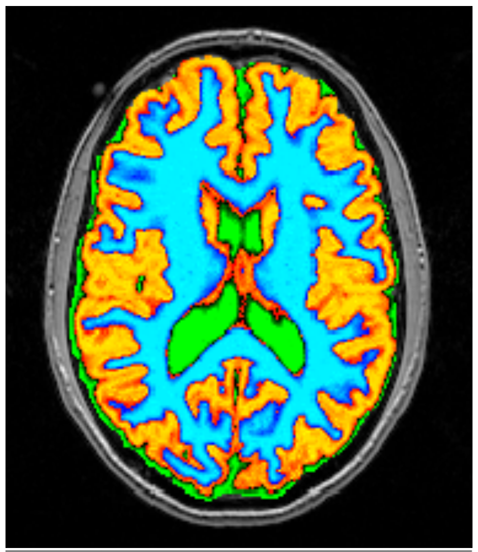
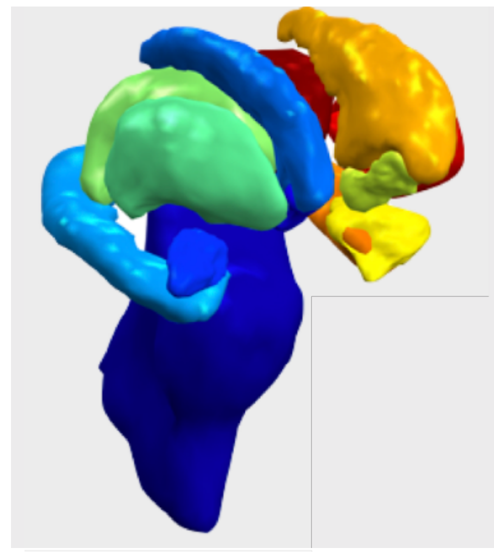
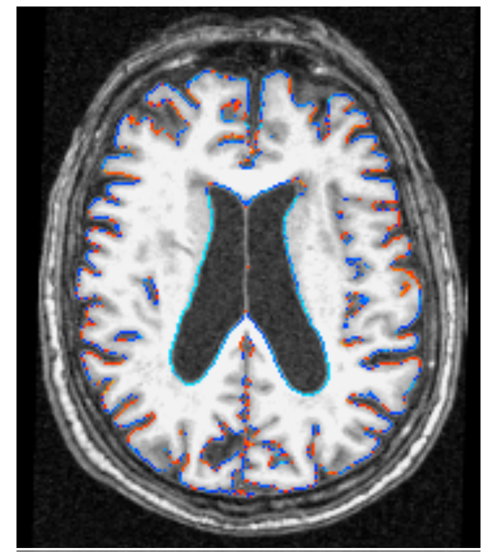
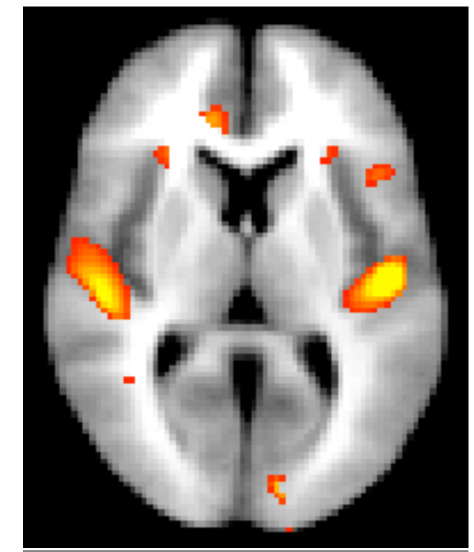
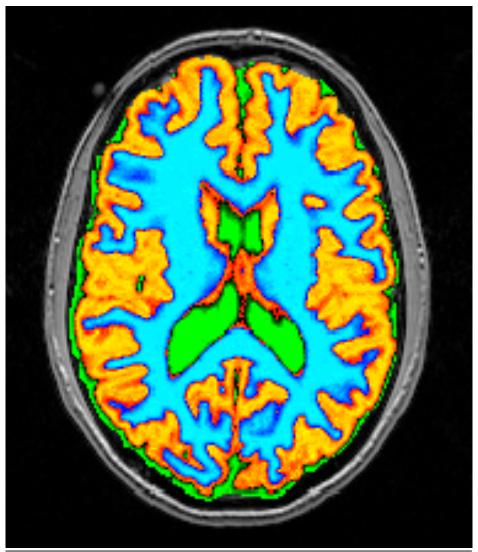
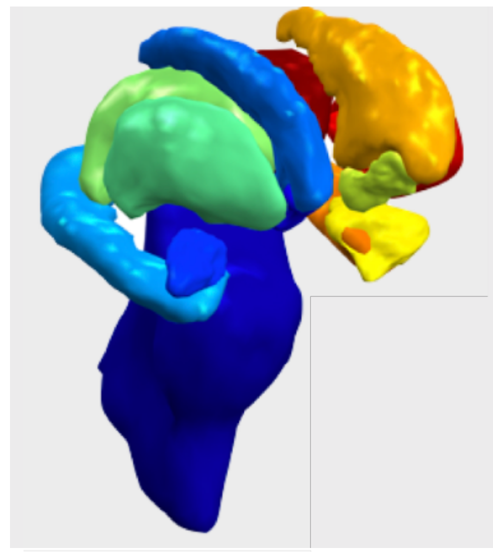
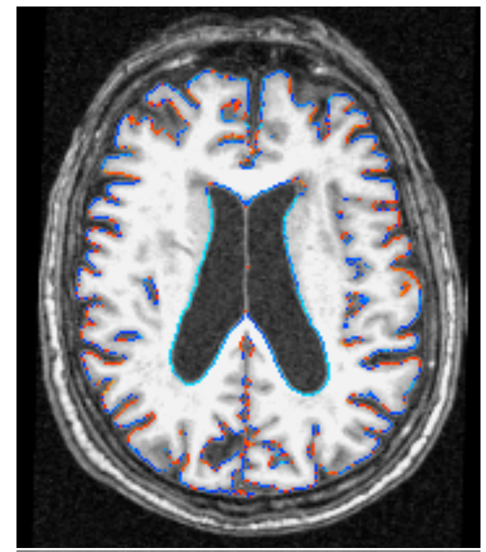
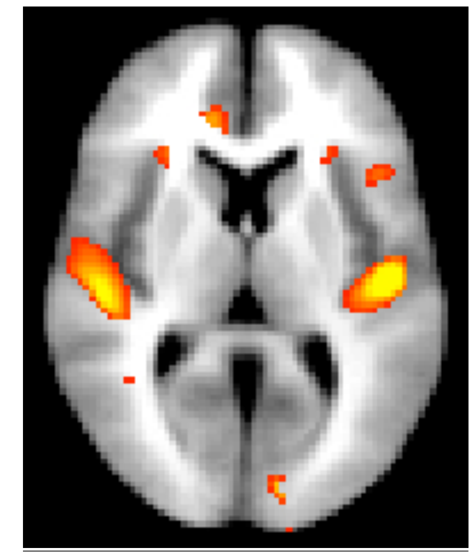
Structural Segmentation

- FAST tissue-type segmentation
- FIRST sub-cortical structure segmentation
- BIANCA segmentation of white matter lesions
- FSL-VBM voxelwise grey-matter density analysis
- SIENA/SIENAX global atrophy estimation

Structural Segmentation

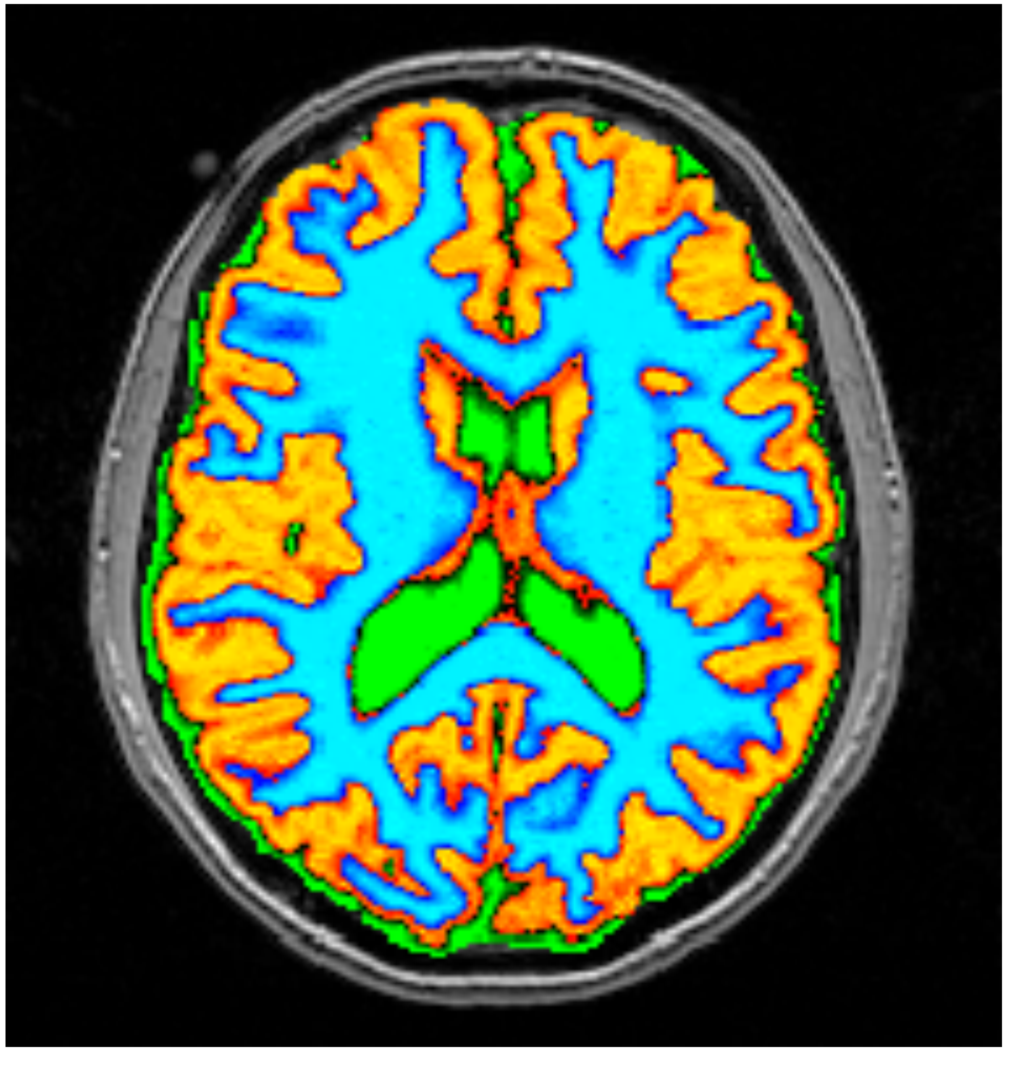
   

- FAST tissue-type segmentation
- FIRST sub-cortical structure segmentation
- BIANCA segmentation of white matter lesions
- FSL-VBM voxelwise grey-matter density analysis
- SIENA/SIENAX global atrophy estimation

