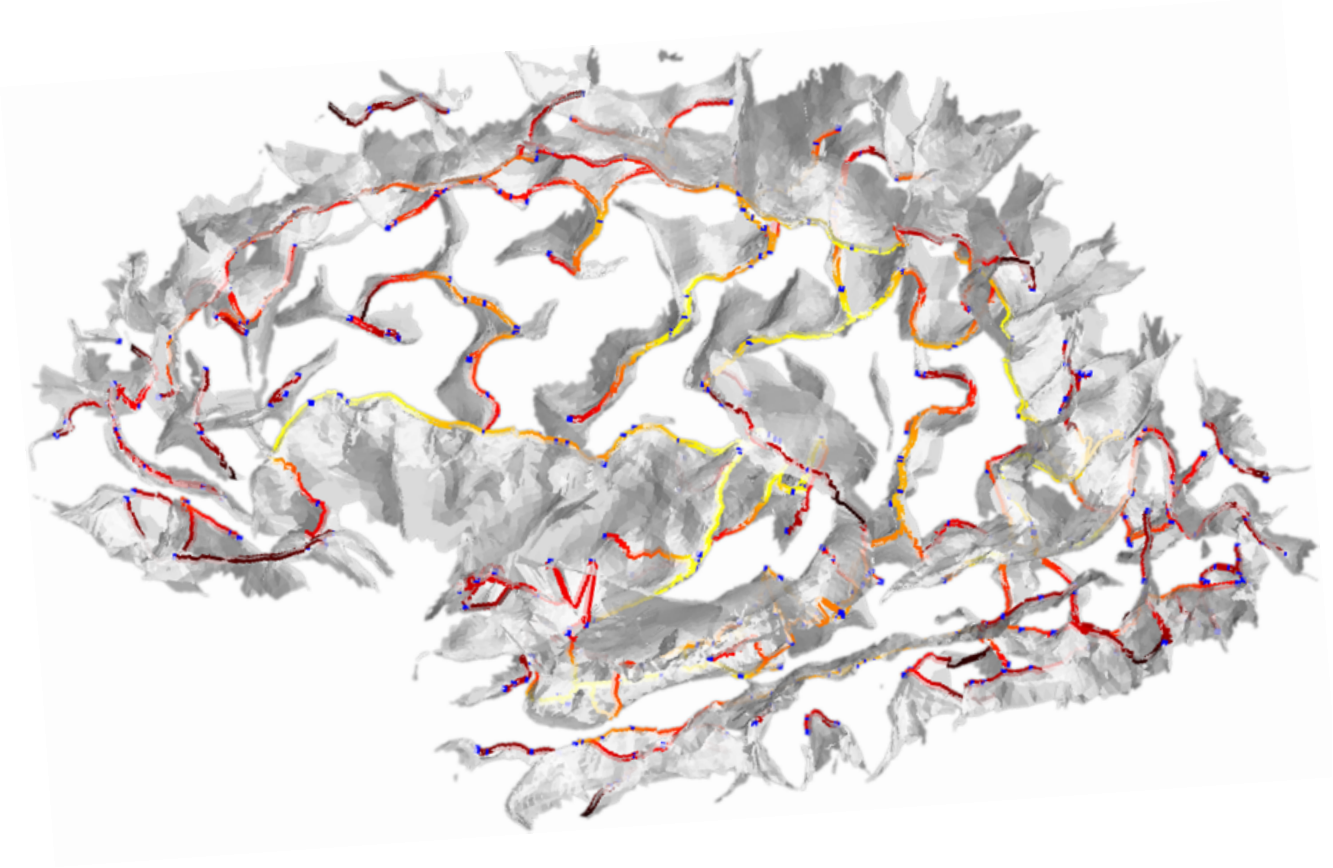
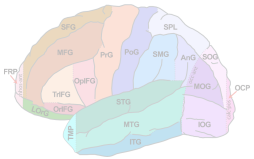


dMRI

Mindboggle



Folds (sulci)



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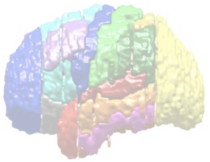
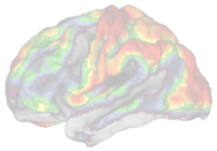


atlas



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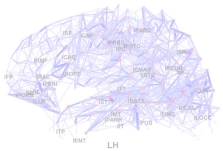
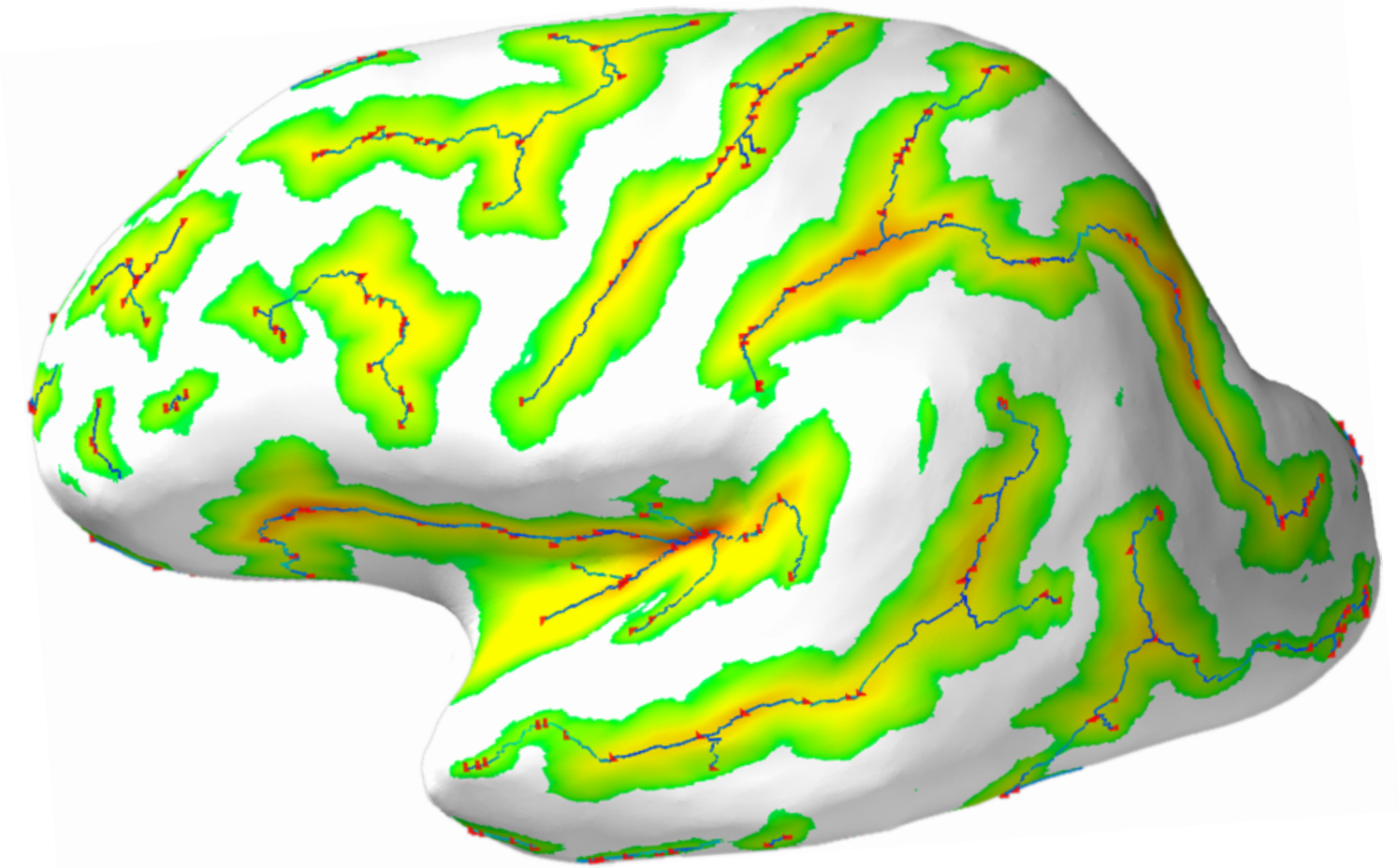
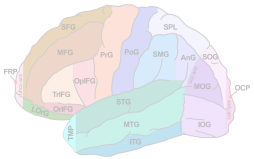


dMRI

Mindboggle



Folds on an inflated surface



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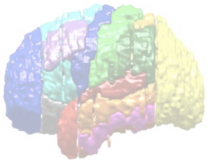

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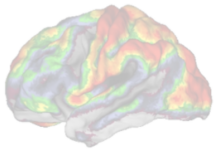

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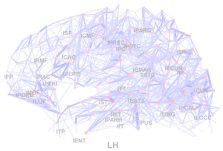
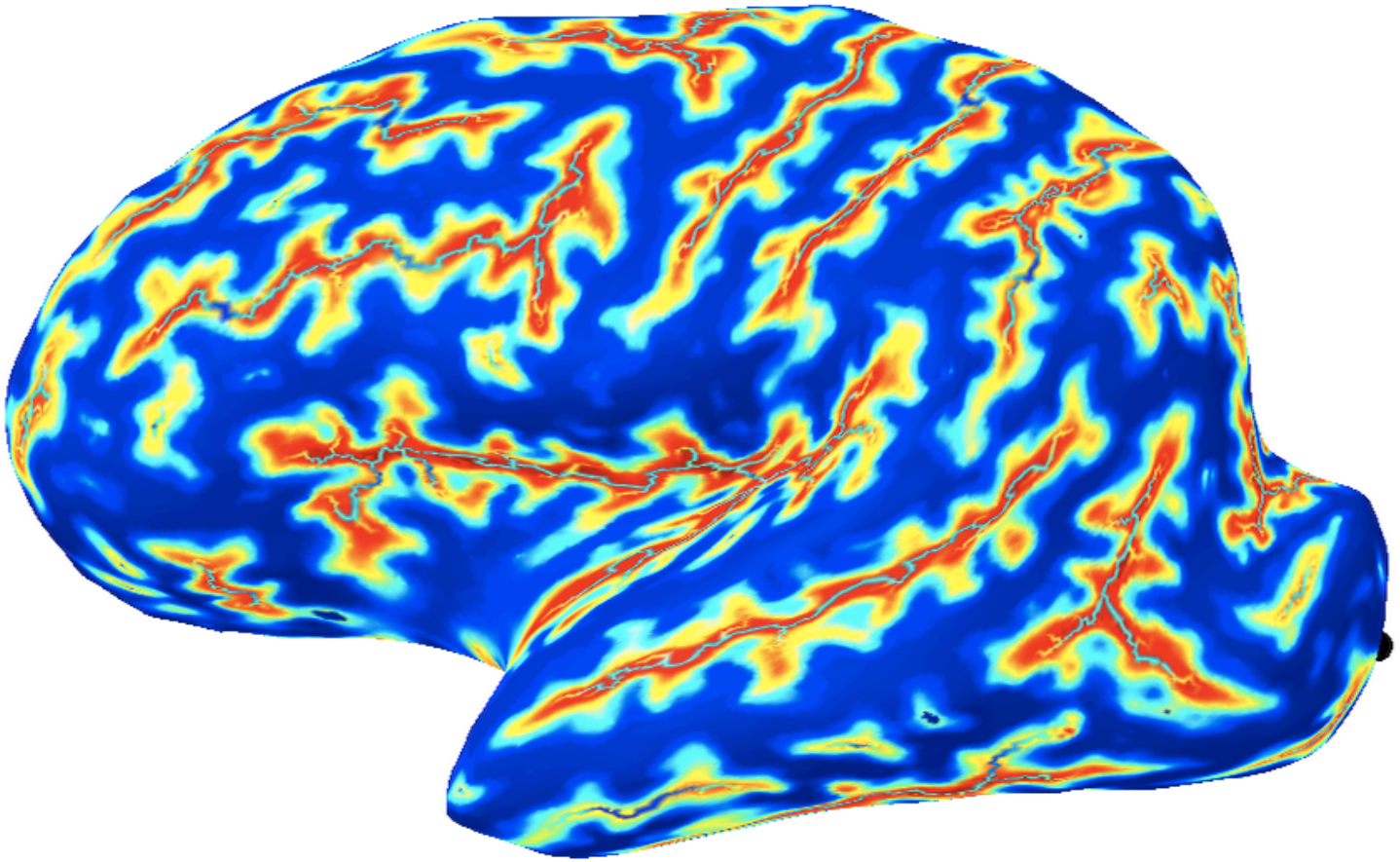
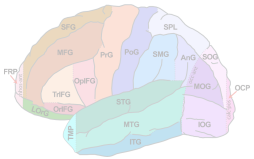


dMRI

Mindboggle



Fundus curves



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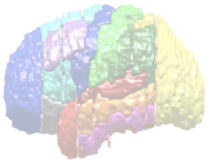
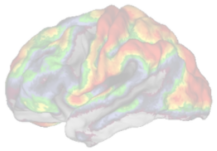


atlas



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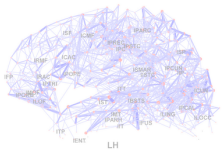
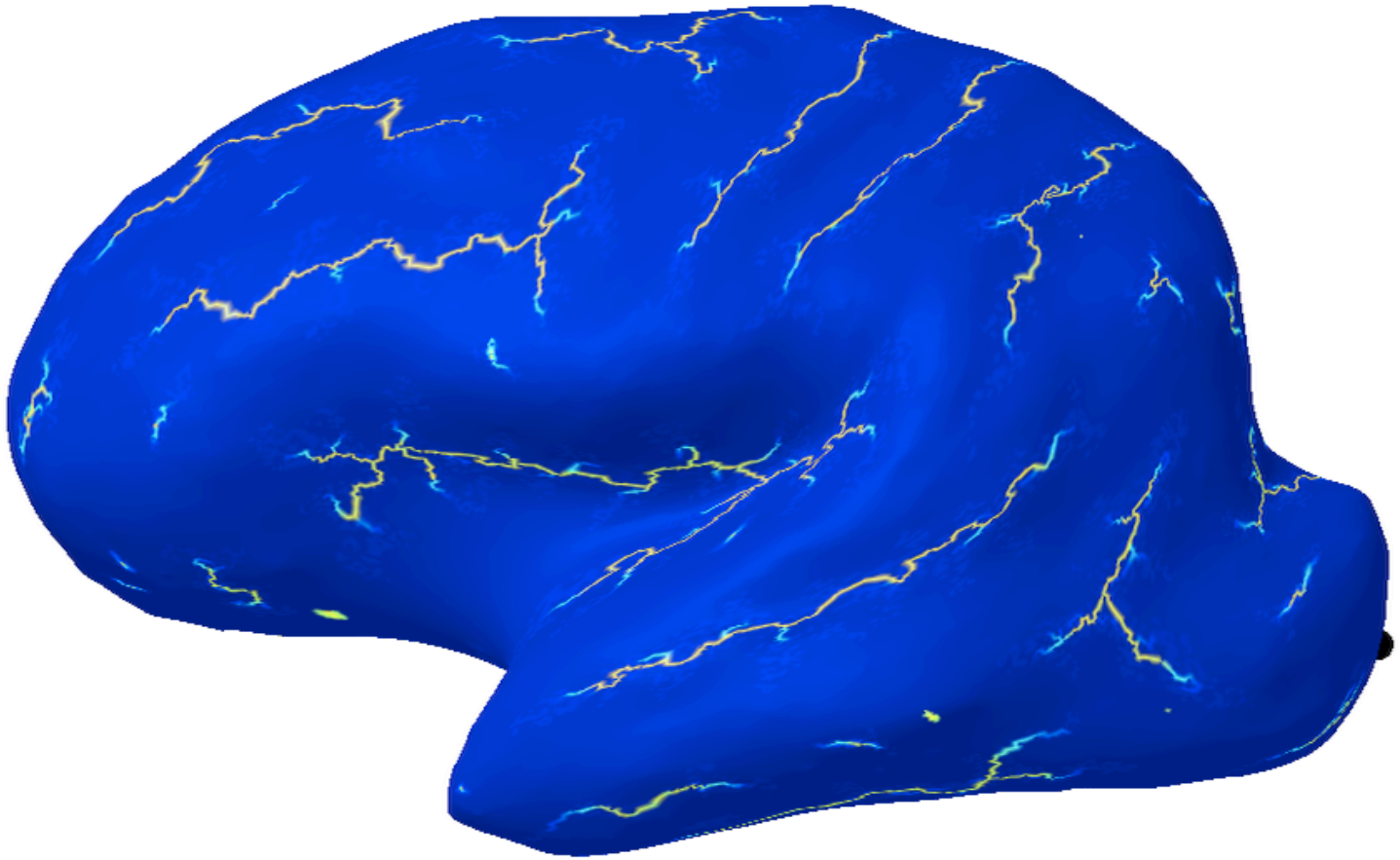
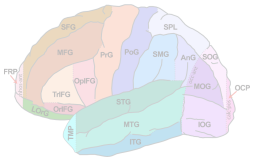


dMRI

Mindboggle



Fundus curves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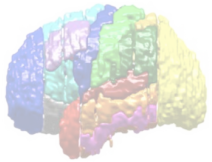
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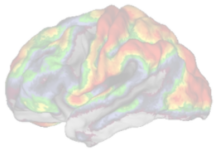
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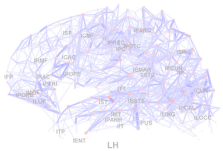
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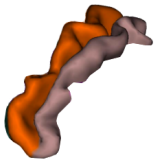
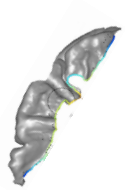
Mindboggle



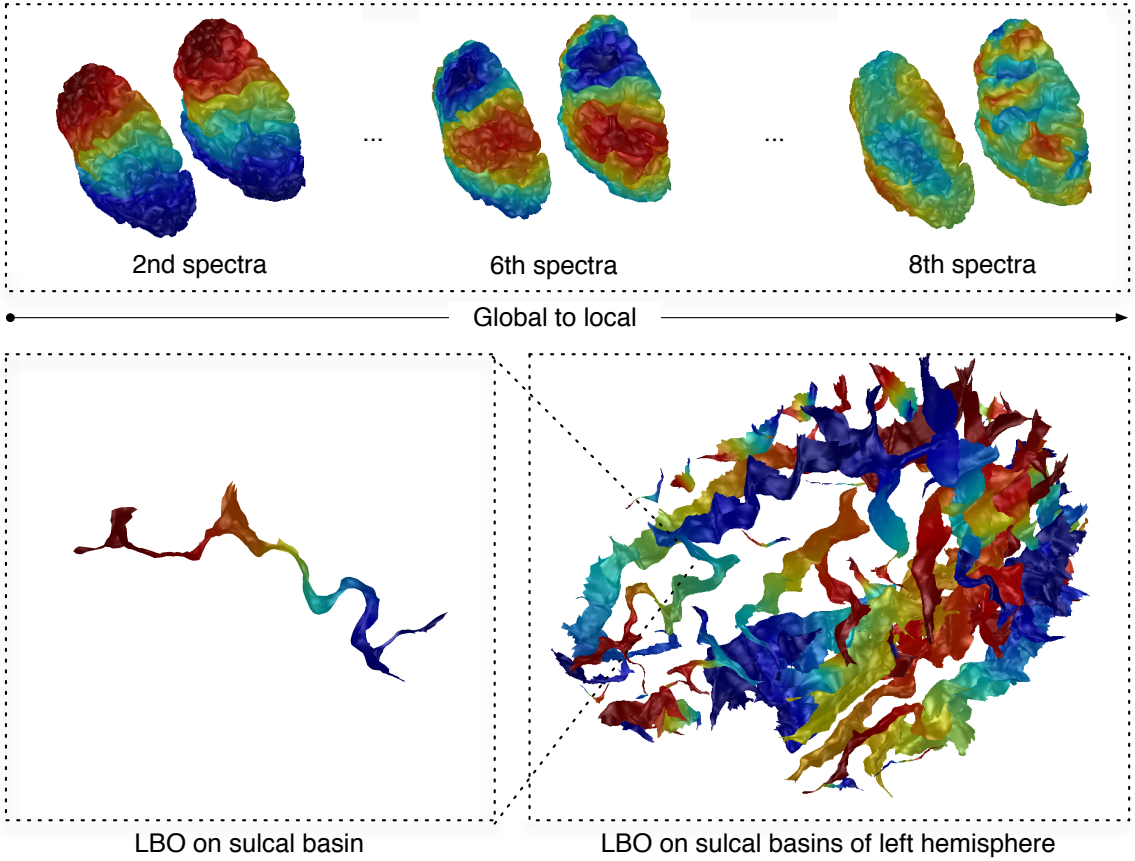
volume
surface area
cortical thickness
...



