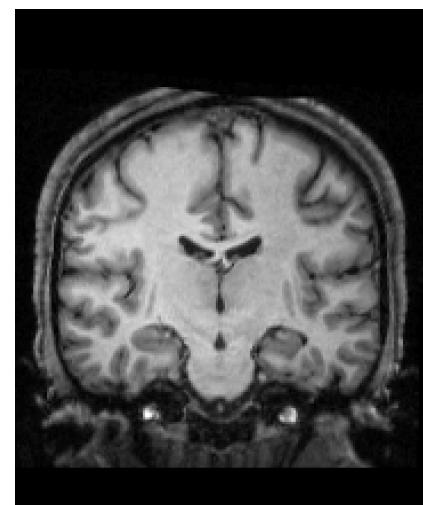
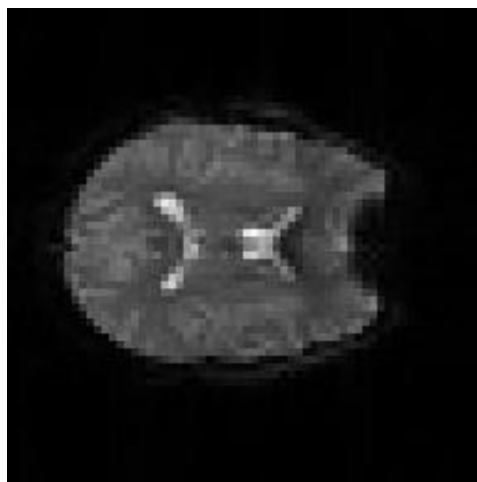
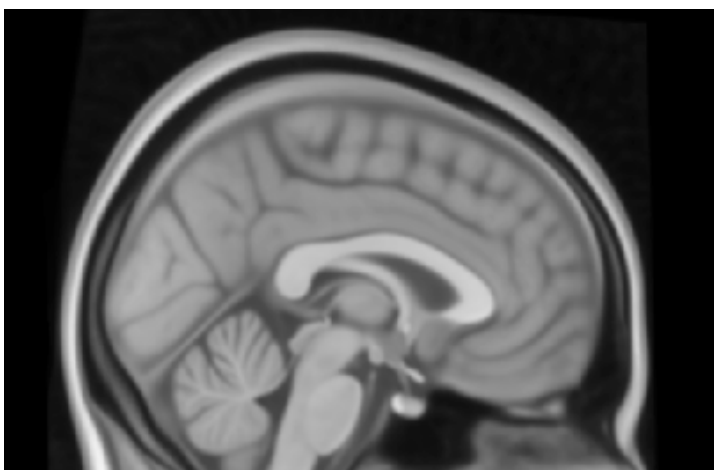
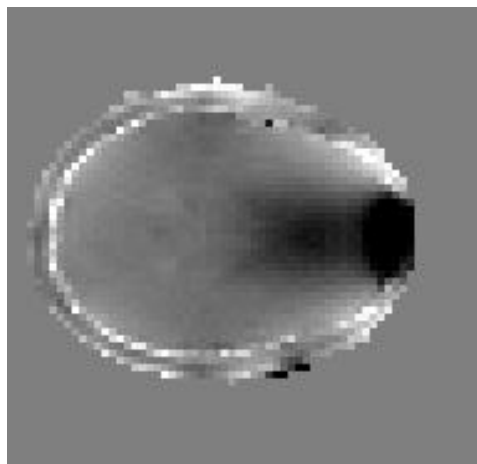
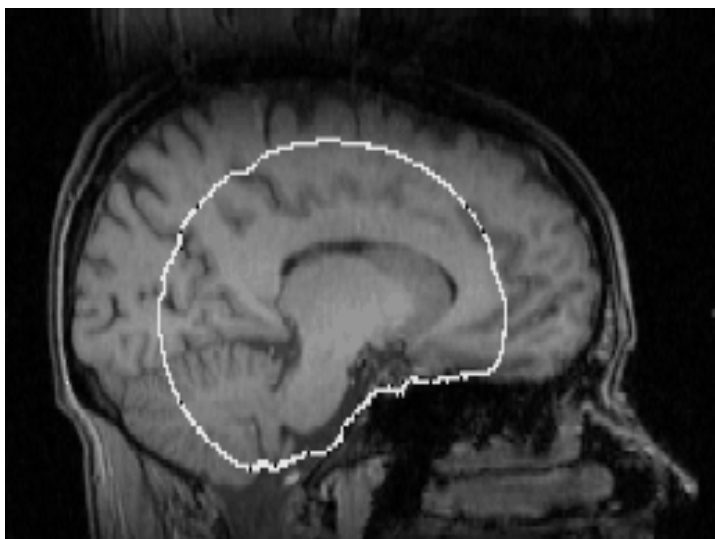


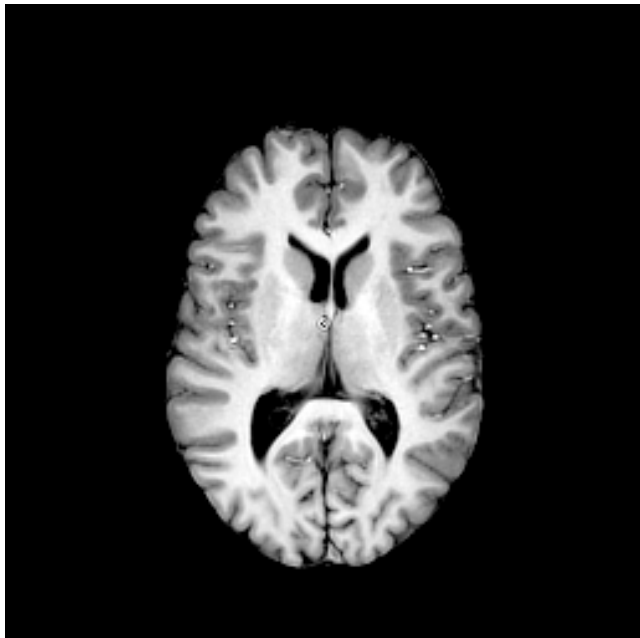
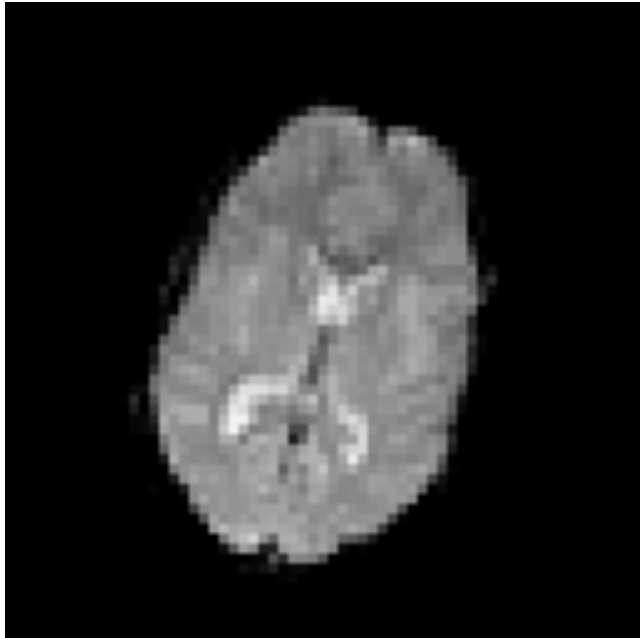


Registration: Cost Functions, Interpolation and Masks





Basic Registration Concepts

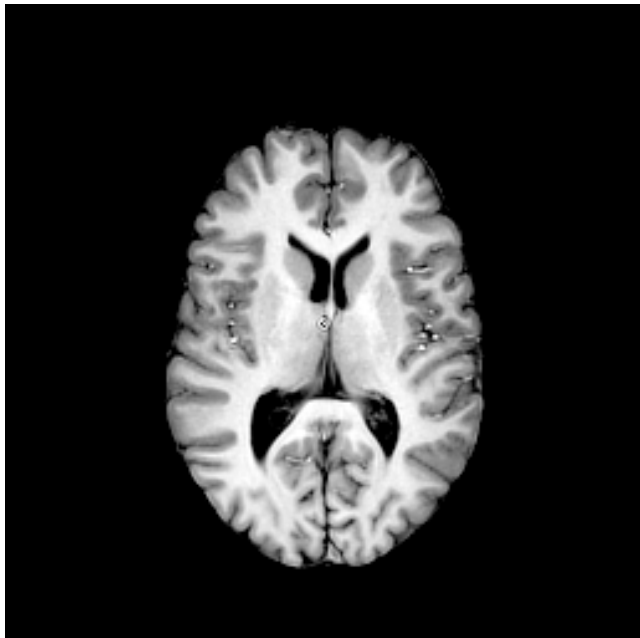
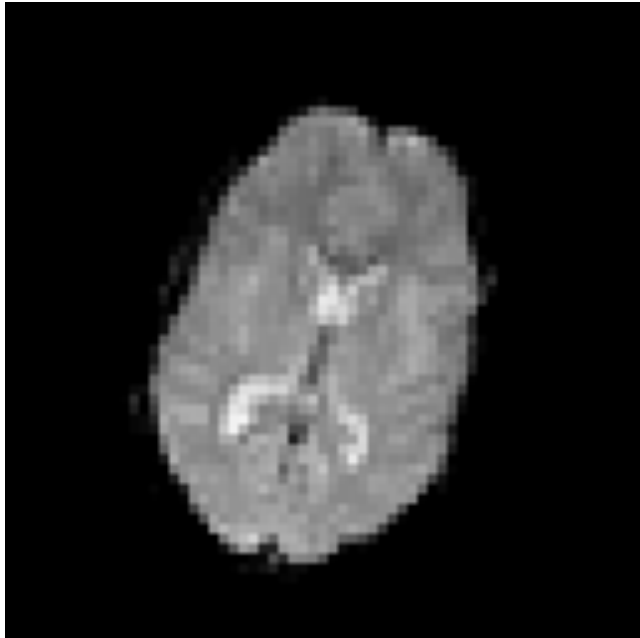


Need to understand:

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



Basic Registration Concepts



Need to understand:

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

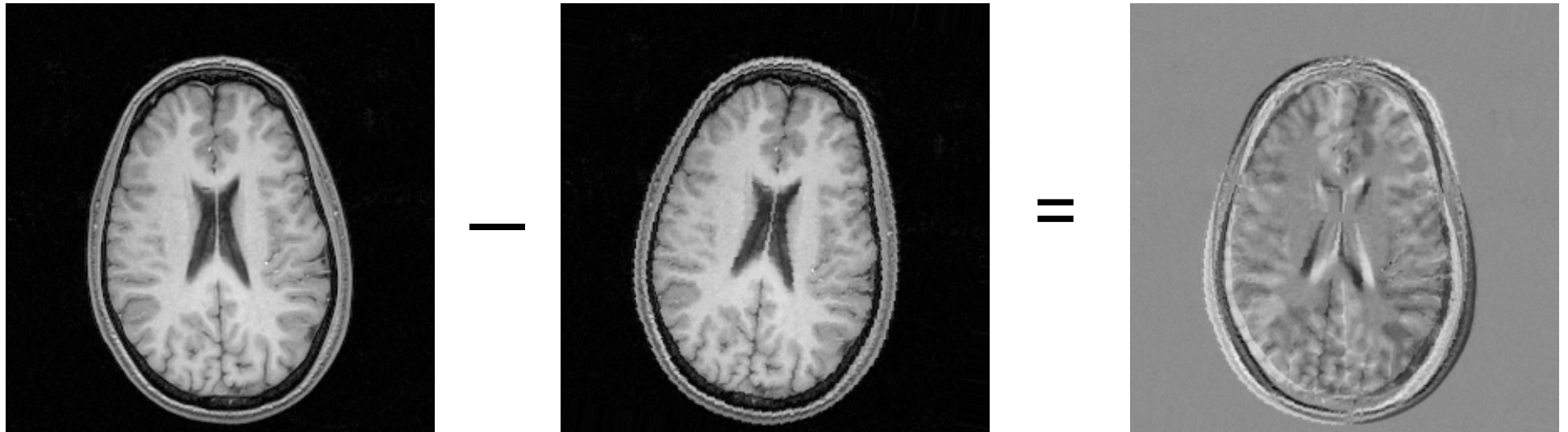


Cost Function

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	<i>Same modality</i> (exact sequence parameters)
Normalised Correlation	<i>Same modality</i> (can change brightness & contrast)
Correlation Ratio	<i>Any MR modalities</i>
Mutual Information	<i>Any modalities</i> (including CT, PET, etc.)
Normalised Mutual Info.	<i>Any modalities</i> (including CT, PET, etc.)
BBR	<i>Within-subject EPI to structural</i> (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

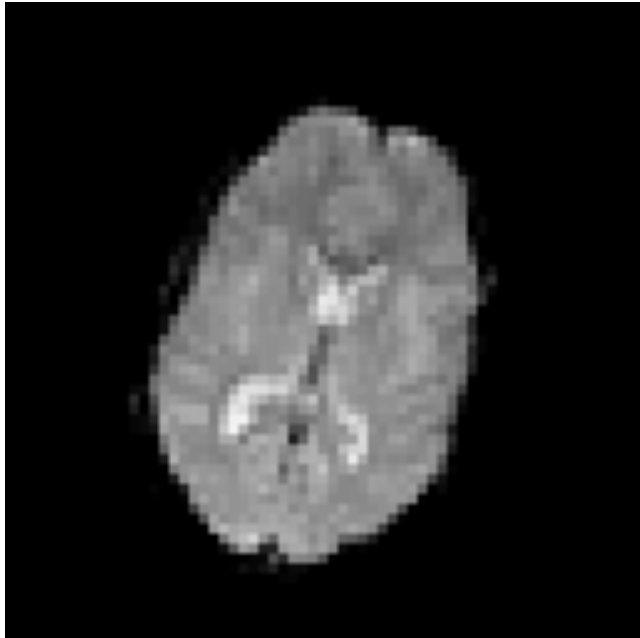


With RF modelling





Basic Registration Concepts



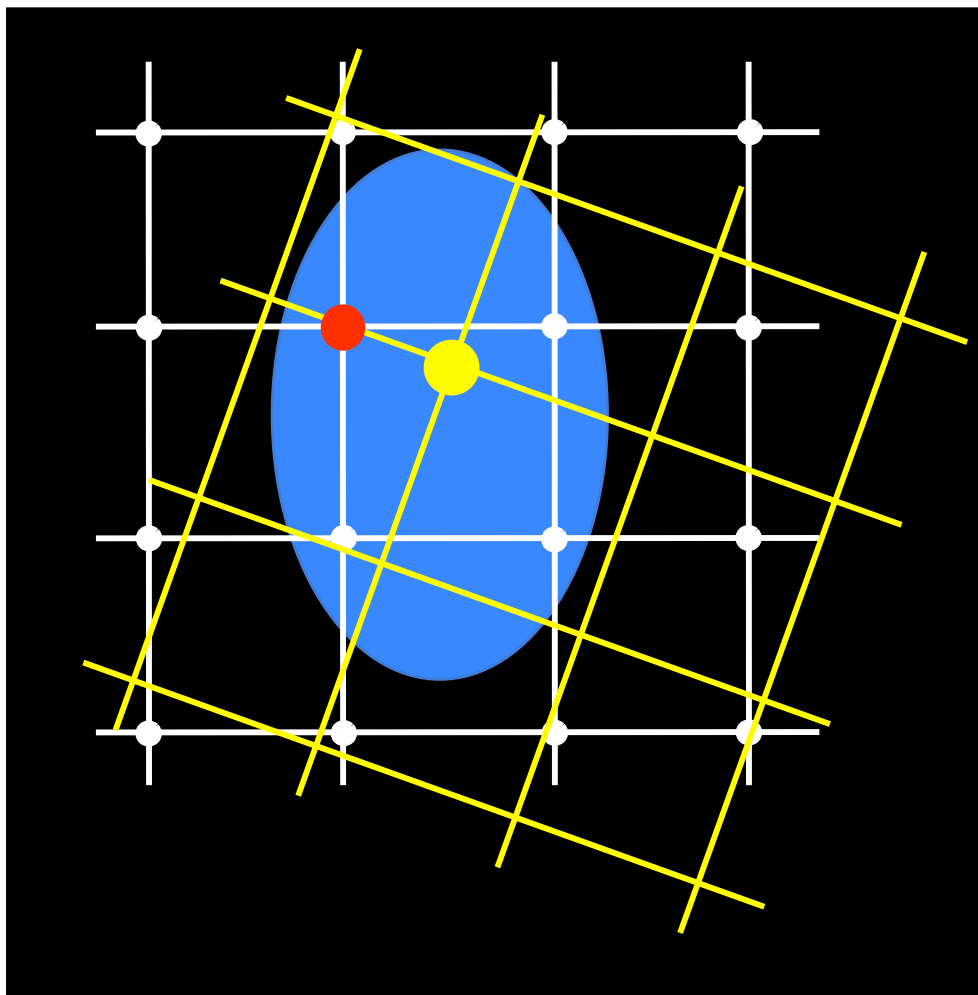
Need to understand:

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



Interpolation

Finds intensity values between grid points



Various types include

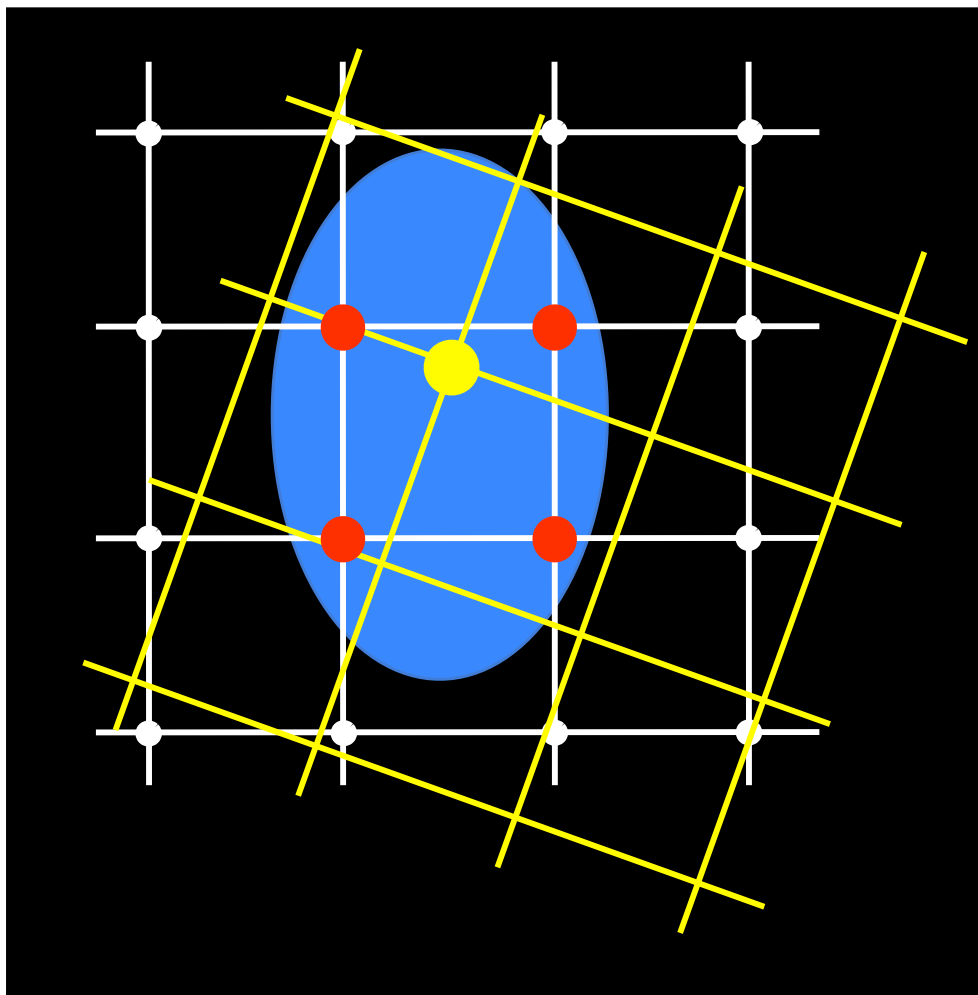
- Nearest Neighbour
- Trilinear
- Spline
- Sinc
- k-Space methods

Fast, but blocky - can be used for discrete labels



Interpolation

Finds intensity values between grid points



Various types include

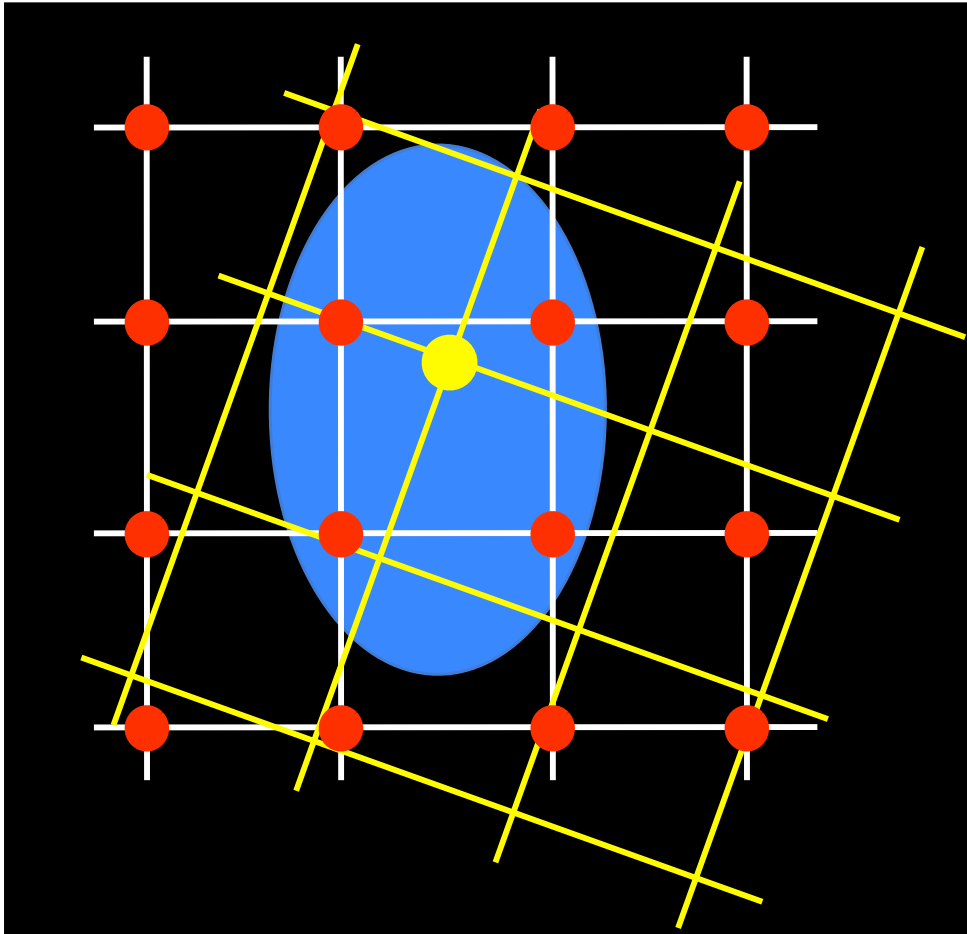
- Nearest Neighbour
- **Trilinear**
- Spline
- Sinc
- k-Space methods

Fast, with some blurring - most common option



Interpolation

Finds intensity values between grid points



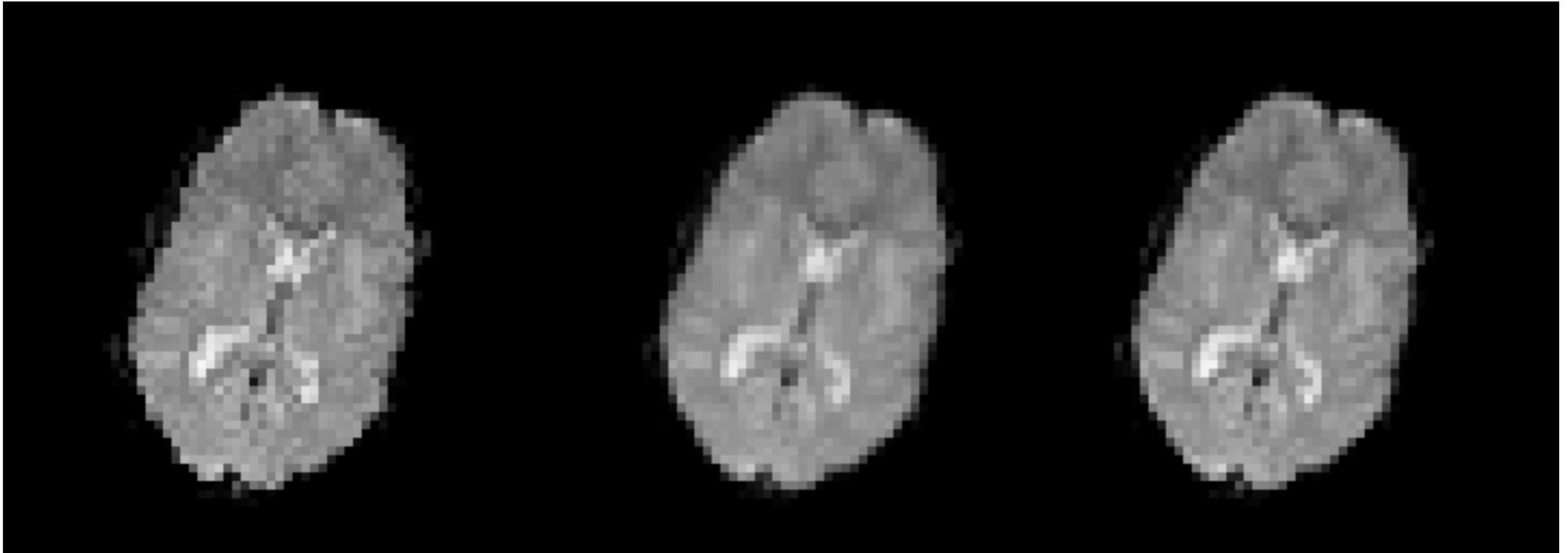
Various types include

- 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

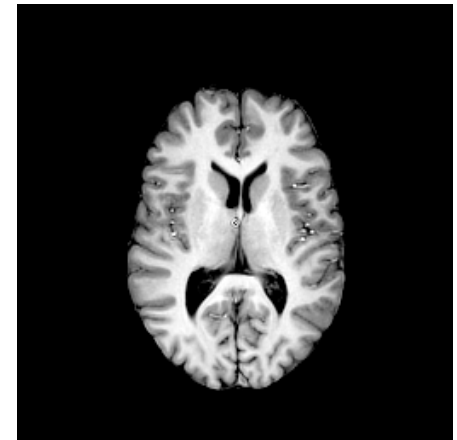
Important for *quantitative imaging*

Can affect size of artefacts

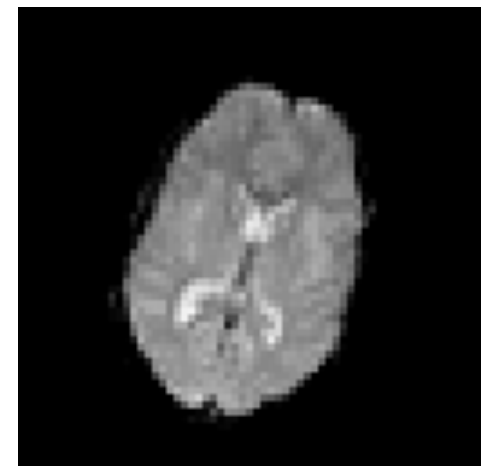


Applying Transformations

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



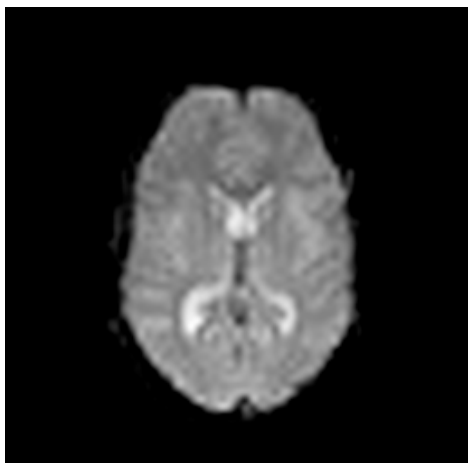
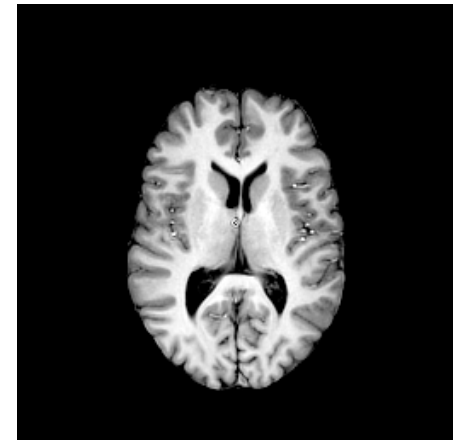
transformation





