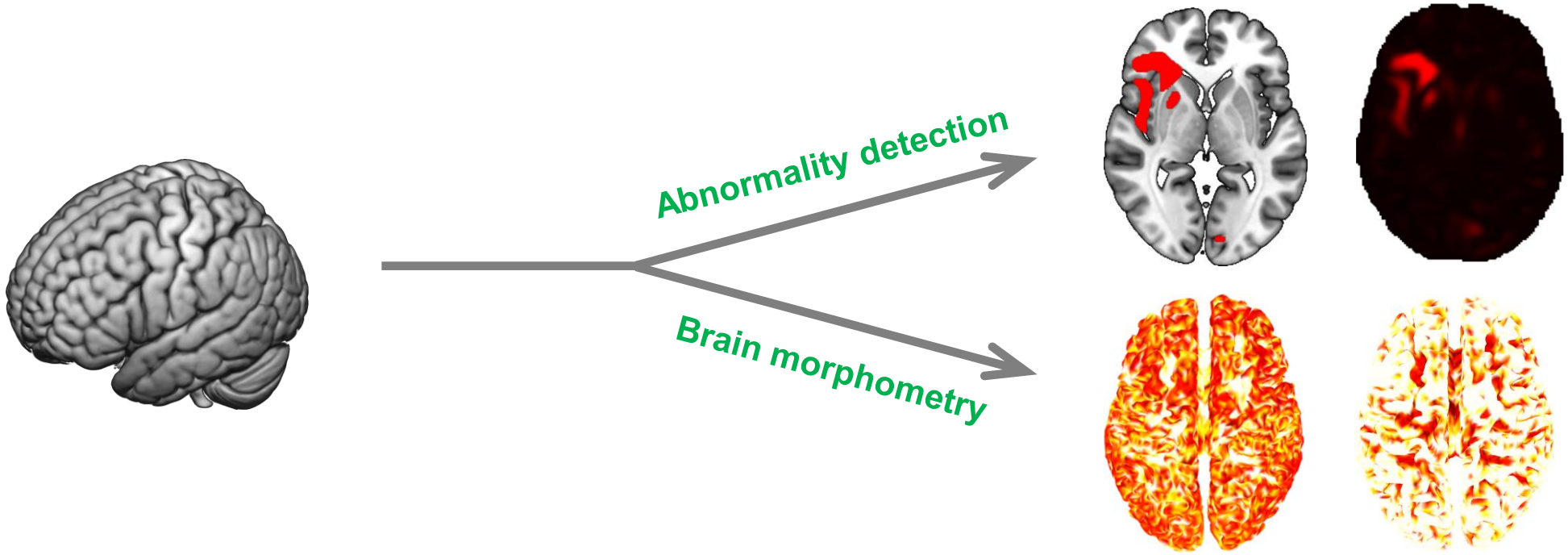
Medical/Bio Research Topics Ⅰ: Week 04 (28.03.2024)

Structural MRI (2): Data Processing

구조 자기공명영상 (2): 데이터 처리 방법

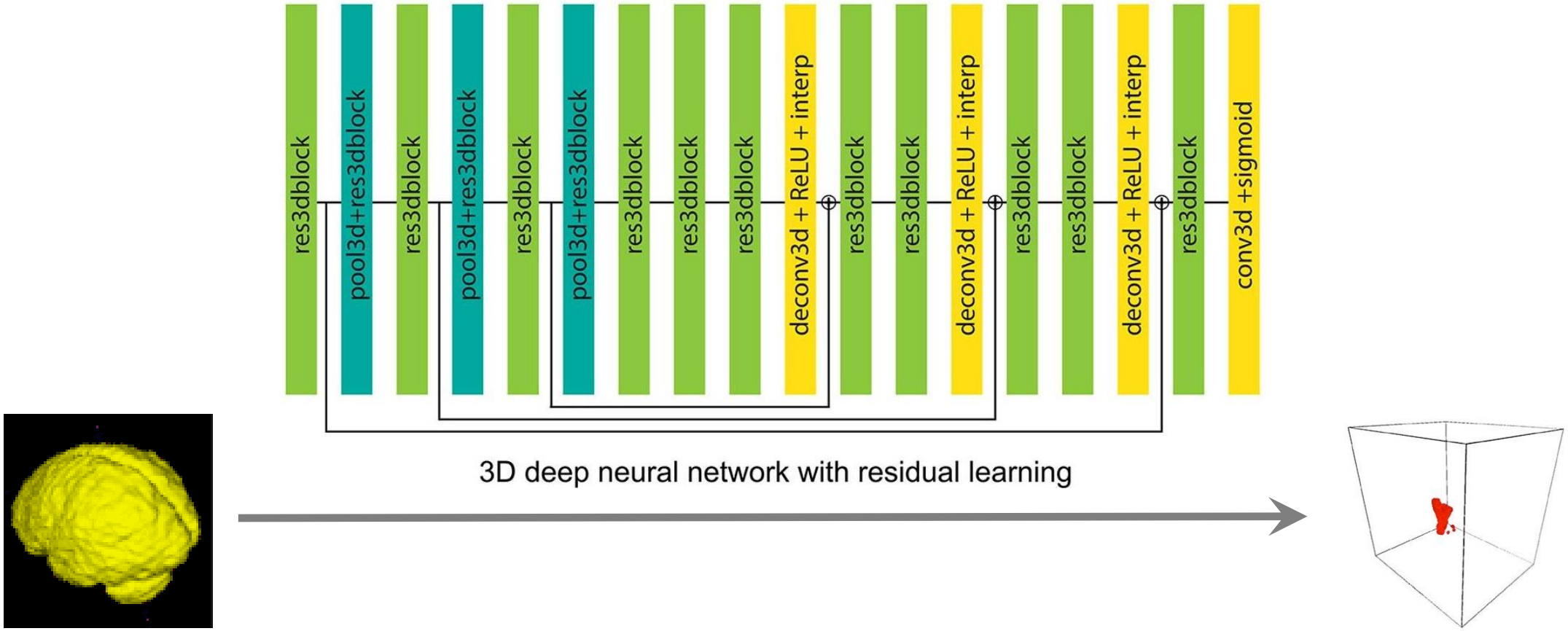
Brain Mapping with Structural MRI (sMRI)

- T1/T2-weighted sMRI



Automatic Abnormality Detection

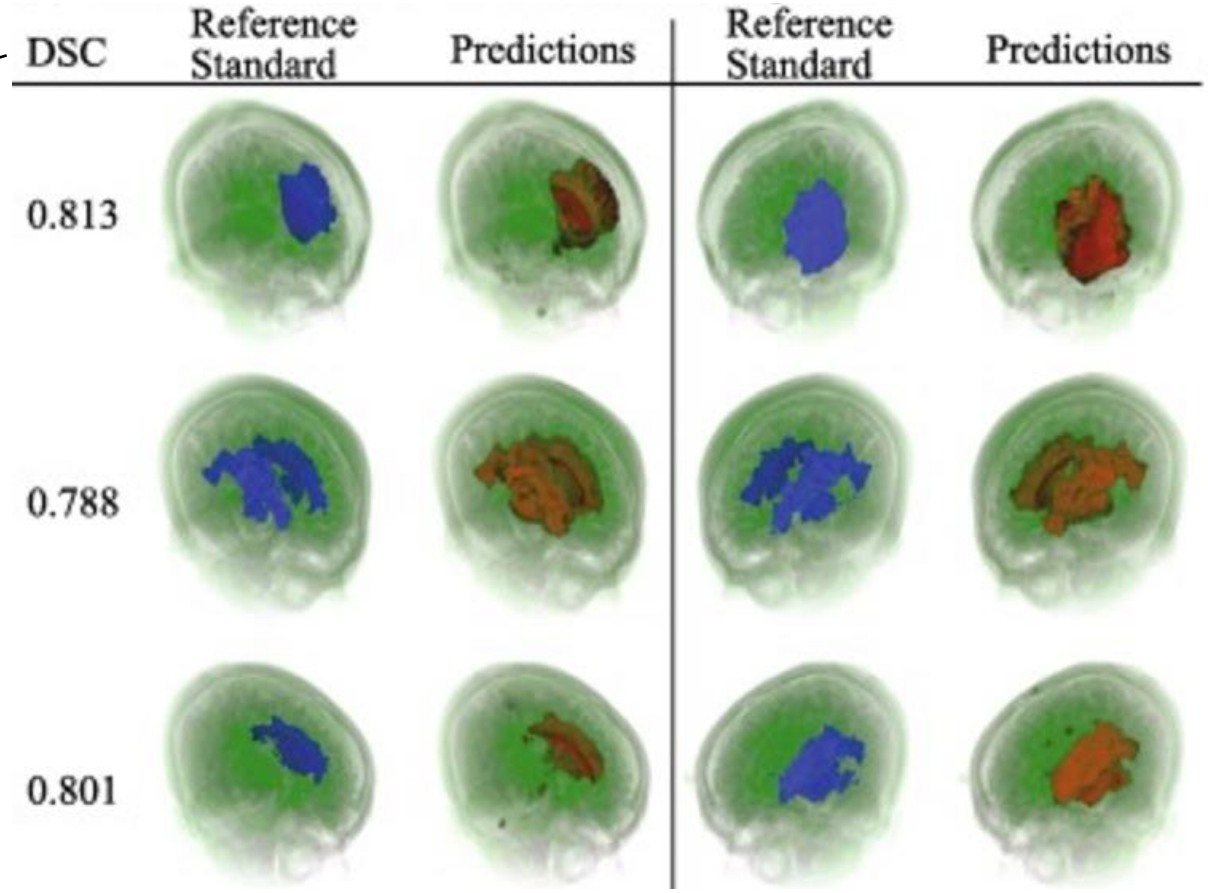
- Segmentation
  - 3D residual convolutional neural network for volumetric segmentation of stroke lesions on a T1-weighted image [Tomita et al., 2020]
- Grading
  - 3D residual convolutional neural network for predicting the severity of enlarged perivascular spaces on a T2-weighted image [Williamson et al., 2022]



[Tomita et al., 2020]

Automatic segmentation of a stroke lesion

$$DSC = \frac{2|X \cap Y|}{|X| + |Y|}$$



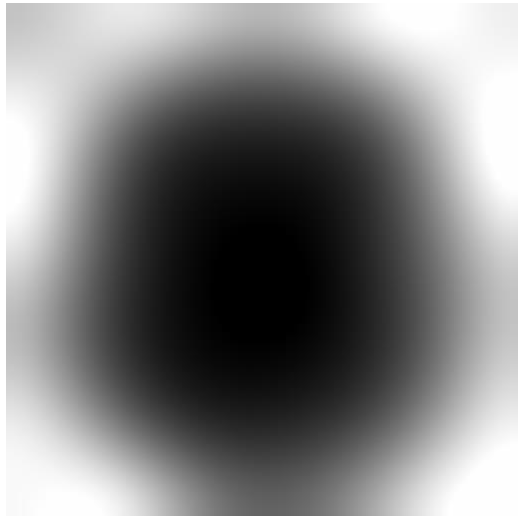
[Tomita et al., 2020]

Evaluation of the performance of stroke lesion segmentation

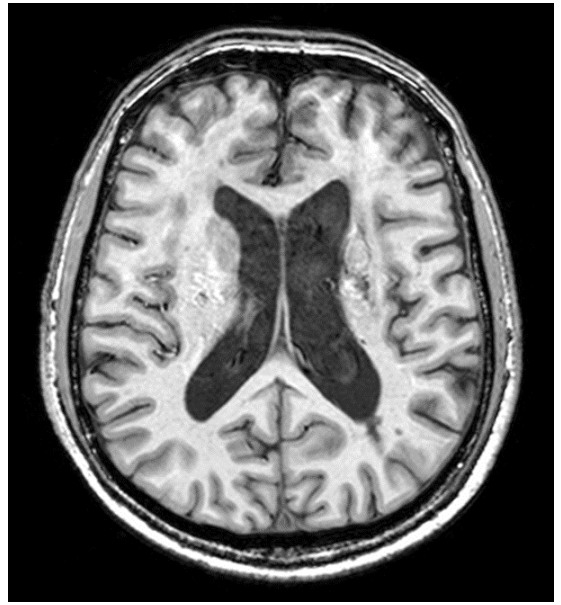
Preprocessing

- Numerous steps to clean and standardise 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

