MRC | Cognition and Brain Sciences Unit

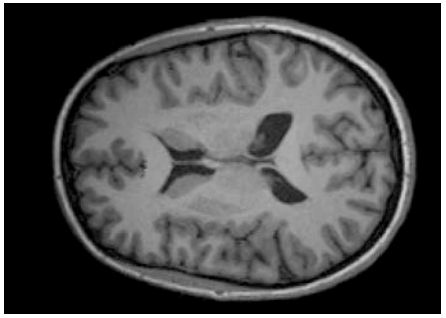
Pre-processing

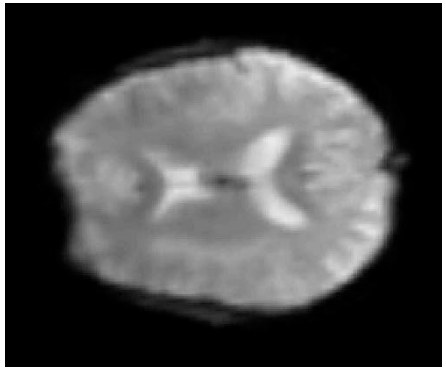
Tibor Auer

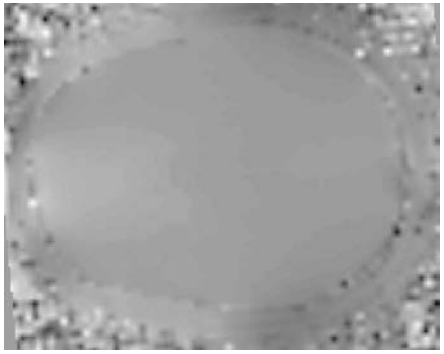
MRC Cognition and Brain Sciences Unit, Methods group

With thanks to Russell Thompson, Matthew Brett, Rik Henson and the authors of the HBF

Data – Types

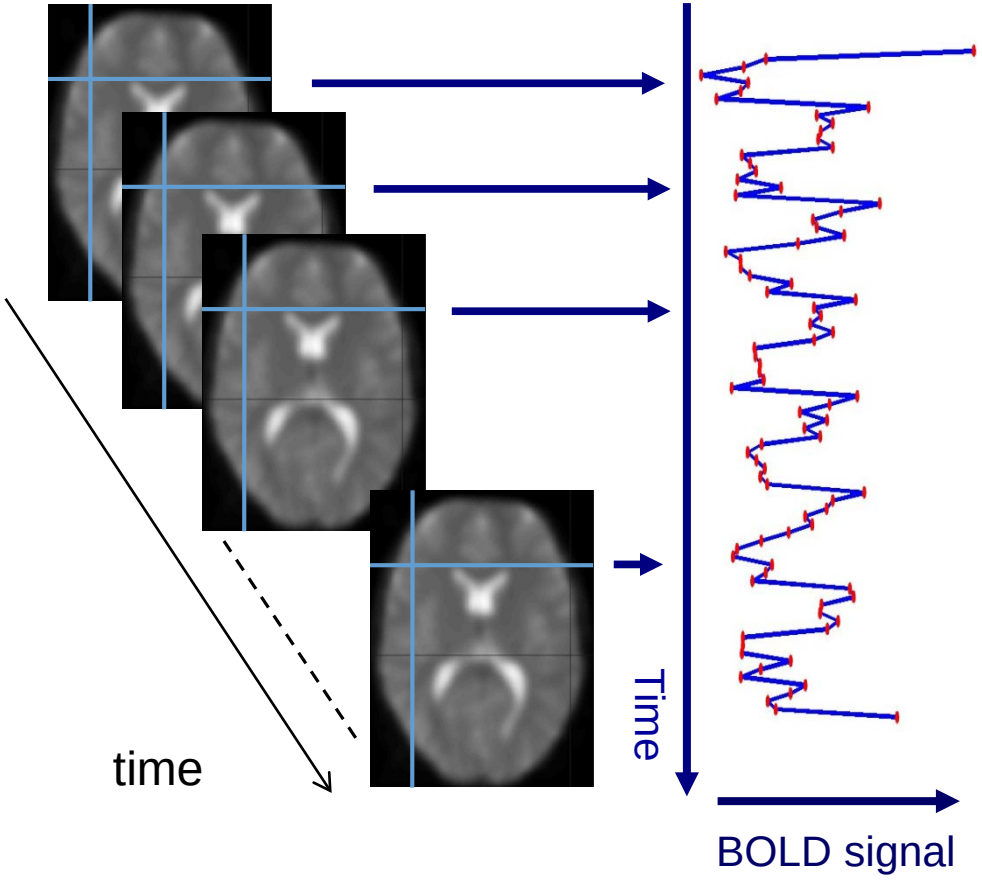






- **Anatomical data: T_1-weighted, 3D, 1/subject or session**
  - (ME)MPRAGE sequence, undistorted
  - High spatial resolution (~1 mm isotropic)
  - Optimised for structural contrast[1]
  - Acquisition time ~5 minutes
- **Functional data: T_{2*}-weighted, 4D, 1/measurement**
  - EPI sequence, distorted
  - Lower spatial resolution (2-3 mm non-isotropic)
  - Optimised for functional contrast[2]
  - Acquisition time ~2 seconds (20-30 slices)
- **Fieldmaps: 2×3D, 1/session**
  - Dual-echo GE sequence, undistorted
  - Lower spatial resolution (same as fMRI)
  - Map of magnetic field inhomogeneities
  - Acquisition time ~1 minute.

Data – Functional



- **Time series**
  - showing BOLD signal changes
  - in each point in the brain
    3D
  - at each repetition (~2 seconds)
    +1D

Overview

Images
in dicom format

Convert to format
used by SPM (NIFTI)

Initial image
diagnostics

Normalise
structural

Within series processing:

- Spatial realignment
- Undistortion
- Temporal realignment

Coregister
EPI to
structural

Normalise
EPI

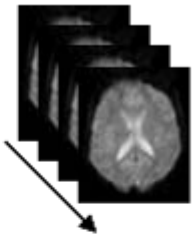
Smooth
EPI

Single
subject
stats

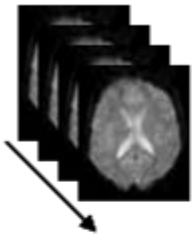
Group
stats

Publish…

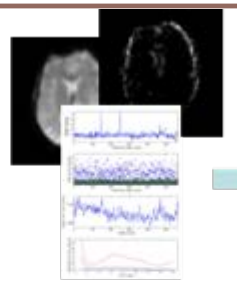
Overview – aa modules (aamod_*)



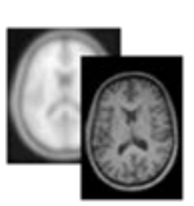
autoidentifyseries_timtrio
get_dicom_structural
get_dicom_epi
get_dicom_fieldmap



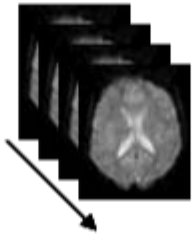
convert_structural
convert_epis
convert_fieldmaps
fieldmap2VDM



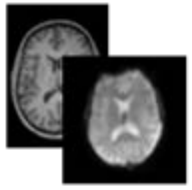
tsdiffana



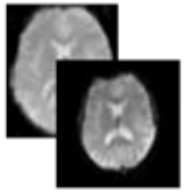
biascorrect_structural
coreg_extended_1
segment8_multichan
dartel_createtemplate
dartel_norm_write
+
freesurfer_initialise
freesurfer_autorecon_all



