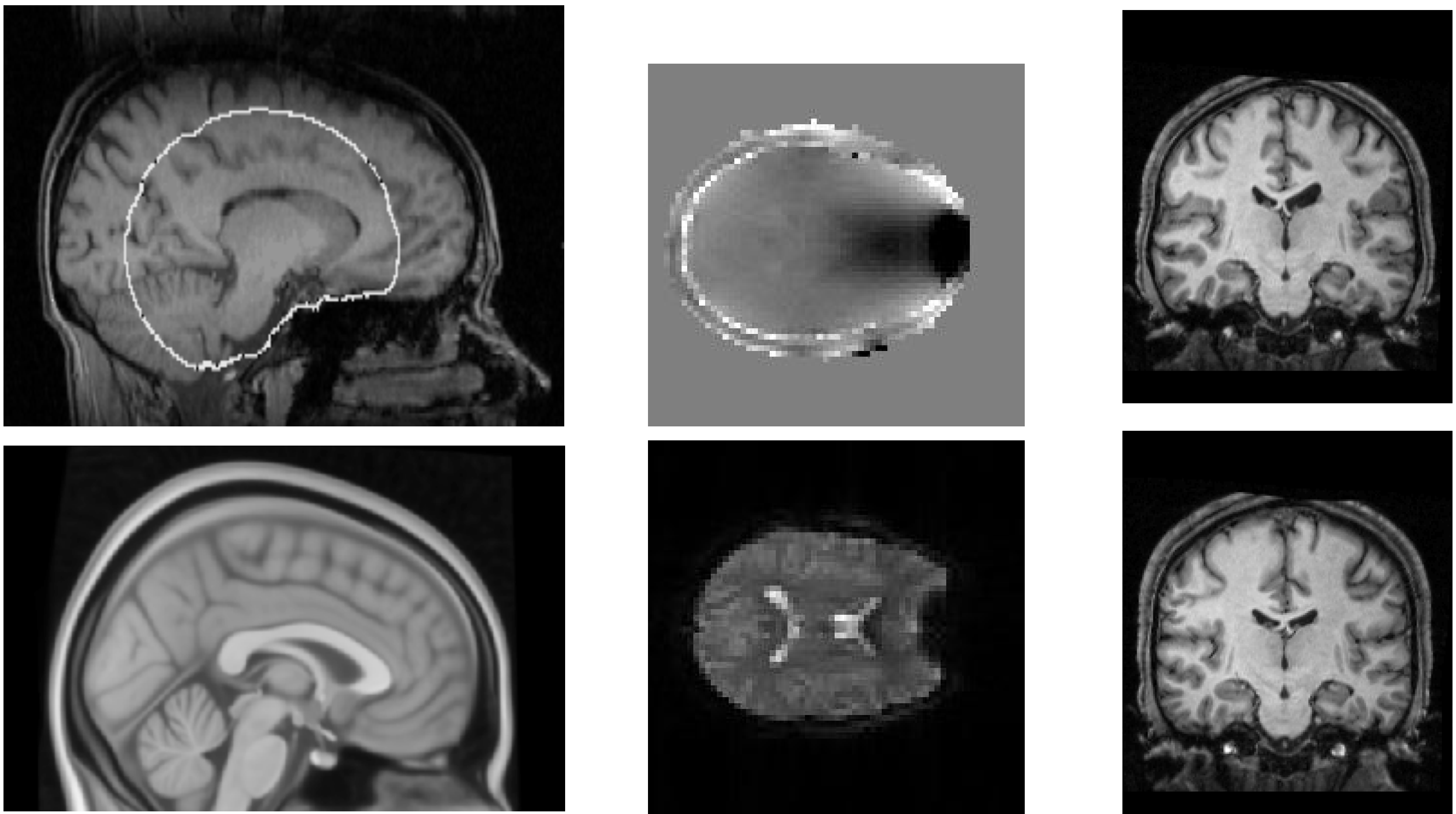
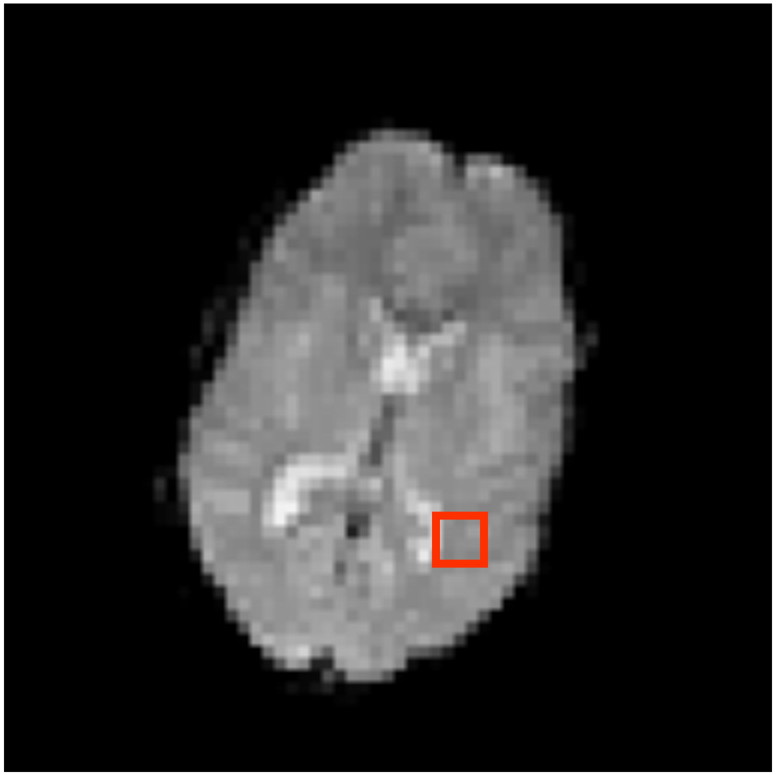
Introduction to Brain Extraction and Registration



What is Registration?



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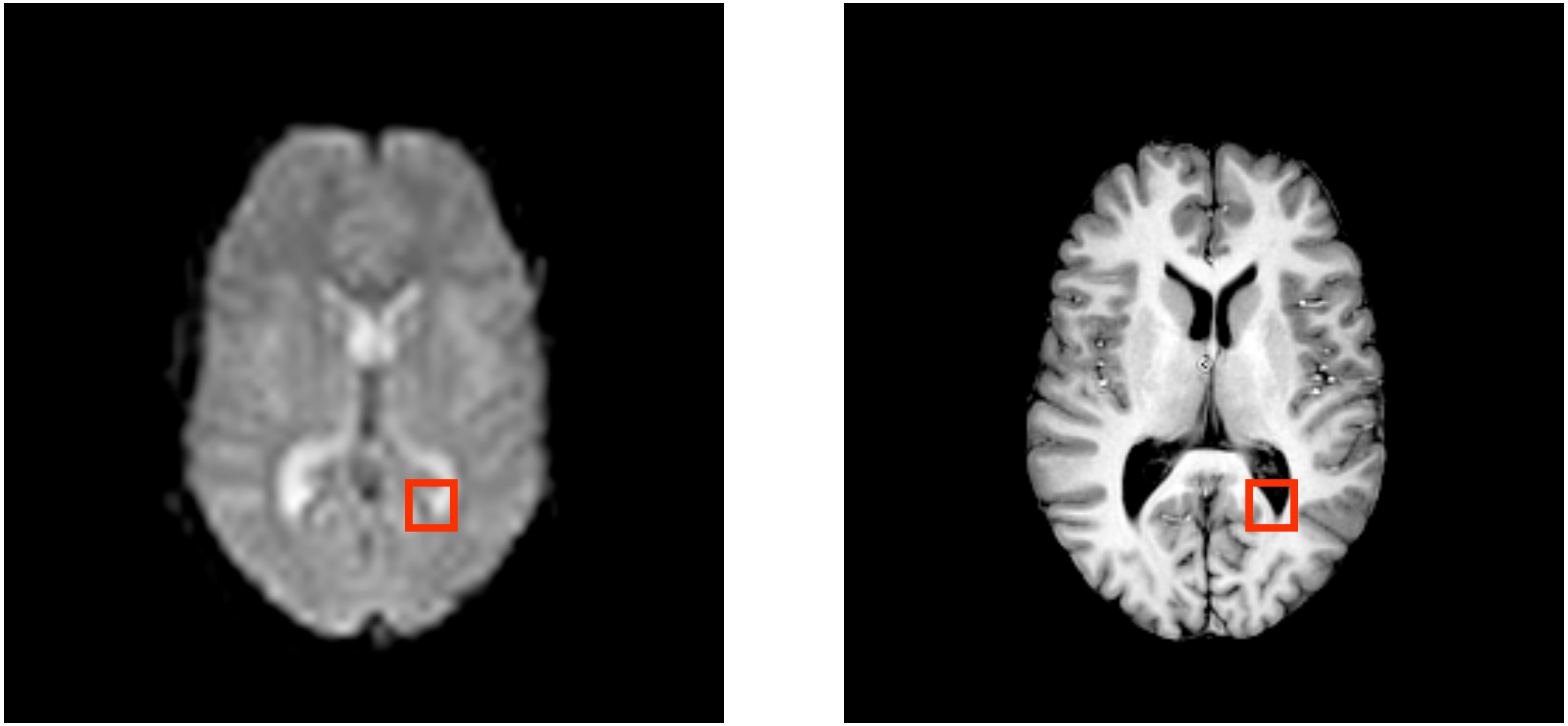


Align images so that

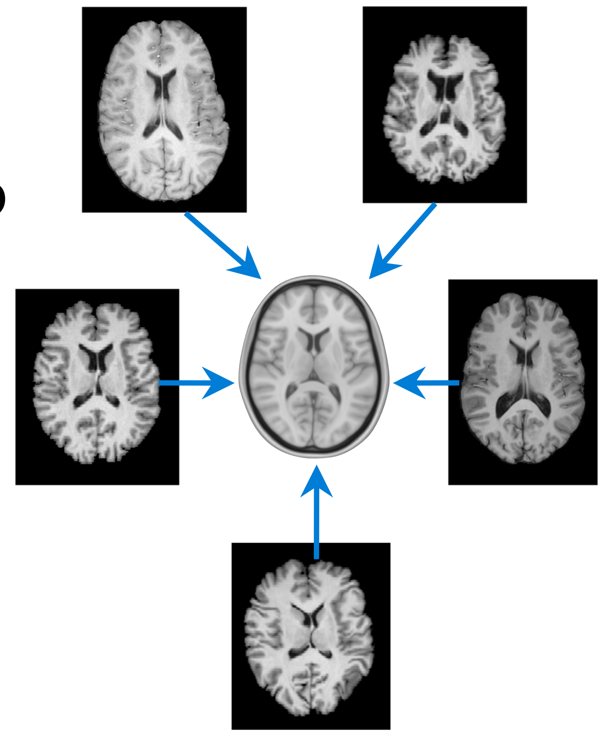
voxel location = anatomical location

with accurate intensity values

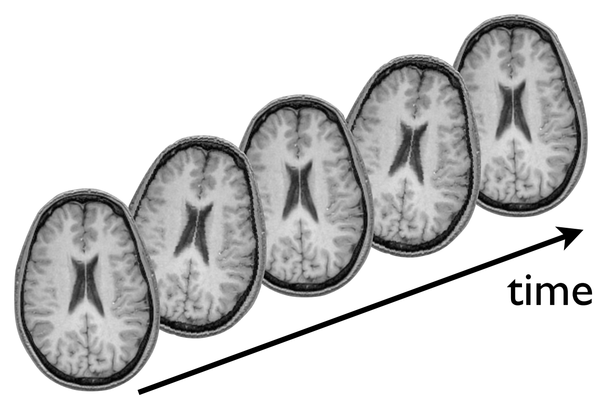
What use is Registration?

Some common uses of registration:

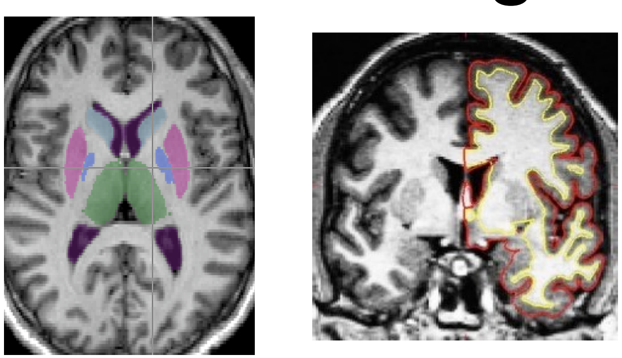
Combining across individuals in group studies: including fMRI & diffusion



Correcting for motion



Quantifying structural change



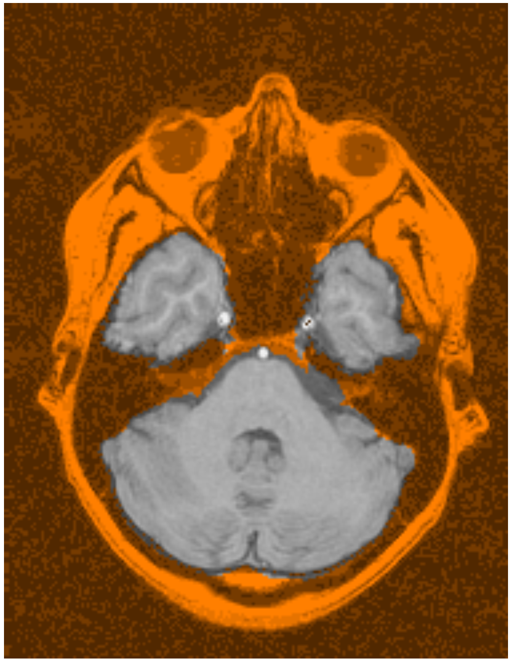
BET: Brain Extraction Tool

Brain / non-brain segmentation

Preparation step for registration and segmentation

Eliminates non-brain tissues with highly variable contrast and geometry (e.g. scalp, marrow, etc.)
- works best if some fat sat is used

Robust to bias fields (by using local intensity changes)

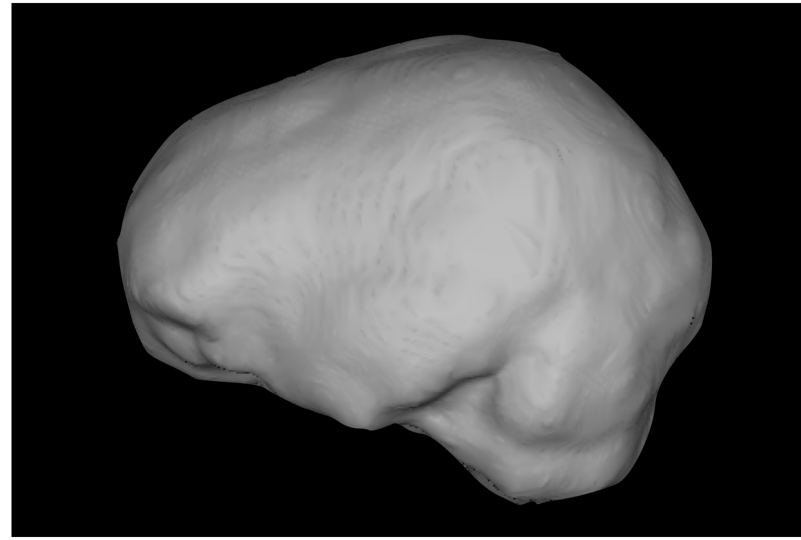


S.M. Smith; Fast robust automated brain extraction; HBM 17(3), 2002.

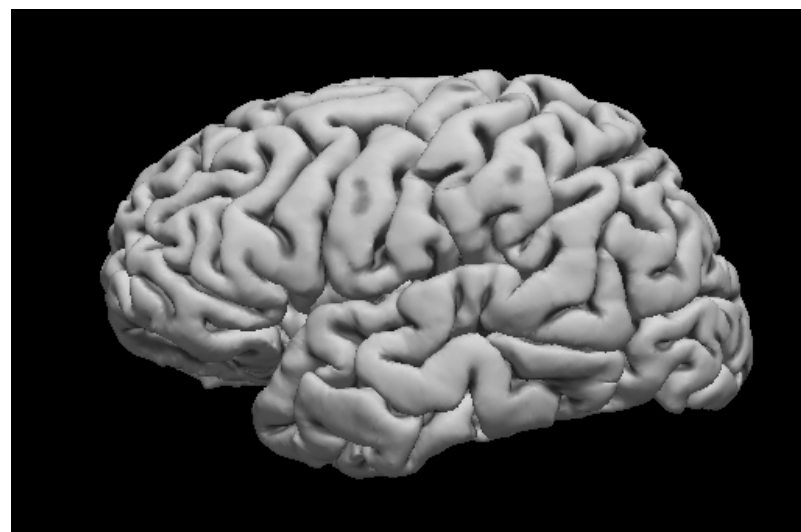
Works with a wide range of MRI sequences (T1, T2, etc.) and resolutions

Example Results

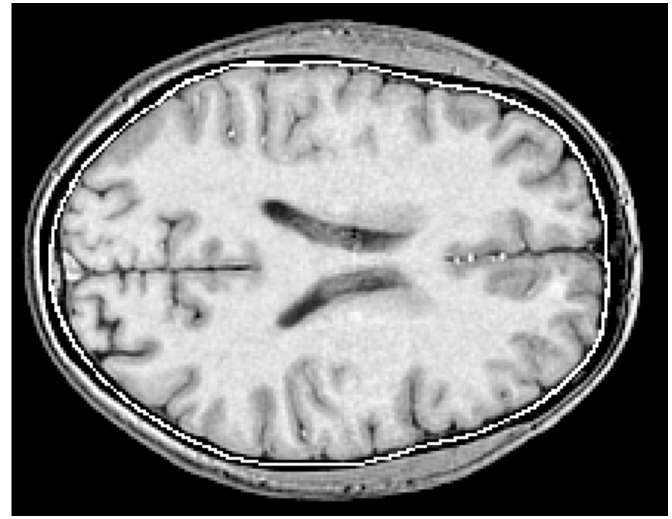
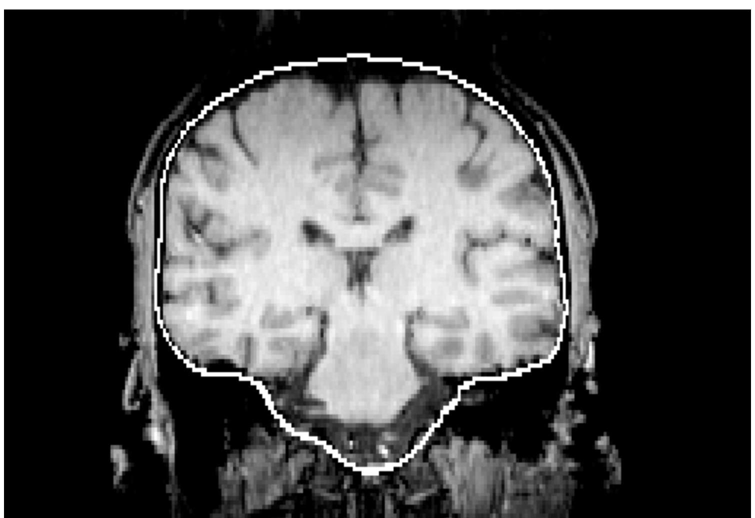
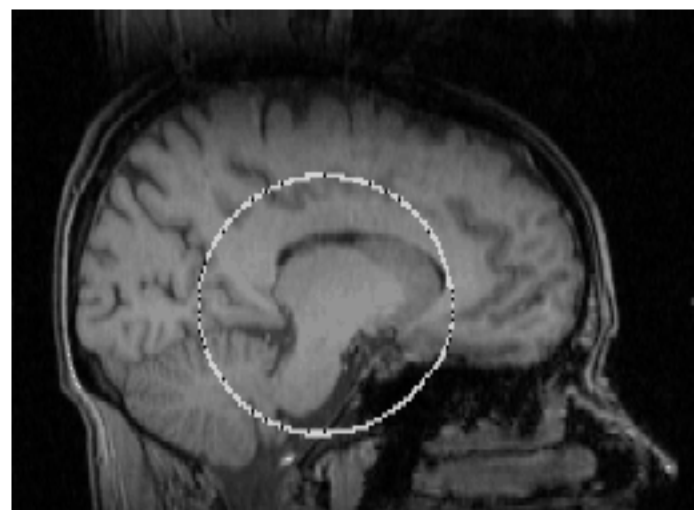
Brain Surface Model



Extracted Brain Surface
(not what we aim for here)

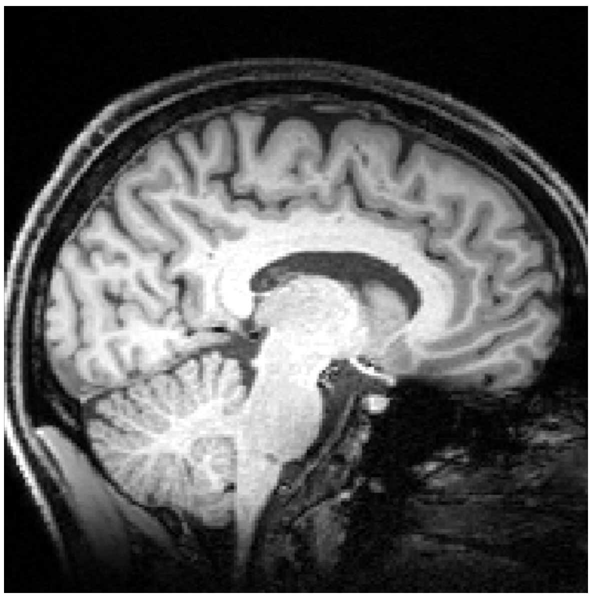


Example Results

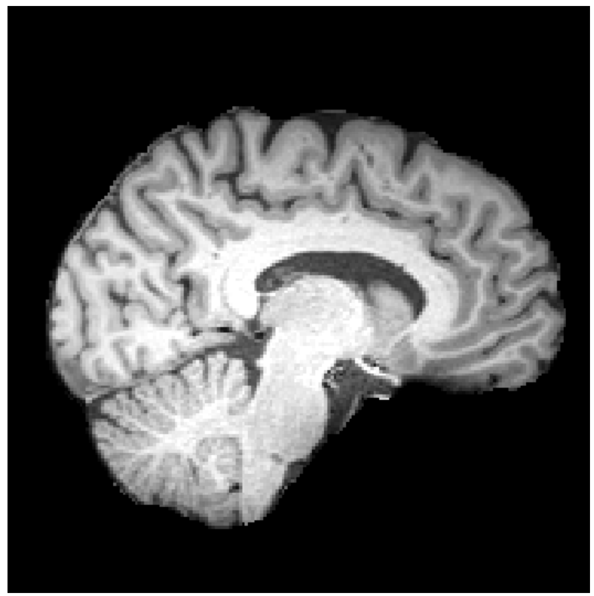





Example Results

Original

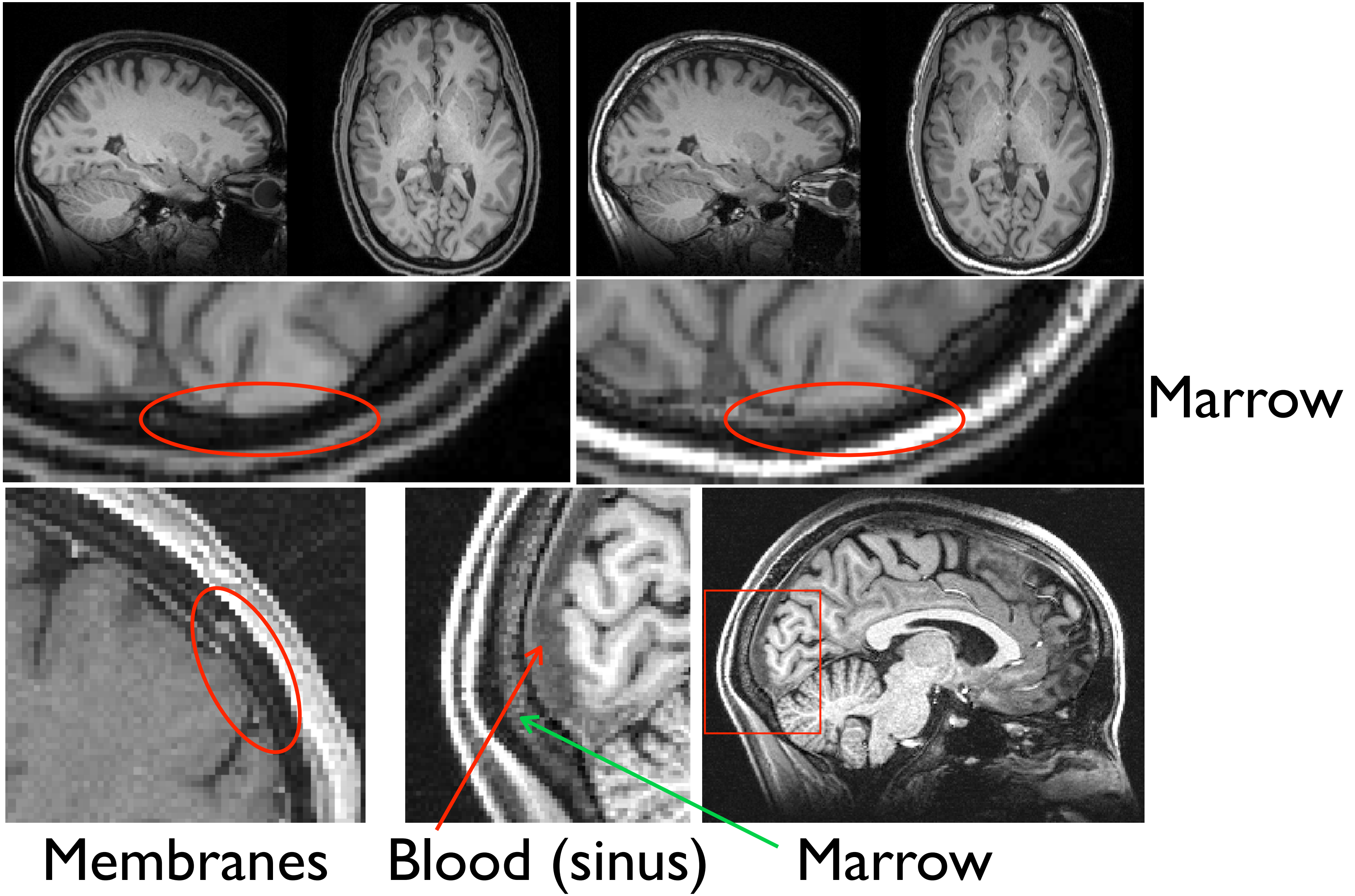


Brain Extracted

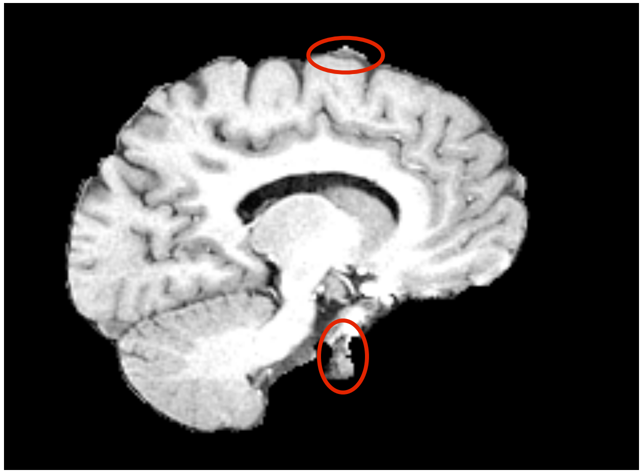


Brain Mask

Difficulties

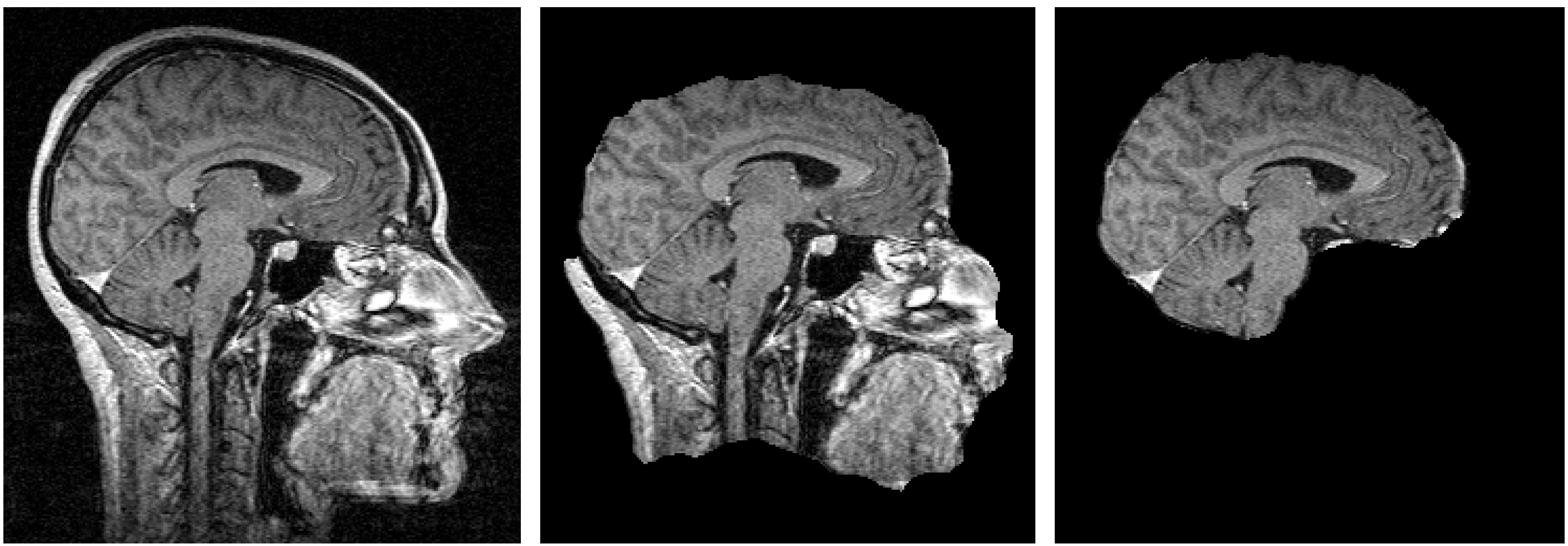


Example Results



Want to remove the majority of non-brain structures, leaving all the brain intact.

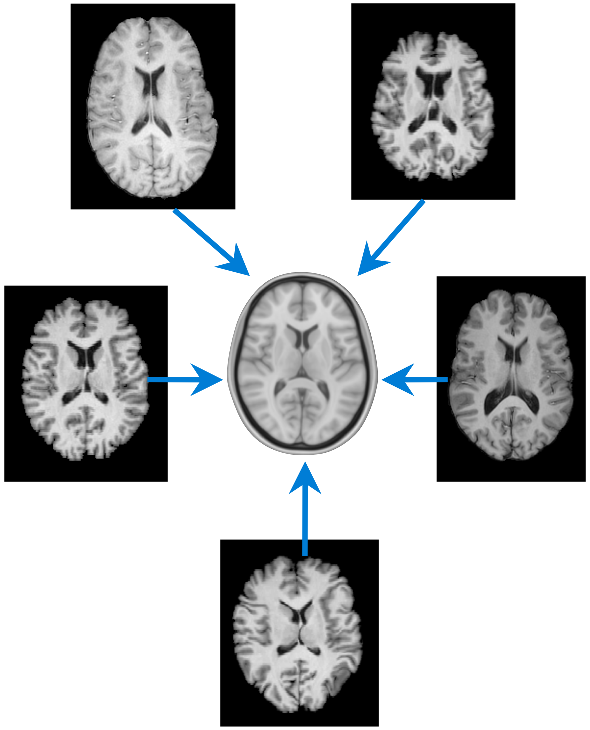
Leaving small pieces of non-brain is *unimportant for linear registration*, but it is important for segmentation.



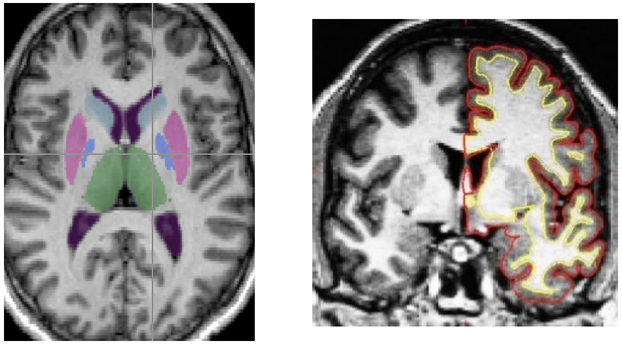
What use is Registration?

Some common uses of registration:

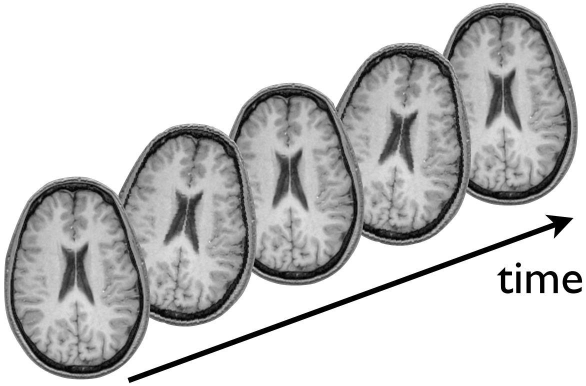
Combining across individuals in group studies: including fMRI & diffusion



Quantifying structural change



Correcting for motion

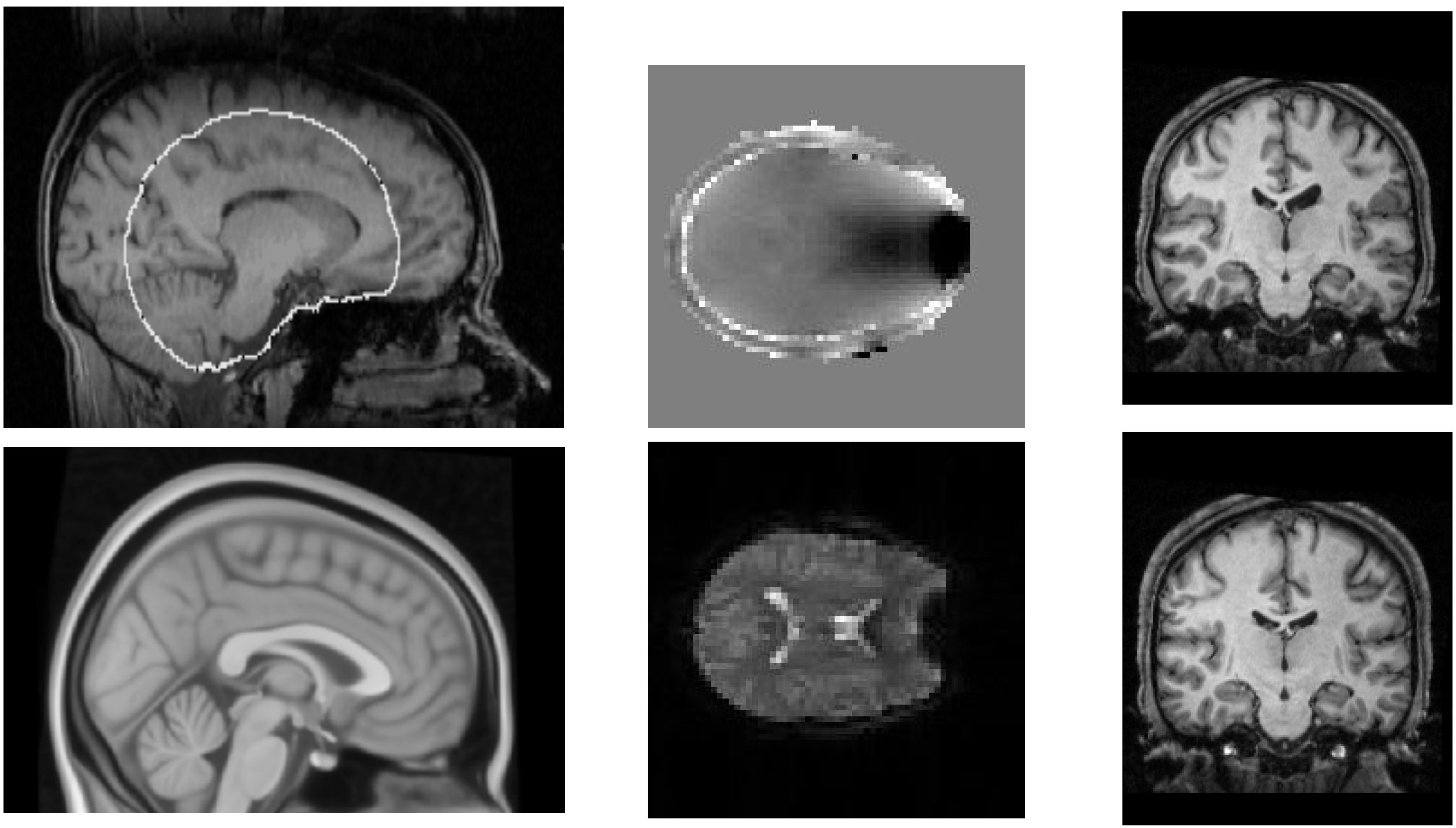


Brain Extraction and Registration

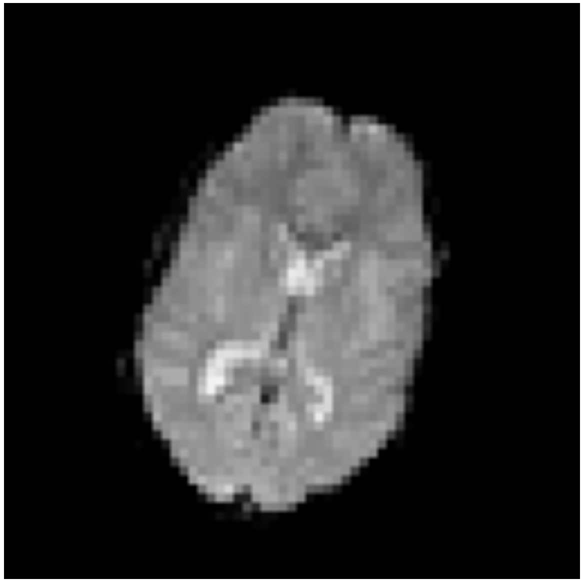
Summary:

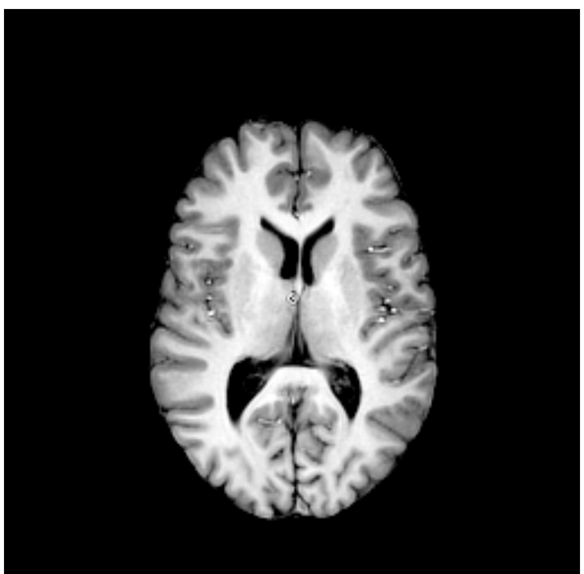
- Registration aims to align images/structures
- Can transform the image to match others
- Important component in *all* group studies
- Can measure motion or anatomical change
- Brain extraction removes bulk of non-brain
- Some errors are to be expected
- Small, isolated errors are not a problem *for registration (but would be for segmentation)*