FAST

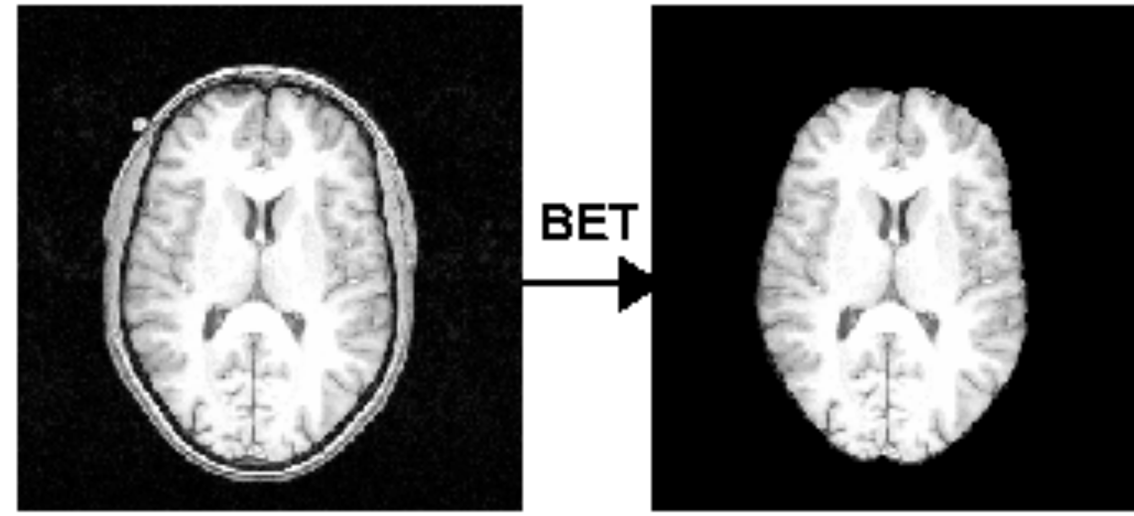
FMRIB's Automated Segmentation Tool

generic tissue-type segmentation and bias field correction



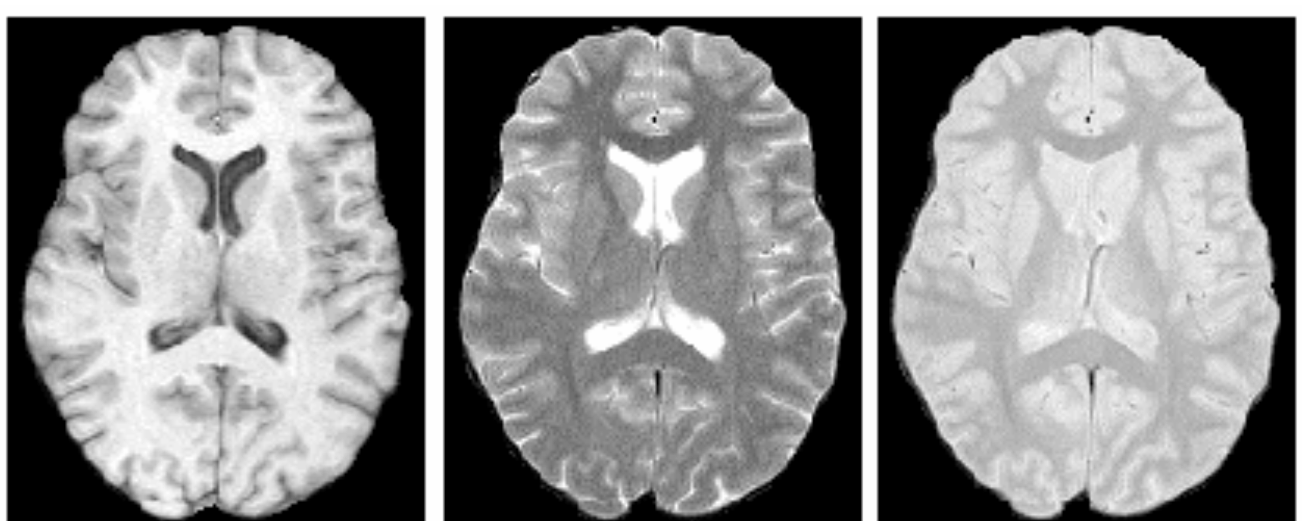
FAST: Input

- First use BET to remove non-brain
  All *volumetric* results are
  highly sensitive to errors here.
  For *bias-field correction alone* the
  errors do not matter that much



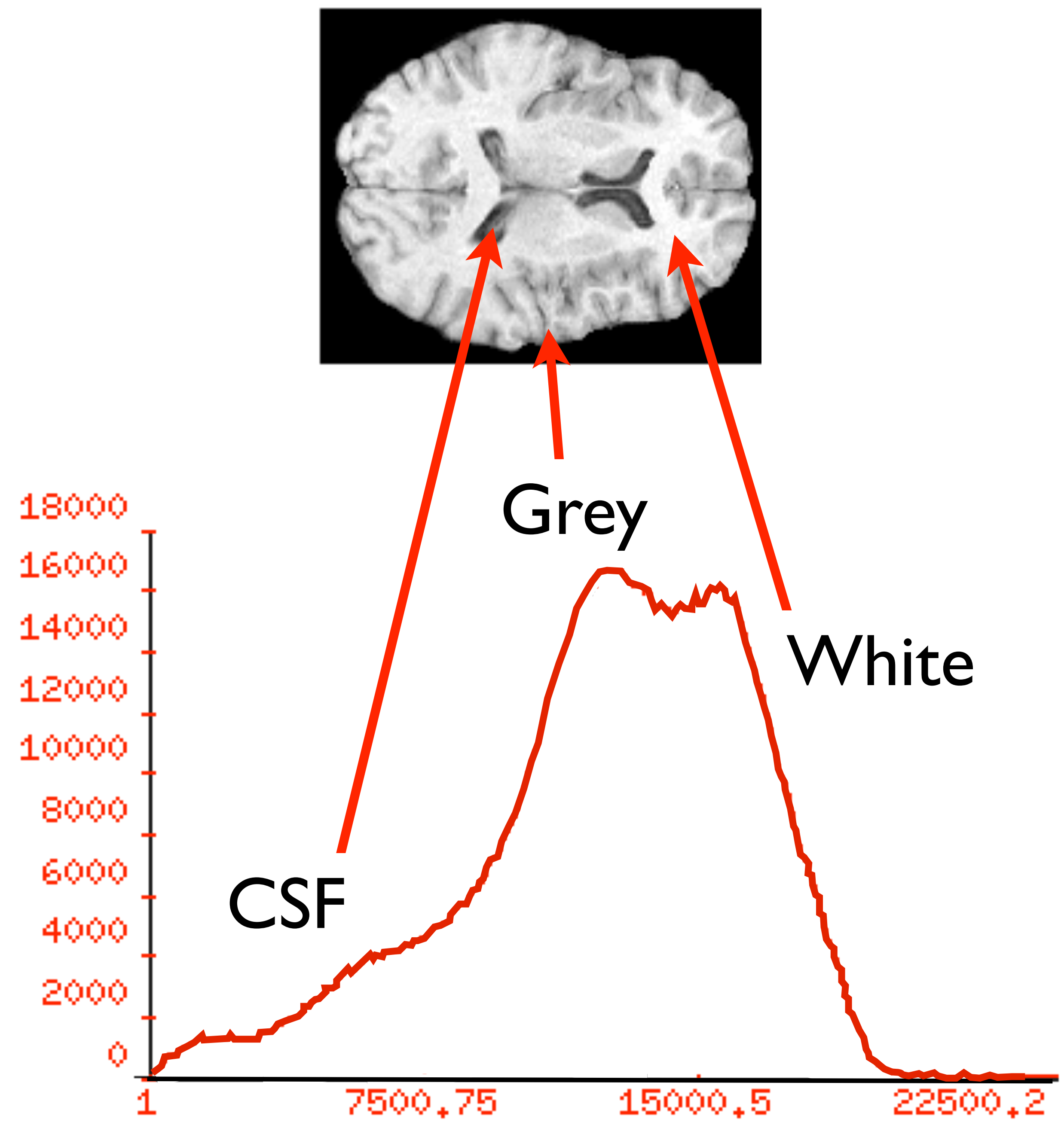
- Input is normally a single image (T1, T2, proton-density....)

- Or several inputs ("multichannel")
- For multi-channel, all must be pre-aligned (FLIRT)



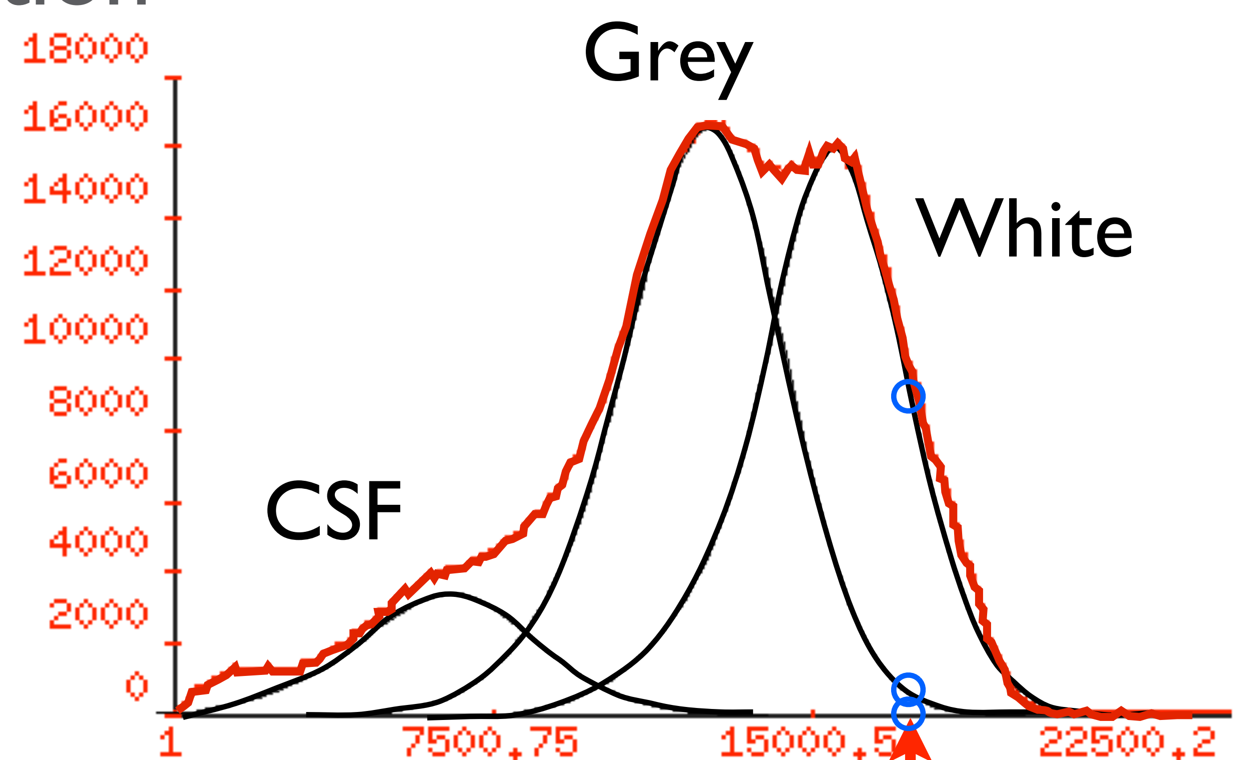
Intensity Model
tissue intensity distributions

- Histogram = voxel count vs. intensity
- Model = mixture of Gaussians
- If well separated, have clear peaks; then segmentation easy
- Overlap worsened by:
  - Bias field
  - Blurring
  - Low resolution
  - Head motion
  - Noise



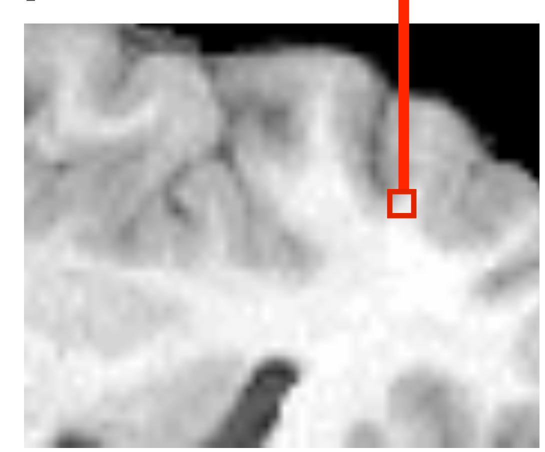
Probability Model

- Histogram = probability distribution function
- Model = mixture of Gaussians
- Probability determined for each tissue class



