

Preprocessing of volumometric brain imaging data

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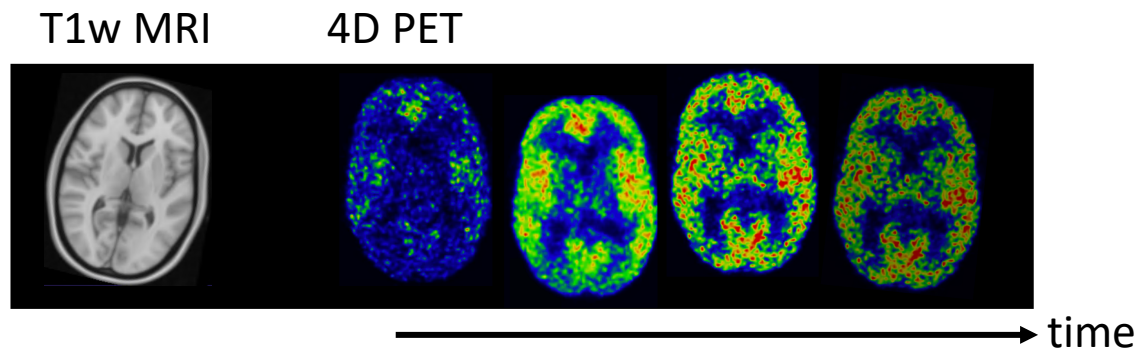
Contents

1. Introduction
 2. Data formats & conversion
 3. Motion correction for functional imaging data
 4. Image registration
 5. Spatial normalisation / MR-image segmentation
 6. Smoothing
- Preprocessing is demonstrated in SPM 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 T1w MRIs (high anatomical detail)
 - Functional images (limited anatomical detail)



- Movement within image modalities
- Different orientations between images

Data formats & conversion

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

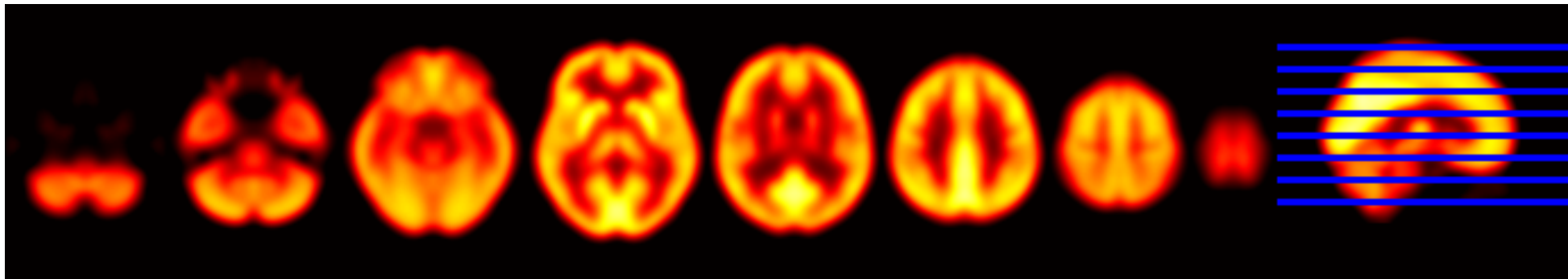
DICOM (.dcm)

- Extensive image format used in data archives
- 1 dicom file = 1 slice of brain, consists of e.g. 256 x 256 pixels

Data formats & conversion

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

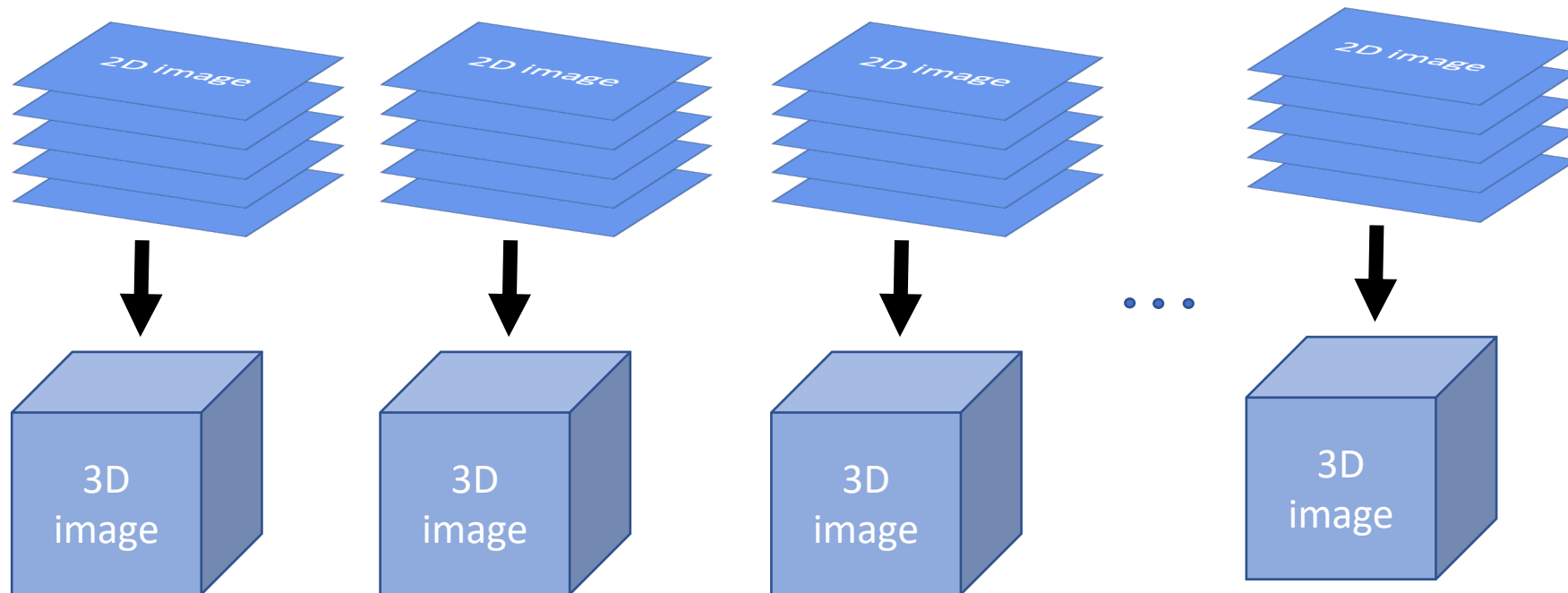
- 2D-slices are combined into 3D-images
- Standard neuroimaging file format
- Supported by several neuroimaging software: SPM, FSL, AFNI, FreeSurfer
- Anonymized format, header contains only image orientation information
- Conversion software: SPM, Mango, MRICro, etc.



Functional 4D-imaging data

4D-images:

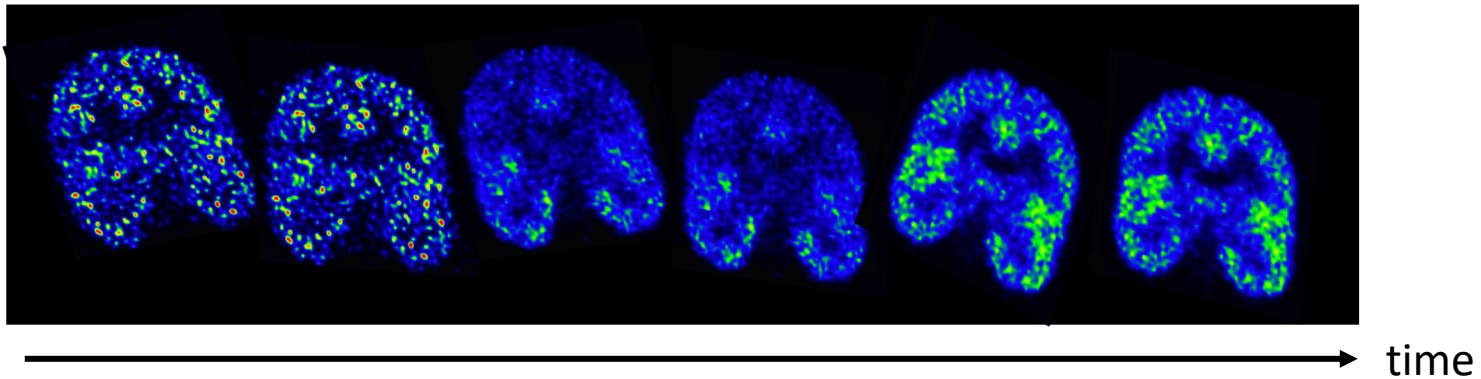
- time-series of 3D-images, all stored under the same file