Registration: Image Spaces and Spatial Transformations



Basic Registration Concepts

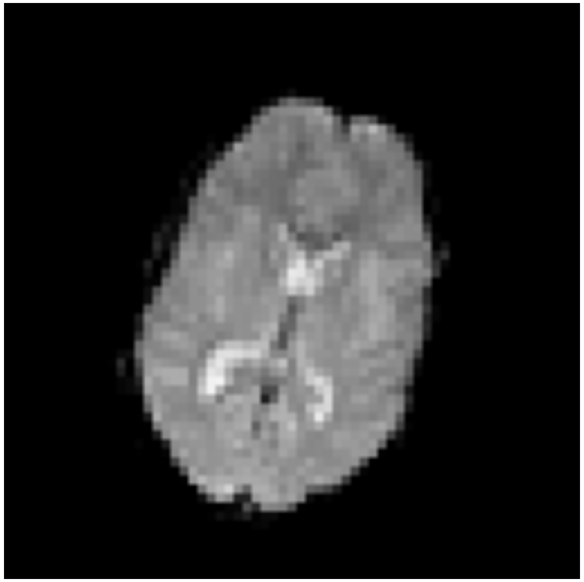


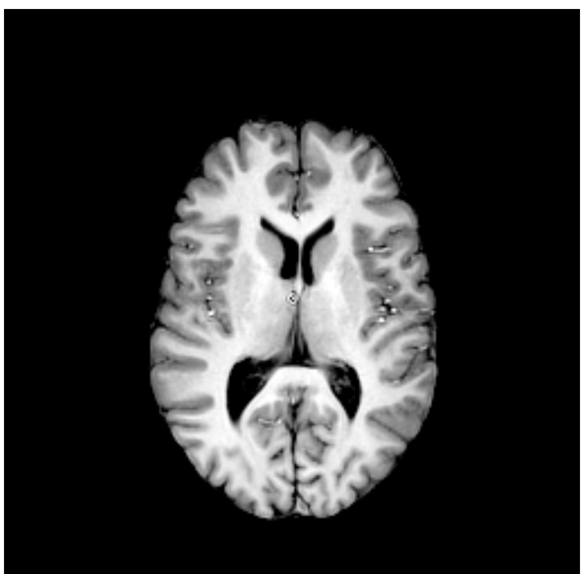


Need to understand:

- Image “spaces”
- Spatial Transformations
- Cost Functions
- Interpolation

Basic Registration Concepts





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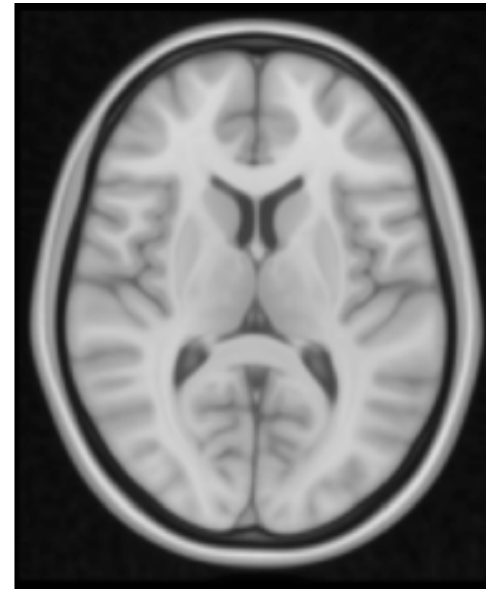
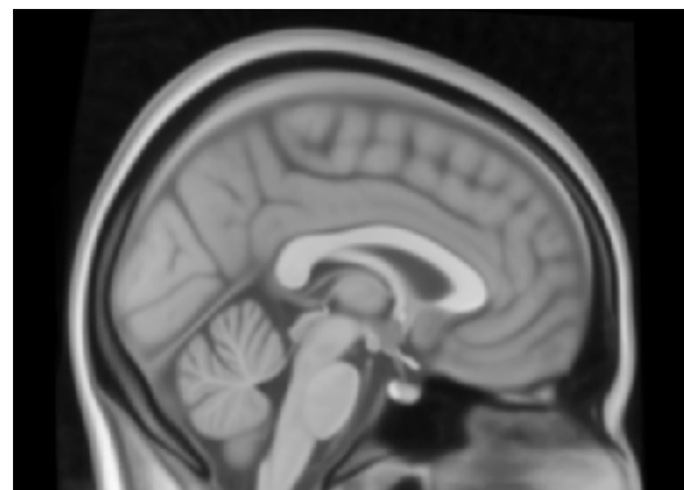
Standard Space

- Common reference coordinate system for reporting/describing
- Register all members of a group to this space for group studies
- Original Talairach & Tournoux coords based on one post-mortem brain
- Now use standard images based on non-linear group average (MNI152)
- MNI is not quite Talairach

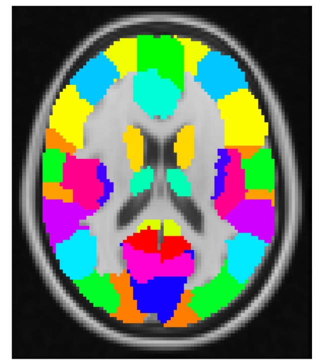




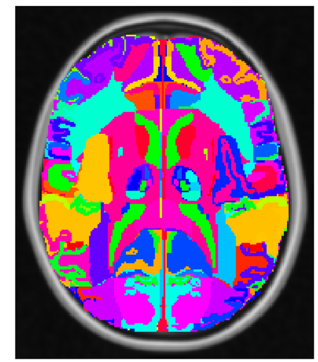
Standard Space: Atlases

- Most atlases are in standard space (esp. MNI152)
- Information is derived from different sources, but in each case this has been brought into the standard space at some point
- To use atlas information for an individual (or group) study it is necessary to "get into" standard space

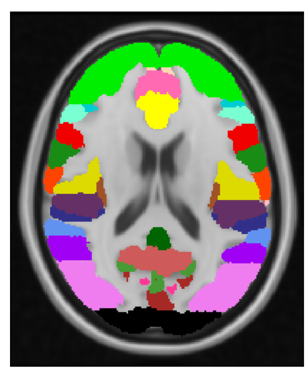
AAL



Talairach

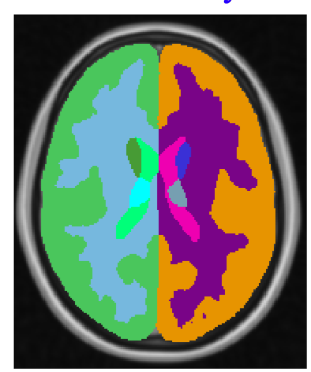


Harvard-Oxford Cortical

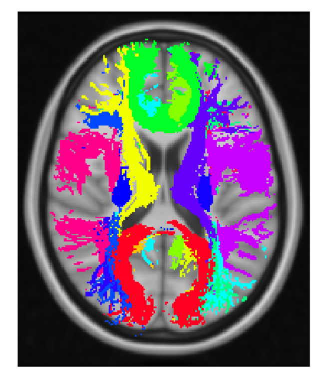


Harvard-Oxford Subcortical

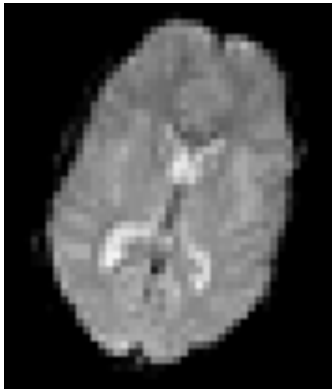
Summary



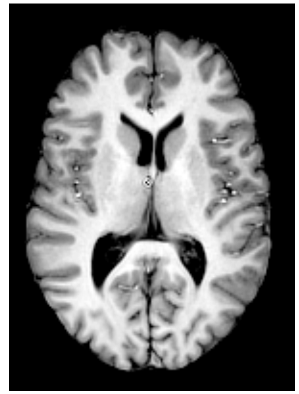
JHU White-Matter Tractography



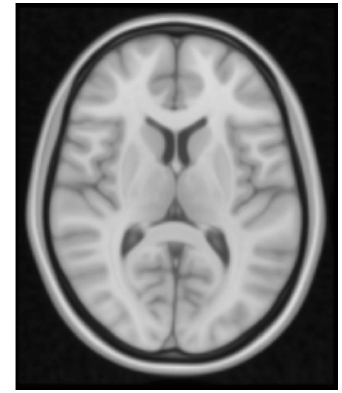
Other "Spaces"



FMRI



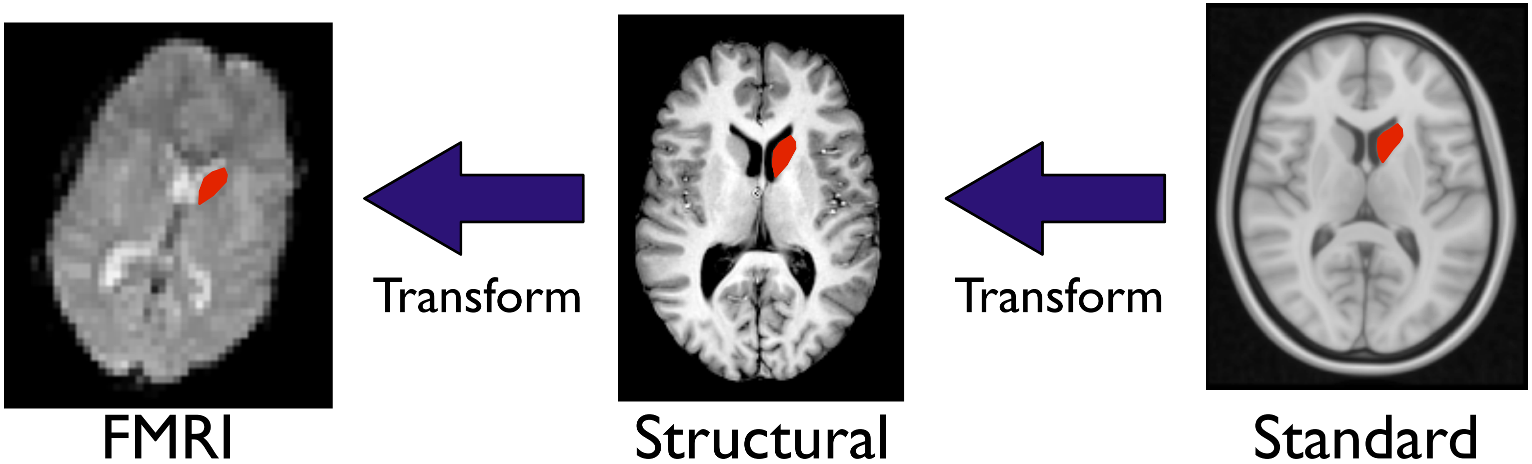
Structural



Standard

- All images in the same "space" are aligned
- Different images ⇒ different "spaces"
  e.g. standard space, structural space, functional space
- Can have different resolution images in the same space
  e.g. 1mm and 2mm versions of standard space images
- Want to move image-related info between spaces
  e.g. a mask from standard space to structural space

Other “Spaces”



- Need to *register between spaces* (via images) and get the transformations before transforming/moving/resampling any image-related info (like masks or atlas ROIs)
- Can have versions of the same “image” (e.g. a mask) in several different spaces
- FSL tools (e.g. FEAT) often move things between spaces

Other "Spaces"

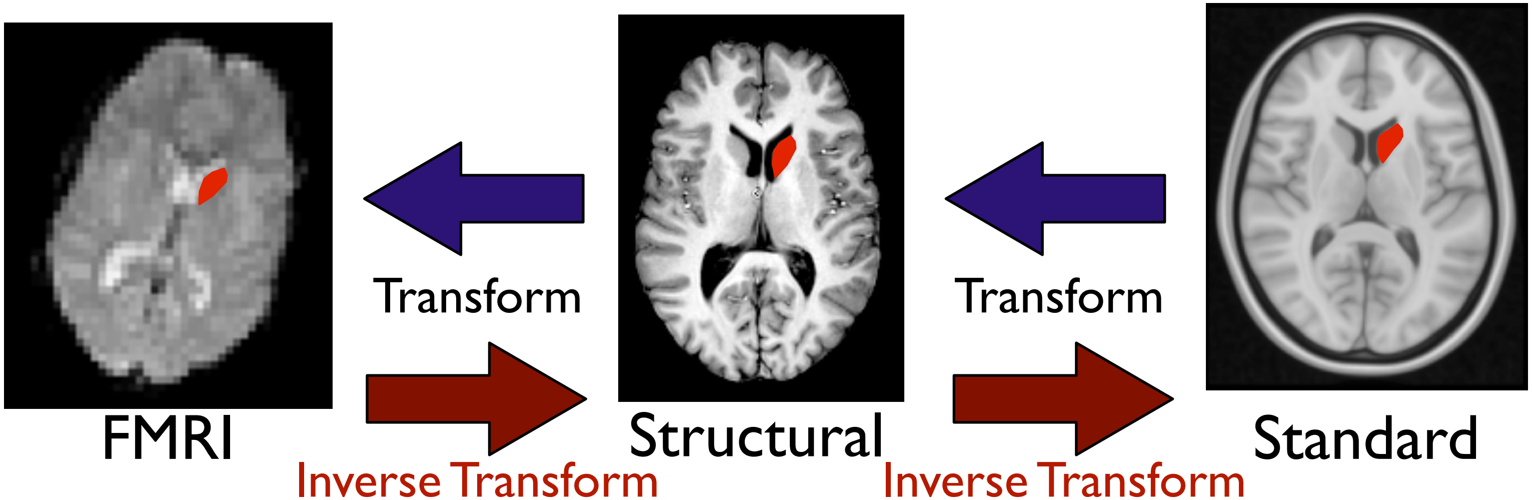


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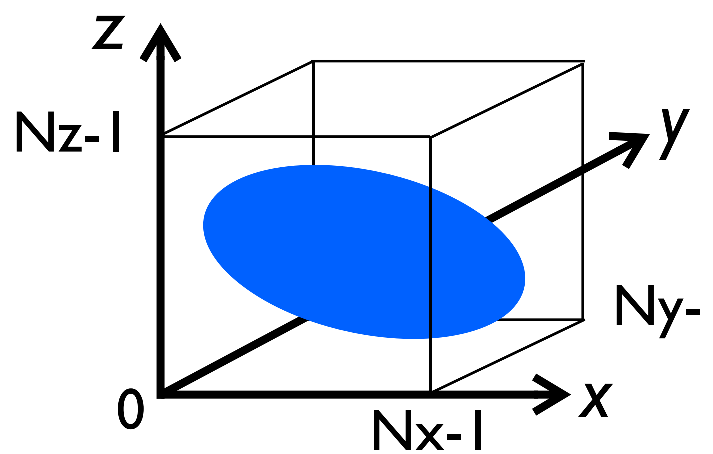
Image (Voxel) Coordinates

Confusingly, there are many types of coordinates

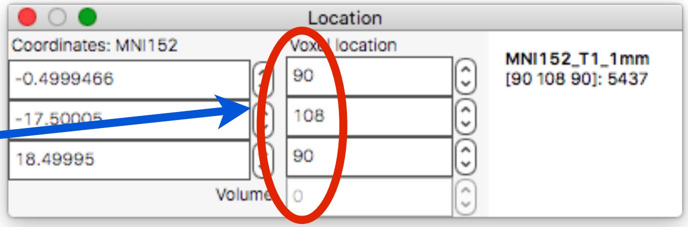
Voxel coordinates in FSL:

- Integers between 0 and N-1 inclusive
- Refer to the whole voxel
- Origin in the lower-left corner: (0,0,0)



Axes are not aligned with the anatomy

- Cannot distinguish left from right by voxel coordinate values



- FSLeyes reports these
- Used by FSL commands & same as NIfTI coords

Standard Space Coordinates

Standard Space coordinates in FSL:

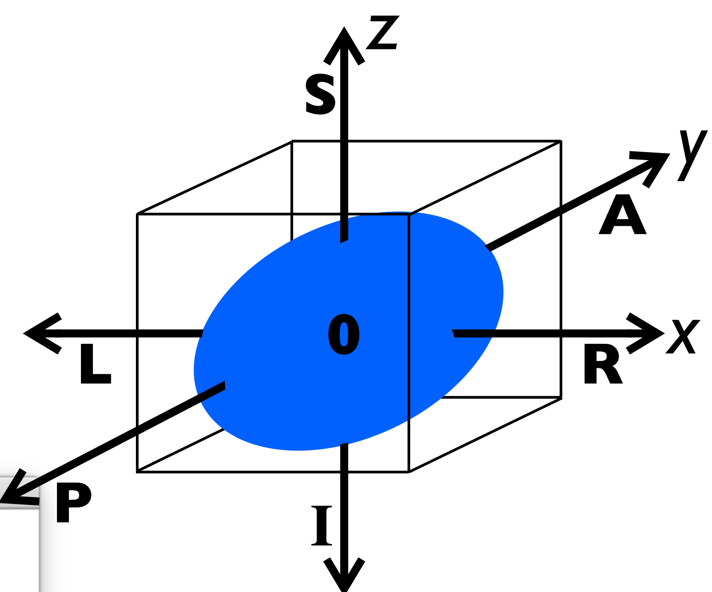
Real numbers, in units of *mm*

Origin (0,0,0) near centre of image

(anatomical landmark; e.g. anterior commisure)

Axes aligned with anatomy

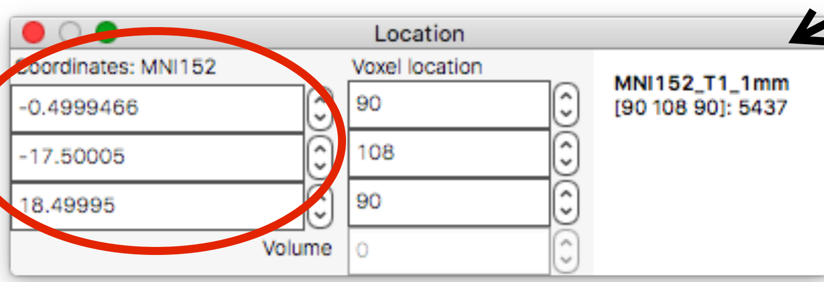
(left and right specified)



Several standard spaces exist:

MNI, Talairach, BrainWeb, etc

FSLeyes also reports these *when possible*



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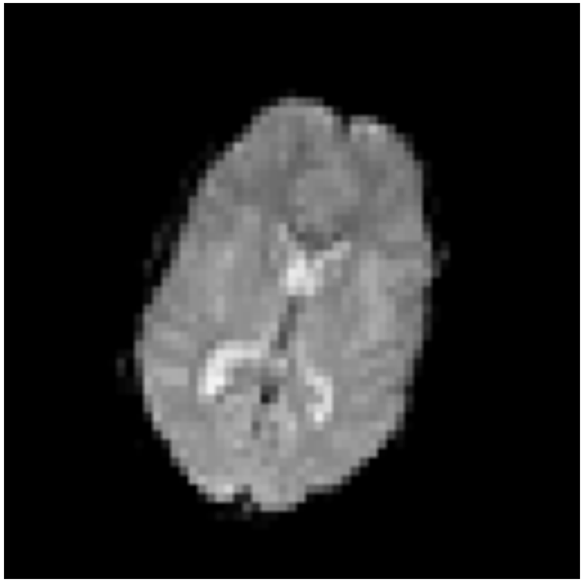
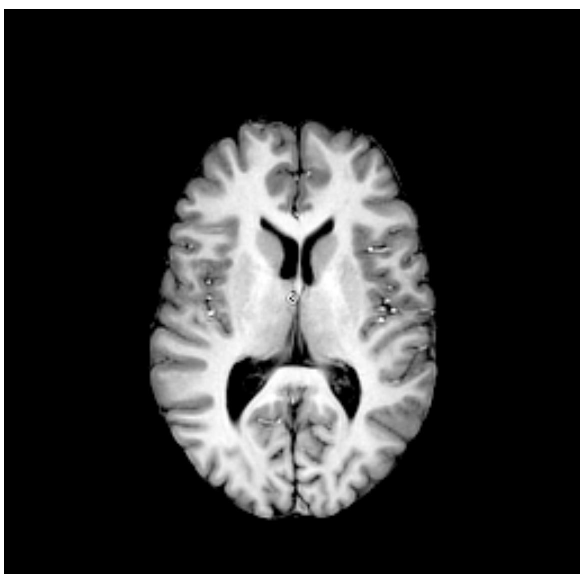




Need to understand:

- Image “spaces”
- Spatial Transformations
- Cost Functions
- Interpolation

Spatial Transformations

To align images must transform them

Many types of transformation

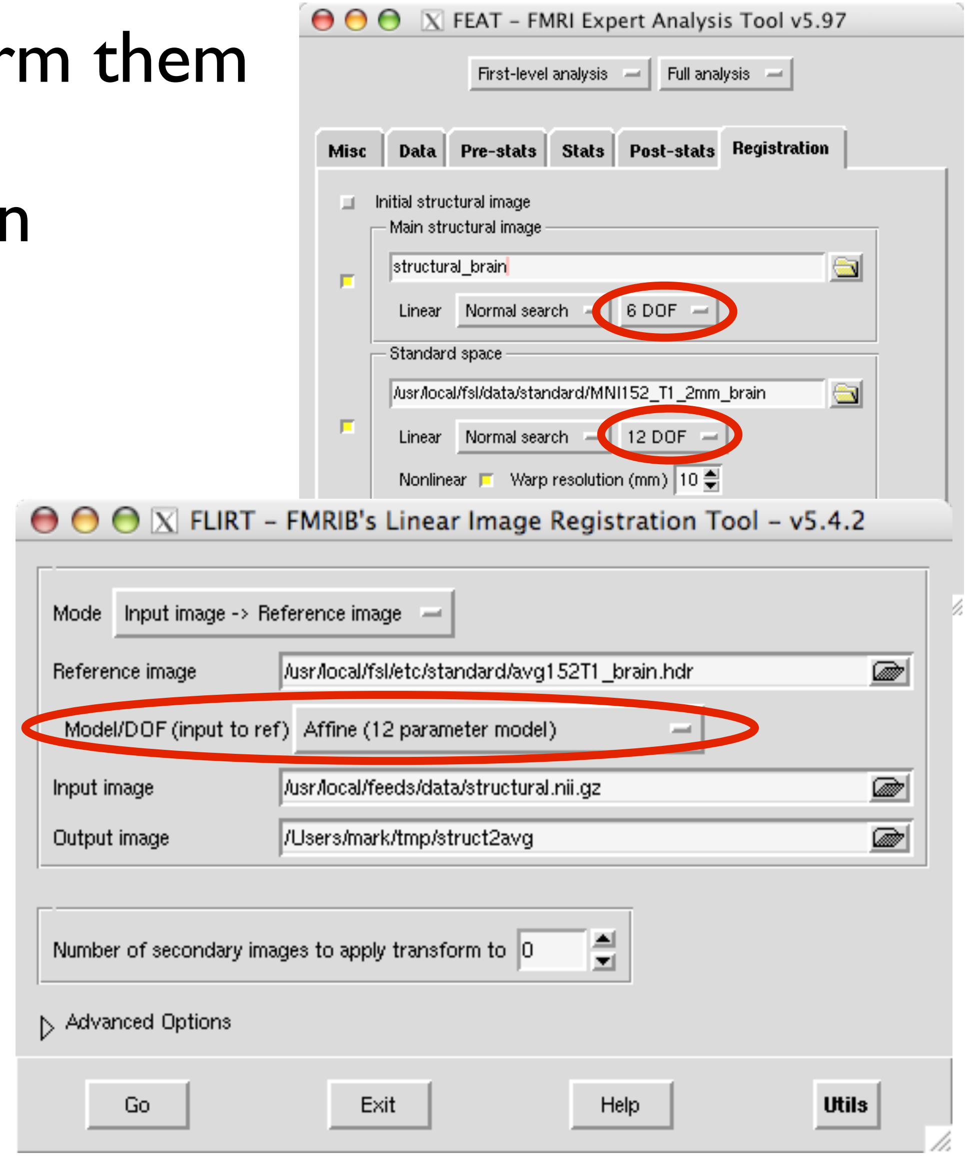
Degrees of Freedom (DOF) partially describe transform

Examples:

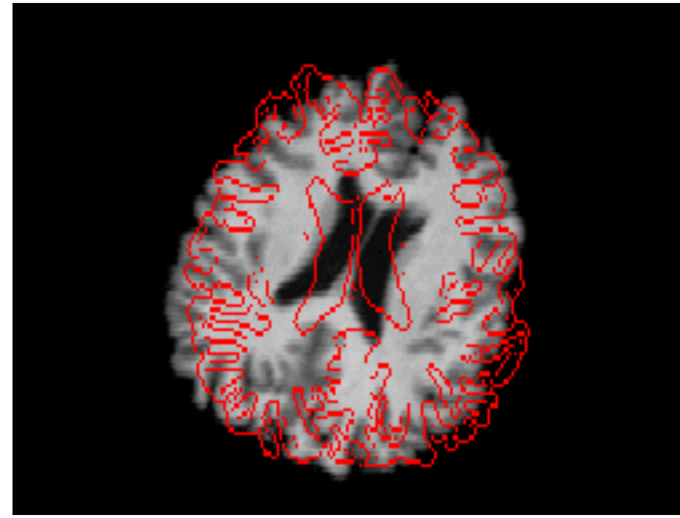
Rigid Body (6 DOF)

Affine (12 DOF)

Non-linear (12 - millions DOF)



Rigid-Body Transformations



6 DOF in 3D

Includes:

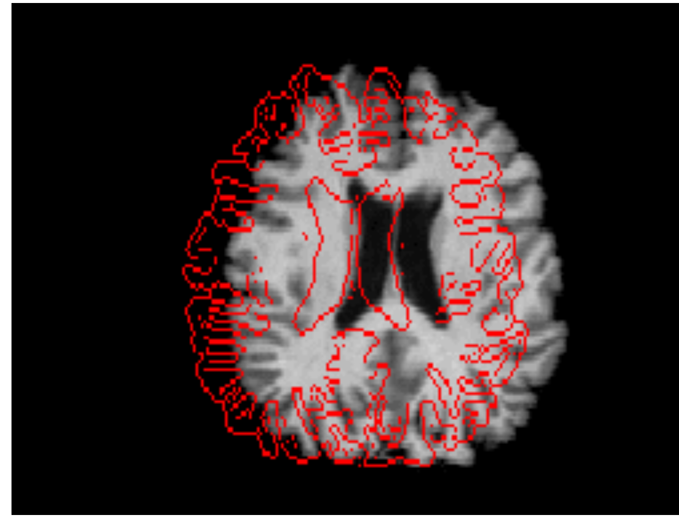
- 3 Rotations

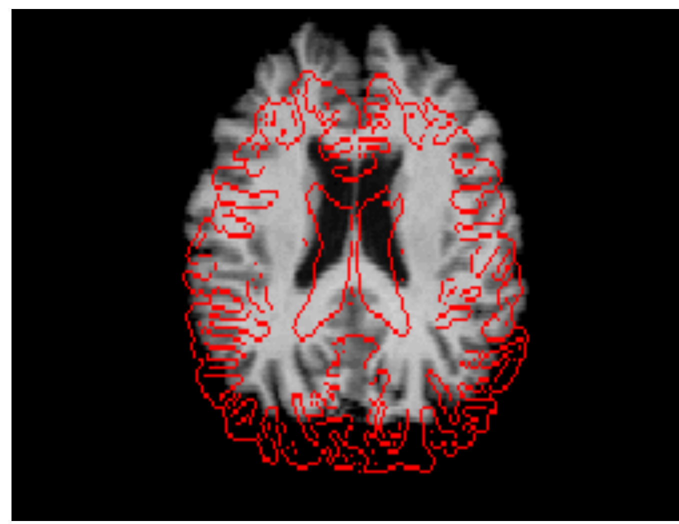
Rigid-Body Transformations

6 DOF in 3D

Includes:

- 3 Rotations
- 3 Translations





Used for **within-subject** registrations

Affine Transformations

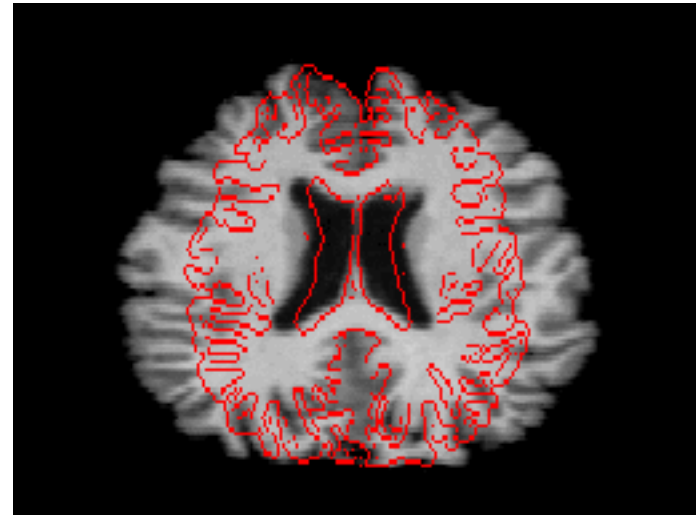
12 DOF in 3D

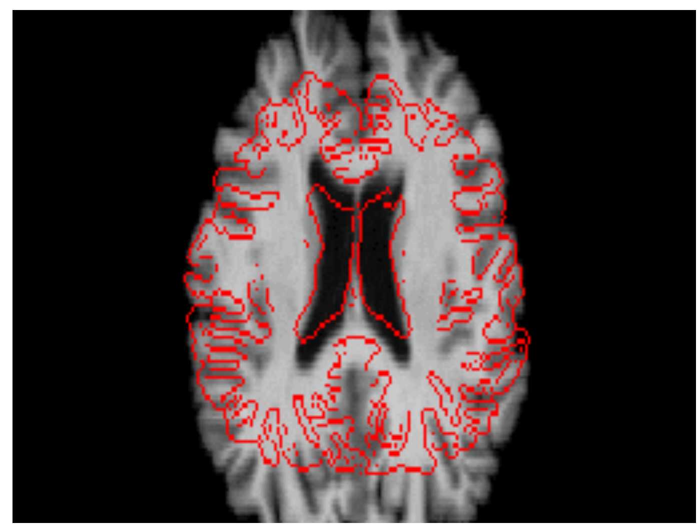
Linear Transf.

Includes:

- 3 Rotations
- 3 Translations

3 Scalings





Affine Transformations

12 DOF in 3D

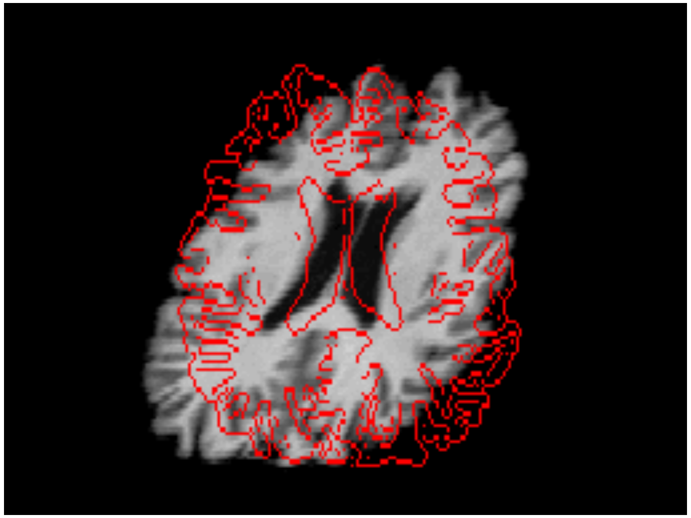
Linear Transf.

Includes:

- 3 Rotations
- 3 Translations

- 3 Scalings

3 Skews/Shears



Used for eddy current correction
and initialising non-linear registration

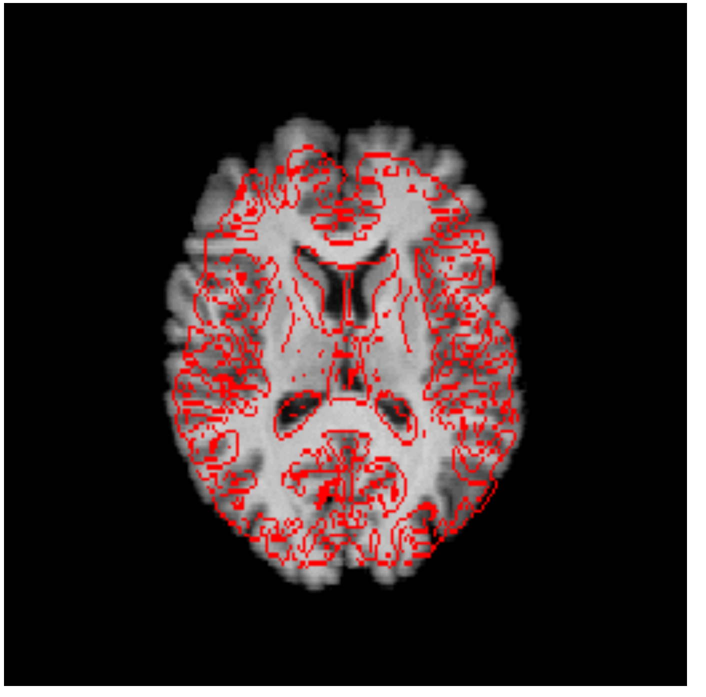
Non-Linear Transformations

More than 12 DOF

Can be purely local

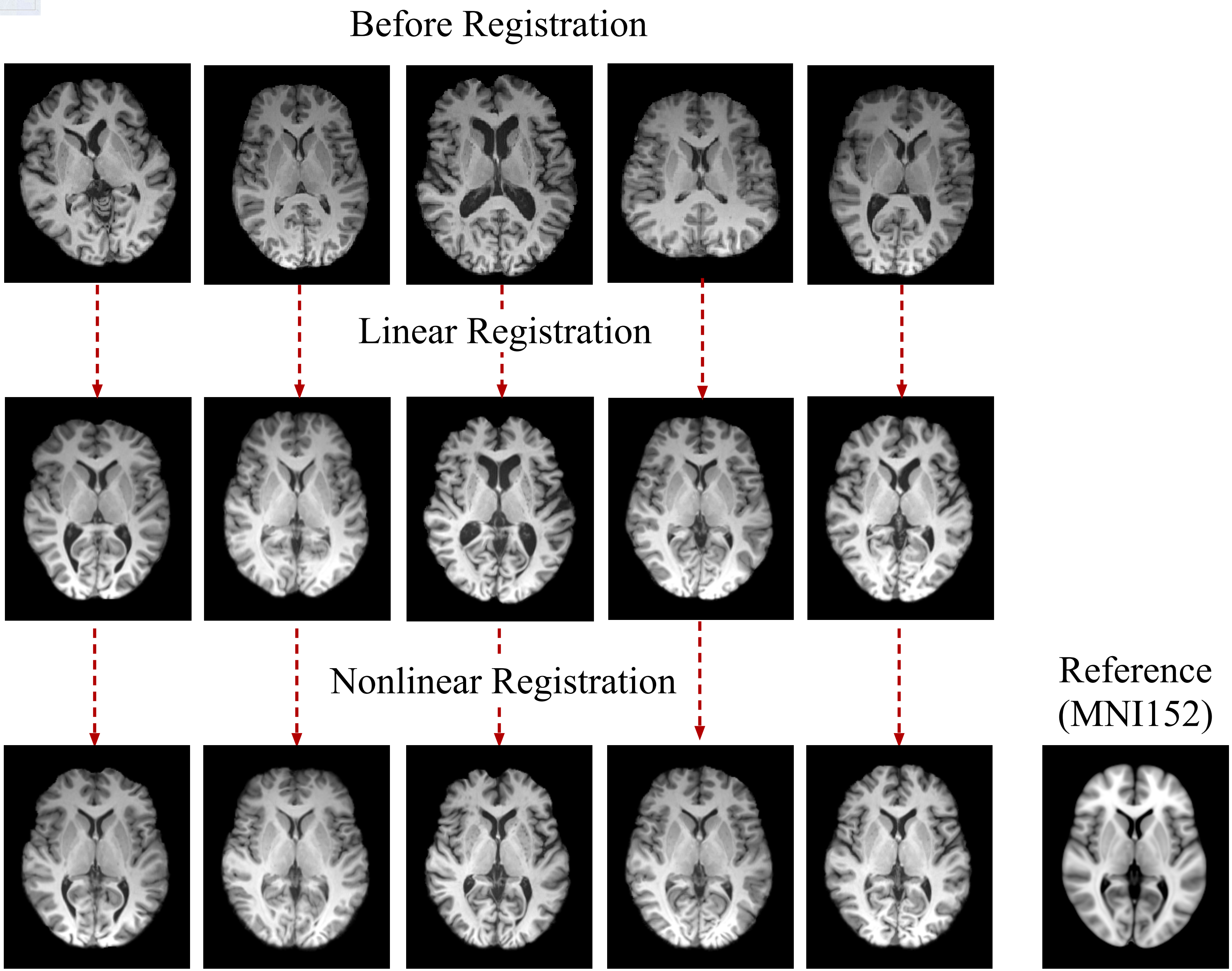
Subject to constraints:

- Basis Functions
  - e.g. B-Splines
- Regularisation
- Topology-preservation



Used for good quality **between-subject** registrations

Non-Linear Transformations



What transform/DOF do I use?

Rigid body (6 DOF)

- within-subject motion

Non-linear (lots of DOF!)

- high-quality image (resolution, contrast) & same modality of reference/template
- better with a non-linear template (e.g. MNI152_T1_2mm)

Affine (12 DOF)

- needed as a starting point for non-linear
- align to affine template, or using lower quality images, or eddy current correction

Global scaling (7 DOF)

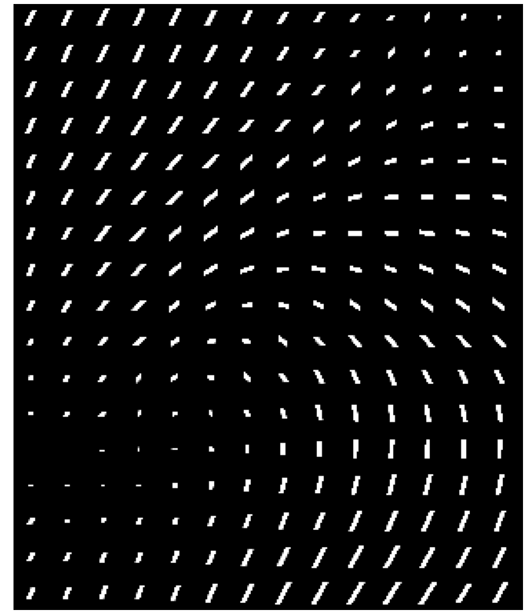
- within-subject but with global scaling (equal in x,y,z)
- corrects for scanner scaling drift in *longitudinal studies*

More DOF is ***NOT*** always better (e.g. within-subject)

What do the transformations look like?

$$A = \begin{pmatrix} a_{11} & a_{12} & a_{13} & a_{14} \\ a_{21} & a_{22} & a_{23} & a_{24} \\ a_{31} & a_{32} & a_{33} & a_{34} \\ 0 & 0 & 0 & 1 \end{pmatrix}$$

An affine transformation is represented by these 12 numbers.
This matrix multiplies coordinate vectors to define the transformed coordinates.



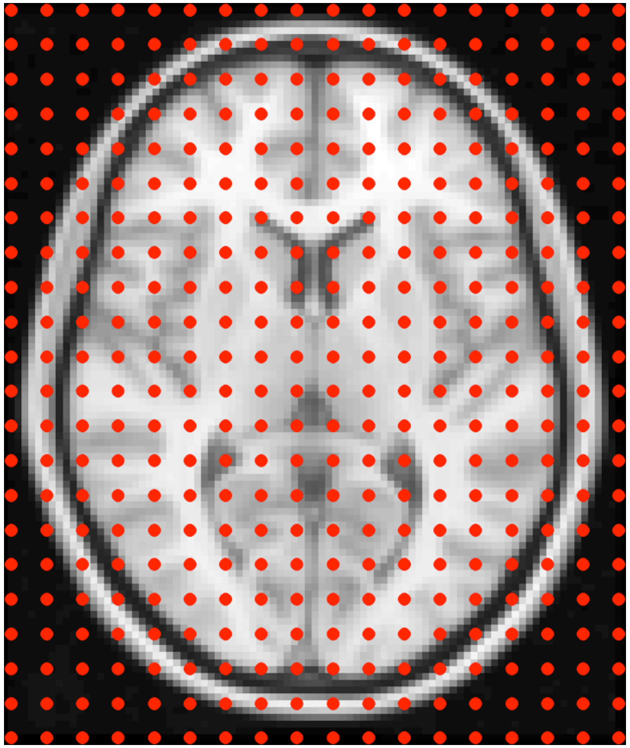
A non-linear transformation can be represented by a ***deformation field***.

