



Image Preprocessing for ~~Idiots~~^{ELL}

*Realignment, slice timing,
normalisation, optimisation, @#!\$%...*



Elliot Freeman, ICN.

Why preprocess?

- Goals:
 - Track patterns of activity over time
 - Localise patterns re. anatomy
 - Compare activity between subjects
- Problems
 - Head movements
 - Different modalities
 - Between-subject differences

Preprocessing sequence


- Realignment
 - Motion correction
- Coregistration
 - Overlay structural and functional
- Normalisation
 - Warp to fit to standard template brain
- Optional extras
 - Slice time correction; unwarping

Realignment (within-modality registration)

- **Benefits**

- Identify common activation sites between successive slices
- Eliminate motion artefacts -> increase S/N
- Covary-out movements correlated with tasks
- Morphometry: coregister and compare structurals

General steps for transforming

- 
- **Coregister images**
 - Choose transformation parameters
 - **Apply transformation**
 - Create new transformed images from old
 - Interpolate over borders of old voxels
 - **Optimise parameters**
 - Measure mismatch between source and reference images.
 - Iterate until mismatch is minimised

Registration

- Rigid-body model

- head movements do not affect head shape
- Six parameters:
 - 3x translations & 3x rotations

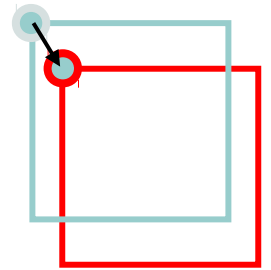
- New coordinates are a linear combination of old:

$$x_1 = mx_0 + my_0 + mz_0 + m$$

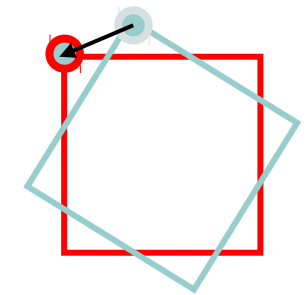
or in matrix algebra

$$[x_1 \ y_1 \ z_1] = M \times [x_0 \ y_0 \ z_0]$$

$$\begin{pmatrix} x_0 \\ y_0 \\ z_0 \\ 1 \end{pmatrix} = \begin{pmatrix} 1 & 0 & 0 & x_t \\ 0 & 1 & 0 & y_t \\ 0 & 1 & 1 & z_t \\ 0 & 1 & 0 & 1 \end{pmatrix} \begin{pmatrix} x_1 \\ y_1 \\ z_1 \\ 1 \end{pmatrix}$$



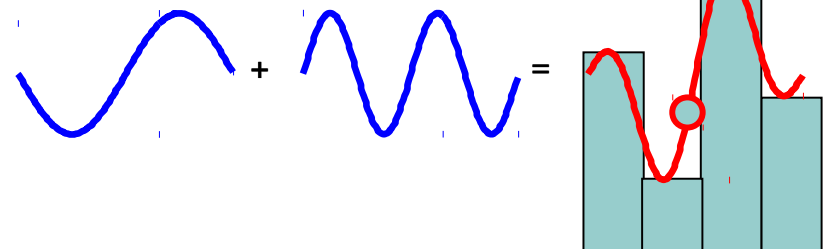
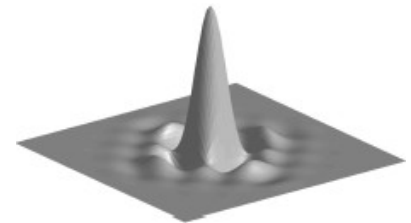
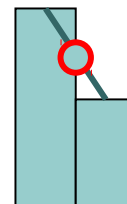
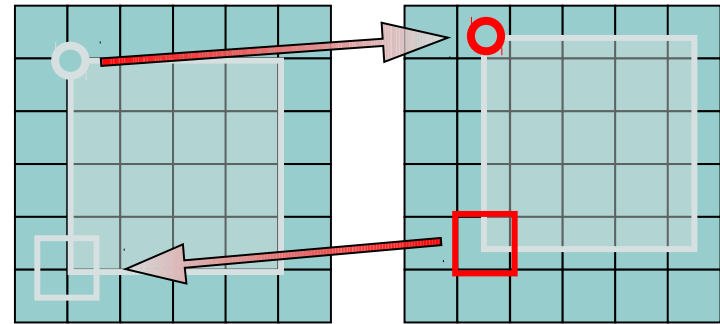
$$\begin{pmatrix} x_0 \\ y_0 \\ z_0 \\ 1 \end{pmatrix} = \begin{pmatrix} \cos(\Omega) & \sin(\Omega) & 0 & 0 \\ -\sin(\Omega) & \cos(\Omega) & 0 & 0 \\ 0 & 1 & 1 & 0 \\ 0 & 1 & 0 & 1 \end{pmatrix} \begin{pmatrix} x_1 \\ y_1 \\ z_1 \\ 1 \end{pmatrix}$$



