

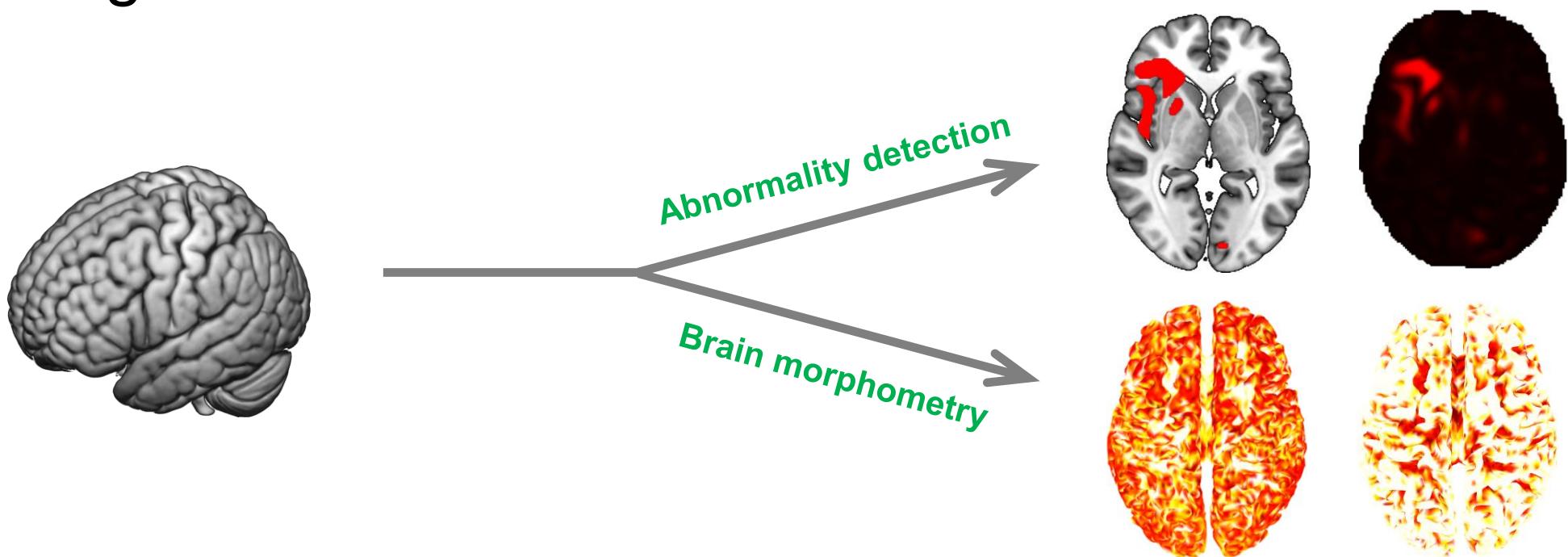
Medical/Bio Research Topics I : Week 04 (25 March 2025)

Structural MRI (2): Data Processing Methods

**구조 자기공명영상 (2):
데이터 처리 방법**

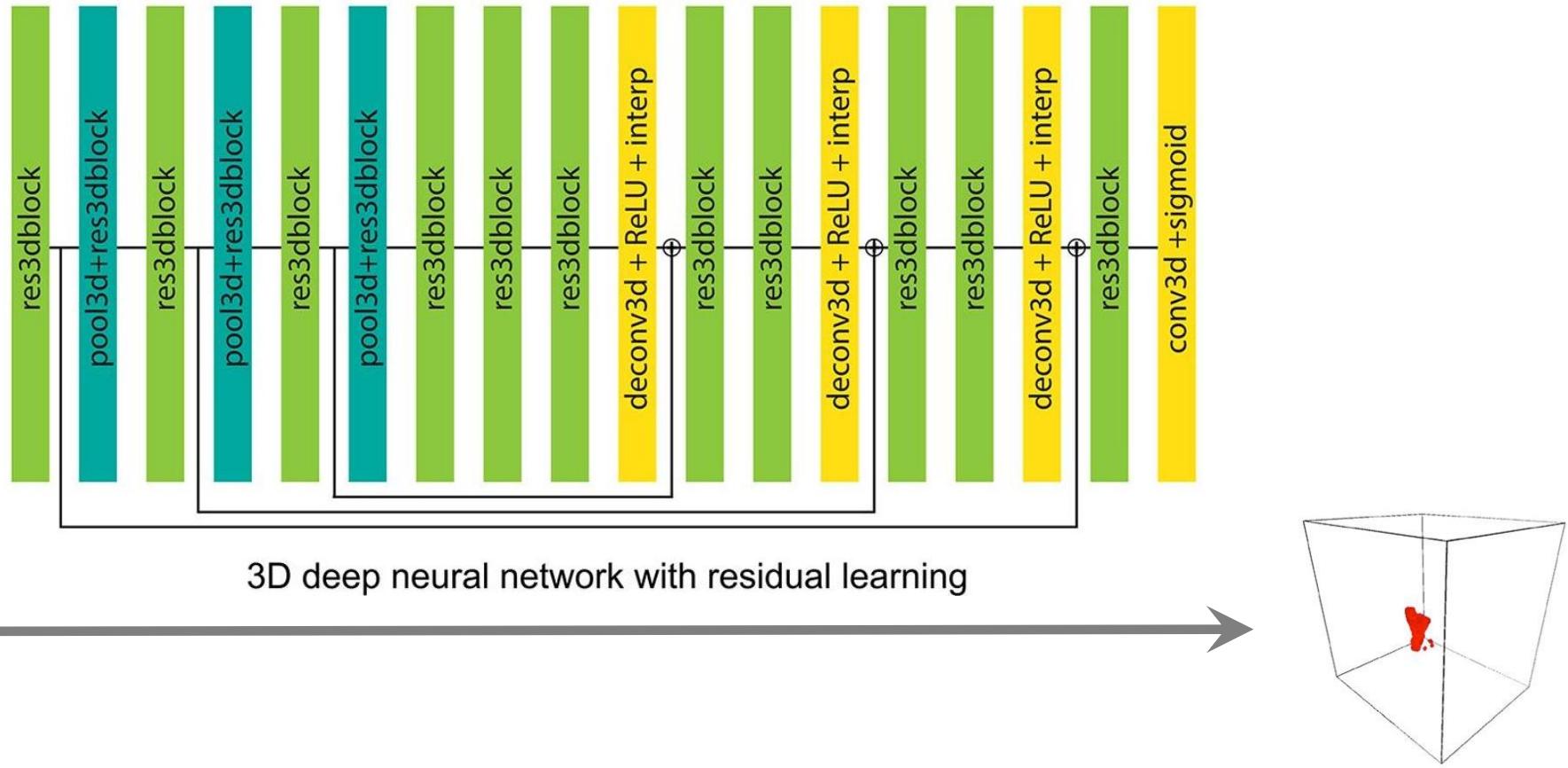
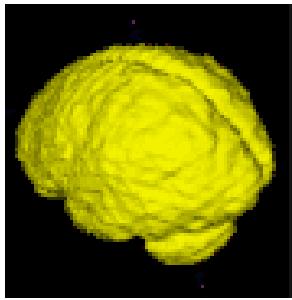
Brain Mapping with Structural MRI (sMRI)

- T1/T2-weighted sMRI



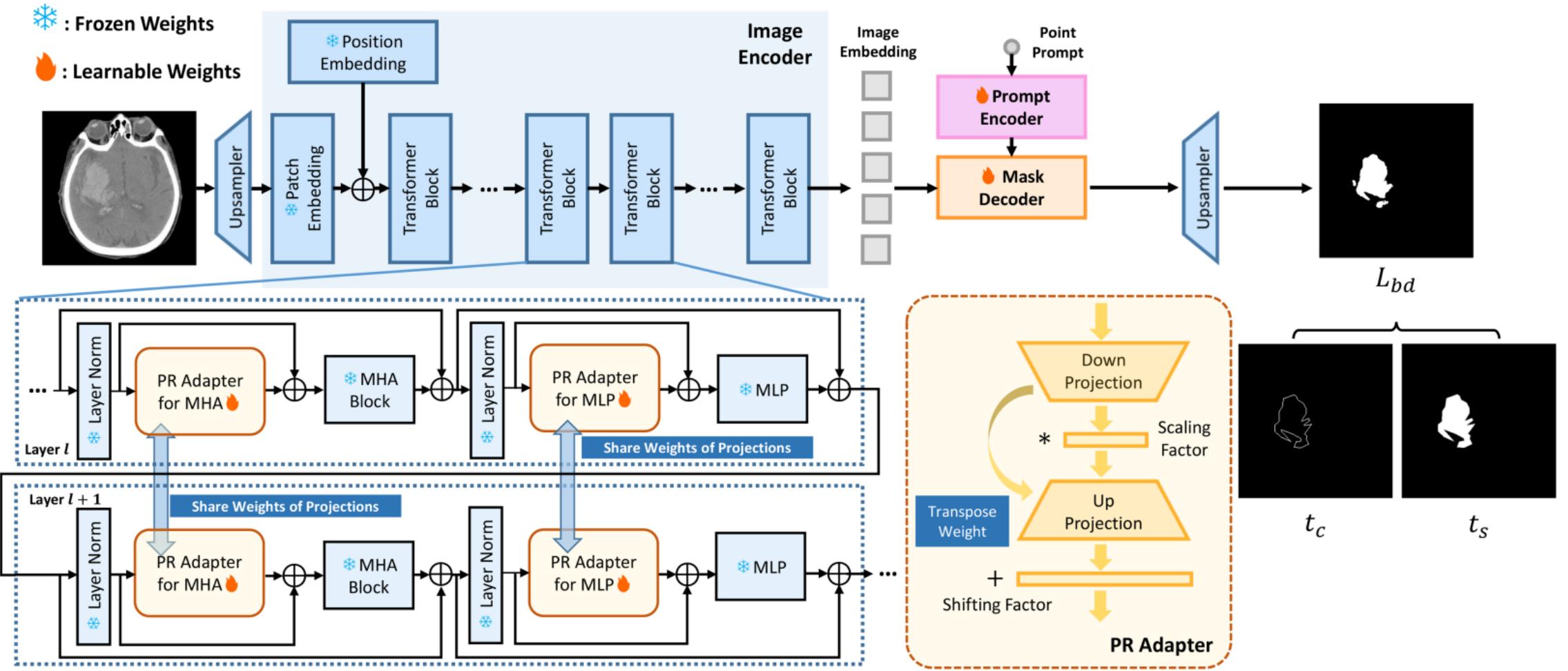
Automated Abnormality Detection

- Leverages deep learning algorithms to detect pathological changes in brain tissue
 - Identifies subtle abnormalities that may be overlooked in visual assessment
- Segmentation: Automated delineation of lesion boundaries with voxel-level precision
- Grading: Standardized classification of abnormality severity using predefined scales



[Tomita et al., 2020]

3D Convolutional Neural Network for Stroke Lesion Segmentation



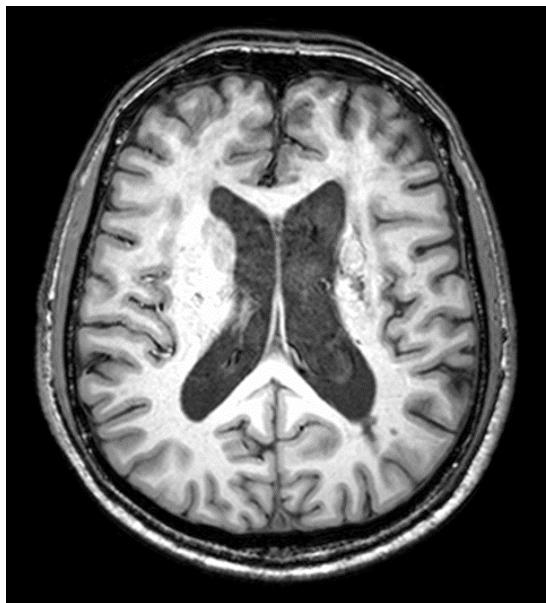
[Wang et al., 2024; <https://github.com/mileswyn/SAMIHS>]

Segment Anything Model (SAM)-based Fine-Tuning for Stroke Lesion Segmentation

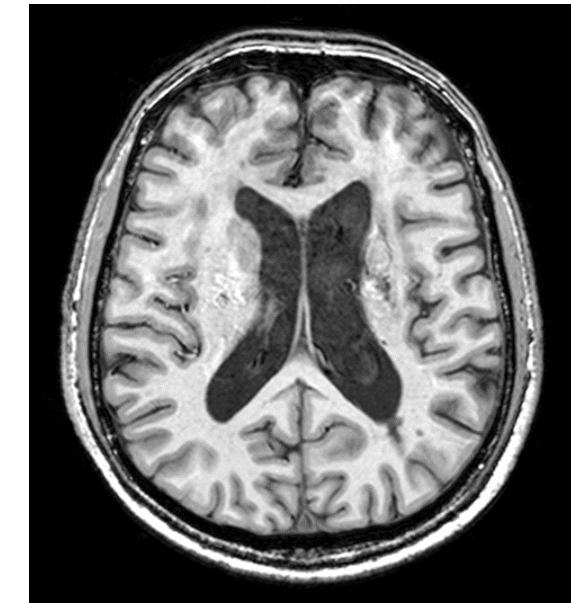
Preprocessing

- Numerous steps to clean and standardize sMRI data before brain morphometry
 - Correction for bias fields (intensity non-uniformities)
 - From a broader range of sources, including imperfections in the MRI scanner's main magnetic field, inhomogeneities in the radiofrequency coil performance, and magnetic susceptibility-induced field inhomogeneities
 - Often characterized by a smooth variation in image brightness

- Segmentation
 - Classifies an image into the non-brain and brain and, furthermore, the brain into different tissues usually including grey matter, white matter, and cerebrospinal fluid
- Normalization
 - Transforms an image from a native space to the standard space usually in the Montreal Neurological Institute (MNI) coordinate system



Intensity non-uniformity



Correction for Intensity Non-uniformity

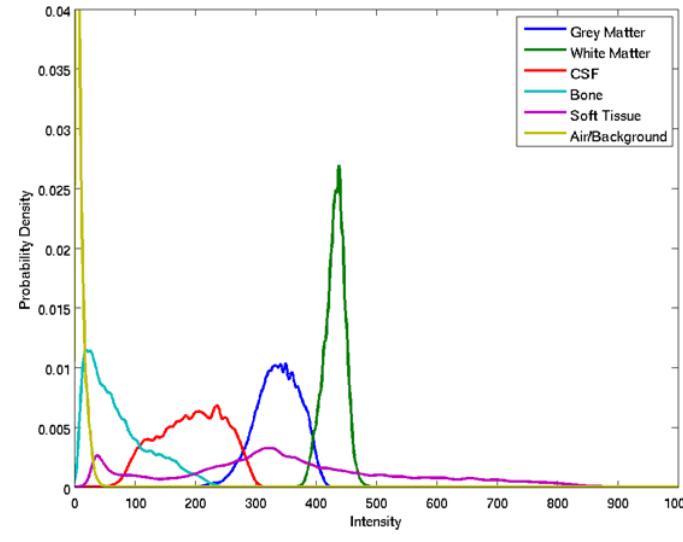
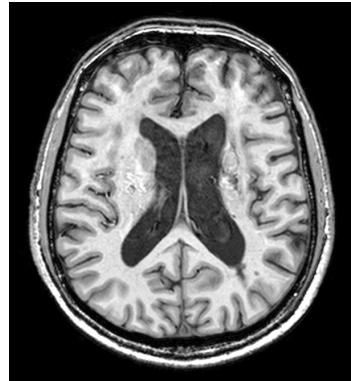
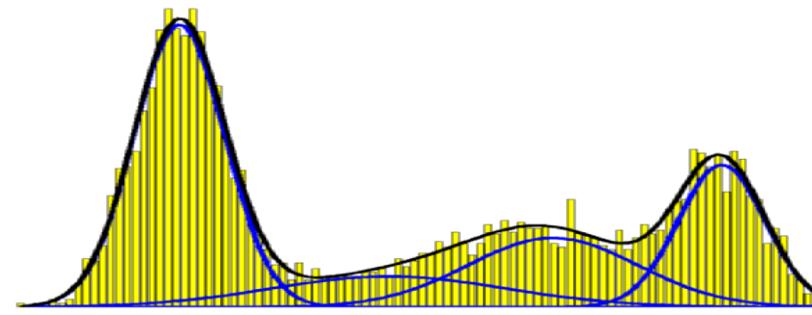
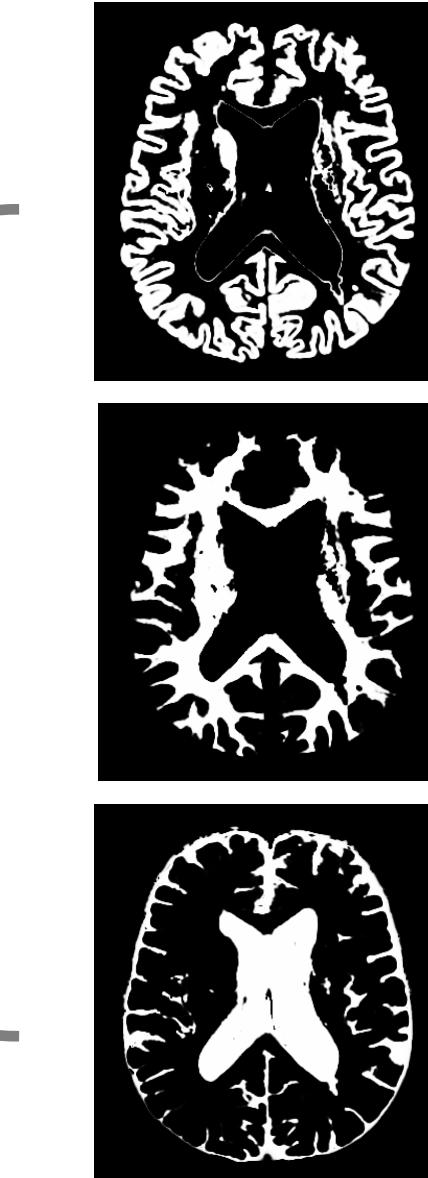