Non-linear deformation

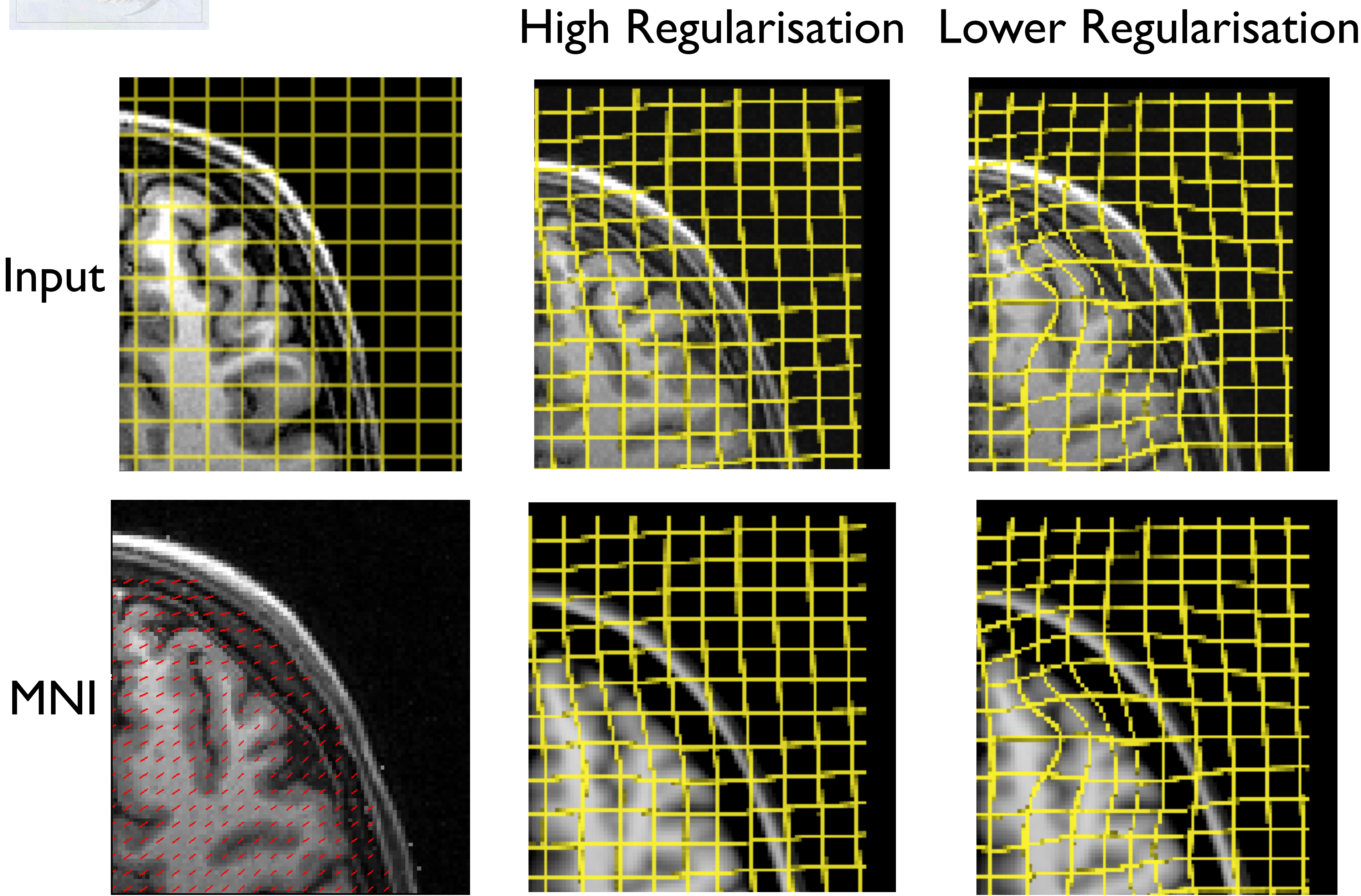
Regularisation, Warp Resolution and DOF

- Various ways of controlling warp *smoothness*
- Less DOF = smoother
- Lower warp resolution = smoother
- Higher regularisation = smoother

Spacing of points = warp resolution = regularisation = DOF



Non-linear deformation

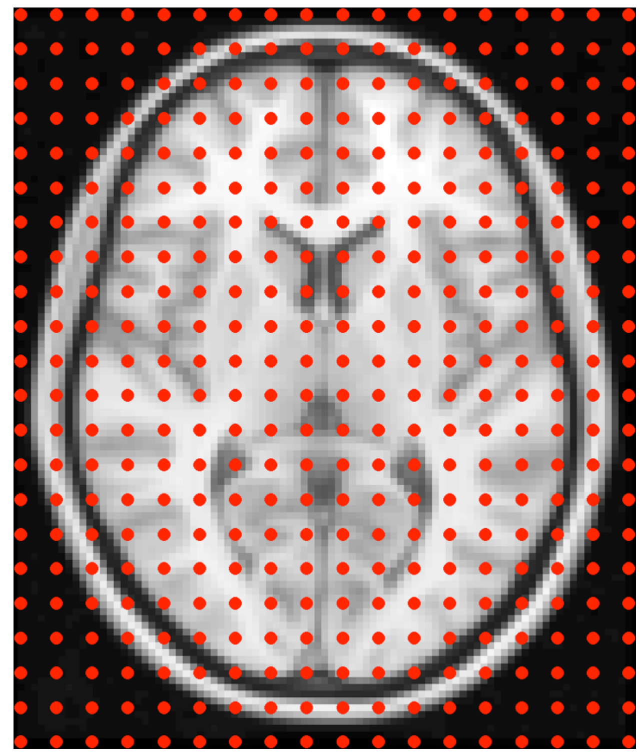


Non-linear deformation

Regularisation, Warp Resolution and DOF

- Various ways of controlling warp *smoothness*
- Less DOF = smoother
- Lower warp resolution = smoother
- Higher regularisation = smoother
- Default warp resolution of 10mm is a good compromise for MNI152
- Between two subjects can use less smooth warps (less regularisation, higher warp resolution, more DOF)

Spacing of points = warp resolution = regularisation = DOF

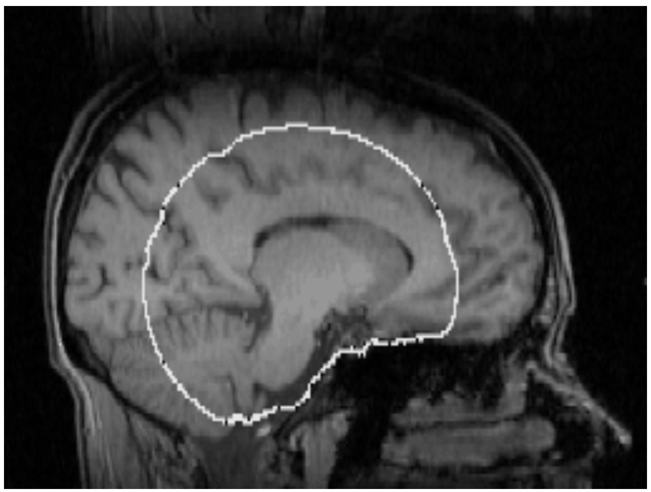


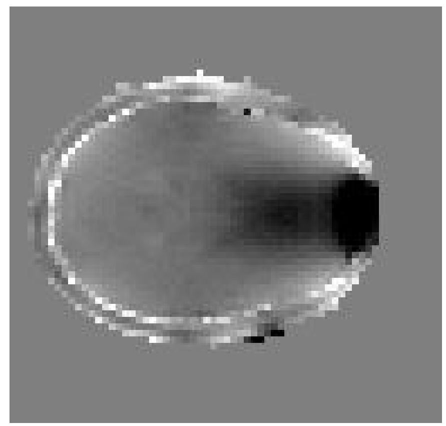
Registration: Image Spaces and Spatial Transformations

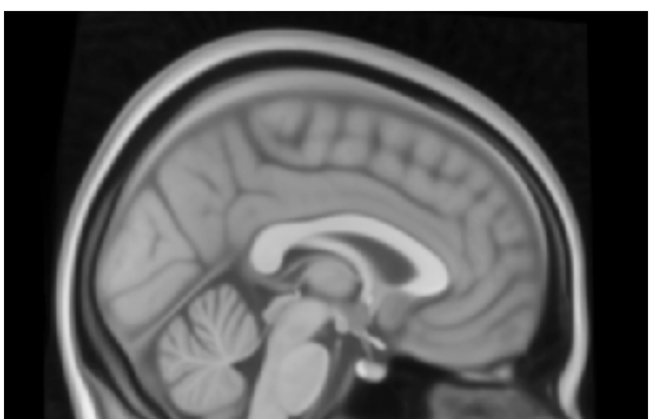
Summary:

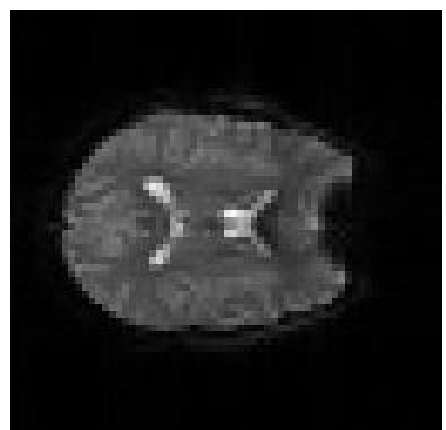
- Standard space is used as a common space
- MNI152 is a commonly used standard space
- Atlases are usually in standard space
- We often move images/info between spaces
- There are voxel and mm (standard) coordinates
- You must choose the transformation type
- Rigid is most appropriate for within-subject
- Nonlinear is most appropriate for between-subject
- Affine is needed to initialise nonlinear
- Regularisation alters flexibility of nonlinear

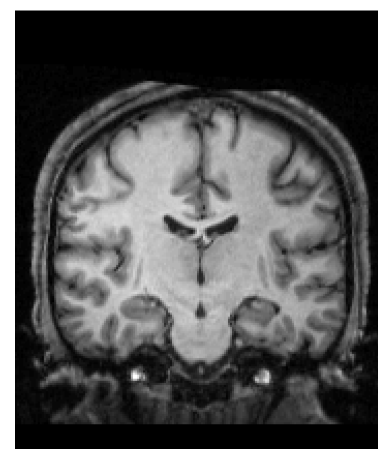
Registration: Cost Functions, Interpolation and Masks



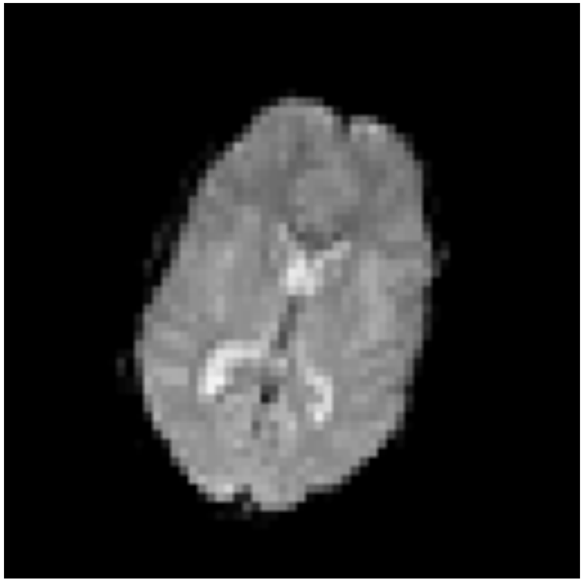








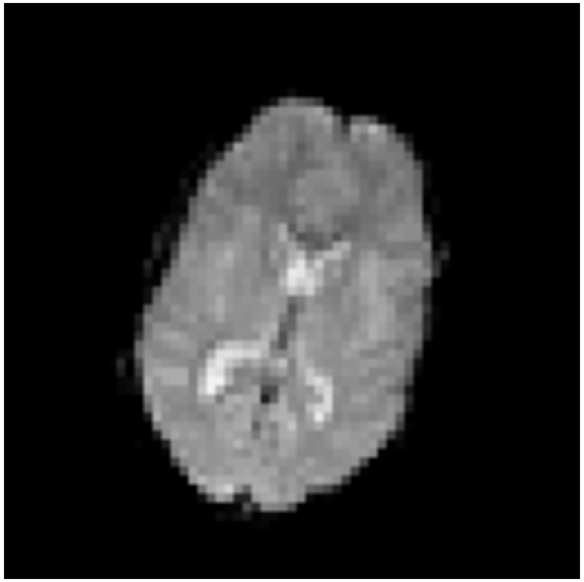
Basic Registration Concepts

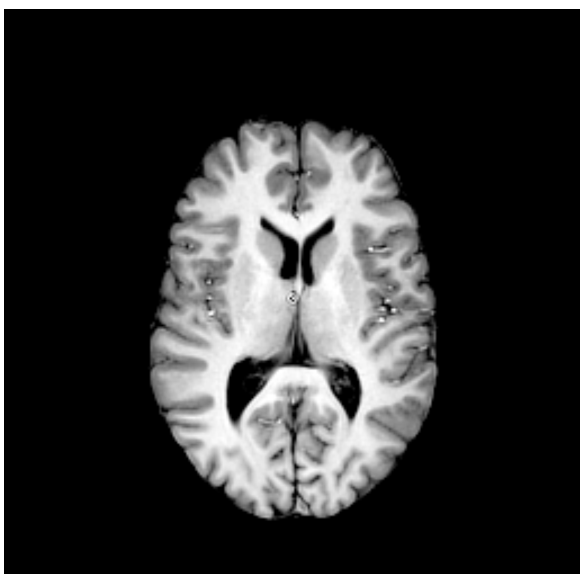


Need to understand:

- Image “spaces”
- Spatial Transformations
- Cost Functions
- Interpolation

Basic Registration Concepts





Need to understand:

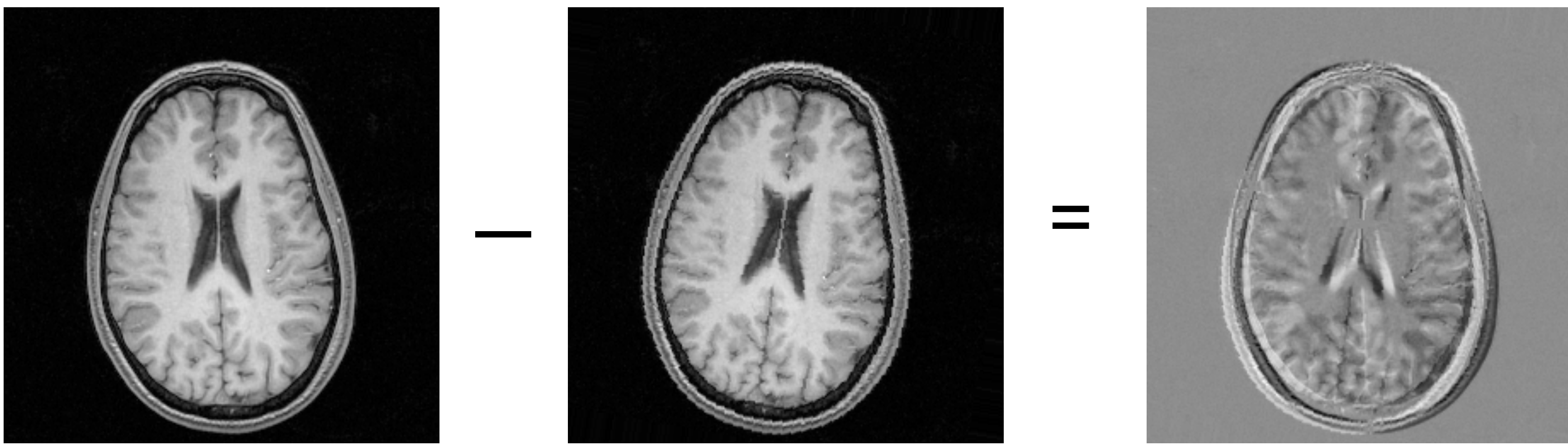
- Image "spaces"
- Spatial Transformations
- Cost Functions
- Interpolation

Cost Function

Measures "goodness" of alignment

Seek the minimum value

Several main varieties



Similarity function is opposite (maximum sought)

FLIRT: Cost Functions

FMRIB's
Linear
Image
Registration
Tool

FLIRT: Cost Functions

Important: Allowable image modalities

Less important: Details

Least Squares	***Same modality*** (exact sequence parameters)
Normalised Correlation	***Same modality*** (can change brightness & contrast)
Correlation Ratio	***Any MR modalities***
Mutual Information	***Any modalities*** (including CT, PET, etc.)
Normalised Mutual Info.	***Any modalities*** (including CT, PET, etc.)
BBR	***Within-subject EPI to structural*** (see later)

FNIRT: Cost Functions

FMRIB's
Non-linear
Image
Registration
Tool

FNIRT: Cost Functions

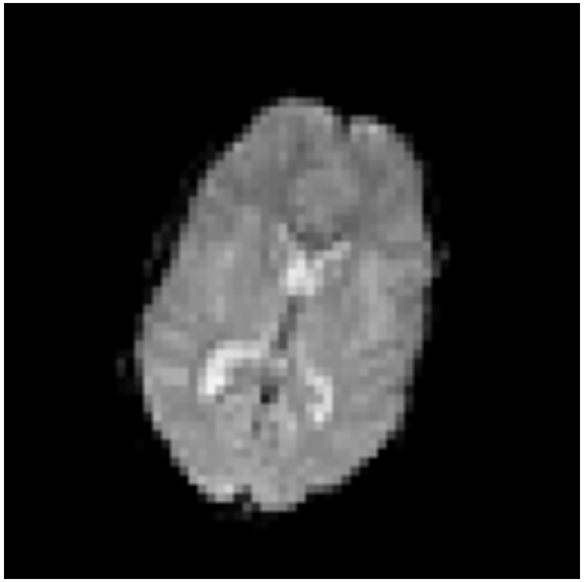
- *Only uses Least Squares* as cost function
  so *images must be of the same modality/sequence*
- Also includes an explicit model for bias field (RF inhomog.)
- Estimate displacement field *and* RF bias field together
- Options exist to control bias field (turn off/on, smoothness)

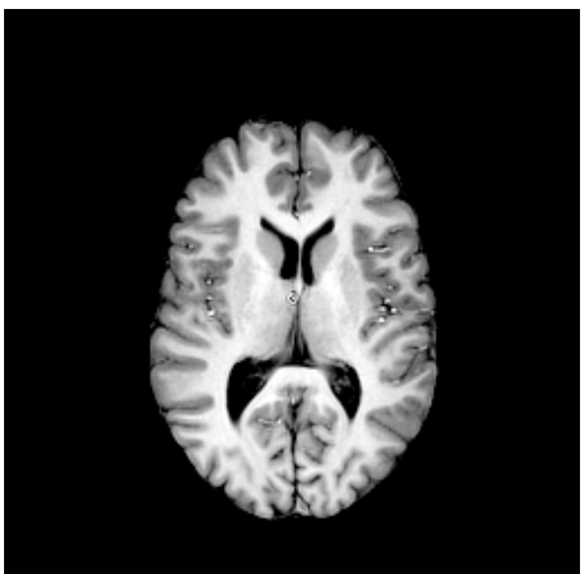
Without RF modelling

Template

With RF modelling

Basic Registration Concepts



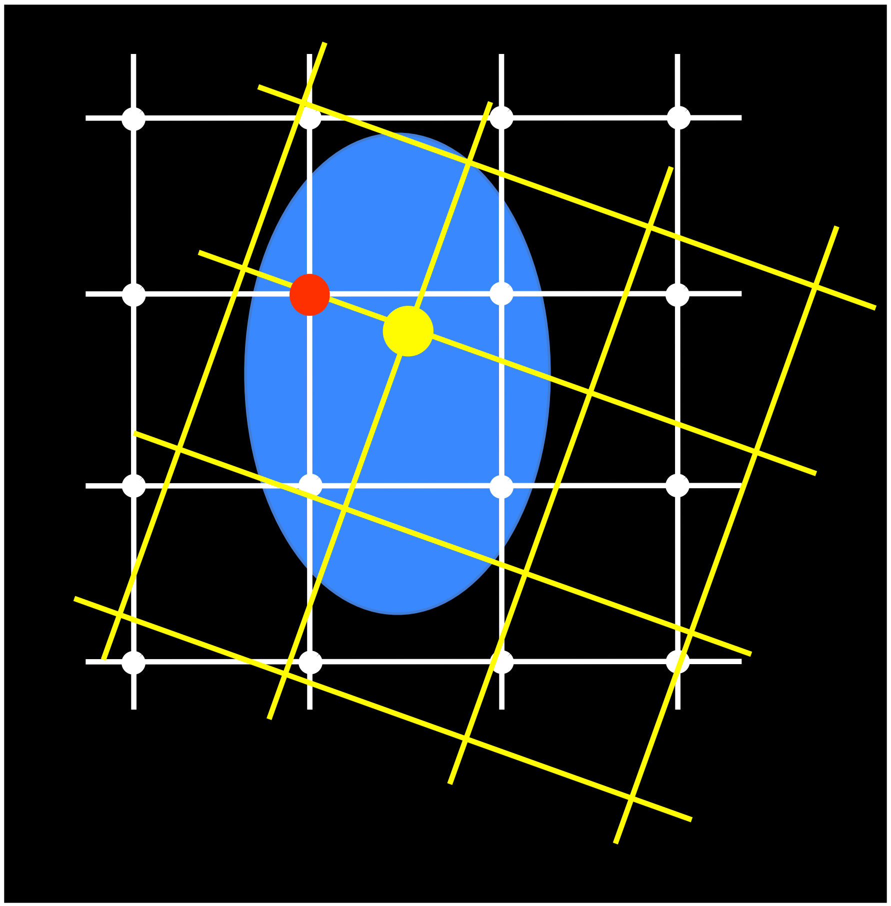


Need to understand:

- Image "spaces"
- Spatial Transformations
- Cost Functions
- Interpolation

Interpolation

Finds intensity values between grid points



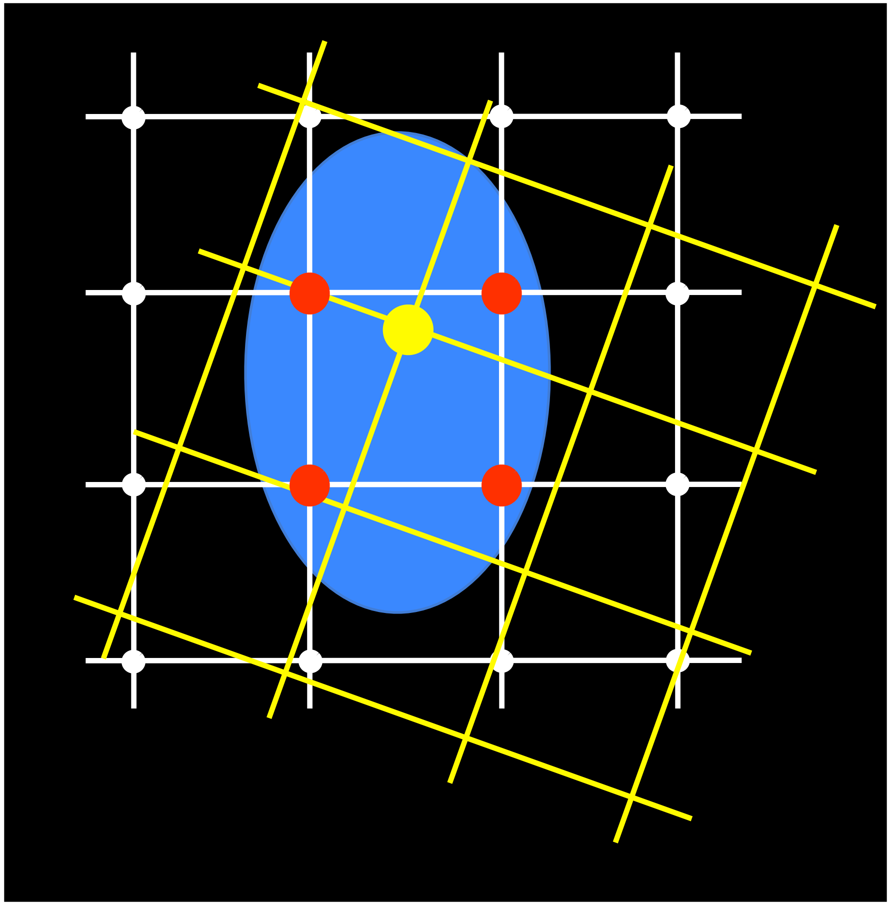
Various types include

- Nearest Neighbour
- Trilinear
- Spline
- Sinc
- k-Space methods

Fast, but blocky - can be used for discrete labels

Interpolation

Finds intensity values between grid points



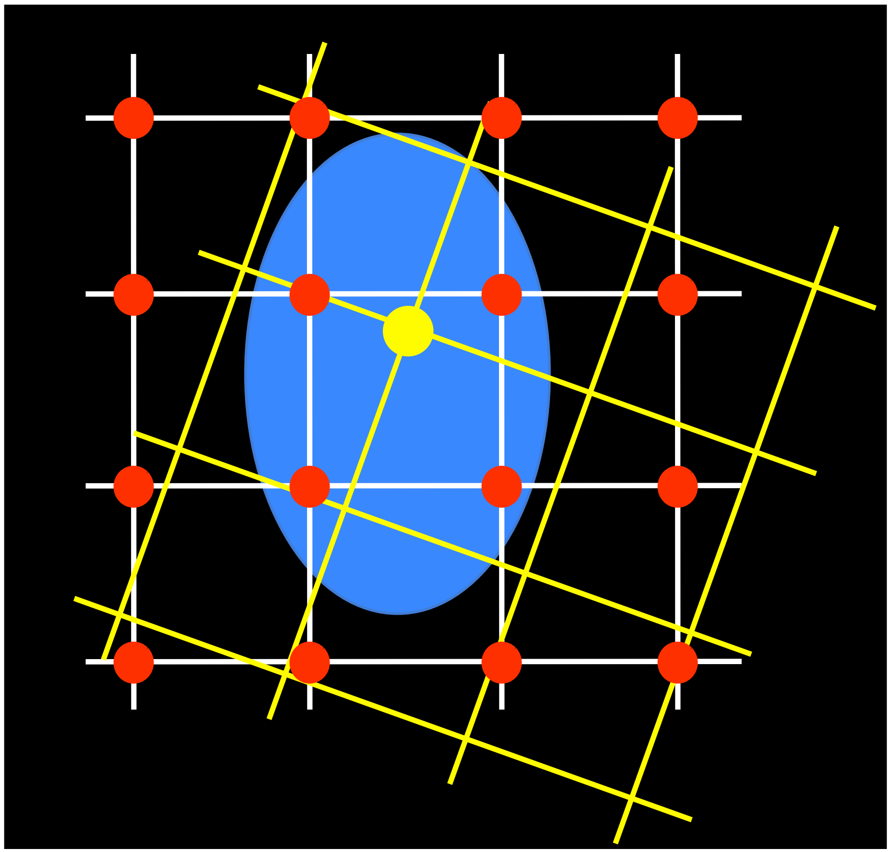
Various types include

- Nearest Neighbour
- Trilinear
- Spline
- Sinc
- k-Space methods

Fast, with some blurring - most common option

Interpolation

Finds intensity values between grid points

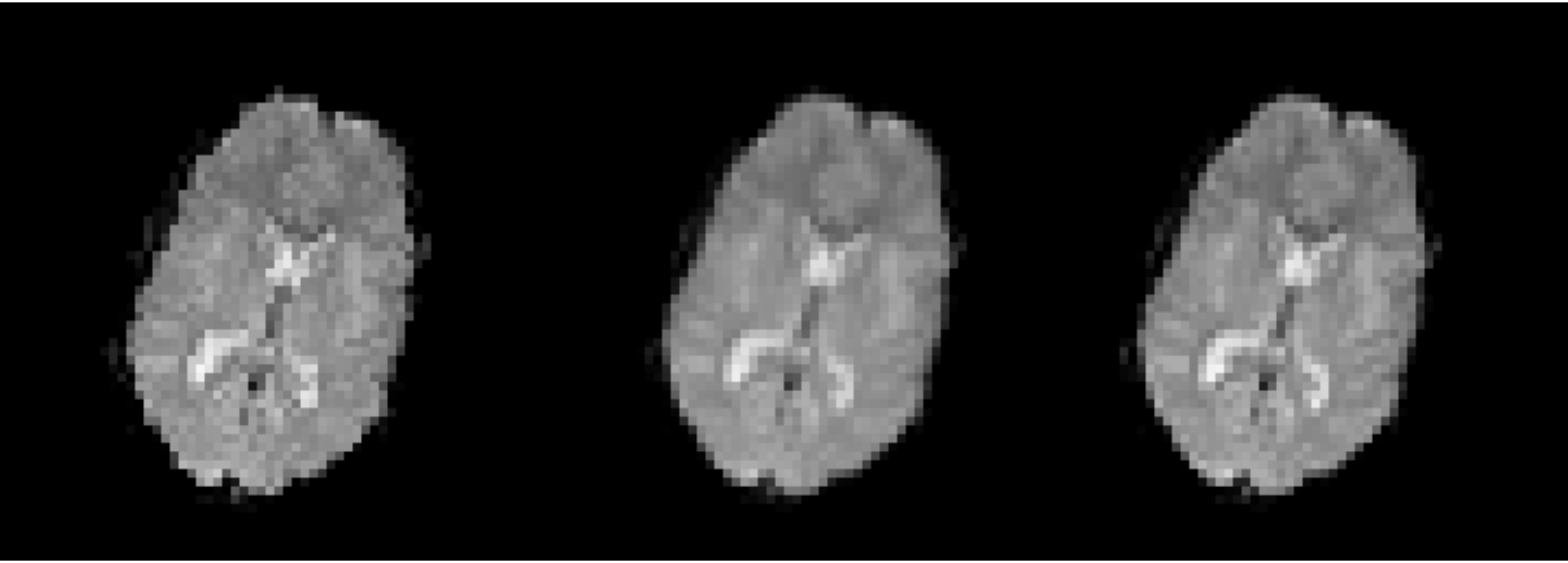


Various types include

- Nearest Neighbour
- Trilinear
- Spline
- Sinc
- k-Space methods

Slower (spline is fairly fast) - creates sharp images but can create values outside the original range

Interpolation



Nearest Neighbour Trilinear Spline

Affects accuracy of subsequent analysis

Important for *quantitative imaging*

Can affect size of artefacts

Applying Transformations

- Step 1: Estimating a transformation
  - finding the transformation
  - no resampling

Applying Transformations

- Step 1: Estimating a transformation
  - finding the transformation
  - no resampling
- Step 2: Resampling
  - *applying* a transformation
  - thus creating a new, modified image
- "Registration" can mean either
- Usually delay *resampling*
  as it *reduces image quality*
- Other terms: coregistration & spatial normalisation

Transforming Masks

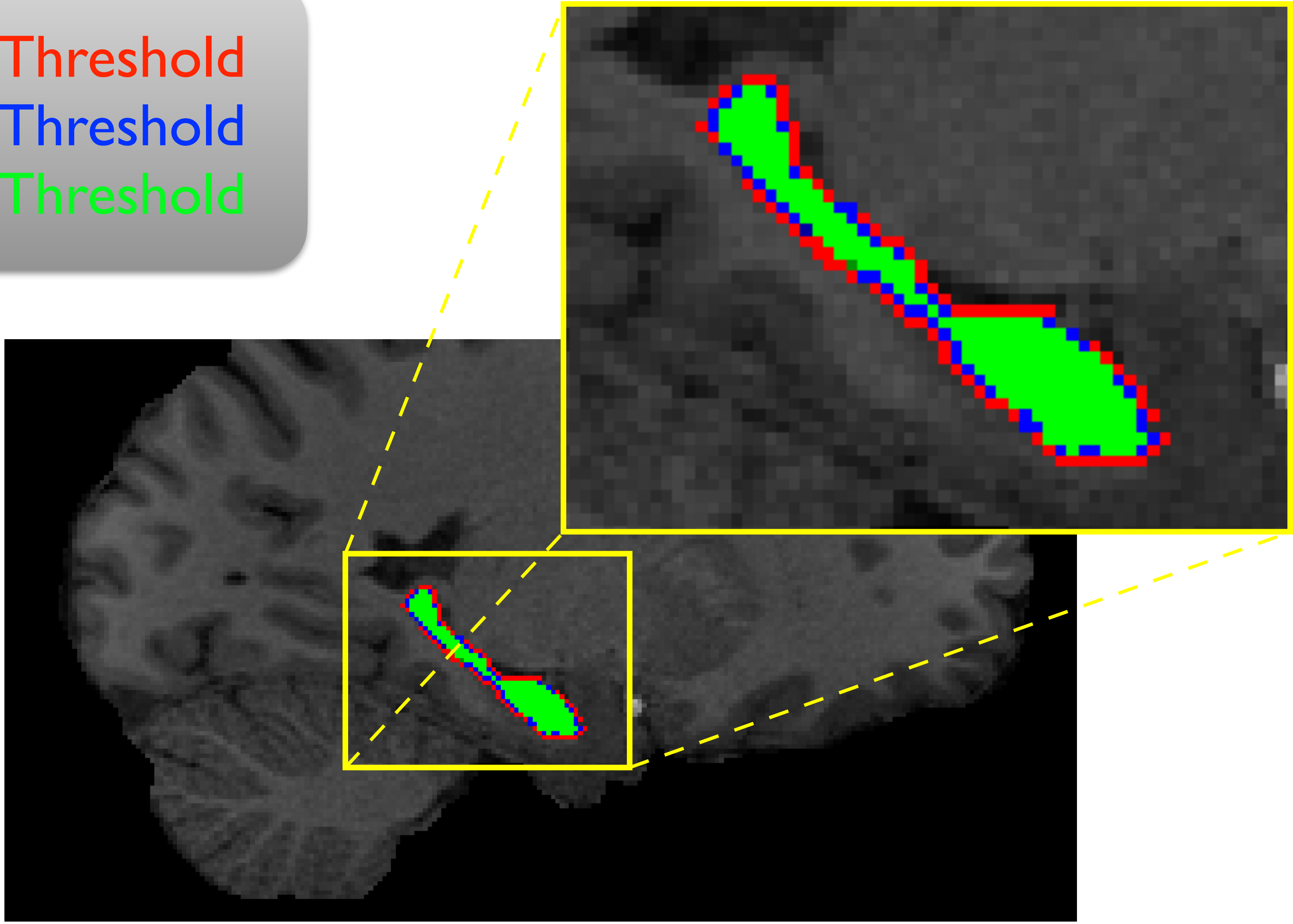
Mask values are normally 0 and 1 (integer format)
Interpolation gives values in between
if rounded to integer ⟹ mask "shrinks"

Ensure output datatype = float *(applywarp & flirt default)*
Re-threshold (binarize) the transformed mask

"Correct" thresholding depends on the particular case
- Threshold near 0.0 to include partial-volume edges
- Threshold near 1.0 to exclude partial-volume edges
- Threshold at 0.5 to keep the same size (approx)

Transforming Masks

0.1 Threshold
0.5 Threshold
0.9 Threshold

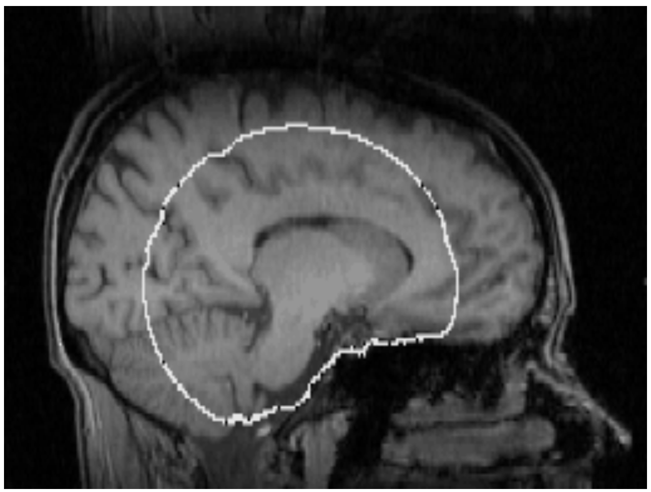
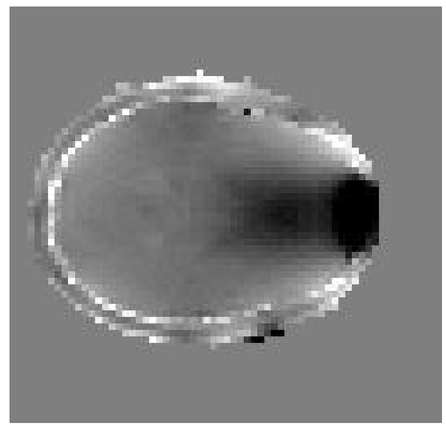
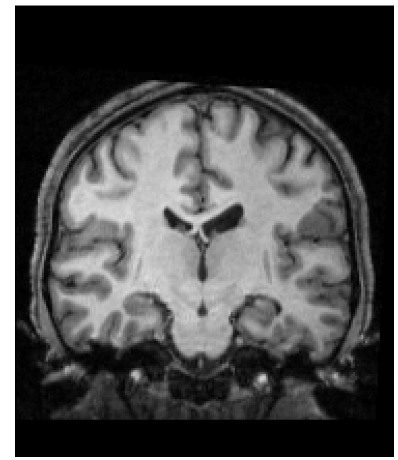
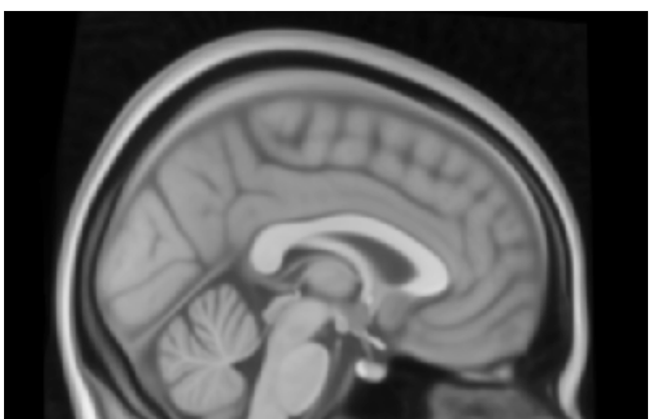
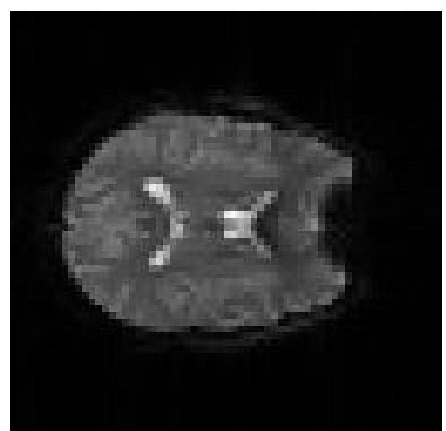
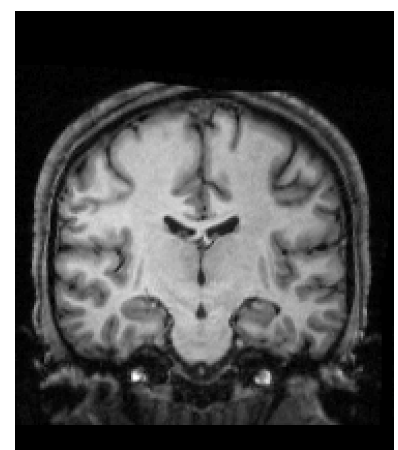


Registration: Cost Functions, Interpolation and Masks

Summary:

- Must choose an appropriate cost function
- Often many valid choices (depends on images)
- Interpolation used to resample images
- Often the interpolation is set within the tool
- When applying transforms want to minimise interpolation-related effects - delay resampling
- Transforming masks requires attention to interpolation and thresholding - depends on task