...Two more matrices for rotations about x and y axes, & two more parameters to estimate...

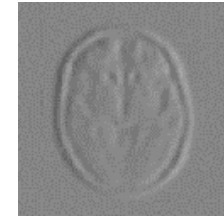
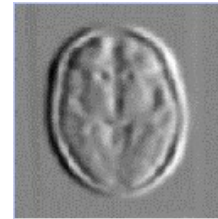
Transformation & interpolation

- Create new transformed image
 - Estimate intensity of a new voxel from corresponding intensity in old image
- Interpolation across old voxel boundaries
 - Estimate from neighbours, trilinear, sinc
 - Generalised (SPM2): reconstruct image from linear combination of basis functions. More efficient.



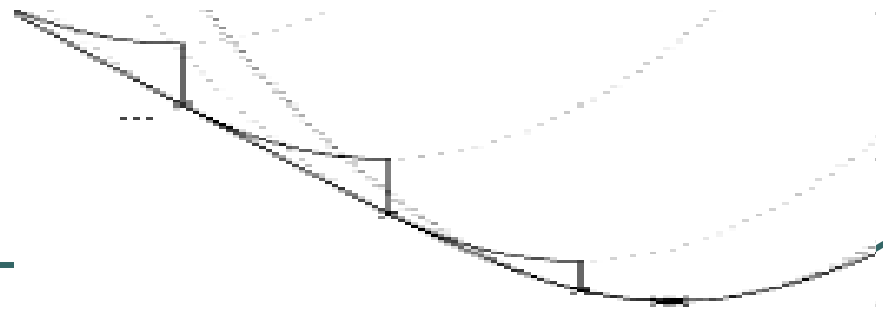
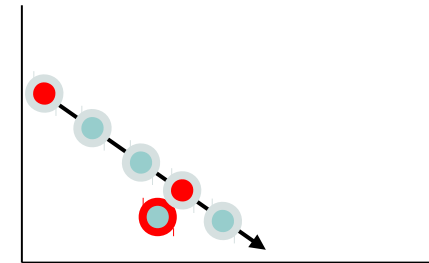
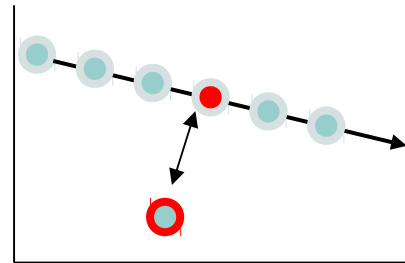
Optimise parameters

- Calculate mismatch between images
- Estimate parameters of transform matrix to reduce mismatch
- Minimise mismatch (χ^2) by adjusting parameters
- Reiterate until there is no further improvement
- Better with smoothing