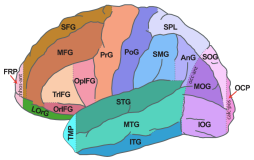
convex hull volume
surface area
depth
curvature
convexity
...

length / tortuosity
depth
curvature
convexity
...

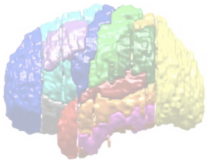
location
sequence
...



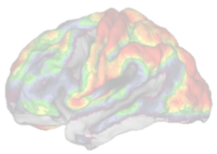
Shape analysis



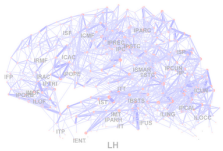
aMRI



atlas

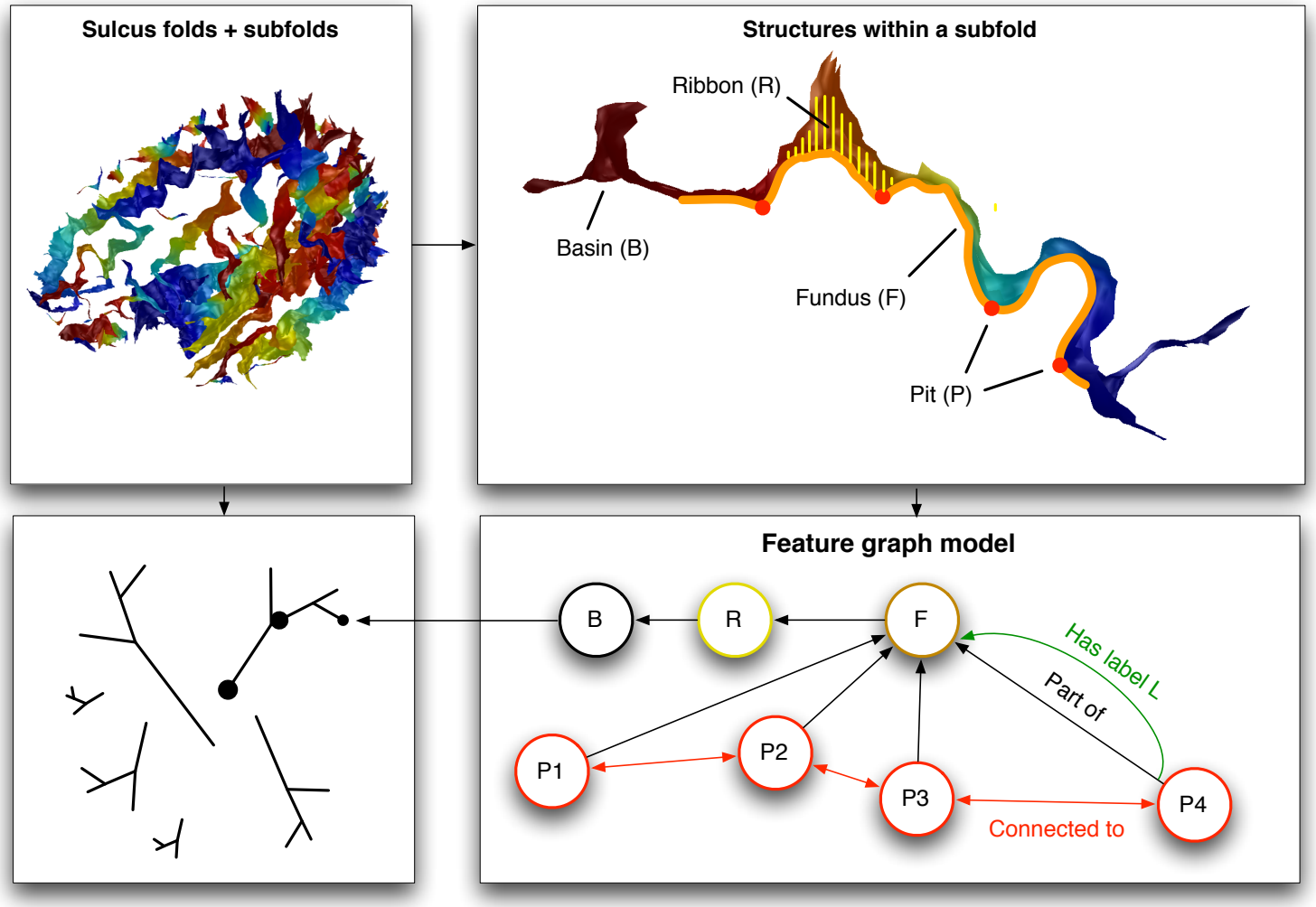


fMRI

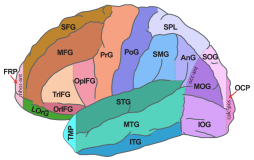


dMRI

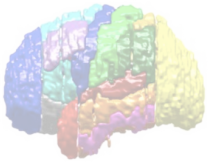
Mindboggle



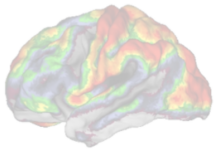
Nested features within a graph-based data model



