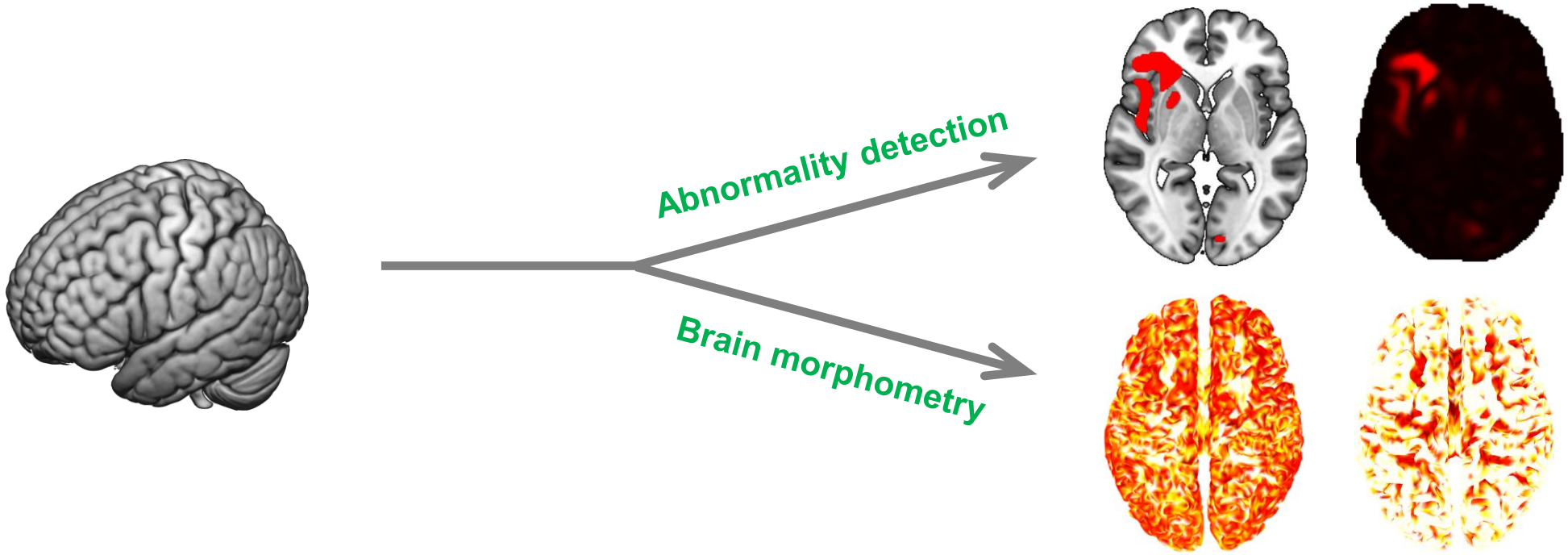
Medical/Bio Research Topics Ⅰ: Week 04 (25 March 2025)

Structural MRI (2):
Data Processing Methods

구조 자기공명영상 (2):
데이터 처리 방법

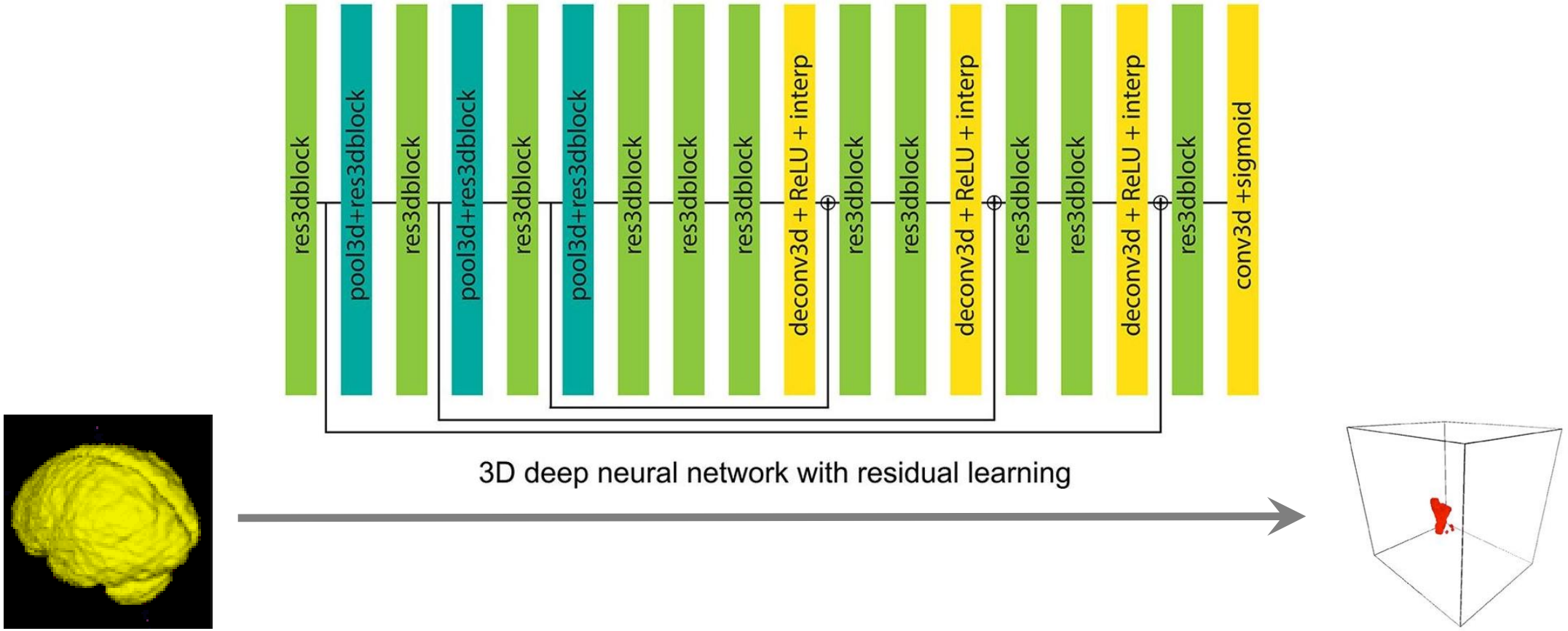
Brain Mapping with Structural MRI (sMRI)

- T1/T2-weighted sMRI



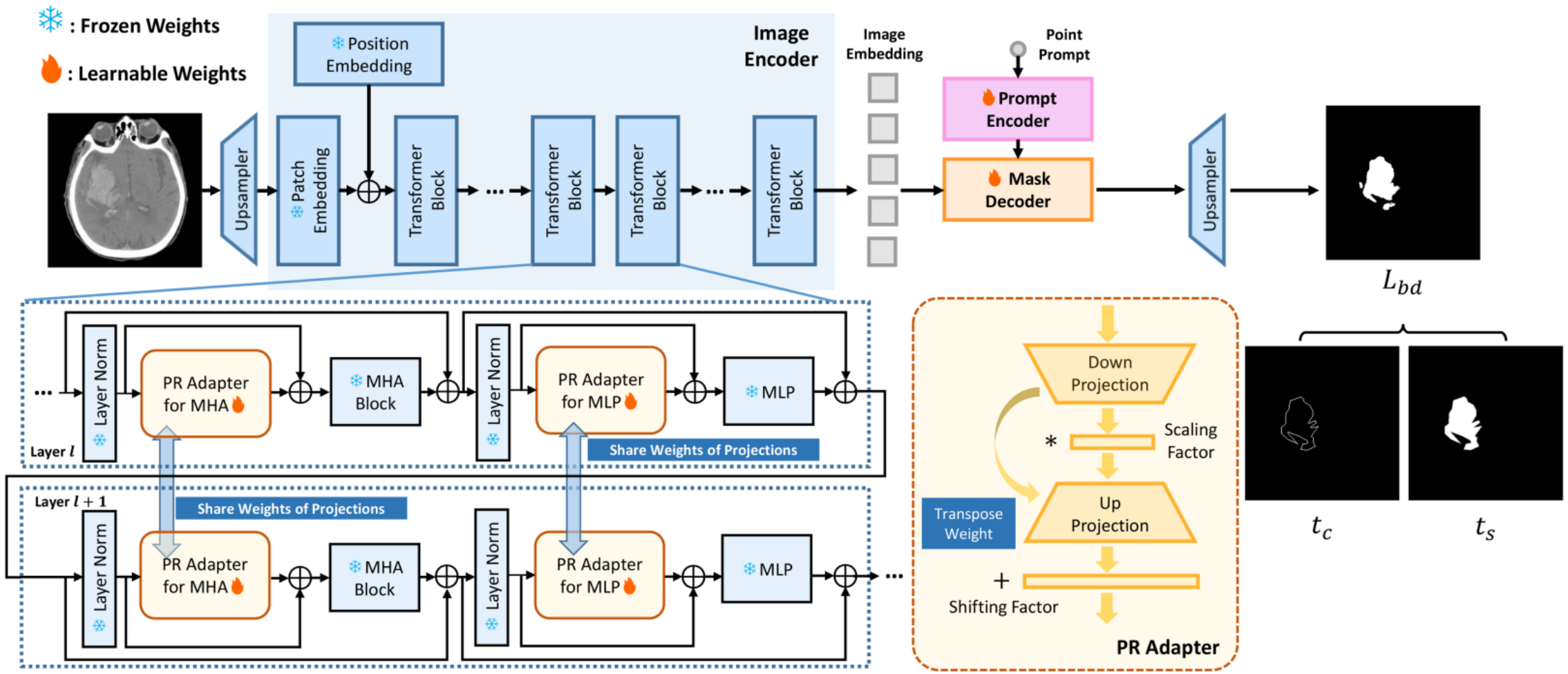
Automated Abnormality Detection

- 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



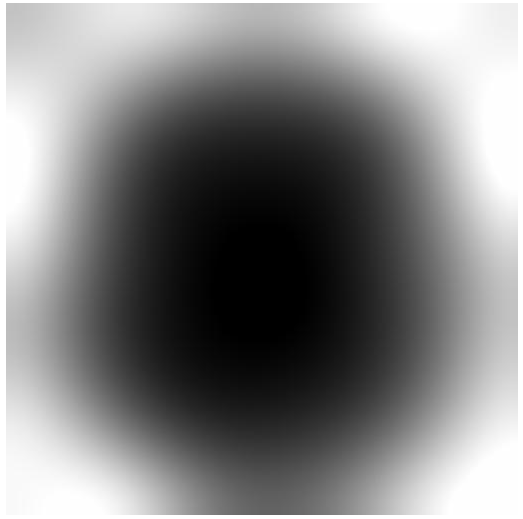
[Wang et al., 2024; https://github.com/mileswyn/SAMIHS]

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

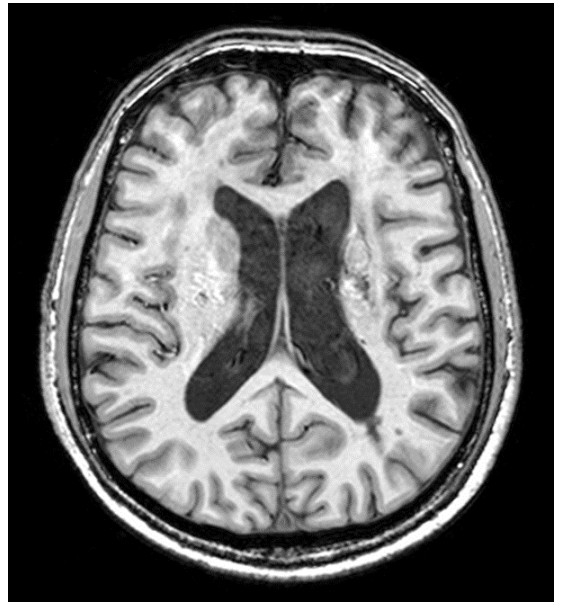
Preprocessing

- 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

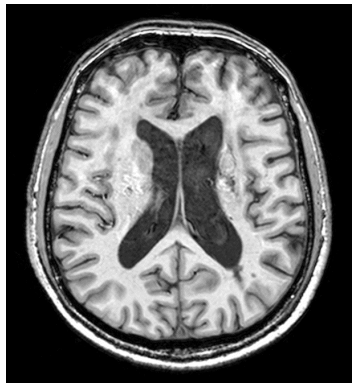
- Segmentation
  - Classifies an image into the non-brain and brain and, furthermore, the brain into different tissues usually including grey matter, white matter, and cerebrospinal fluid
- Normalization
  - Transforms an image from a native space to the standard space usually in the Montreal Neurological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



Intensity non-uniformity



Correction for Intensity Non-uniformity



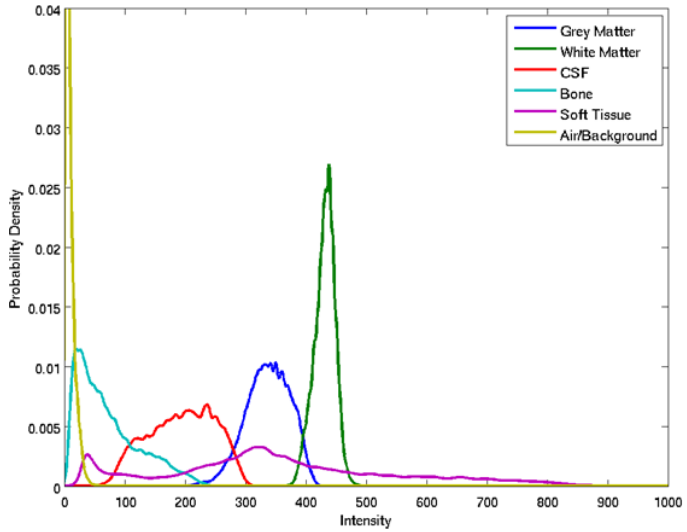
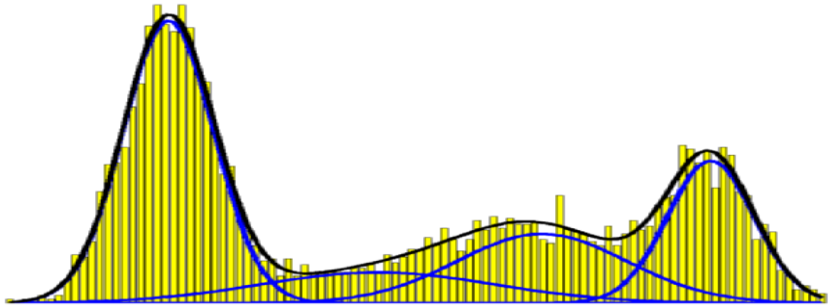