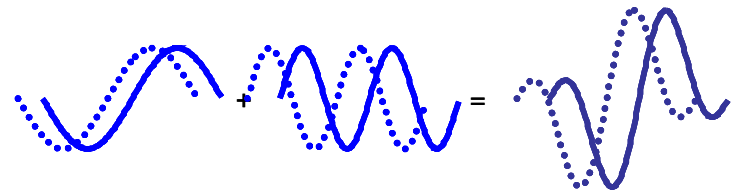
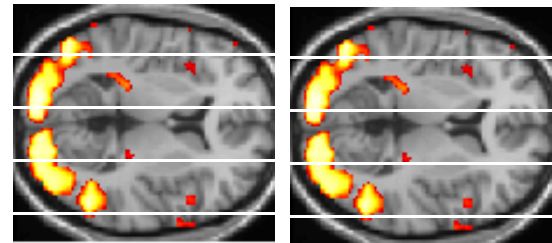
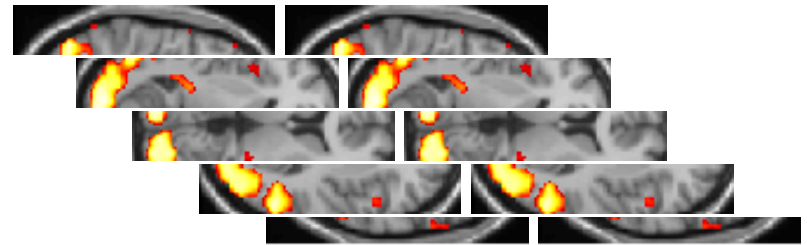
$$\begin{bmatrix} m_{11} & m_{12} & m_{13} & m_{14} \\ m_{21} & m_{22} & m_{23} & m_{24} \\ m_{31} & m_{32} & m_{33} & m_{34} \\ 0 & 0 & 0 & 1 \end{bmatrix}$$

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Slice timing correction

- Different slices acquired at different times
- 'Time warp', as if slices were acquired simultaneously
- Centre reference slice limits maximum lag to $TR/2$: centre. User-adjusted to minimise interpolation over region-of-interest
- Option to synchronize events with covariates
- Temporal interpolation: shift phase of sinusoidal components of signal



Slice timing correction: issues

- Before realignment?
 - Assume head is still: one slice of brain per slice of time.
 - Head movements can cause slice-overlap or separation
-> interpolation over wrong brain areas
 - Realignment may propagate error to other volumes.
- After realignment?
 - Realignment after head movement may shift voxels onto successive slices -> incorrect temporal ordering
- Generally best with shorter TR

Unwarping

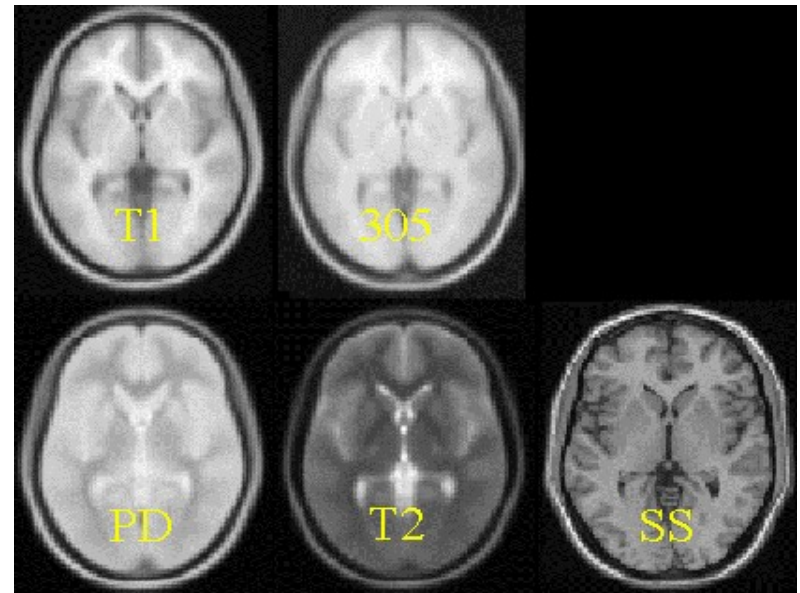
- Different tissues react differently to magnetization -> field distortions at interfaces
- Pattern depends on subject's position in field gradient -> 'susceptibility-by-movement' interaction: Fairground mirror effect.
- Movement creates variance in image.
- Cannot be corrected by rigid-body model
- Model 'deformation field'
- Predict (and covary out) variance caused by motion through distorting field

Residual errors

- Head movements within a TR violate non-rigid model
- Resampling errors.
- Better with dithering
- Spin-excitation history: delay for tissue to recover from magnetism; movement causes different regions to be excited on each cycle
- Estimated motion parameters can be used as covariates, but only if they don't correlate with experimental variables

Between-modality coregistration

- Benefits
 - Match activations with anatomical sites, PET
 - Increase precision of normalisation based on structural details
- Problems
 - Different modalities have very different intensity maps. Often non-linear relationship
 - fMRI images usually distorted in phase-encode direction. Differences between scanners. Need non-linear warping too.