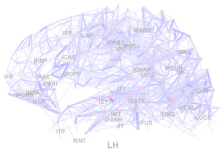
aMRI



atlas

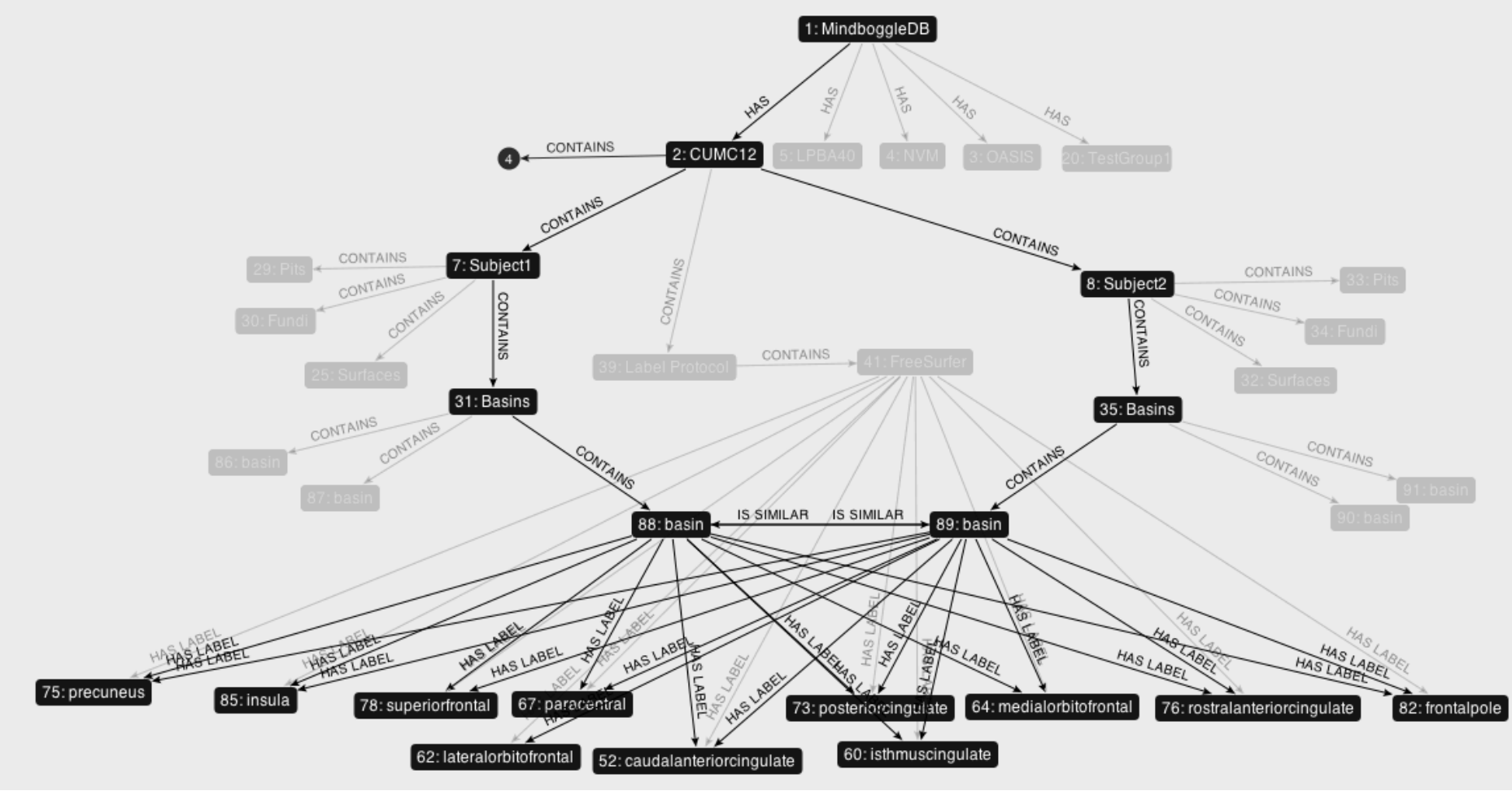


fMRI



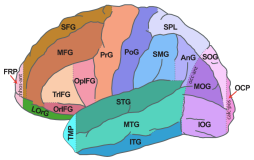
dMRI

Mindboggle

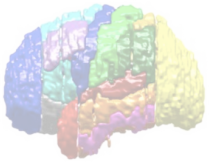


Graph-based database of hierarchical brain features

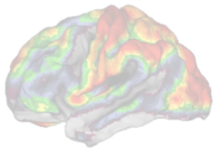
finding similar features



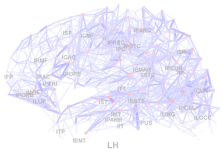
aMRI



atlas

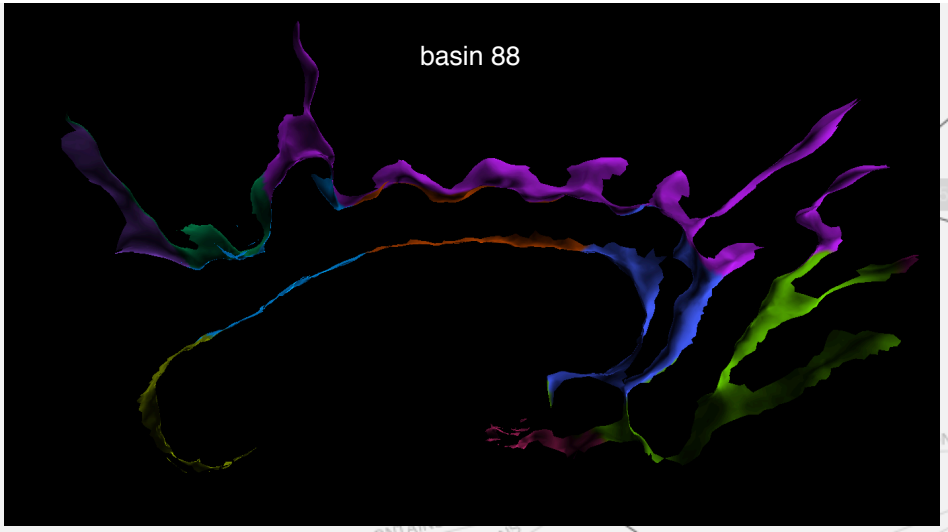


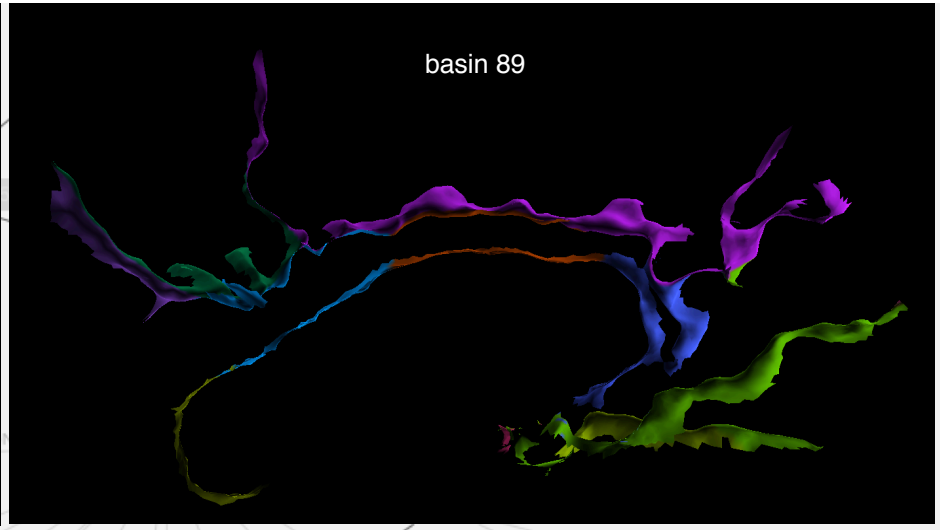
fMRI

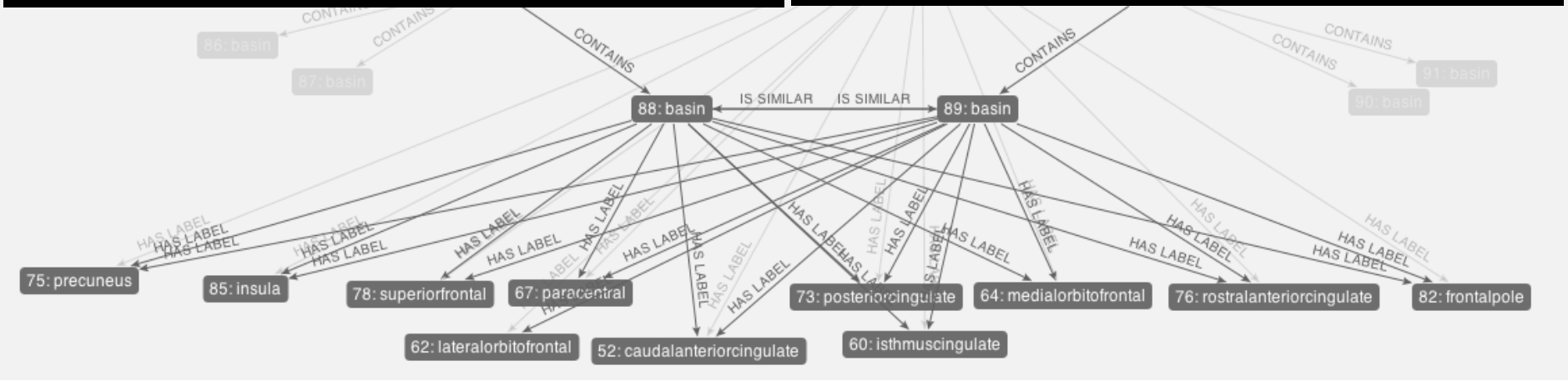


dMRI

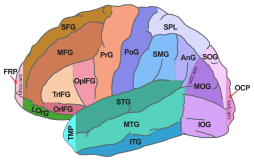
Mindboggle



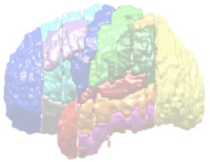




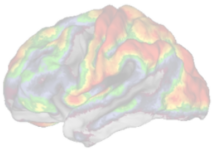
Graph-based database: example query



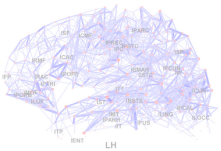
aMRI



atlas



fMRI

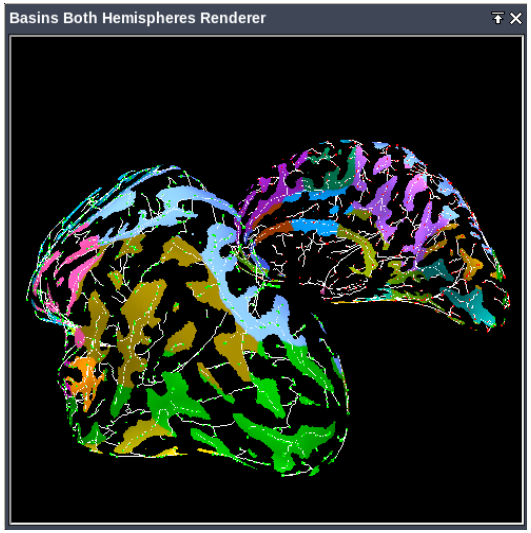


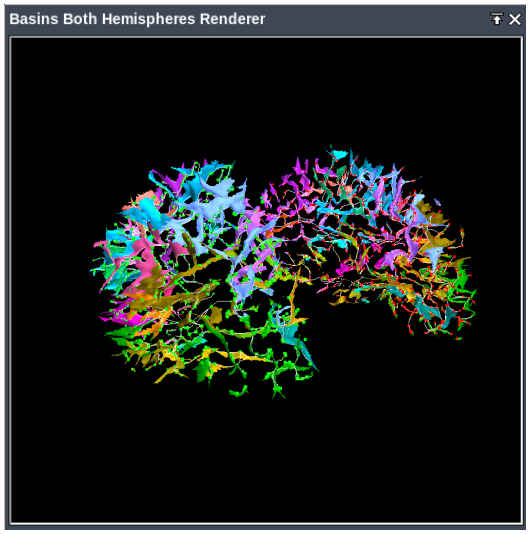
dMRI

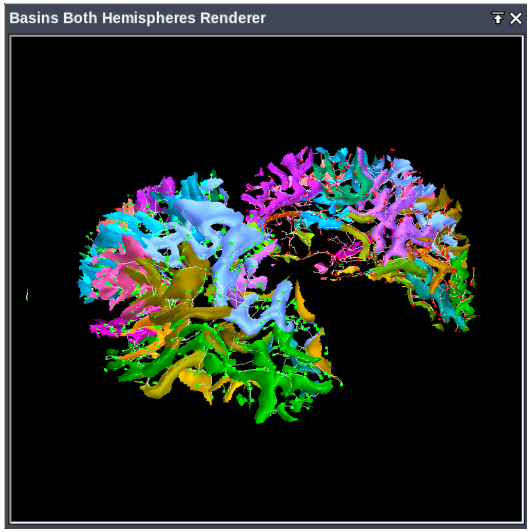
Mindboggle

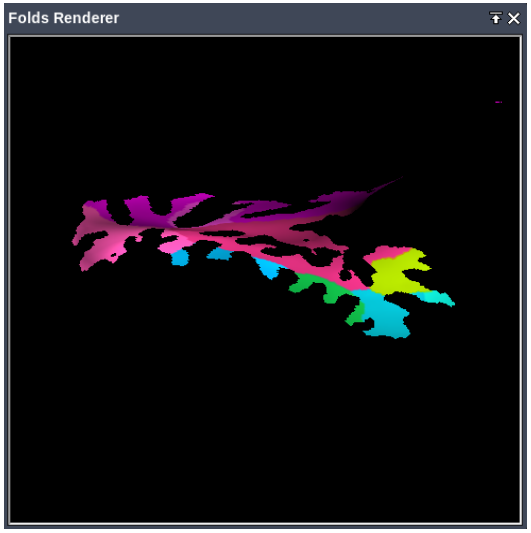
whole brain

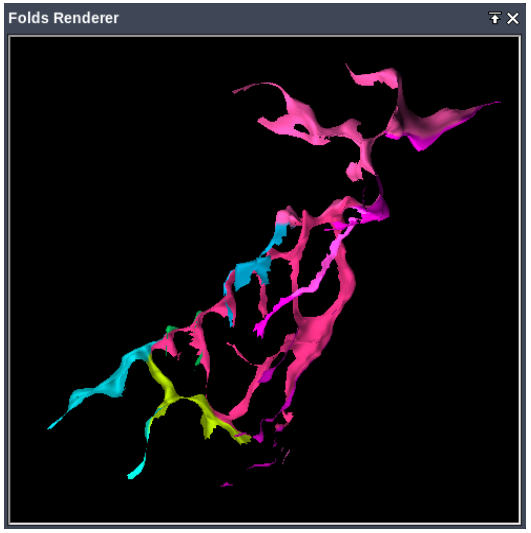
single folds

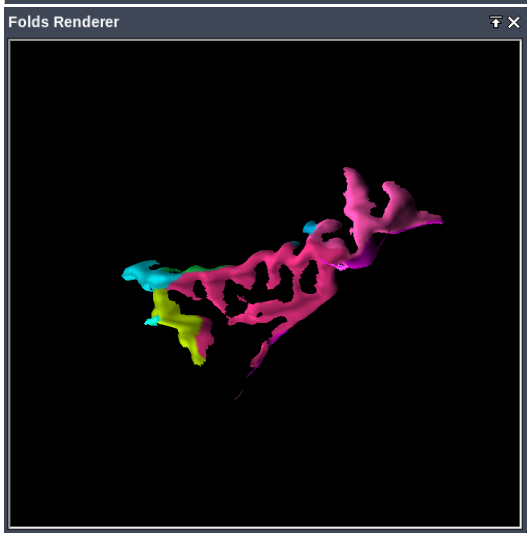








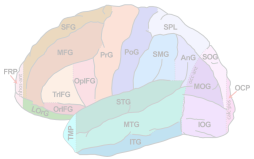




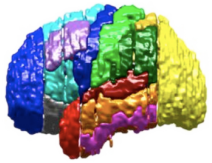
inflated

pial

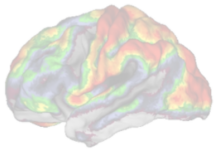
white matter



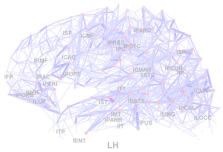
aMRI



atlas



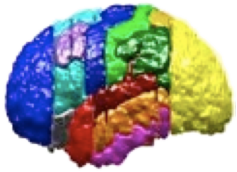
fMRI

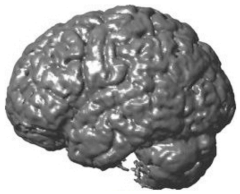


dMRI

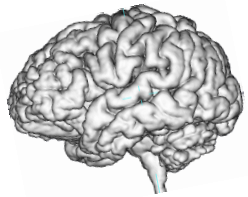
Mindboggle

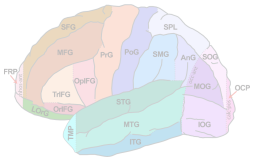
atlas



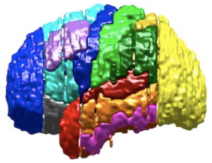


target

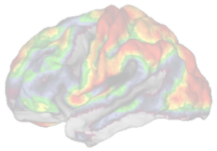




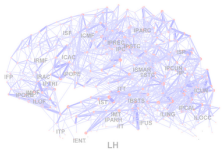
aMRI



atlas



fMRI



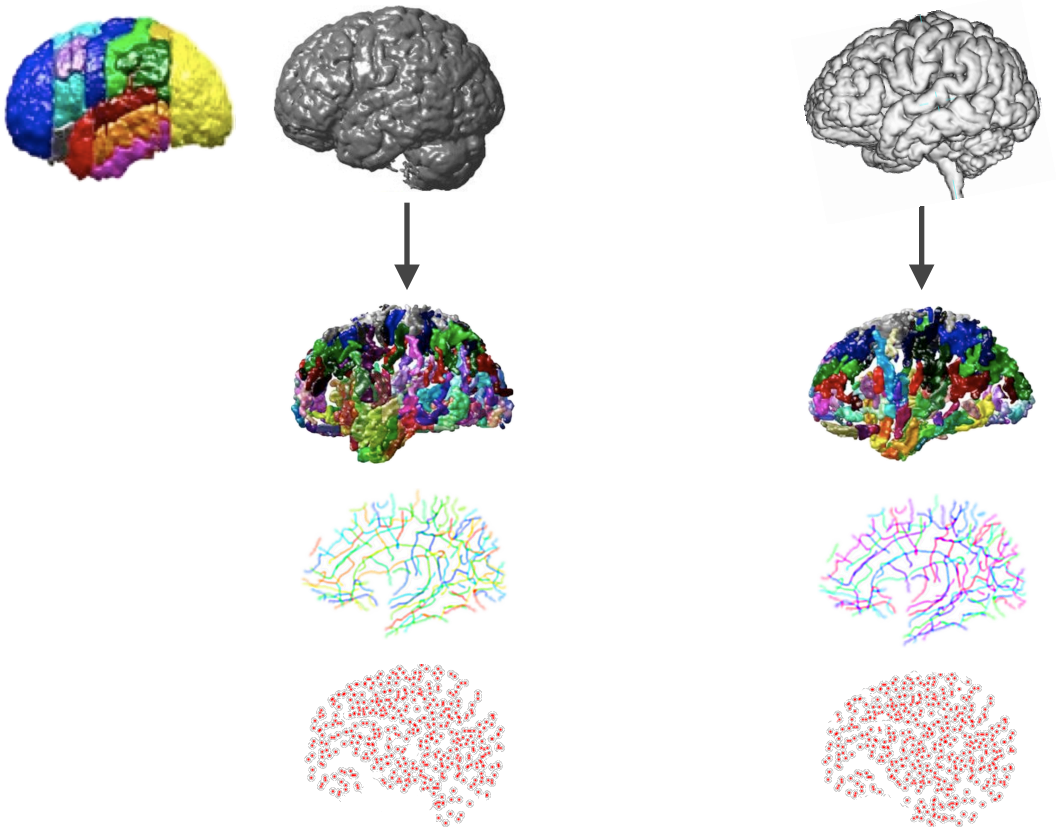
dMRI

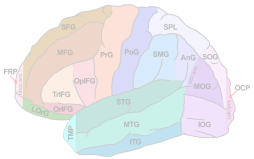
Mindboggle

Mindboggle step 1: extract features, compute their shape measures

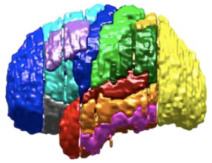
atlas

target

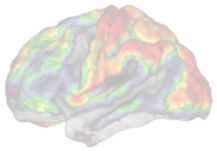




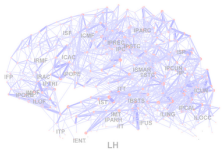
aMRI



atlas



fMRI



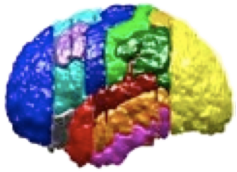
dMRI

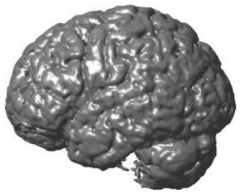
Mindboggle

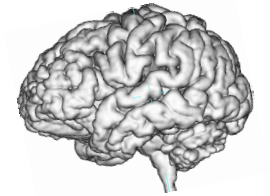
Mindboggle step 2: match atlas and target features

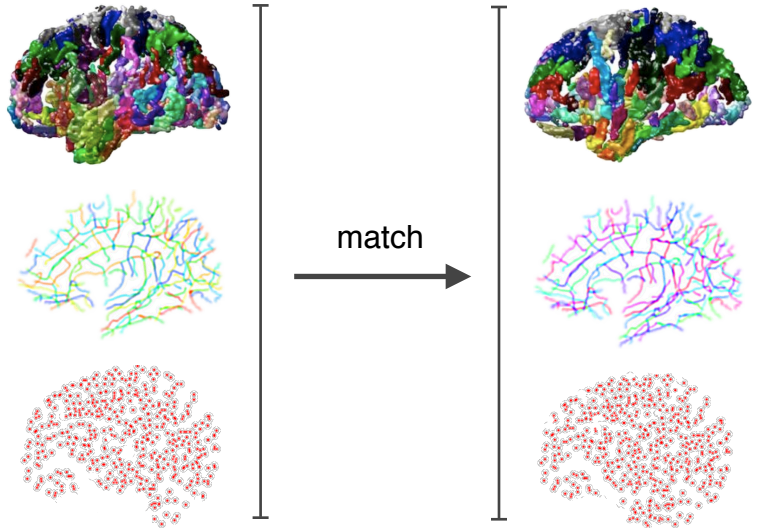
atlas

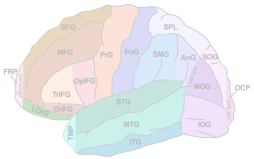
target



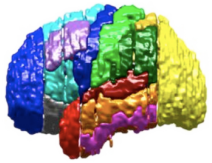




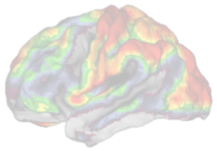




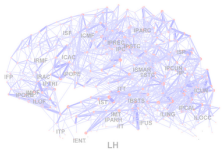
aMRI



atlas



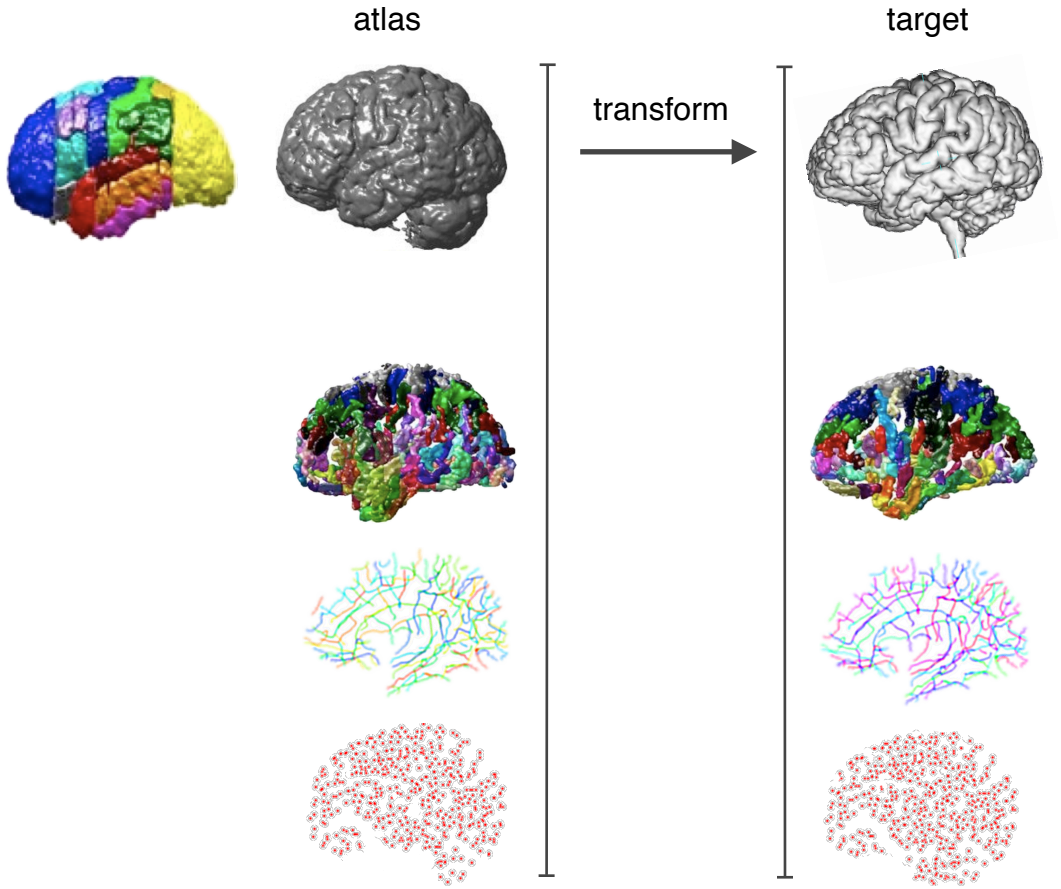
fMRI

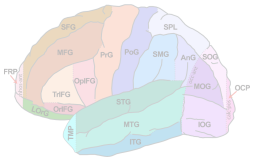


dMRI

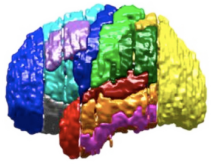
Mindboggle

Mindboggle step 3: compute feature-driven transform from atlas to target

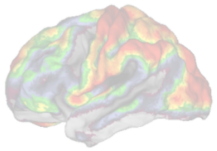




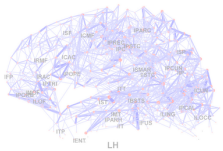
aMRI



atlas



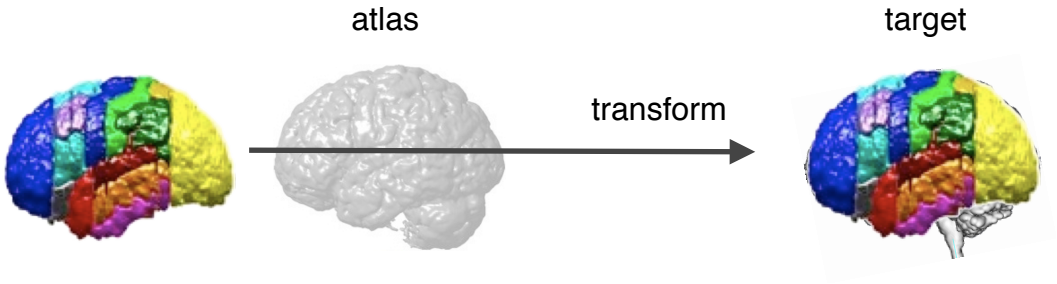
fMRI

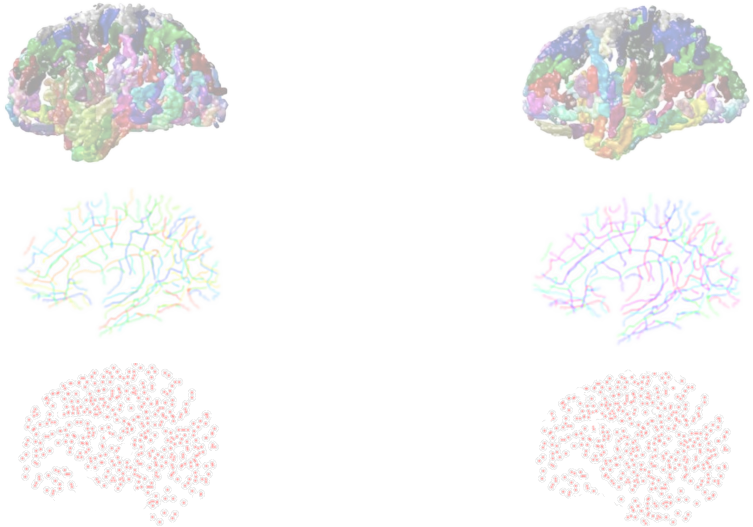


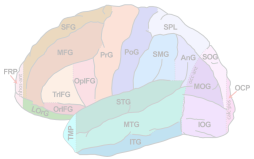
dMRI

Mindboggle

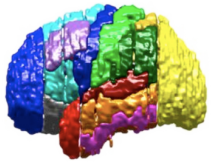
Mindboggle step 4: apply transform to labels







aMRI



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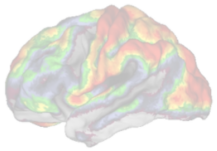
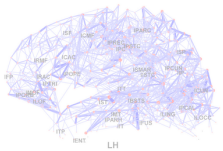


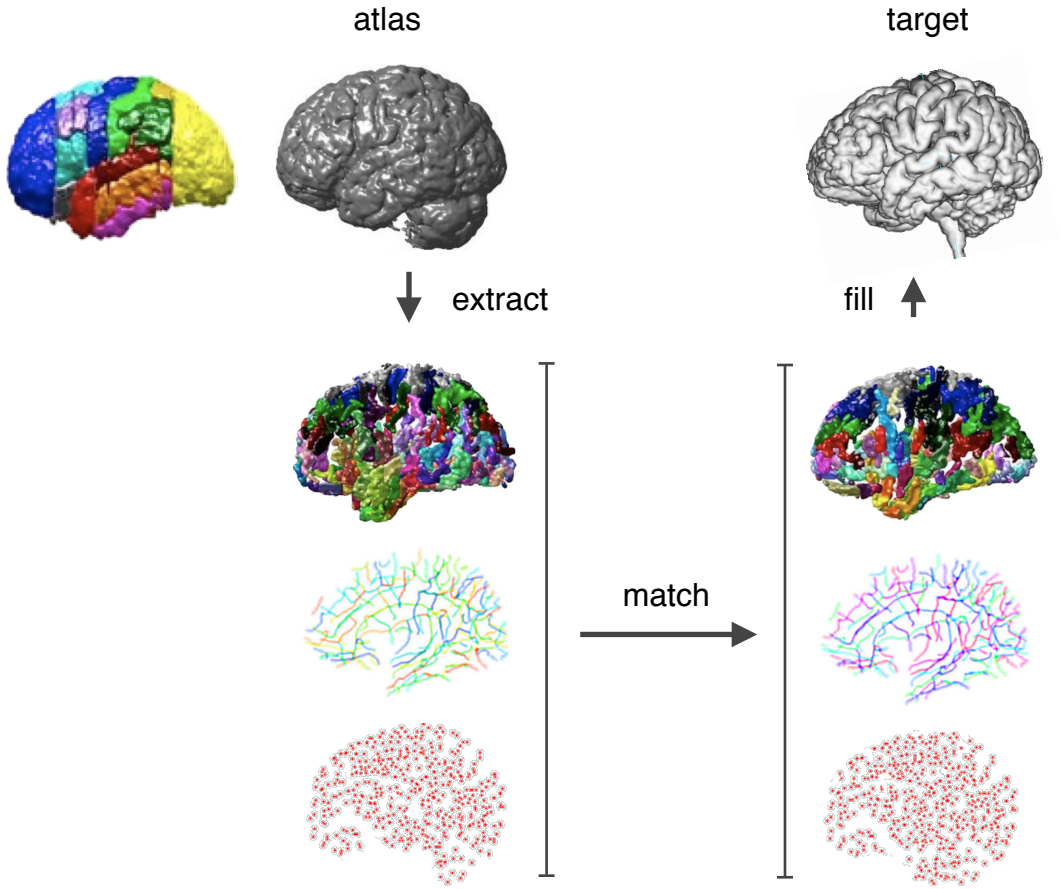
fMRI

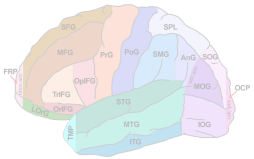


dMRI

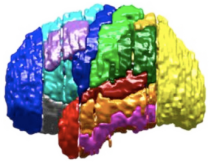
Mindboggle

OR extract, match, and fill labels without registration!