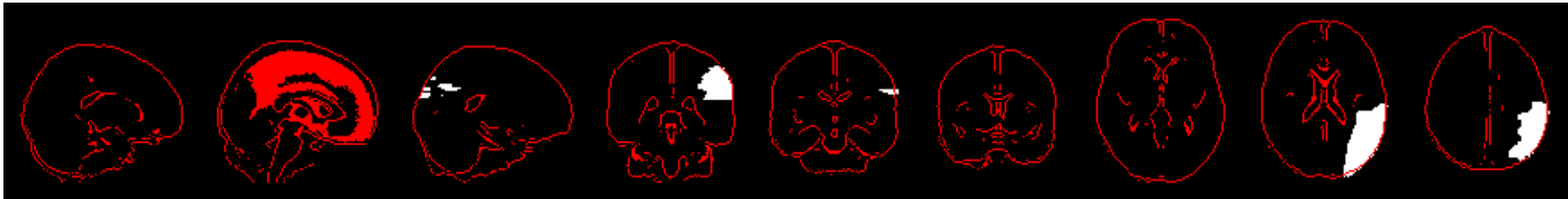
Applying Transformations

- 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 \implies 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)

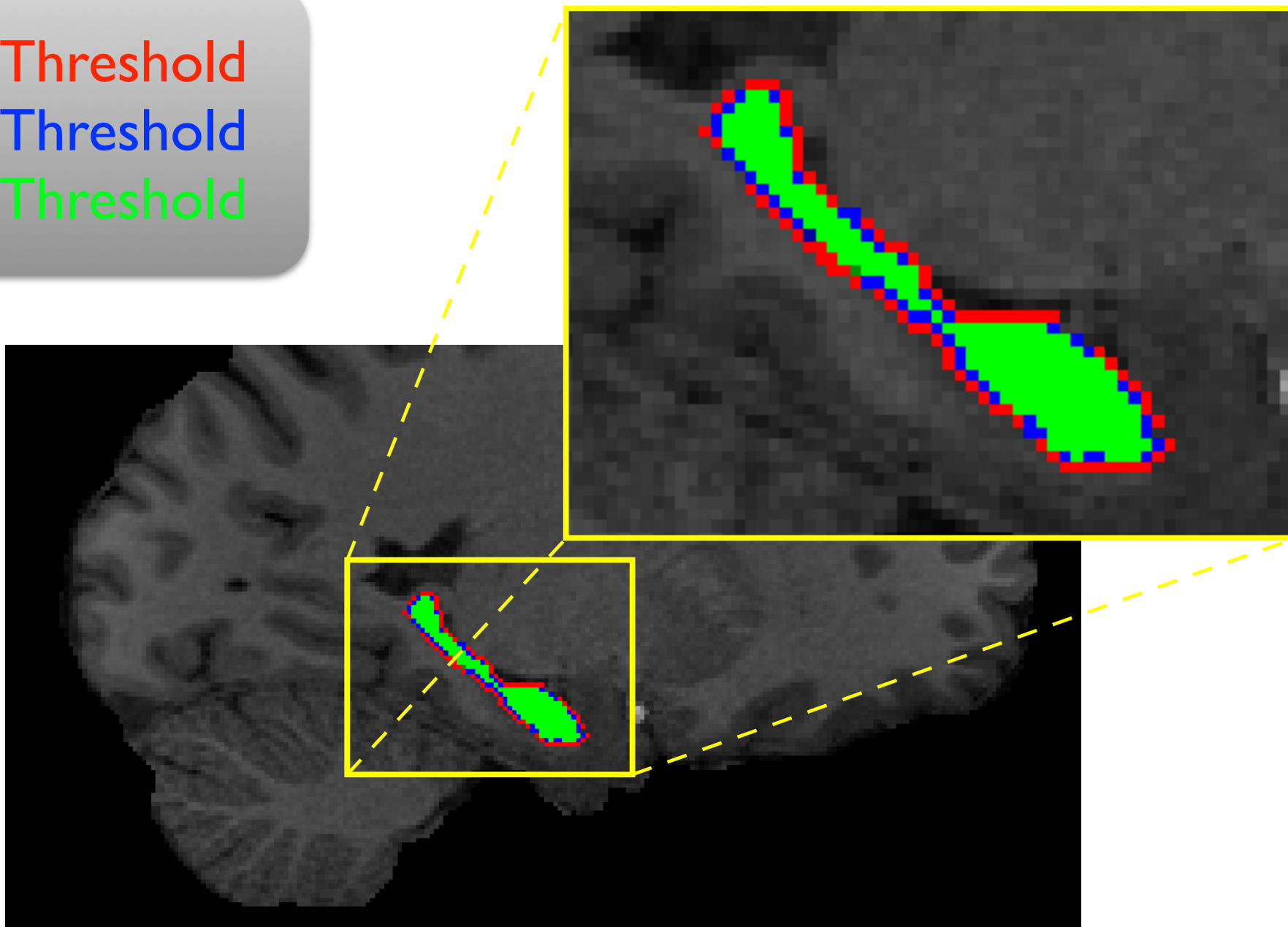


Transforming Masks

0.1 Threshold

0.5 Threshold

0.9 Threshold





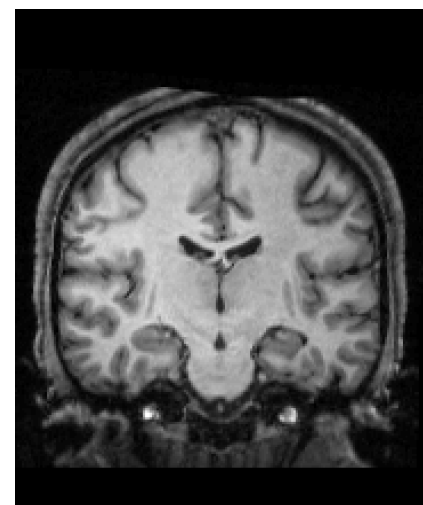
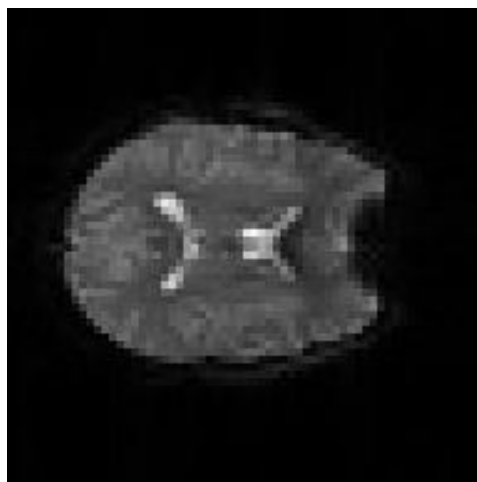
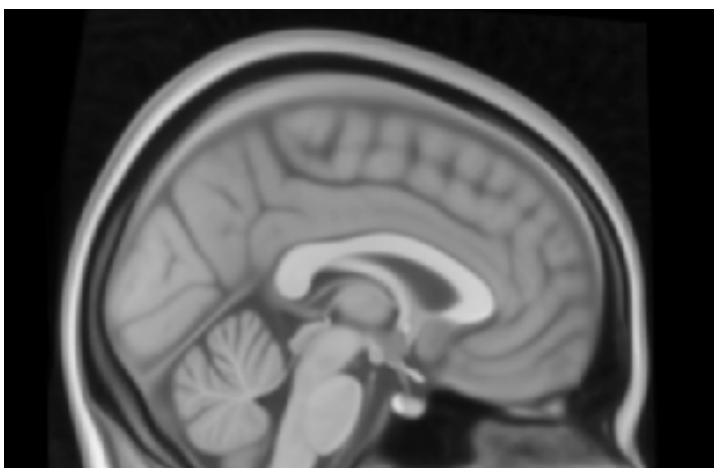
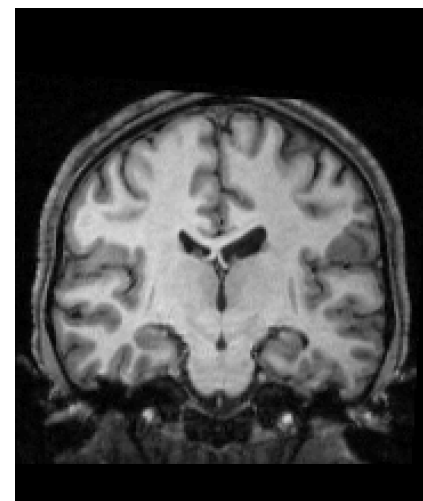
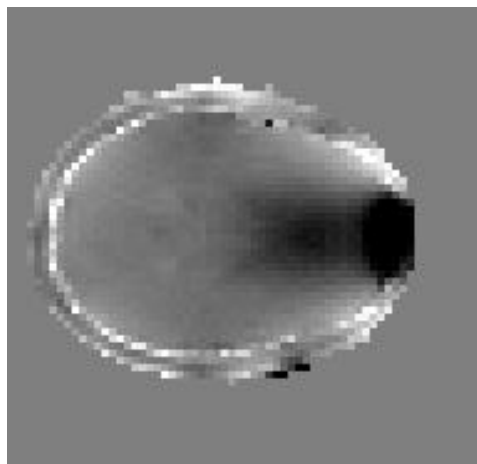
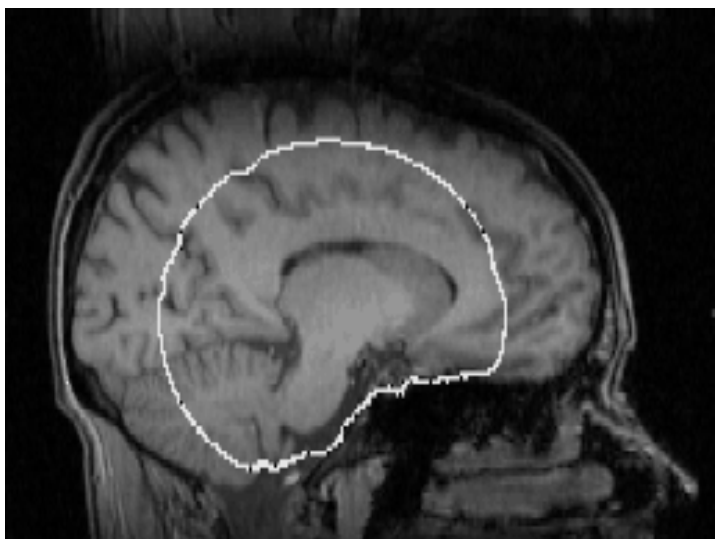
Registration: Cost Functions, Interpolation and Masks

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



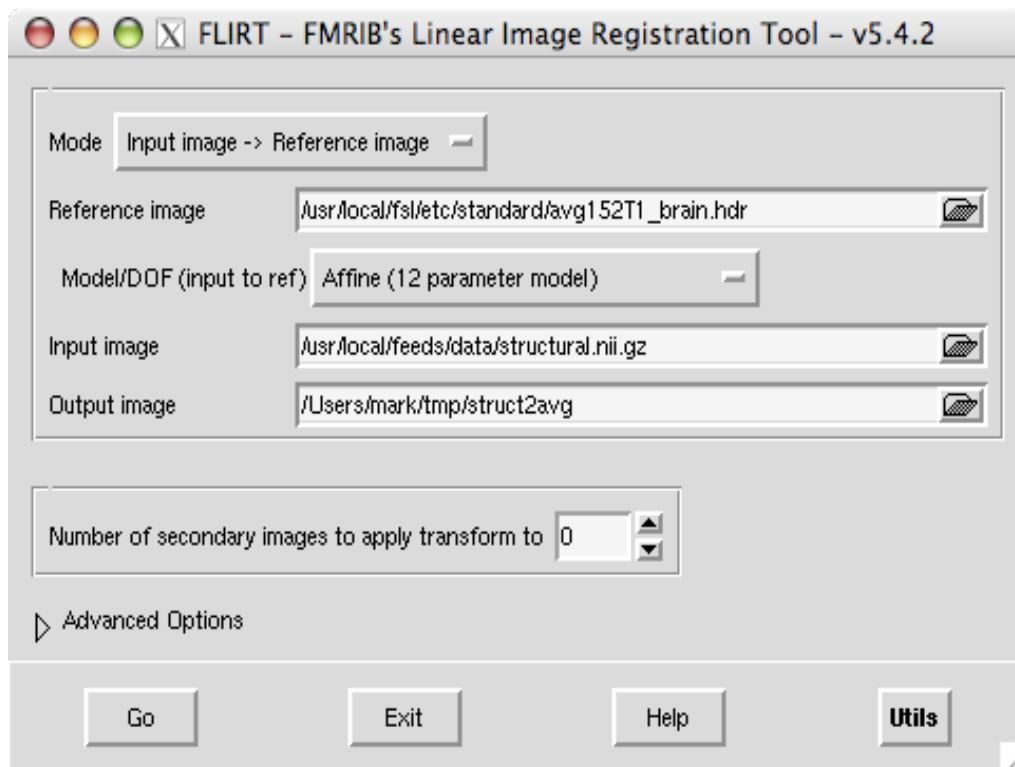
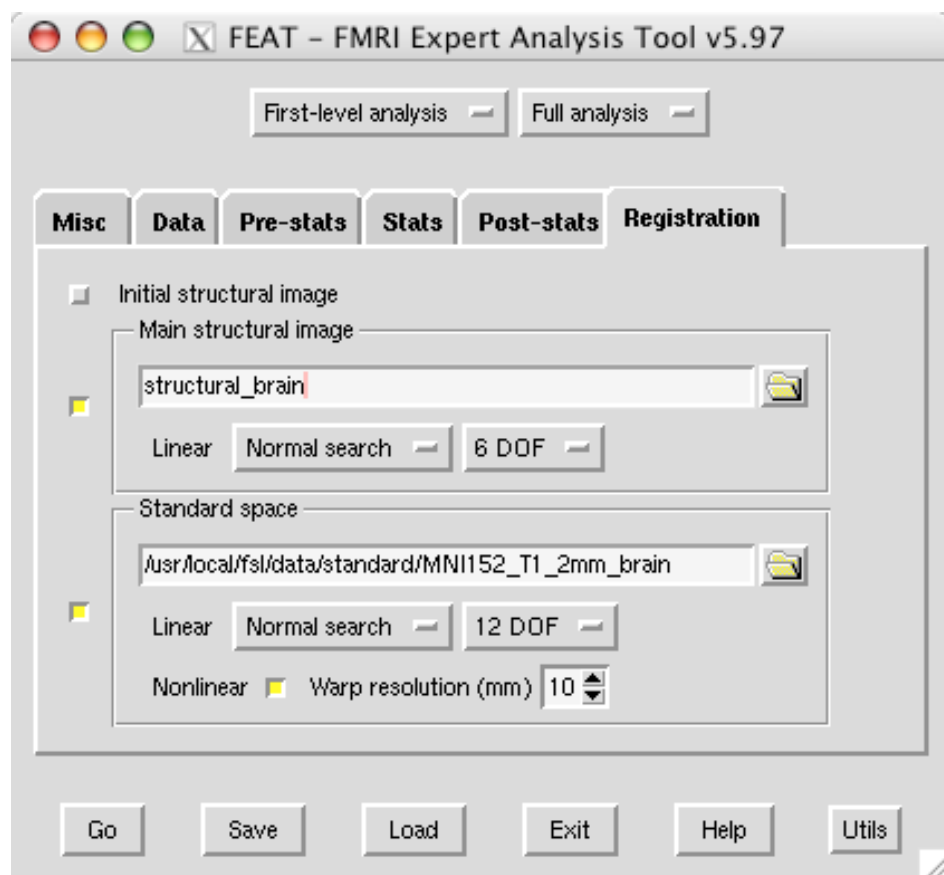


Registration with FSL

Two main tools:

FNIRT & **FLIRT**

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



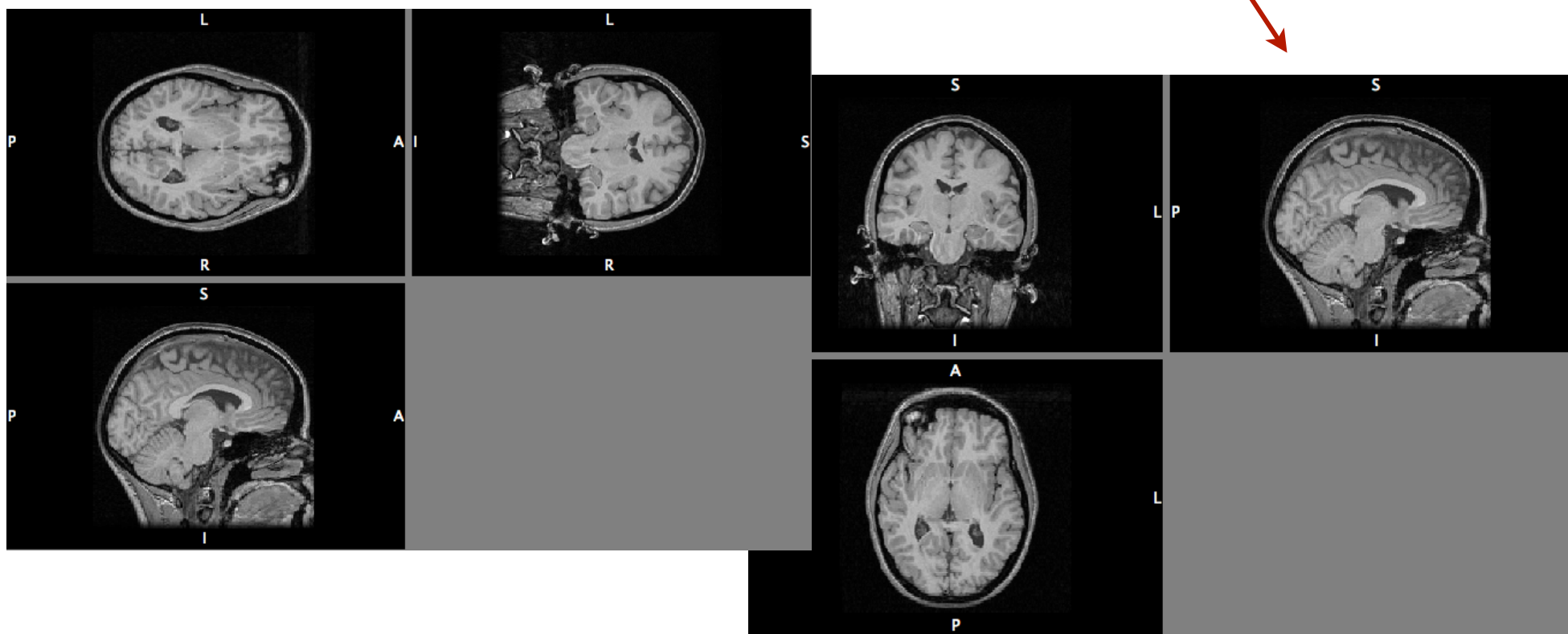
Both tools used by FMRI
and Diffusion tools
(*FEAT, MELODIC & FDT*)



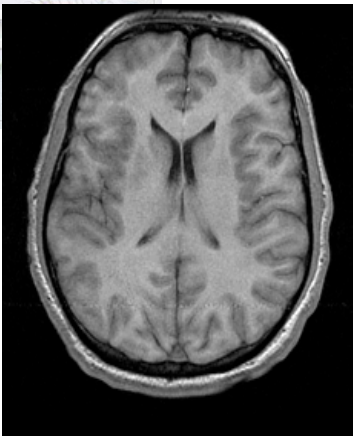
Preliminary Steps

Recommended steps:

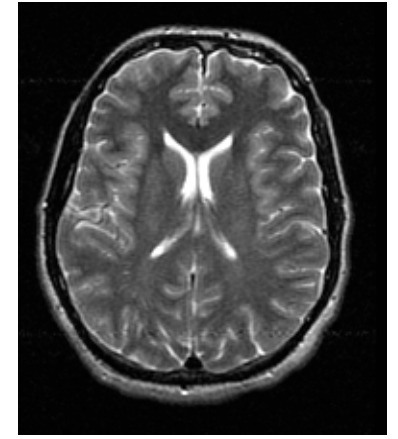
- Reorientation (`fslreorient2std`)
- Brain Extraction (BET)
- Bias-field correction (FAST - see later)



Note that labels are correct in both cases



Single-Stage Registration



Scenario:

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

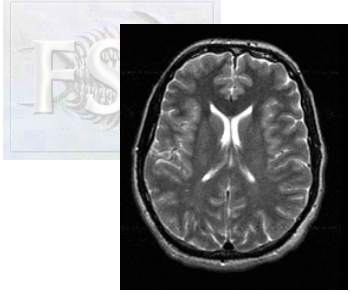
For example, T_1 -weighted and T_2 -weighted images

Objective:

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

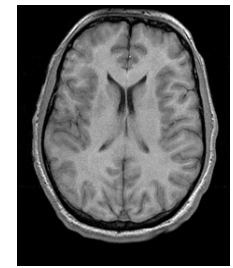
Solution:

FLIRT with 6 DOF (rigid-body)



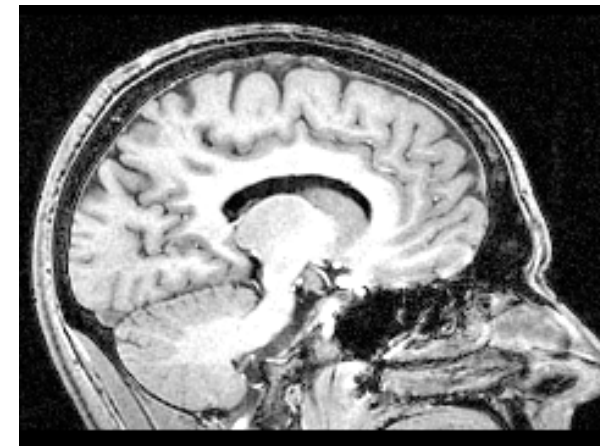
Input

Single-Stage Registration

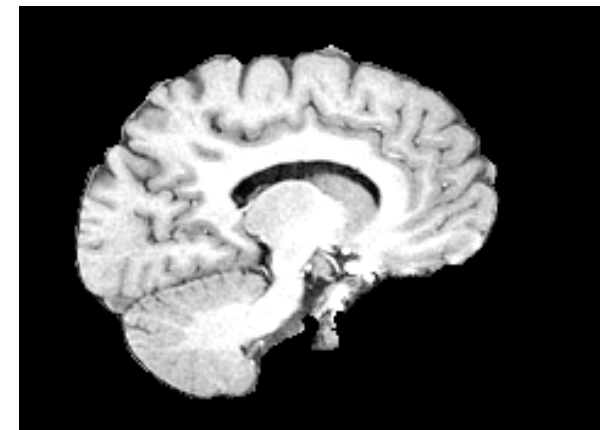


Reference

- Single subject \Rightarrow 6 DOF = FLIRT
- T_2 -wt to T_1 -wt \Rightarrow 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



BET

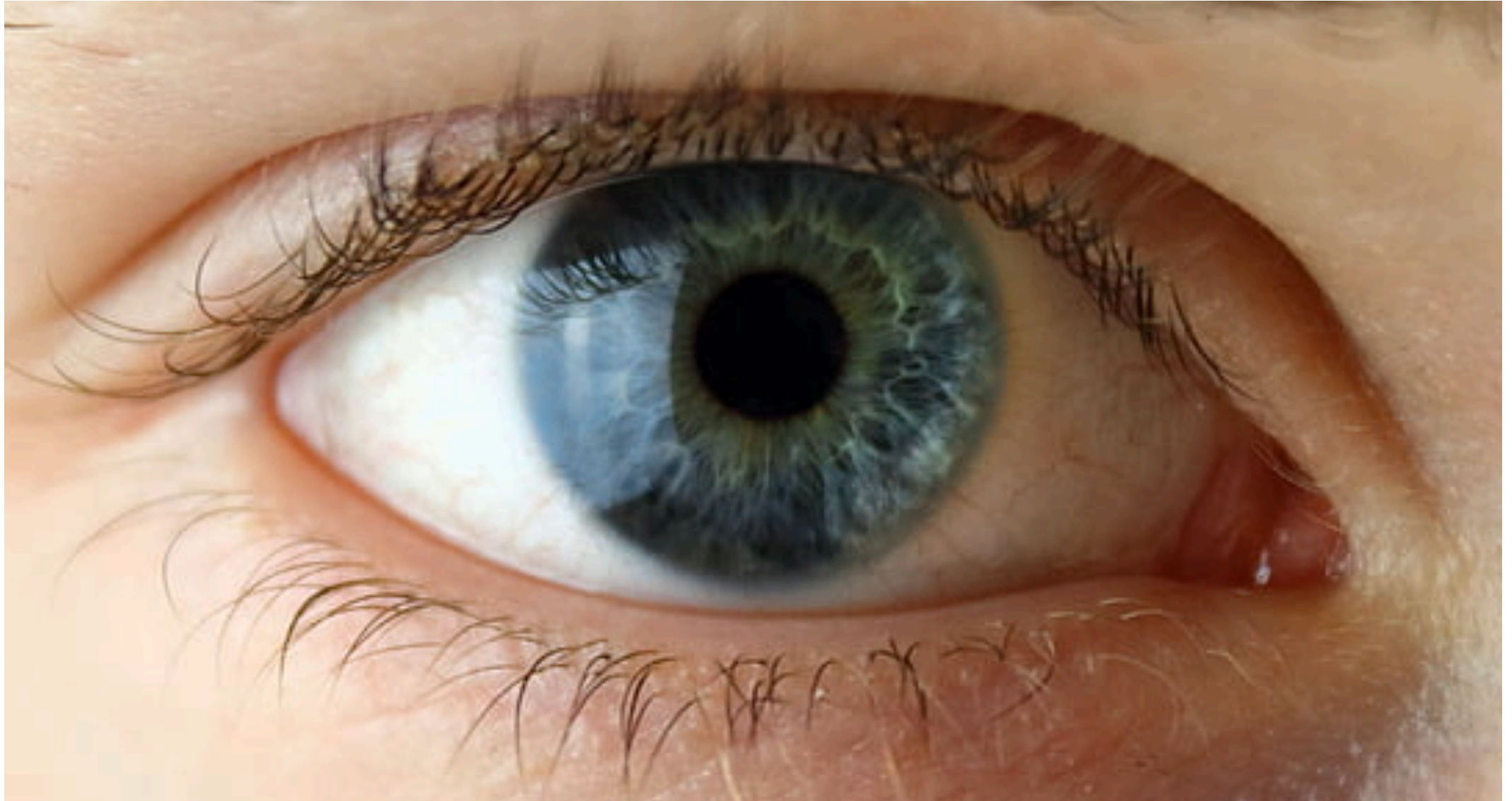




Artefaction Detection Device



LOOK AT YOUR DATA!





