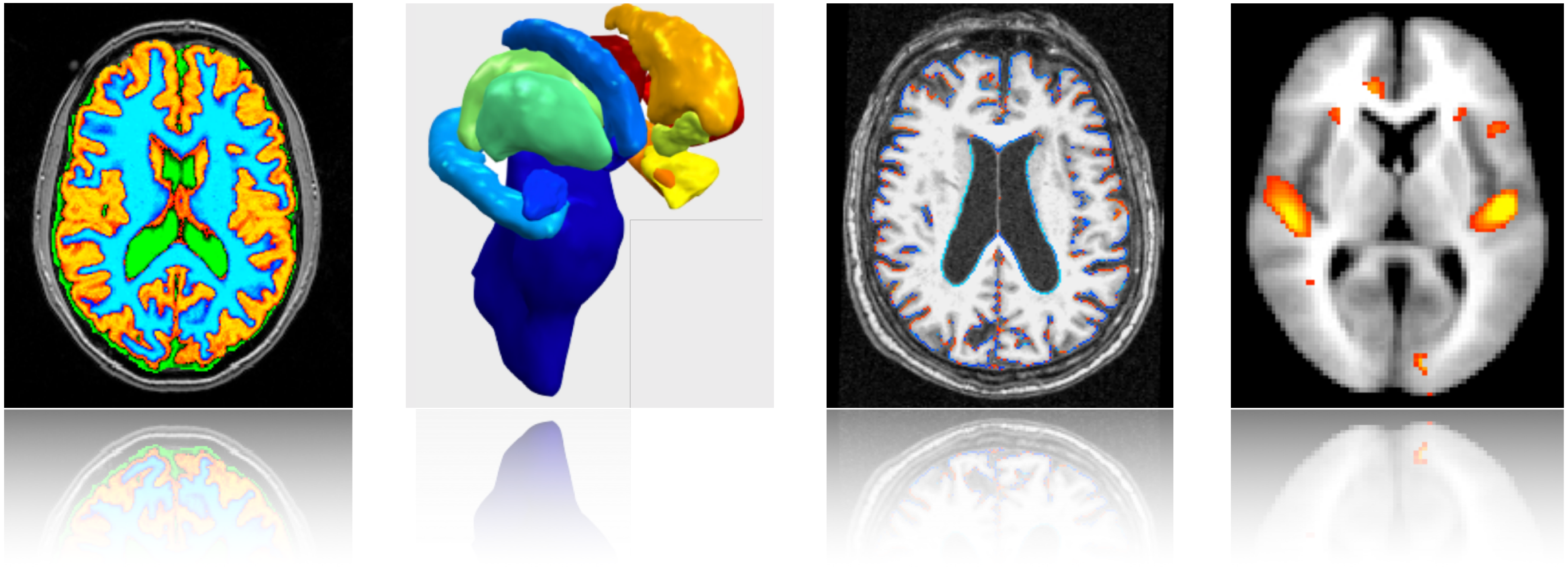
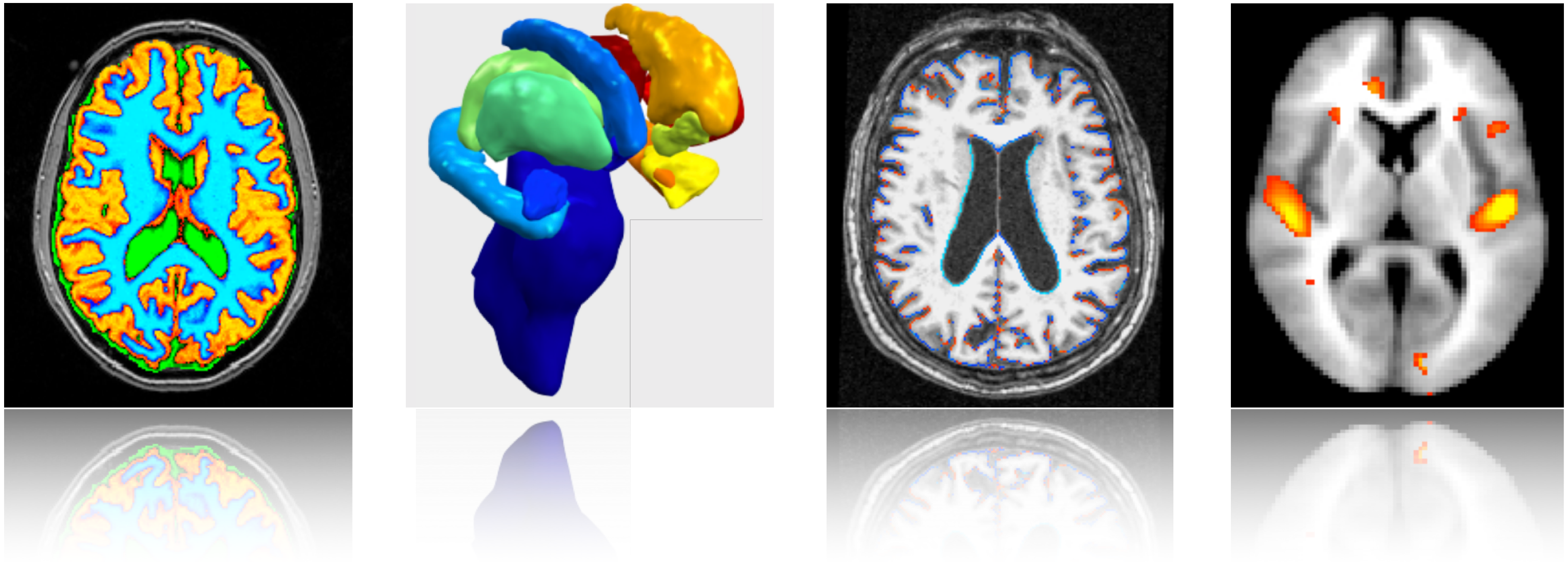
Structural Segmentation



- 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



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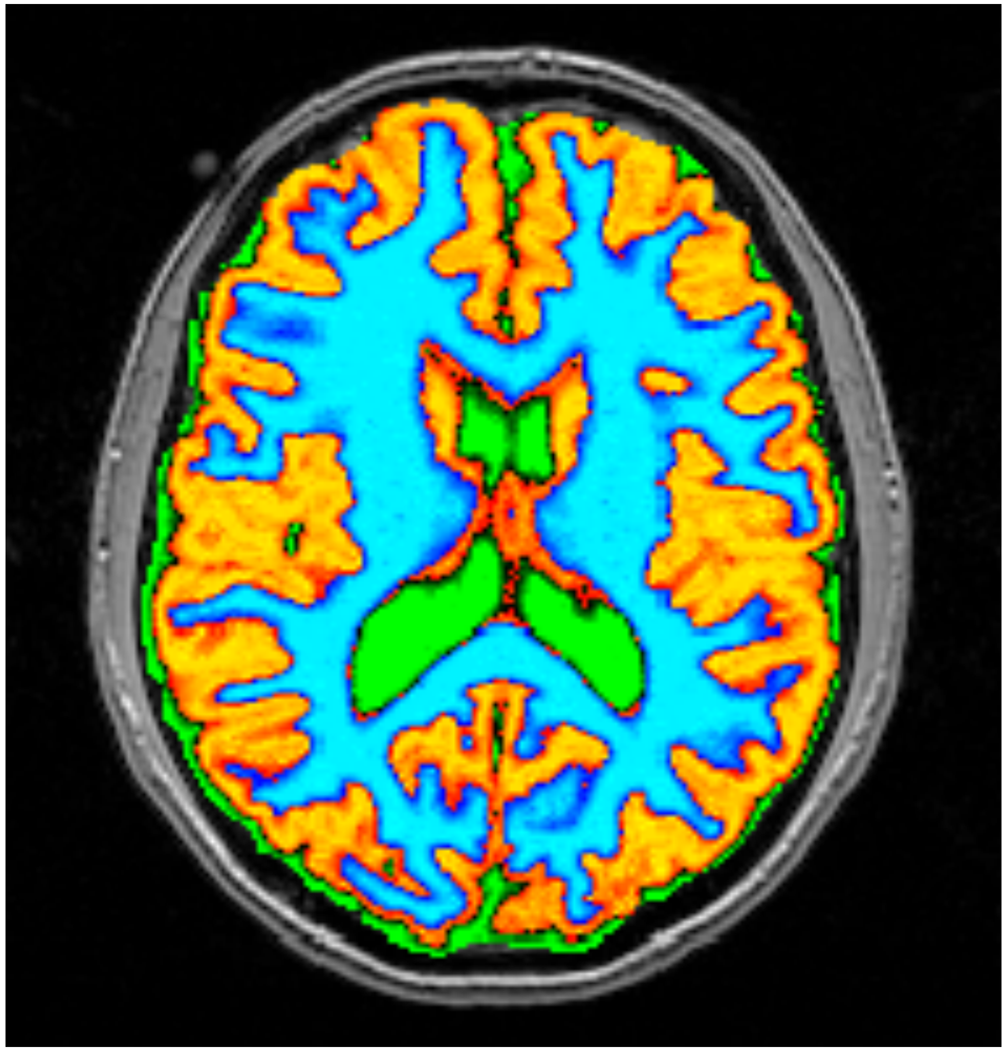
FAST

FMRIB's Automated Segmentation Tool

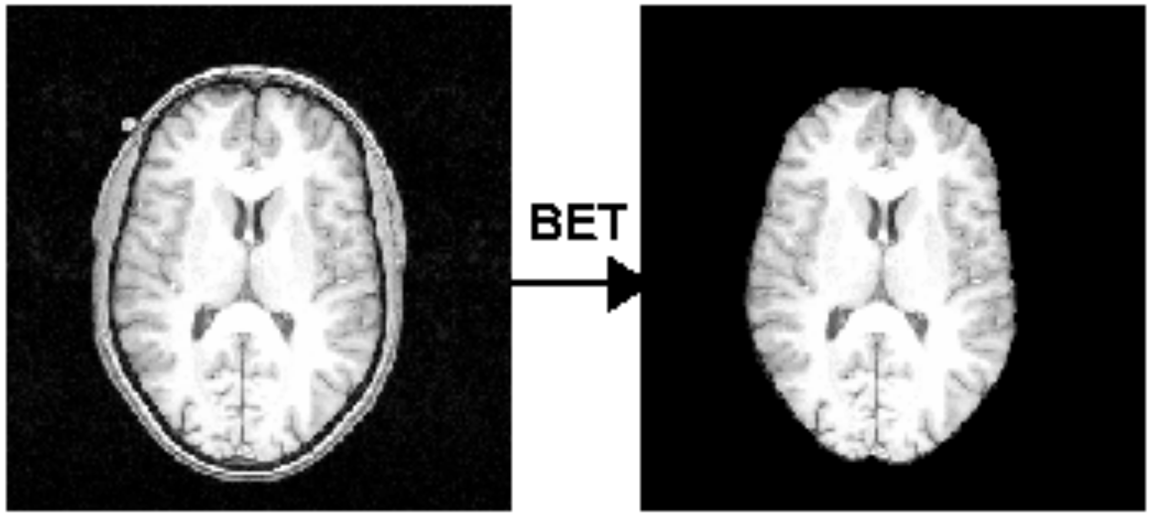
generic tissue-type segmentation and bias field correction