Motion

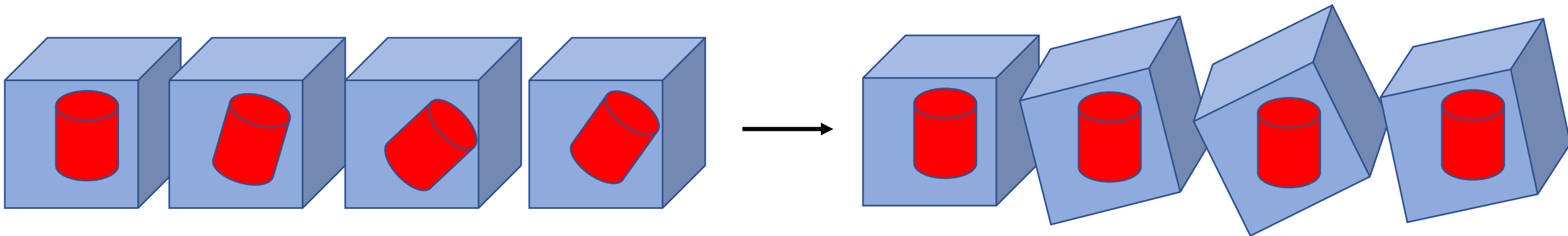
- Increases variance and decreases sensitivity
- May create artificial effects, or e.g. correlate with the imaged task
- Possibly increases during long scans

4D PET data

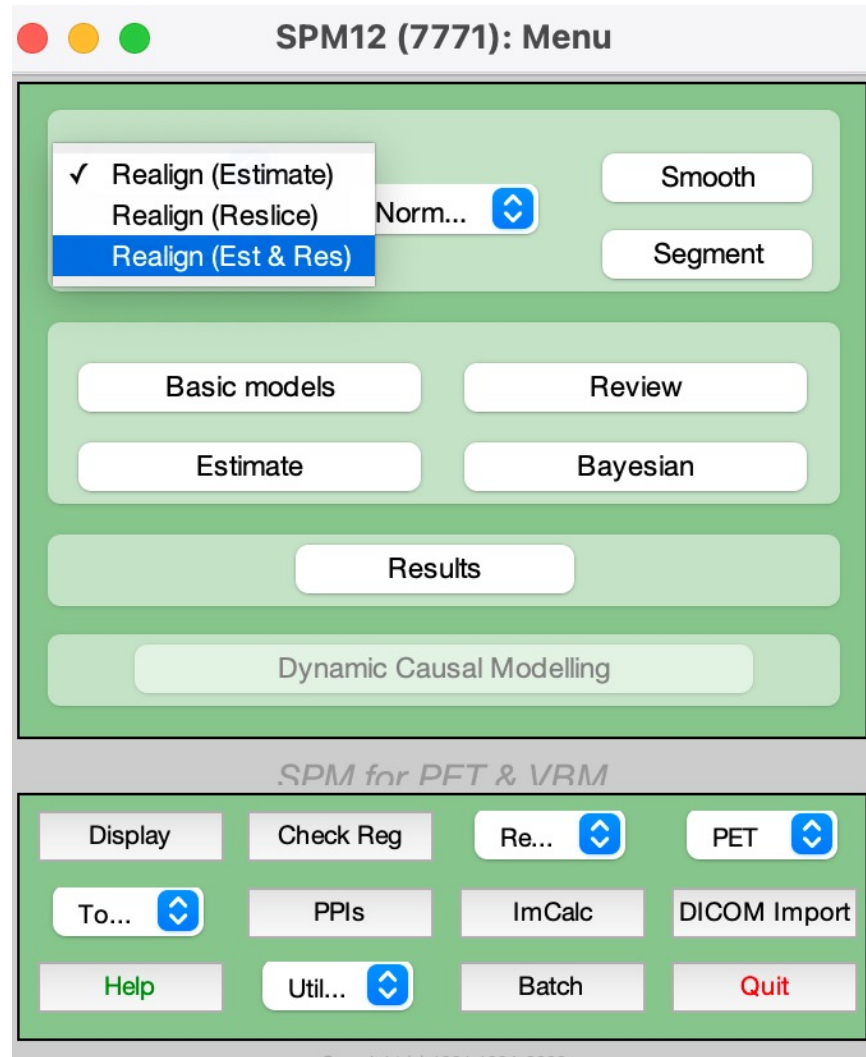


Motion correction

- 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 in SPM



Motion correction in SPM

PETdata_nativespace/././pet_nrm2018baseline1_nativespace_motion.nii

The screenshot displays the SPM software interface for the 'Current Module: Realign: Estimate & Reslice'. The 'Data' section is expanded to show '21 files', which is highlighted with a red box and an arrow pointing to a secondary window. The secondary window shows a list of files for motion correction, including 'pet_nrm2018baseline1_nativespace_motion.nii,1' through 'pet_nrm2018baseline1_nativespace_motion.nii,8'. The 'Filter' field is set to '*'. The 'Current Item: Session' section shows the file path: 'O:\data\NRM2018_orig\neuroimaging_course_data\PETdata_nativespace\nrm2018baseline1_nativespace\PET\nii\pet_nrm2018baseline1_nativespace_motion.nii'. A 'Specify...' button is visible at the bottom left.

Current Module: Realign: Estimate & Reslice

Data

. Session **21 files**

Estimation Options

. Quality 1

. Separation 2

. Smoothing (FWHM) 7

. Num Passes Register to mean

. Interpolation Trilinear (1st Degree)

. Wrapping No wrap

. Weighting 0 files

Reslice Options

. Resliced images All Images + Mean Image

. Interpolation Trilinear

. Wrapping No wrap

. Masking Mask images

. Filename Prefix r

Current Item: Session

O:\data\NRM2018_orig\neuroimaging_course_data\PETdata_nativespace\nrm2018baseline1_nativespace\PET\nii\pet_nrm2018baseline1_nativespace_motion.nii,1

O:\data\NRM2018_orig\neuroimaging_course_data\PETdata_nativespace\nrm2018baseline1_nativespace\PET\nii\pet_nrm2018baseline1_nativespace_motion.nii,2

O:\data\NRM2018_orig\neuroimaging_course_data\PETdata_nativespace\nrm2018baseline1_nativespace\PET\nii\pet_nrm2018baseline1_nativespace_motion.nii,3

O:\data\NRM2018_orig\neuroimaging_course_data\PETdata_nativespace\nrm2018baseline1_nativespace\PET\nii\pet_nrm2018baseline1_nativespace_motion.nii,4

O:\data\NRM2018_orig\neuroimaging_course_data\PETdata_nativespace\nrm2018baseline1_nativespace\PET\nii\pet_nrm2018baseline1_nativespace_motion.nii,5

O:\data\NRM2018_orig\neuroimaging_course_data\PETdata_nativespace\nrm2018baseline1_nativespace\PET\nii\pet_nrm2018baseline1_nativespace_motion.nii,6

O:\data\NRM2018_orig\neuroimaging_course_data\PETdata_nativespace\nrm2018baseline1_nativespace\PET\nii\pet_nrm2018baseline1_nativespace_motion.nii,7

O:\data\NRM2018_orig\neuroimaging_course_data\PETdata_nativespace\nrm2018baseline1_nativespace\PET\nii\pet_nrm2018baseline1_nativespace_motion.nii,8

Filter Reset *

1:23

Specify...