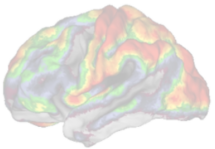




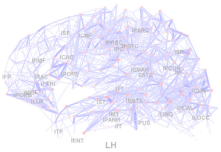
aMRI



atlas

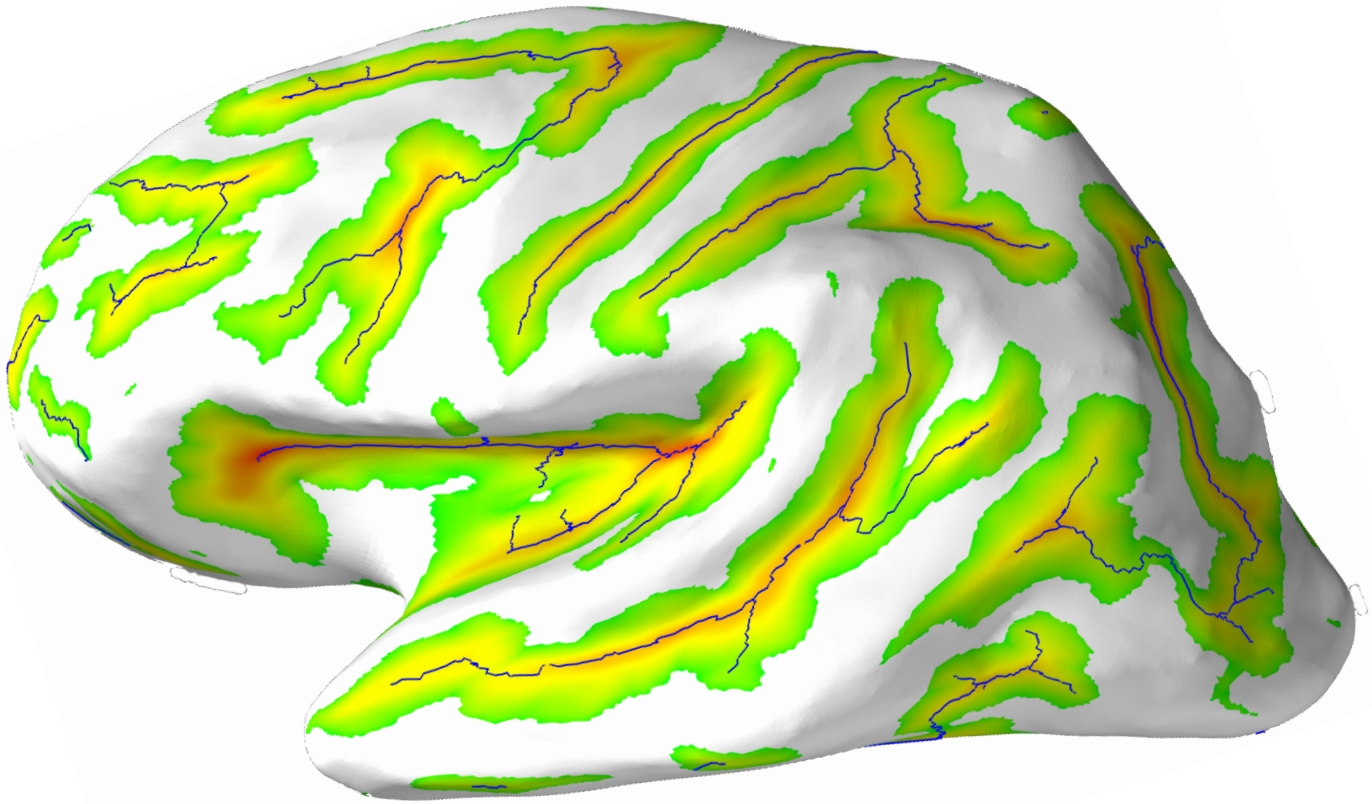


fMRI

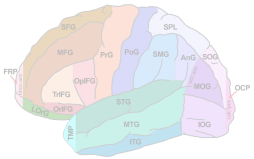


dMRI

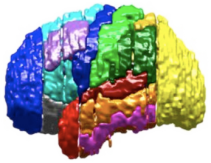
Mindboggle



Sulcal fundi



aMRI



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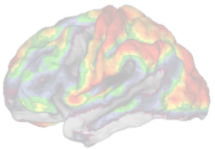

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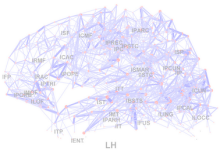
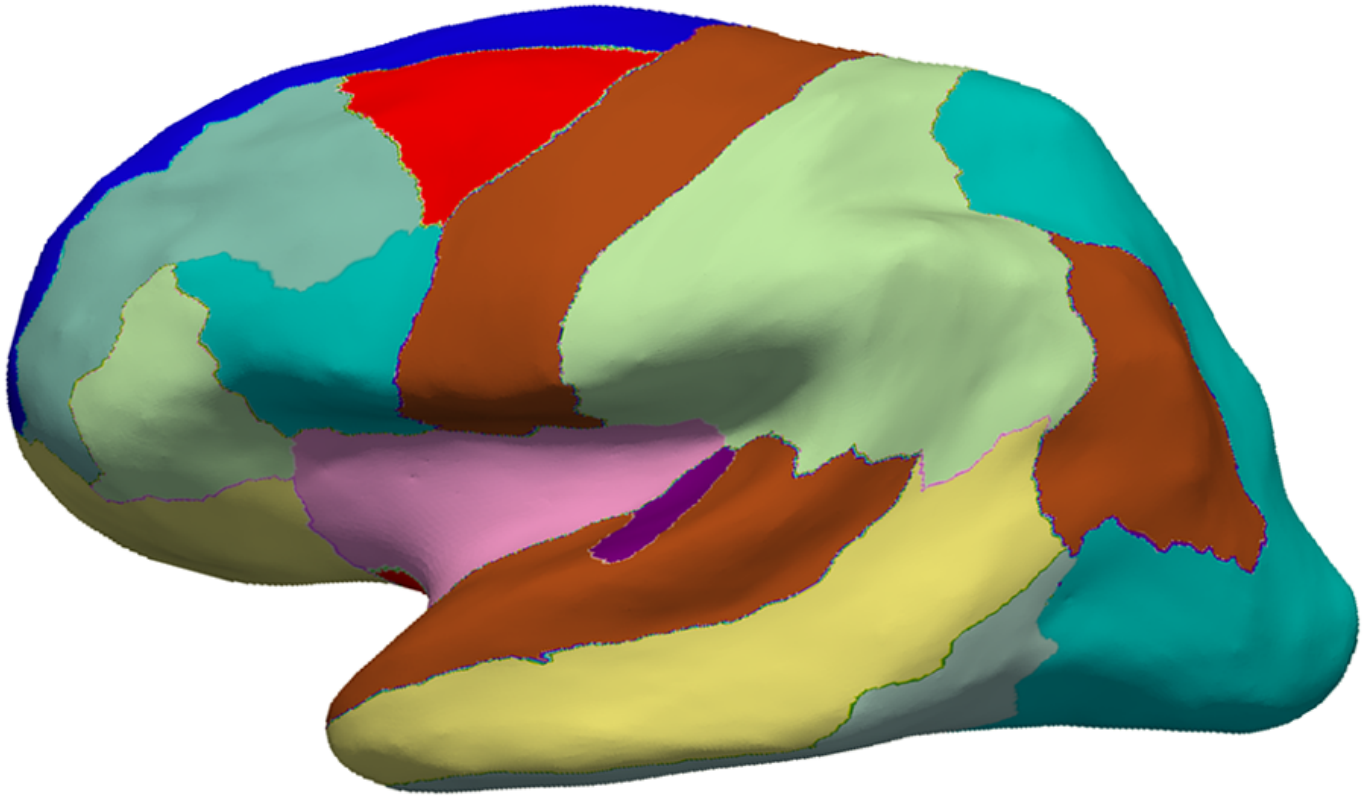
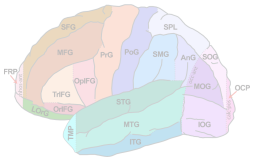


dMRI

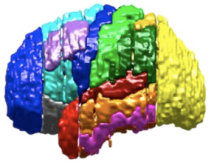
Mindboggle



Initial label propagation test: manual labels



aMRI



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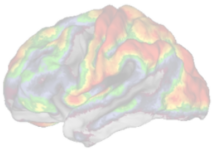
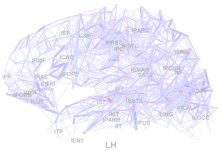
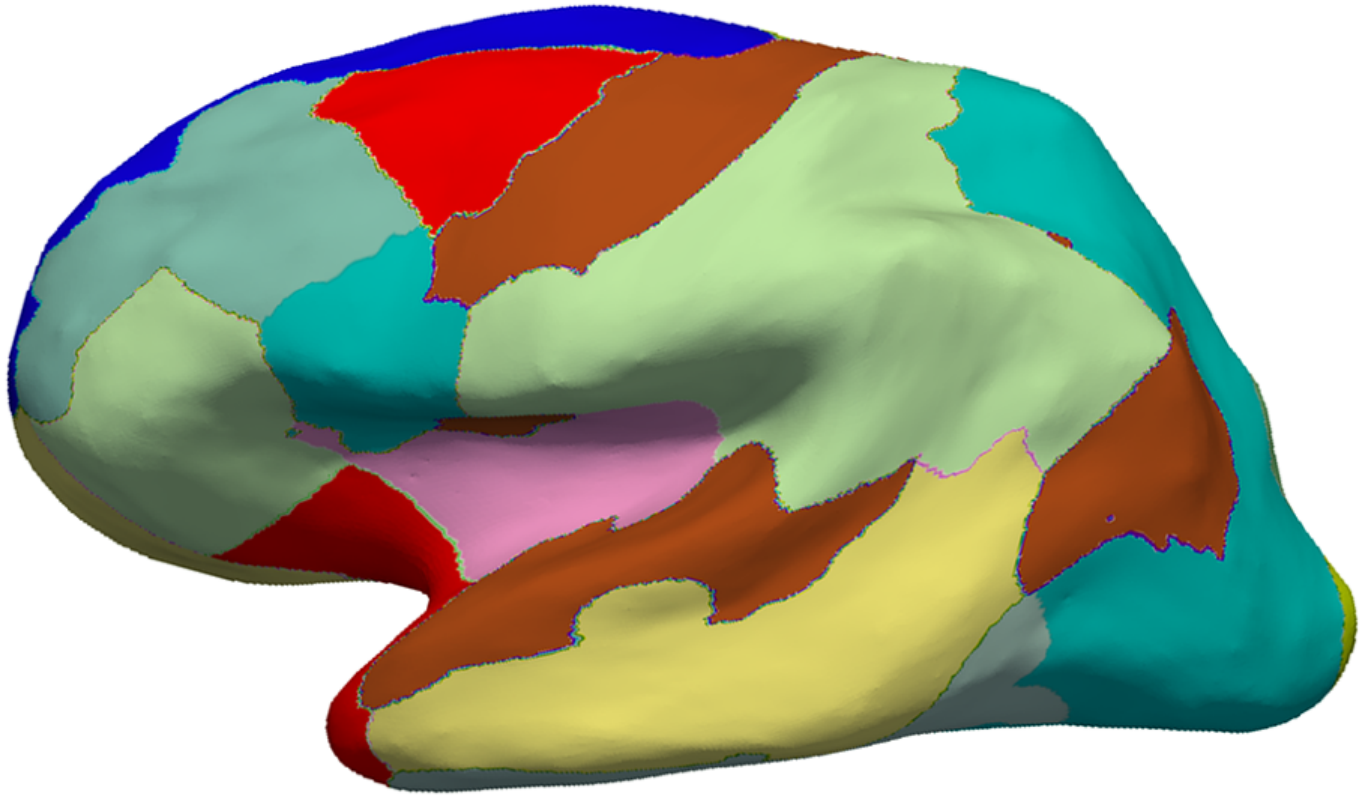


fMRI

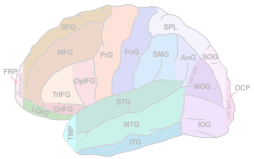


dMRI

Mindboggle



Initial label propagation test: results



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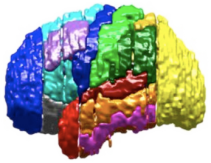

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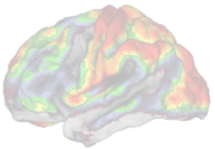
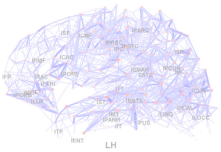
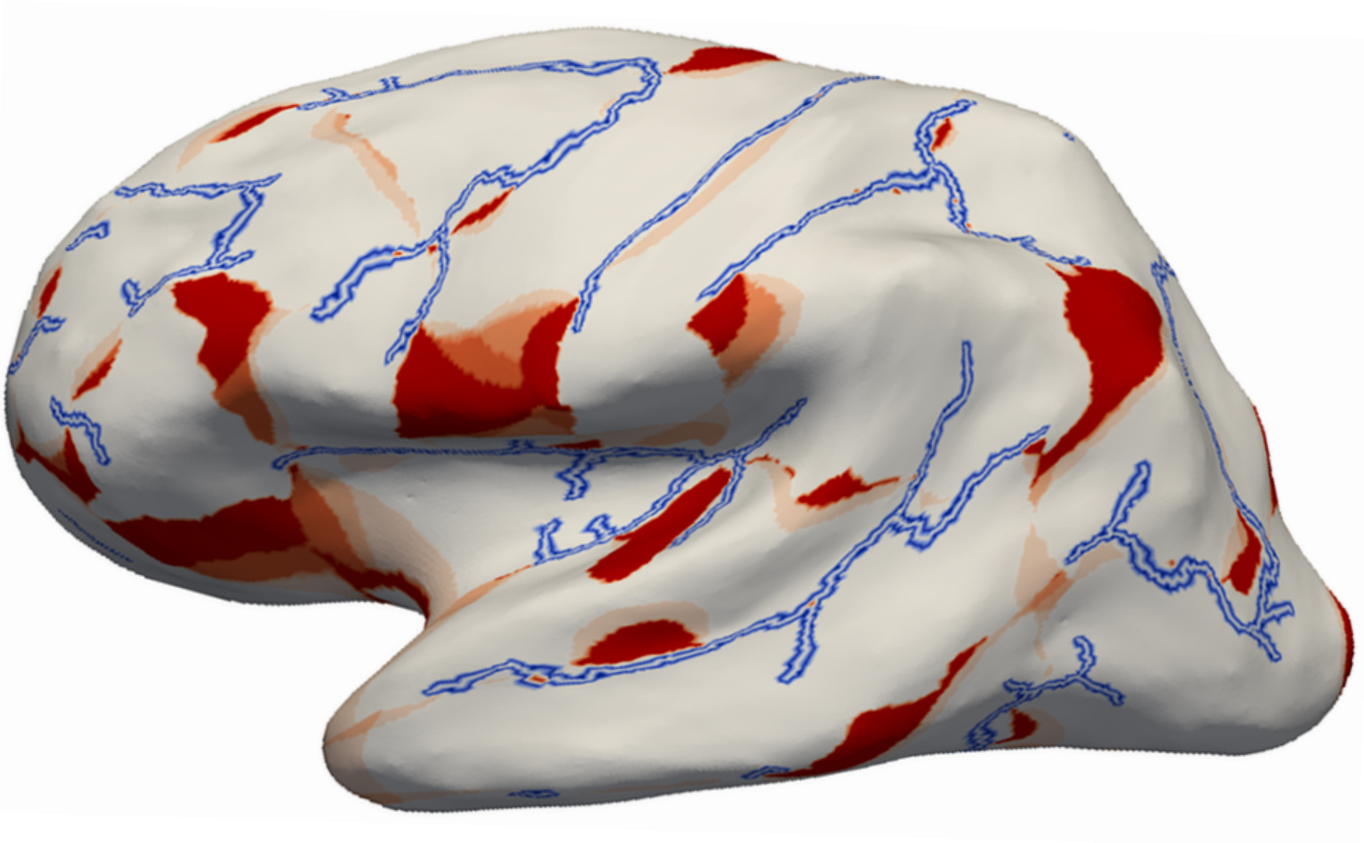


