

PRE-PROCESSING OF VOLUMETRIC BRAIN IMAGING DATA

Turku PET Centre Brain Imaging Course 2025

Jouni Tuisku, Turku PET Centre
jouni.tuisku@tyks.fi



CONTENTS

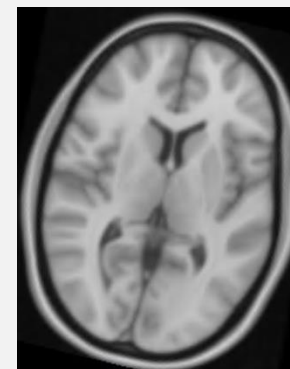
1. Introduction
 2. Data formats
 3. Motion correction for functional imaging data
 4. Image registration
 5. Spatial normalisation / MR-image segmentation
 6. Smoothing
- Pre-processing is demonstrated in SPM software with the course example data:
 - NRM2018 grand challenge data: <https://openneuro.org/datasets/ds001705/versions/1.0.1>

WHY PREPROCESSING?

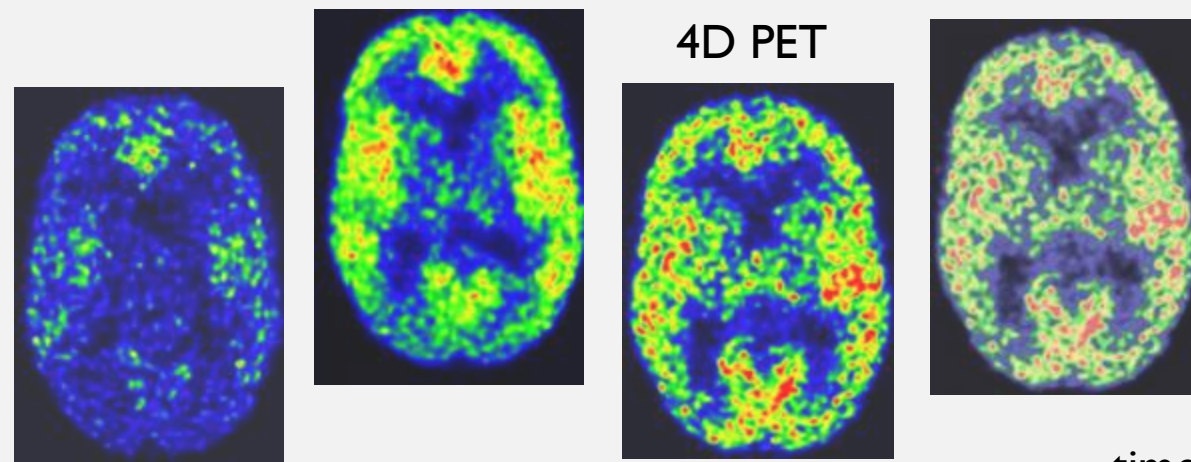
Typical imaging study includes:

- Various images from different modalities with different data formats
 - Structural MRIs (high anatomical detail)
 - Functional images (limited anatomical detail)
- Different orientations between images
- Movement within image modalities

T1w MRI



4D PET



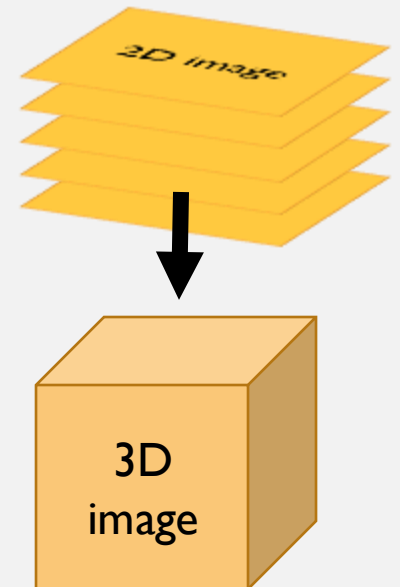
time

DATA FORMATS & CONVERSION

- After image reconstruction, the data are stored in PACS storage
 - PACS = Picture Archiving and Communication Systems

DICOM (.dcm)

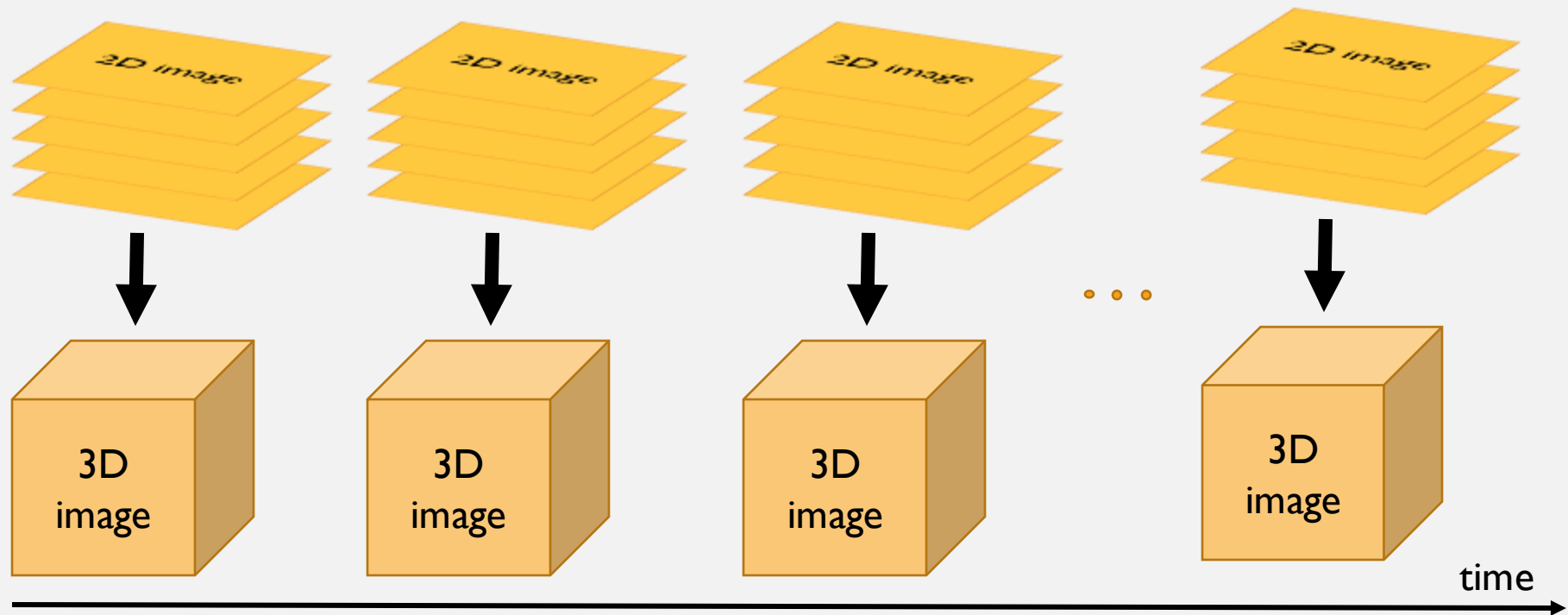
- Extensive image format used in data archives
- 1 dicom file = 1 slice of brain, consists of e.g. 256 x 256 pixels
- 2D-slices are combined into 3D-images (voxel data)



FUNCTIONAL 4D-IMAGING DATA

4D-images of dynamic data:

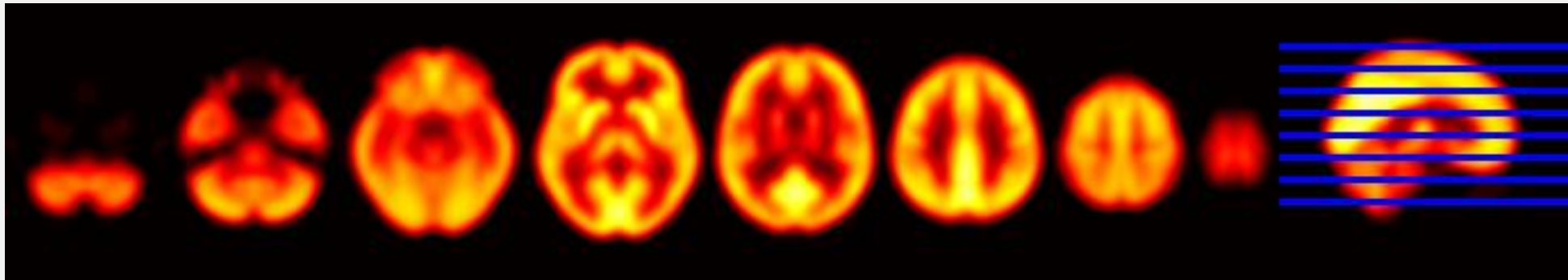
- Time-series of static 3D-images



DATA FORMATS & CONVERSION

NIfTI two files .img + .hdr, or single .nii file

- Standard neuroimaging file format
- Supported by several neuroimaging software: SPM, FSL, AFNI, FreeSurfer, ...
- Conversion software: SPM, Mango, MRICro, etc.