Image intensity distribution



Mixture of Gaussians model

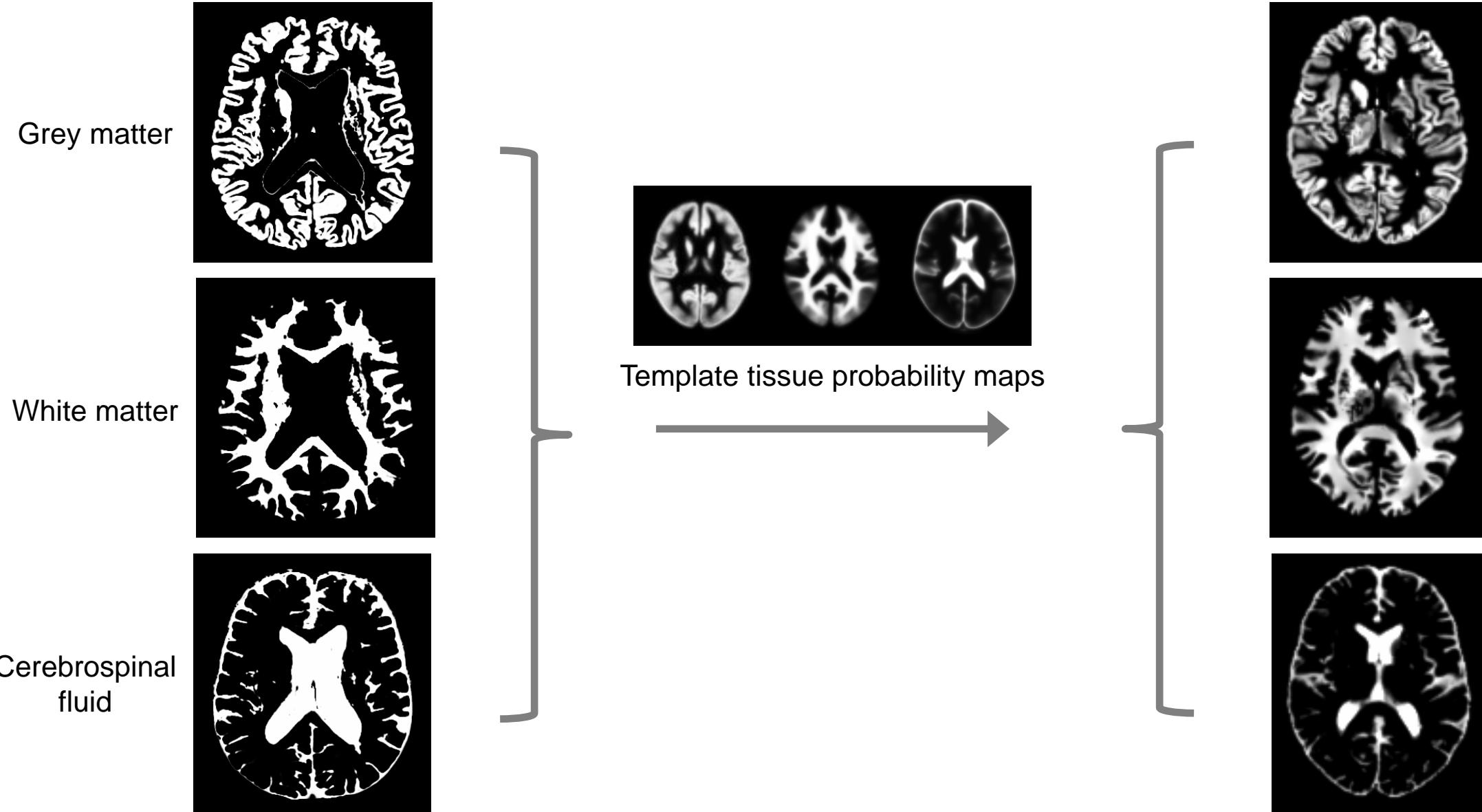


Grey matter

White matter

Cerebrospinal fluid

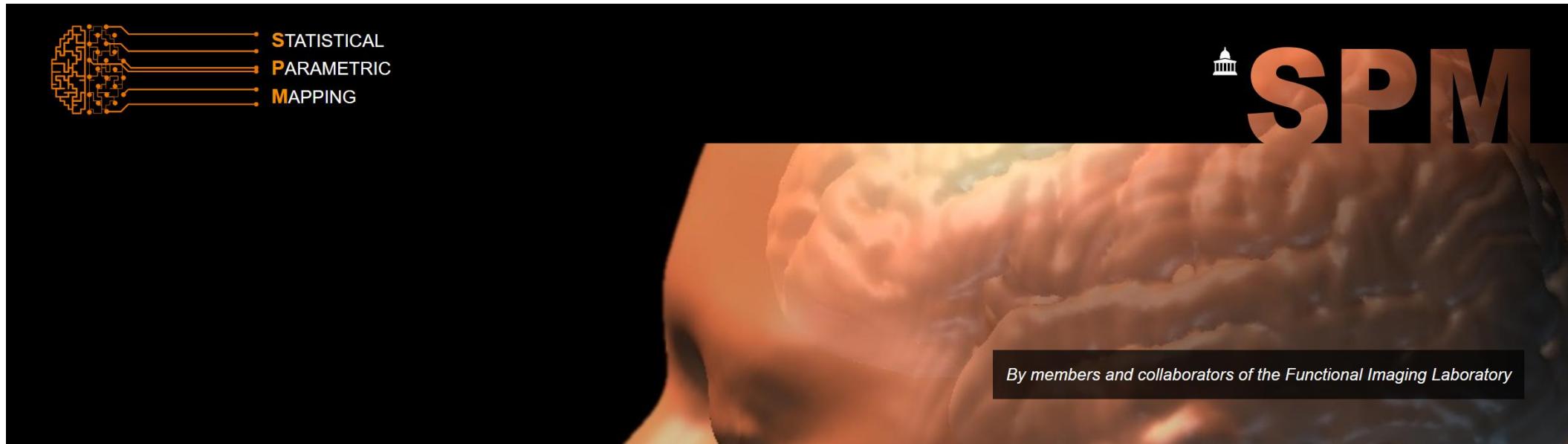
Segmentation into Different Tissues

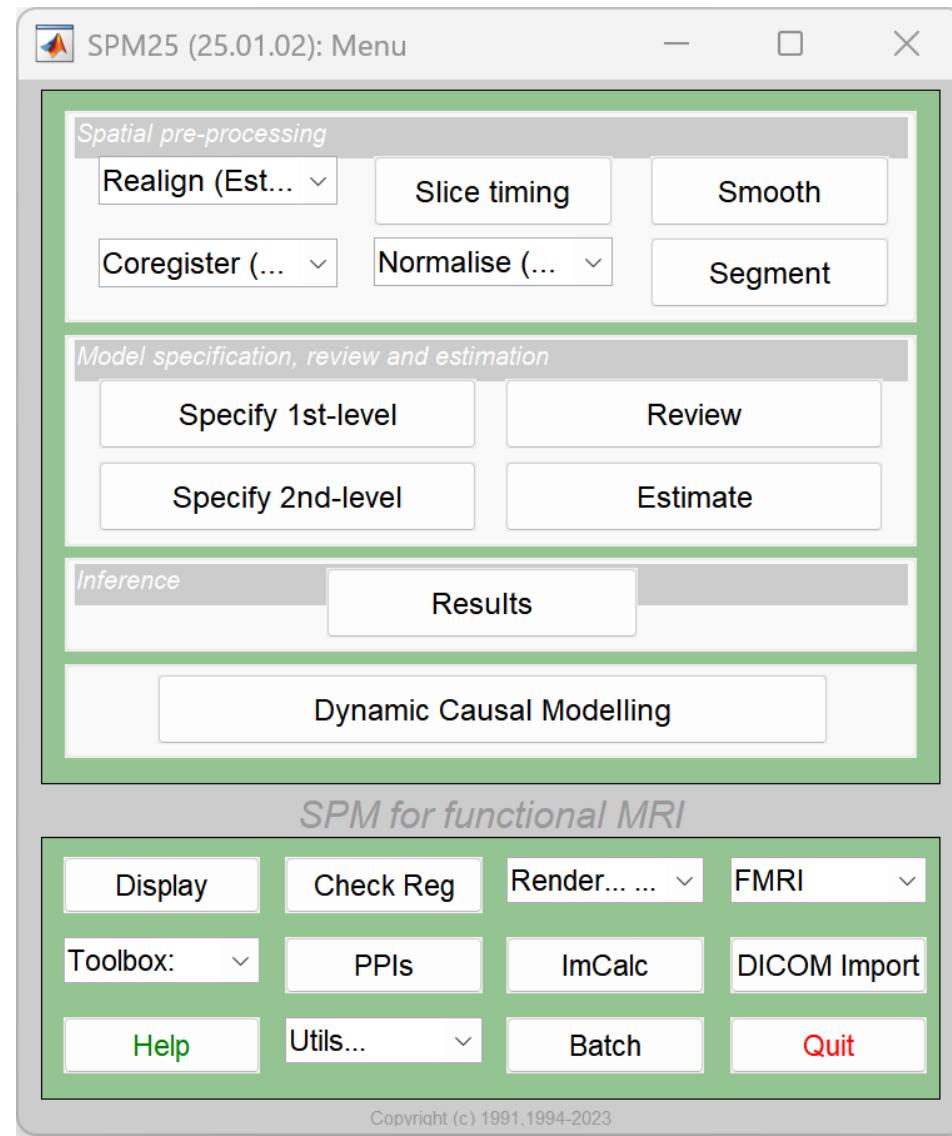


Normalization

[Preprocessing of sMRI]

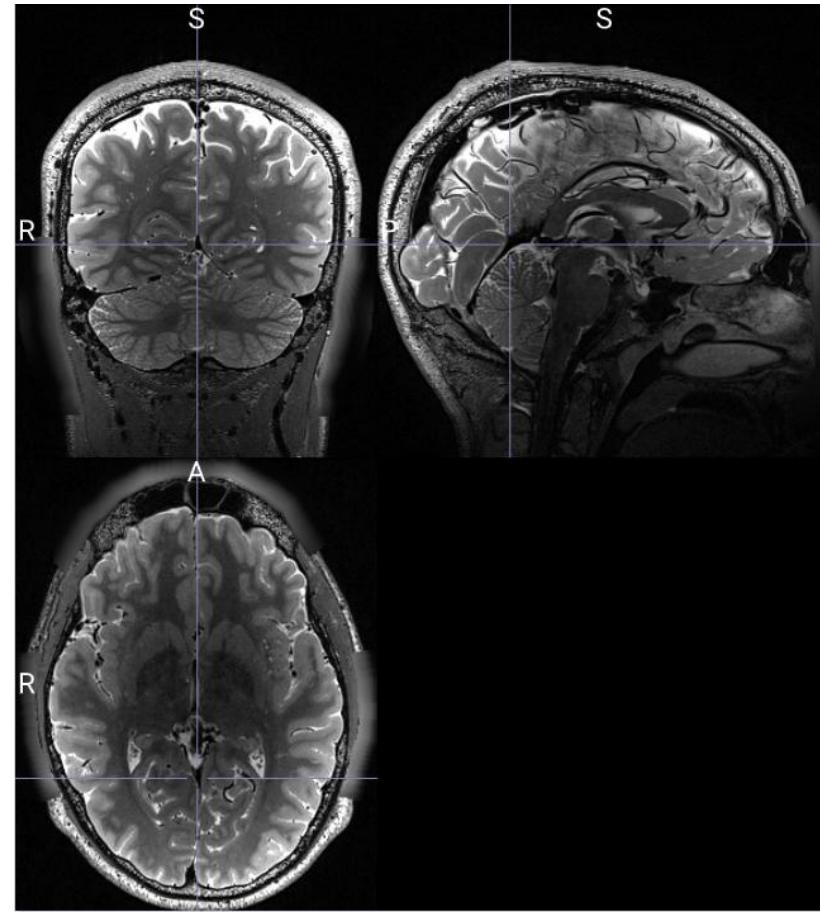
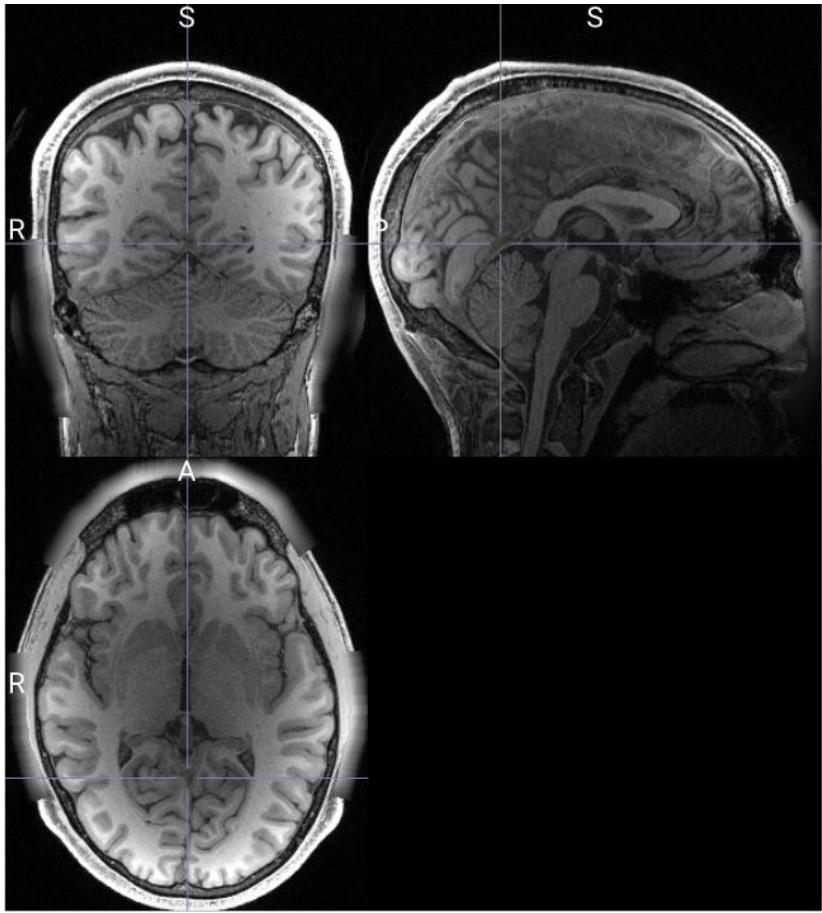
- SPM25 [\[https://github.com/spm/spm\]](https://github.com/spm/spm)





GUI of the SPM Toolbox

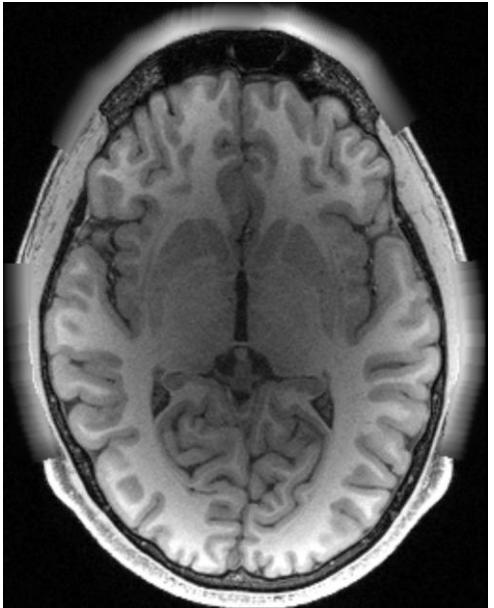
Input



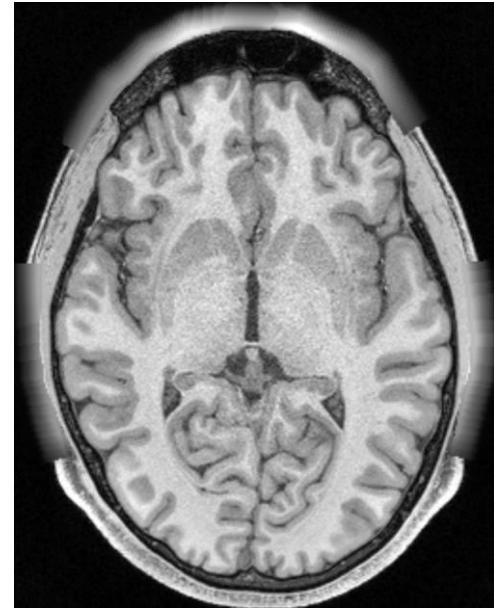
T1-weighted and T2-weighted sMRI

Output

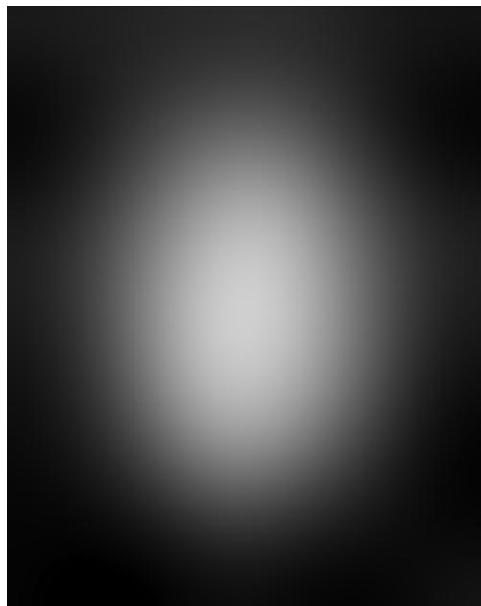
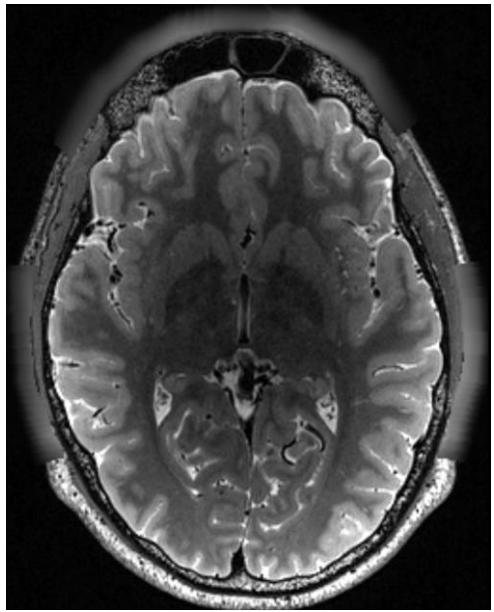
Correction for intensity non-uniformity