FAST: Input

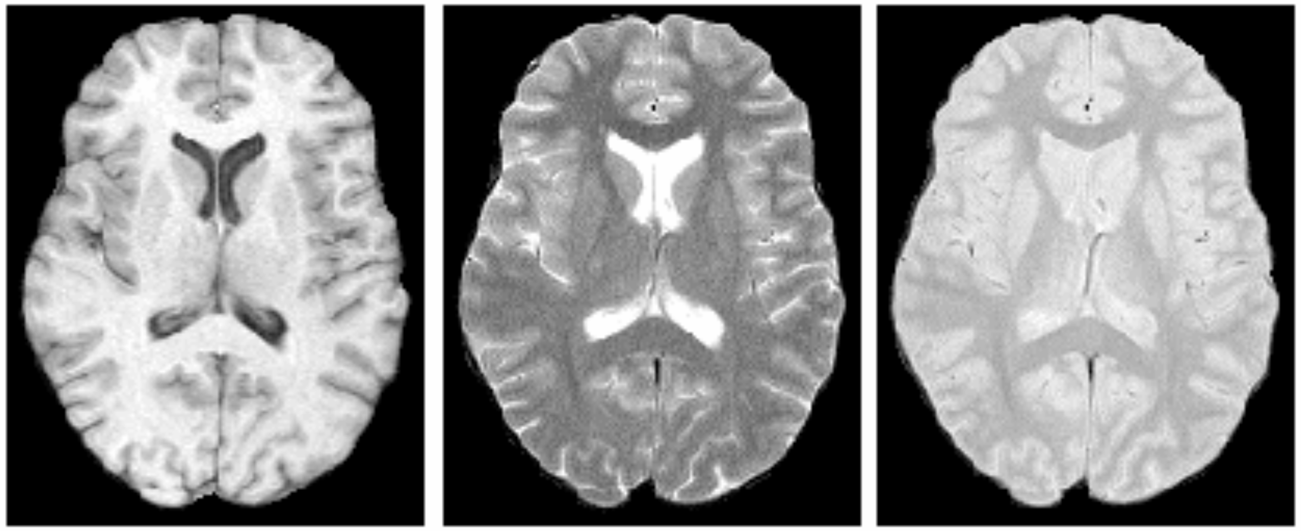
- First use BET to remove non-brain

  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....)

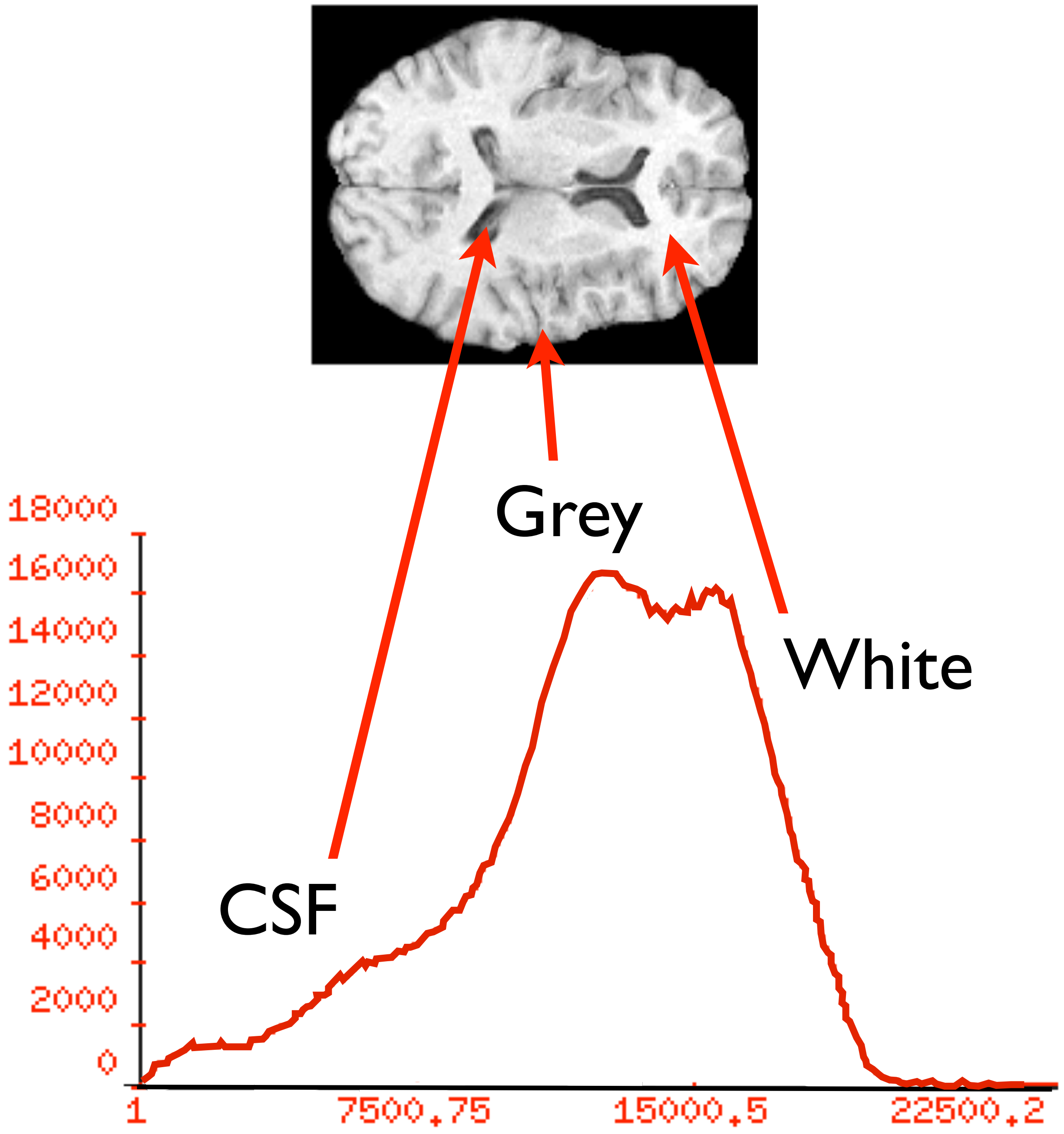
- Or several inputs ("multichannel")
- For multi-channel, all must be pre-aligned (FLIRT)