Image intensity distribution



Mixture of Gaussians model

Grey matter

White matter

Cerebrospinal fluid

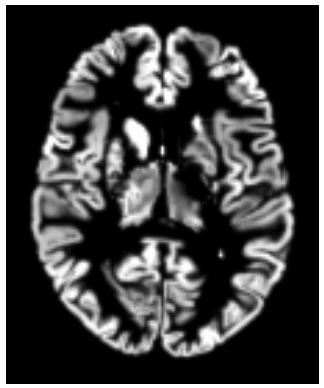
Segmentation into Different Tissues

Grey matter

White matter

Cerebrospinal fluid

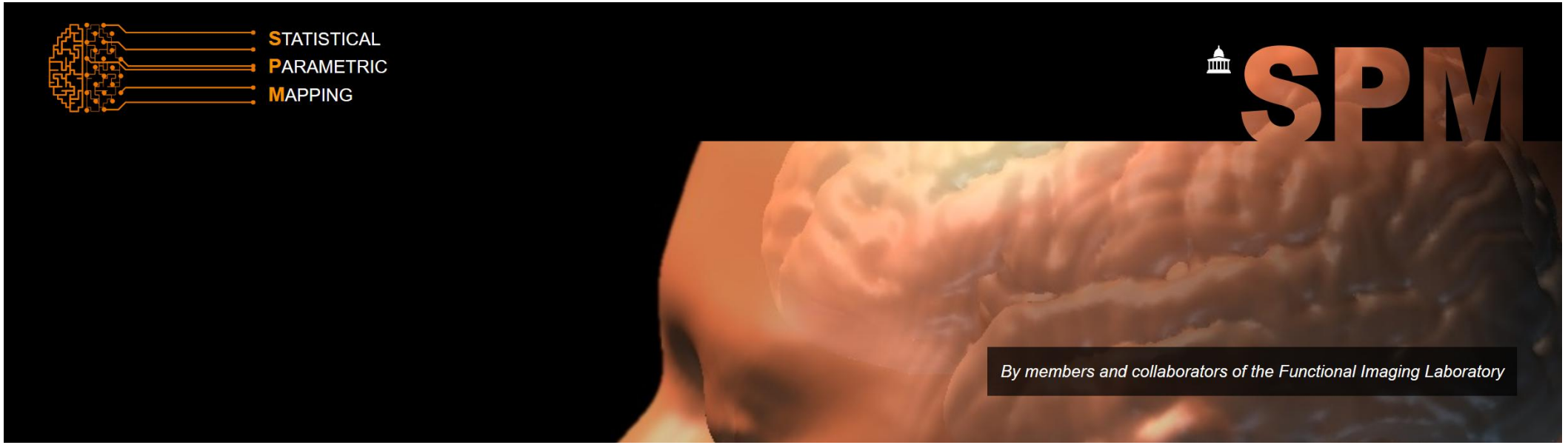
Template tissue probability maps

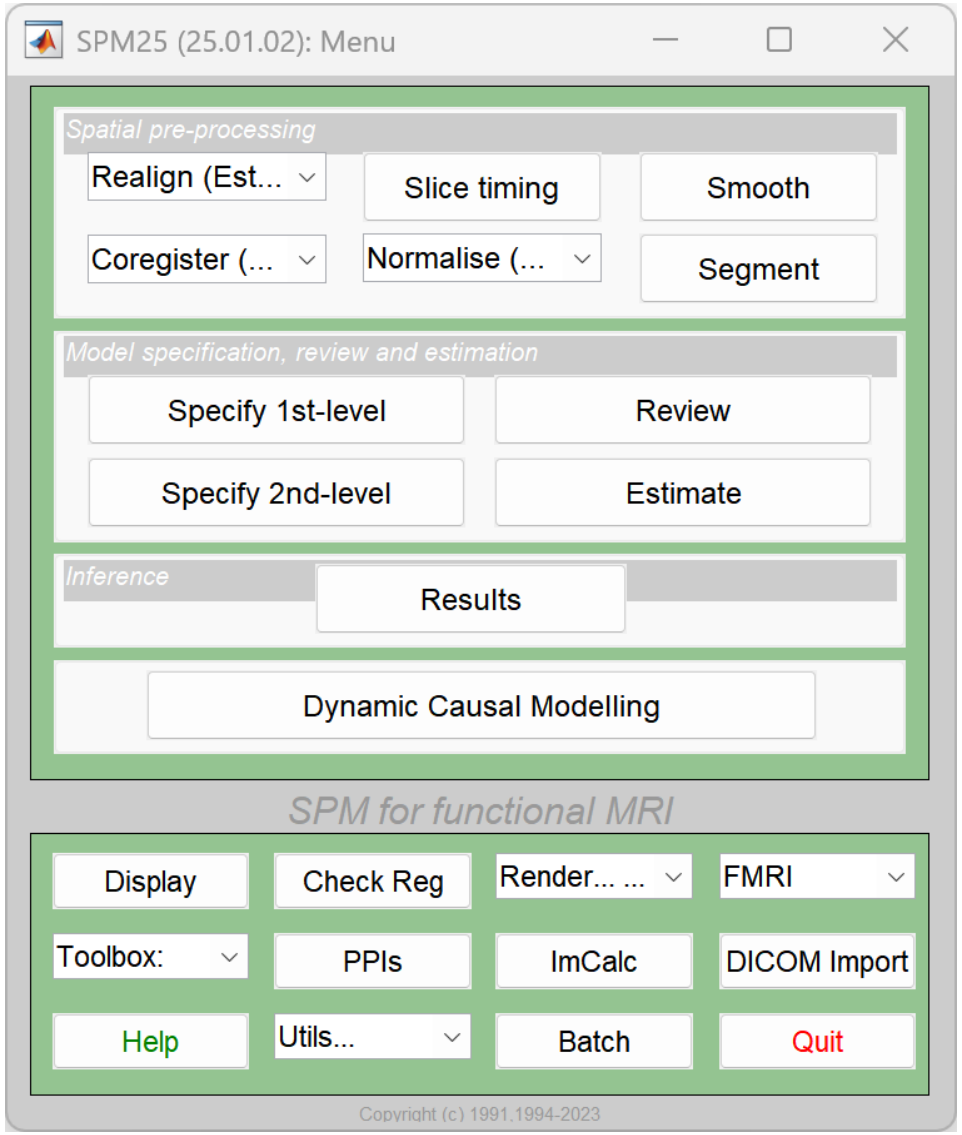


Normalization

[Preprocessing of sMRI]

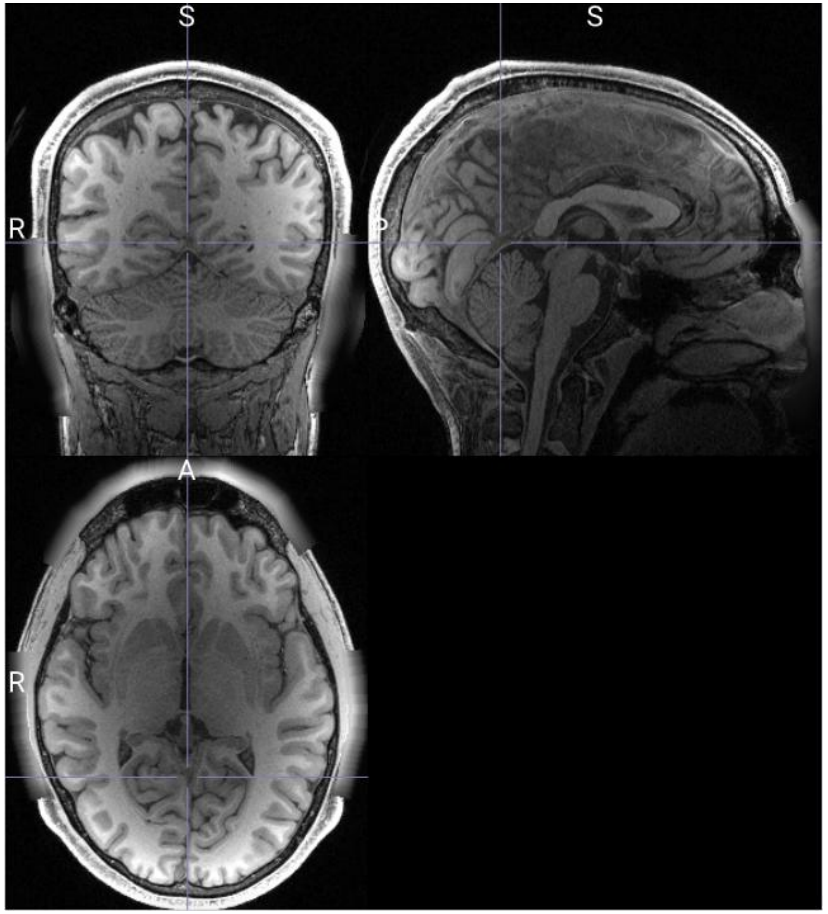
- SPM25 [https://github.com/spm/spm]