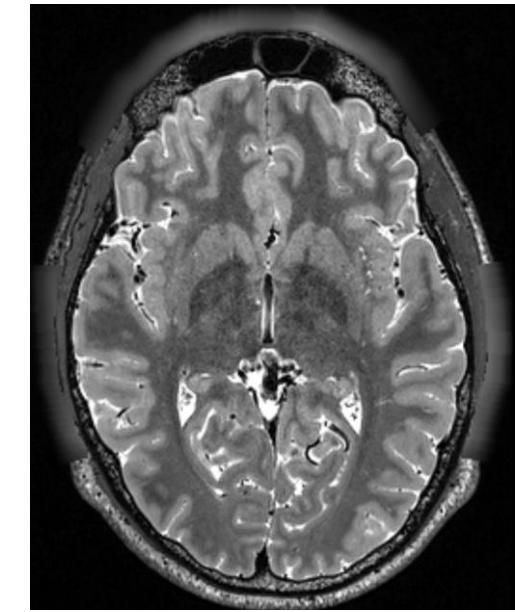
Intensity non-uniformity



Correction of the T1-weighted Image for Intensity Non-uniformity



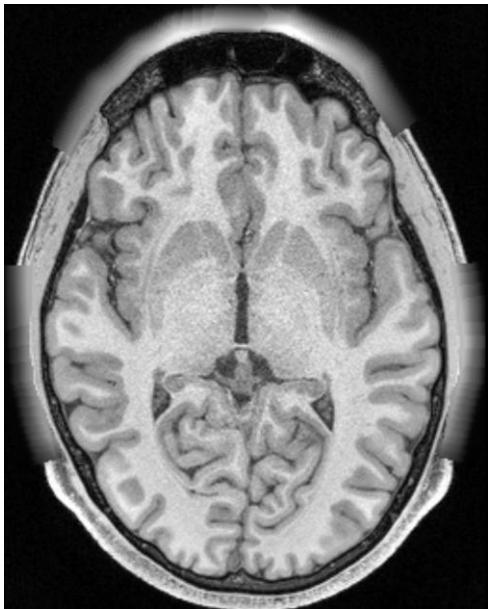
Intensity non-uniformity



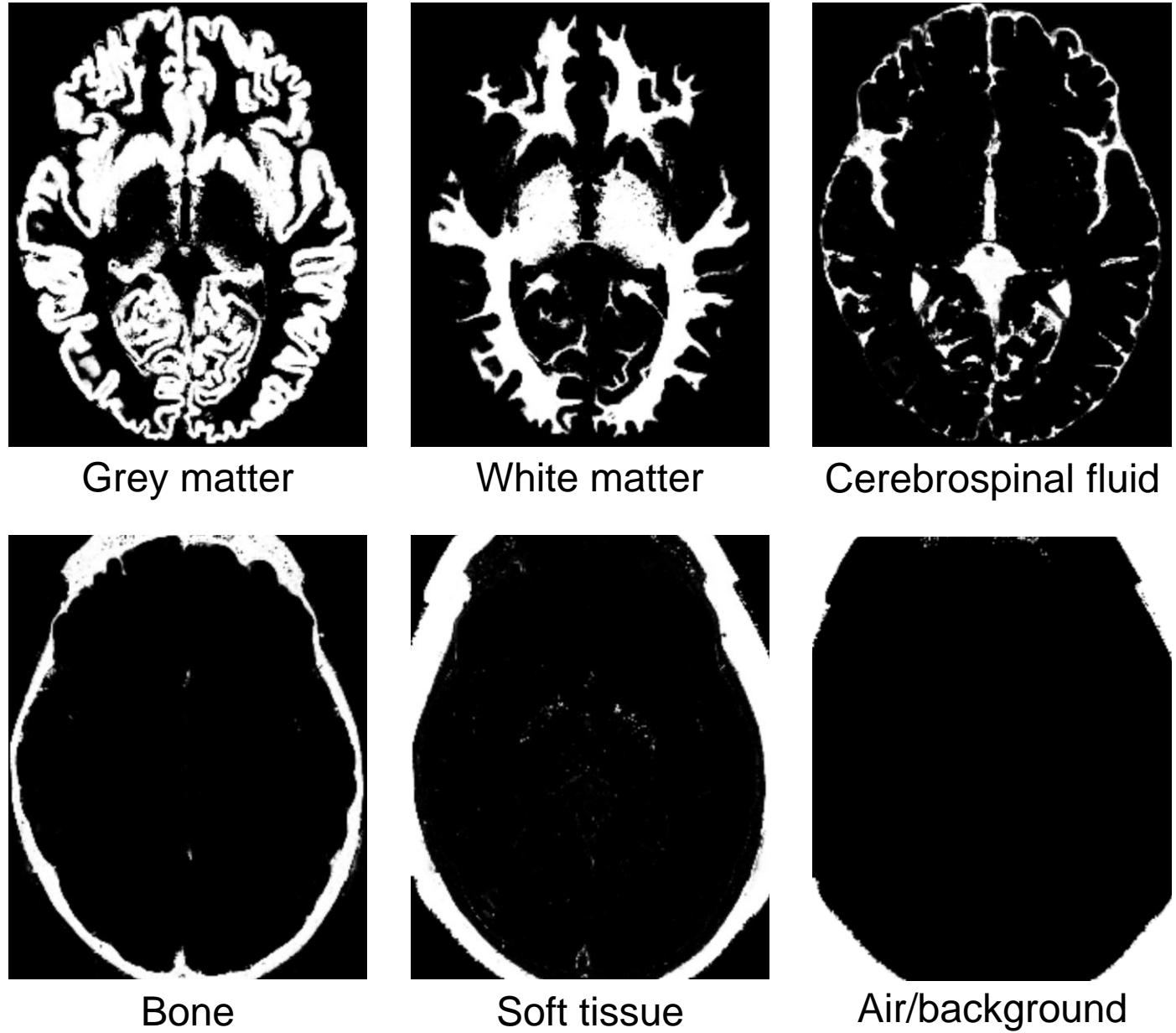
Correction of the T2-weighted Image for Intensity Non-uniformity

Output

Segmentation



Segmentation



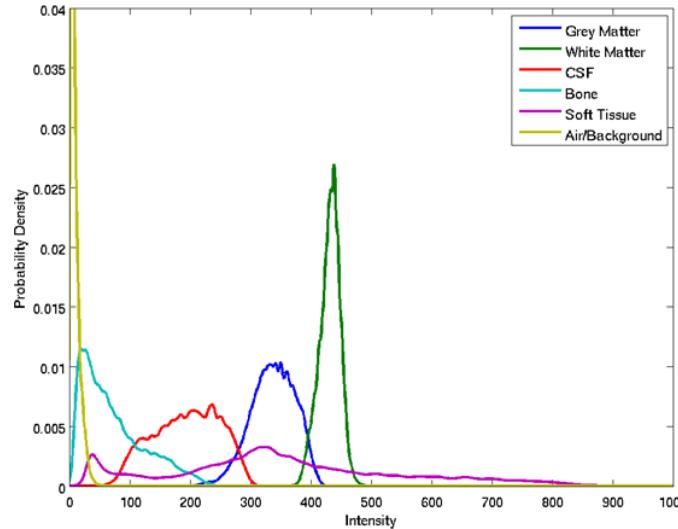
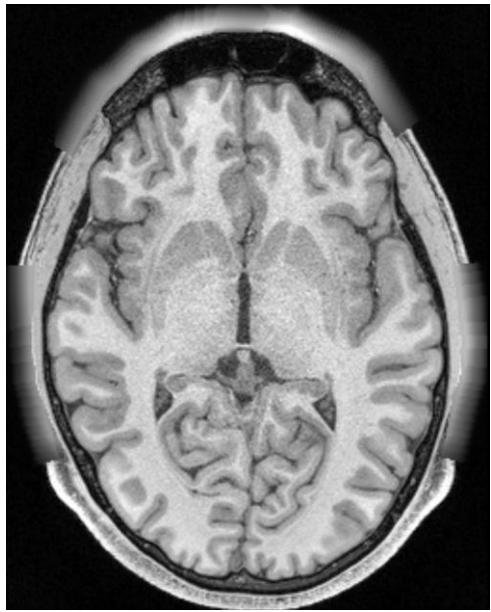
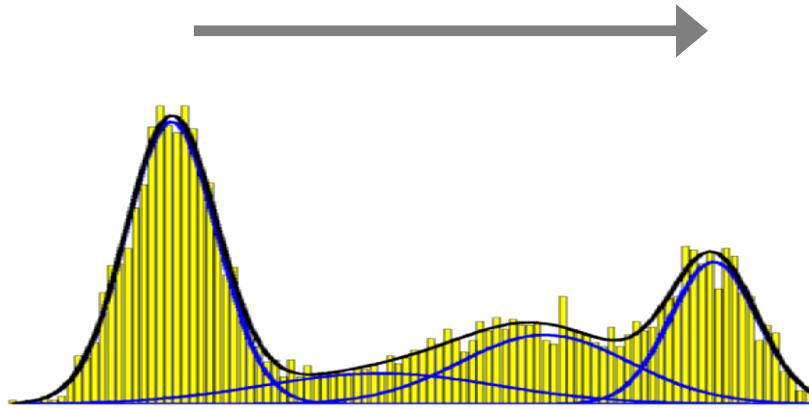
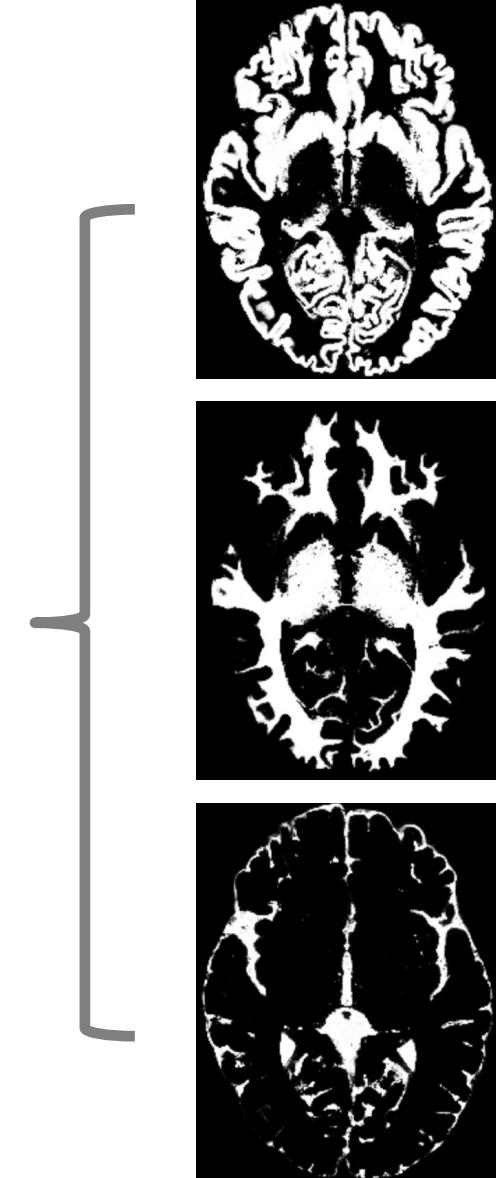


Image intensity distribution



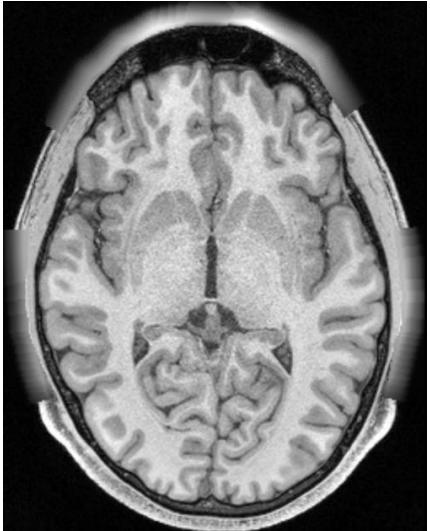
Mixture of Gaussians model



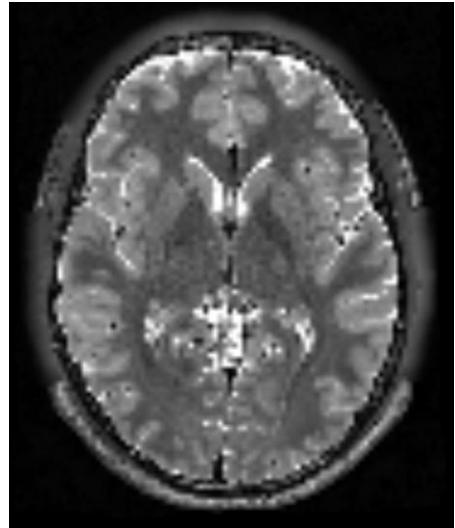
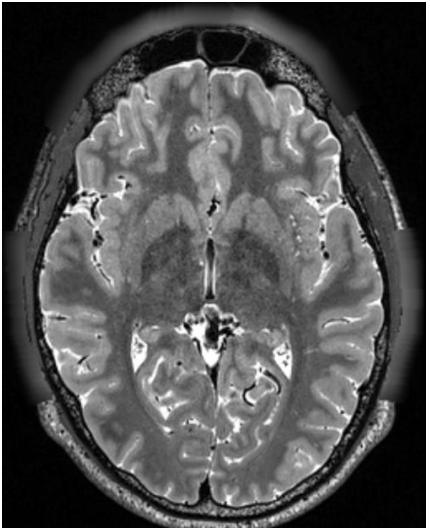
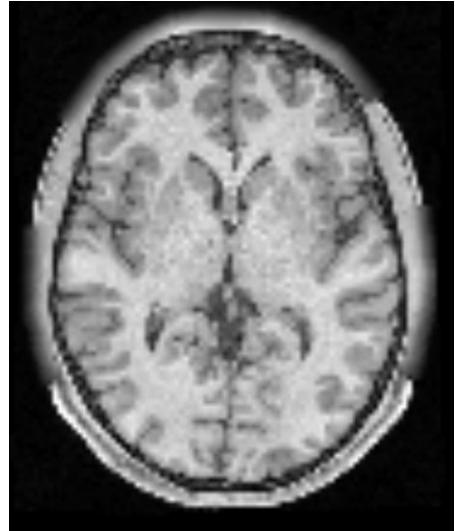
Tissue Classification based on a Mixture of Gaussians

Output

Normalization



Normalization



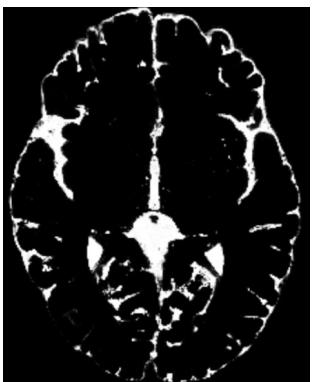
Grey matter



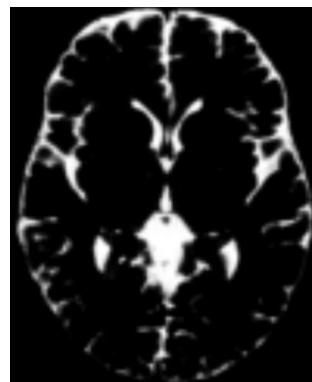
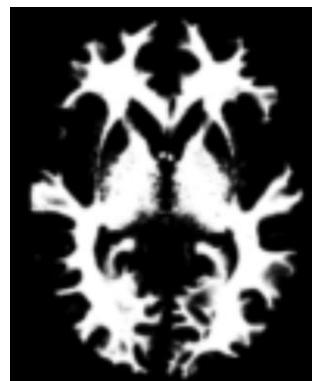
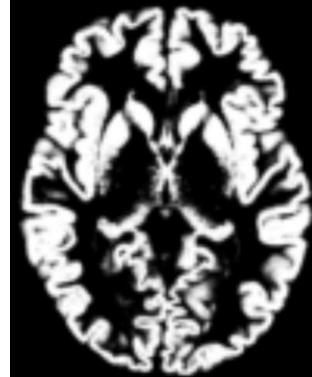
White matter