Visual Check

Always assess registration quality visually!

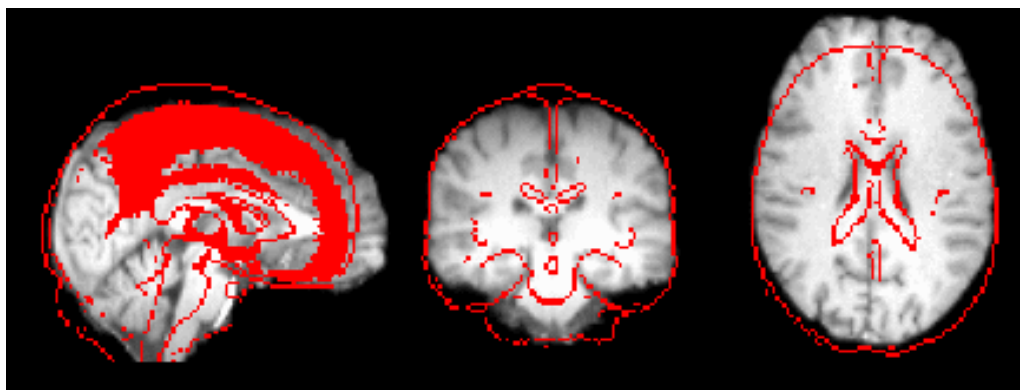
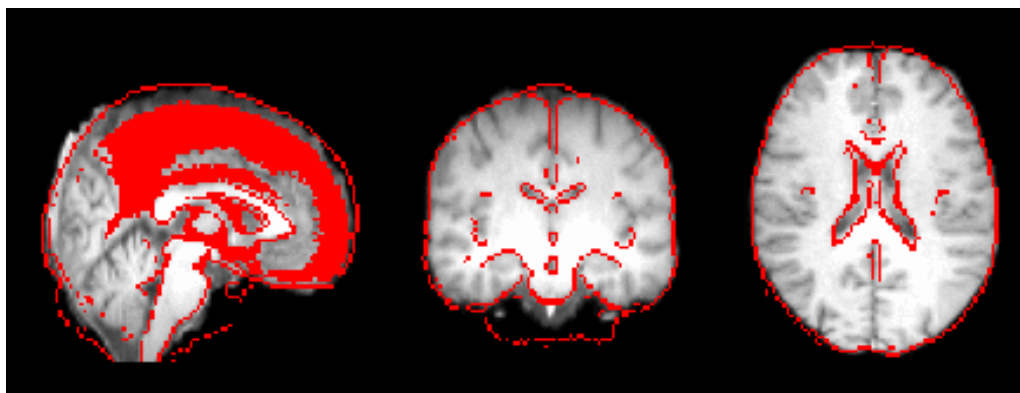
Can use:

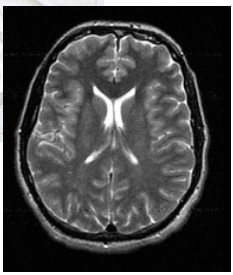
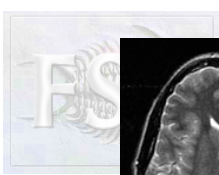
- *FSLEyes* (using overlay or flicking between images)
- *slices* for a static view use (as in FEAT)

slices T2_to_T1im T1im

Grayscale from
first image

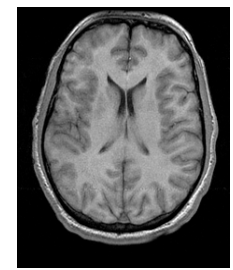
Red edges from
second image





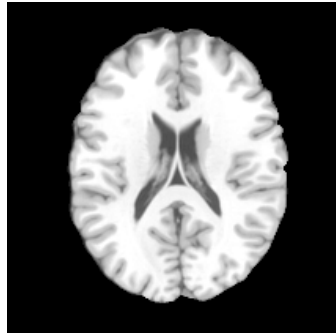
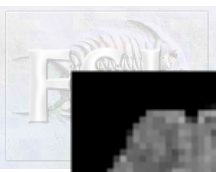
Input

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

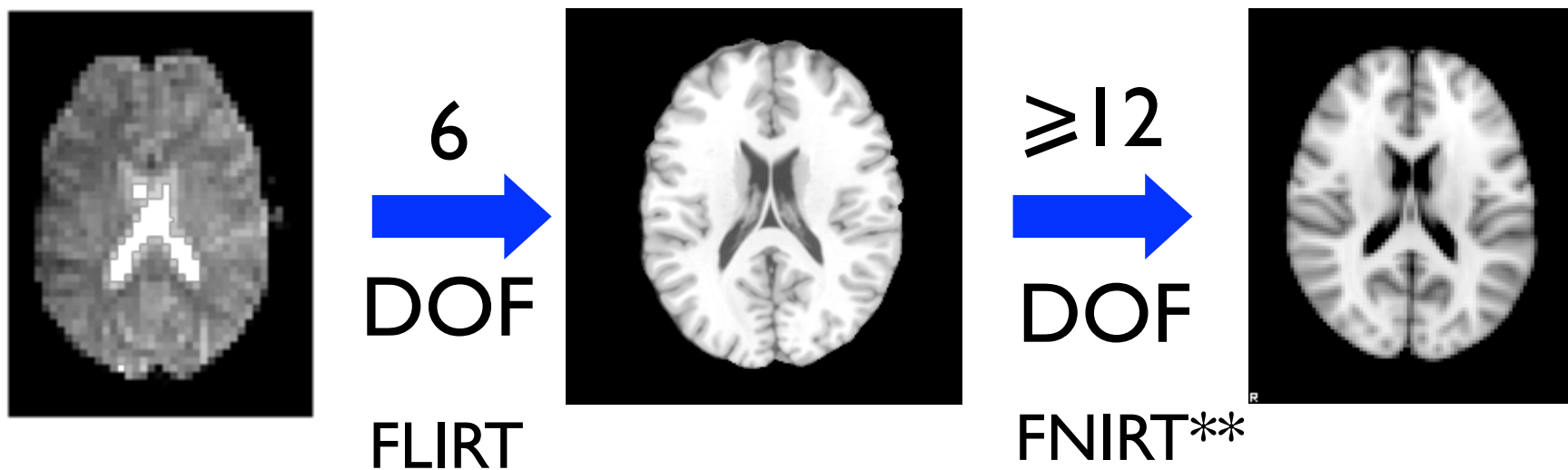
Registering very different images is difficult due to:

- 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

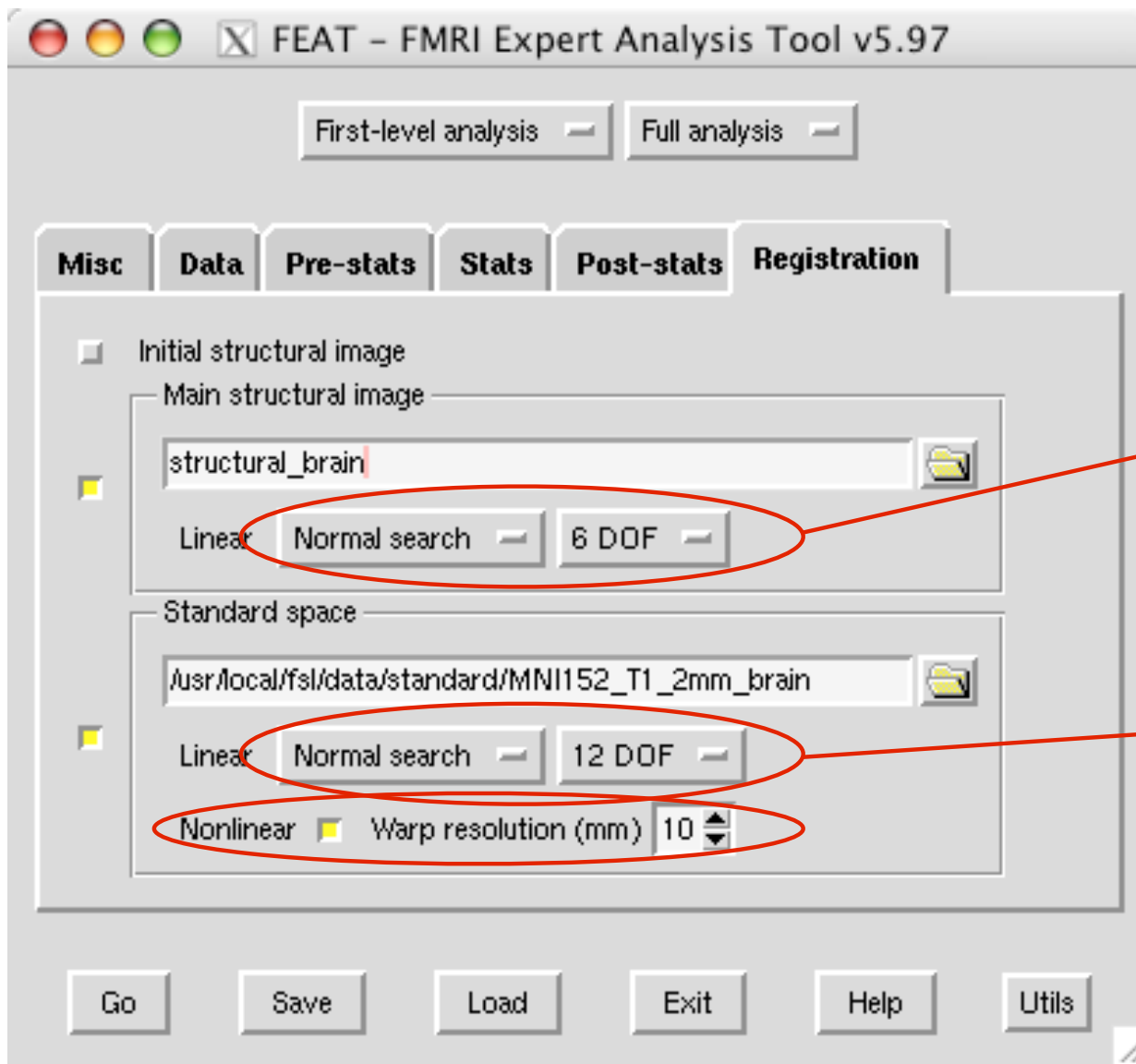
Automatically done by FEAT GUI (some user control)

Need to manually run brain extraction (not on EPI usually*)





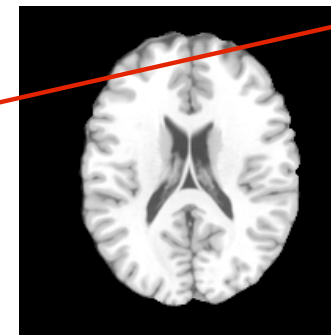
Registration for FMRI Analysis (FEAT)



FMRI
(implicit)



FLIRT



Main
Structural



FLIRT
+
FNIRT

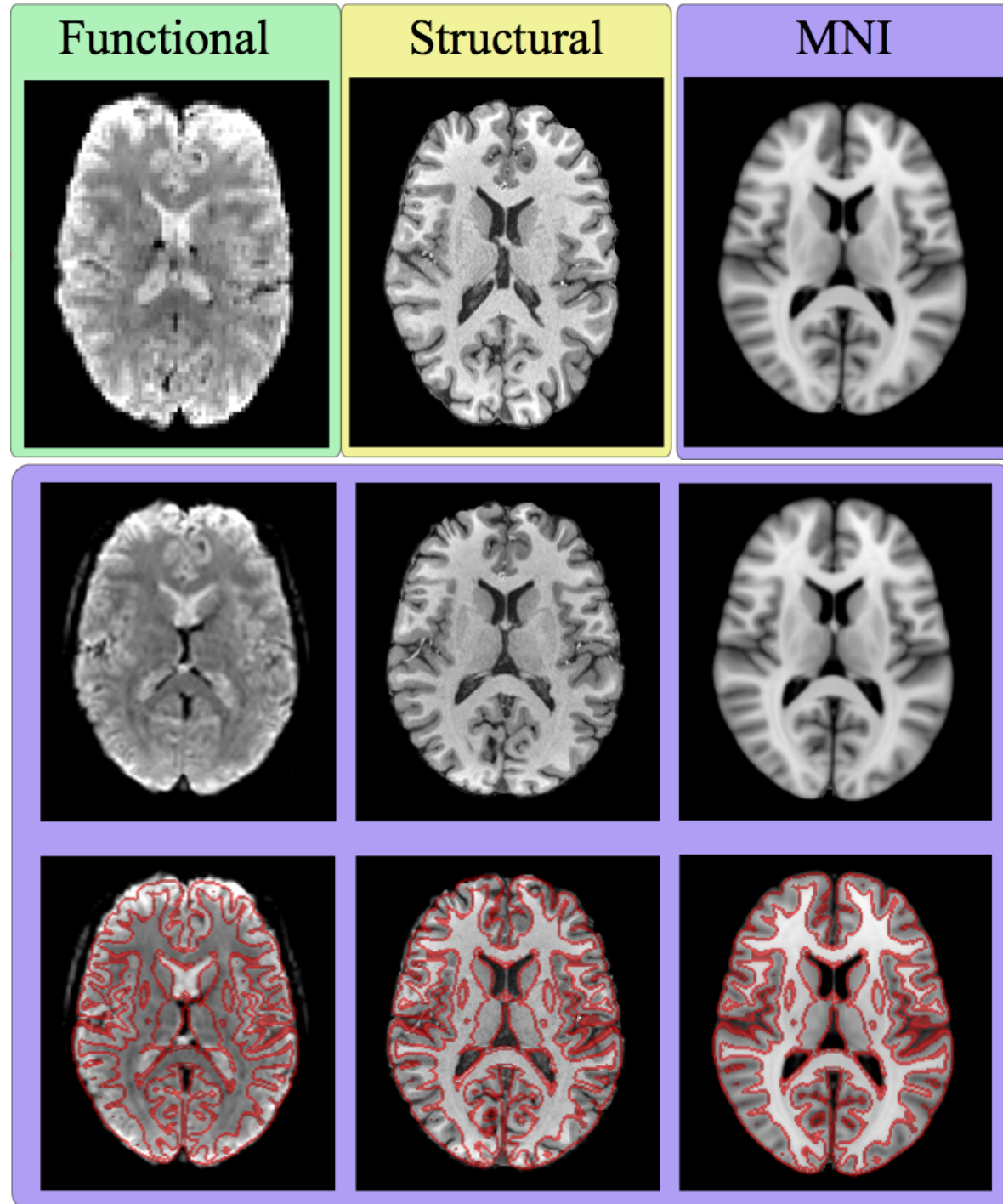


Standard

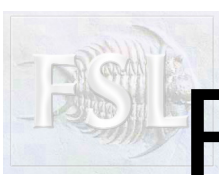
NB: actually need brain extracted **and** original images for FNIRT