Intensity Model

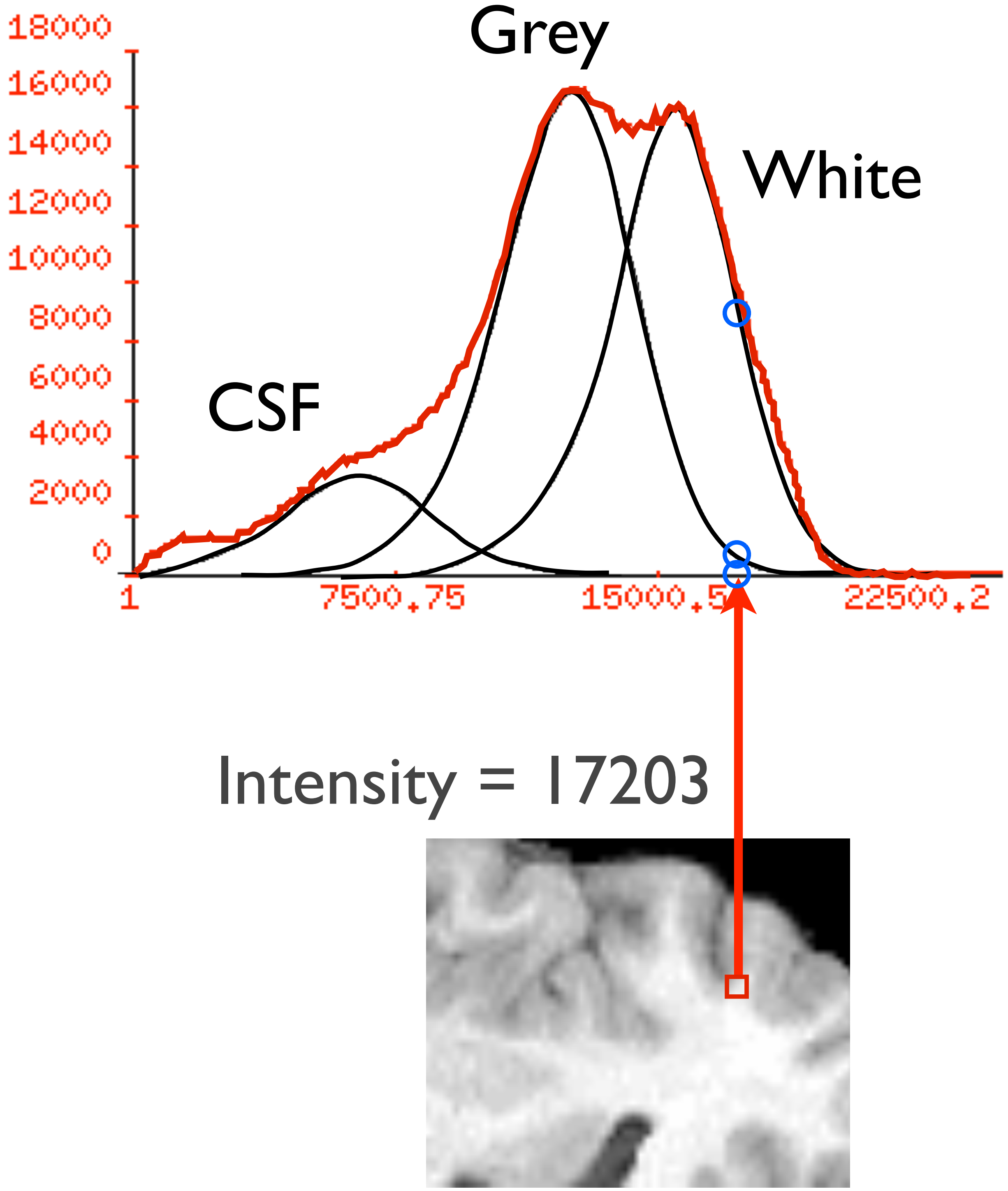
tissue intensity distributions

- 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

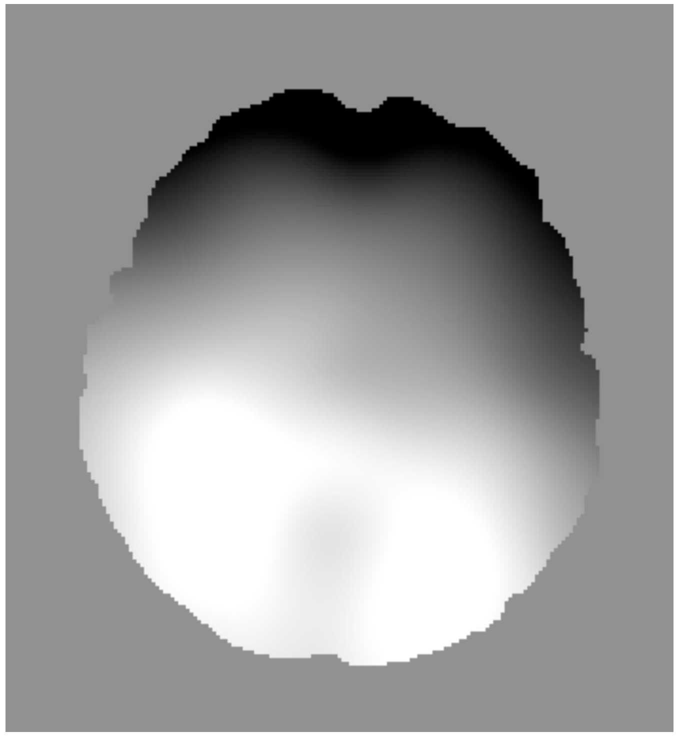


For example:
Voxel near WM/GM border

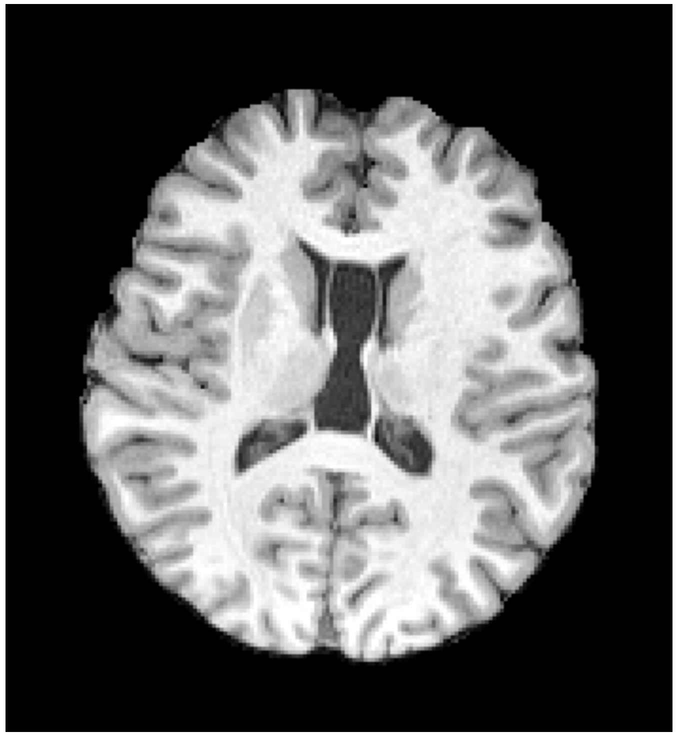
P(CSF) near zero
P(GM) low
P(WM) moderate

Bias Field Correction

Original



Bias

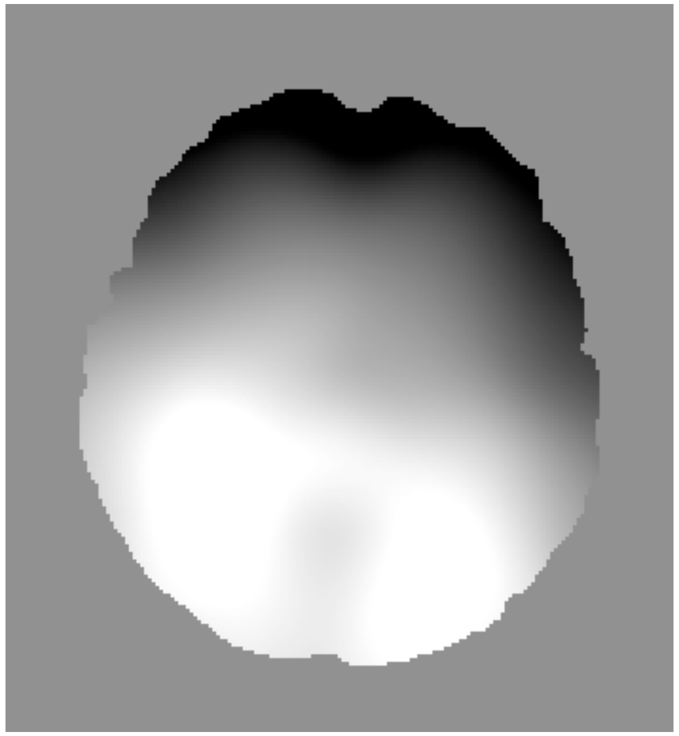


Restored

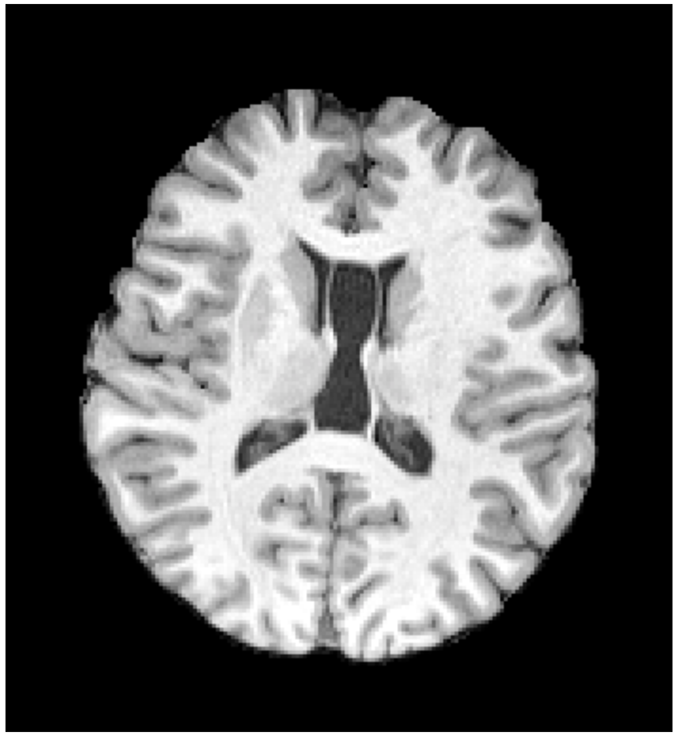
- MRI RF (radio-frequency field) inhomogeneity causes intensity variations across space
- Causes problems for segmentation
- Need to remove bias field before or during segmentation
