

NeuroMaps – A Compact Fingerprint for Analyzing Brain Activity

Stefan Lengauer¹, Benedikt Kantz¹, Peter Waldert¹, Gaia Tussardi^{1,2},
and Nils Kohn³, and Tobias Schreck¹

1 – Institute of Visual Computing, Graz University of Technology, Austria

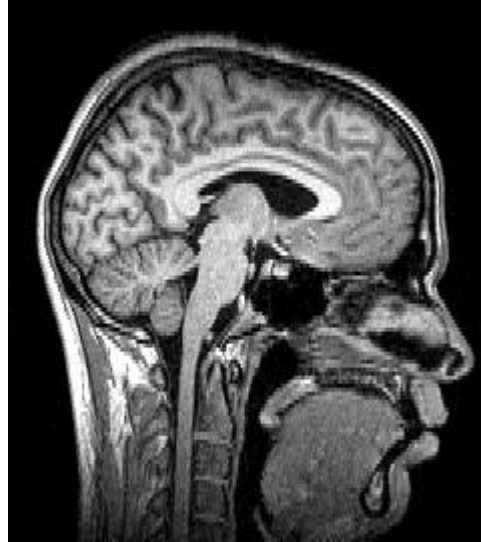
2 – Department of Information Engineering, University of Padova, Italy

3 – Donders Institute for Brain, Cognition and Behaviour, Radboud University
Medical Center, Netherlands

Challenges of Neuroimaging

Neuroimaging := use of quantitative techniques to study the structure and function of the brain.

- Brain-imaging techniques: CT, PET, MRI/fMRI, DOI, MEG, etc.



Sagittal brain MRI

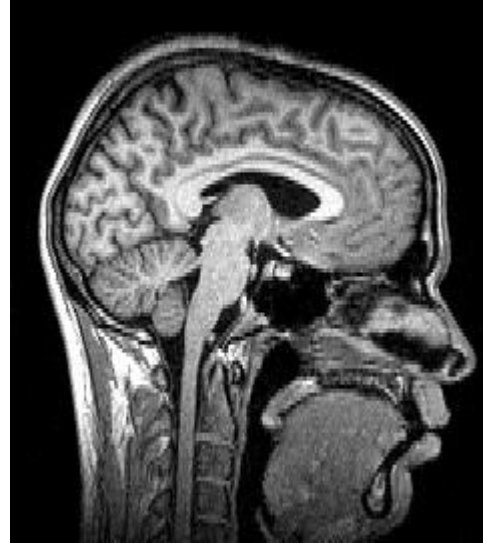
https://en.wikipedia.org/wiki/File:Sagittal_brain_MRI.jpg

^[1] Menon, Ravi S., and Bradley G. Goodyear. "Spatial and temporal resolution in fMRI." *Functional MRI: an introduction to methods* (2001): 145-158.

Challenges of Neuroimaging

Neuroimaging := use of quantitative techniques to study the structure and function of the brain.

- Brain-imaging techniques: CT, PET, MRI/fMRI, DOI, MEG, etc.
- fMRI: images showing neural activity
 - Changes based on blood flow
 - Stimuli/task-based
 - 2mm spatial resolution^[1]
 - → reveal brain regions associated with certain thoughts or actions



Sagittal brain MRI
https://en.wikipedia.org/wiki/File:Sagittal_brain_MRI.jpg



fMRI image showing blood-oxygenation-level changes
Fair use, <https://en.wikipedia.org/w/index.php?curid=3335842>

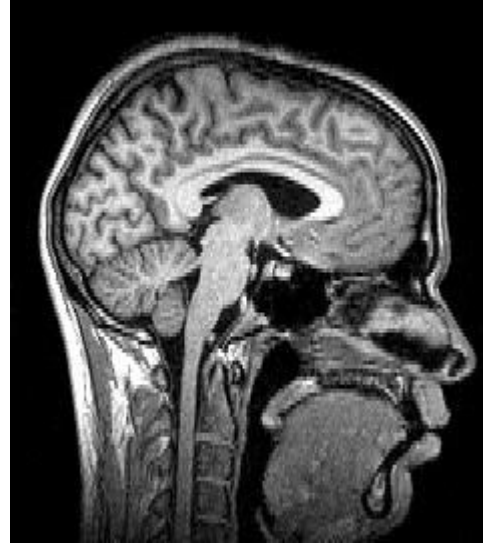
^[1] Menon, Ravi S., and Bradley G. Goodyear. "Spatial and temporal resolution in fMRI." *Functional MRI: an introduction to methods* (2001): 145-158.

Challenges of Neuroimaging

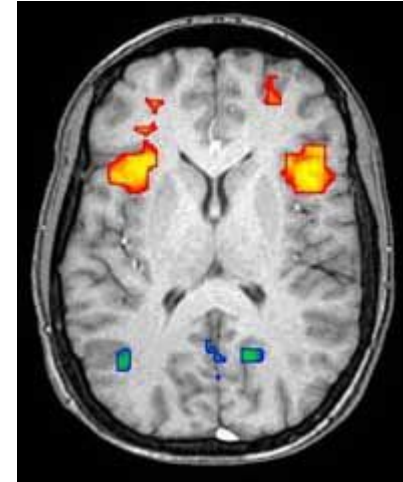
Neuroimaging := use of quantitative techniques to study the structure and function of the brain.

- Brain-imaging techniques: CT, PET, MRI/fMRI, DOI, MEG, etc.
- fMRI: images showing neural activity
 - Changes based on blood flow
 - Stimuli/task-based
 - 2mm spatial resolution^[1]
 - → reveal brain regions associated with certain thoughts or actions

Challenge: Efficient and holistic visualizations of activities.



Sagittal brain MRI
https://en.wikipedia.org/wiki/File:Sagittal_brain_MRI.jpg



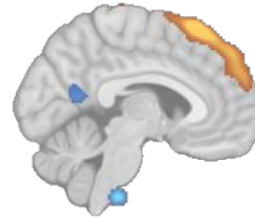
fMRI image showing blood-oxygenation-level changes
Fair use, <https://en.wikipedia.org/w/index.php?curid=3335842>

^[1] Menon, Ravi S., and Bradley G. Goodyear. "Spatial and temporal resolution in fMRI." *Functional MRI: an introduction to methods* (2001): 145-158.

