Preprocessing I: Within Subject

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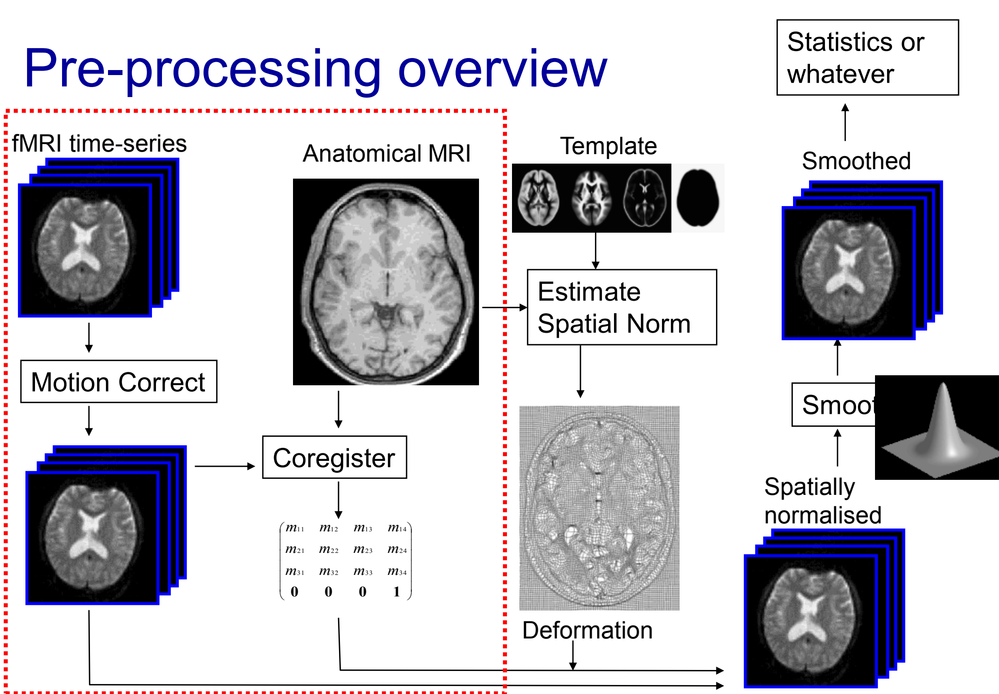
Pre-processing overview



Contents

* **Preliminaries**
  * **Rigid-body and affine transformations**
  * **Optimisation and objective functions**
  * **Transformations and interpolation**
* Realignment
* Coregistration

Rigid-body transformations

* Assume that brain of the same subject doesn't change shape or size in the scanner.
  * Head can move, but remains the same shape and size.
  * Some exceptions:
    * Image distortions.
    * Brain slops about slightly because of gravity.
    * Brain growth or atrophy over time.
* If the subject's head moves, we need to correct the images.
  * Do this by image registration.

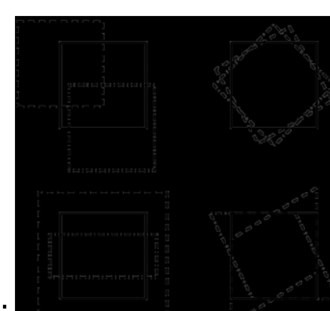
Image registration

Two components:

- **Registration** - i.e. Optimise the parameters that describe a spatial transformation between the source and reference images

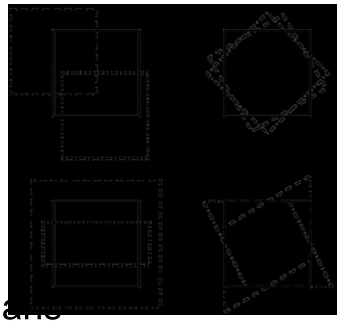
- **Transformation** - i.e. Re-sample according to the determined transformation parameters

2D affine transforms



* Translations by t_x and t_y
  * $x_1 = x_0 + t_x$
  * $y_1 = y_0 + t_y$
* Rotation around the origin by Θ radians
  * $x_1 = \cos(\Theta)\, x_0 + \sin(\Theta)\, y_0$
  * $y_1 = -\sin(\Theta)\, x_0 + \cos(\Theta)\, y_0$
* Zooms by s_x and s_y
  * $x_1 = s_x\, x_0$
  * $y_1 = s_y\, y_0$
* Shear
  * $x_1 = x_0 + h\, y_0$
  * $y_1 = y_0$