fMRI

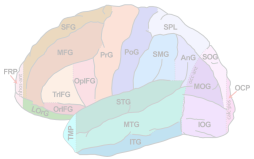


dMRI

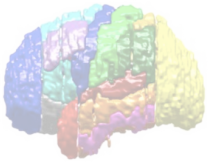
Mindboggle



Initial label propagation test: rank label errors



aMRI



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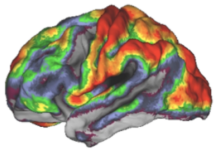
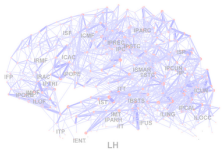
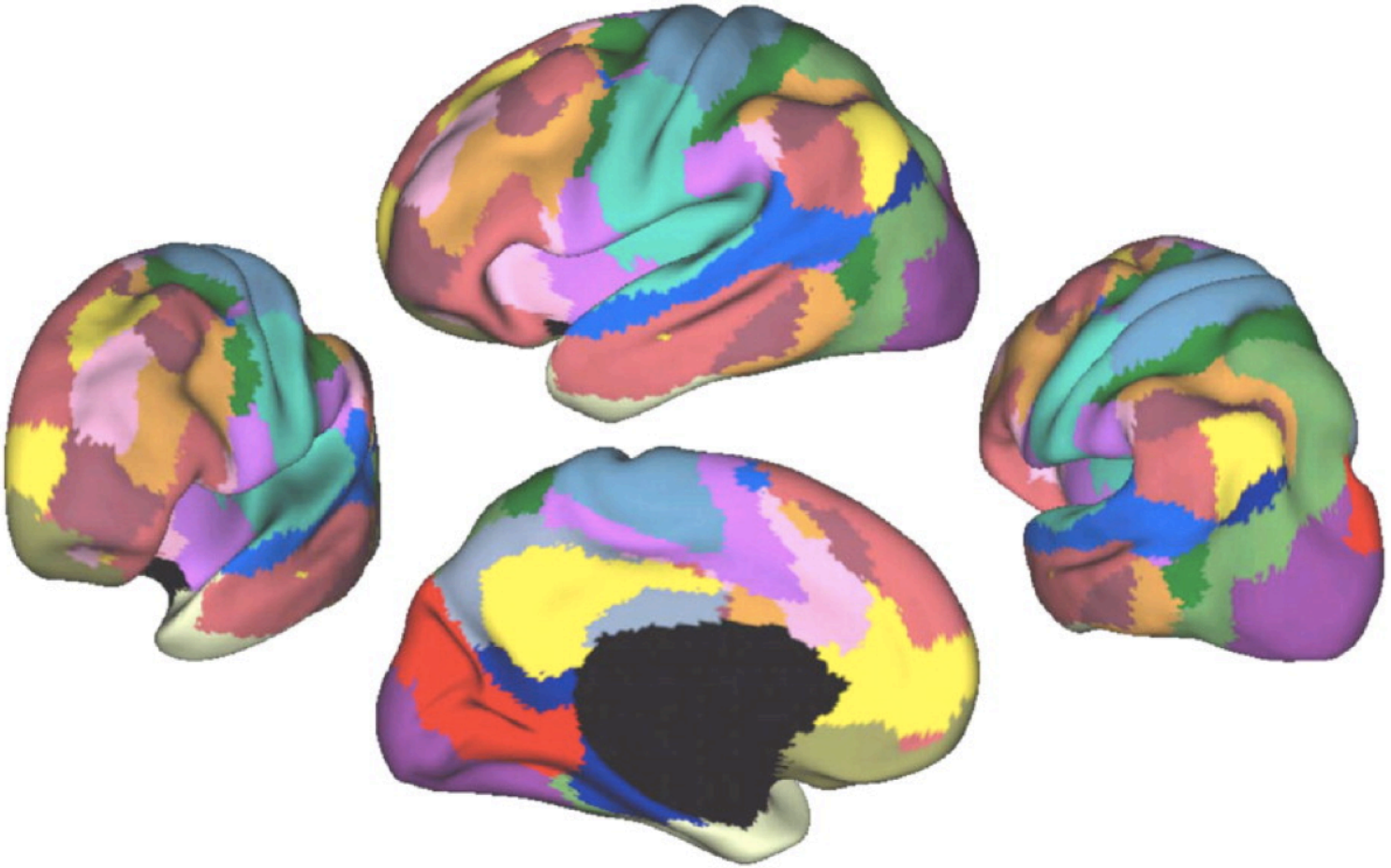


fMRI



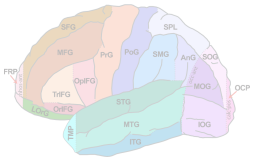
dMRI

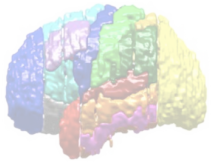
Mindboggle



fMRI “connectivity” clusters as features

Yeo, et al., JNeurophysiology, 2011


aMRI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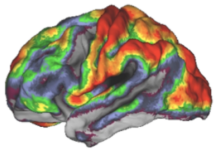
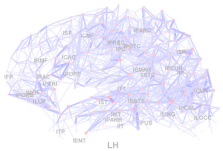
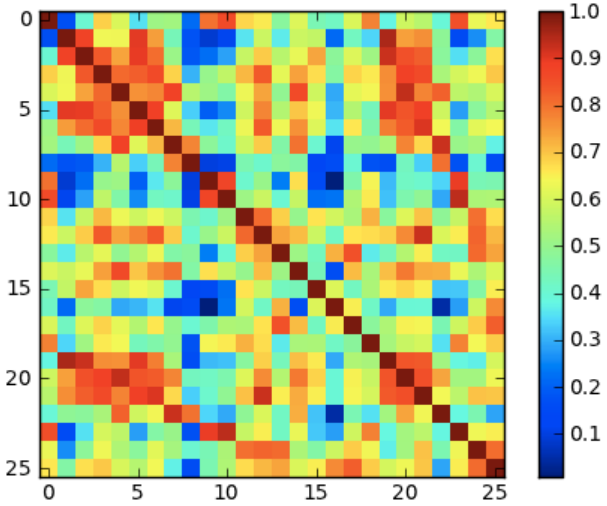
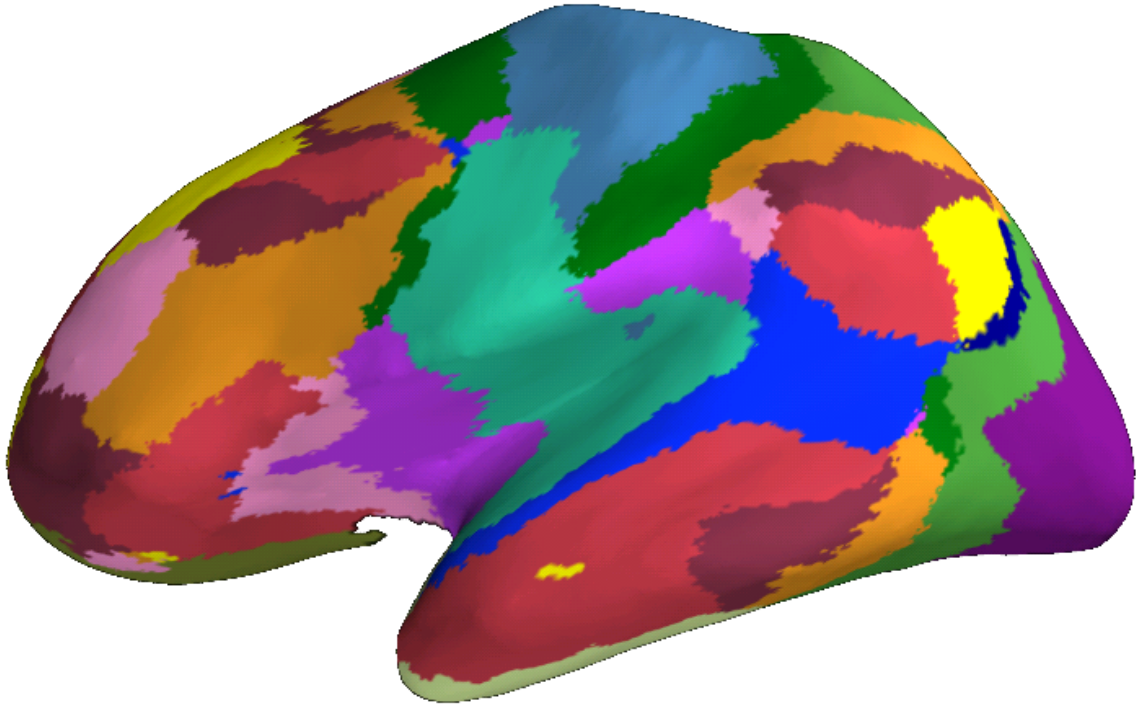