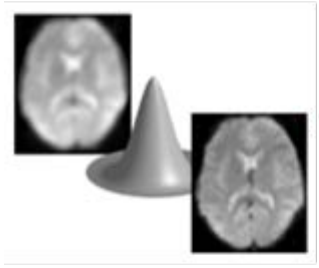
realignunwarp
slicetiming



coreg_extended_2epi



norm_write_dartel
worm_write_meanepi_dartel



smooth

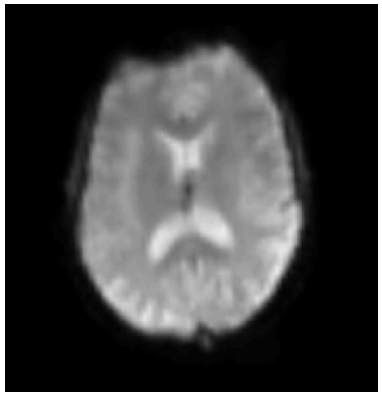
firstlevel_model
firstlevel_contrasts
firstlevel_threshold
firstlevel_threshold_register2FS

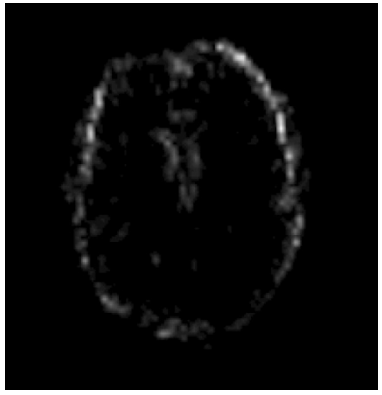
secondlevel_model

paper_maker ???

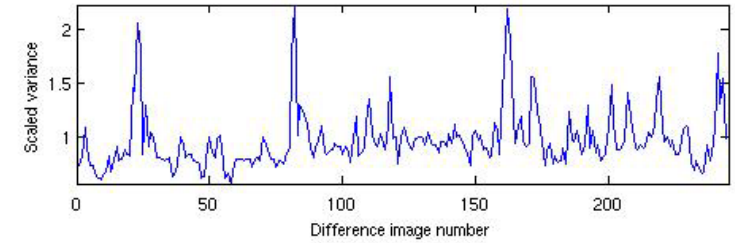
Preprocessing – Initial diagnostics

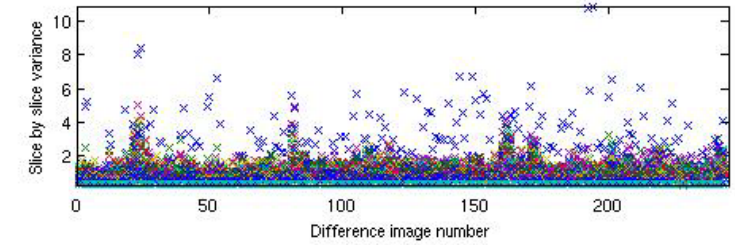
Mean and variance images:

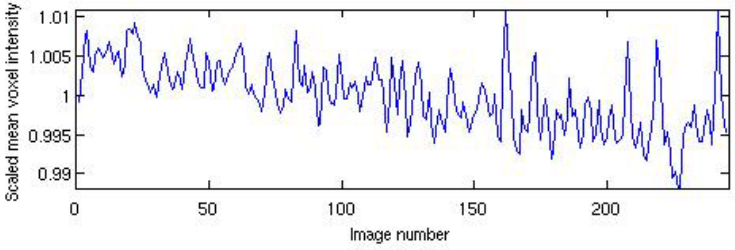


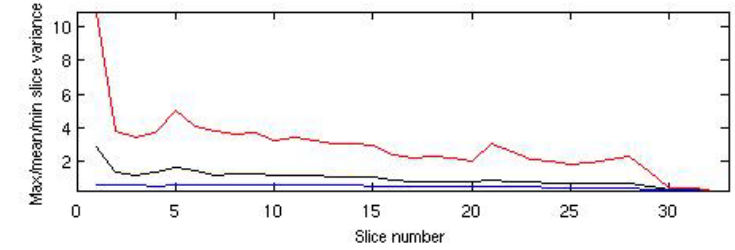


Diagnostic plots:









Scaled variance of difference from the 1st vol.:

- Volumewise
- Slicewise

Descriptive stats:

- Volumewise
- Slicewise

Preprocessing – Normalization

Challenge

- **People have different shaped brains**
- **Goal: transforming brain so its shape matches that of a template**
  - Group studies
  - Cross study comparison, meta analysis

- **Template: universal space**
  - Talairach and Tournoux, 1988 (based on a single subject)

  - Montreal Neurological Institute: MNI152
    - Averaged from T_1 images of 152 subjects

  - Information eXtraction from Images (London): IXI (in SPM12)
    - Also in MNI
    - Fewer subjetcs, but may be more representative locally
    - More classes (segmentation)

Preprocessing – Normalization

Approaches

- **Direct:**
  1. EPI → MNI — modality + resolution/smoothness + shape

- **Indirect (Coreg[1]+Norm):**
  1. EPI → Structural — modality + resolution
  2. Structural →[2] MNI — smoothness + shape

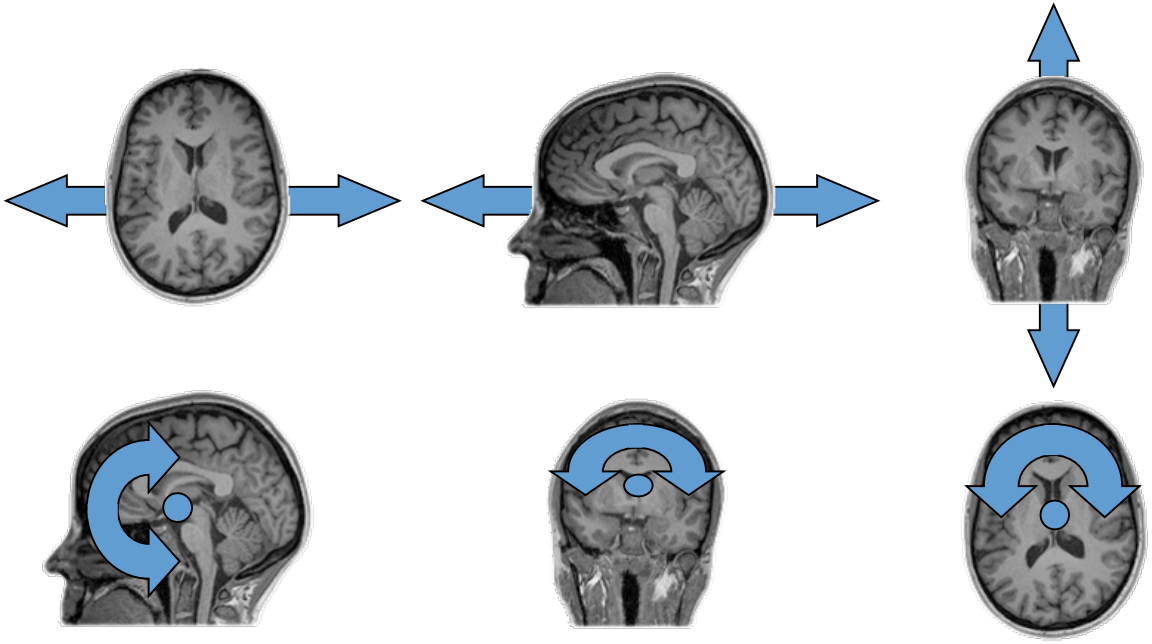
- **Indirect+ (Coreg[1]+DARTEL+Norm)[3]:**
  1. EPI → Structural — modality + resolution
  2. Structural →[2] Study template — smoothness + shape (int.)
  3. Study template → MNI — shape (int.)