2D affine transforms



* Translations by t_x and t_y
  * $x_1 = 1\ x_0 + 0\ y_0 + t_x$
  * $y_1 = 0\ x_0 + 1\ y_0 + t_y$
* Rotation around the origin by Θ radians
  * $x_1 = \cos(\Theta)\ x_0 + \sin(\Theta)\ y_0 + 0$
  * $y_1 = -\sin(\Theta)\ x_0 + \cos(\Theta)\ y_0 + 0$
* Zooms by s_x and s_y:
  * $x_1 = s_x\, x_0 + 0\ y_0 + 0$
  * $y_1 = 0\ x_0 + s_y\, y_0 + 0$
* Shear
  * $x_1 = 1\ x_0 + h\ y_0 + 0$
  * $y_1 = 0\ x_0 + 1\ y_0 + 0$

3D rigid-body transformations

* A 3D rigid body transform is defined by:
  * 3 translations - in X, Y & Z directions
  * 3 rotations - about X, Y & Z axes
* The order of the operations matters

$$\begin{pmatrix} 1 & 0 & 0 & X_{trans} \\ 0 & 1 & 0 & Y_{trans} \\ 0 & 0 & 1 & Z_{trans} \\ 0 & 0 & 0 & 1 \end{pmatrix} \times \begin{pmatrix} 1 & 0 & 0 & 0 \\ 0 & \cos\Phi & \sin\Phi & 0 \\ 0 & -\sin\Phi & \cos\Phi & 0 \\ 0 & 0 & 0 & 1 \end{pmatrix} \times \begin{pmatrix} \cos\Theta & 0 & \sin\Theta & 0 \\ 0 & 1 & 0 & 0 \\ -\sin\Theta & 0 & \cos\Theta & 0 \\ 0 & 0 & 0 & 1 \end{pmatrix} \times \begin{pmatrix} \cos\Omega & \sin\Omega & 0 & 0 \\ -\sin\Omega & \cos\Omega & 0 & 0 \\ 0 & 0 & 1 & 0 \\ 0 & 0 & 0 & 1 \end{pmatrix}$$

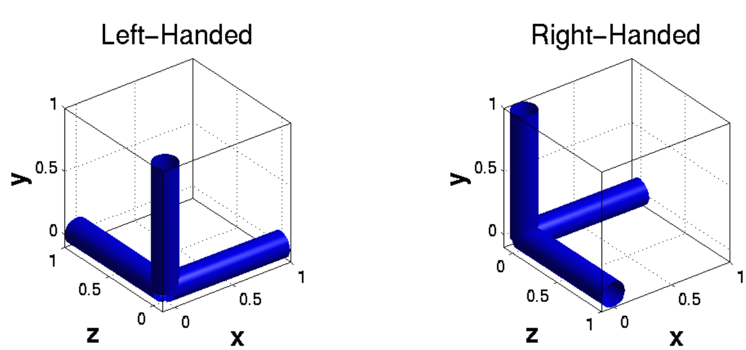
Translations | Pitch about x axis | Roll about y axis | Yaw about z axis