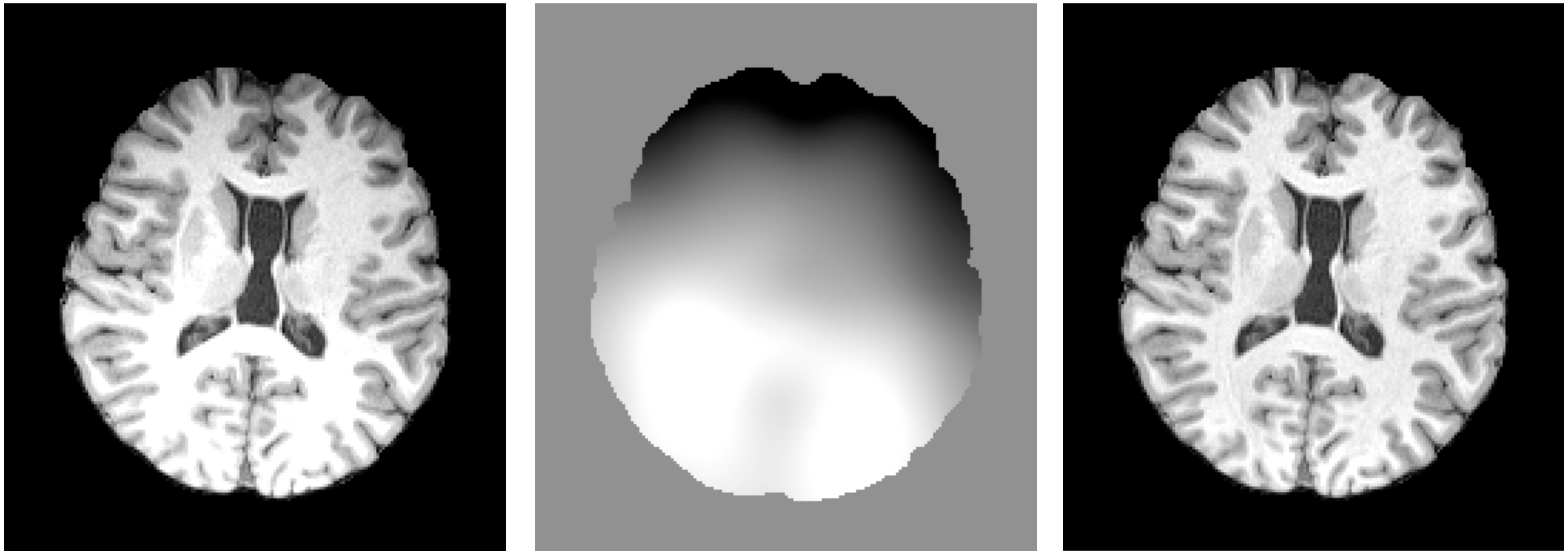
For example:
Voxel near WM/GM border

Intensity = 17203



P(CSF) near zero
P(GM) low
P(WM) moderate

Bias Field Correction

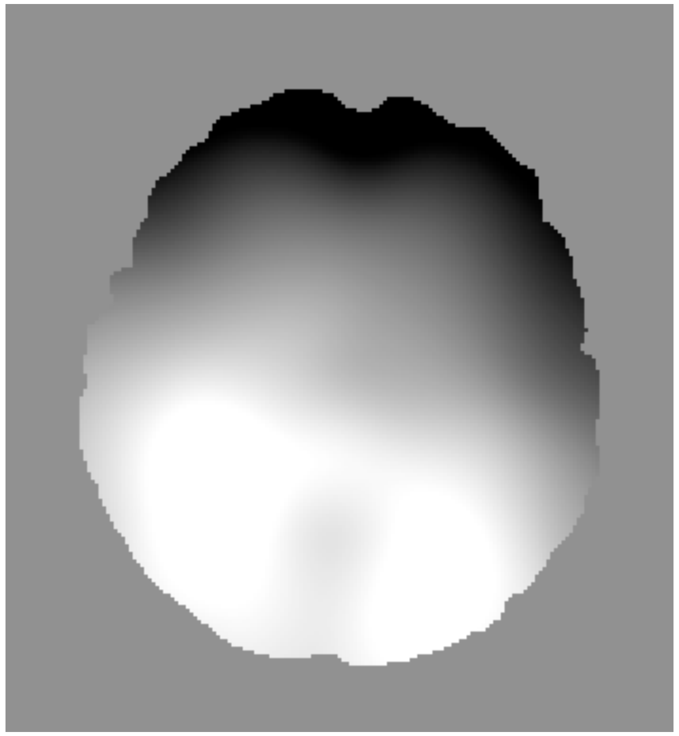


Original   Bias   Restored

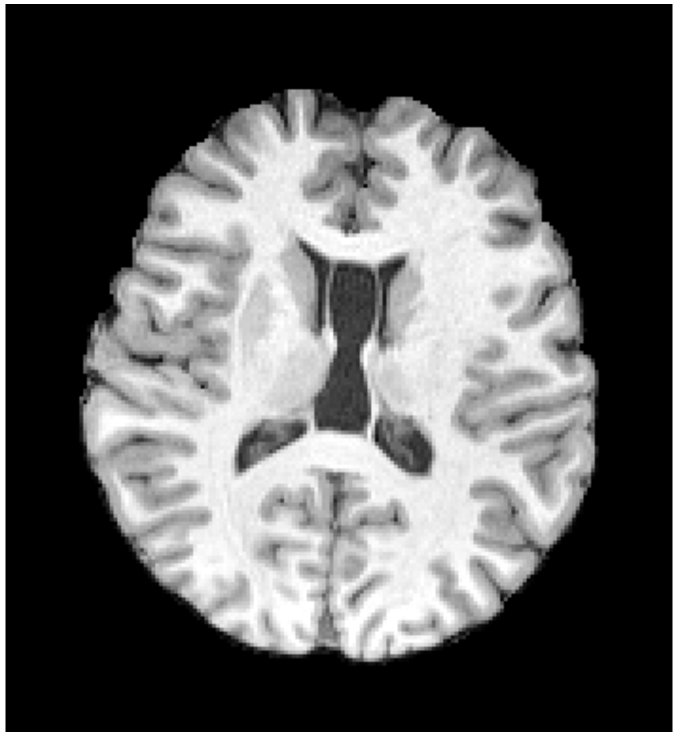
- MRI RF (radio-frequency field) inhomogeneity causes intensity variations across space
- Causes problems for segmentation
- Need to remove bias field before or during segmentation
- Becomes more common and problematic at high field

Bias Field Correction

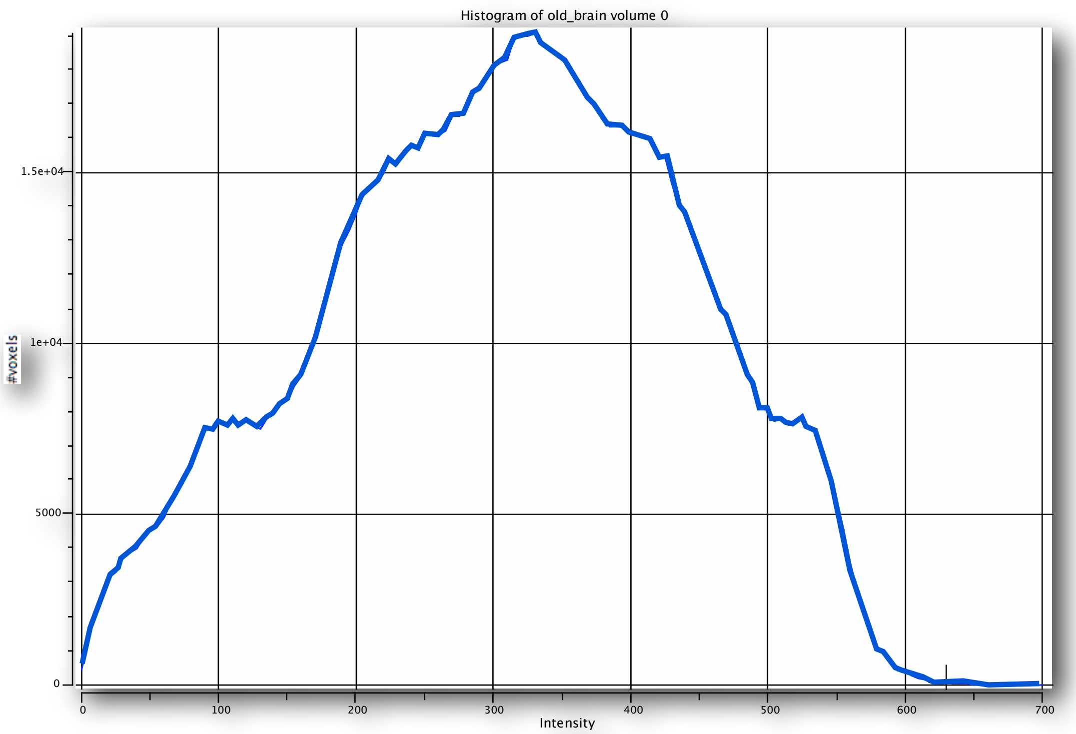
Original

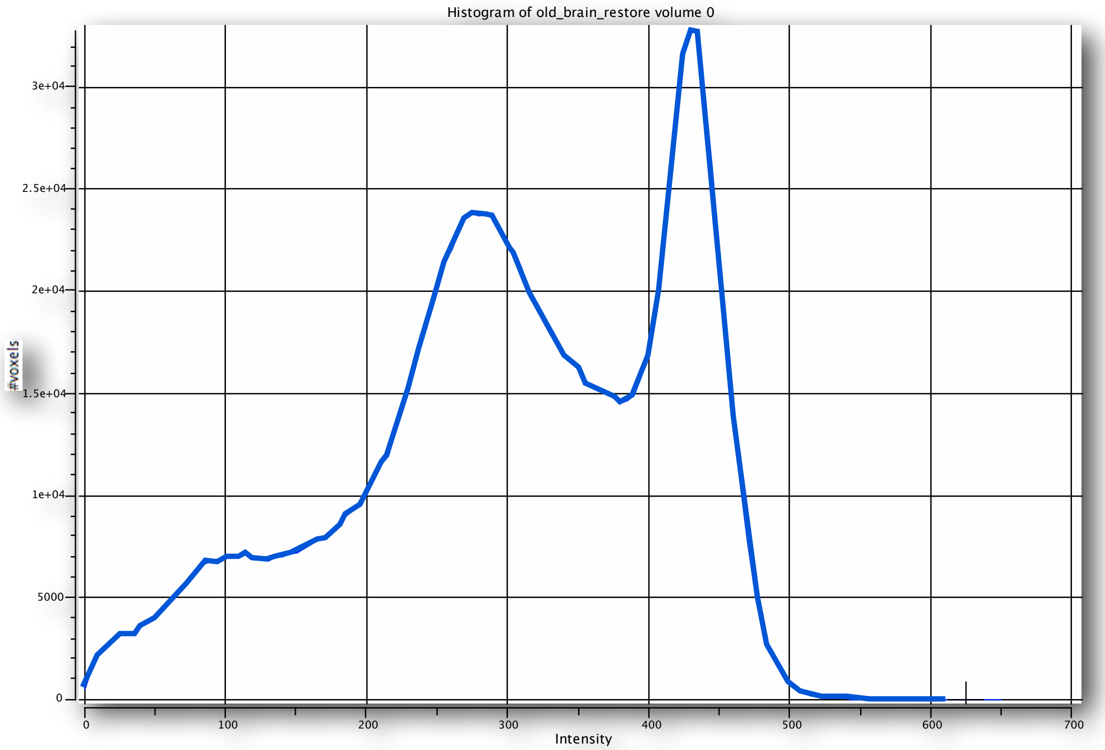


Bias



Restored

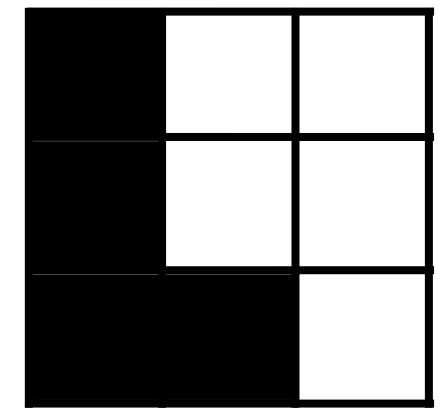




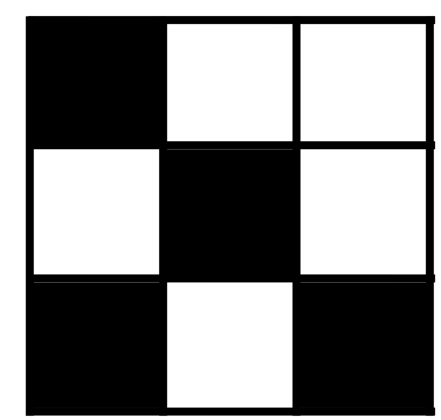
Histograms

Use Spatial Neighbourhood Information (MRF)

- Neighbourhood information: "if my neighbours are grey matter then I probably am too"
- Simple classifiers (like K-means) do not use spatial neighbourhood information
- More robust to noise
- Need the right balance between believing neighbours or intensity



Likely configuration
High probability



Unlikely configuration
Low probability

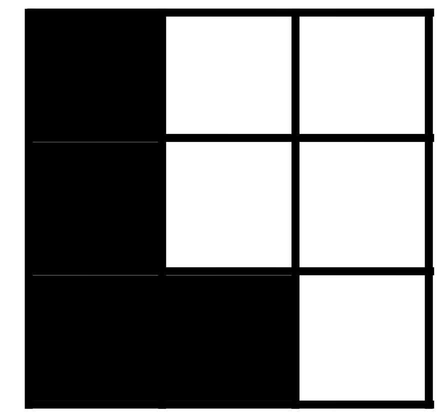
Use Spatial Neighbourhood Information (MRF)

Combine with probability based on Gaussian Mixture Model:

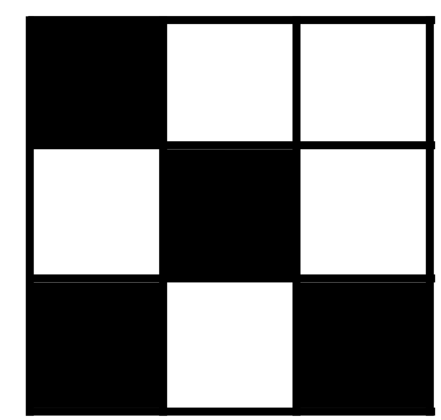
Final log probability =
log p(intensity) + β log p(MRF)