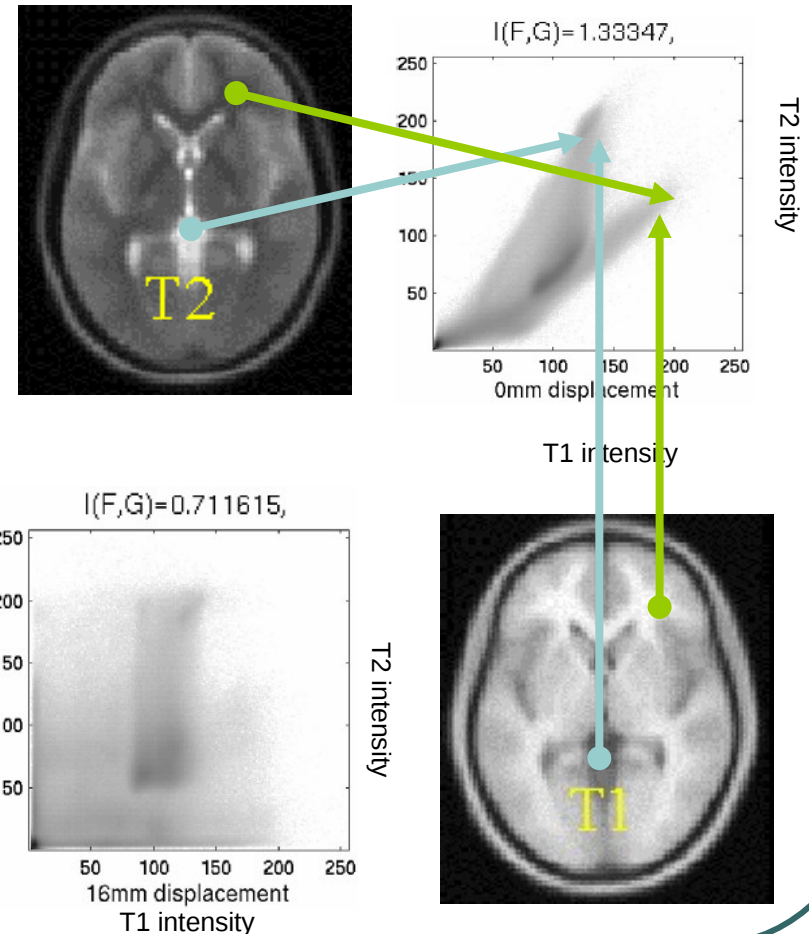


Coregistration methods

- Partitioning method (3 step):
 - Determine same-modality transformation to functional and structural templates
 - Segment images using Bayesian probability maps: produces modality-independent images
 - Coregister image partitions, constrained by boundaries identified by segmentation
- Obsolete in SPM2

Coregistration: Information Theoretic approach

- Assume close mapping between intensities from different modalities
- Joint histograms
 - Scan voxel by voxel
 - Find intensity of same voxel in T1 and T2
 - Increment bin for that specific combination
- Mutual Information
 - Quantifies dependence between images
 - Related to deviation from diagonal and dispersion (entropy) of pattern
- Transform images to maximise MI



Normalisation

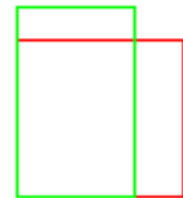
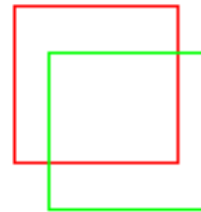
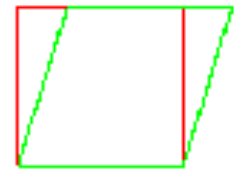
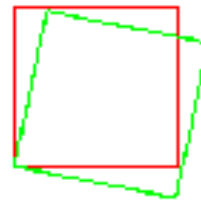
- **Goals**
 - Identify commonalities and differences between subjects
 - Morphometry
 - Increase signal-to-noise
 - Derive group statistics
 - Essential for performing contrasts
 - Report results in standard coordinates (e.g. Talairach)