fMRI

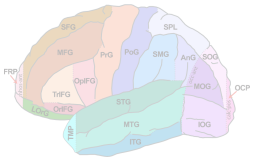

dMRI

Mindboggle

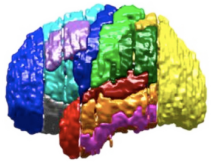




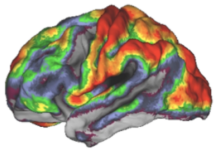
fMRI-connected fMRI features: ADHD



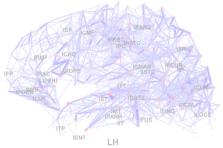
aMRI



atlas

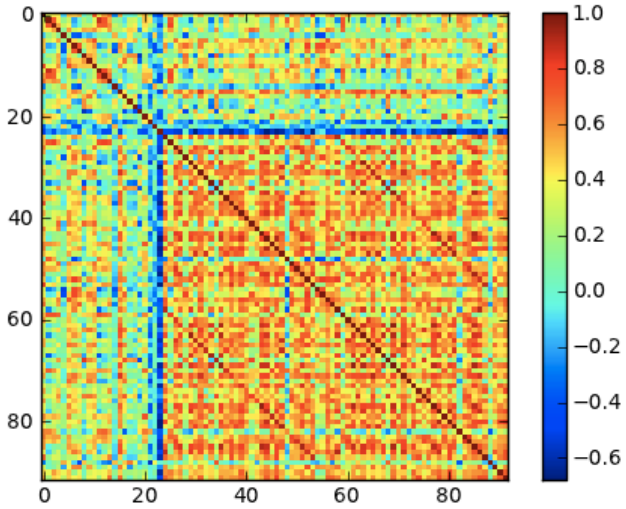


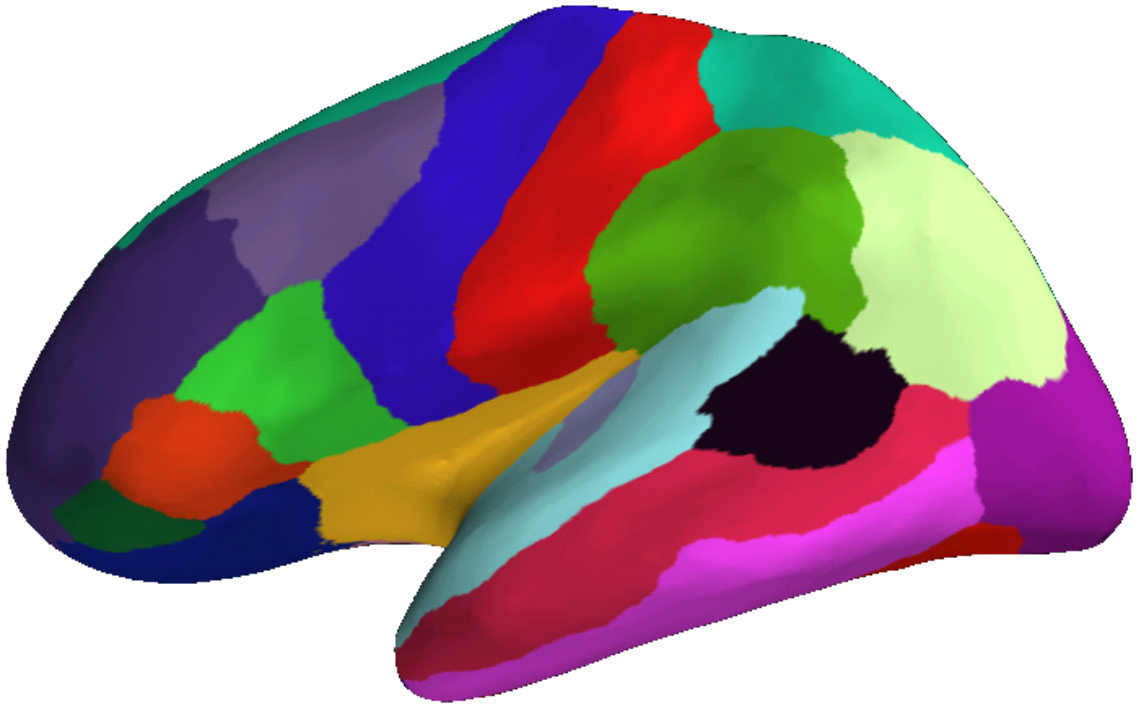
fMRI



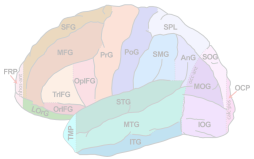
dMRI

Mindboggle

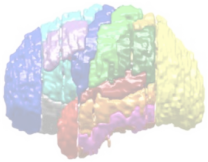




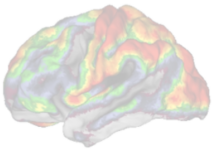
fMRI-connected aMRI features: ADHD



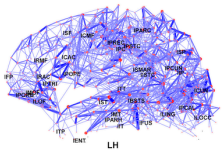
aMRI



atlas

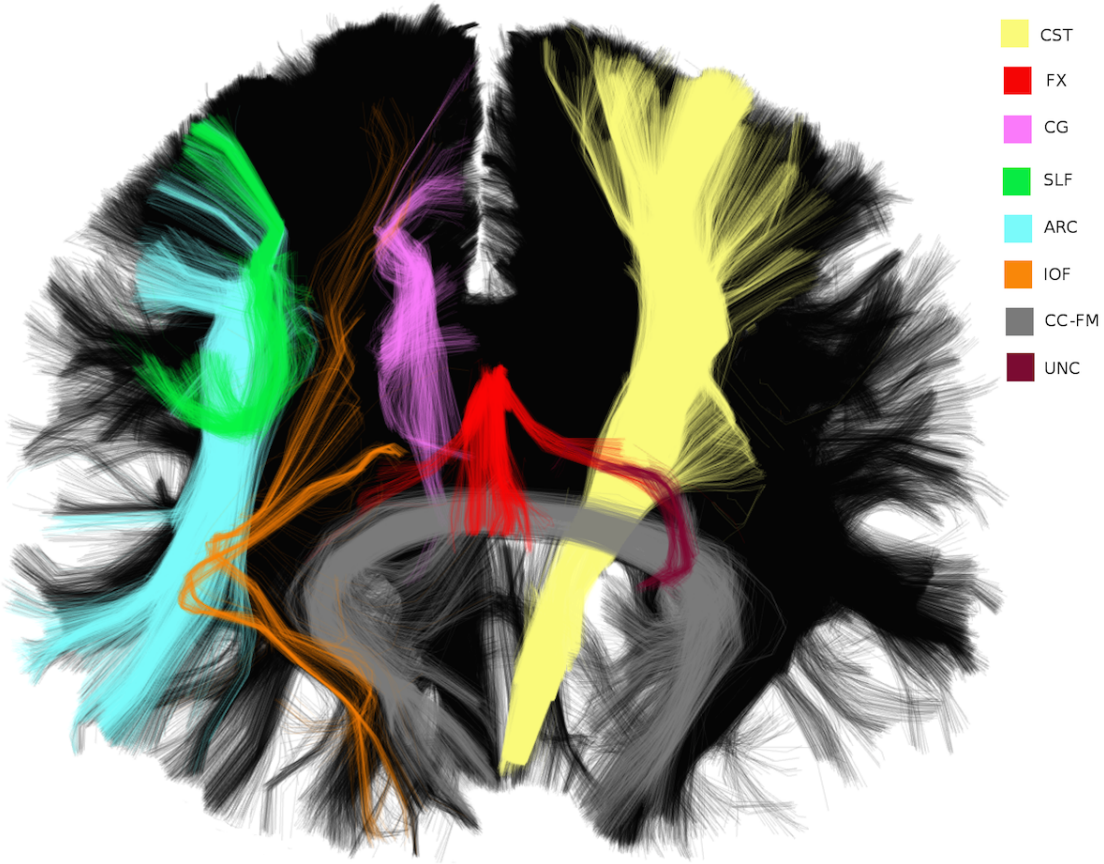


fMRI

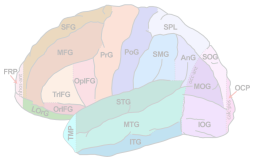


dMRI

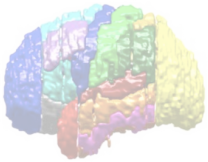
Mindboggle



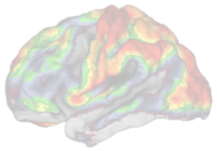
dMRI tract clusters as features



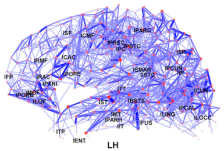
aMRI



atlas

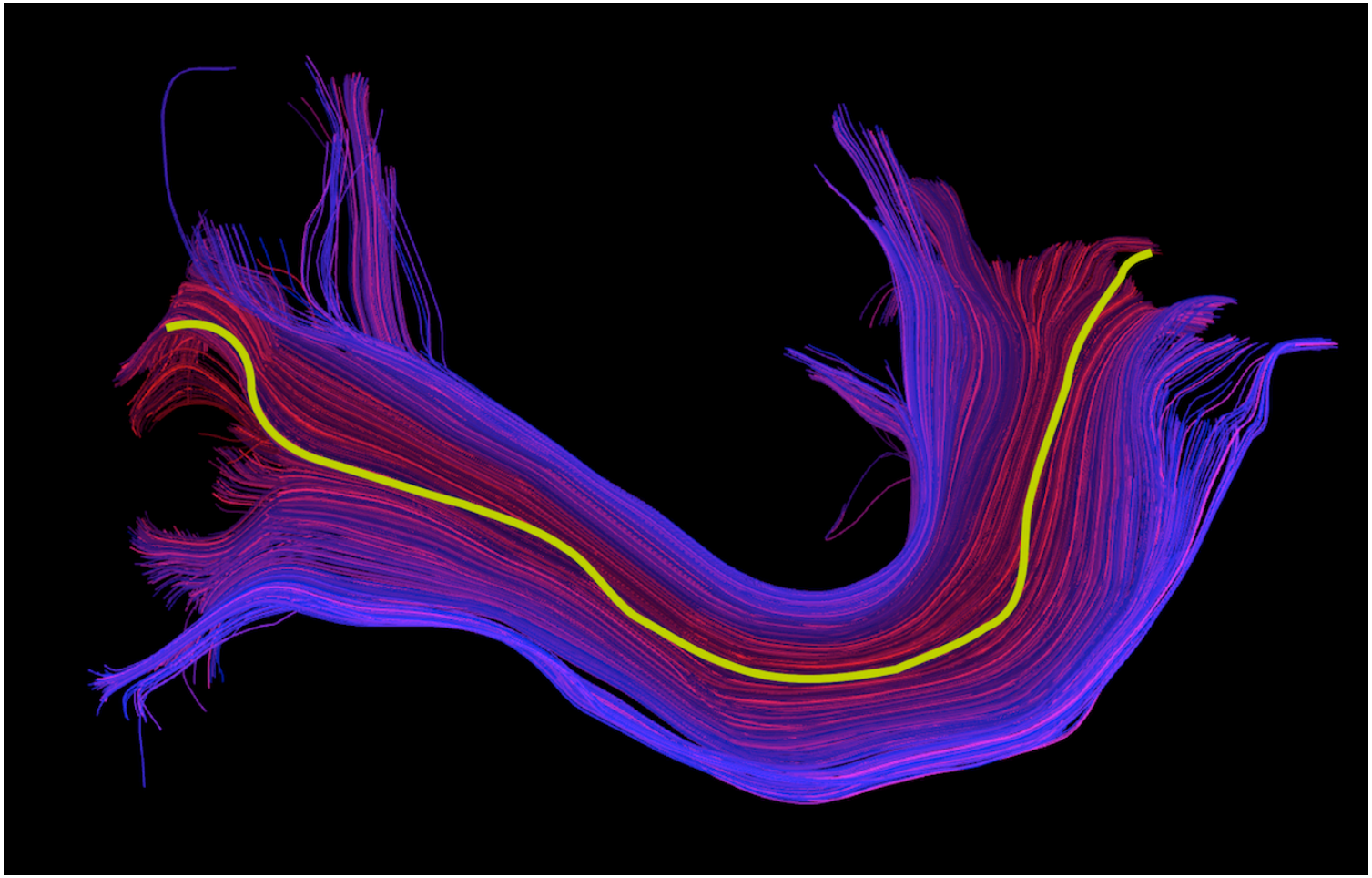


fMRI

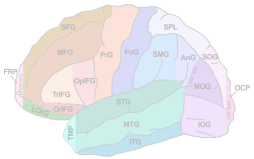


dMRI

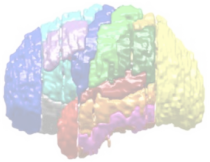
Mindboggle



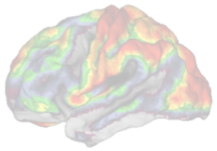
dMRI tract clusters as features



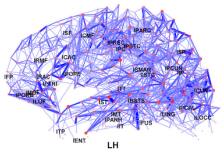
aMRI



atlas

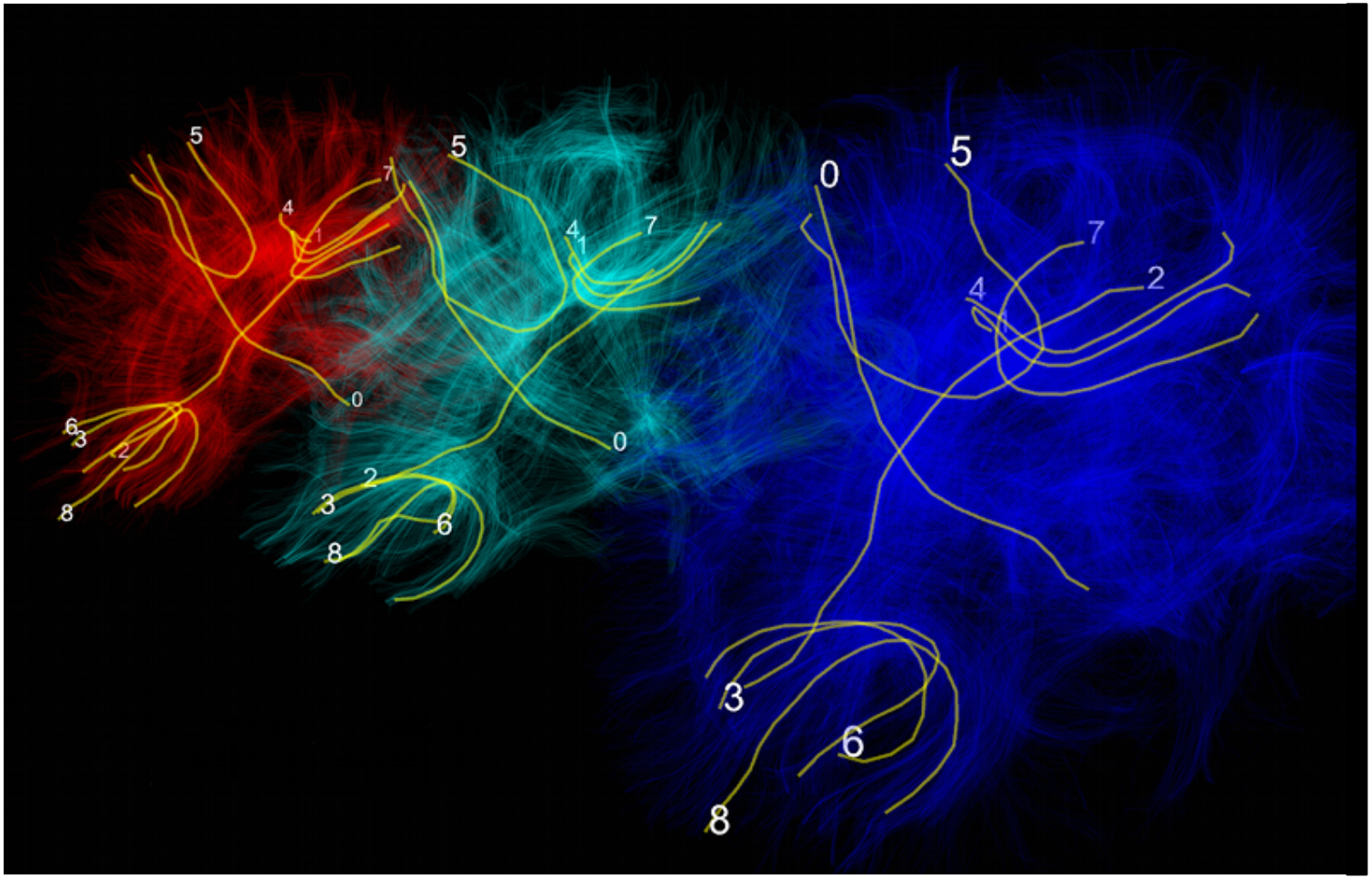


fMRI

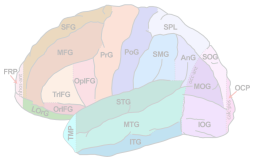


dMRI

Mindboggle



dMRI tract clusters as features



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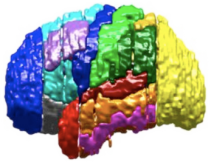

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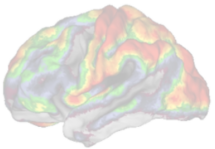

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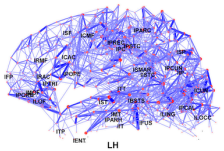
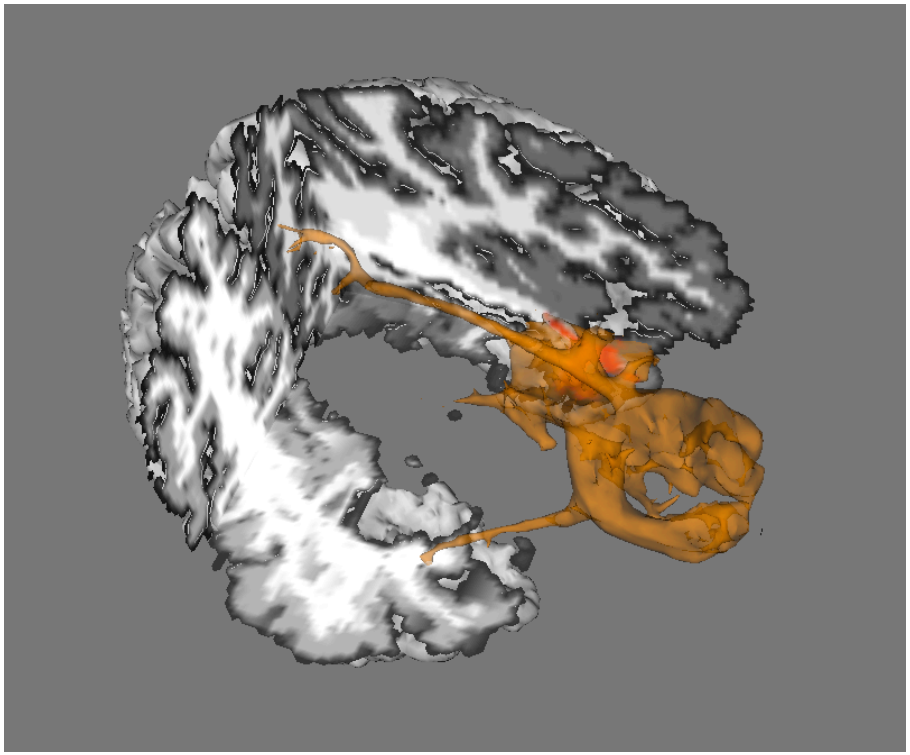
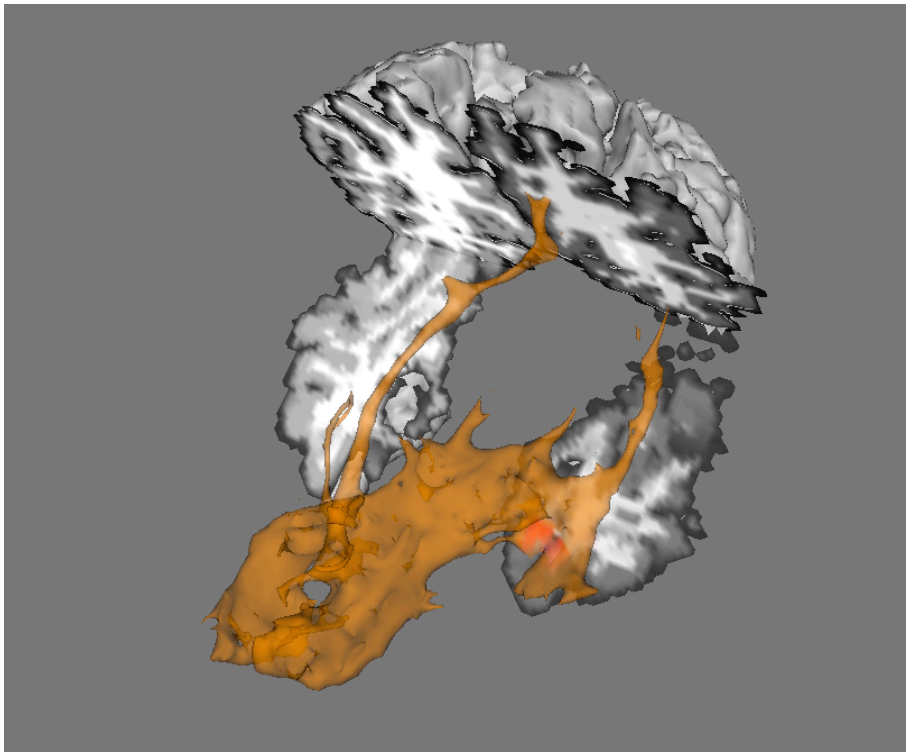


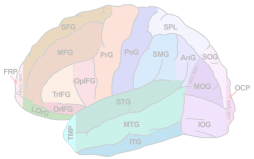
dMRI

Mindboggle

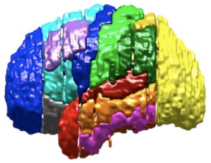




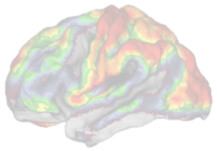
dMRI-connected aMRI features



aMRI



atlas



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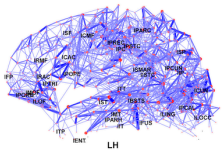
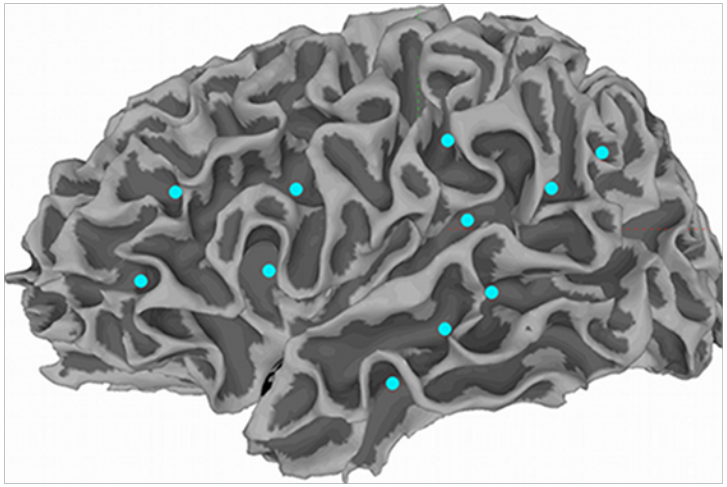
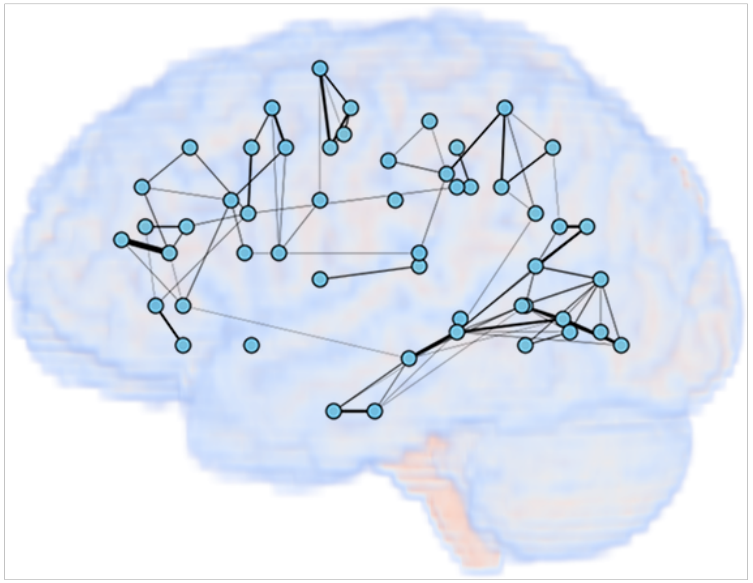


dMRI

Mindboggle

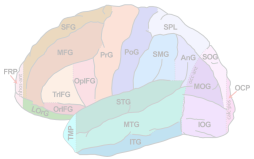


A gray/white matter surface (left lateral view) with visible sulcal pits highlighted (cyan circles). These features go by different names (sulcal roots, buried or annectant gyrii, plis de passage) and may be well conserved structures formed early in development.

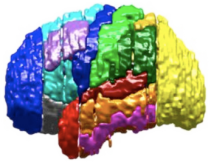


DTI connectivity graph (same subject). Vertices represent all extracted sulcal pits and each edge width indicates a connection probability greater than 0.01 between two vertices (and does not follow a tractography path).

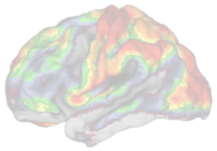
dMRI-connected aMRI features



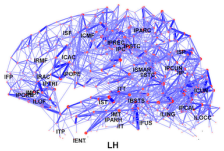
aMRI



atlas

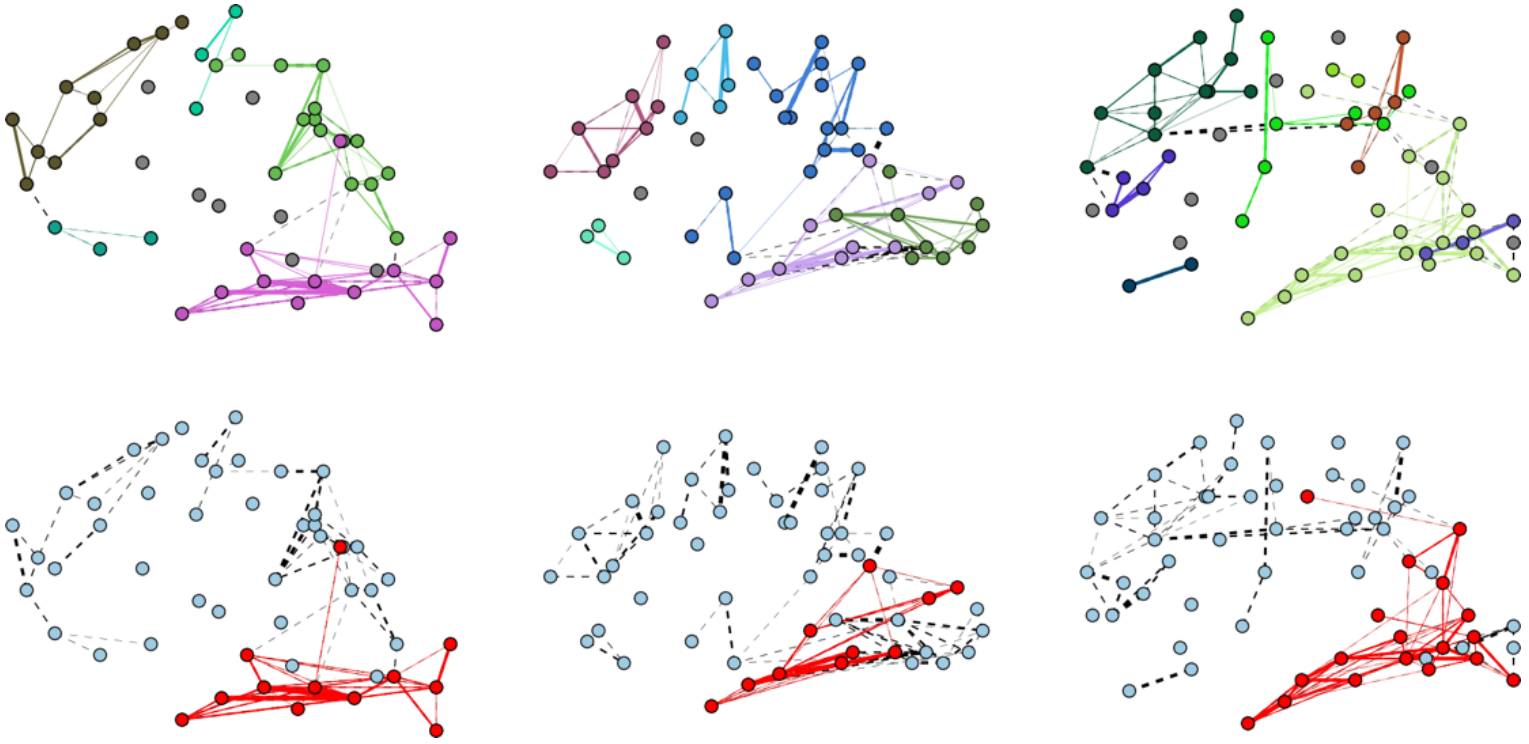


fMRI



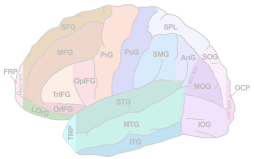
dMRI

Mindboggle

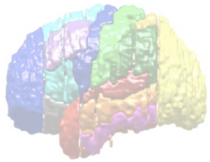


Early attempt at subgraph extraction (upper row) and matching (lower row).
These graphs were constructed from (left to right) a remitter, non-remitter, and control subject.
The subgraphs in red in the lower row have the highest small-worldness ratio.