Preprocessing – Normalization

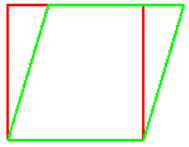
Transformation

- **Affine (12 DOF) registration:**
  - 3 translations
  - 3 rotation

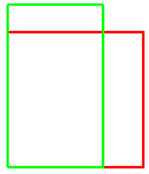
  } Rigid-body (6DOF)



  - 3 shears
  - 3 zooms



Shear

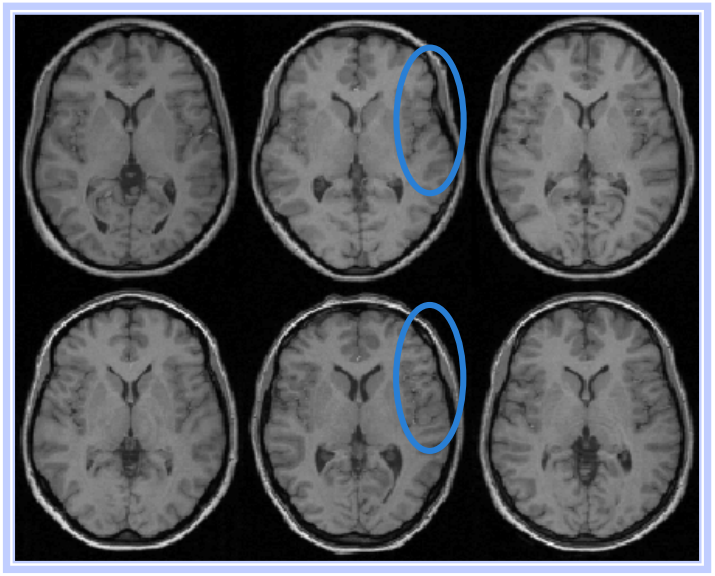


Zoom

Preprocessing – Normalization

Transformation

- **Linear transformations:**
  - Assumes linear relationship
    - between position and transformation
  - Able to match overall size and shape,
    - but not small details



- **Nonlinear transformations:**
  - Deformation fields: nonlinear relationship between position and transformation
    - large DOF → overfitting (unnecessary warps) makea brains exactly the same

↓

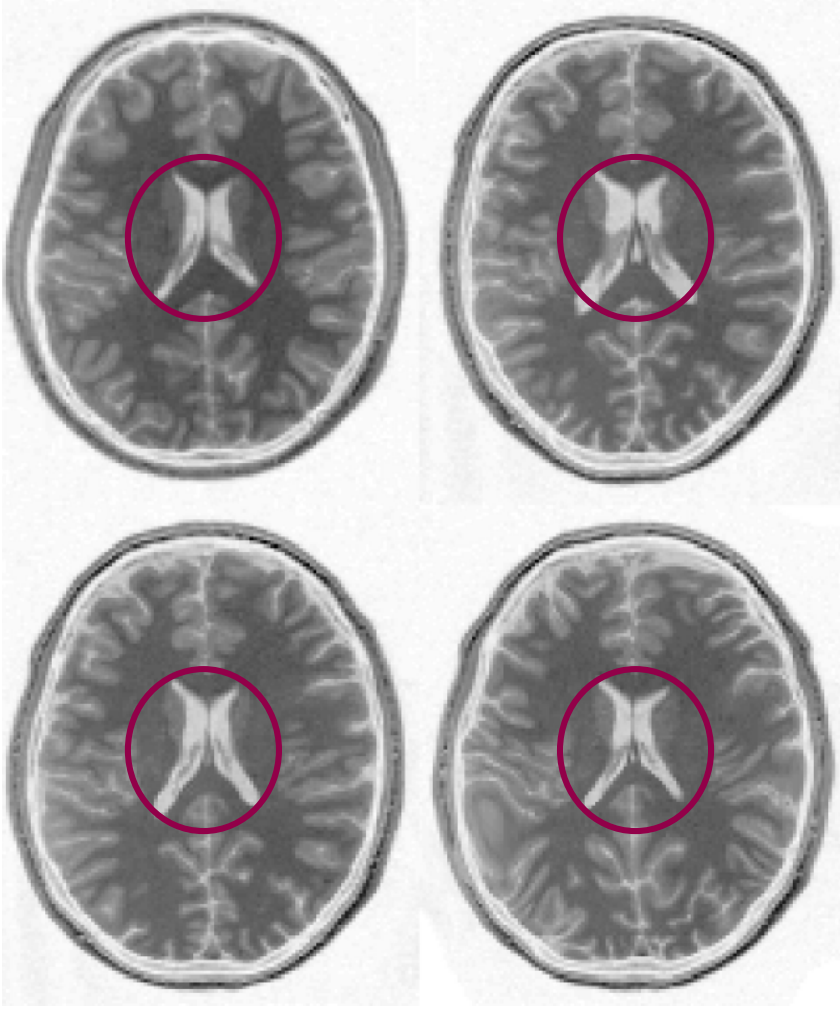
  - Regularisation: transformation within a certain range based on *a priori* knowledge[1]

