

Spatial Preprocessing



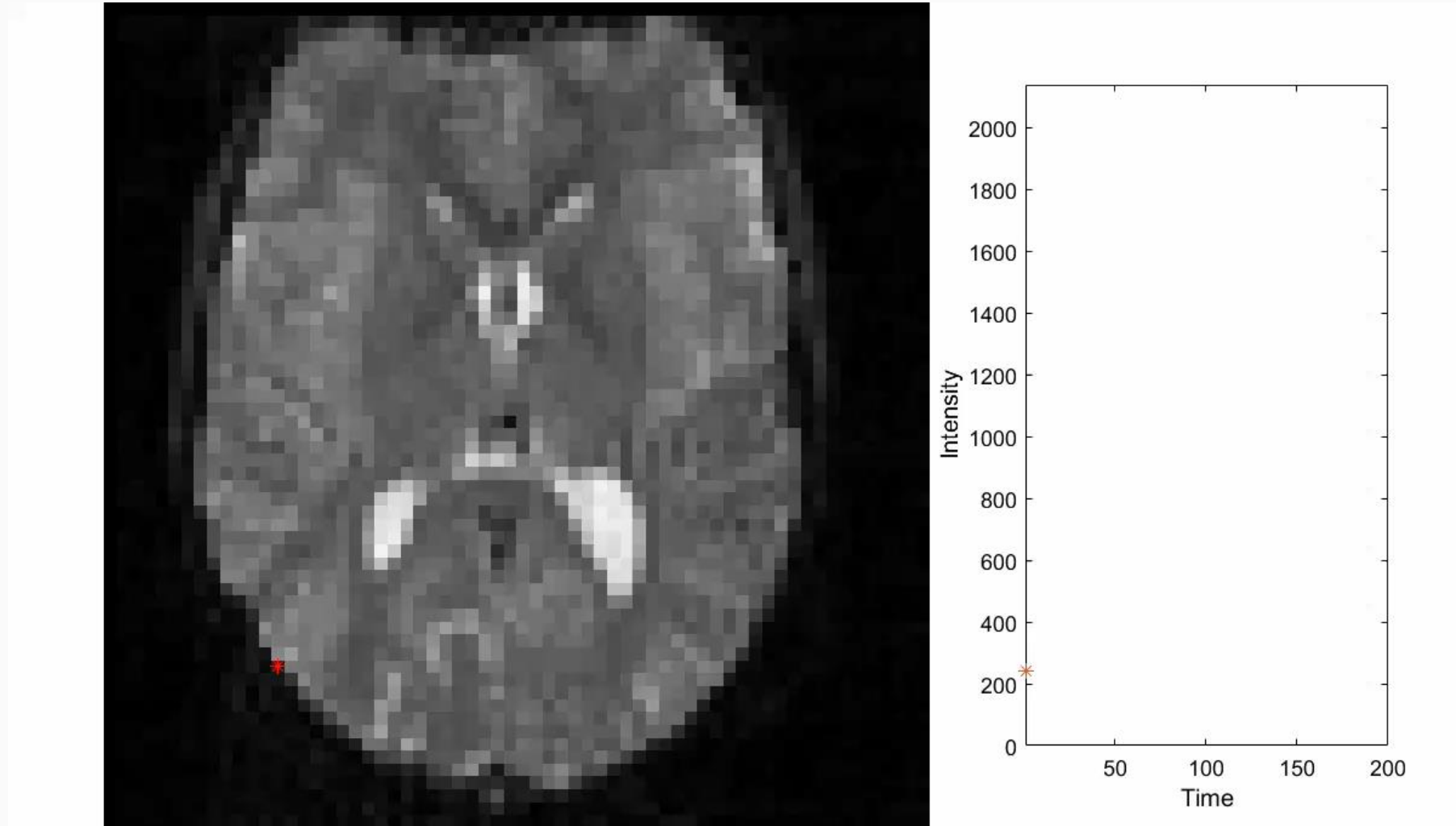
Yaël Balbastre

SPM fMRI/VBM course – May 2026

Functional Imaging Laboratory
Department of Imaging Neuroscience

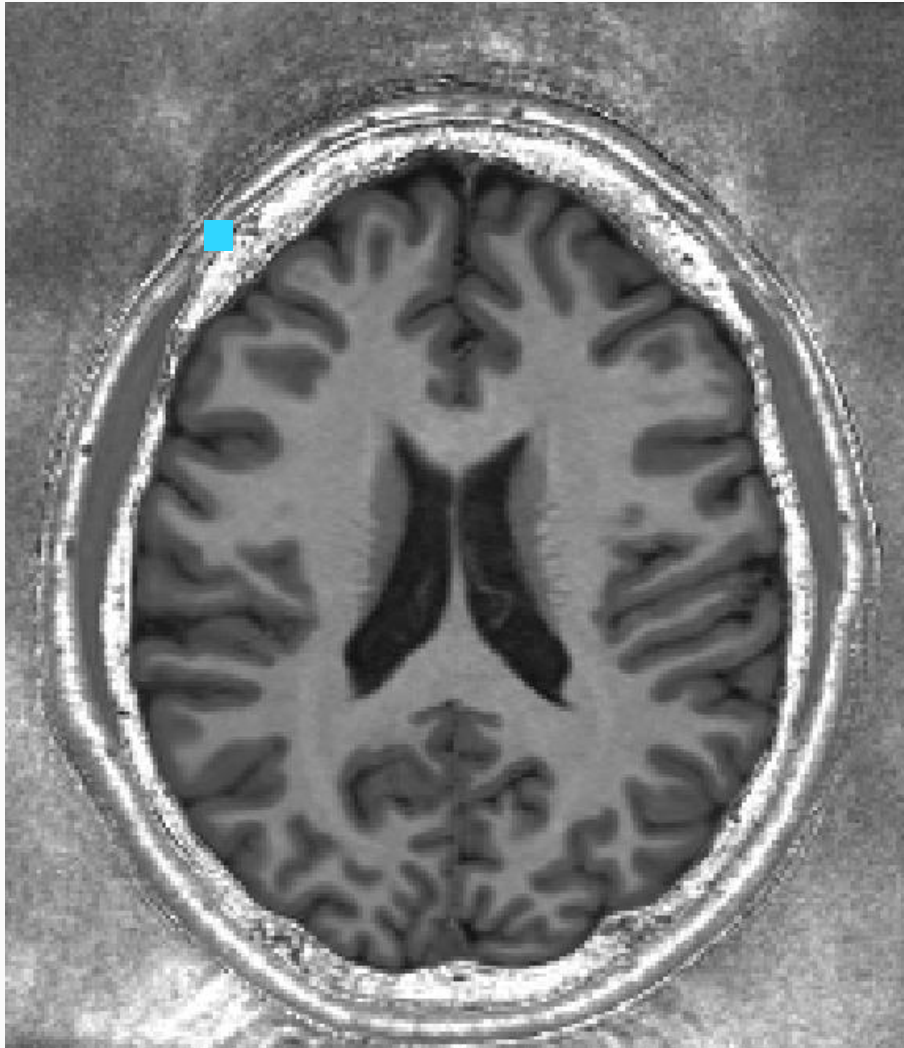


Why do we need preprocessing?

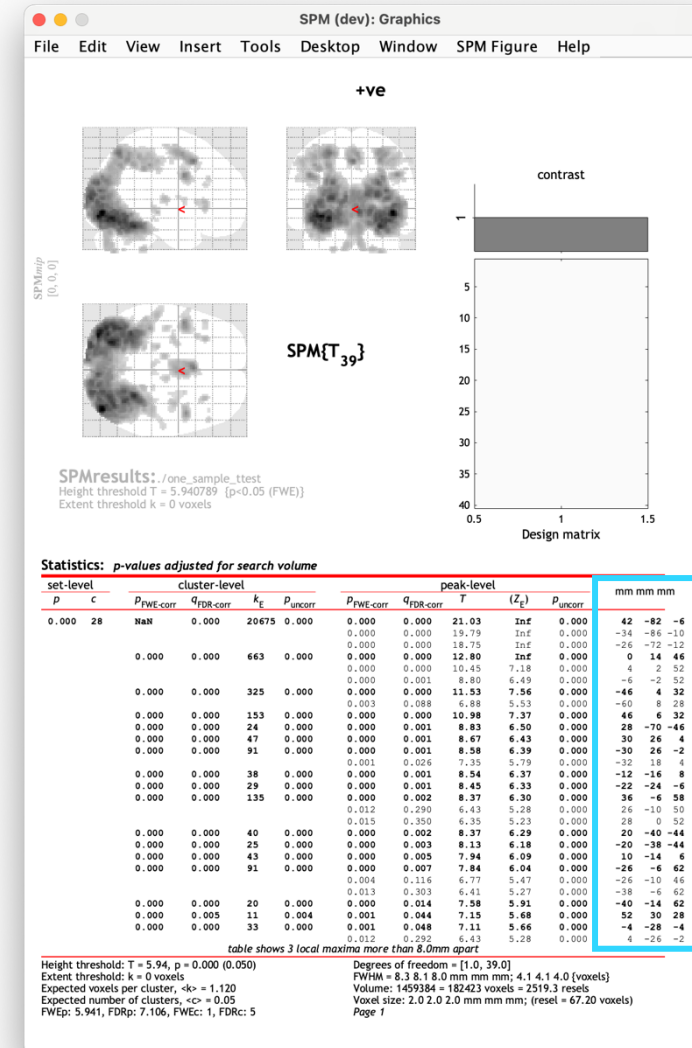


Why do we need preprocessing?

Group analysis



Standardised reporting



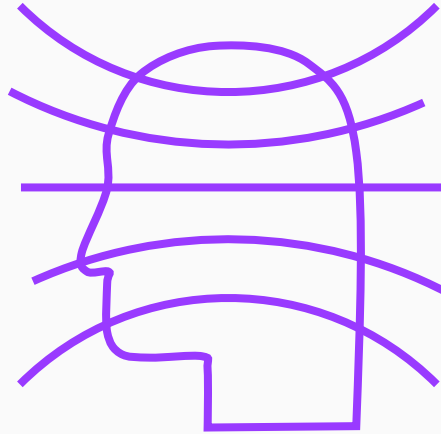
Sources of variance

Head motion



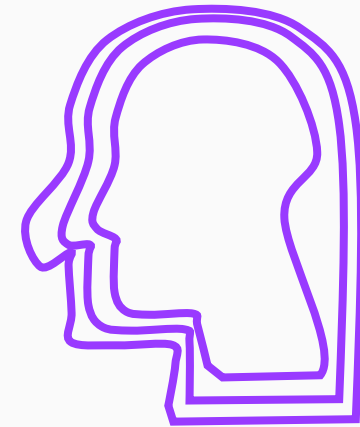
→ Realign

Field inhomogeneity



→ Unwarp

Inter-individual
variability



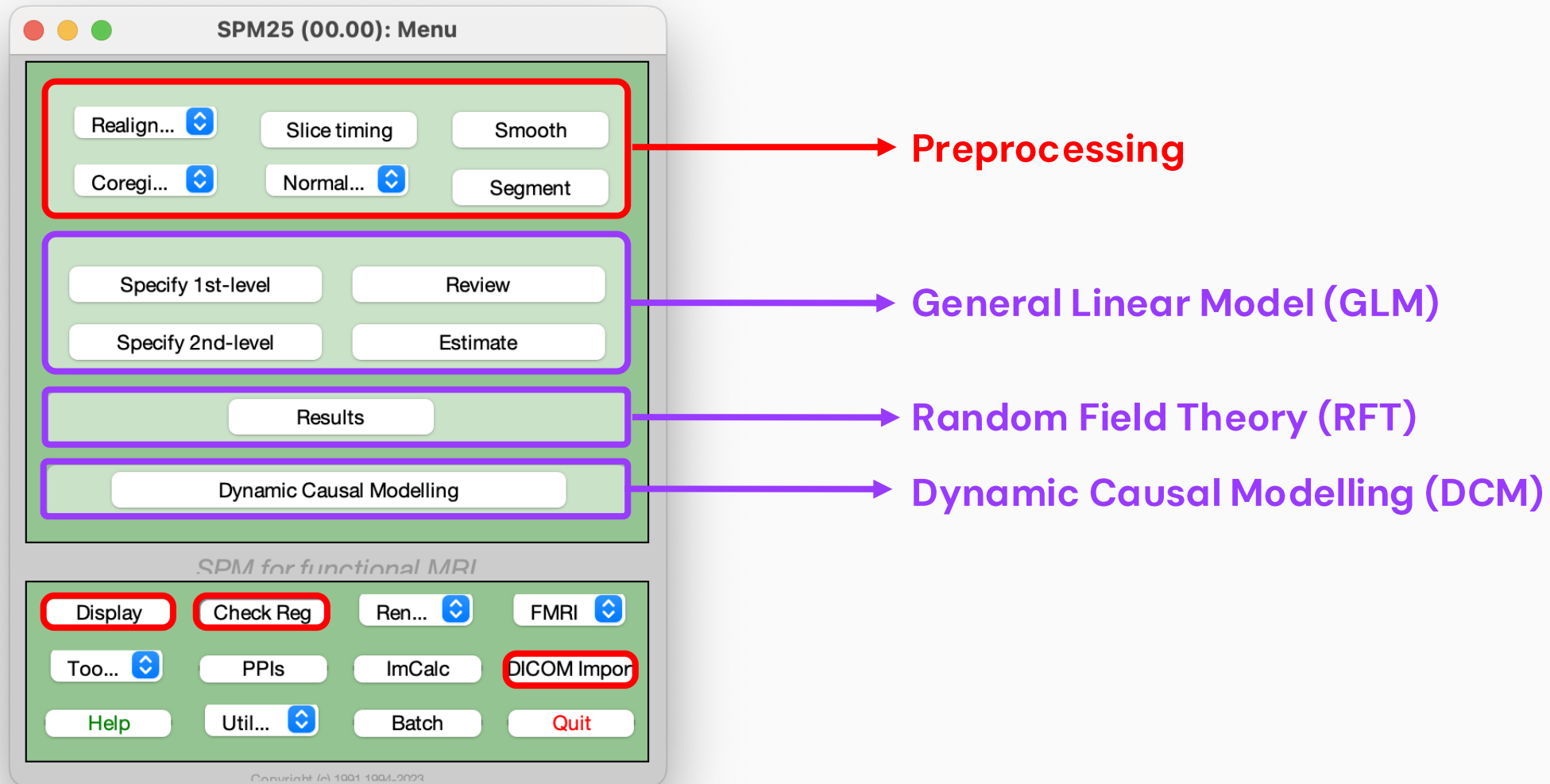
→ Normalise

First level (subject)

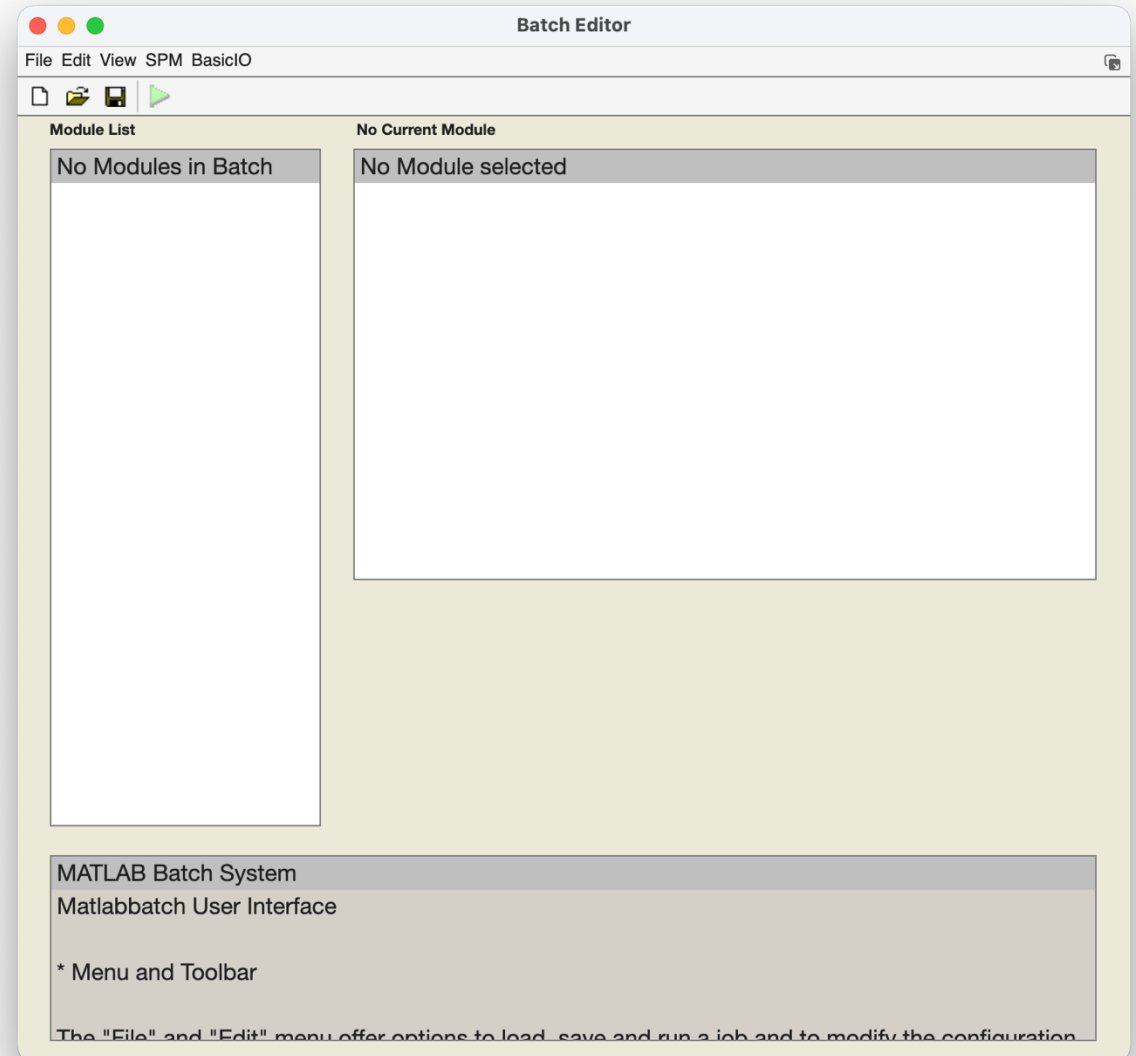
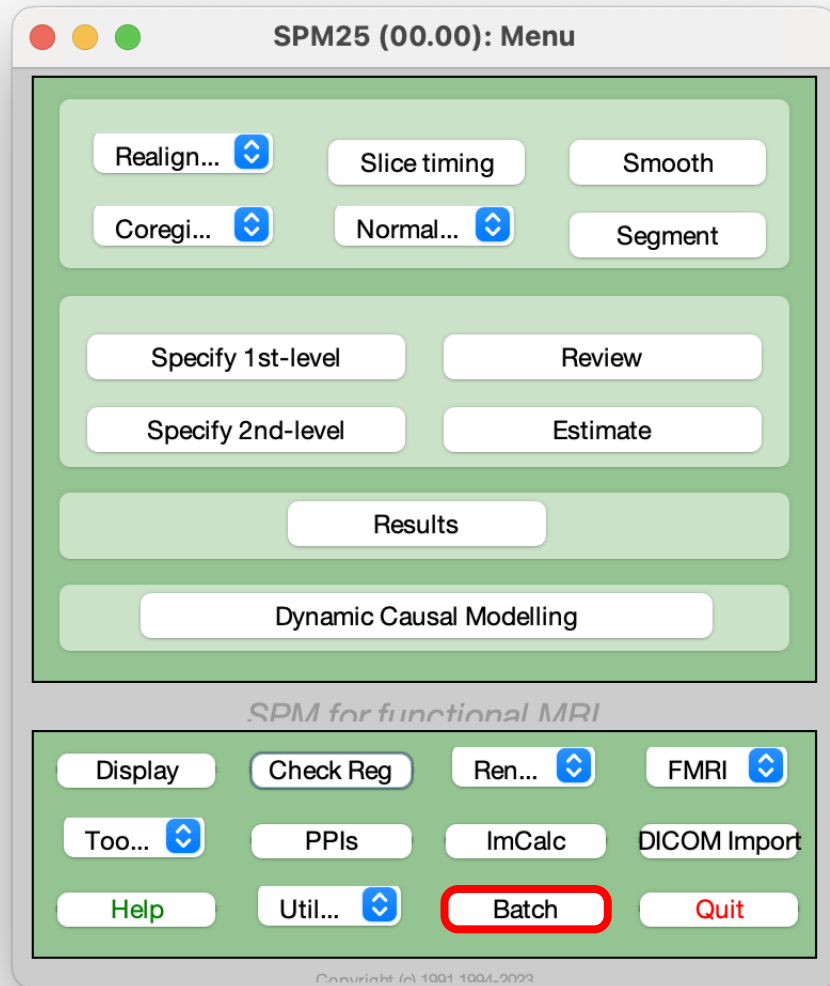
Second level (group)



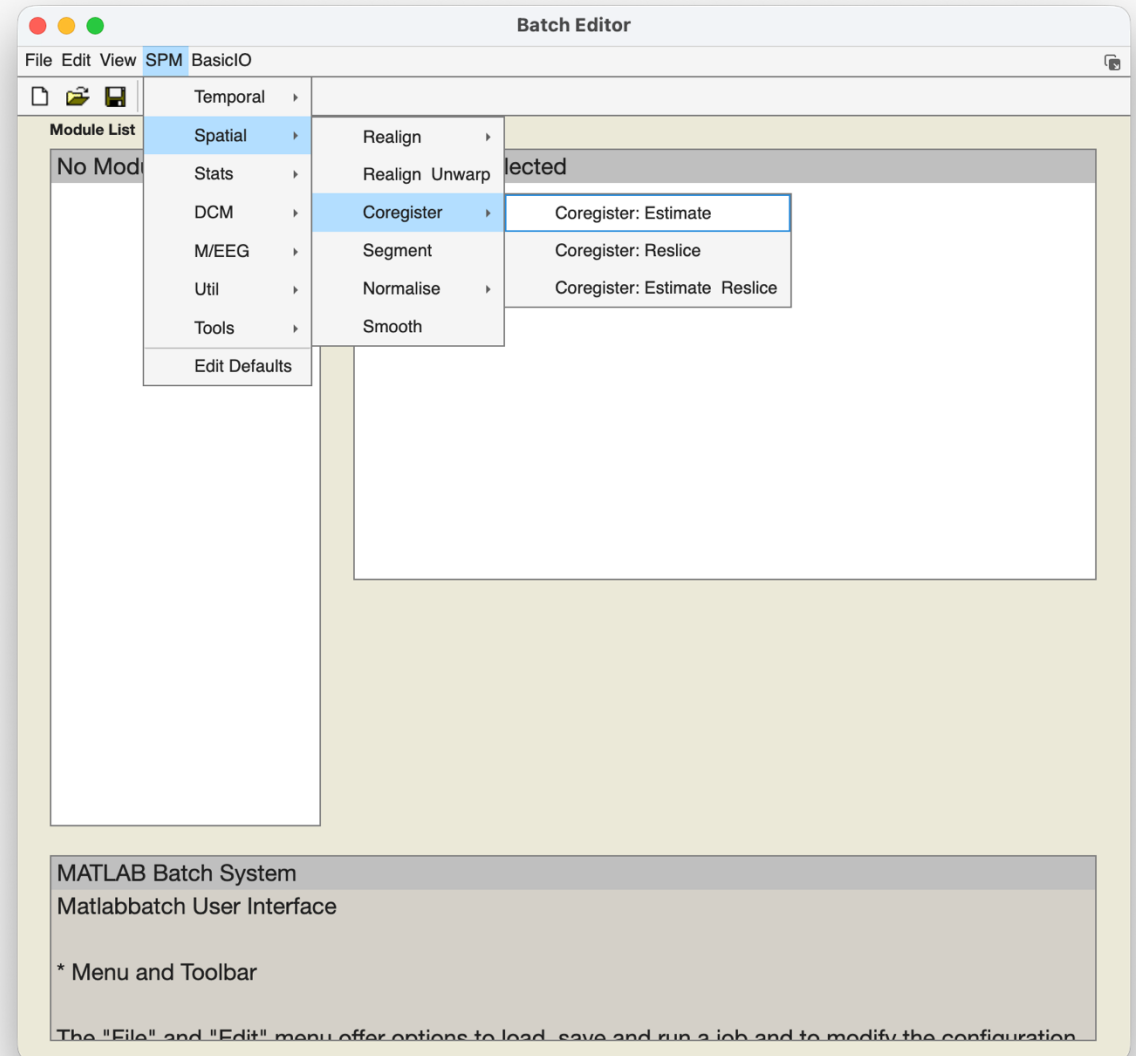
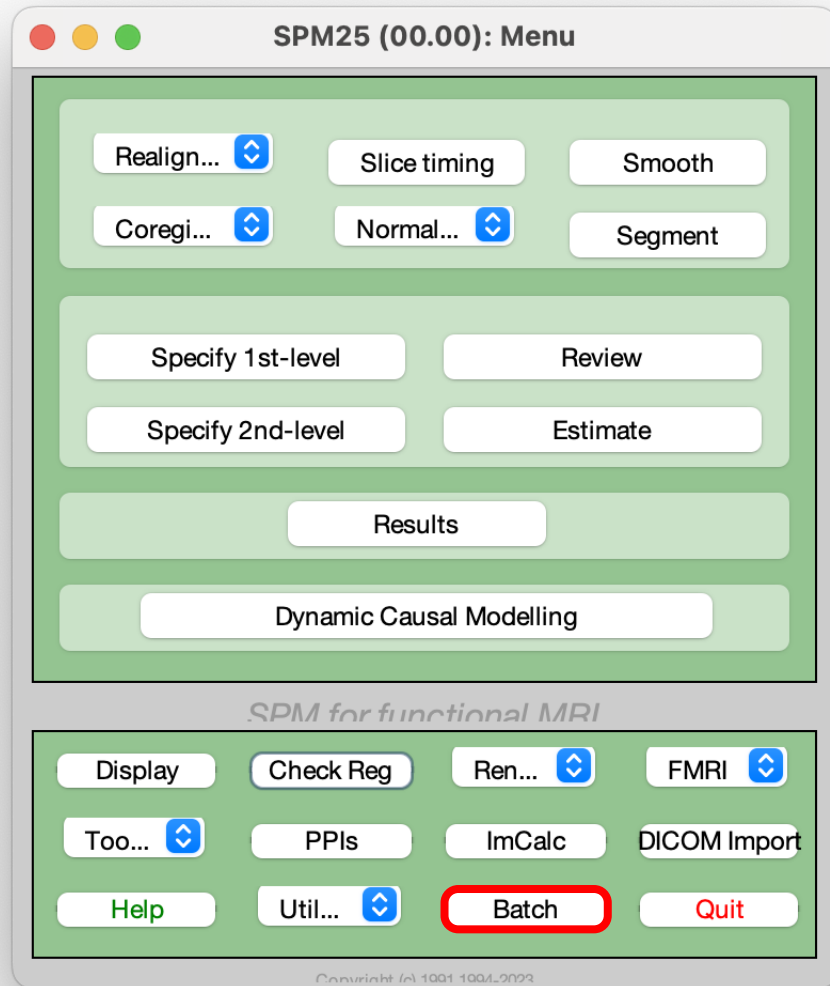
Spatial preprocessing in SPM