Cerebrospinal fluid



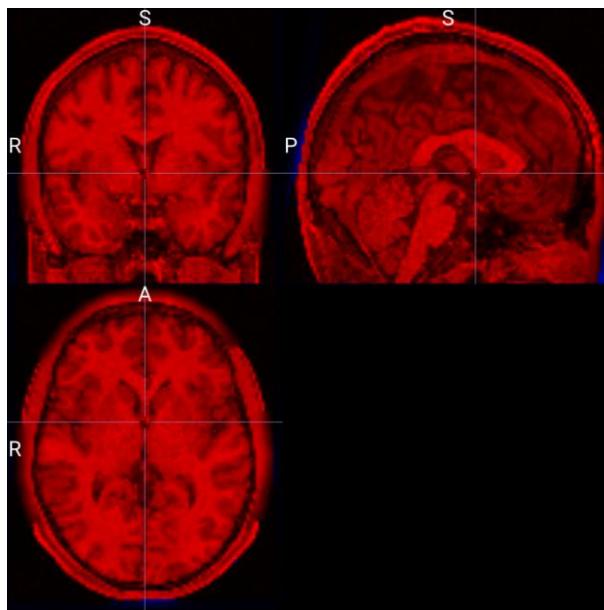
Template tissue probability maps



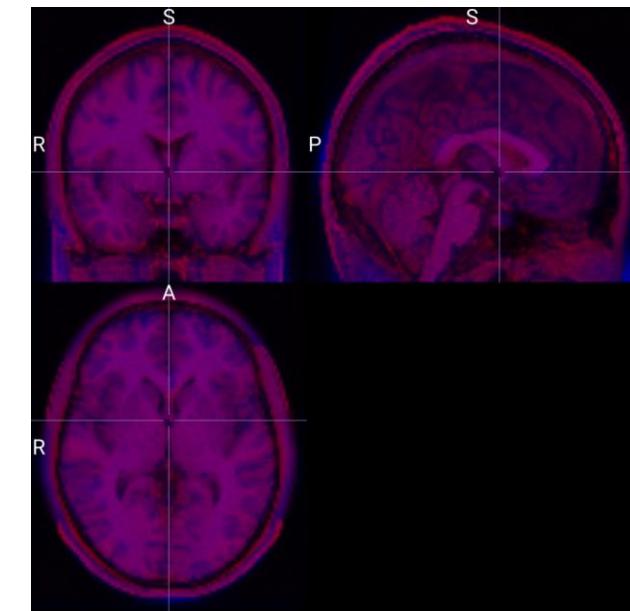
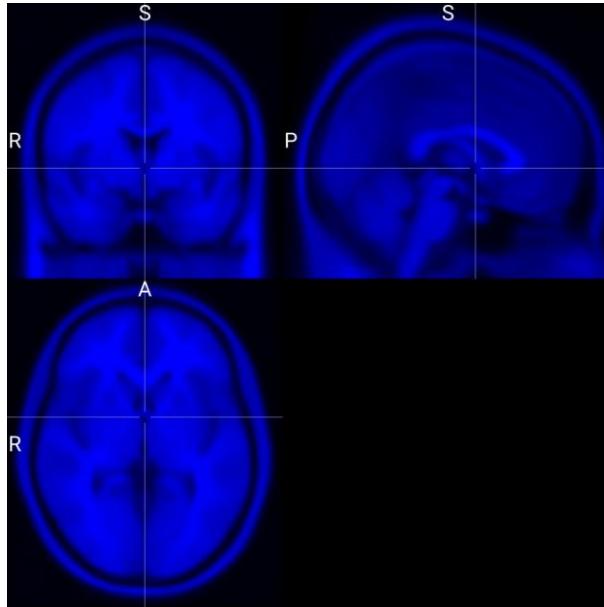
Unified Segmentation and Normalization

Confirmation

Individual's normalized brain

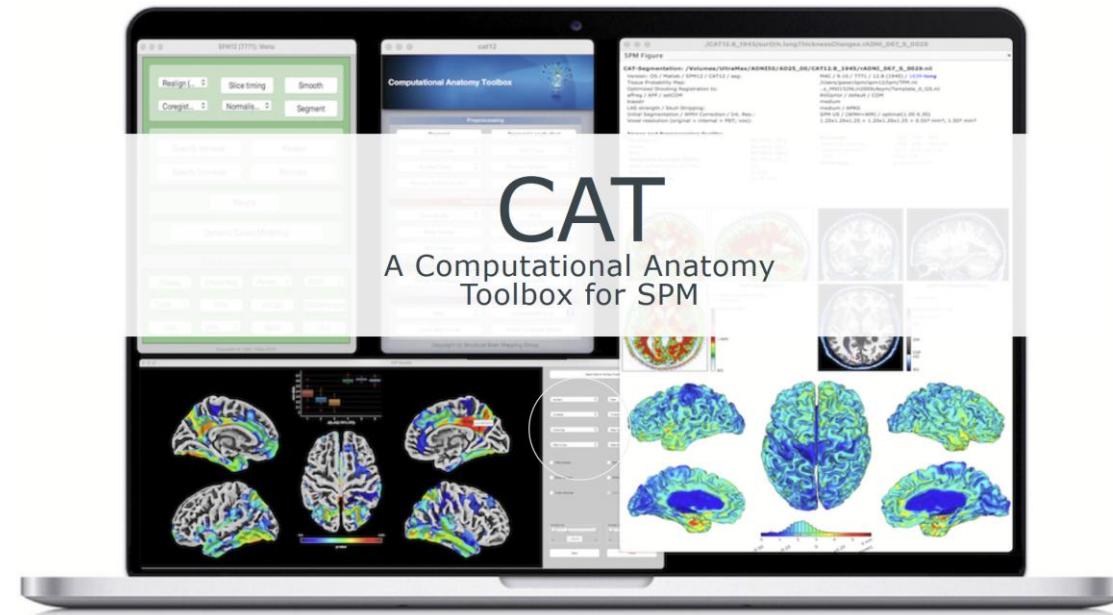


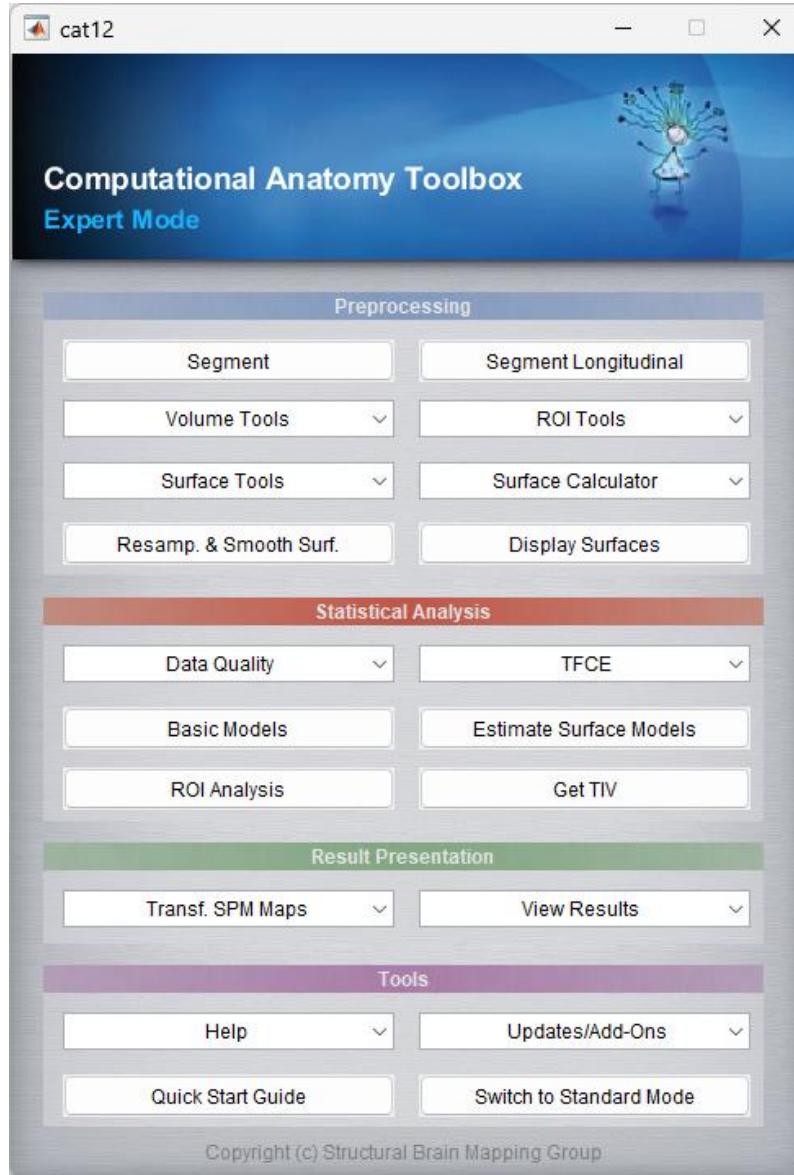
MNI152 template brain



Voxel-based Morphometry

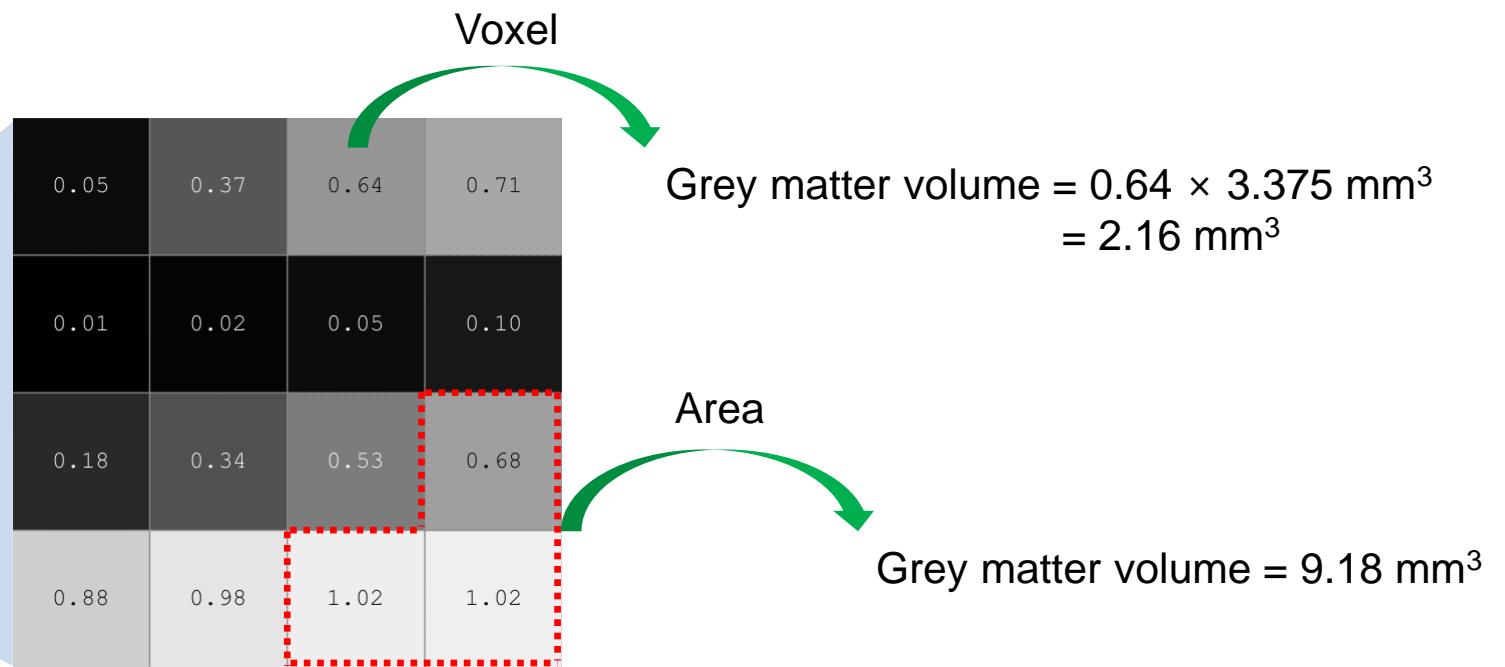
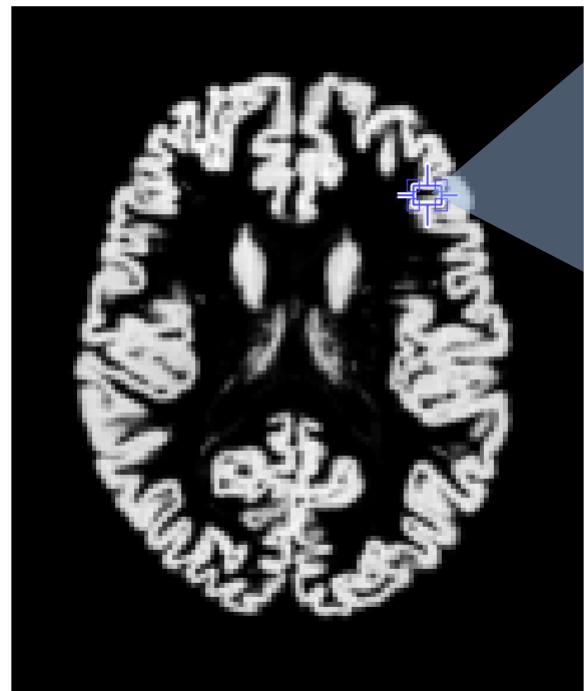
- Without defining boundaries and modeling cortical surfaces
- CAT12 [<https://github.com/ChristianGaser/cat12>]





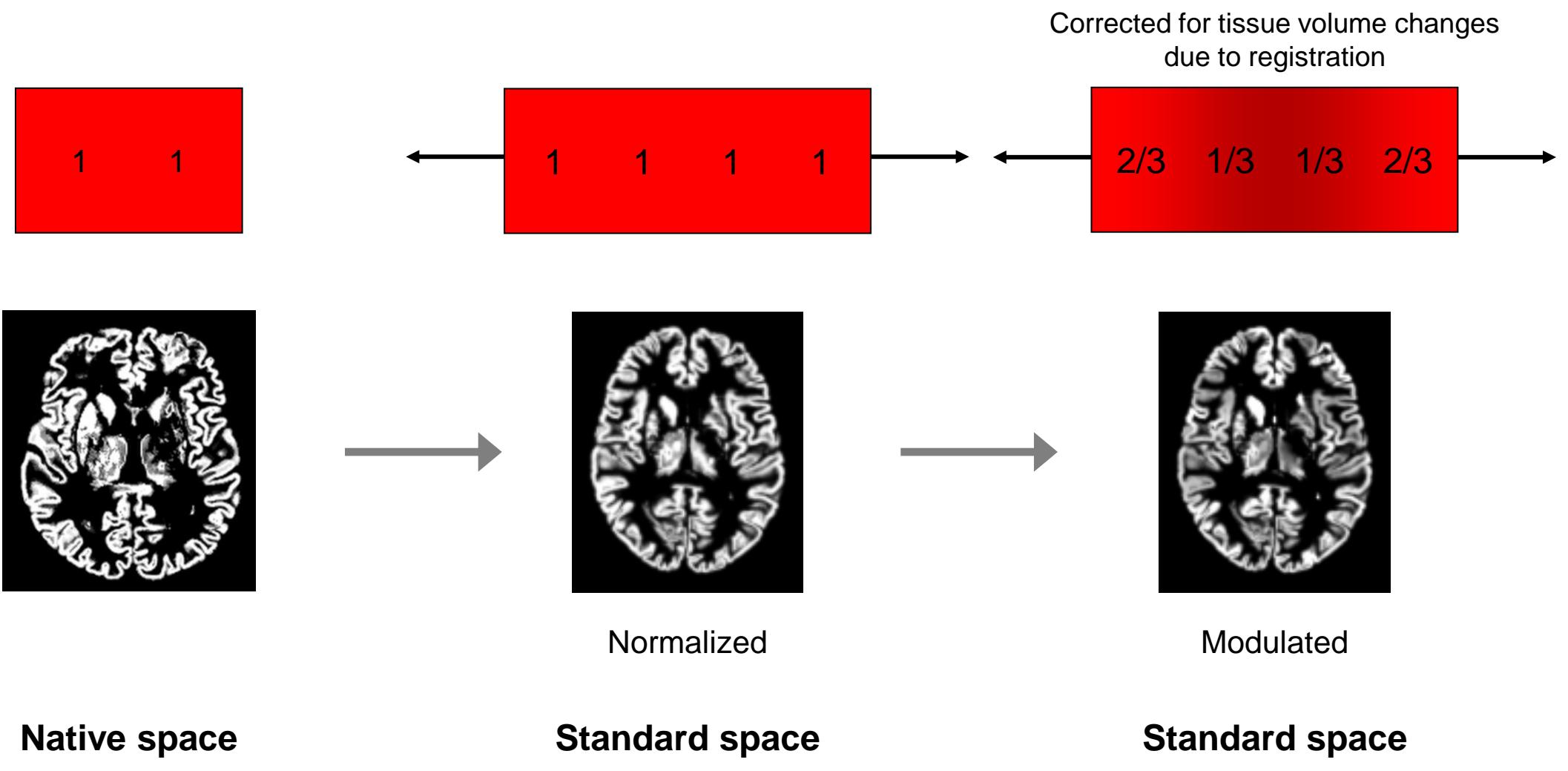
CAT12 Toolbox

- Grey matter volume
 - Computed by multiplying voxel-wise grey matter probability by voxel volume
 - For a grey matter probability map in the native space or its modulated one in the standard space