Final result depends on β value

This is user-adjustable

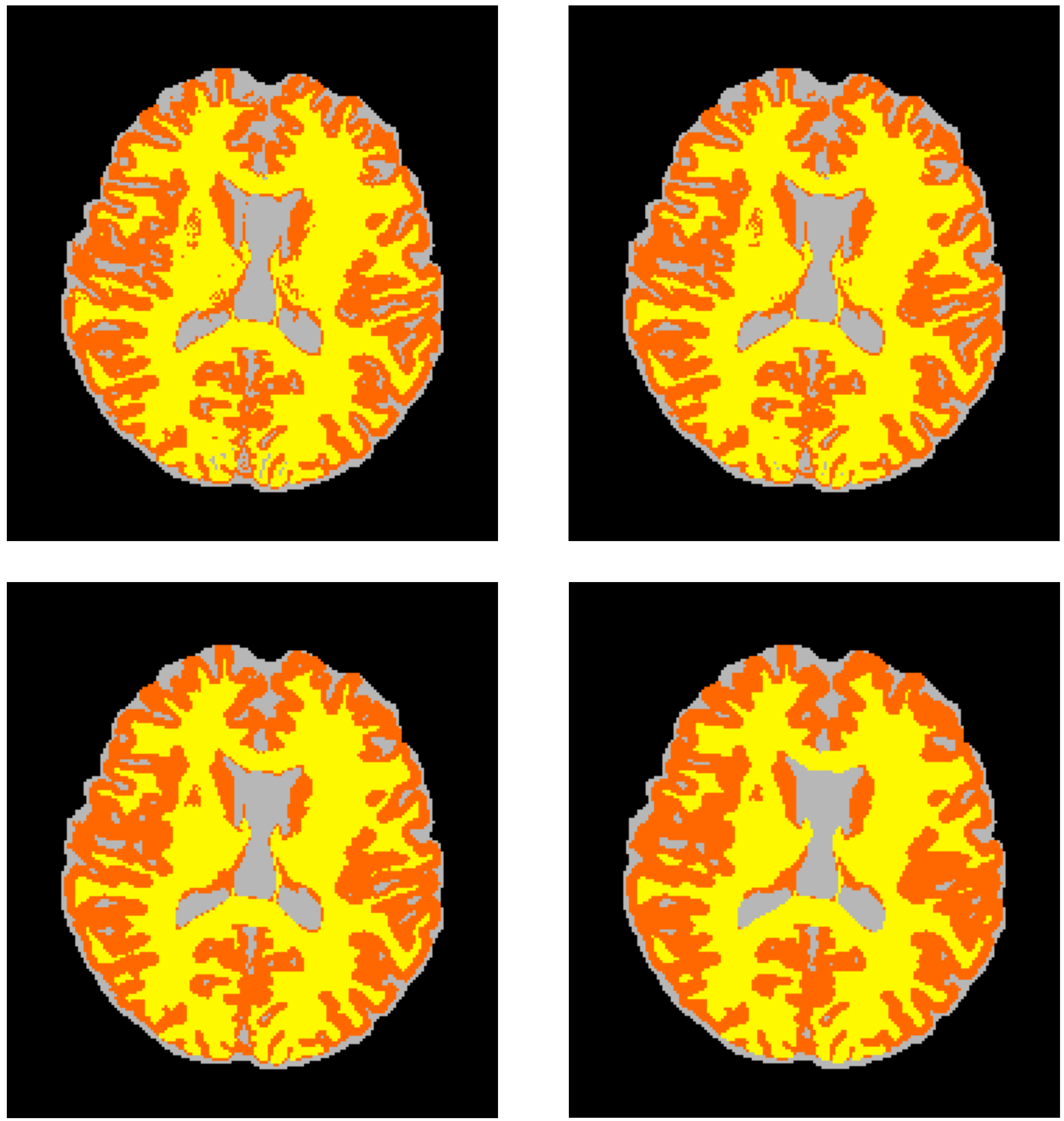


Likely configuration
High probability



Unlikely configuration
Low probability

Effect of MRF Weighting



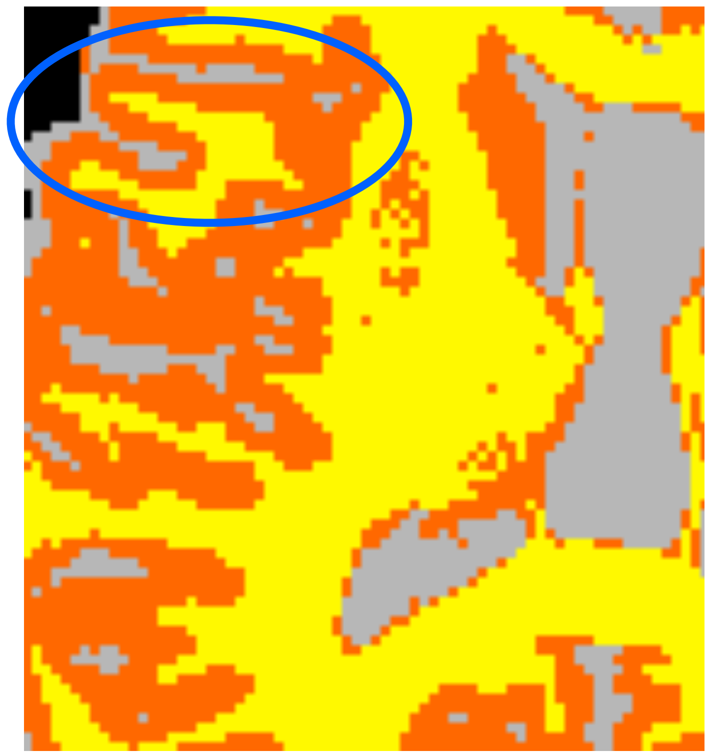
β=0

β=0.1

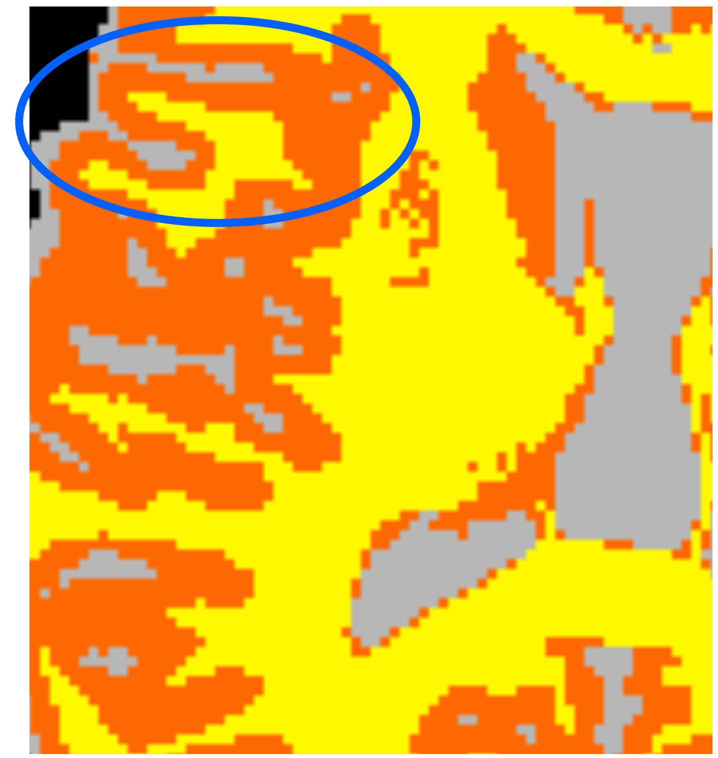
β=0.3

β=0.5

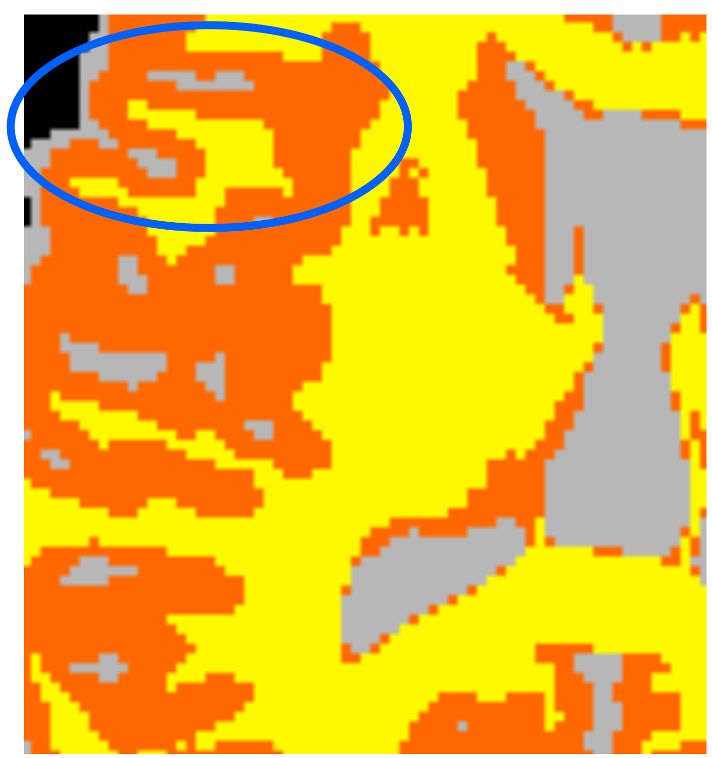
Effect of MRF Weighting



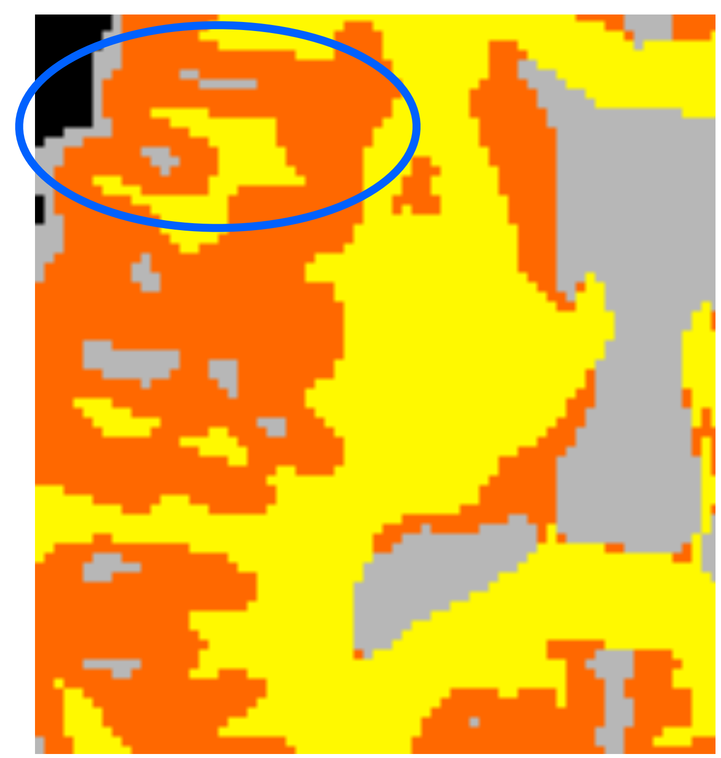
β=0



β=0.1



β=0.3

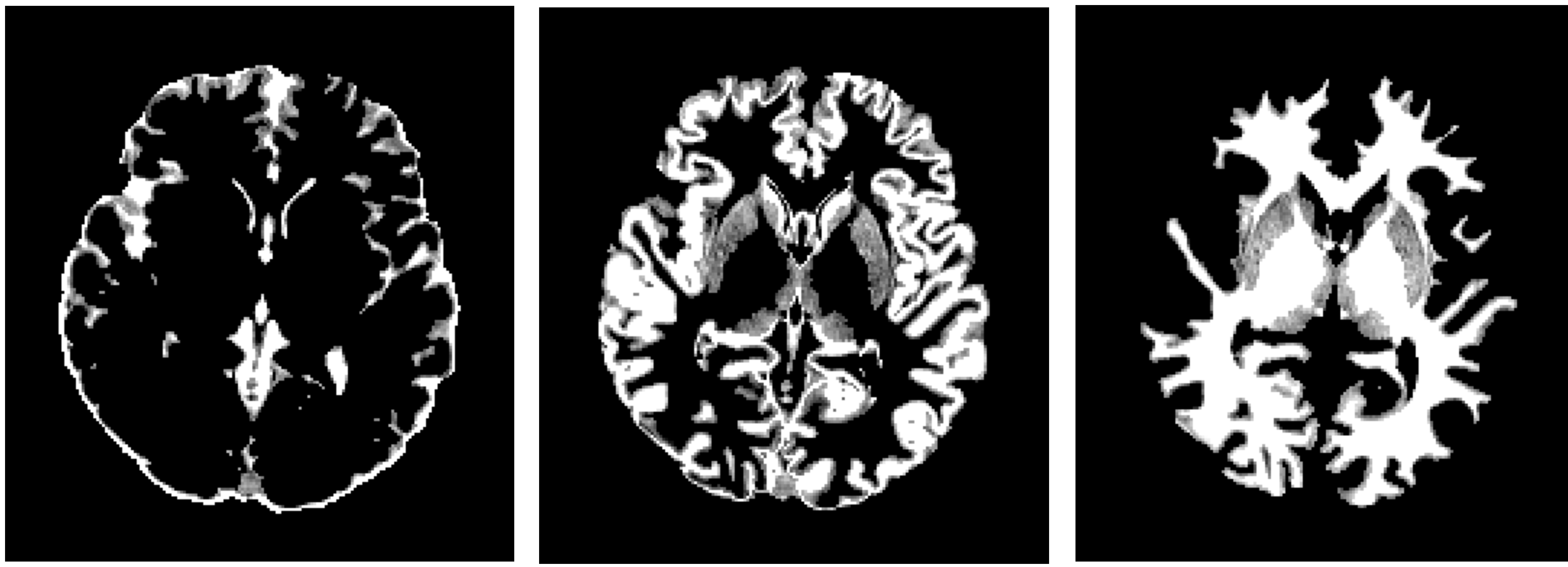


β=0.5

Partial Volume Modelling

- A better model is what fraction of each voxel is tissue X?
- "partial volume" = fraction of CSF, GM or WM