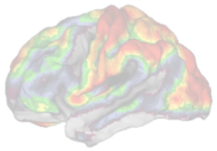
dMRI-connected aMRI features



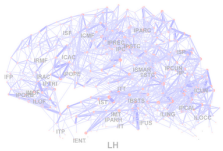
aMRI



atlas

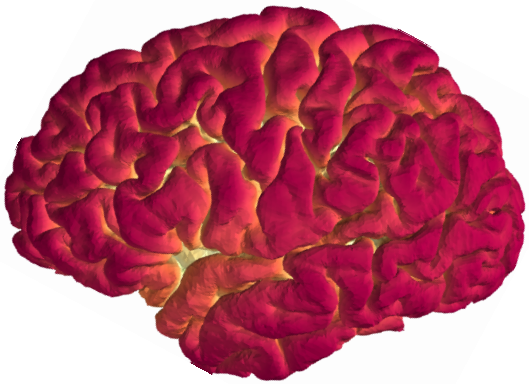


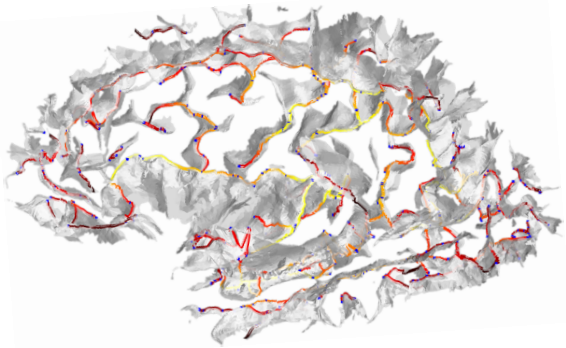
fMRI

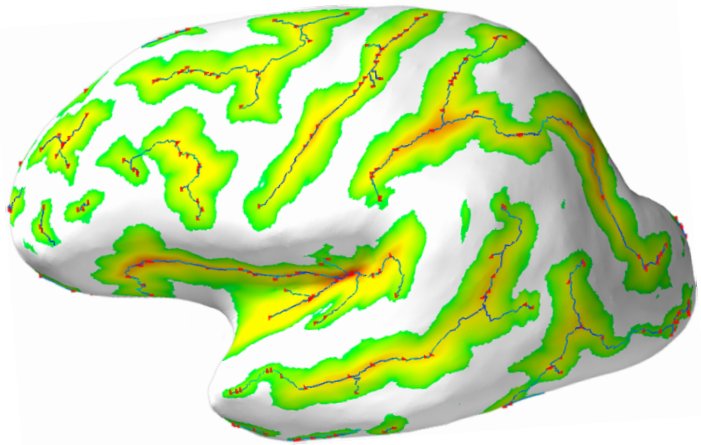


dMRI

Mindboggle







Clinical application: Prediction of treatment response based on feature shapes

Mindboggle team

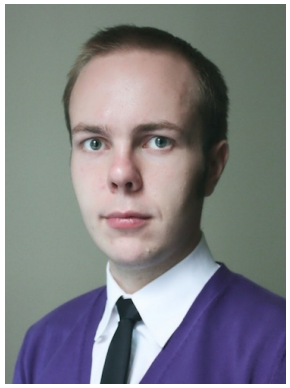
Depth map

Joachim Giard
Univ. Catholique de Louvain, Belgium

Nested features

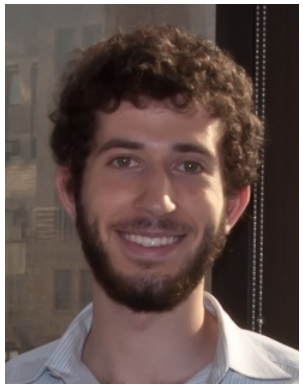
Forrest Bao
Texas Tech

Probabilistic features



Yrjö Häme
Columbia PhD student

Shape analysis & label propagation



Eliezer Stavsky
Columbia PhD student

Anatomical labeling

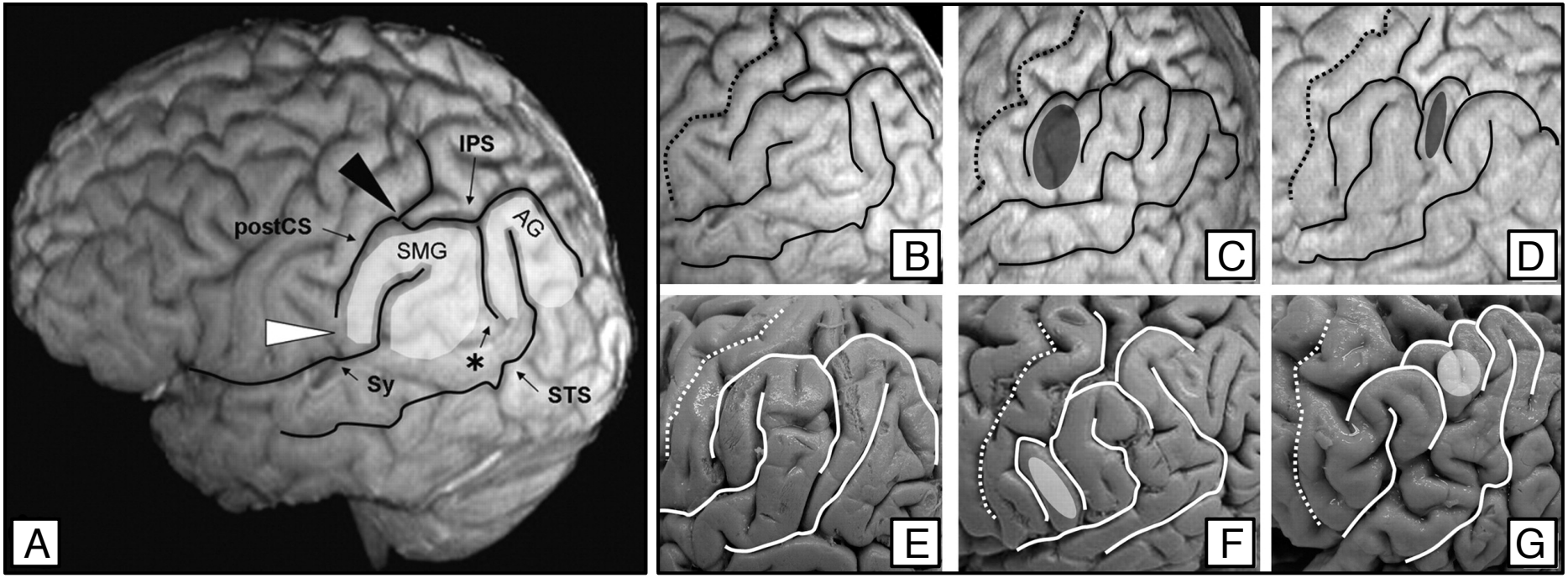
Jason Tourville
Boston U.

Early visualization

Noah Lee
former postdoc

Graph database

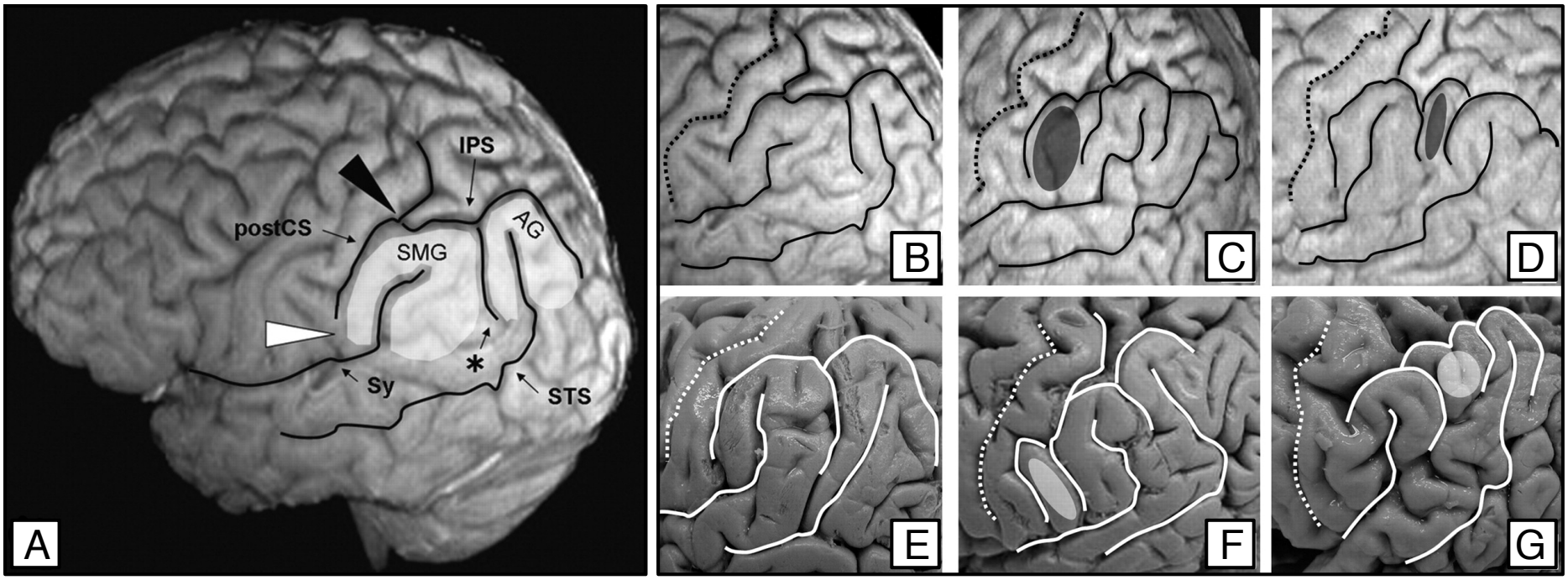
Nolan Nichols
Washington U.

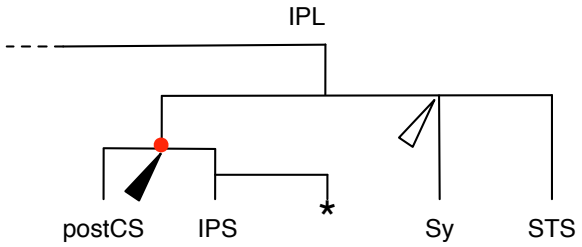


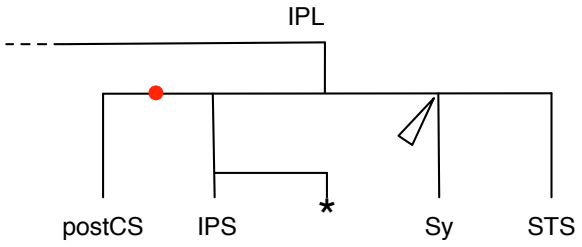
Example of natural morphological variability: left inferior parietal lobule (IPL; Kiriyama et al. 2009).
(A-D) are MRI data and (E-G) are post-mortem specimens.
(A) IPL is highlighted and folds are outlined.
(B,E) Typical folding pattern.
(C,F) PreSMG pattern: an additional gyrus (ellipse) lies between postCS and SMG.
(D,G) PreAG pattern: an additional gyrus (ellipse) lies between SMG and AG.

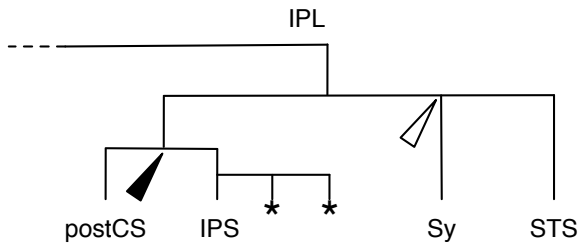
[SMG: supramarginal gyrus; AG: angular gyrus; postCS: postcentral sulcus; IPS: intraparietal sulcus;
Sy: Sylvian fissure, STS: superior temporal sulcus; *sulcus intermedius primus]

Characterize anatomical variability

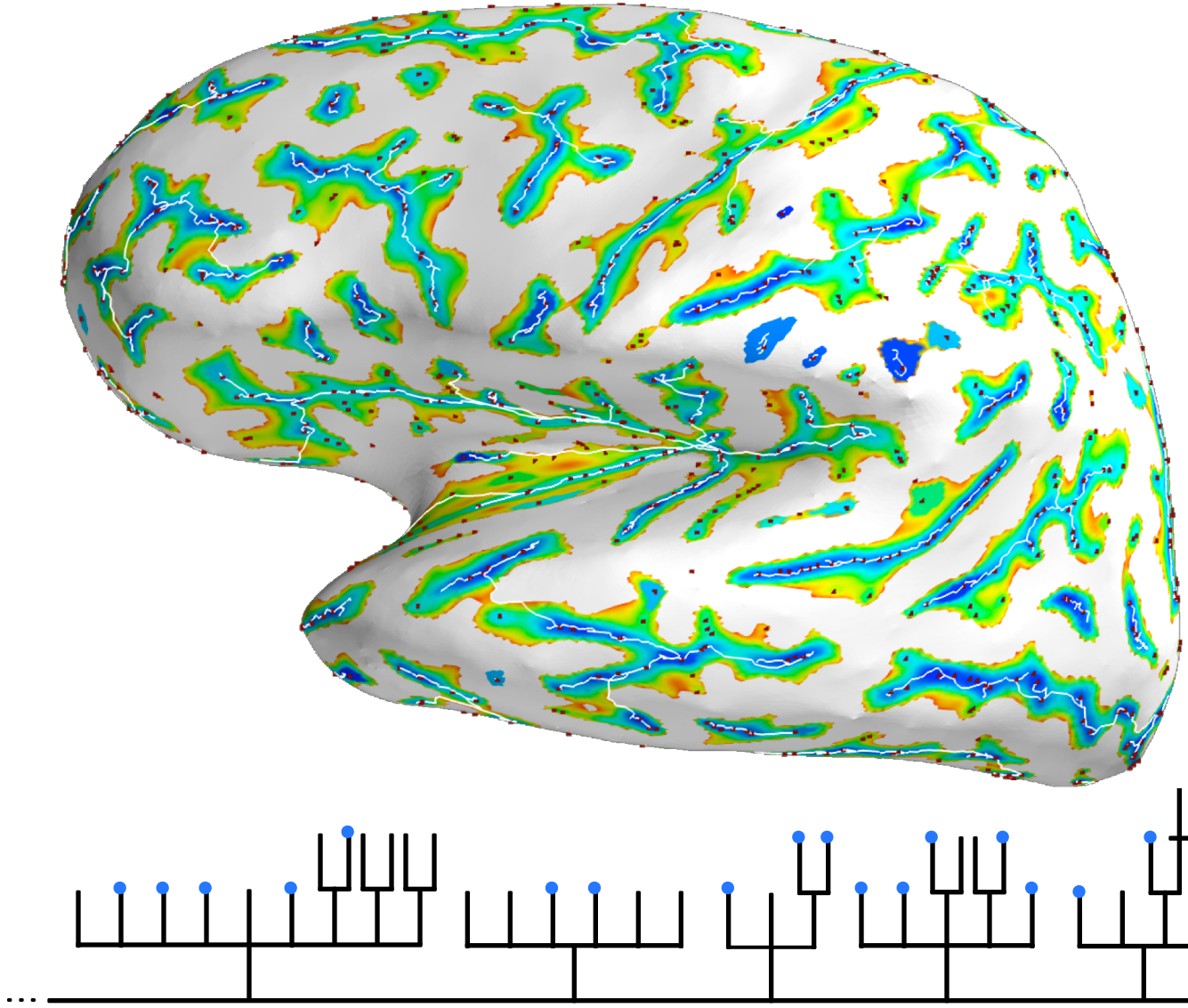




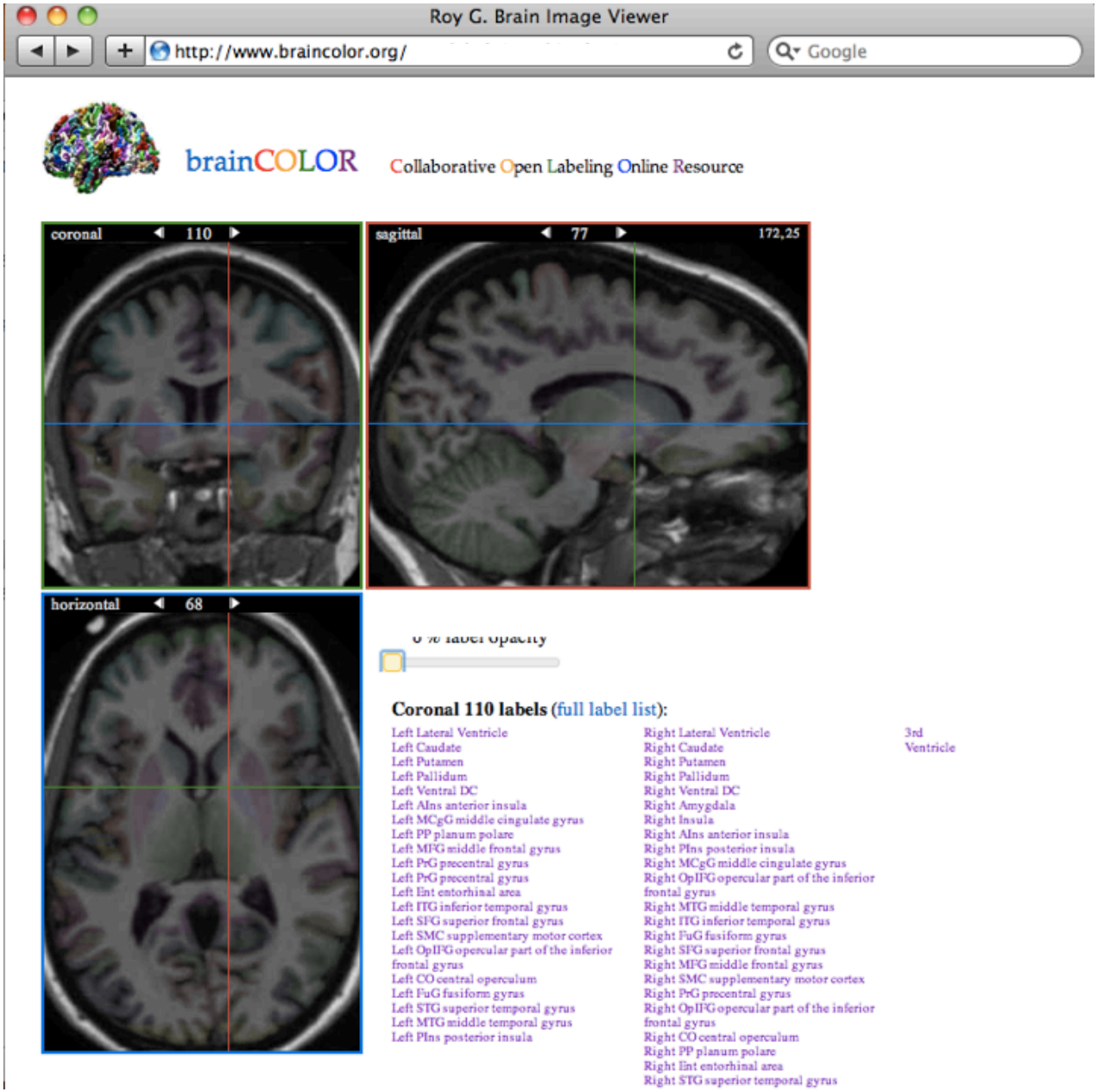




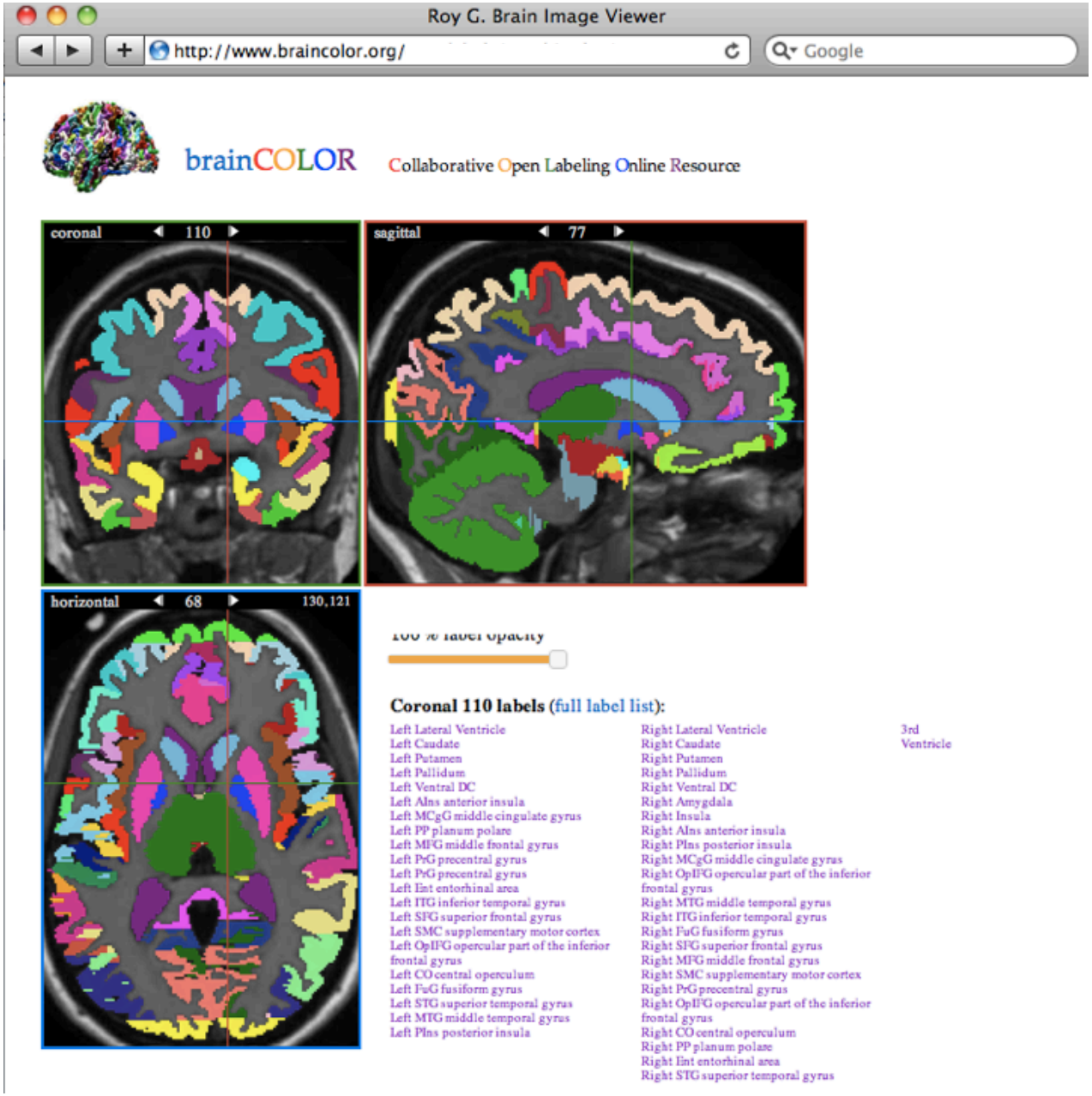
Convert one brain graph into another!