Voxel-to-world transforms

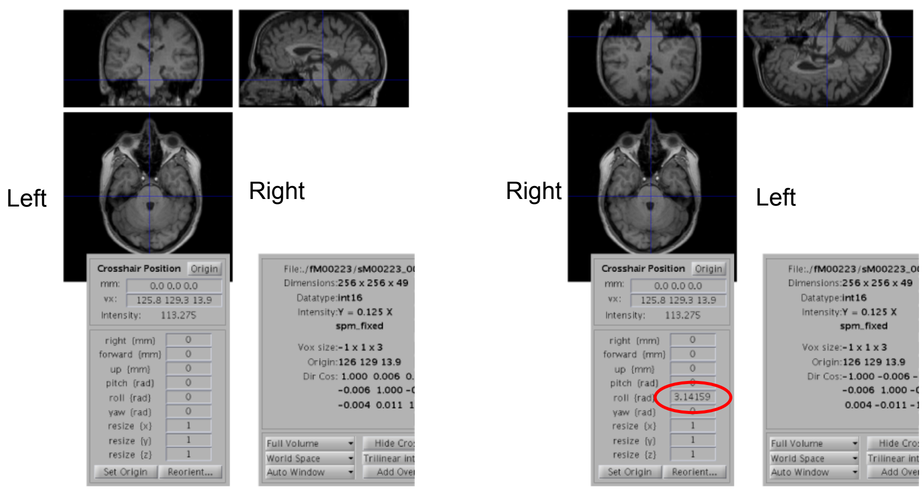
* Affine transform associated with each image
  * Maps from voxels ($x=1..n_x$, $y=1..n_y$, $z=1..n_z$) to some world co-ordinate system. e.g.,
    * Scanner co-ordinates - images from DICOM toolbox
    * T&T/MNI coordinates - spatially normalised
* Registering image B (source) to image A (target) will update B's voxel-to-world mapping
  * Mapping from voxels in A to voxels in B is by
    * A-to-world using M_A, then world-to-B using M_B^{-1}
    * $M_B^{-1} M_A$

Left- and right-handed coordinate systems

* NIfTI format files are stored in either a left- or right-handed system
  * Indicated in the header
* Talairach & Tournoux uses a right-handed system
* Mapping between them sometimes requires a flip
  * Affine transform has a negative determinant

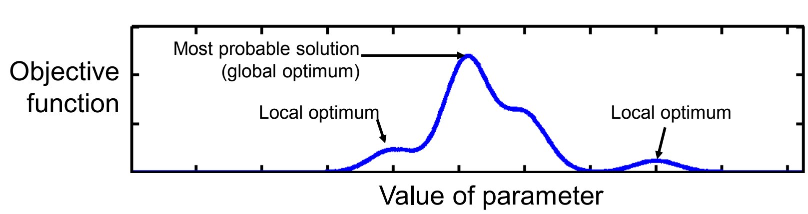


“Radiological” and “neurological” conventions



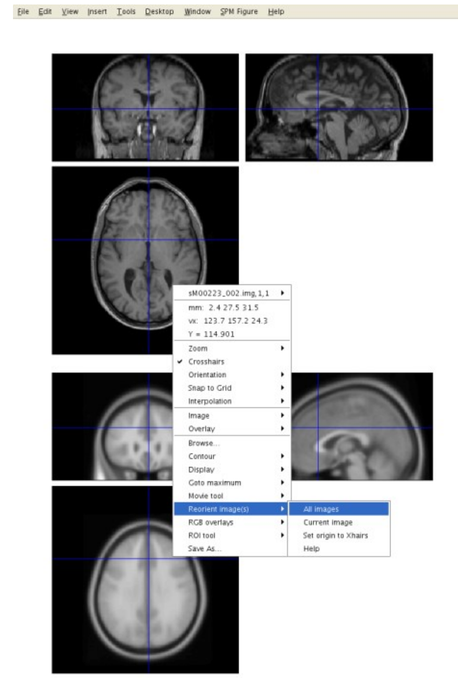
Optimisation

* Image registration is done by optimisation.
* Optimisation involves finding some “best” parameters according to an “objective function”, which is either minimised or maximised
* The “objective function” is often related to a probability based on some model



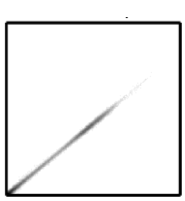
Optimisation

* Because registration only finds a *local optimum*, some manual reorienting of the images may be needed before doing anything else in SPM.

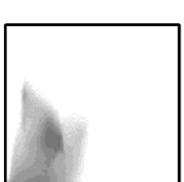


An MNI-space image from spm12/canonical directory.