State-of-the-art in fMRI Visualization

Established techniques

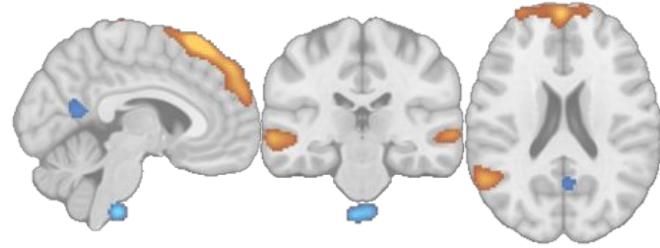
- Slices



State-of-the-art in fMRI Visualization

Established techniques

- Slices



Limits of standard visualizations

- Multiple views necessary
- Occlusion

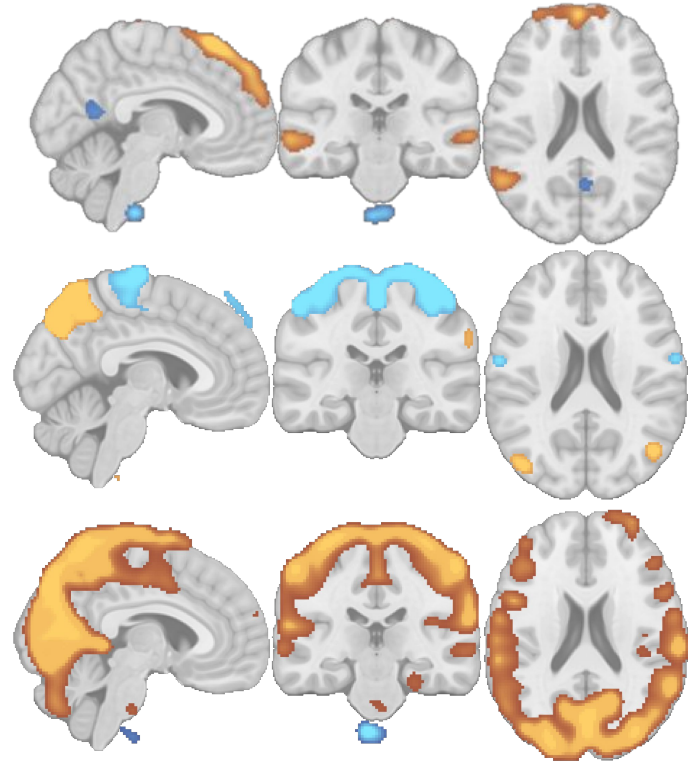
State-of-the-art in fMRI Visualization

Established techniques

- Slices

Limits of standard visualizations

- Multiple views necessary
- Occlusion



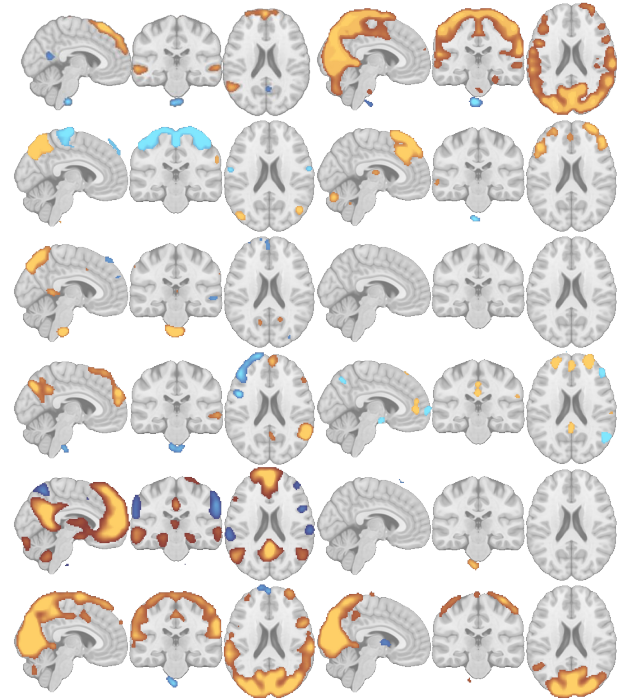
State-of-the-art in fMRI Visualization

Established techniques

- Slices

Limits of standard visualizations

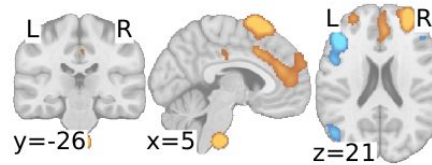
- Multiple views necessary
- Occlusion



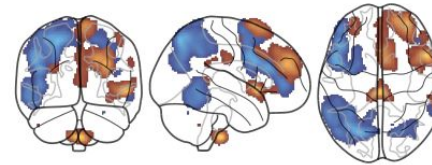
State-of-the-art in fMRI Visualization

Established techniques

- Slices
- Glass brains



(a) Canonical Brain Slices



(b) Glass Brain

Limits of standard visualizations

- Multiple views necessary
- Occlusion

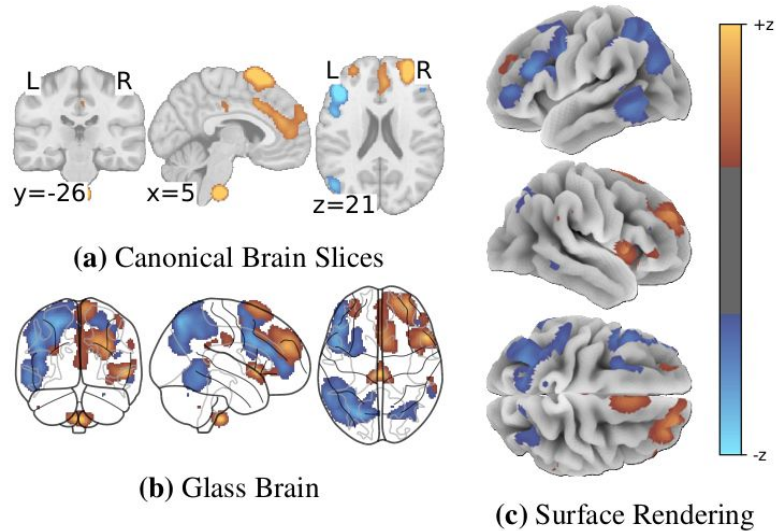
State-of-the-art in fMRI Visualization

Established techniques

- Slices
- Glass brains
- Surface Renderings

Limits of standard visualizations

- Multiple views necessary
- Occlusion



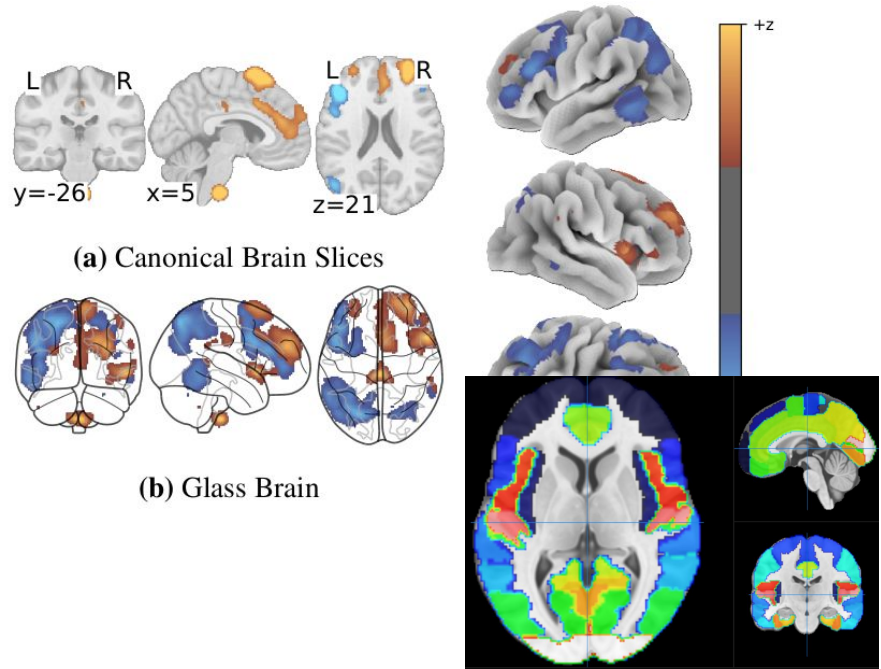
State-of-the-art in fMRI Visualization

Established techniques

- Slices
- Glass brains
- Surface Renderings

Limits of standard visualizations

- Multiple views necessary
- Occlusion
- No indication of structural regions
- Limited between-subject comparison



The NeuroMaps Design

The NeuroMaps Design

Objectives

- Multiple views necessary
- Occlusion
- No indication of structural regions
- Limited between-subject comparison

The NeuroMaps Design

Objectives

- Multiple views necessary
- Occlusion
- No indication of structural regions
- Limited between-subject comparison

→ Information-dense **single image** preview

The NeuroMaps Design

Objectives

- Multiple views necessary
 - Occlusion
 - No indication of structural regions
 - Limited between-subject comparison
- Information-dense **single image** preview
 - **Morphing** and **Optimal** viewing angle

The NeuroMaps Design

Objectives

- Multiple views necessary
 - Occlusion
 - No indication of structural regions
 - Limited between-subject comparison
- Information-dense **single image** preview
 - **Morphing** and **Optimal** viewing angle
 - Additional **visual cues**

The NeuroMaps Design

Objectives

- Multiple views necessary → Information-dense **single image** preview
- Occlusion → **Morphing** and **optimal** viewing angle
- No indication of structural regions → Additional **visual cues**
- Limited between-subject comparison → Compact fingerprint

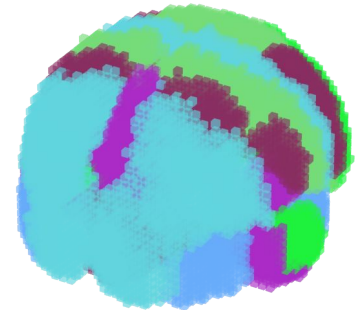
The NeuroMaps Design

Objectives

- Multiple views necessary → Information-dense **single image** preview
- Occlusion → **Morphing** and **optimal** viewing angle
- No indication of structural regions → Additional **visual cues**
- Limited between-subject comparison → Compact fingerprint

Approach

1. Slightly alter the brain morphology (optional)



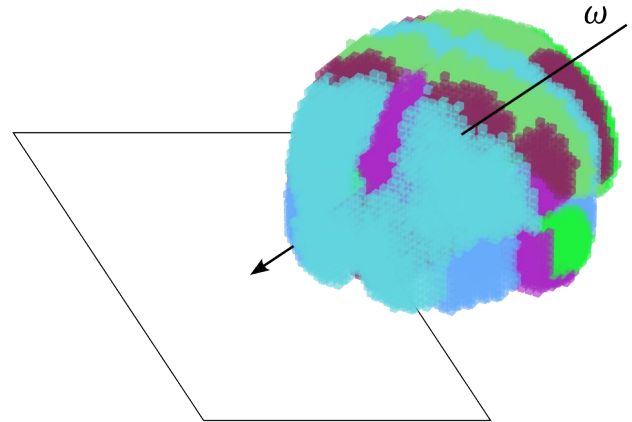
The NeuroMaps Design

Objectives

- Multiple views necessary → Information-dense **single image** preview
- Occlusion → **Morphing** and **optimal** viewing angle
- No indication of structural regions → Additional **visual cues**
- Limited between-subject comparison → Compact fingerprint

Approach

1. Slightly alter the brain morphology (optional)
2. Find an **optimal** viewing angle ω



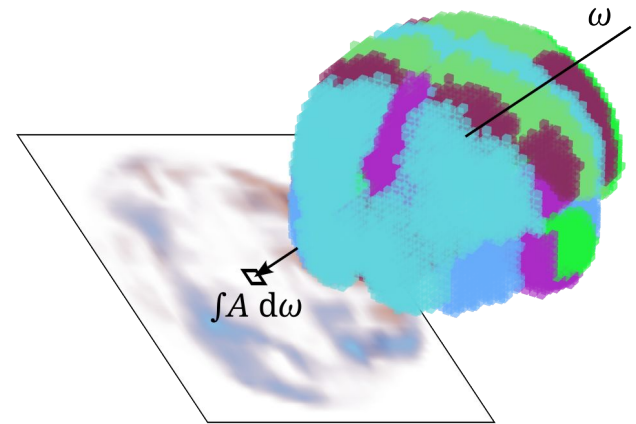
The NeuroMaps Design

Objectives

- Multiple views necessary → Information-dense **single image** preview
- Occlusion → **Morphing** and **optimal** viewing angle
- No indication of structural regions → Additional **visual cues**
- Limited between-subject comparison → Compact fingerprint