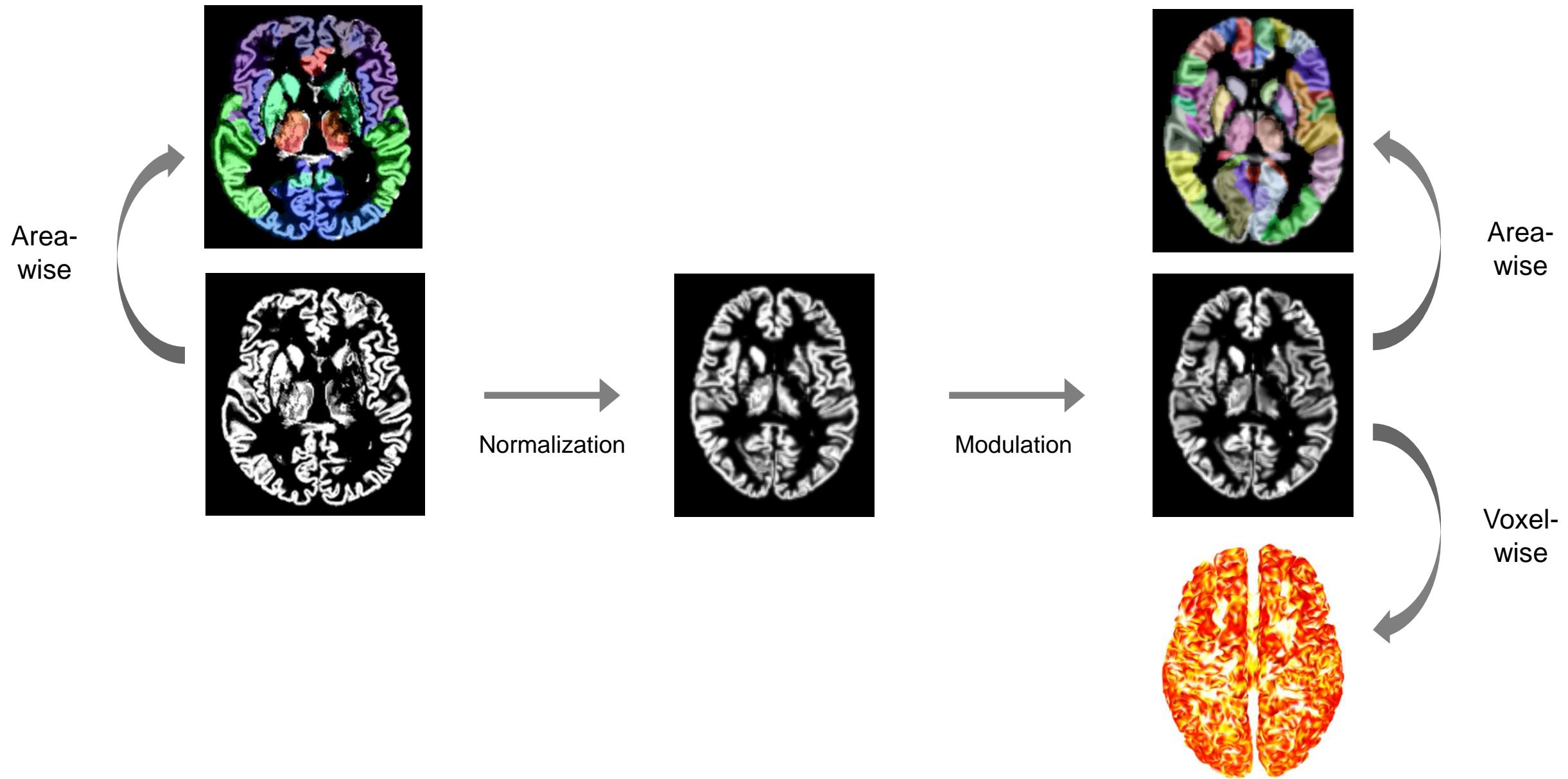


Voxel size: $1.5 \text{ mm} \times 1.5 \text{ mm} \times 1.5 \text{ mm}$
Voxel volume: 3.375 mm^3

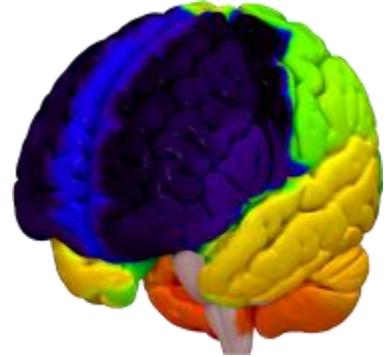
Computation of Grey Matter Volume for a Voxel or an Area



Normalization and Modulation



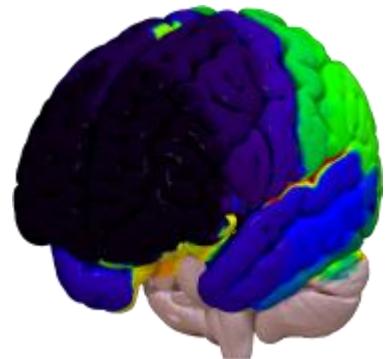
Features of Grey Matter Volume



AAL atlas



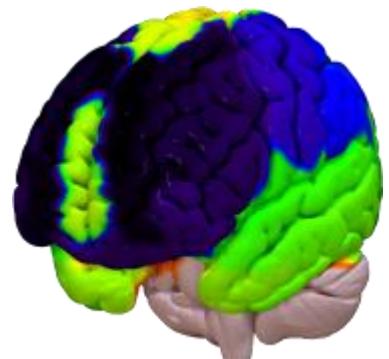
Hammers atlas



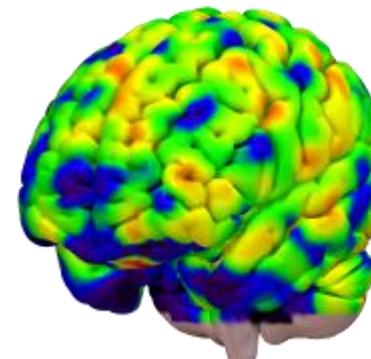
Harvard-Oxford atlas



Yeo atlas

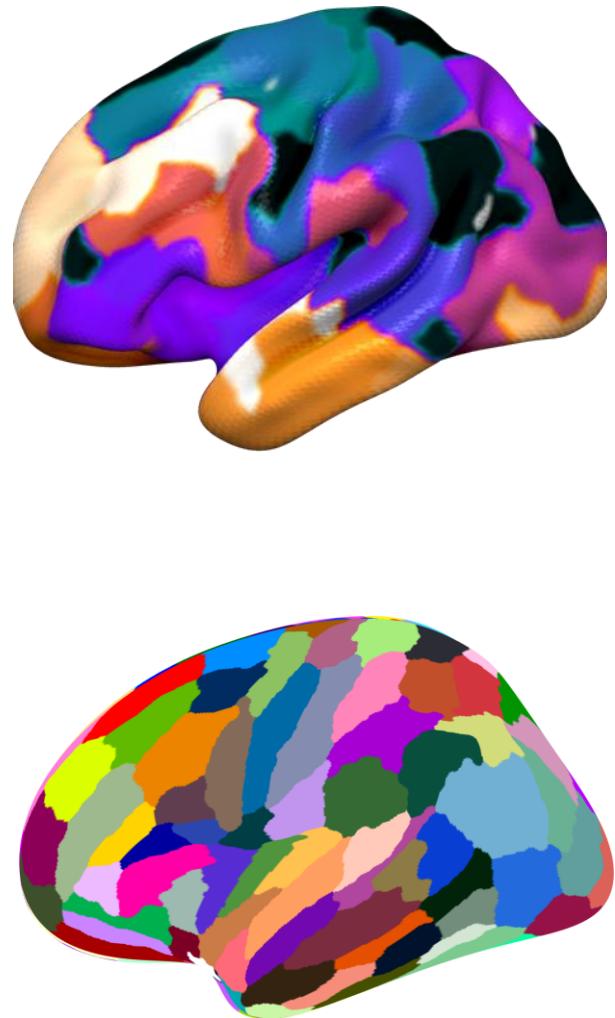


AICHA atlas

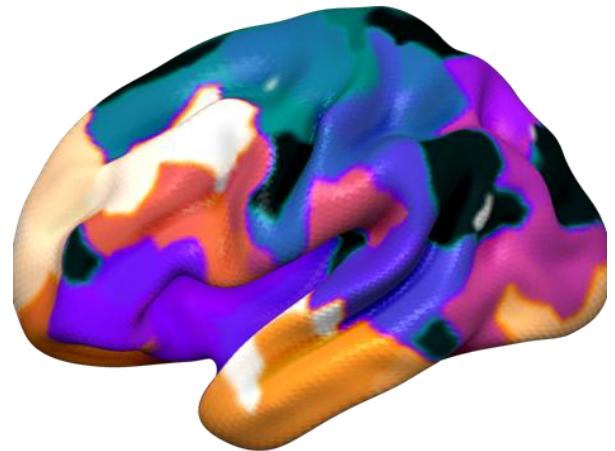


Craddock atlas

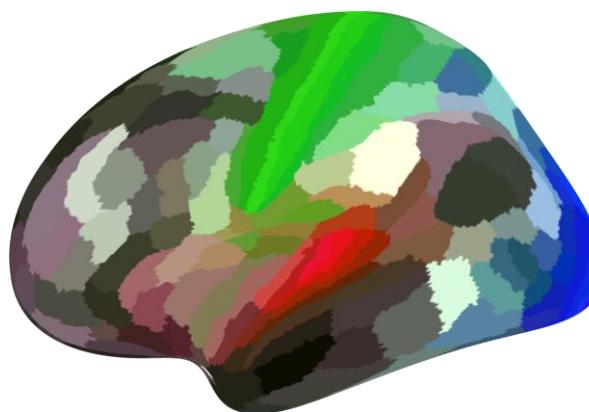
Brain Atlases



246 areas
Brainnetome atlas

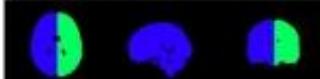
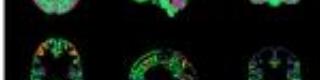
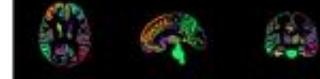


333 areas
Resting-State Correlations atlas



360 areas
HCP MMP 1.0 atlas

Higher-resolution Brain Atlases

Atlas	# of regions	Horizontal	Sagittal	Coronal	Atlas	# of regions	Horizontal	Sagittal	Coronal
Hemispheric	2				Desikan	70			
Tissue	3				DKT	83			
Yeo-7	7				AAL	116			
Yeo-7-Lib	7				Glasser	360			
Yeo-17	17				CPAC200	200			
Yeo-17-Lib	17				Schaefer200	200			
HOS	21				Schaefer300	300			
Brodmann	41				Schaefer400	400			
HOC	48				Slab907	907			
JHU	48				Schaefer1000	1000			
PrincetonVis	49				Slab1068	1068			
PP264	58				Talairach	1105			

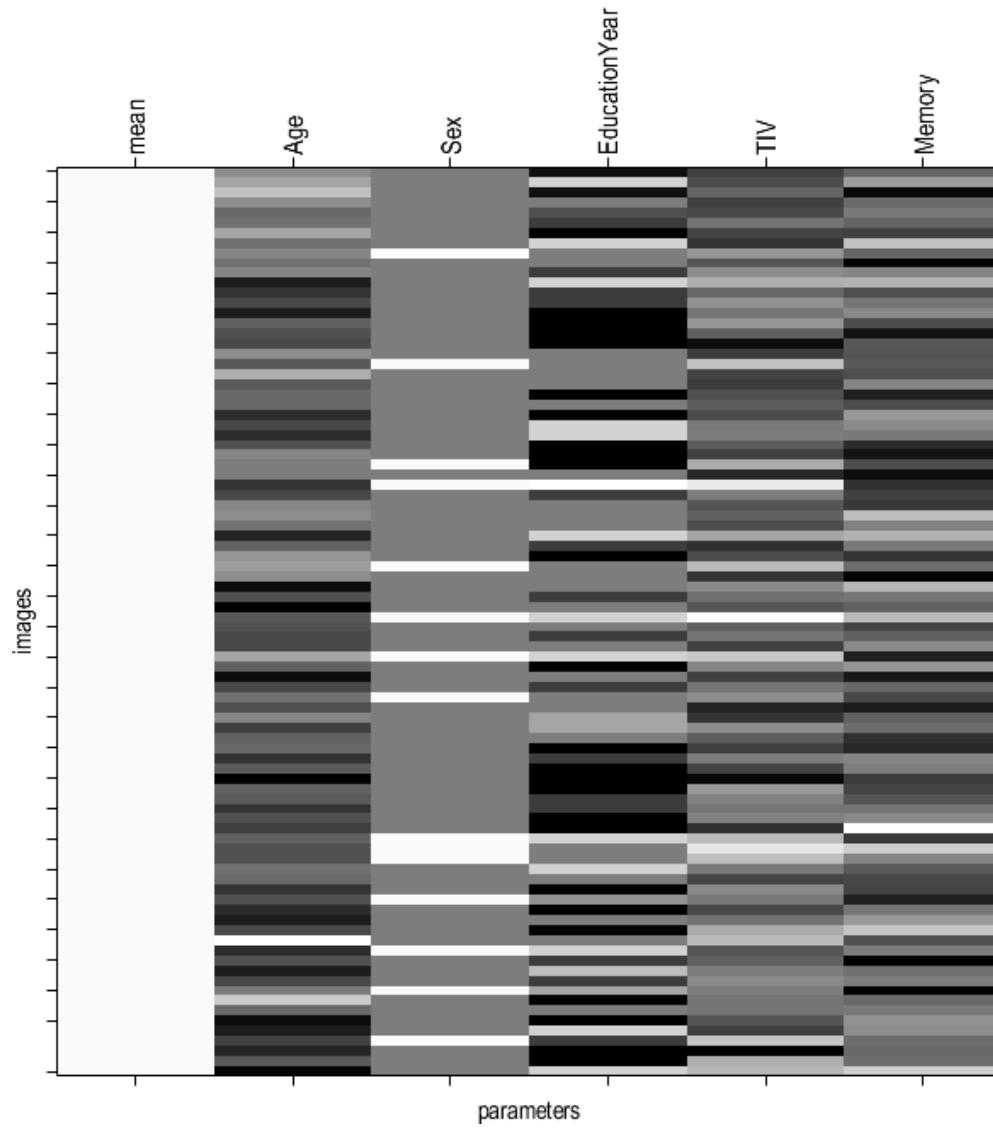
[<https://github.com/neurodata/neuroparc>]

Repository of Human Brain Parcellations

[Statistical Analysis of sMRI]

- Grey matter volume ~
 - Age +
 - Sex +
 - Education year +
 - Total intracranial volume (TIV) +
 - Memory performance

Design matrix

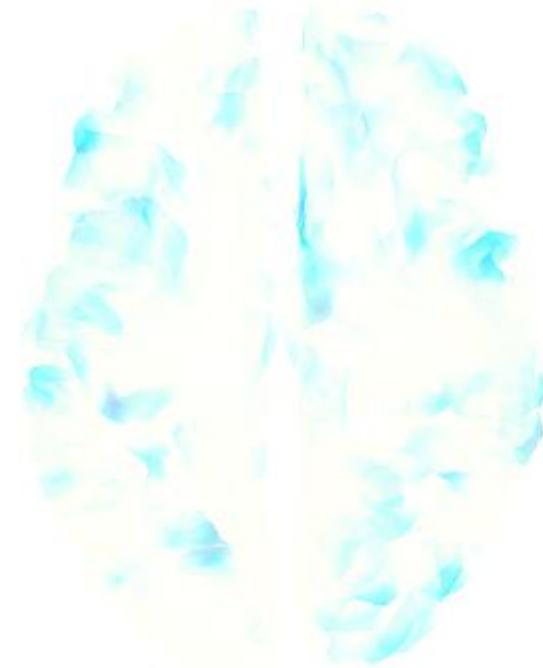


Output

Regression



Positive correlation

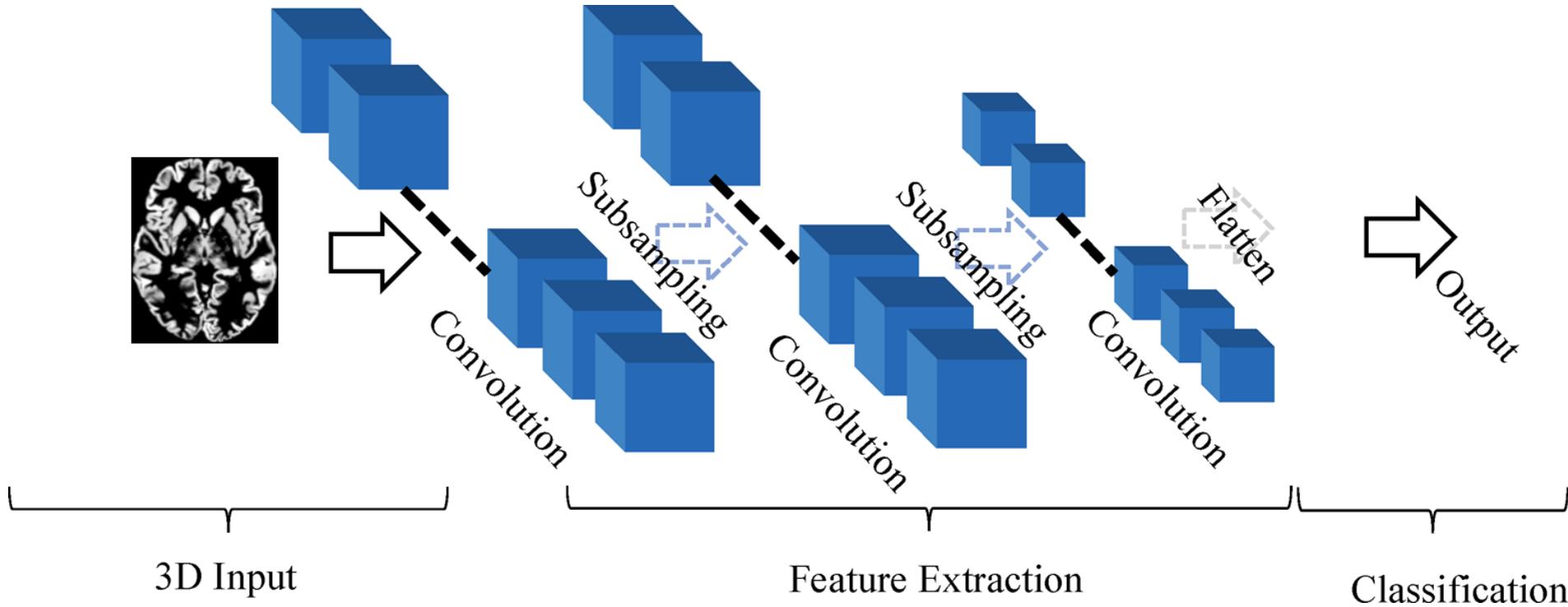


Negative correlation

- Input to machine learning models
 - Table of voxel-wise or area-wise grey matter volume values