PVE
CSF, GM, WM



Image

"Hard" Segmentation

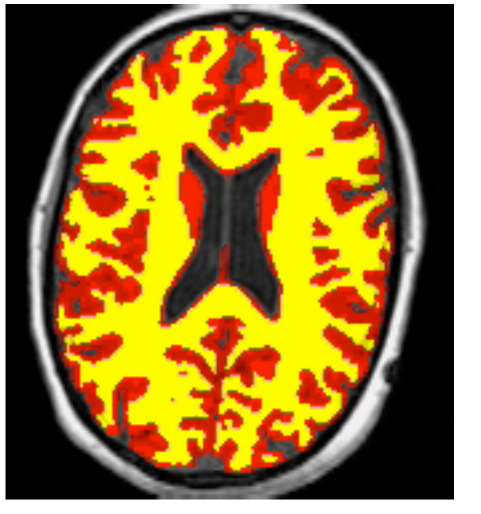
PVE (GM)

- This substantially improves accuracy of volume estimation

FAST - The Overview

- Initial (approximate) segmentation
    - Tree-K-means

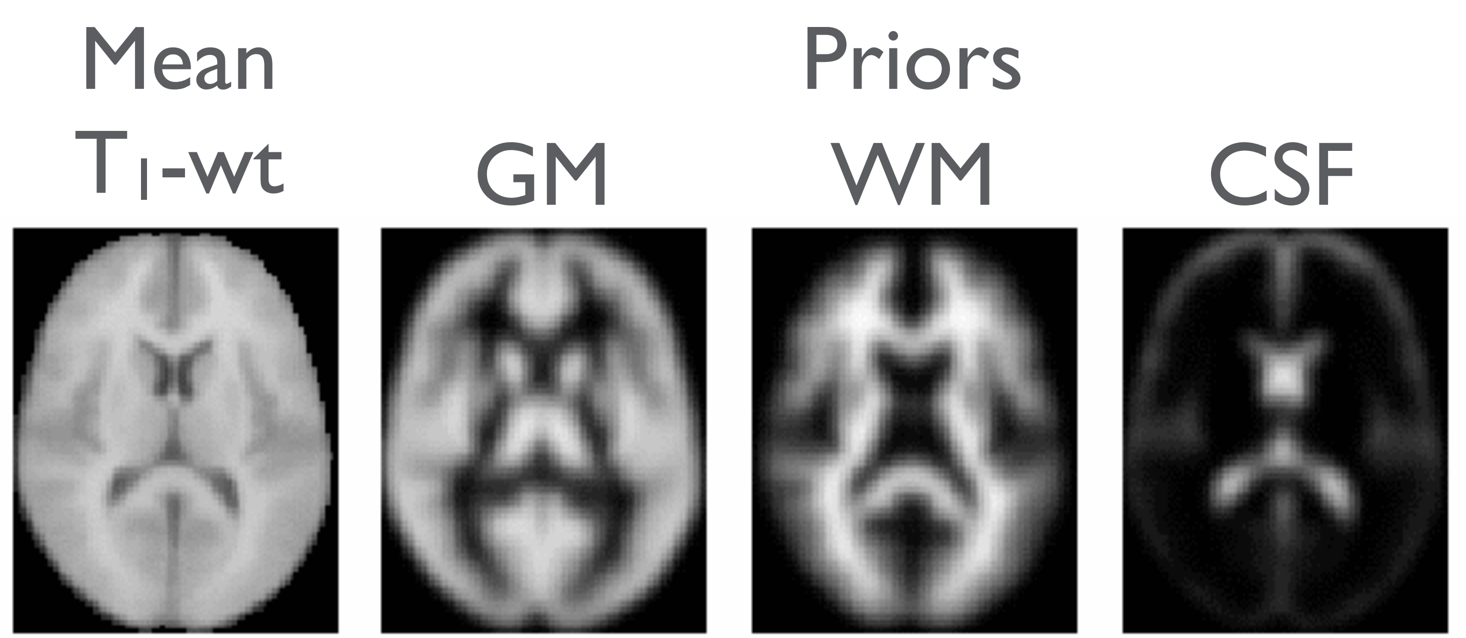
- Iterate
  - Estimate bias field
  - Estimation segmentation; iterate
    - Update segmentation (intensity + MRF)
    - Update tissue class parameters (mean and standard deviation)



- Apply partial volume model
  - MRF on mixel-type (how many tissues)
  - PV Estimation

Optional Use of Priors (tissue probability maps)

- Segmentation priors = average of many subjects' segmentations
- Can use priors to weight segmentation, but can skew results (e.g. due to misalignment)
- FAST does not use priors by default
- If bias field is very bad, priors can be turned on to help initial segmentation (alternatively, do more iterations)
- Can also be turned on to feed into final segmentation (e.g. to aid segmentation of deep grey .... but see FIRST)



Other Options

FAST:

- **Bias field smoothing (-l)**
  - vary spatial smoothing of the bias field
- **MRF beta (-H)**
  - vary spatial smoothness of the segmentation
- **Iterations (-I)**
  - vary number of main loop iterations

fsl_anat:

- This is an alternative tool that performs brain extraction and bias field correction (along with other things) in a different way and so is worth trying out too

FAST

FMRIB's Automated Segmentation Tool

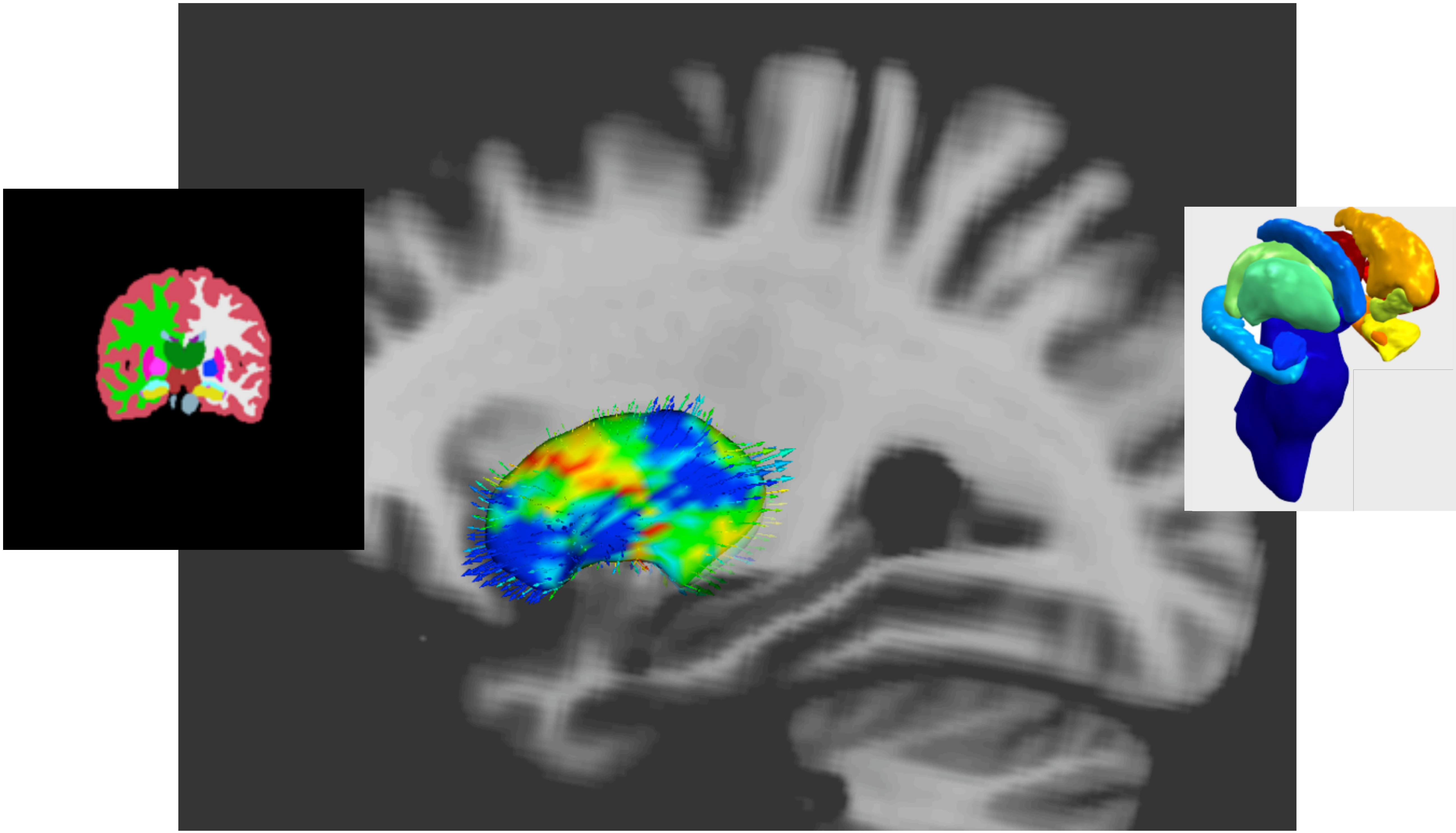
Summary

- Typically use a single T1-weighted image
- Multichannel is an option
- Segments into three main tissue-types:
    - Grey Matter, White Matter and CSF
- Models and corrects for bias field
    - Can be used just for bias field correction
- Combines intensity and neighbourhood information
- Partial Volumes Estimates (PVE) are most useful and more accurate for volume calculations
- Can use priors, but can cause bias, so not the default
- Have several adjustable parameters to optimise output

FIRST

FMRIB's Integrated Registration & Segmentation Tool

Segmentation of subcortical brain structures



FIRST

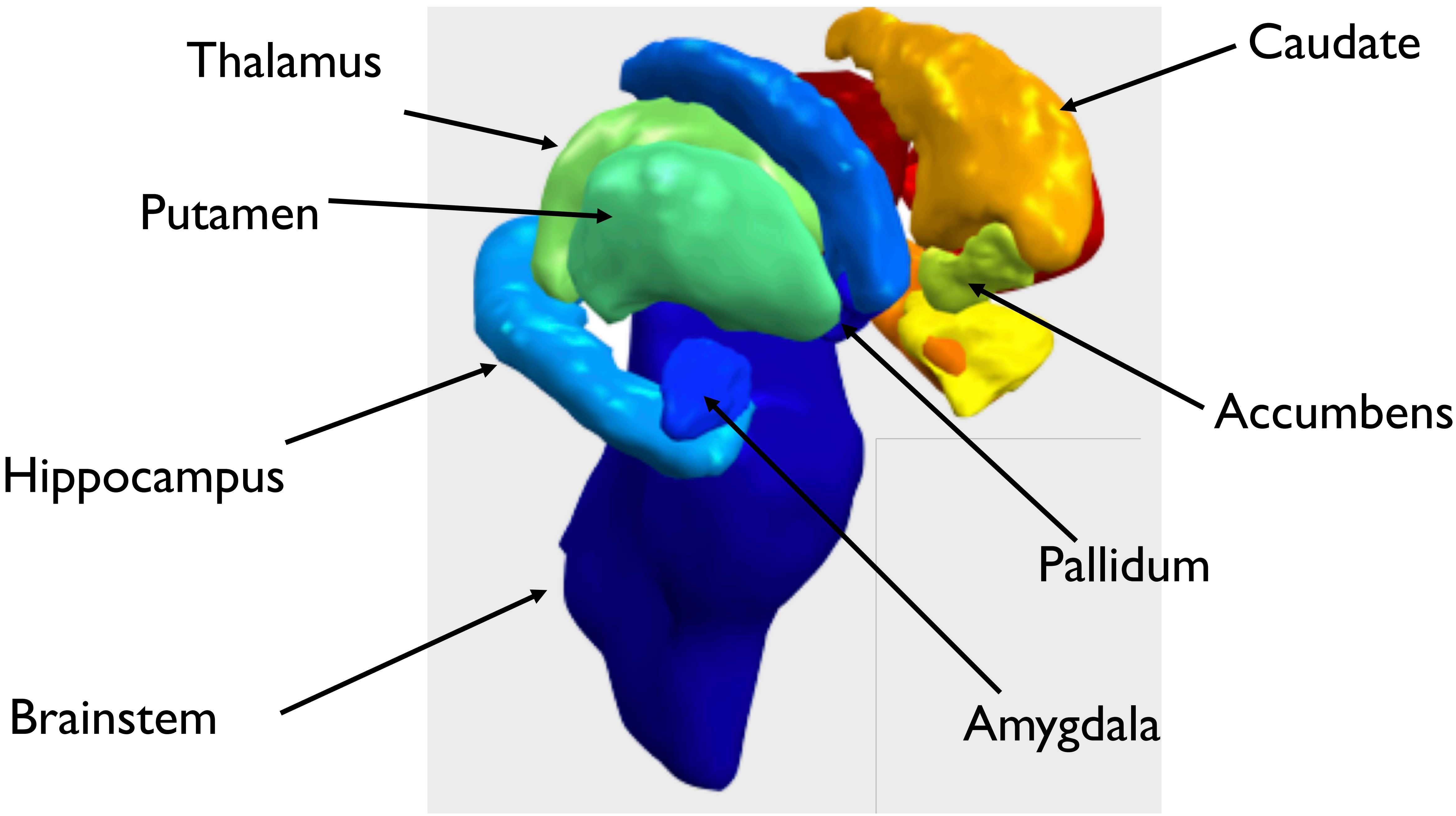
FMRIB's Integrated Registration & Segmentation Tool