Approach

1. Slightly alter the brain morphology (optional)
2. Find an **optimal** viewing angle ω
3. Integrate activities A along this line



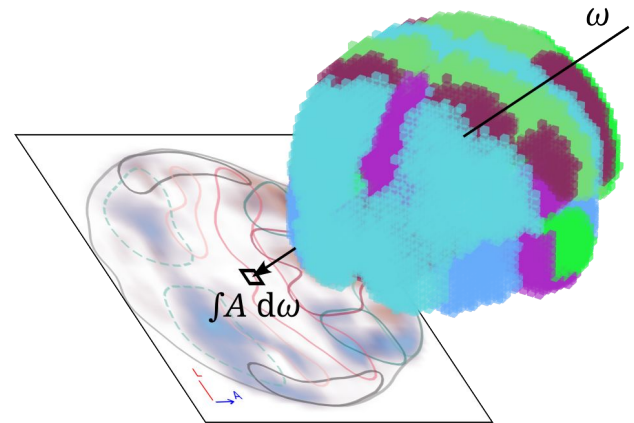
The NeuroMaps Design

Objectives

- Multiple views necessary → Information-dense **single image** preview
- Occlusion → **Morphing** and **optimal** viewing angle
- No indication of structural regions → Additional **visual cues**
- Limited between-subject comparison → Compact fingerprint

Approach

1. Slightly alter the brain morphology (optional)
2. Find an **optimal** viewing angle ω
3. Integrate activities A along this line
4. Add visual cues for context

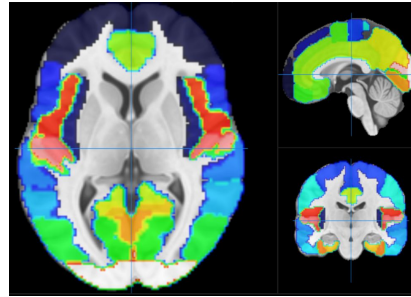


Methods

Methods – Morphing

Onion-like structure of the human brain.

Assumption: Untangling the dome shape leads to a better separability in projection space

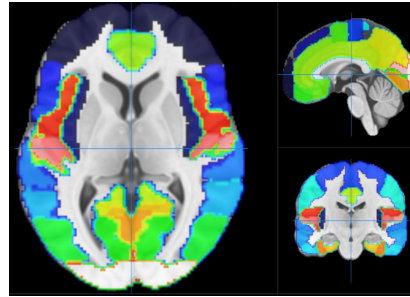


Typical brain parcellation
<https://neurovault.org/images/1699/>

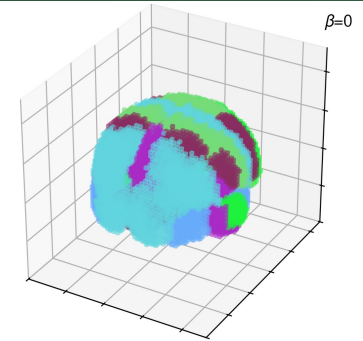
Methods – Morphing

Onion-like structure of the human brain.

Assumption: Untangling the dome shape leads to a better separability in projection space



Typical brain parcellation
<https://neurovault.org/images/1699/>



Plastic handheld lemon squeezer
<https://commons.wikimedia.org/wiki/File:Zitronenpresse2.jpg>

^[3]Snyder, John Parr, and Philip M. Voxland. *An album of map projections*. No. 1453. US Government Printing Office, 1989.

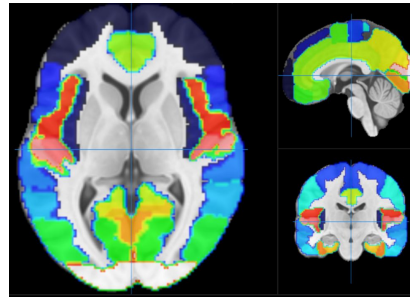
Methods – Morphing

Onion-like structure of the human brain.

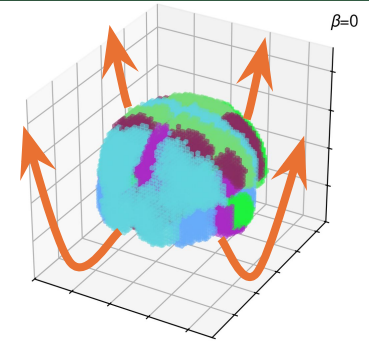
Assumption: Untangling the dome shape leads to a better separability in projection space

(Experimental) Solution: Combined

1. Azimuthal equidistant projection^[3]



Typical brain parcellation
<https://neurovault.org/images/1699/>



Plastic handheld lemon squeezer
<https://commons.wikimedia.org/wiki/File:Zitronenpresse2.jpg>

^[3]Snyder, John Parr, and Philip M. Voxland. *An album of map projections*. No. 1453. US Government Printing Office, 1989.

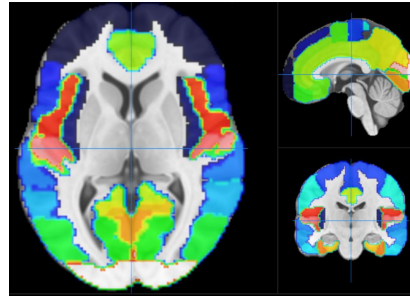
Methods – Morphing

Onion-like structure of the human brain.

Assumption: Untangling the dome shape leads to a better separability in projection space

(Experimental) Solution: Combined

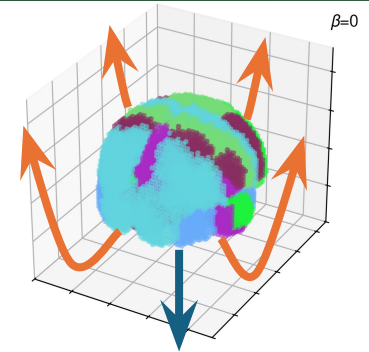
1. Azimuthal equidistant projection^[3]
2. Vertical movement



Typical brain parcellation
<https://neurovault.org/images/1699/>



Plastic handheld lemon squeezer
<https://commons.wikimedia.org/wiki/File:Zitronenpresse2.jpg>



^[3]Snyder, John Parr, and Philip M. Voxland. *An album of map projections*. No. 1453. US Government Printing Office, 1989.

Methods – Morphing

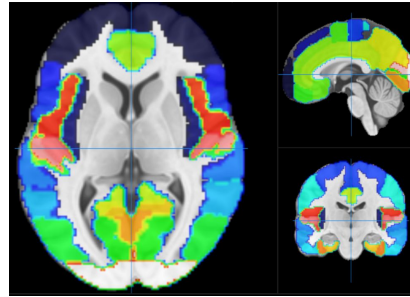
Onion-like structure of the human brain.

Assumption: Untangling the dome shape leads to a better separability in projection space

(Experimental) Solution: Combined

1. Azimuthal equidistant projection^[3]
2. Vertical movement

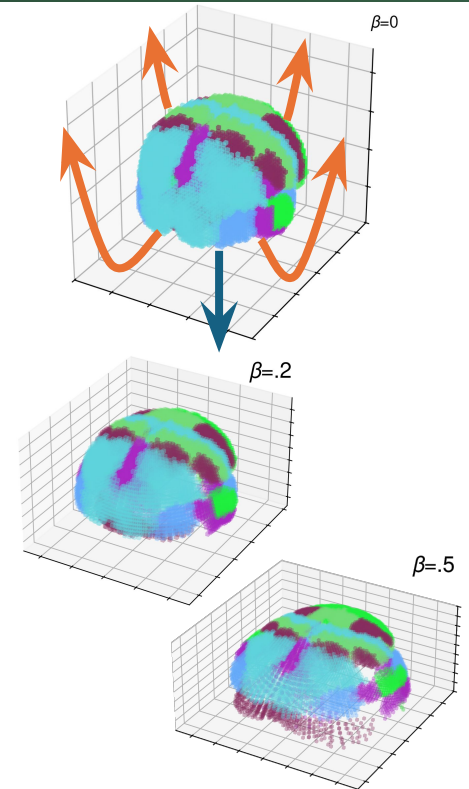
Linear interpolation β between initial state ($\beta=0$) and final state ($\beta=1$).



Typical brain parcellation
<https://neurovault.org/images/1699/>



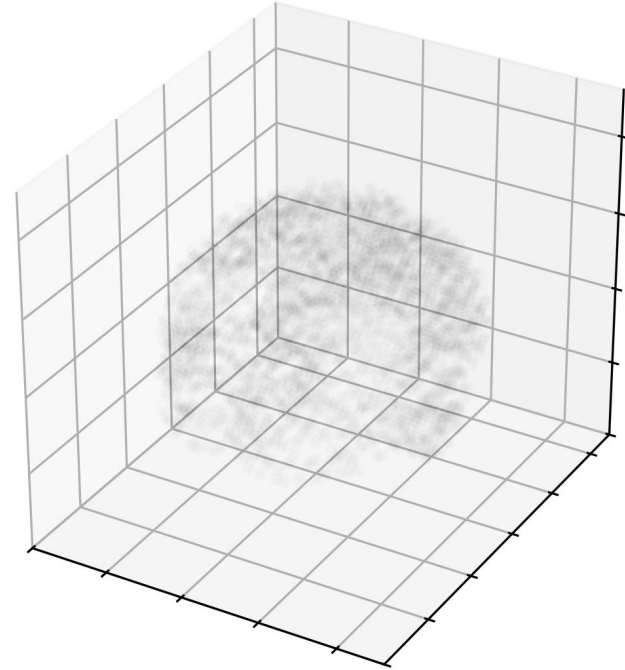
Plastic handheld lemon squeezer
<https://commons.wikimedia.org/wiki/File:Zitronenpresse2.jpg>



^[3]Snyder, John Parr, and Philip M. Voxland. *An album of map projections*. No. 1453. US Government Printing Office, 1989.