DATA FORMATS & CONVERSION

NIfTI (.img + .hdr, or .nii)

- Simple format; header contains only image orientation information

Image dimensions

Dimension	Length	Spacing	Unit
I Space	105	1.5000	Millimeter
J Space	127	1.5000	
K Space	105	1.5000	

Voxel size

Rotation matrix

X	-1.50000	0.00000	0.00000
Y	0.00000	1.50000	0.00000
Z	0.00000	0.00000	1.50000

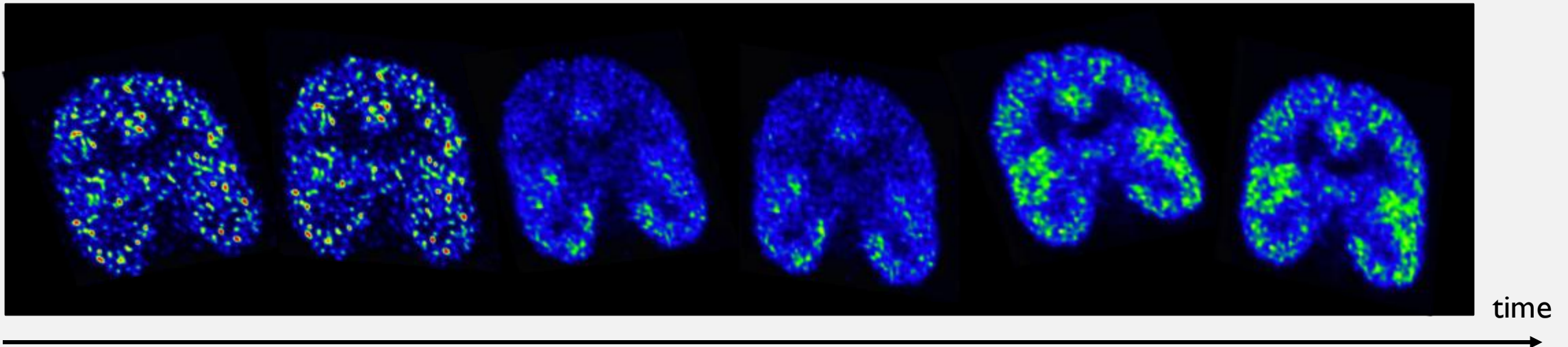
Image origin

78.00000
-112.00000
-70.00000

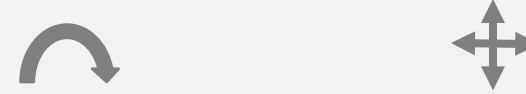
MOTION

- Increases variance and decreases sensitivity
- May create artificial effects, or e.g. correlate with the imaged task
- Possibly increases during long scans
- Preferably restricted using head restraint while scanning