	Features				
	Voxel or Area 1 grey matter volume	Voxel or Area 2 grey matter volume	Voxel or Area 3 grey matter volume	...	
Samples	Subject 1	-	-	-	-
	Subject 2	-	-	-	-
	Subject 3	-	-	-	-
	:	-	-	-	-

- Grey matter volume map



[Adapted from Singh et al., 2020]

Application of Deep Learning to Grey Matter Volume Maps

Surface-based Morphometry

- Independent of registration and modulation
- Not applicable to subcortical regions
- FreeSurfer [\[https://github.com/freesurfer/freesurfer\]](https://github.com/freesurfer/freesurfer)

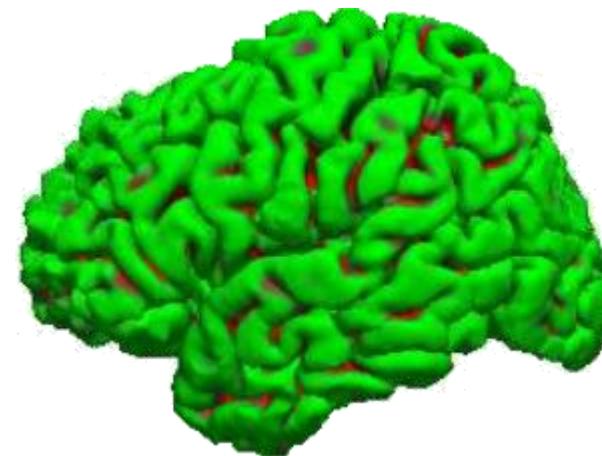


FreeSurfer

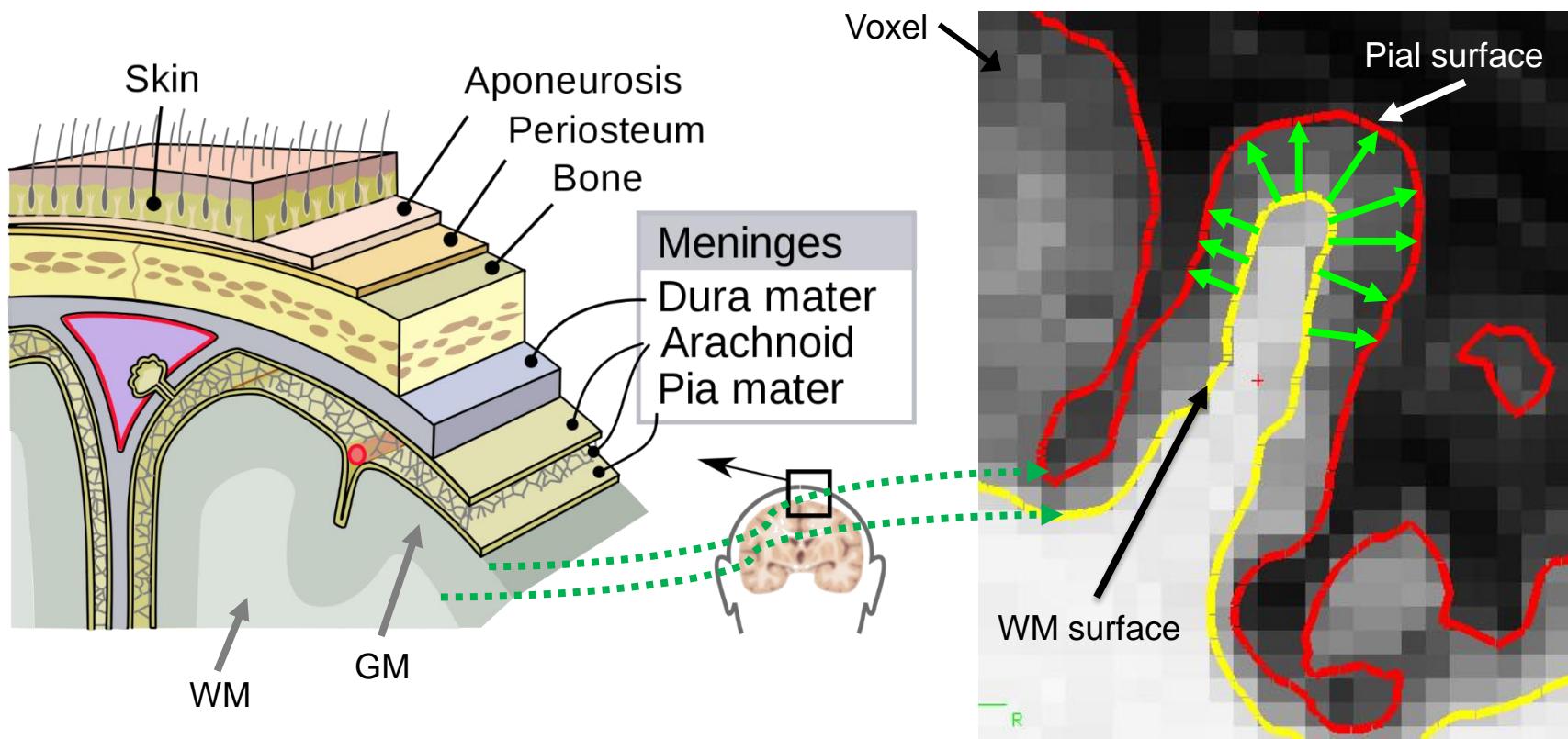
- Surface reconstruction
 - White matter surface: inner cortical boundary between the grey matter and white matter
 - Pial surface: outer cortical boundary between the grey matter and pia mater



White matter surface

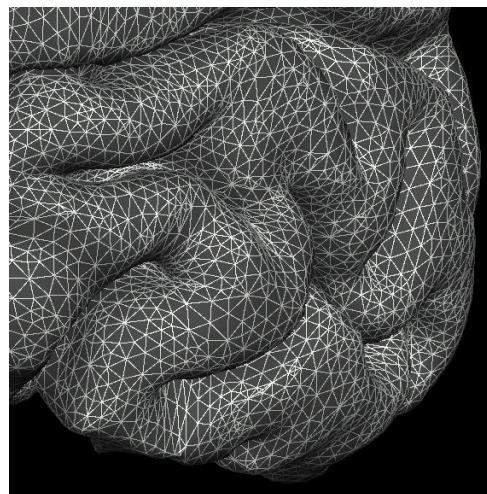
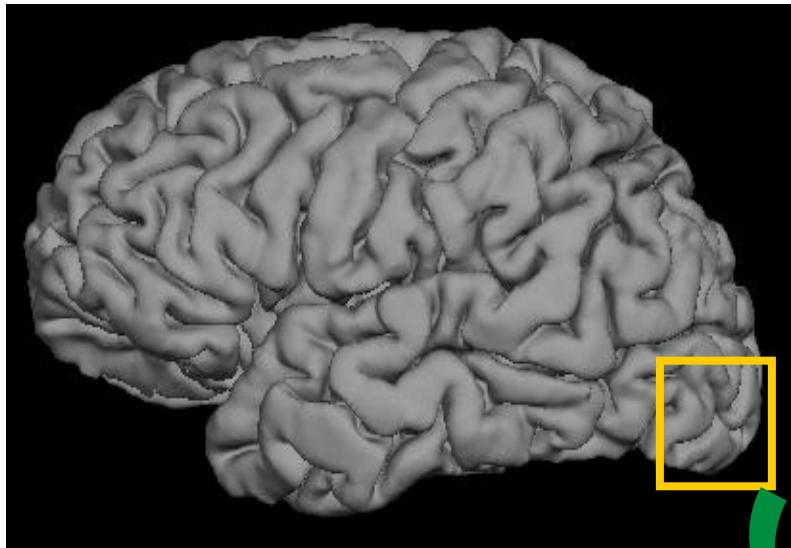


Pial surface



[<https://www.physio-pedia.com/Meninges>]

Cortical Surfaces beneath Cranial Meninges

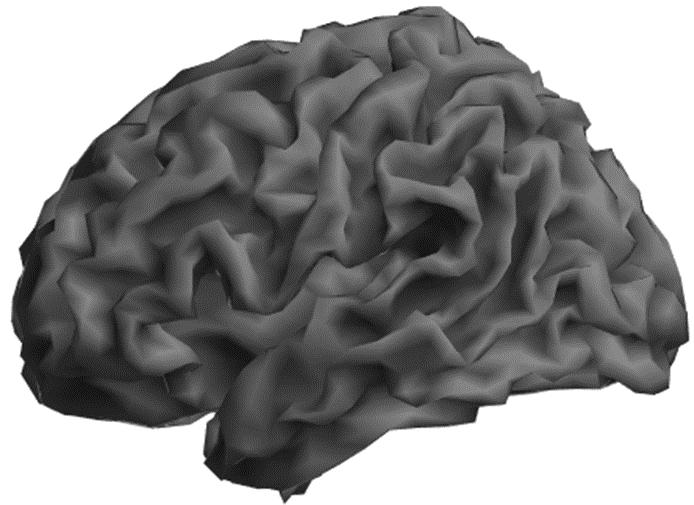


Vertices and faces

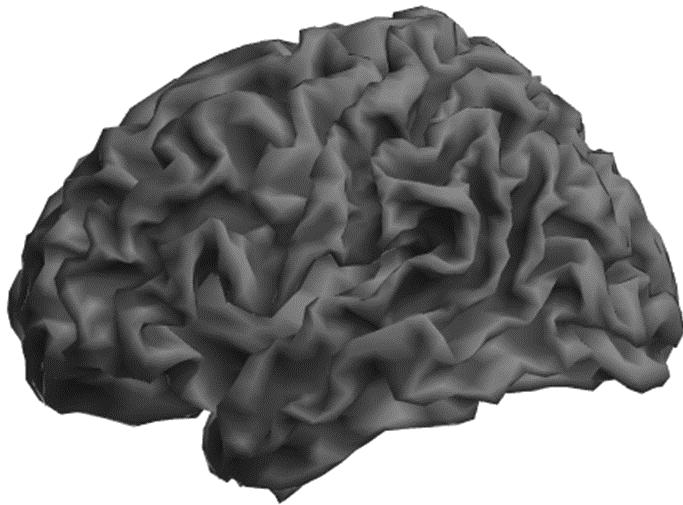


[<https://surfer.nmr.mgh.harvard.edu/>]

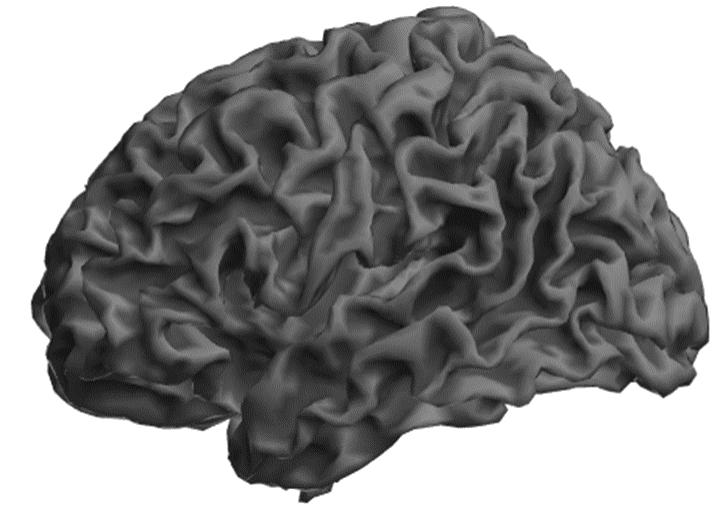
Surface Representation of the Brain



5124 vertices



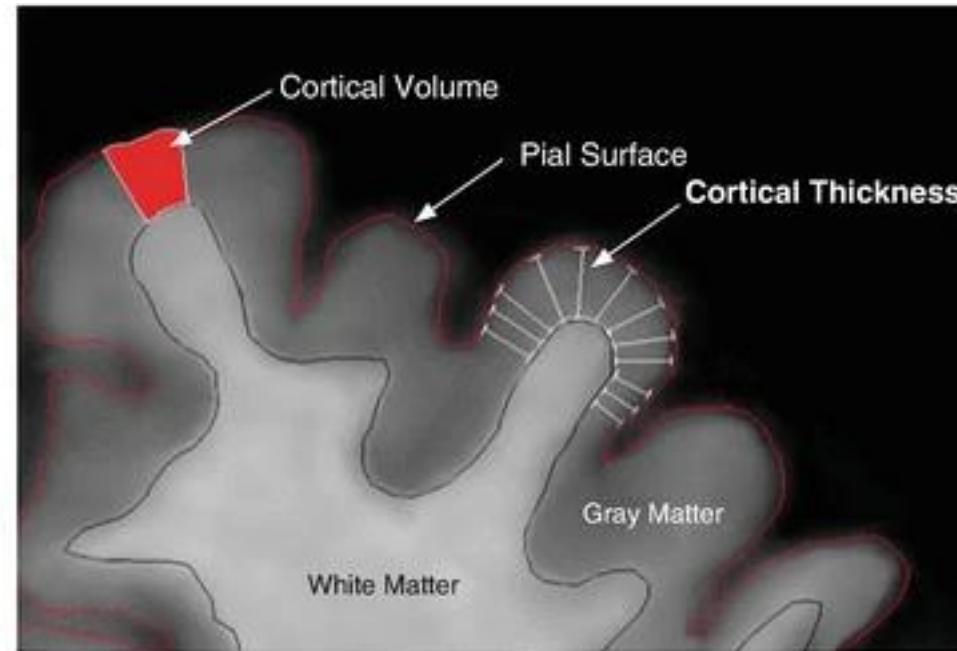
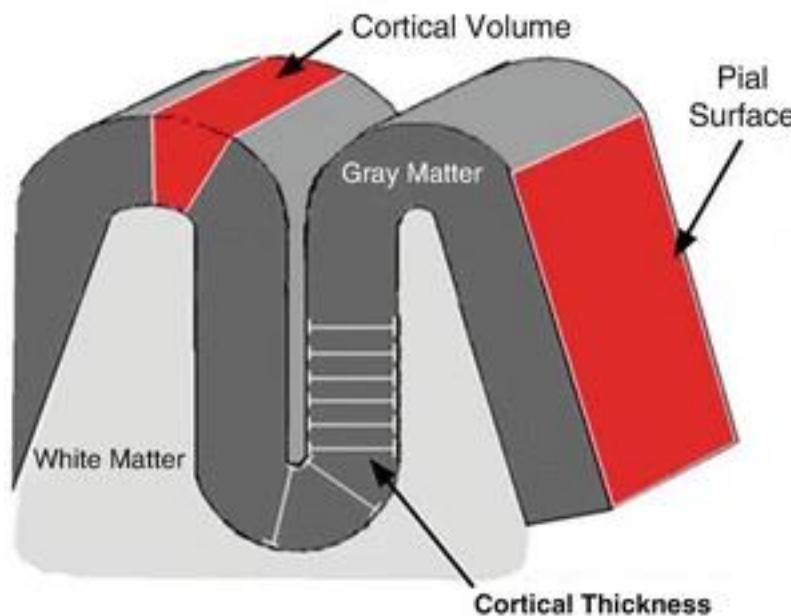
8196 vertices