- Becomes more common and problematic at high field

Bias Field Correction

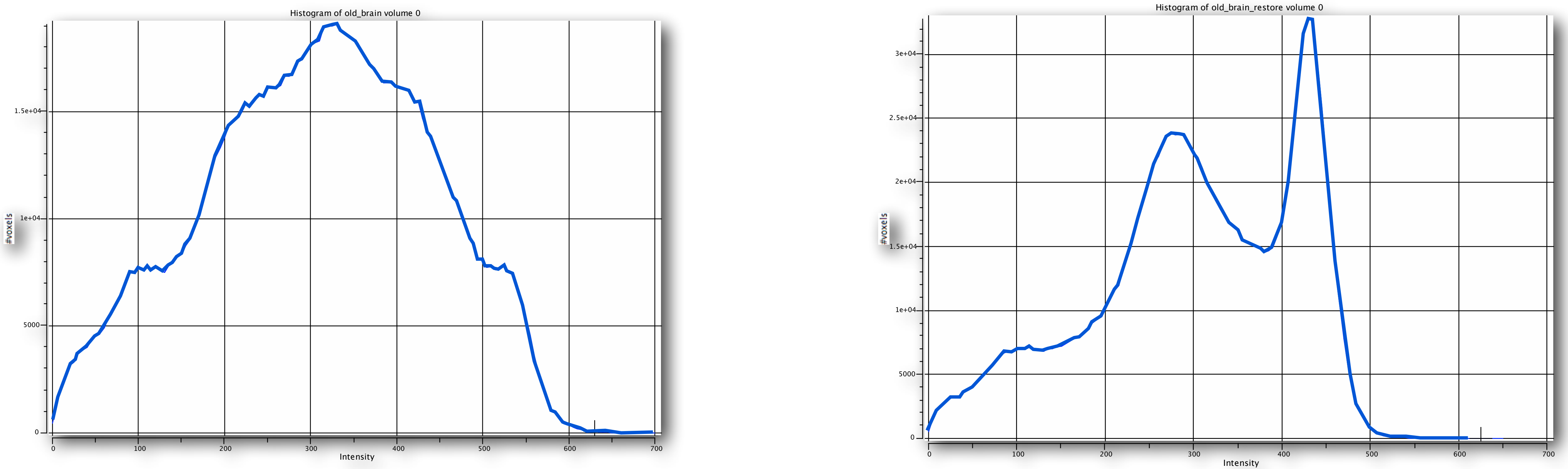
Original



Bias



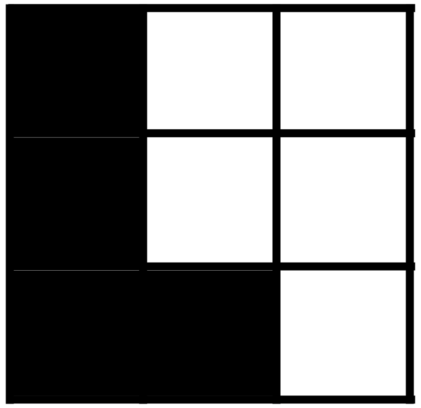
Restored



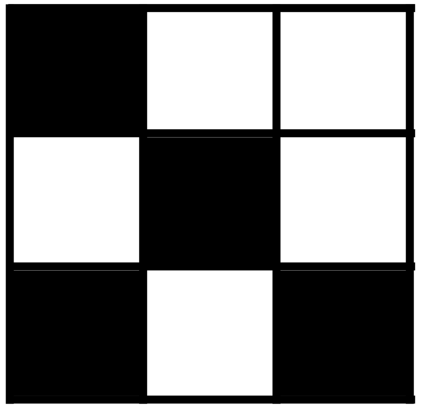
Histograms

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

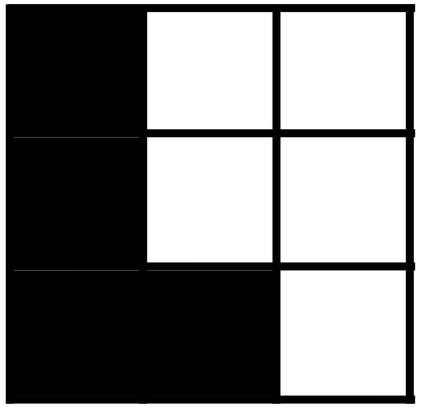
Use Spatial Neighbourhood Information (MRF)

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



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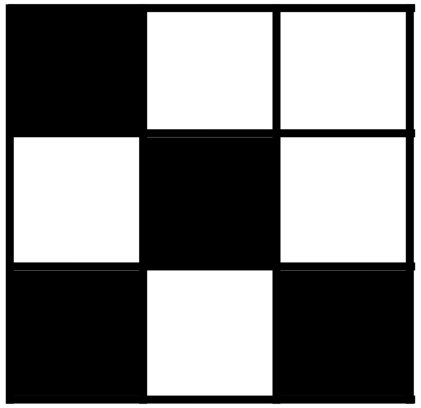
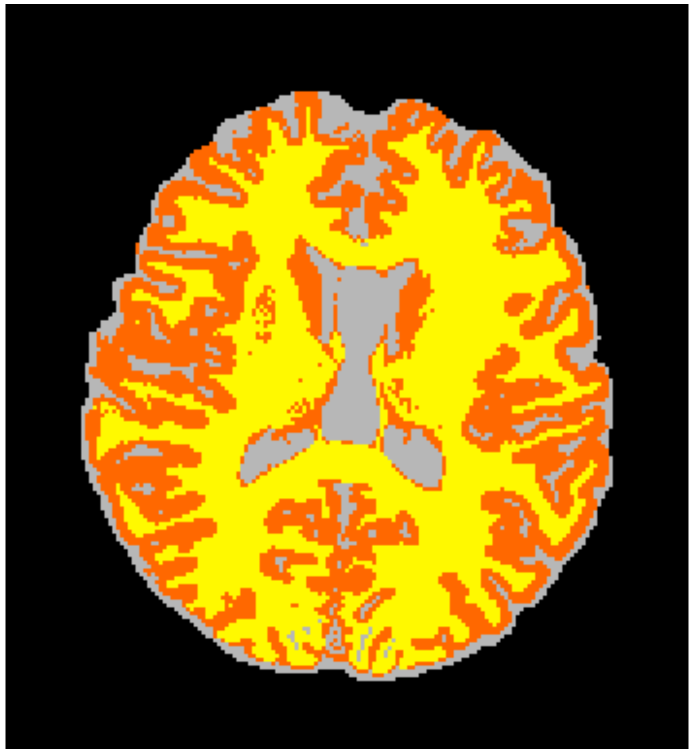
High probability