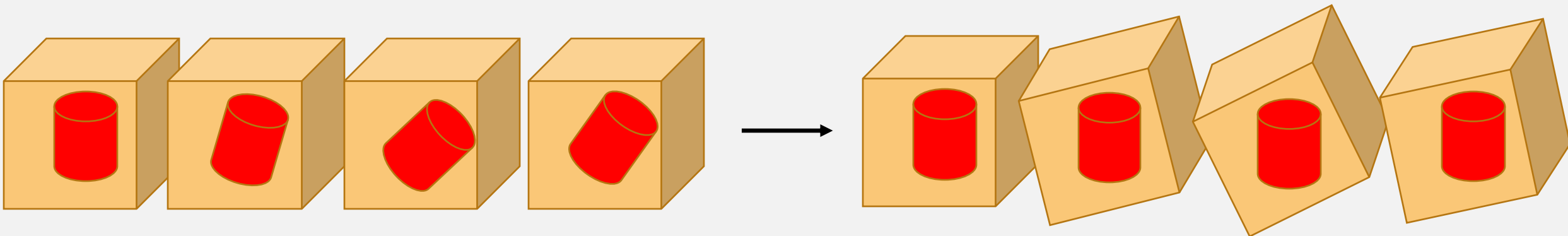
4D PET
data



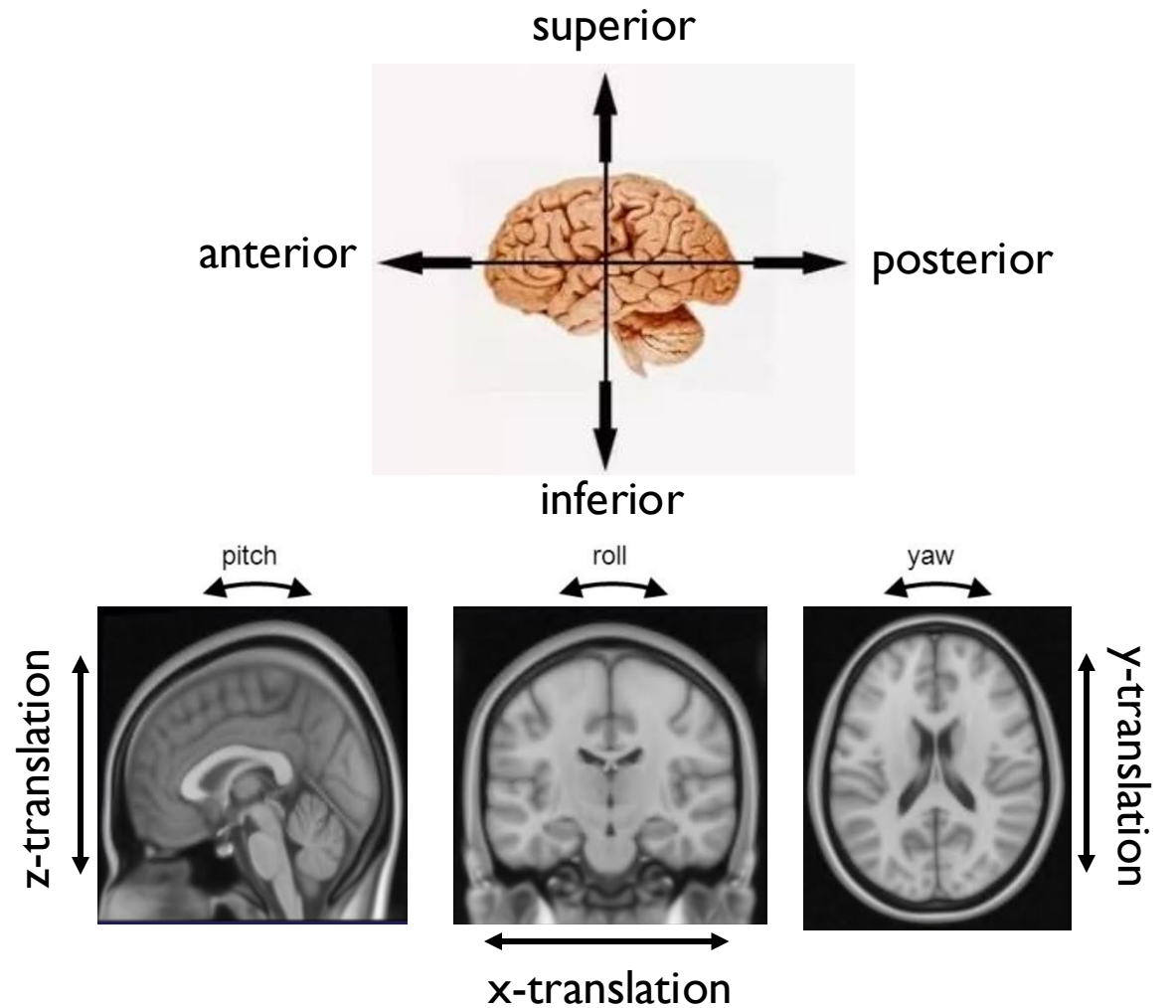
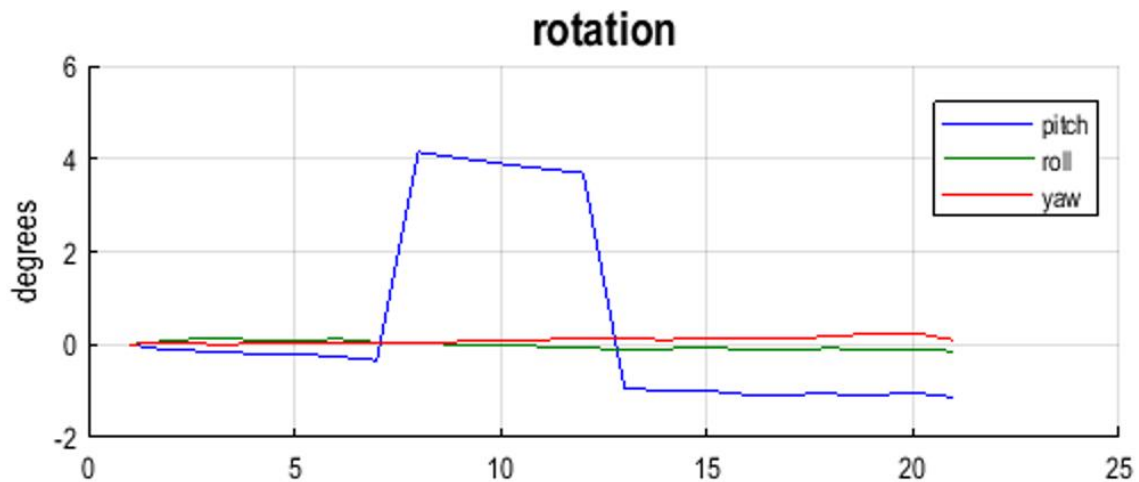
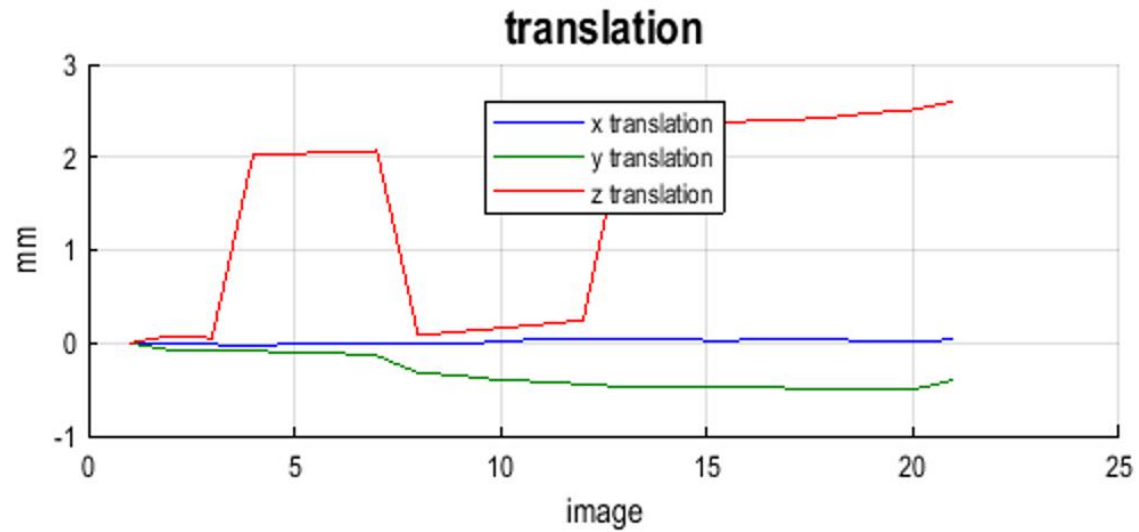
MOTION CORRECTION



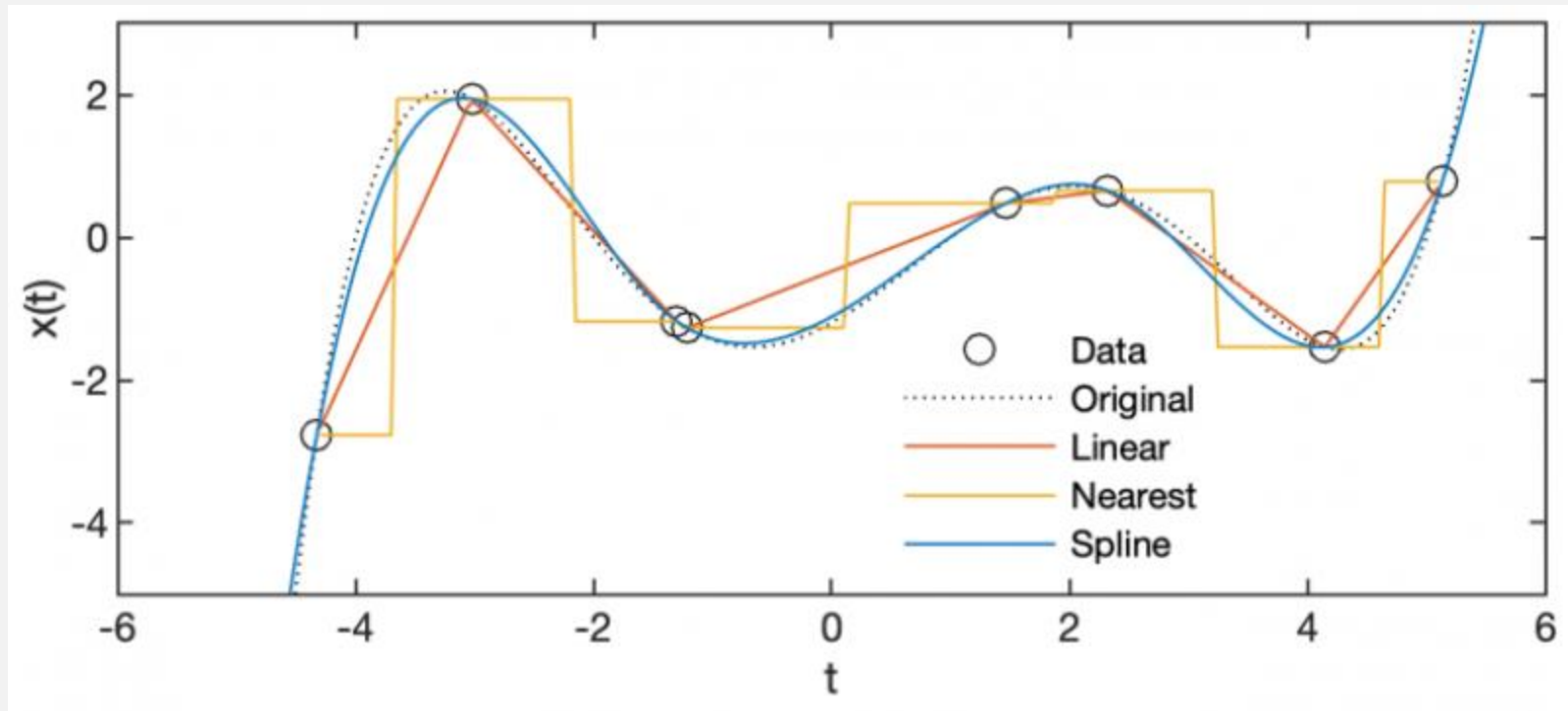
- Rigid-object transformation = rotation and translation
- Realigns the brains inside the 3D image volumes
- Realignment corrects only the motion between the sequential 3D images, not within the images



MOTION CORRECTION QC

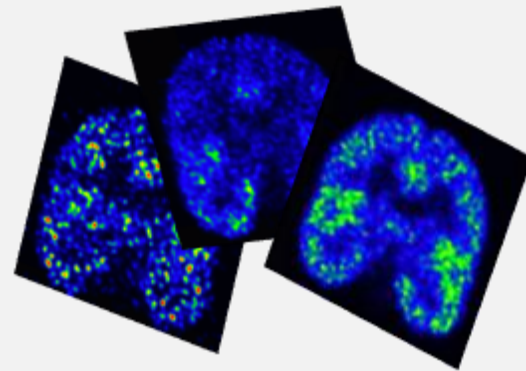


INTERPOLATION



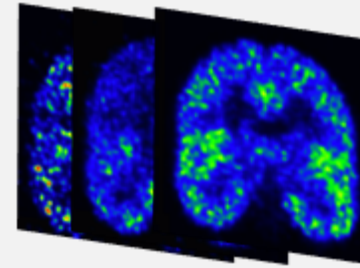
<http://mres.uni-potsdam.de/index.php/2023/06/27/interpolating-unevenly-spaced-data-with-matlab/>