Objective functions



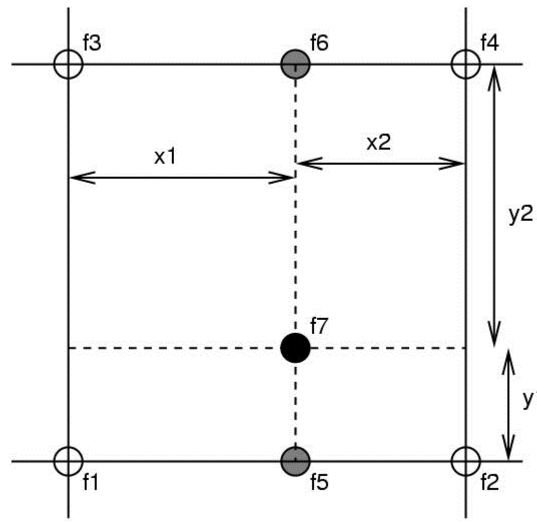
* Intra-modal
  * Mean squared difference (minimise)
  * Normalised cross correlation (maximise)



* Inter-modal (or intra-modal)
  * Mutual information (maximise)
  * Normalised mutual information (maximise)
  * Entropy correlation coefficient (maximise)

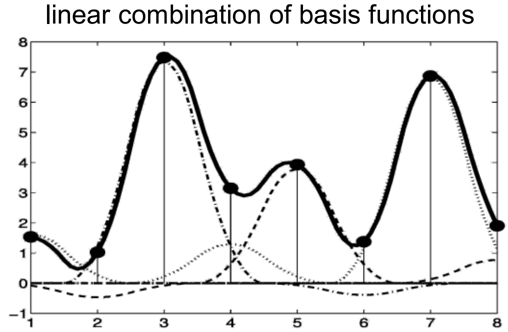
Simple interpolation

* Nearest neighbour
  * Take the value of the closest voxel
* Tri-linear
  * Just a weighted average of the neighbouring voxels
  * $f_5 = f_1\, x_2 + f_2\, x_1$
  * $f_6 = f_3\, x_2 + f_4\, x_1$
  * $f_7 = f_5\, y_2 + f_6\, y_1$

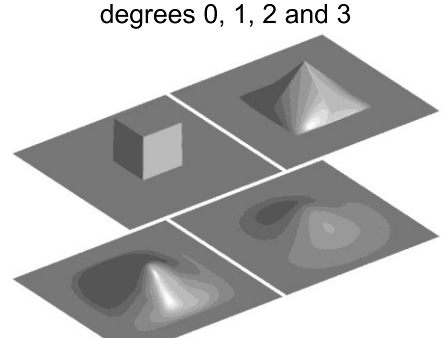


B-spline interpolation

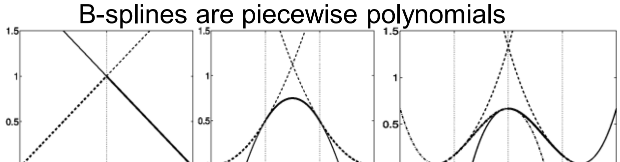
A continuous function is represented by a linear combination of basis functions



2D B-spline basis functions of degrees 0, 1, 2 and 3



B-splines are piecewise polynomials



Nearest neighbour and trilinear interpolation are the same as B-spline interpolation with degrees 0 and 1.

Contents

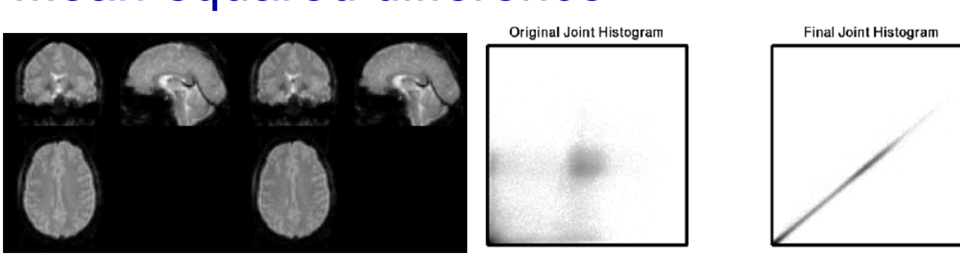
* Preliminaries

* Realignment

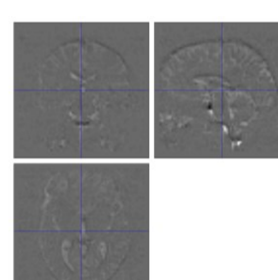
  * **Realignment by minimising mean-squared difference**
  * **Residual artifacts and distortion correction**

