Anatomical Measures

John Ashburner
John@fil.Ion.Ucl.Ac.Uk

- Segmentation
- Morphometry

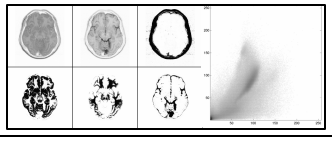
Contents

- Segmentation
  - Gaussian mixture model
  - Including prior probability maps
  - Intensity non-uniformity correction
- Morphometry

$$E = -\log P(y \mid ?) = -\sum_{i=1}^{I} \log P(y_i \mid ?) = -\sum_{i=1}^{I} \log \left[\sum_{k=1}^{K} P(y_i \mid k, ?) P(k) \right] = -\sum_{i=1}^{I} \log \left[\sum_{k=1}^{K} \frac{\gamma_k}{\sqrt{2\pi\sigma_k^2}} \exp\left(-\frac{(y_i - \mu_k)^2}{2\sigma_k^2} \right) \right]$$

Segmentation - Mixture Model

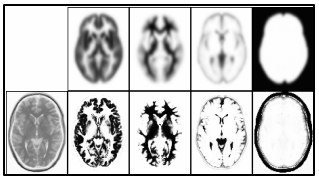
- Intensities are modelled by a mixture of K gaussian distributions, parameterised by:
  - Means
  - Variances
  - Mixing proportions
- Can be multi-spectral
  - Multivariate gaussian distributions



$$E = -\sum_{i=1}^{I} \log \left[\sum_{k=1}^{K} \frac{\gamma_k}{\sqrt{2\pi\sigma_k^2}} \frac{q_{ij}}{\sum_{j=1}^{J} q_{ij}} \exp\left(-\frac{(y_i - \mu_k)^2}{2\sigma_k^2} \right) \right]$$

Segmentation - Priors

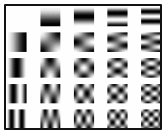
- Overlay prior belonging probability maps to assist the segmentation
  - Prior probability of each voxel being of a particular type is derived from segmented images of 151 subjects
    - Assumed to be representative
  - Requires initial registration to standard space

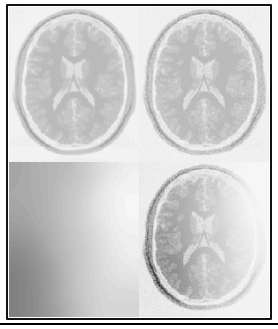


$$E = -\sum_{i=1}^{I} \log \left[\rho_i(\beta) \sum_{k=1}^{K} \frac{\gamma_k}{\sqrt{2\pi\sigma_k^2}} \frac{q_{ij}}{\sum_{j=1}^{J} q_{ij}} \exp\left(-\frac{(\rho_i(\beta) y_i - \mu_k)^2}{2\sigma_k^2} \right) \right]$$

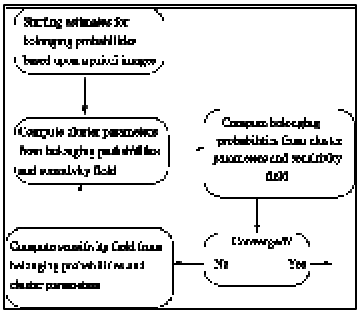
Segmentation - Bias Correction

- A smooth intensity modulating function can be modelled by a linear combination of DCT basis functions



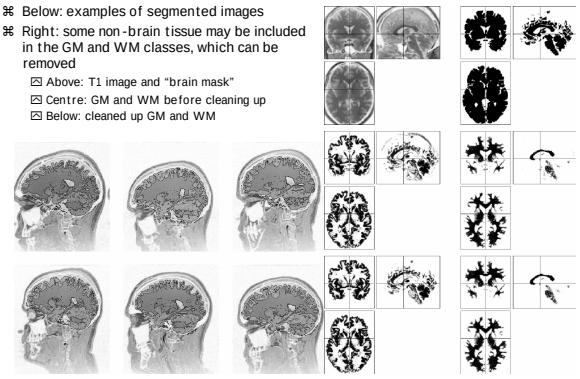


Segmentation - Algorithm



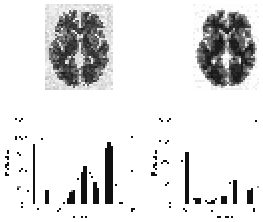
- Results contain some non-brain tissue
- Removed automatically using morphological operations
  - Erosion
  - Conditional dilation

- Below: examples of segmented images
- Right: some non-brain tissue may be included in the GM and WM classes, which can be removed
  - Above: T1 image and "brain mask"
  - Centre: GM and WM before cleaning up
  - Below: cleaned up GM and WM

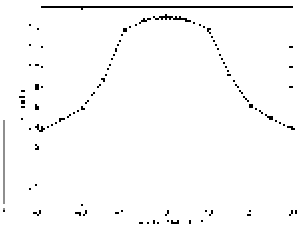


Known Problems

Partial volume effects can be problematic - no longer Gaussian



Mis-registration with the prior probability images results in poor classification. This figure shows the effect of translating the image relative to the priors before segmenting.