SPM Batch

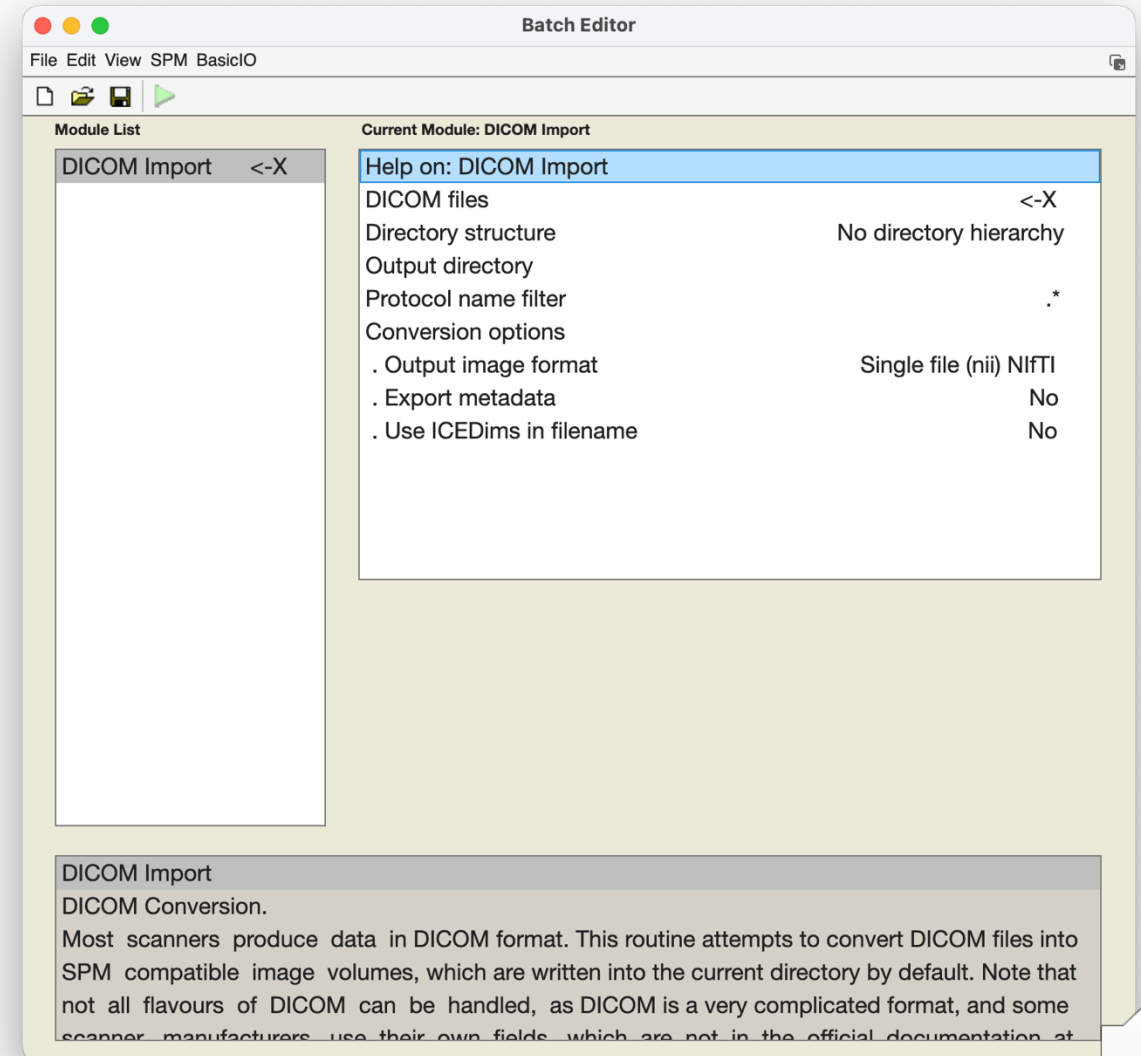
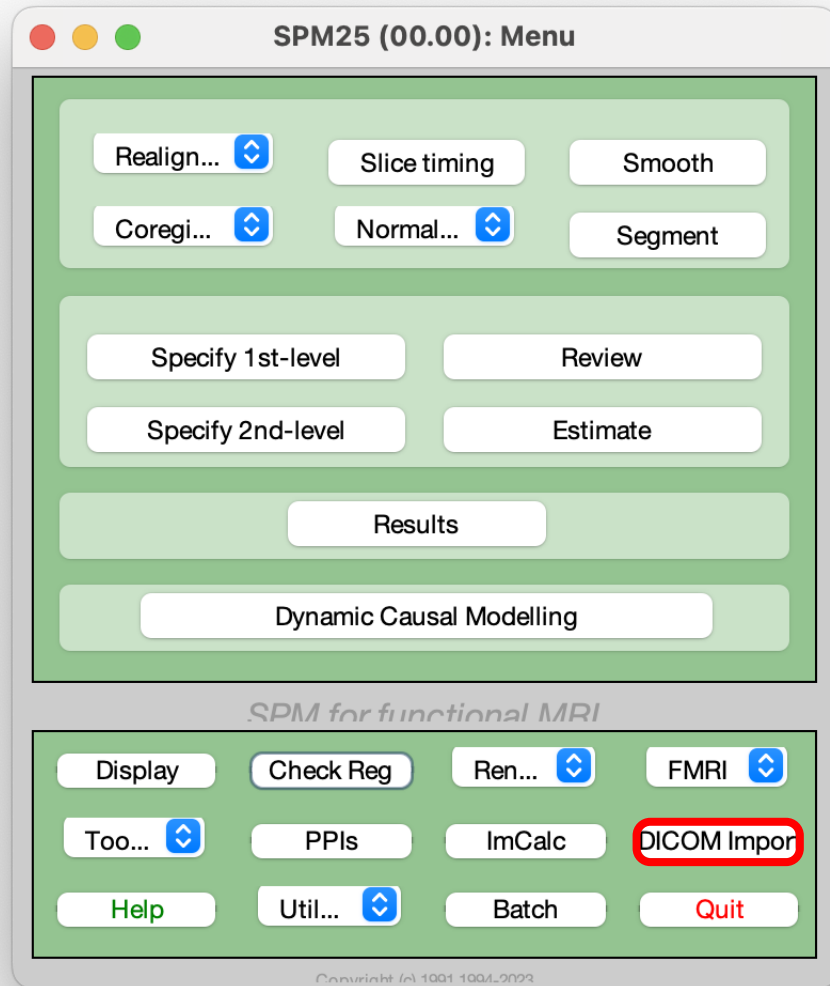


SPM Batch

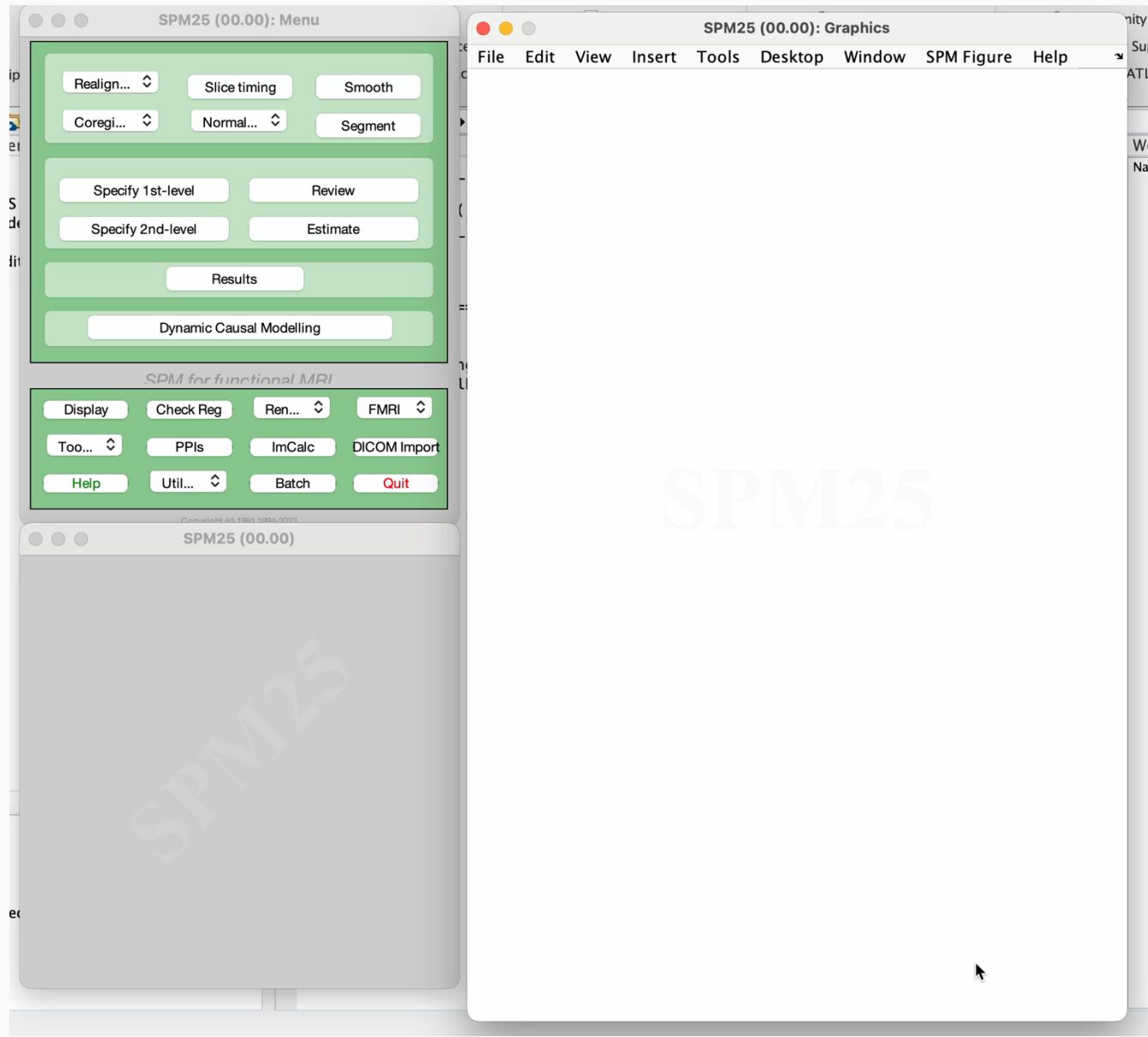


File formats

DICOM to NIfTI

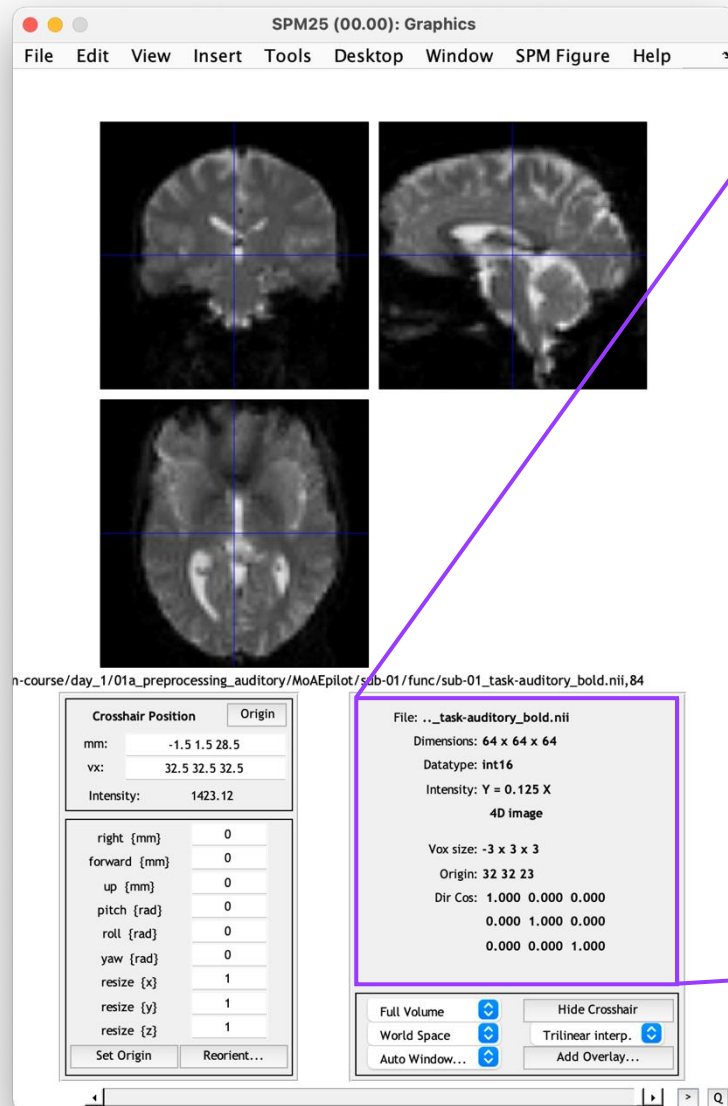


Always check your data!



Anatomy of a NIfTI file (.nii)

Metadata



File: **.._task-auditory_bold.nii**

Dimensions: **64 x 64 x 64**

Datatype: **int16**

Intensity: **Y = 0.125 X**

4D image

Vox size: **-3 x 3 x 3**

Origin: **32 32 23**

Dir Cos: **1.000 0.000 0.000**

0.000 1.000 0.000

0.000 0.000 1.000



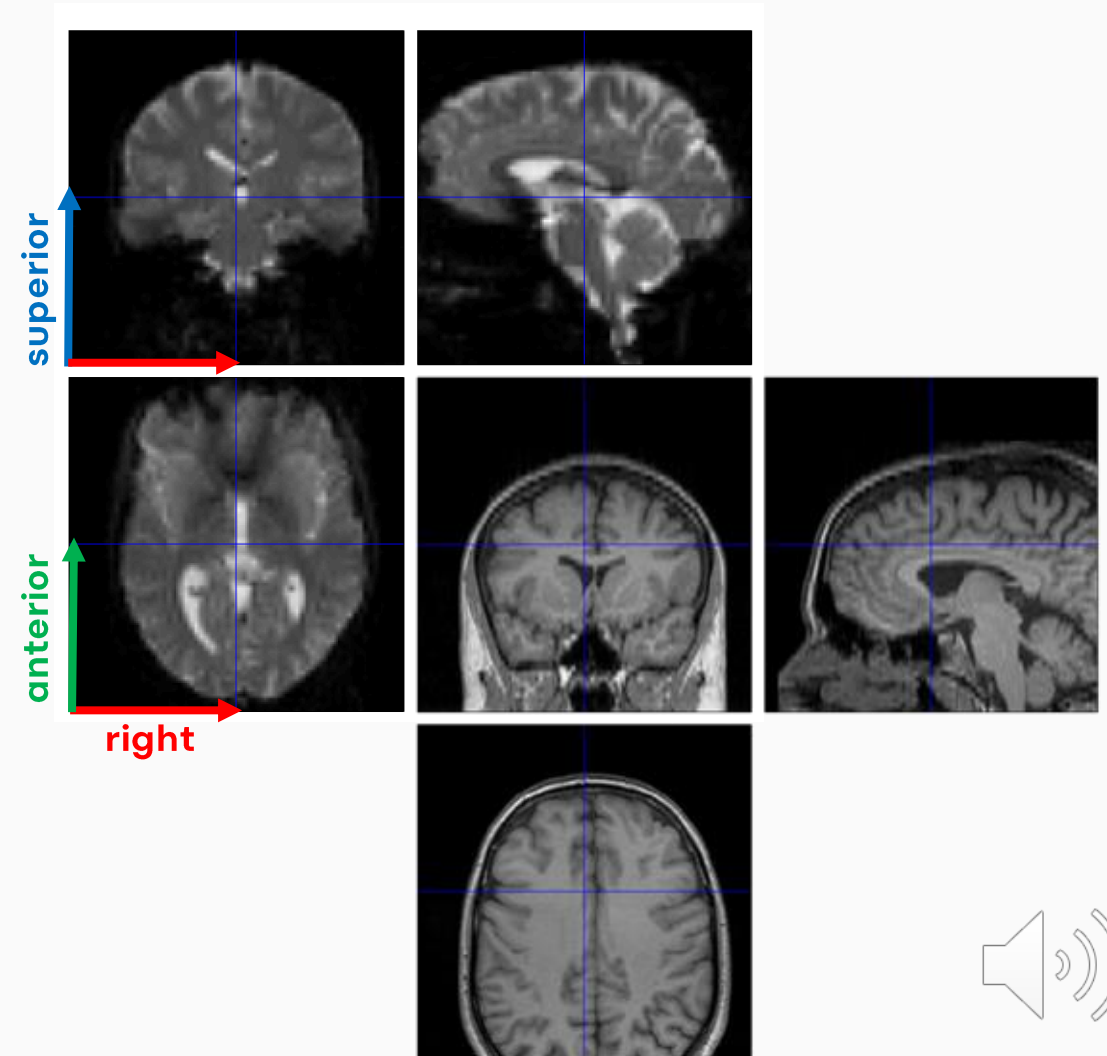
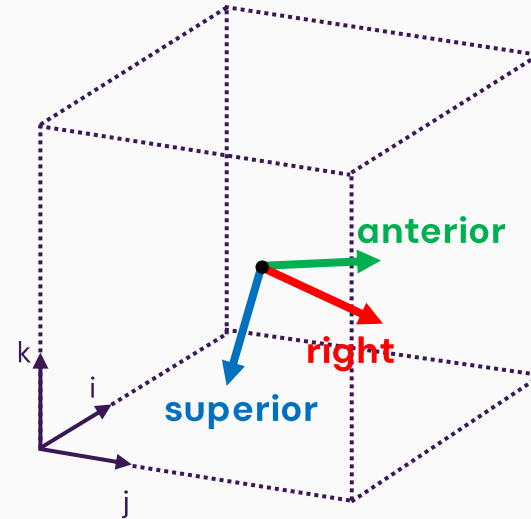
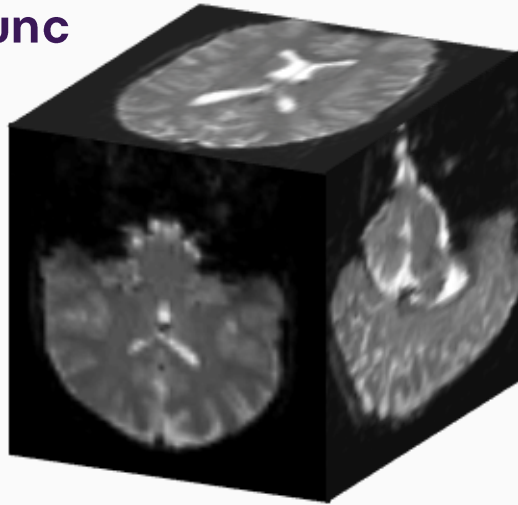
Anatomy of a NIfTI file (.nii)