IMAGE REGISTRATION

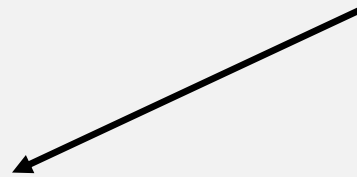


4D Functional
imaging data

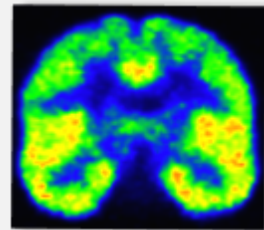
Motion
correction



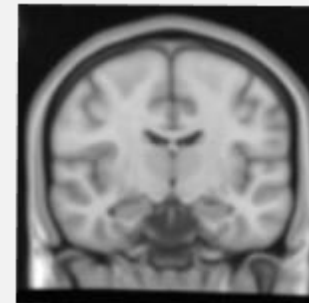
Motion corrected
data



Registration +
interpolation



Mean functional
image

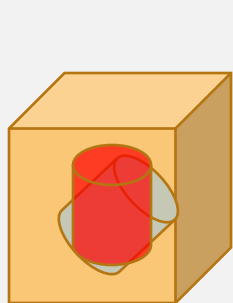
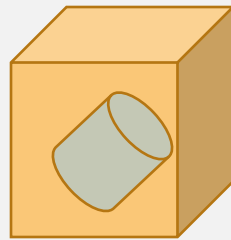
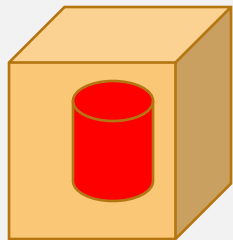


T1w MRI

IMAGE REGISTRATION

- Process of estimating the optimal transformation between images

Reference image Source/target image



Registration

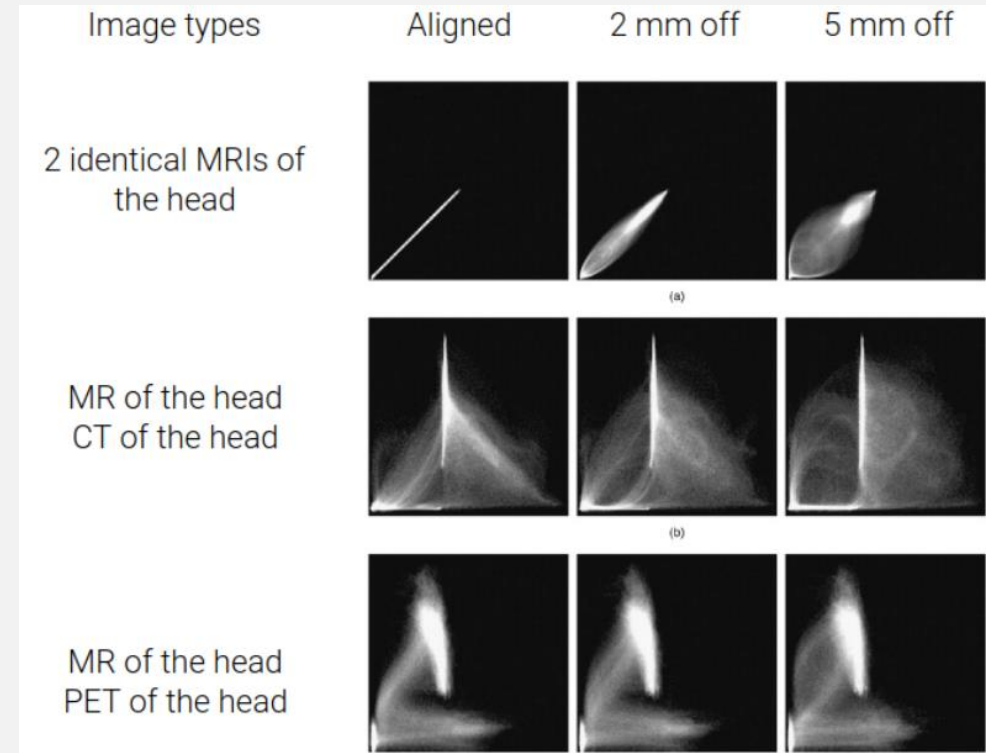
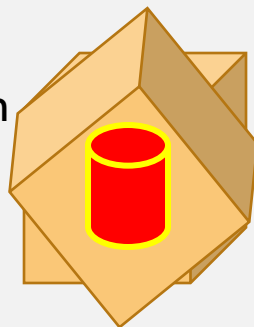
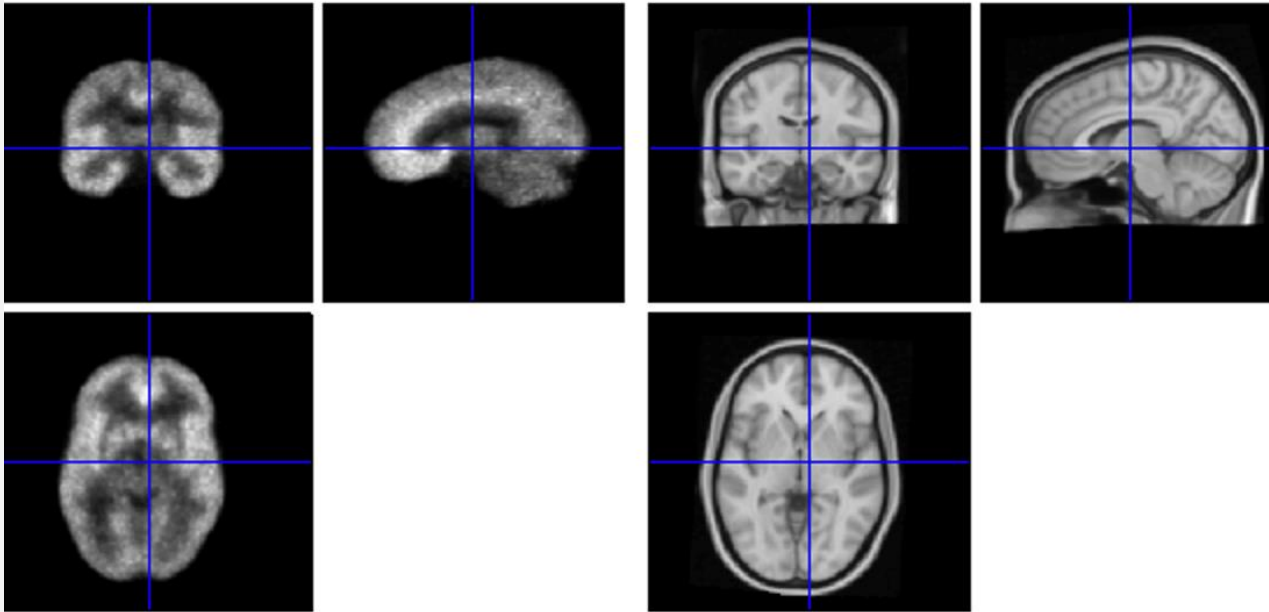