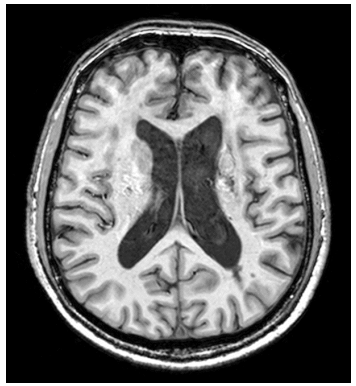
- Segmentation
  - Classifies an image into the non-brain and brain and, furthermore, the brain into different tissues usually including grey matter, white matter, and cerebrospinal fluid
- Normalisation
  - Transforms an image from a native space to the standard space usually in the Montreal Neurological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



Intensity non-uniformity



Correction for intensity non-uniformity



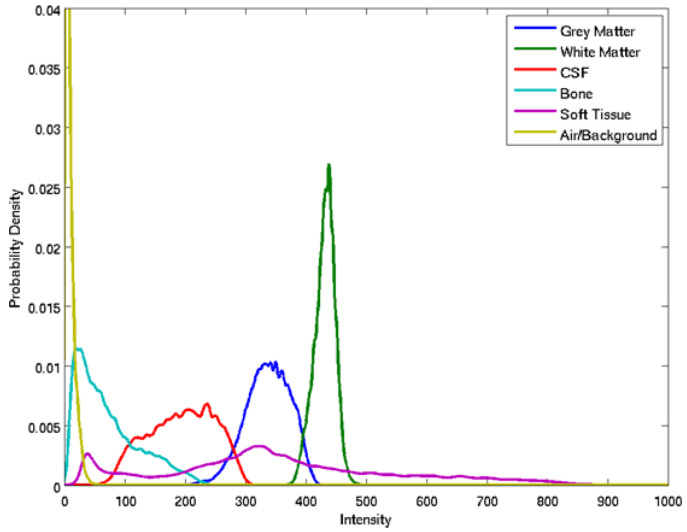
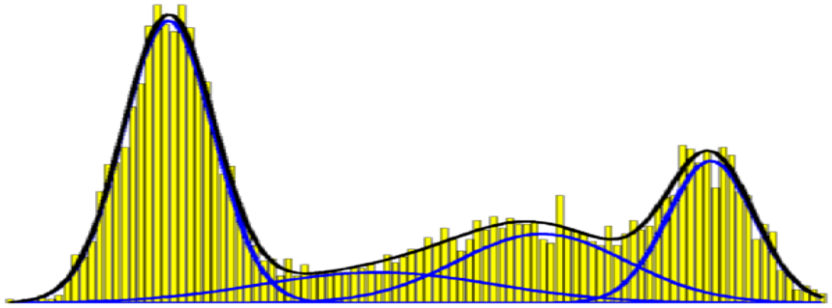


Image intensity distribution



Mixture of Gaussians model

Grey matter

White matter

Cerebrospinal fluid

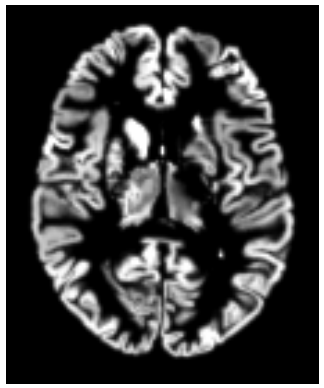
Segmentation into different tissues

Grey matter

White matter

Cerebrospinal fluid

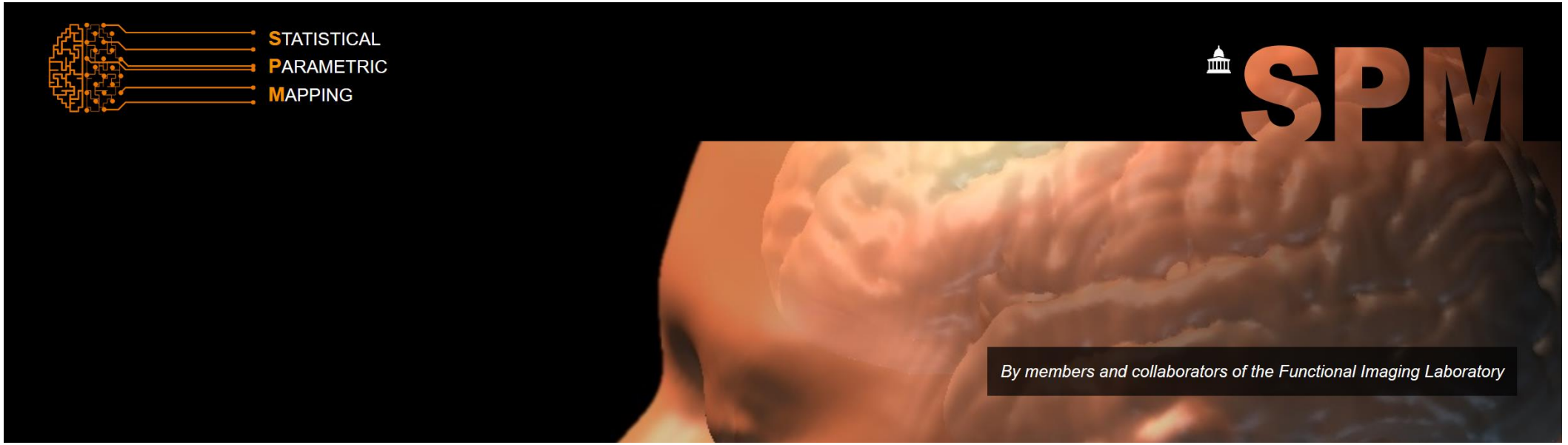
Template tissue probability maps

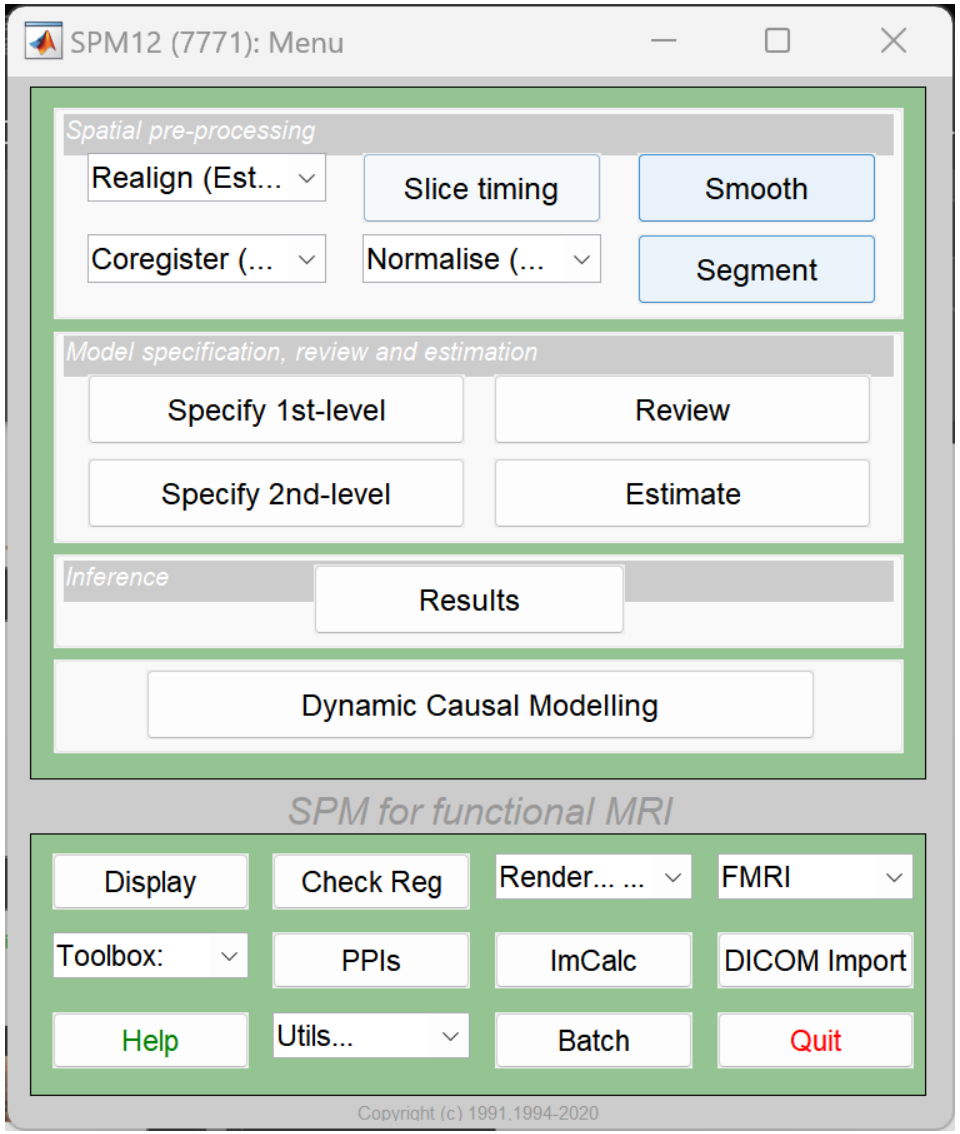


Normalisation

[Preprocessing of sMRI]

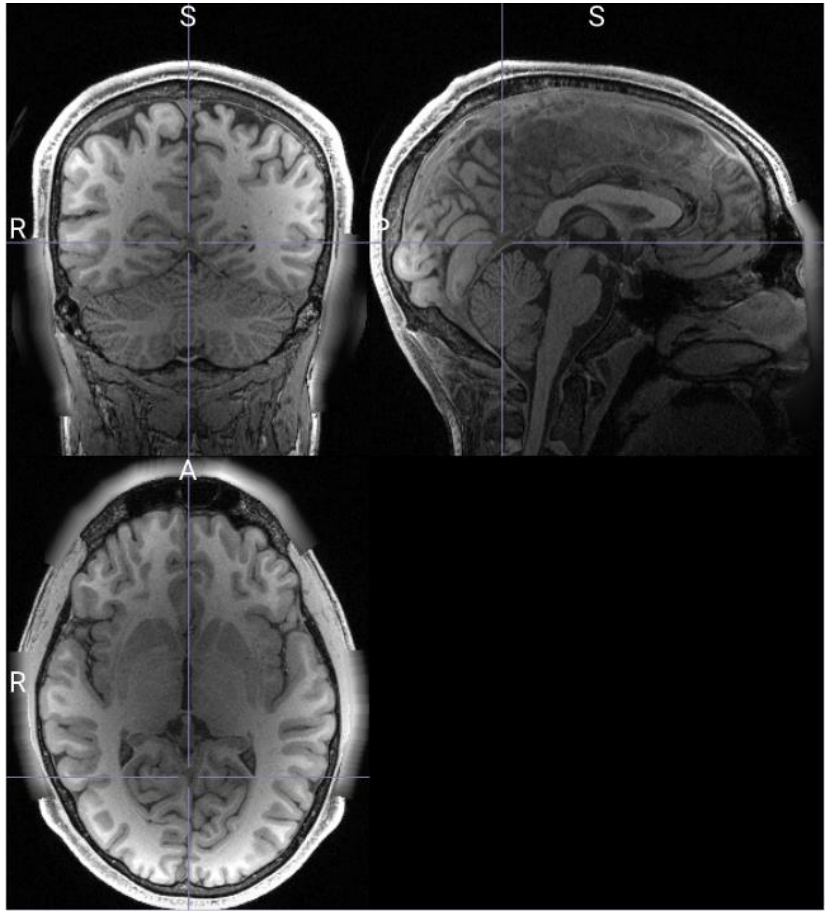
- SPM12 [https://www.fil.ion.ucl.ac.uk/spm/software/spm12/]