Normalisation: issues

- Affine transforms not sufficient: Non-linear solutions required
 - Optimally, move each voxel around until it fits. Millions of dimensions.
 - Trade off dimensionality with performance
- Perfection is not good enough:
 - Structural alignment doesn't guarantee functional alignment.
 - Fit is limited by differences in gyral anatomy and physiology between subjects. Perfect mapping will fold brain to create non-existent features
 - Smoothing eliminates unnecessary fine detail
- Regularization: use prior information about what fit is most likely.

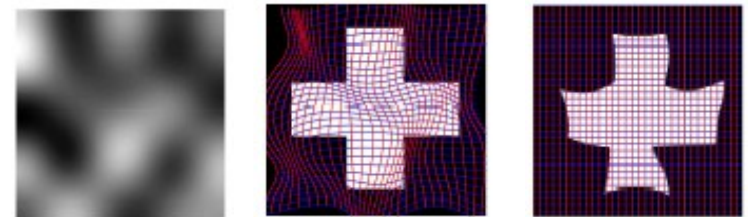
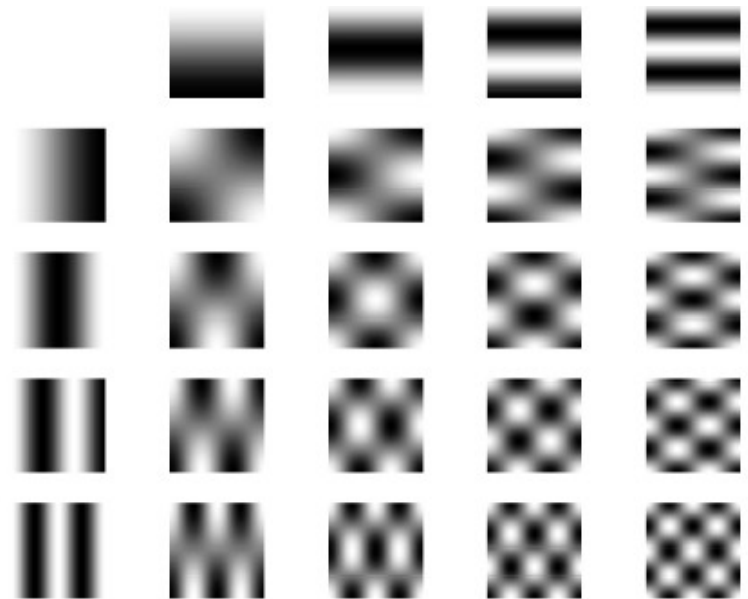
Normalisation: methods

- affine transform
 - rigid-body + shears and zooms = 12 params
 - zoom fails with insufficient slices (e.g. non-isotropic voxels)
 - prior data helps predict z-zoom from x&y-zoom