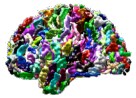
Identify nested structures in our data



Online brain image viewer



Online brain image viewer



An interactive tool for constructing optimal brain colormaps

Arno Klein — NY State Psych. Inst. Columbia University, NY
Andrew Worth — Neuromorphometrics, Inc., MA
Jason Tourville — Cognitive & Neural Systems Boston University, MA
Bennett Landman — Vanderbilt University Nashville, TN
Tito Dal Canton — NY State Psych. Inst. Columbia University, NY
Satrajit S. Ghosh — Research Laboratory of Electronics, MIT, MA
David Shattuck — Laboratory of NeuroImaging UCLA, CA

Goal

Create a software tool to aid in the construction of optimal colormaps for viewing and labeling brain anatomical images.

Background

The application of color is an indispensible means of visually distinguishing anatomical regions of the brain [1,2]. The need to facilitate visualization of brain images has become particularly urgent with the inception of large-scale anatomical labeling projects, such as the BrainCOLOR project, in which hundreds of MR images of the human brain are being manually labeled (www.braincolor.org/protocols) as well as viewed online (www.braincolor.org/roygbiv).

Choosing a color space

Our colormap must consist of colors that are perceptually distinct, so it is reasonable to choose a color space that is perceptually uniform, where a separation between two colors in the color space is as discriminable as the same separation between two other colors in the color space.
The International Commission on Illumination (CIE) devised a color space in 1931 that facilitates color description (Fig.1). Subsequent improvements led to the CIELAB and CIELUV color spaces, as well as a cylindrical variant, CIELch, all of which attempt to be perceptually uniform.

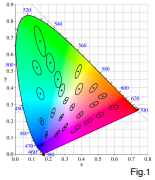


Fig.1

Constructing a colormap

We uniformly sampled hues from the CIELch cylinder (Fig.2) at different distances from the center (70-100% chrominance) and at different lightness values. The resulting colormap (Fig.3) has the same number of colors as regions we wish to color (49 cortical regions in the BrainCOLOR protocol). We intend to expand the number of colors to include subcortical and other regions.

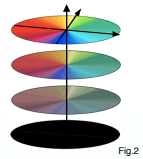


Fig.2

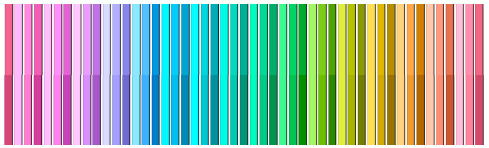


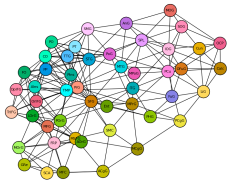
Fig.3

1. Schott GD (2010) Colored illustrations of the brain: some conceptual and contextual issues. Neuroscientist. 16(5):508-18.
2. Schoonover, C (2010) Portraits of the Mind: Visualizing the Brain from Antiquity to the 21st Century. Abrams (ISBN-13: 978-0810990334)

CIE1931 figure: http://en.wikipedia.org/wiki/File:CIExy1931_MacAdam.png
CIELch figure: http://www.colorbasics.com/ColorSpace/

Maximizing discriminability of adjacent regions

To easily distinguish brain regions from each other, we wish to maximize the color difference between adjacent regions. We do this by constructing a graph that represents connections (edges) between regions (nodes).



We define an *optimal mapping* of colors as the combination of colors assigned to nodes with the maximum sum of color differences between connected nodes, defined by the CIE2000 Delta E measure (http://en.wikipedia.org/wiki/Color_difference).
However, we cannot compute 8.8×10^{18} permutations of the 49 colors in the colormap, so we break up the brain into sublobes and compute the permutations of portions of the colormap at a time:

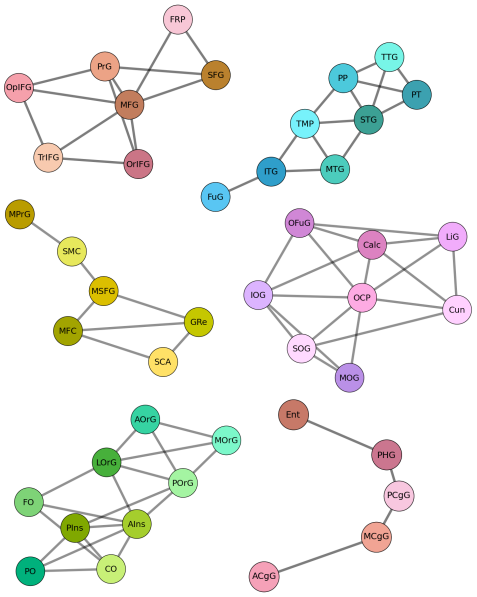
Frontal Lobe (7,6,9):
- Lateral Surface (7)
- Medial Surface (6)
- Inferior Surface (4)
- Opercular Region (3)
- Insular Region (2)

Temporal Lobe (8):
- Lateral Surface (4)
- Supratemporal Surface (3)
- Inferior Surface (1)

Parietal lobe (6):
- Lateral Surface (4)
- Medial Surface (2)

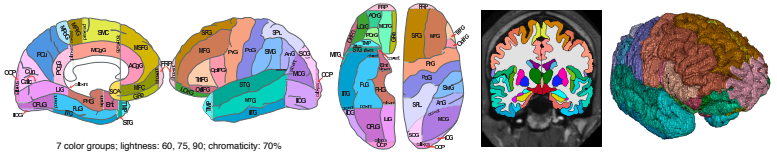
Occipital Lobe (8):
- Lateral Surface (4)
- Inferior Surface (1)
- Medial Surface (3)

Limbic Cortex (5):
- Cingulate Cortex (3)
- Medial Temporal Cortex (2)

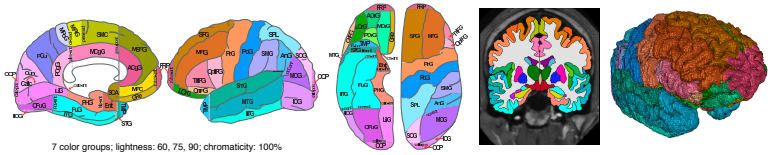


Grouping regions by using similar colors

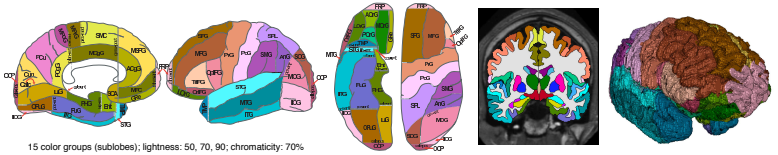
For labeling a brain image, maximum discriminability is paramount. For viewing a brain image, however, it is useful to visually group regions by assigning similar colors to the regions within a group. To create this visual grouping, we colored each subgraph with a neighborhood of colors (sampled within a wedge of the CIELch cylinder).



7 color groups; lightness: 60, 75, 90; chromaticity: 70%



7 color groups; lightness: 60, 75, 90; chromaticity: 100%



15 color groups (sublobes); lightness: 50, 70, 90; chromaticity: 70%

Conclusion and Future Work

We have created Python software for creating and applying colormaps to brain images.
Download the software from: http://binarybottle.github.com/brainCOLORmap
The software calls the Python libraries: *NumPy, NetworkX, Python-Colormath, Matplotlib, and xlrd,* to:

1. convert a table of adjacent regions (an adjacency matrix) to a weighted graph of colored nodes
2. compute permutations of colors for each subgraph to optimally distinguish colors of adjacent regions
3. apply similar colors to predefined groups of regions

There are many improvements we could pursue. We have targeted the following for future work:

- Develop an optimization algorithm for whole graphs or larger subgraphs.
- Restrict the color space to colors that can be displayed; currently, the CIELch colors that should appear different from one another may appear similar after conversion to SRGB colors.
- Seed color values to better control the range of colors for each group of regions.
- Accommodate visual concerns such as color blindness by adapting the colormap accordingly.

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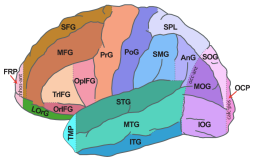
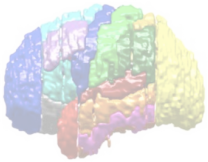
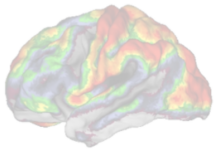
Optimal brain colormaps



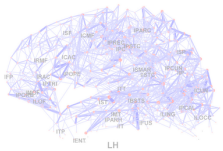
aMRI



atlas

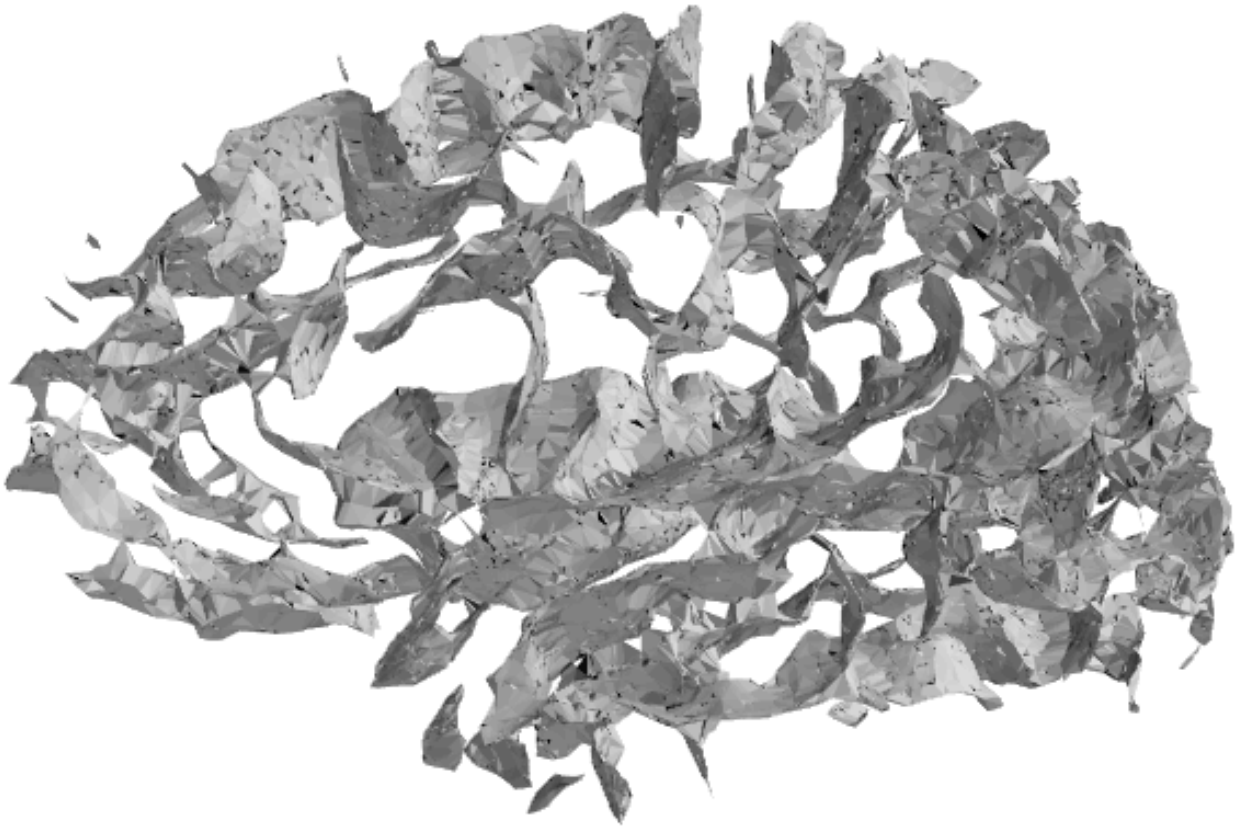


fMRI

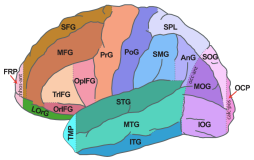


dMRI

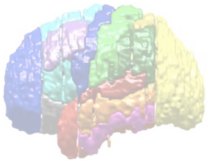
Mindboggle



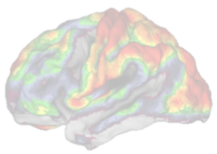
Medial surfaces of folds



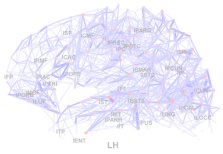
aMRI



atlas

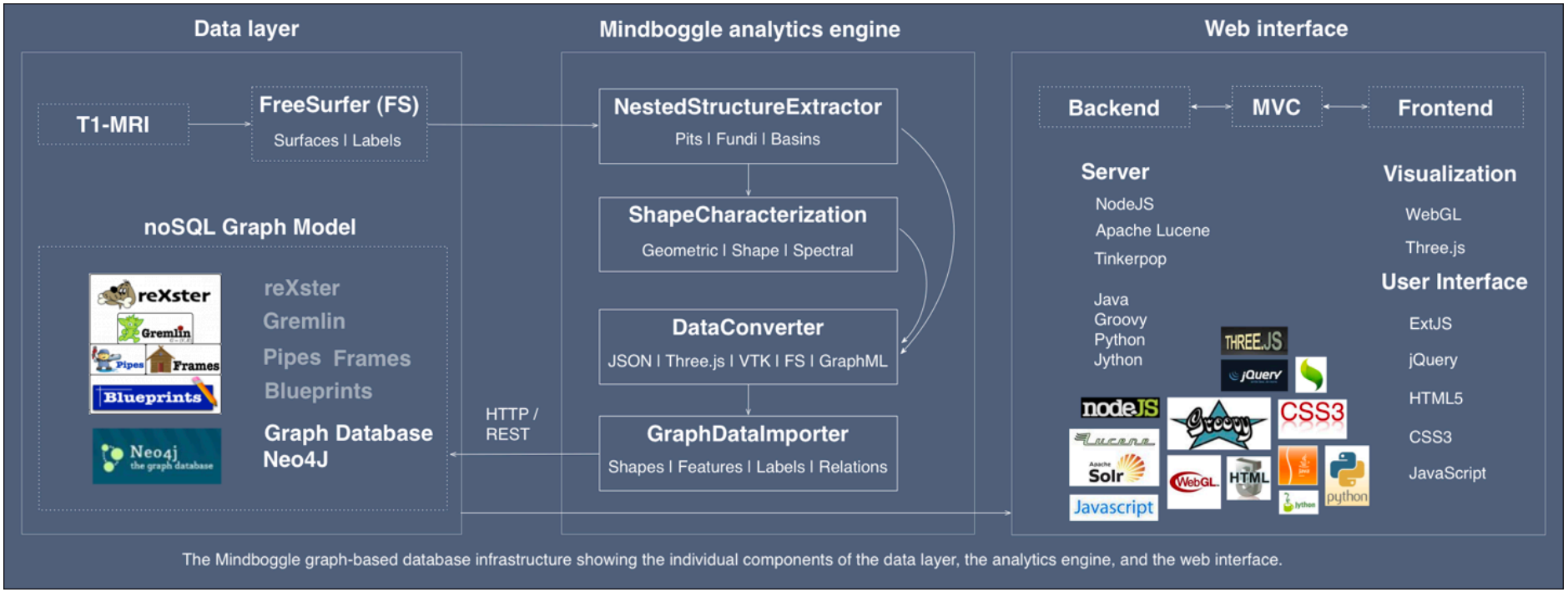


fMRI



dMRI

Mindboggle



The Mindboggle graph-based database infrastructure showing the individual components of the data layer, the analytics engine, and the web interface.

The graph model can be queried via REST, Cypher, reXster, or Gremlin. This example shows how to query all outgoing relations from basin 88:

Gremlin query:

```
{
"script": "g.v(88).outE"
}
```

JSON response:


```
[{
  "start" : "http://192.168.23.219:7474/db/data/node/88",
  "data" : {
  },
  "type" : "IS SIMILAR",
  "extensions" : {
  },
  "end" : "http://192.168.23.219:7474/db/data/node/89"
}, {
  "start" : "http://192.168.23.219:7474/db/data/node/88",
  "data" : {
  },
   "type" : "HAS LABEL",
  "extensions" : {
  },
  "end" : "http://192.168.23.219:7474/db/data/node/60"
},
```


Graph-based database schematic

Within the larger context of biomedical informatics, human brain images present a vast amount of information and no clear guide on how to organize, query, and use this information. Labeling images and identifying features within the images are important for establishing correspondences across time, conditions, image types, and individuals. Shape analysis can be used to compare corresponding labeled regions and identified features. Together, labels, features, and shapes introduce interesting informatics challenges and opportunities. I will outline the Mindboggle software that we are developing to address these challenges (www.mindboggle.info).