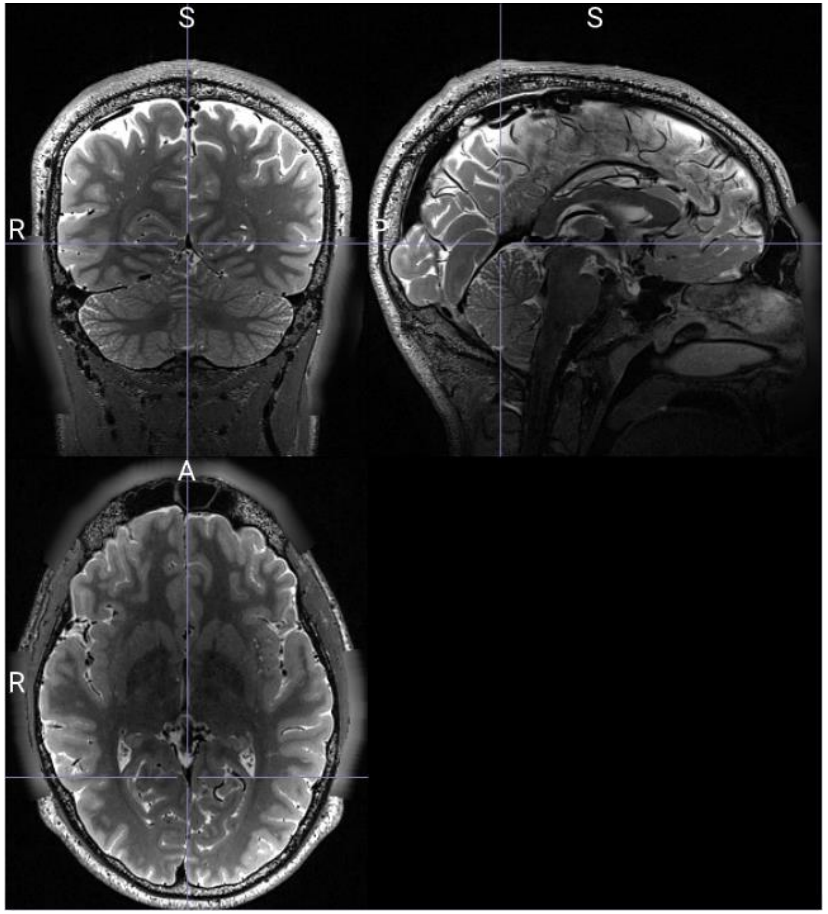




GUI of the SPM toolbox

Input

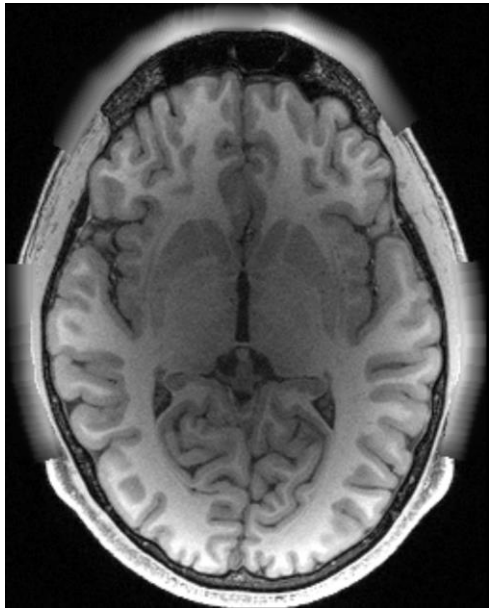


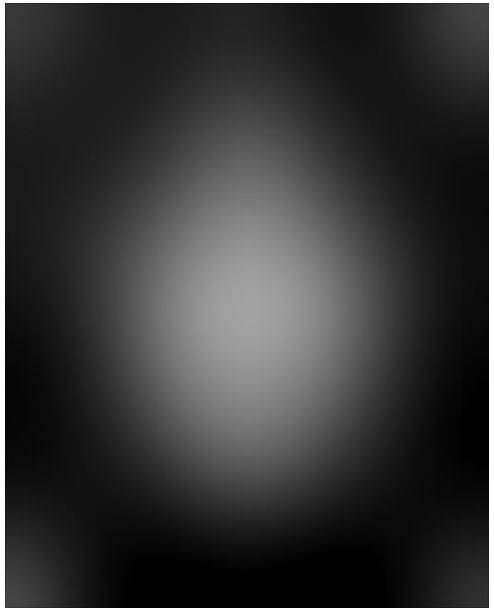


T1-weighted and T2-weighted sMRI

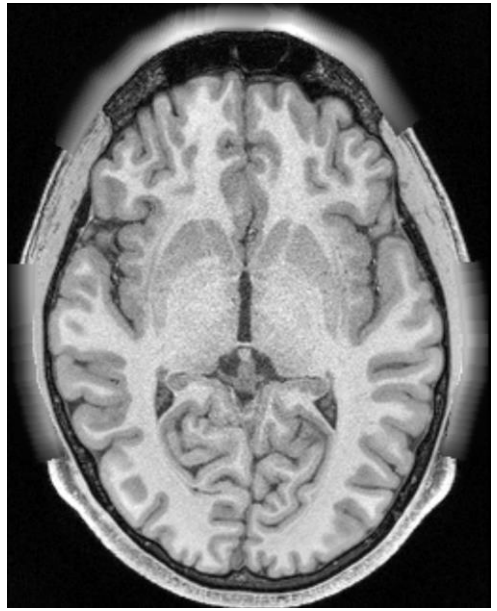
Output

Correction for intensity non-uniformity

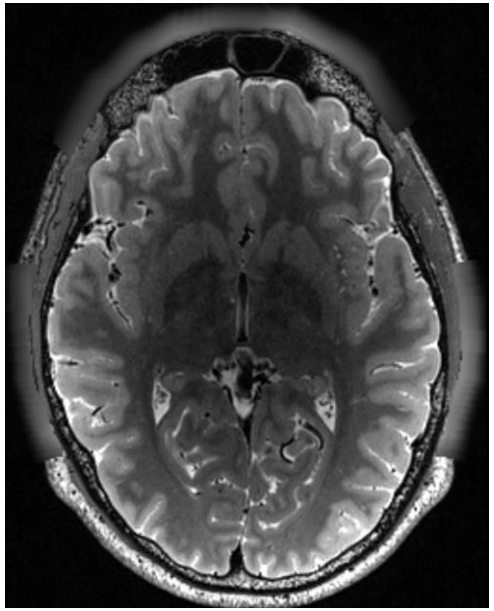


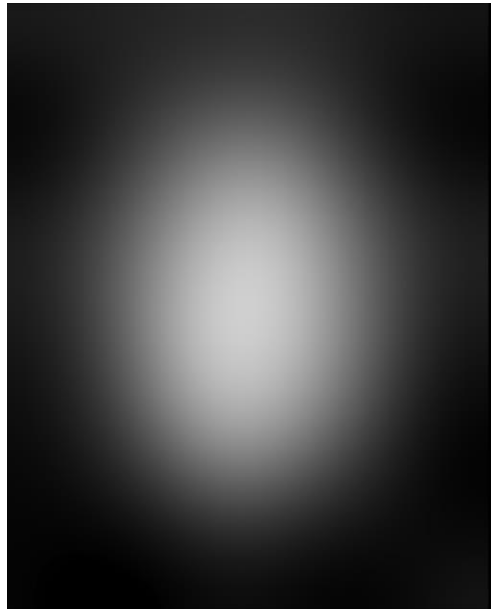


Intensity non-uniformity

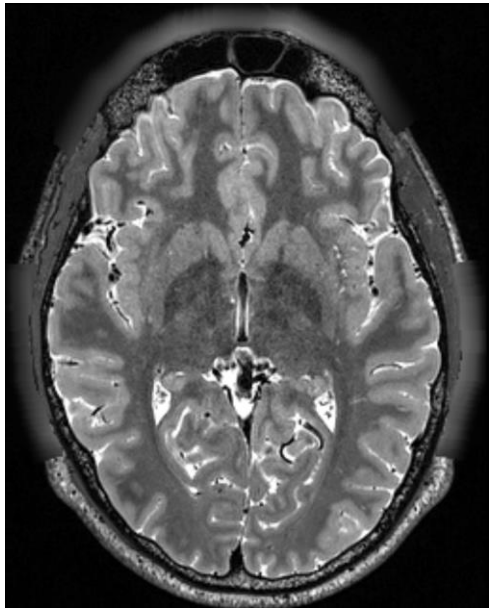


Correction of the T1-weighted image for intensity non-uniformity





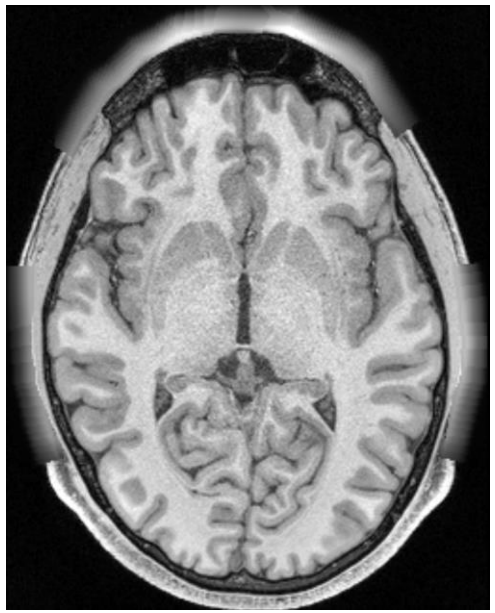
Intensity non-uniformity



Correction of the T2-weighted image for intensity non-uniformity

Output

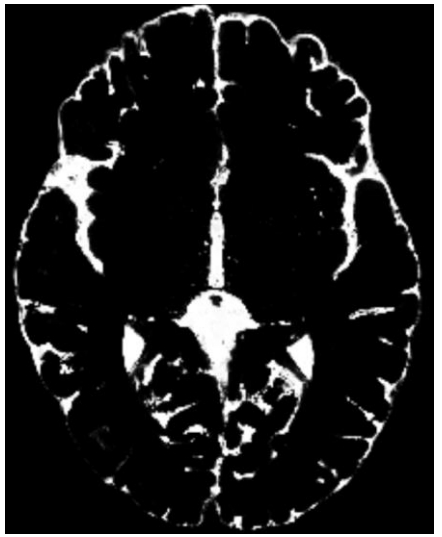
Segmentation



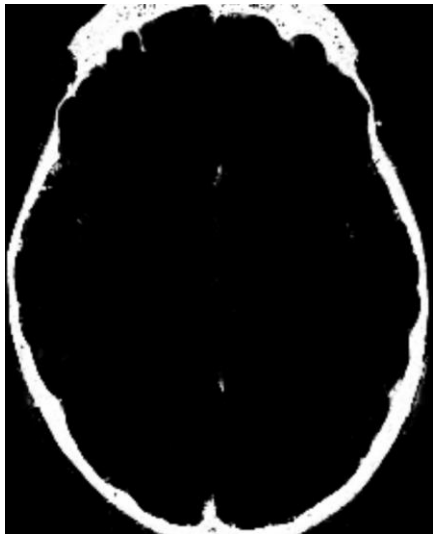
Segmentation

Grey matter

White matter

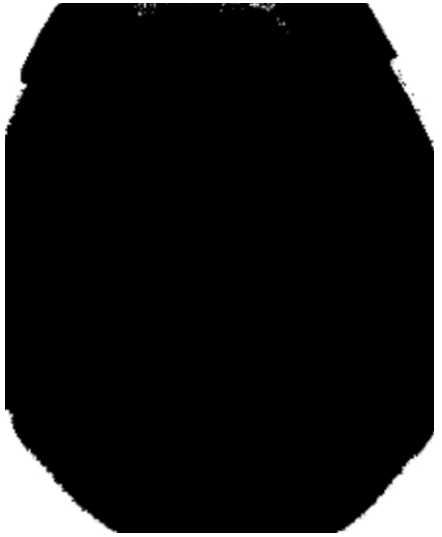


Cerebrospinal fluid

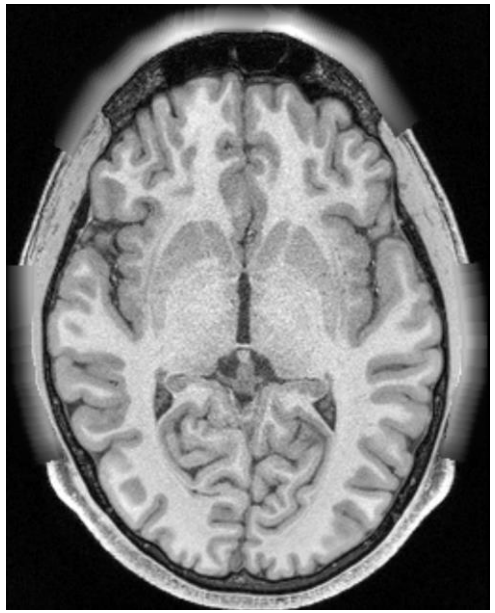


Bone

Soft tissue



Air/background



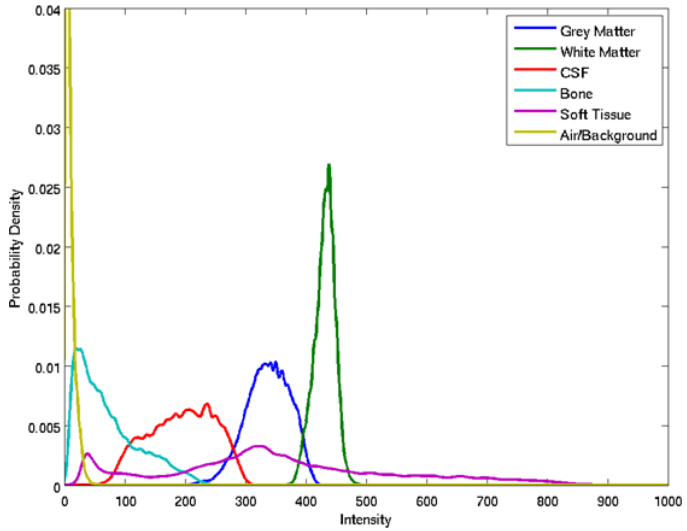
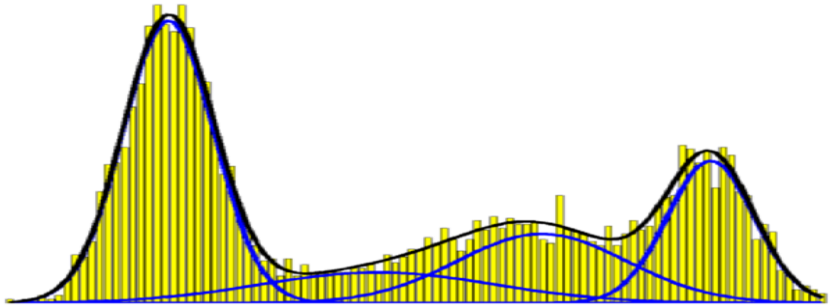
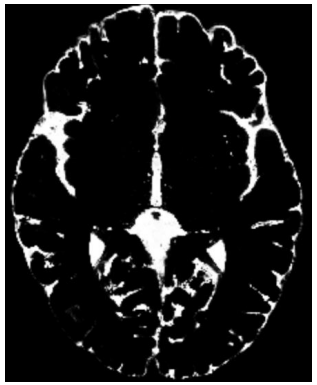