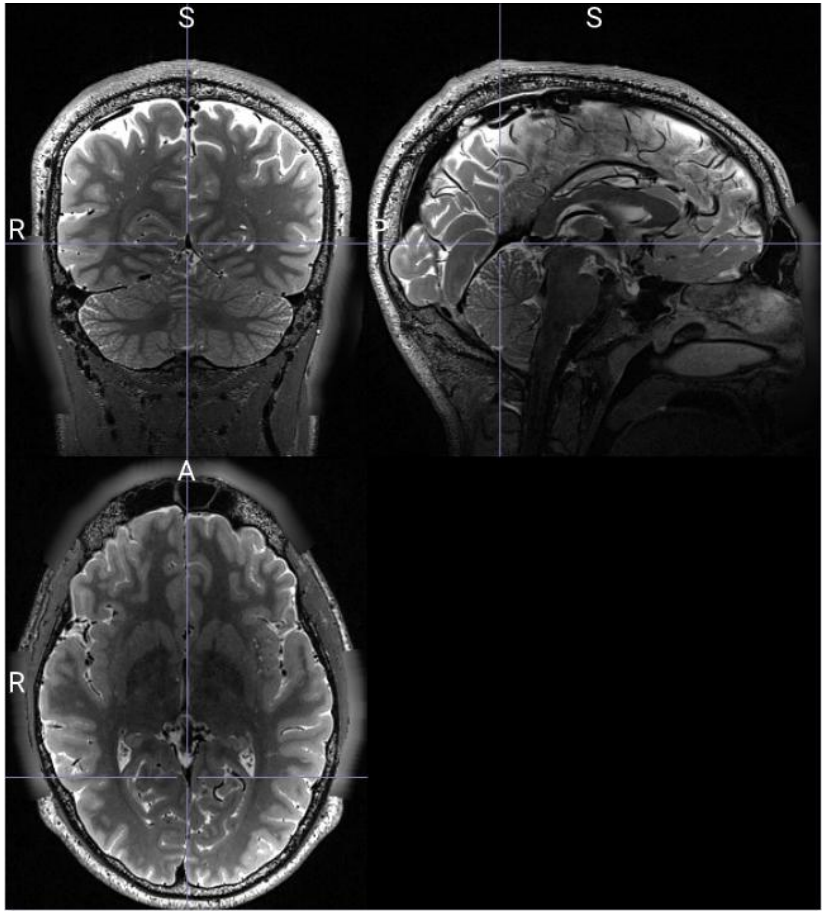




GUI of the SPM Toolbox

Input

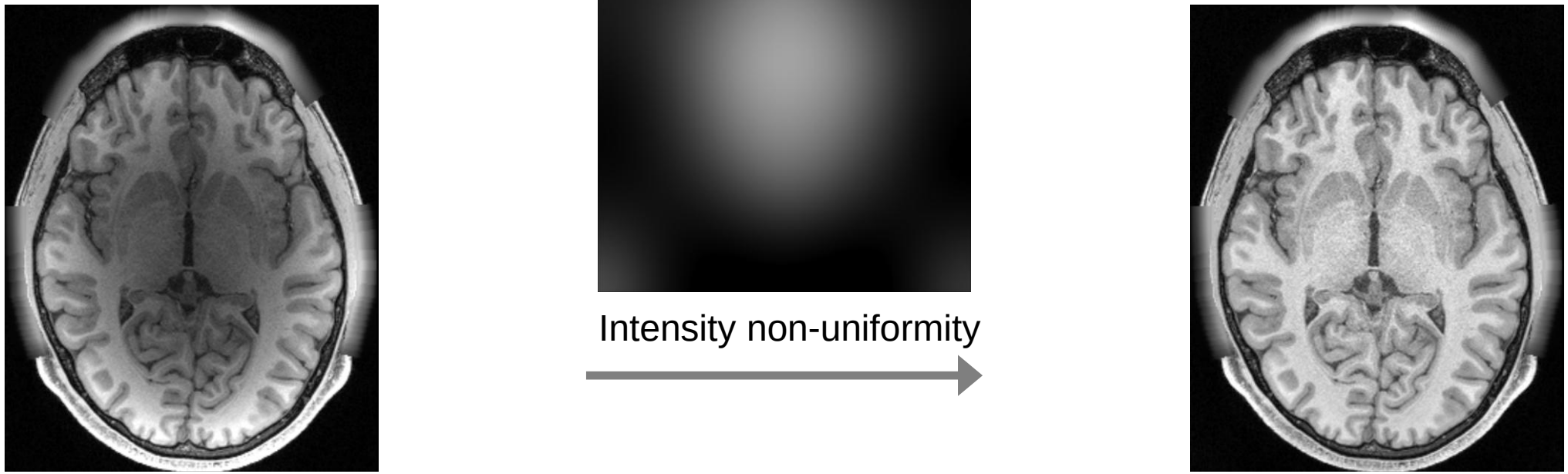




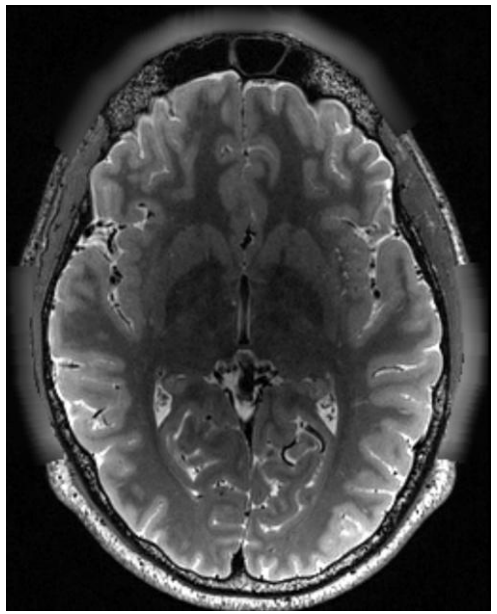
T1-weighted and T2-weighted sMRI

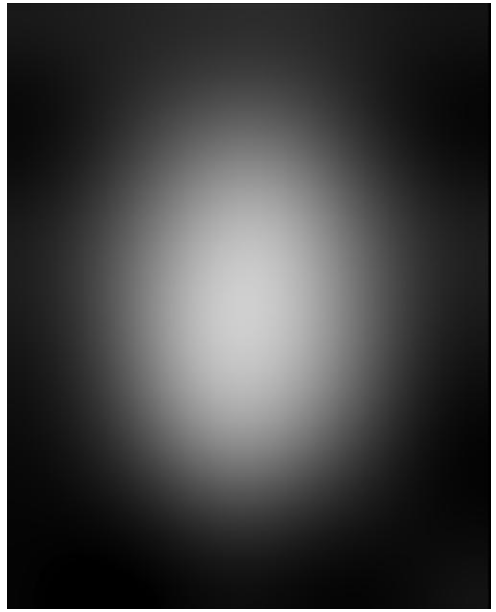
Output

Correction for intensity non-uniformity

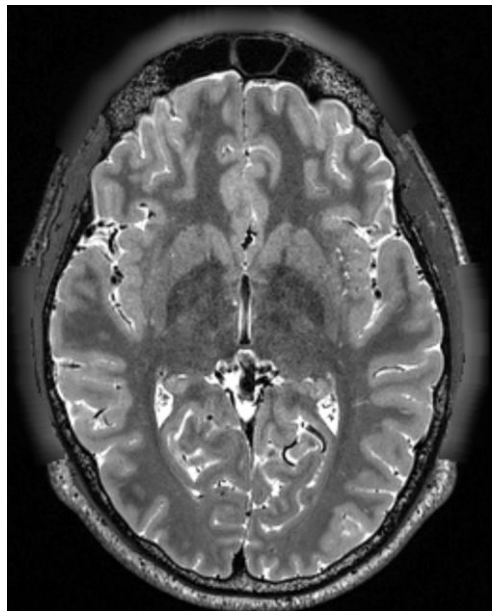


Correction of the T1-weighted Image for Intensity Non-uniformity





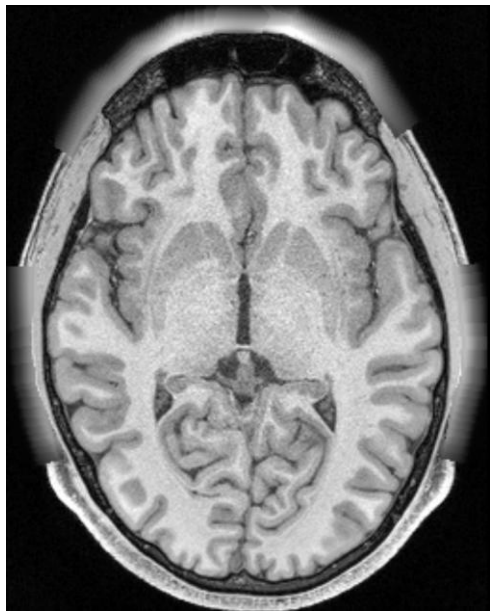
Intensity non-uniformity



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

Output

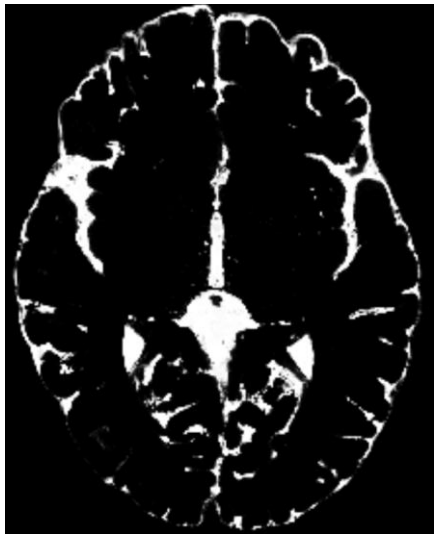
Segmentation



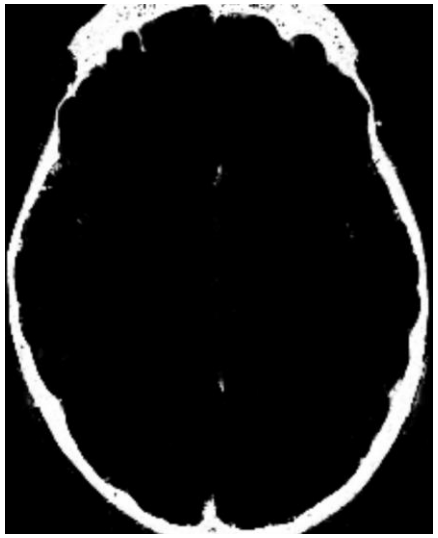
Segmentation

Grey matter

White matter

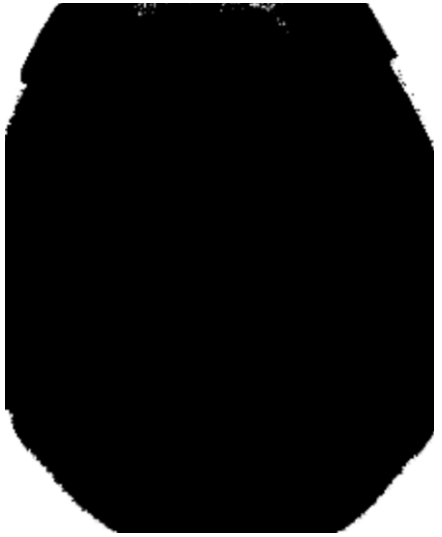


Cerebrospinal fluid

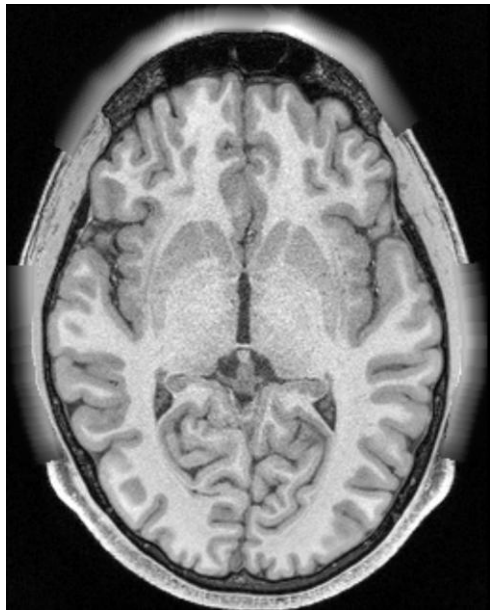


Bone

Soft tissue



Air/background



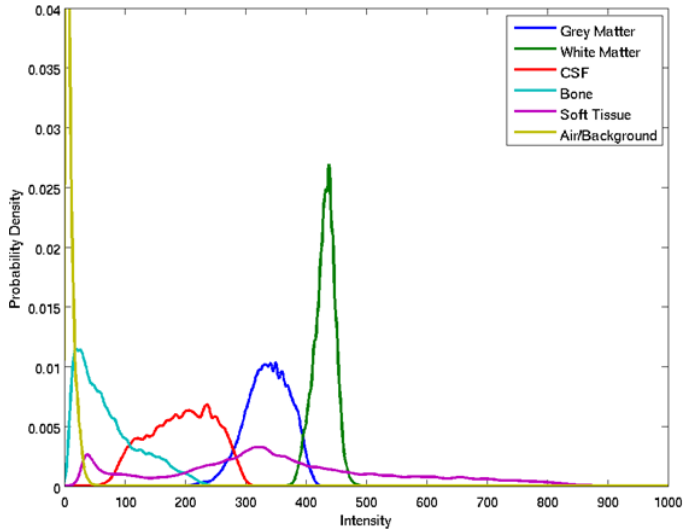
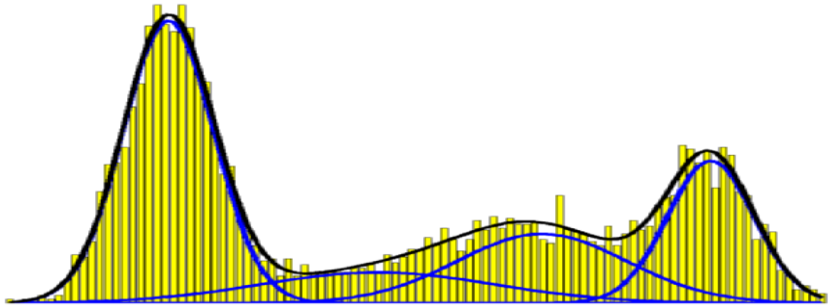
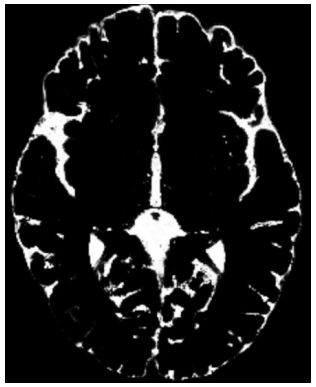