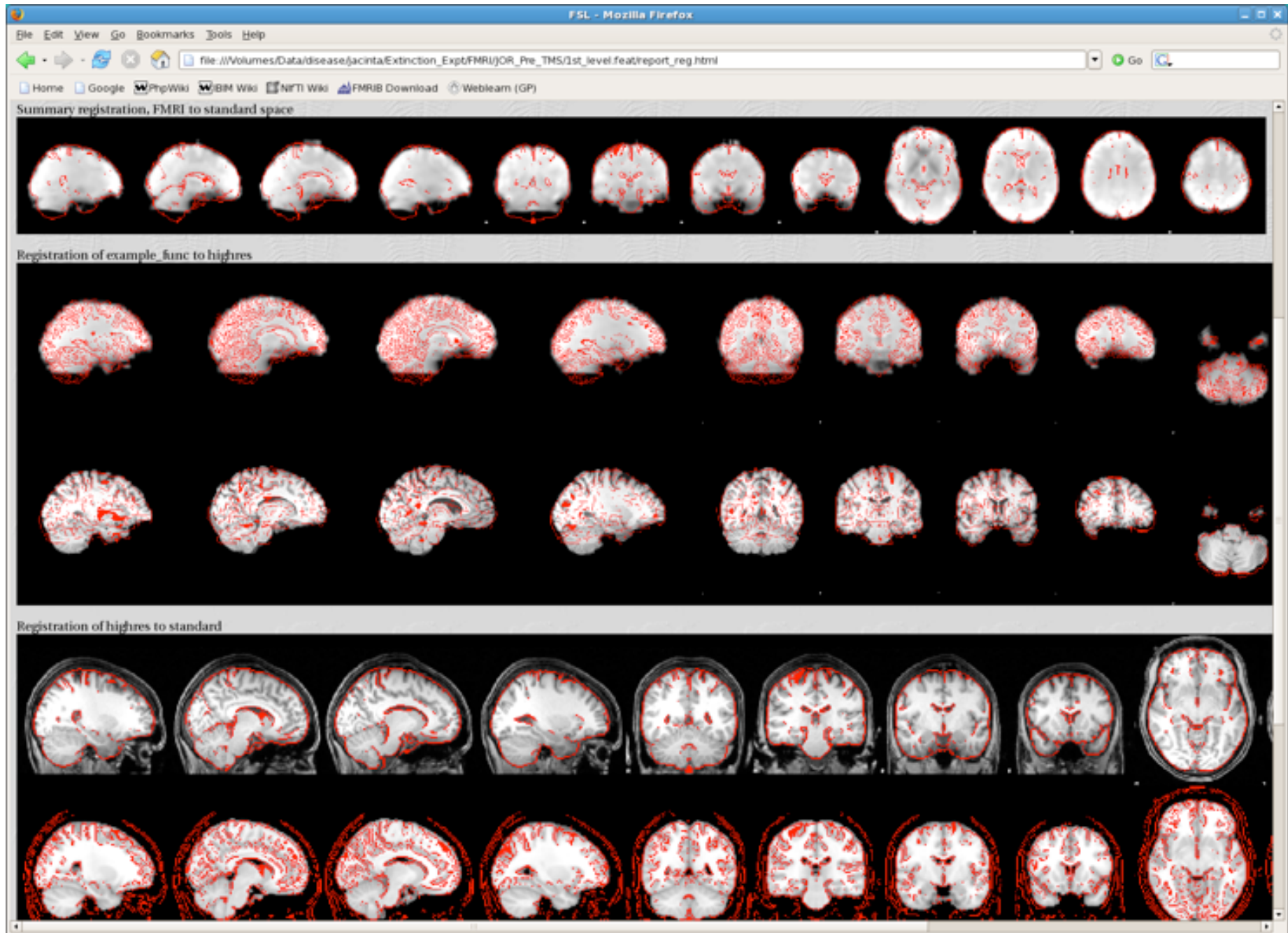
Registration Registration



MNI
Space

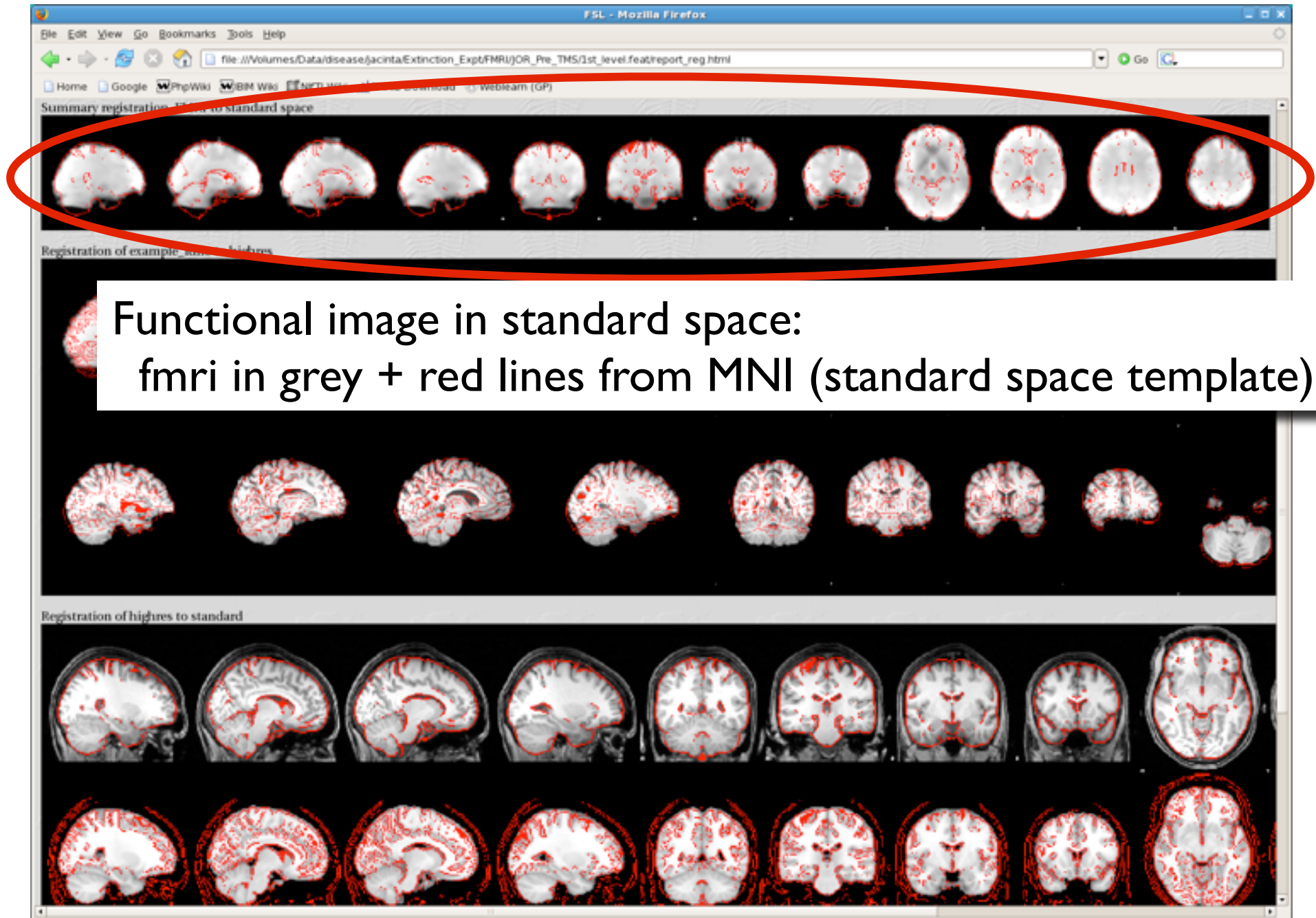


Registration for FMRI Analysis



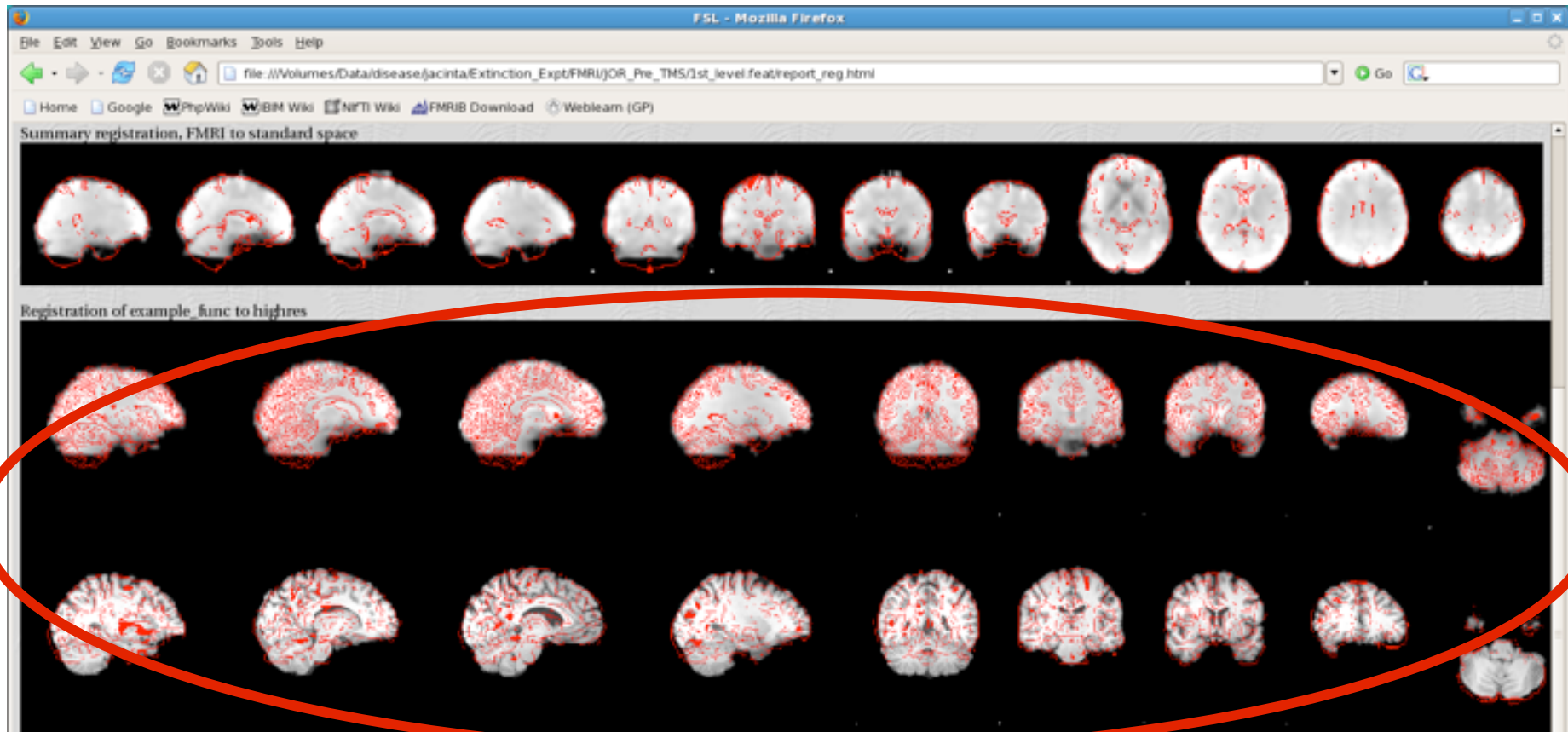


Registration for FMRI Analysis

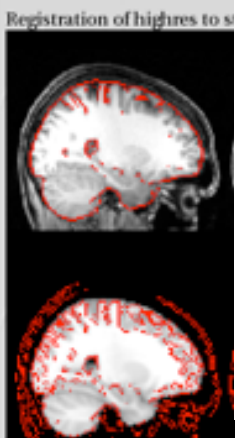


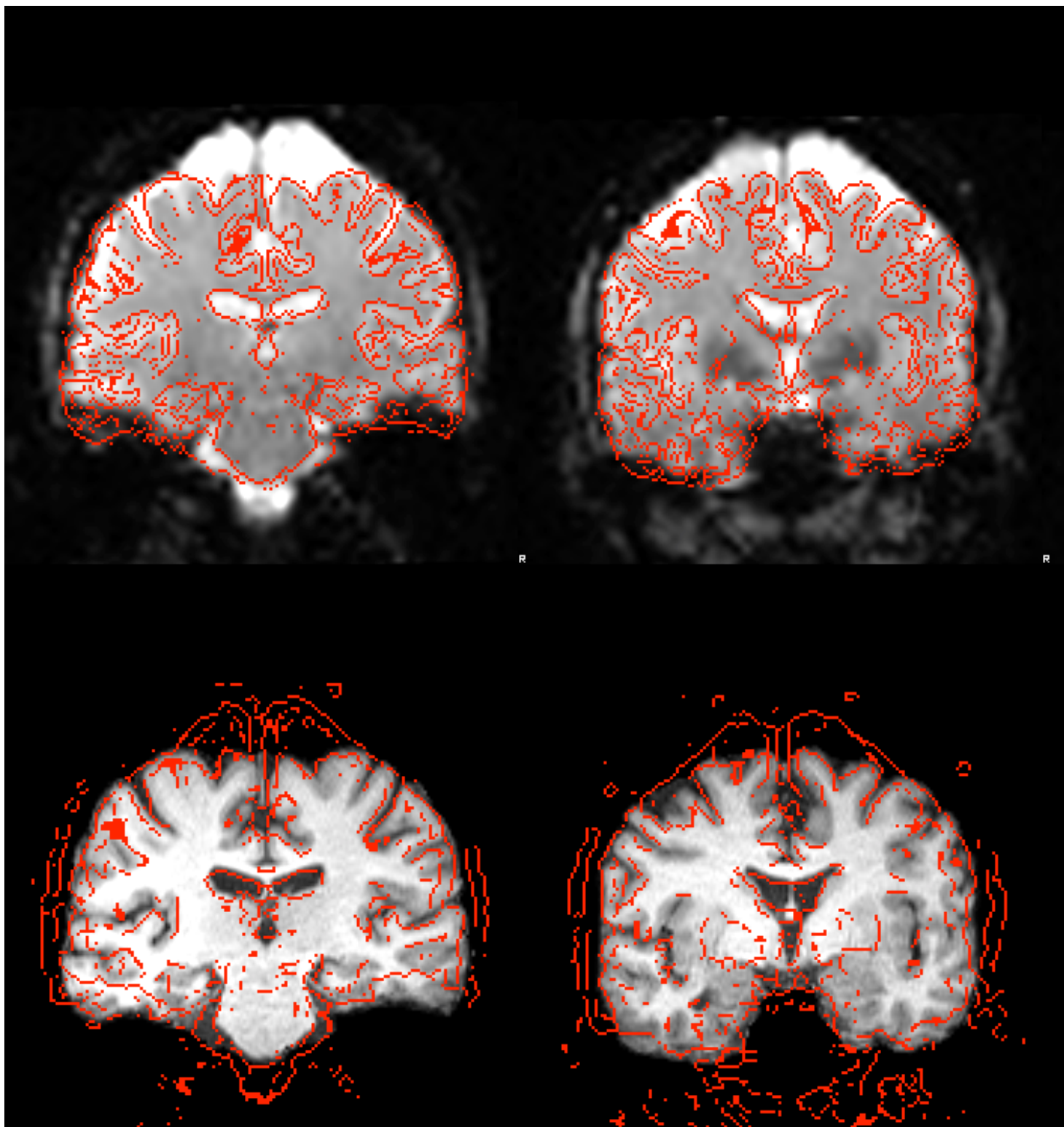


Registration for FMRI Analysis



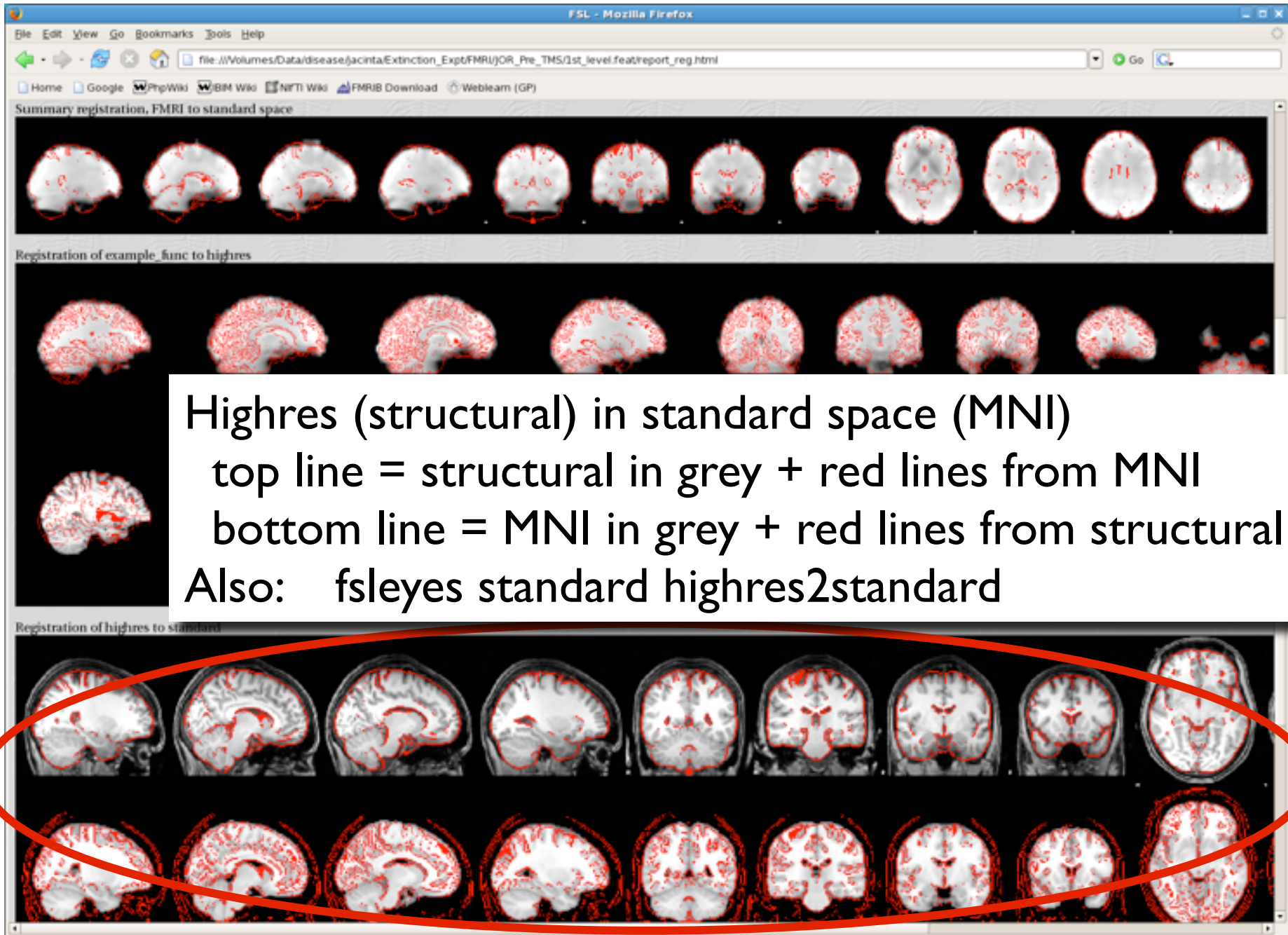
Example func (fmri) in highres (structural) space:
top line = fmri in grey + red lines from structural
bottom line = structural in grey + red lines from fmri
Also: `fsleyes highres example_func2highres`
(in `reg` subdirectory of `feat` directory)



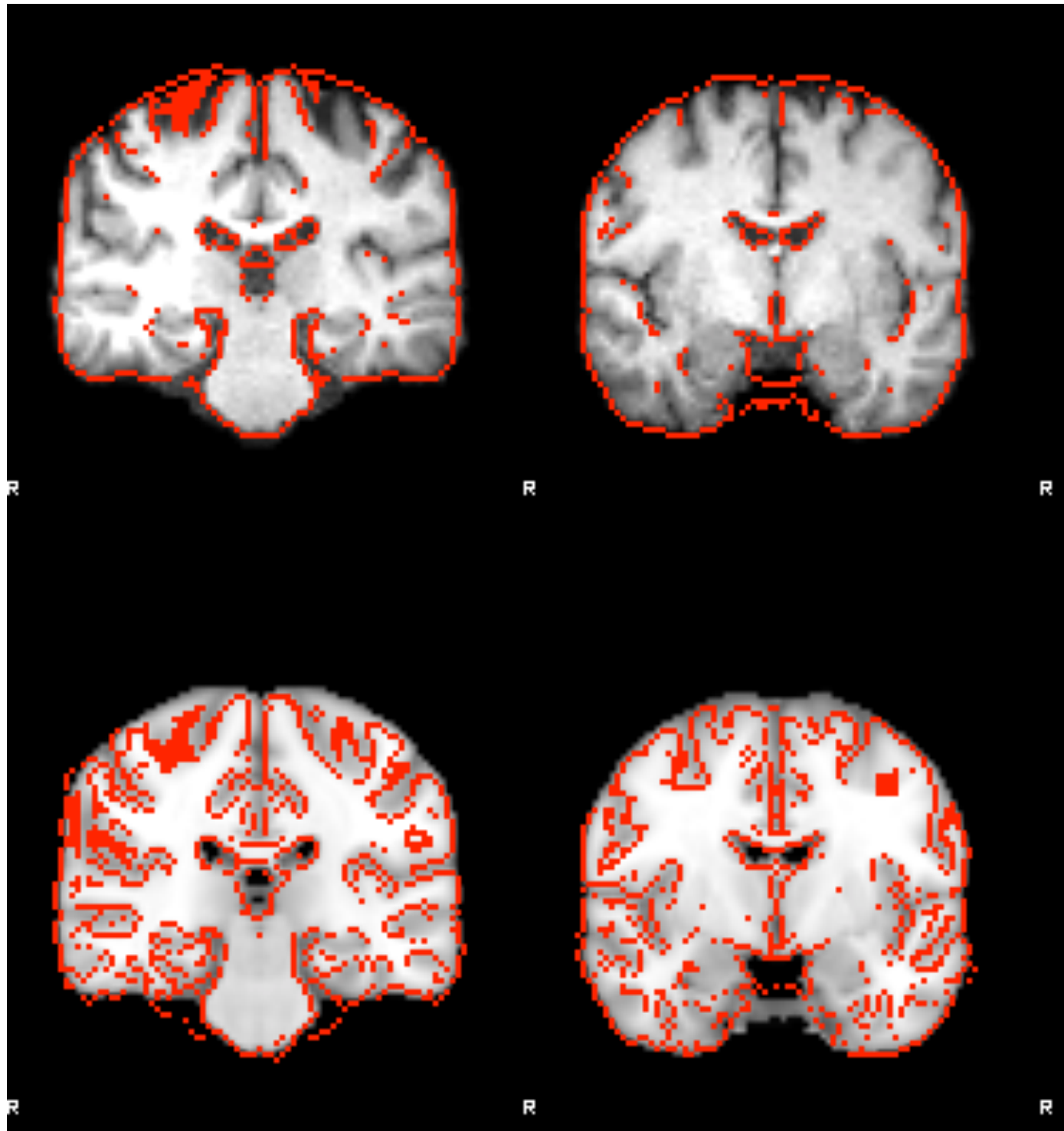




Registration for FMRI Analysis

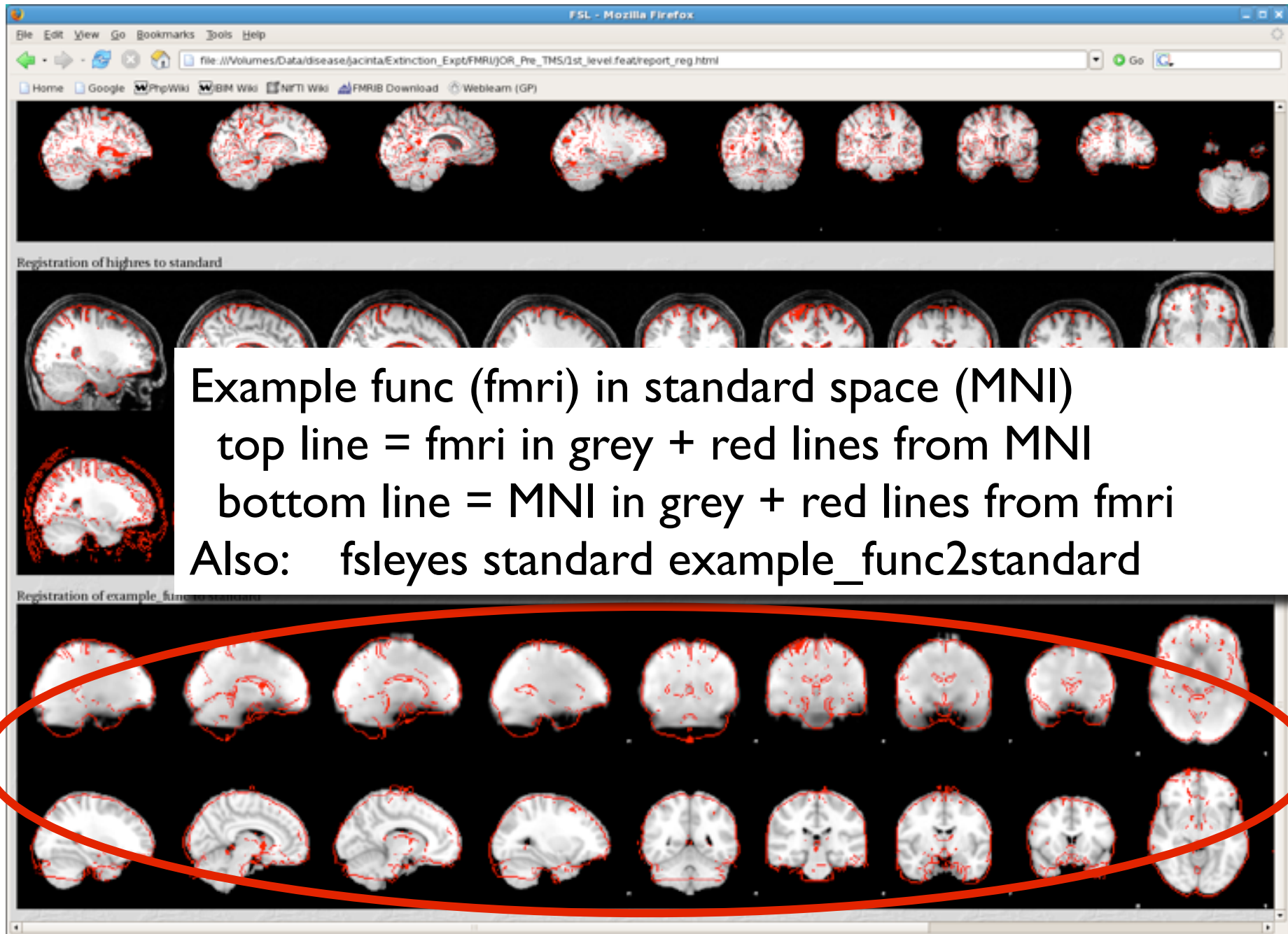


Highres (structural) in standard space (MNI)
top line = structural in grey + red lines from MNI
bottom line = MNI in grey + red lines from structural
Also: `fsleyes standard highres2standard`





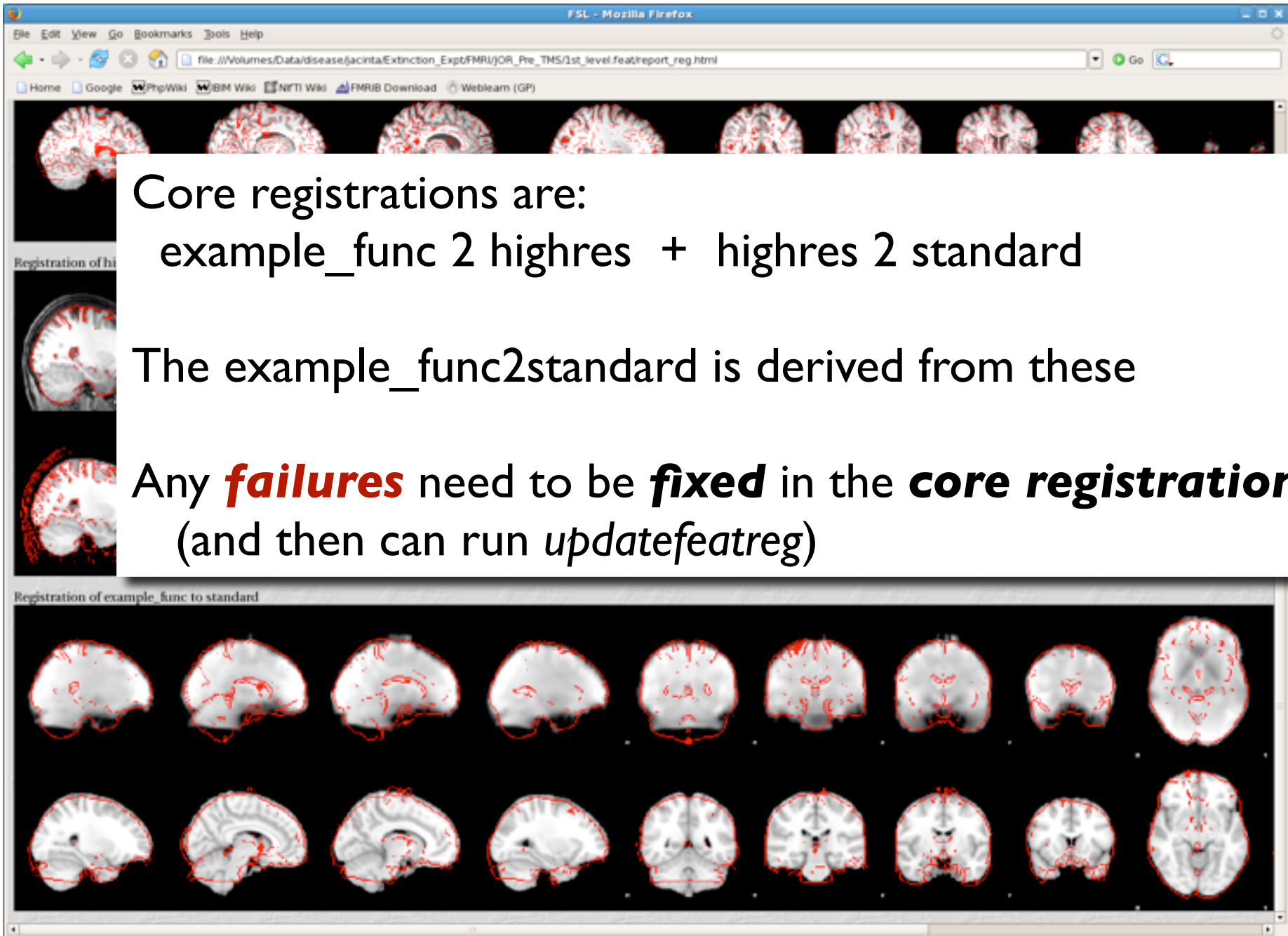
Registration for FMRI Analysis



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*)



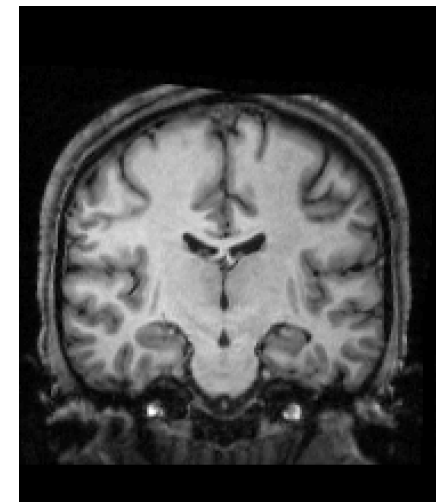
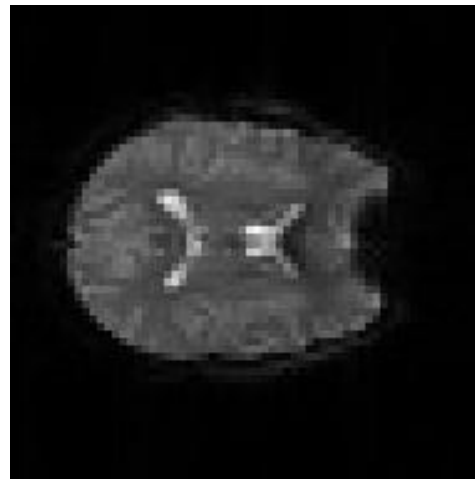
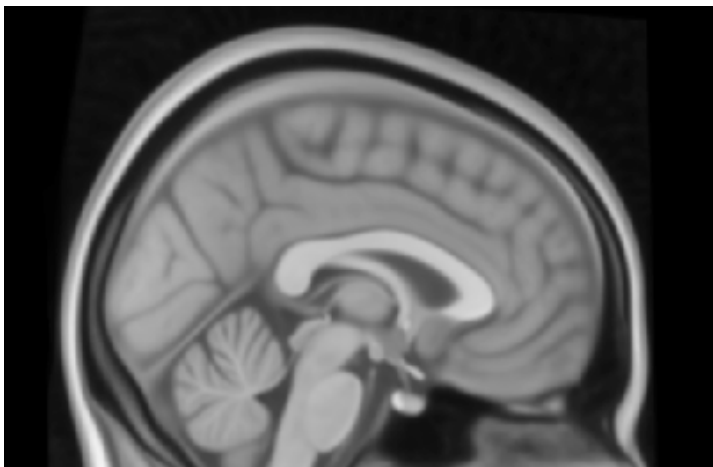
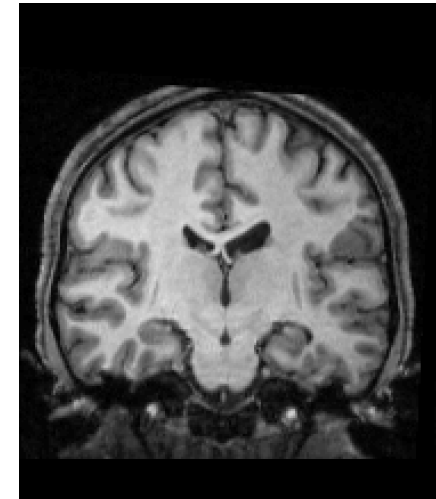
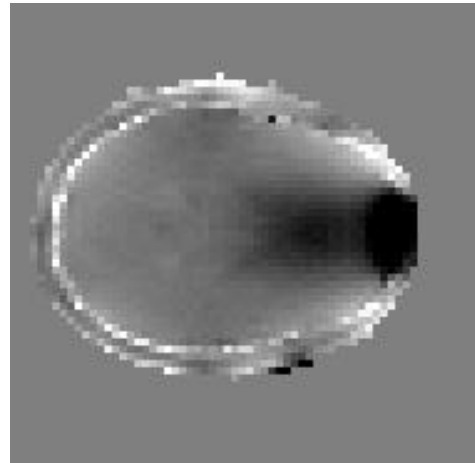
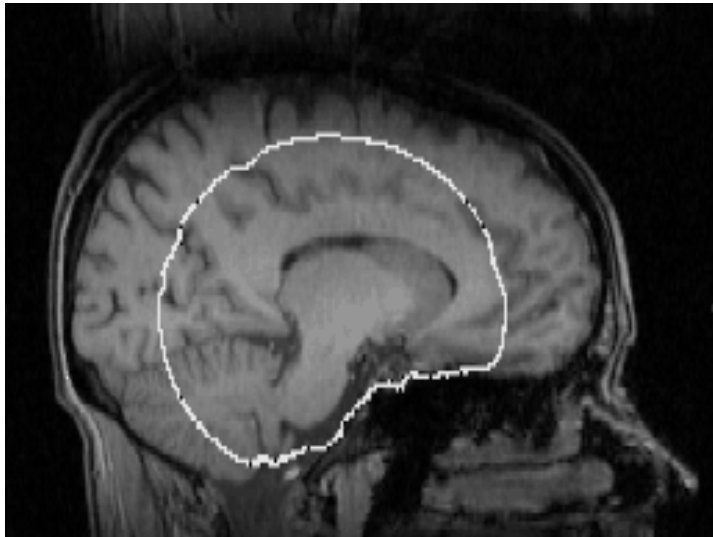
Registration: Single-Stage and Multi-Stage Applications

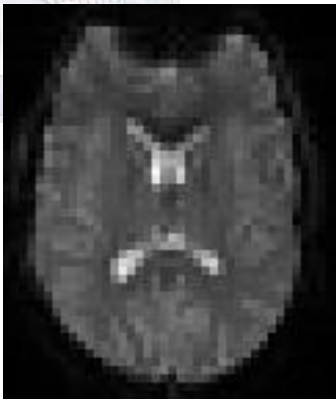
Summary:

- 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)

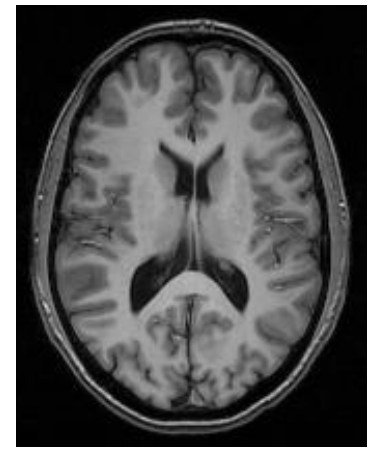


Registration: EPI Distortion Correction and Registration





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

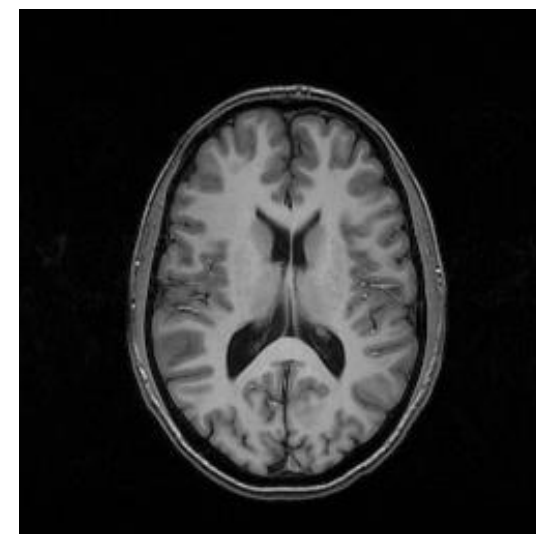
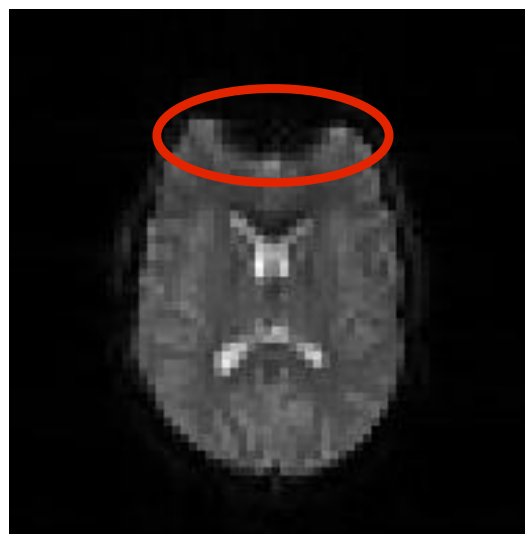
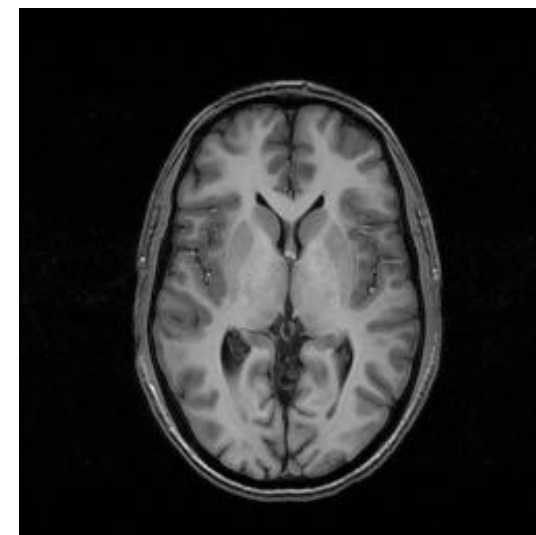
Solution:

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

EPI

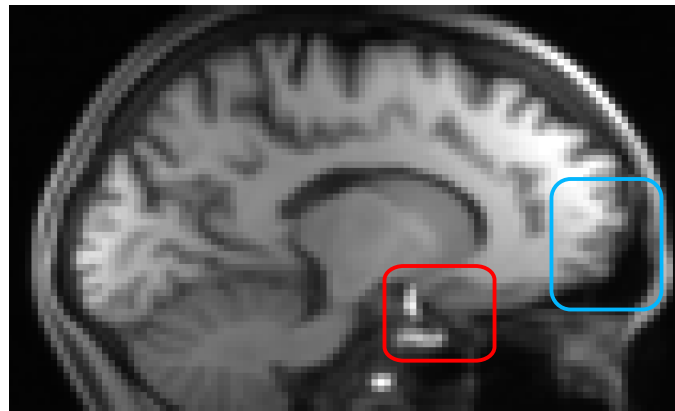


T₁-weighted anatomical

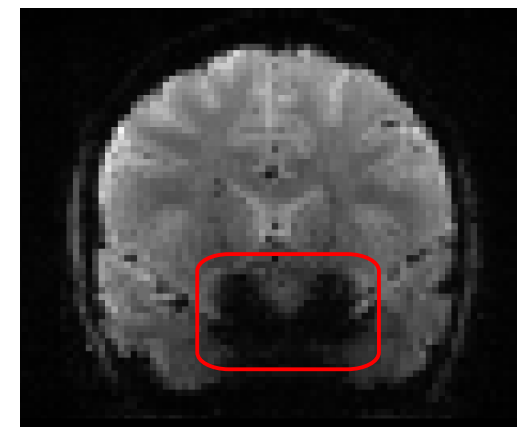
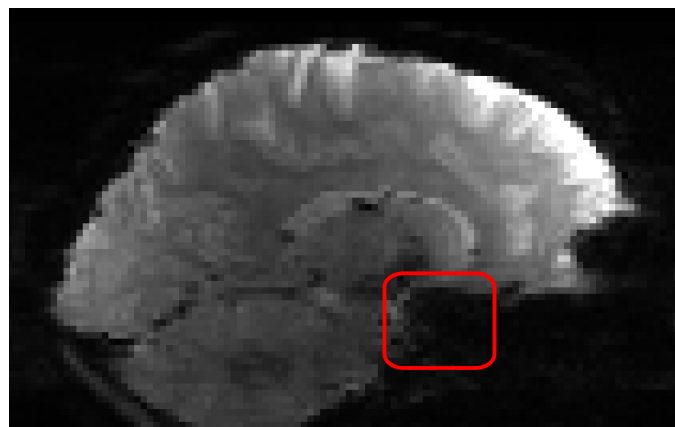




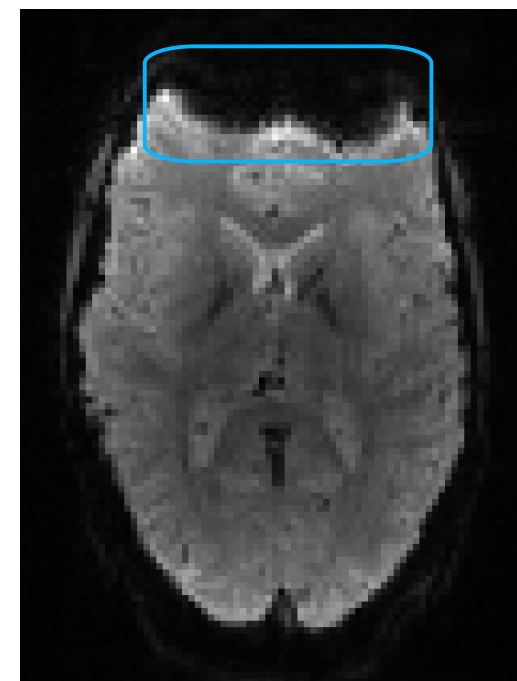
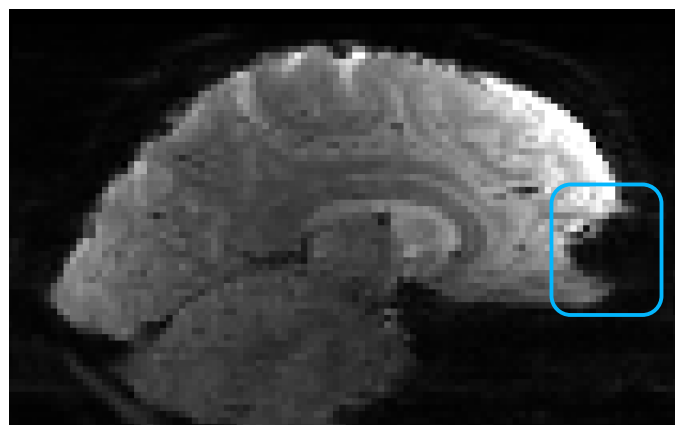
T1-weighted
(aligned)



Signal Loss



Distortion



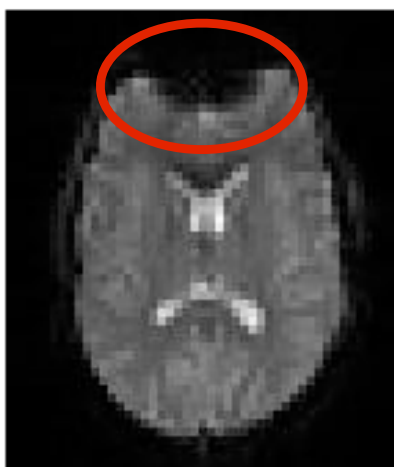
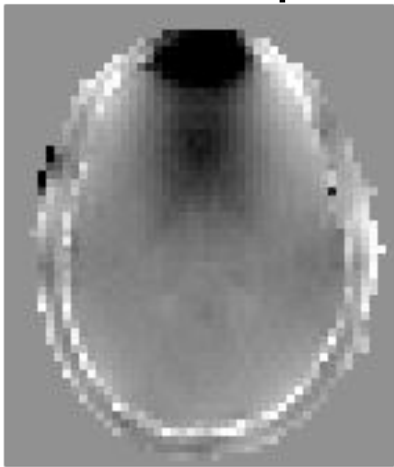
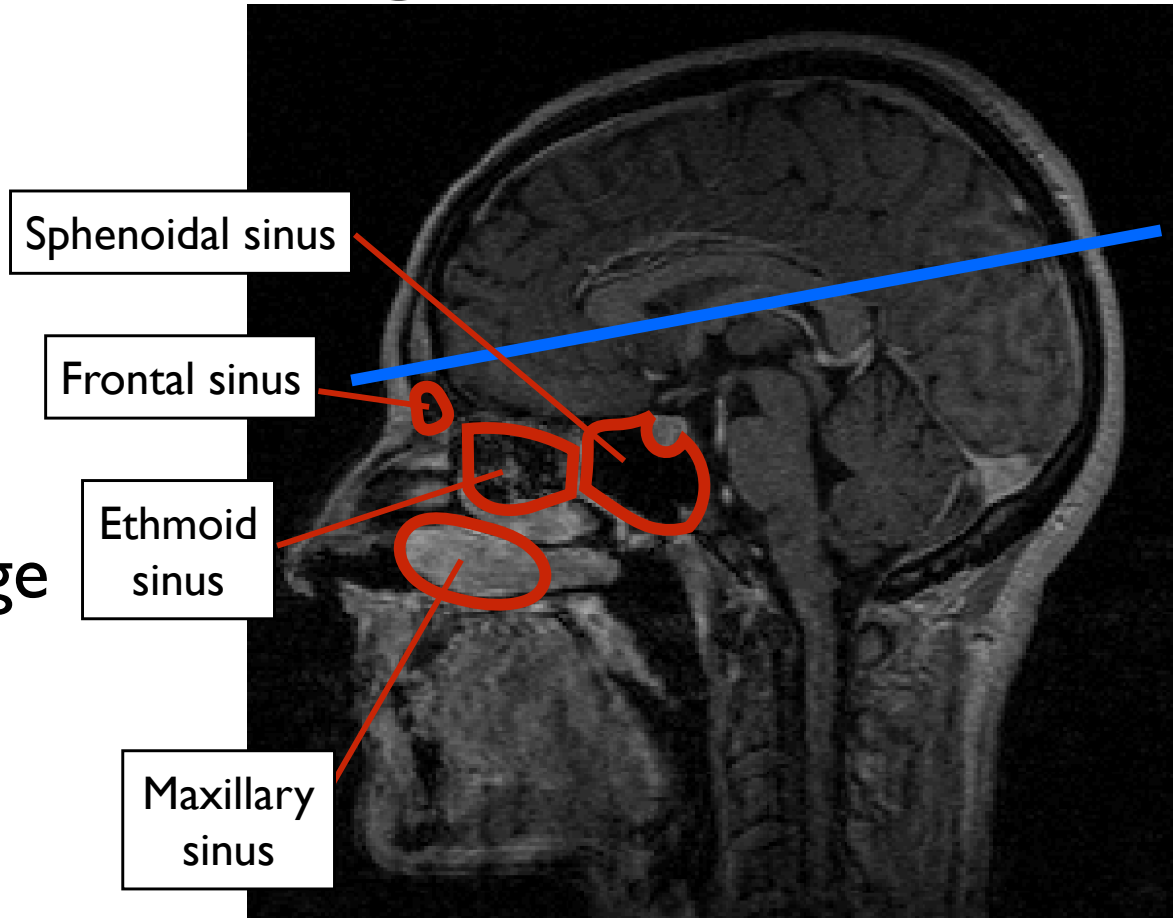


B₀ Field Inhomogeneities

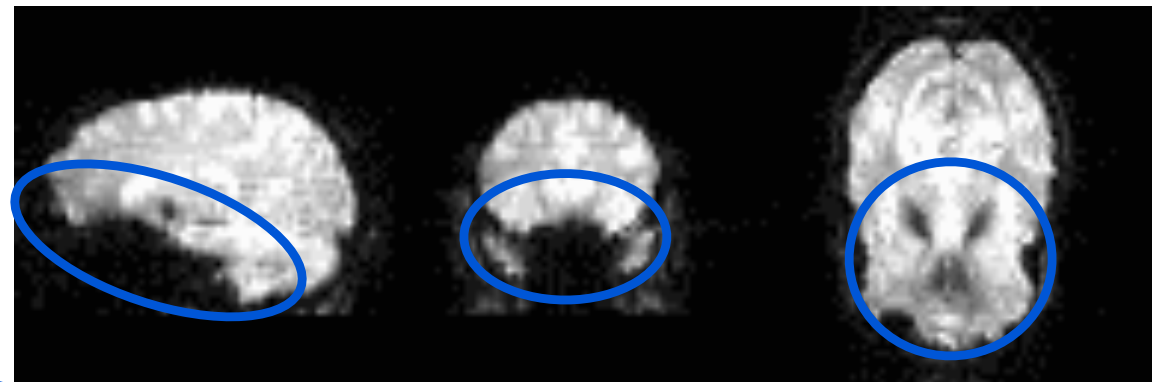
EPI is very sensitive to any deviations from a perfectly uniform B₀ field

Air-tissue interfaces cause magnetic disturbances

A separate **fieldmap** image measures the B₀ deviations



distortion
signal loss



Courtesy of D. Greve, MGH

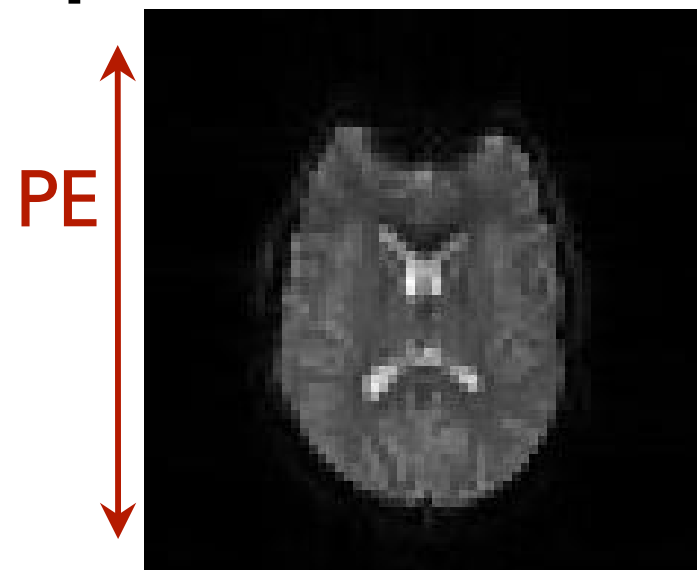


Using Fieldmaps

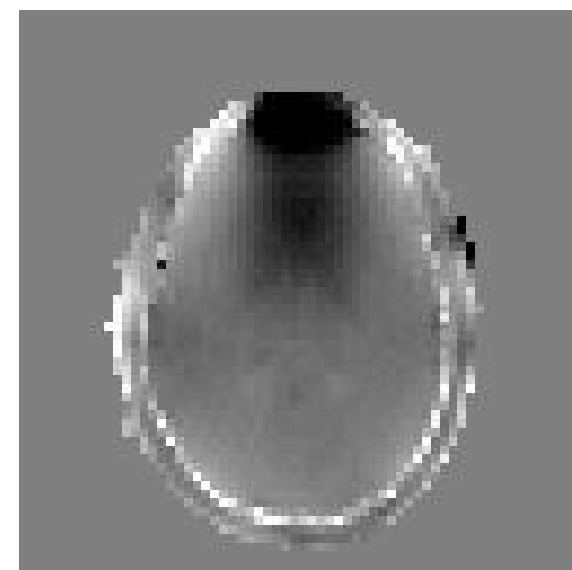
From the fieldmap image we get:

Magnitude of spatial distortions
(phase-encode direction only)

Estimate of signal loss



EPI



B₀ Fieldmap

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)

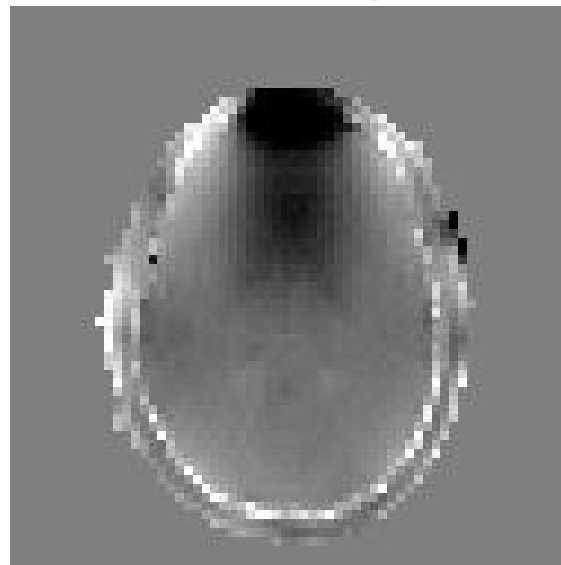


Unwarping with Fieldmaps

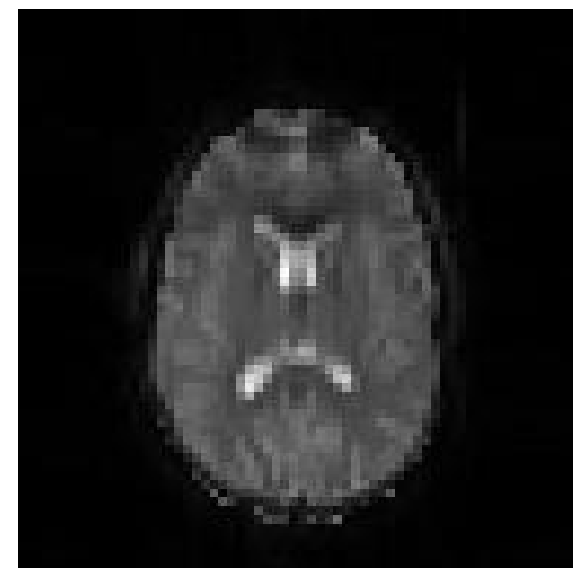
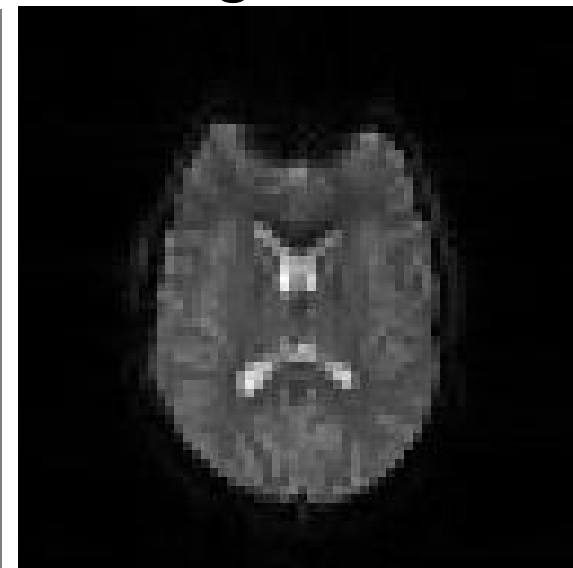
Used to improve **registration** of EPI and structural scan

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

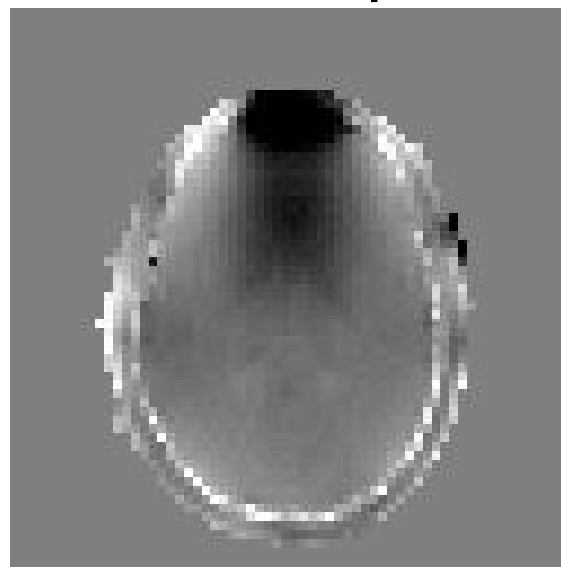
It **does not** restore signal in the frontal lobe

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

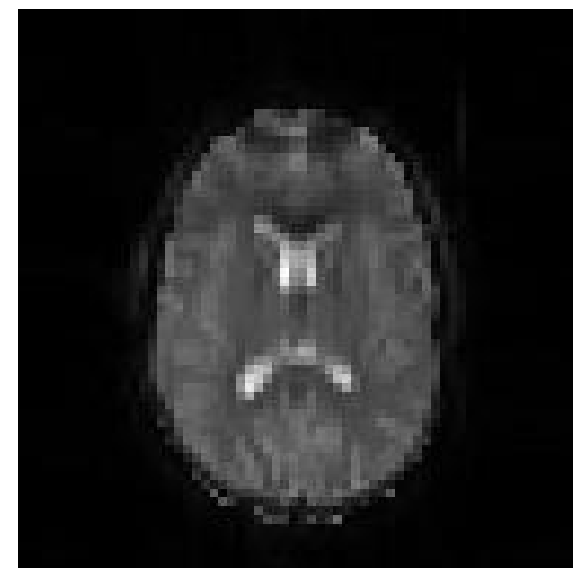
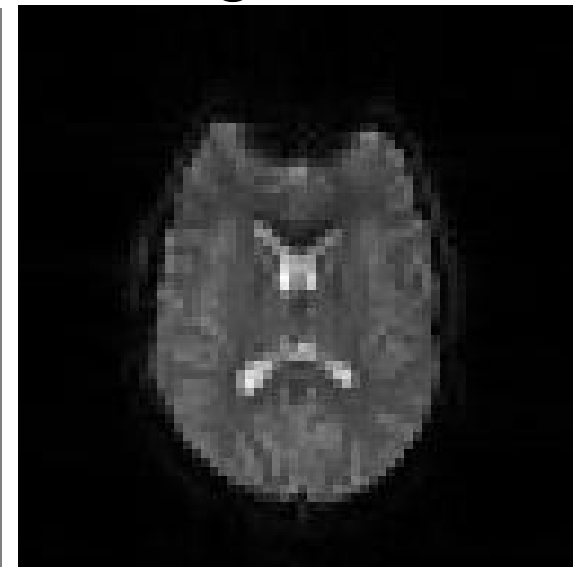
It **does** use fieldmap image to calculate distortion and “unwarp” EPI

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)

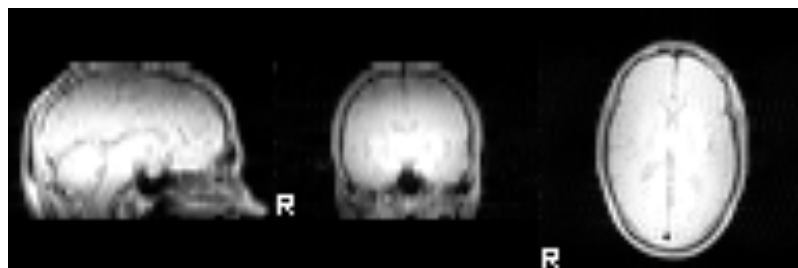
Four main types of acquisitions:

- Gradient Echo
- Asymmetric Spin Echo
- EPI
- Blip-reversed b=0 pair (EPI)

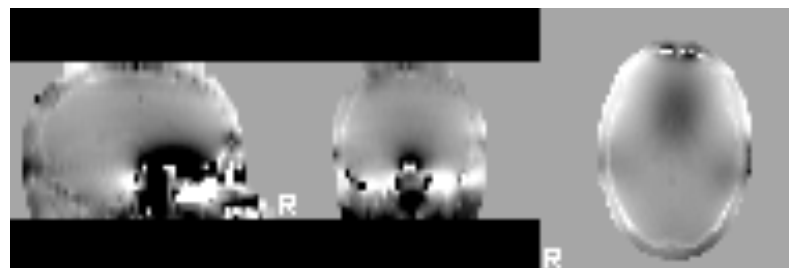


Distortion & Signal Loss

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



Magnitude part of fieldmap

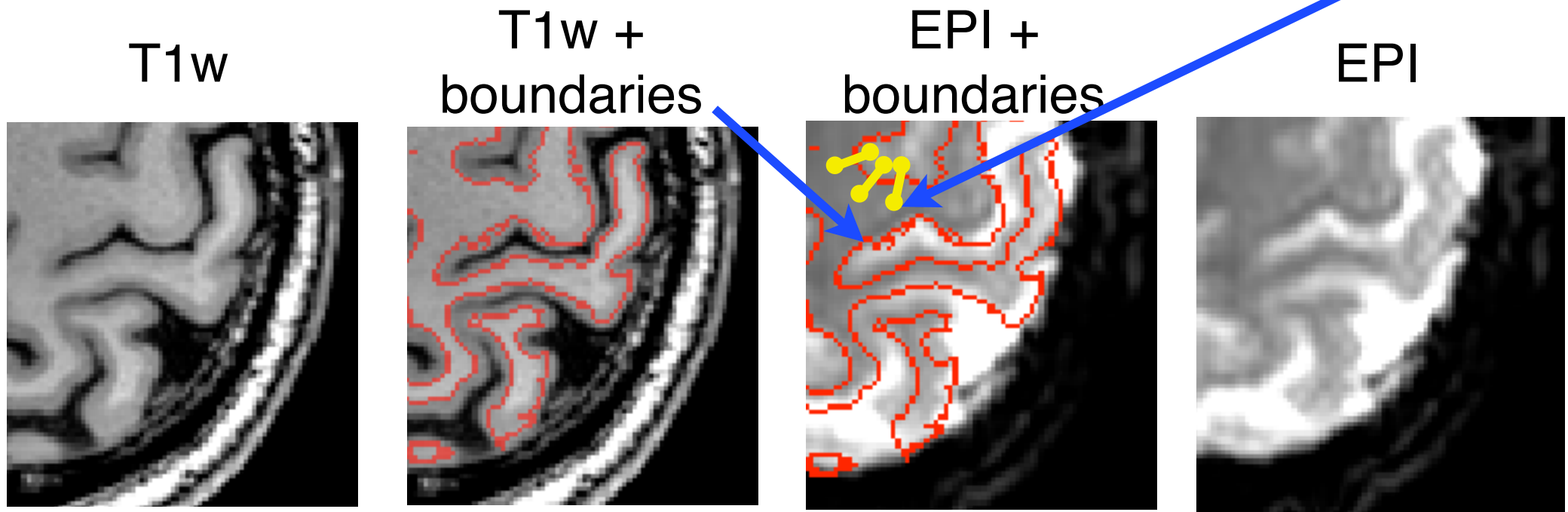


Phase difference of images

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

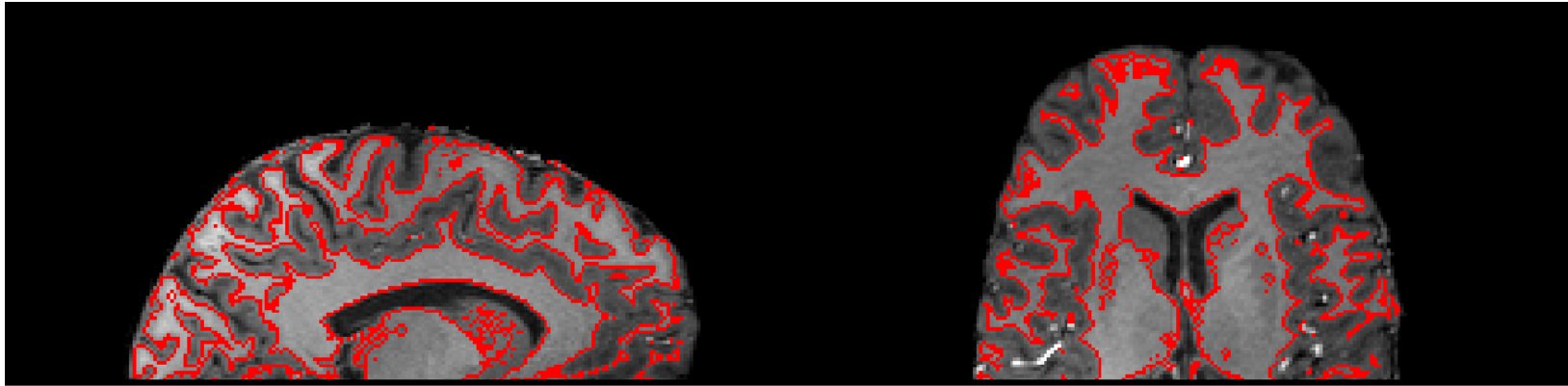
Boundary-Based Registration (BBR)