Image intensity distribution



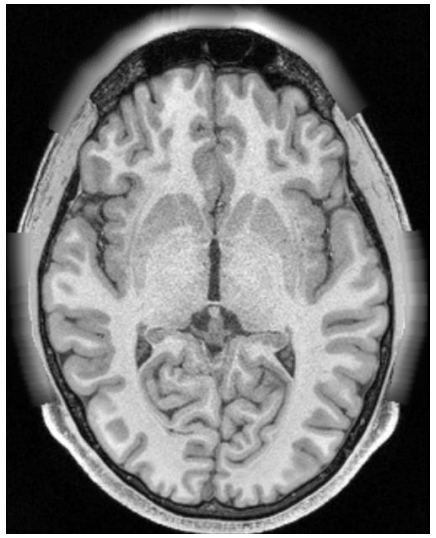
Mixture of Gaussians model

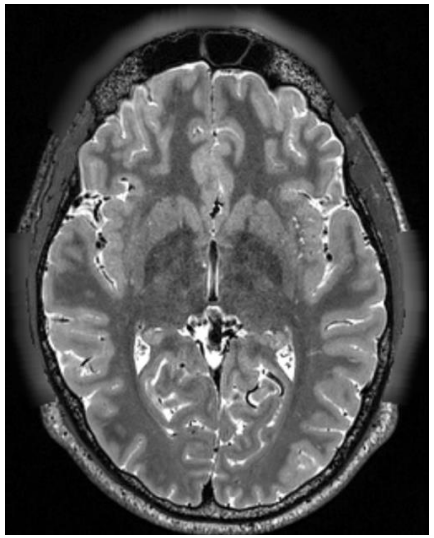


Tissue classification based on a mixture of Gaussians

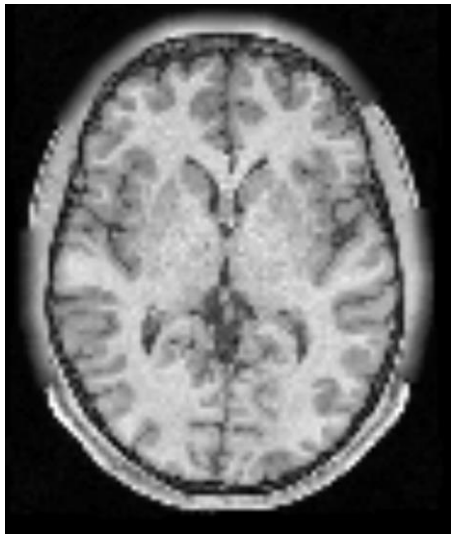
Output

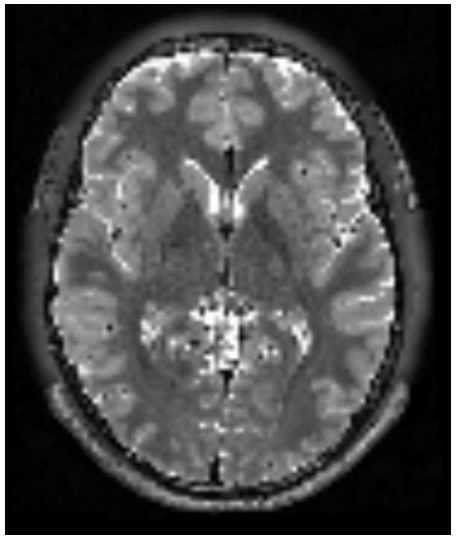
Normalisation





Normalisation

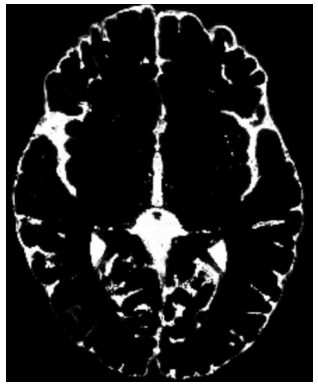




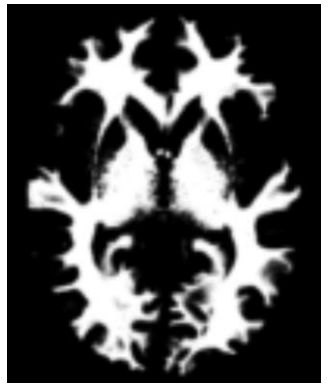
Grey matter

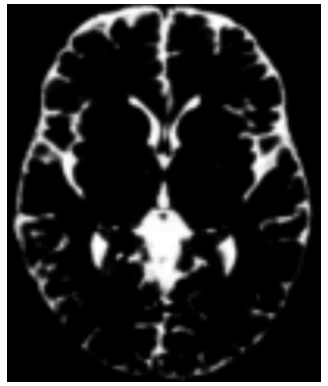
White matter

Cerebrospinal fluid



Template tissue probability maps

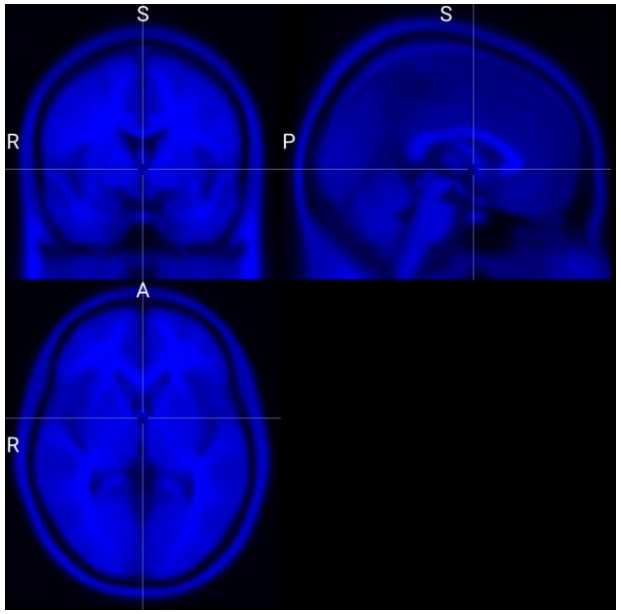