Registration: Single-Stage and Multi-Stage Applications

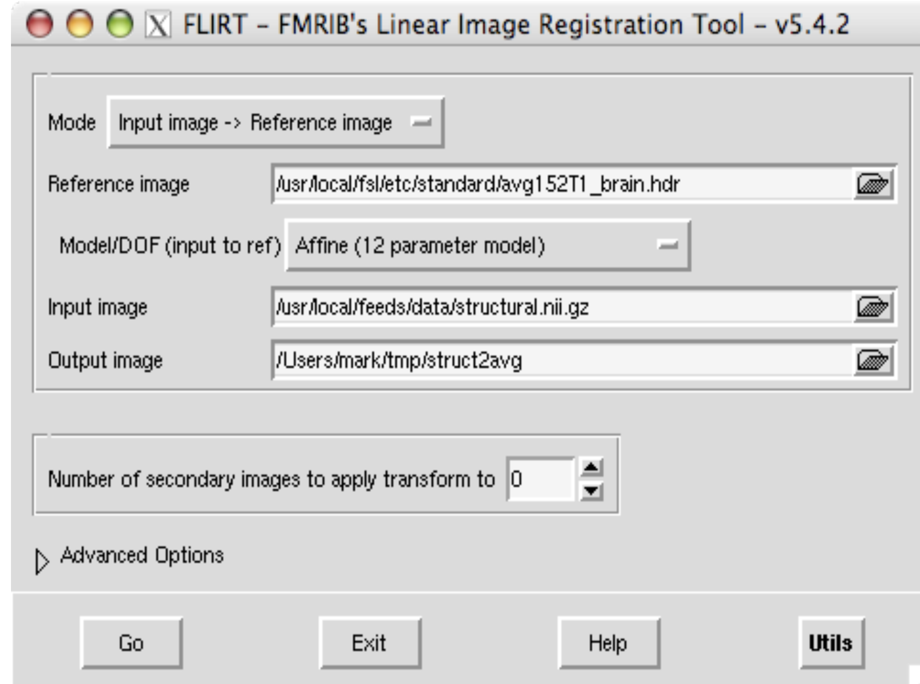







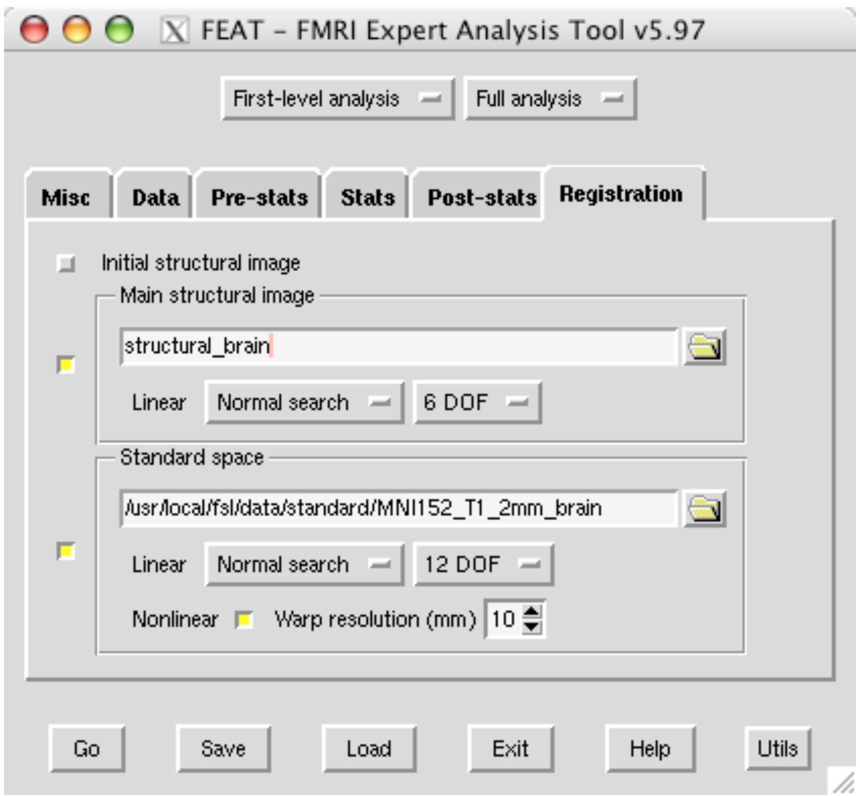
Registration with FSL

Two main tools:

FNIRT & *FLIRT*

(FMRIB's Non-Linear/Linear Image Registration Tool)





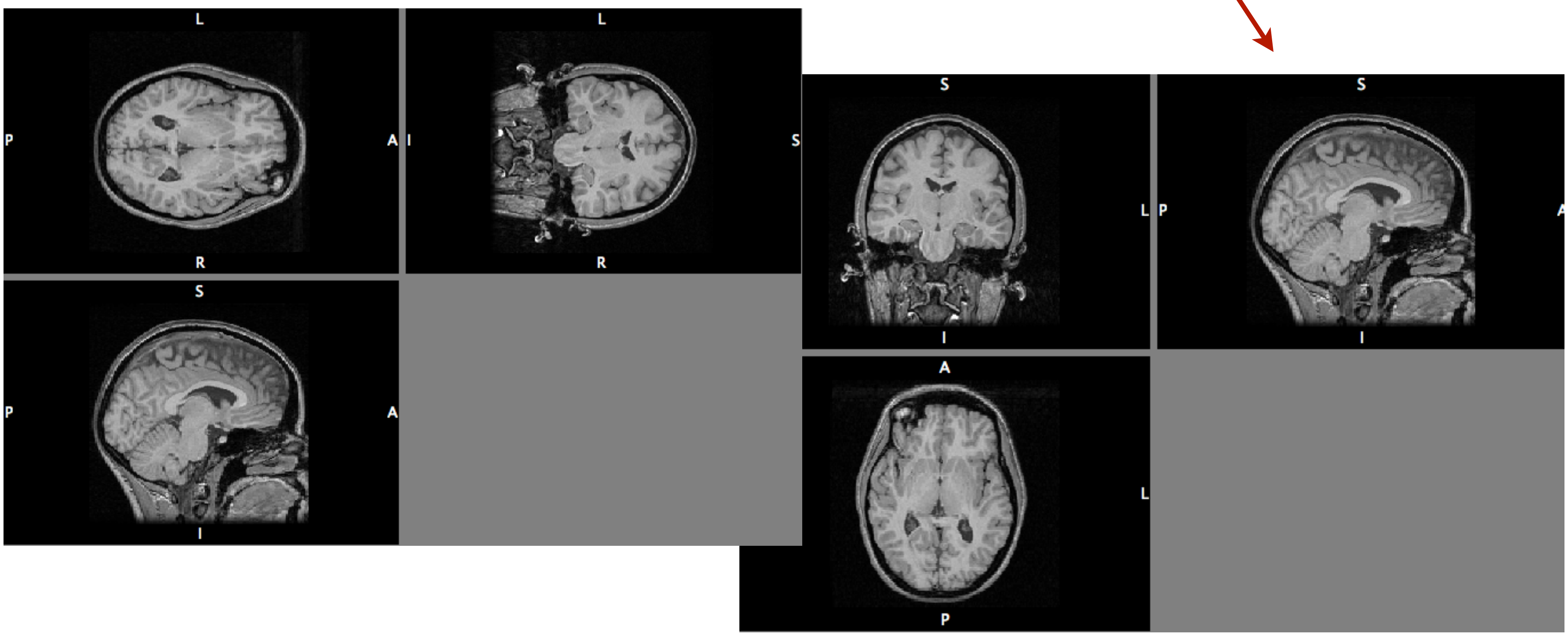
Both tools used by FMRI and Diffusion tools

(FEAT, MELODIC & FDT)

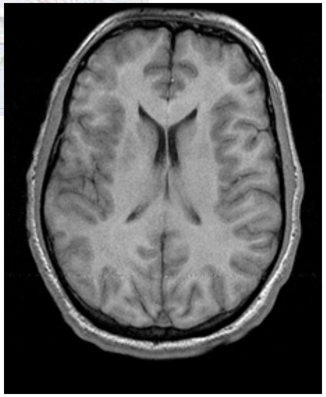
Preliminary Steps

Recommended steps:

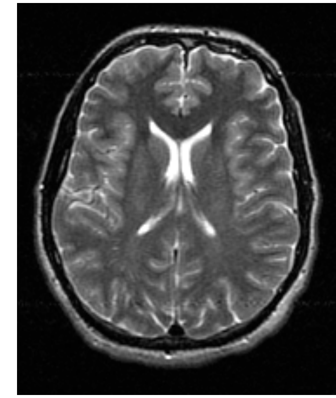
- Reorientation (fslreorient2std)
- Brain Extraction (BET)
- Bias-field correction (FAST - see later)



Note that labels are correct in both cases



Single-Stage Registration



Scenario:

Have two (or more) different types of images from the *same subject*

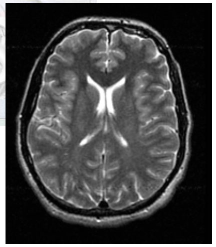
For example, T_1-weighted and T_2-weighted images

Objective:

Have images aligned so that, for example, they can be used for multi-modal segmentation

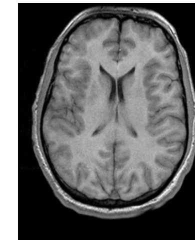
Solution:

FLIRT with 6 DOF (rigid-body)



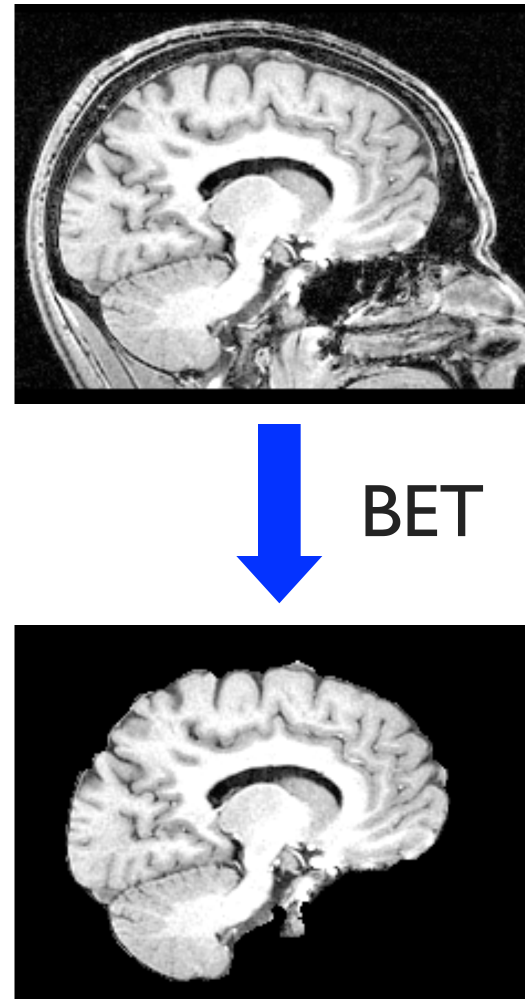
Input

Single-Stage Registration



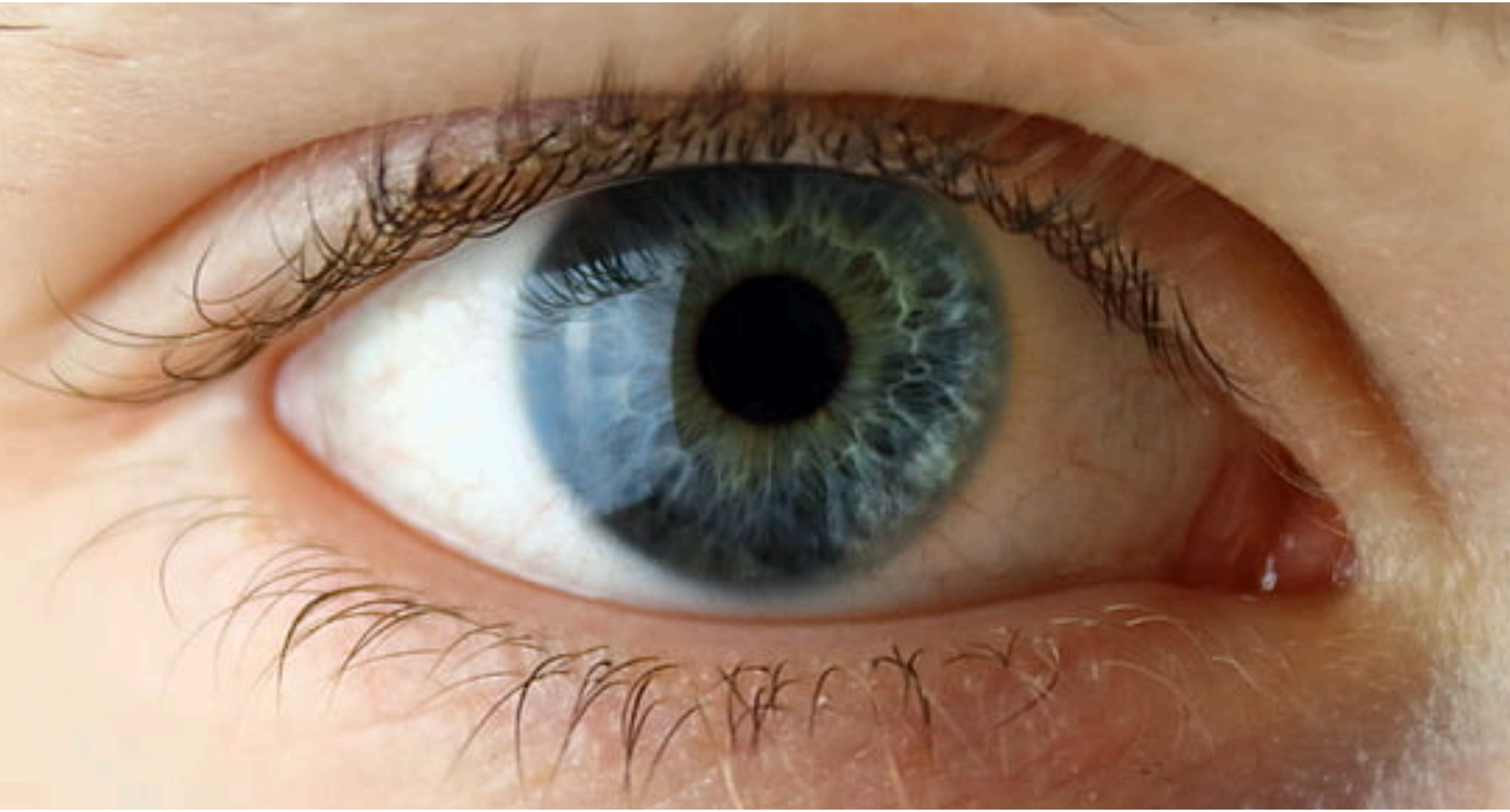
Reference

- Single subject ⇒ 6 DOF = FLIRT
- T_2-wt to T_1-wt ⇒
  multi-modal cost function
  (e.g. default of correlation ratio)
- Run *brain extraction* on *both images*
- Choose image with better resolution
  or contrast as the reference
- Always check your output



Artefaction Detection Device

LOOK AT YOUR DATA!



www.pickpik.com

Visual Check

Always assess registration quality visually!

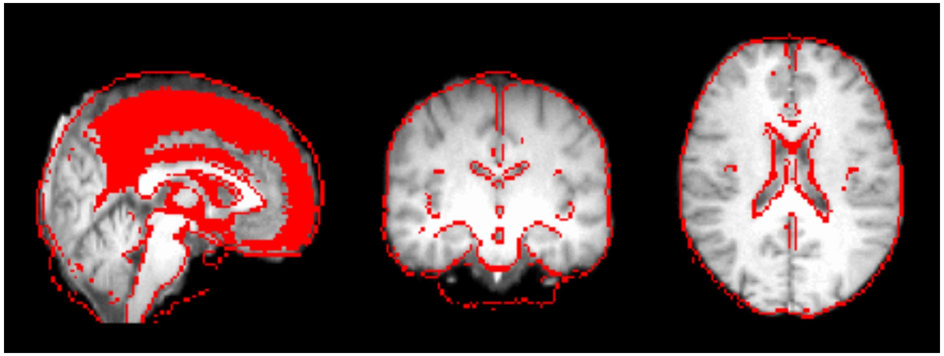
Can use:

- *FSLeyes* (using overlay or flicking between images)
- *slices* for a static view use (as in FEAT)

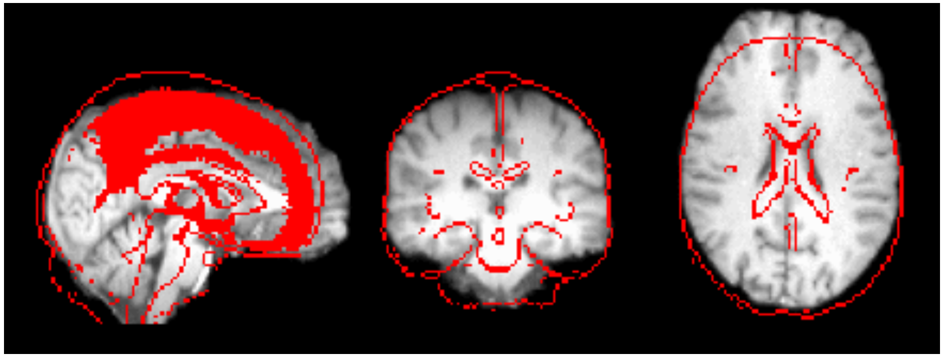
slices T2_to_T1im T1im

Grayscale from first image

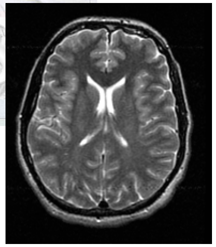
Red edges from second image



✔

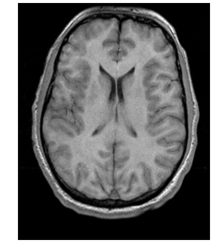


✘



Input

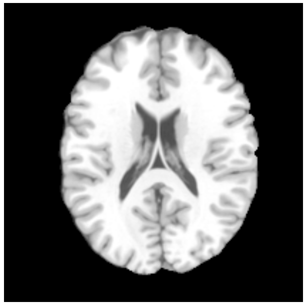
Registration in FSL



Reference

- In FSL the ***reference image*** controls the *FOV and resolution of the output image*
- Transformations are given:

  from input space ***to*** reference space
- Inverse transformations can easily be calculated to go from reference space to input space when needed
- Can overlay images in FSLeyes with different FOV or resolution: i.e. images can be in different spaces and resolutions
- Images can be ***resampled*** into a different space by applying a previously derived transformation



Multi-Stage Registration

Scenario:

Doing a functional (or diffusion) study

Have EPI and T_1-weighted of each subject

Objective:

Need to register images to a common (standard) space to allow the group study to be performed

Solution:

2-stage registration with FLIRT & FNIRT (in FEAT)

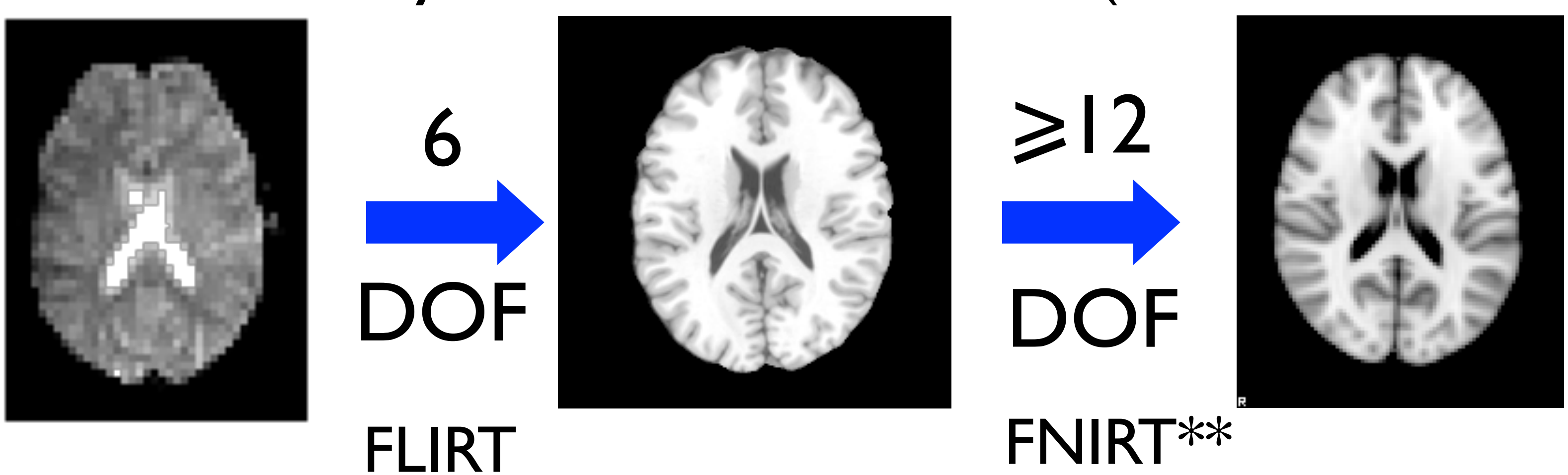
Two Stage Registration

Registering very different images is difficult due to:

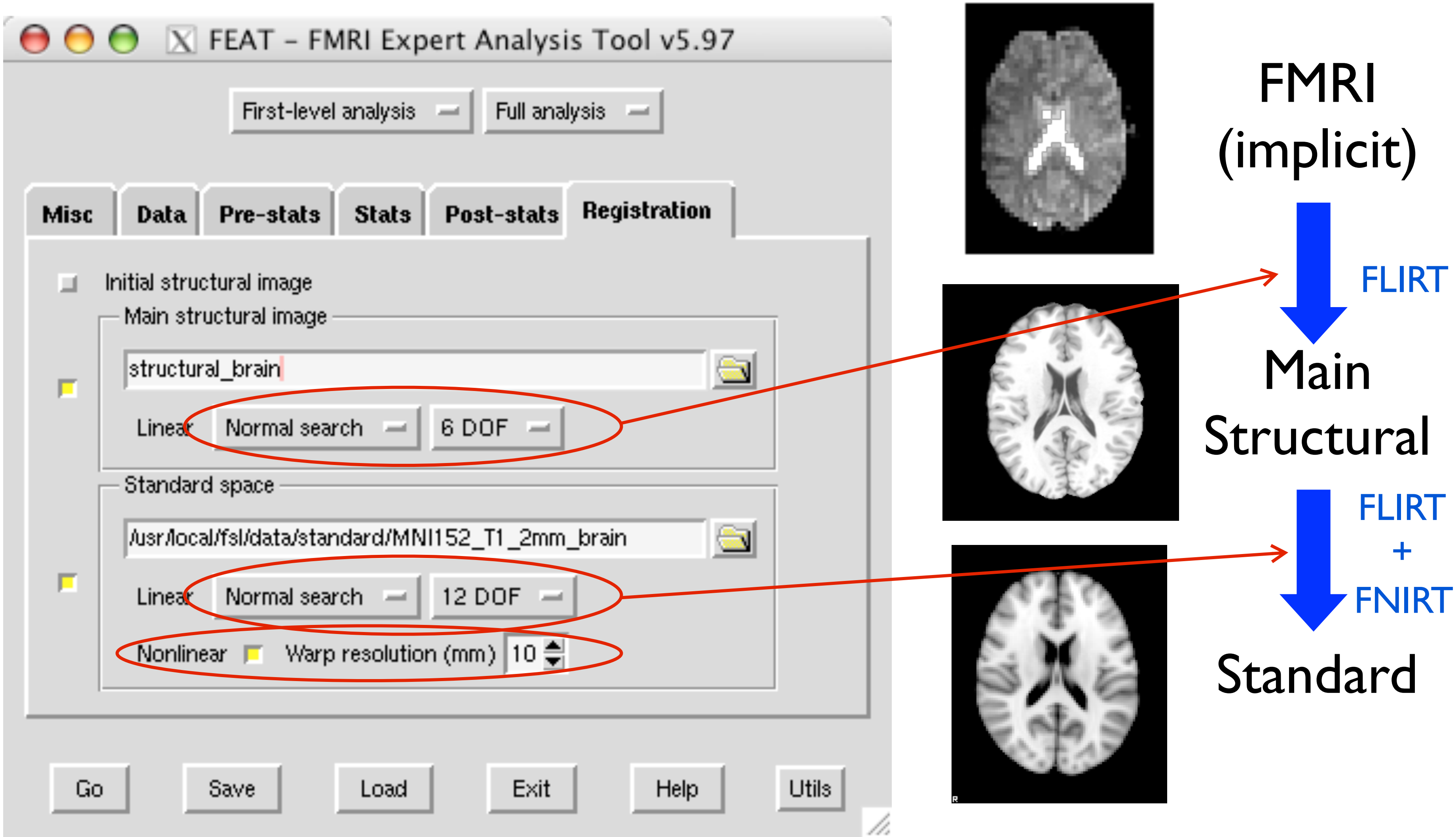
- Differences in individual anatomies
- Different contrasts in various modalities
- Distortions which differ between images

To register an EPI to a standard space template (e.g. MNI152) use a structural intermediate image

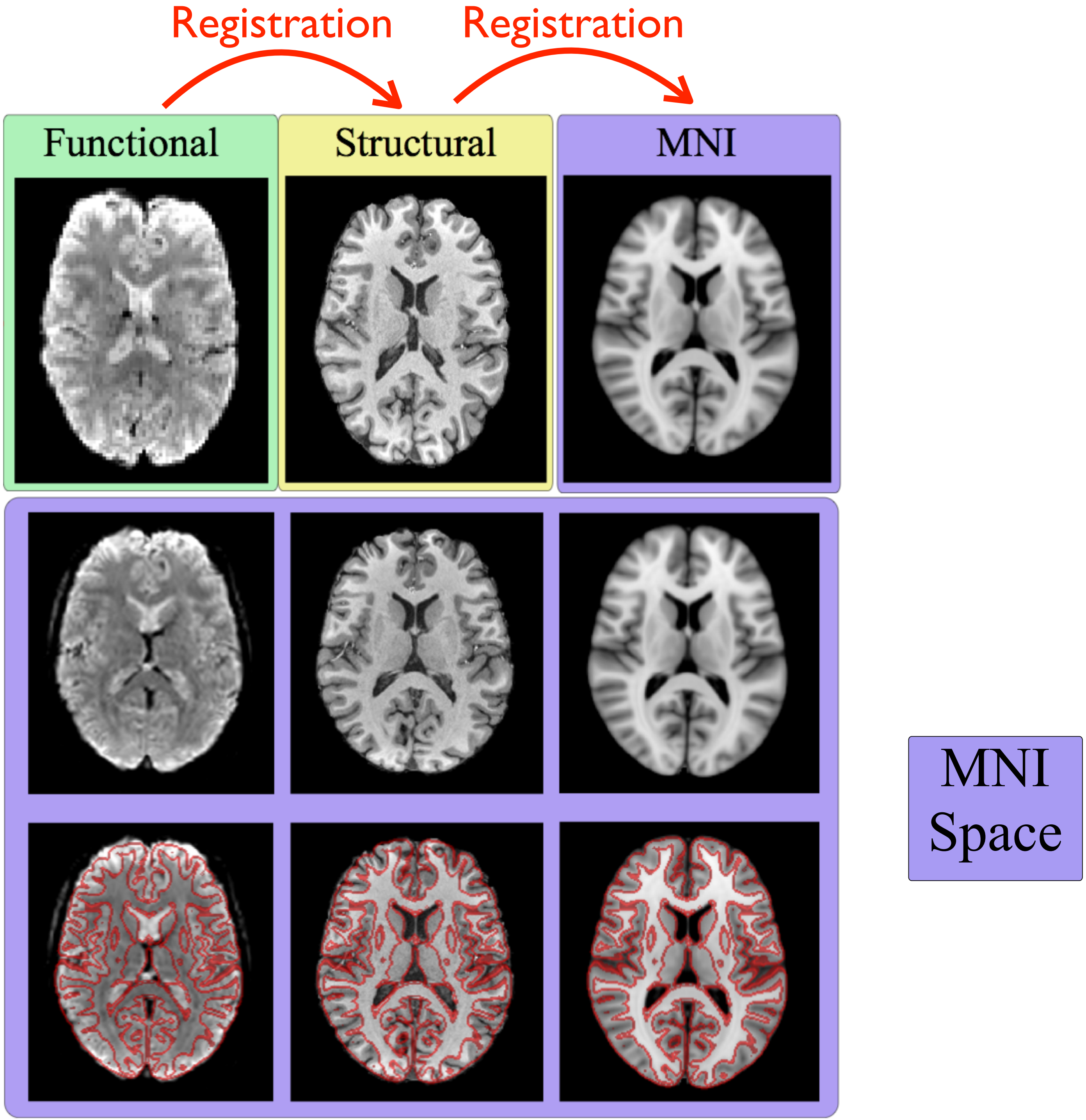
Automatically done by FEAT GUI (some user control)
Need to manually run brain extraction (not on EPI usually*)



Registration for FMRI Analysis (FEAT)

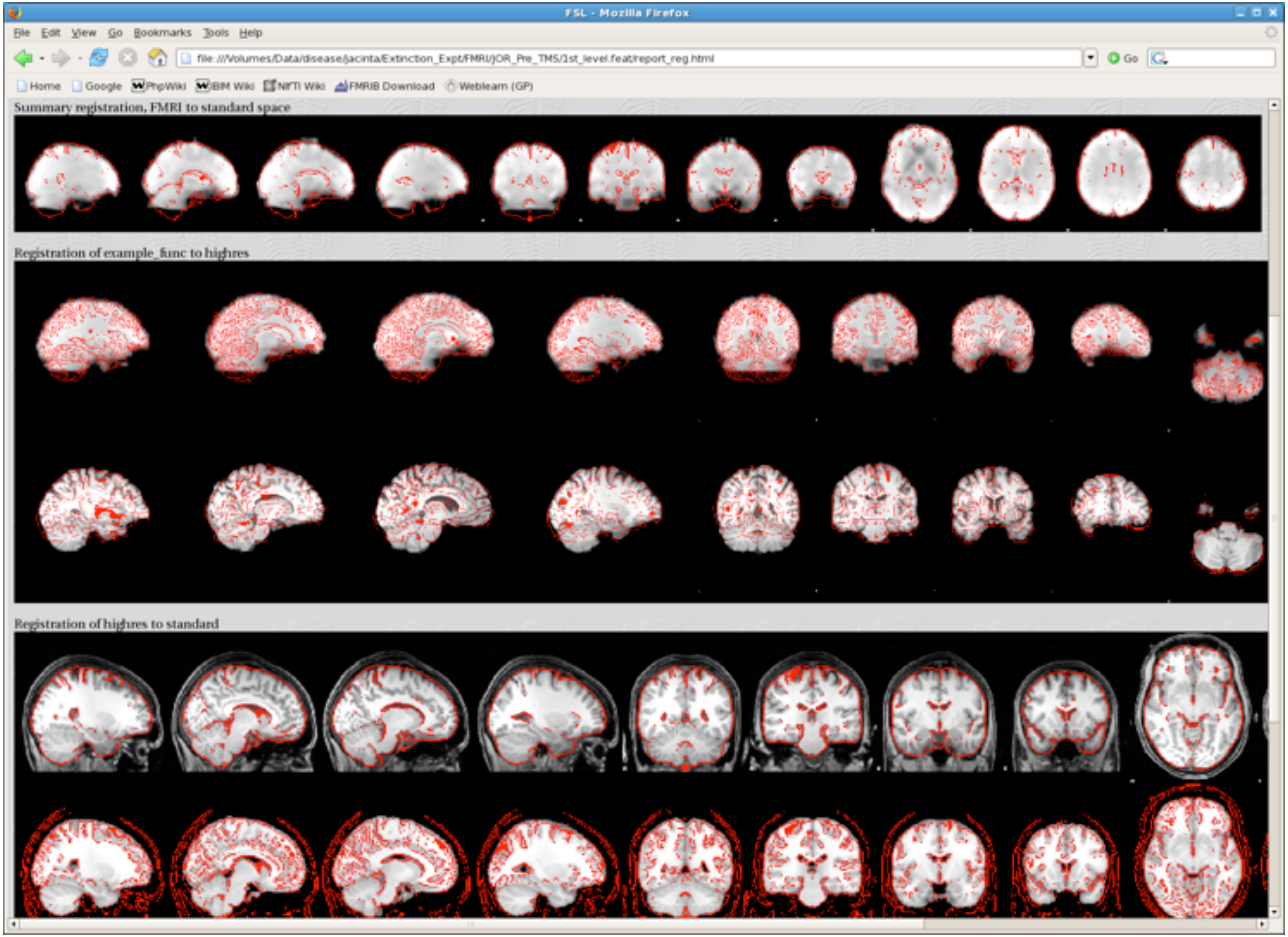


NB: actually need brain extracted ***and*** original images for FNIRT

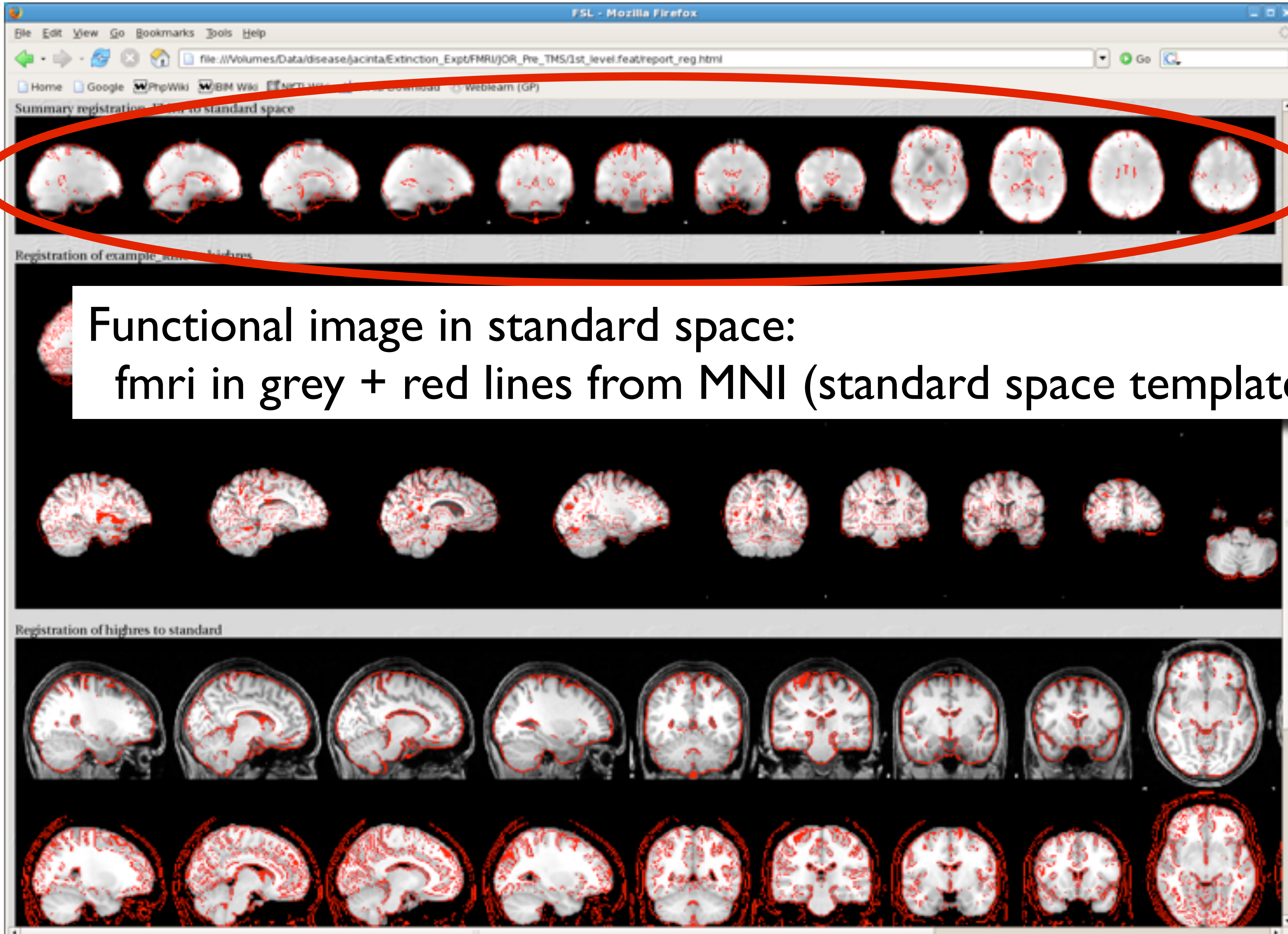


Registration
Registration
Functional
Structural
MNI
MNI Space

Registration for FMRI Analysis

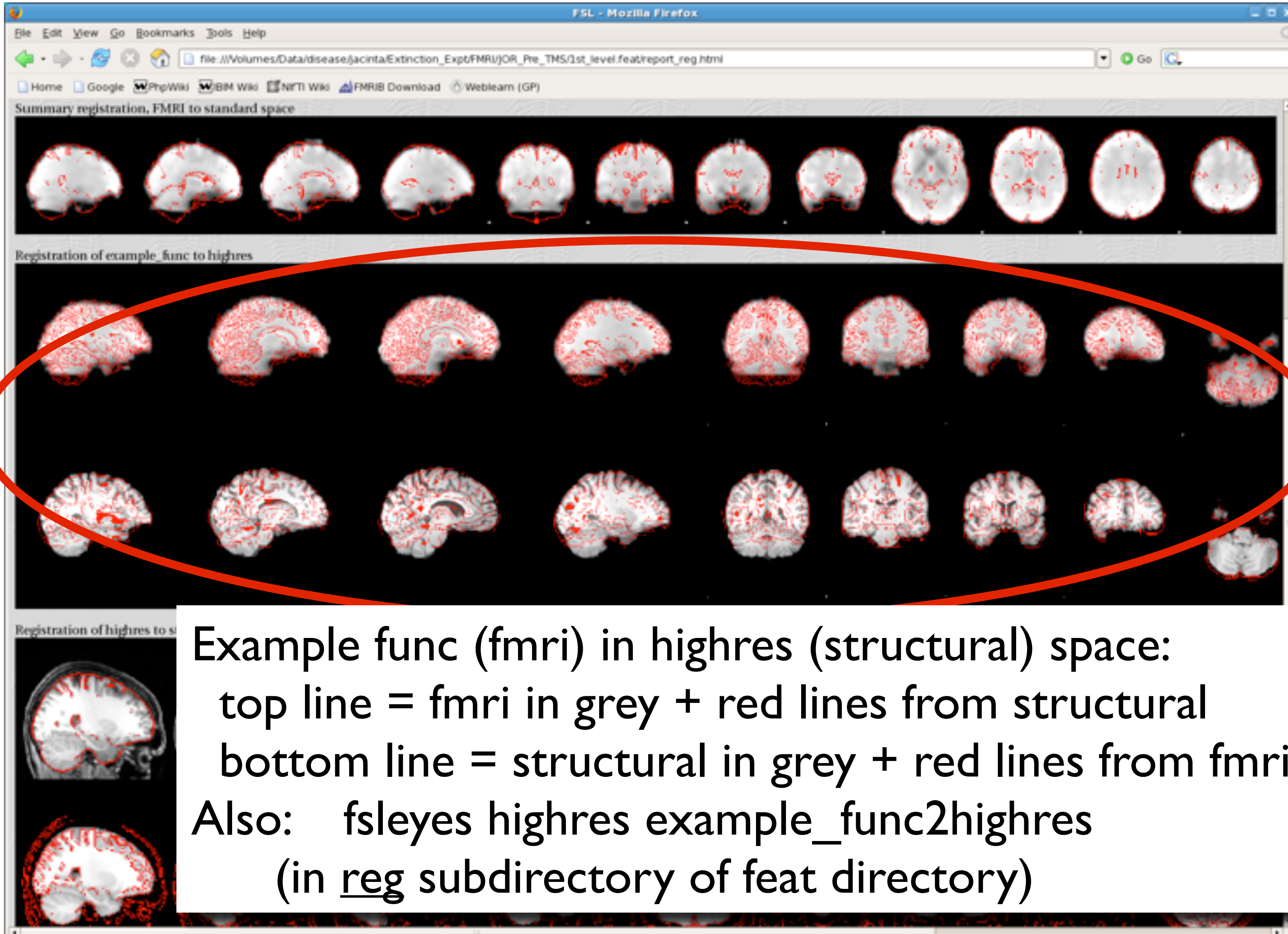


Registration for FMRI Analysis

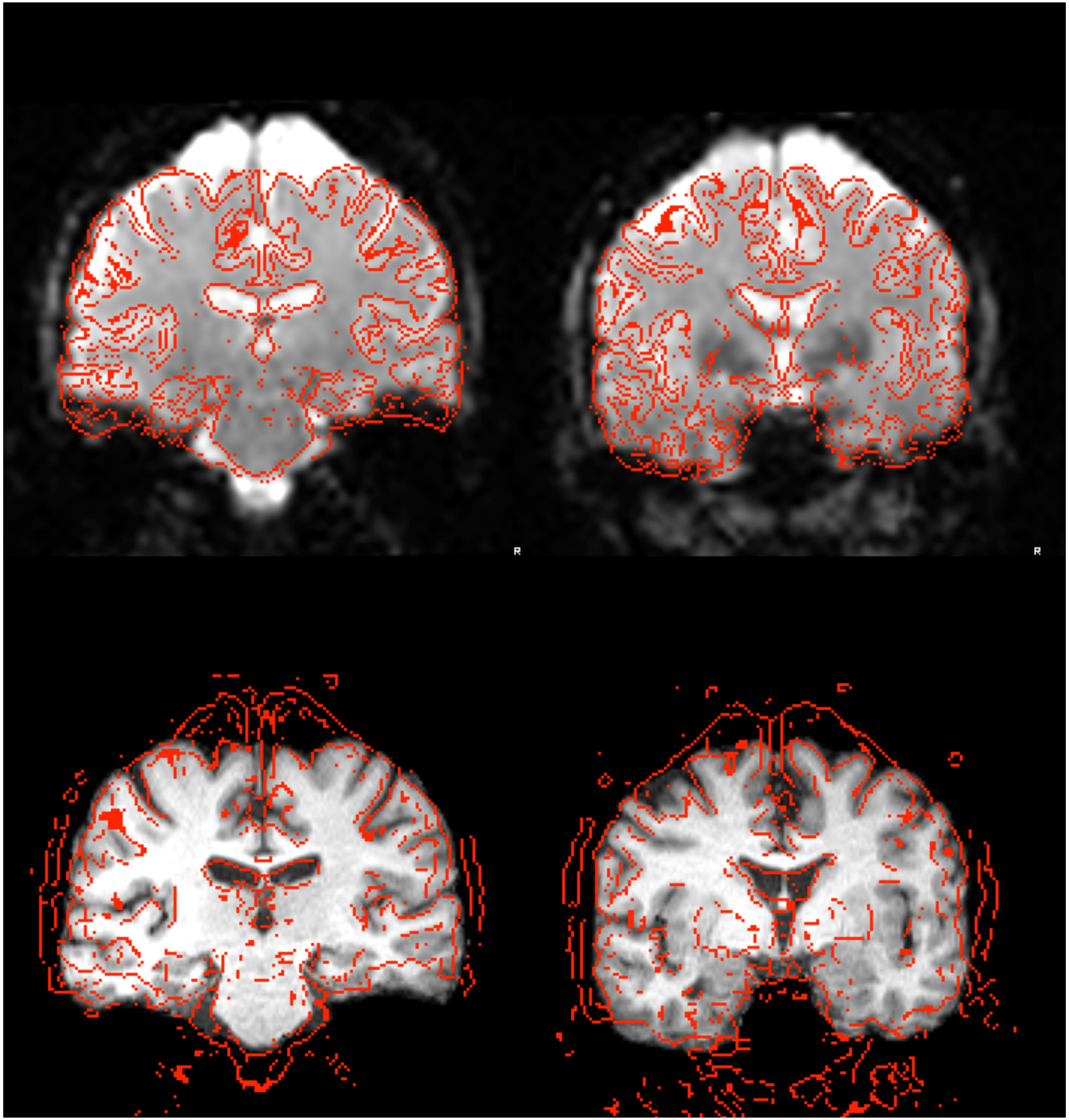


Functional image in standard space:
fmri in grey + red lines from MNI (standard space template)