SPM motion correction results

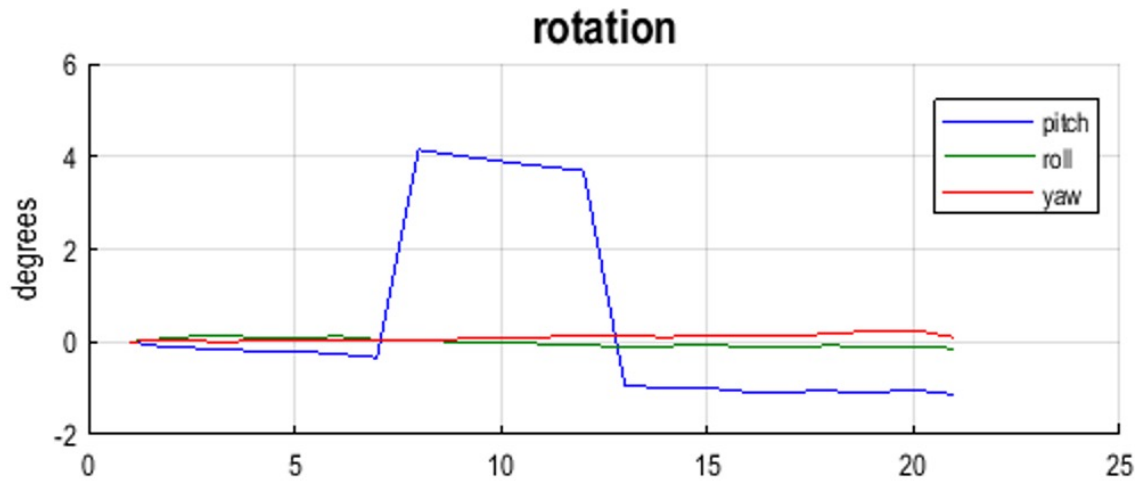
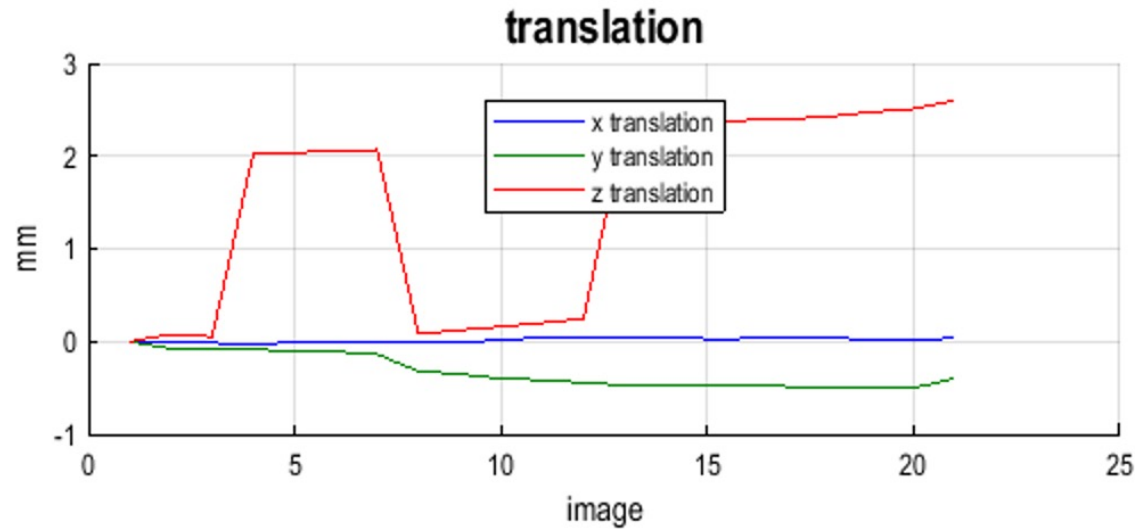
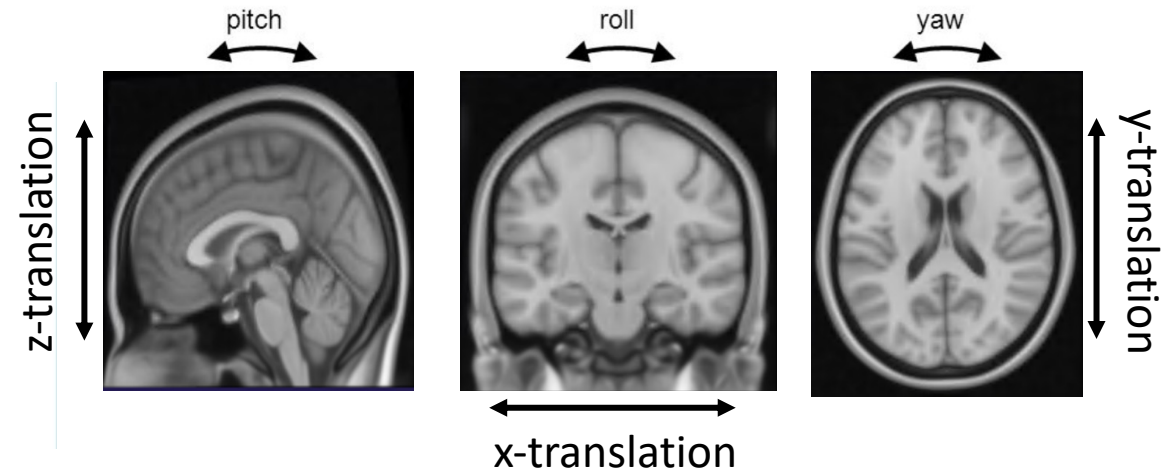
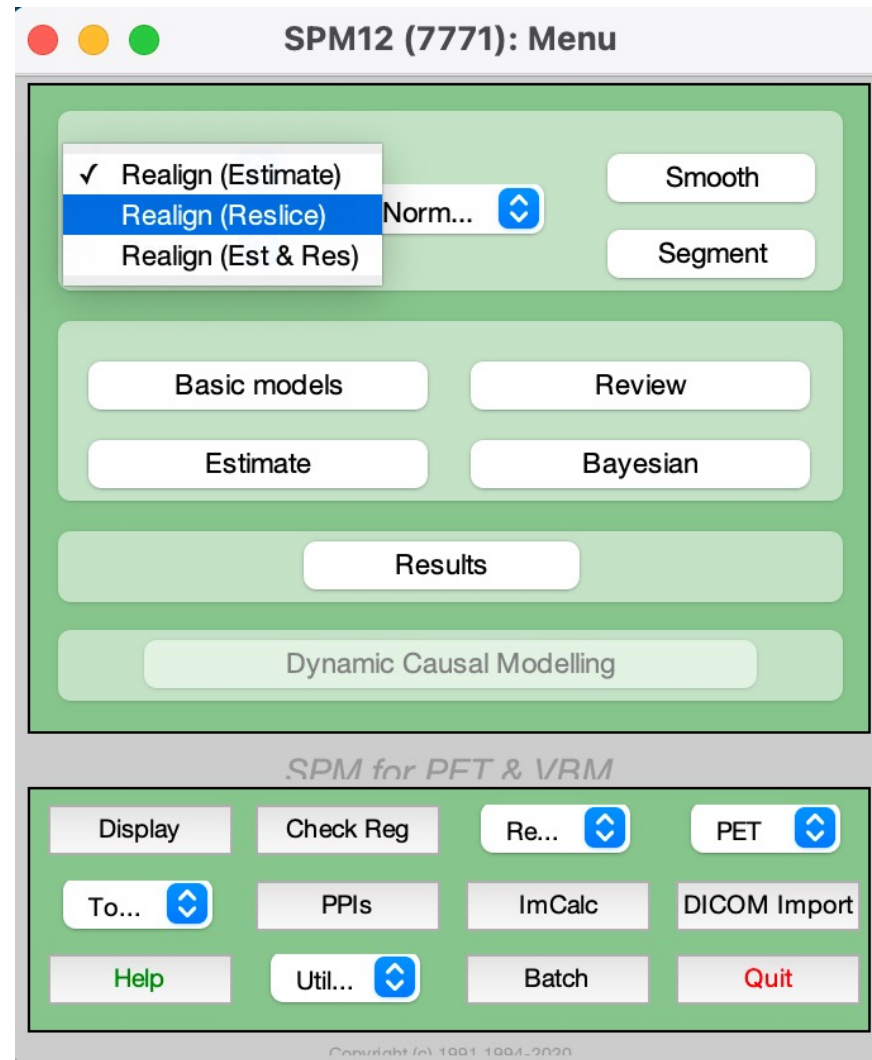


Image realignment

```
1 O:\data\NRM2018_orig\neuroimaging_course_data\PETdata_nativespace\nm2018baseline1_n
2 O:\data\NRM2018_orig\neuroimaging_course_data\PETdata_nativespace\nm2018baseline1_n
3 O:\data\NRM2018_orig\neuroimaging_course_data\PETdata_nativespace\nm2018baseline1_n
4 O:\data\NRM2018_orig\neuroimaging_course_data\PETdata_nativespace\nm2018baseline1_n
5 O:\data\NRM2018_orig\neuroimaging_course_data\PETdata_nativespace\nm2018baseline1_n
6 O:\data\NRM2018_orig\neuroimaging_course_data\PETdata_nativespace\nm2018baseline1_n
7 O:\data\NRM2018_orig\neuroimaging_course_data\PETdata_nativespace\nm2018baseline1_n
8 O:\data\NRM2018_orig\neuroimaging_course_data\PETdata_nativespace\nm2018baseline1_n
9 O:\data\NRM2018_orig\neuroimaging_course_data\PETdata_nativespace\nm2018baseline1_n
10 O:\data\NRM2018_orig\neuroimaging_course_data\PETdata_nativespace\nm2018baseline1_n
11 O:\data\NRM2018_orig\neuroimaging_course_data\PETdata_nativespace\nm2018baseline1_n
12 O:\data\NRM2018_orig\neuroimaging_course_data\PETdata_nativespace\nm2018baseline1_n
..... etc
```



Interpolation of motion corrected data



Interpolation of motion corrected data

Current Module: Realign: Reslice

Help on: Realign: Reslice

Images 23 files

Reslice Options

- . Resliced images
- . Interpolation
- . Wrapping
- . Masking
- . Filename Prefix

All Images + Mean Image

- Trilinear
- No wrap
- Mask images

Current Item: Images

data\PETdata_nativespace\nrm2018baseline1_nativespace\PET\nii\pet_nrm2018baseline1_nativespace_motion.nii,1
data\PETdata_nativespace\nrm2018baseline1_nativespace\PET\nii\pet_nrm2018baseline1_nativespace_motion.nii,2
data\PETdata_nativespace\nrm2018baseline1_nativespace\PET\nii\pet_nrm2018baseline1_nativespace_motion.nii,3
data\PETdata_nativespace\nrm2018baseline1_nativespace\PET\nii\pet_nrm2018baseline1_nativespace_motion.nii,4
data\PETdata_nativespace\nrm2018baseline1_nativespace\PET\nii\pet_nrm2018baseline1_nativespace_motion.nii,5