Image intensity distribution



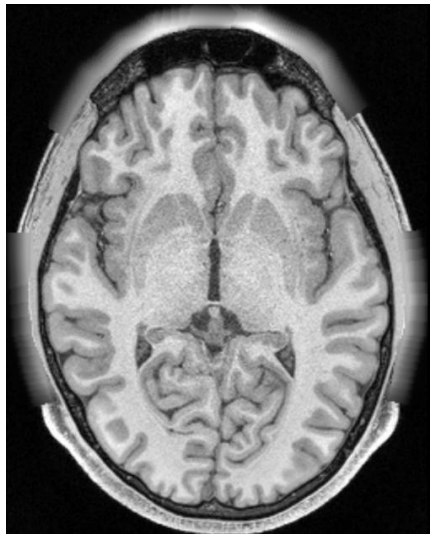
Mixture of Gaussians model

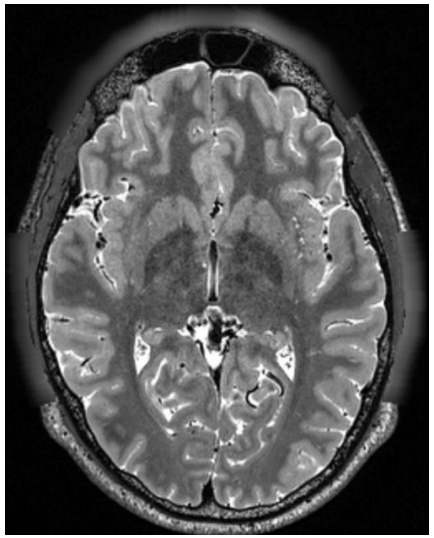


Tissue Classification based on a Mixture of Gaussians

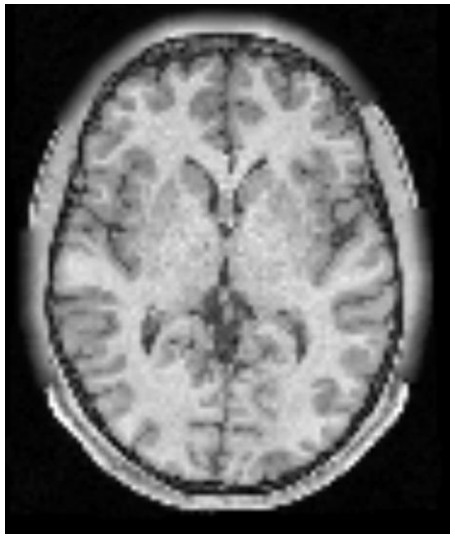
Output

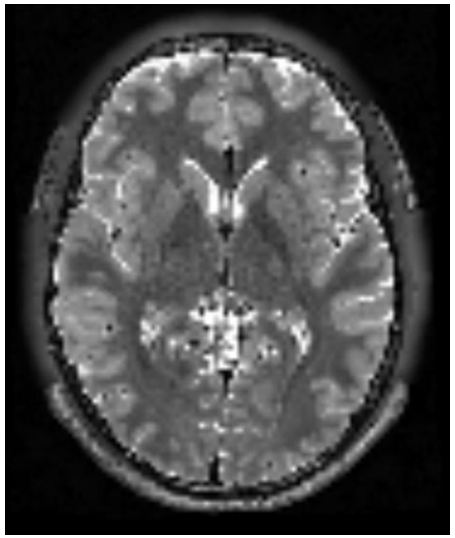
Normalization





Normalization

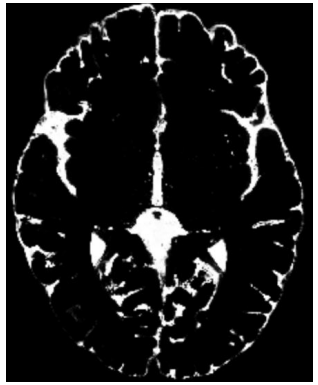




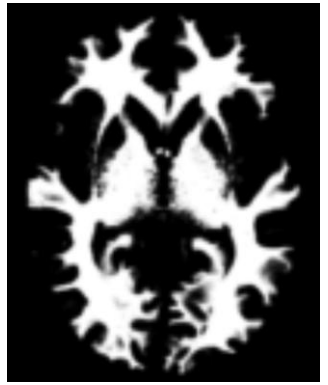
Grey matter

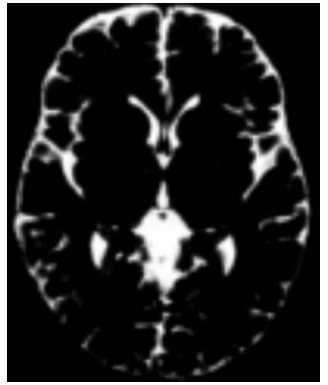
White matter

Cerebrospinal fluid



Template tissue probability maps

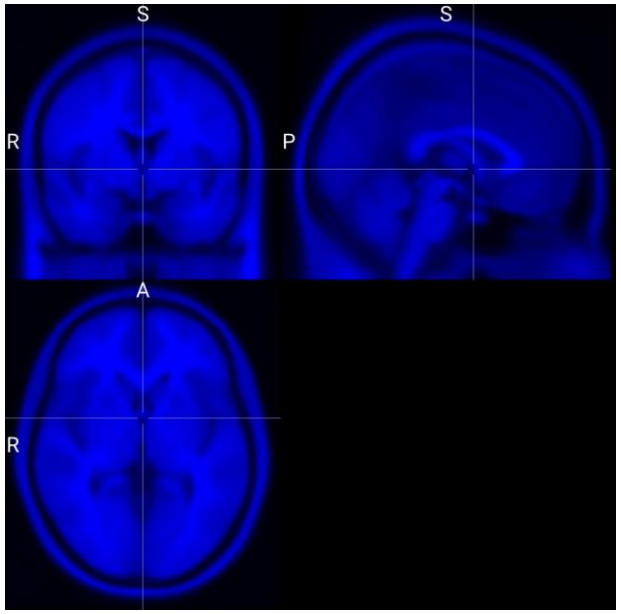


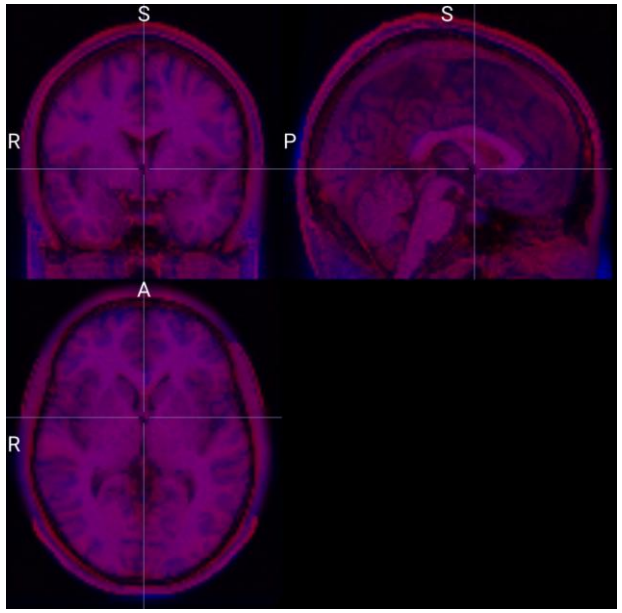


Unified Segmentation and Normalization

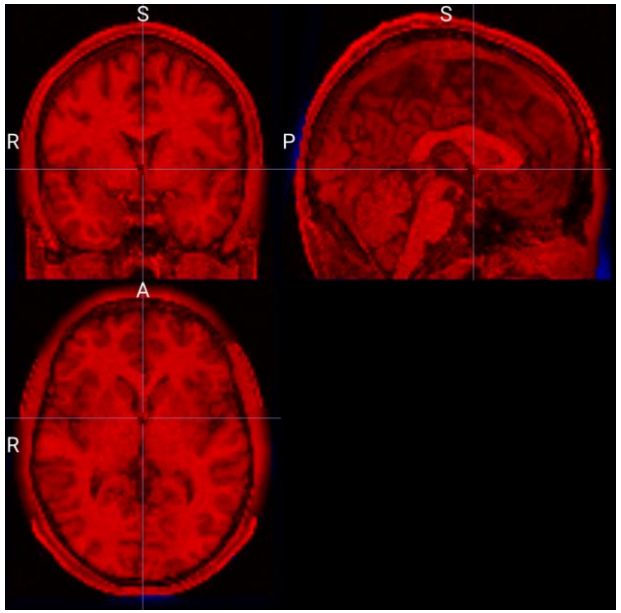
Confirmation

MNI152 template brain



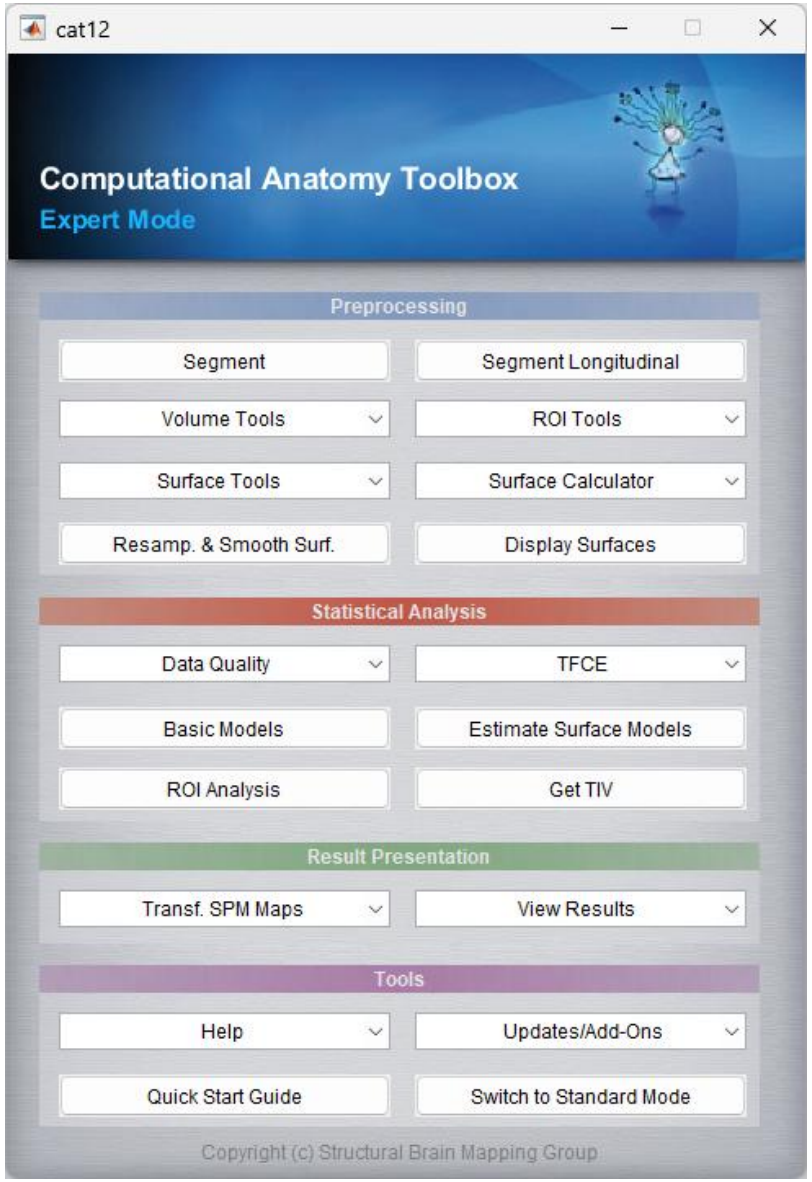


Individual's normalized brain



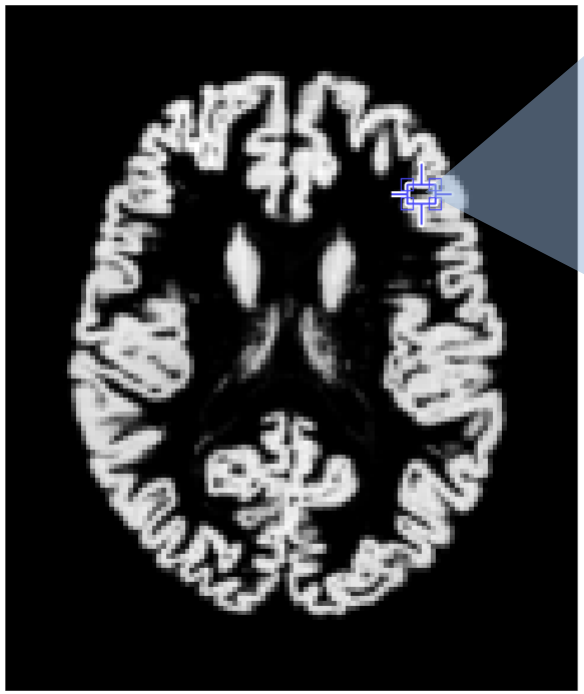
Voxel-based Morphometry

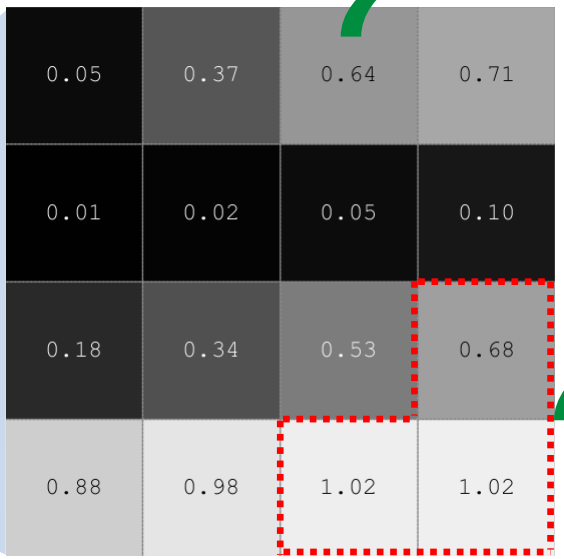
- Without defining boundaries and modeling cortical surfaces
- CAT12 [https://github.com/ChristianGaser/cat12]



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

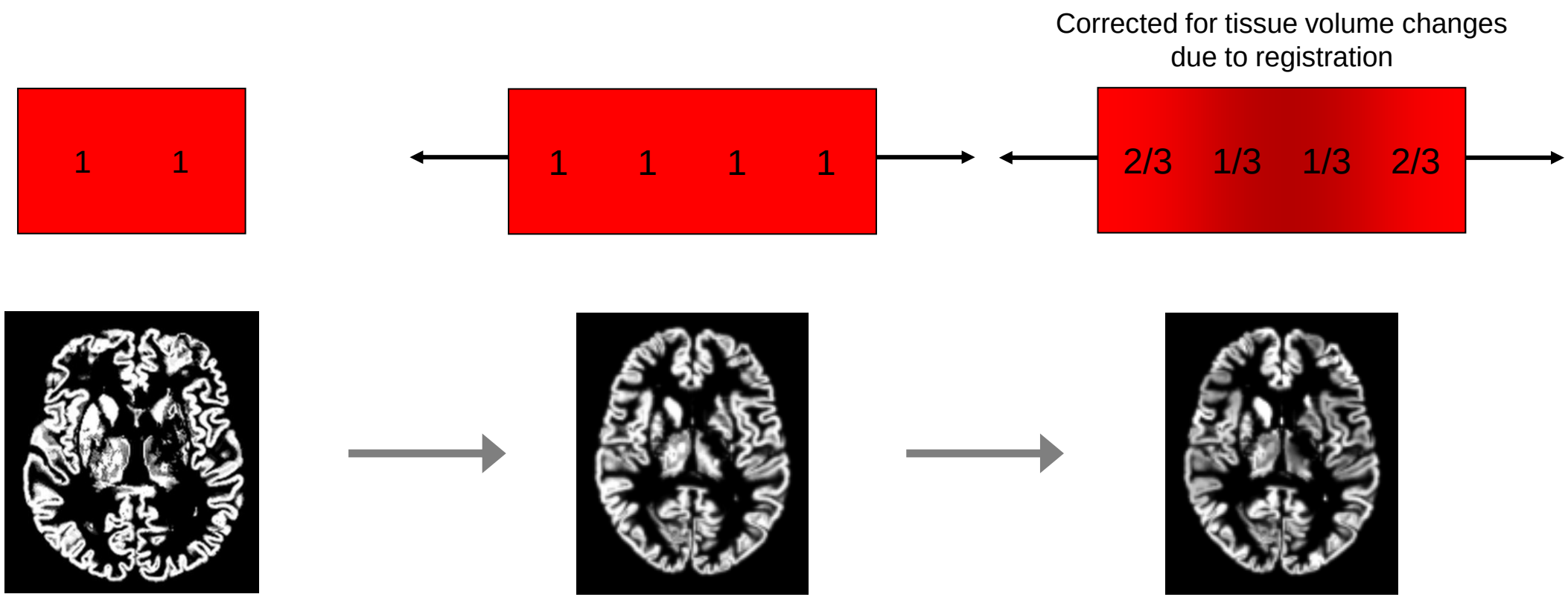
Grey matter volume = 0.64 × 3.375 mm^3
= 2.16 mm^3

Area

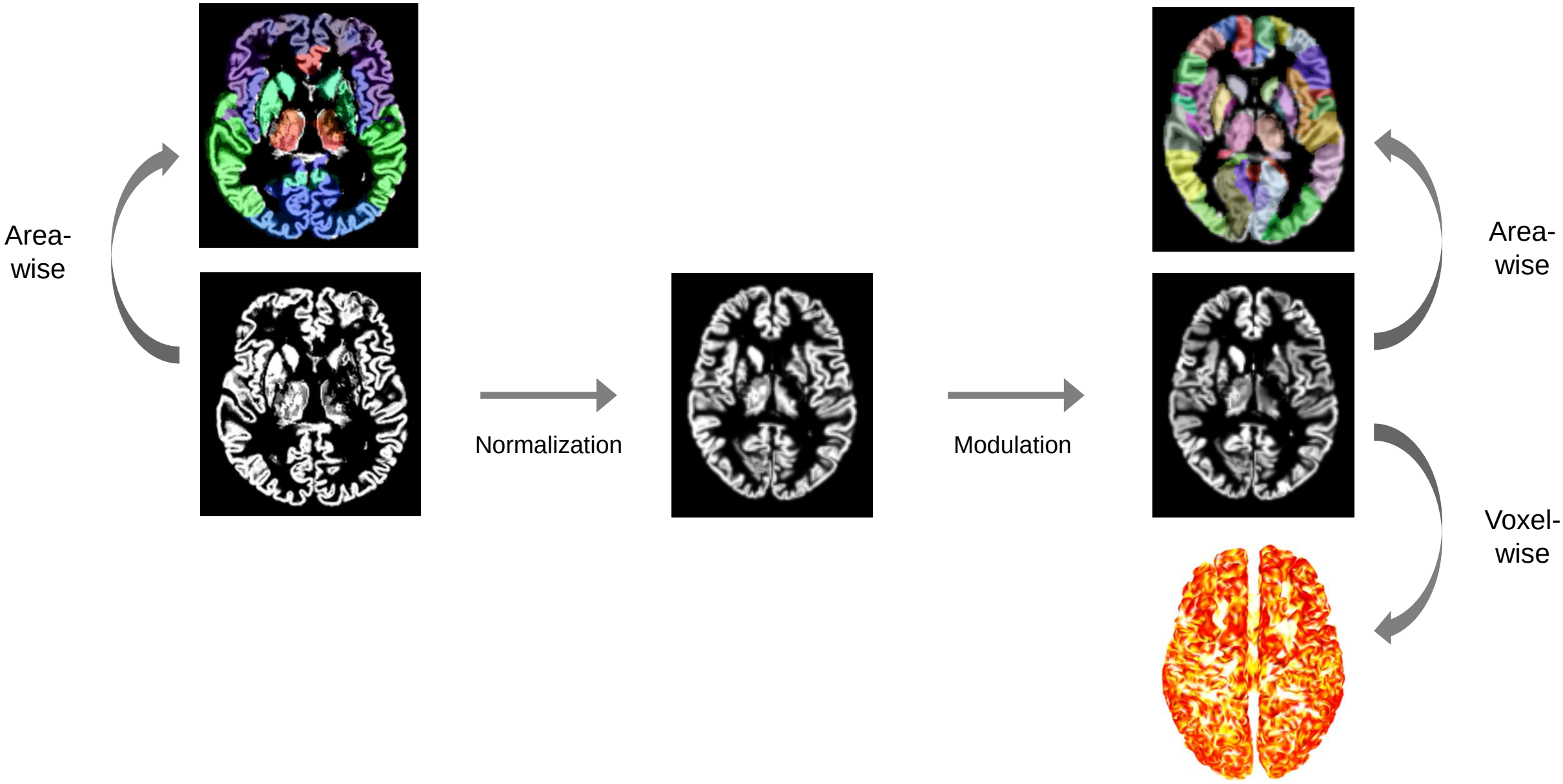
Grey matter volume = 9.18 mm^3

Voxel size: 1.5 mm × 1.5 mm × 1.5 mm
Voxel volume: 3.375 mm^3

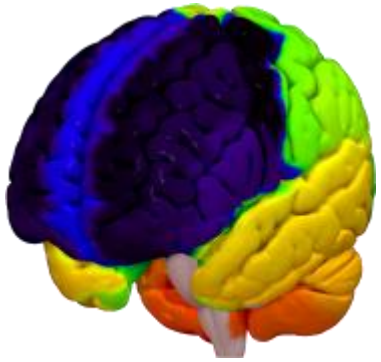
Computation of Grey Matter Volume for a Voxel or an Area