Preprocessing – Normalization

Transformation

- **Nonlinear transformations:**

Template



Affine only
- some differences in shape

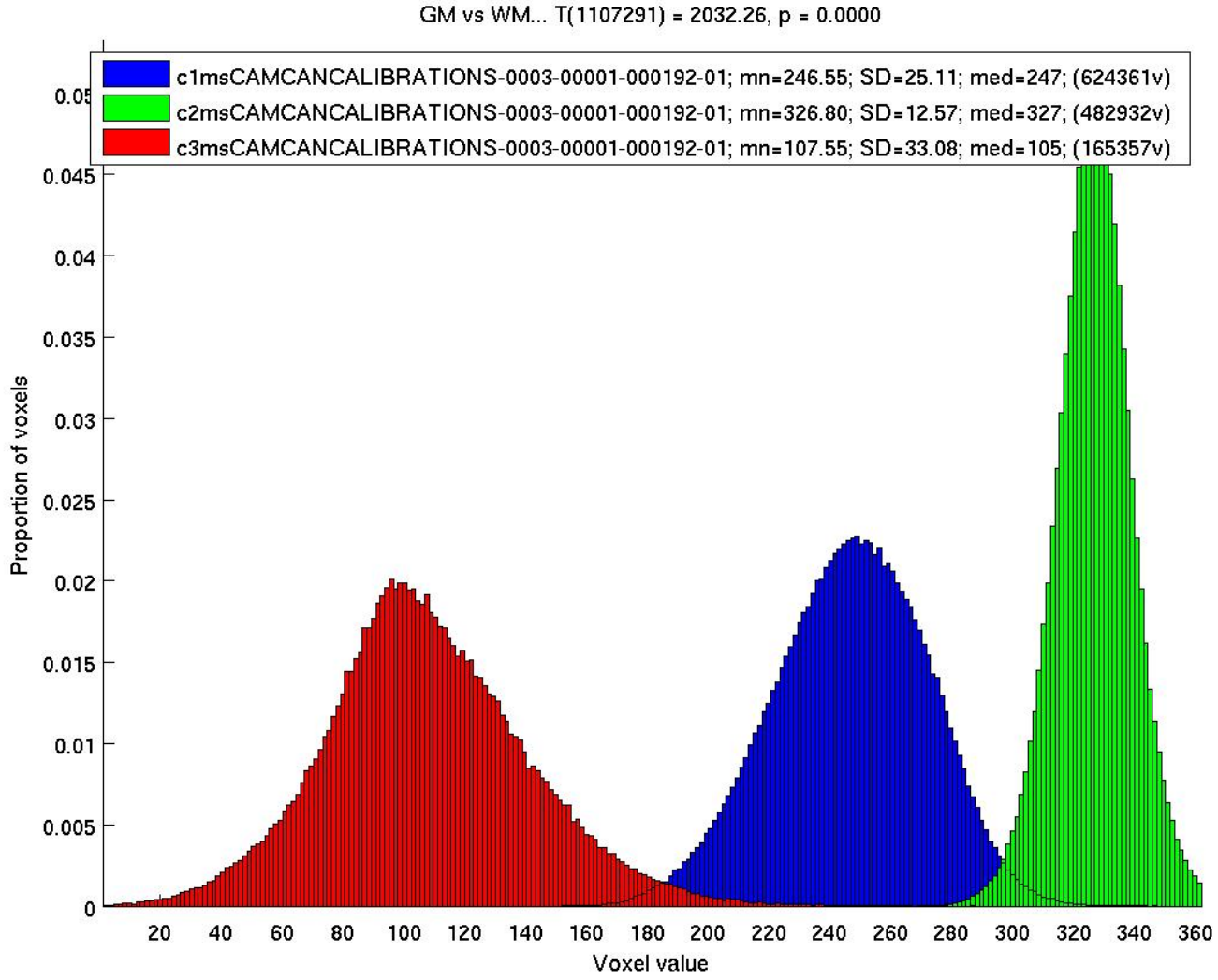
Affine + nonlinear with regularization
- good match to overall shape
- some differences in details

Affine + nonlinear without regularization
- overfitting

Preprocessing – Normalization

Diagnostics

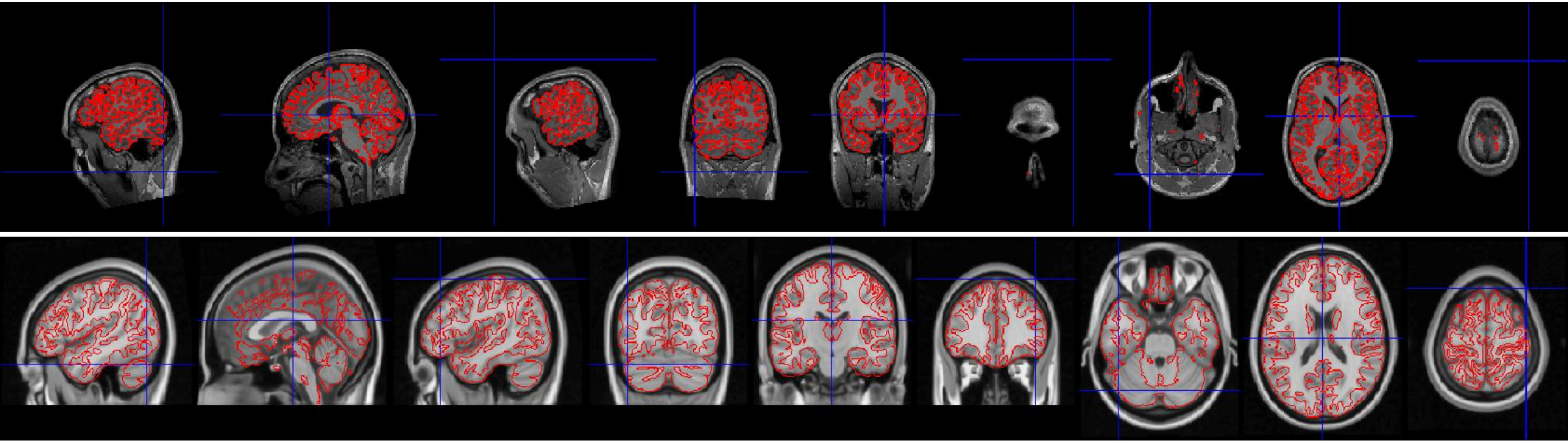
- **Segmentation**



Preprocessing – Normalization

Diagnostics

- **Segmentation**

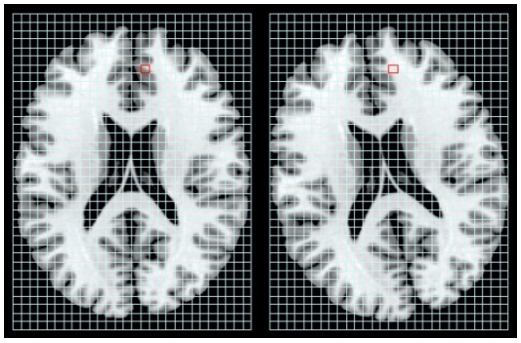


- **Normalisation (structural)**
  - (manually)

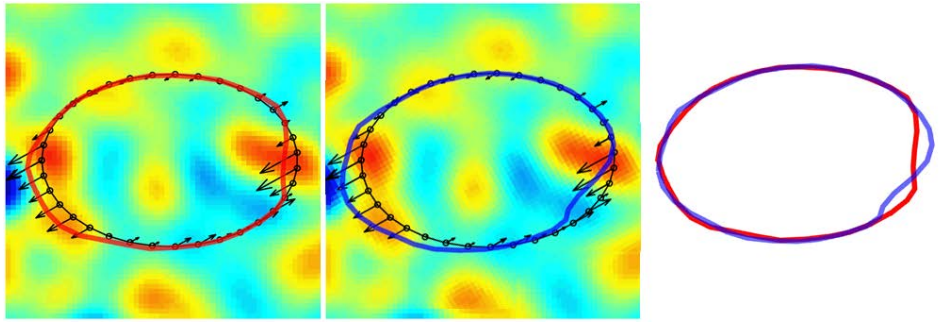
Preprocessing – Motion correction

Challenge

- **Movement confounds data:**
  - Signal recorded from different position
    - Correspondence
    - PVE (e.g. WM – GM)



  - Signal recorded at a different field strength
    - Local inhomogeneities in the magnetic field affecting the brain area

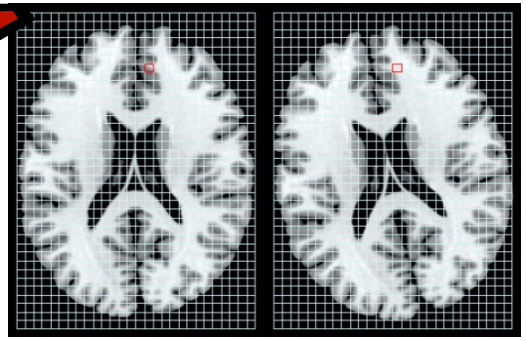


  - Aliasing caused by gap between the slices

Preprocessing – Motion correction

Challenge

- **Movement confounds data:**
  - Signal recorded from different
    - Correspondence
    - PVE (e.g. W