Specify...

data\PETdata_nativespace\nrm2018baseline1_nativespace
data\PETdata_nativespace\nrm2018baseline1_natives...
data\PETdata_nativespace\nrm2018baseline1_natives...
pet_nrm2018baseline1_nativespace_motion.nii,1
pet_nrm2018baseline1_nativespace_motion.nii,2
pet_nrm2018baseline1_nativespace_motion.nii,3
pet_nrm2018baseline1_nativespace_motion.nii,4
pet_nrm2018baseline1_nativespace_motion.nii,5
pet_nrm2018baseline1_nativespace_motion.nii,6
pet_nrm2018baseline1_nativespace_motion.nii,7

Filter *

1:23

Image registration

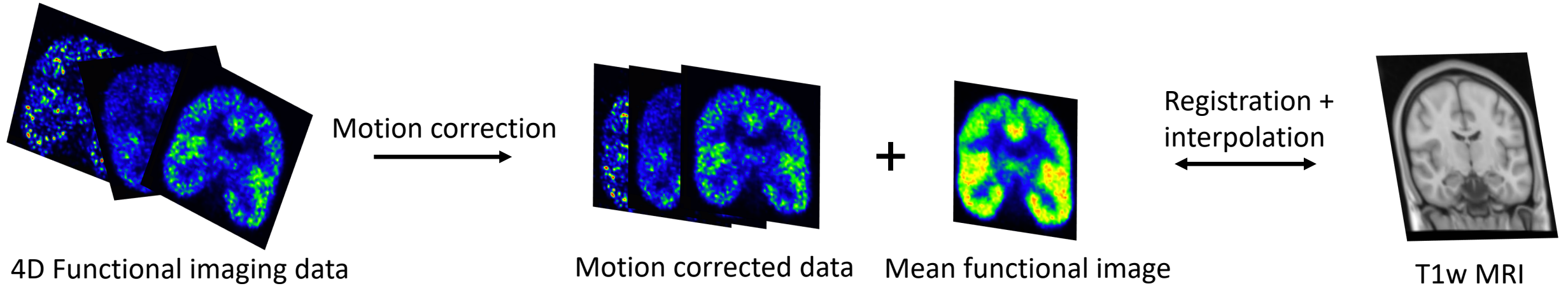


Image registration

- Process of estimating the optimal transformation between images
- Within modality registration (find affine translation + rotation)
- Between modality registration (maximize image similarity)
 - PET mean image contains more details compared to single frame
- Interpolation (reslice) to match the image dimensions & voxel sizes

Reference image

Source image

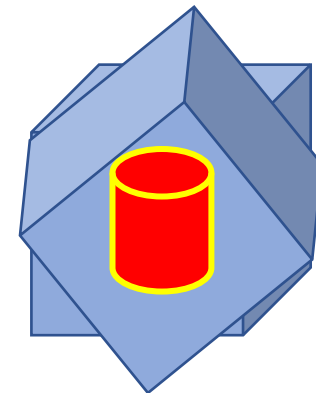
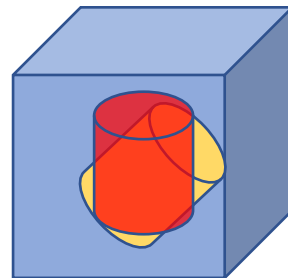
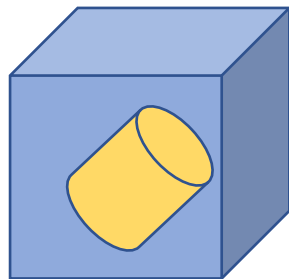
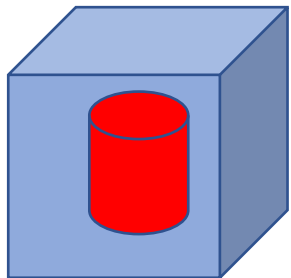