Segmentation of subcortical brain structures

Sub-Cortical Structure Models

Incorporate prior anatomical information via explicit shape models

Have 15 different sub-cortical structures (left/right separately)



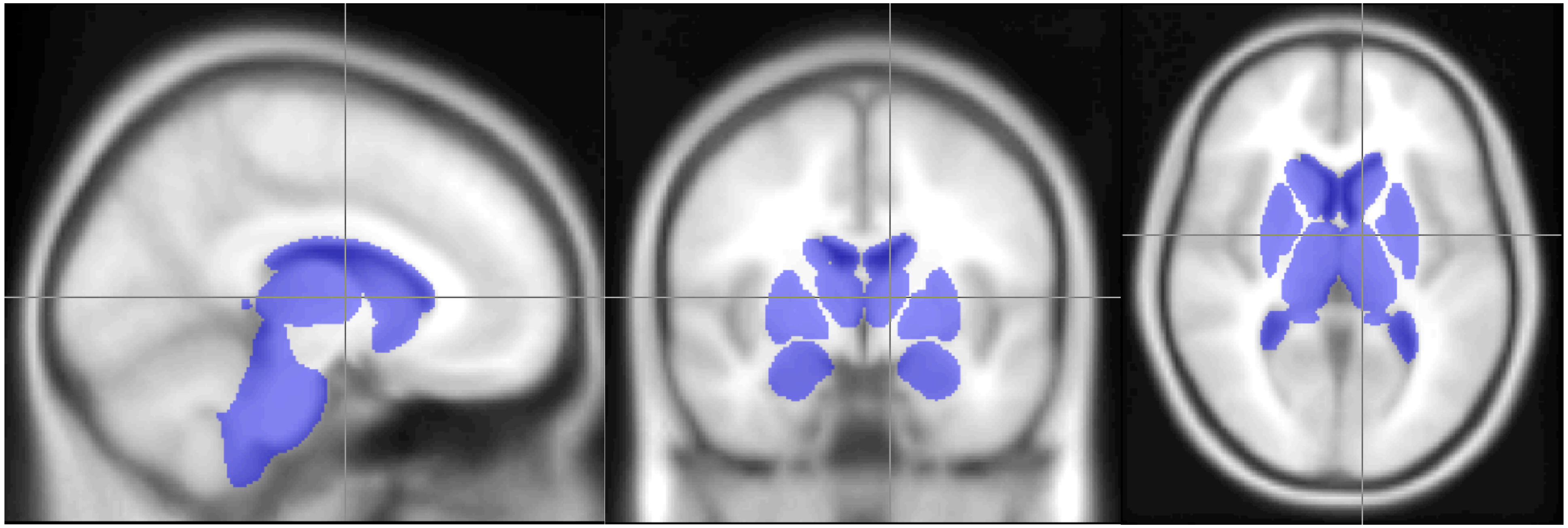
Training Data

- Manual segmentations courtesy of David Kennedy, Center for Morphometric Analysis (CMA), Boston
- 336 complete data sets
- T_1-weighted images only
- Age range 4 to 87
  - Adults: Ages 18 to 87, Normal, schizophrenia, AD
  - Children: Ages 4 to 18, Normal, ADHD, BP, prenatal cocaine exposure, schizophrenia.

Model Training : Alignment to MNI152 space

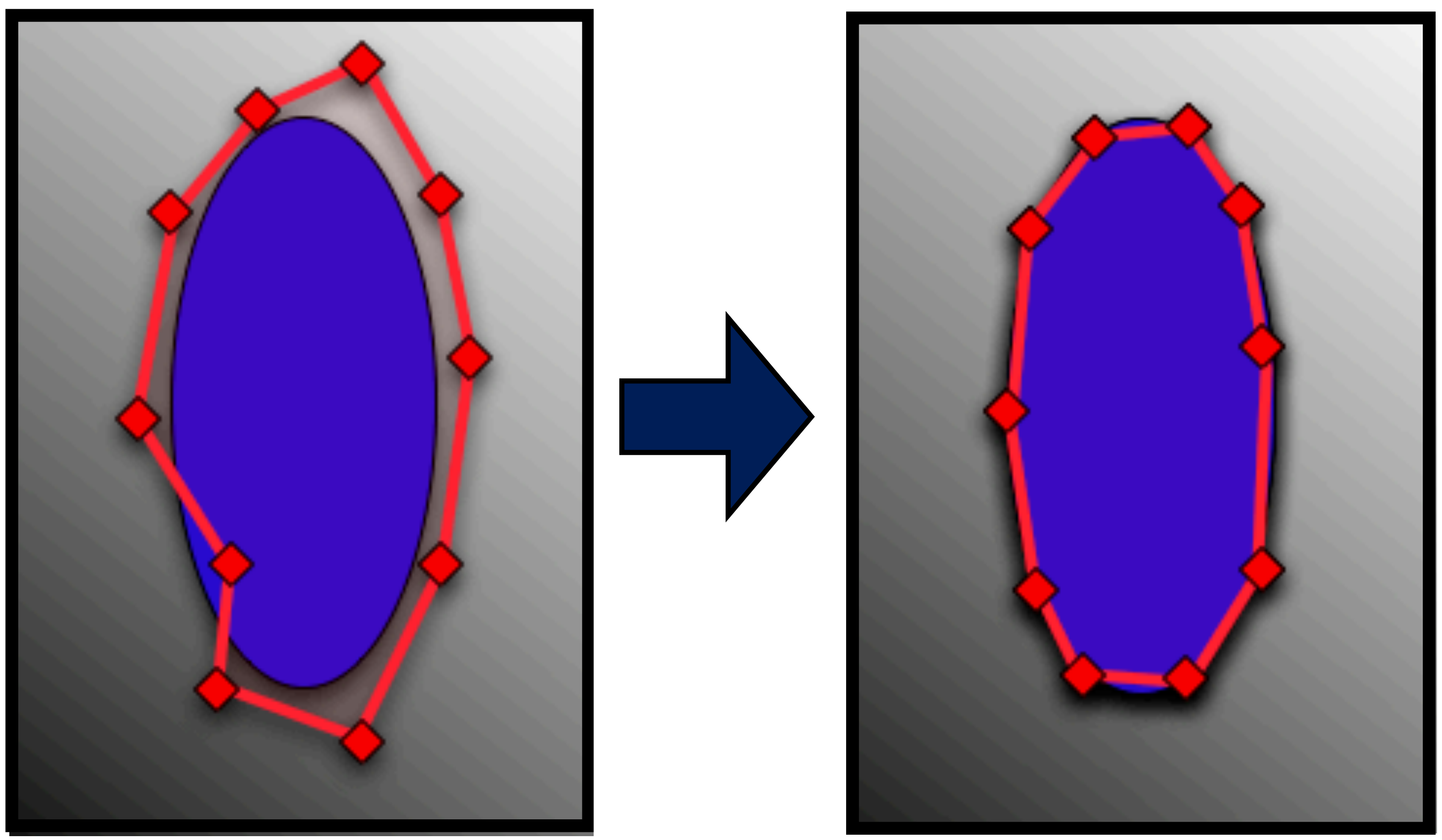
- All CMA data affine-registered to MNI152 space
  - 1mm resolution, using FLIRT

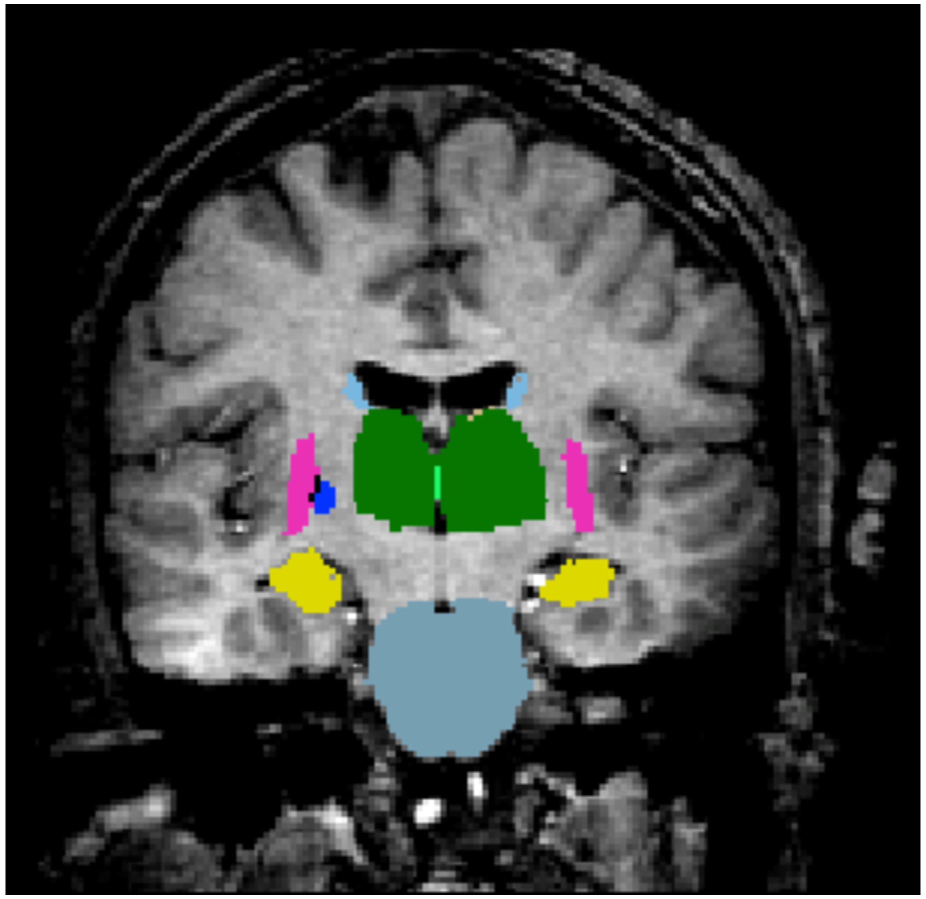
- 2-stage process:
  - Whole head 12 DOF affine
  - 12 DOF affine with MNI-space sub-cortical mask



Deformable Models

- Model: 3D mesh
- Use anatomical info on shape & intensity (from training)
- Deformation: iterative displacement of vertices
- Maintain point (vertex) correspondence across subjects





The Model: Shape

- Model average shape (from vertex locations)
- Also model/learn *likely variations* about this mean
  - modes of variation of the population; c.f. PCA
  - also call eigenvectors
- Average shape and the modes of variation serve as prior information (known before seeing the new image that is to be segmented)
  - formally it uses a Bayesian formulation

The Model: Shape

- Model average shape (from vertex locations)

- Also model/learn *likely variations* about this mean
  - modes of variation of the population; c.f. PCA
  - also call eigenvectors