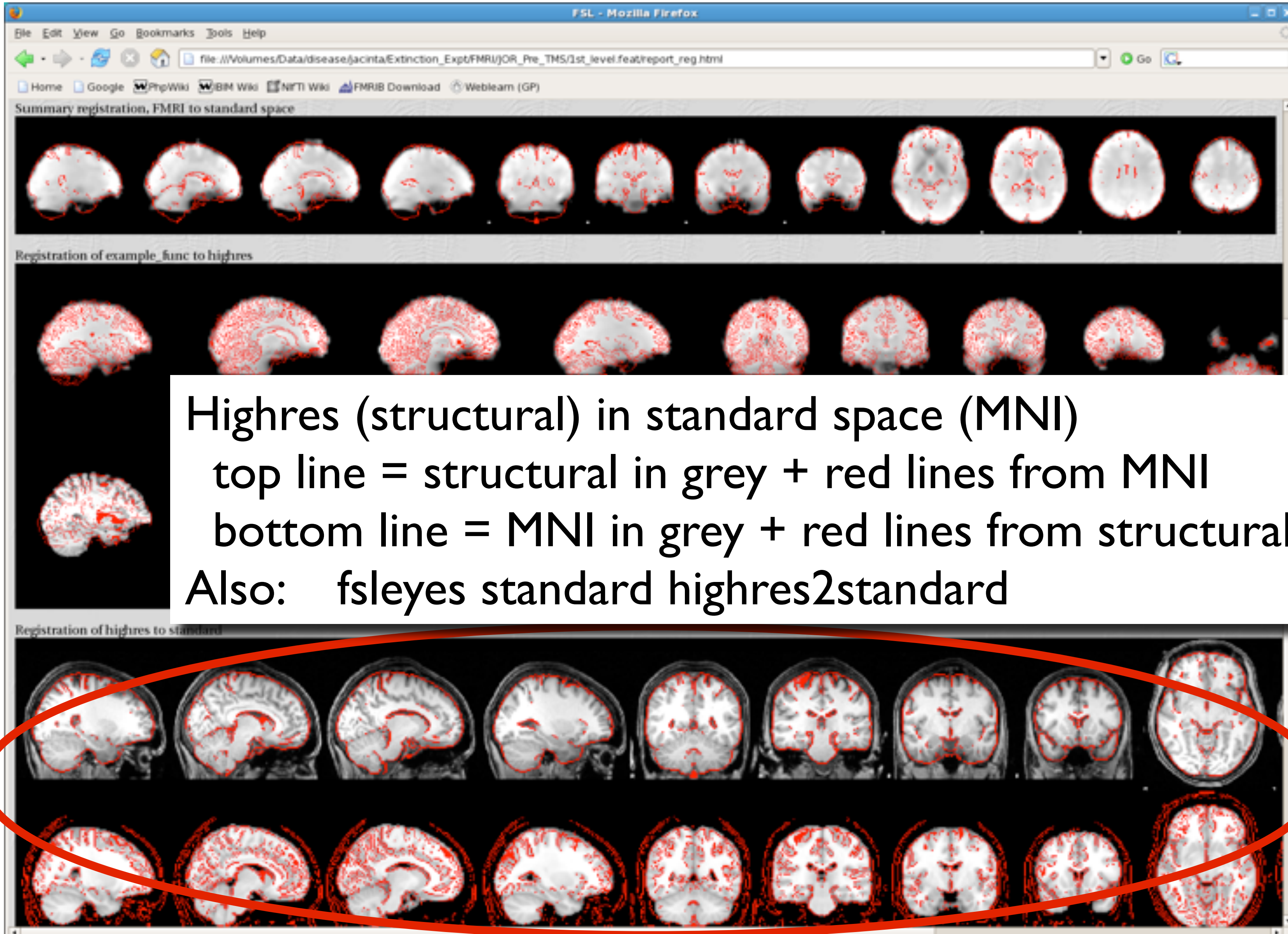
Registration for FMRI Analysis



Example func (fmri) in highres (structural) space:
  top line = fmri in grey + red lines from structural
  bottom line = structural in grey + red lines from fmri
Also: fsleyes highres example_func2highres
      (in reg subdirectory of feat directory)


R
R

Registration for FMRI Analysis

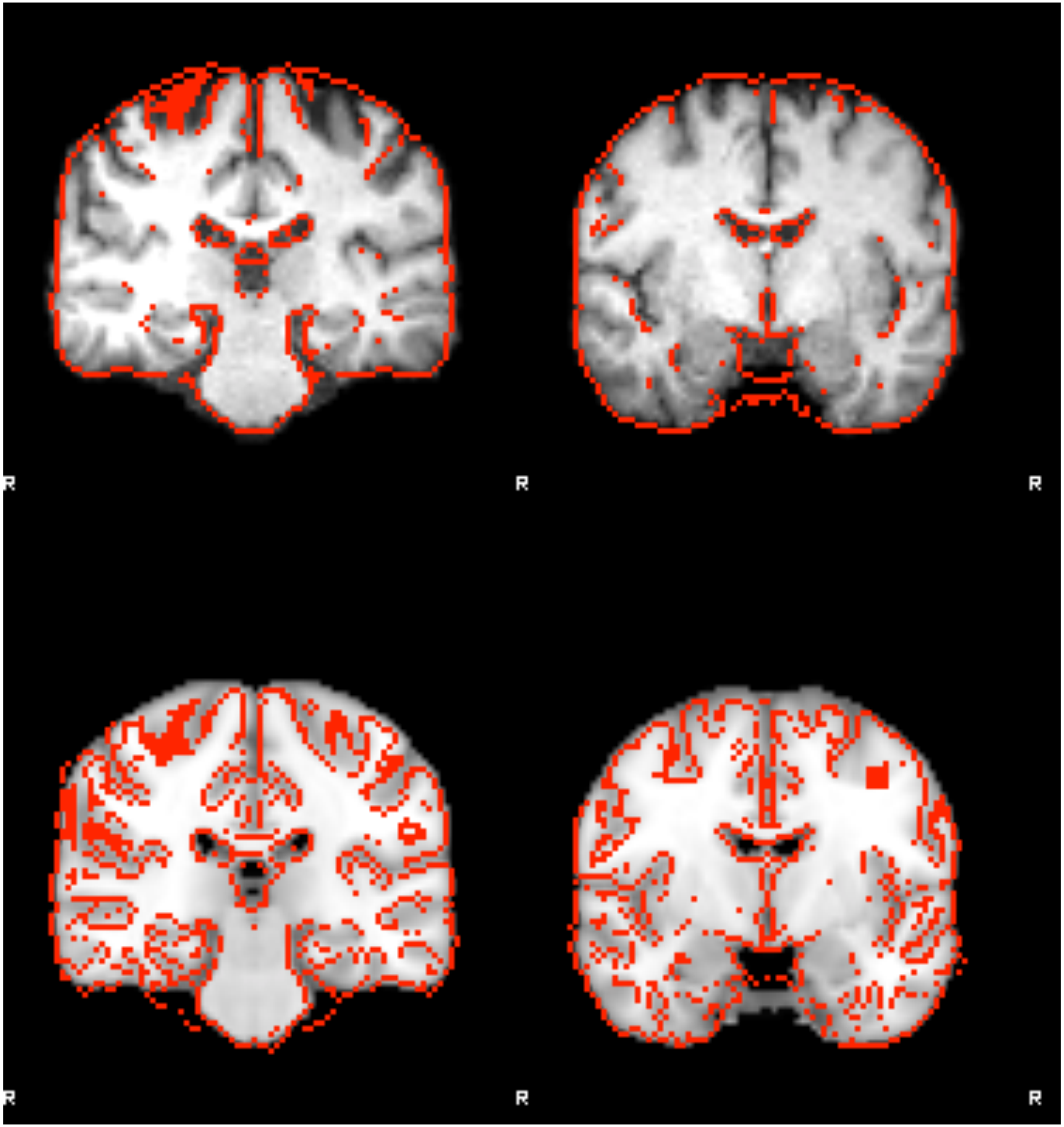


Highres (structural) in standard space (MNI)

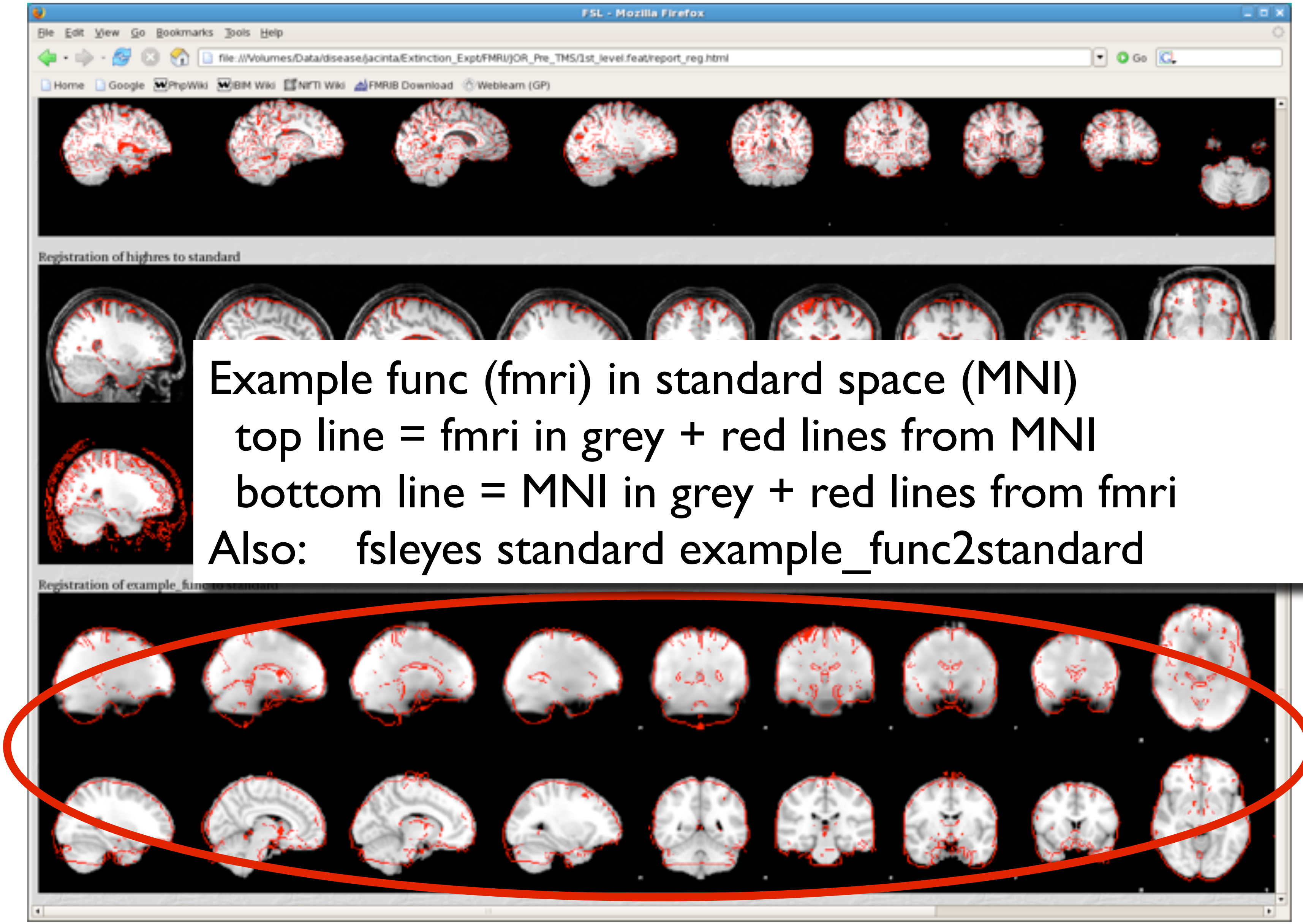
top line = structural in grey + red lines from MNI

bottom line = MNI in grey + red lines from structural

Also: fsleyes standard highres2standard


R
R
R
R
R
R

Registration for FMRI Analysis



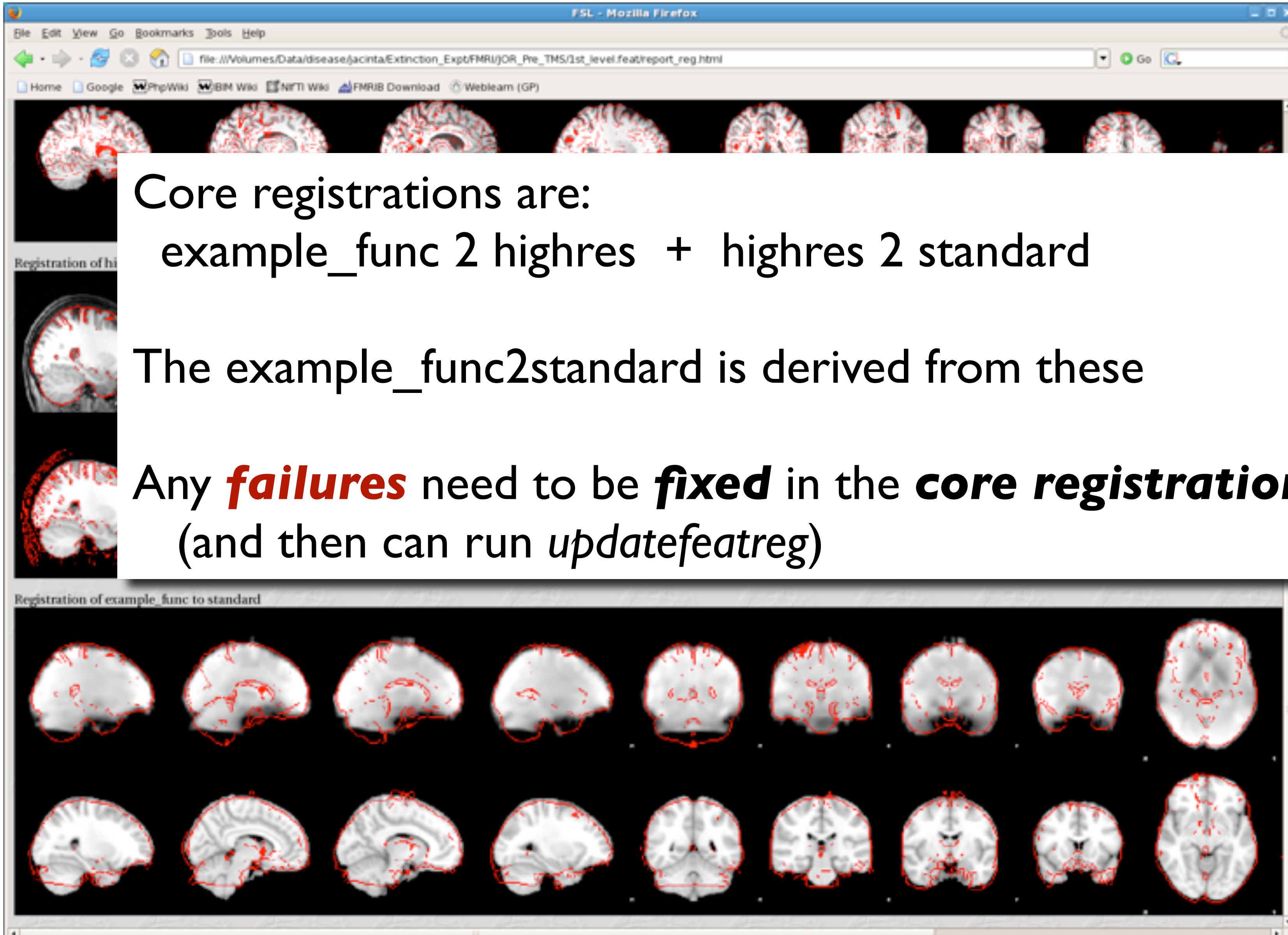
Example func (fmri) in standard space (MNI)

top line = fmri in grey + red lines from MNI

bottom line = MNI in grey + red lines from fmri

Also: fsleyes standard example_func2standard

Registration for FMRI Analysis



Core registrations are:

example_func 2 highres + highres 2 standard

The example_func2standard is derived from these

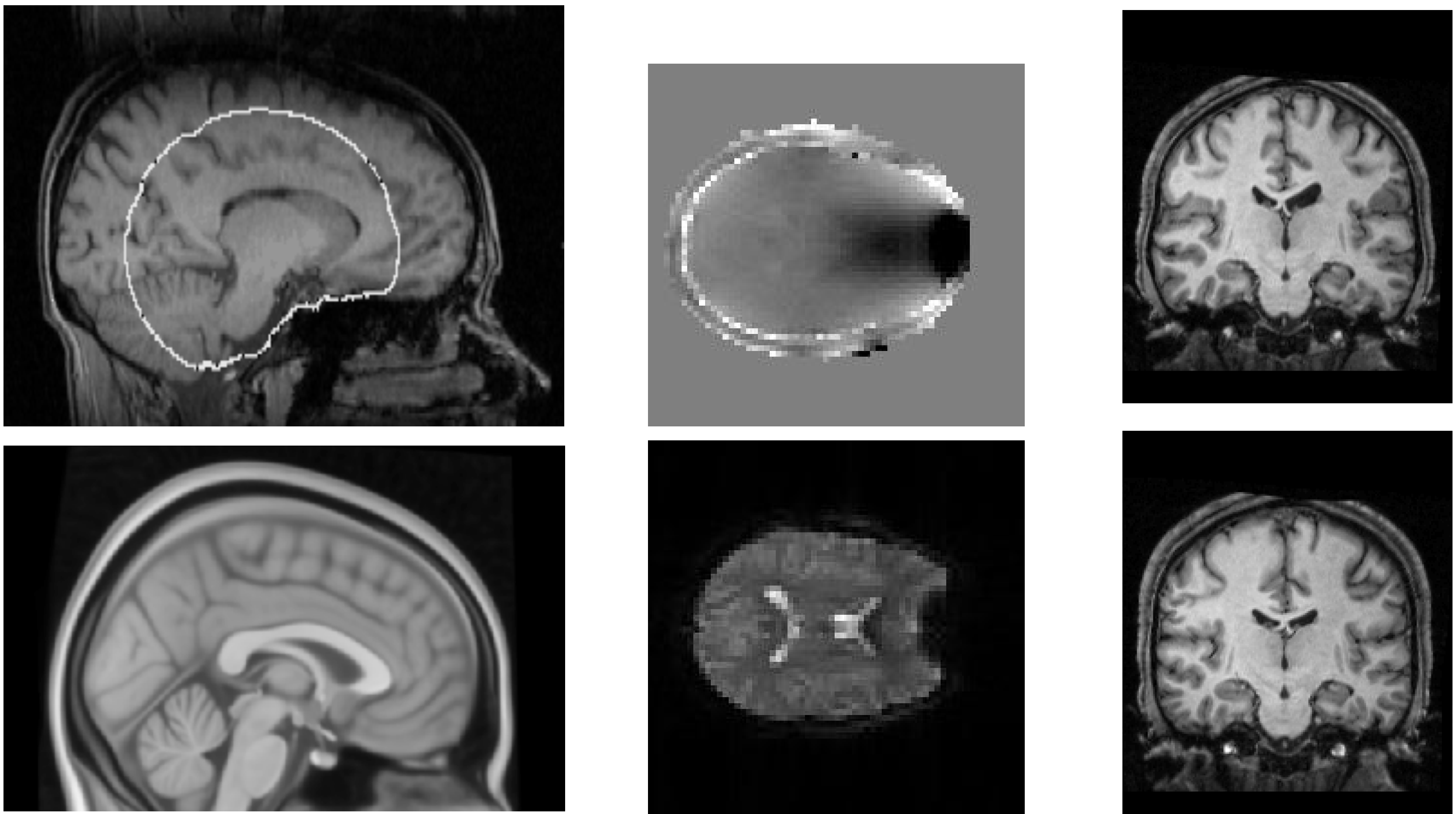
Any ***failures*** need to be ***fixed*** in the ***core registrations*** (and then can run *updatefeatreg*)

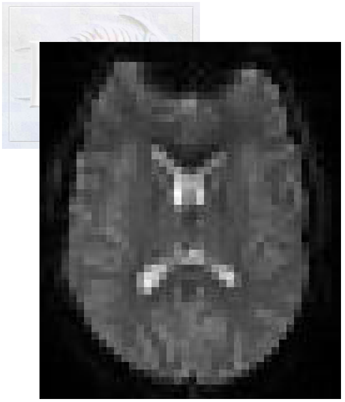
Registration: Single-Stage and Multi-Stage Applications

Summary:

- Preliminary processing using reorientation, brain extraction and artefact correction (e.g. bias field)
- Single-stage for structural images: choose spatial transformation, cost function
- Important to **visually check** results!
- Multi-stage for multiple modalities/spaces
- Each stage benefits from fewer differences
- Evaluate results for each stage (and combined)

Registration: EPI Distortion Correction and Registration





EPI Distortion Correction

Scenario:

Doing a functional (or diffusion) study

Objective:

Want to correct for distortions in EPI
as otherwise the registrations are inaccurate

Solution:

Fieldmap-based correction using FUGUE/FEAT

Registration of EPI

Problem:

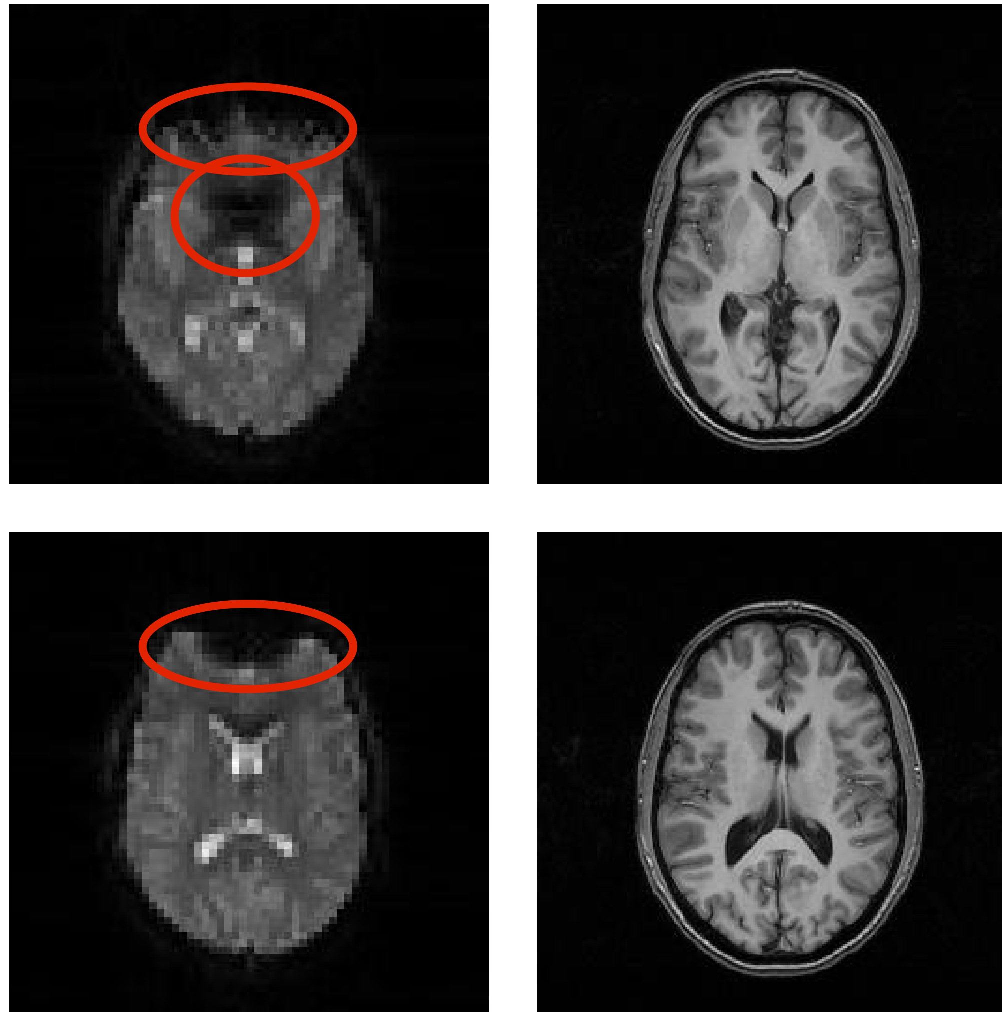
- EPI images distorted and suffer signal loss
- standard registration does not work well

Solution:

- undo distortion by "unwarping"
- ignore areas of high signal loss
- *needs a* **fieldmap** (special acquisition)

EPI

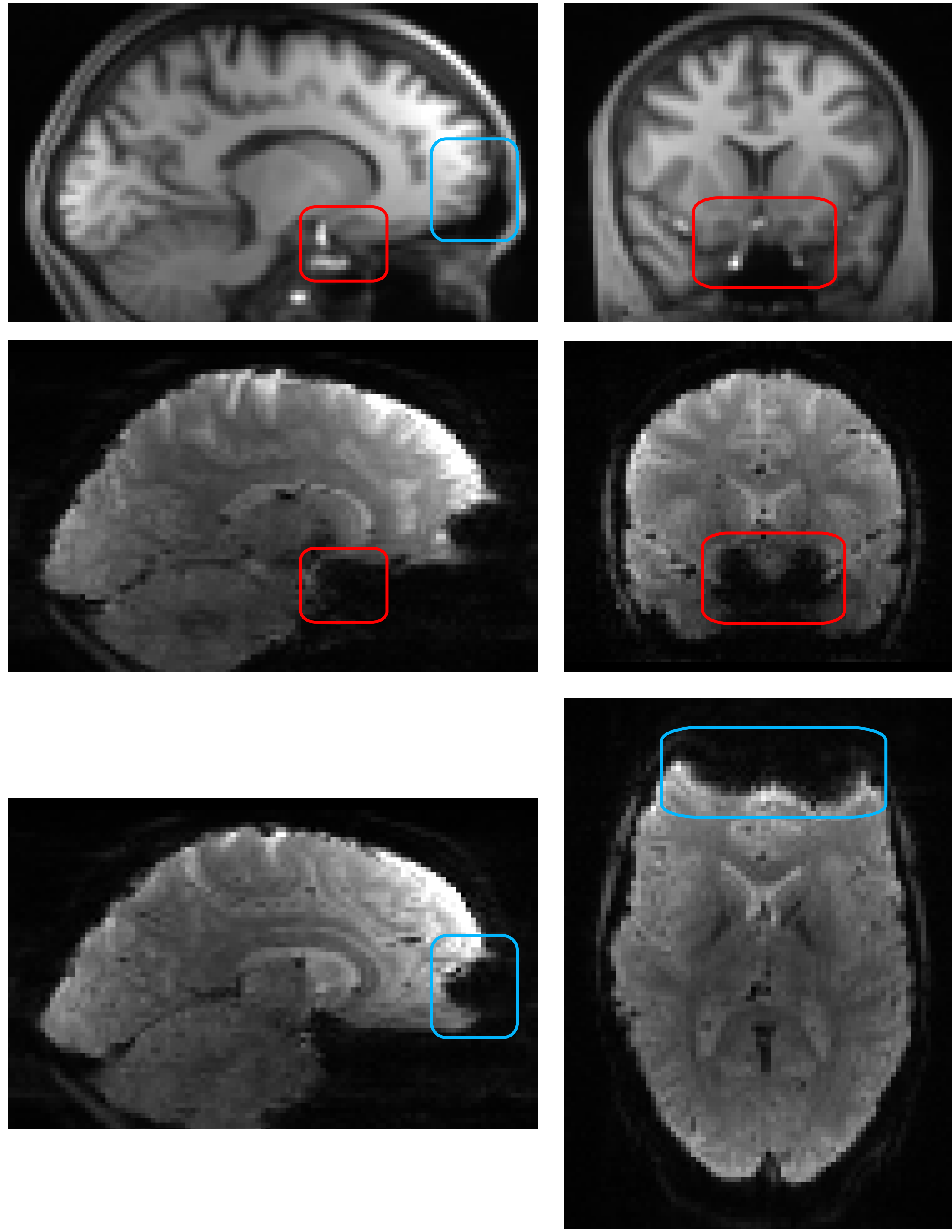
T_1-weighted anatomical



T1-weighted
(aligned)

Signal Loss

Distortion

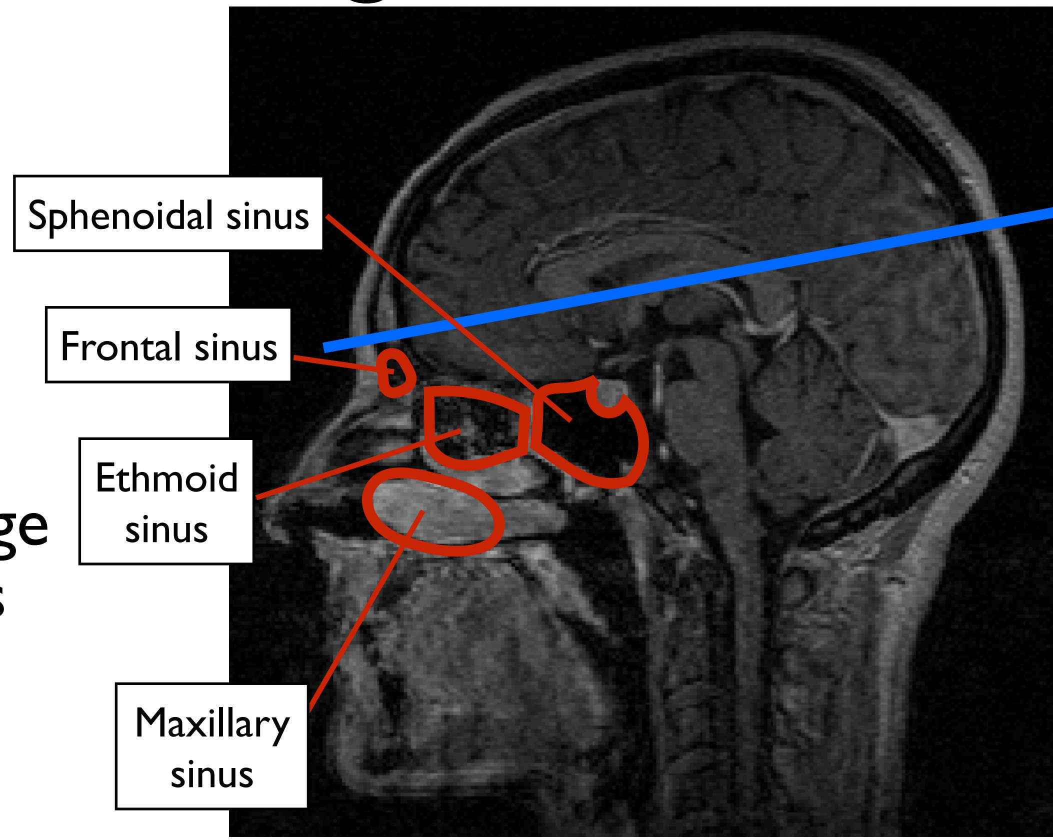


B_0 Field Inhomogeneities

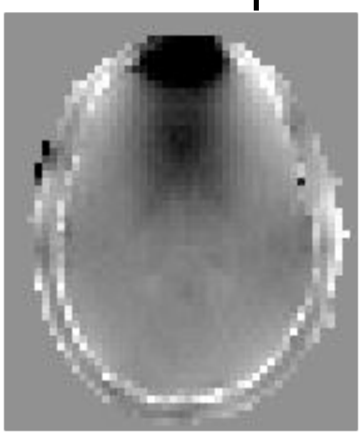
EPI is very sensitive to any deviations from a perfectly uniform B_0 field

Air-tissue interfaces cause magnetic disturbances

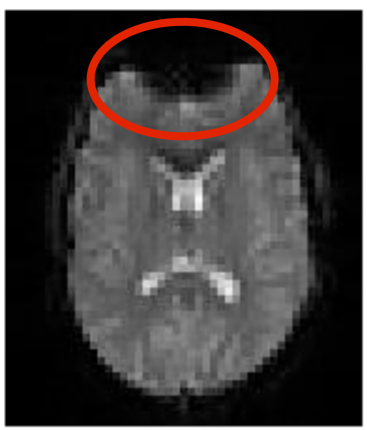
A separate ***fieldmap*** image measures the B_0 deviations



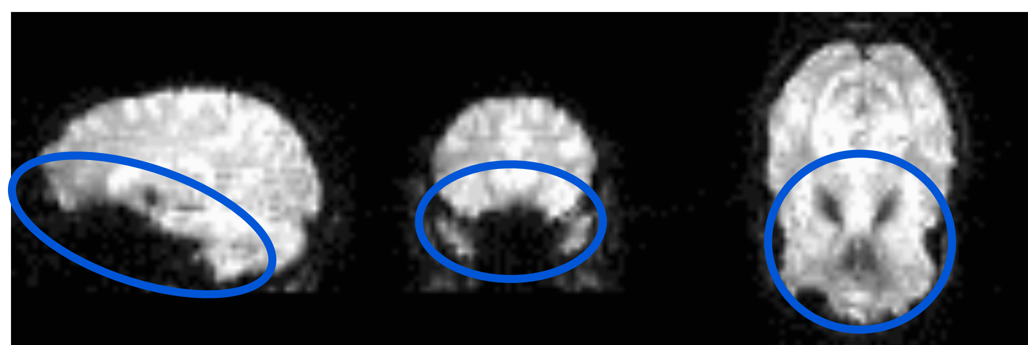
fieldmap



EPI



distortion



signal loss

Courtesy of D. Greve, MGH

Using Fieldmaps

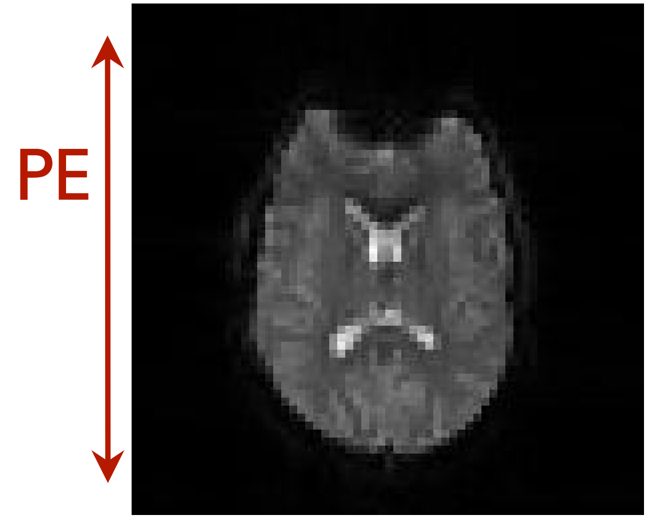
From the fieldmap image we get:

Magnitude of spatial distortions
(phase-encode direction only)

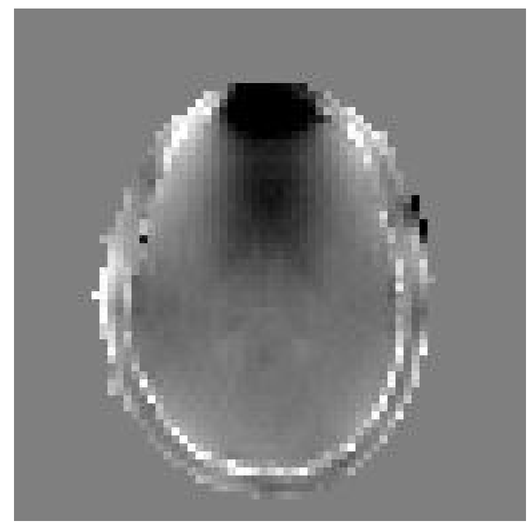
Estimate of signal loss

Only takes a few minutes to acquire one fieldmap - and it *massively* improves registration

Need a new fieldmap for each scanning session as it changes
(e.g. it depends on head orientation)