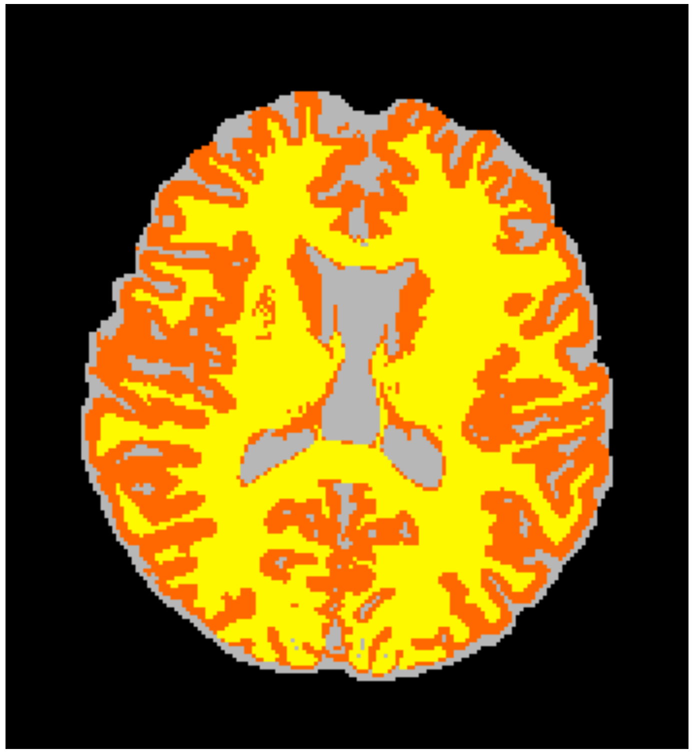


Unlikely configuration
Low probability

Effect of MRF Weighting

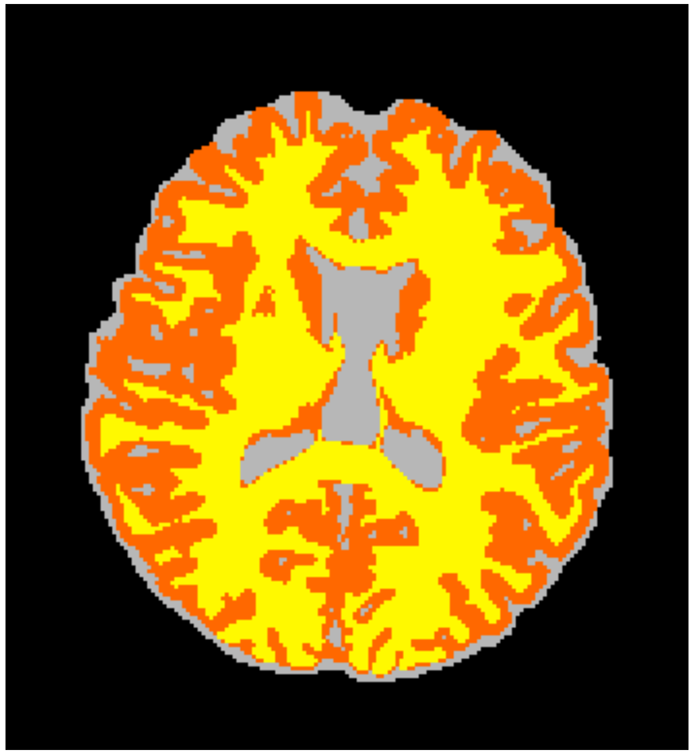
$\beta=0$





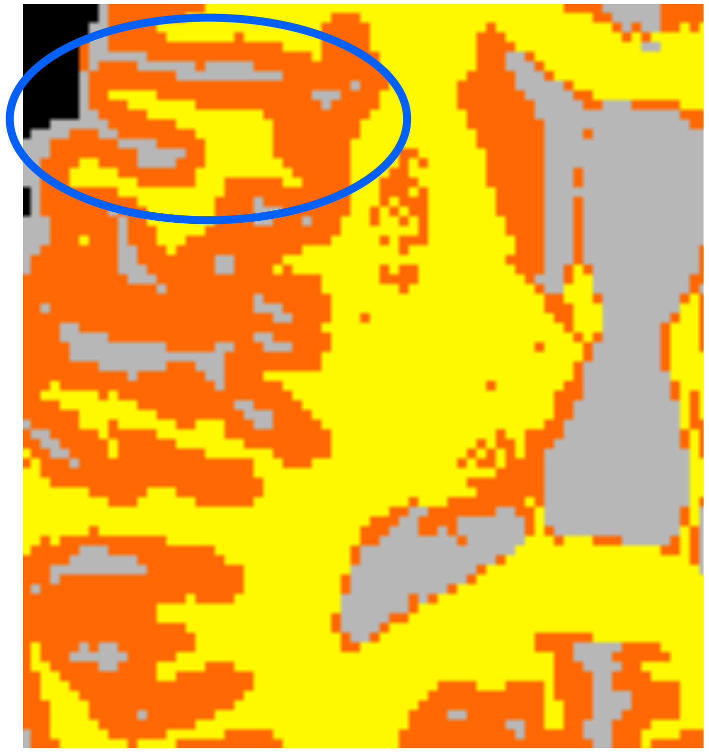
$\beta=0.1$

$\beta=0.3$

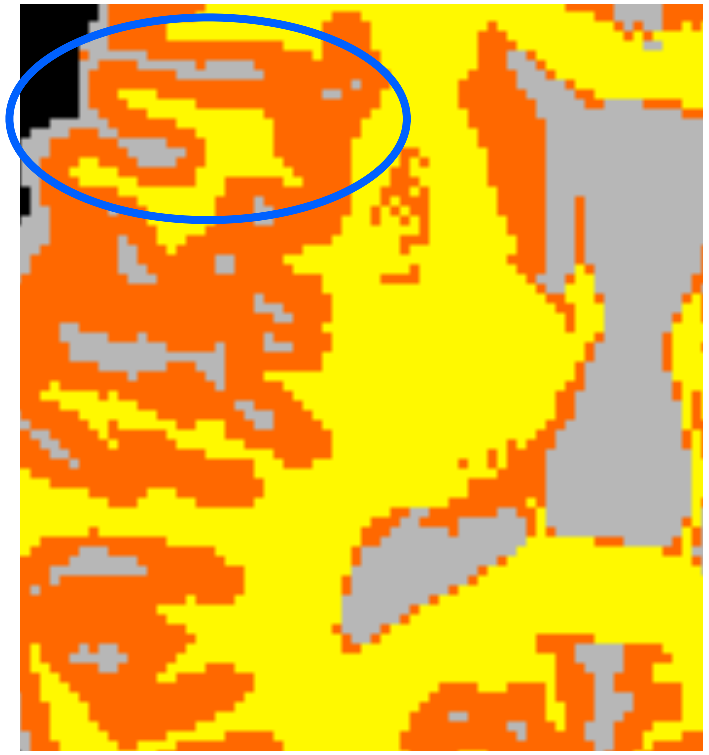


$\beta=0.5$

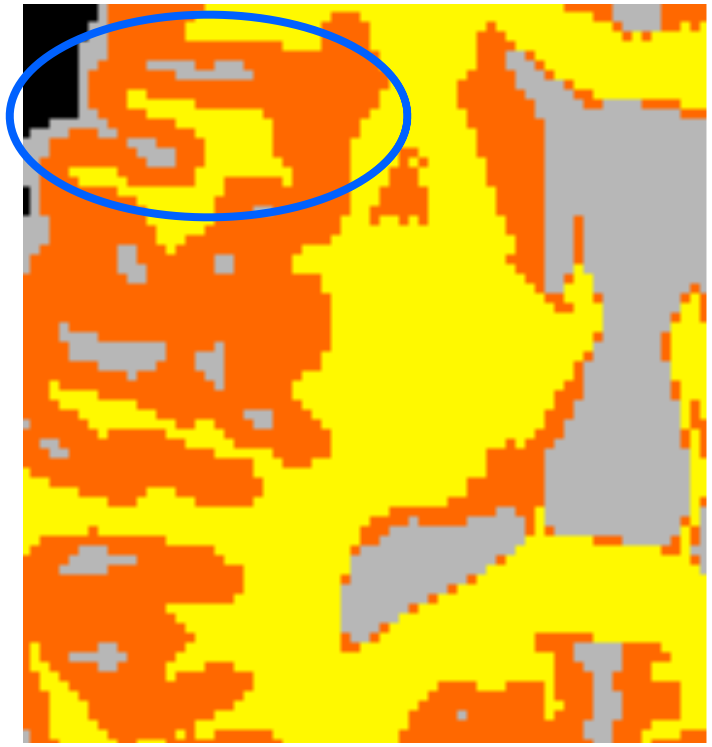
Effect of MRF Weighting



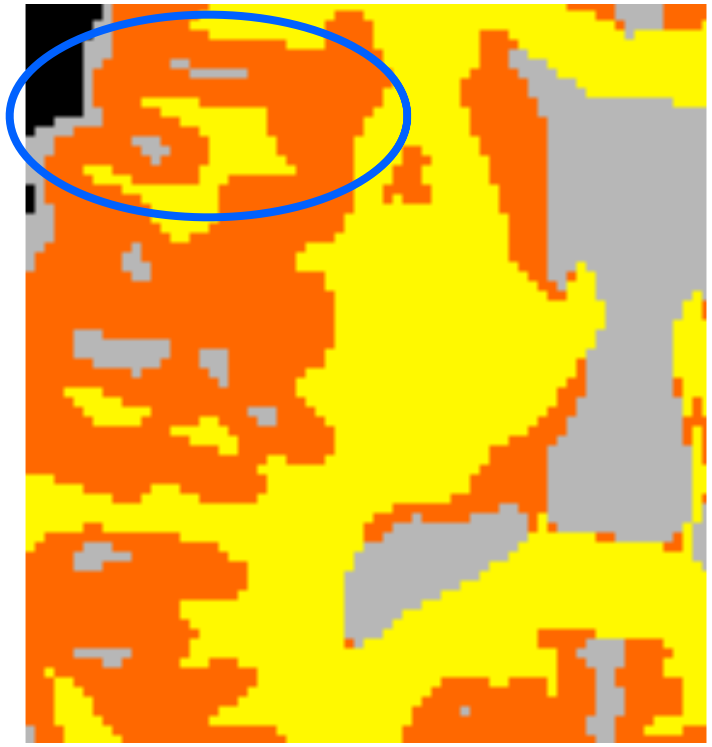
β=0



β=0.1



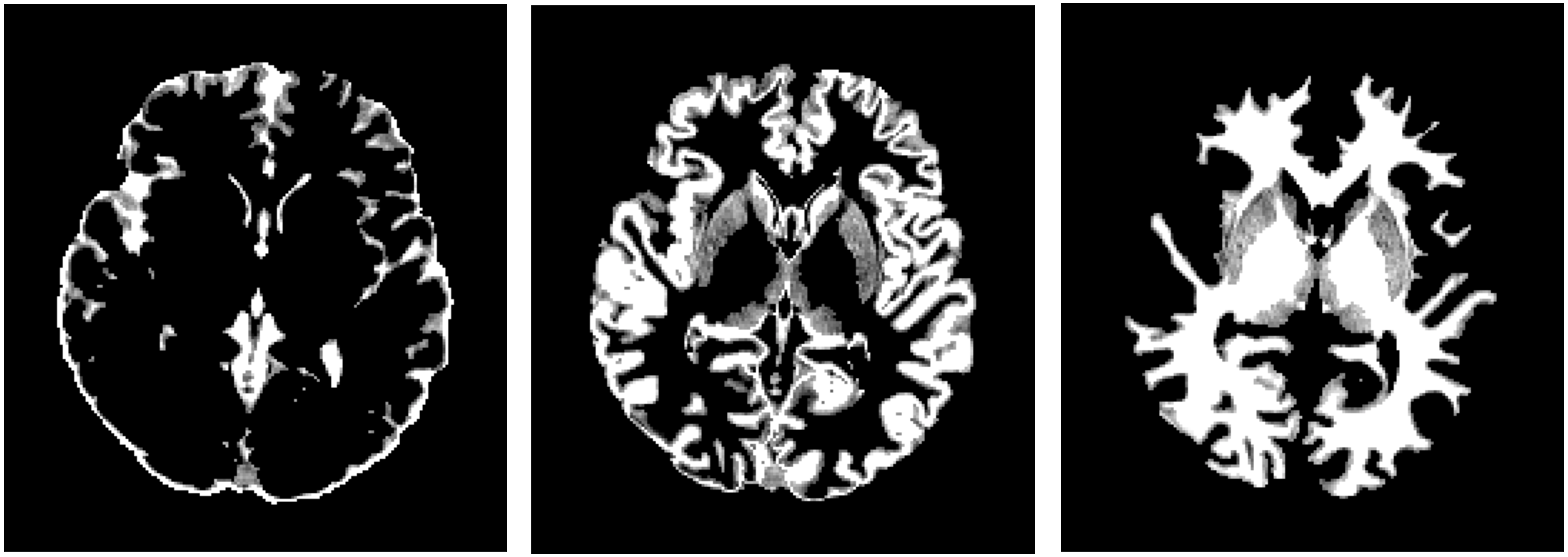
β=0.3



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

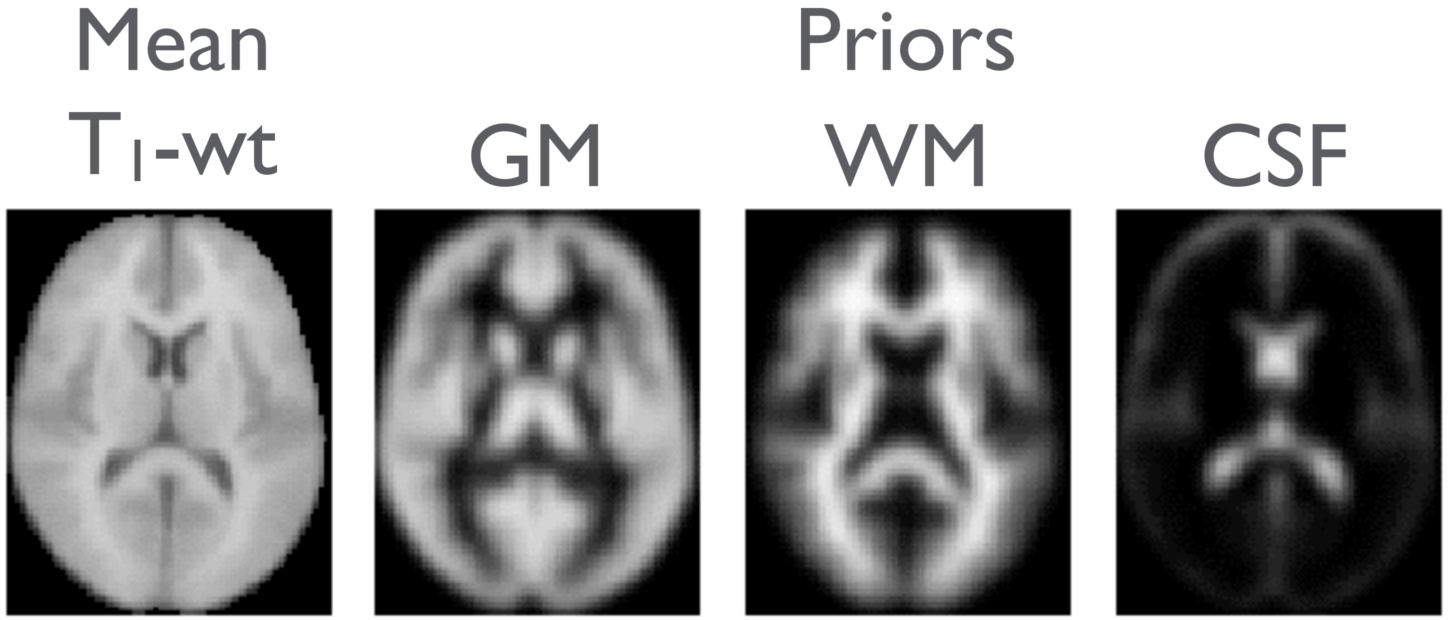
- Initial (approximate) segmentation
    - Tree-K-means

- 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 (e.g. less smooth for high field strength)
- **MRF beta (-H)**
  - vary spatial smoothness of the segmentation (default 0.1)
- **Iterations (-I)**
  - vary number of main loop iterations (default 4)