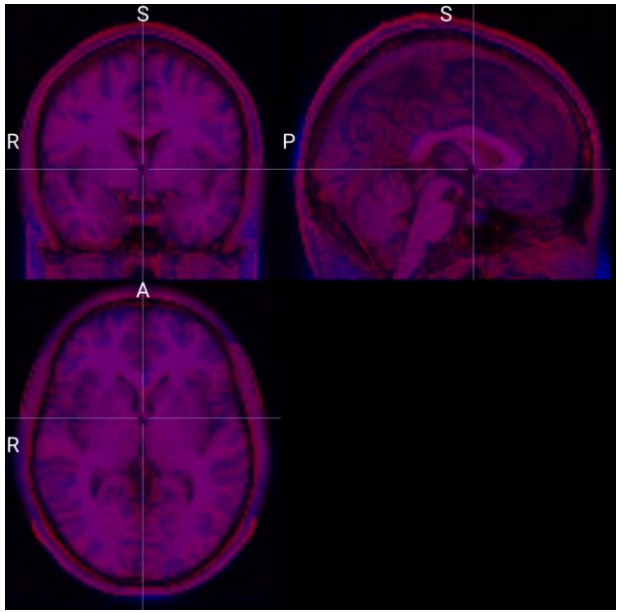


Unified segmentation and normalisation

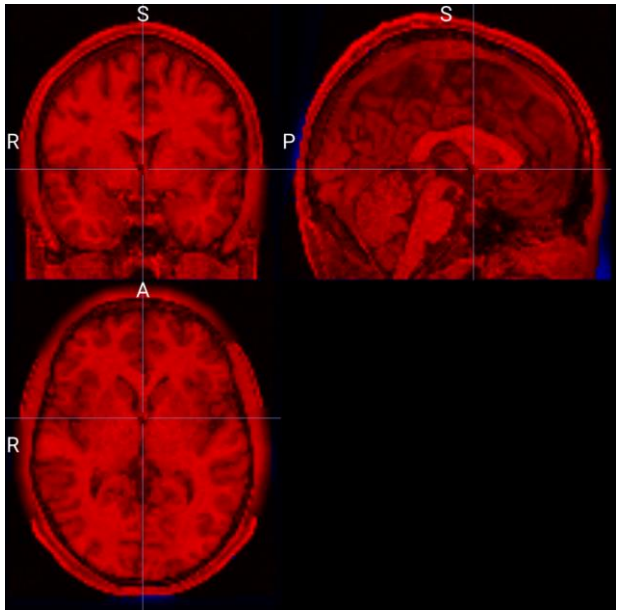
Confirmation

MNI152 template brain



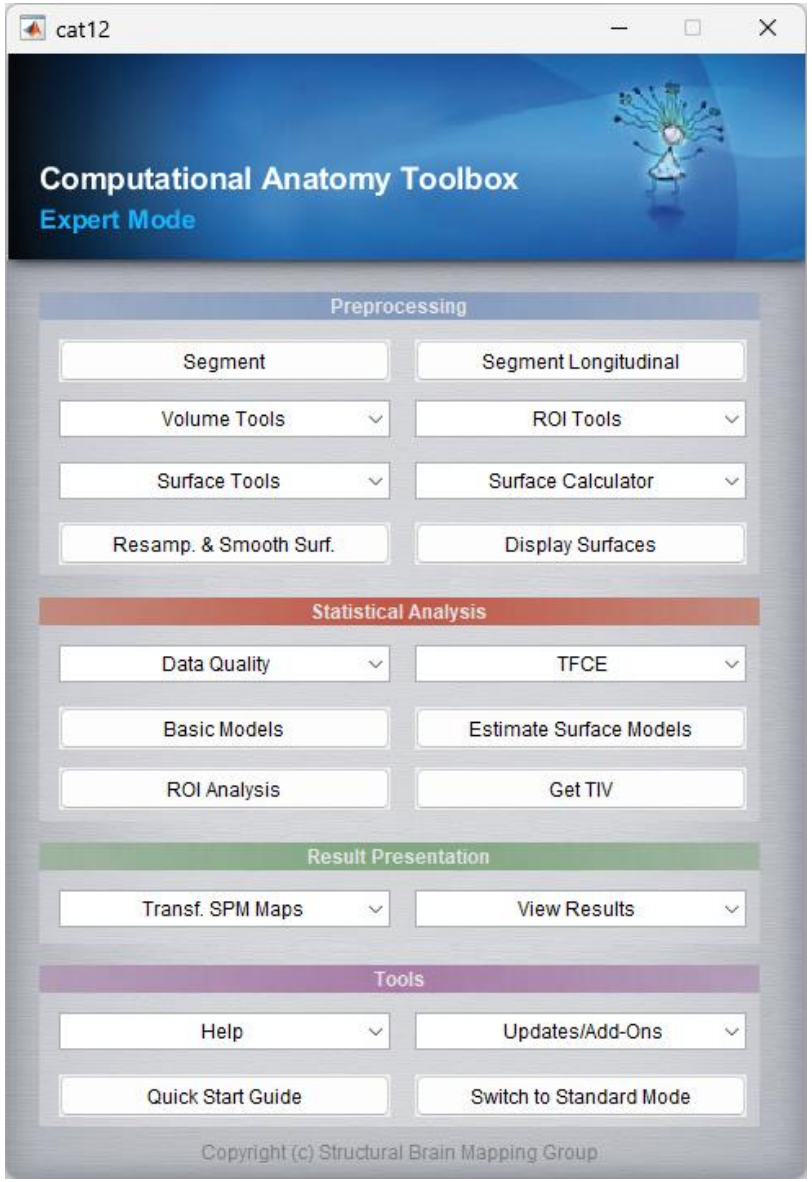


Individual's normalized brain



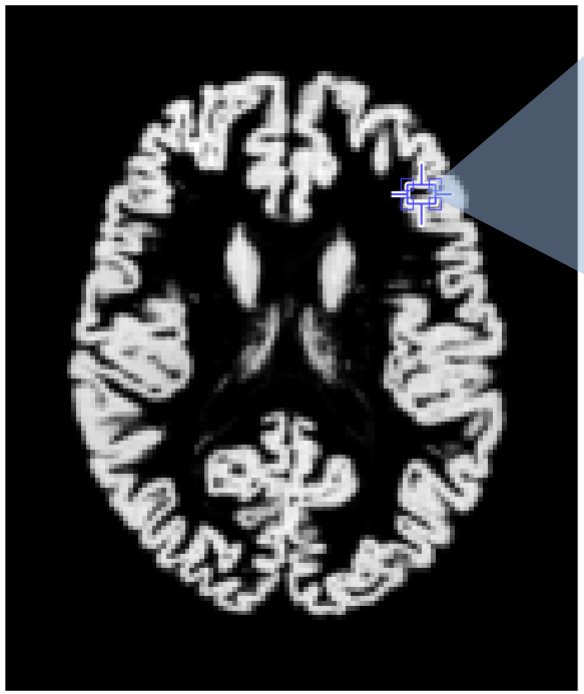
Voxel-based Morphometry

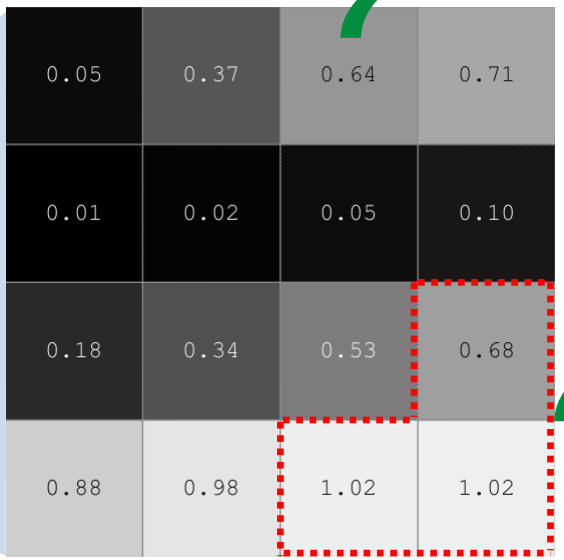
- Without defining boundaries and modelling cortical surfaces
- CAT12 [https://neuro-jena.github.io/cat/]



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

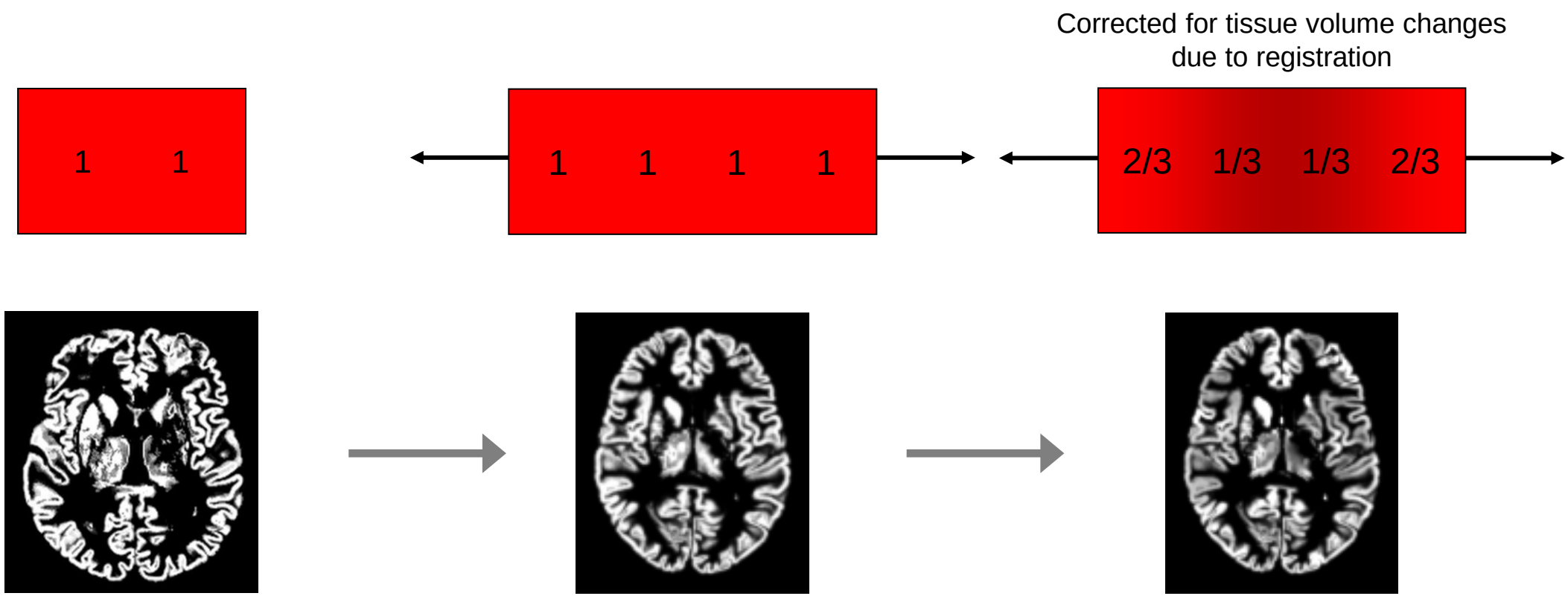
Grey matter volume = 0.64 × 3.375 mm^3
= 2.16 mm^3