Methods – Projection

Usually only few selected regions are relevant.

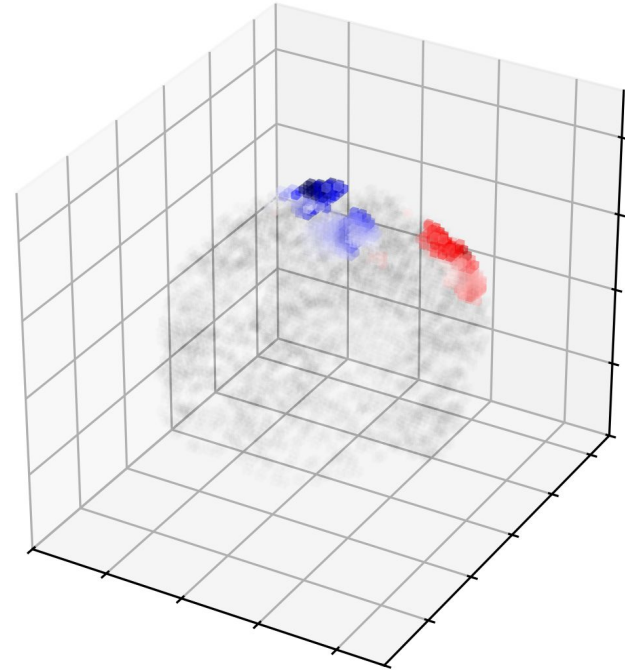


^[4]Silversmith, William. "cc3d: Connected components on multilabel 3D & 2D images." Zenodo (2021).

^[5]Fukunaga, Keinosuke. *Introduction to statistical pattern recognition*. Elsevier, 2013.

Methods – Projection

Usually only few selected regions are relevant.



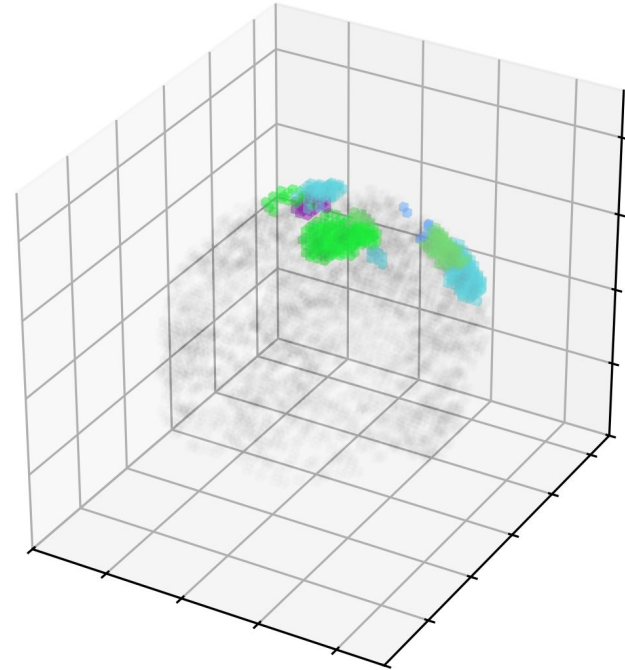
^[4]Silversmith, William. "cc3d: Connected components on multilabel 3D & 2D images." Zenodo (2021).

^[5]Fukunaga, Keinosuke. *Introduction to statistical pattern recognition*. Elsevier, 2013.

Methods – Projection

Usually only few selected regions are relevant.

- Group by sign and brain region → 3D connected component analysis^[4]



^[4]Silversmith, William. "cc3d: Connected components on multilabel 3D & 2D images." Zenodo (2021).

^[5]Fukunaga, Keinosuke. *Introduction to statistical pattern recognition*. Elsevier, 2013.

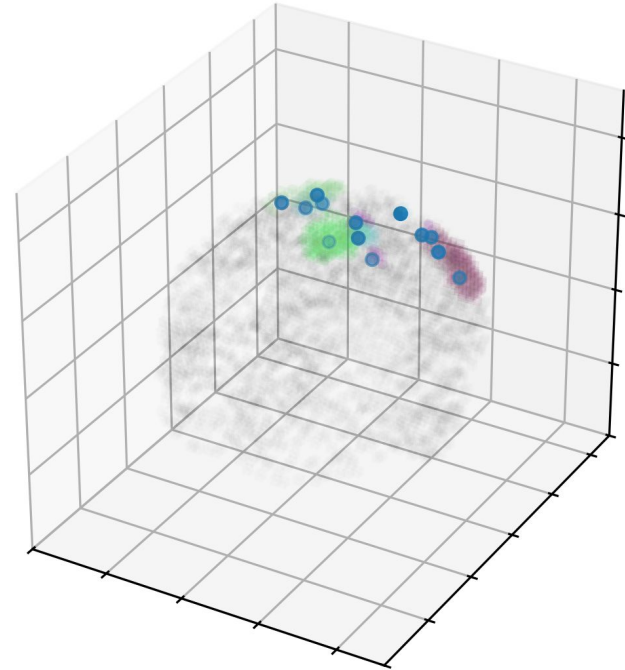
Methods – Projection

Usually only few selected regions are relevant.

- Group by sign and brain region → 3D connected component analysis^[4]
- Determine projection axis that:
 1. maximize **between-class covariance**
 2. minimize **within-class covariance**

→ Fisher's Linear Discriminant^[5]

$$J = \frac{\omega \Sigma_B \omega^T}{\omega \Sigma_W \omega^T}$$



^[4]Silversmith, William. "cc3d: Connected components on multilabel 3D & 2D images." Zenodo (2021).

^[5]Fukunaga, Keinosuke. *Introduction to statistical pattern recognition*. Elsevier, 2013.

Methods – Projection

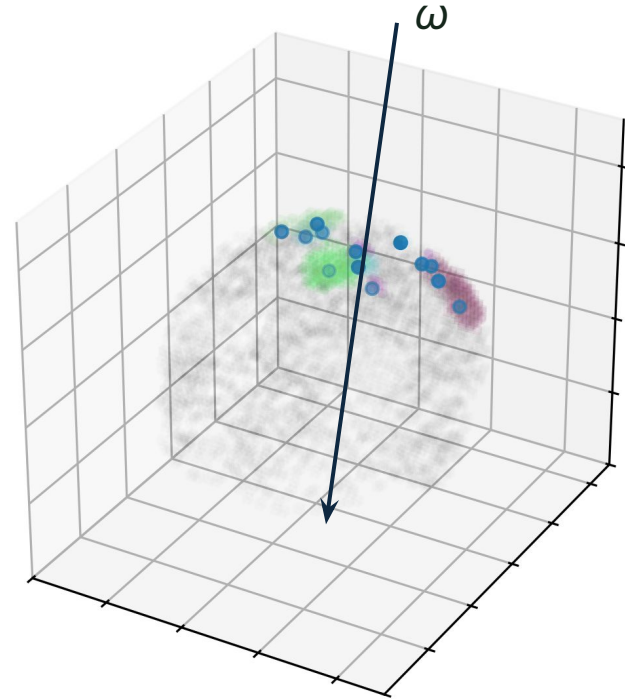
Usually only few selected regions are relevant.

- Group by sign and brain region → 3D connected component analysis^[4]
- Determine projection axis that:
 1. maximize **between-class covariance**
 2. minimize **within-class covariance**

→ Fisher's Linear Discriminant^[5]

$$J = \frac{\omega \Sigma_B \omega^T}{\omega \Sigma_W \omega^T}$$

- Solve for ω (=projection axis)

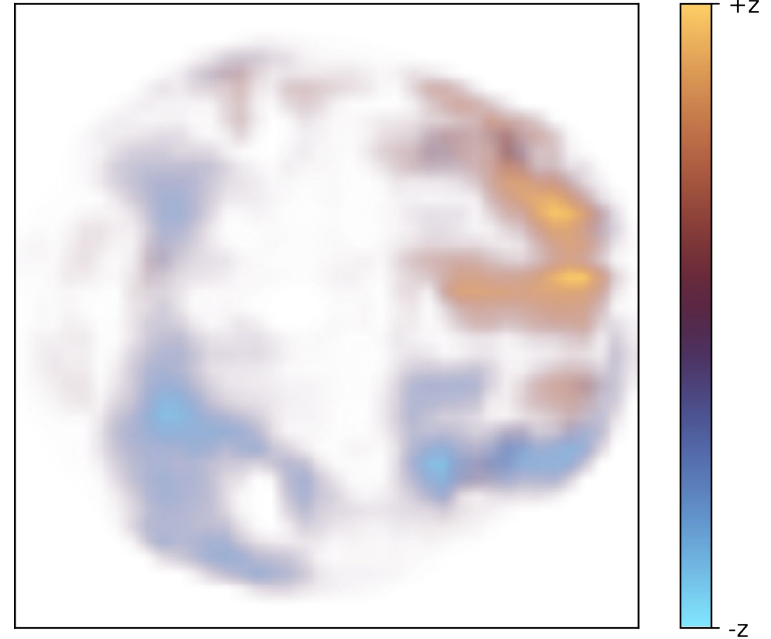


^[4]Silversmith, William. "cc3d: Connected components on multilabel 3D & 2D images." Zenodo (2021).