↓

same modality, same resolution, same shape

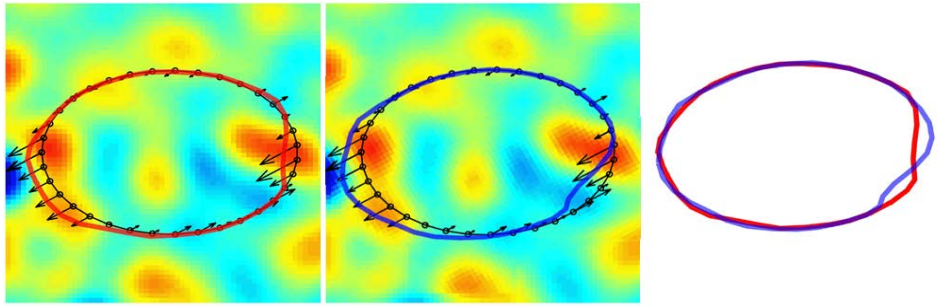
↓

Rigid-body (6DOF)

Preprocessing – Motion correction

Challenge

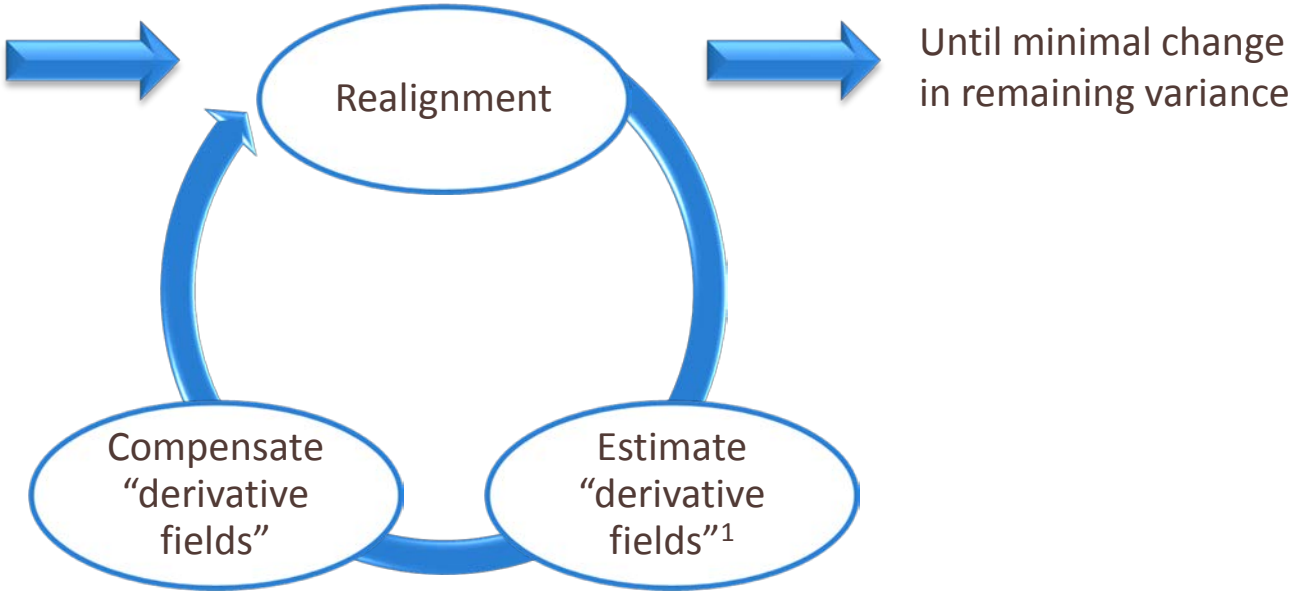
- **Movement confounds data:**
  - Signal recorded at a different field strength
    - Local inhomogeneities in the magnetic field affecting the brain area



- **Include the realignment parameters as covariates in the statistical model**
  - Capture any movement related variance in the data.
  - However!
    - Reduces design's degree of freedom (usually > 100)
    - Problematic if movement is correlated with effects of interest
    - (e.g. button pushes, verbal responses etc.)
    - Can remove the effects of interest.

Preprocessing – Motion correction: +Unwarping

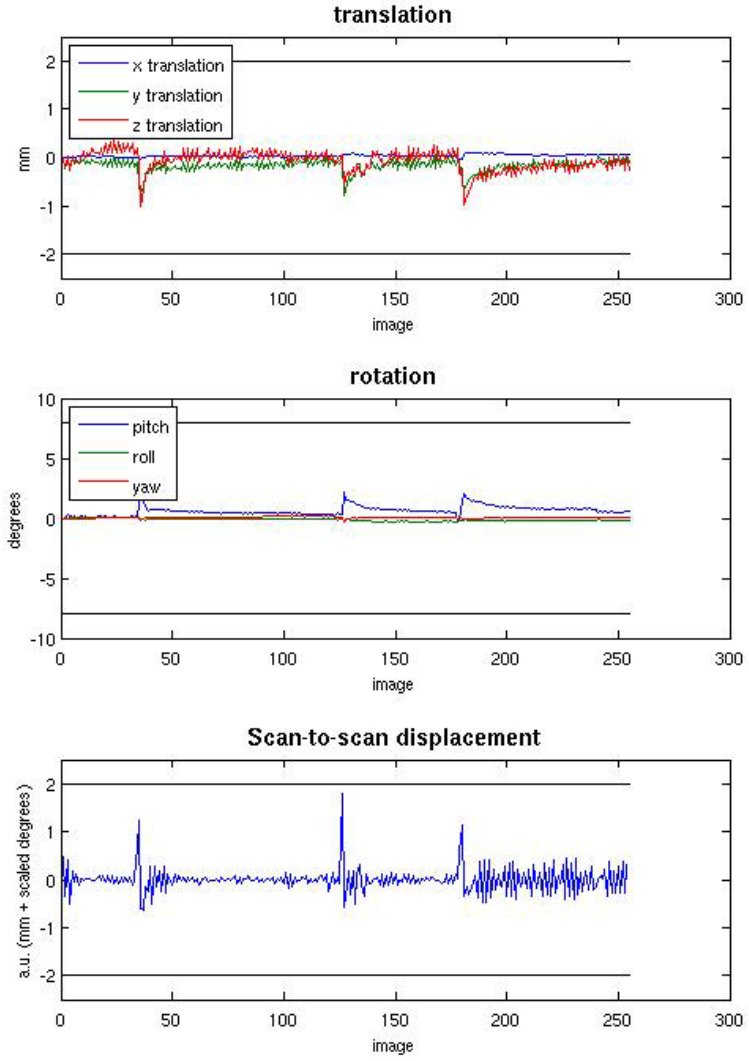
- **Motion correction with Unwarping:**
  - Iteratively estimate the effects and compensate for them