Image registration in SPM

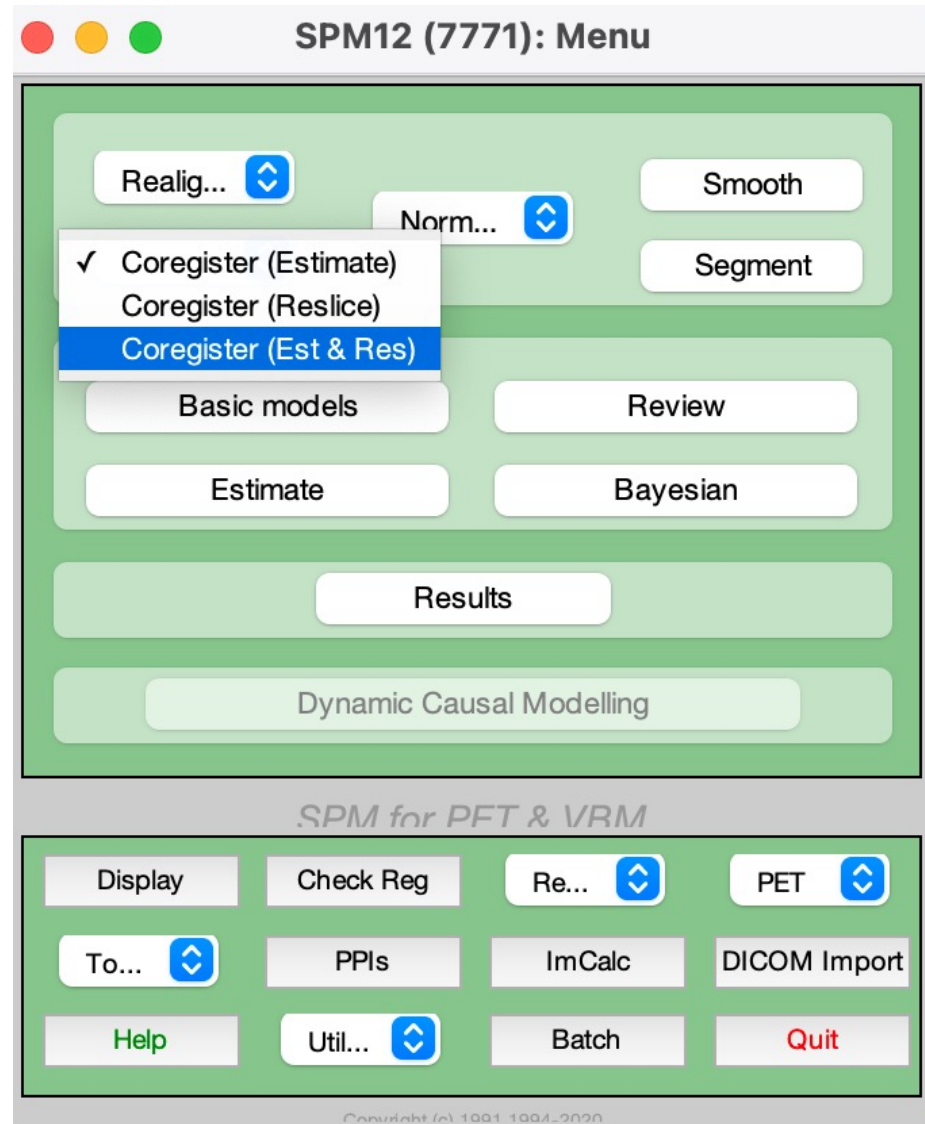


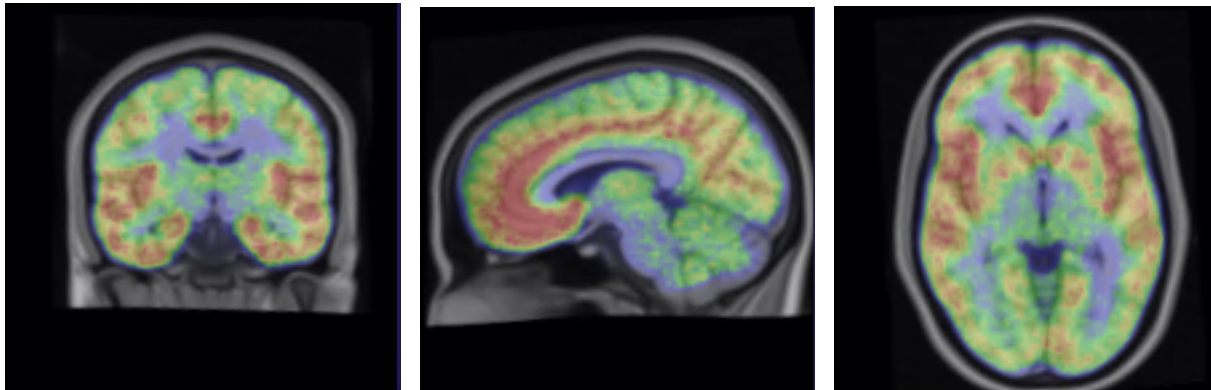
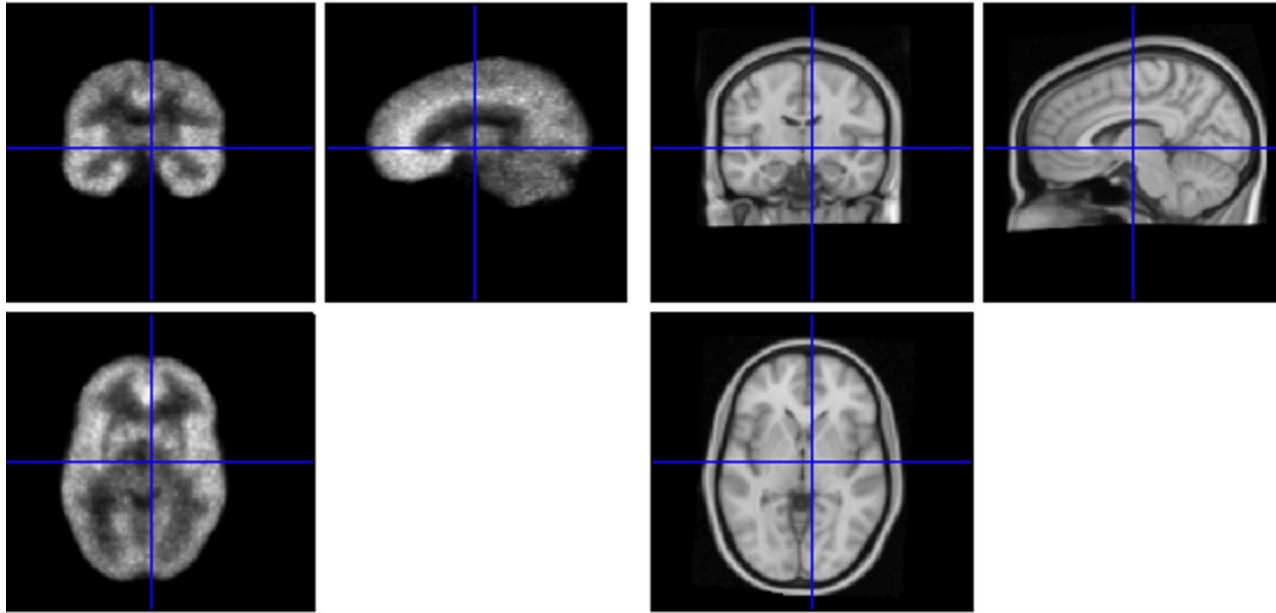
Image registration in SPM

Current Module: Coregister: Estimate & Reslice

Help on: Coregister: Estimate & Reslice

Reference Image	..._nativespace\PET\nii\meanpet_nrm2018baseline1_nativespace_motion.nii,1
Source Image	...ata_nativespace\nrm2018mri_nativespace\T1\nrm2018mri_nativespace.nii,1
Other Images	
Estimation Options	
. Objective Function	Normalised Mutual Information
. Separation	[4 2]
. Tolerances	1x12 double
. Histogram Smoothing	[7 7]
Reslice Options	
. Interpolation	Trilinear
. Wrapping	No wrap
. Masking	Dont mask images
. Filename Prefix	r

Image registration in SPM



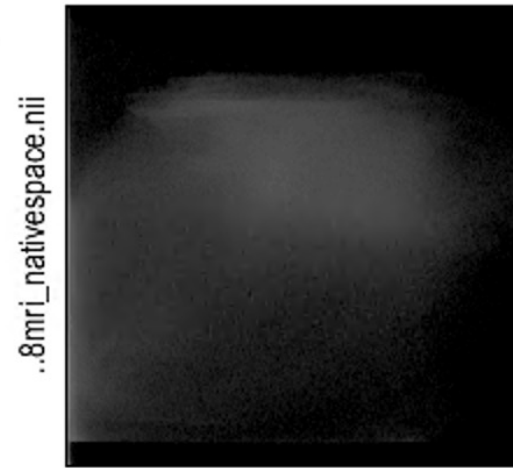
Normalised Mutual Information Coregistration

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

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

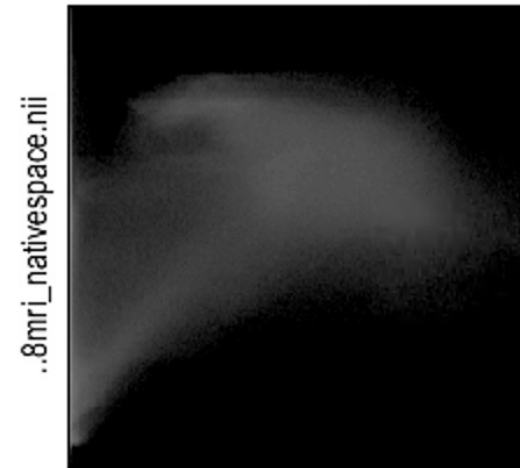
$$Z1 = -0.103*X + 0.022*Y + 0.994*Z + 4.679$$

Original Joint Histogram



..tivespace_motion.nii

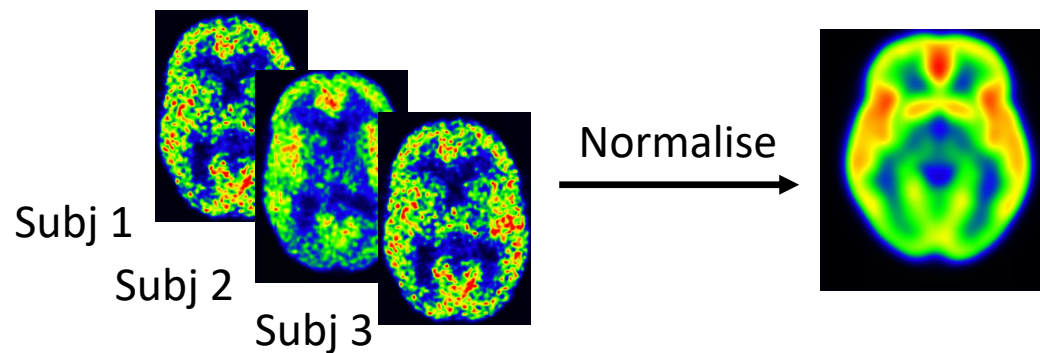
Final Joint Histogram



..tivespace_motion.nii

Registration to standard space image

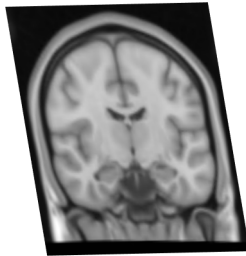
- Brains differ in size and shape
 - Individual native space images are not suitable for the voxel-level statistical analysis
- Native-space images are matched approximately with a template image in a standard space:
 - Affine transformations (translations, rotations, scaling/zoom, shearing/skewing)
 - Nonlinear warps



Spatial normalisation (MRI & PET-templates)

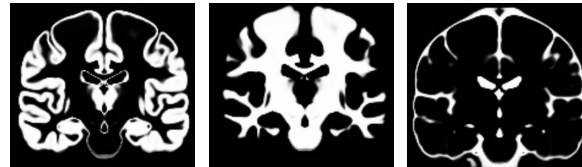
- MRI-based normalisation via MRI-segmentation
 - Tissue class segments (GM, WM, CSF) are matched with template TPMs