- Average shape and the modes of variation serve as prior information (known before seeing the new image that is to be segmented)
  - formally it uses a Bayesian formulation

$$X = \mu_X + UDb_X$$

mean: μ_X

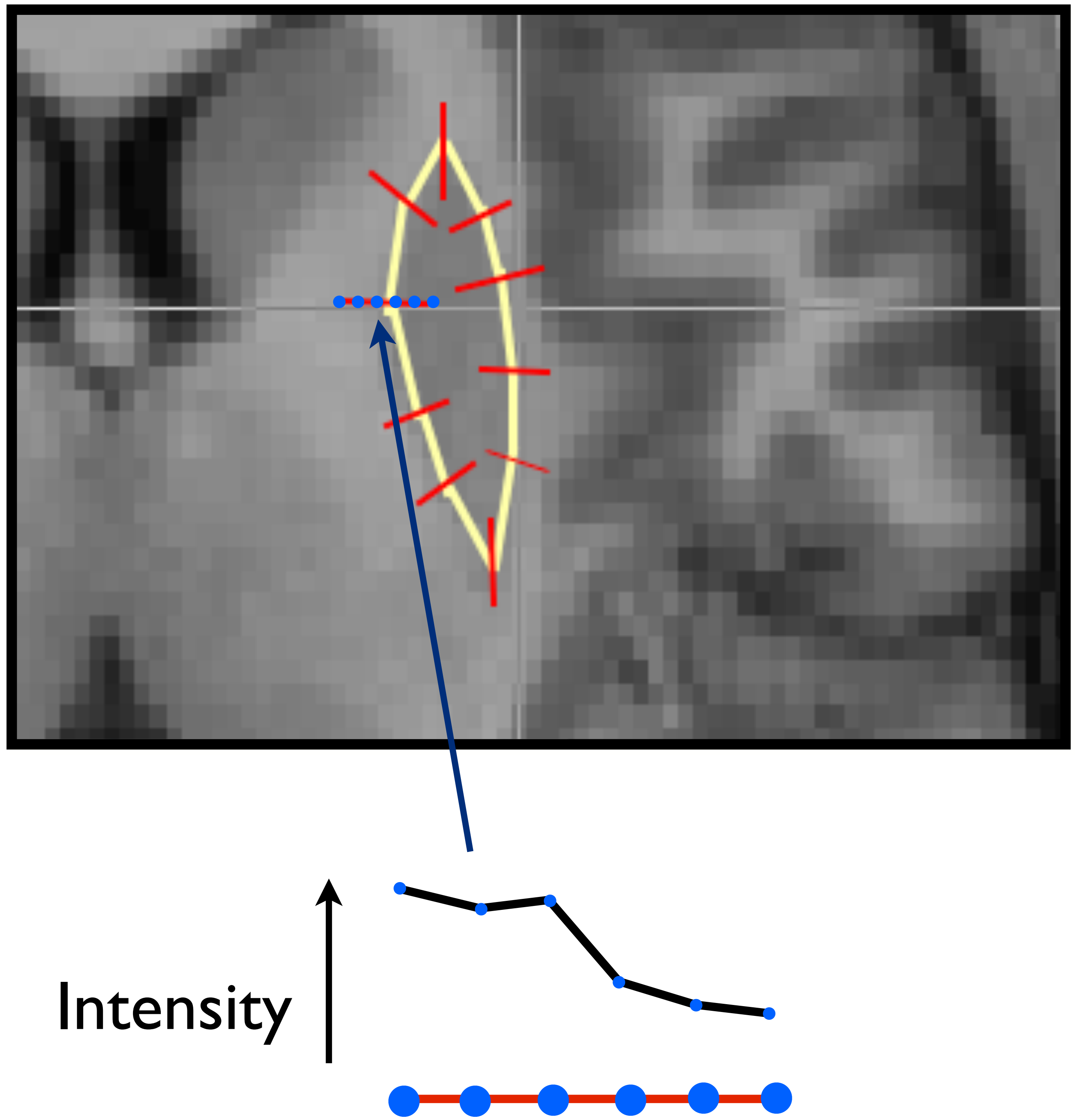
Singular values: D

Eigenvectors (modes): U

Shape parameters: b_X

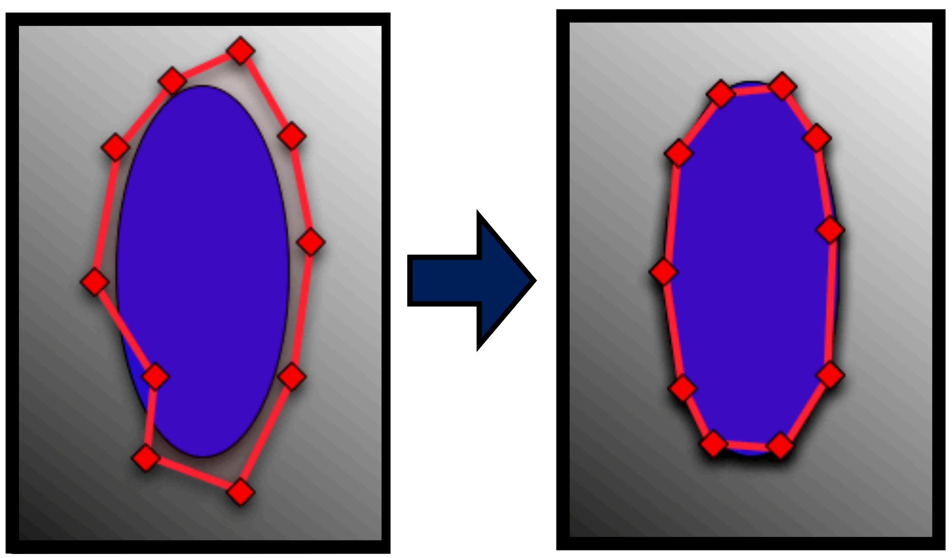
The Model: Intensity

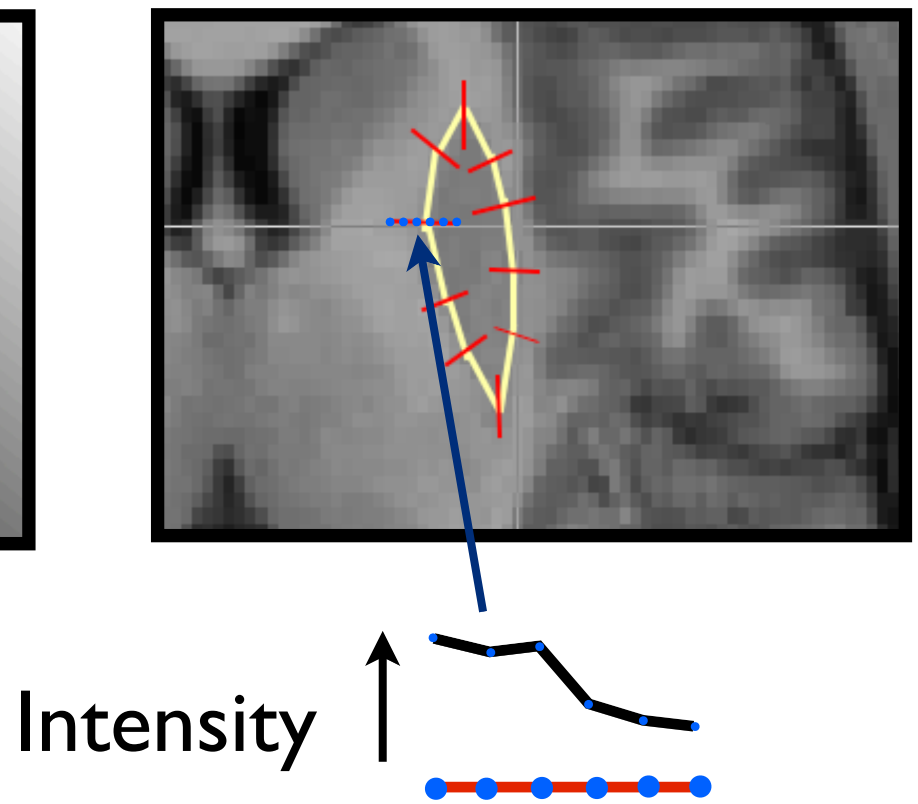
- Intensity is then sampled along the surface normal and stored
- Learn average intensity and “modes of variation”
- Aside: the intensities are re-scaled to a common range and the mode of the intensities in the structure is subtracted

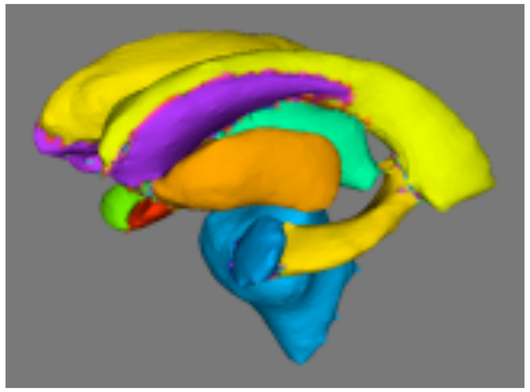


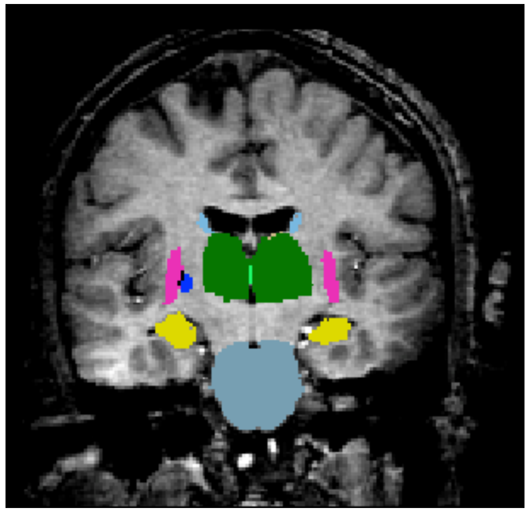
FIRST - Model

- <u>Model</u>: 3D mesh
- <u>Training the model</u>: learn average shape/intensity and likely variations ("modes of variation") about both
- <u>Fitting the model</u>: Find the "best" shape by searching along modes of variation and uses intensity match to judge fitting success



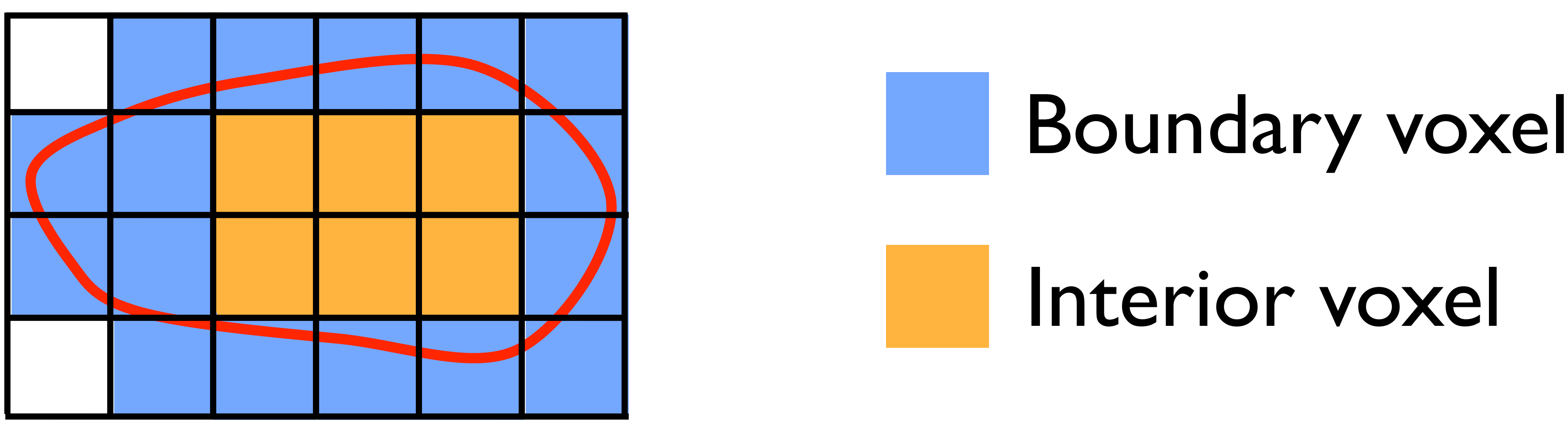






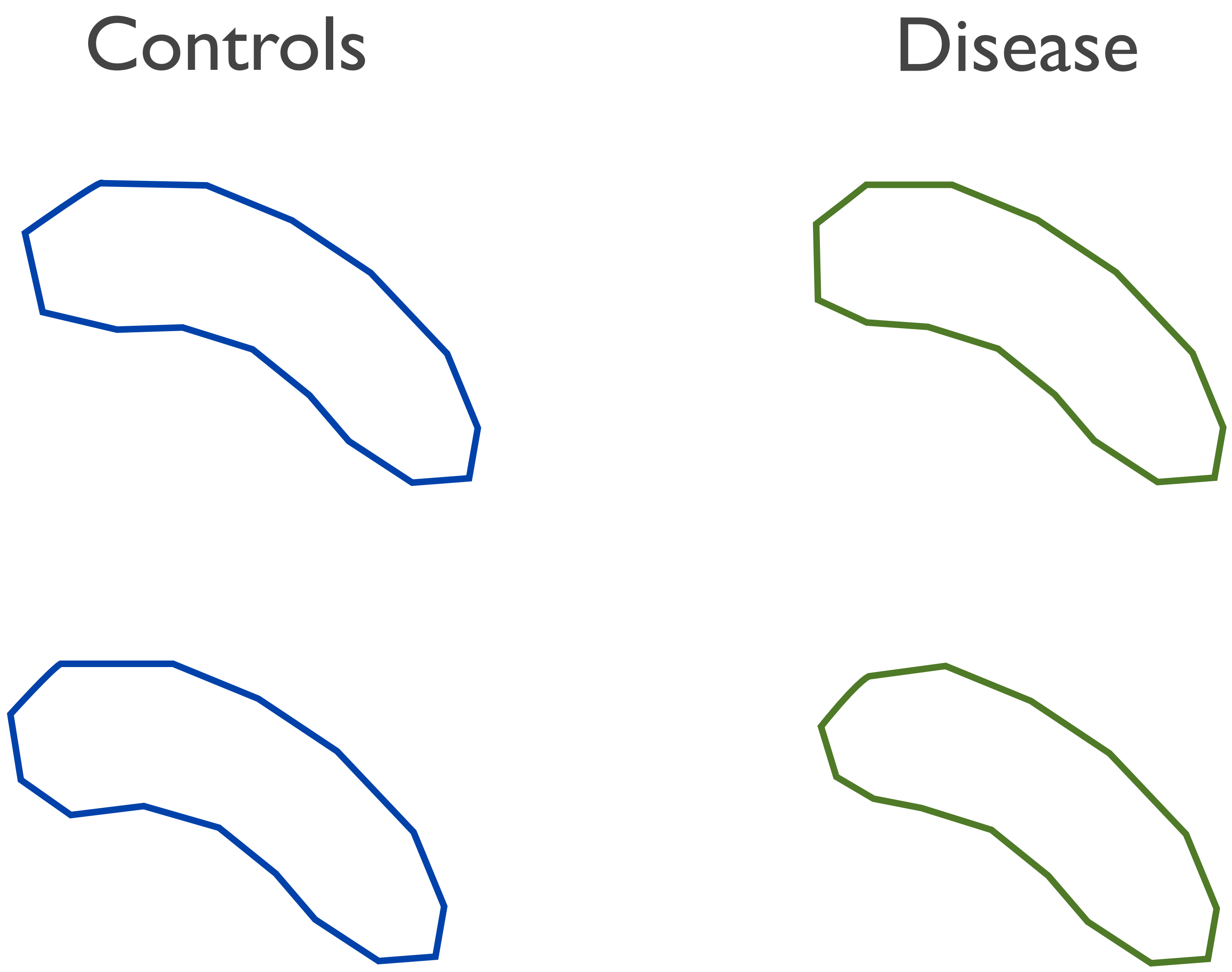
Boundary Correction

- FIRST models all structures by meshes
- Converting from meshes to images gives two types of voxels:
  - boundary voxels
  - interior voxels
- Boundary correction is necessary to decide whether the boundary voxels should belong to the structure or not
- Default correction uses FAST classification method and is run automatically (uncorrected image is also saved)
  - ensures that neighbouring structures do not overlap