IMAGE REGISTRATION QC



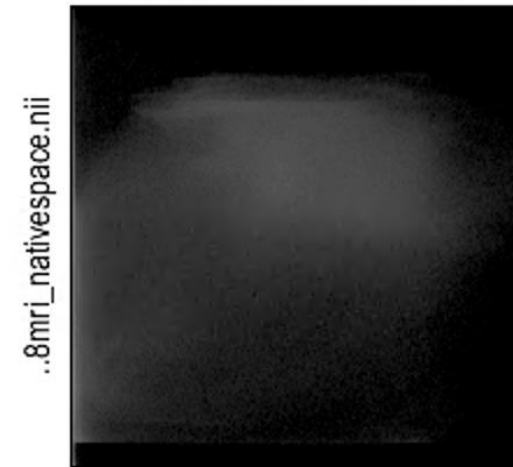
Normalised Mutual Information Coregistration

$$X1 = 0.989 \cdot X - 0.108 \cdot Y + 0.104 \cdot Z + 0.904$$

$$Y1 = 0.110 \cdot X + 0.994 \cdot Y - 0.011 \cdot Z - 9.382$$

$$Z1 = -0.103 \cdot X + 0.022 \cdot Y + 0.994 \cdot Z + 4.679$$

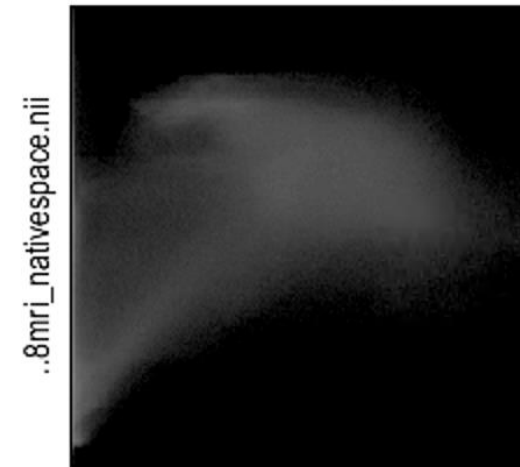
Original Joint Histogram



`..tivespace_motion.nii`

fuzzy

Final Joint Histogram

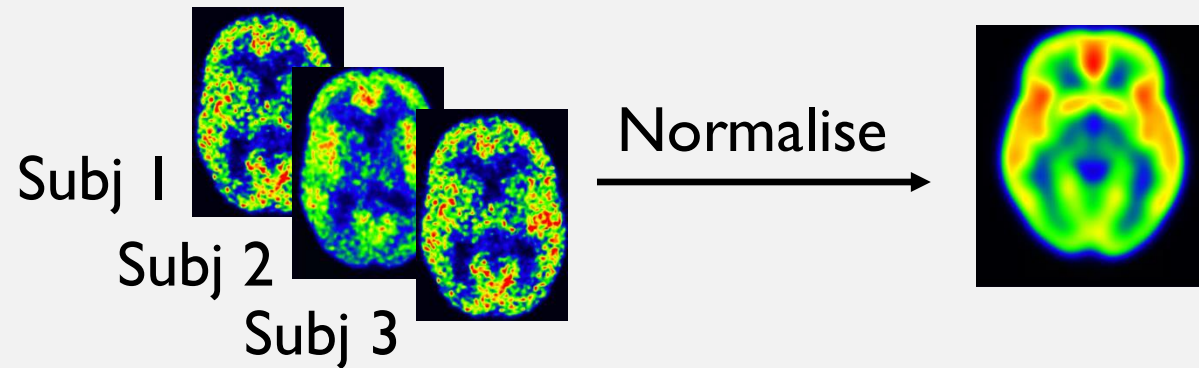


`..tivespace_motion.nii`

sharp

REGISTRATION TO STANDARD SPACE IMAGE

- Brains differ in size and shape
 - Individual native space images are not suitable for the voxel-level statistical analysis
- Native-space images are matched approximately with a template image in a standard space



REGISTRATION TO STANDARD SPACE IMAGE

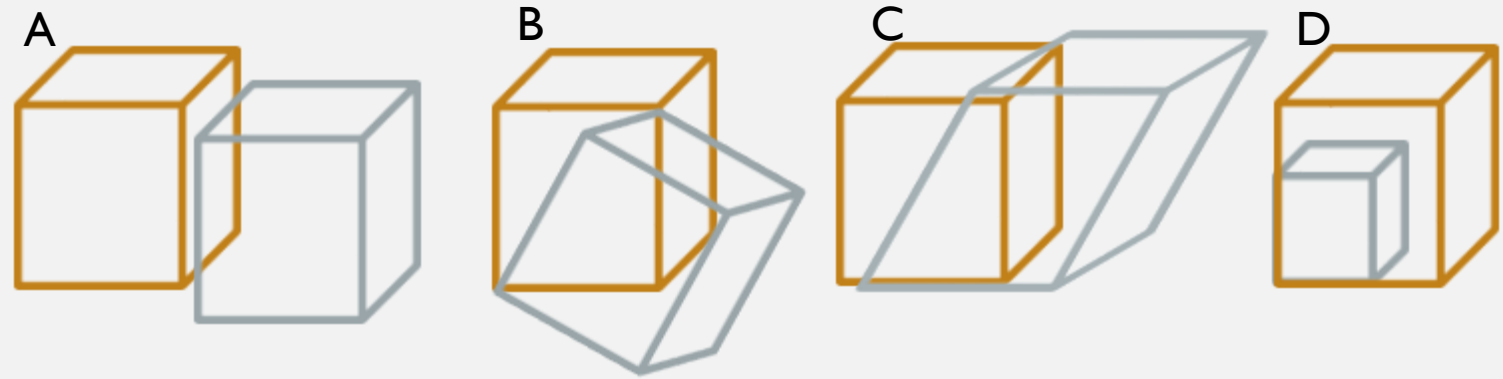
- Affine transformations (12df)

A. Translations (3df)

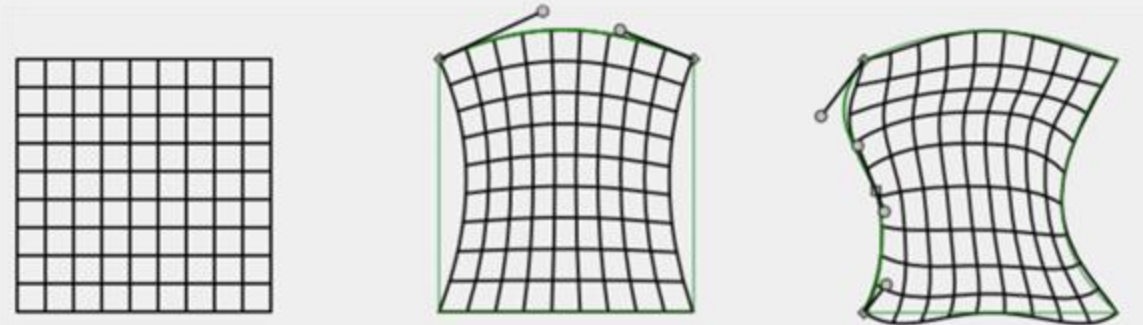
B. Rotations (3df)