FAST

FMRIB's Automated Segmentation Tool

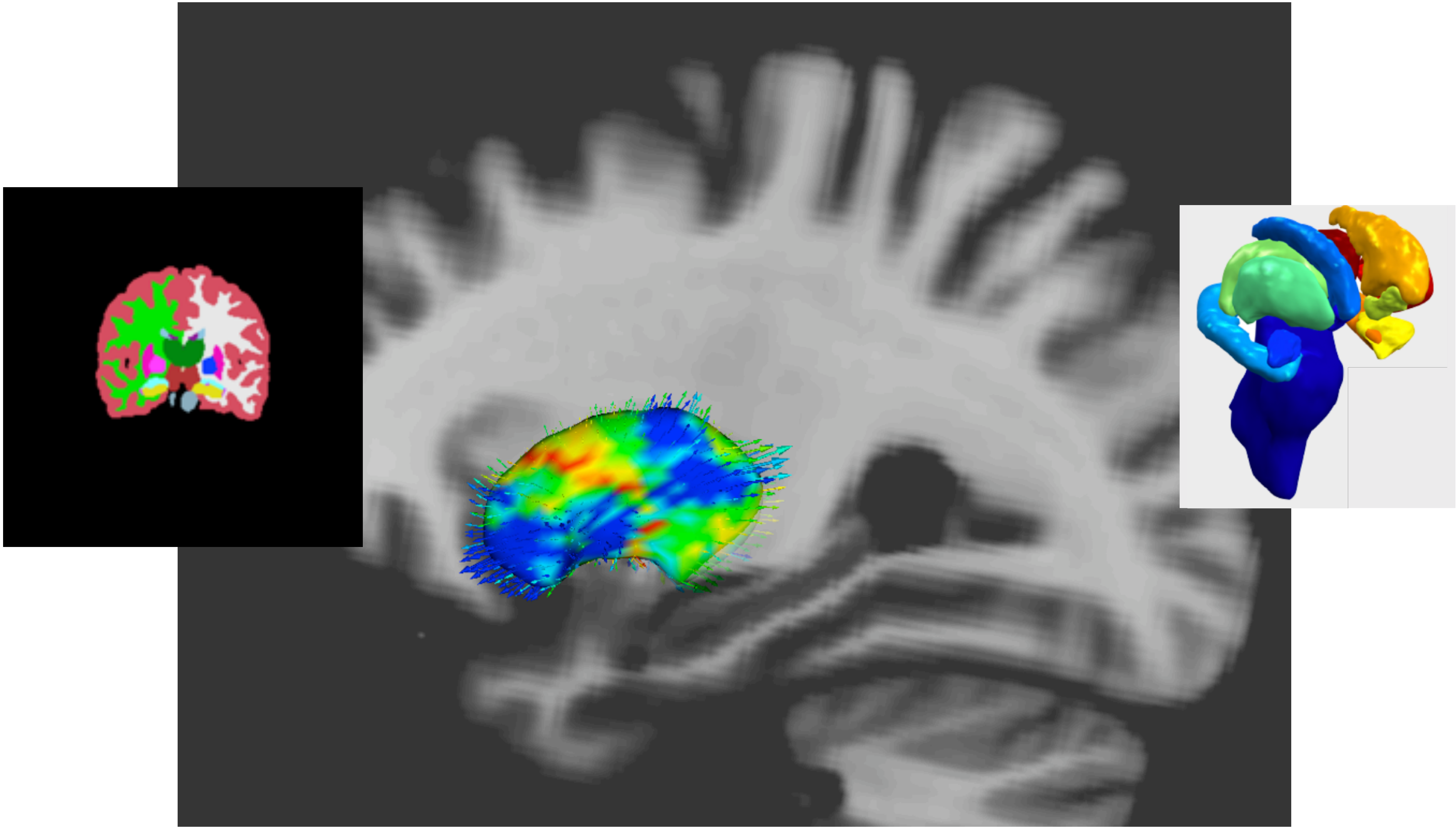
Summary

- 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

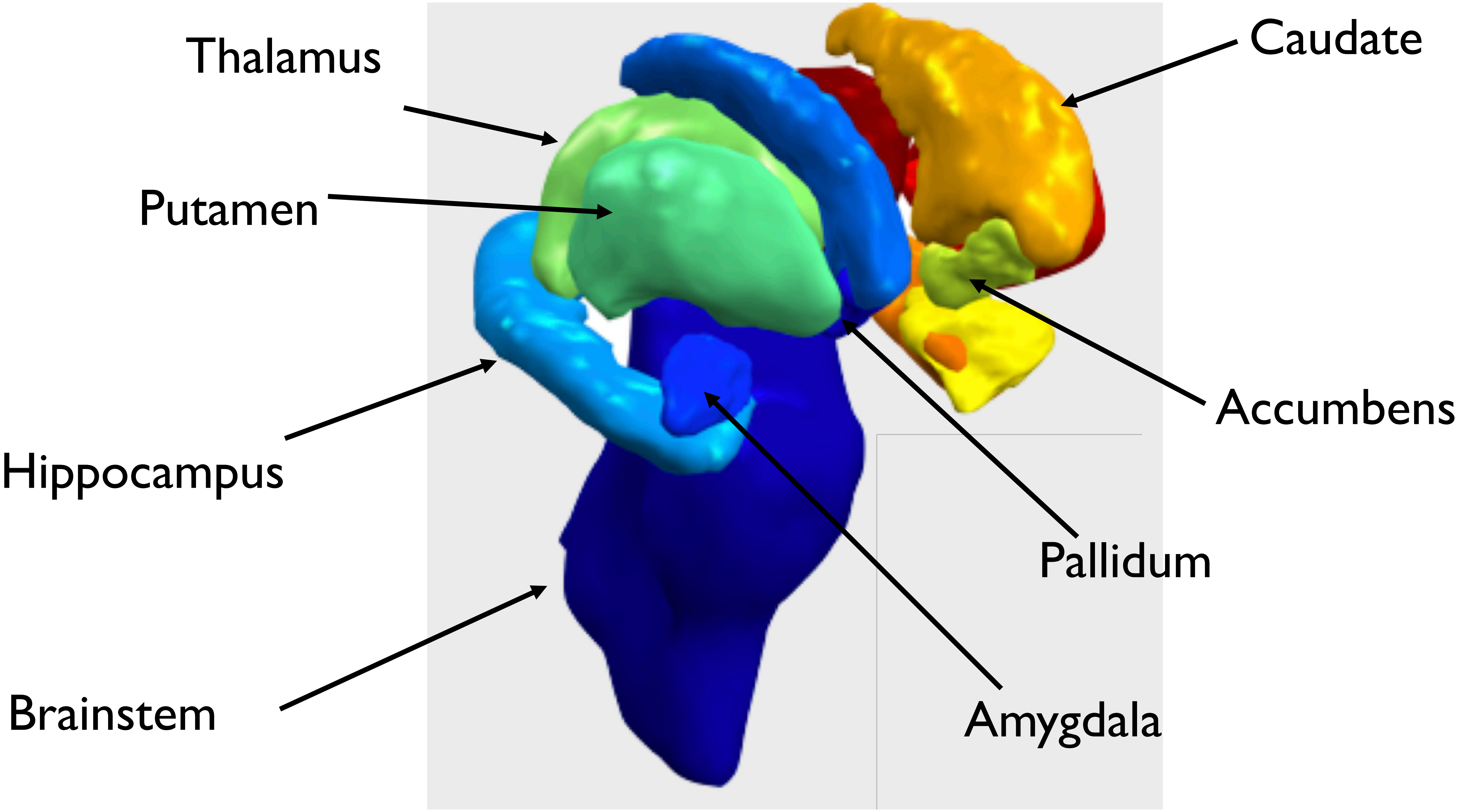
FMRIB's Integrated Registration & Segmentation Tool

Segmentation of subcortical brain structures

Sub-Cortical Structure Models

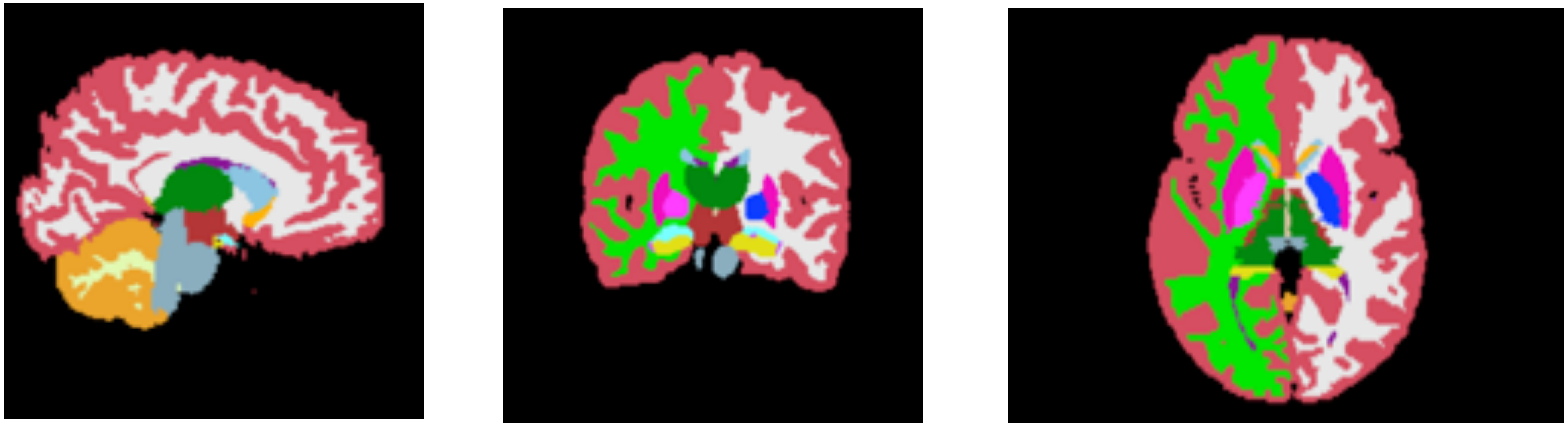
Incorporate prior anatomical information via explicit shape models

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



Training Data

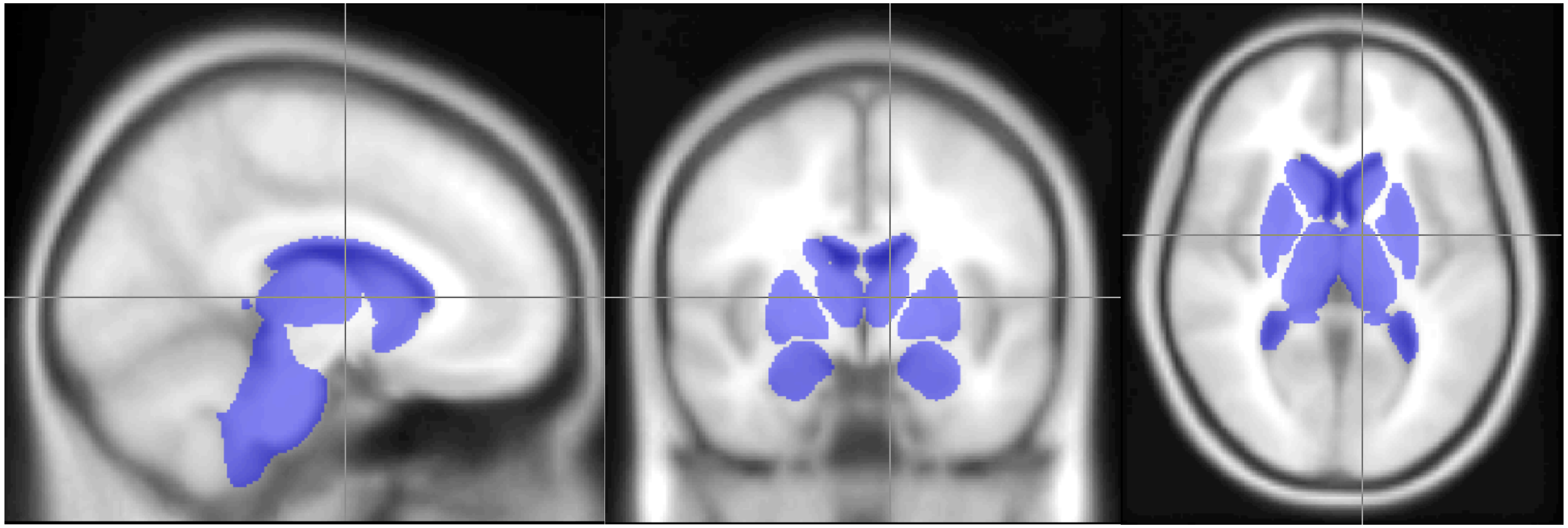
- Manual segmentations courtesy of David Kennedy, Center for Morphometric Analysis (CMA), Boston
- 336 complete data sets
- T_1-weighted images only
- Age range 4 to 87
  - Adults: Ages 18 to 87, Controls, schizophrenia, AD
  - Children: Ages 4 to 18, Controls, ADHD, BP, prenatal cocaine exposure, schizophrenia.



Model Training :
Alignment to MNI152 space

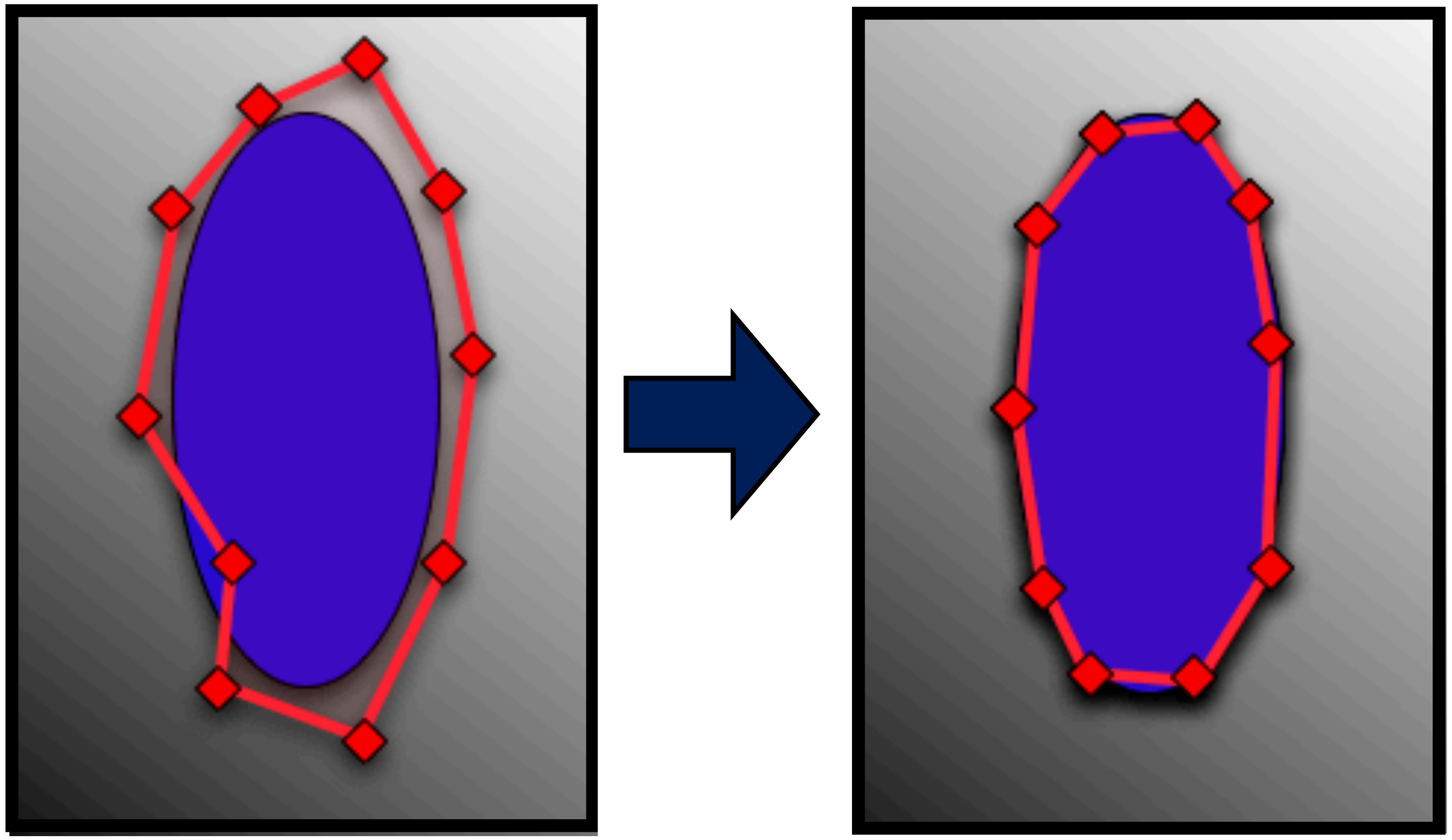
- All CMA data affine-registered to MNI152 space
  - 1mm resolution, using FLIRT