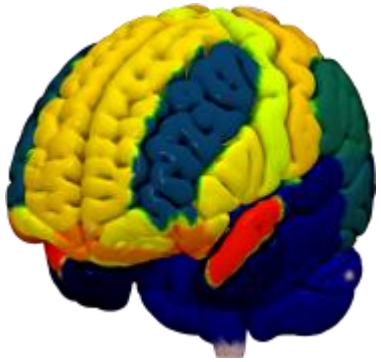
Normalization and Modulation



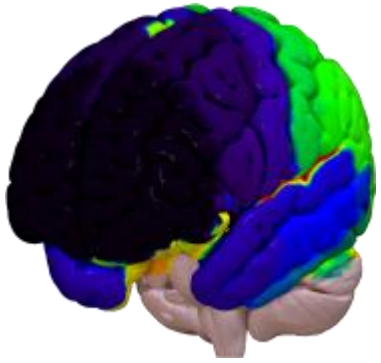
Features of Grey Matter Volume



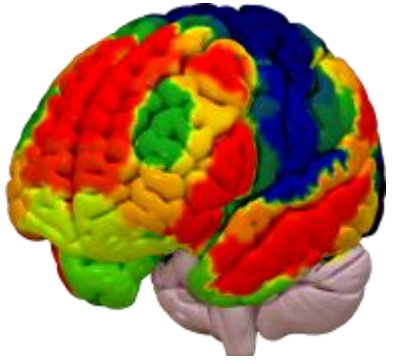
AAL atlas



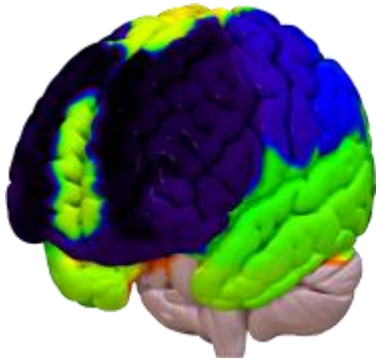
Hammers atlas



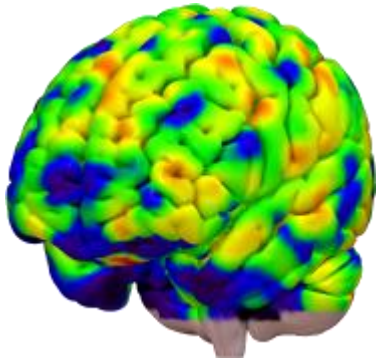
Harvard-Oxford atlas



Yeo atlas

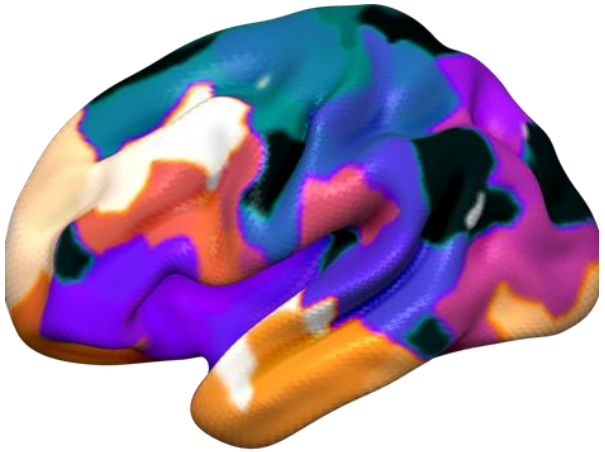


AICHA atlas

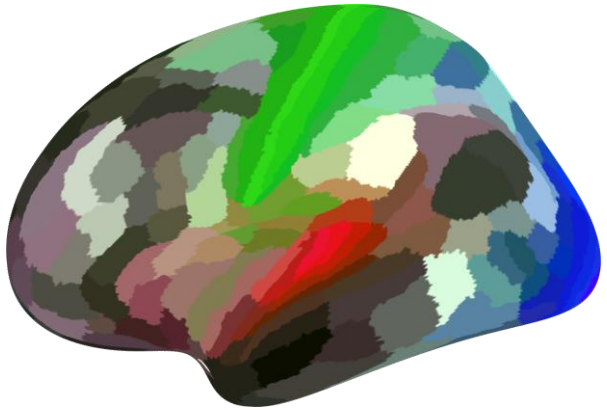


Craddock atlas

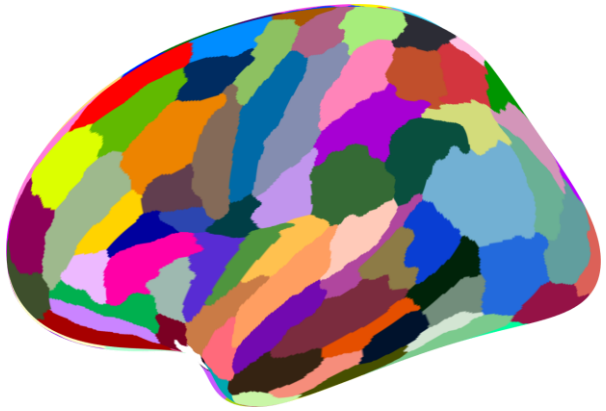
Brain Atlases



333 areas
Resting-State Correlations atlas

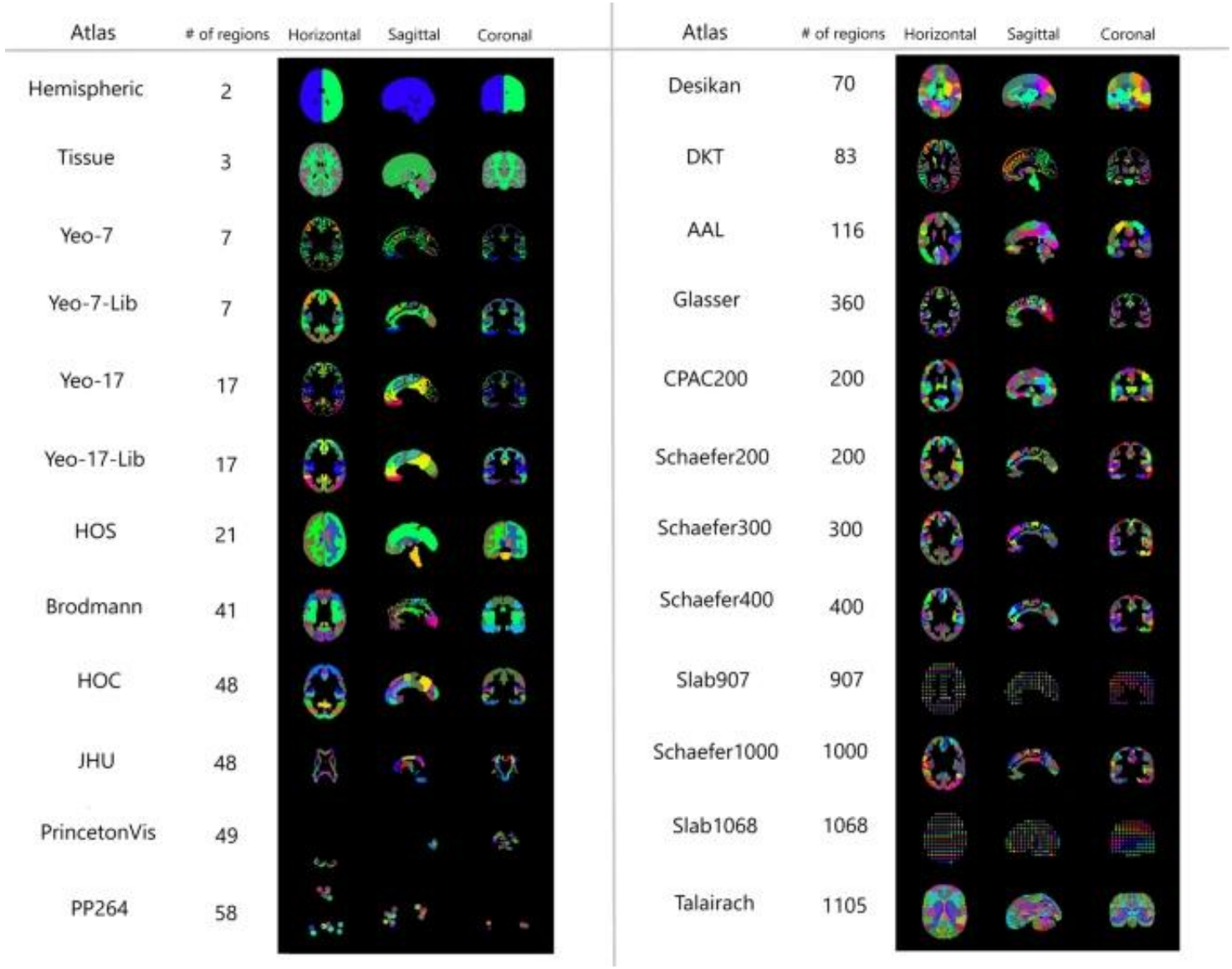


360 areas
HCP MMP 1.0 atlas



246 areas
Brainnetome atlas

Higher-resolution Brain Atlases



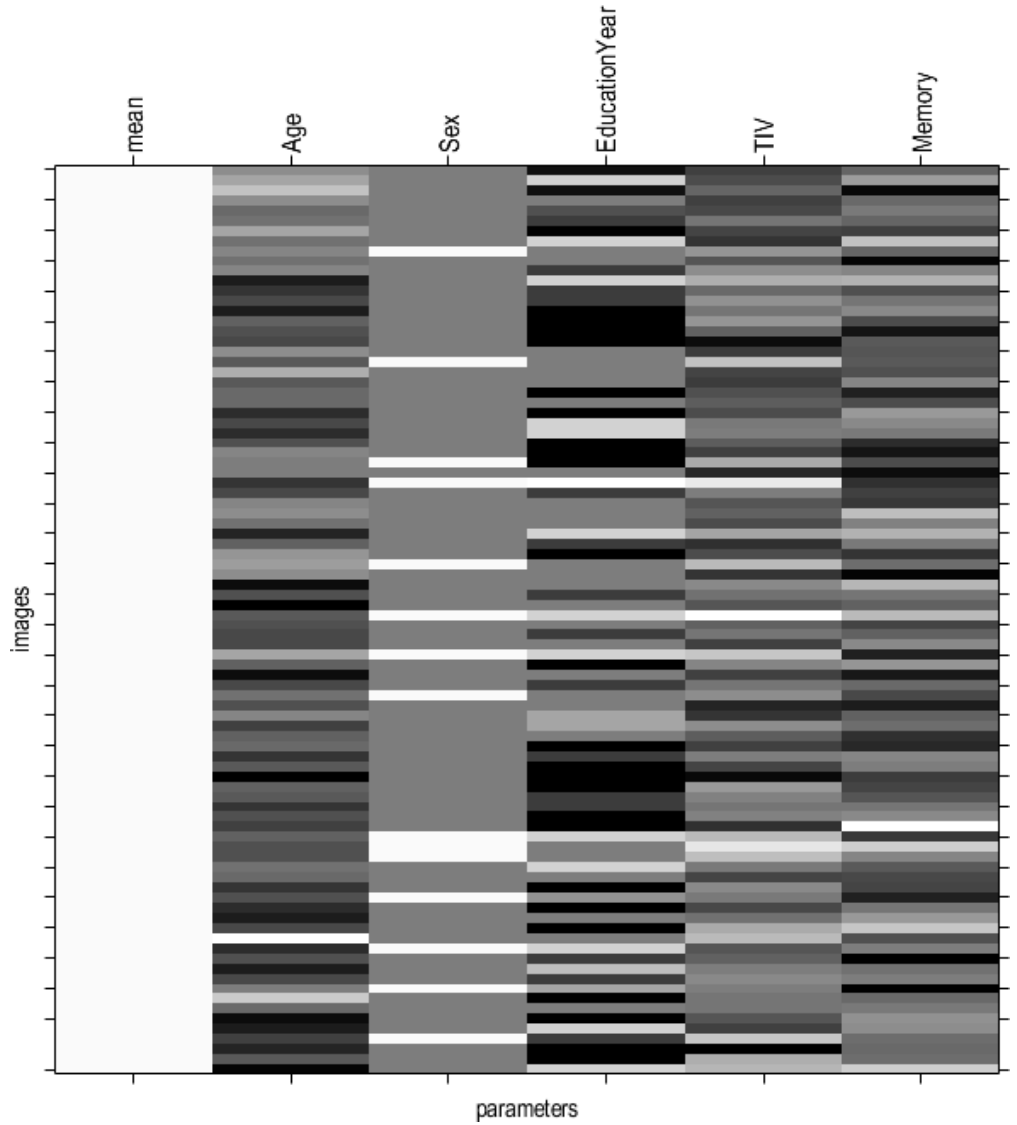
[https://github.com/neurodata/neuroparc]

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

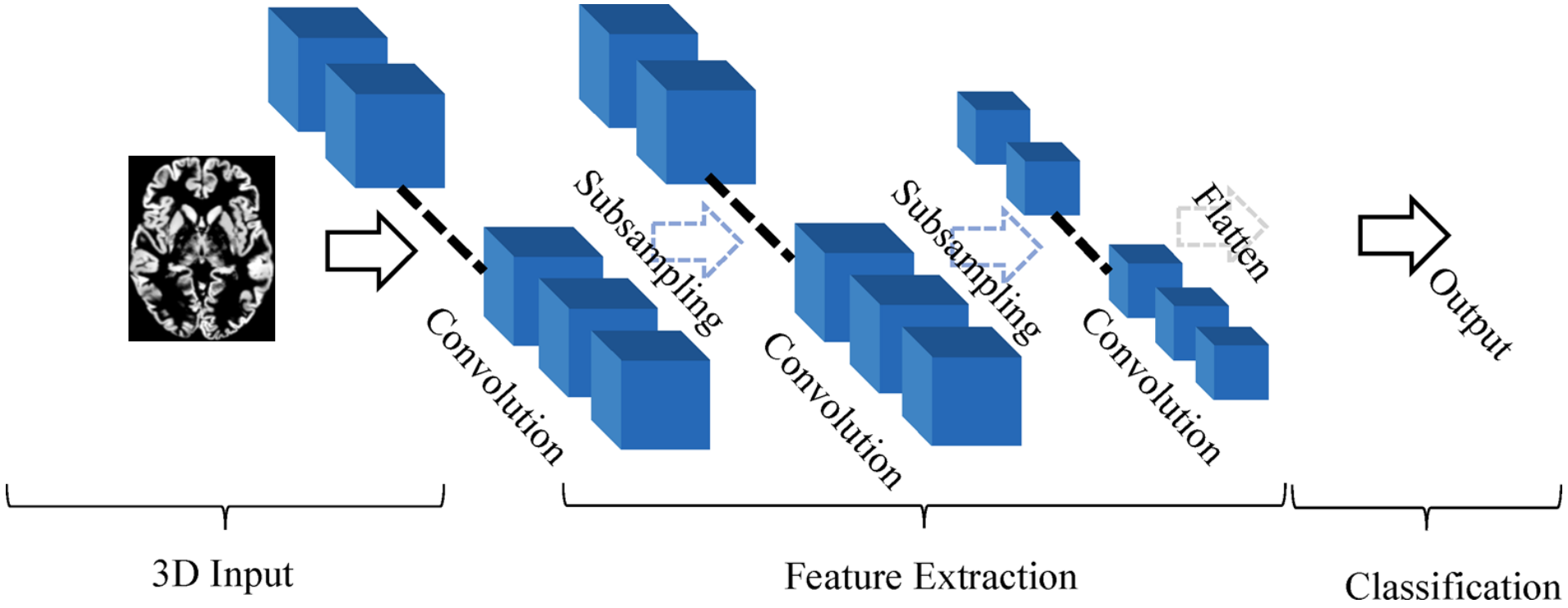
- Input to machine learning models
  - Table of voxel-wise or area-wise grey matter volume values