C. Shearing/skewing (3df)

D. Scaling/zoom (3df)

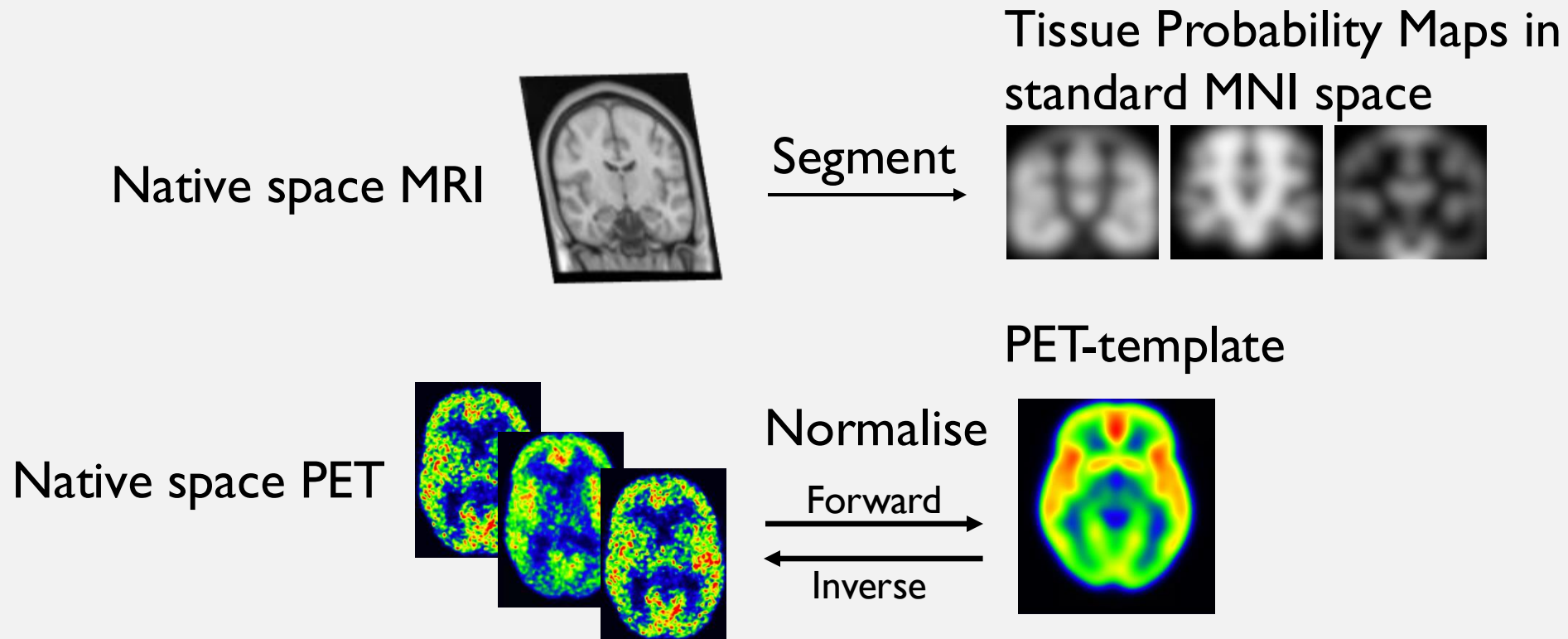


- Nonlinear transformations using deformation fields



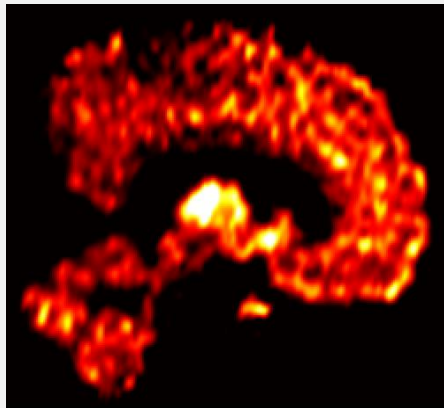
SPATIAL NORMALISATION

- MRI-based normalisation via MRI-segmentation
 - Tissue class segments (GM, WM, CSF) are matched with template TPMs

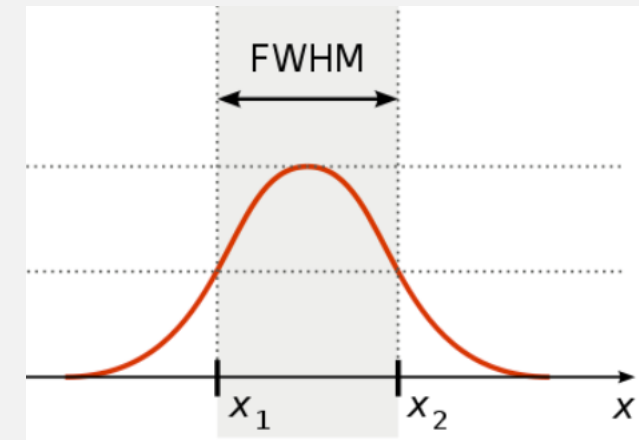
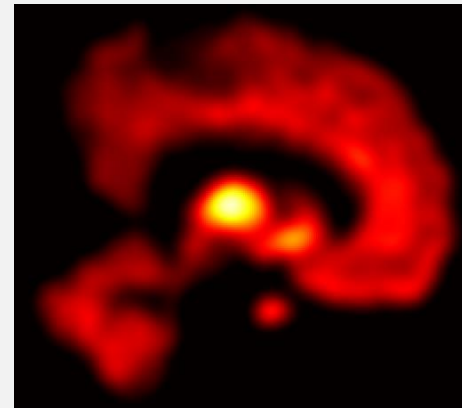


SMOOTHING

- The resulting normalised images are noisy
 - Violates the normality assumption in the voxel-level statistical analysis
- Smoothing increases signal-to-noise ratio and compensates the normalisation errors
- Drawback: reduced spatial resolution



Gaussian 8mm
FWHM smooth
→



MASK IMAGES



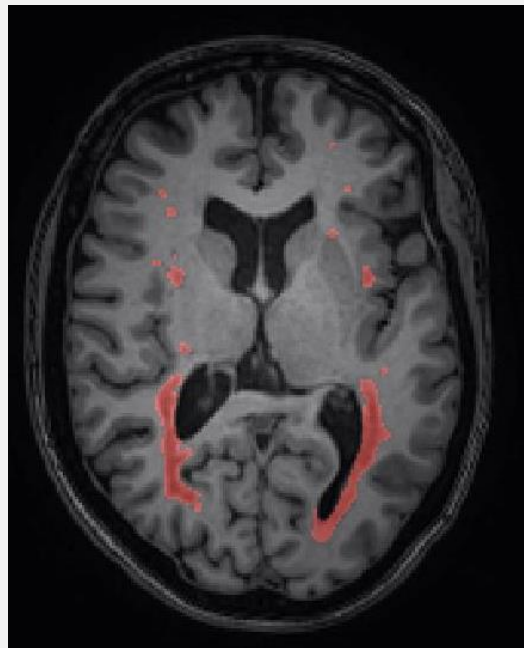
GM



WM

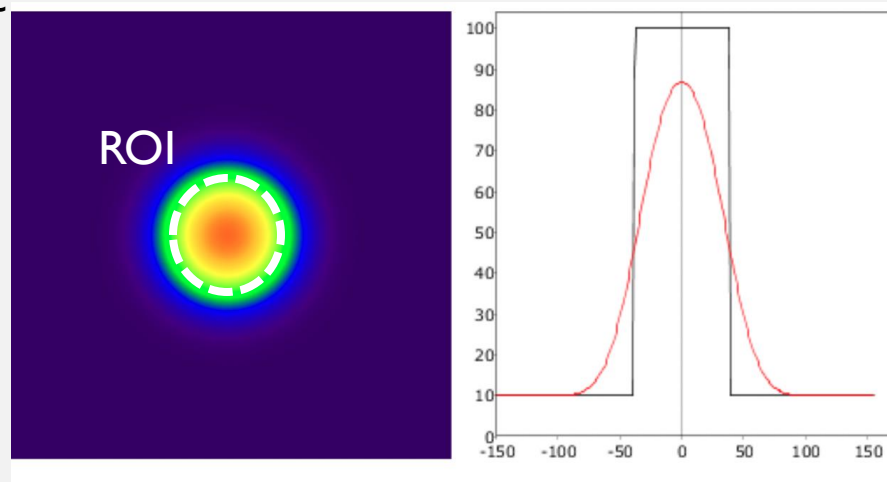


CSF

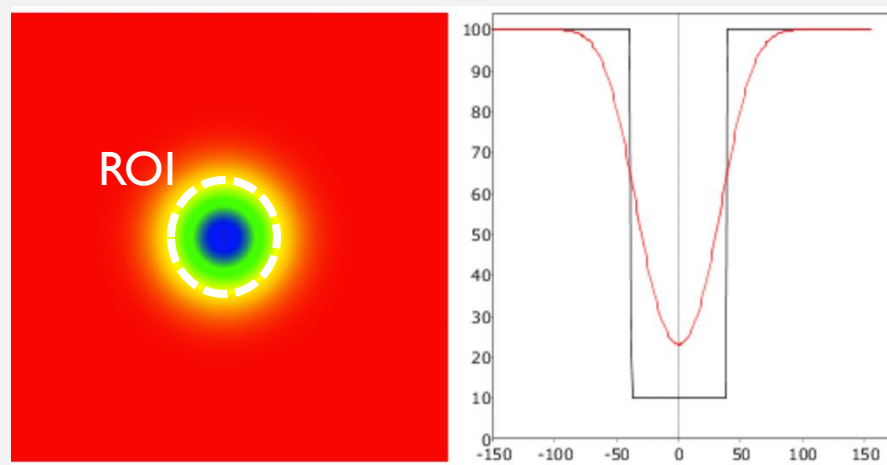


PARTIAL VOLUME EFFECT

Spill-out

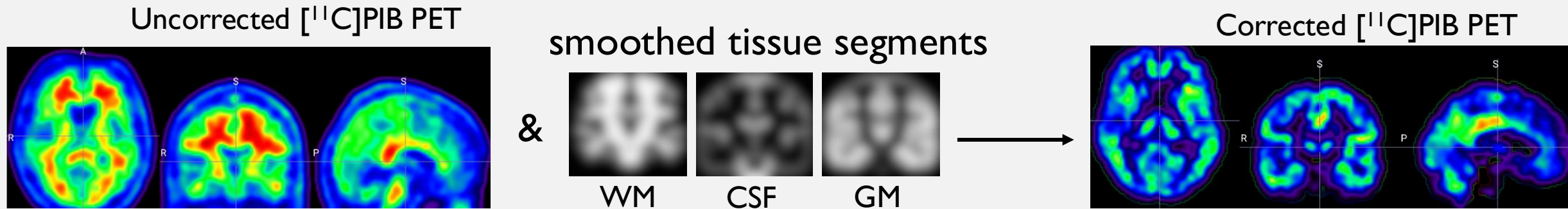


Spill-in



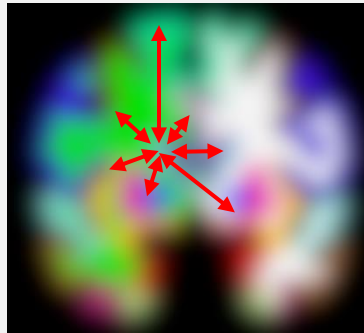
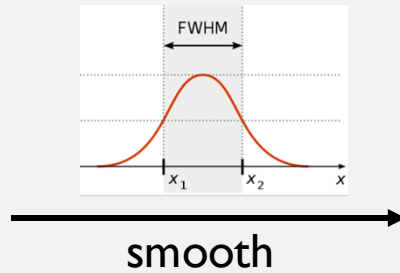
PARTIAL VOLUME EFFECT