EPI



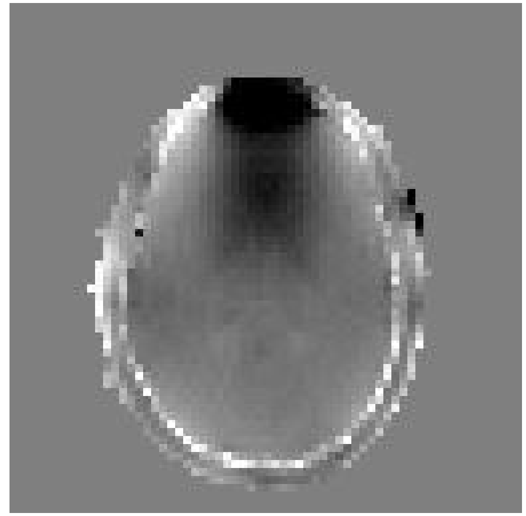
B_0 Fieldmap

Unwarping with Fieldmaps

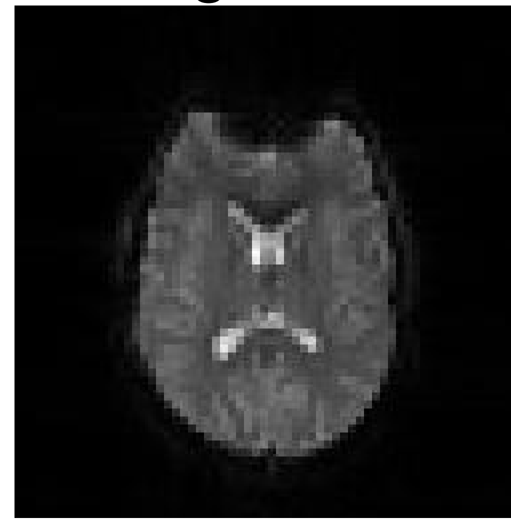
Used to improve **registration** of EPI and structural scan

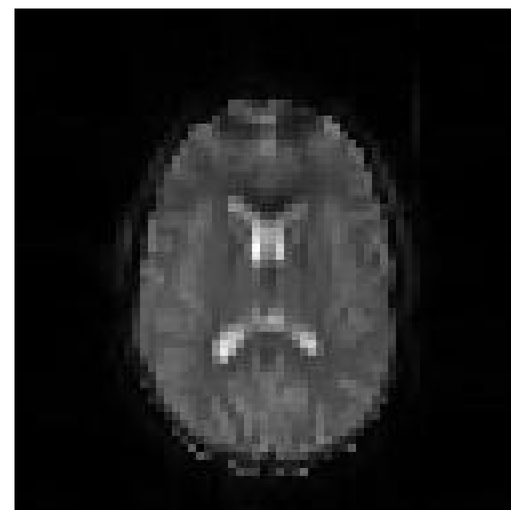
It **does not** restore signal in the frontal lobe

Fieldmap



Original EPI





Unwarped EPI

Unwarping with Fieldmaps

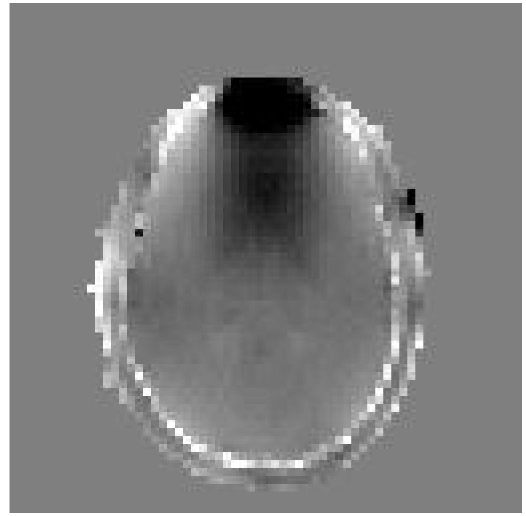
Used to improve **registration** of EPI and structural scan

It **does not** restore signal in the frontal lobe

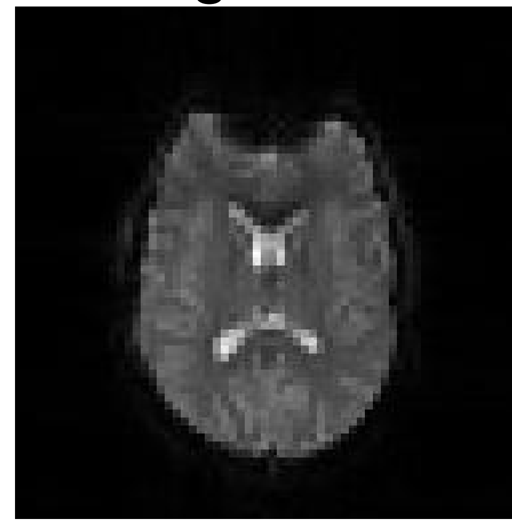
It **does not** do anything about motion correction

It **does** use fieldmap image to calculate distortion and "unwarp" EPI

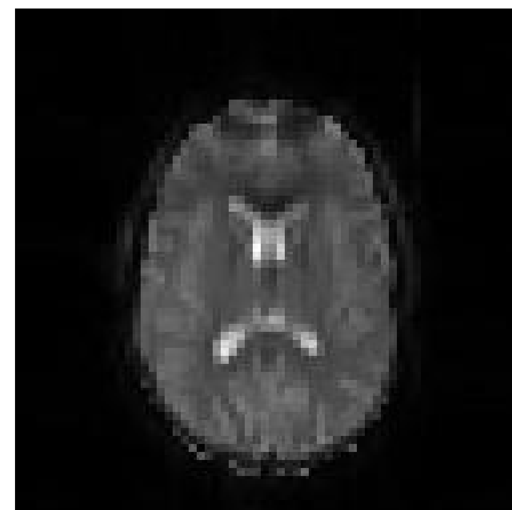
It **does** deweight areas with substantial signal loss *in the registration*



Fieldmap



Original EPI



Unwarped EPI

Fieldmap Acquisition

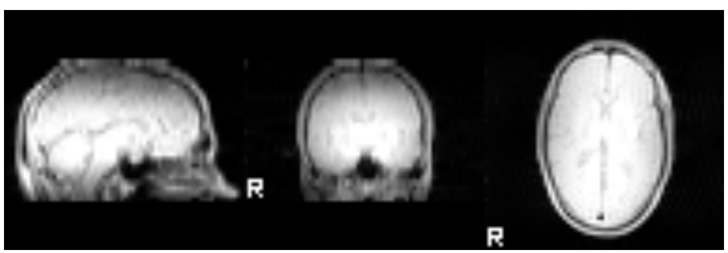
Fieldmaps are becoming standard sequences

Only takes a few minutes to acquire - best either immediately before or after EPI scans (but this is not crucial)

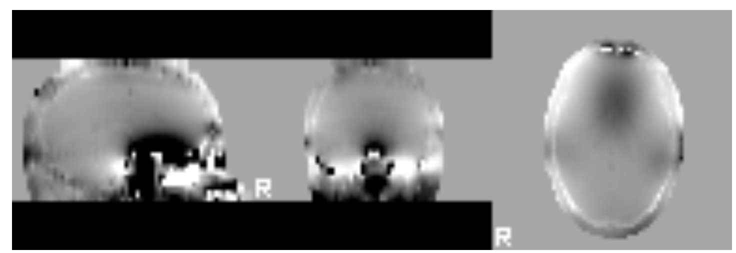
Four main types of acquisitions:

- Gradient Echo ✔
- Asymmetric Spin Echo ✔
- EPI ✘ Distortion & Signal Loss
- Blip-reversed b=0 pair (EPI) ✔

Each based on a pair of images with different TE (*record* these TE values)



Magnitude part of fieldmap



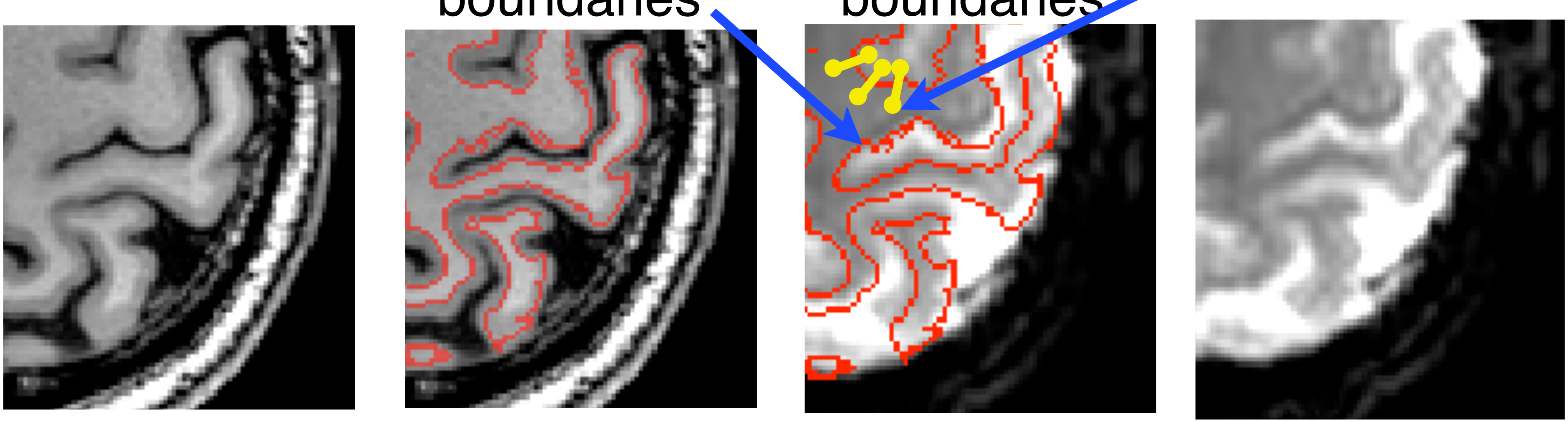
Phase difference of images

Crucially requires the *phase information* (not only the magnitude, unlike the vast majority of other images)

Boundary-Based Registration (BBR)

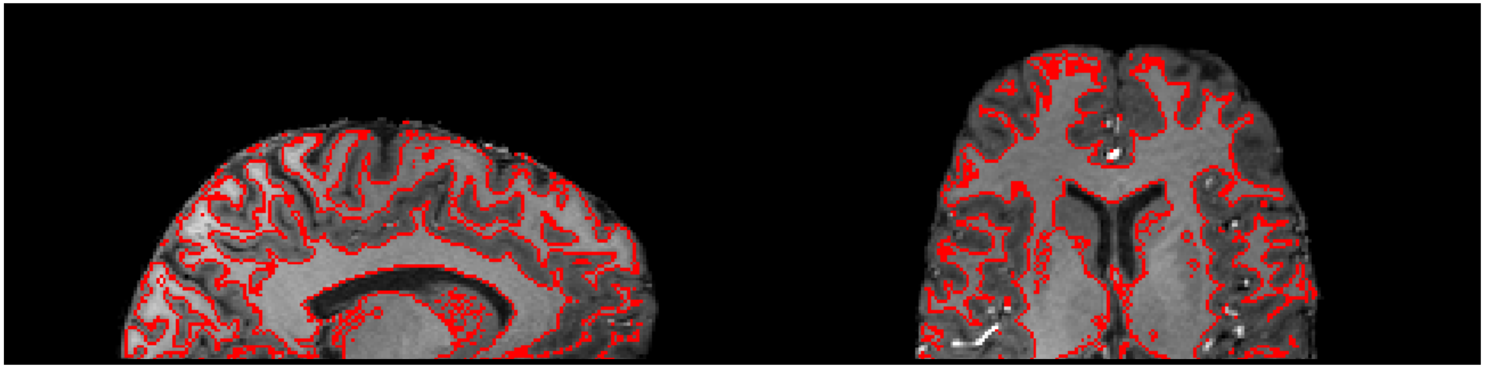
- *EPI to structural registration* (Greve & Fischl, NeuroImage, 2009)
  - incorporates ***fieldmap*** correction (previously FUGUE)
  - used in FEAT (B0 unwarping)
- Uses ***white-matter boundaries*** (via T1w segmentation)
  - Need good structurals (not too much bias field)
  - Also ***requires anatomical contrast in the EPI***
  - Driven by intensity difference across boundary (samples)
- More robust to pathologies and artefacts in EPI

T1w | T1w + boundaries | EPI + boundaries | EPI

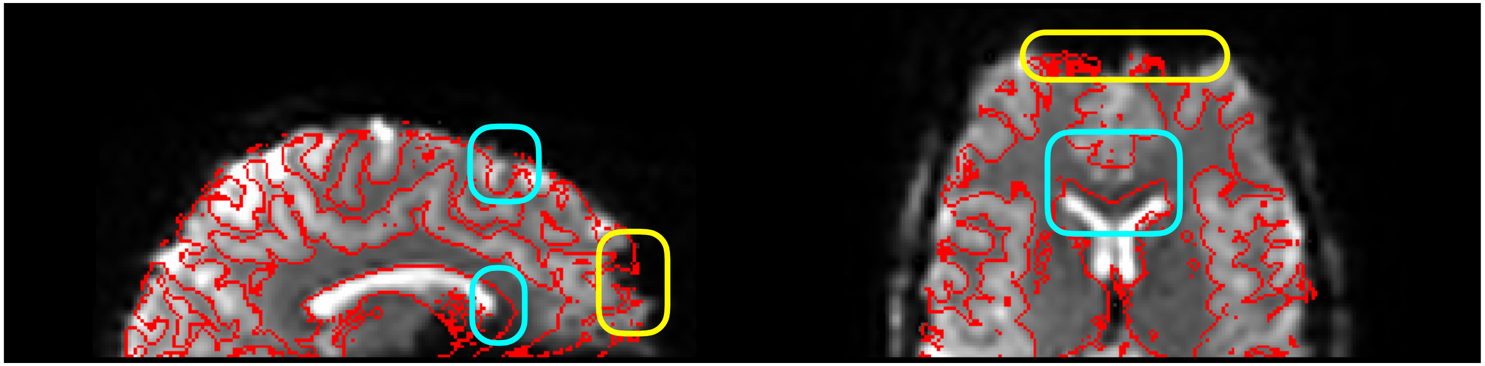


Distortion Correction

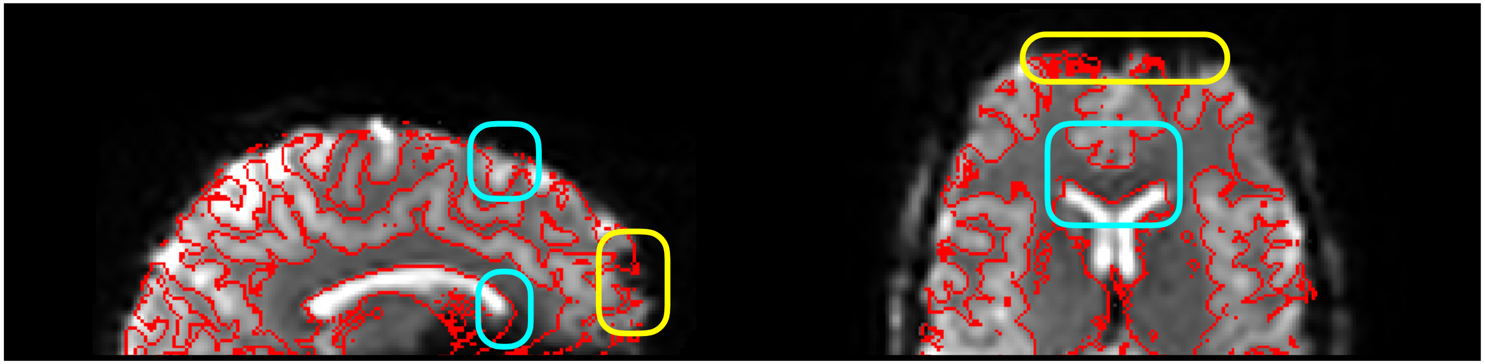
Structural Image



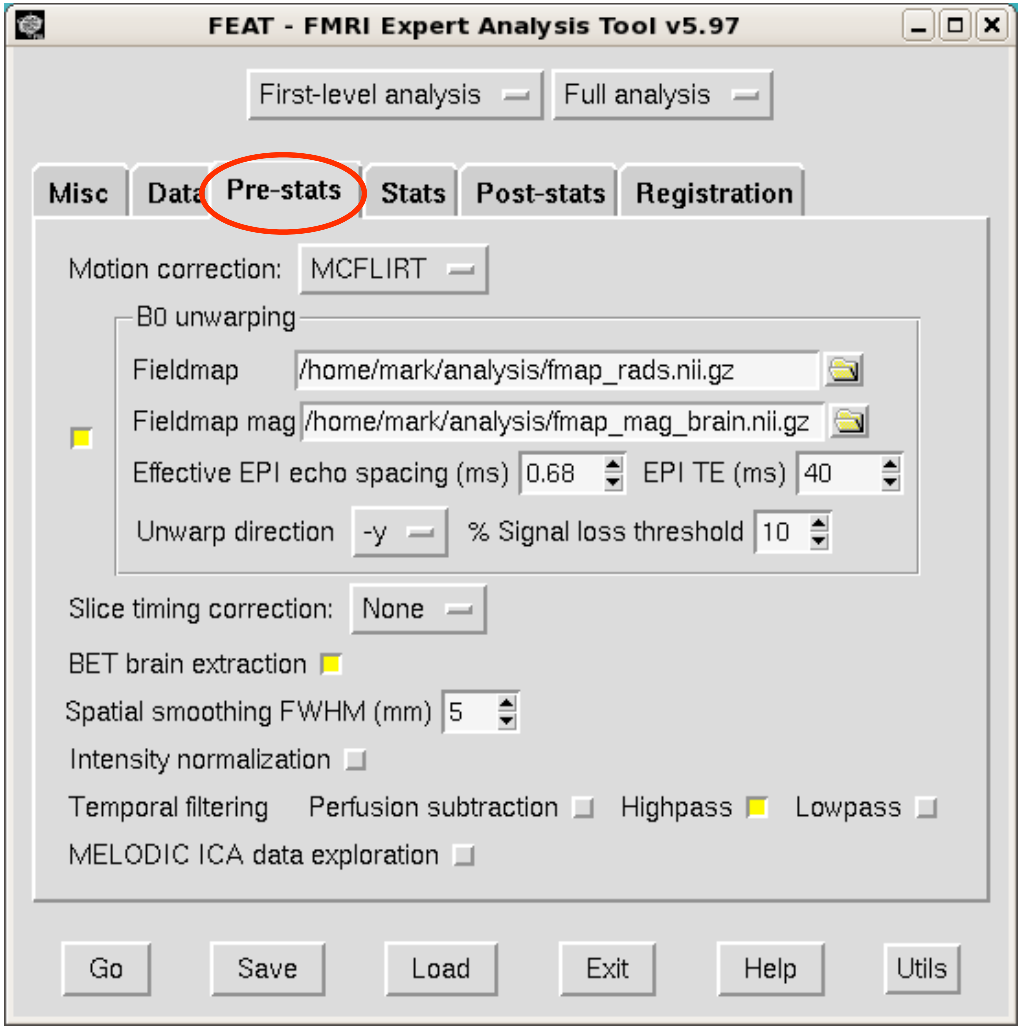
Registration without Distortion Correction



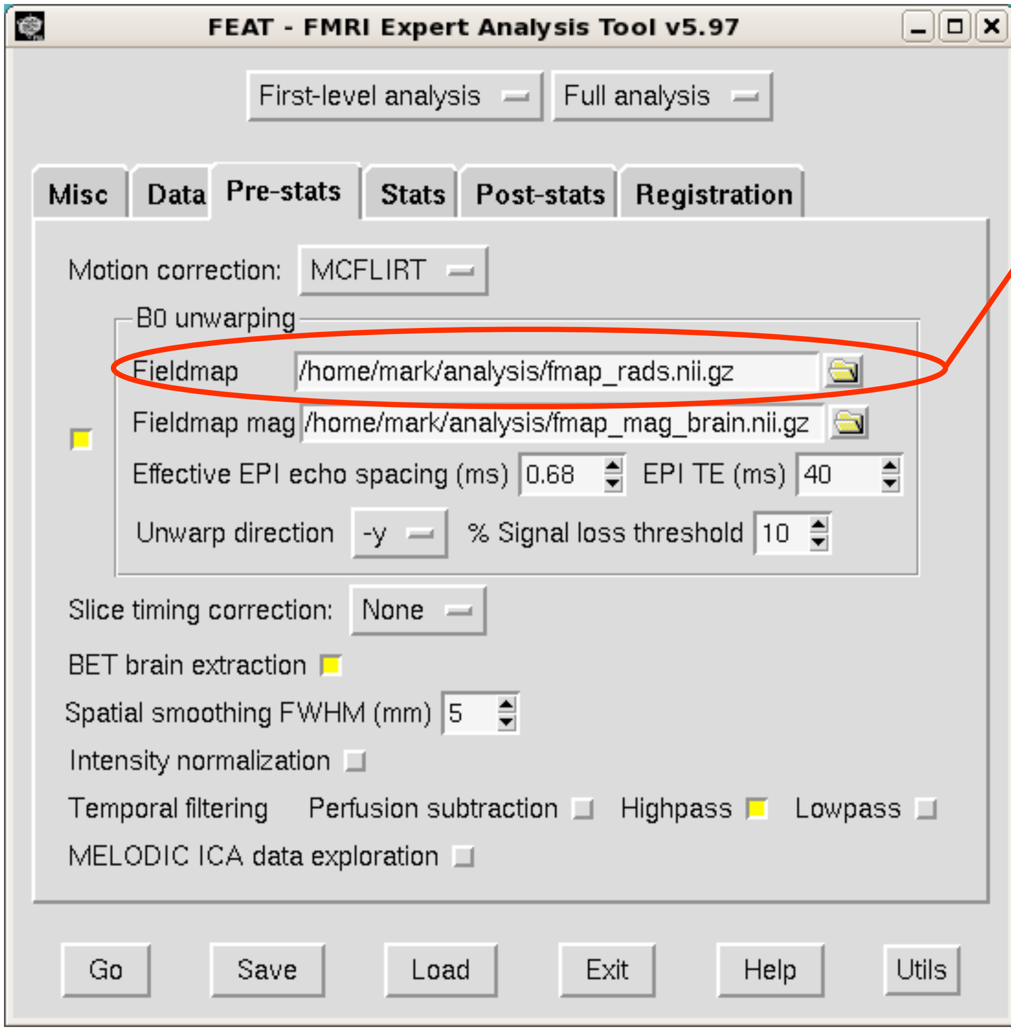
Registration with Distortion Correction



Distortion Correction within FEAT

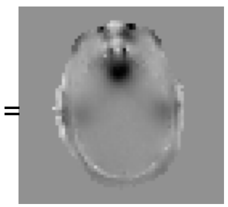


Distortion Correction within FEAT



Fieldmap in rad/s

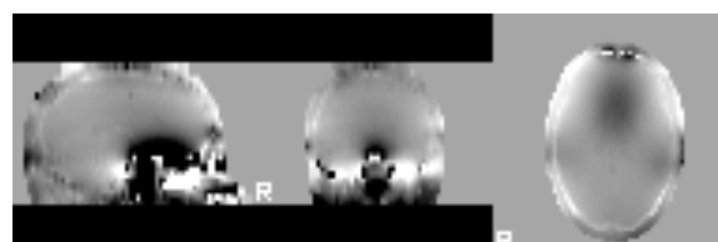
/ TE difference (sec) =



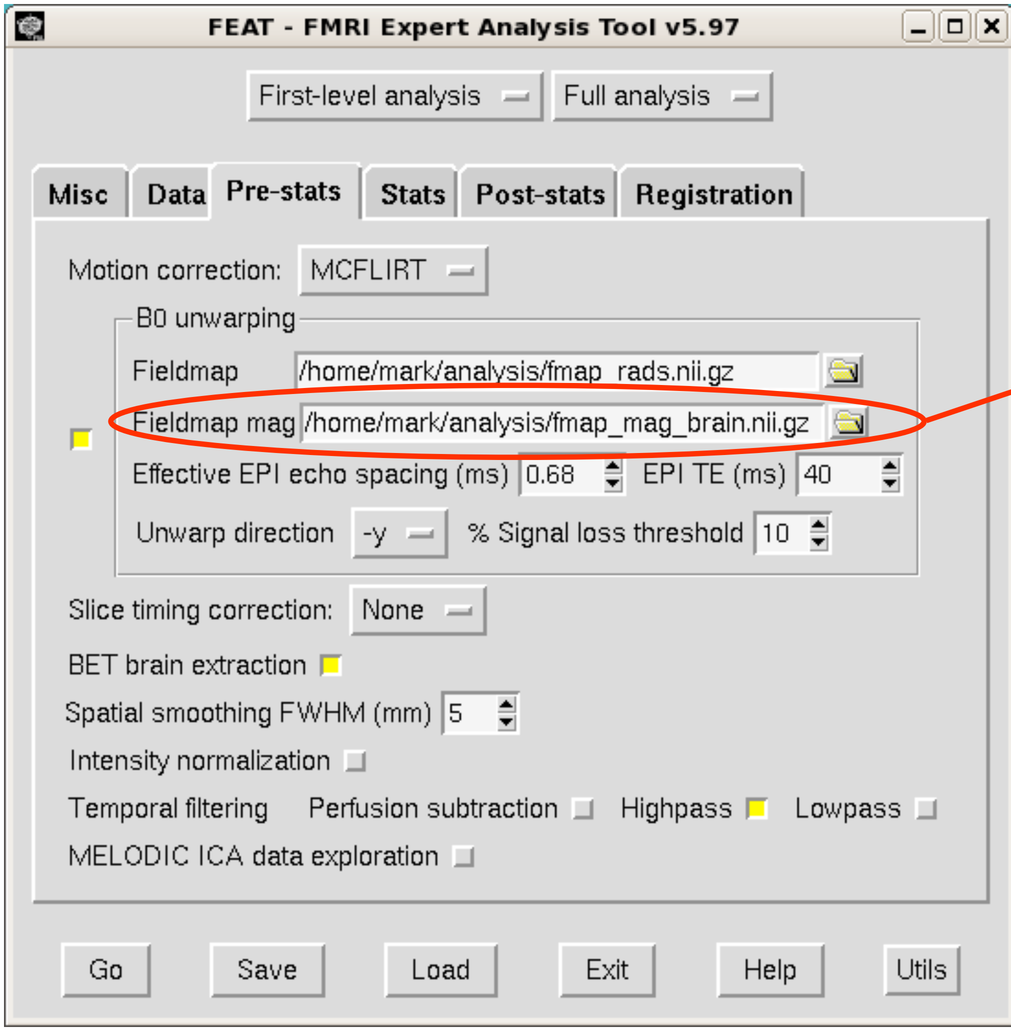
Phase difference (rad)

B_0 Field (rad/s)

Need to prepare the fieldmap image: *Fsl_prepare_fieldmap* (for Siemens)



Distortion Correction within FEAT

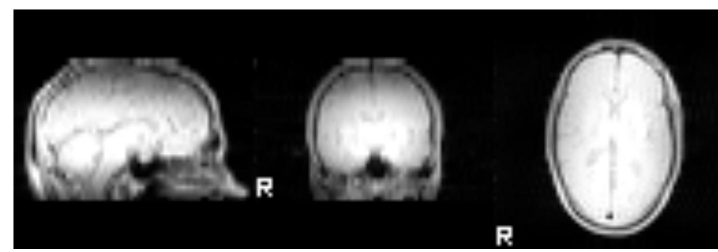


Input file = brain extracted file ...
but also needs to find original*

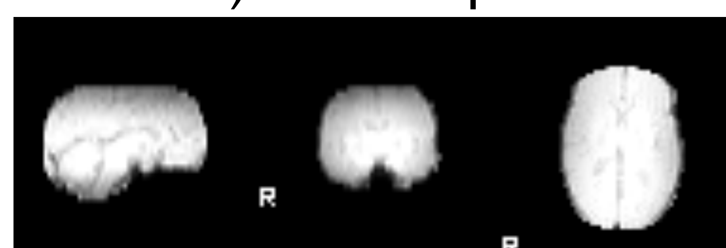
Fieldmap in rad/s

Fieldmap Magnitude

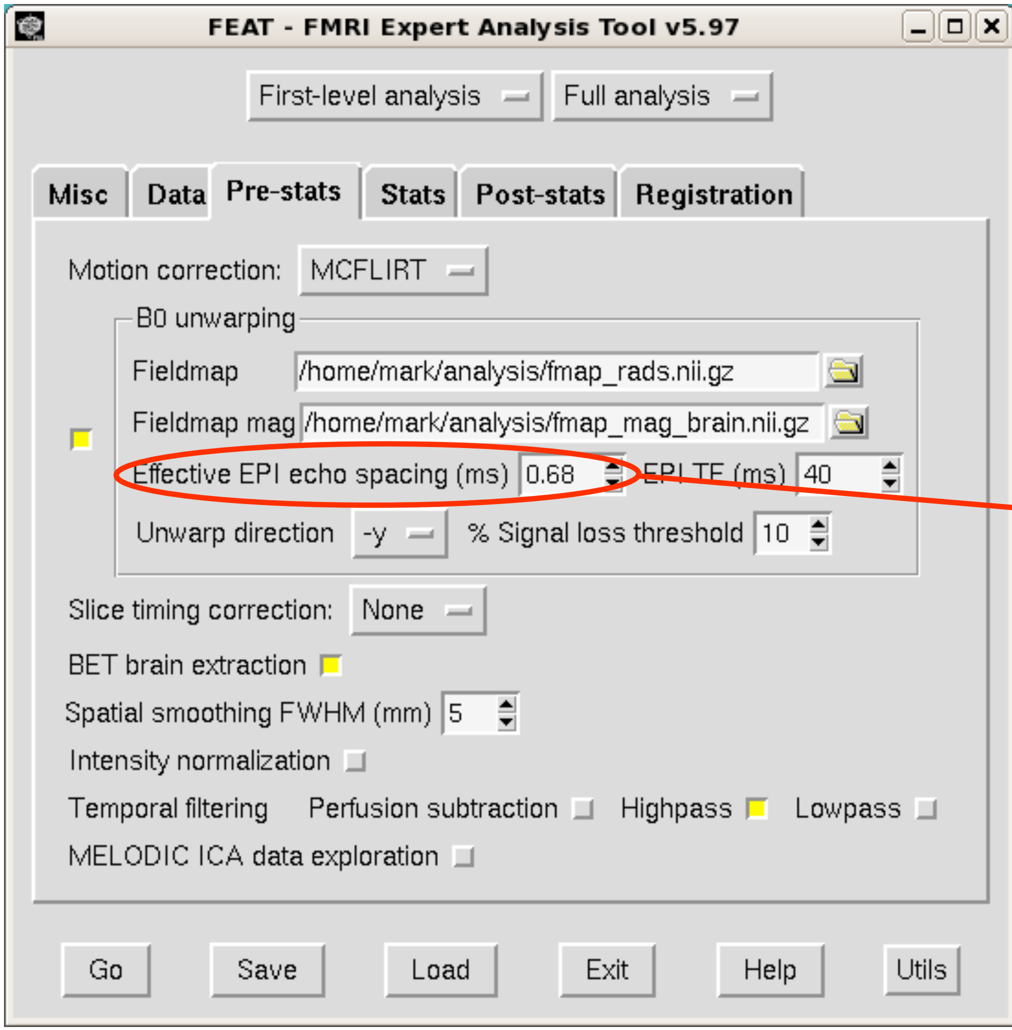
... needs this ...



... and aggressive BET (leave **no** non-brain) for best performance



Distortion Correction within FEAT



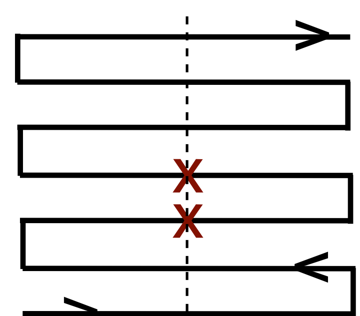
Fieldmap in rad/s

Fieldmap Magnitude

EPI echo spacing (ms)

Also called dwell time

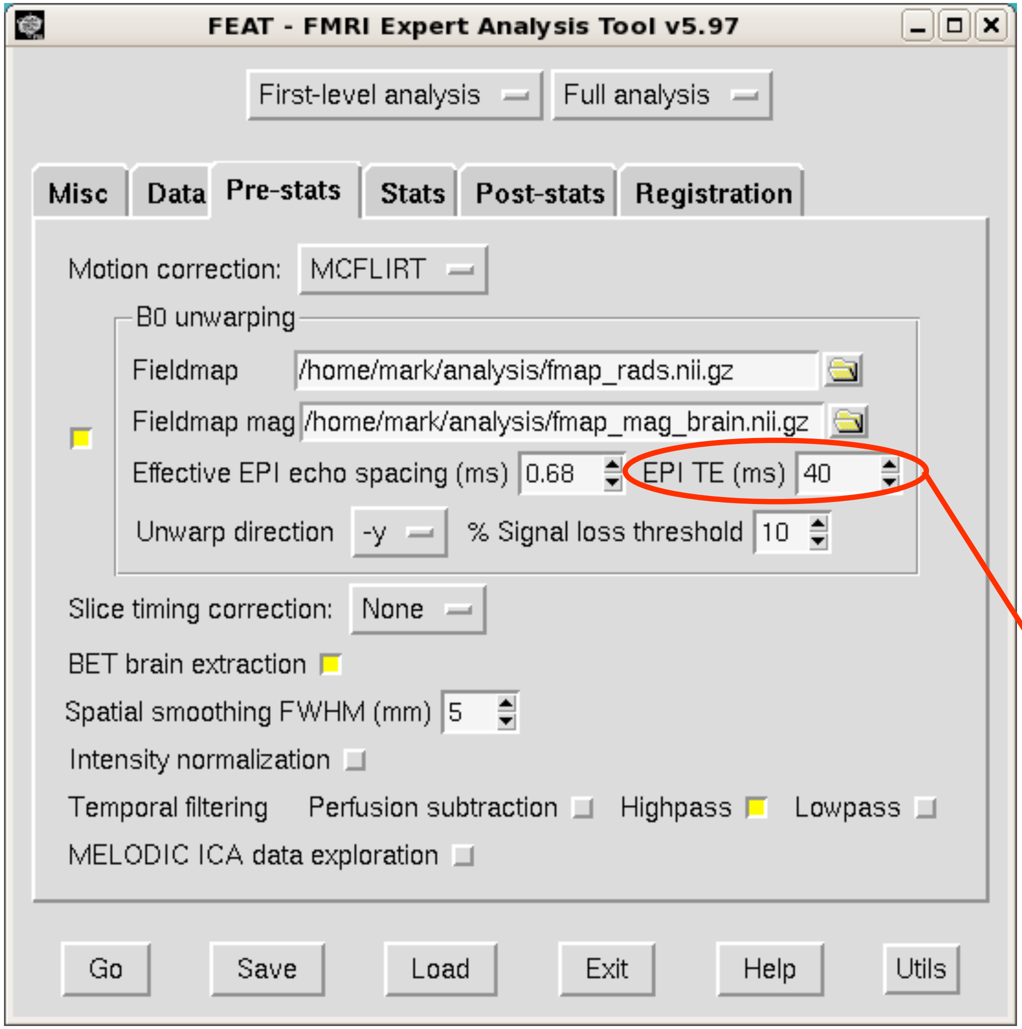
Normally about 0.5-0.7ms



Time between echos in k-space

Divide value by any acceleration factor

Distortion Correction within FEAT



Fieldmap in rad/s

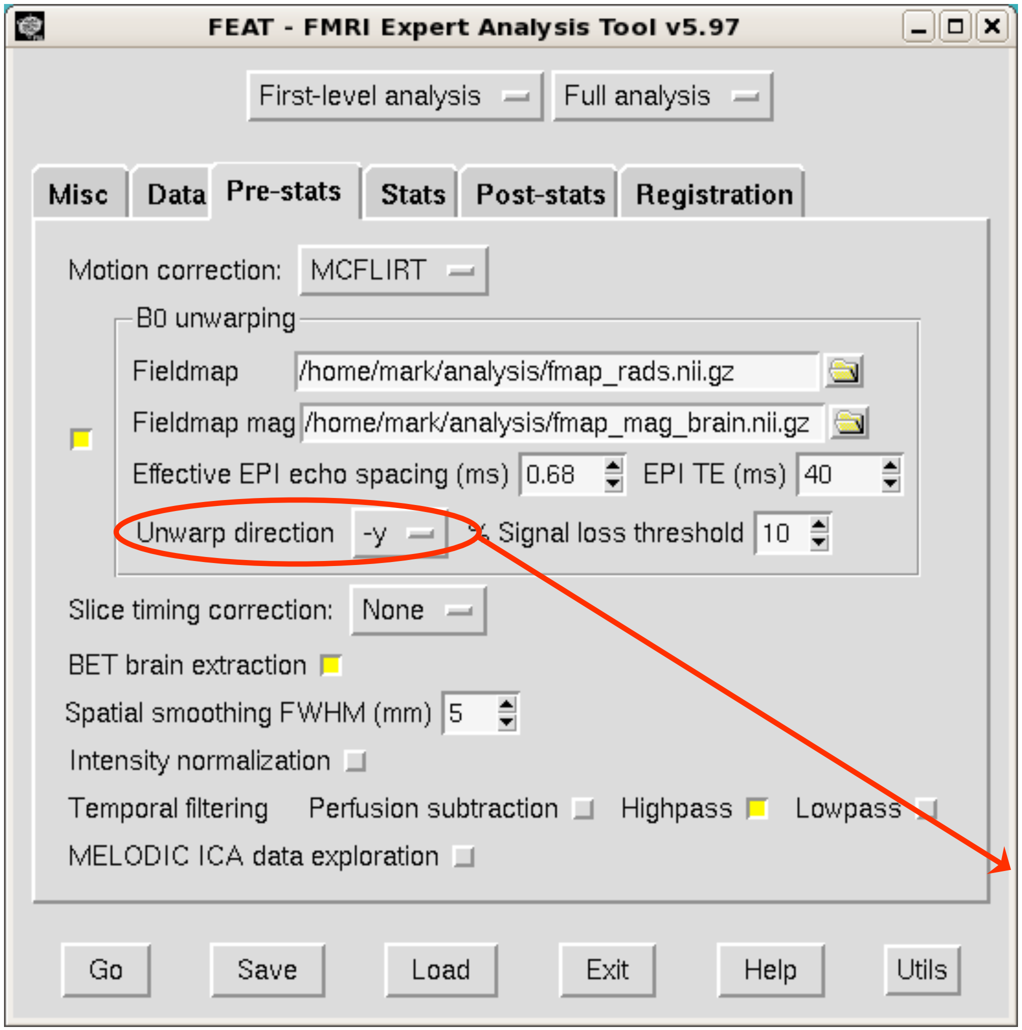
Fieldmap Magnitude

EPI echo spacing (ms)

EPI echo time (ms)