^[5]Fukunaga, Keinosuke. *Introduction to statistical pattern recognition*. Elsevier, 2013.

Methods – Post-processing

Mere projected activities had to interpret → additional visual cues provide context.



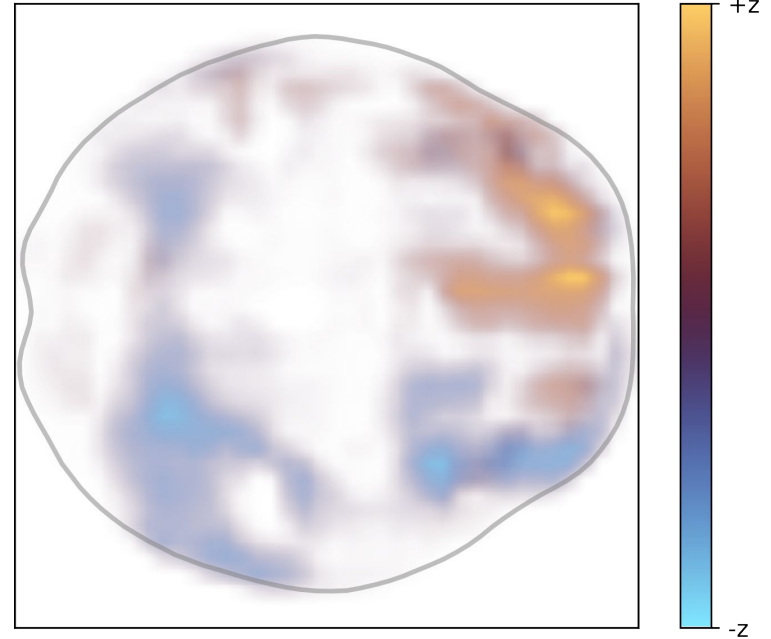
^[6] Suzuki, Satoshi. "Topological structural analysis of digitized binary images by border following." *Computer vision, graphics, and image processing* 30.1 (1985): 32-46.

^[7] Savitzky, Abraham, and Marcel JE Golay. "Smoothing and differentiation of data by simplified least squares procedures." *Analytical chemistry* 36.8 (1964): 1627-1639.

Methods – Post-processing

Mere projected activities had to interpret → additional visual cues provide context.

- Contour outline around brain shape



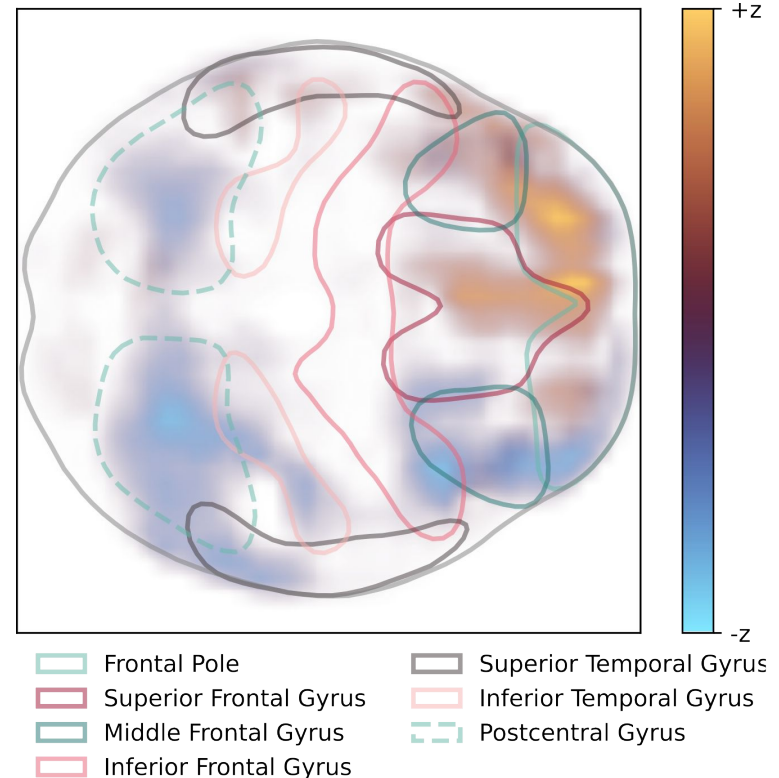
^[6] Suzuki, Satoshi. "Topological structural analysis of digitized binary images by border following." *Computer vision, graphics, and image processing* 30.1 (1985): 32-46.

^[7] Savitzky, Abraham, and Marcel JE Golay. "Smoothing and differentiation of data by simplified least squares procedures." *Analytical chemistry* 36.8 (1964): 1627-1639.

Methods – Post-processing

Mere projected activities had to interpret → additional visual cues provide context.

- Contour outline around brain shape
- Contour outlines around affected brain regions (+legend)
 - Volume intersection of activity and regions
 - Projection along ω
 - Outer contour detection^[6] + smoothing^[7]



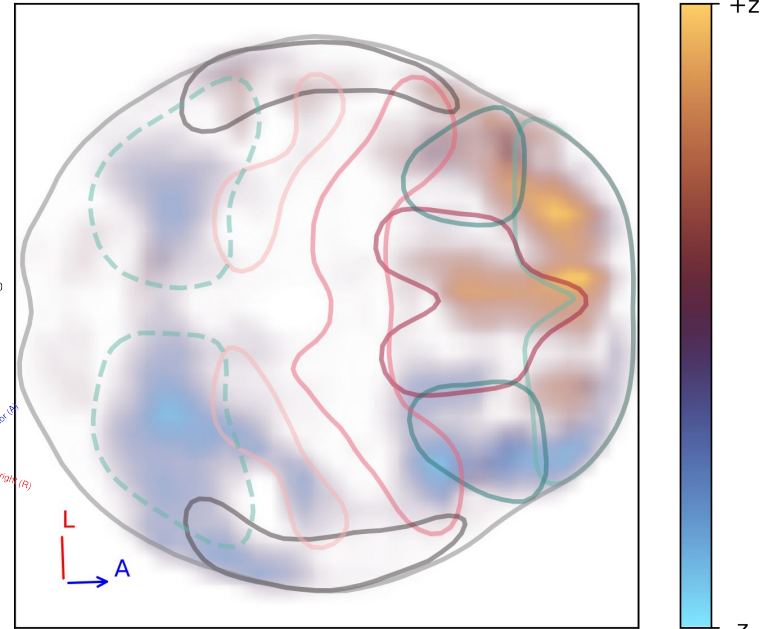
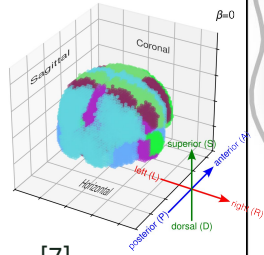
^[6] Suzuki, Satoshi. "Topological structural analysis of digitized binary images by border following." *Computer vision, graphics, and image processing* 30.1 (1985): 32-46.

^[7] Savitzky, Abraham, and Marcel JE Golay. "Smoothing and differentiation of data by simplified least squares procedures." *Analytical chemistry* 36.8 (1964): 1627-1639.

Methods – Post-processing

Mere projected activities had to interpret → additional visual cues provide context.

- Contour outline around brain shape
- Contour outlines around affected brain regions (+legend)
 - Volume intersection of activity and regions
 - Projection along ω
 - Outer contour detection^[6] + smoothing^[7]
- Compass as indication of projection plane w.r.t. the reference brain



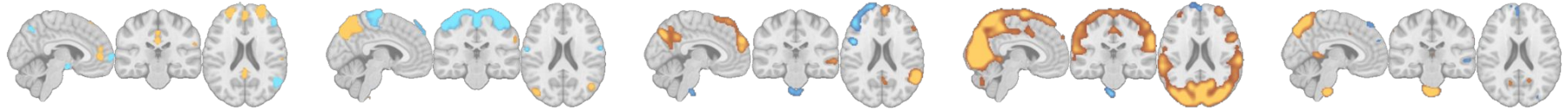
- | | |
|------------------------|-------------------------|
| Frontal Pole | Superior Temporal Gyrus |
| Superior Frontal Gyrus | Inferior Temporal Gyrus |
| Middle Frontal Gyrus | Postcentral Gyrus |
| Inferior Frontal Gyrus | |

^[6] Suzuki, Satoshi. "Topological structural analysis of digitized binary images by border following." *Computer vision, graphics, and image processing* 30.1 (1985): 32-46.