MRI in native space



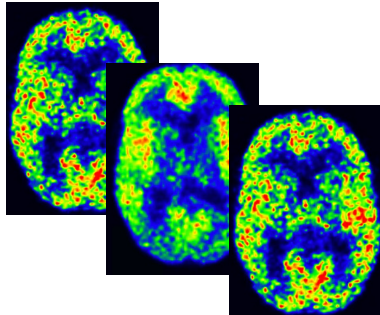
Segment →

Tissue Probability Maps in standard MNI space



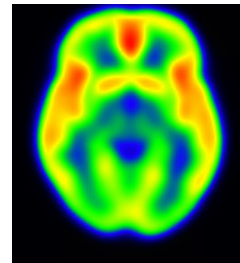
- PET-template-based normalisation

Native space PET-images

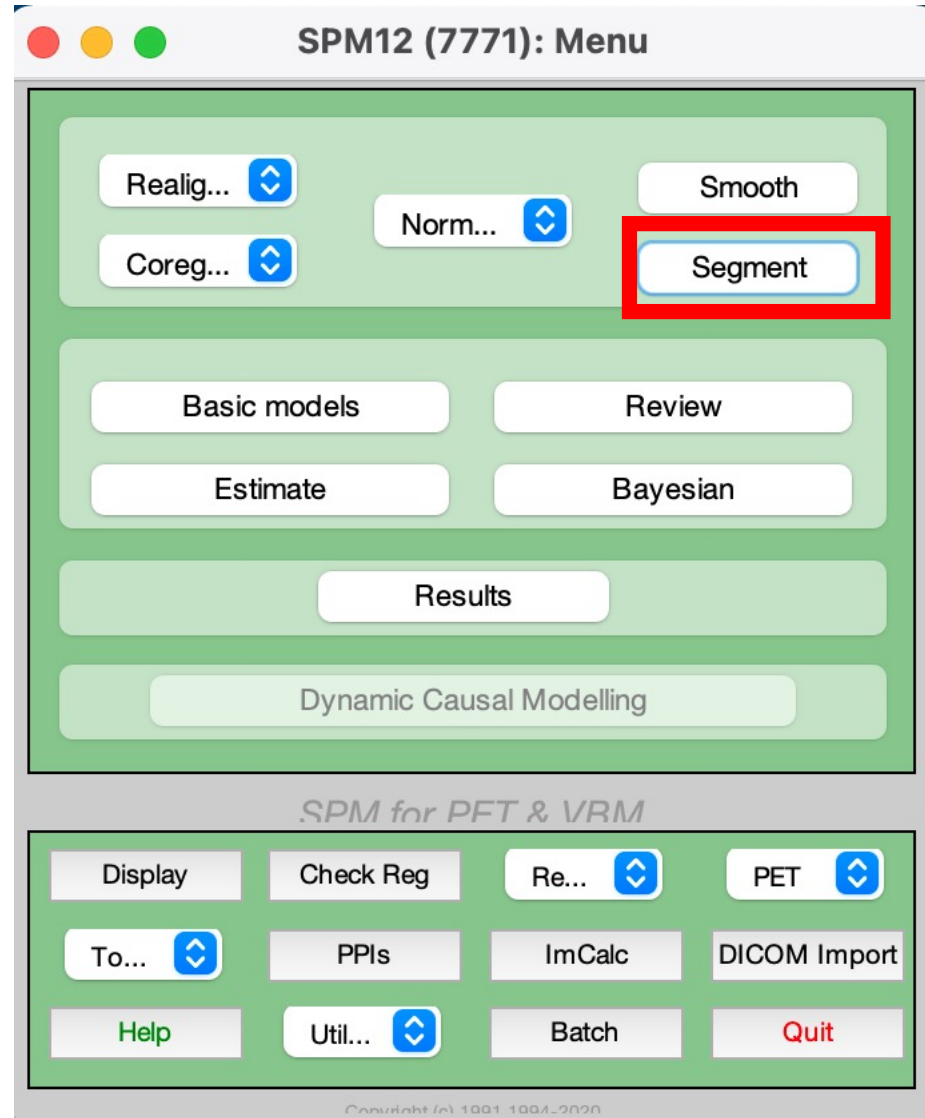


Normalise →

PET-template in MNI-space



Spatial normalisation in SPM (MRI-based)



Spatial normalisation in SPM (MRI-based)

Current Module: Segment

Help on: Segment

Data

- . Channel
- .. Volumes `..._data\MRldata_nativespace\nrm2018mri_nativespace\T1\nrm2018mri_nativespace.nii,1`
- .. Bias regularisation `light regularisation (0.001)`
- .. Bias FWHM `60mm cutoff`
- .. Save Bias Corrected `Save Nothing`

Tissues

- . Tissue
- .. Tissue probability map `o:\spm12\tpm\TPM.nii,1`

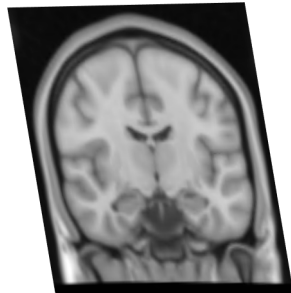
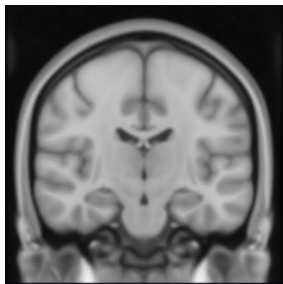
. Smoothness `0`

. Sampling distance `3`

. Deformation Fields `Inverse + Forward`

Current Item: Deformation Fields

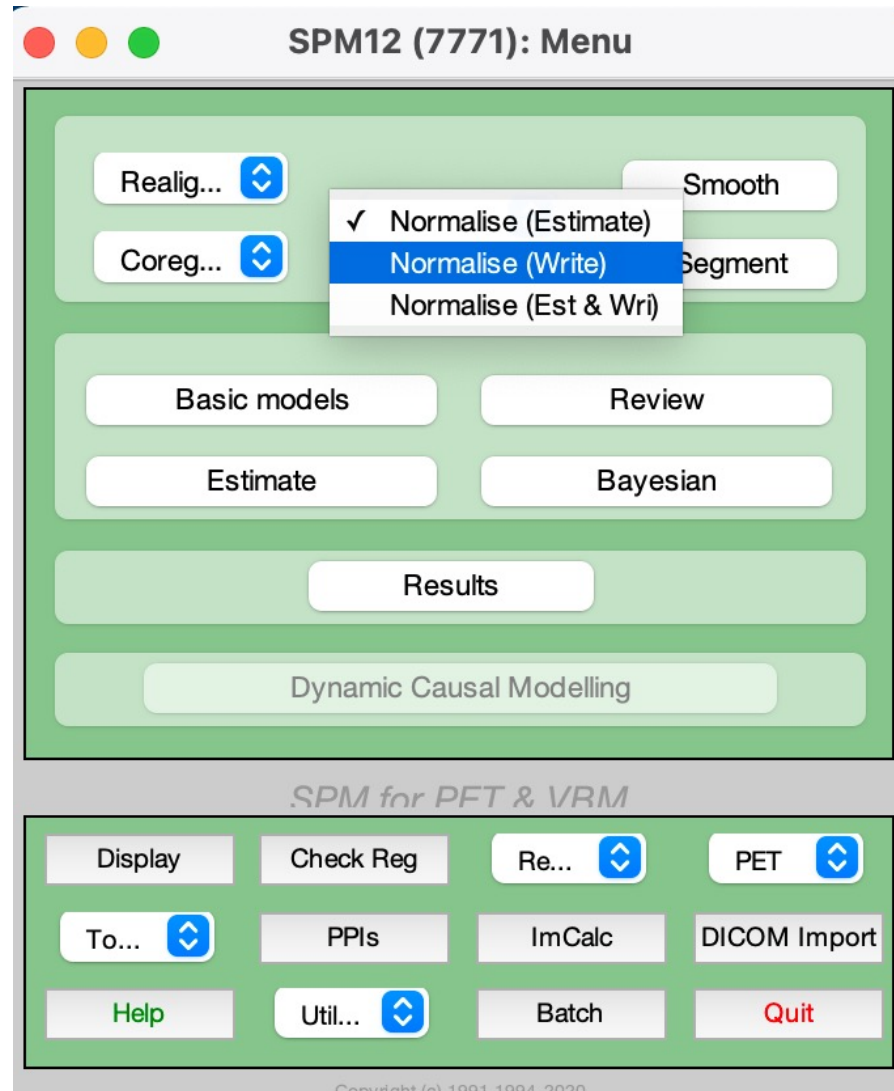
- None
- Inverse
- Forward
- *Inverse + Forward**

Native  $\xrightarrow{\text{Forward}}$  MNI

$\xleftarrow{\text{Inverse}}$

The diagram illustrates the spatial normalisation process. It shows a 'Native' MRI slice on the left, which is tilted and distorted. An arrow labeled 'Forward' points to an 'MNI' MRI slice on the right, which is upright and standardized. A return arrow labeled 'Inverse' points from the MNI slice back to the Native slice, indicating the reverse transformation.