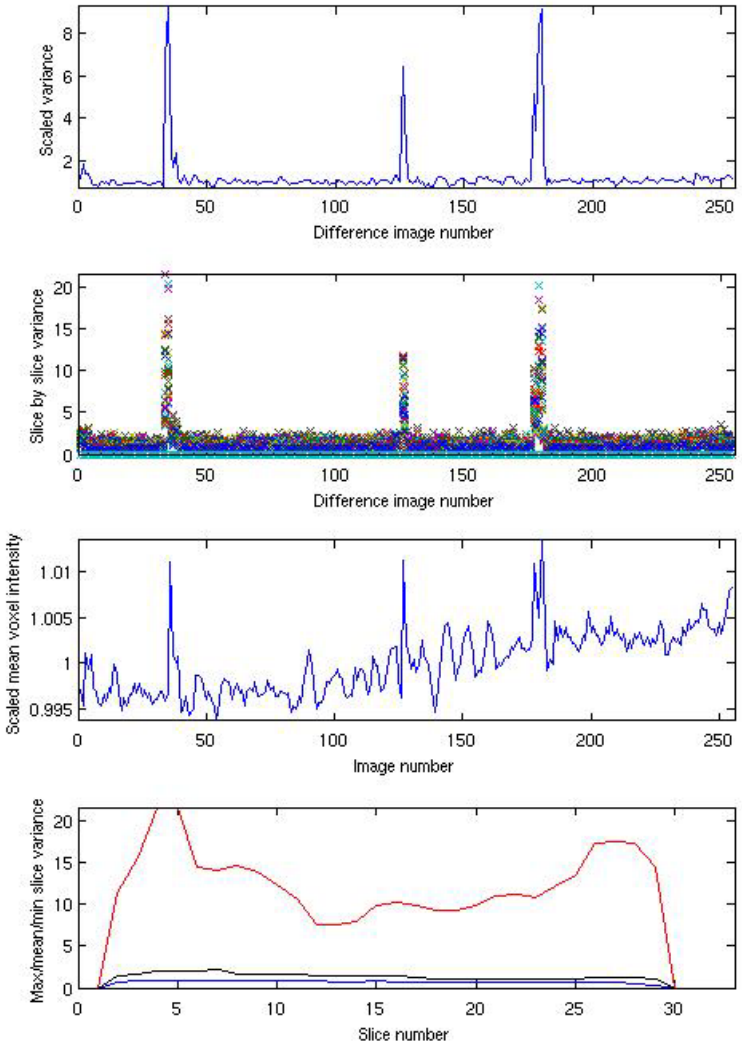
Preprocessing – Motion correction

Diagnostics

MoCo parameters



QA

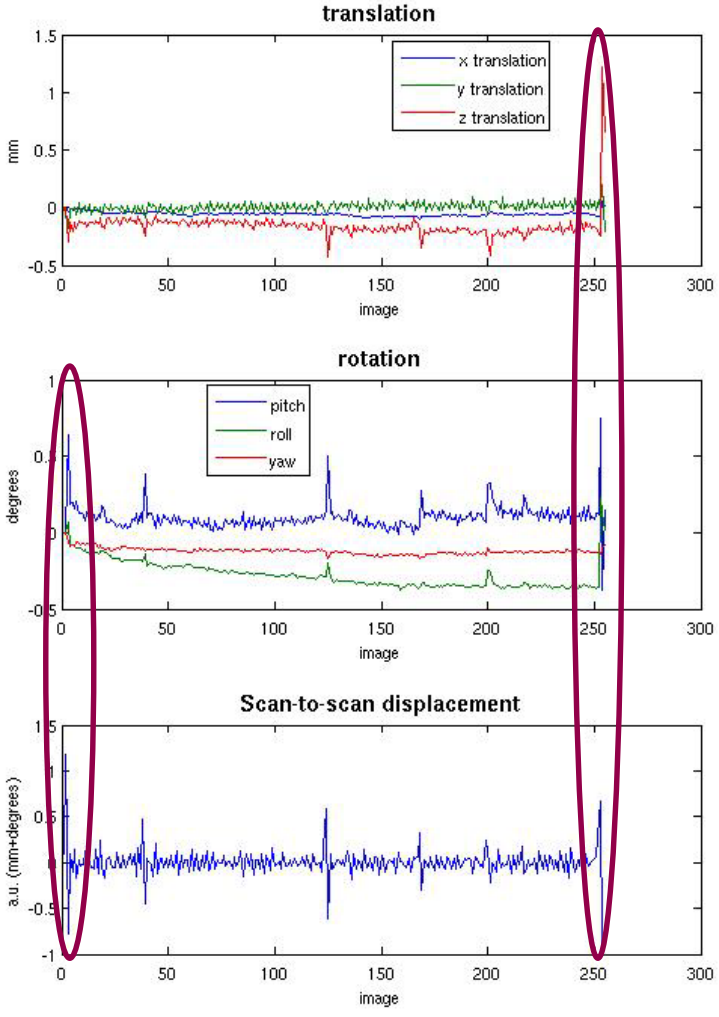


Preprocessing – Motion correction

Diagnostics

- **Best solution: reduce movement to the minimum**
  - Comfort[1]
  - Discourage talk during breaks (between-session movement[2])
  - Dummy scans
  - "End of measurement"

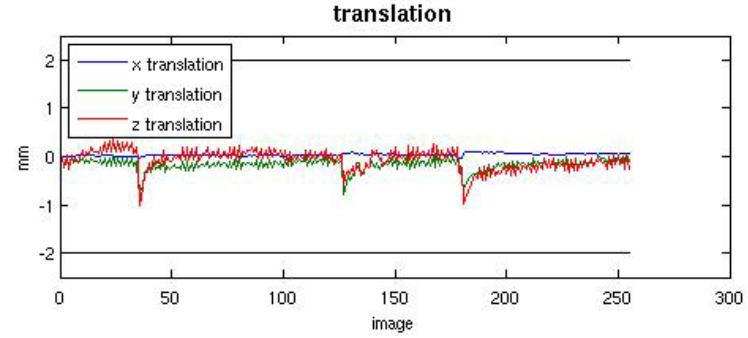
- **Reject data to reduce heterogeneity (Summary)**
  - Scans
  - Subjects