Region

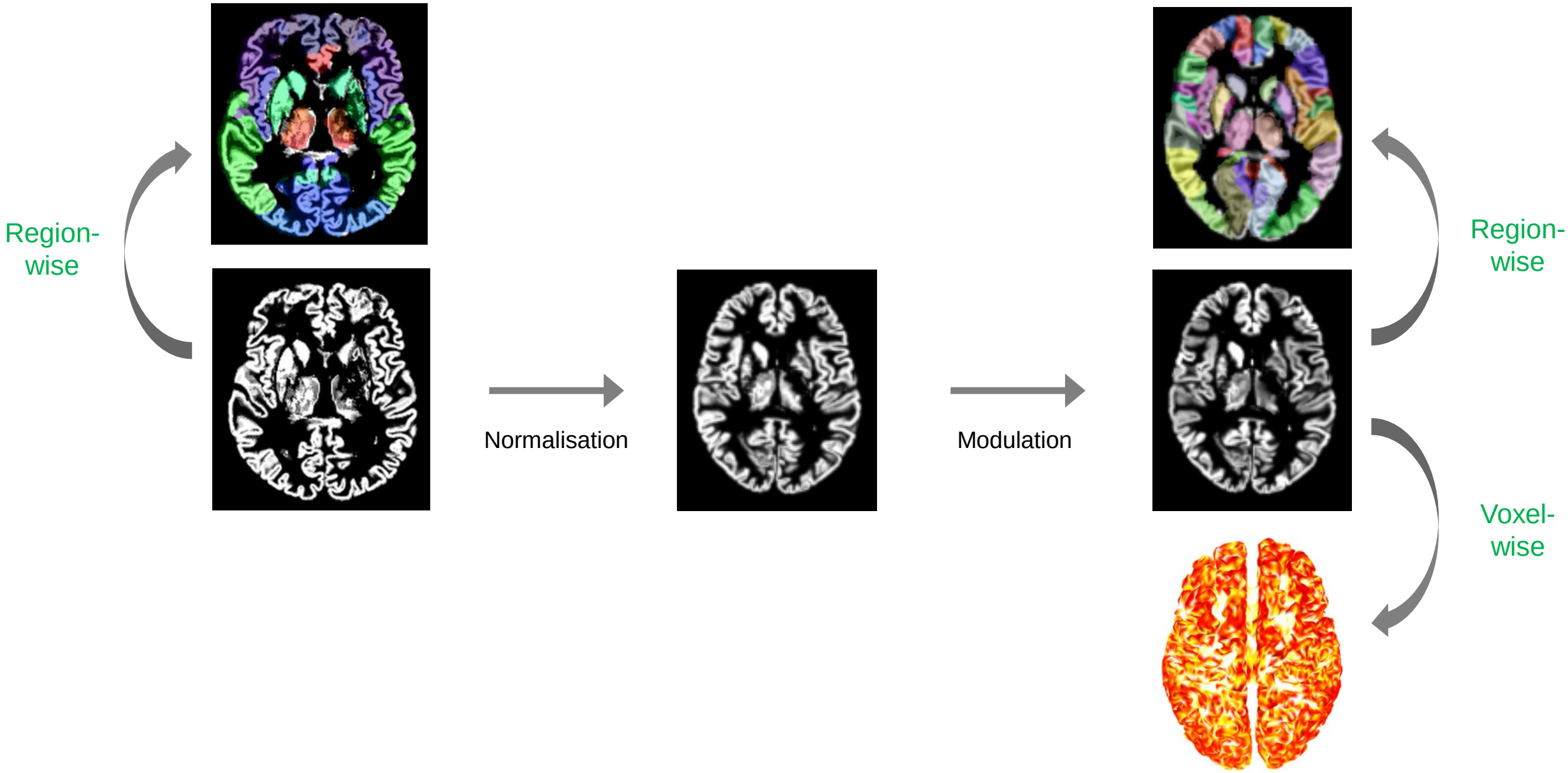
Grey matter volume = 9.18 mm^3

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 a region



Normalisation and modulation

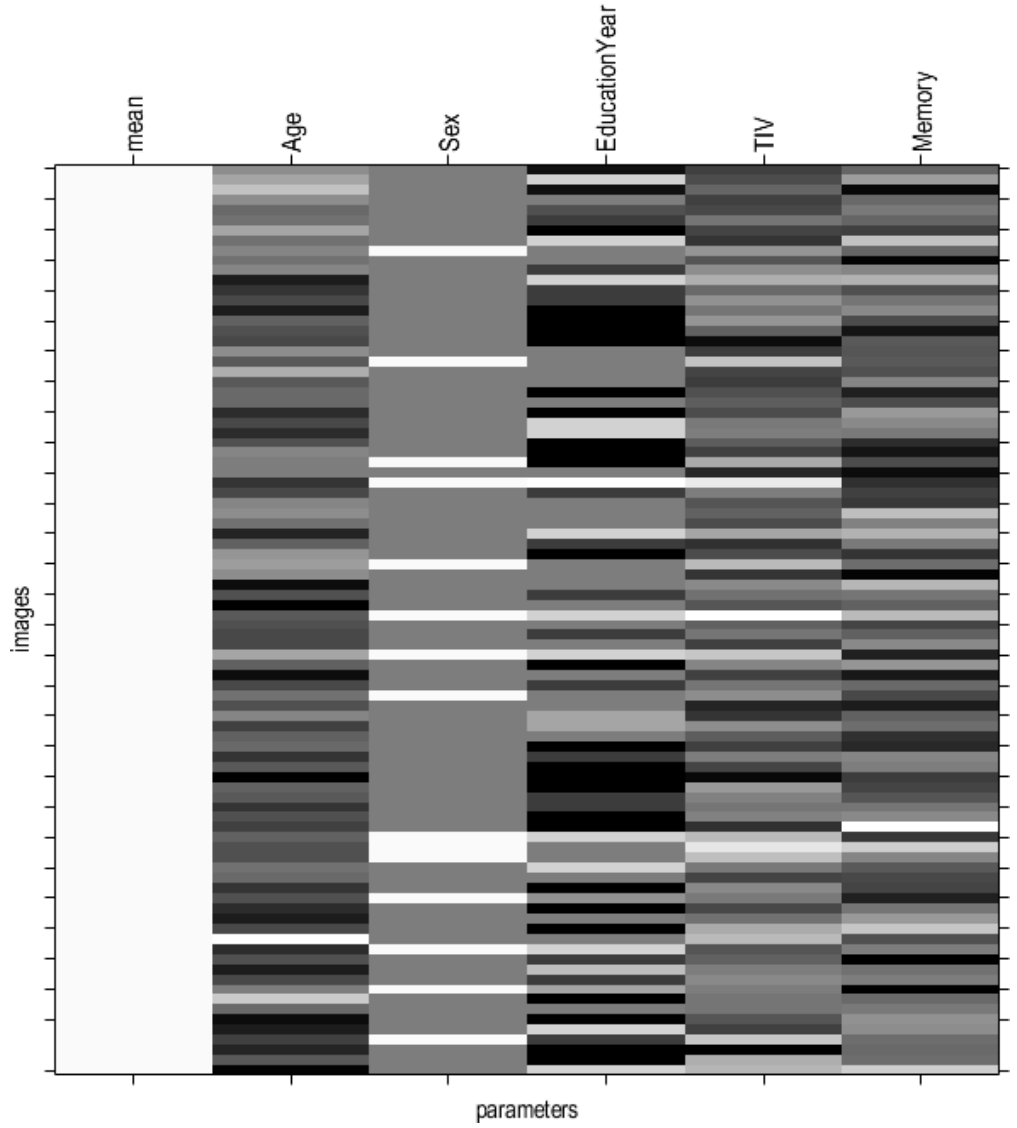


Features of grey matter volume

[Statistical Analysis of sMRI]

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

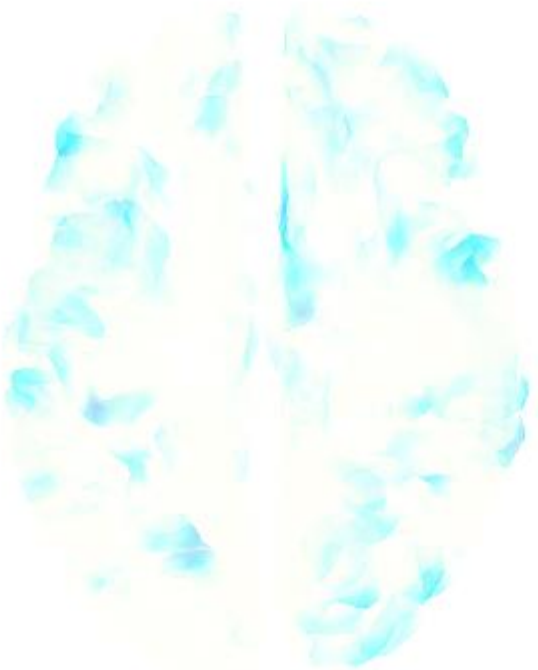
Design matrix



Output

Regression

Positive correlaton



Negative correlation

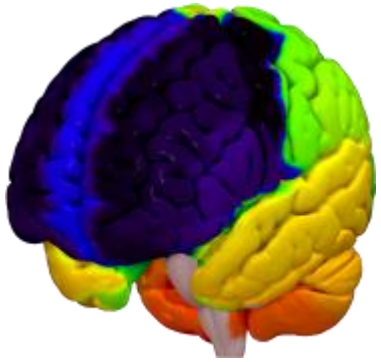
- Input to machine learning models
  - Table of voxel-wise or region-wise grey matter volume values