Spatial normalisation in SPM (MRI-based)



Spatial normalisation in SPM (MRI-based)

Current Module: Normalise: Write

Help on: Normalise: Write

Data

- . Subject
- .. Deformation Field ...e_data\MRIdata_nativespace\nrm2018mri_nativespace\T1\y_rnm2018mri_nativespace.nii
- .. Images to Write ...e_data\MRIdata_nativespace\nrm2018mri_nativespace\T1\rnm2018mri_nativespace.nii,1

Writing Options

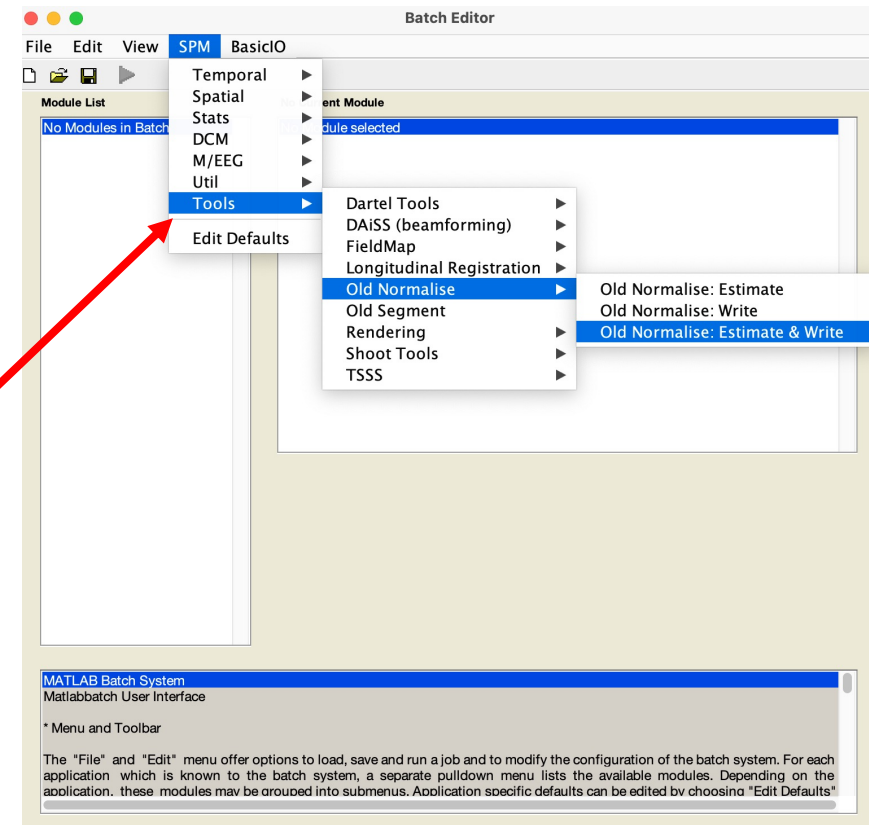
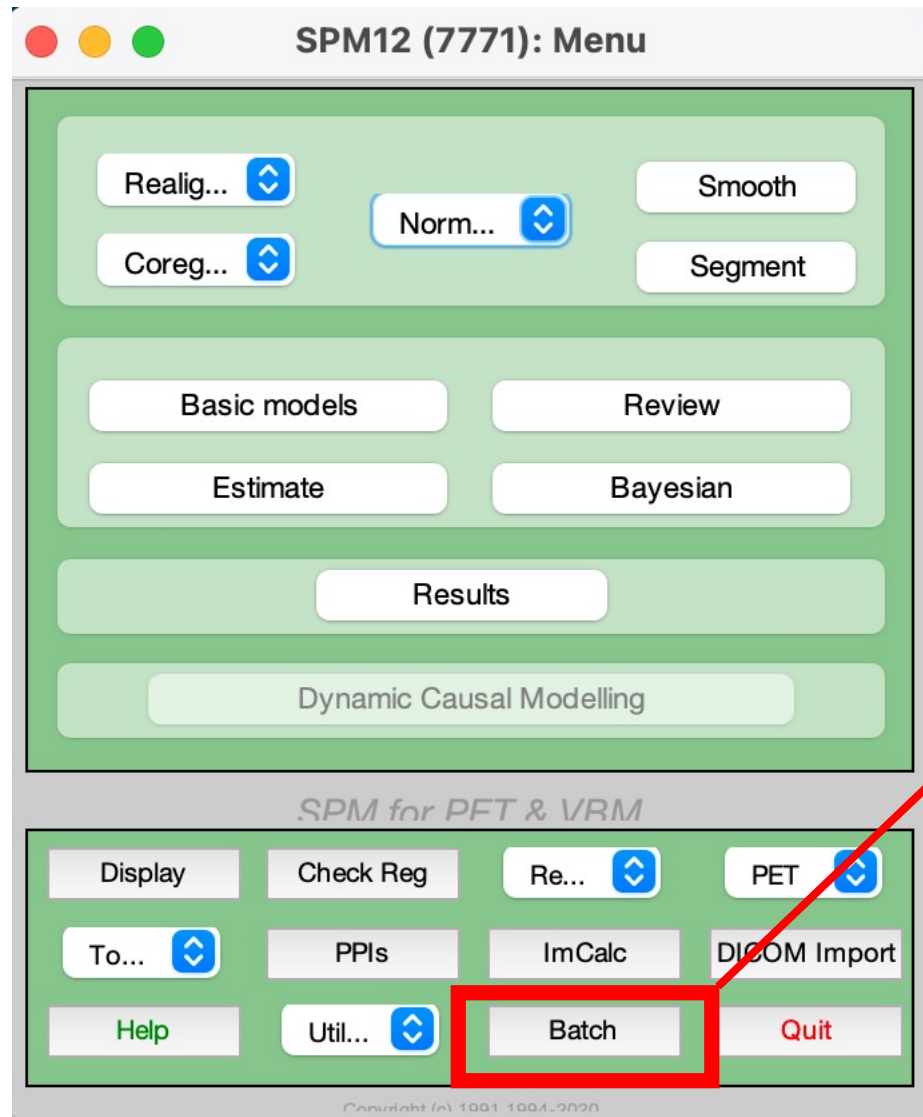
- . Bounding box 2x3 double
- . Voxel sizes [1 1 1]
- . Interpolation Trilinear
- . Filename Prefix w_MRI-based_

Current Item: Bounding box

-90 -126 -72
91 91 109

Specify...

Spatial normalisation in SPM (PET-template)



Spatial normalisation in SPM (PET-template)

Current Module: Old Normalise: Estimate & Write

Help on: Old Normalise: Estimate & Write

Data

- . Subject
- .. Source Image ...\\nii\meanpet_nrm2018baseline1_nativespace_motion.nii,1
- .. Source Weighting Image 0 files
- .. Images to Write 24 files**

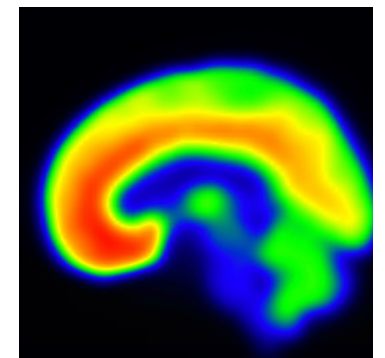
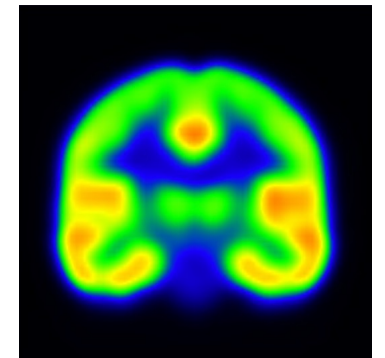
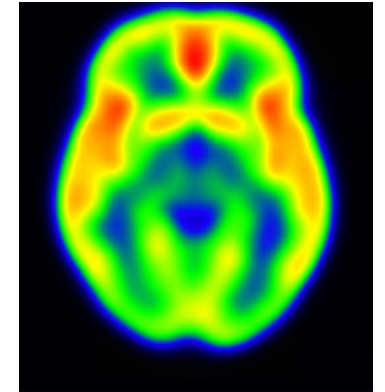
Estimation Options

- . Template Image ...ging_course_data\rs8mm_RO15_PET_template_MNI.nii,1
- . Template Weighting Image 0 files
- . Source Image Smoothing 8
- . Template Image Smoothing 0
- . Affine Regularisation ICBM space template
- . Nonlinear Frequency Cutoff 25

Current Item: Images to Write

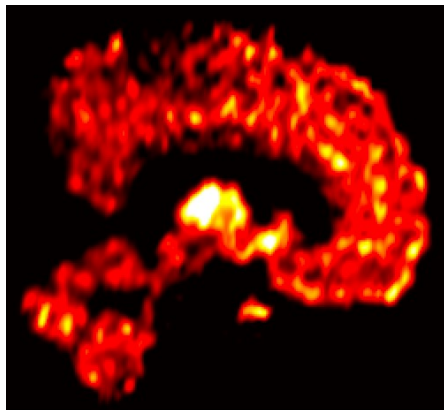
- ativespace\nrm2018baseline1_nativespace\PET\nii\pet_nrm2018baseline1_nativespace_motion.nii,21
- ativespace\nrm2018baseline1_nativespace\PET\nii\pet_nrm2018baseline1_nativespace_motion.nii,22
- ativespace\nrm2018baseline1_nativespace\PET\nii\pet_nrm2018baseline1_nativespace_motion.nii,23
- tivespace\nrm2018mri_nativespace\T1\nrm2018mri_nativespace.nii,1

Specify...