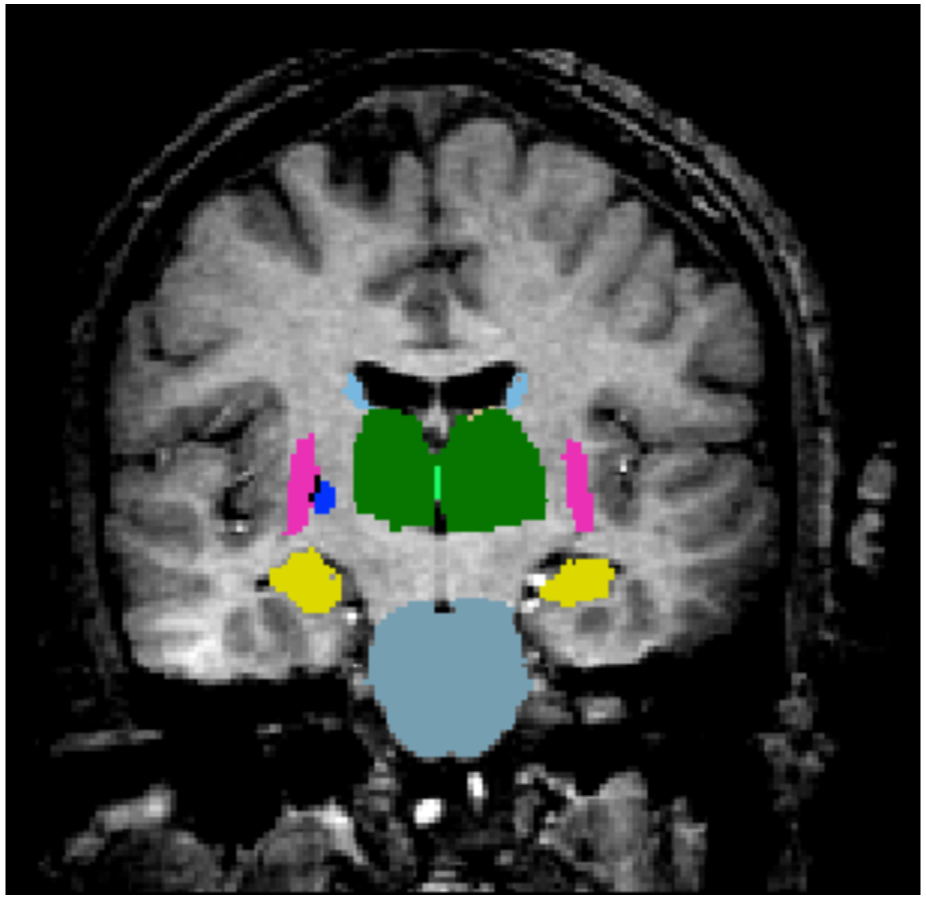
- 2-stage process:
  - Whole head 12 DOF affine
  - 12 DOF affine with MNI-space sub-cortical mask



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

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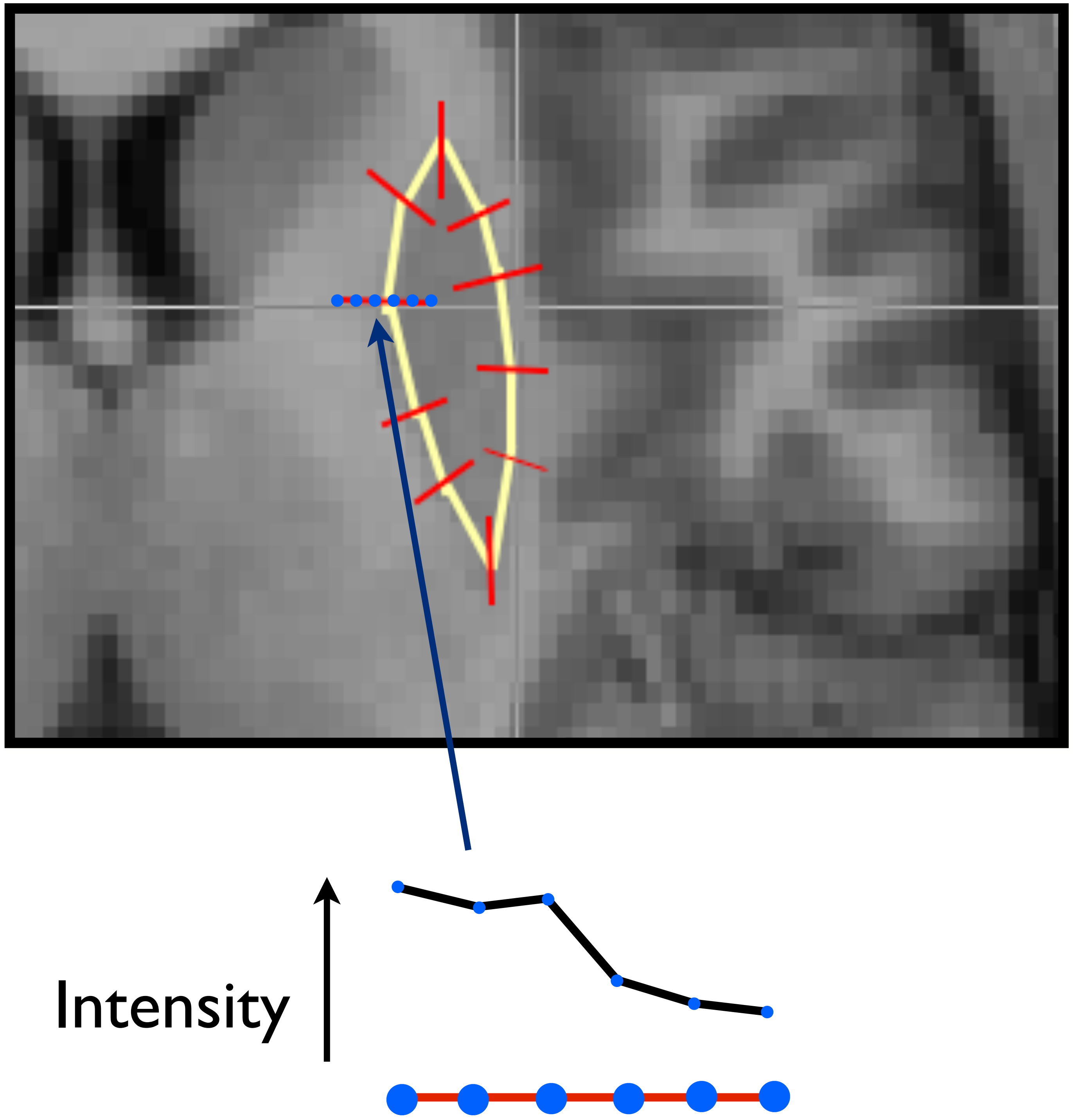
  - formally it uses a Bayesian formulation

$$X = \overset{\text{mean}}{\mu_X} + \underset{\text{Eigenvectors (modes)}}{U}\,\overset{\text{Singular values}}{D}\,\underset{\text{Shape parameters}}{b_X}$$

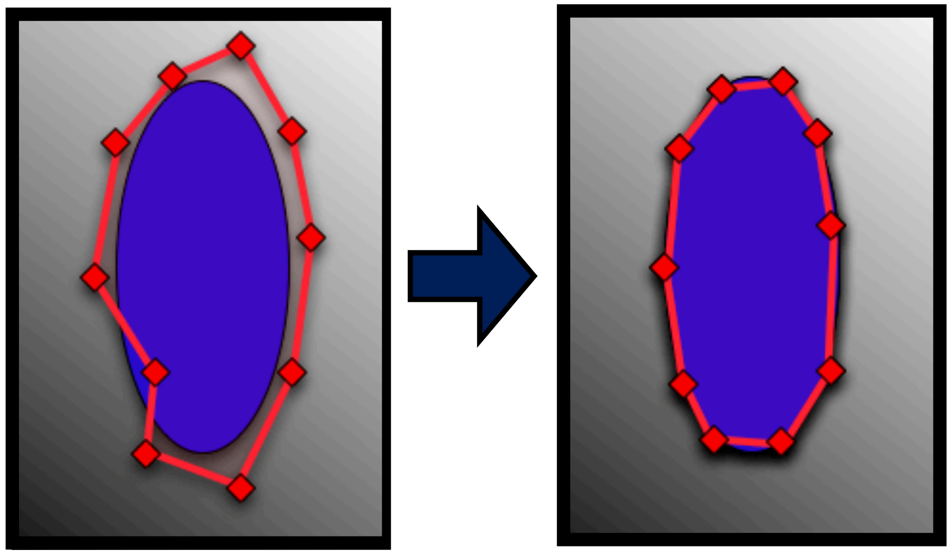
The Model: Intensity

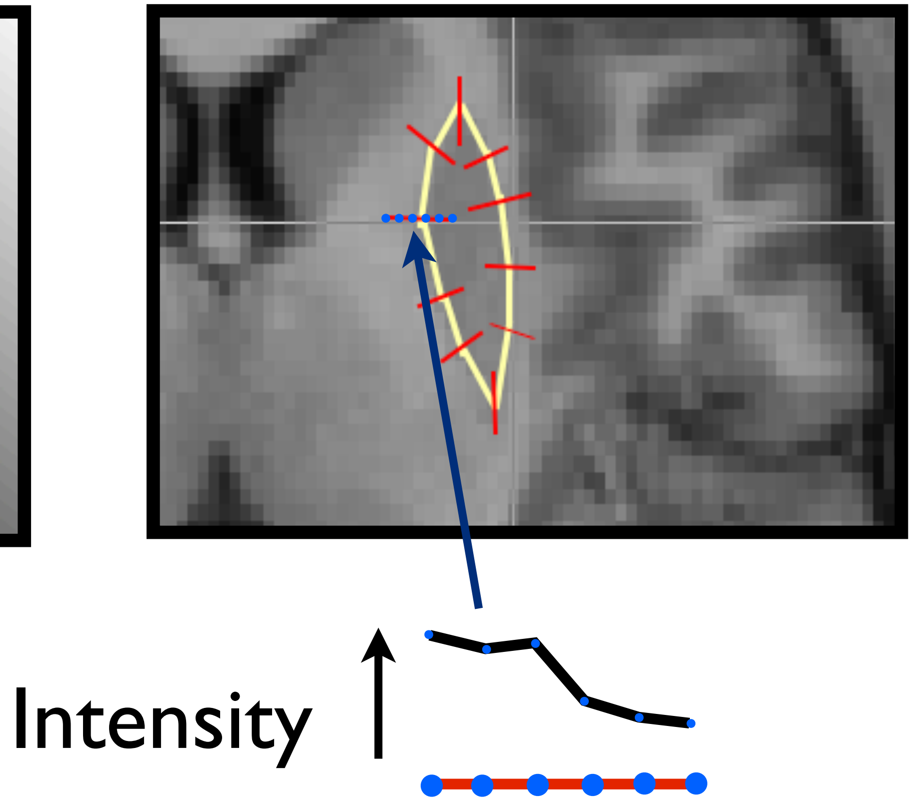
- Intensity is then sampled along the surface normal and stored
- Learn average intensity and “modes of variation”
- Aside: the intensities are re-scaled to a common range and the mode of the intensities in the structure is subtracted