Data

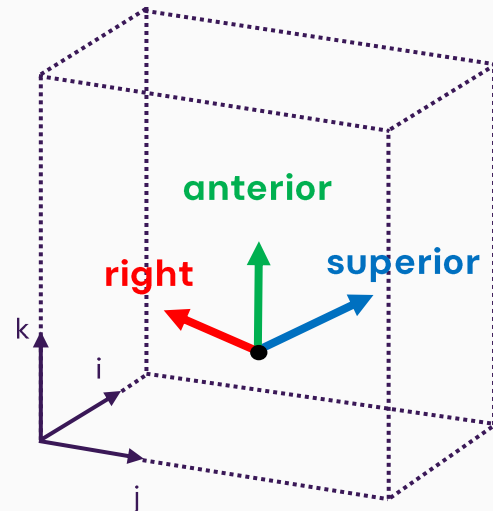
Orientation metadata

Oriented data

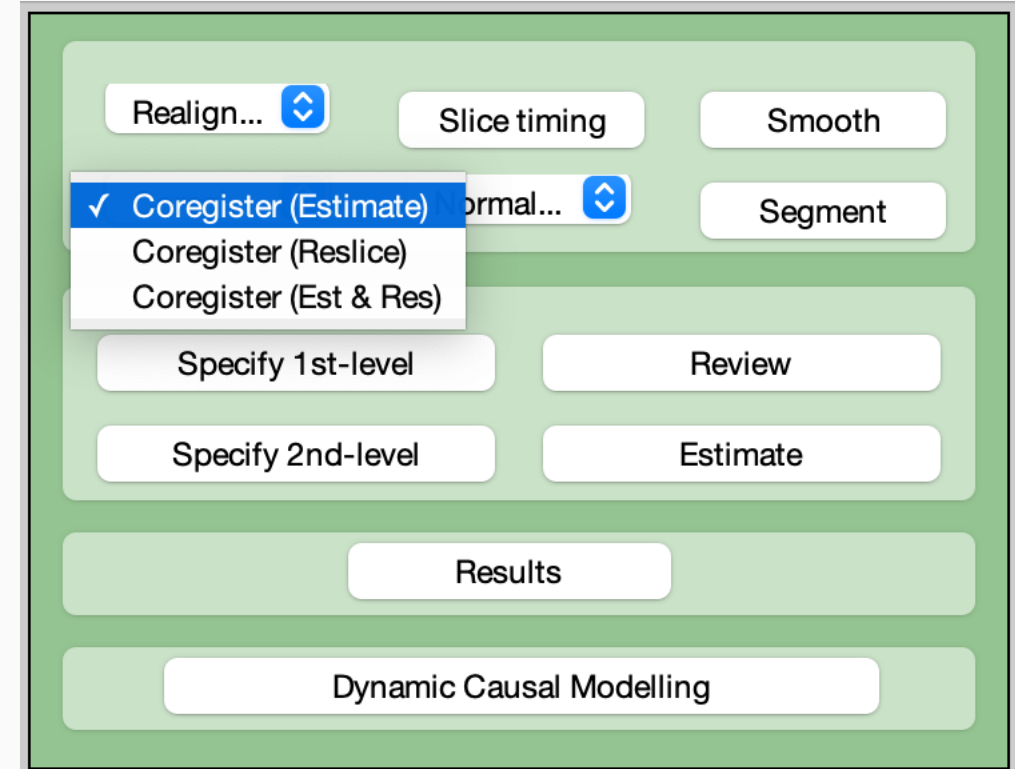
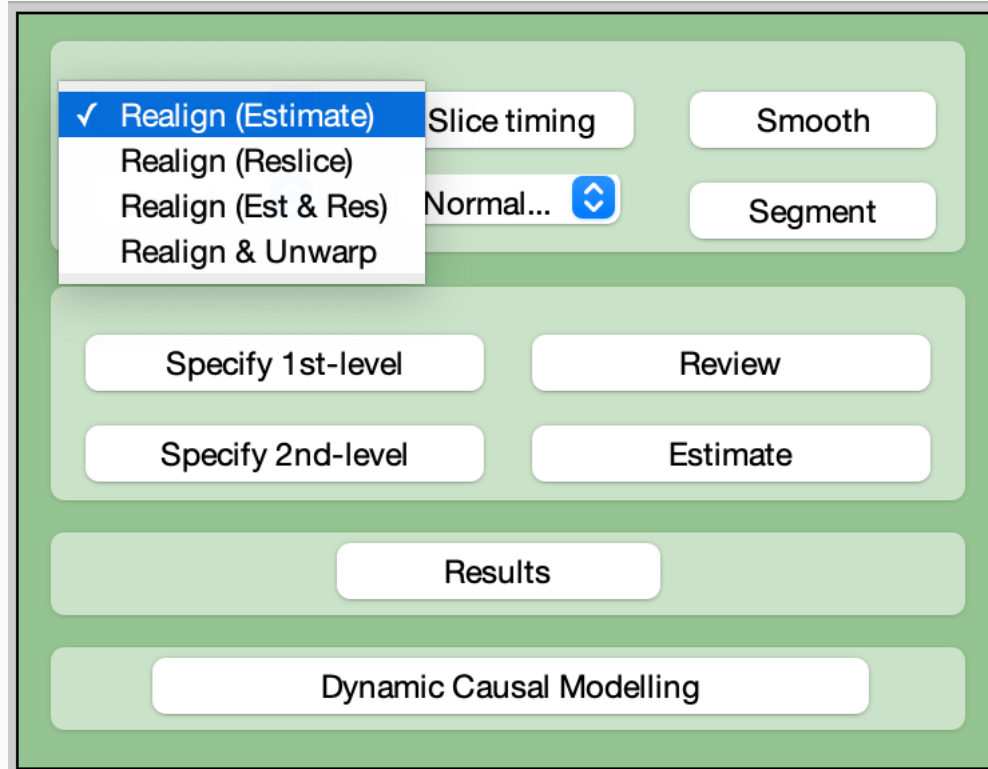
func



anat

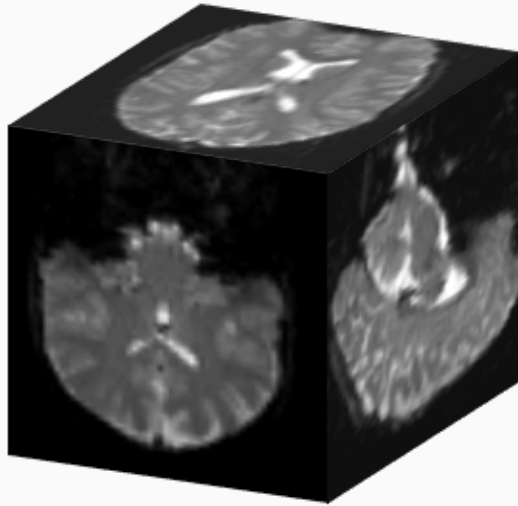


Estimate vs Reslice

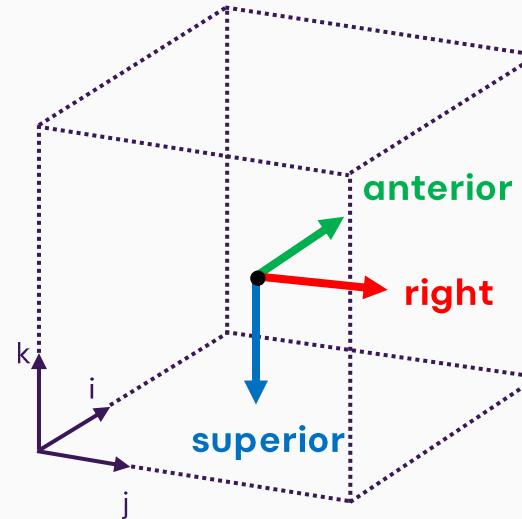


Estimate vs Reslice

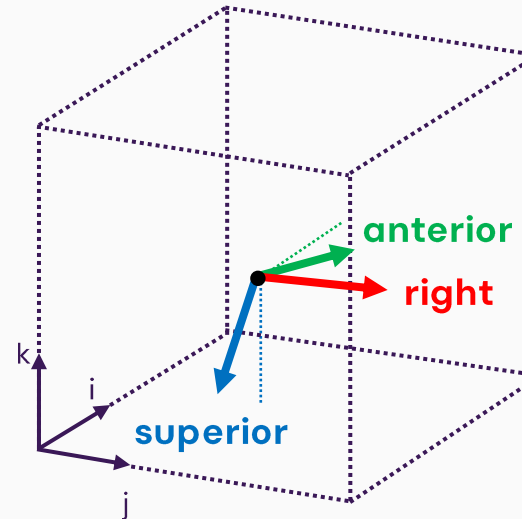
Data



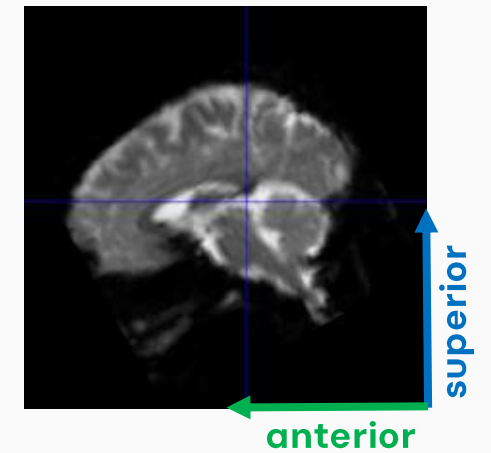
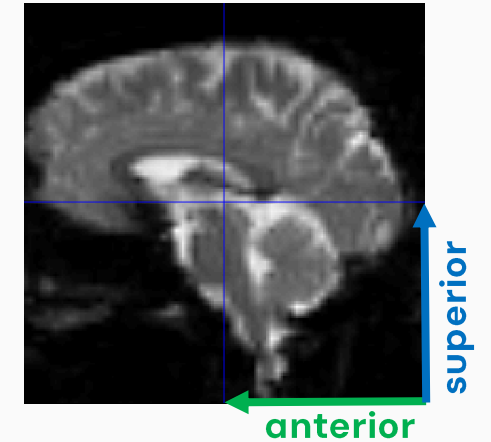
Orientation metadata



30° pitch

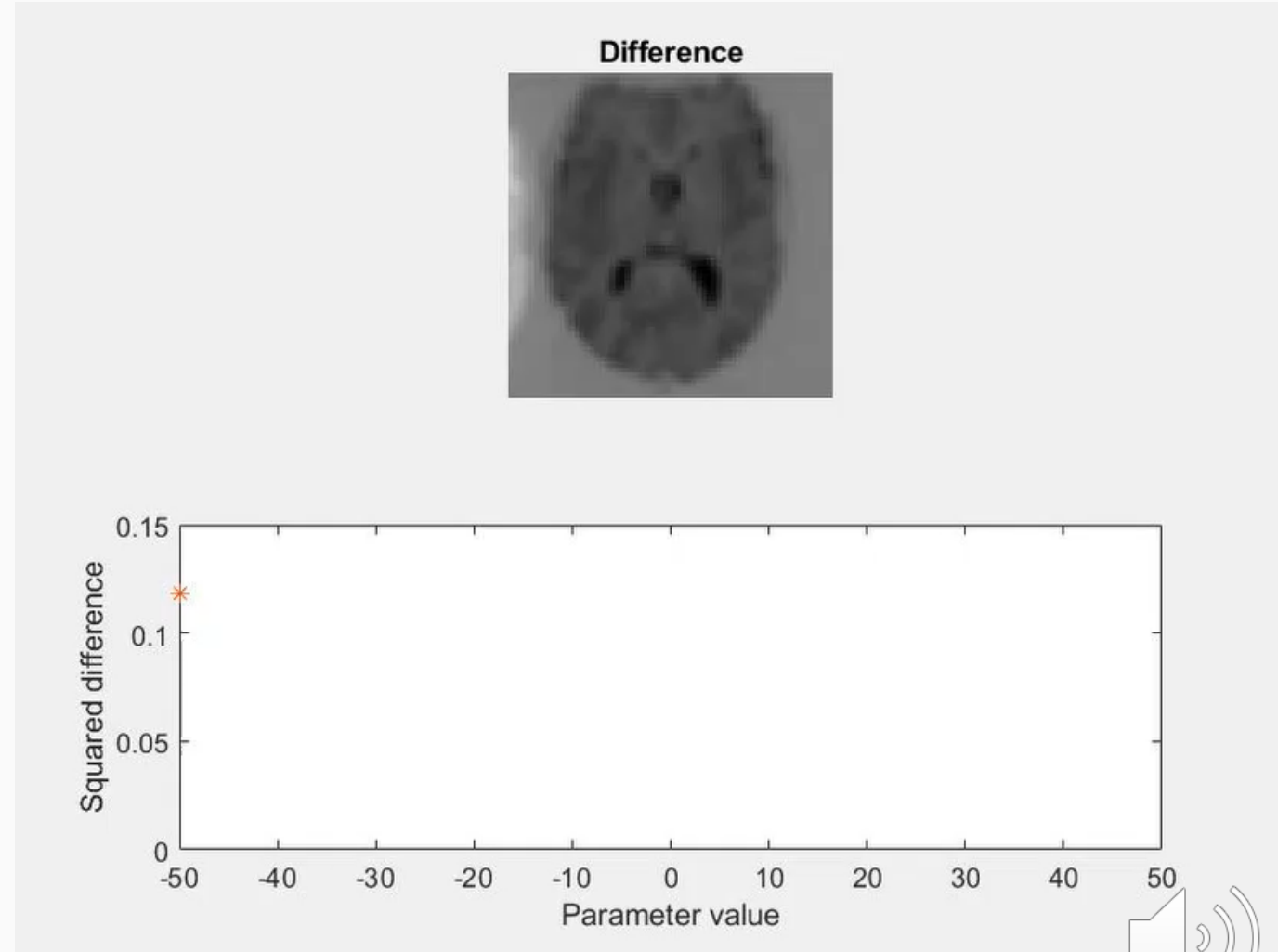
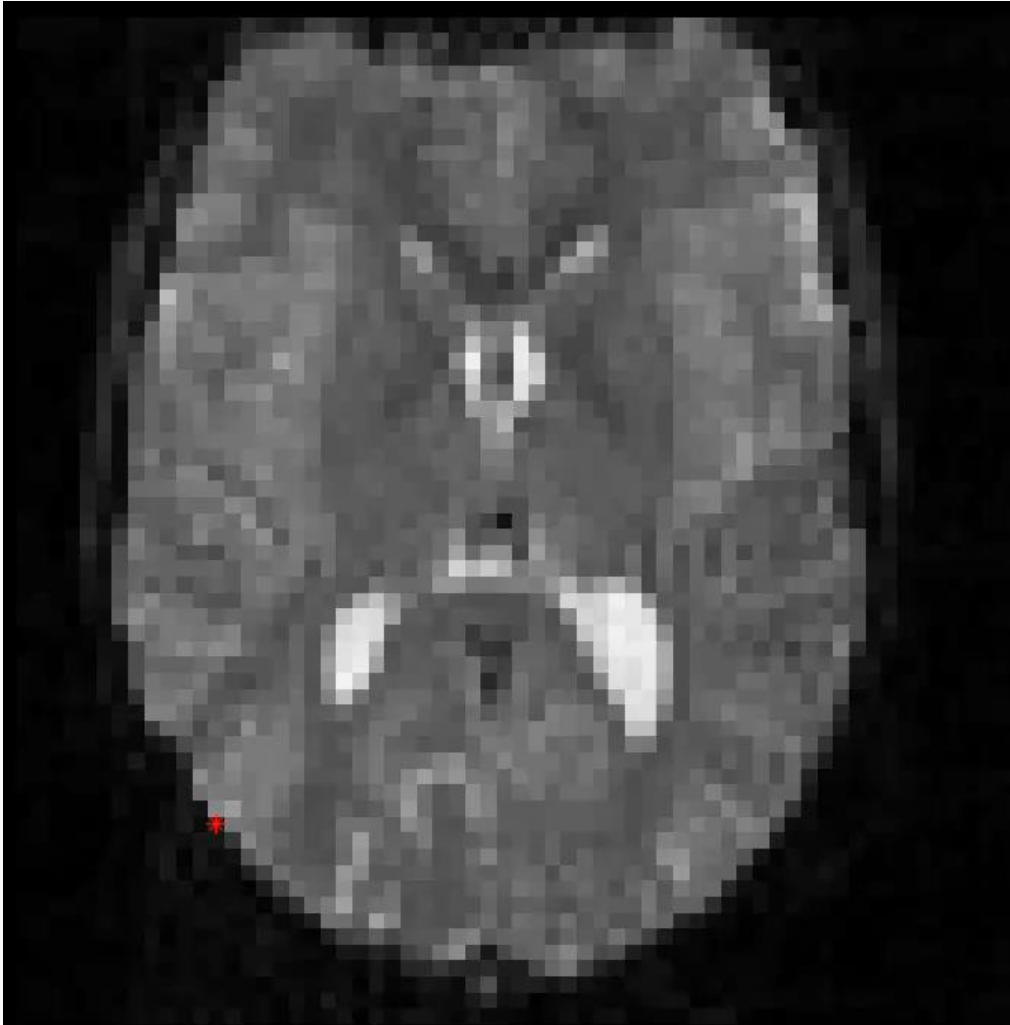


Oriented data



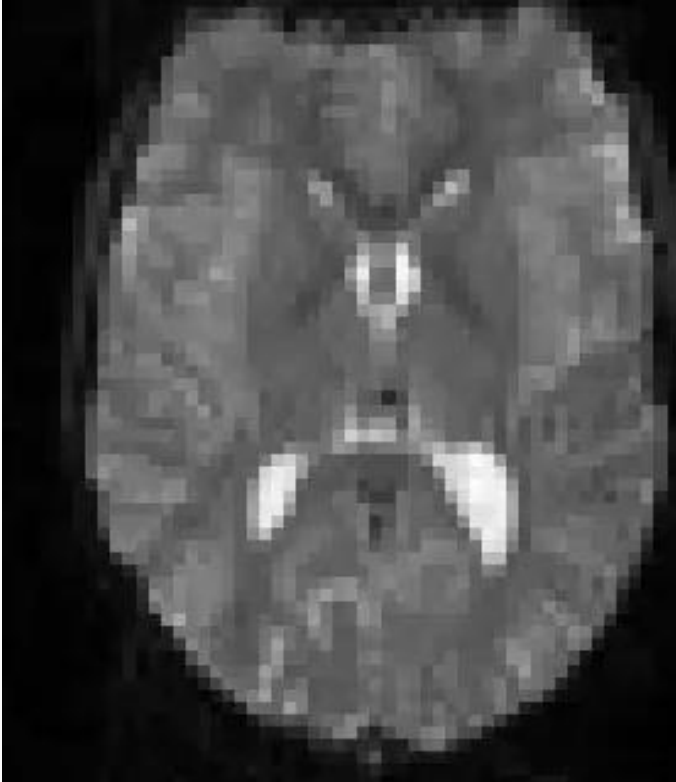
fMRI preprocessing

Head motion → Realign

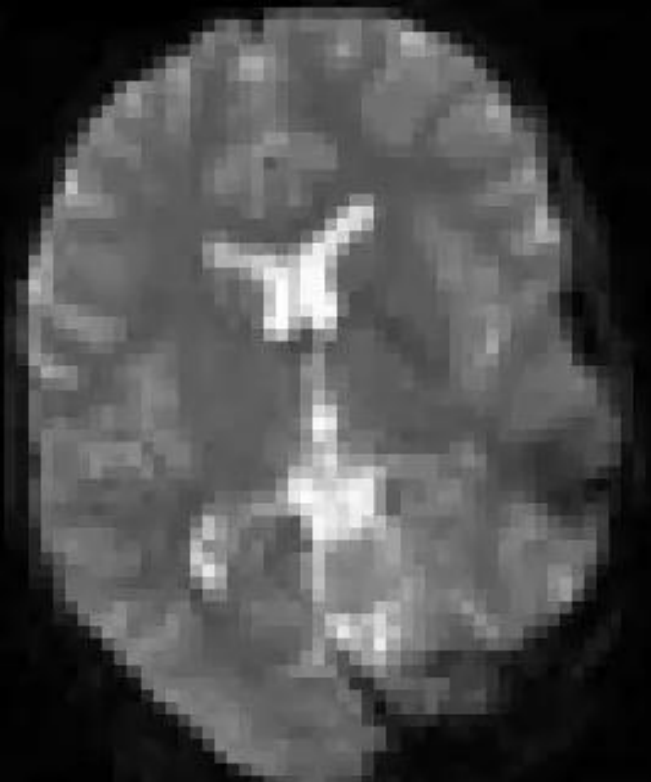


Head motion → Realign

Target



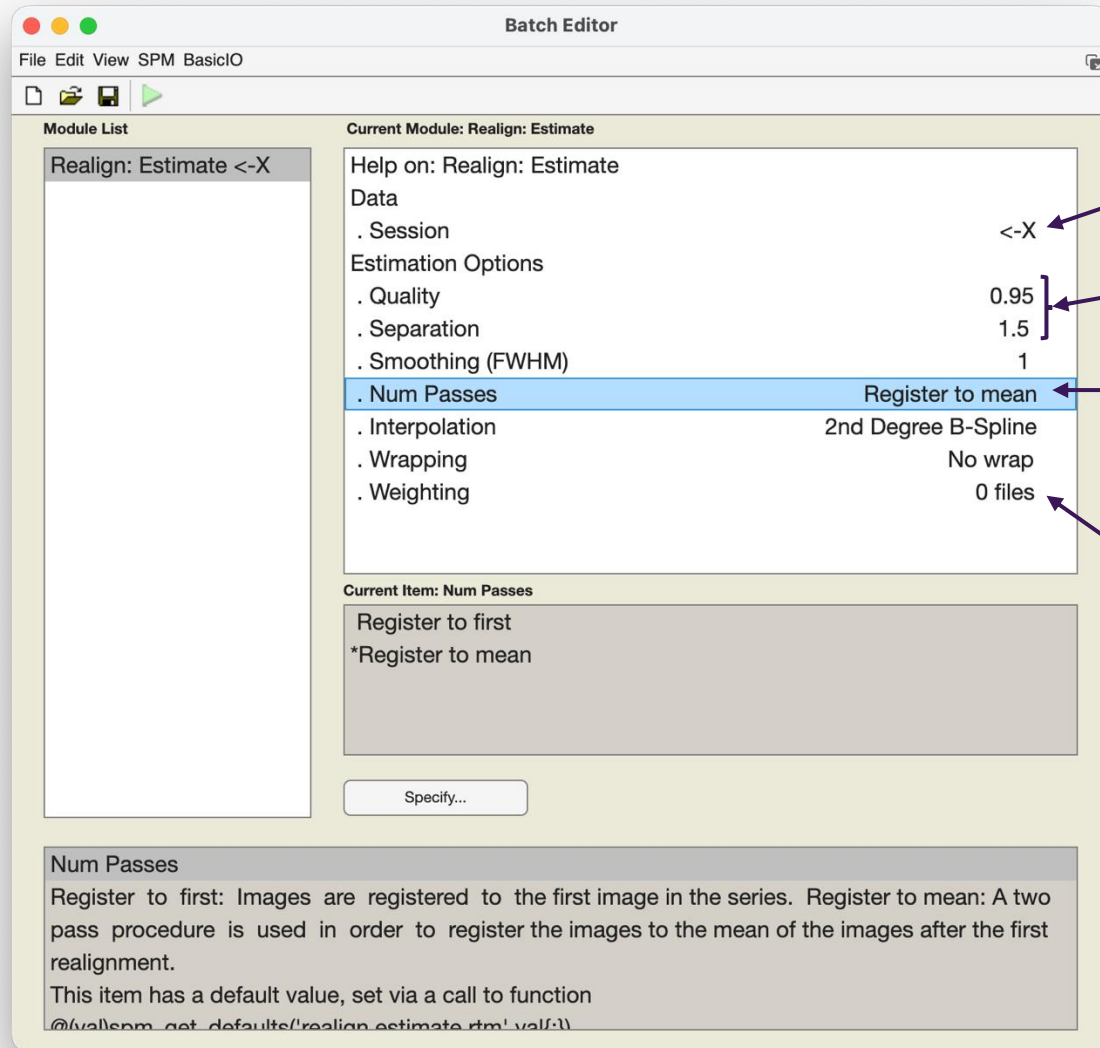
Moving



Difference



SPM → Spatial → Realign: Estimate



sub-01_bold.nii

Speed vs accuracy trade-off

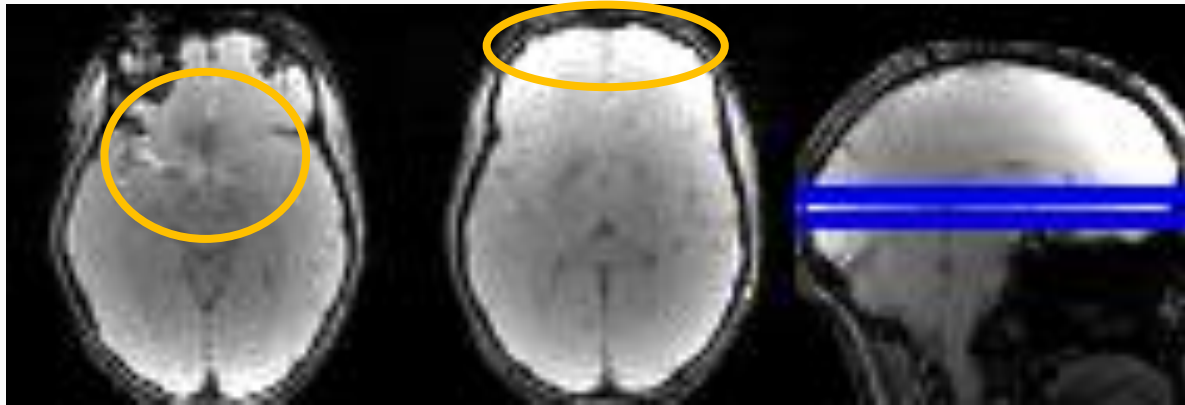
Do not register to an arbitrary frame

Provide a weight or mask
(e.g. lesion mask)