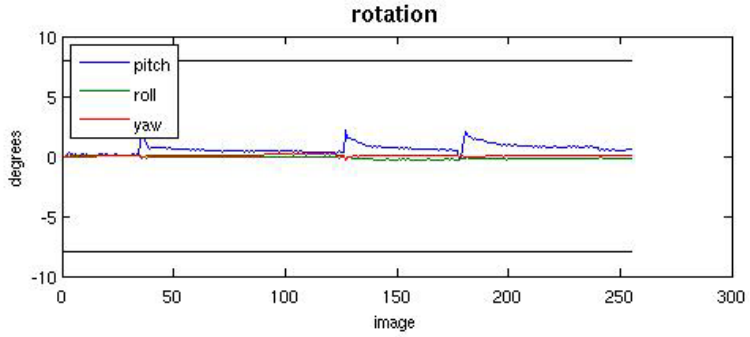


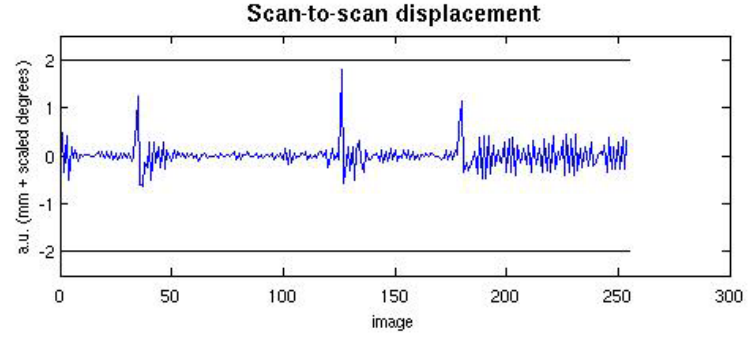
Preprocessing – Motion correction

Diagnostics

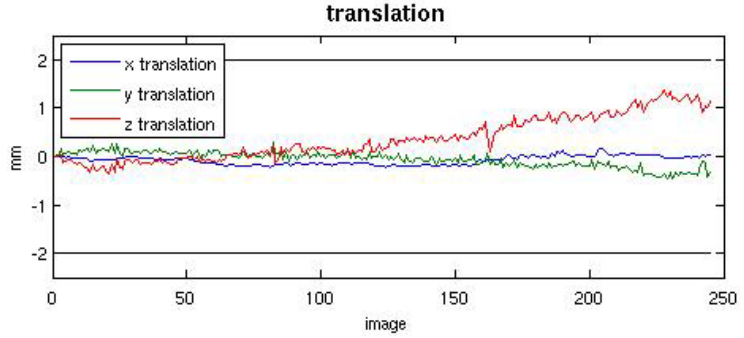
Subject1 MoCo parameters

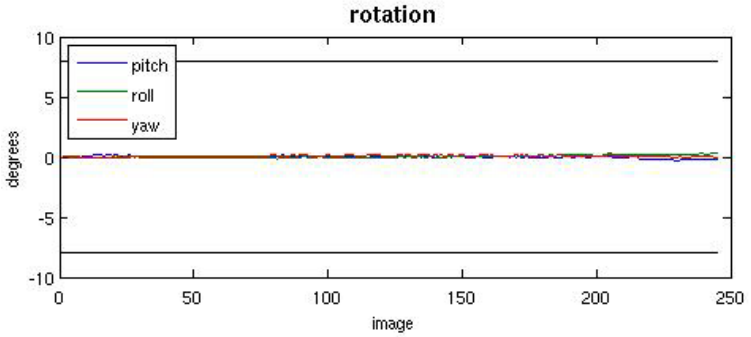


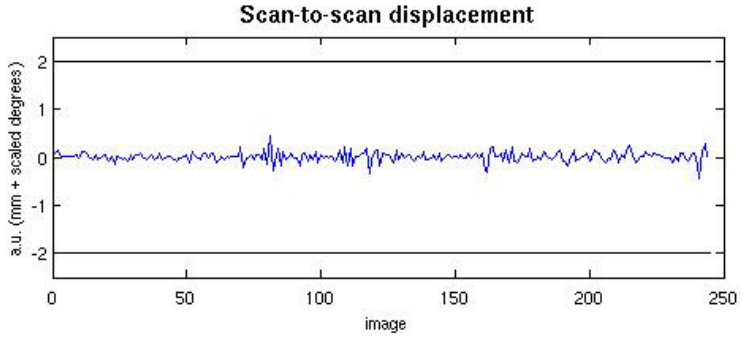




Subject2 MoCo parameters



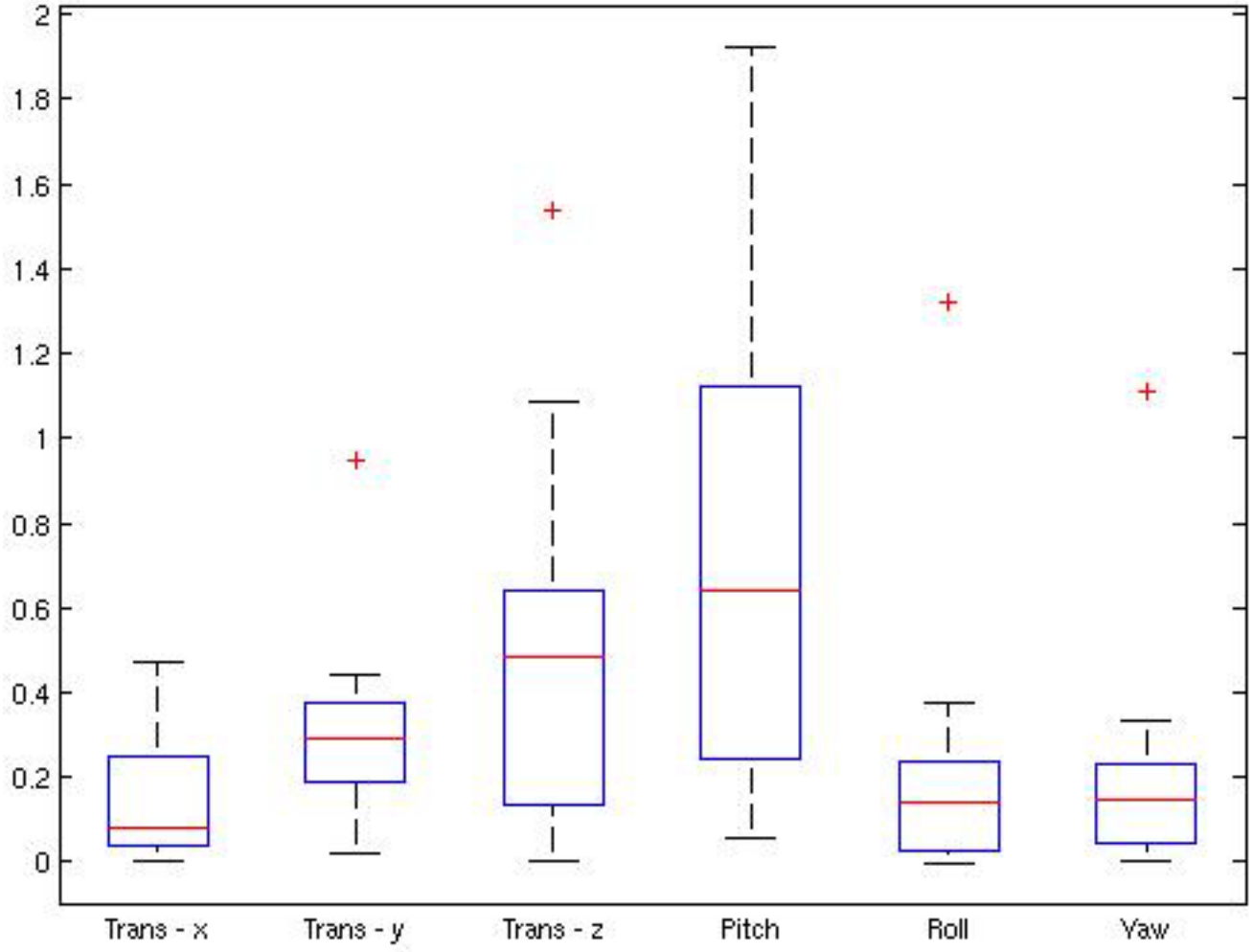




Preprocessing – Motion correction

Diagnostics

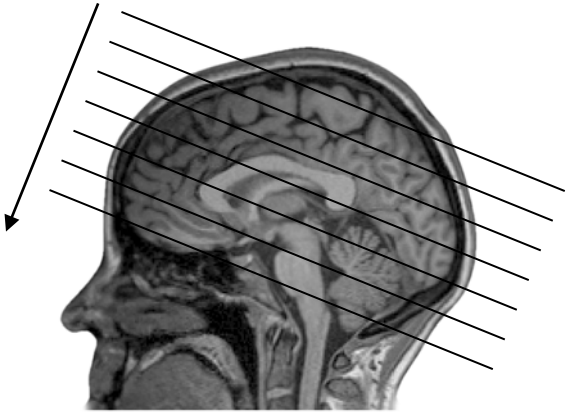
- **Summary (outliers)**
  - Trans - x: None
  - Trans - y: 12
  - Trans - z: 1
  - Pitch: None
  - Roll: 19
  - Yaw: 19