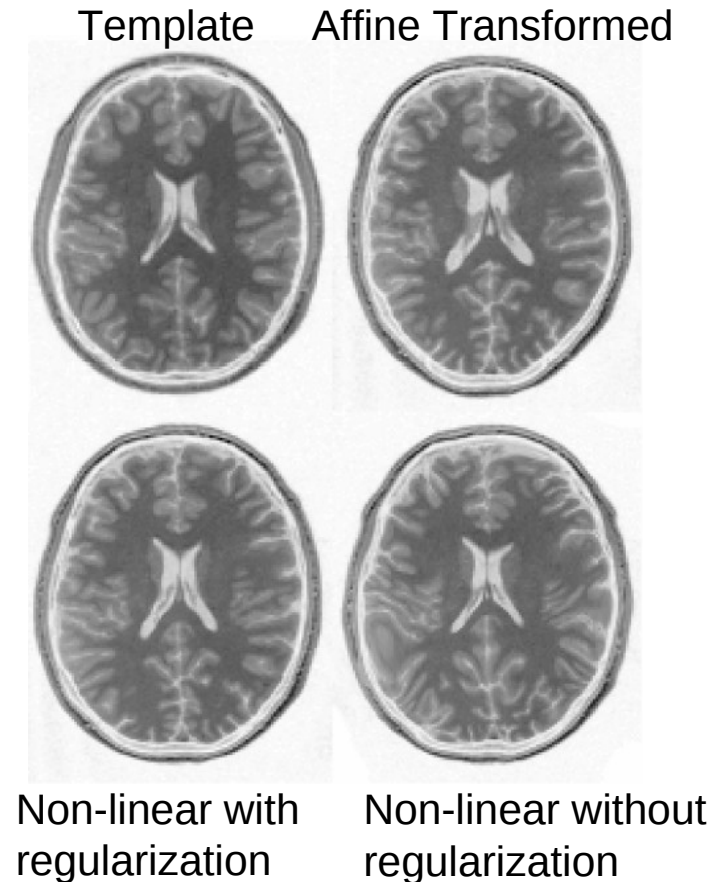
Non-linear warping: low dimensionality

- Construct transformation from a linear combination of bases
 - Each function describes transformation: positive and negative values shift voxel in opposite directions.
 - E.g. stretch function = [1 2 3 4 5 ...]
 - Only a few functions required -> few dimensions to search



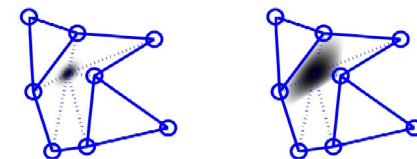
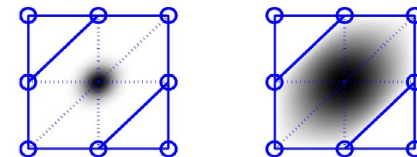
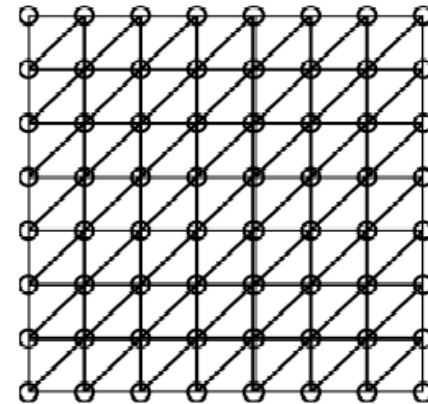
Optimisation & Regularisation

- Optimisation
 - Minimise sum of square differences χ^2 by updating weighting for each base
- Regularization
 - Minimise deviation of parameters from prior expectation



High-dimensional warping

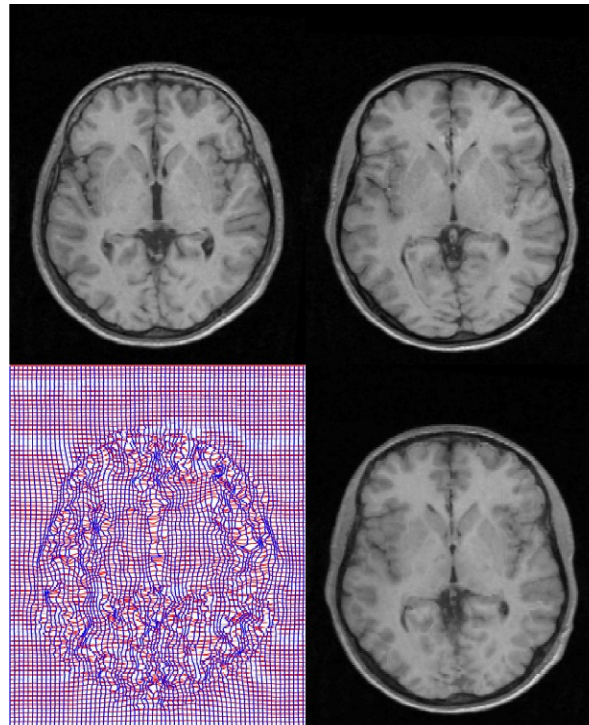
- Model brain as mesh of interlocking triangles
- Perform affine transformation for local clusters of nodes
- Minimise image mismatch
- Simultaneously minimise how much the deformation field deviates from prior map of most likely distortions



Warping Results

Source

Template



Deformation
field

Warped
image

How dumb was that?