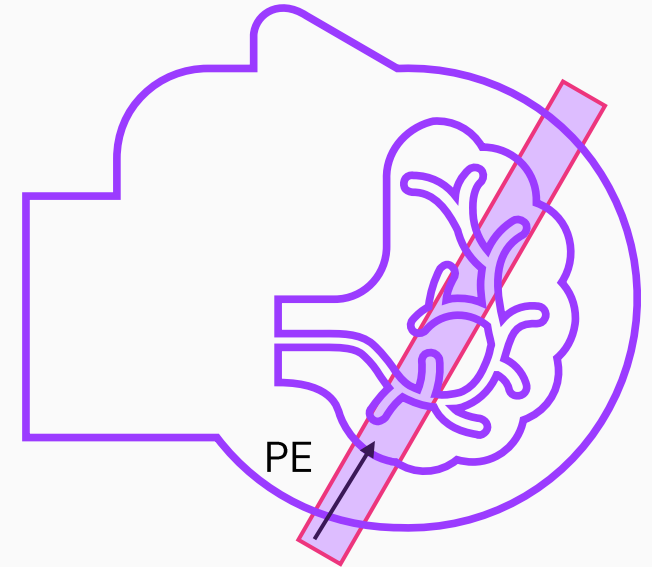
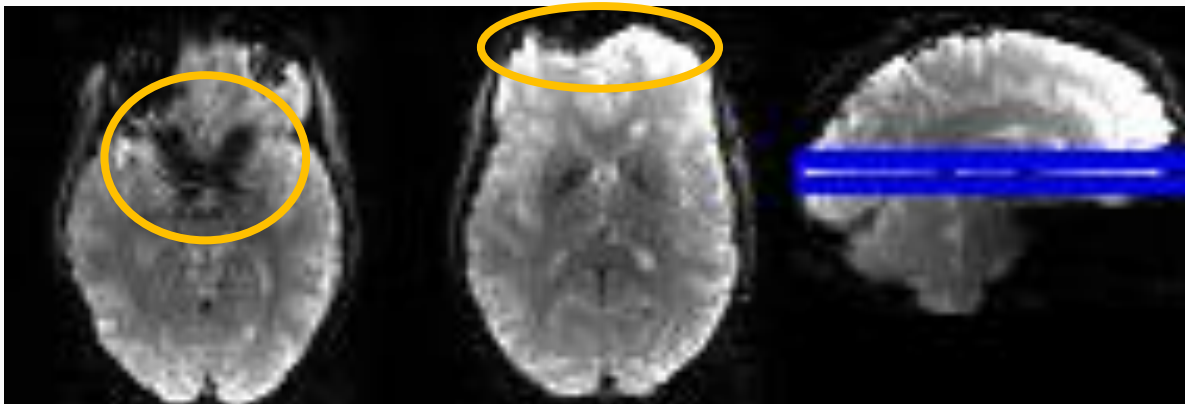


Distortions

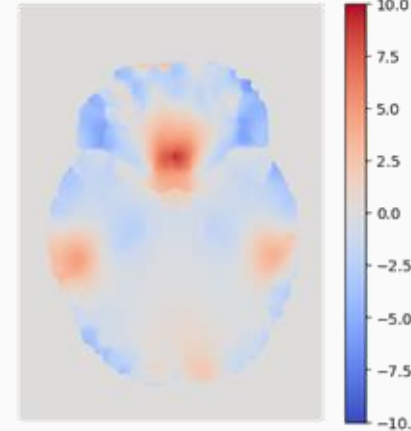
Multi-shot Gradient echo (slice in 2.4s)



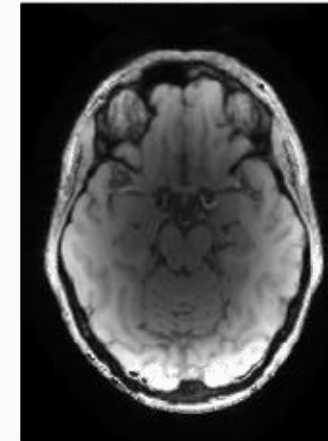
Single Shot EPI (slice in 60 ms)



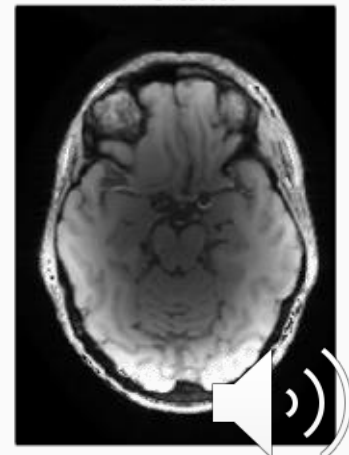
Voxel displacement map (voxels)



A>>P Readout

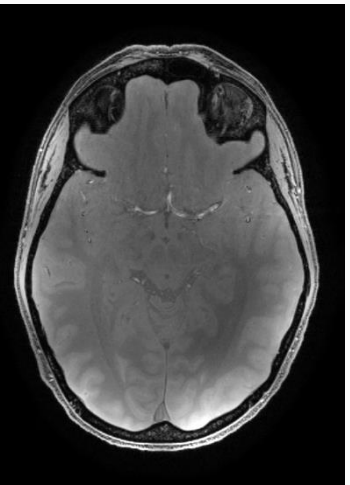


R>>L Readout

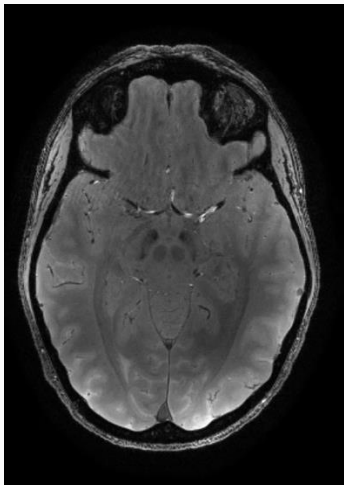


Distortions → Field map

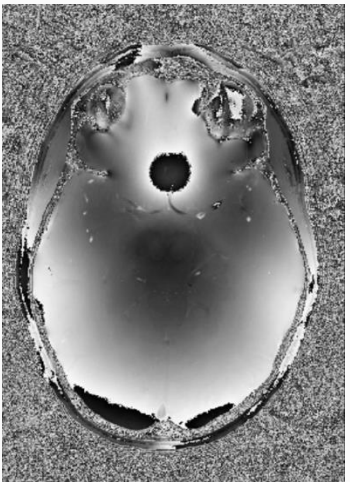
$|f_1|$



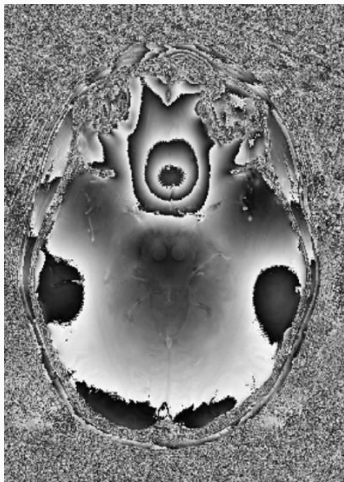
$|f_2|$



ψ_1



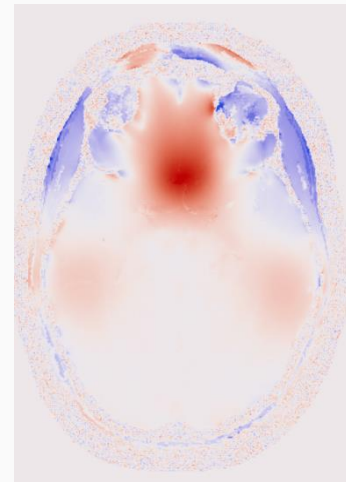
ψ_2



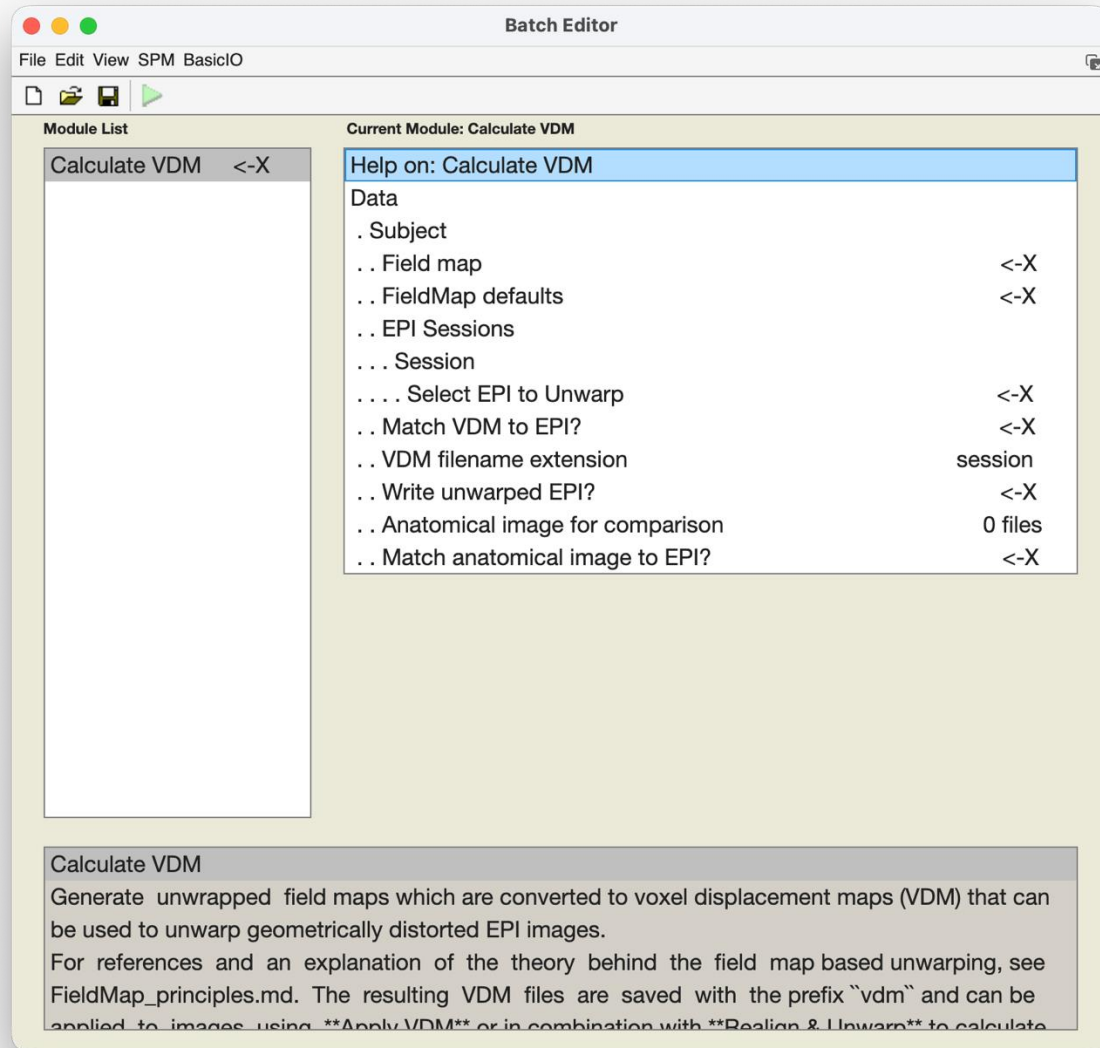
- Acquire Gradient Echo images at 2 different echo times
- Take the difference of the phases
- Convert Radians to Hertz

$$\frac{\psi_2 - \psi_1}{2\pi(\text{TE}_2 - \text{TE}_1)}$$

φ



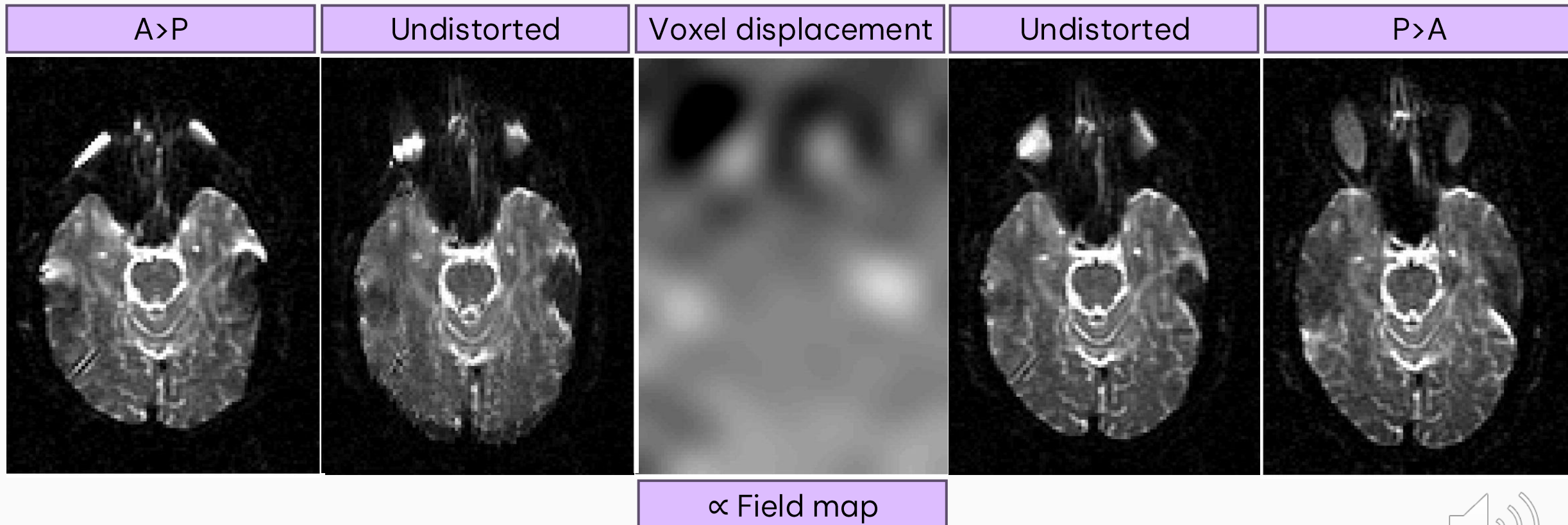
SPM → Tools → FieldMap → Calculate VDM



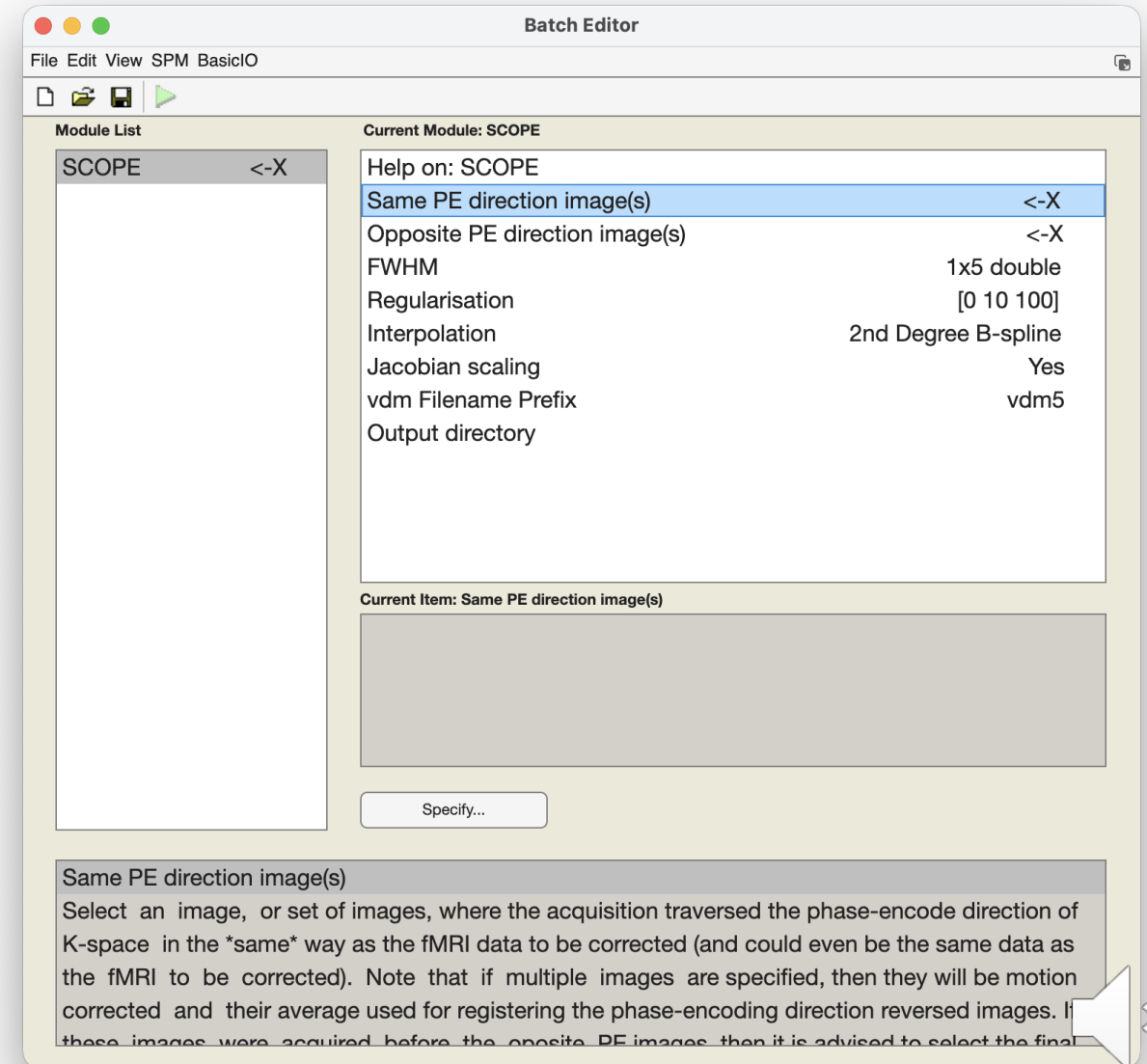
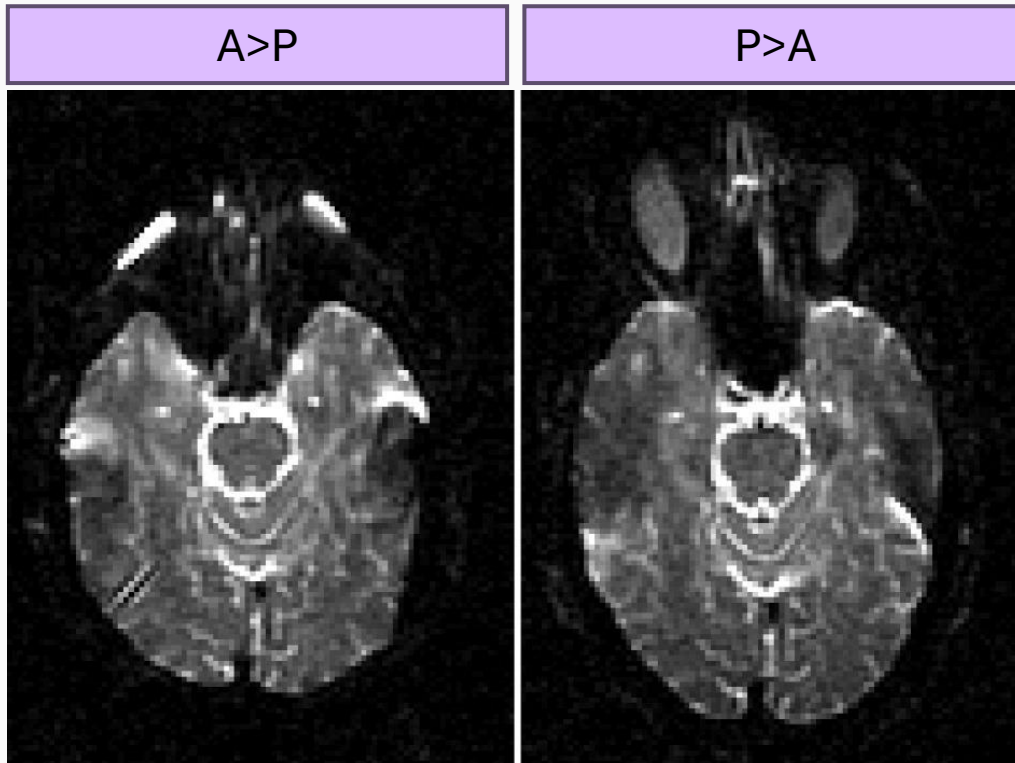
Distortions → Reverse polarity

Voxel displacement = Field (Hz) x Total Readout Time (s) x Phase Encoding direction

=> Voxel displacement (A>P) = - Voxel displacement (P>A)



SPM → Tools → Spatial Tools → SCOPE



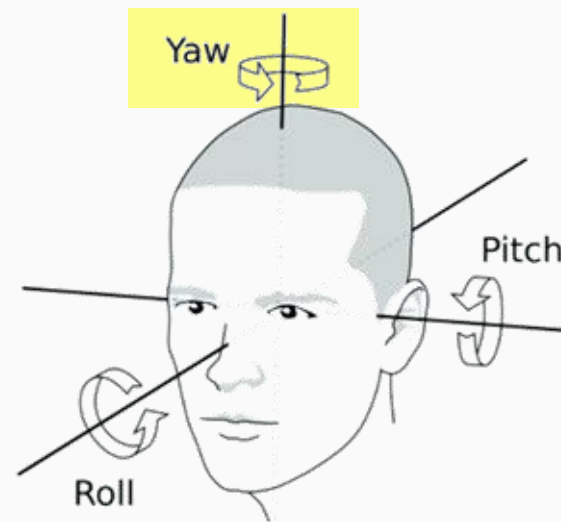
Distortions → Unwarp

-10 deg

Rotation

+10 deg

$$\varphi_{\theta} - \varphi_0$$



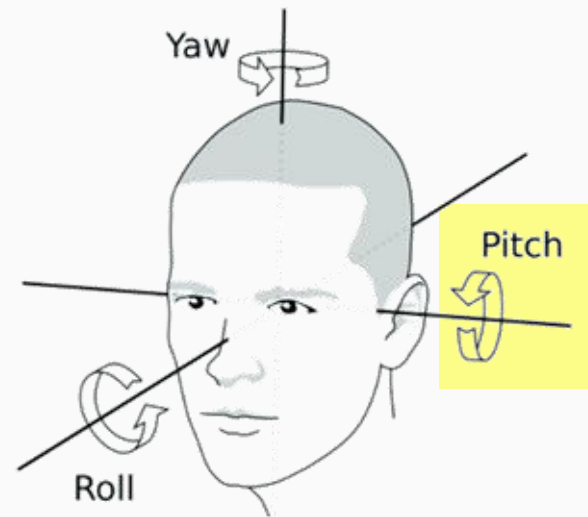
Distortions → Unwarp

-10 deg

Rotation

+10 deg

$\varphi_\theta - \varphi_0$



Distortions → Unwarp

-10 deg

Rotation

+10 deg

$\varphi_{\theta} - \varphi_0$



- ❑ First, realign the time series

→ One set of rotation parameters per frame: $\{\theta_t, \alpha_t\}$

- ❑ First-order Taylor expansion:

$$\varphi_{\theta, \alpha}(\mathbf{x}) = \varphi_0(\mathbf{x}) + \theta \cdot \dot{\varphi}_{\theta}(\mathbf{x}) + \alpha \cdot \dot{\varphi}_{\alpha}(\mathbf{x})$$

- ❑ Corresponds to a General Linear Model with design matrix $[\theta, \alpha]$ and coefficients $[\dot{\varphi}_{\theta}, \dot{\varphi}_{\alpha}]$