Features →

Samples ↓

	Voxel or Area 1 grey matter volume	Voxel or Area 2 grey matter volume	Voxel or Area 3 grey matter volume	…
Subject 1	-	-	-	-
Subject 2	-	-	-	-
Subject 3	-	-	-	-
⋮	-	-	-	-

  - Grey matter volume map



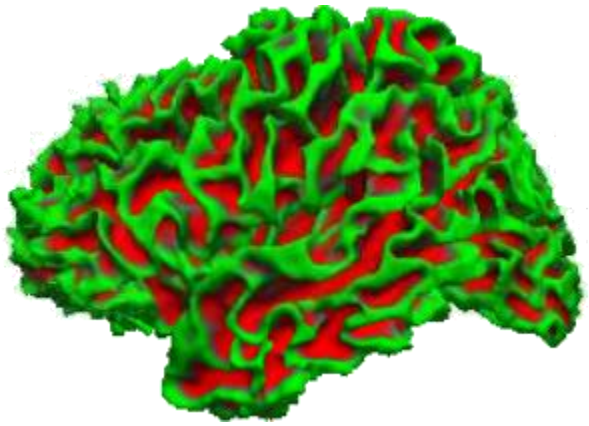
[Adapted from Singh et al., 2020]

Application of Deep Learning to Grey Matter Volume Maps

Surface-based Morphometry

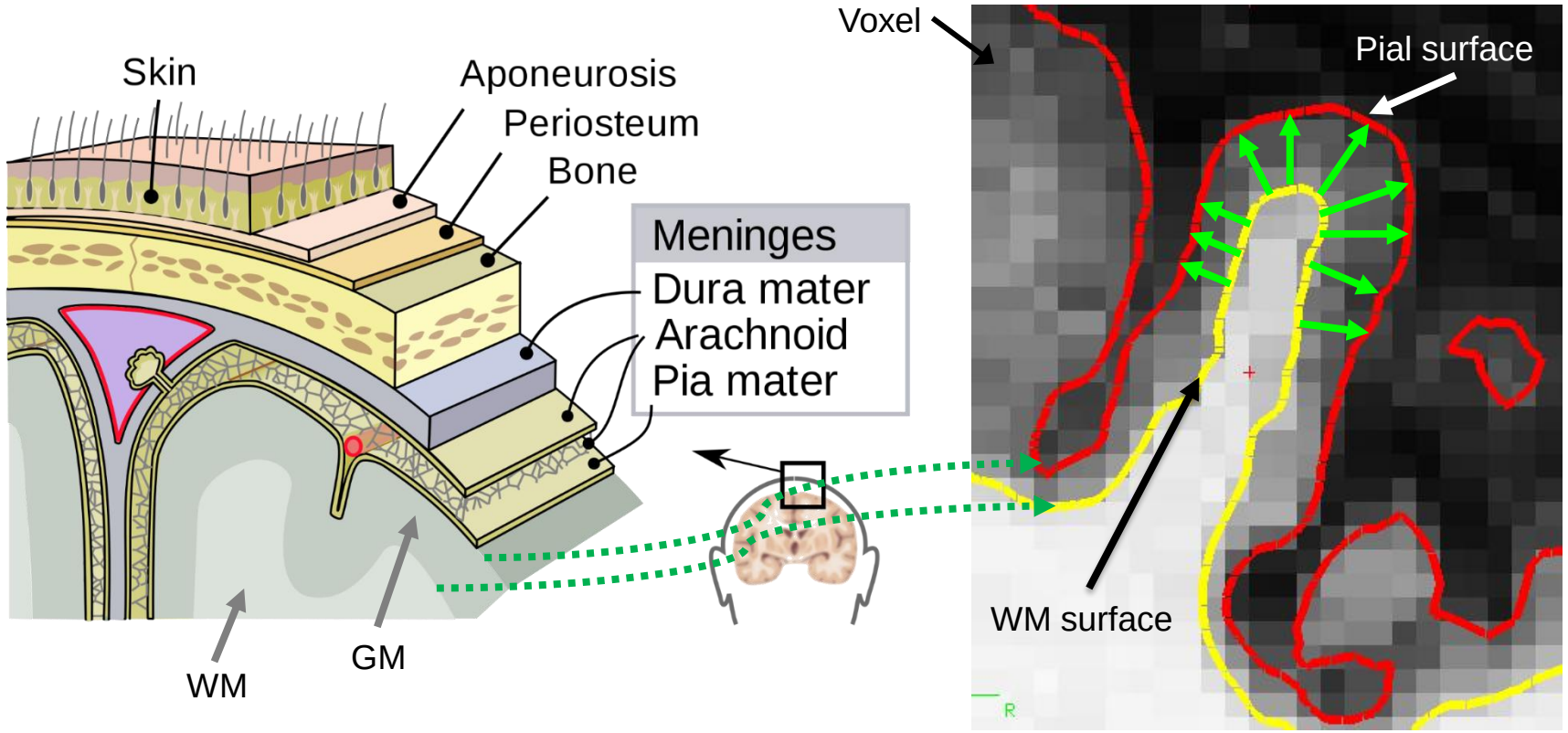
- Independent of registration and modulation
- Not applicable to subcortical regions
- FreeSurfer [https://github.com/freesurfer/freesurfer]

- 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



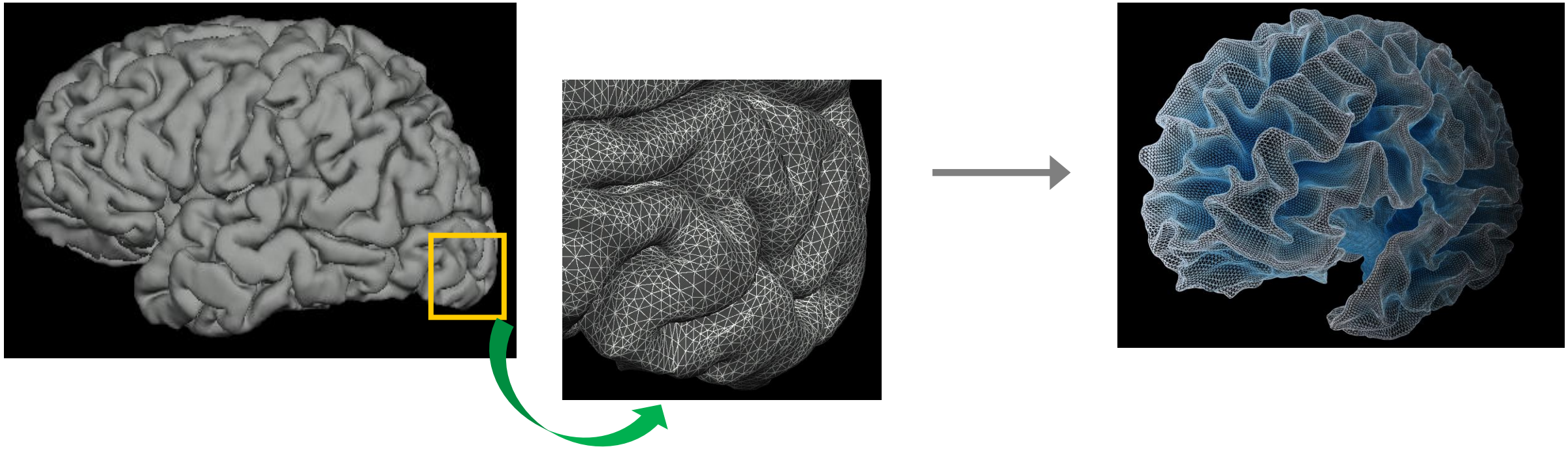
White matter surface

Pial surface



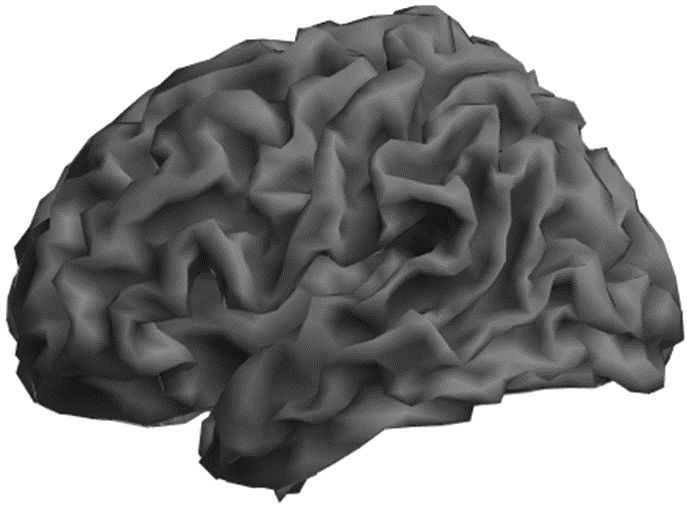
[https://www.physio-pedia.com/Meninges]

Cortical Surfaces beneath Cranial Meninges

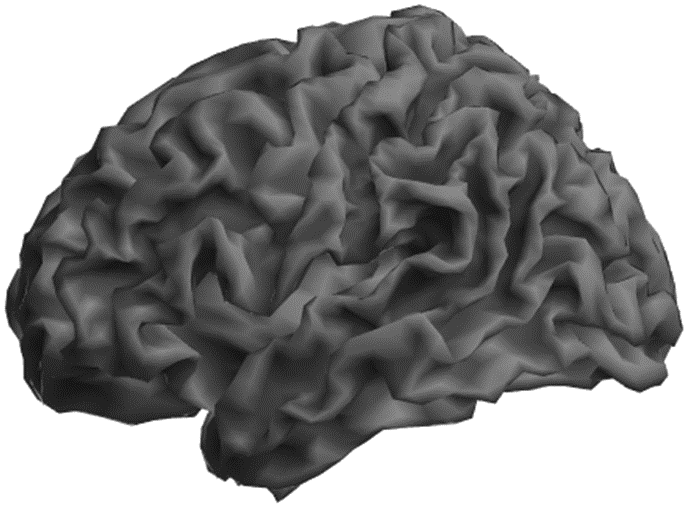


[https://surfer.nmr.mgh.harvard.edu/]