Preprocessing – Temporal realignment

Challenge

- **Acquisition**
  - 2D EPI sequence collect volume slice-by-slice
  - Each slice is acquired at a different time
  - TR = 2s, 32 slices:
    - 62.5 ms between-slice difference
    - ~1.9 s difference between the first and the last slices



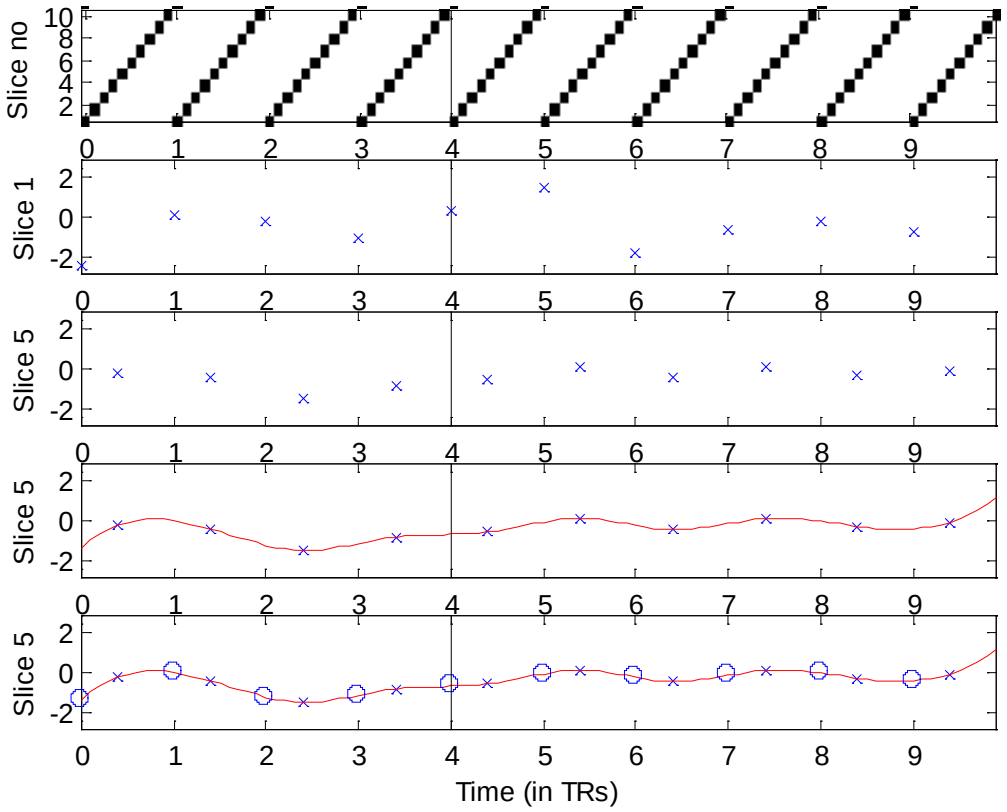
↓

  - Confound precise timing if TR is long (> 1s)
    - Event-related vs. epoch-based

Preprocessing – Temporal realignment

Solution

- **Slice time correction**
  - Interpolate timecourse[1]
  - Preprocessing:
    - Calculate time shift
    - "Tags" slices
  - Interpolation during HRF-estimation



Preprocessing – Temporal realignment

Input

- **Sliceorder/Slice timings**
  - Timings are more accurate than orders
  - Specified manually (automatic in *aa!*)

- **Reference slice: all other slices will be "adjusted" to it**
  - Middle slice: ↓ the maximum interpolation necessary → ↓ interpolation artefacts

  - It will not be altered: Chose according to your area of interest!

  - Scanner sync pulse is at the acquisition of the first slice
    - Stimuli timing adjusted to the first slice

      or
    - Model needs to be adjusted (automatic in *aa*!)

Preprocessing – Coregistration

Challenge

- **Goal: the functional in the same space as the structural**
  - Overlay functional results onto the structure to enhance localisation
  - Use anatomy as a precursor to spatial normalization
    1. Normalise the structural image[1]
    2. Apply the parameters to the functional data
- **Data types**
  - Reference image: Structural: T_1-weighted, high resolution, fewer artefacts
  - Source image: Functional: T_{2*}-weighted, low resolution

↓

modality + resolution (but same shape)

↓

Rigid-body (6DOF)

Preprocessing – Coregistration

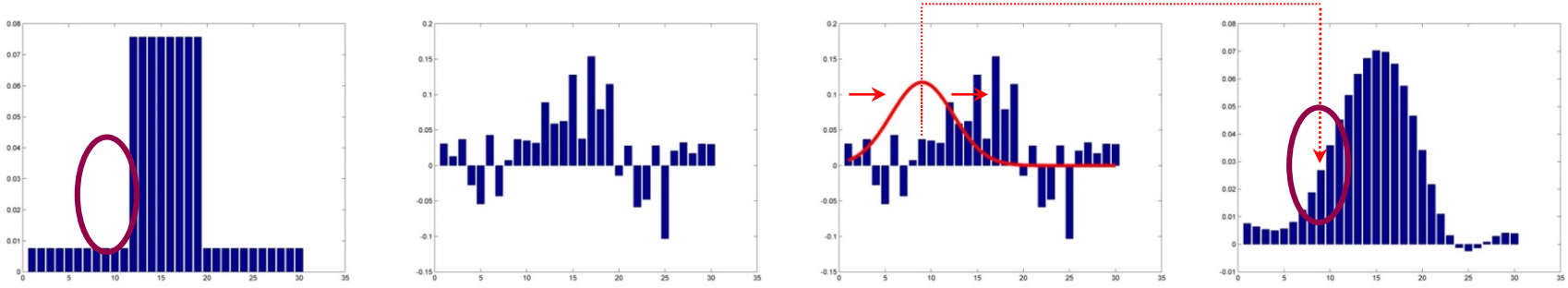
Source image

- **Functional image to estimate transformation**
  - example EPI from ca. the middle – FSL
  - mean EPI (temporally averaged) – SPM, aa
    - Smaller (effective) spatial resolution
    - Smaller noise

- **Requirement**
  - Reasonably good starting point (local optima)
    - Similar acquisition position (AutoAlign)
    - Reorient (?)
  - Adequate overlapping with structural
    - Partial-brain fMRI → two-step coregistration via a "whole-brain EPI"[1]
      1. Partial-brain EPI → whole-brain EPI
      2. Whole-brain EPI → Structural

Preprocessing – Smoothing

- **Spatial weighted averaging: usually Gaussian kernel**
  - Value at each voxel: a weighted average of the values in surrounding voxels



Original signal | Signal plus noise | Apply kernel to each point | Recovered signal

  - ↑ signal-to-noise ratio: assuming random noise
  - Spreads signal (**depends on kernel size**):
    - ↑ between-subject spatial correspondence (by blurring minor differences)
    - ↓ effective spatial resolution (RESEL) ↓ the number of multiple comparisons
    - "False" positives!

Preprocessing – Smoothing

Kernel Size

- **Amount to smooth:**
  - Full Width at Half Maximum height (FWHM)
  - Ideally: hypothesis-dependent[1]
    - According to the spatial extent of the signal
    - Neuroanatomical assumptions
      - Visual areas: smaller kernel
      - Prefrontal: larger kernel
  - Methodologically: GRFT-dependent (inference)
    - Ensure minimum smoothness (RESEL ≥ 3×voxel)
    - Iterative?
  - Practically:
    - Resolution-dependent: 1.5×voxel-size
    - 8-10 mm is common (SPM default, history!)