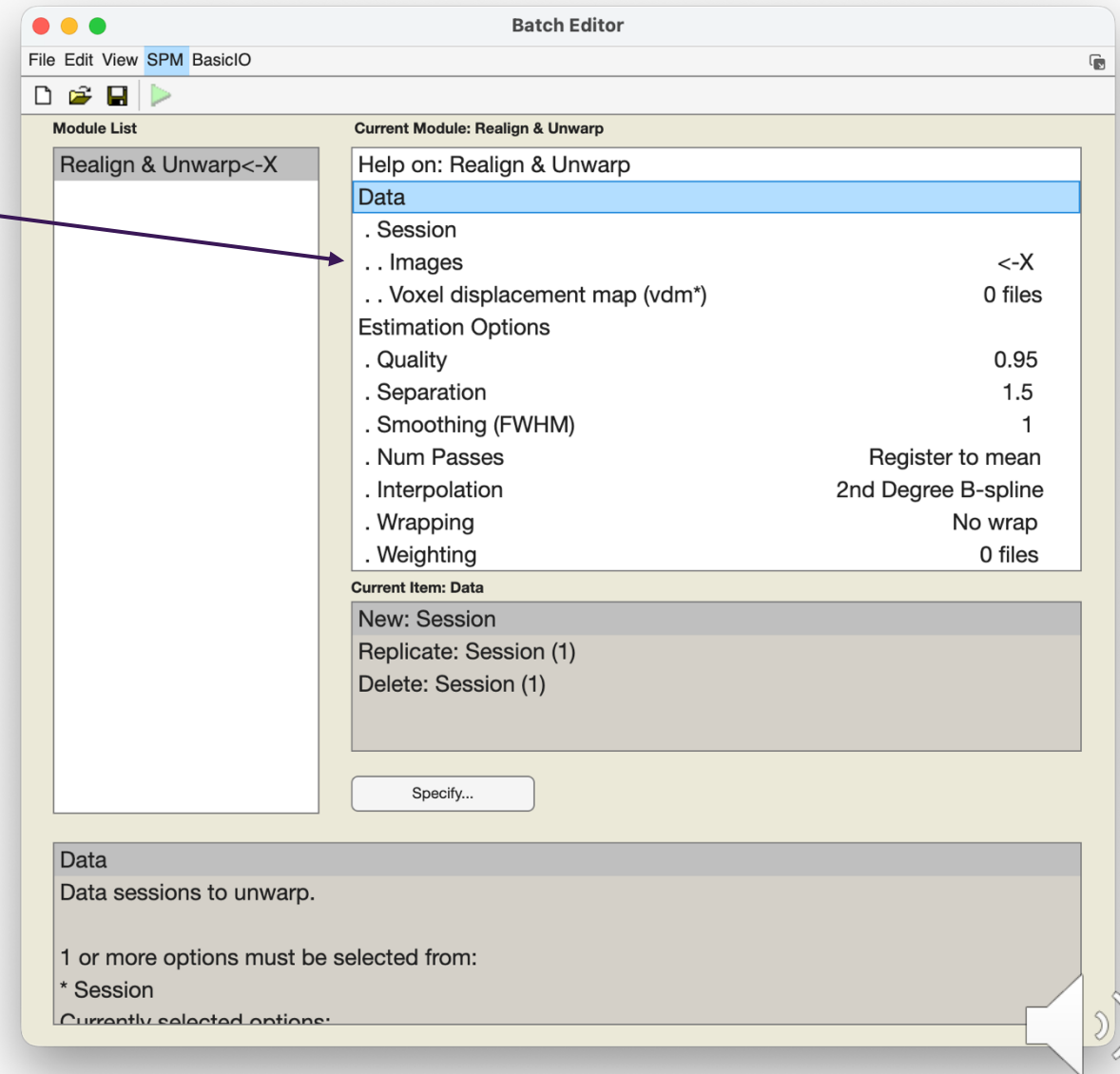
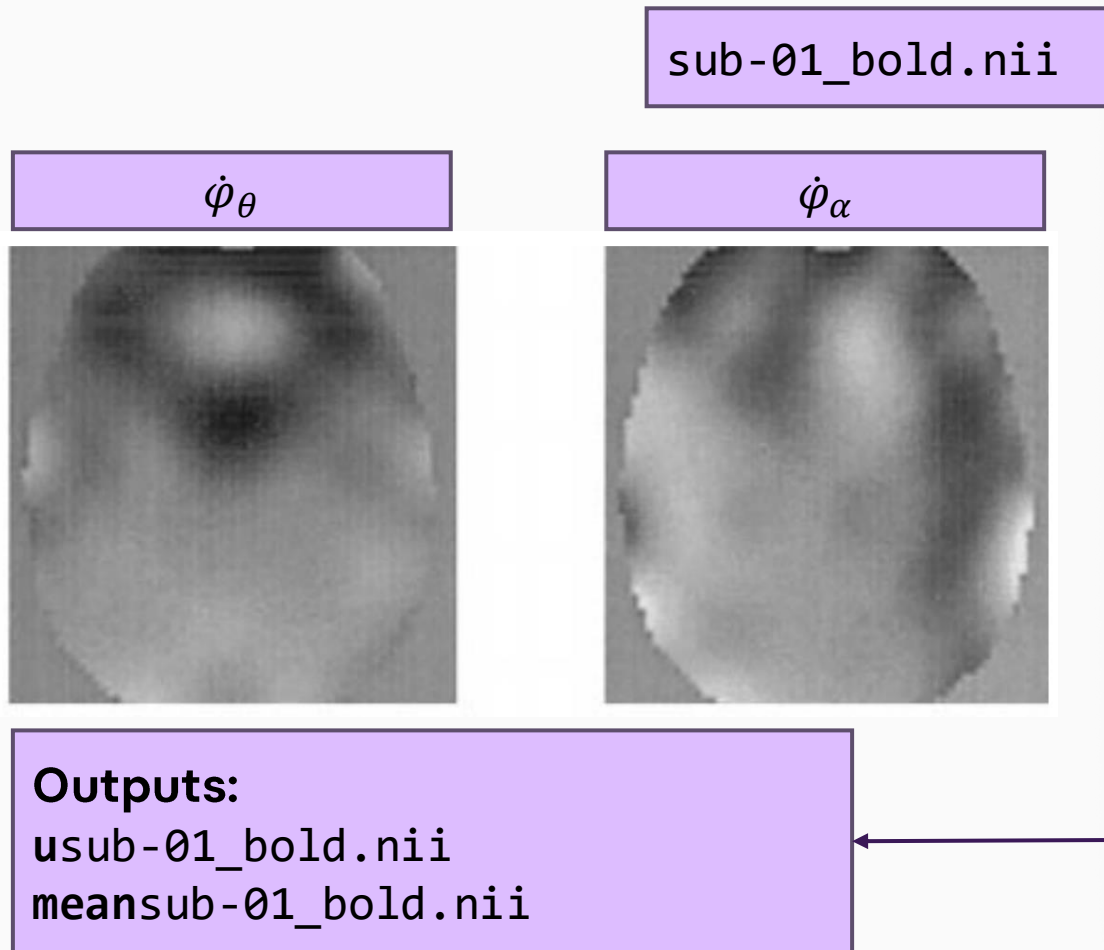
- ❑ Plug it into the deformation model:

$$f_t(\mathbf{x}) = f(\varphi_{\theta_t, \alpha_t}(\mathbf{x}) \cdot \mathbf{n}_{\theta_t, \alpha_t})$$

- ❑ Optimise for the undistorted mean image f and the coefficients $[\dot{\varphi}_{\theta}, \dot{\varphi}_{\alpha}]$

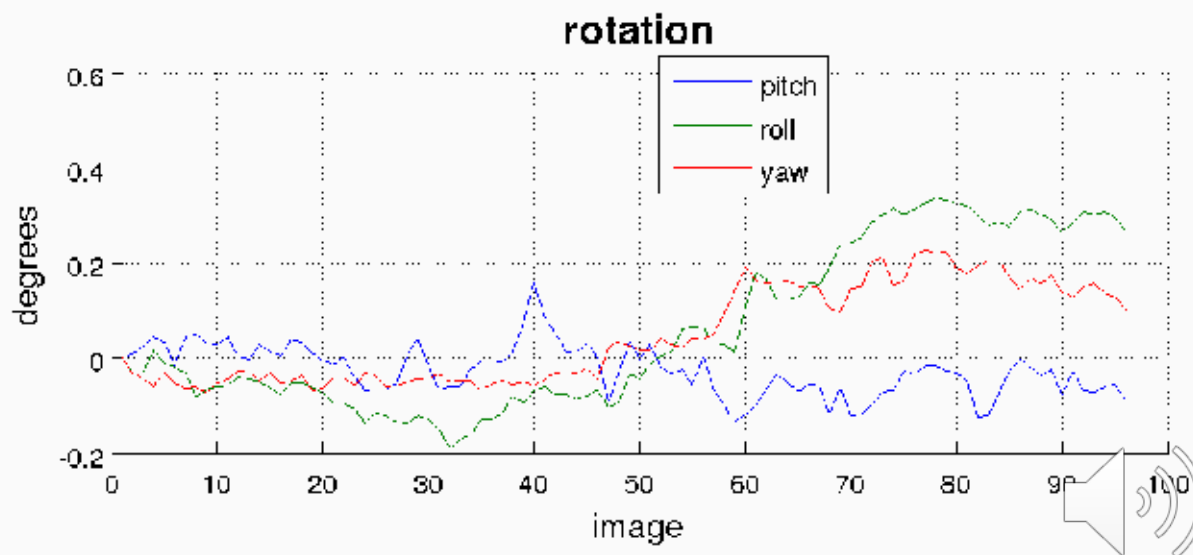


SPM → Spatial → Realign & Unwarp



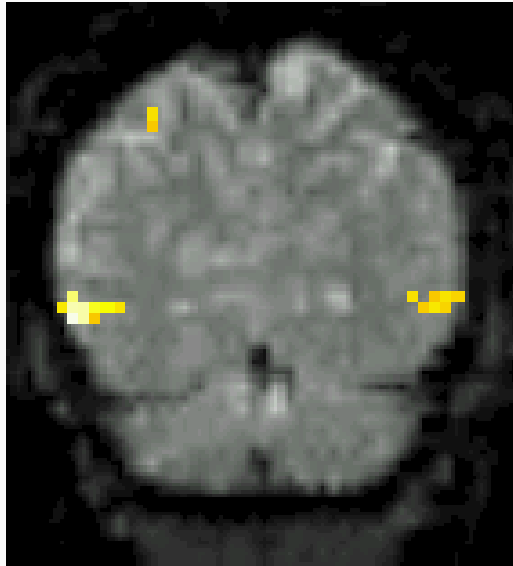
Motion-related residual errors

- ❑ Interpolation artefacts due to reslicing.
 - ❑ Within volume motion.
 - ❑ Spin history effects.
 - ❑ Residual distortions.
- Use motion parameters as regressors

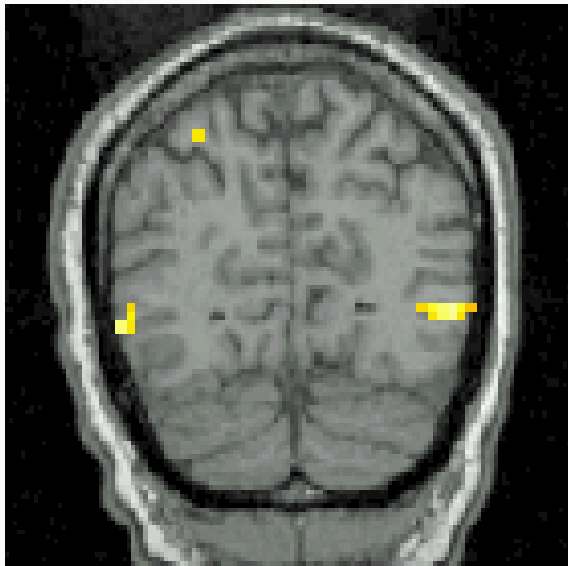


Co-registration

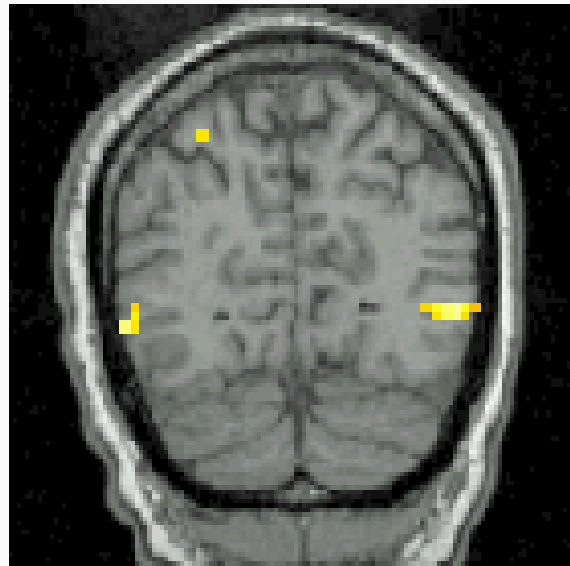
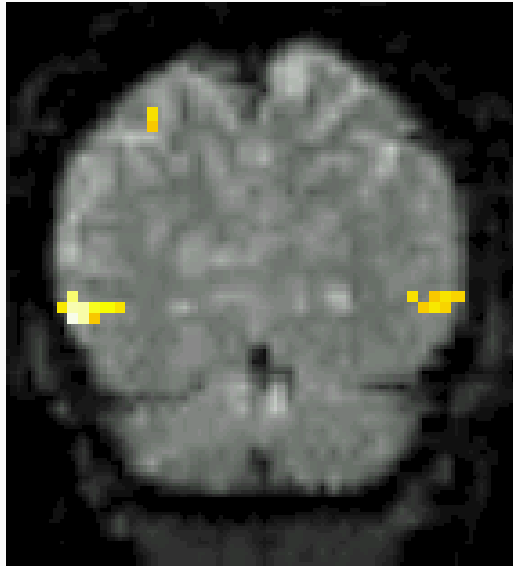
Coregistration



- ❑ Anatomical localisation of single-subject activations.
- ❑ More precise spatial normalisation.
- ❑ Cross-modality alignment.
 - Same subject but different contrast

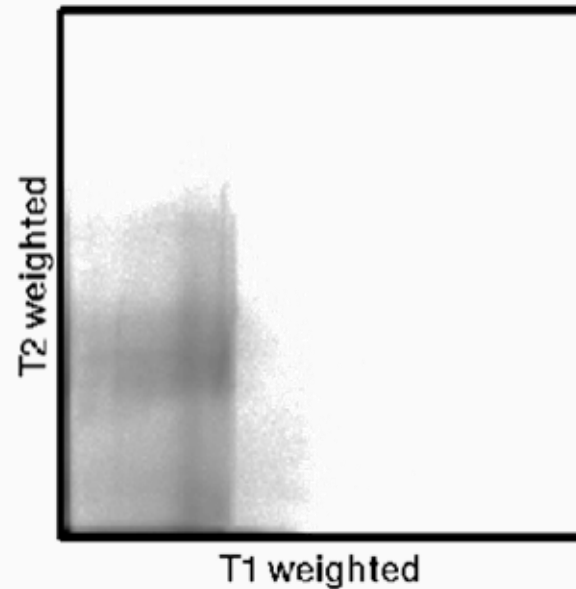


Mutual Information

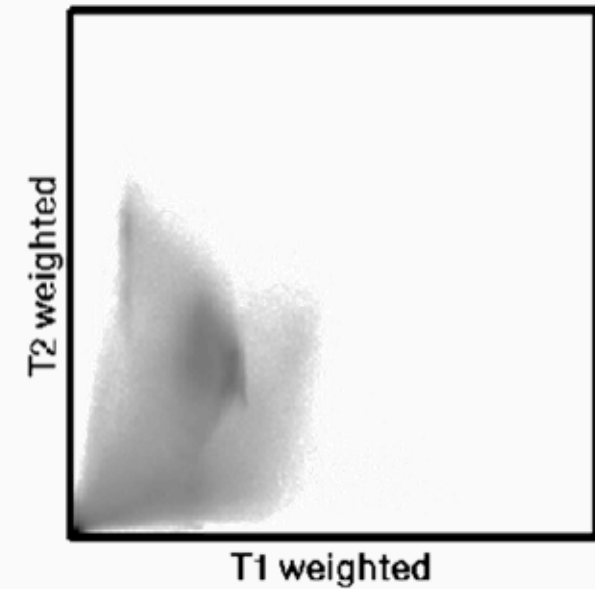


- ☐ Alignment metric
= how easy is it to predict the intensity of an image if I know the intensity in the other image?
- ☐ Related to the dispersion of the joint histogram.

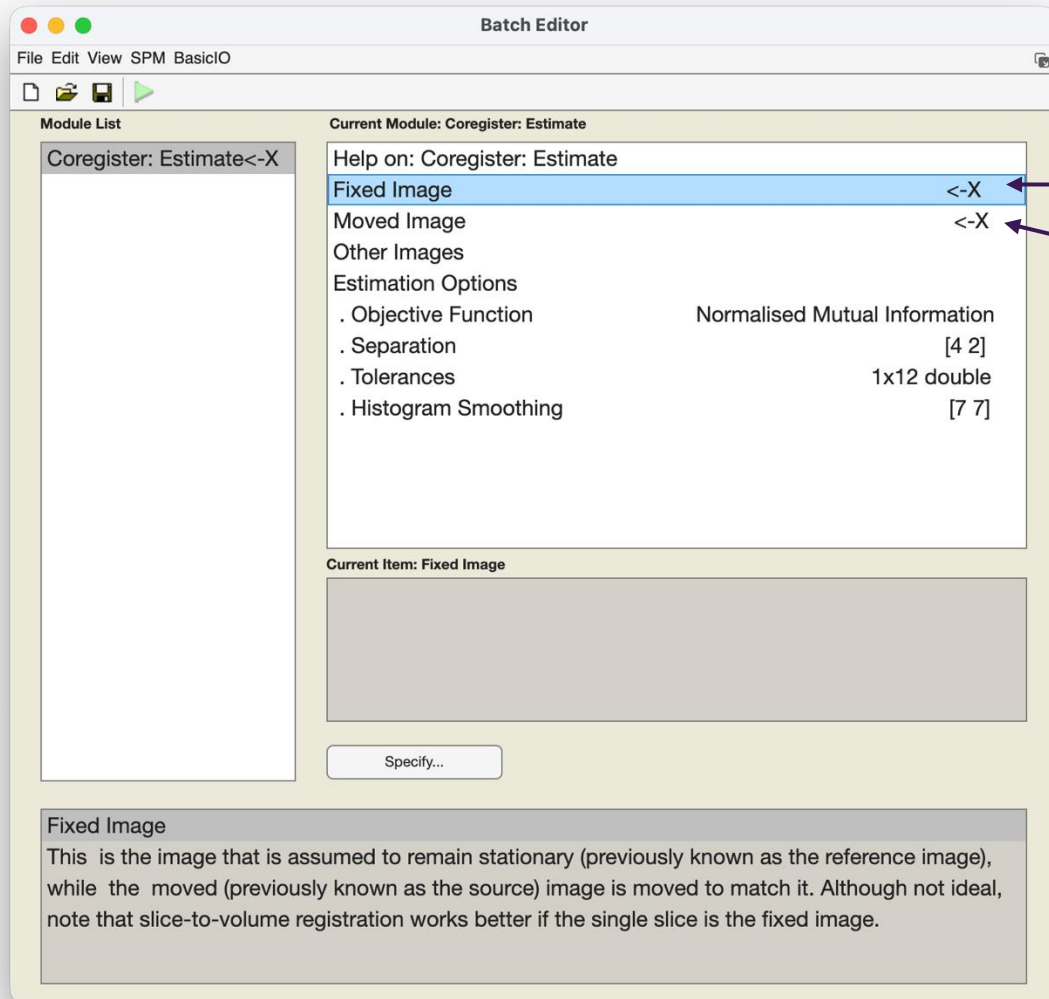
Unaligned



Aligned



SPM → Spatial → Coregister: Estimate

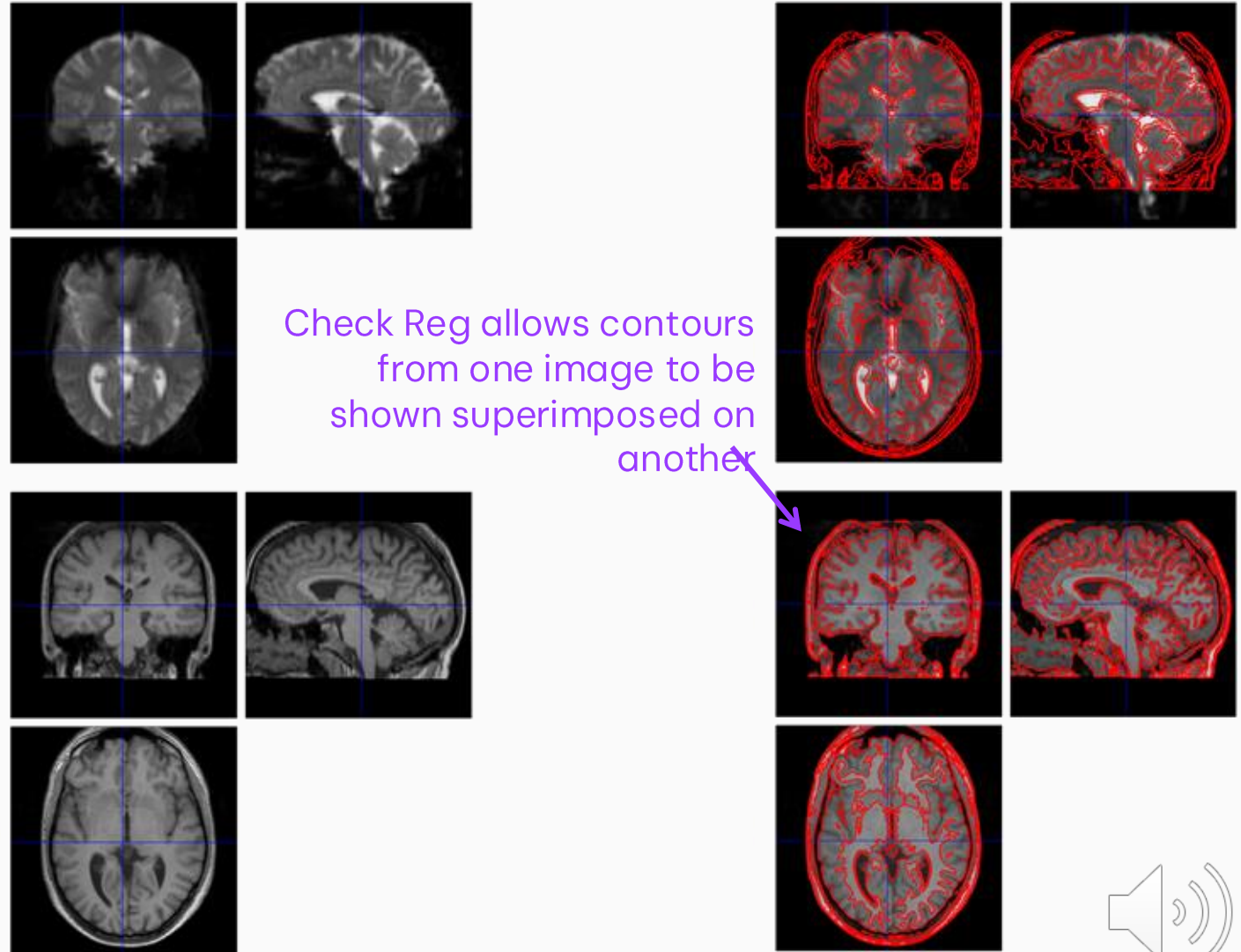
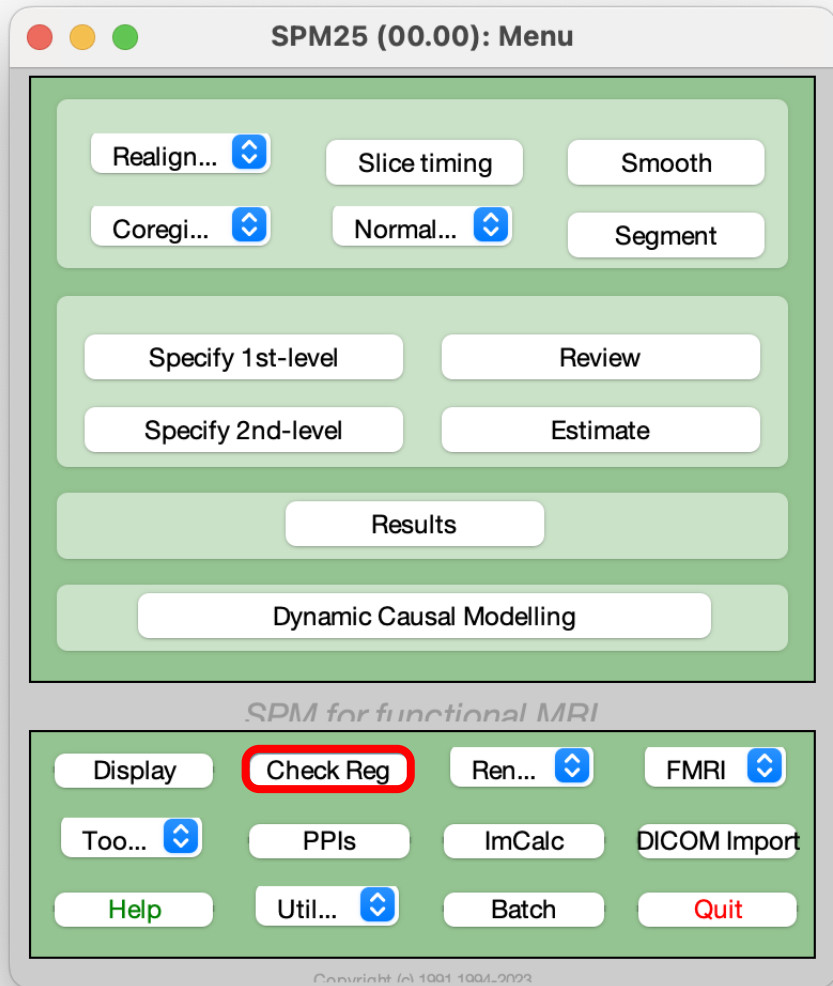