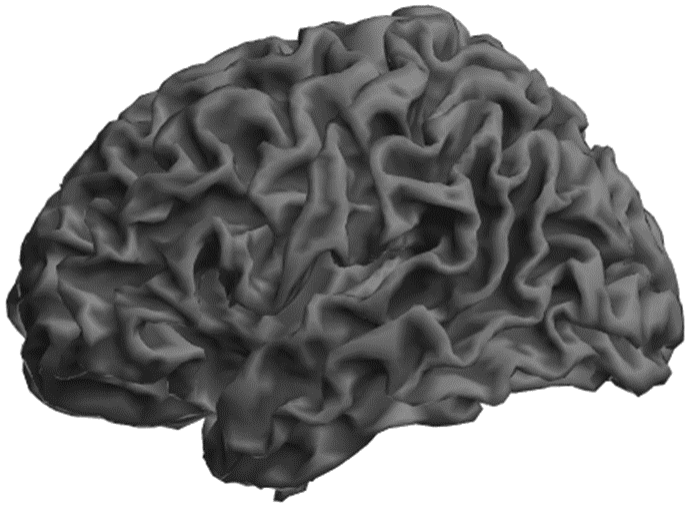
Surface Representation of the Brain



5124 vertices



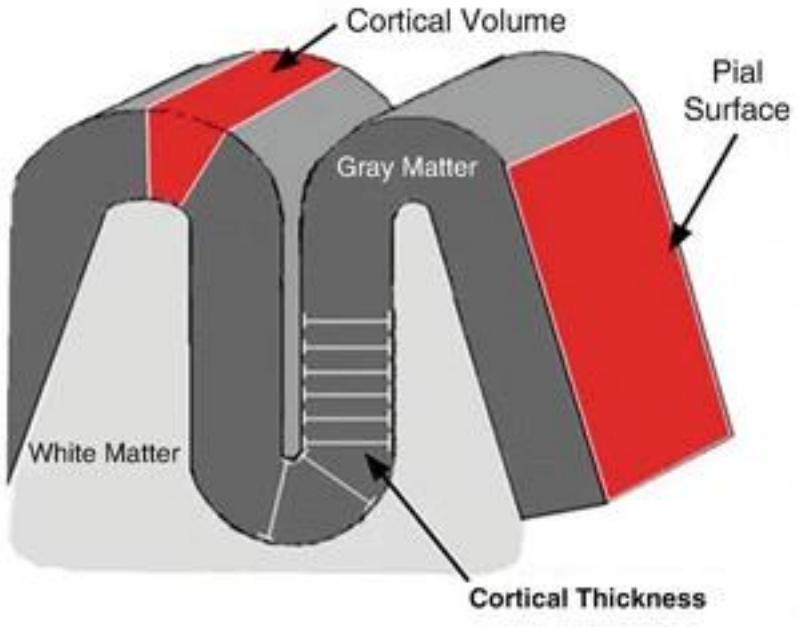
8196 vertices

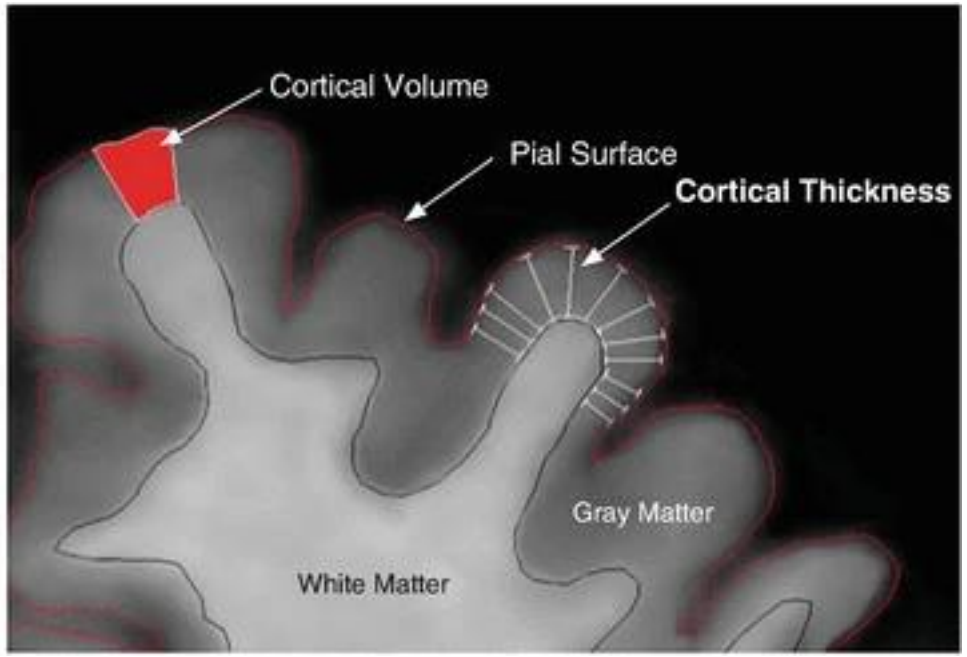


20484 vertices

Surface Representation with Different Numbers of Vertices

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

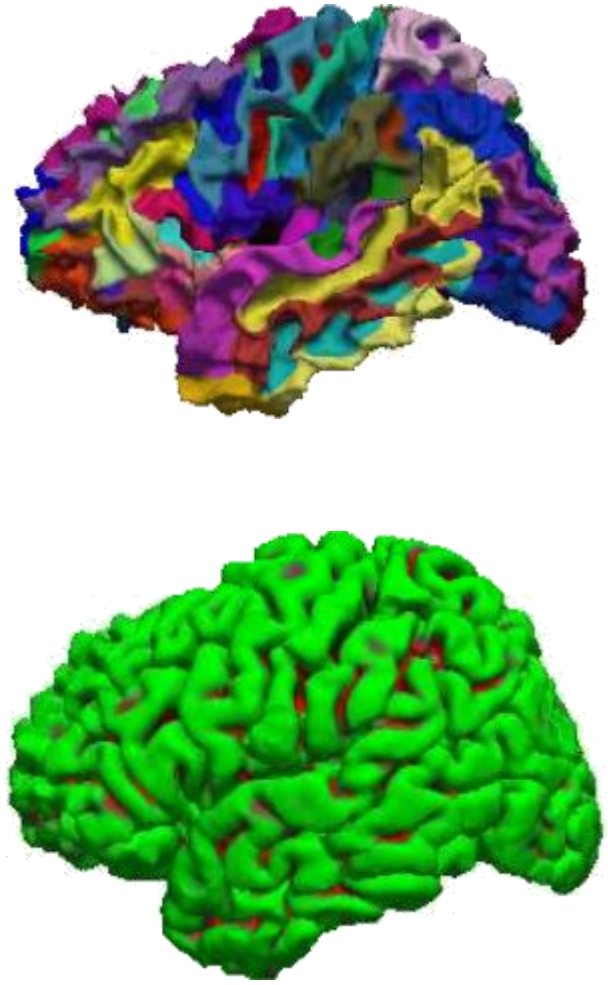


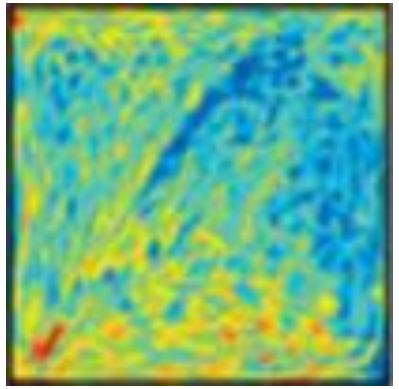


[Gale and Huff, 2017]

Area-wise

Vertex-wise





2D planar image

Features of Cortical Thickness

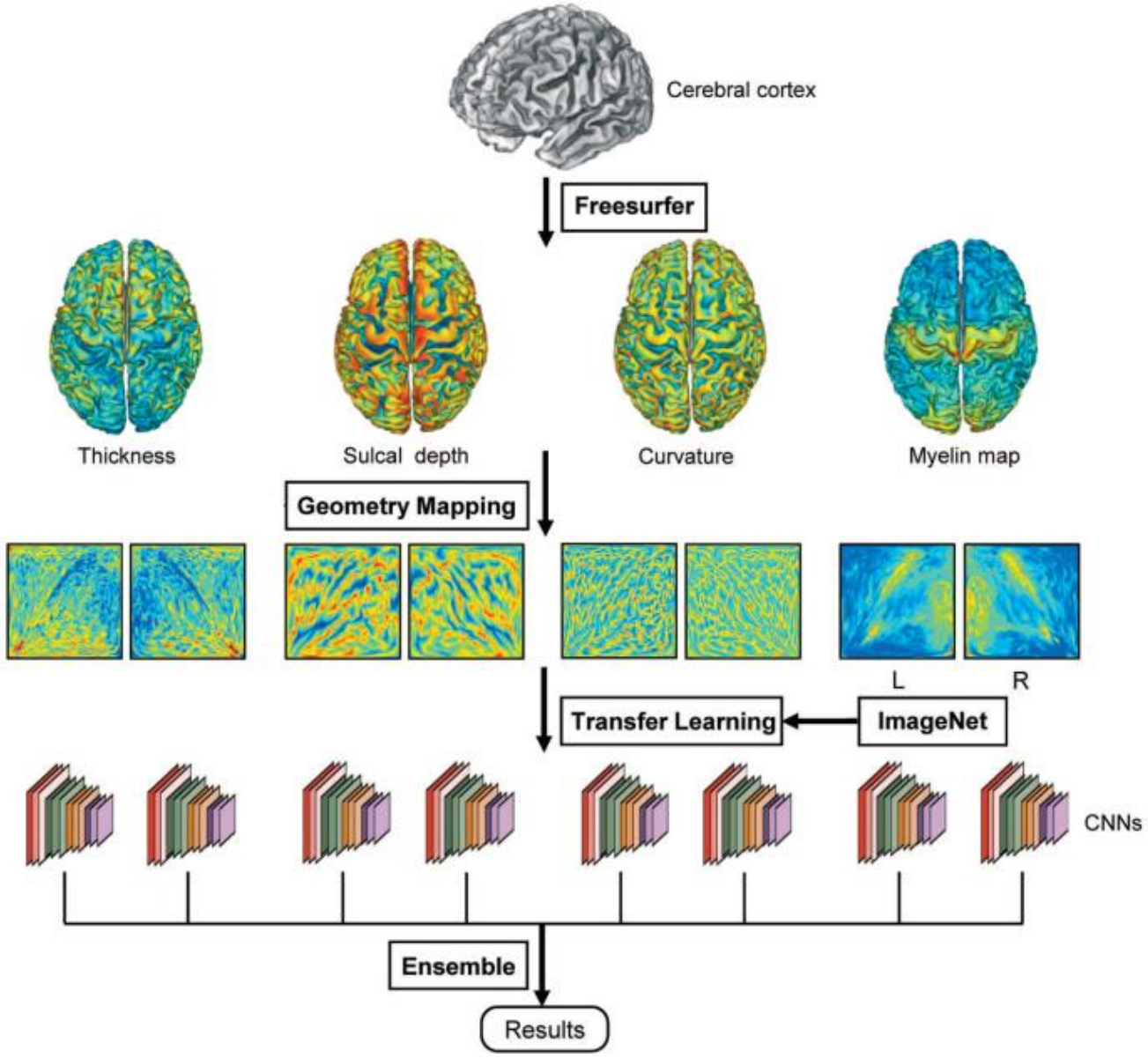
- Input to machine learning models
  - Table of vertex-wise or area-wise cortical thickness values

Features →

Samples ↓

	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

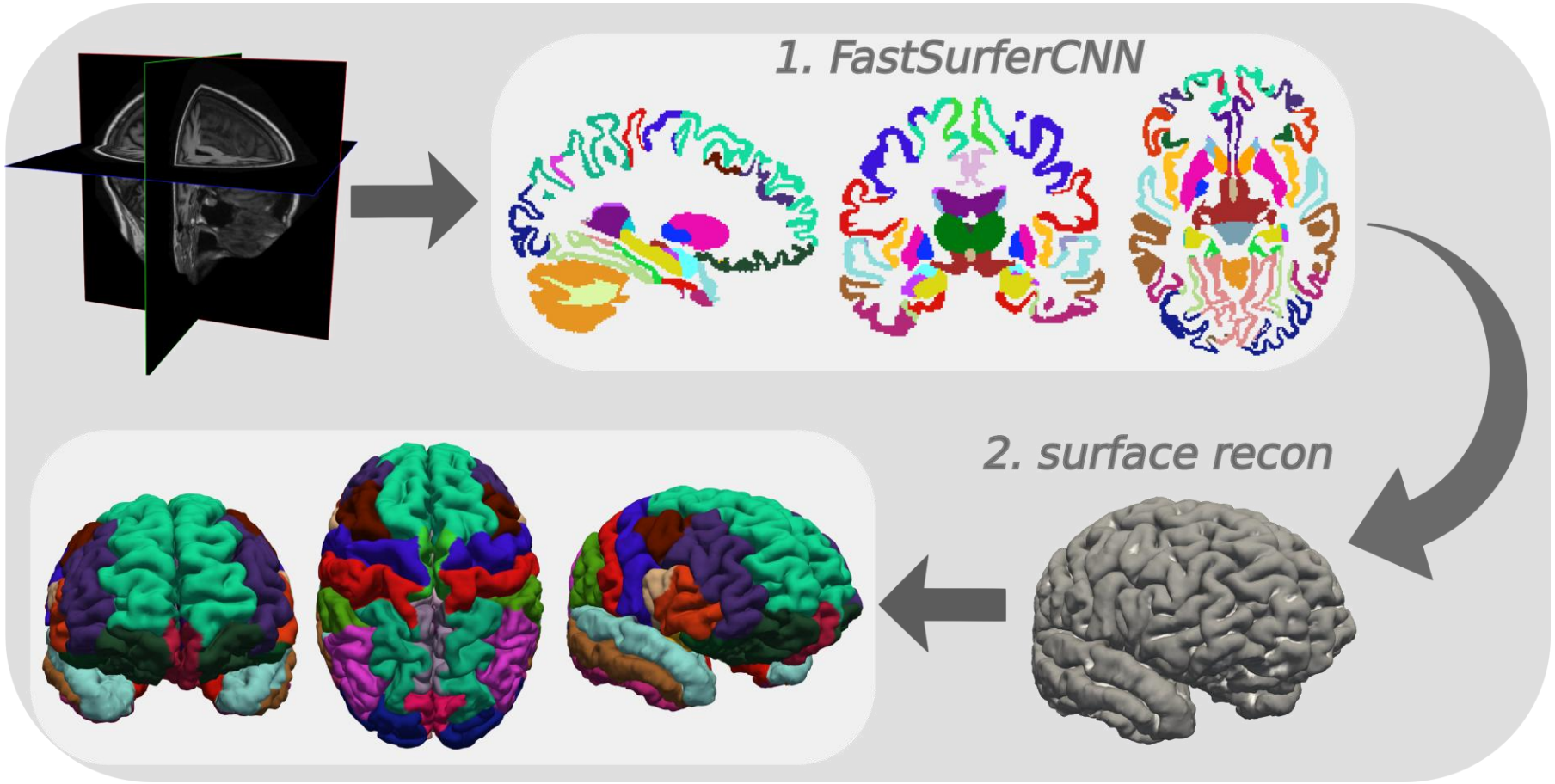


[Gao et al., 2022]

Application of Deep Learning to Cortical Morphometric Maps

Automated Brain Morphometry

- Employs deep learning algorithms to provide 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://icometrix.com/	EU	Icometrix	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	

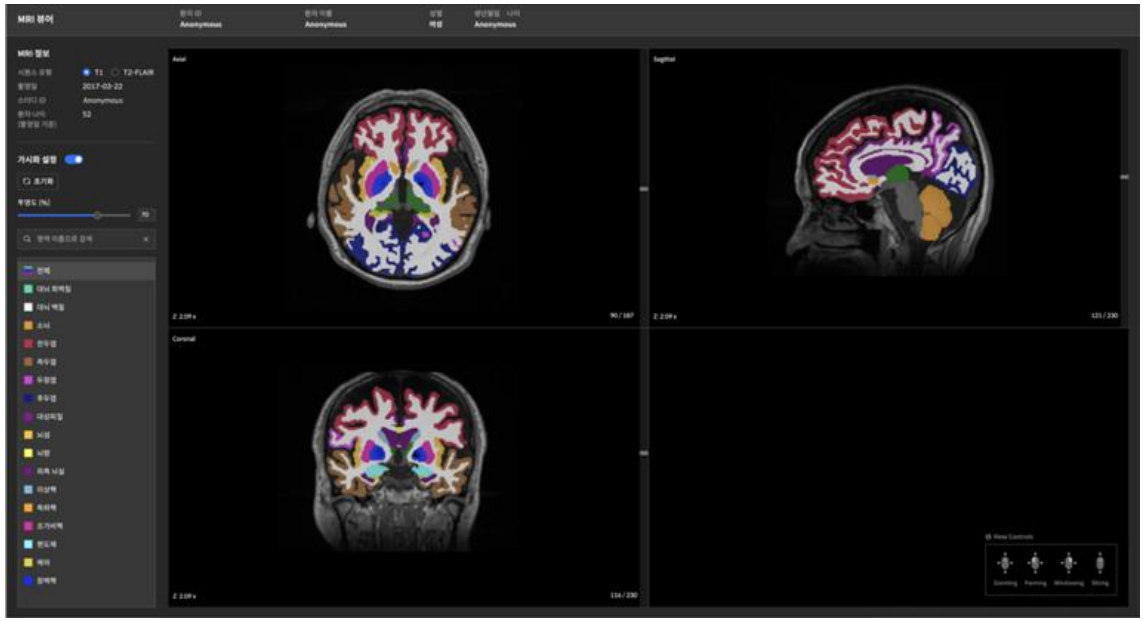
*LesionQuant: measurement of WM lesion volume.
†Multicontrast: acquisition of multiple pre-defined contrast weighted images such as T1W, T2W and T2W FLAIR, as well as double inversion recovery and phase sensitive inversion recovery using synthetic MRI.
CSF = cerebrospinal fluid, EU CE Marked = conformite 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