Voxel-level data: Müller-Gärtner (MG) method:



PARTIAL VOLUME EFFECT

Regional data: Geometric Transfer Matrix (GTM) method:



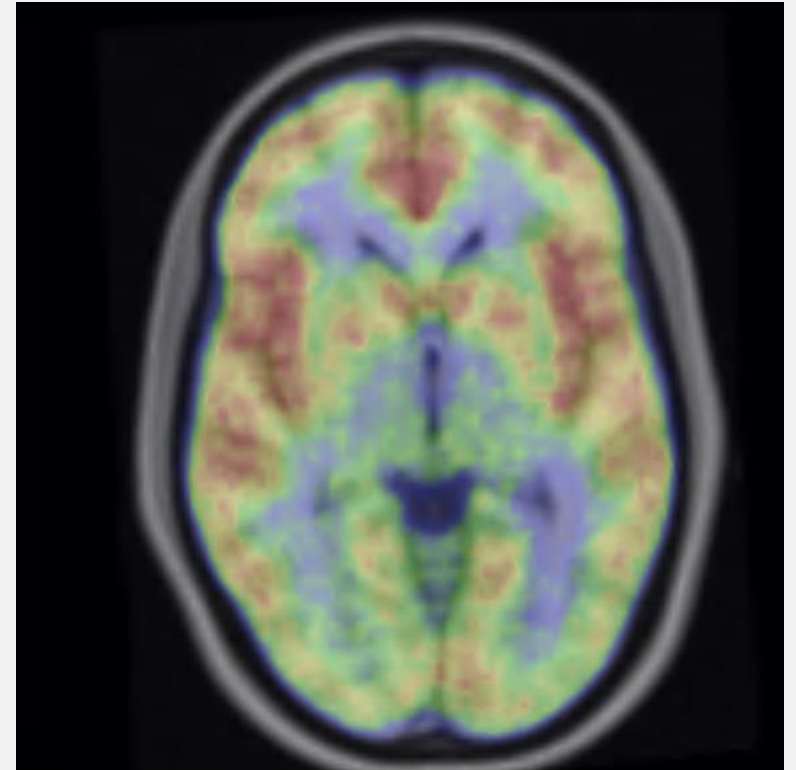
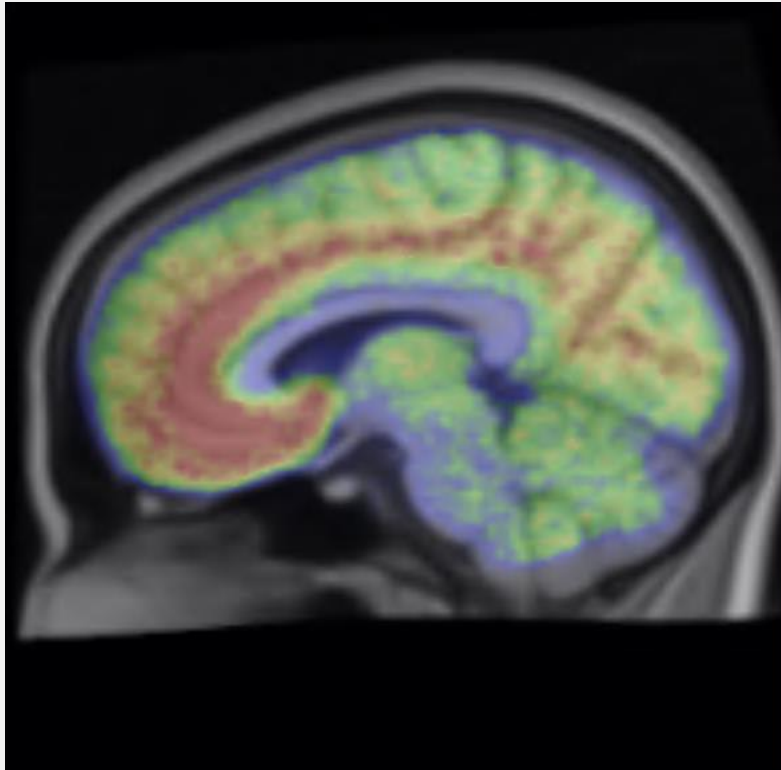
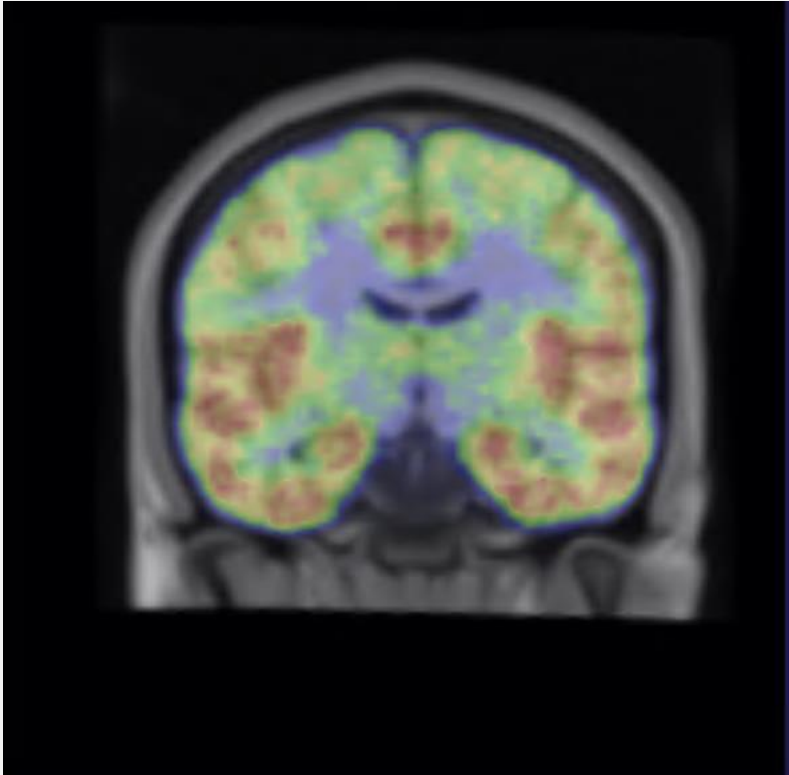
$$C_{\text{measured}} = \text{GTM} \times C_{\text{true}}$$