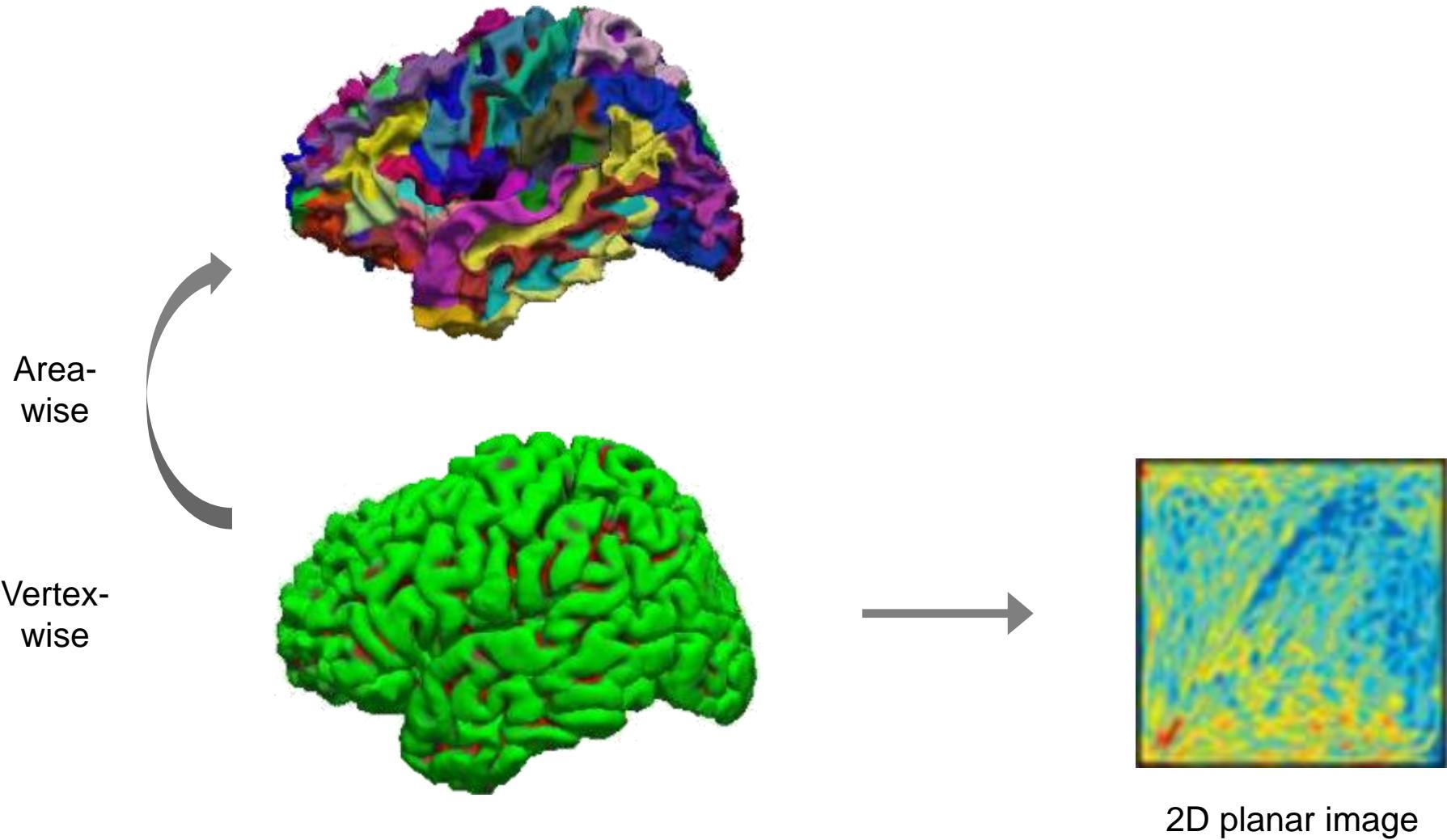
20484 vertices

Surface Representation with Different Numbers of Vertices

- Cortical thickness
 - Distance between the inner (white matter surface) and outer (pial surface) cortical boundaries



[Gale and Huff, 2017]

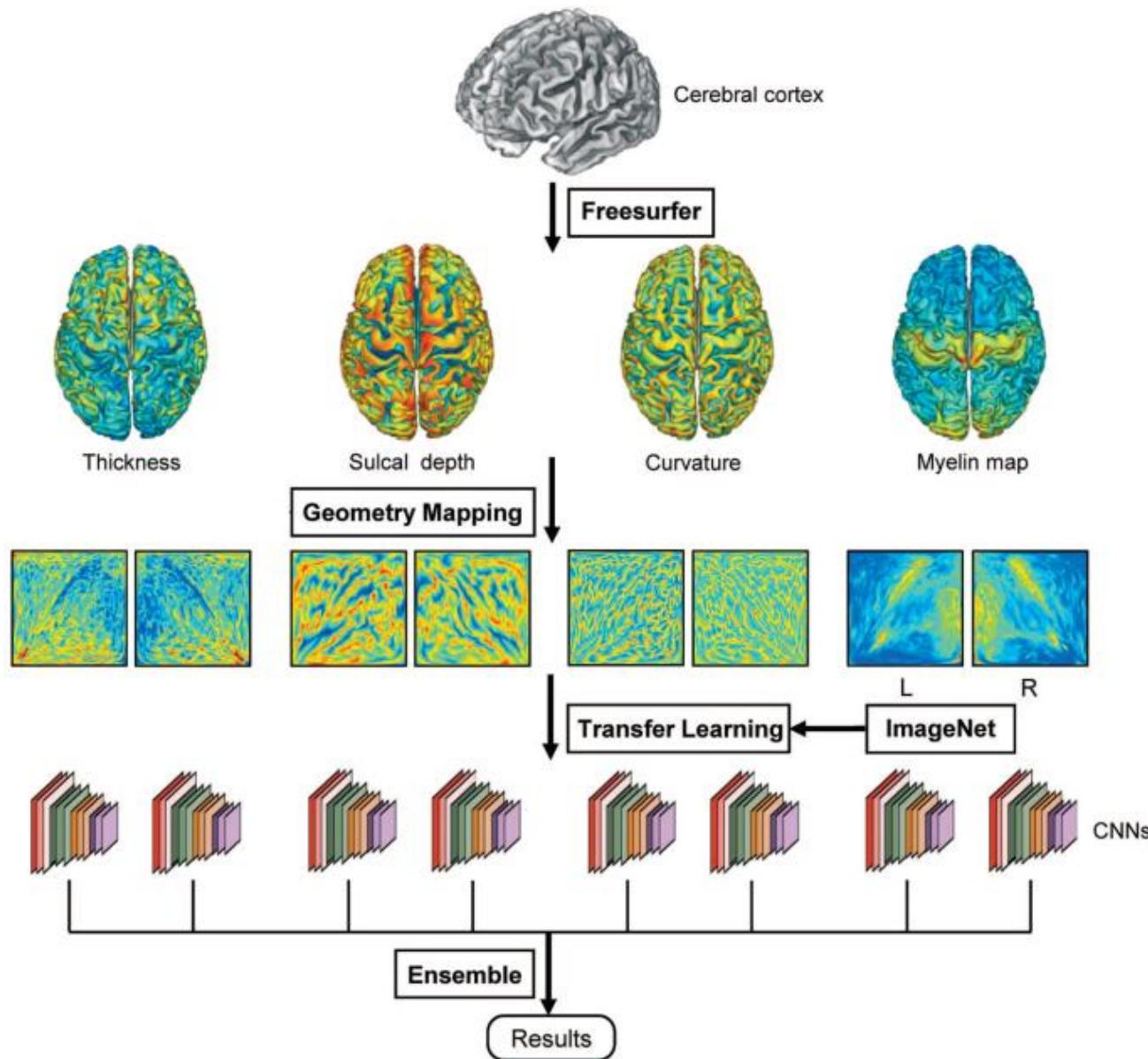


Features of Cortical Thickness

- Input to machine learning models
 - Table of vertex-wise or area-wise cortical thickness values

	Features				
	Vertex or Area 1 cortical thickness	Vertex or Area 2 cortical thickness	Vertex or Area 3 cortical thickness	...	
Subject 1	-	-	-	-	
Subject 2	-	-	-	-	
Subject 3	-	-	-	-	
:	-	-	-	-	

- Cortical thickness planar map

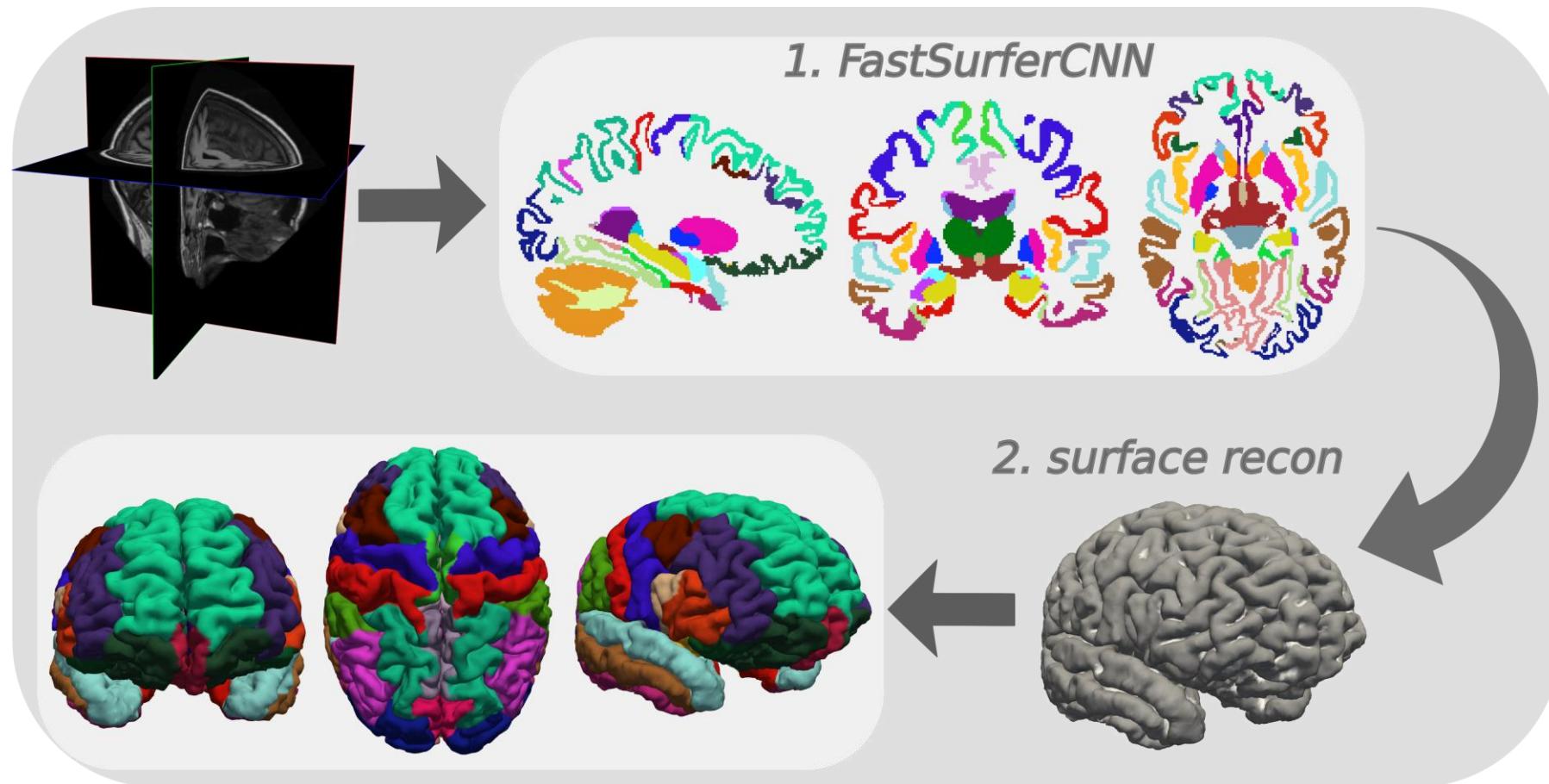


[Gao et al., 2022]

Application of Deep Learning to Cortical Morphometric Maps

Automated Brain Morphometry

- Provides objective measurements of brain structures and their relationships
- Cortical metrics: Automated measurement of cortical thickness, surface area, and volume
- Subcortical segmentation: Precise delineation and volumetric analysis of deep brain structures



[Henschel et al., 2020; <https://github.com/Deep-MI/FastSurfer>]

FastSurfer: Volumetric and Surface-based Cortical Thickness Analysis

Software	FDA Approved	MFDS Approved	EU CE Marked	URL	Country	Company	Character
NeuroQuant®	FDA approved	NA	CE marked	https://cortechs.ai/	USA	Cortechs Lab	NeuroQuant, LesionQuant*
Neuroreader®	FDA approved	NA	CE marked	https://brainreader.net/	USA	Brainreader	
Icobrain	FDA approved	NA	CE marked	https://icomatrix.com/	EU	Icomatrix	Icobrain MS, Icobrain DM, Icobrain TBI, Icobrain ep
Quantib® Brain	FDA approved	NA	CE marked	https://www.quantib.com/	Netherlands	Quantib	
syMRI® Neuro	FDA approved	NA	CE marked	https://syntheticmr.com/	Sweden		Multicontrast [†] Volumetry (GM, WM, CSF volume)
InBRAIN®	NA	MFDS approved	NA	https://www.inbrain.co.kr/	South Korea	Midas IT	
Neurol	NA	MFDS approved	NA	http://www.infomeditech.com/ https://neurozen.ai/	South Korea	Infomeditech	
mdbrain	NA	NA	CE marked	https://www.qmenta.com	EU	Qmenta Inc	
DeepBrain®	NA	MFDS approved	CE marked	https://www.vuno.co/	South Korea	Vuno	
Atroscan	NA	MFDS approved	NA	http://jlkgroup.com	South Korea	JLK	

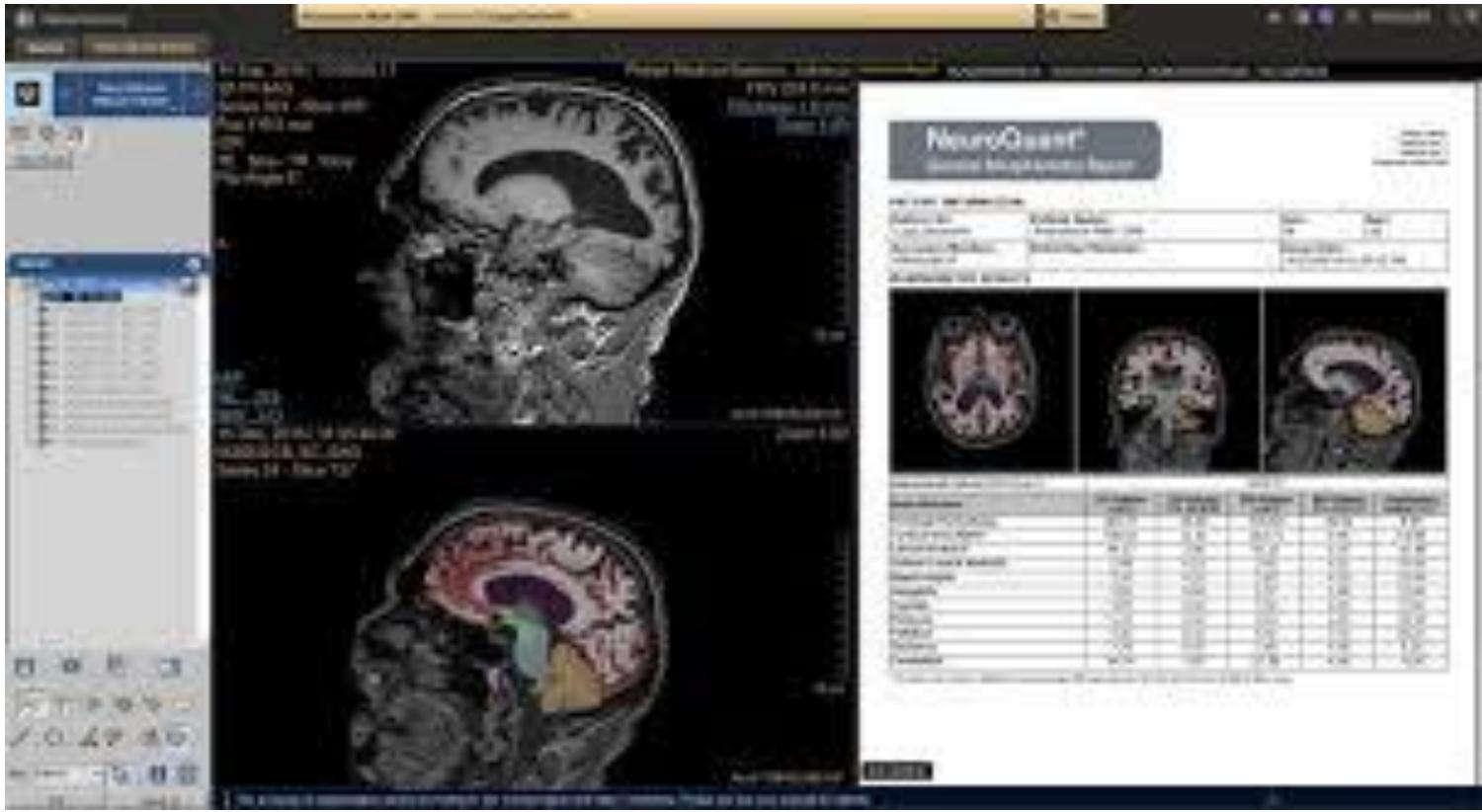
*LesionQuant: measurement of WM lesion volume.

[†]Multicontrast: acquisition of multiple pre-defined contrast weighted images such as T1W, T2W and T2W FLAIR, as well as double inversion recovery and phase sensitive inversion recovery using synthetic MRI.