Features →

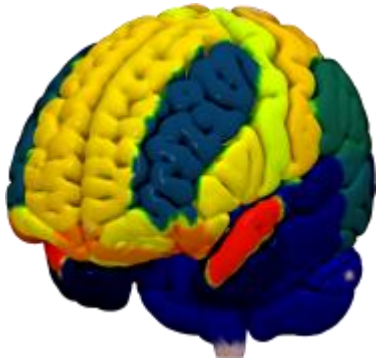
Samples ↓

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

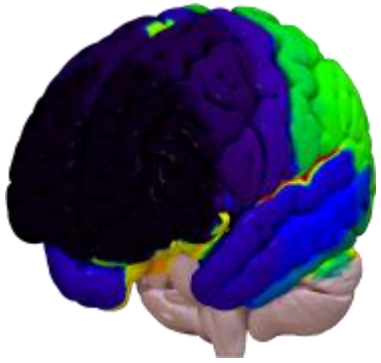
  - Grey matter volume map



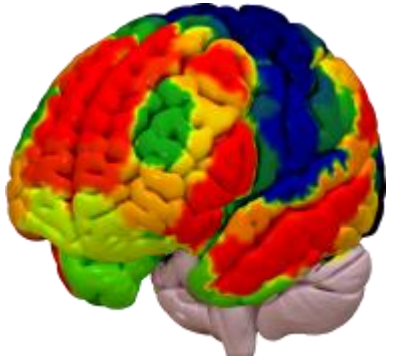
AAL atlas



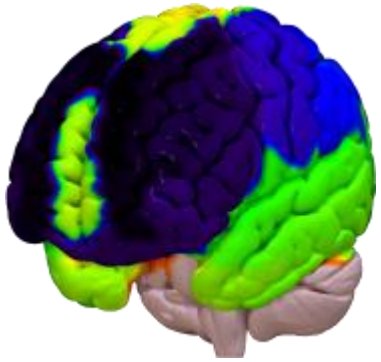
Hammers atlas



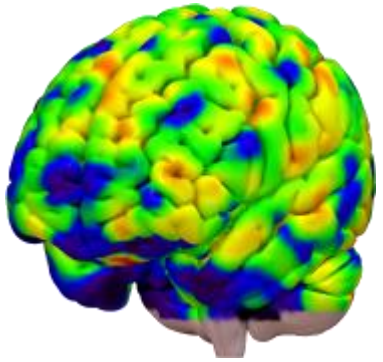
Harvard-Oxford atlas



Yeo atlas

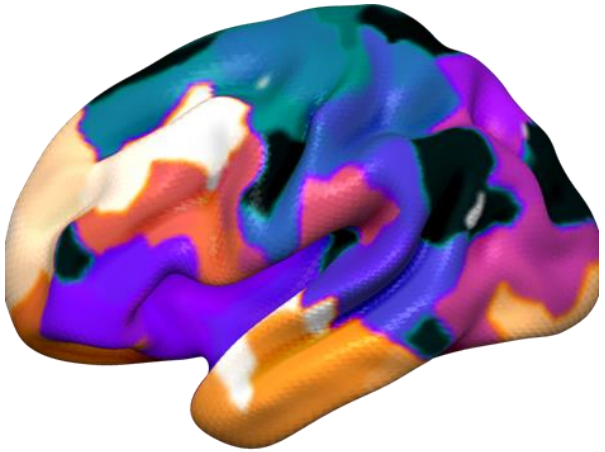


AICHA atlas

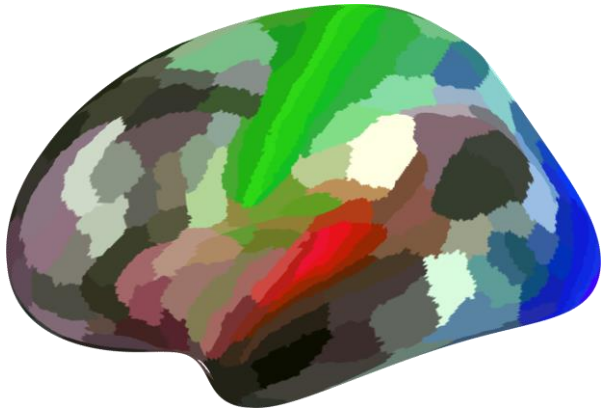


Craddock atlas

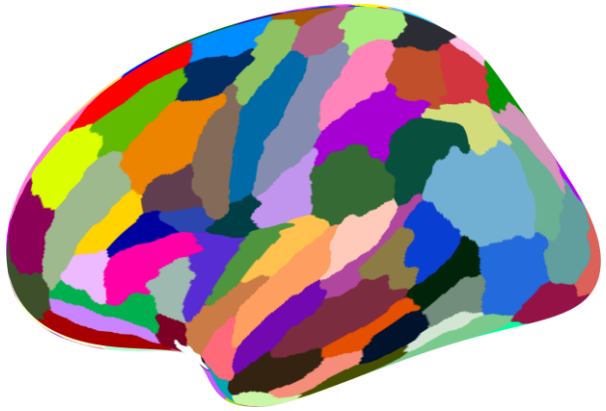
Brain atlases



333 areas
Resting-State Correlations atlas



360 areas
HCP MMP 1.0 atlas



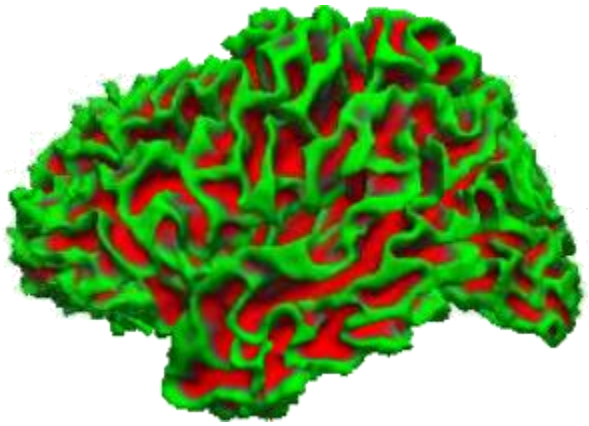
246 areas
Brainnetome atlas

Higher-resolution brain atlases

Surface-based morphometry

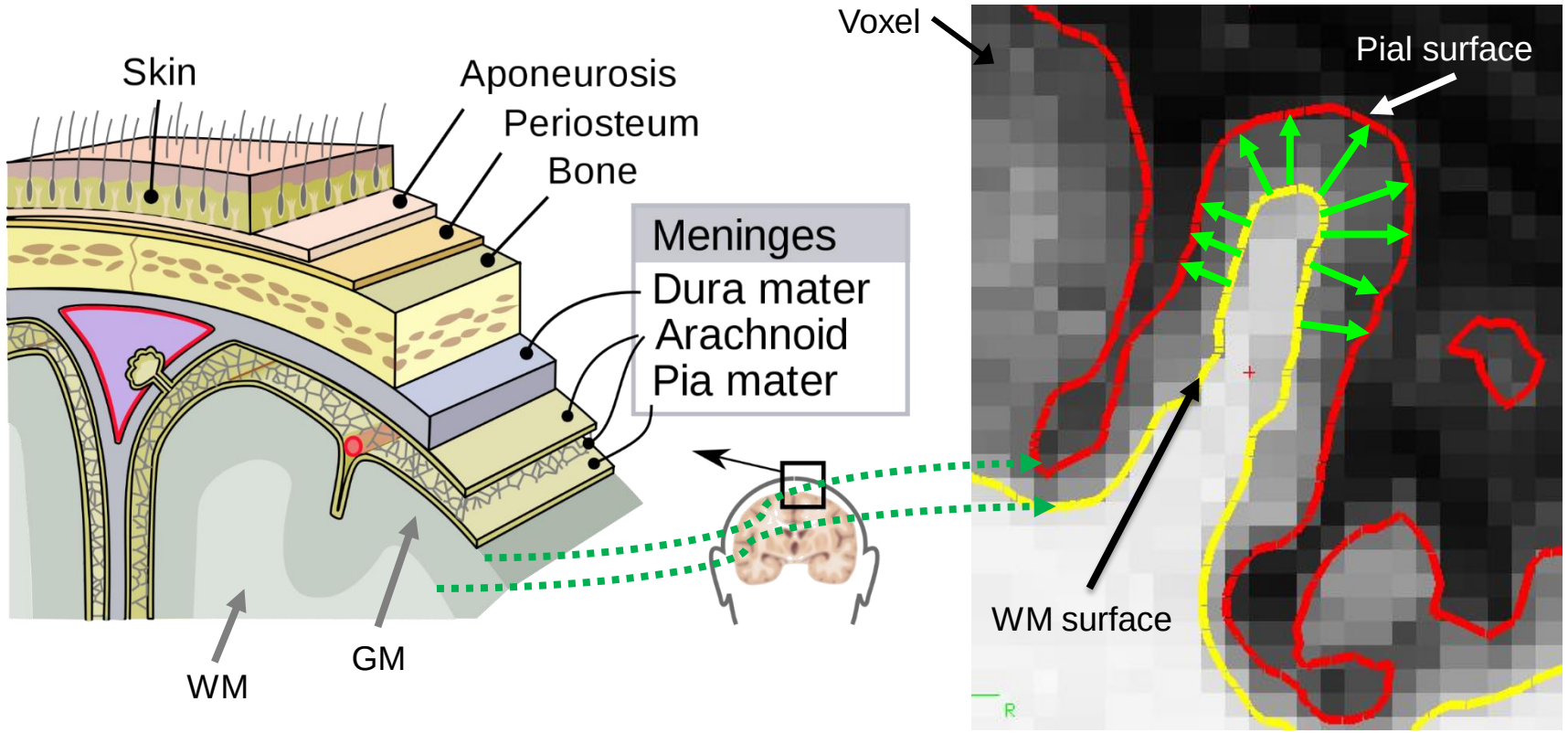
- Independent of registration and modulation
- Not applicable to subcortical regions
- FreeSurfer [https://surfer.nmr.mgh.harvard.edu/]
  - sMRI analysis software of choice for the Human Connectome Project

- 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



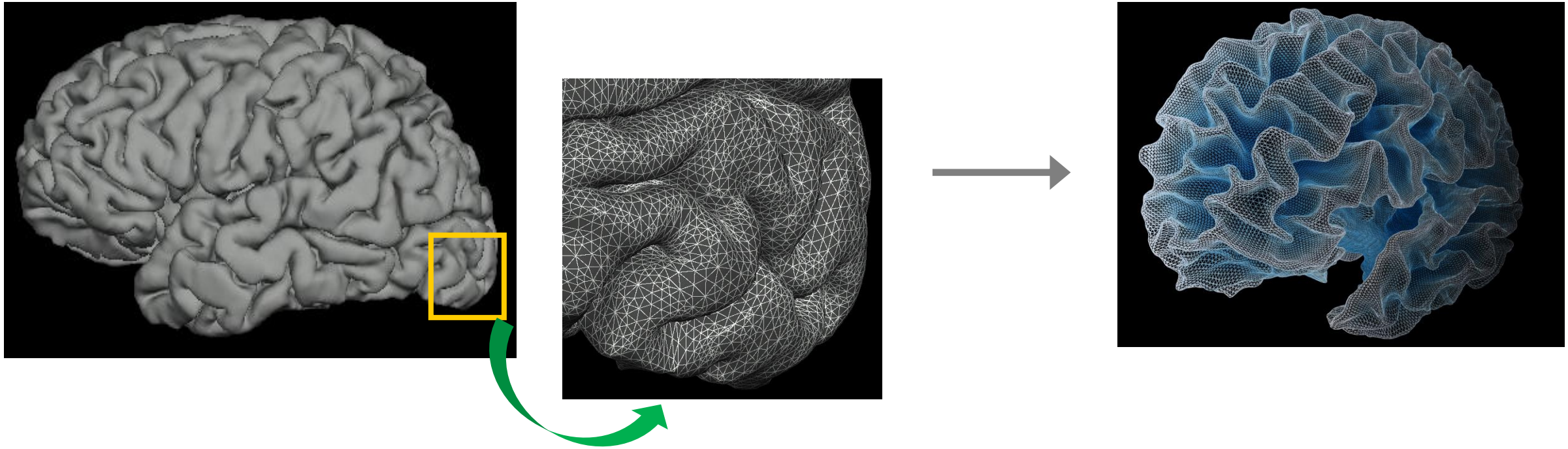
White matter surface

Pial surface



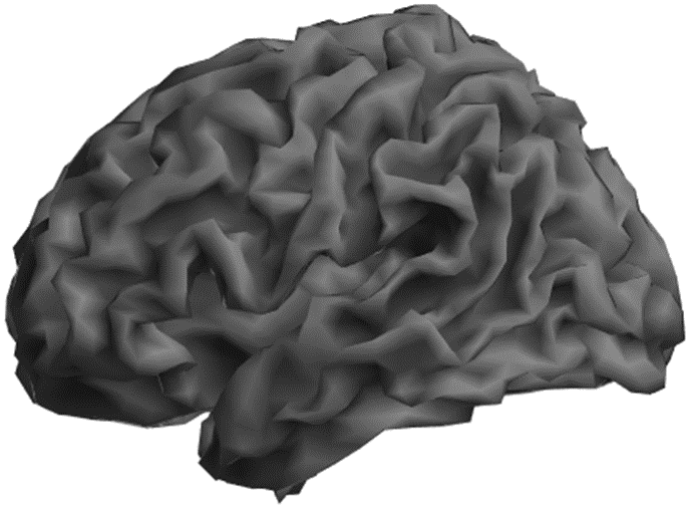
[https://www.physio-pedia.com/Meninges]

Cortical surfaces beneath cranial meninges

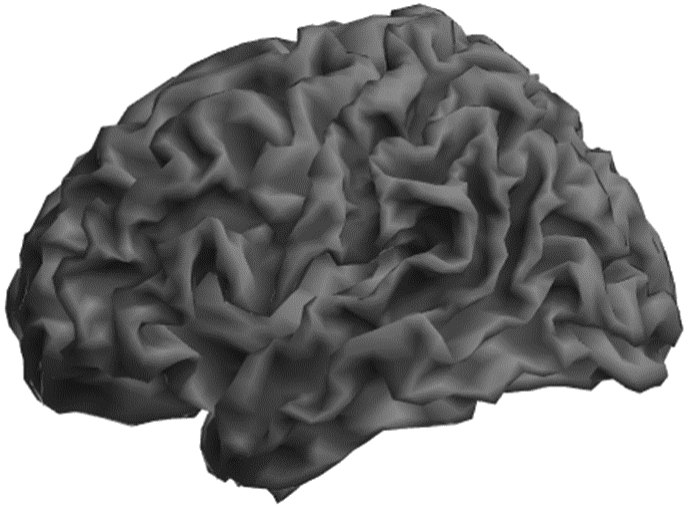


[https://surfer.nmr.mgh.harvard.edu/]

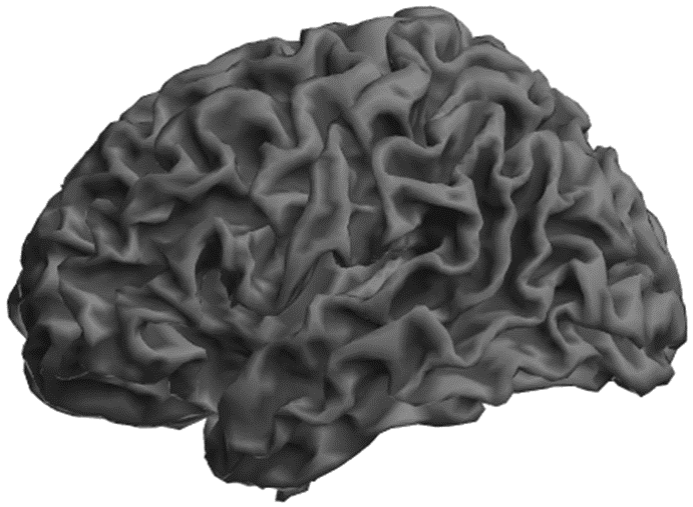
Surface representation of the cerebral cortex