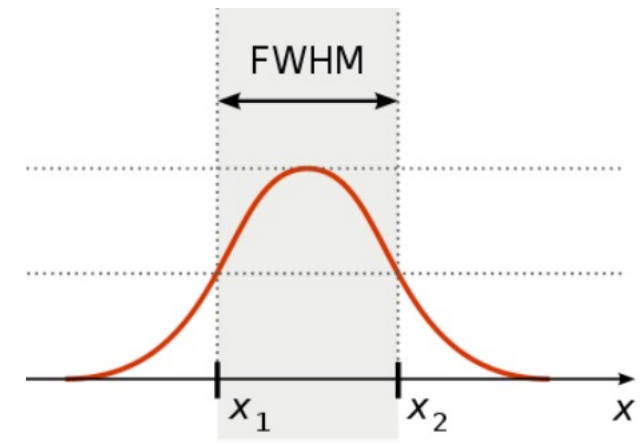
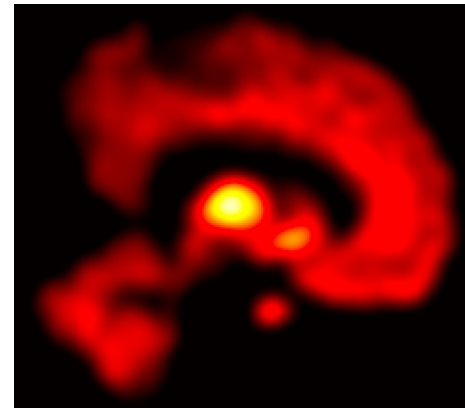


Smoothing

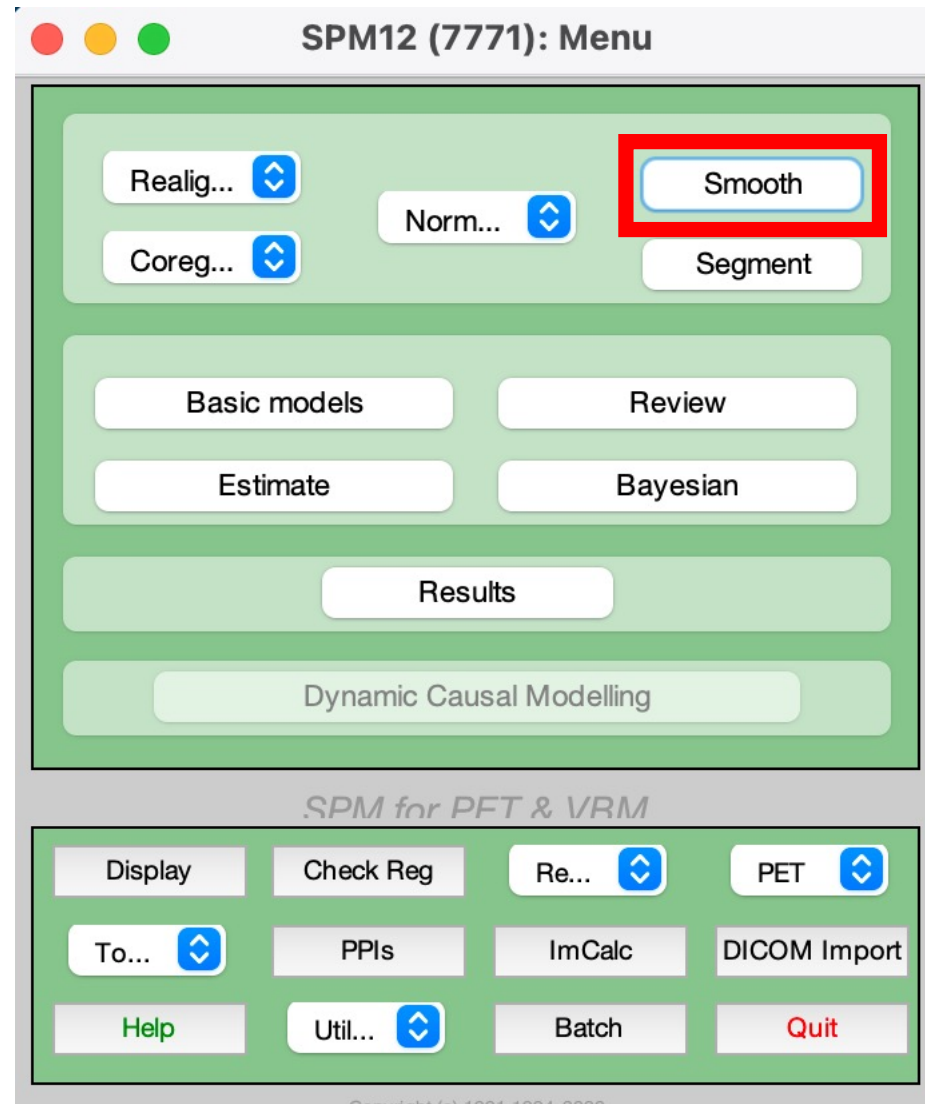
- The resulting normalised images are noisy
 - Violates the normality assumption in the voxel-level statistical analysis
- Smoothing increases signal-to-noise ratio and compensates the normalisation errors
- Cost: reduced spatial resolution



Gaussian 8mm
FWHM smooth



Smoothing in SPM



Smoothing in SPM

Current Module: Smooth

Help on: Smooth

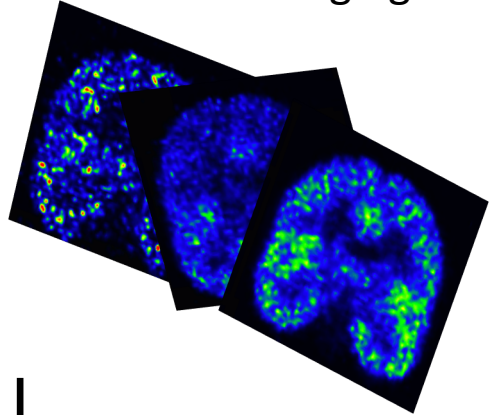
Images to Smooth ...	mri freesurfer/results/wsrpet_nrm2018baseline1_bfsrtm_BP.nii,1
FWHM	[8 8 8]
Data Type	SAME
Implicit masking	No
Filename Prefix	s8mm_

Current Item: Images to Smooth

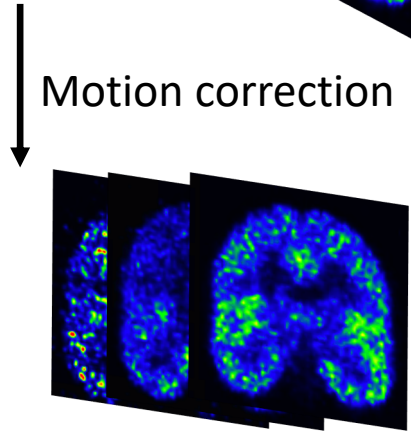
m2018baseline1\srtm_mri_freesurfer/results/wsrpet_nrm2018baseline1_bfsrtm_BP.nii,1

Preprocessing overview

4D Functional imaging data

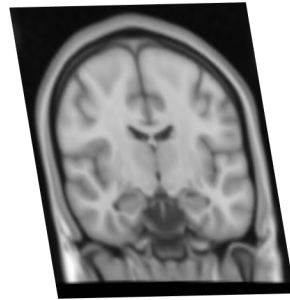


Motion correction



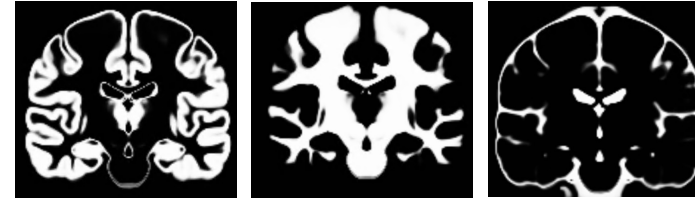
Motion corrected data

Anatomical MRI



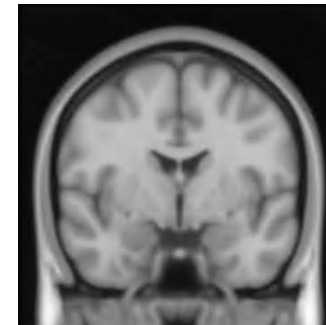
Segment

Tissue Probability Maps (TPM)



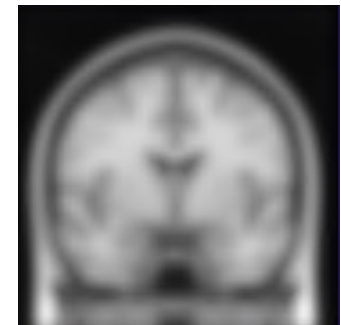
Normalisation

Registration +
interpolation



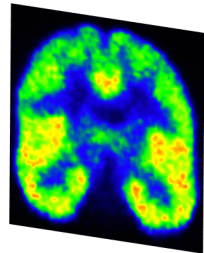
Normalised image in
MNI space

Smooth



Analysis

Mean functional image



Further details

- R. Frackowiak, K. Friston et al., Human brain function, 2003
 - online book: <https://www.fil.ion.ucl.ac.uk/spm/doc/books/hbf2/>
- SPM spatial preprocessing tutorial / preprocessing demo (Ged Ridgway / John Ashburner):
 - <https://www.fil.ion.ucl.ac.uk/spm/course/video/>
- Nifti format
 - <https://brainder.org/2012/09/23/the-nifti-file-format/>