Vertex Analysis

- Use a univariate test at each vertex to measure difference in location (e.g. between means of two groups of subjects)

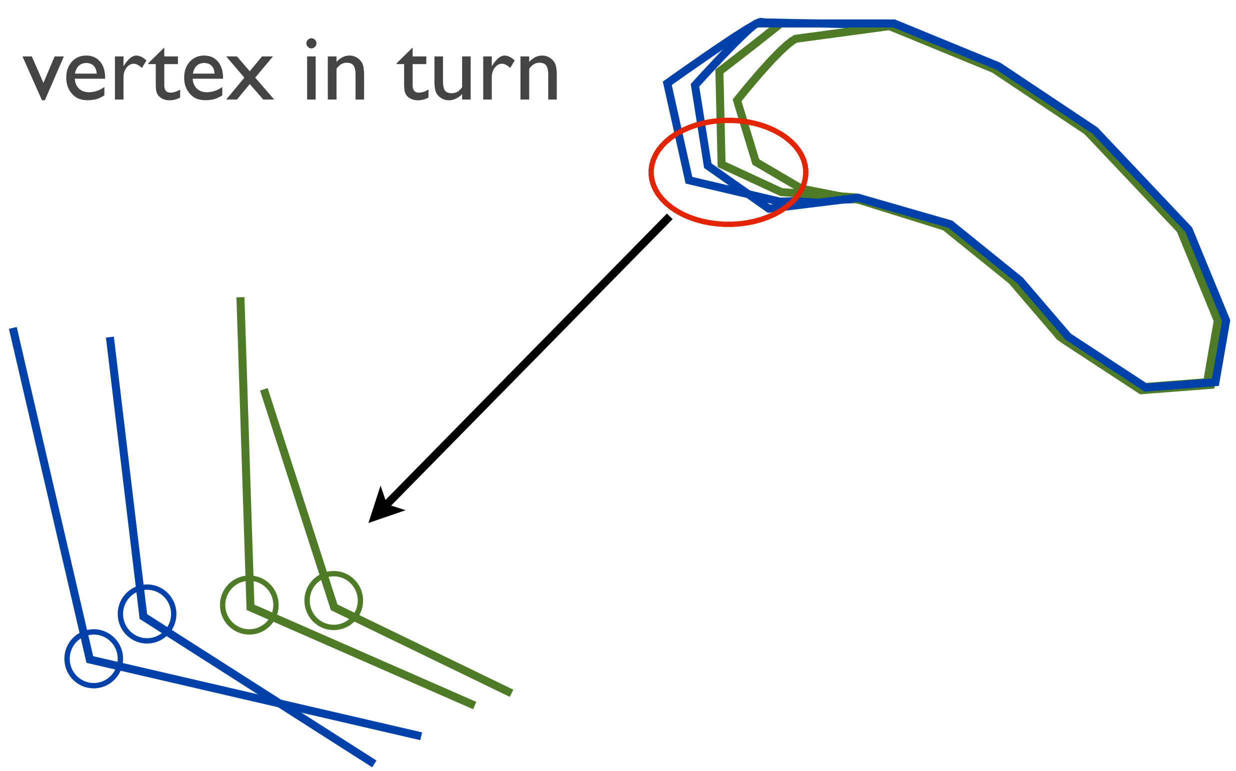


Vertex Analysis

- Use a univariate test at each vertex to measure difference in location (e.g. between means of two groups of subjects)

Controls　　　　　　Disease

Consider each vertex in turn

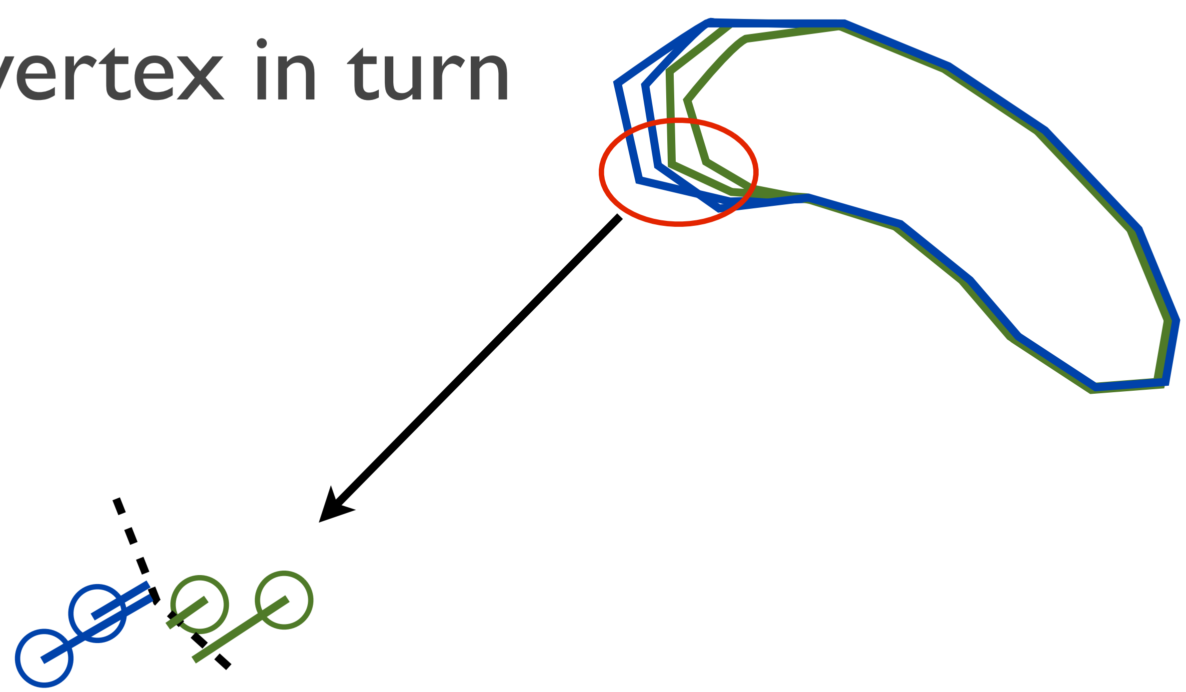


Vertex Analysis

- Use a univariate test at each vertex to measure difference in location (e.g. between means of two groups of subjects)

Controls Disease

Consider each vertex in turn



Do a test on distance of these vertices to average shape

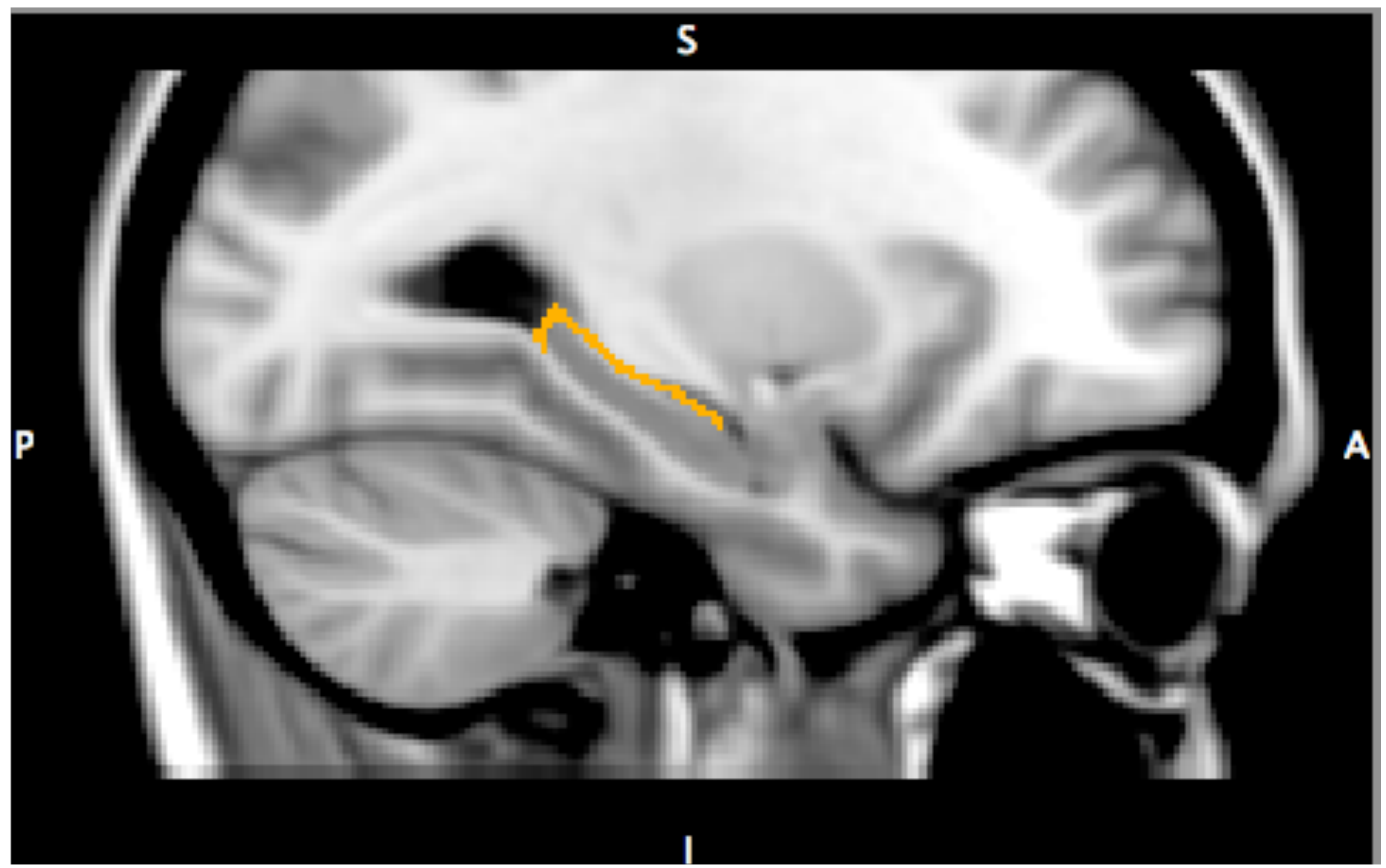
Vertex Analysis

- Use a univariate test at each vertex to measure difference in location (e.g. between means of two groups of subjects) using distance along surface normals

- Results are now given as ***images*** and statistics done with ***randomise***

- Can do analysis in MNI space or native structural space

- MNI space analysis ***normalises for brain size***



Running FIRST

- Inputs:
  - T_1-weighted image
  - Model (built from training data) - provided with FSL

- Applying FIRST
  - A single command: run_first_all
    1. registers image to MNI152 1mm template
    2. fits structure models (meshes) to the image
    3. applies boundary correction (for volumetric output)

- Analysis:
  - Use command: first_utils
    - volumetric analysis (summary over whole structure)
    - vertex analysis (localised change in shape and/or size)
    - randomise (with multiple comparison correction)

FIRST

FMRIB's Integrated Registration & Segmentation Tool

Summary

- Specific to certain deep grey structures
- Uses broad training set - very general demographics
- Can only work with T1-weighted images
- Models average and variations of shape and intensity
- Represents the boundary as a set of points
- Separate boundary correction step to get voxel labels

- Can perform vertex analysis to look at changes in shape and size