* Coregistration

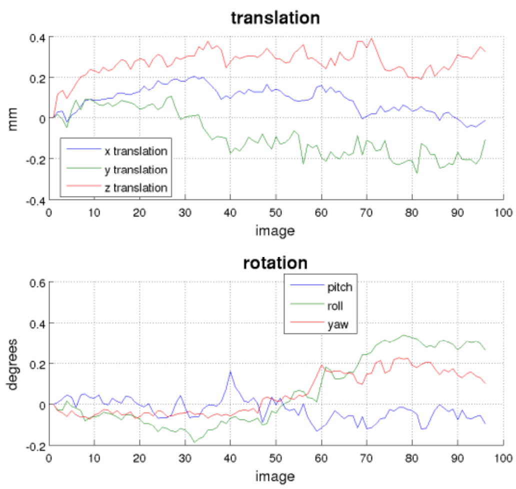
Mean-squared difference

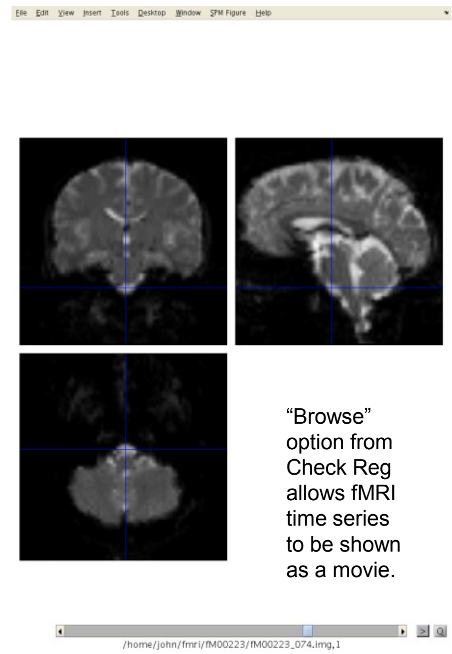


* Minimising mean-squared difference works for intra-modal registration (realignment)
* Simple relationship between intensities in one image, versus those in the other
  * Assumes normally distributed differences



Motion estimates





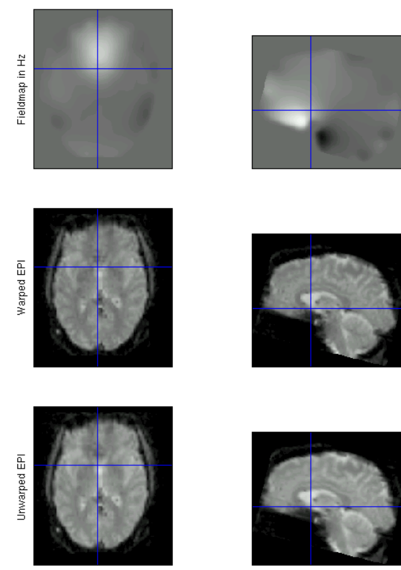
"Browse" option from Check Reg allows fMRI time series to be shown as a movie.

Residual errors from aligned fMRI

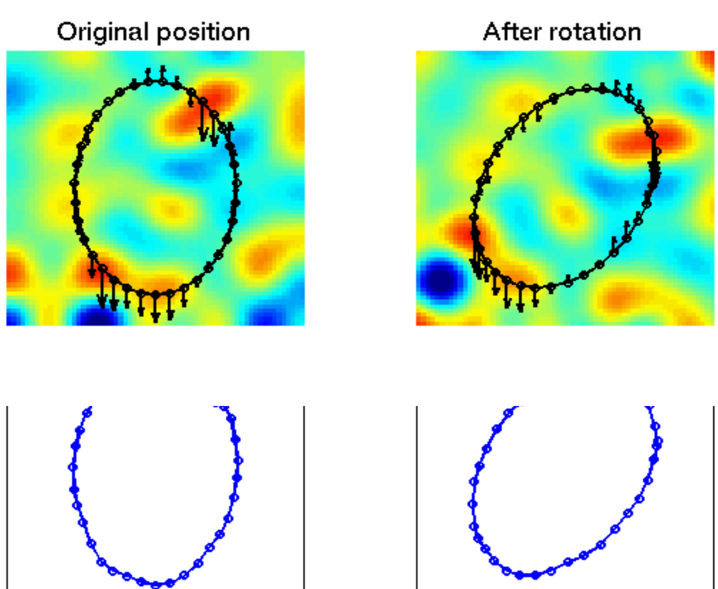
* Re-sampling can introduce interpolation errors
  * especially tri-linear interpolation
* Gaps between slices can cause aliasing artefacts
* Slices are not acquired simultaneously
  * rapid movements not accounted for by rigid body model
* Image artefacts may not move according to a rigid body model
  * image distortion
  * image dropout
  * Nyquist ghost
* BOLD signal changes influence the estimated motion.
* Functions of the estimated motion parameters can be modelled as confounds in subsequent analyses