5124 vertices



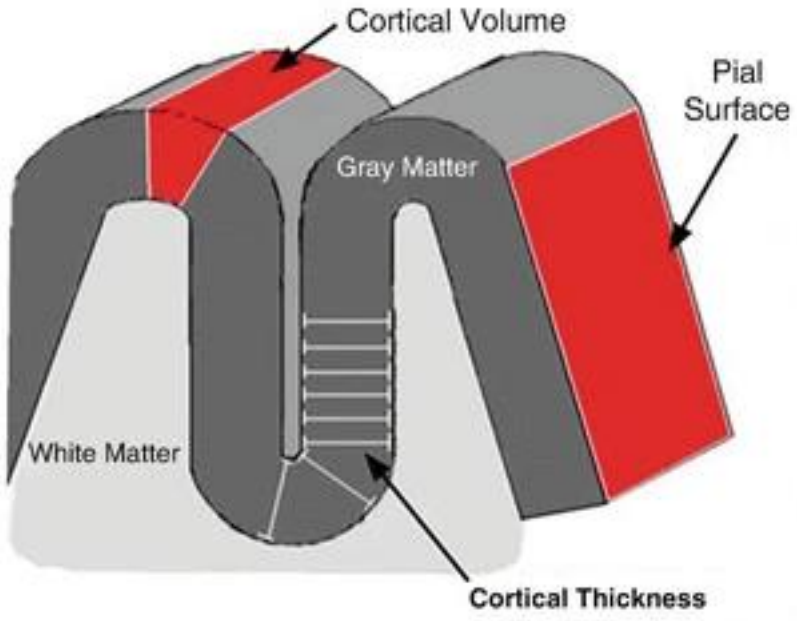
8196 vertices

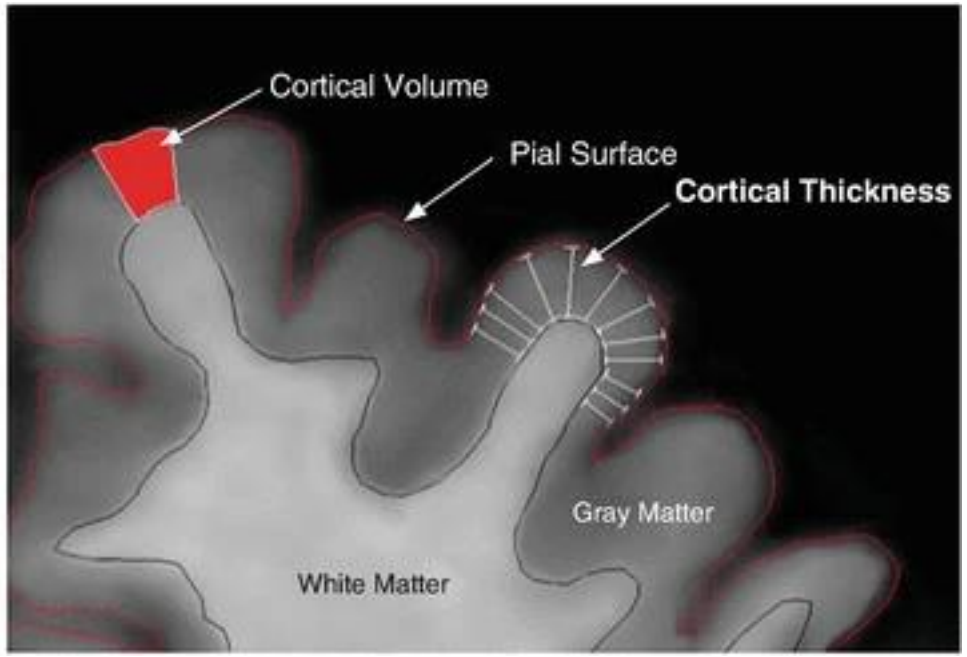


20484 vertices

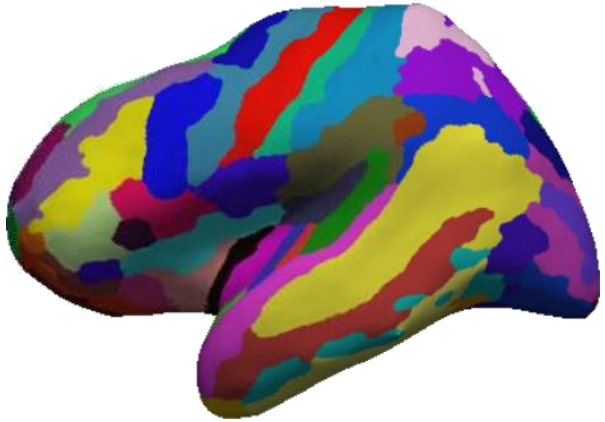
Surface representation with different numbers of vertices

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





[Gale and Huff, 2017]



Inflated

Region-wise

Vertex-wise

Features of cortical thickness

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

Features →

Samples ↓

	Vertex or region 1 cortical thickness	Vertex or region 2 cortical thickness	Vertex or region 3 cortical thickness	…
Subject 1	-	-	-	-
Subject 2	-	-	-	-
Subject 3	-	-	-	-
⋮	-	-	-	-

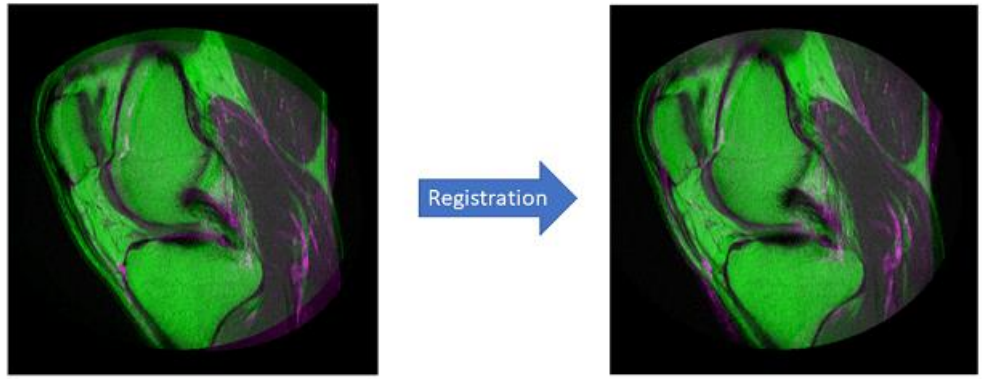
sMRI as an Individual's Spatial Reference

- Anatomical localization 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)



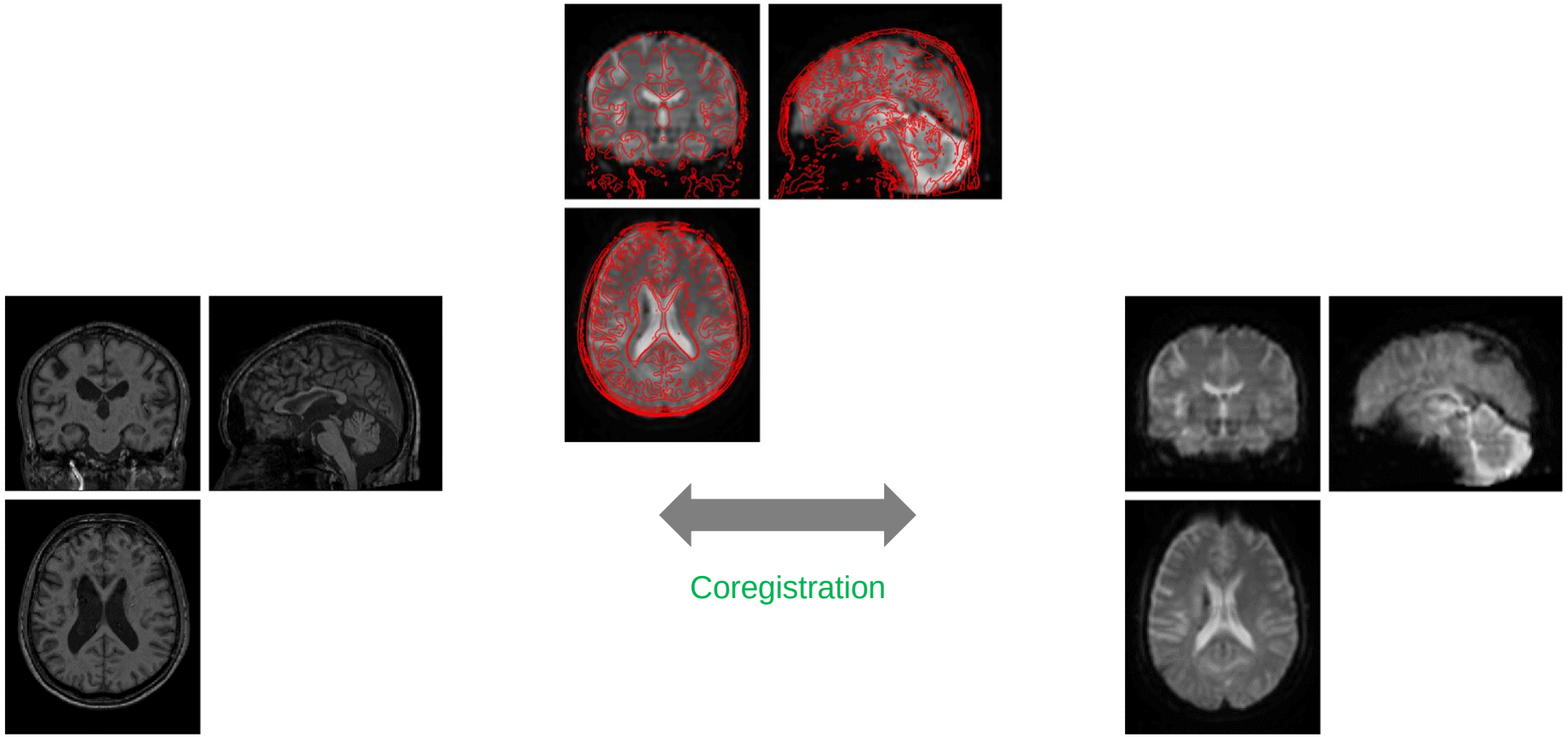
Within-subject between-modality

Deformable registration
(local transformations)

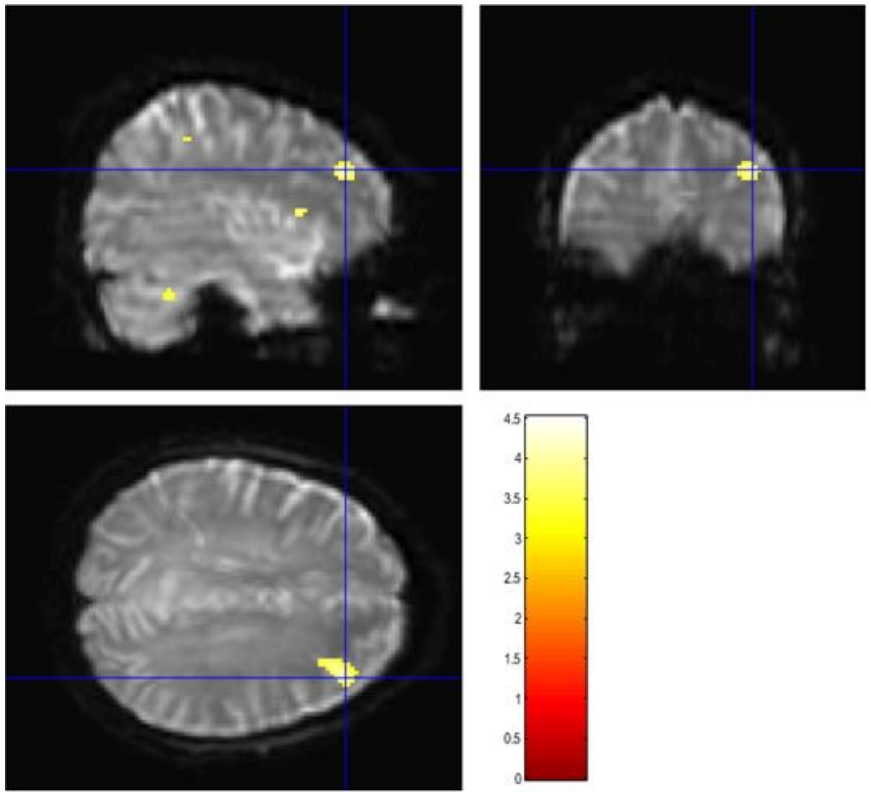
Between-subject

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

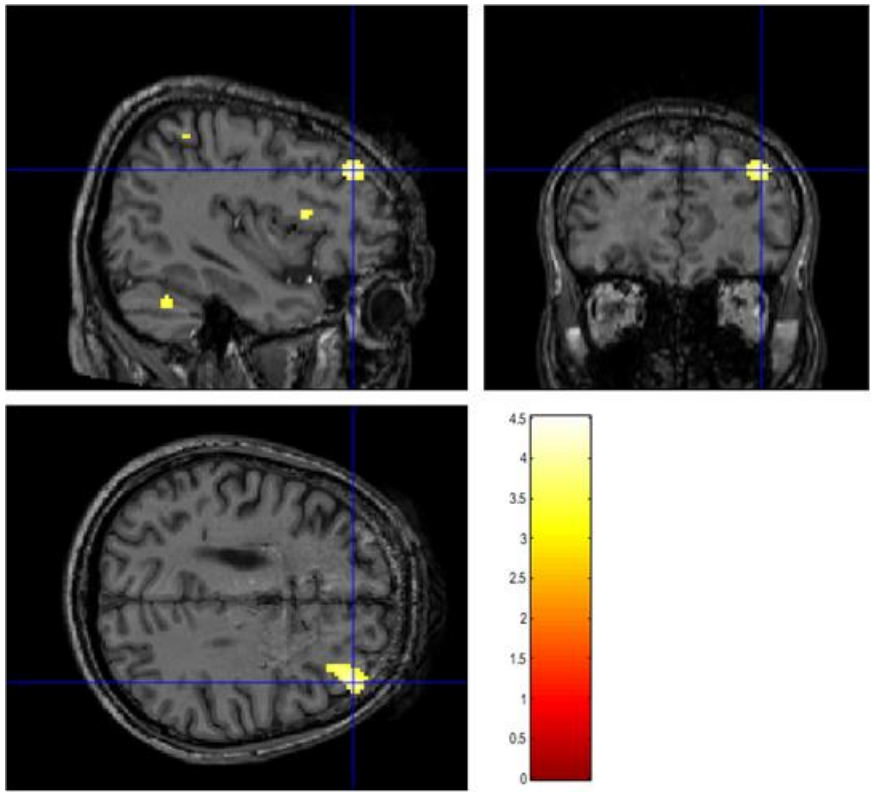
Image registration



Coregistration between sMRI and functional MRI



Brain activity on a functional image



Brain activity on a structural image

Anatomical localization of brain activity