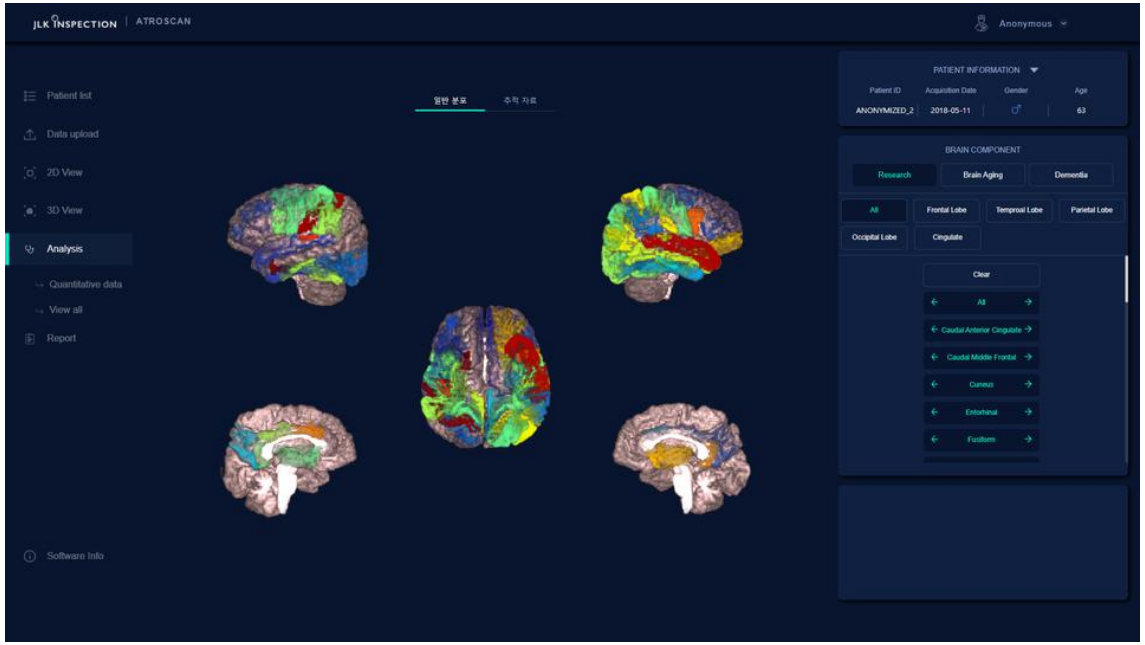
[https://www.cortechs.ai/]

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

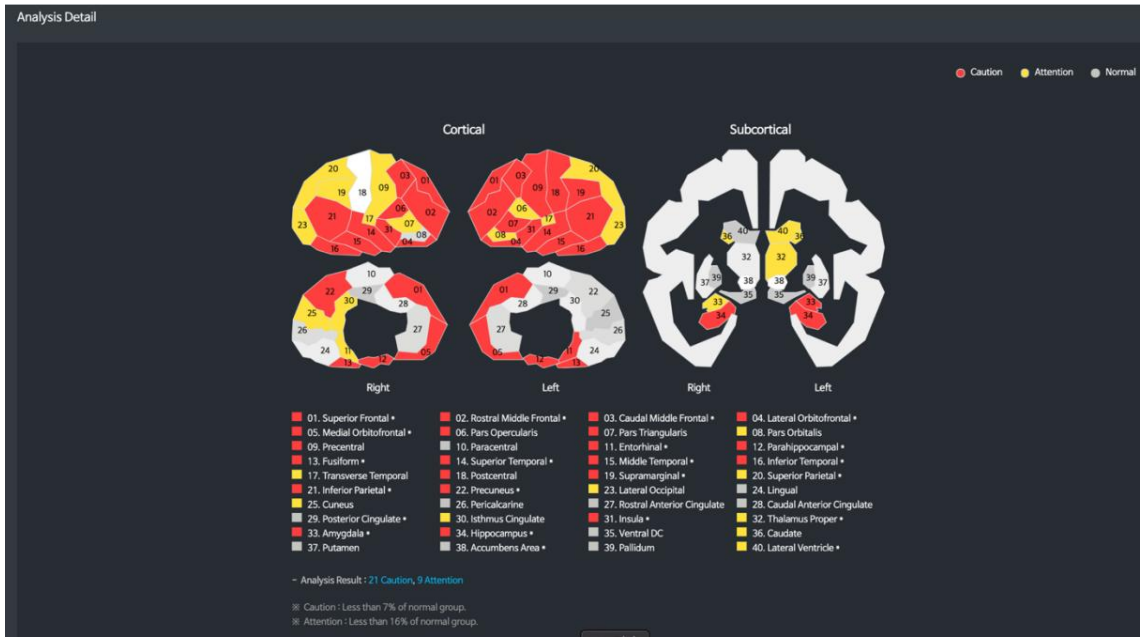


neurophet **AQUA**

VUNO **Med-DeepBrain**



JLK **ATROSCAN**



NEUROZEN **Neuro I**

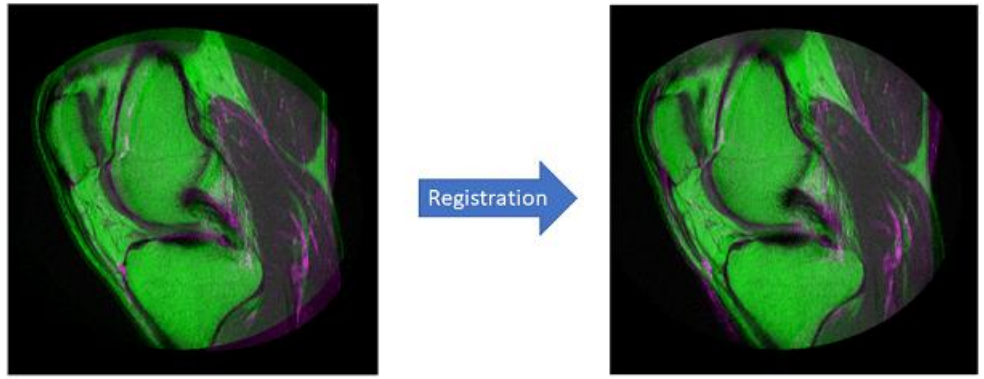
sMRI as Anatomical Reference

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

Rigid registration
(global shift and rotation)

Within-subject within-modality

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



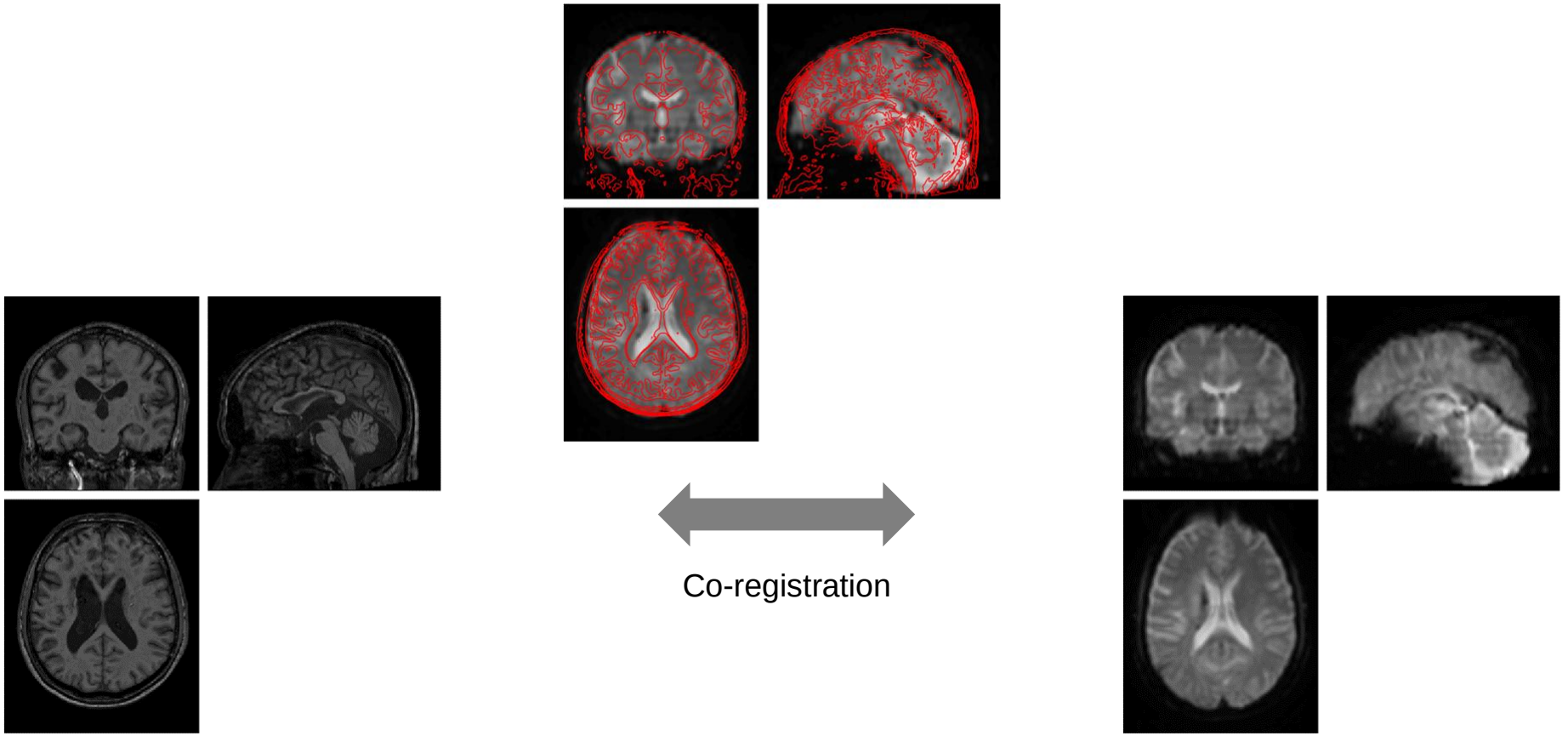
Within-subject between-modality

Deformable registration
(local transformations)

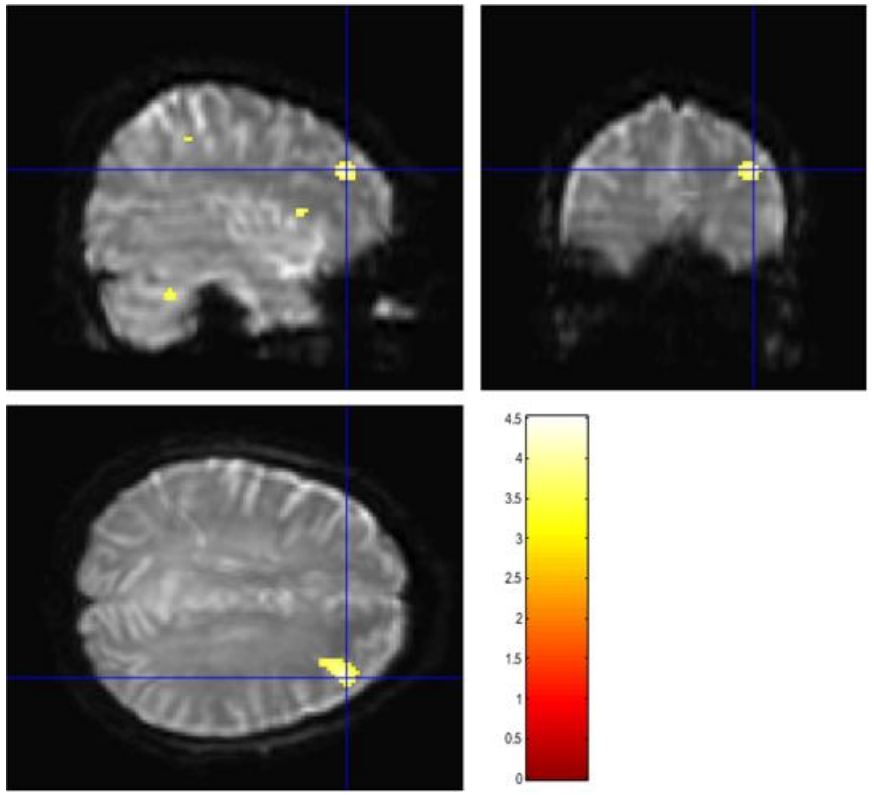
Between-subject

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

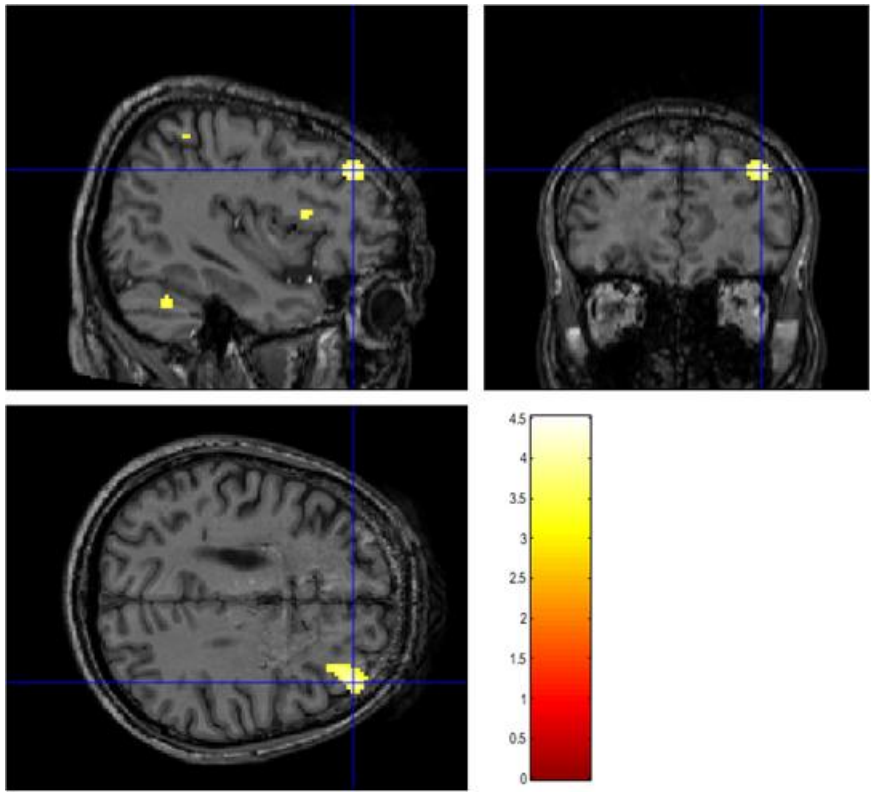
Image Registration



Co-registration between sMRI and Functional MRI



Brain activity map overlaid on a functional image



Brain activity map overlaid on a structural image

Anatomical Localization of Brain Activity