Normally about 30-40ms at 3T

Distortion Correction within FEAT



Fieldmap in rad/s

Fieldmap Magnitude

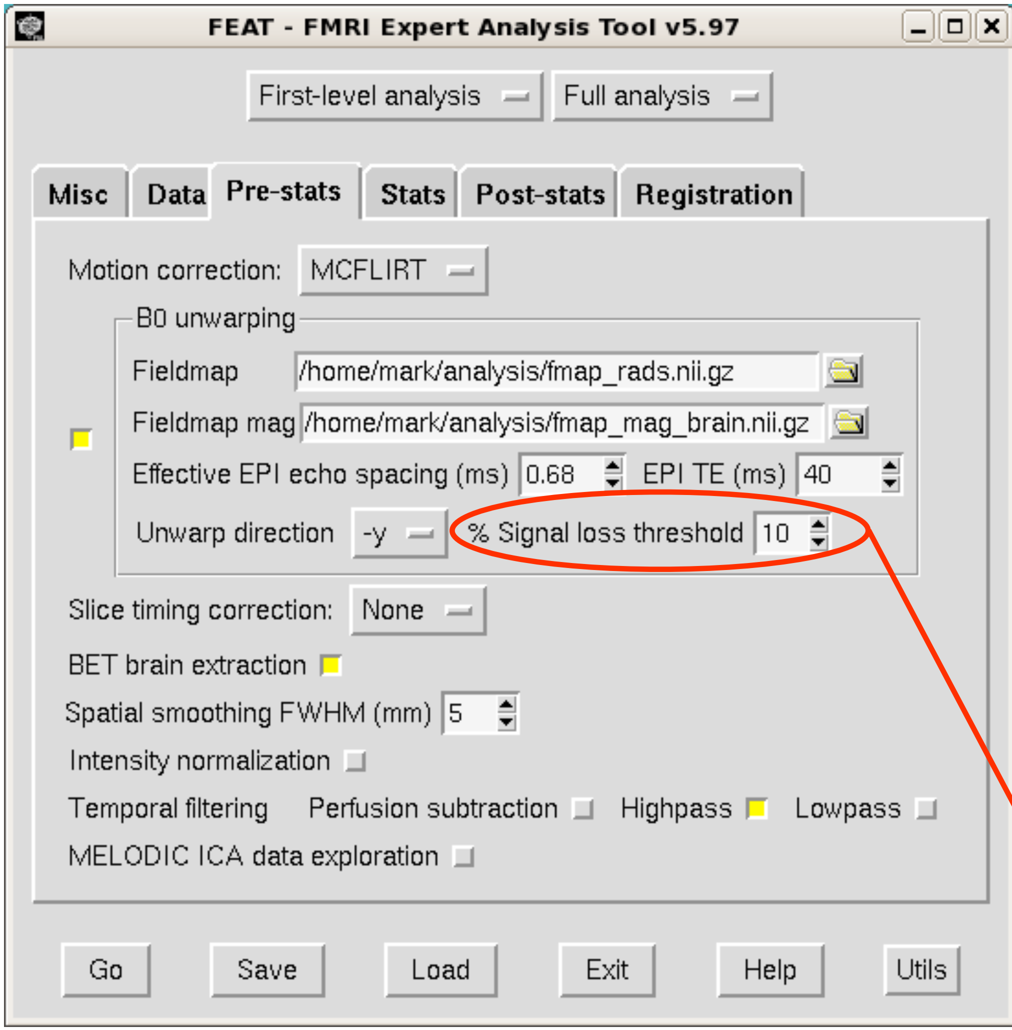
EPI echo spacing (ms)

EPI echo time (ms)

Unwarp (PE) direction

- Often A-P but can be anything
- Cannot tell if it is + or -
- *Try both* and see what works (see practical)

Distortion Correction within FEAT



Fieldmap in rad/s

Fieldmap Magnitude

EPI echo spacing (ms)

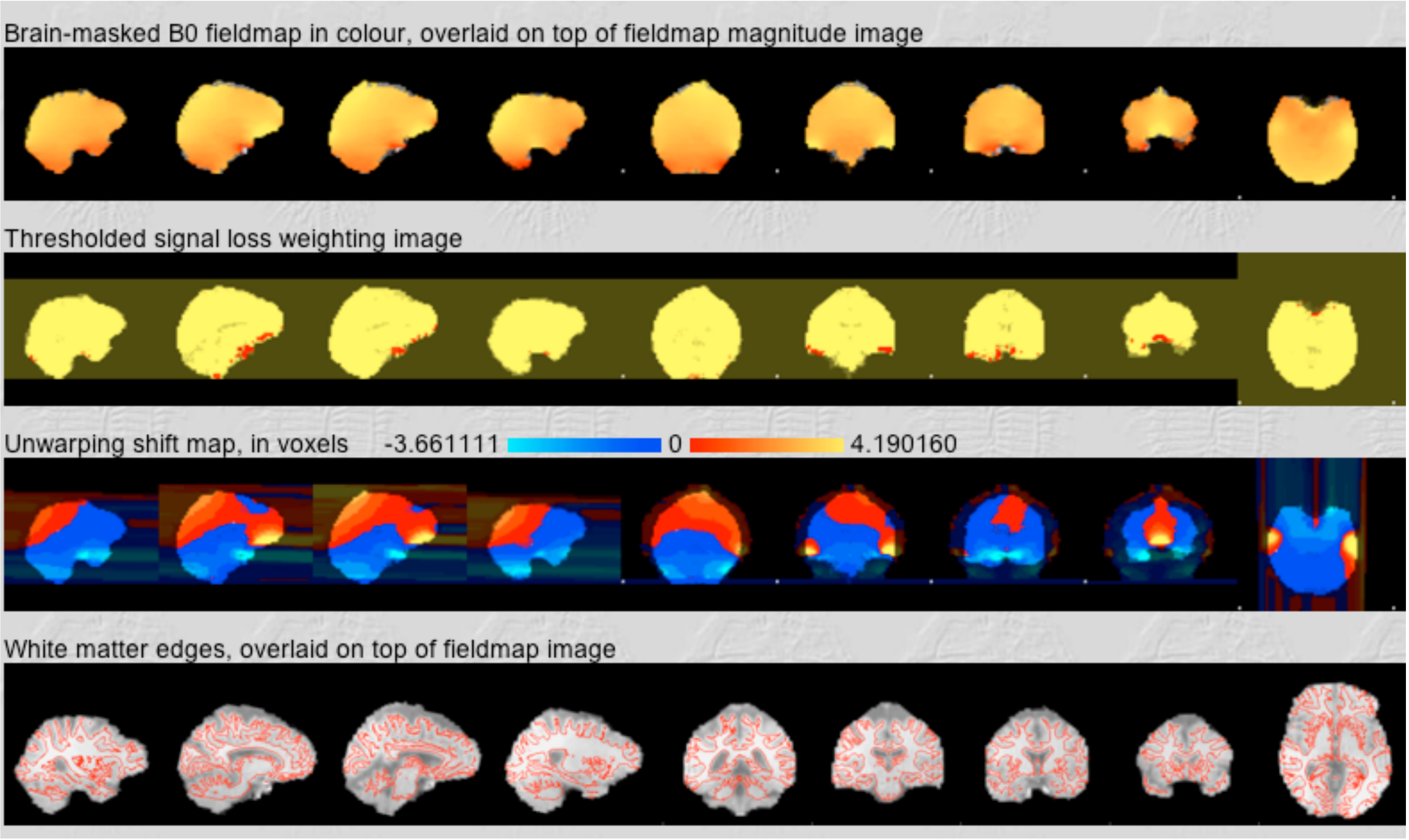
EPI echo time (ms)

Unwarp (PE) direction

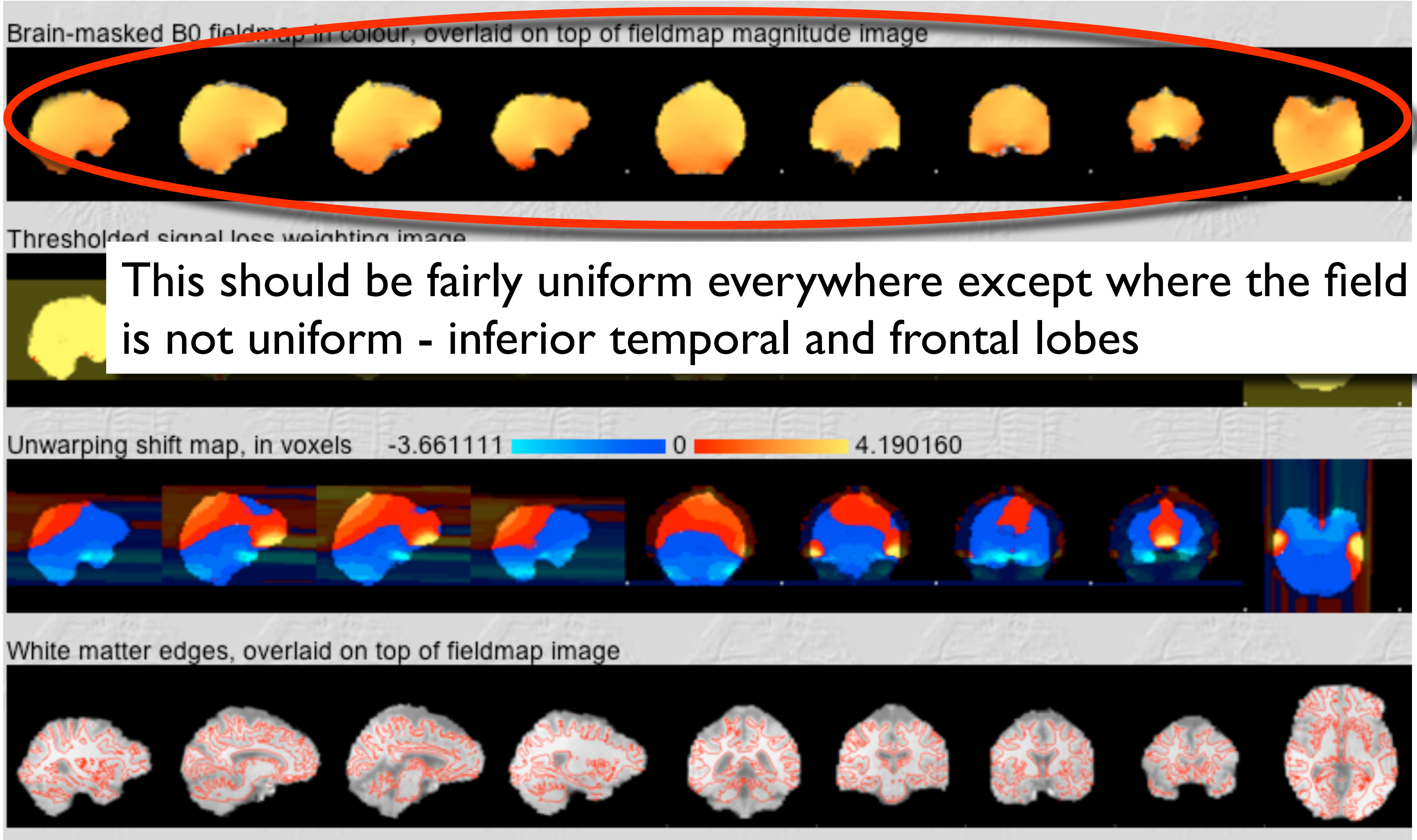
Signal loss thresh %

Ignore voxels with more than this signal loss in registration

Fieldmap use in FEAT

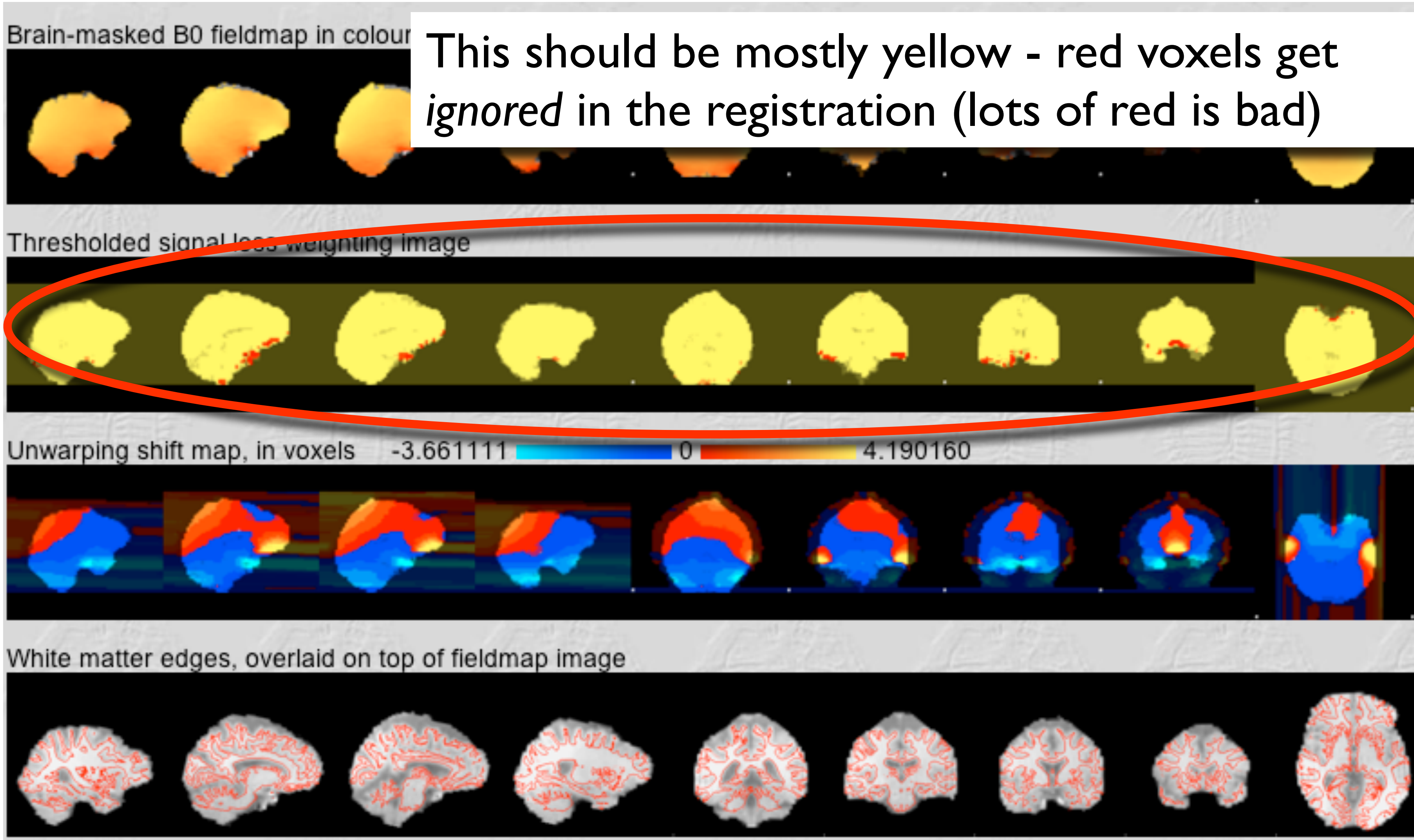


Fieldmap use in FEAT



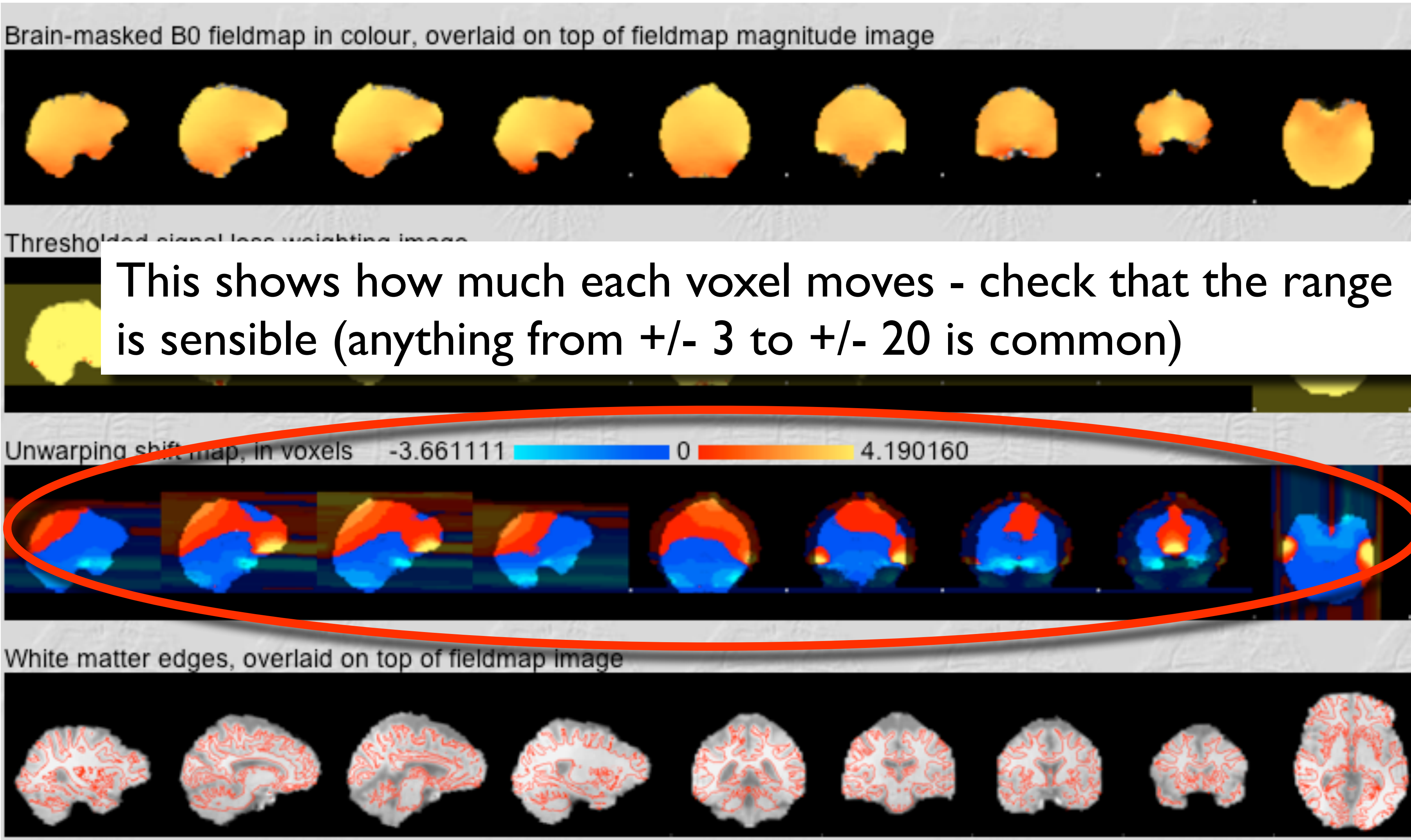
This should be fairly uniform everywhere except where the field is not uniform - inferior temporal and frontal lobes

Fieldmap use in FEAT



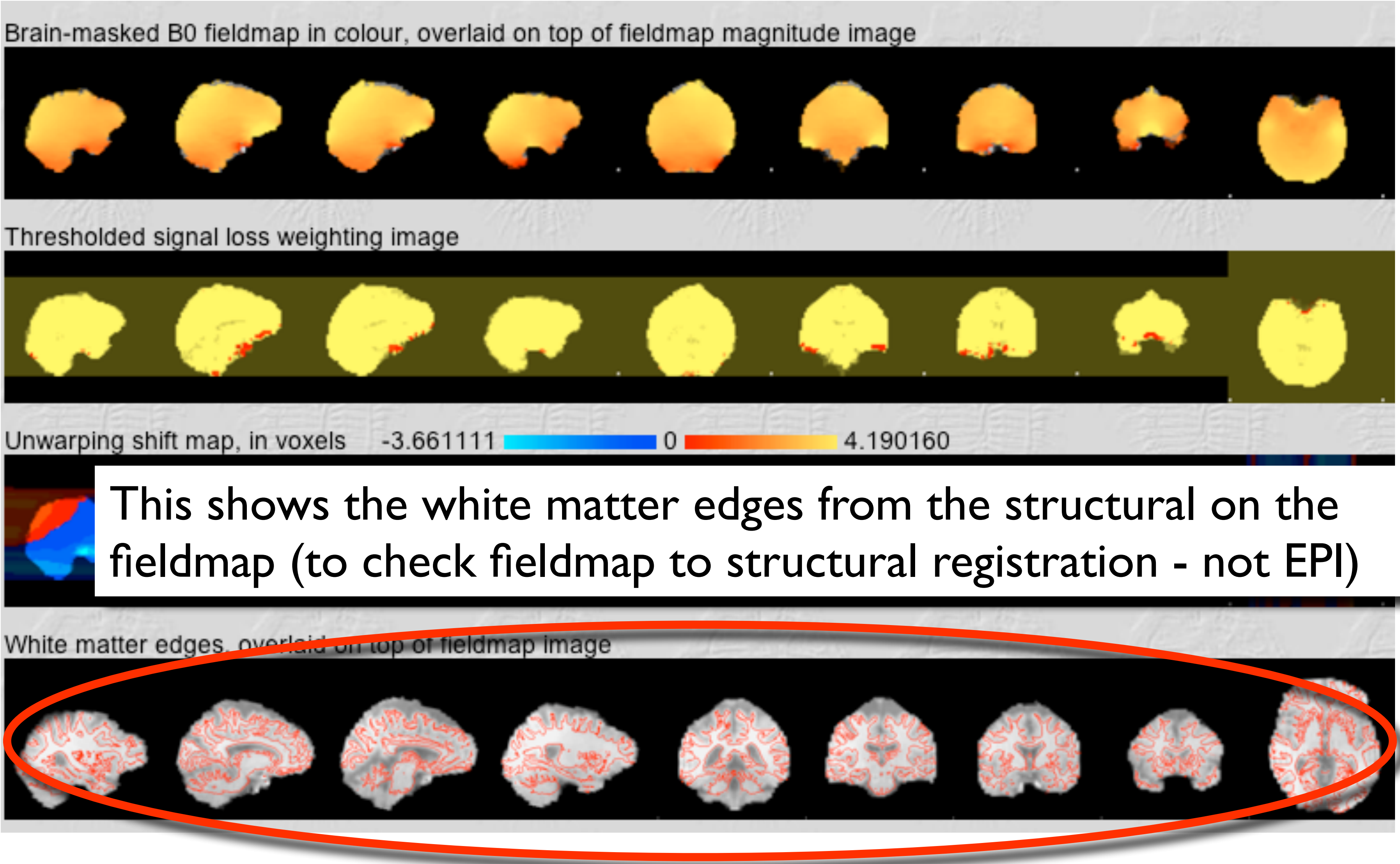
This should be mostly yellow - red voxels get *ignored* in the registration (lots of red is bad)

Fieldmap use in FEAT



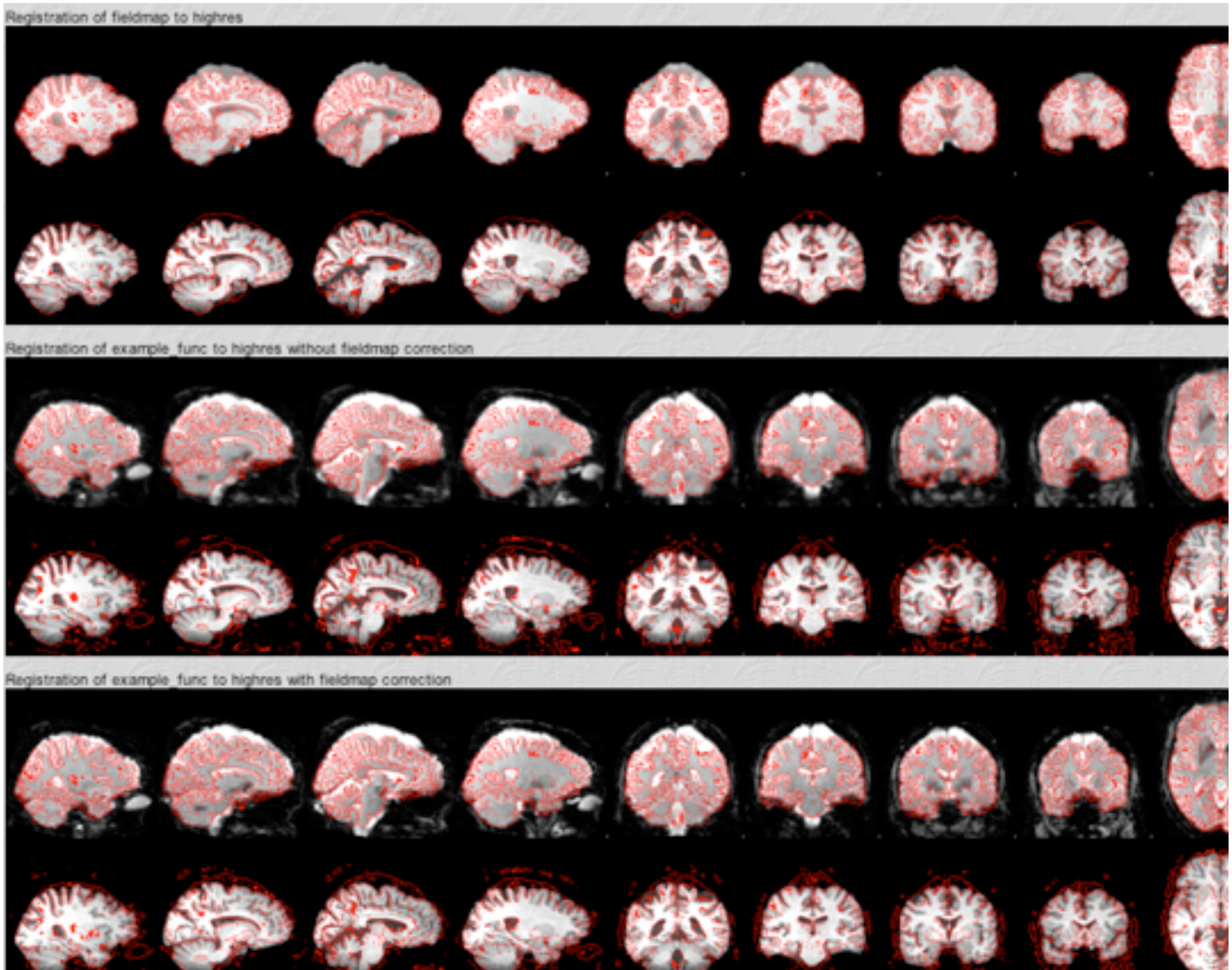
This shows how much each voxel moves - check that the range is sensible (anything from +/- 3 to +/- 20 is common)

Fieldmap use in FEAT



This shows the white matter edges from the structural on the fieldmap (to check fieldmap to structural registration - not EPI)

Fieldmap use in FEAT

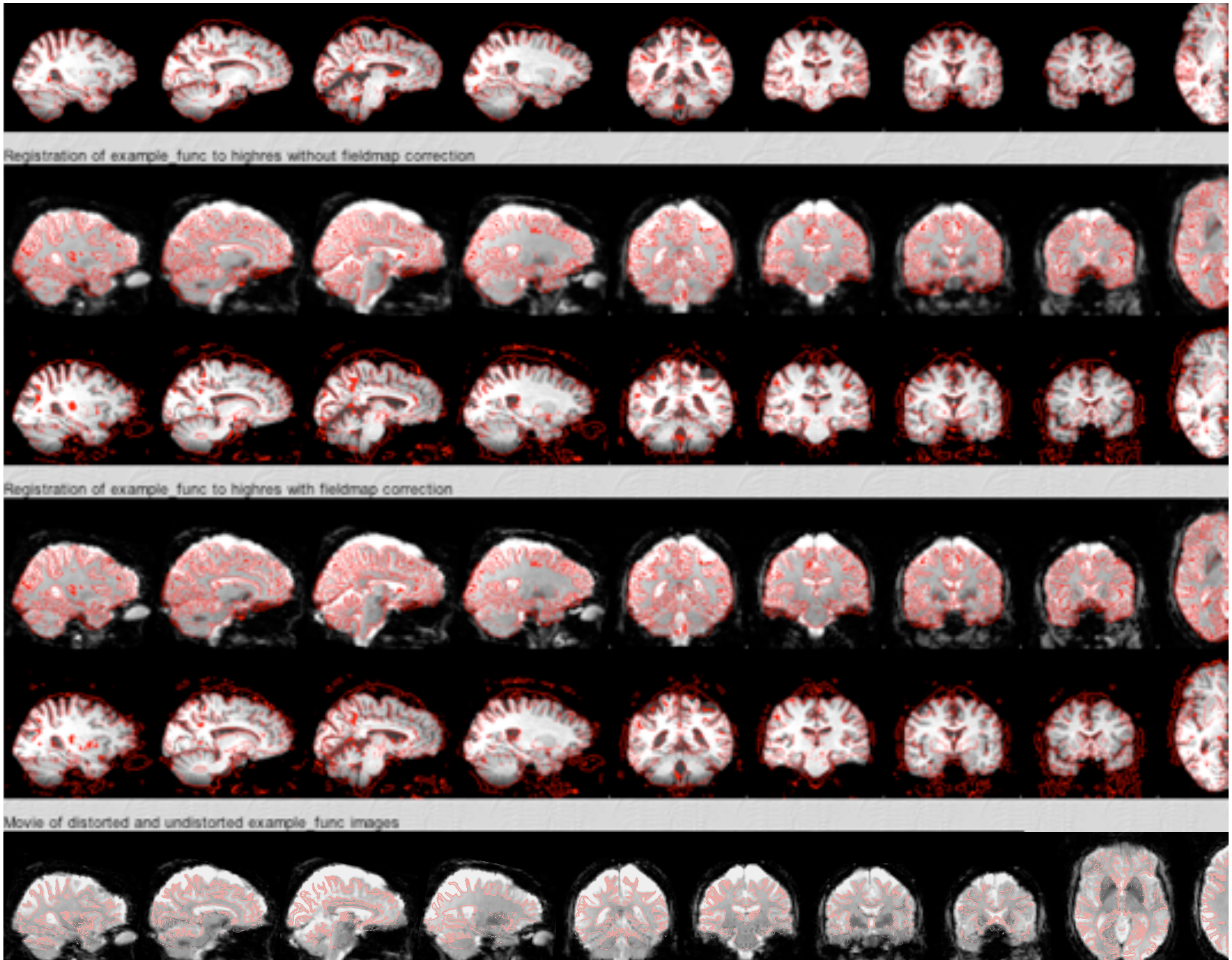


Fieldmap to highres (structural)

Functional (EPI) to highres (structural) - no correction

Functional (EPI) to highres (structural) - with fieldmap correction

Fieldmap use in FEAT



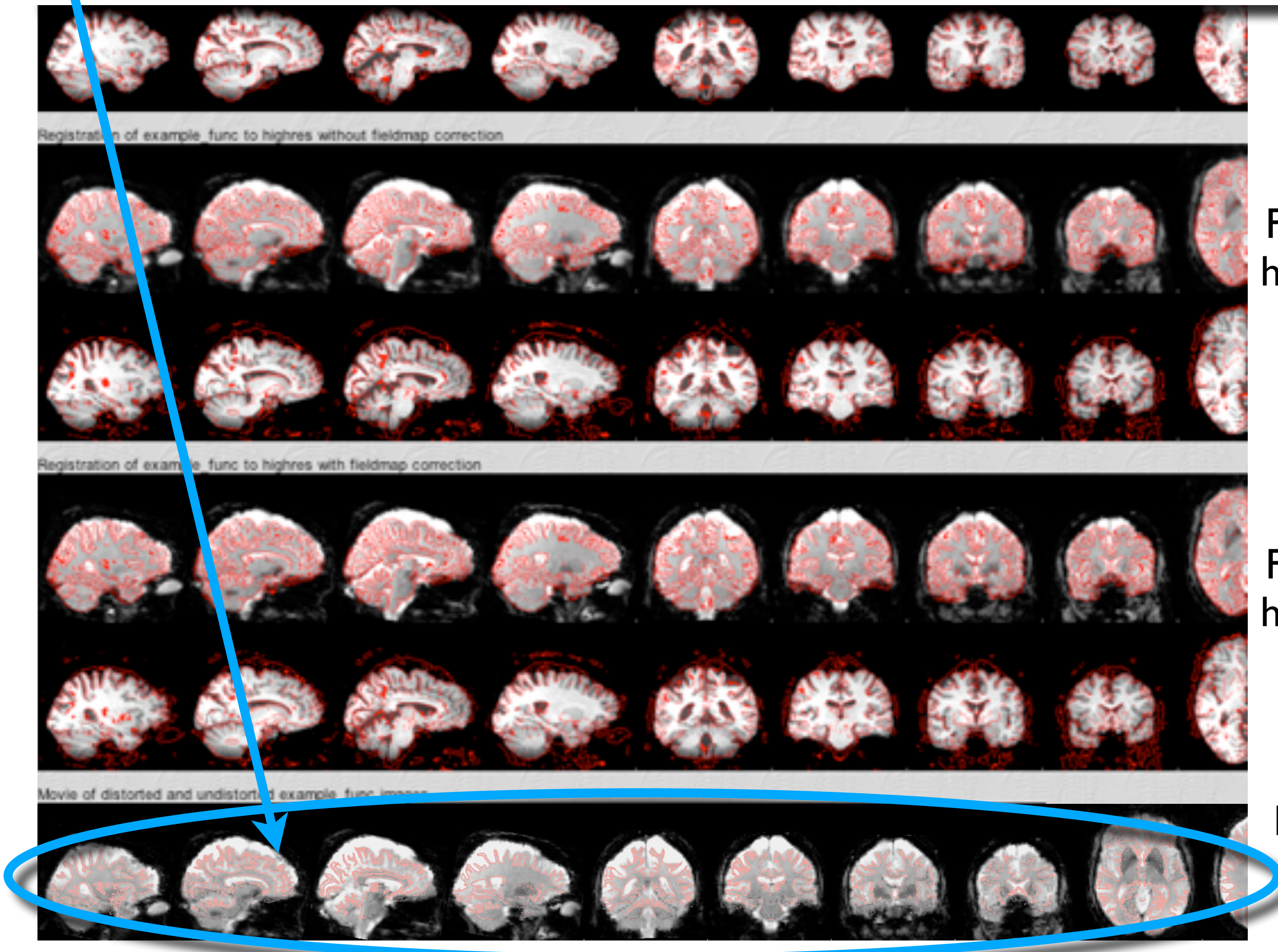
Functional (EPI) to highres (structural) - no correction

Functional (EPI) to highres (structural) - with fieldmap correction

Movie of EPI with and without correction

Fieldmap use in FEAT

Look for areas where unwarping (correction) changes brain shape



Functional (EPI) to highres (structural) - no correction

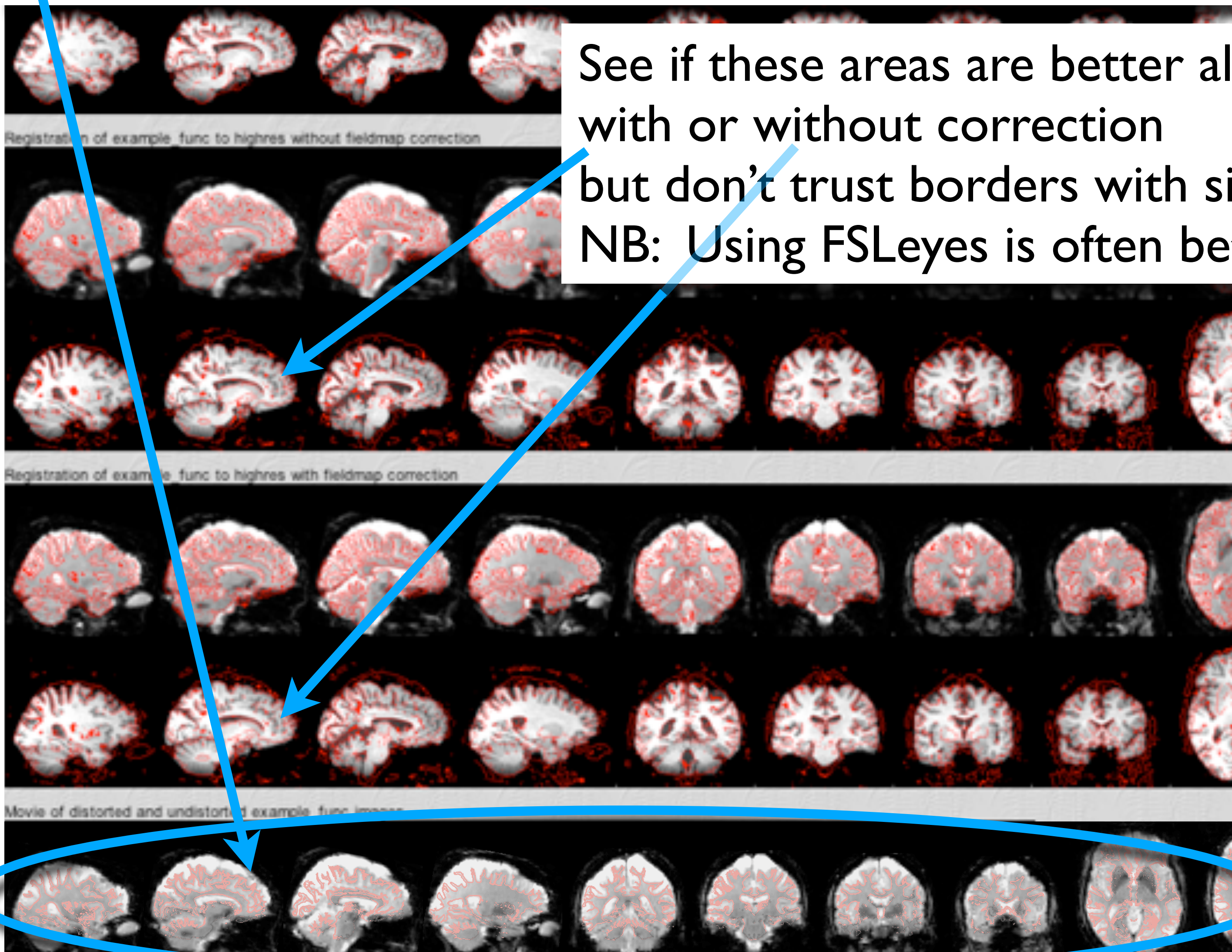
Functional (EPI) to highres (structural) - with fieldmap correction

Movie of EPI with and without correction

Fieldmap use in FEAT

Look for areas where unwarping (correction) changes brain shape

See if these areas are better aligned
with or without correction
but don't trust borders with signal loss areas
NB: Using FSLeyes is often better