Other Limitations

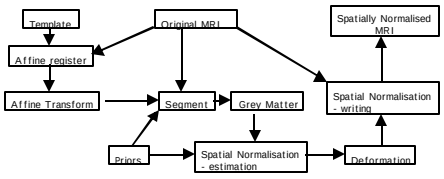
- Assumes that the brain consists of only GM and WM, with some CSF around it.
  - No model for lesions (stroke, tumours, etc)
- Prior probability model is based on relatively young and healthy brains.
  - Less appropriate for subjects outside this population.
- Needs reasonable quality images to work with
  - artefact-free
  - good separation of intensities

Spatial Normalisation using Tissue Classes

- Multi-subject functional imaging requires GM of different brains to be in register.
- Better spatial normalisation by matching GM from segmented images, with a GM template.
- The future: Segmentation, spatial normalisation and bias correction combined into the same model.

Spatial Normalisation using Tissue Classes

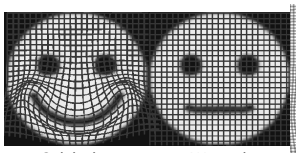
- The same strategy as for "Optimised VBM"



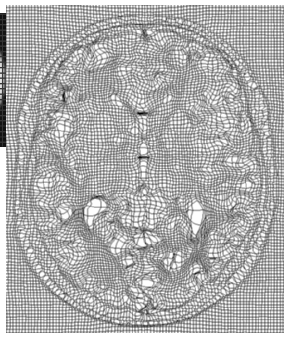
Contents

- Segmentation
- Morphometry
  - Volumes from deformations
  - Serial scans
  - Voxel-based morphometry

Deformation Field



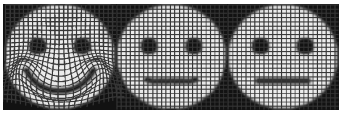
Original Warped

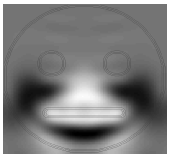


Deformation field

$$\begin{bmatrix} x' \\ y' \\ z' \end{bmatrix} = \begin{bmatrix} t_1(x,y,z) \\ t_2(x,y,z) \\ t_3(x,y,z) \end{bmatrix}$$

Jacobians





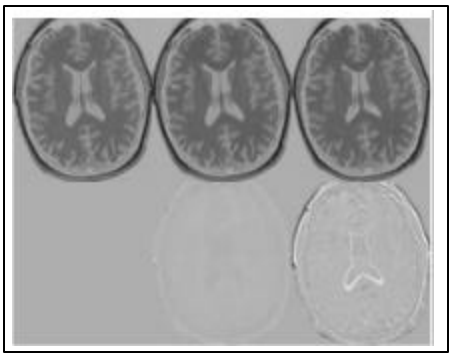
Jacobian Matrix (or just "Jacobian")

$$J = \begin{bmatrix} j_{11} & j_{12} & j_{13} \\ j_{21} & j_{22} & j_{23} \\ j_{31} & j_{32} & j_{33} \end{bmatrix} = \begin{bmatrix} \partial x'/\partial x & \partial x'/\partial y & \partial x'/\partial z \\ \partial y'/\partial x & \partial y'/\partial y & \partial y'/\partial z \\ \partial z'/\partial x & \partial z'/\partial y & \partial z'/\partial z \end{bmatrix}$$

Jacobian Determinant (or just "Jacobian") - relative volumes

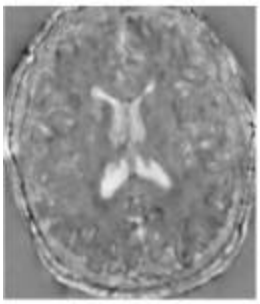
$$|J| = j_{11}(j_{22}j_{33} - j_{23}j_{32}) - j_{21}(j_{12}j_{33} - j_{13}j_{32}) + j_{31}(j_{12}j_{23} - j_{13}j_{22})$$