meansub-01_bold.nii

sub-01_T1w.nii



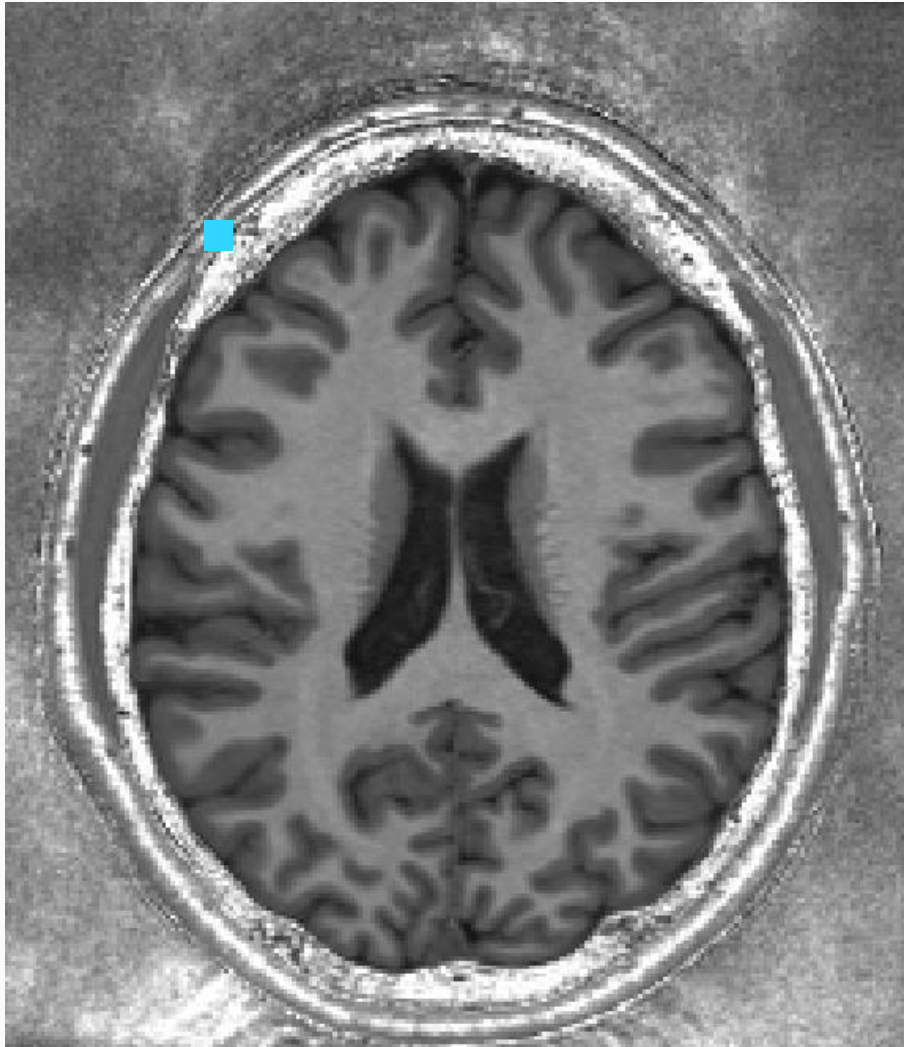
Check Reg



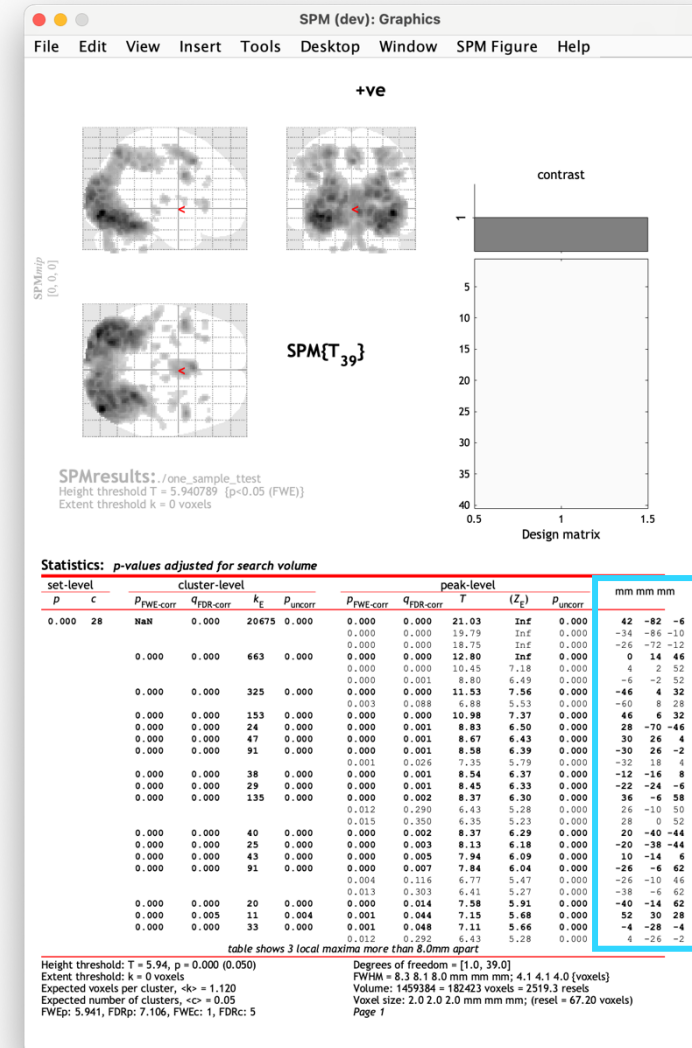
Spatial normalisation

Why do we need normalisation?

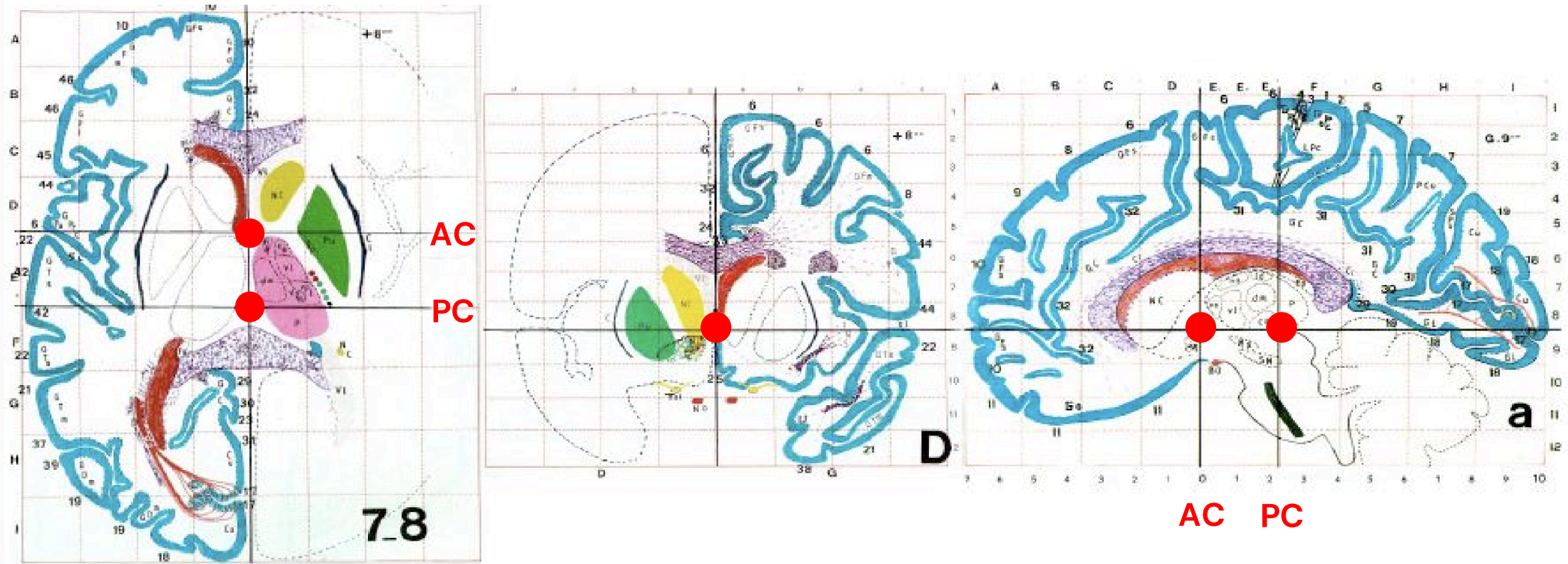
Group analysis



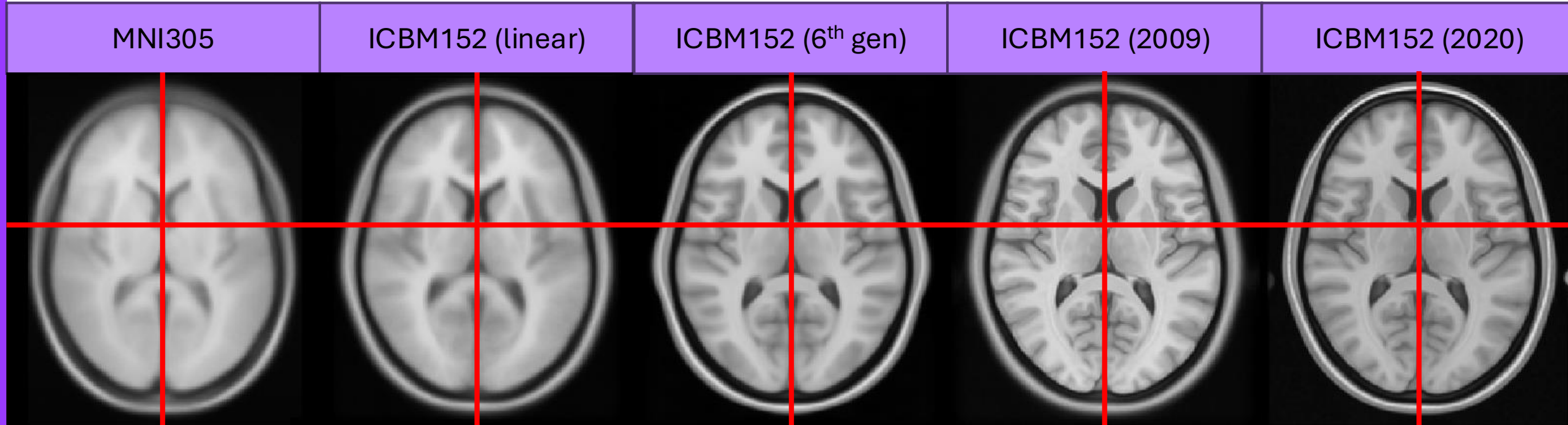
Standardised reporting



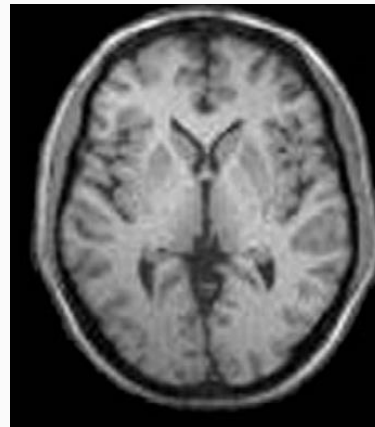
Talairach



MNI



Almost all software packages “normalise” by computing a nonlinear transformation between a T1w scan and the T1w ICBM152 template, using some similarity metric (CC, MI).

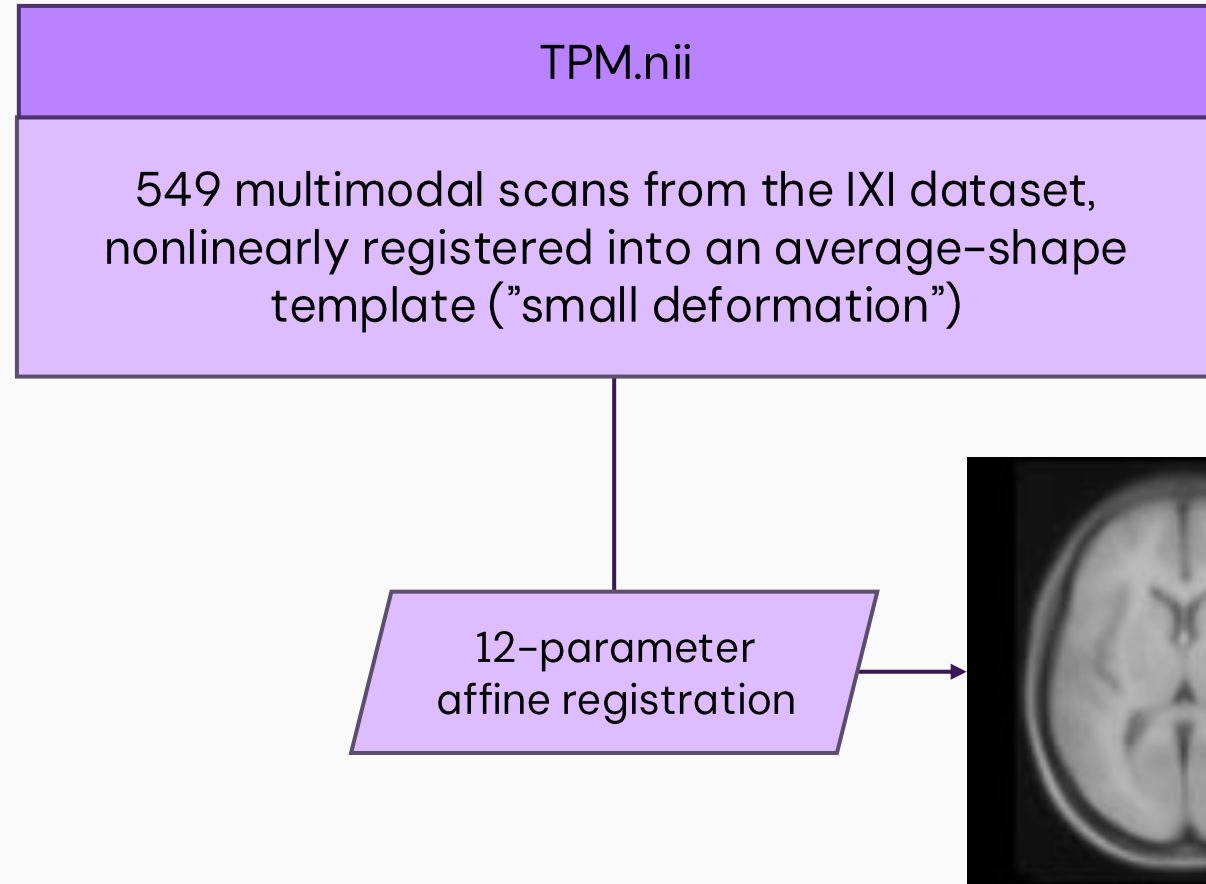
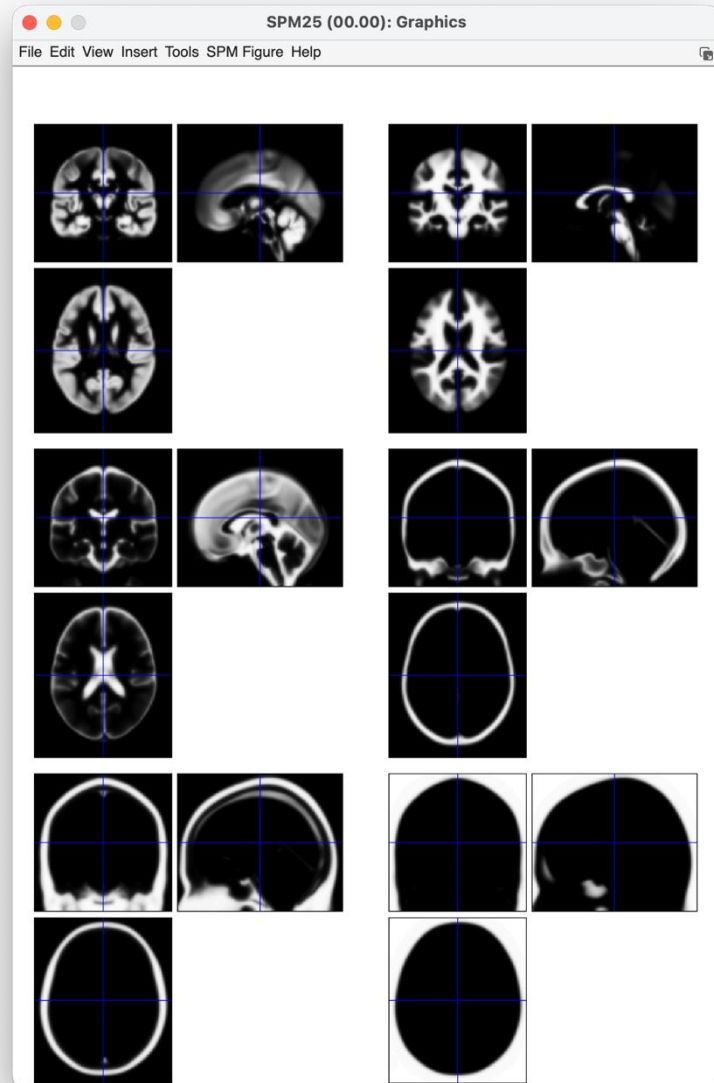


Nonlinear registration

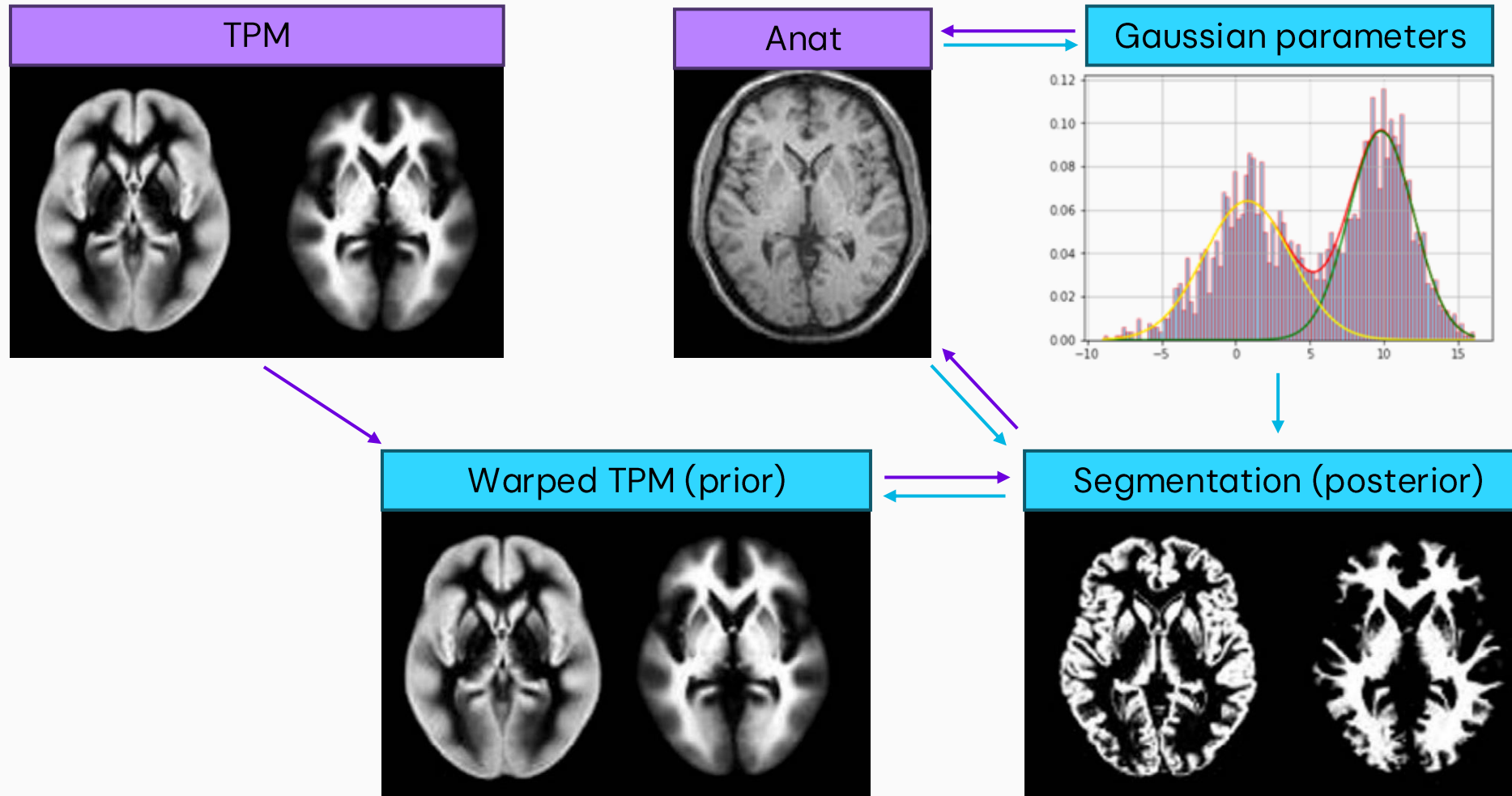
- **fmriPrep**: ANTs SyN
- **FSL**: FNIRT
- **AFNI**: @auto_tlrc



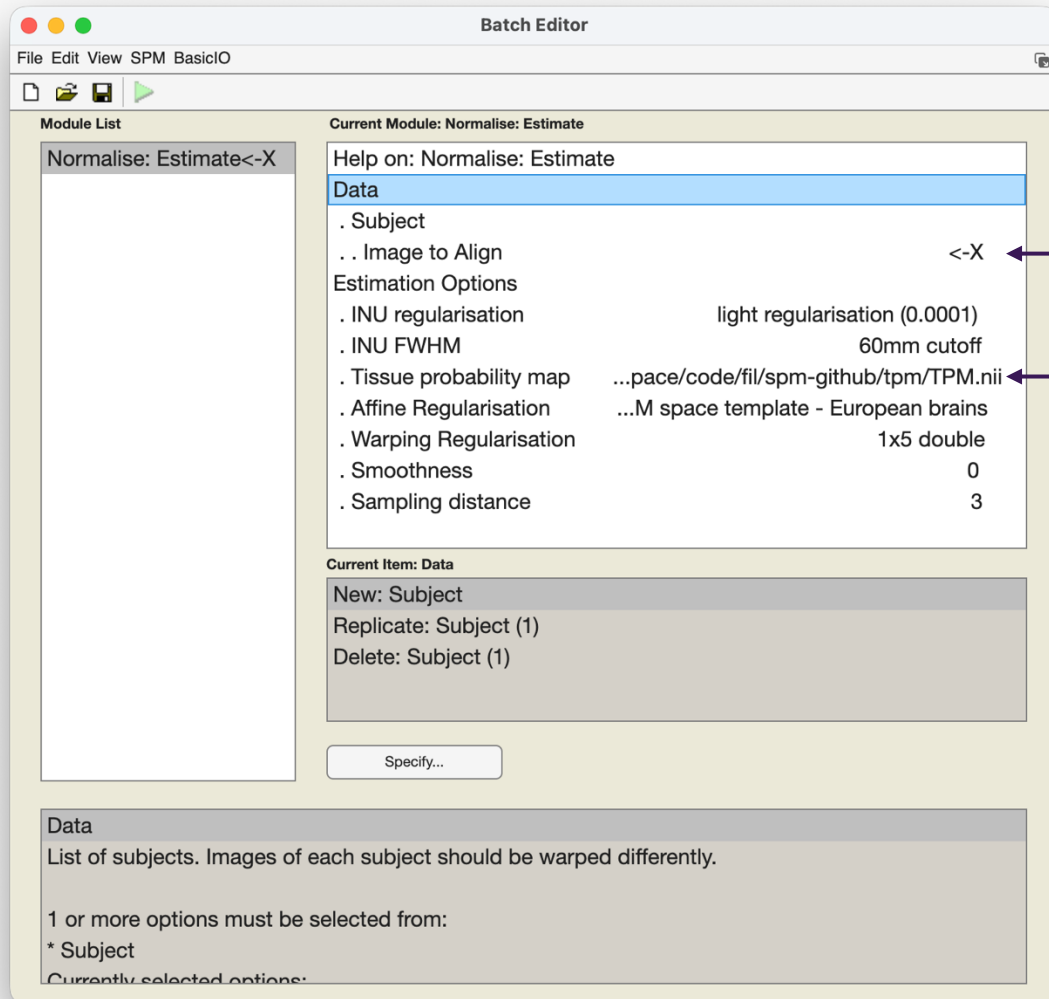
SPM's Tissue Probability Map (TPM)