- *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

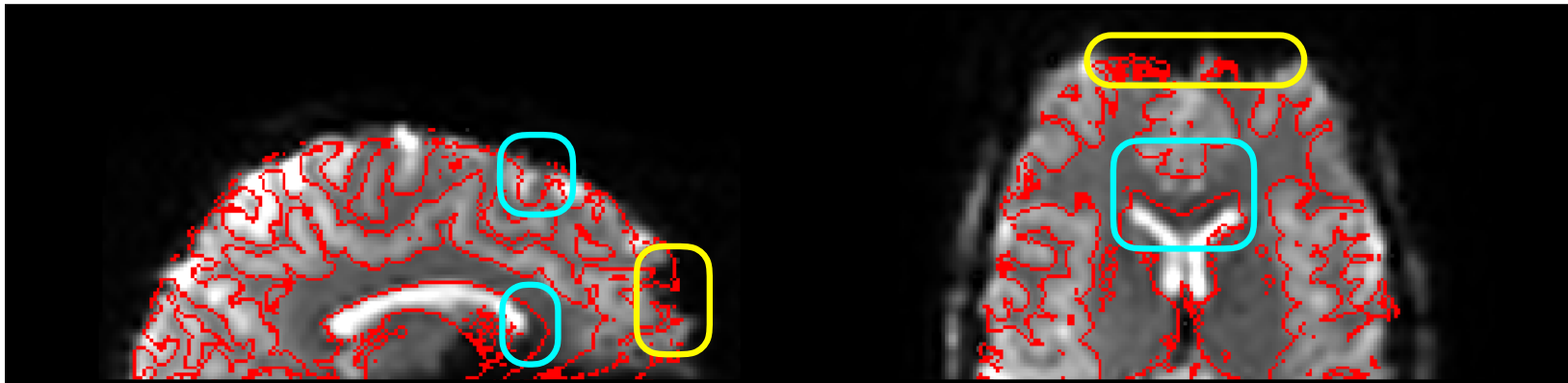


Distortion Correction

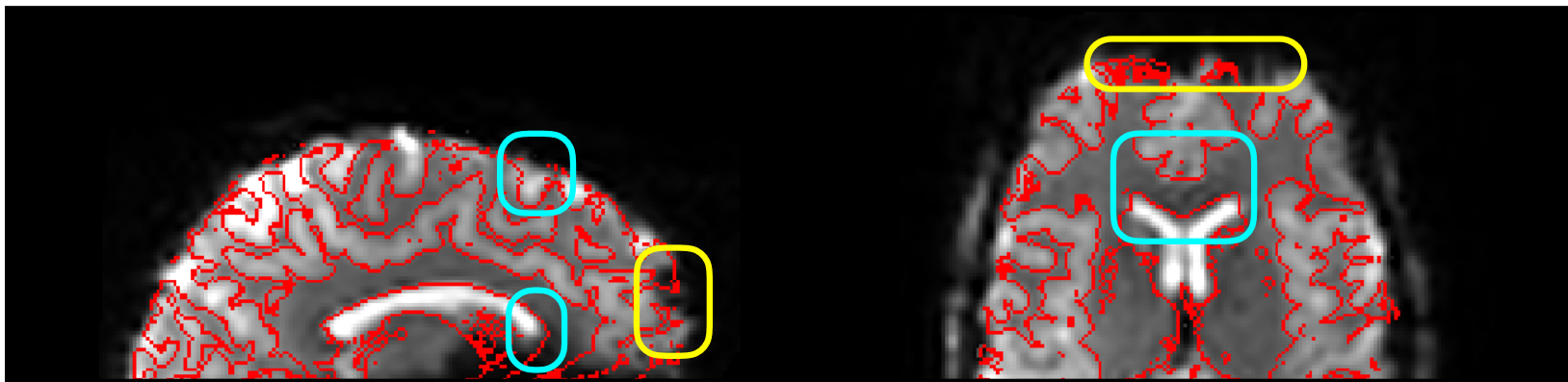
Structural Image



Registration without Distortion Correction

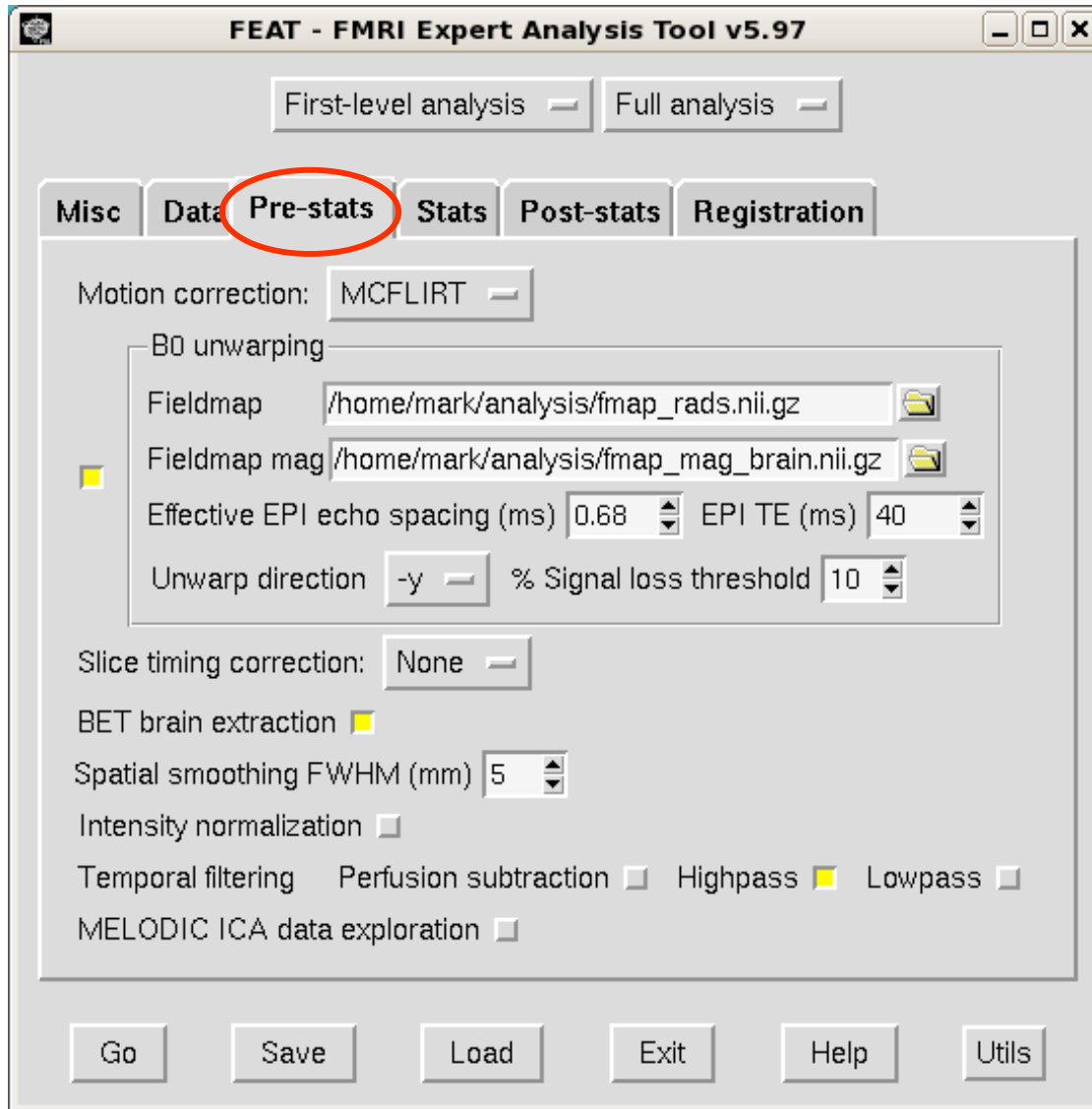


Registration with Distortion Correction



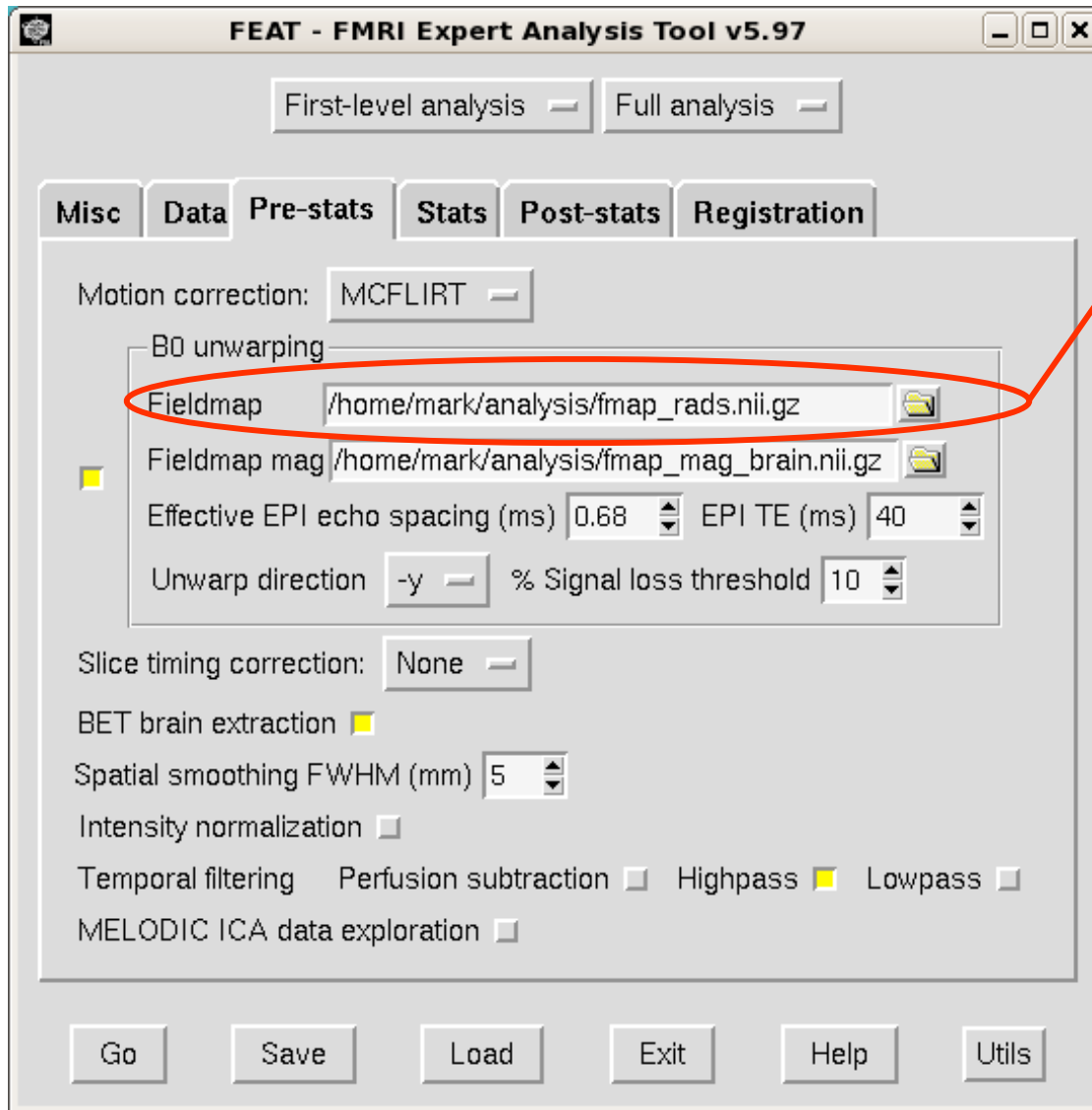


Distortion Correction within FEAT

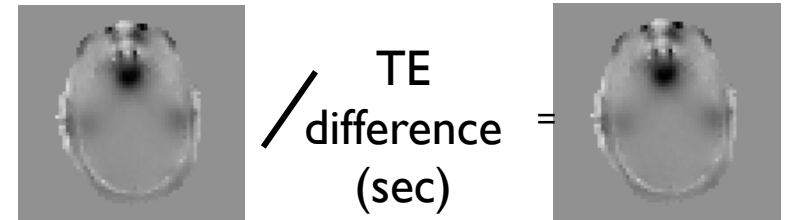




Distortion Correction within FEAT



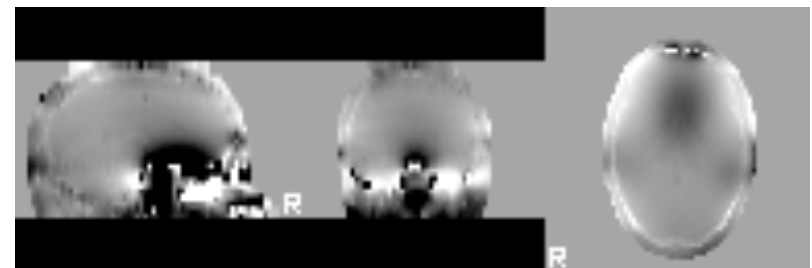
Fieldmap in rad/s



Phase difference (rad)

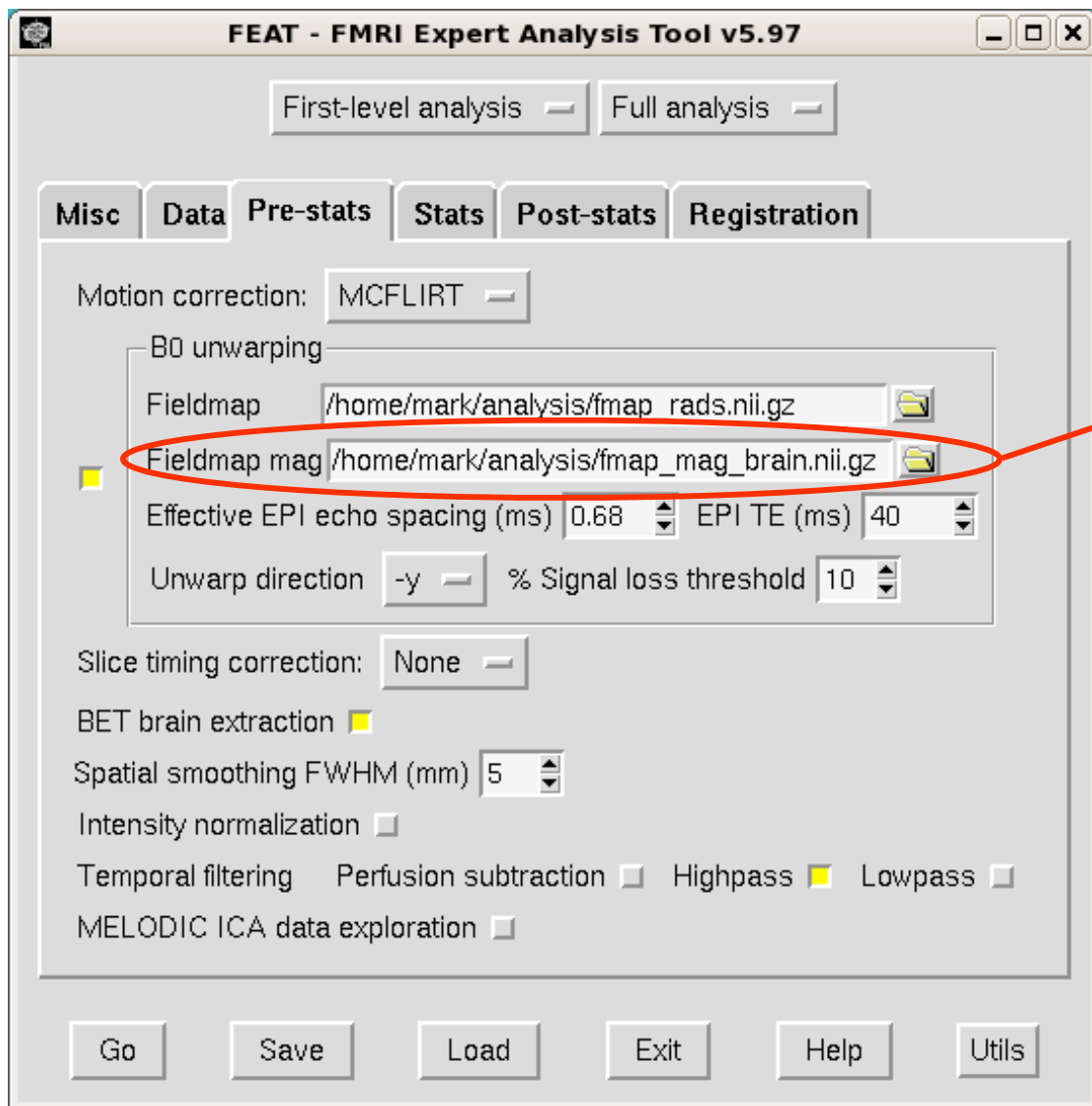
B_0 Field (rad/s)

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





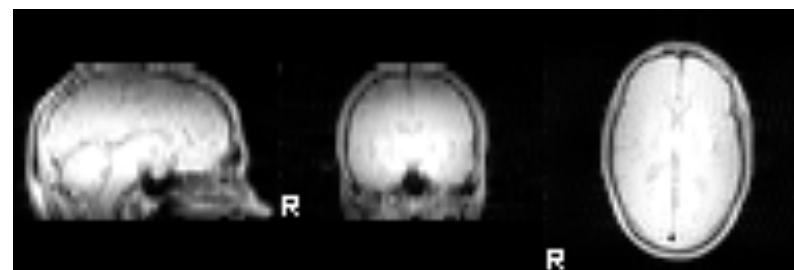
Distortion Correction within FEAT



Fieldmap in rad/s

Fieldmap Magnitude

... needs this ...



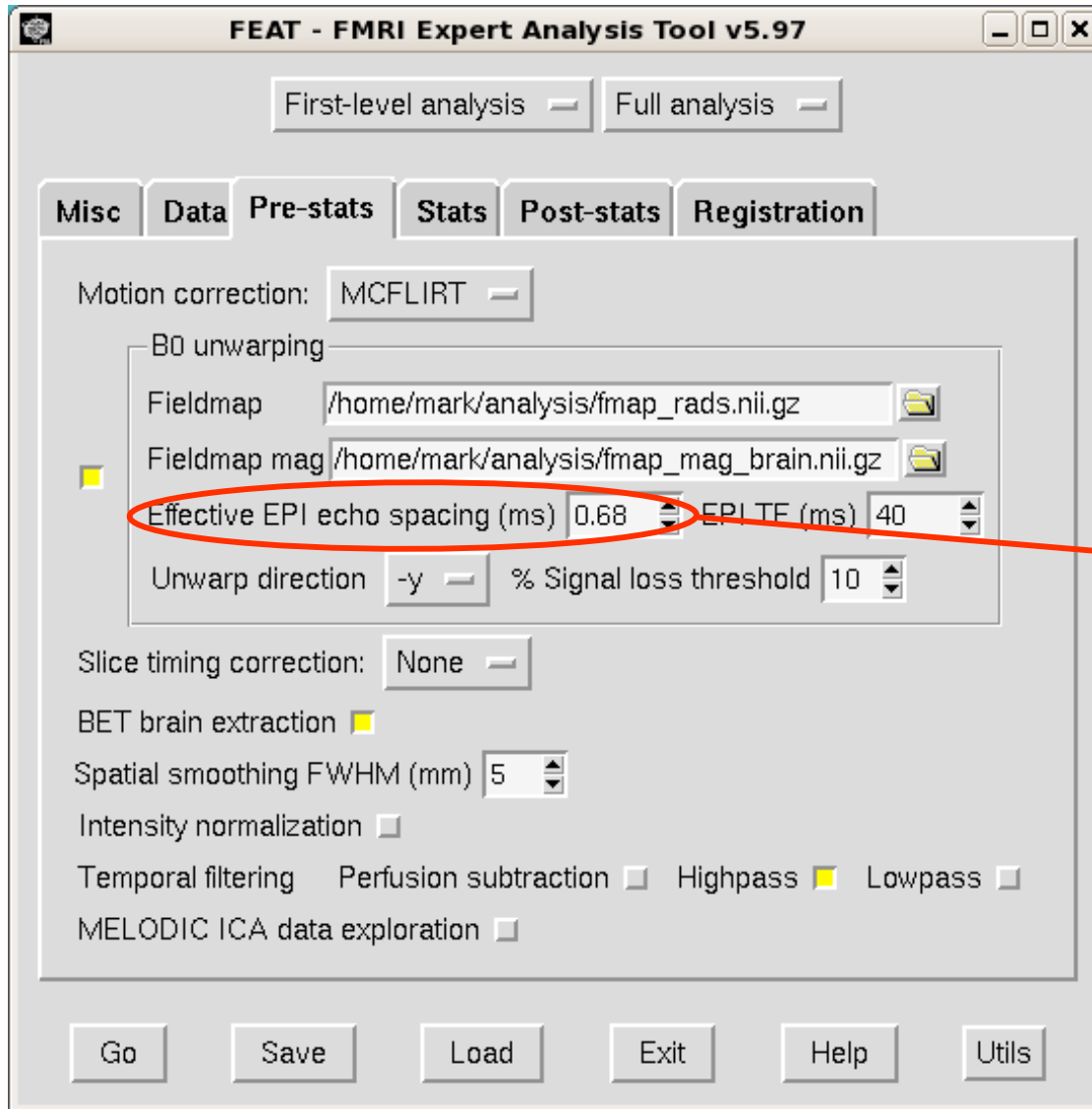
... and aggressive BET (leave **no** non-brain) for best performance



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



Distortion Correction within FEAT



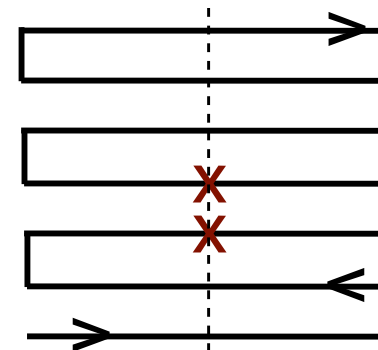
Fieldmap in rad/s

Fieldmap Magnitude

EPI echo spacing (ms)

Also called dwell time

Normally about 0.5-0.7ms

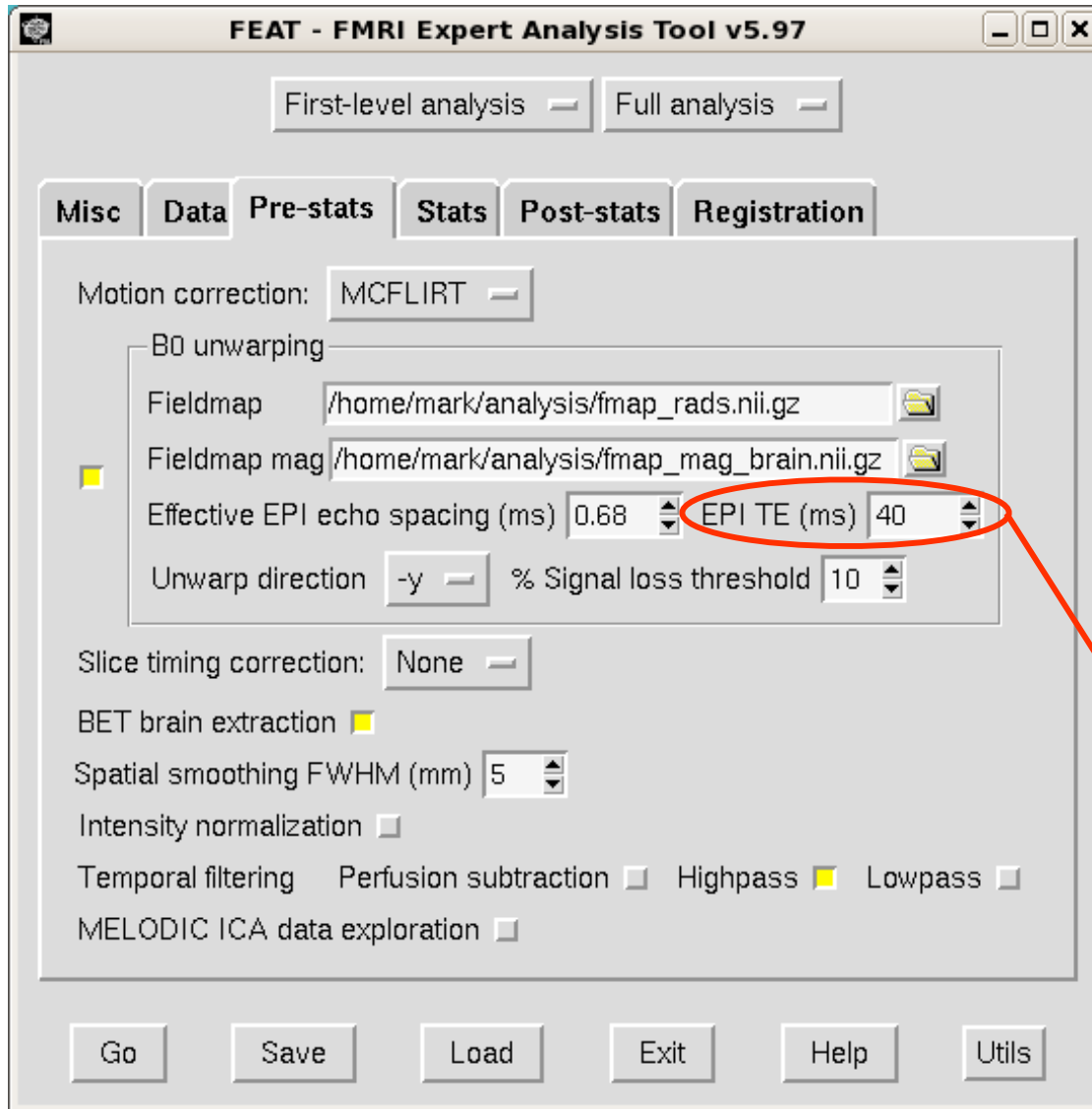


Time between echos in k-space

Divide value by any acceleration factor



Distortion Correction within FEAT



Fieldmap in rad/s

Fieldmap Magnitude

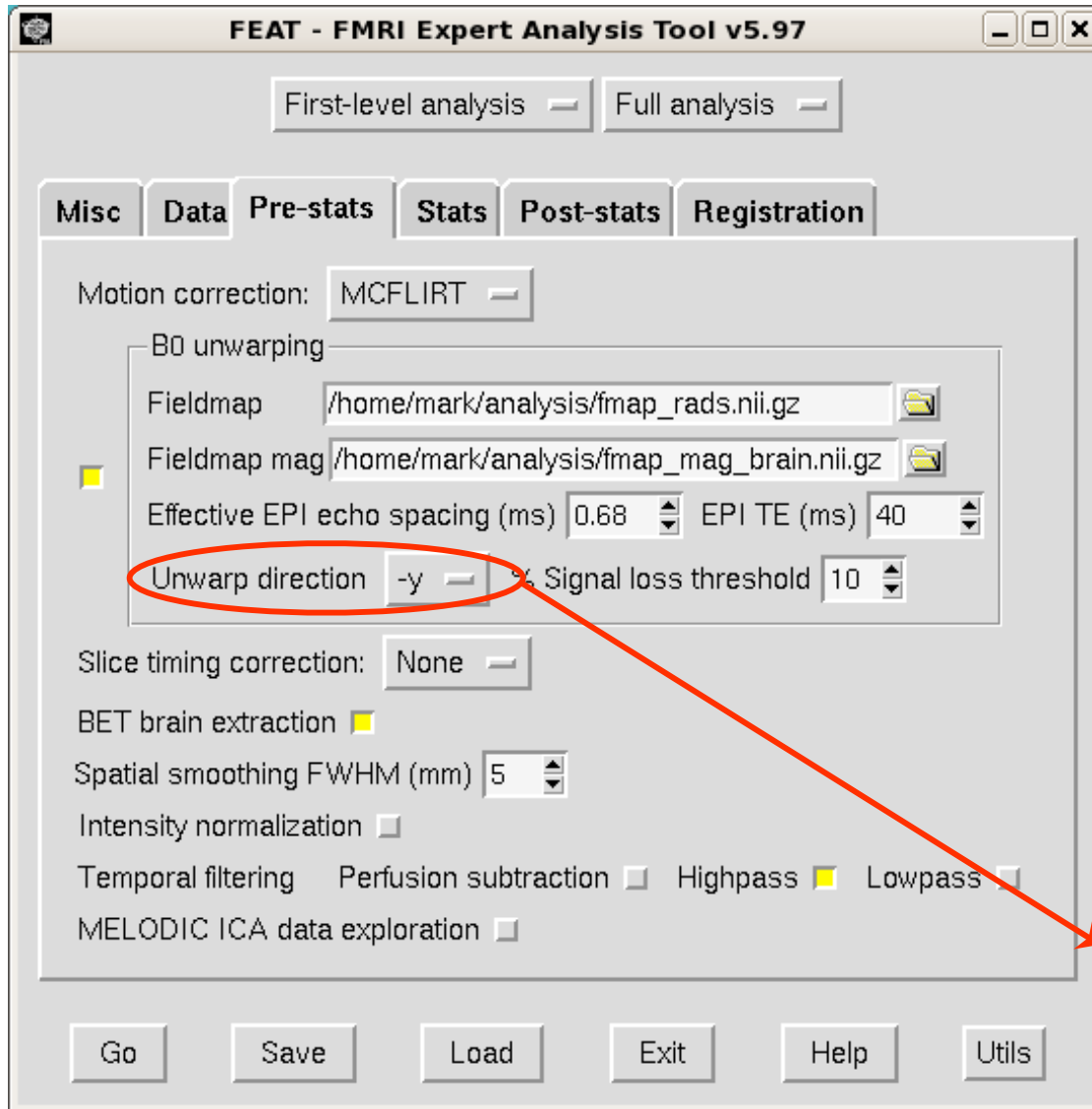
EPI echo spacing (ms)