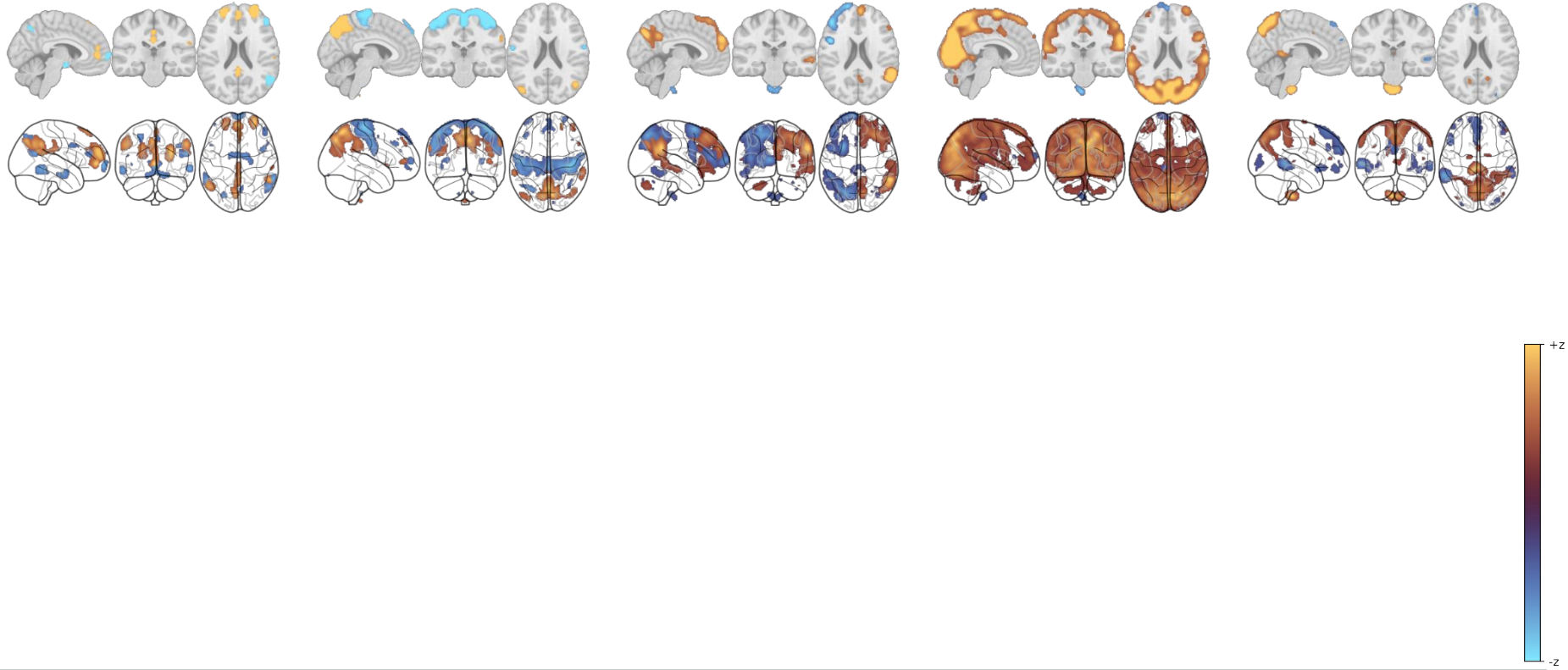
^[7] Savitzky, Abraham, and Marcel JE Golay. "Smoothing and differentiation of data by simplified least squares procedures." *Analytical chemistry* 36.8 (1964): 1627-1639.

Experimental Results

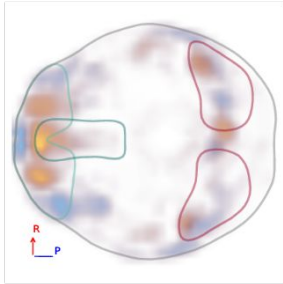
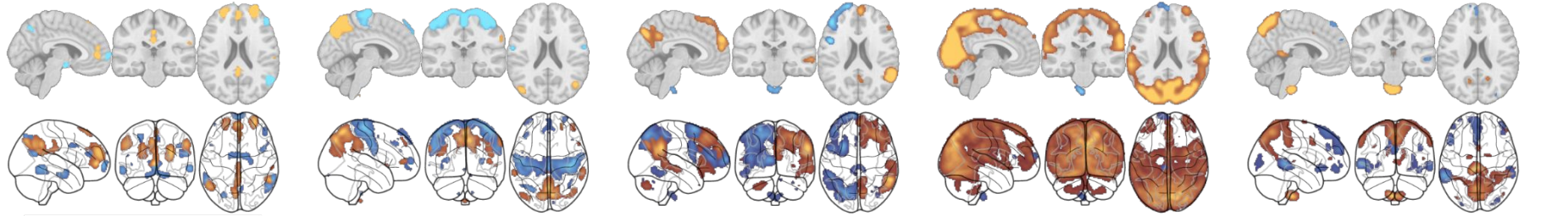
Experimental Results



Experimental Results



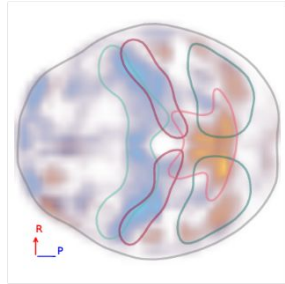
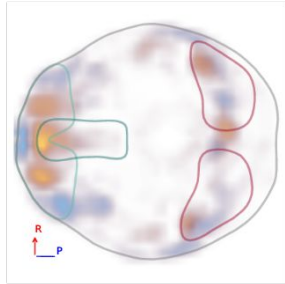
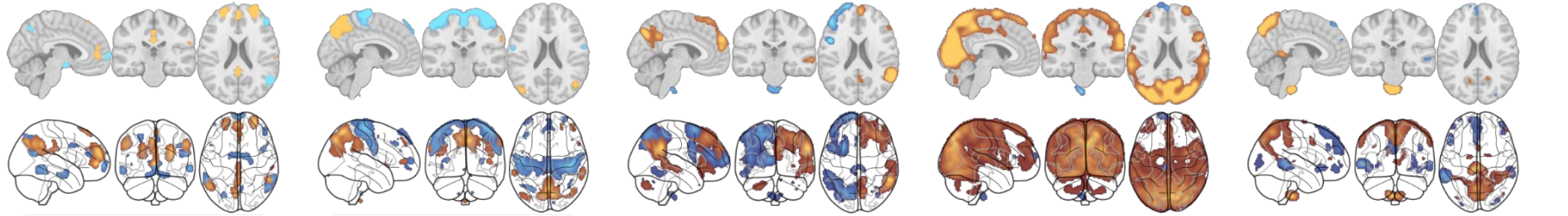
Experimental Results