Normalise → Segment



SPM → Spatial → Normalise: Estimate



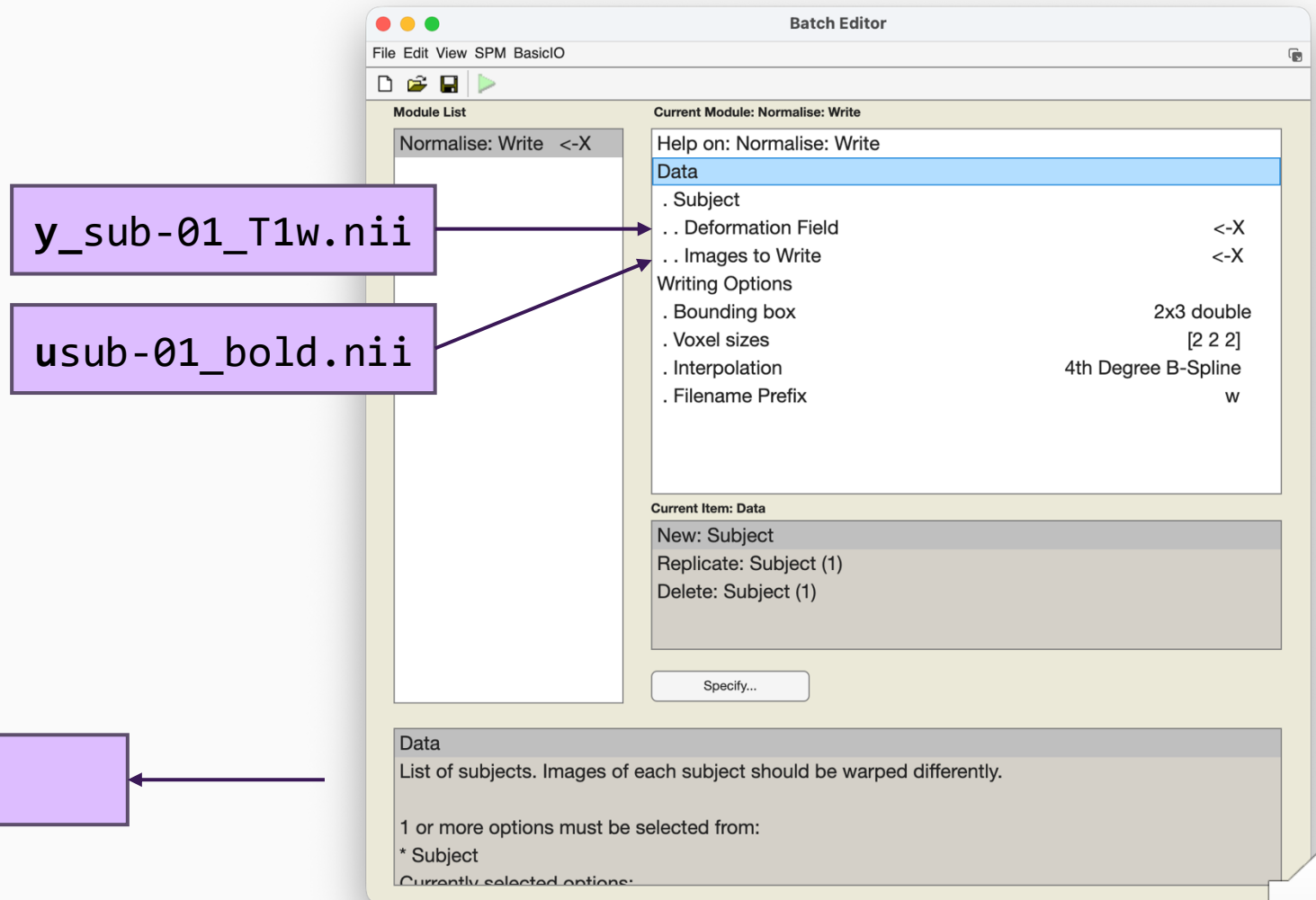
sub-01_T1w.nii

TPM.nii

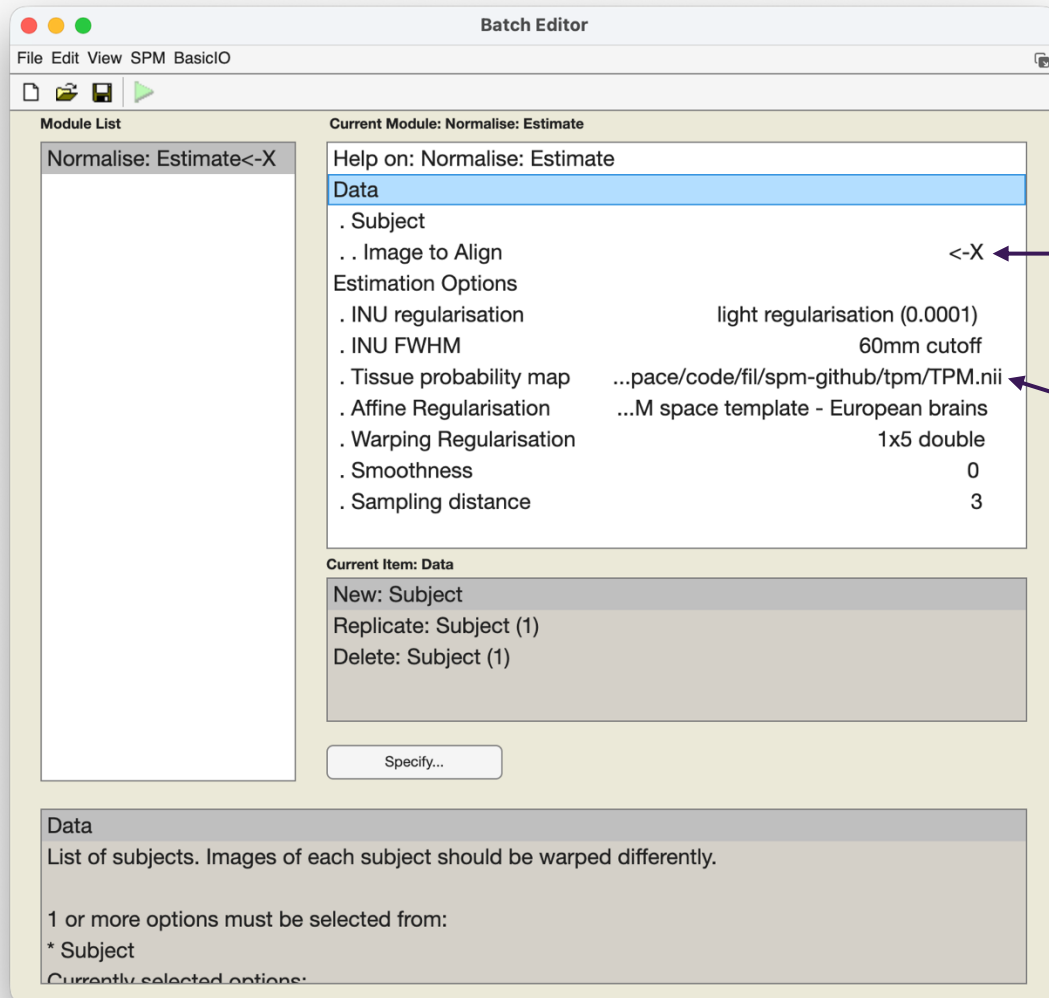
Output: y_sub-01_T1w.nii



SPM → Spatial → Normalise: Write

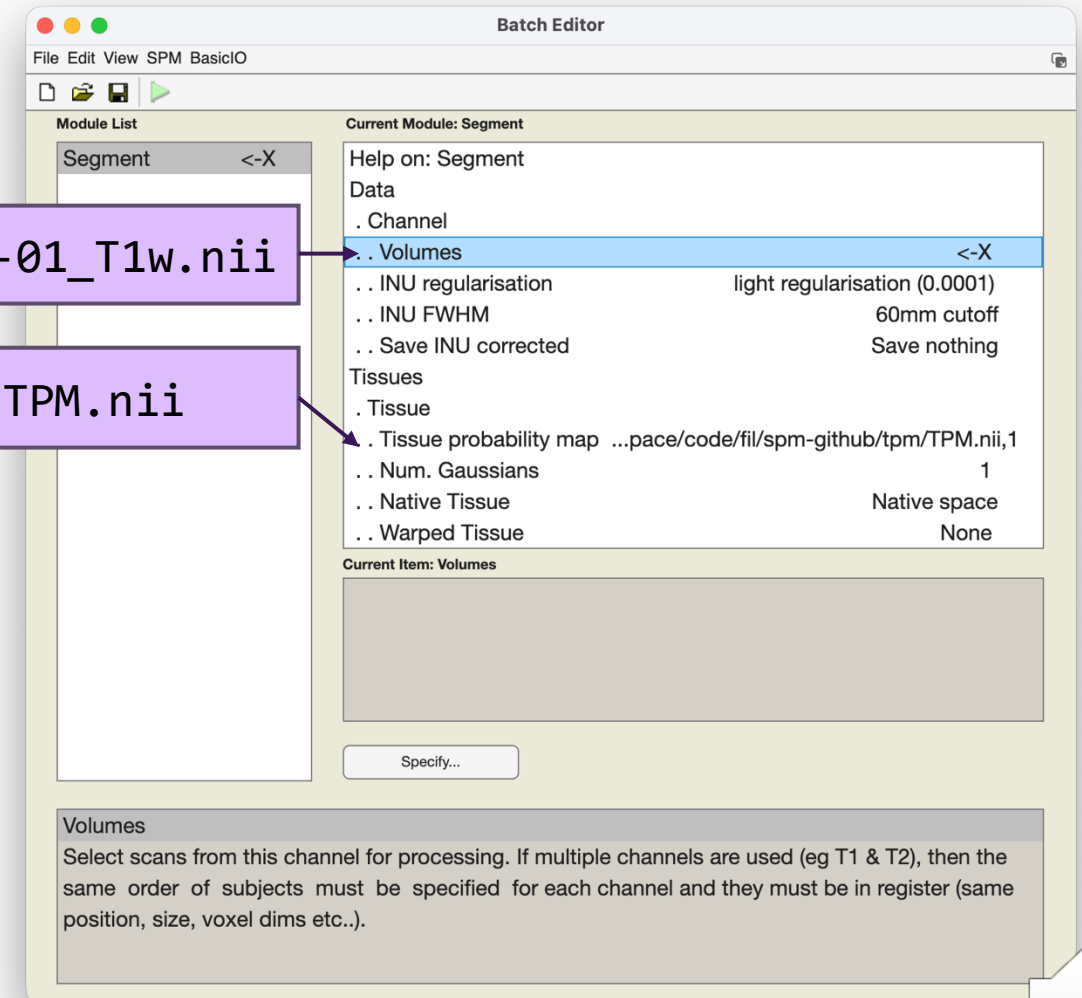


SPM → Spatial → Segment

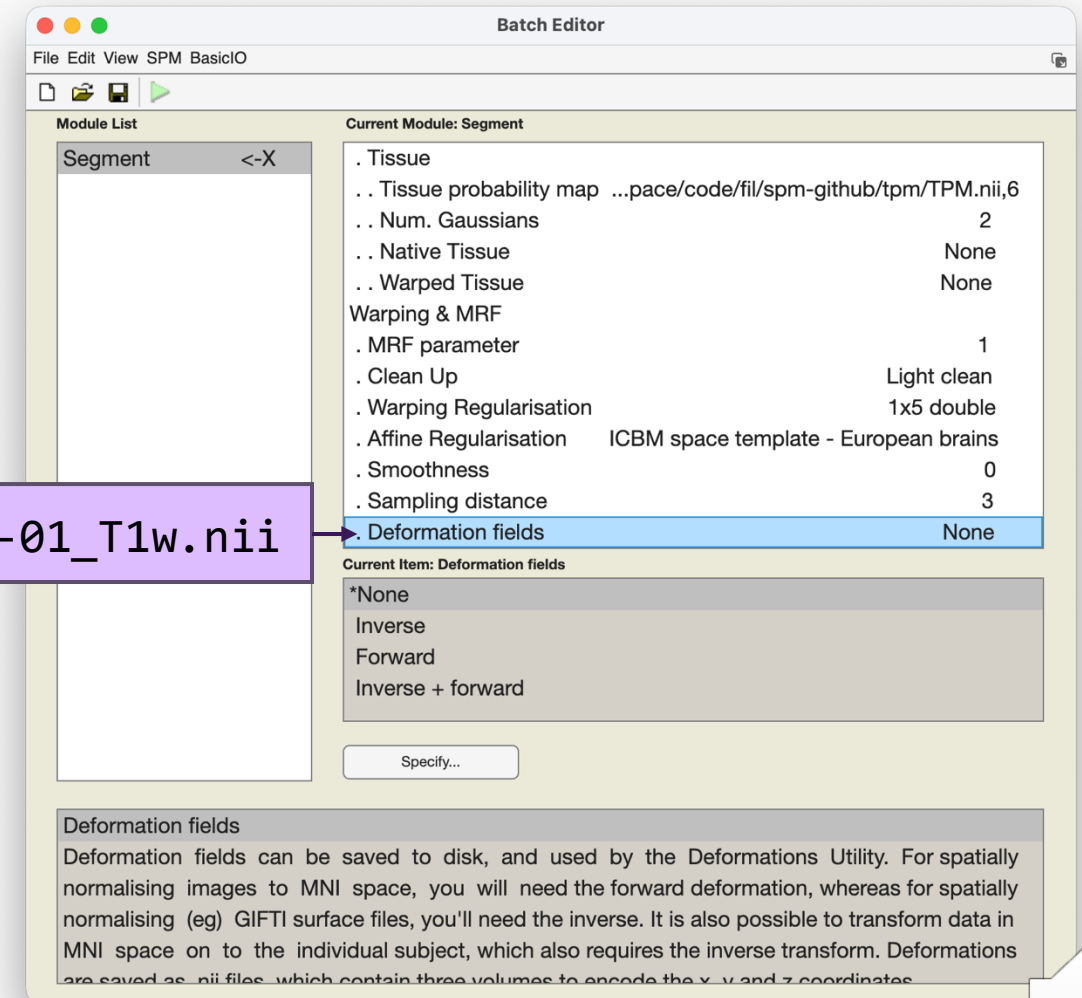
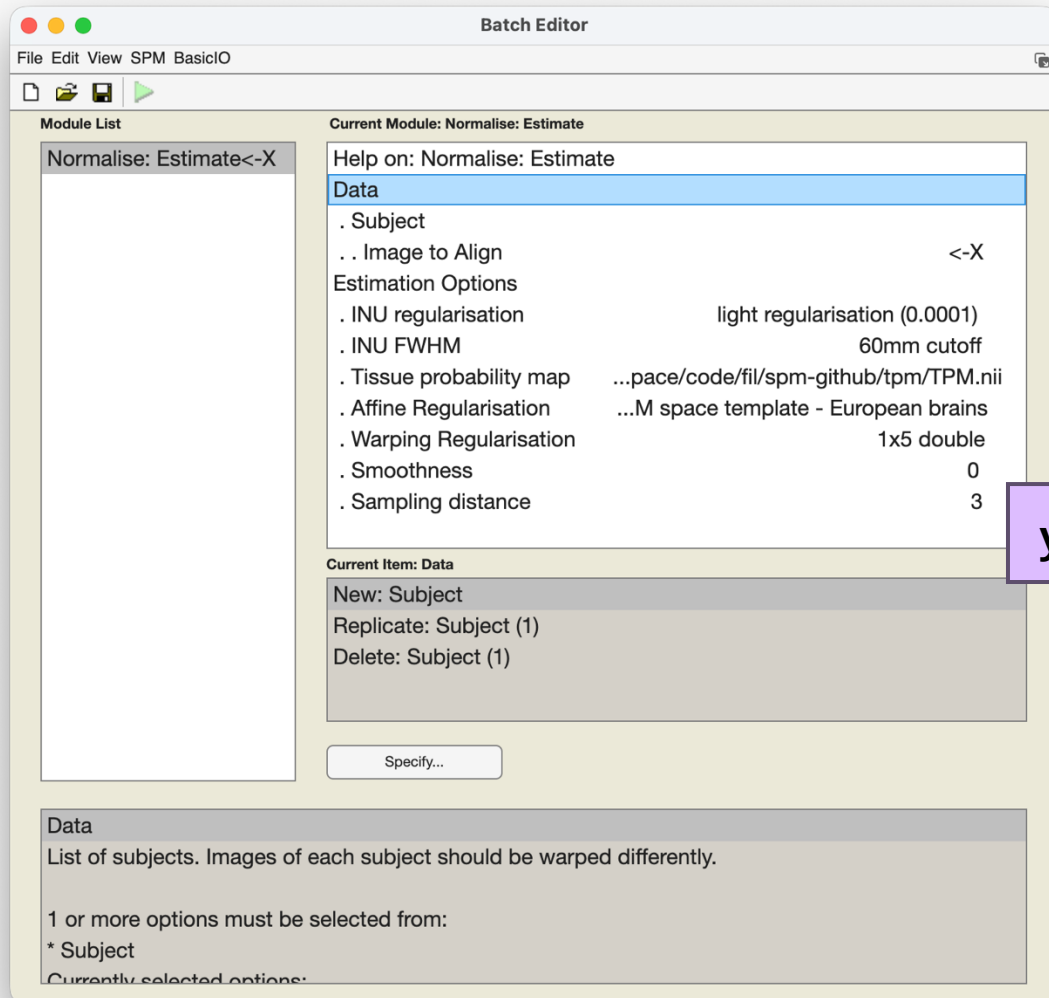


sub-01_T1w.nii

TPM.nii



SPM → Spatial → Segment

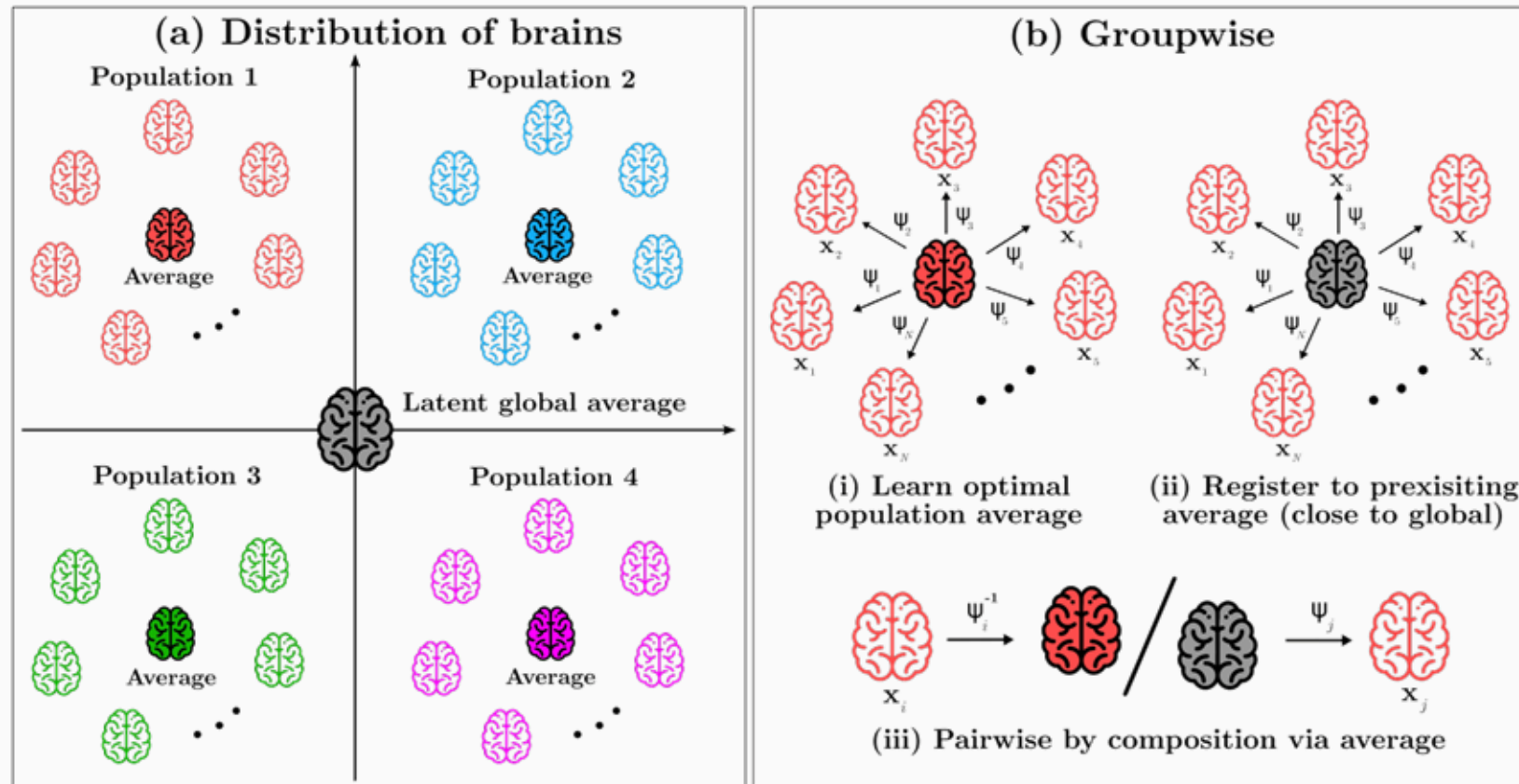


y_sub-01_T1w.nii



Study-specific template

Group space vs Standard space

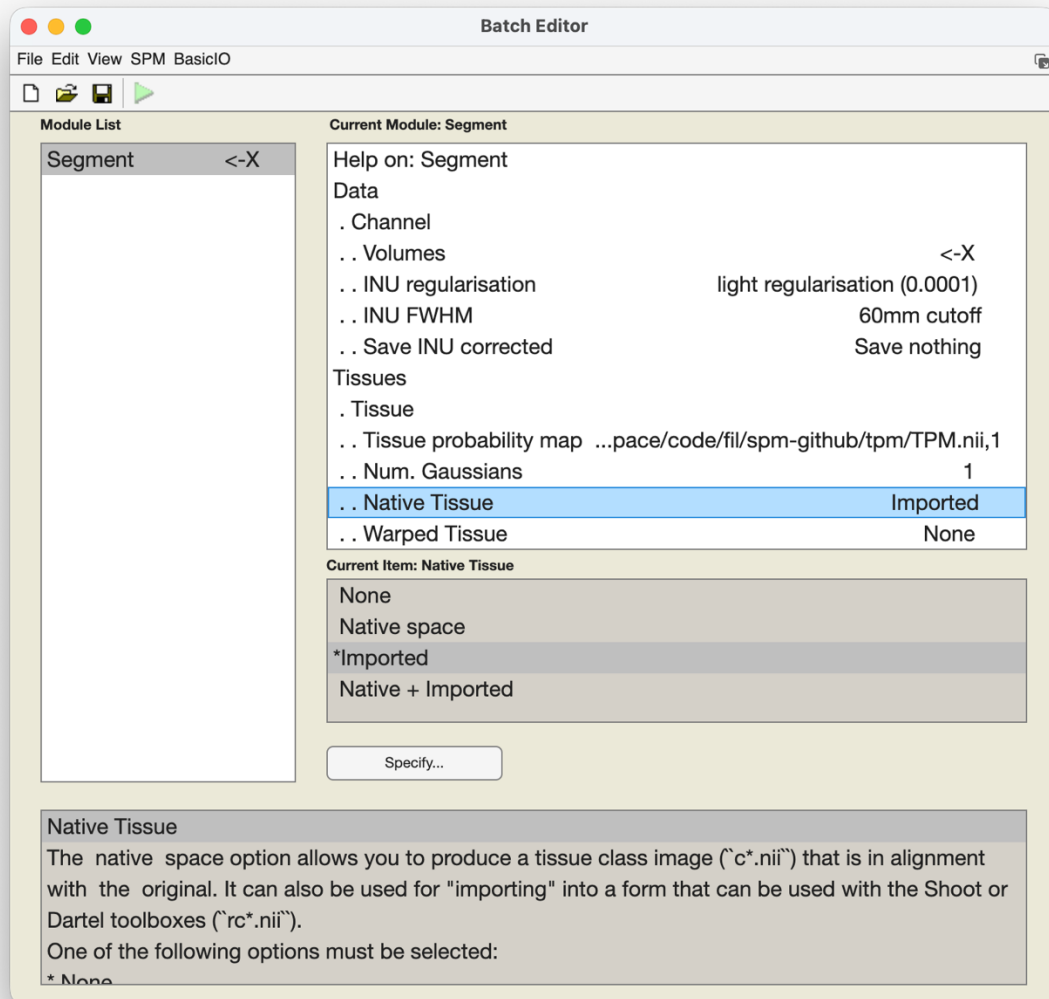


→ Shoot

- ❑ Study-specific template
- ❑ Large deformation model



'Native' vs 'Imported' files



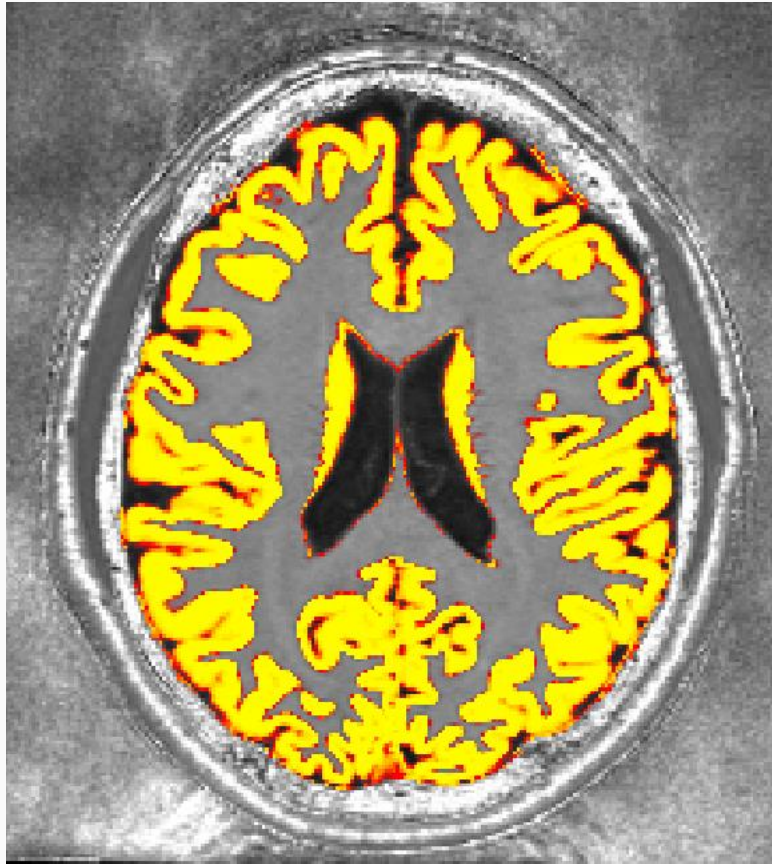
Outputs:

c1sub-01_T1w.nii
rc1sub-01_T1w.nii

= Native
= Imported



'Native' vs 'Imported' files



Native

→ Same space *and* grid as the input MRI

Imported

→ Same grid as the SPM template (1.5 mm)