Regional estimates of corrected data

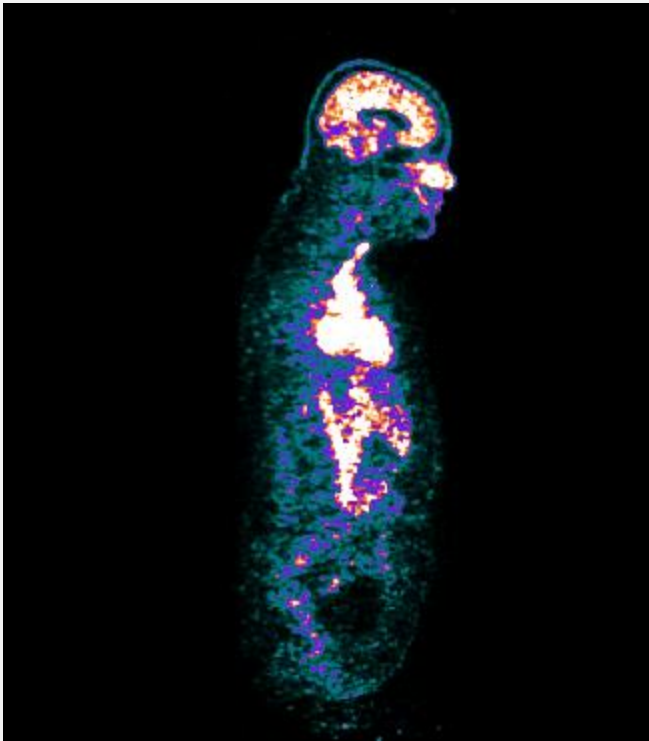


QUALITY CONTROL

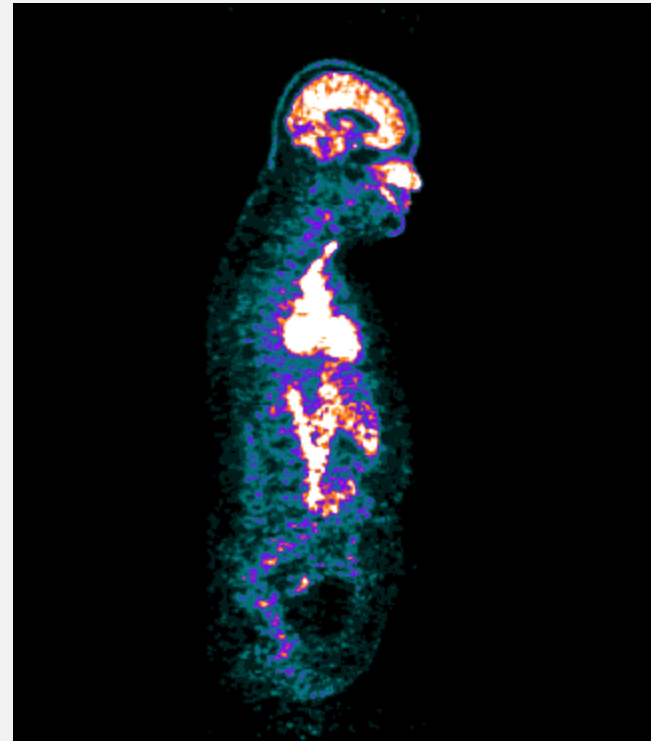


QUALITY CONTROL

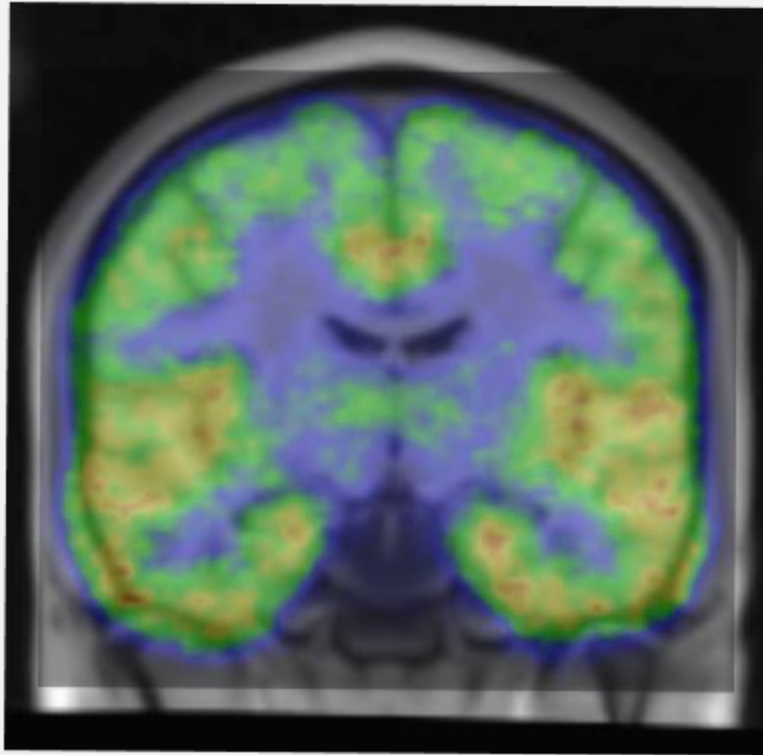
Uncorrected



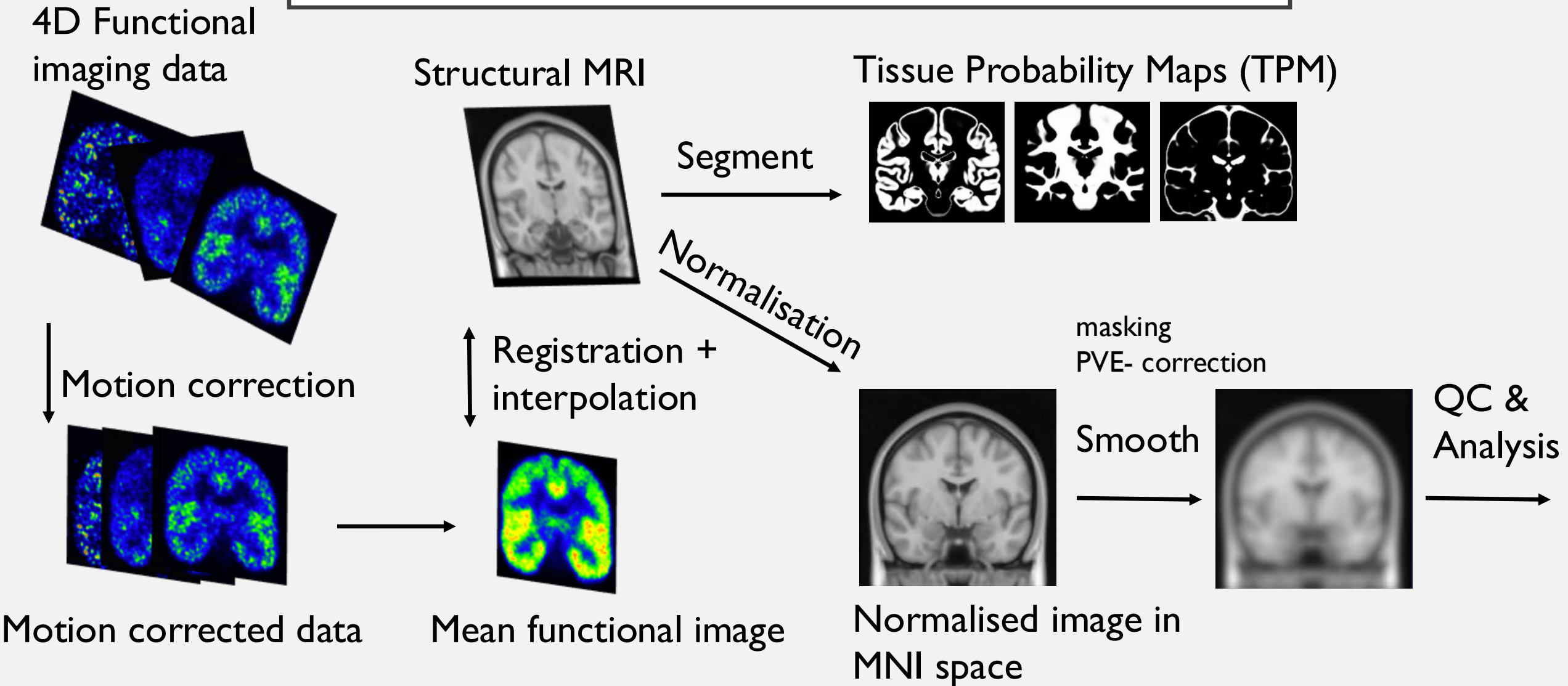
Motion corrected



QUALITY CONTROL



PRE-PROCESSING OVERVIEW



FURTHER DETAILS

- Yoder KK, Basic PET Data Analysis Techniques. Positron Emiss Tomogr - Recent Dev Instrumentation, Res Clin Oncol Pract. December 2013.
- R. Frackowiak, K. Friston et al., Human brain function, 2003 online book: <https://www.fil.ion.ucl.ac.uk/spm/doc/books/hbf2/>
- Nifti format
 - <https://brainder.org/2012/09/23/the-nifti-file-format/>
- NRM2018 grand challenge data:
 - <https://openneuro.org/datasets/ds001705/versions/1.0.1>
- Turku PET centre analysis reference:
 - <http://www.turkupetcentre.net/petanalysis/>