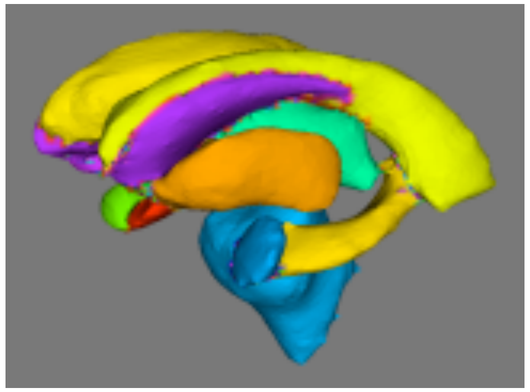


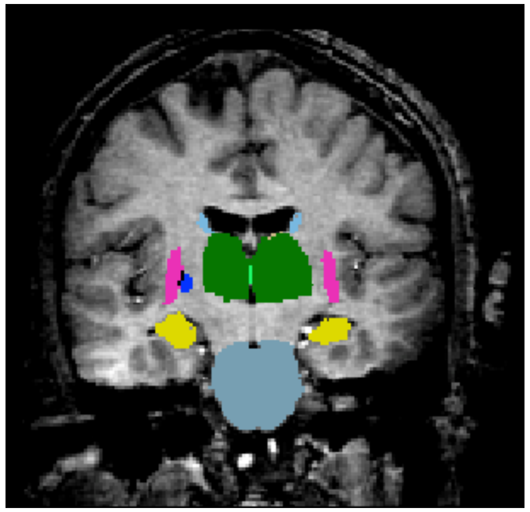
FIRST - Model

- <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



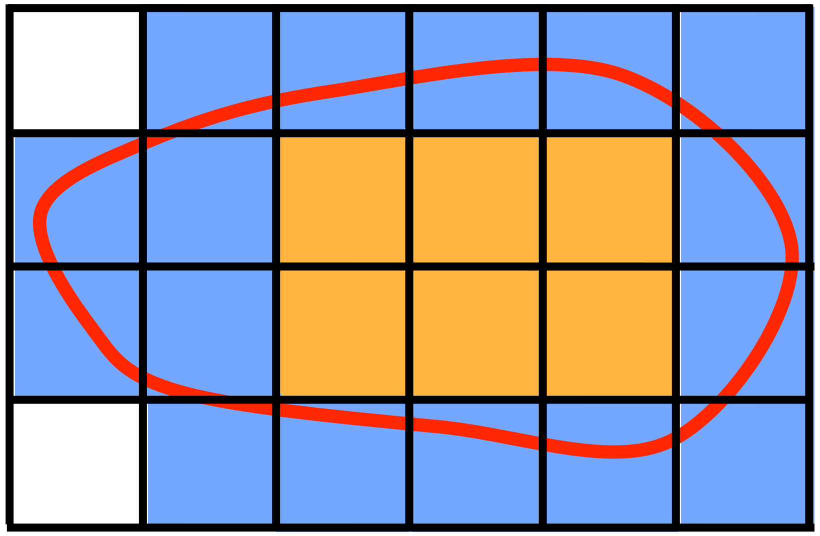






Boundary Correction

- 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

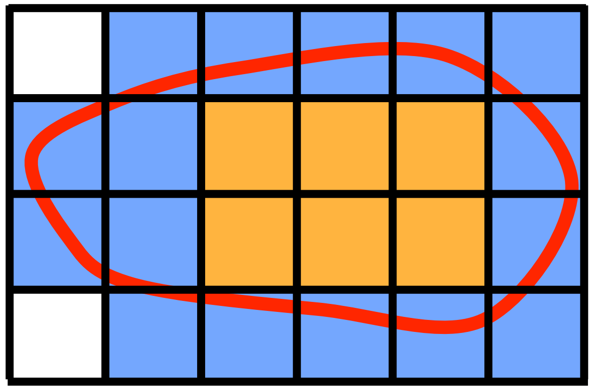


🟦 Boundary voxel

🟧 Interior voxel

FIRST - Output/Analyses

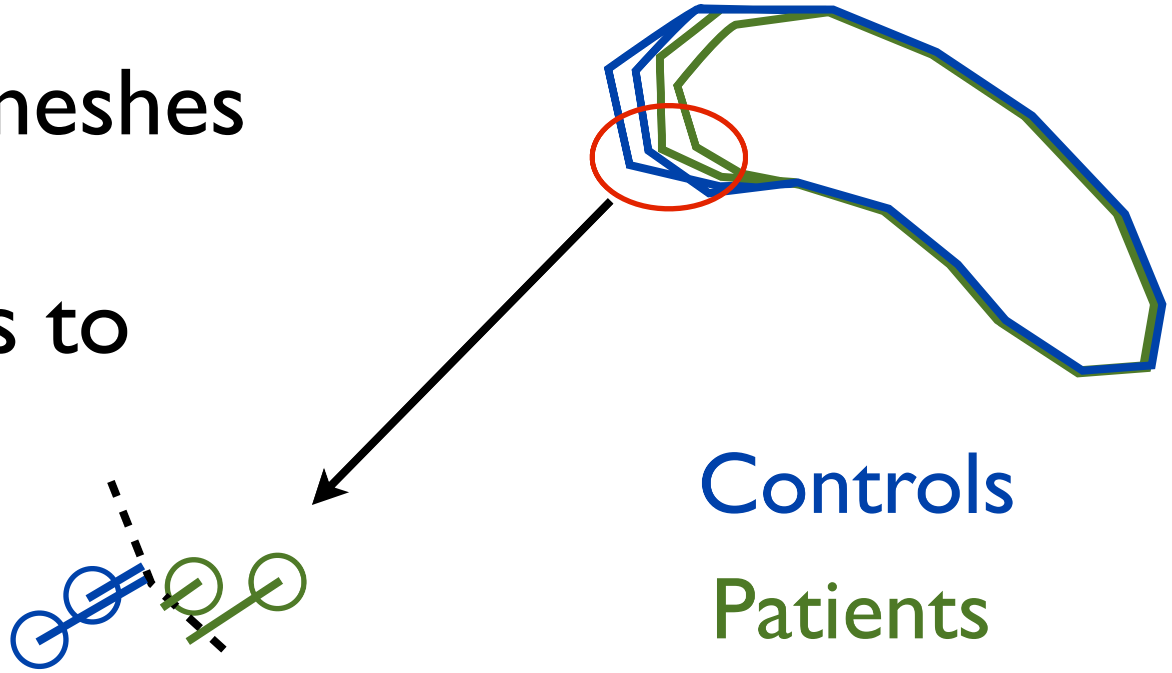
- *Volumetric analysis*
  - FIRST converts meshes to images applying boundary correction to decide whether boundary voxels belong to the structure or not



🟦 Boundary voxel

🟧 Interior voxel

- *Vertex analysis*
  - FIRST models all structures by meshes
  - Consider each vertex in turn
  - Do a test on distance of vertices to average shape



Running FIRST

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

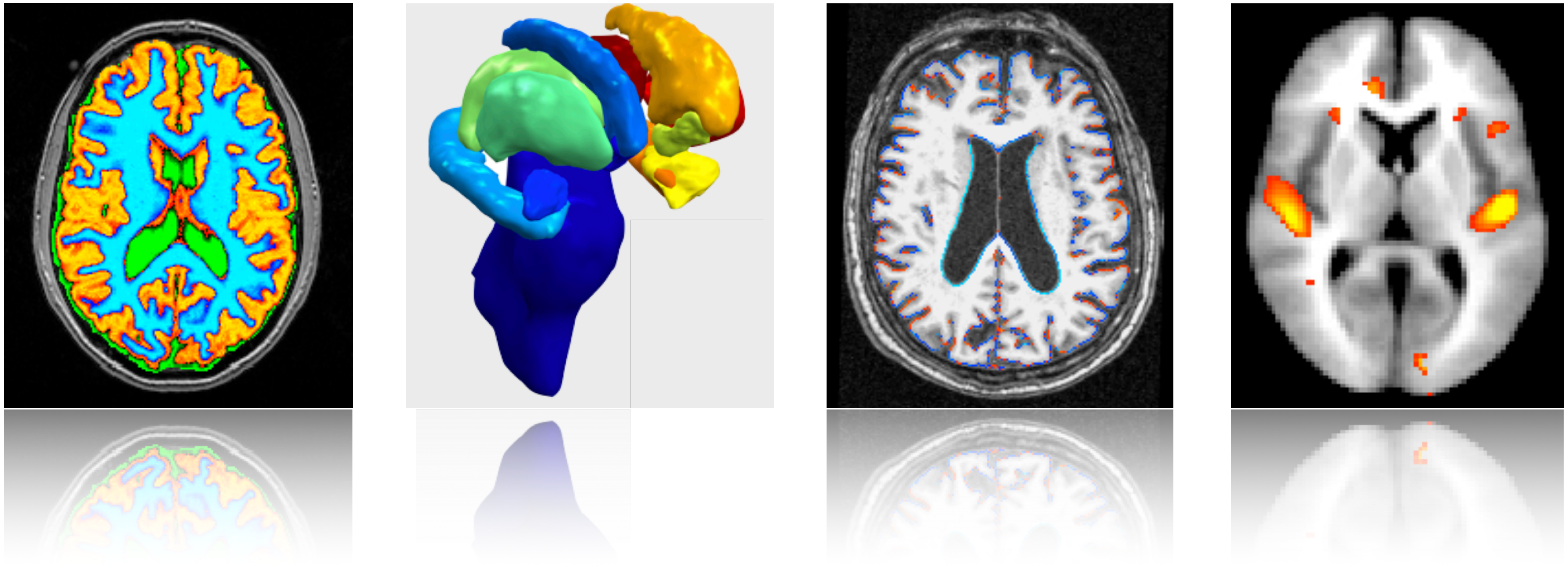
- Applying FIRST
  - A single command: run_first_all
    1. registers image to MNI152 1mm template
    2. fits structure models (meshes) to the image
    3. applies boundary correction (for volumetric output)

- 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)

fsl_anat - Anatomical processing script

- General pipeline for processing anatomical images with FSL tools
- Specific features:
    - Brain extraction is registration-based (alternative to bet)
    - Bias-field correction improved (especially for strong bias-fields).
- The stages in the pipeline (in order) are:
    - reorient the images to MNI: **fslreorient2std**
    - automatically crop the image: **robustfov**
    - bias-field correction: **fast**
    - registration to standard space (linear and non-linear): **flirt** + **fnirt**
    - registration-based brain-extraction: **fnirt**
    - tissue-type segmentation: **fast**
    - subcortical structure segmentation: **first**
- Run-time depends on image resolution (30-90’ would be typical).

After the break…



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