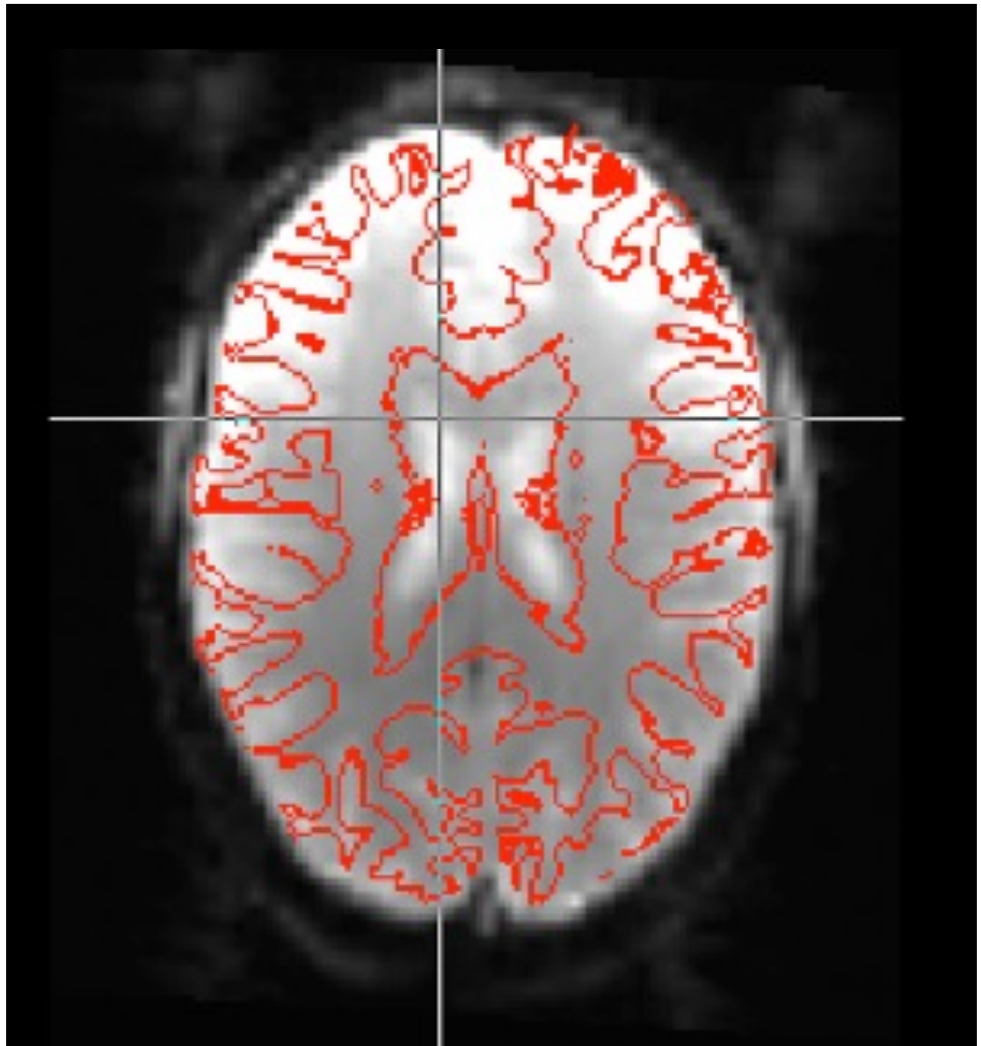
- with fieldmap
correction

Functional (EPI) to
highres (structural)
- no correction

Movie of EPI with
and without
correction

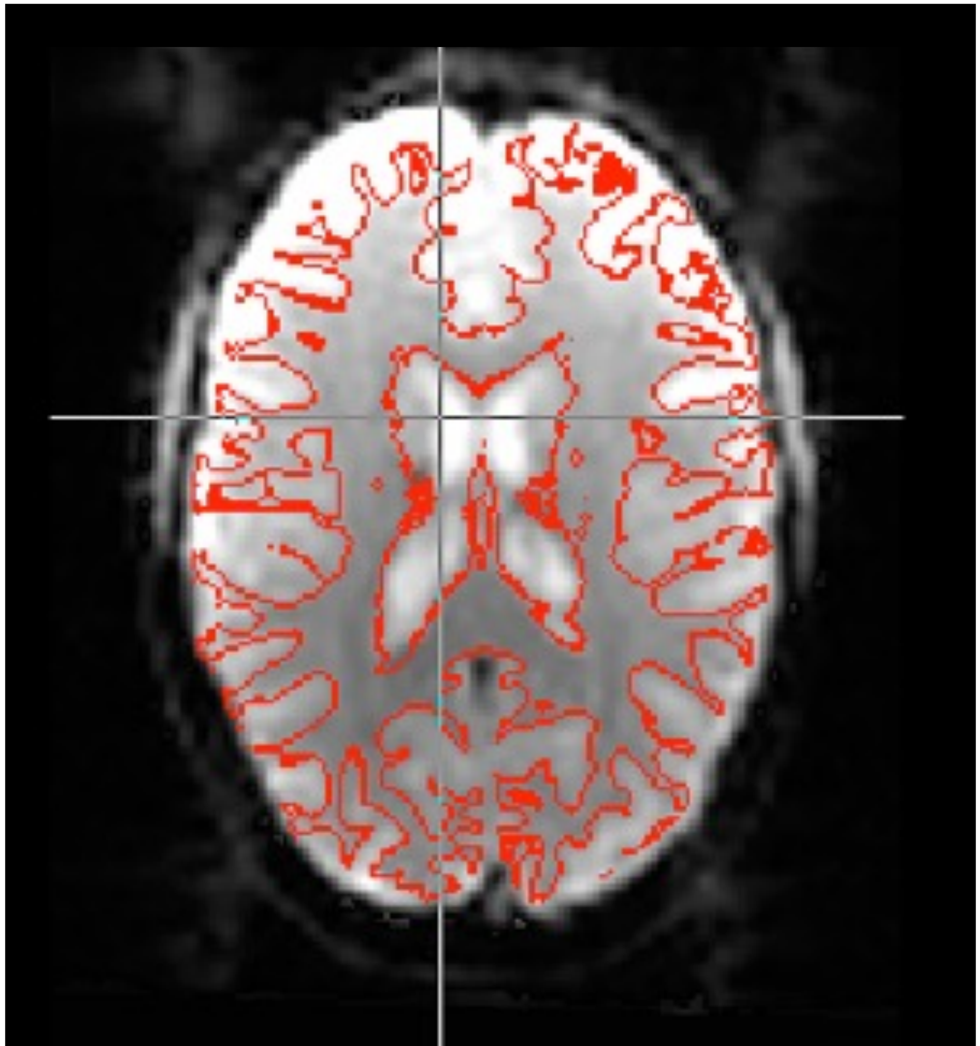
BBR and Fieldmaps

Standard FLIRT



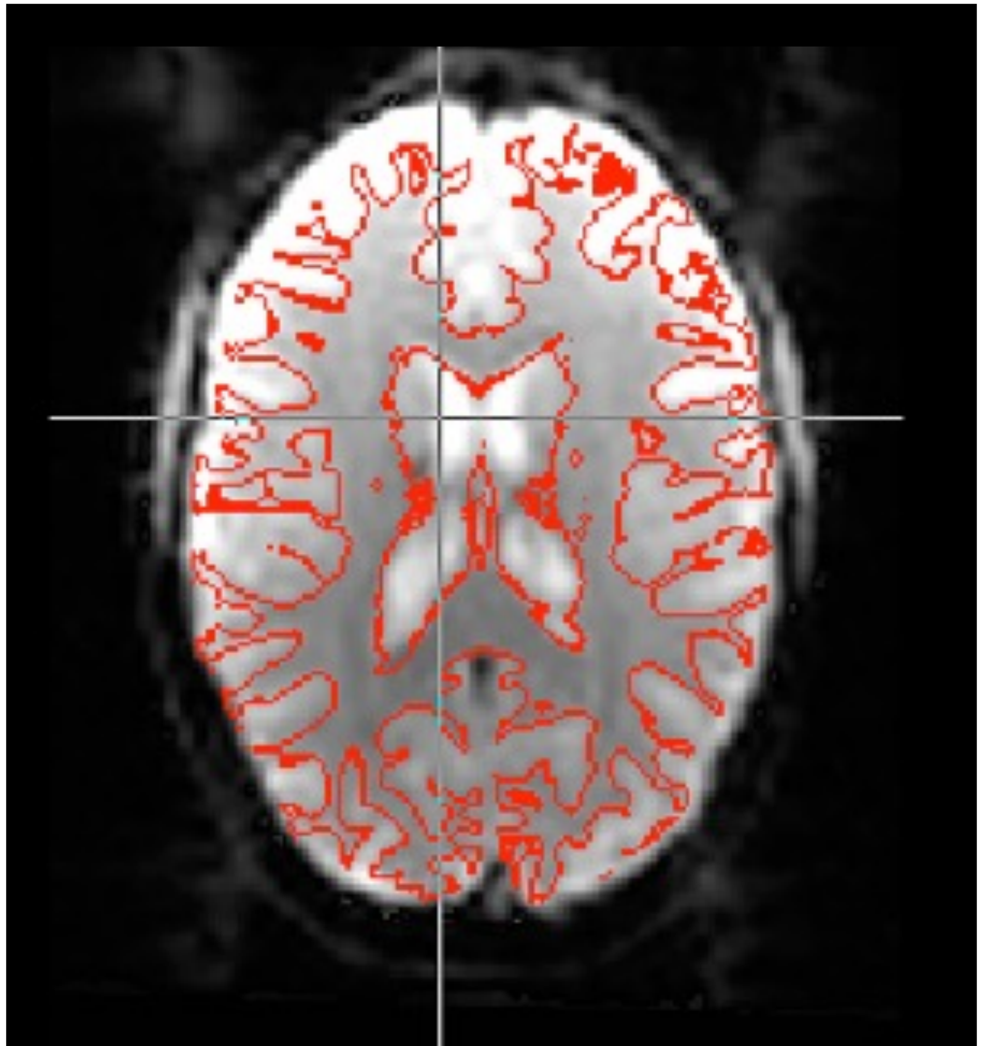
BBR and Fieldmaps

BBR FLIRT



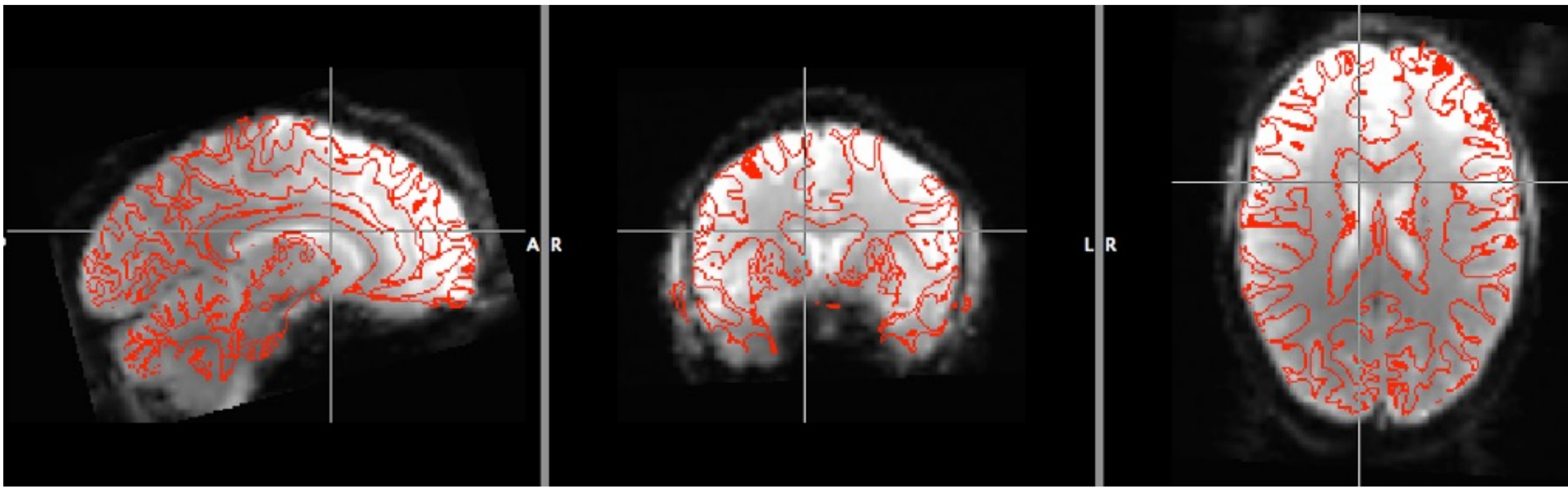
BBR and Fieldmaps

BBR FLIRT with Fieldmap



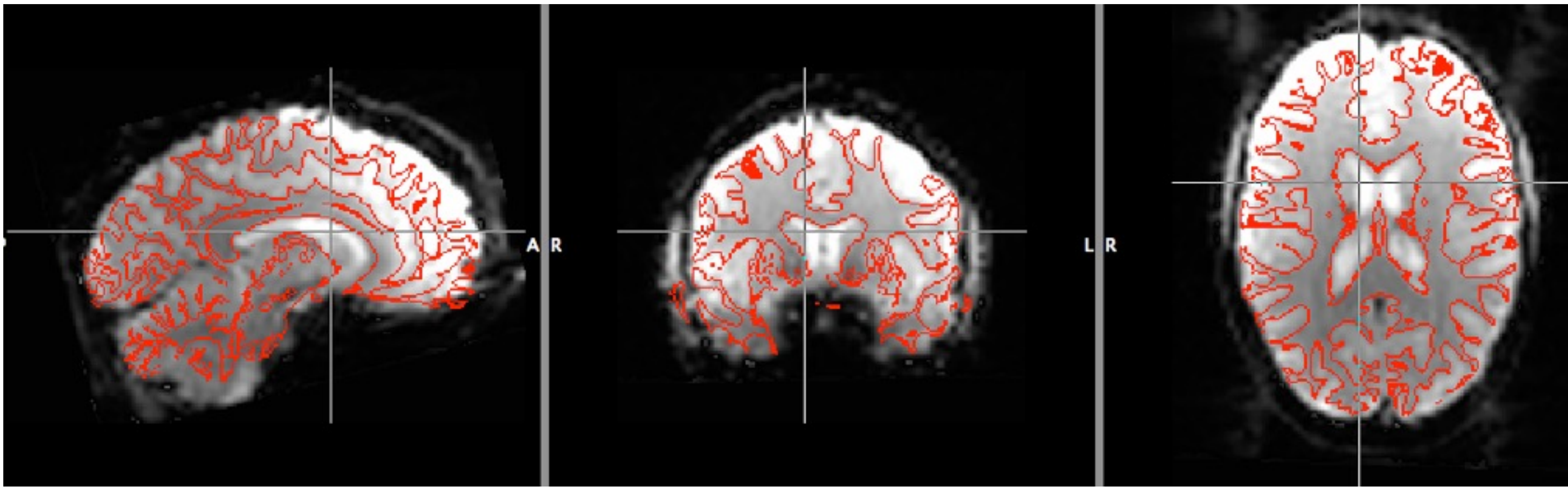
BBR and Fieldmaps

Standard FLIRT



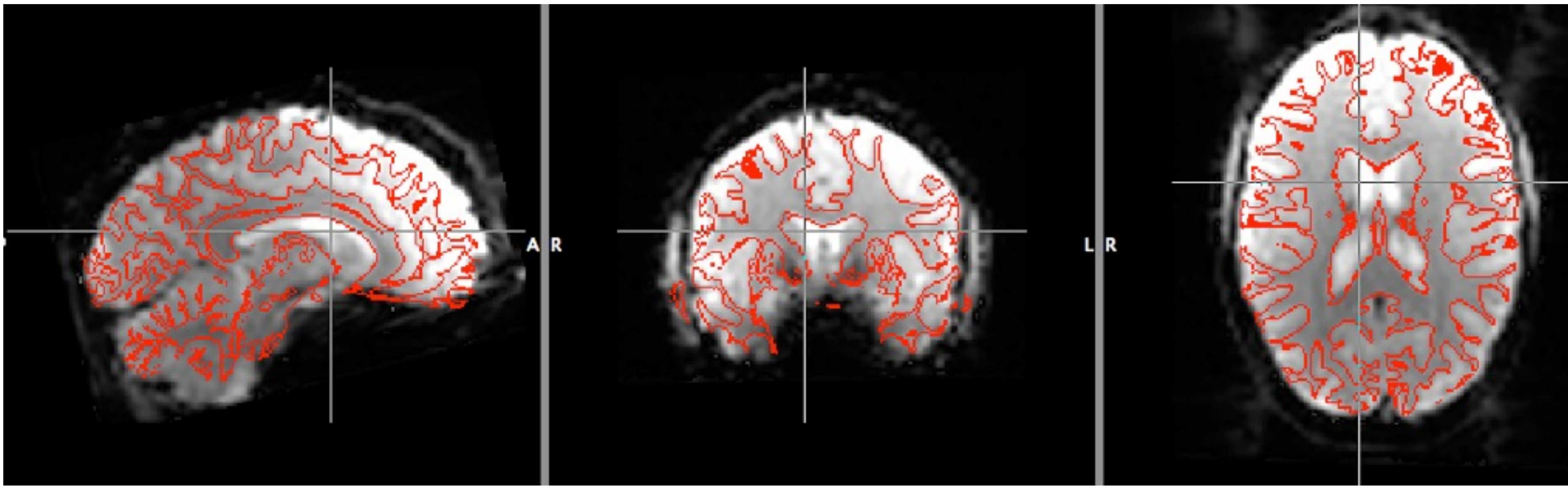
BBR and Fieldmaps

BBR FLIRT



BBR and Fieldmaps

BBR FLIRT with Fieldmap

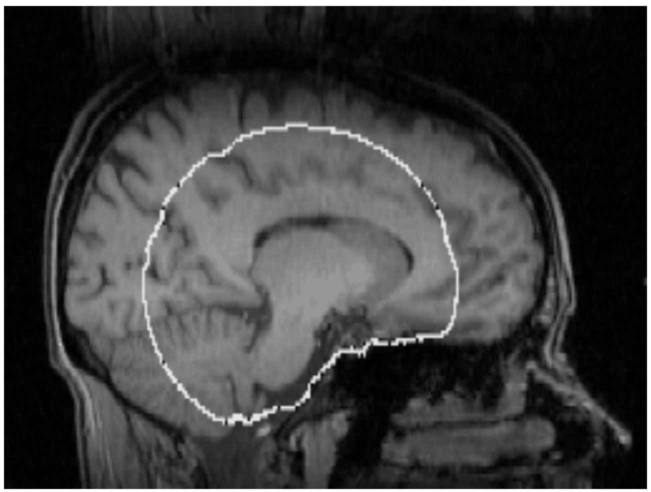
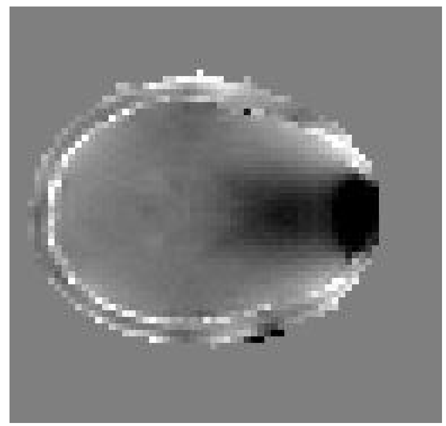


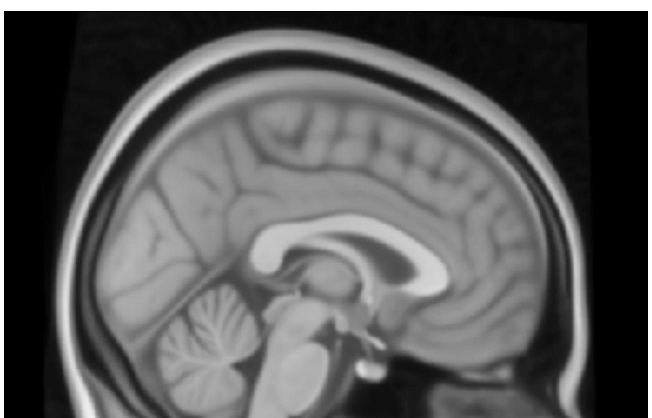
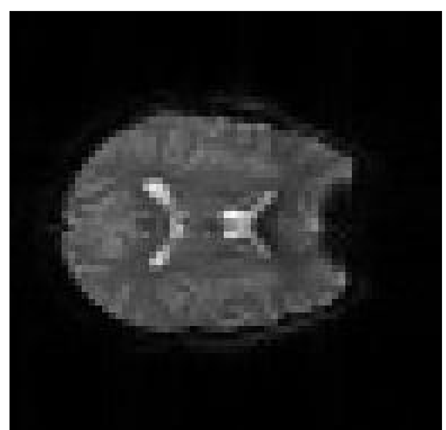
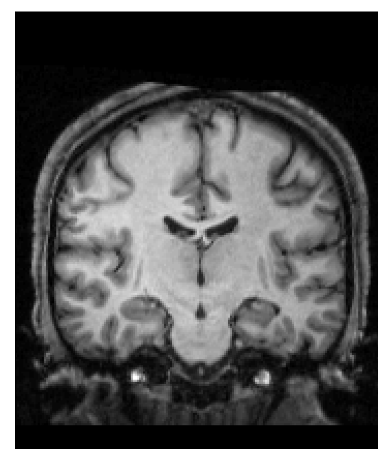
Registration: EPI Distortion Correction and Registration

Summary:

- Geometric distortions and signal dropouts affect fMRI acquisitions (using EPI)
- We can correct for geometric distortions and take account of signal loss using fieldmaps
- BBR is the cost function used for EPI-structural registration with fieldmaps
- Look at results in typical areas of distortion (inferior frontal and temporal lobes)

Registration: Cost Function Weighting and Small FOV

Pathological Image Registration

Scenario:

Have images containing a known pathology (or artefact) which looks different in different images

For example, some sequences (e.g. FLAIR) highlight lesions that are hard to see in other sequences

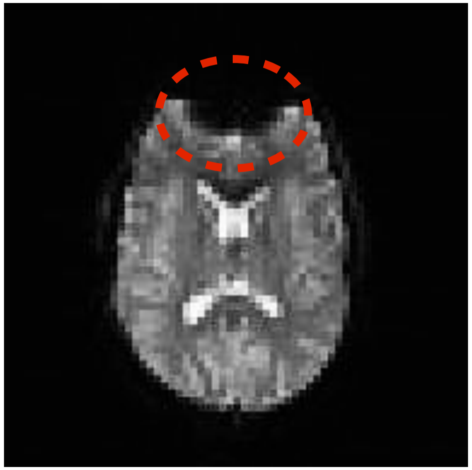
Objective:

Align the images based on the healthy tissue, but “ignoring” the area of the pathology (or artefact)

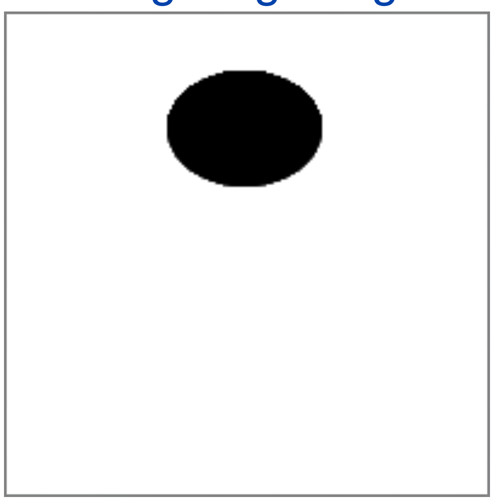
Solution:

Cost-Function Weighting (FLIRT or FNIRT)

Cost Function Weighting



weighting image



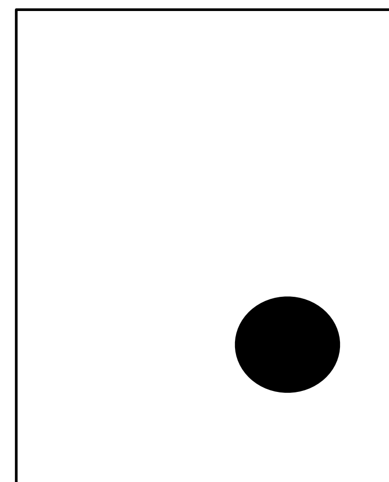
black=0; white=1

Artefacts and pathologies introduce *non-matching* image regions

Cost (similarity) functions assume that all of the images can be matched

Use a *weighting image* to down-weight non-matching regions

weighting image



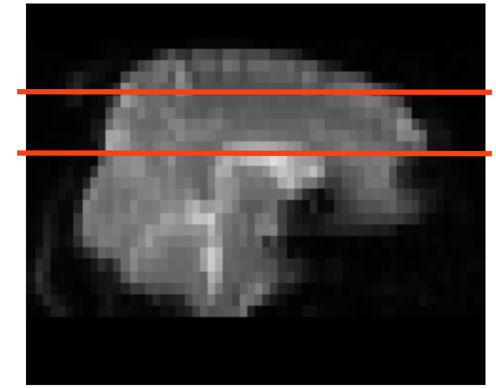
Cost Function Weighting

- *All* FLIRT & FNIRT cost functions can be weighted
- Weighting for reference image, input image or both
- Voxel weights are *relative*, reflecting its importance in overall matching
  - Zero, or small, values for corrupted areas

    e.g. gross pathology or artefact
  - Large values for important areas/regions

    e.g. ventricular matching
- Do *not* assign zero to the background as then the brain/background contrast is lost

Small FOV Registration



Scenario:

Functional study using a small FOV (e.g. a few slices)

Often done to obtain better resolution scans over ROI

Objective:

Get activation results registered well to the full brain (and standard space)

Solution:

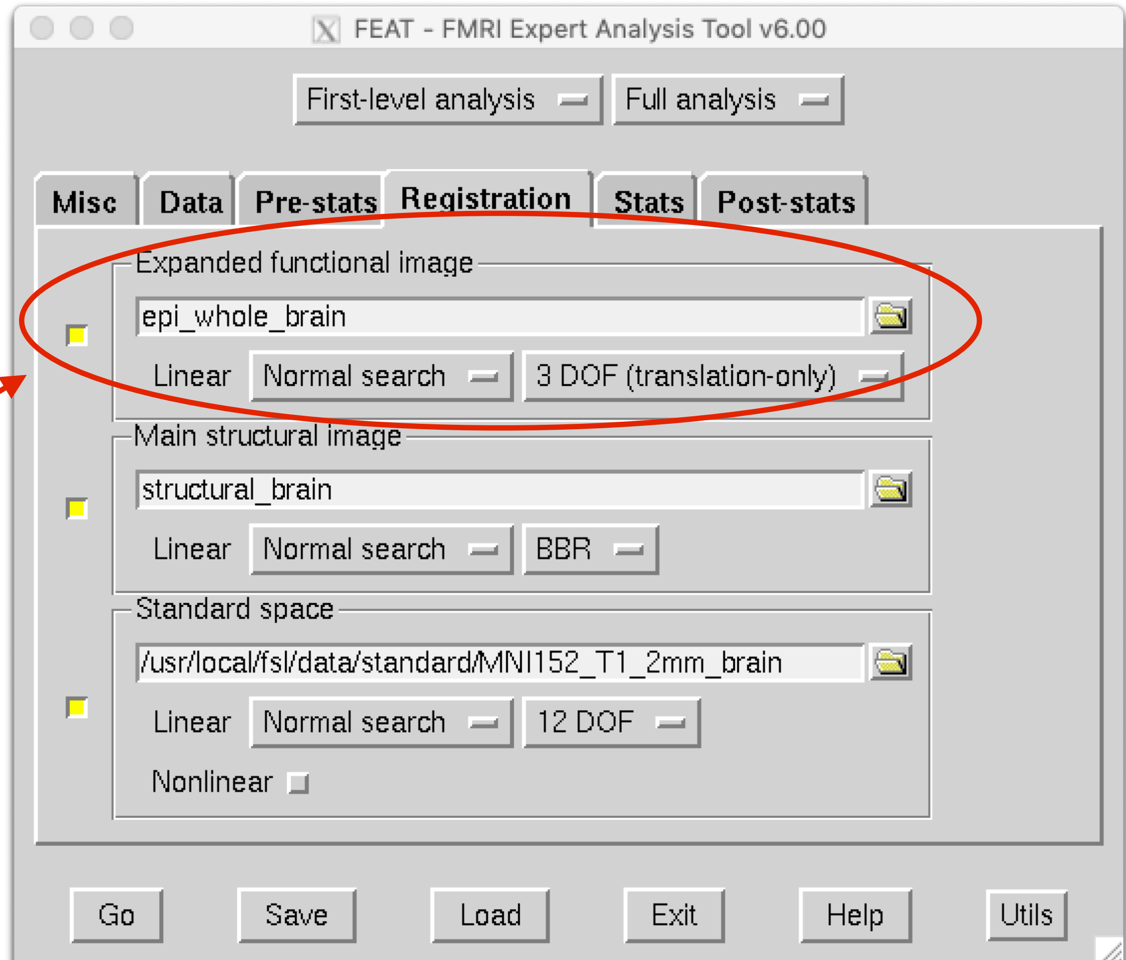
Scan one whole-brain EPI and use a 3-stage registration

Registration within FEAT (small FOV)

If your FMRI scans only cover part of the brain...

Acquire *one* ***whole-brain EPI*** volume: it only takes a few seconds to scan but makes registration work *much* better

Then use the 3-stage approach

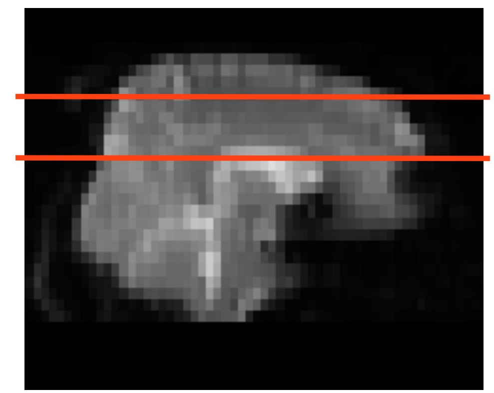


Partial Brain EPI & Unwarping

In partial FOV studies, registration is *massively* improved by multi-stage registration:

1. Partial Brain to Full Brain EPI
    - Desirable for full brain to contain exactly the same slices so that registration is simple (can be done without unwarping)
    - If slices are different or movement is significant, then unwarping should be applied (outside of FEAT)
2. Full Brain EPI to Structural
    - apply unwarping (full brain field map)
3. Structural to Standard

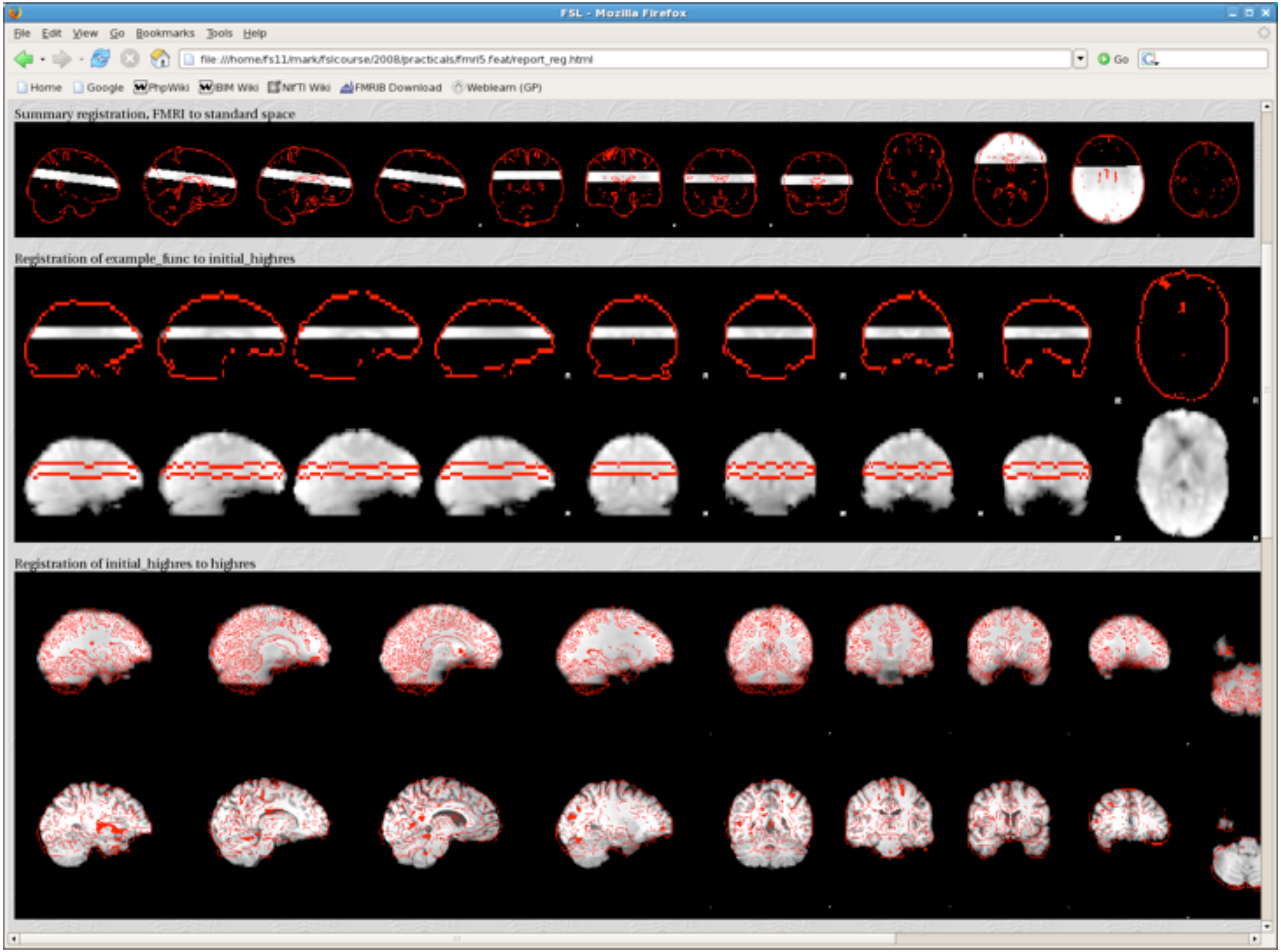
Partial Brain
FMRI timeseries



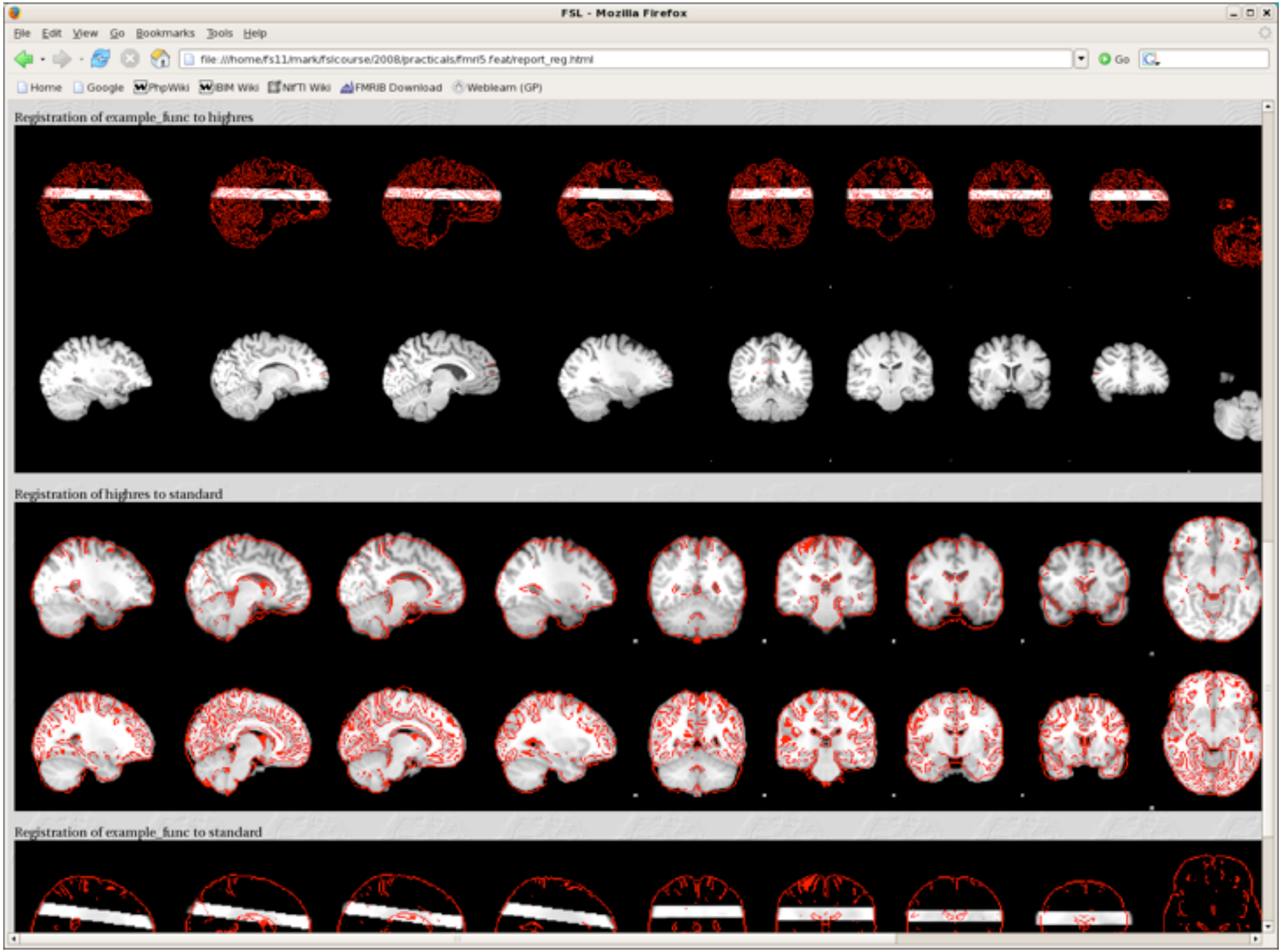
Full Brain
Single Image
(an extra acquisition - but only takes seconds!)

Can be run entirely within the FEAT GUI

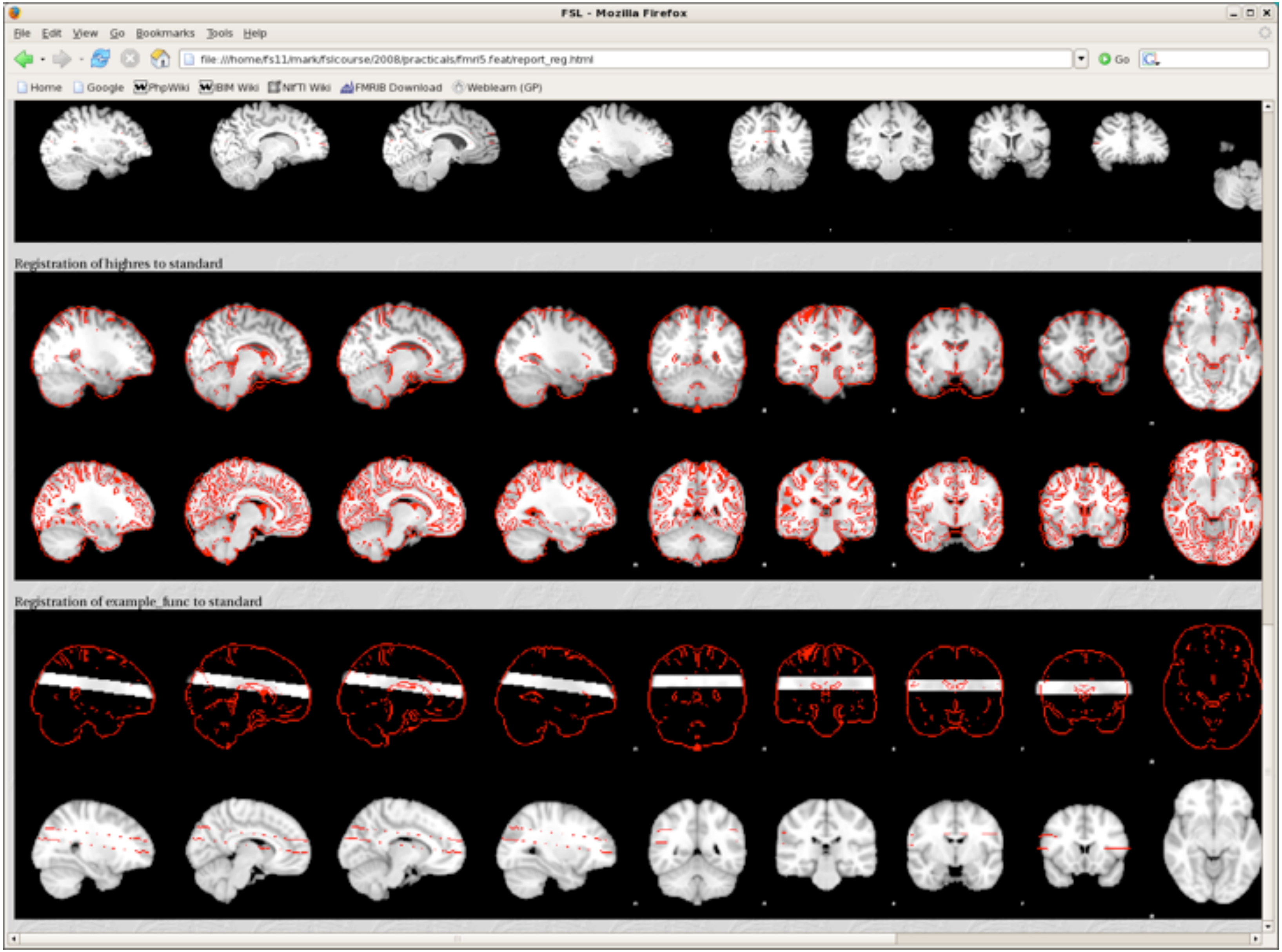
Registration within FEAT (small FOV)



Registration within FEAT (small FOV)



Registration within FEAT (small FOV)



Troubleshooting Registrations

- *Check the images:* voxel sizes, artefacts, large bias field
- *Check the brain extraction:* look for large/consistent errors
- *For EPI:* acquire and use fieldmap to unwarp distortion
- *For FMRI or diffusion:* use multi-stage registration (e.g. via GUIs) with a structural image for best results
- *If pathologies/artefacts exist:* use cost-function deweighting
- *If images are nearly aligned:* try limiting the search
- *For FLIRT:* can try different cost functions
- *For FNIRT:* check initial affine alignment is OK
- *For small FOV:* acquire whole-brain EPI for multi-stage reg