EPI echo time (ms)

Normally about 30-40ms
at 3T



Distortion Correction within FEAT



Fieldmap in rad/s

Fieldmap Magnitude

EPI echo spacing (ms)

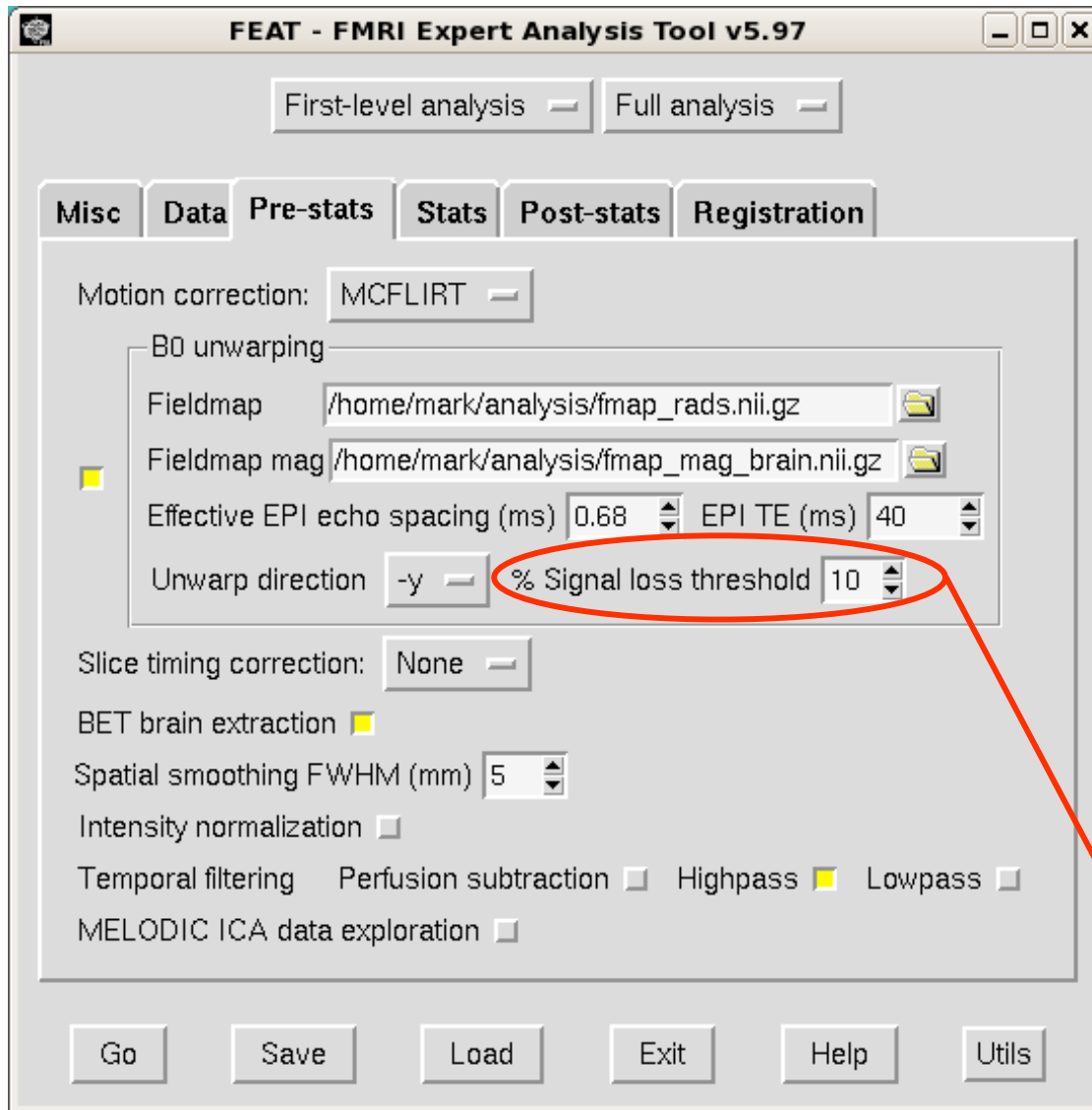
EPI echo time (ms)

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

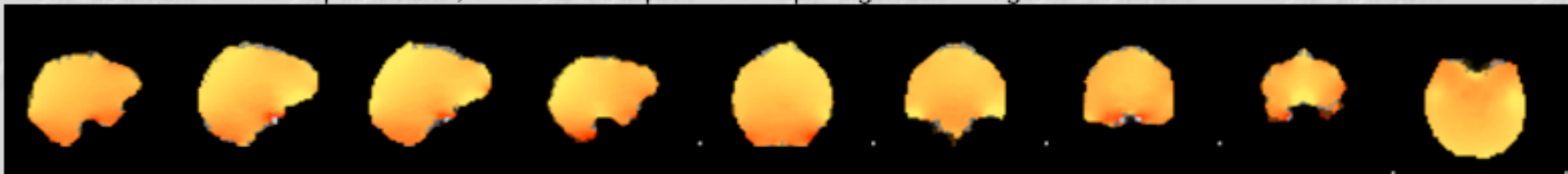
Signal loss thresh %

Ignore voxels with more than this signal loss in registration



Fieldmap use in FEAT

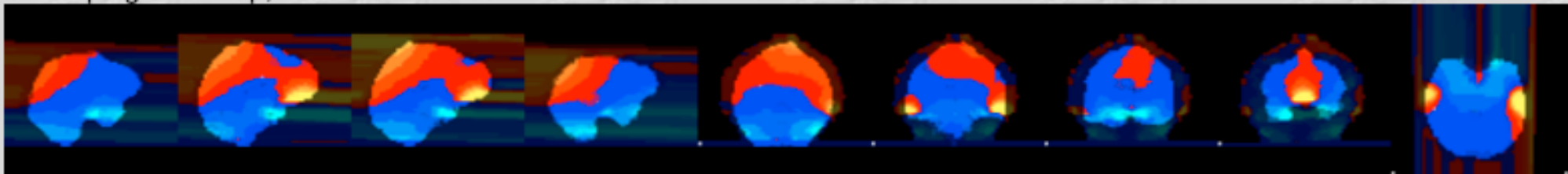
Brain-masked B0 fieldmap in colour, overlaid on top of fieldmap magnitude image



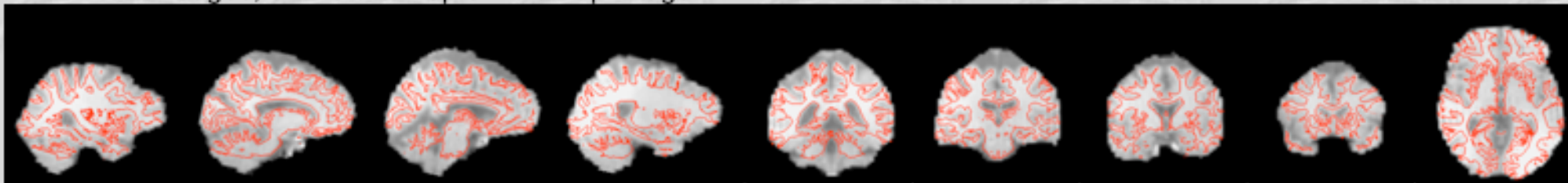
Thresholded signal loss weighting image



Unwarping shift map, in voxels -3.661111 0 4.190160



White matter edges, overlaid on top of fieldmap image



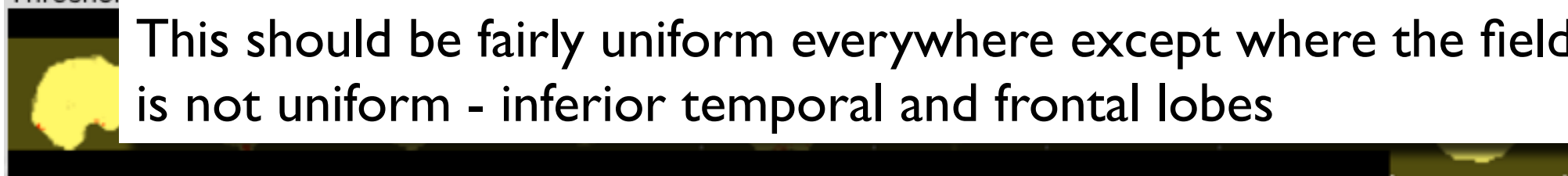


Fieldmap use in FEAT

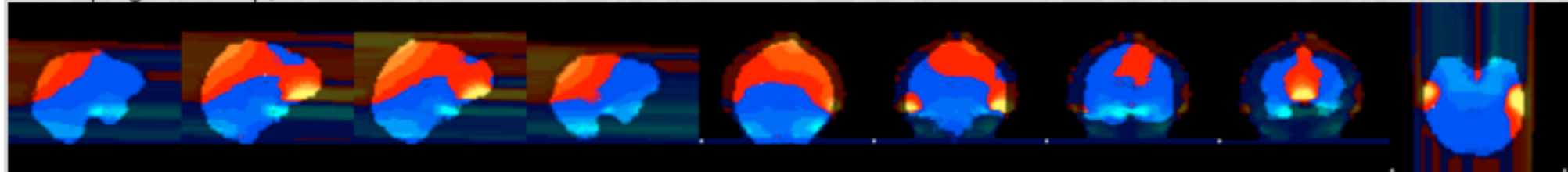
Brain-masked B0 fieldmap in colour, overlaid on top of fieldmap magnitude image



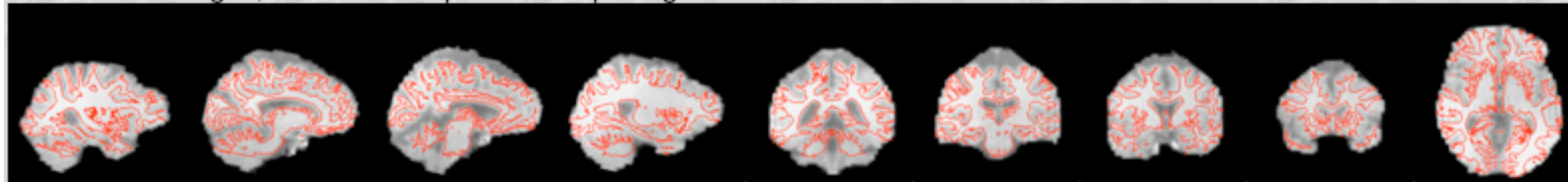
Thresholded signal loss weighting image



Unwarping shift map, in voxels -3.661111 0 4.190160



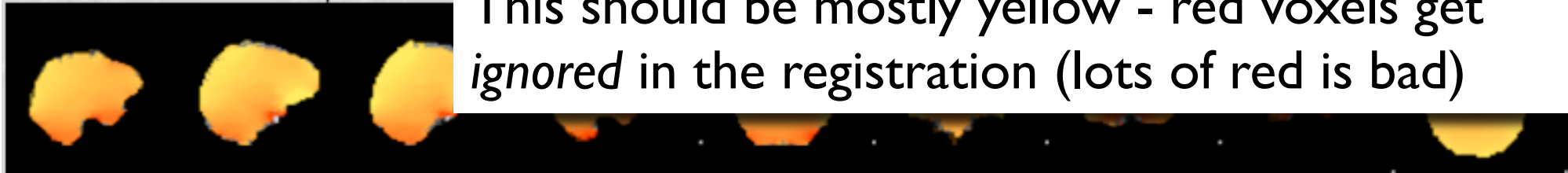
White matter edges, overlaid on top of fieldmap image





Fieldmap use in FEAT

Brain-masked B0 fieldmap in colour

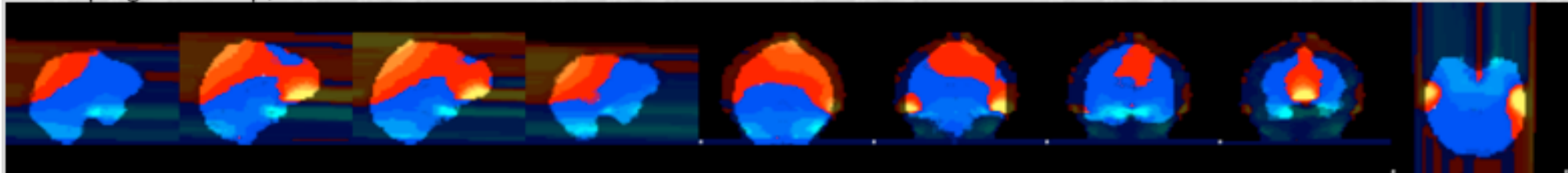


This should be mostly yellow - red voxels get ignored in the registration (lots of red is bad)

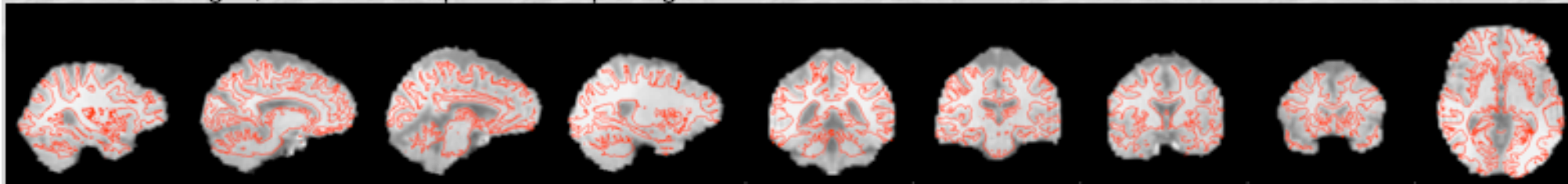
Thresholded signal less weighting image



Unwarping shift map, in voxels -3.661111 0 4.190160



White matter edges, overlaid on top of fieldmap image



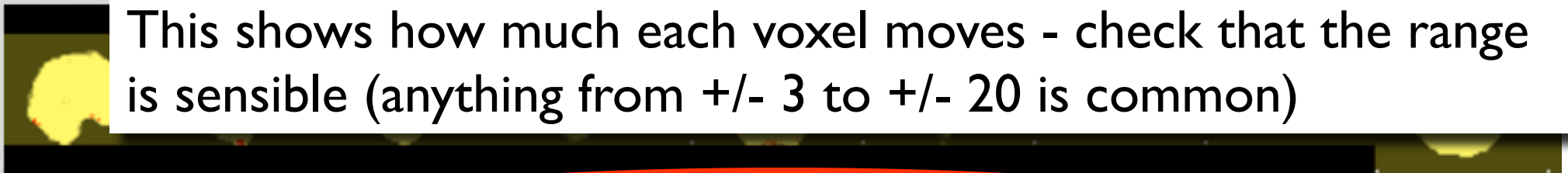


Fieldmap use in FEAT

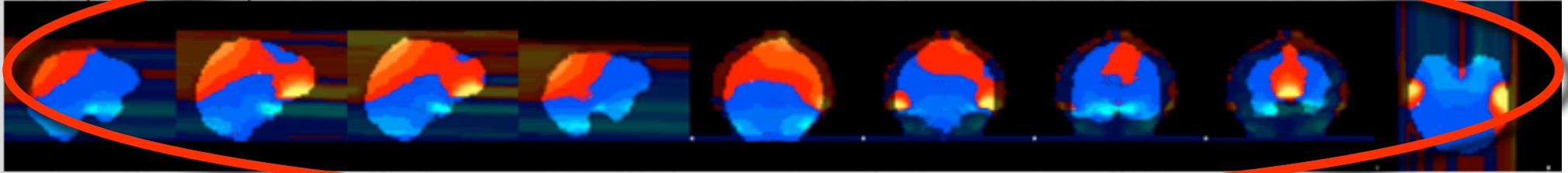
Brain-masked B0 fieldmap in colour, overlaid on top of fieldmap magnitude image



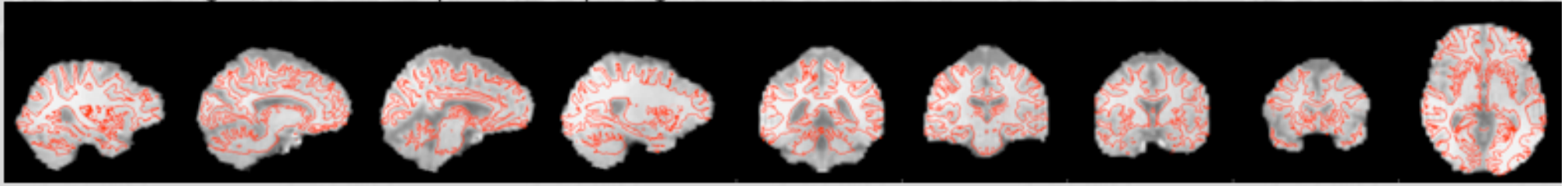
Thresholded signal loss weighting image



Unwarping shift map, in voxels -3.661111 0 4.190160



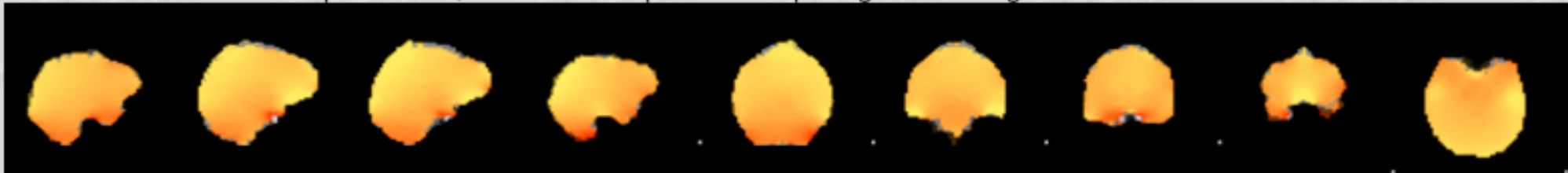
White matter edges, overlaid on top of fieldmap image





Fieldmap use in FEAT

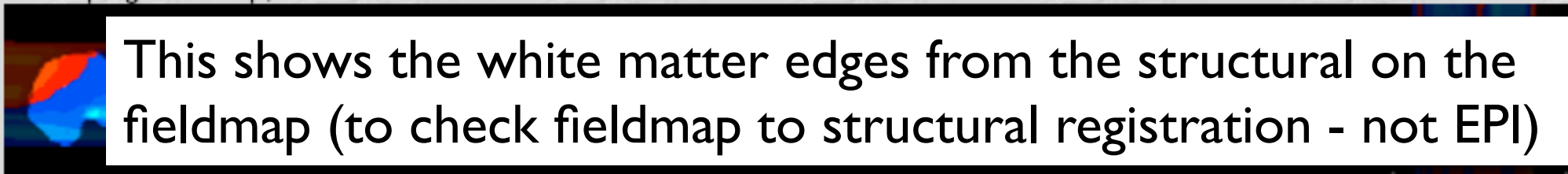
Brain-masked B0 fieldmap in colour, overlaid on top of fieldmap magnitude image



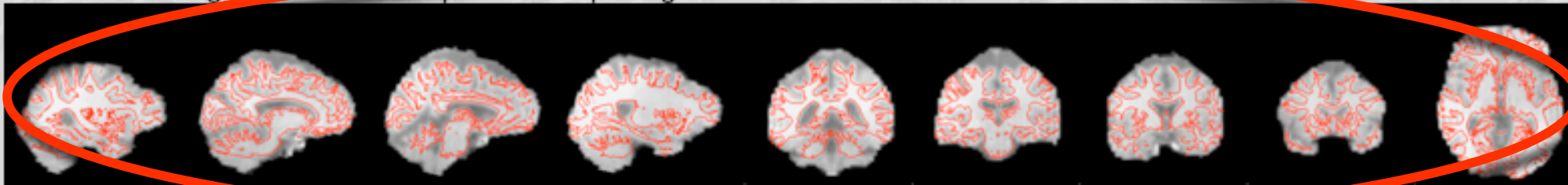
Thresholded signal loss weighting image



Unwarping shift map, in voxels -3.661111 0 4.190160



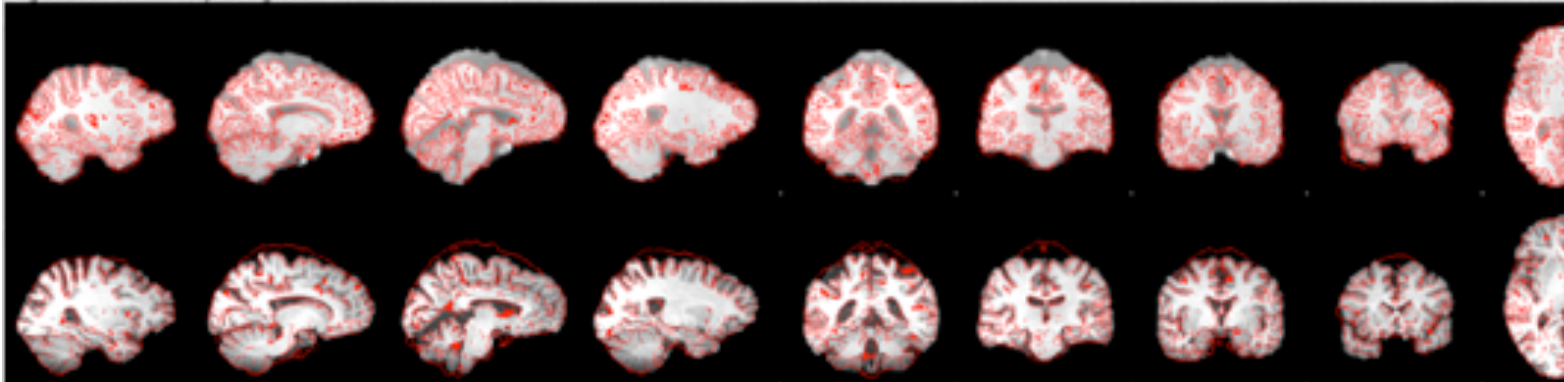
White matter edges, overlaid on top of fieldmap image





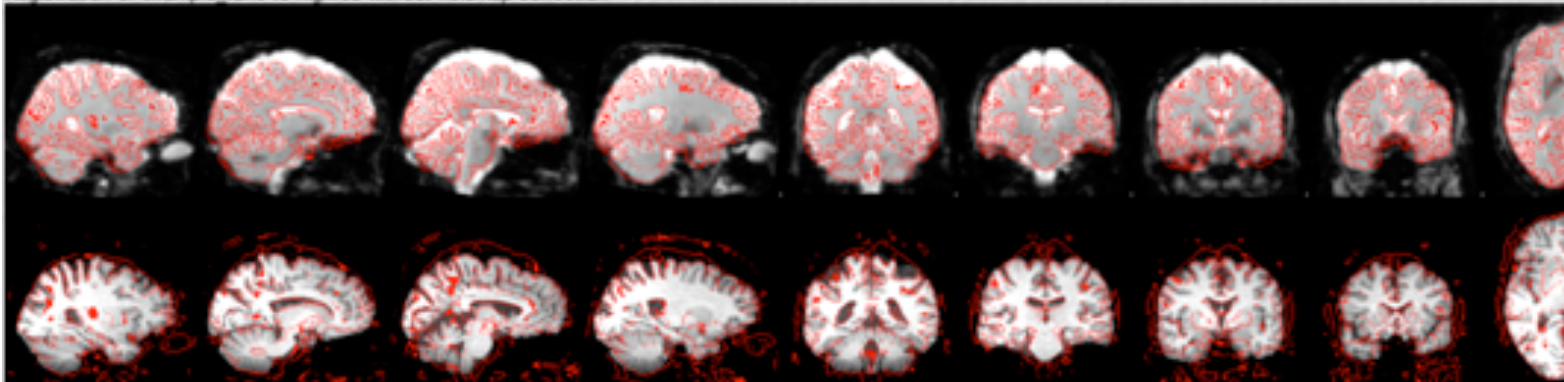
Fieldmap use in FEAT

Registration of fieldmap to highres



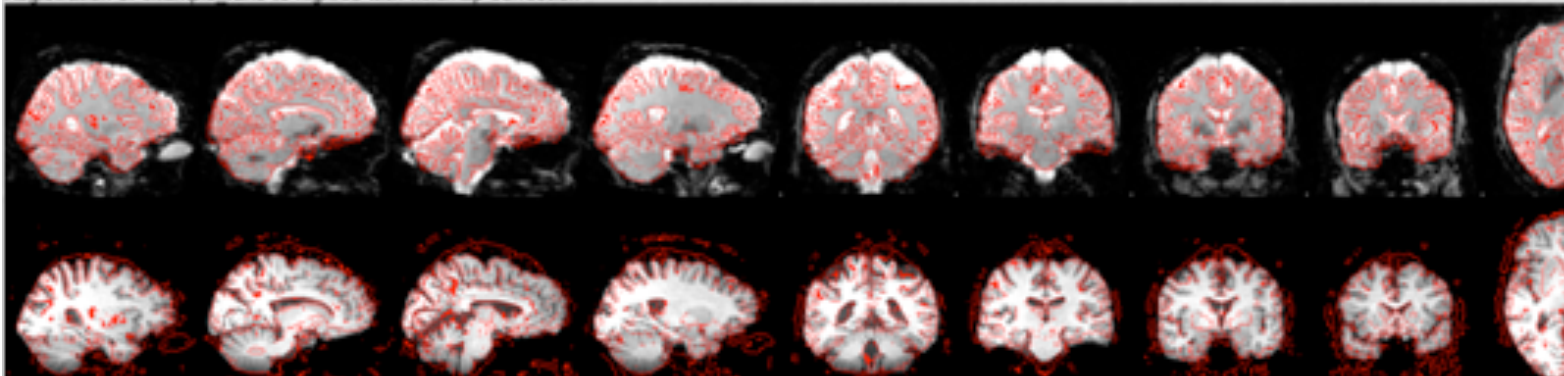
Fieldmap to
highres (structural)

Registration of example func to highres without fieldmap correction



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

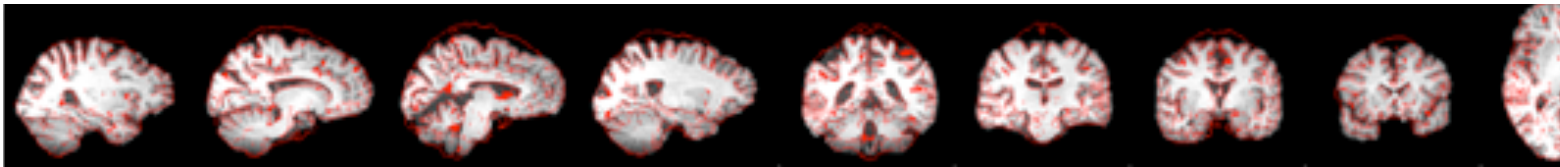
Registration of example func to highres with fieldmap correction



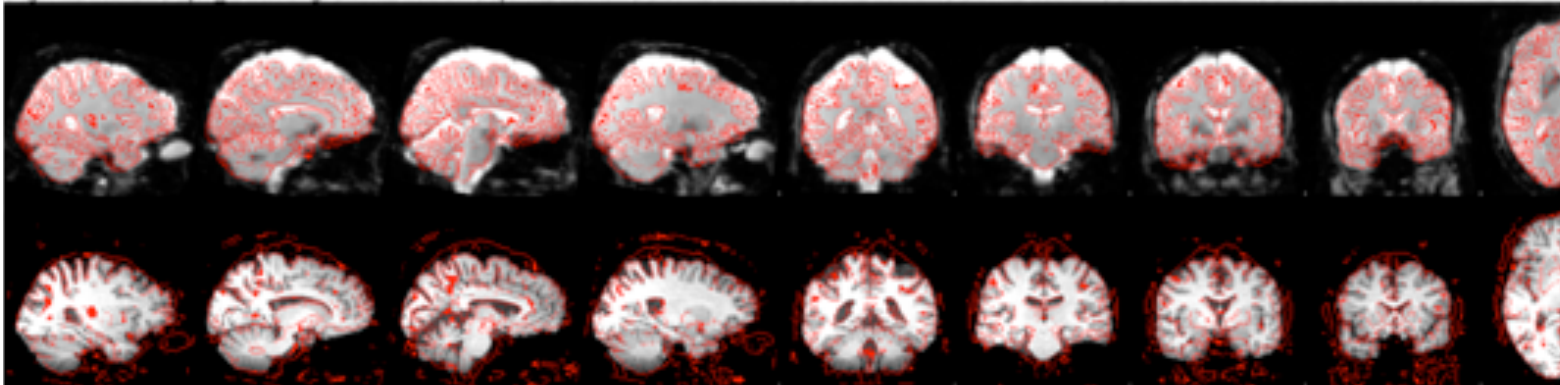
Functional (EPI) to
highres (structural)
- with fieldmap
correction