Movement-by-distortion interaction of fMRI

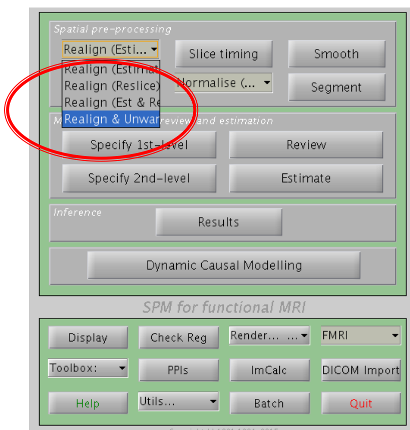
- *Subject disrupts B_0 field, rendering it inhomogeneous
  - * distortions in phase-encode direction
- *Subject moves during EPI time series
- *Distortions vary with subject orientation
  - *shape varies

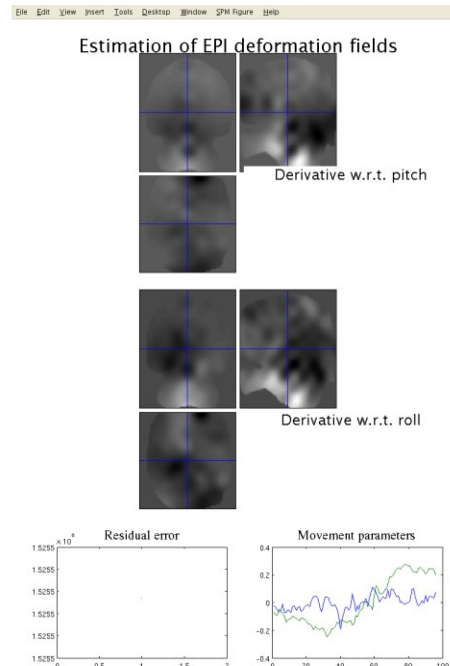


Movement-by-distortion interaction

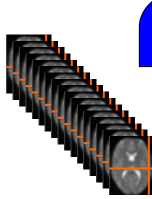


Realign & Unwarp





Correcting for distortion changes

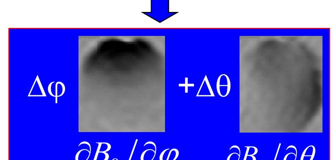


Estimate movement parameters.

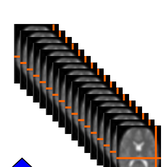
Estimate reference from mean of all scans.

Estimate new distortion fields for each image:

- estimate rate of change of field with respect to the current estimate of movement parameters in **pitch** and **roll**.



Unwarp time series.



Andersson et al, 2001

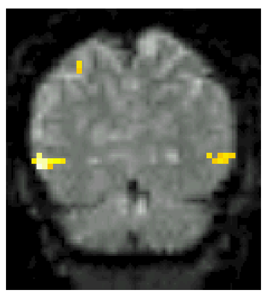
Contents

* Preliminaries
* Realignment

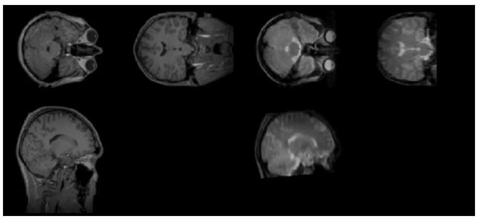
* **Coregistration**
  * **Coregistration by maximising mutual information**

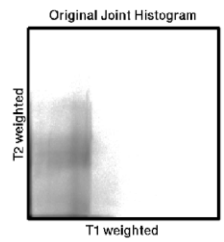
Coregistration

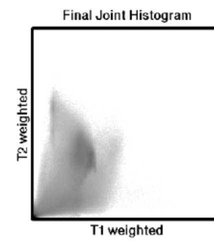
- Inter-modal registration.
- Match images from same subject but different modalities:
  - anatomical localisation of single subject activations
  - achieve more precise spatial normalisation of functional image using anatomical image.