CSF = cerebrospinal fluid, EU CE Marked = conformite Europeenne marked, FDA = Food and Drug Administration, FLAIR = fluid attenuated inversion recovery, GM = grey matter, MFDS = Ministry of Food and Drug Safety, NA = not applicable, T1W = T1-weighted, T2W = T2-weighted, WM = white matter

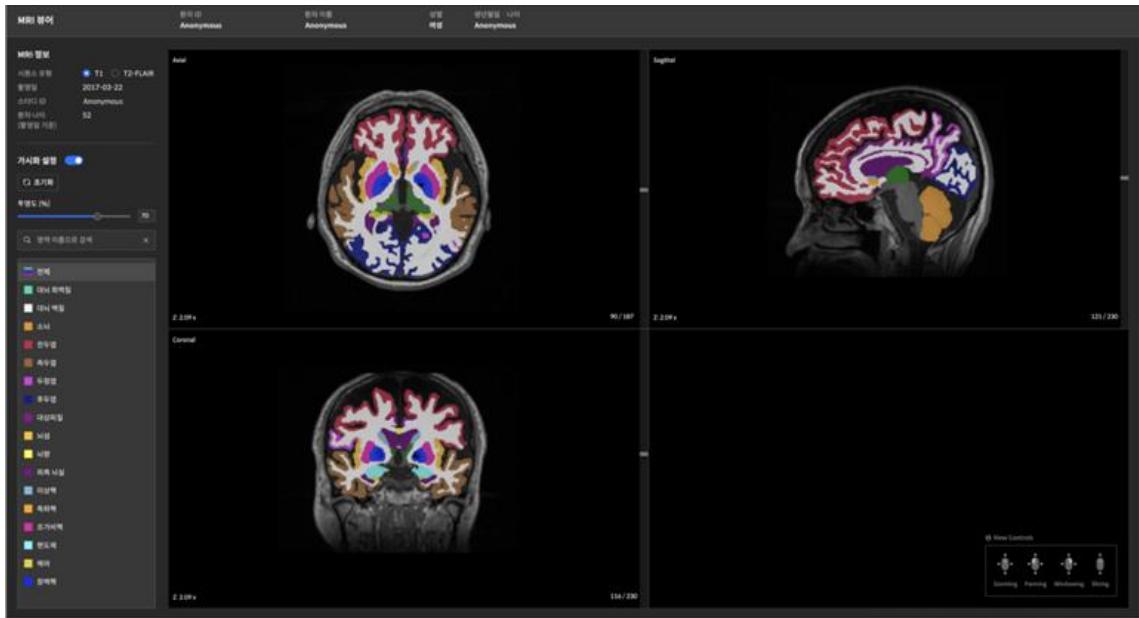
[Lee et al., 2021]

Commercially Available Brain Morphometry Software



[<https://www.cortechs.ai/>]

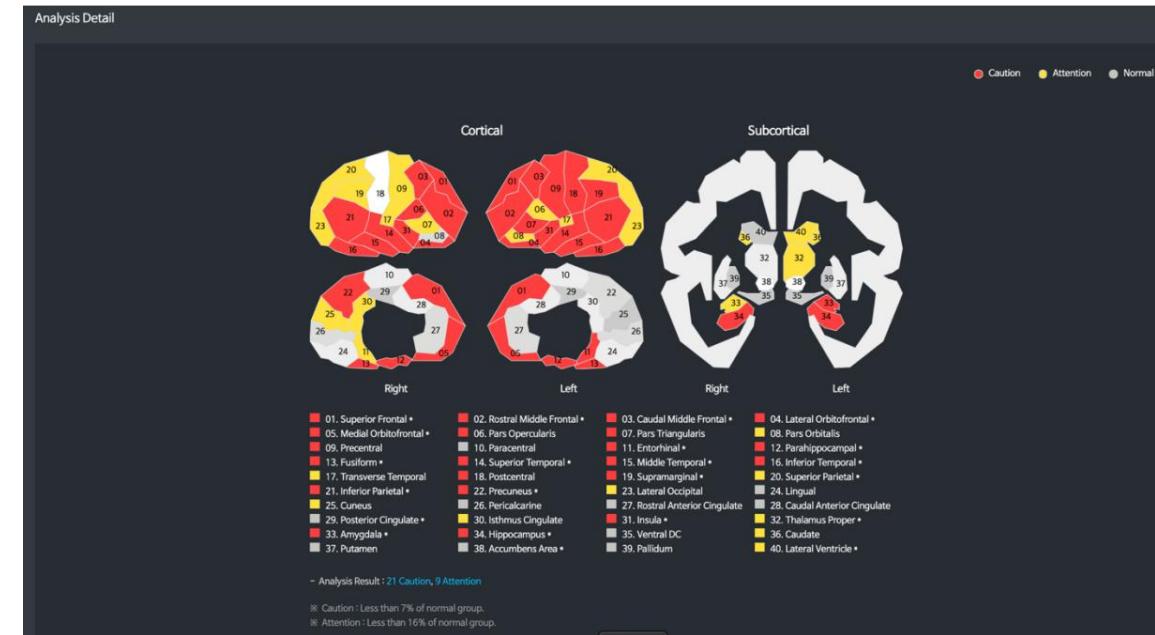
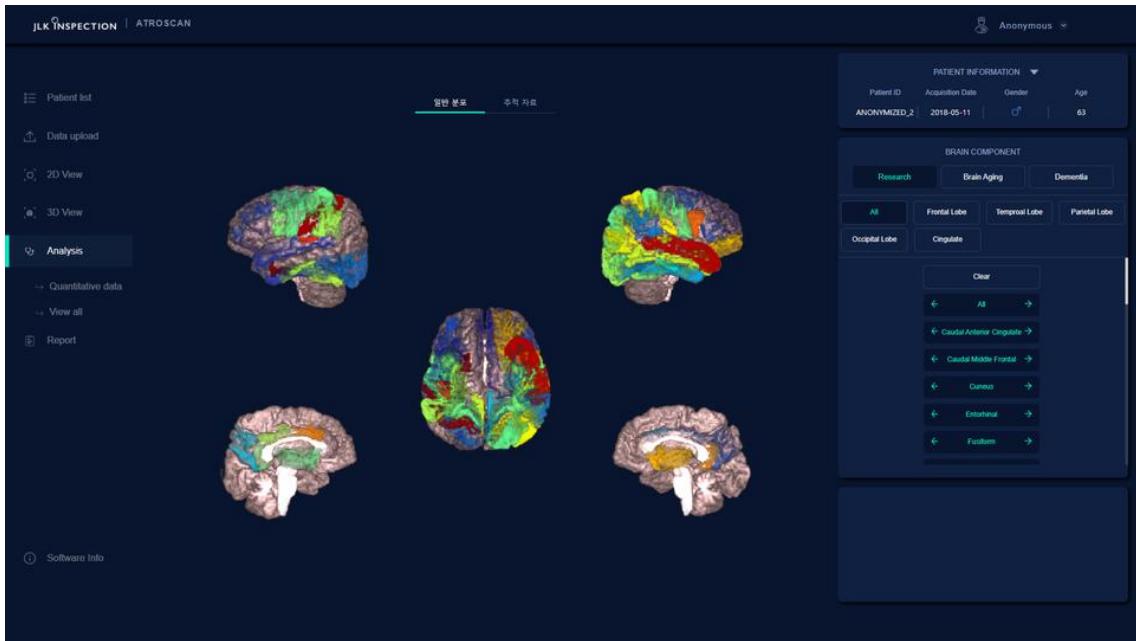
NeuroQuant, Developed by Cortechs.ai, Offering Automated Volumetric Brain Structure Analysis



neurophet AQUA



VUNO® Med-DeepBrain

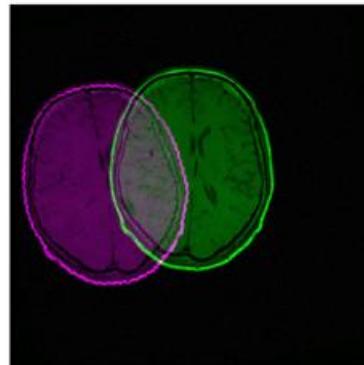


NEUROZEN Neuro I

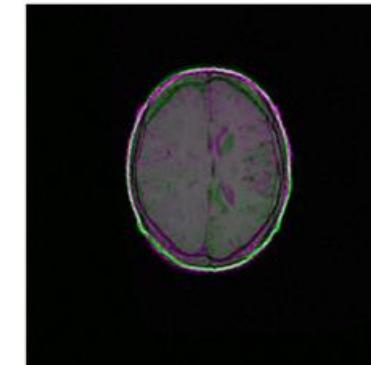
sMRI as Anatomical Reference

- Anatomical alignment of other modalities of MRI
 - Within-subject between-modality registration

Rigid registration
(global shift and rotation)

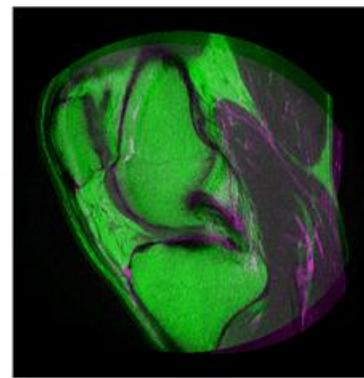


Registration

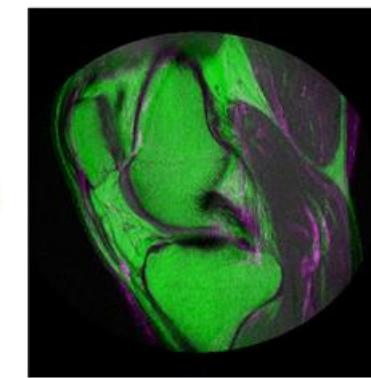


Within-subject within-modality

Affine registration
(global shift, rotation, scale, and shear)



Registration



Within-subject between-modality

Deformable registration
(local transformations)



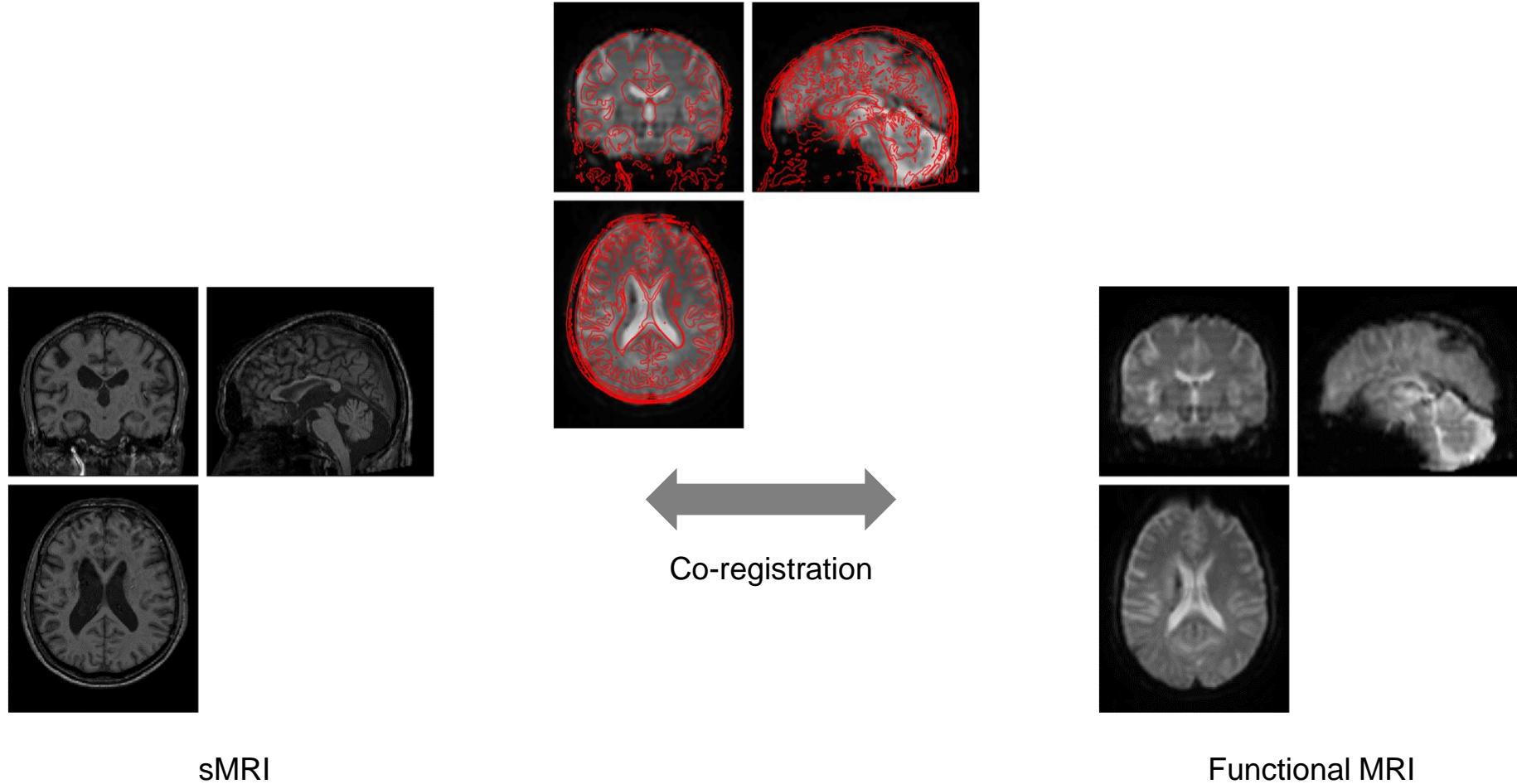
Registration



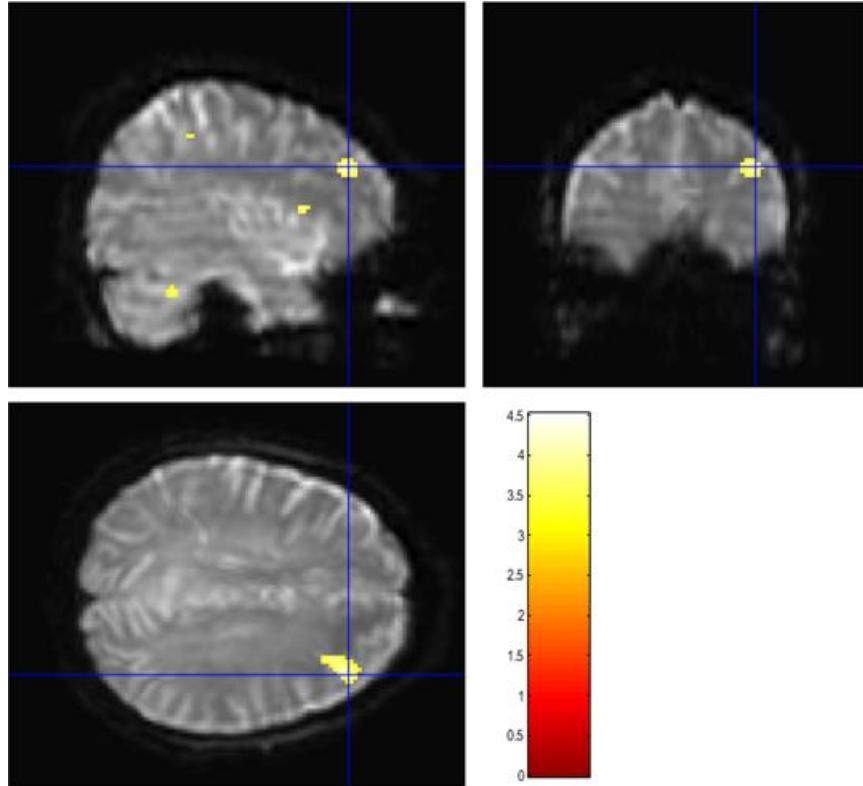
Between-subject

[<https://kr.mathworks.com/help/medical-imaging/ug/medical-image-registration.html>]

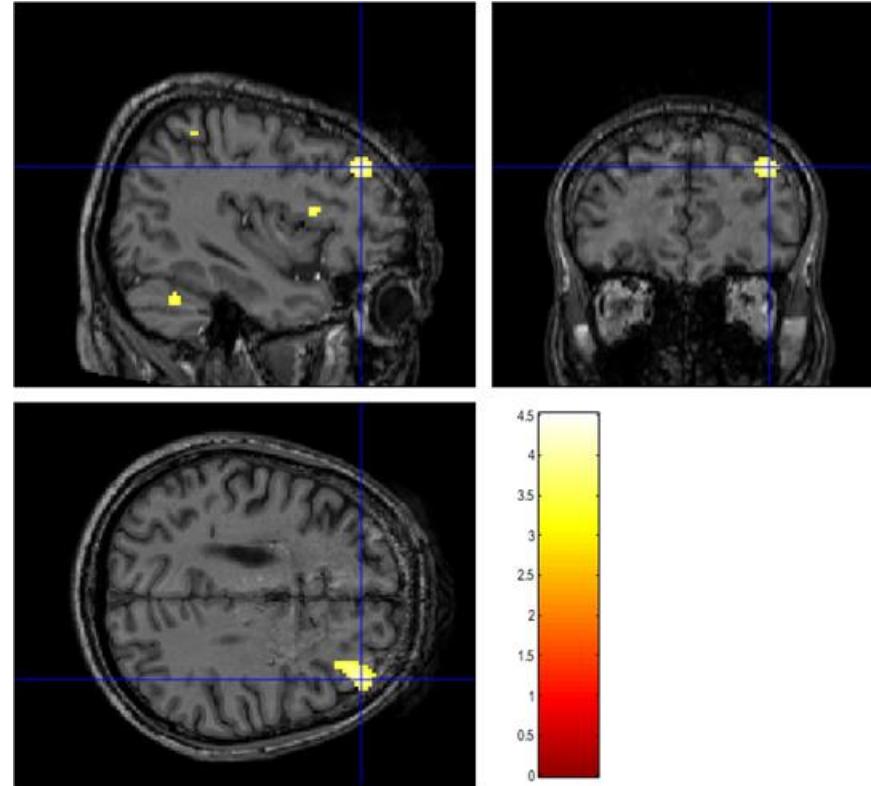
Image Registration



Co-registration between sMRI and Functional MRI



Brain activation map overlaid on a functional image



Brain activation map overlaid on a structural image

Anatomical Localization of Brain Activation