→ Rigidly aligned to the SPM template

→ (Preserves a mapping to the native space)

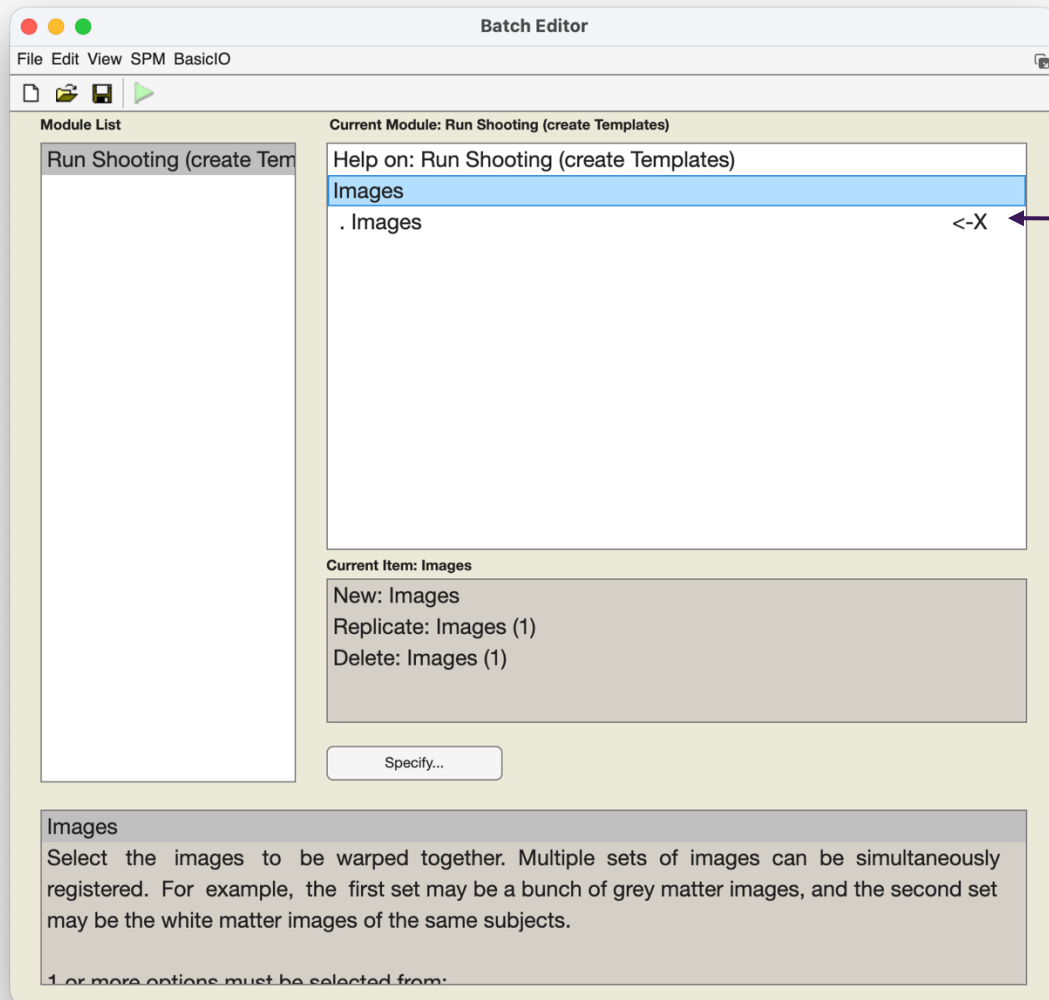
Why?

→ Computational efficiency (smaller voxel size)

→ Good starting point (rigid-aligned to the same space)



SPM → Tools → Shoot Tools → Create Template



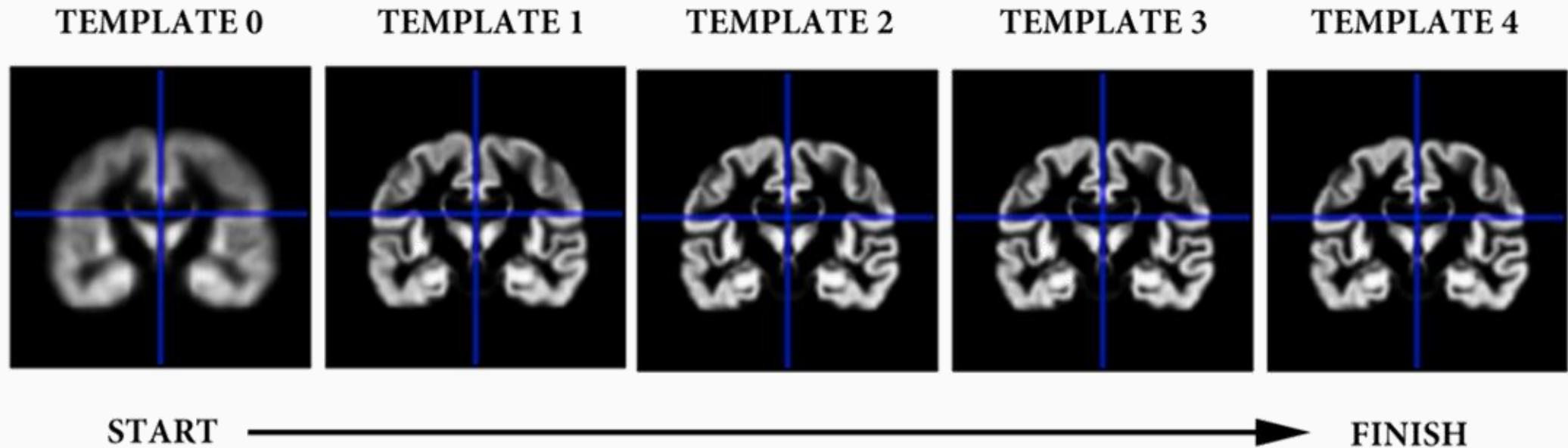
rc1sub-01_T1w.nii
rc2sub-01_T1w.nii

Outputs:

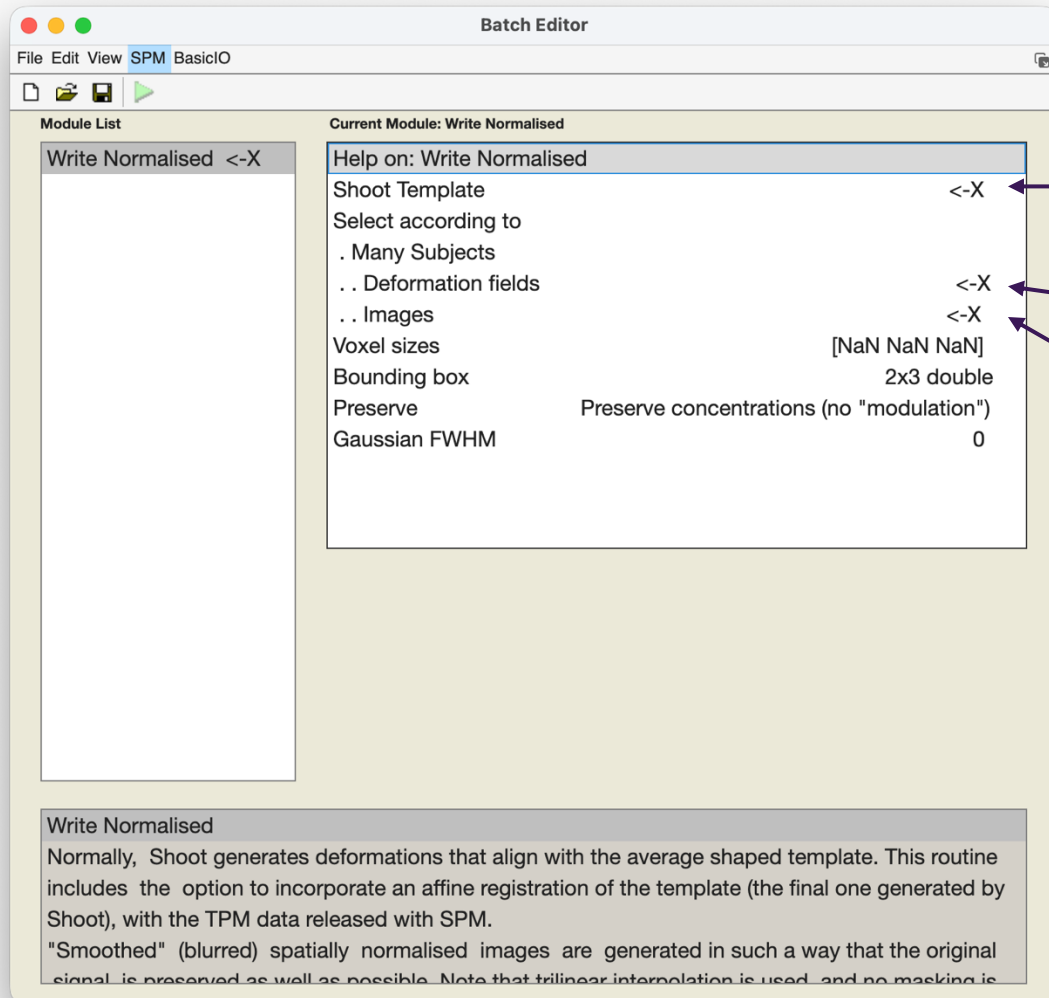
rc1sub-01_T1w_Template0.nii
rc1sub-01_T1w_Template1.nii
rc1sub-01_T1w_Template2.nii
rc1sub-01_T1w_Template3.nii



Output templates



SPM → Tools → Shoot Tools → Write Normalised



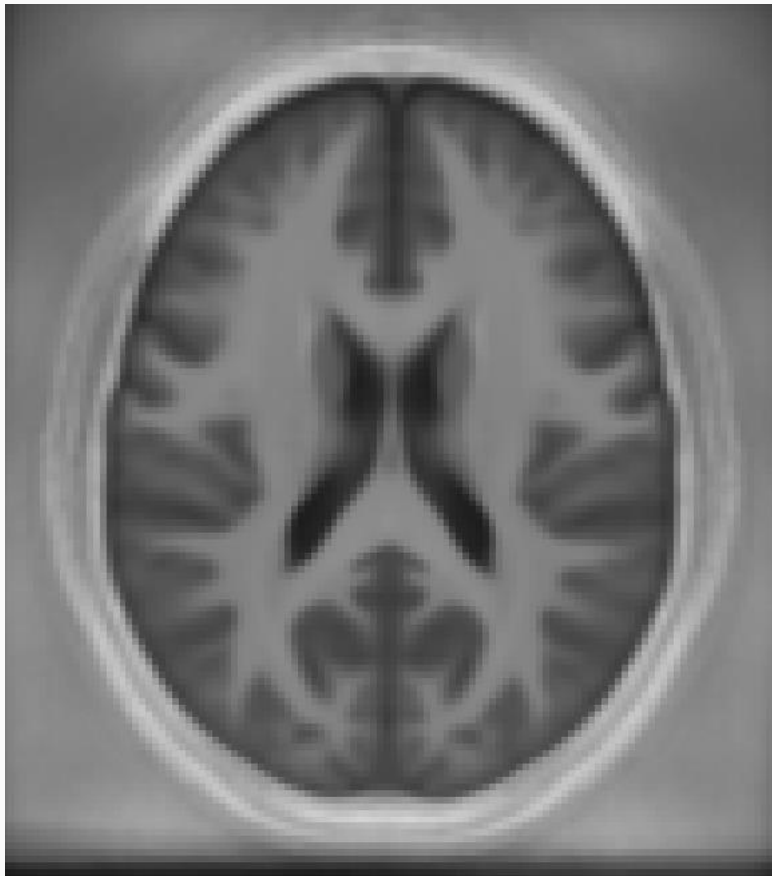
rc1sub-01_T1w_Template3.nii

y_rc1sub-01_T1w.nii

usub-01_bold.nii

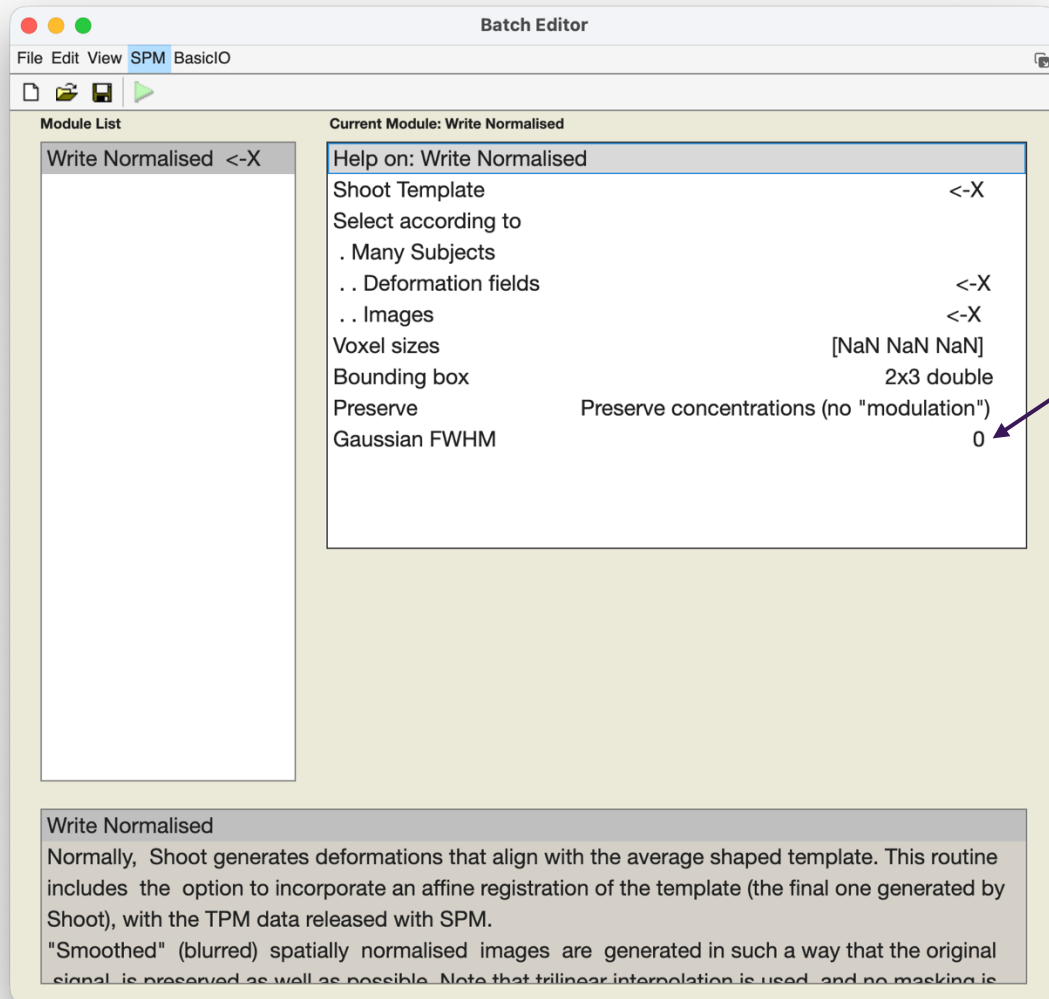


Normalisation is never perfect

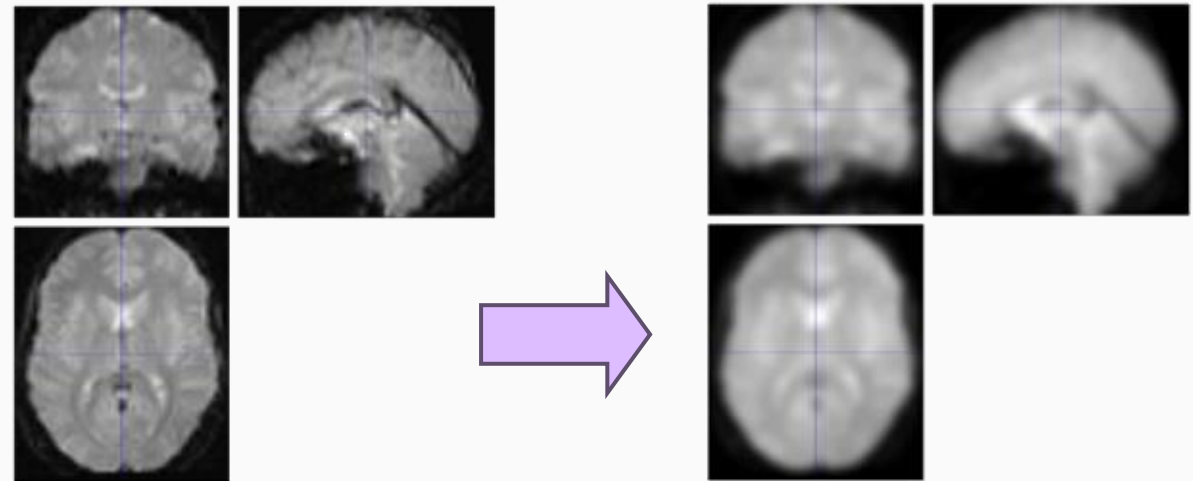


Smoothing

Smooth



Width of smoothing kernel

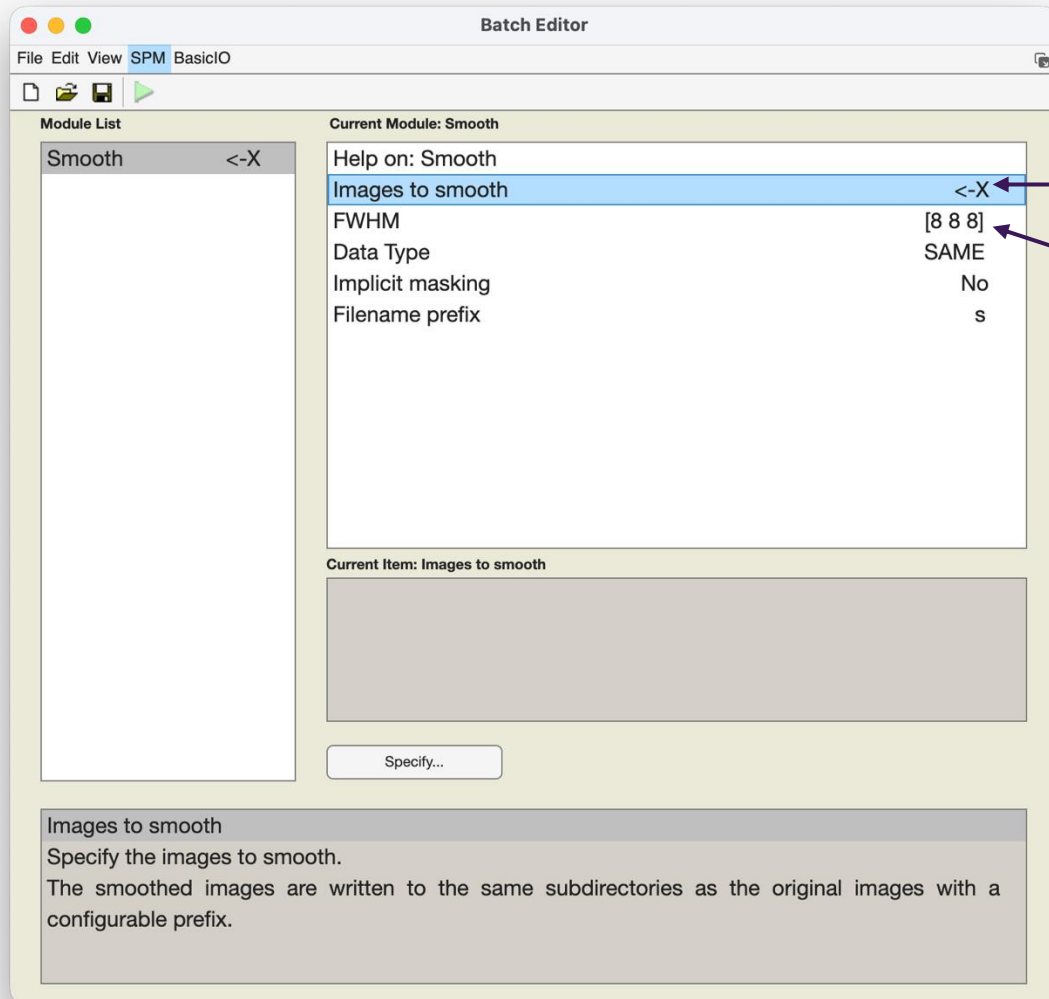


Why do we smooth?

- ❑ Increase the signal-to-noise ratio
(at the cost of less precise localisation)
- ❑ Correct for misalignment
(across volumes or across subjects)
- ❑ Ensures validity of the random field correction
(see later lecture)



SPM → Spatial → Smooth



wusub-01_bold.nii

Width of smoothing kernel

Output: swusub-01_bold.nii