Coregistration maximises Mutual Information

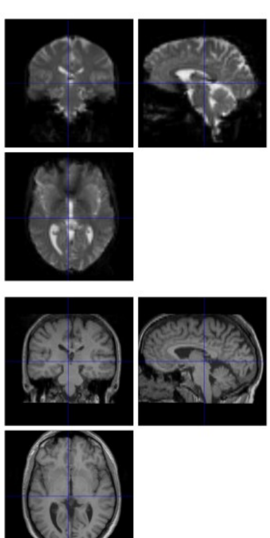




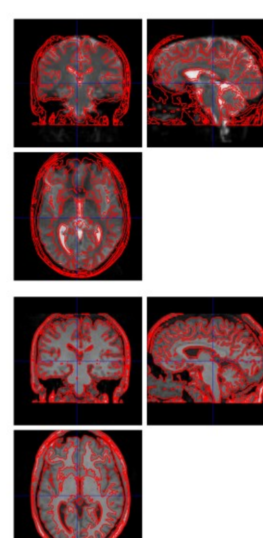


- Used for between-modality registration
- Derived from joint histograms
- MI= $\int_{ab} P(a,b) \log_2 [P(a,b)/(P(a) P(b))]$
  - Related to entropy: MI = -H(a,b) + H(a) + H(b)
    - Where $H(a) = -\int_a P(a) \log_2 P(a)$ and $H(a,b) = -\int_a P(a,b) \log_2 P(a,b)$

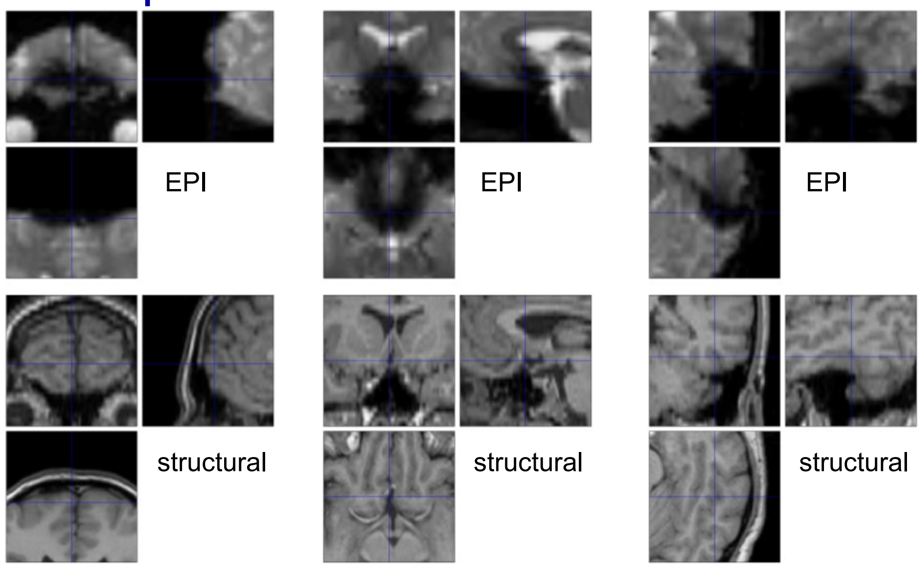
"Check Reg" to assess alignment



Check Reg allows contours from one image can be shown superimposed on another



EPI dropout and distortion



References

* Friston et al. *Spatial registration and normalisation of images*. Human Brain Mapping 3:165-189 (1995).
* Collignon et al. *Automated multi-modality image registration based on information theory*. IPMI’95 pp 263-274 (1995).
* Thévenaz et al. *Interpolation revisited*. IEEE Trans. Med. Imaging 19:739-758 (2000).
* Andersson et al. *Modeling geometric deformations in EPI time series*. Neuroimage 13:903-919 (2001).