- Frontal Pole
- Postcentral Gyrus
- Supramarginal Gyrus



Experimental Results

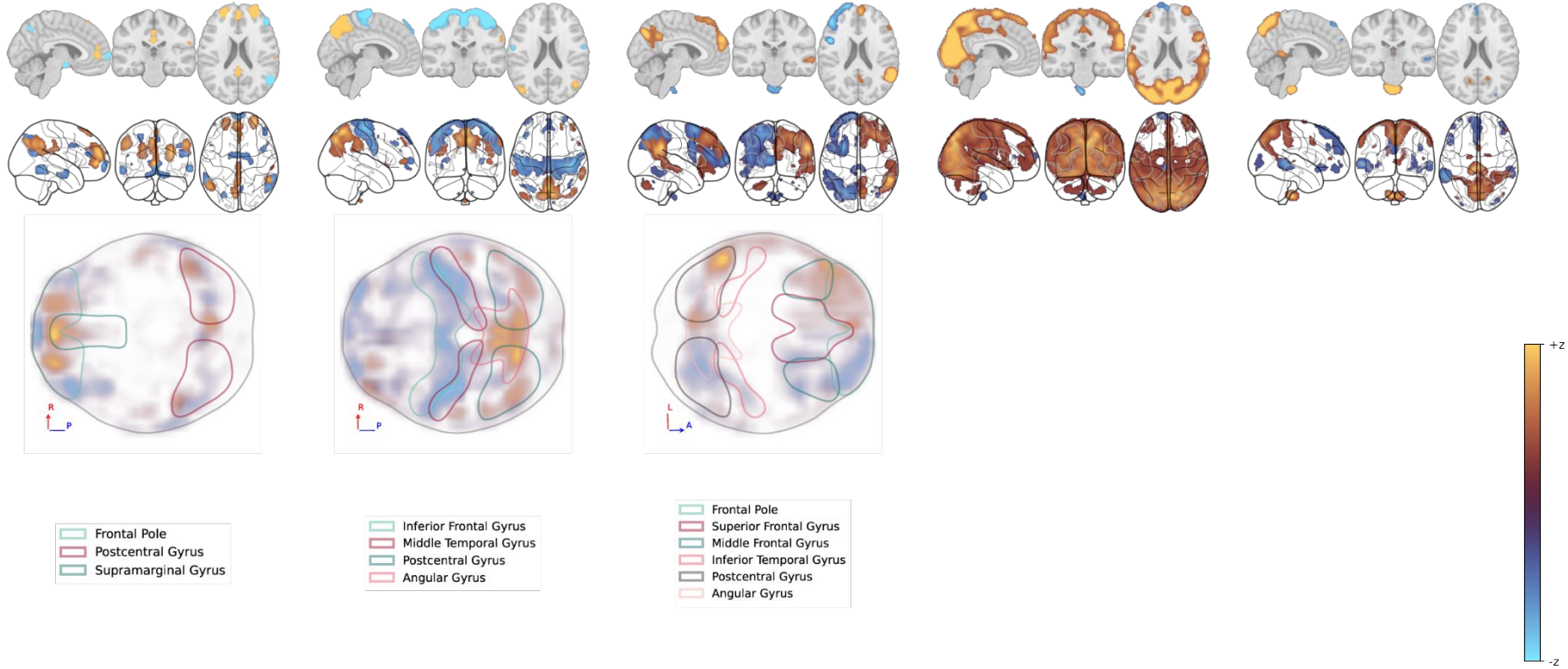


- Frontal Pole
- Postcentral Gyrus
- Supramarginal Gyrus

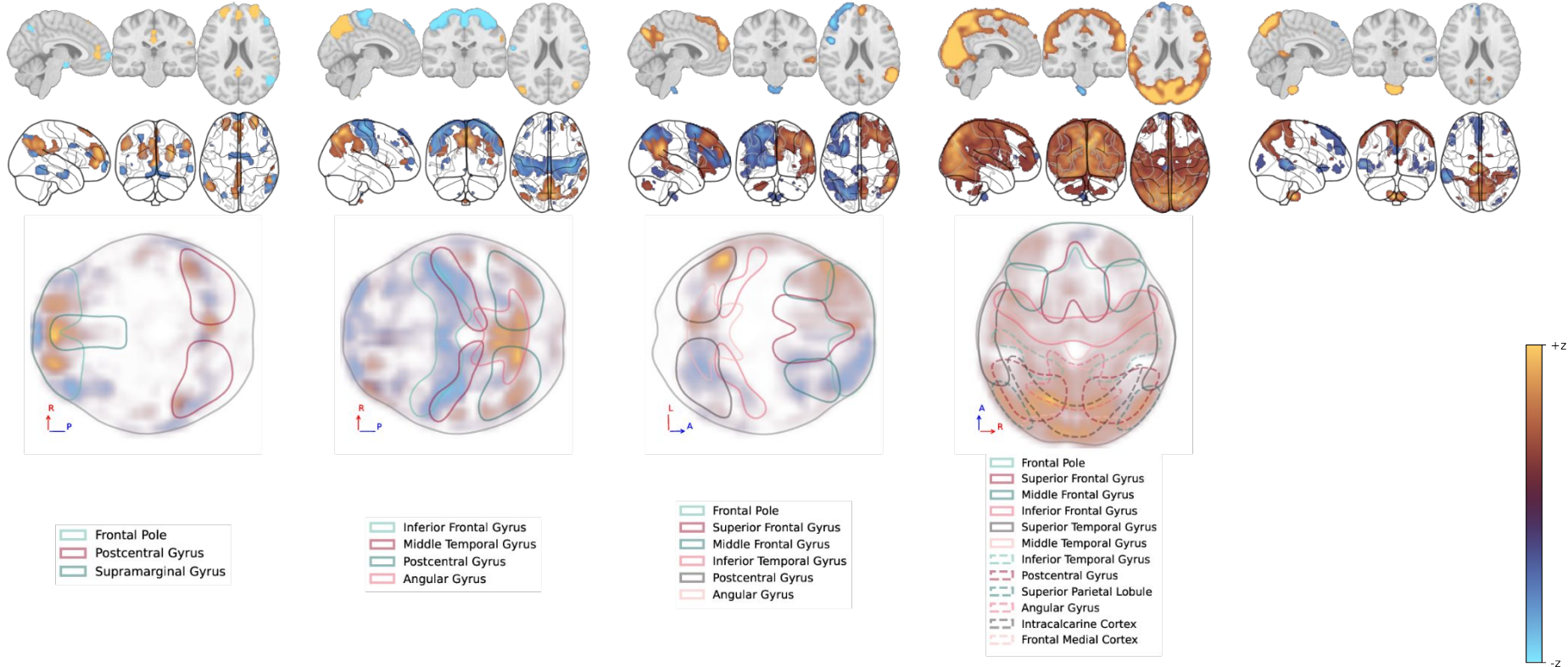
- Inferior Frontal Gyrus
- Middle Temporal Gyrus
- Postcentral Gyrus
- Angular Gyrus



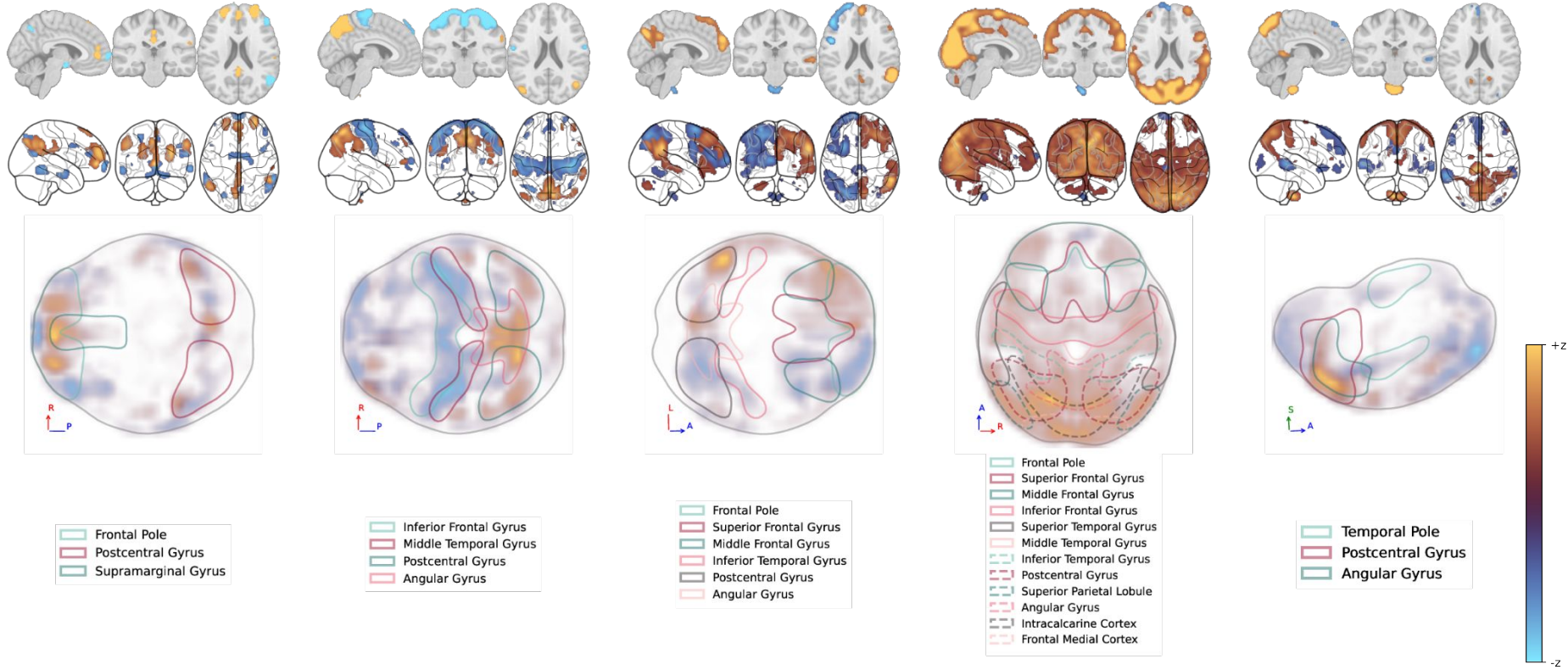
Experimental Results



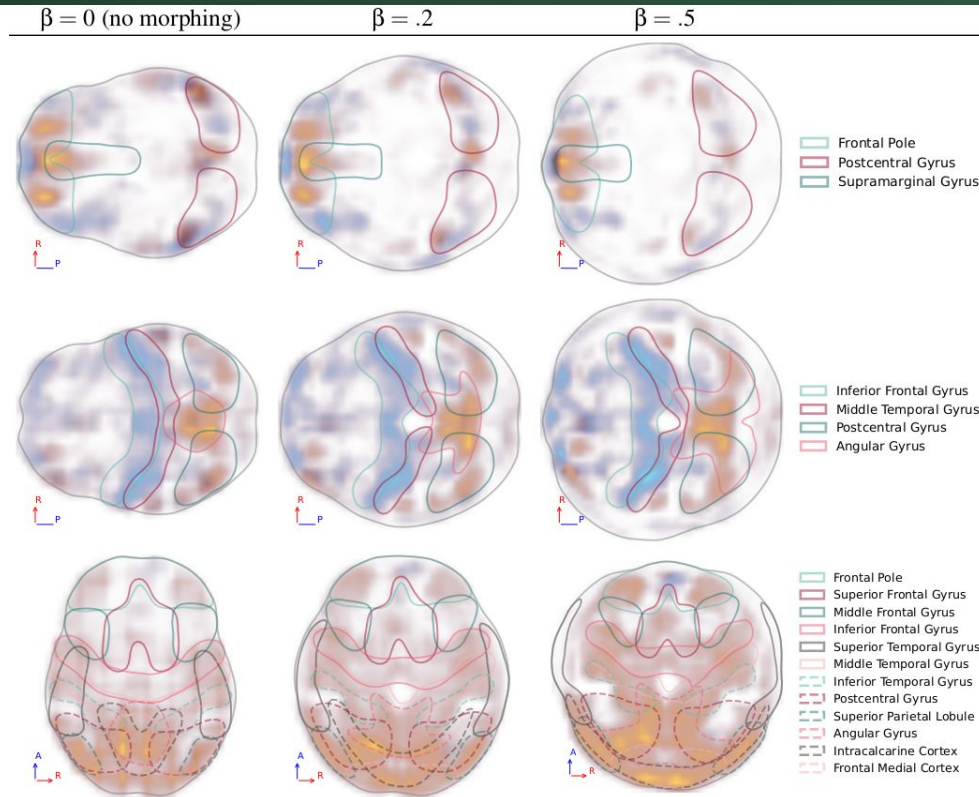
Experimental Results



Experimental Results

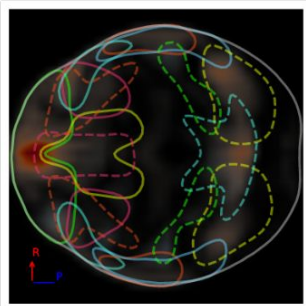


Experimental Results

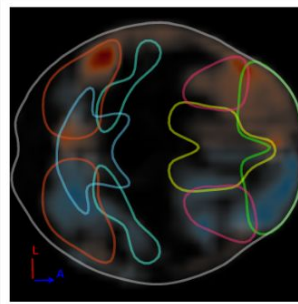


Experimental Results

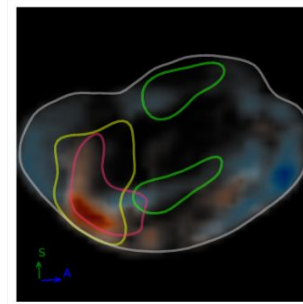
Alternative dark mode for on-screen usage