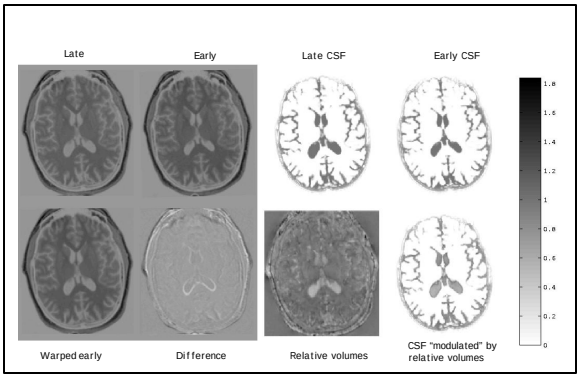
Serial Scans

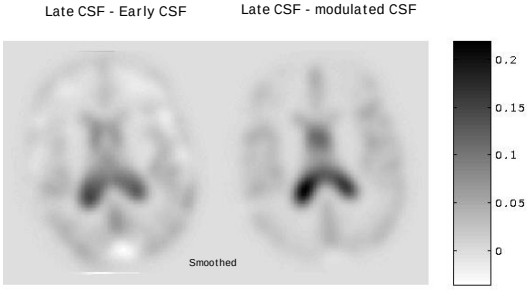


Regions of expansion and contraction

- Relative volumes encoded in Jacobian determinants.
- "Deformations Toolbox" can be used for this.
  - Begin with rigid-registration



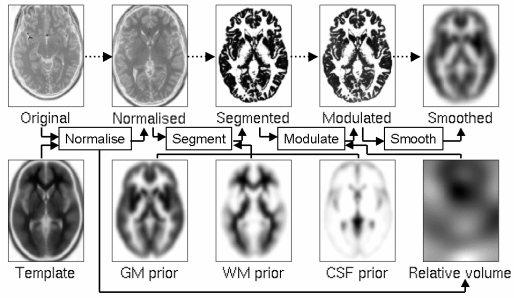




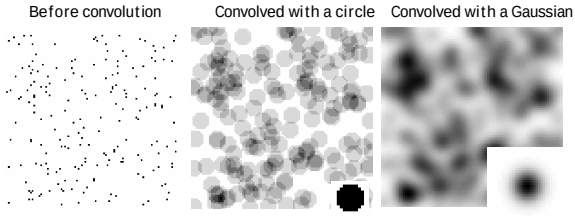
Voxel-based Morphometry

- Pre-process images of several subjects to highlight particular differences.
  - Tissue volumes
- Use mass-univariate statistics (t- and F-tests) to detect differences among the pre-processed data.
- Use Gaussian Random Field Theory to interpret the blobs.

Pre-processing for Voxel-Based Morphometry (VBM)



Units for pre-processed data



Units are mm^3 of original grey matter per mm^3 of spatially normalised space

"Globals" for VBM

- Shape is multivariate
  - Dependencies among volumes in different regions
- SPM is mass univariate
  - "globals" used as a compromise
  - Can be either ANCOVA or proportional scaling

Where should any difference between the two "brains" on the left and that on the right appear?

Nonlinearity

Caution may be needed when looking for linear relationships between grey matter concentrations and some covariate of interest.

Circles of uniformly increasing area.

Smoothed

Plot of intensity at circle centres versus area

Validity of the statistical tests in SPM

- Residuals are not normally distributed.
  - Little impact on uncorrected statistics for experiments comparing groups.
  - Probably invalidates experiments that compare one subject with a group.
    - Need to use nonparametric tests that make less assumptions.
- Corrections for multiple comparisons.
  - OK for corrections based on peak heights.
  - Not valid for corrections based on cluster extents.
    - SPM makes the inappropriate assumption that the smoothness of the residuals is stationary.
      - Bigger blobs expected in smoother regions.

References

Friston et al (1995): *Spatial registration and normalisation of images.*
Human Brain Mapping 3(3):165-189

Ashburner & Friston (1997): *Multimodal image coregistration and partitioning - a unified framework.*
NeuroImage 6(3):209-217

Collignon et al (1995): *Automated multi-modality image registration based on information theory.*
IPMI'95 pp 263-274

Ashburner et al (1997): *Incorporating prior knowledge into image registration.*
NeuroImage 6(4):344-352

Ashburner et al (1999): *Nonlinear spatial normalisation using basis functions.*
Human Brain Mapping 7(4):254-266

Ashburner & Friston (2000): *Voxel-based morphometry - the methods.*
NeuroImage 11:805-821