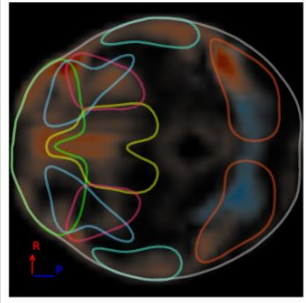
- Frontal Pole
- Superior Frontal Gyrus
- Middle Frontal Gyrus
- Precentral Gyrus
- Temporal Pole
- Superior Temporal Gyrus
- Inferior Temporal Gyrus
- Postcentral Gyrus
- Supramarginal Gyrus
- Angular Gyrus
- Lateral Occipital Cortex



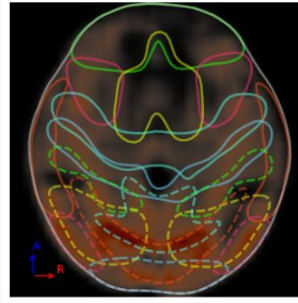
- Frontal Pole
- Superior Frontal Gyrus
- Middle Frontal Gyrus
- Inferior Temporal Gyrus
- Postcentral Gyrus
- Angular Gyrus



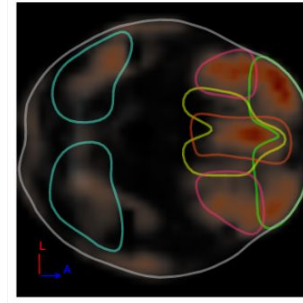
- Temporal Pole
- Postcentral Gyrus
- Angular Gyrus



- Frontal Pole
- Superior Frontal Gyrus
- Middle Frontal Gyrus
- Temporal Pole
- Postcentral Gyrus
- Lateral Occipital Cortex

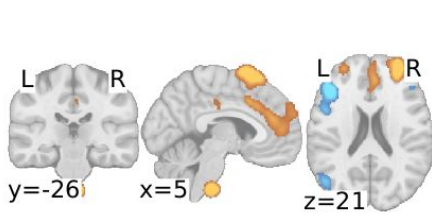


- Frontal Pole
- Superior Frontal Gyrus
- Middle Frontal Gyrus
- Inferior Frontal Gyrus
- Superior Temporal Gyrus
- Middle Temporal Gyrus
- Inferior Temporal Gyrus
- Postcentral Gyrus
- Superior Parietal Lobule
- Angular Gyrus
- Intracalcarine Cortex
- Frontal Medial Cortex

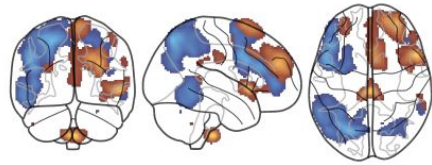


- Frontal Pole
- Superior Frontal Gyrus
- Middle Frontal Gyrus
- Postcentral Gyrus
- Supramarginal Gyrus

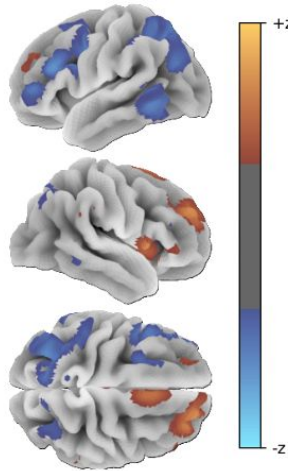
Thank you



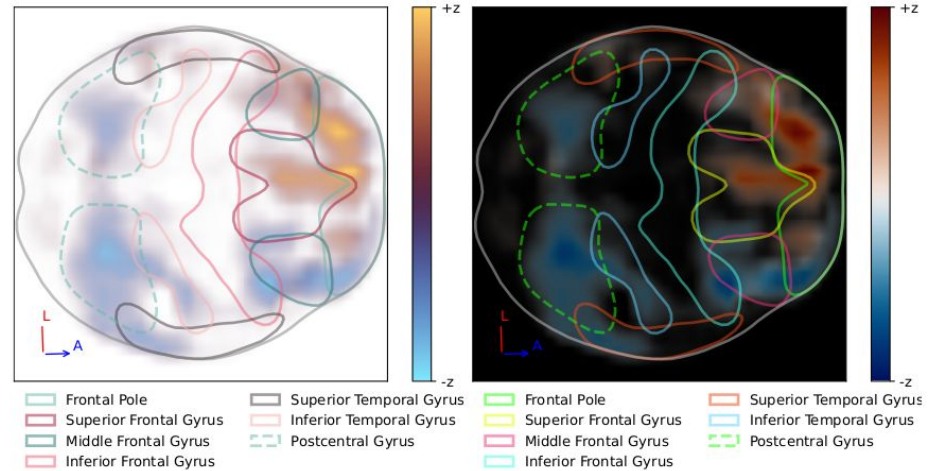
(a) Canonical Brain Slices



(b) Glass Brain



(c) Surface Rendering

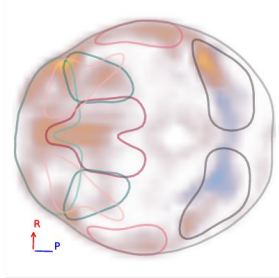
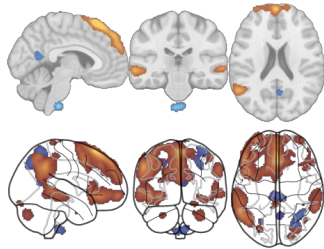


(d) NeuroMaps

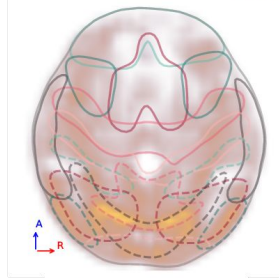
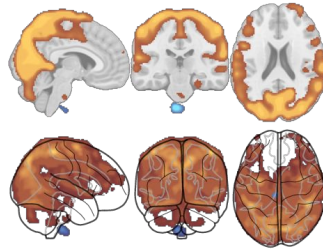
Source Code on Github: <https://github.com/lenxn/neuromaps>



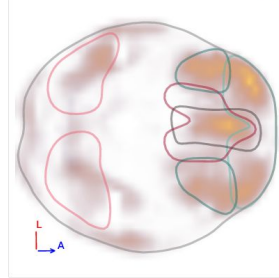
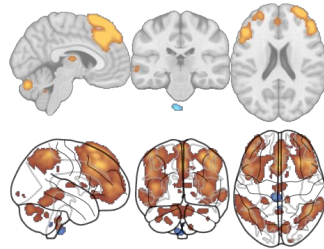
Experimental Results (Alternatives)



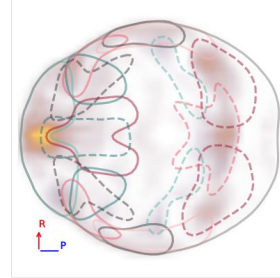
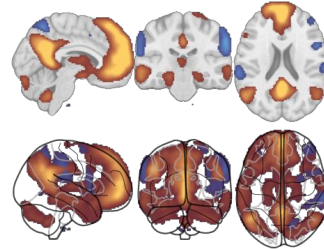
- Frontal Pole
- Superior Frontal Gyrus
- Middle Frontal Gyrus
- Temporal Pole
- Postcentral Gyrus
- Lateral Occipital Cortex



- Frontal Pole
- Superior Frontal Gyrus
- Middle Frontal Gyrus
- Inferior Frontal Gyrus
- Superior Temporal Gyrus
- Middle Temporal Gyrus
- Inferior Temporal Gyrus
- Postcentral Gyrus
- Superior Parietal Lobule
- Angular Gyrus
- Intracalcarine Cortex
- Frontal Medial Cortex



- Frontal Pole
- Superior Frontal Gyrus
- Middle Frontal Gyrus
- Postcentral Gyrus
- Supramarginal Gyrus



- Frontal Pole
- Superior Frontal Gyrus
- Middle Frontal Gyrus
- Precentral Gyrus
- Temporal Pole
- Superior Temporal Gyrus
- Inferior Temporal Gyrus
- Postcentral Gyrus
- Supramarginal Gyrus
- Angular Gyrus
- Lateral Occipital Cortex