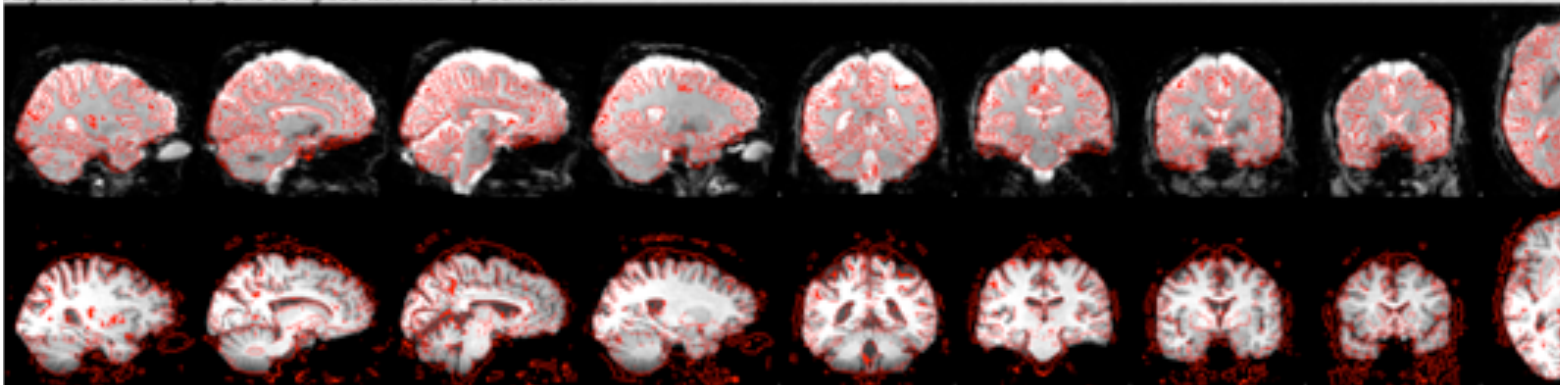
Fieldmap use in FEAT



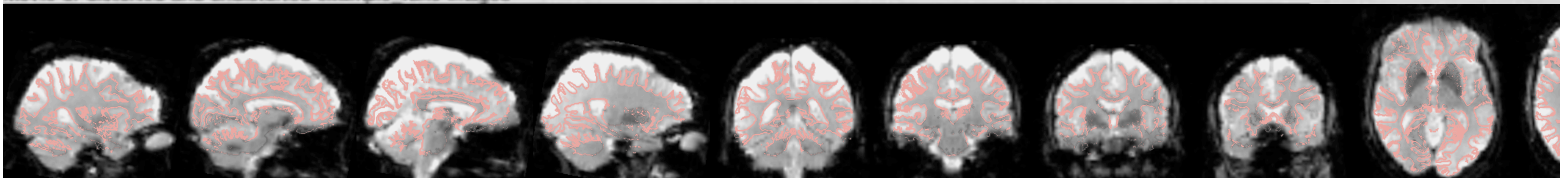
Registration of example func to highres without fieldmap correction



Registration of example func to highres with fieldmap correction



Movie of distorted and undistorted example func images



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

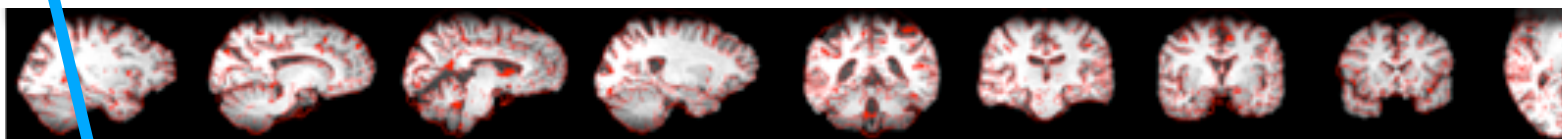
Functional (EPI) to highres (structural)
- with fieldmap correction

Movie of EPI with and without correction

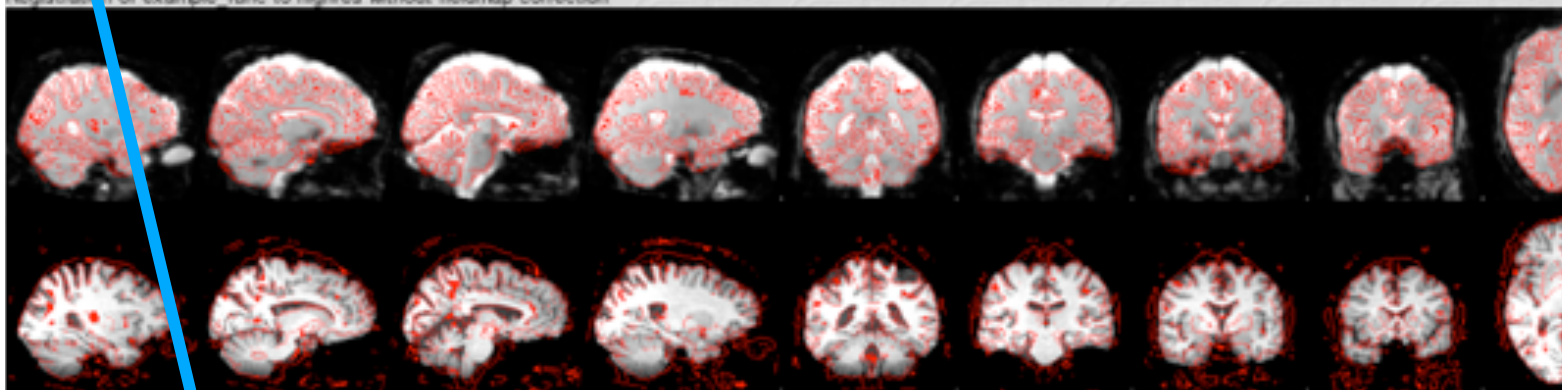


Fieldmap use in FEAT

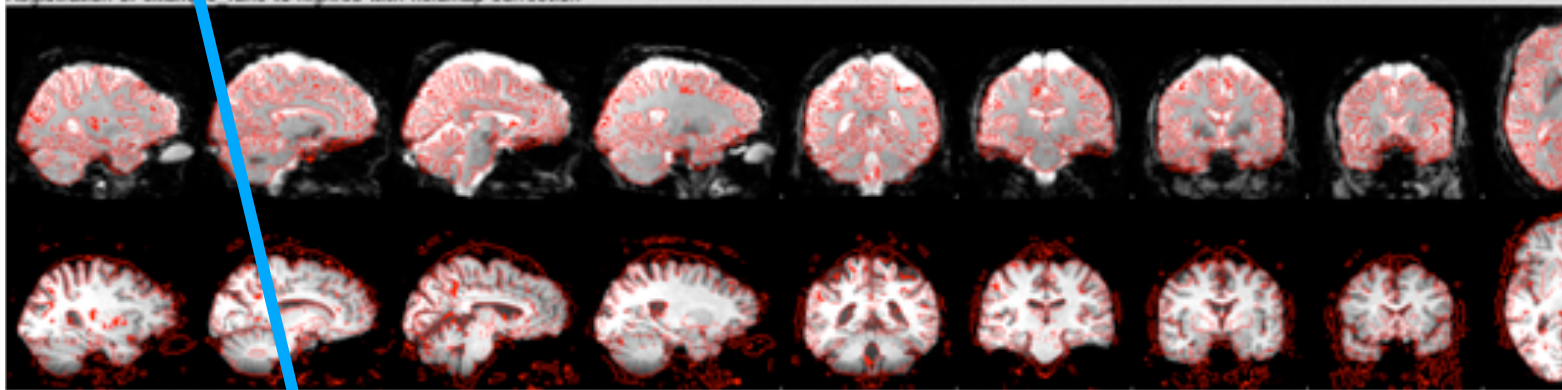
Look for areas where unwarping (correction) changes brain shape



Registration of example func to highres without fieldmap correction



Registration of example func to highres with fieldmap correction

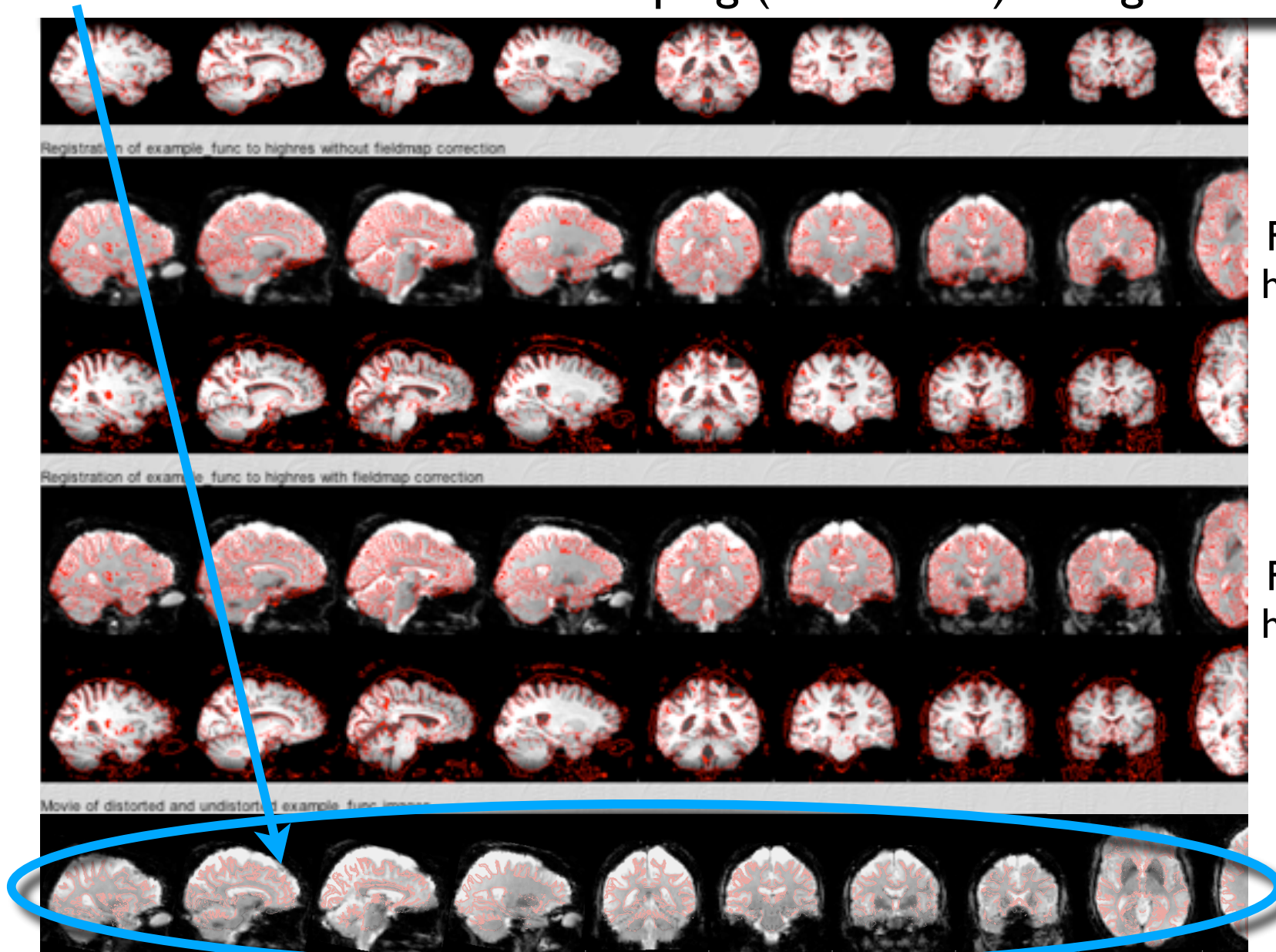


Movie of distorted and undistorted example func images

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

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

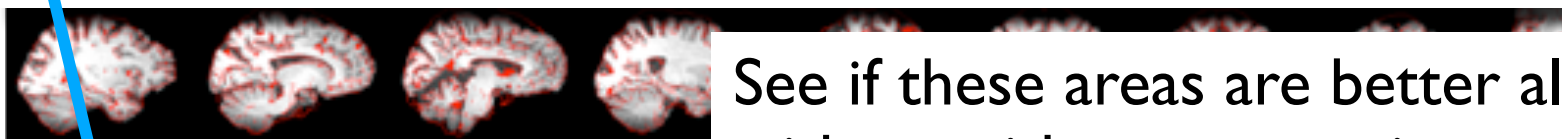
Movie of EPI with and without correction





Fieldmap use in FEAT

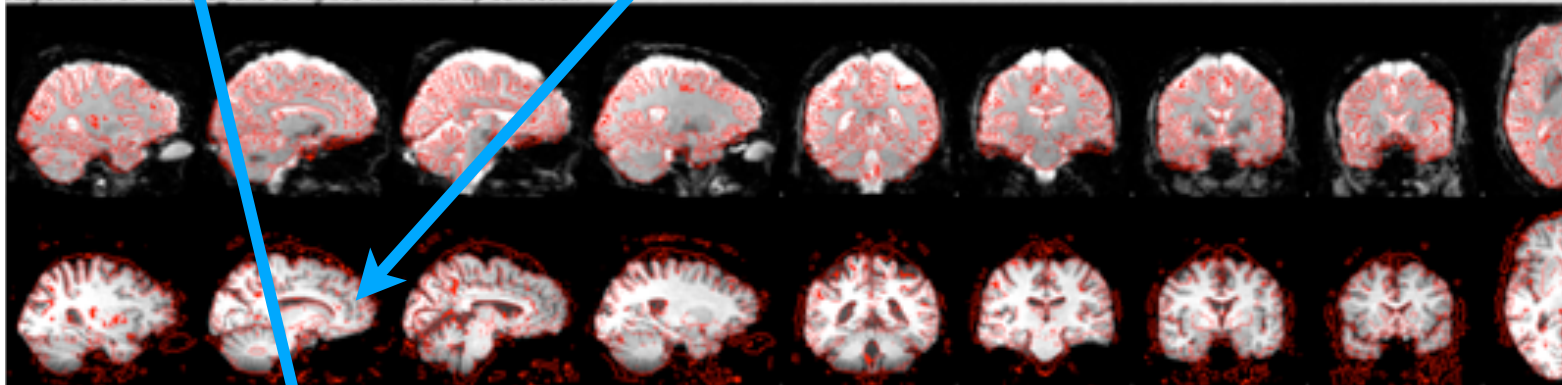
Look for areas where unwarping (correction) changes brain shape



Registration of example func to highres without fieldmap correction



Registration of example func to highres with fieldmap correction



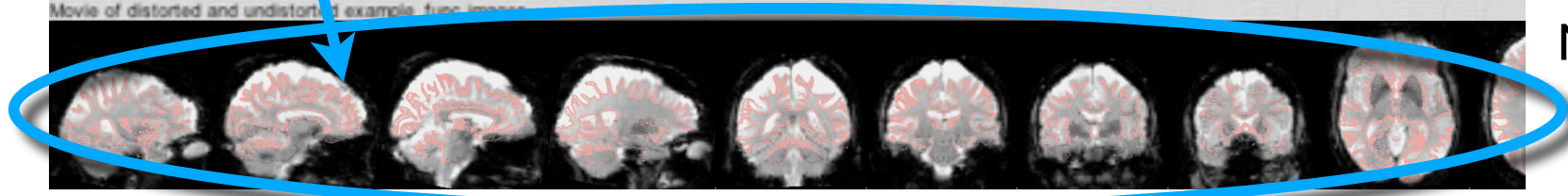
Movie of distorted and undistorted example func images

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

highres (structural)
- with fieldmap correction

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

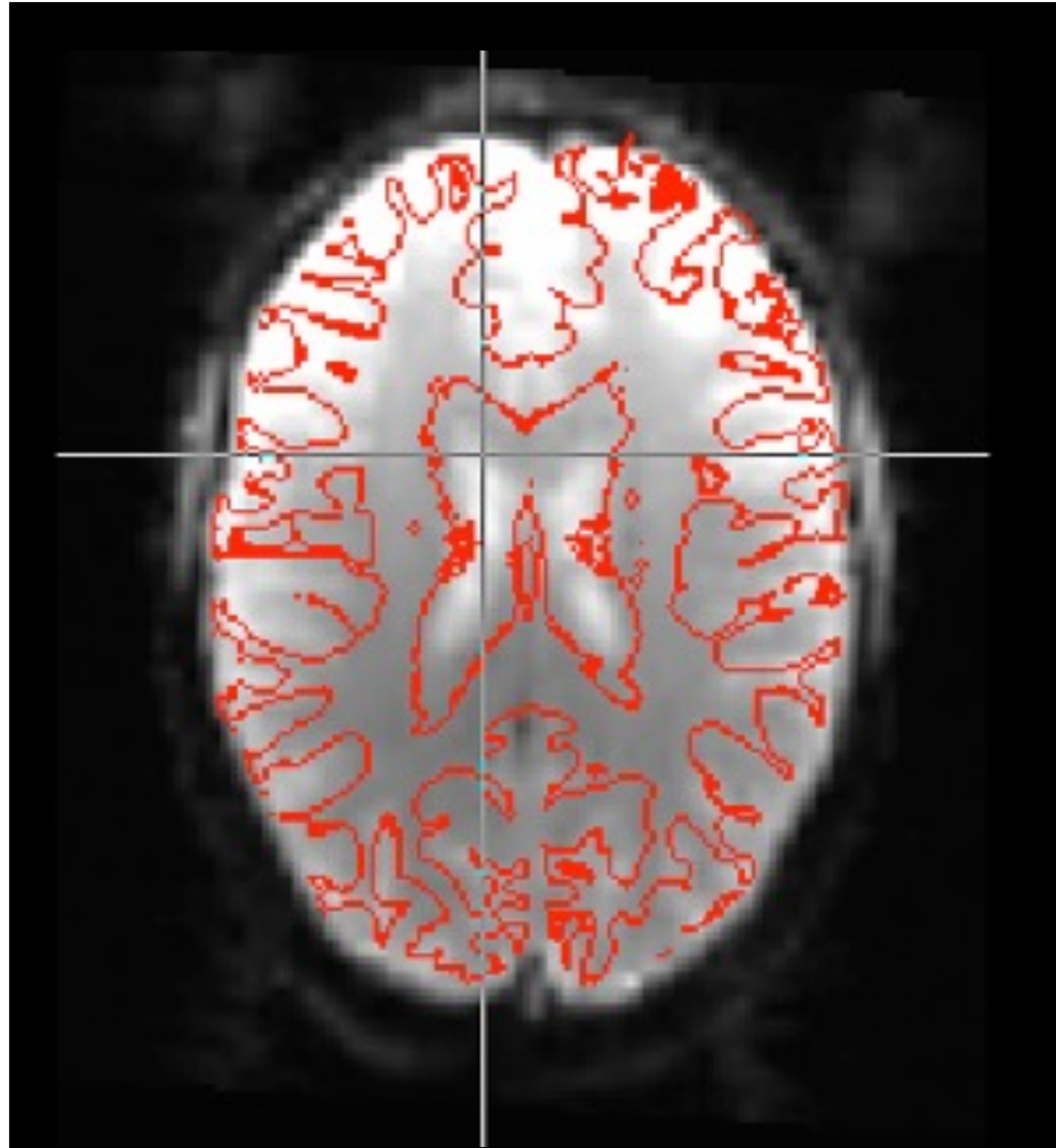
Movie of EPI with and without correction





BBR and Fieldmaps

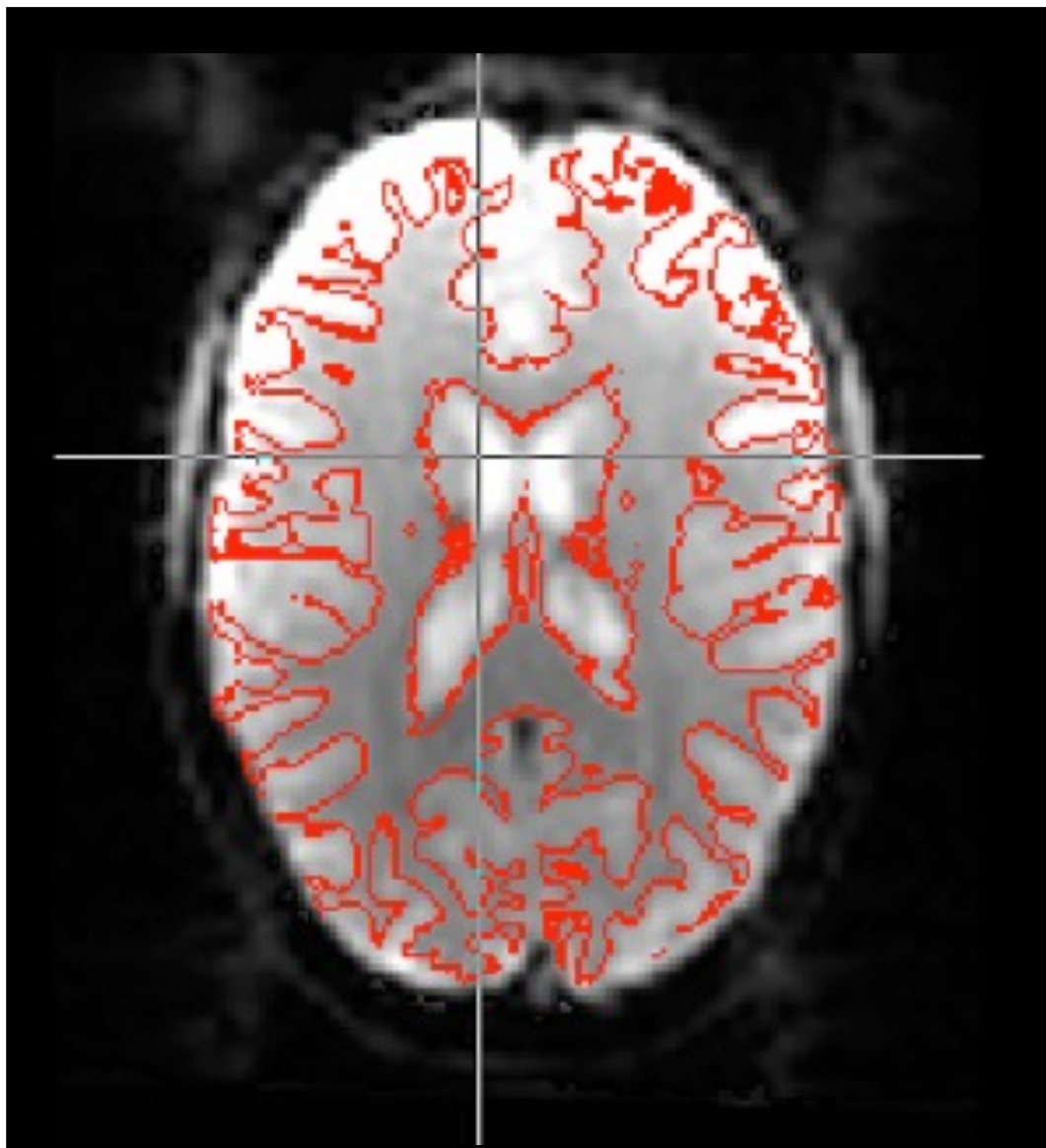
Standard FLIRT





BBR and Fieldmaps

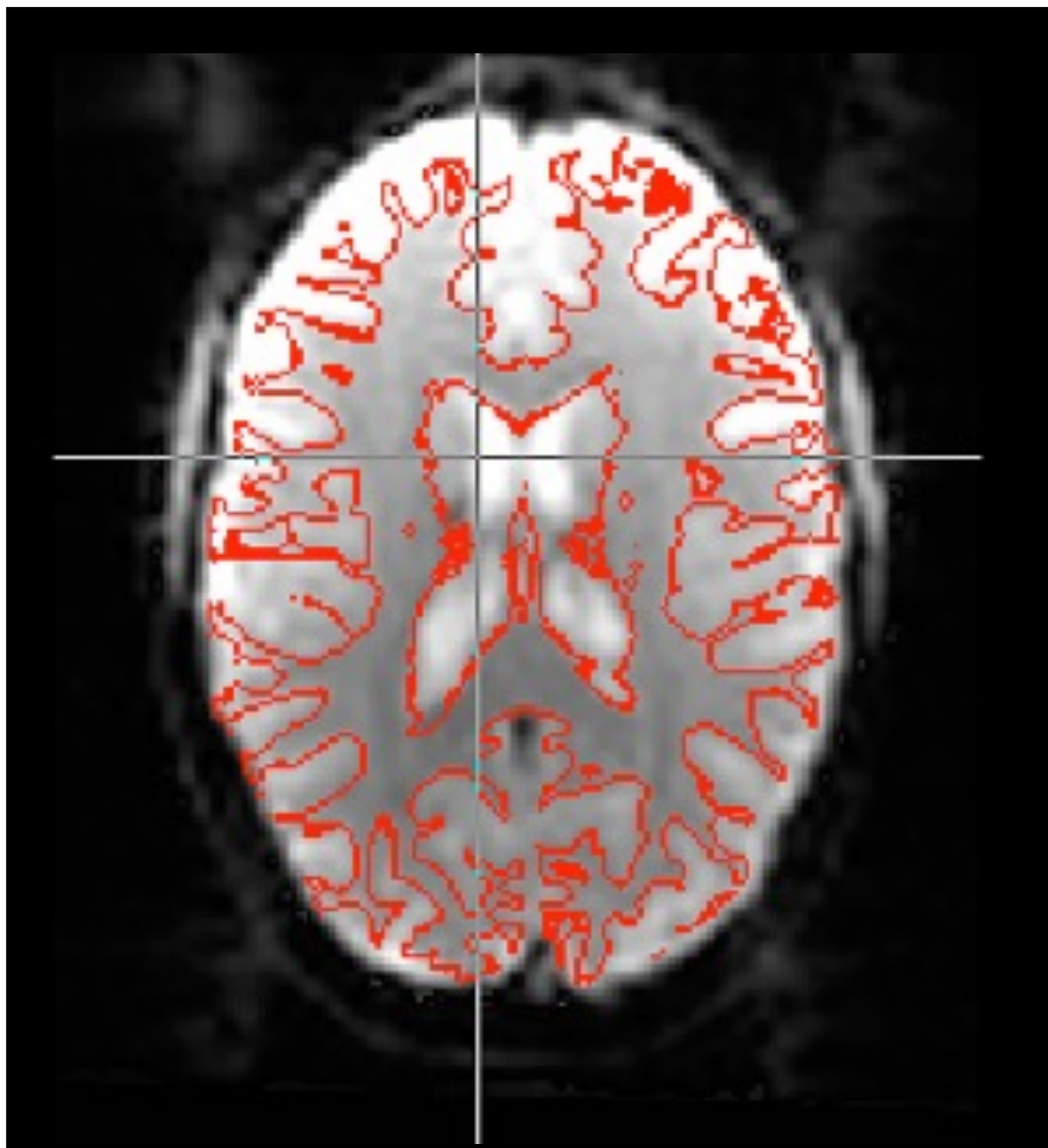
BBR FLIRT





BBR and Fieldmaps

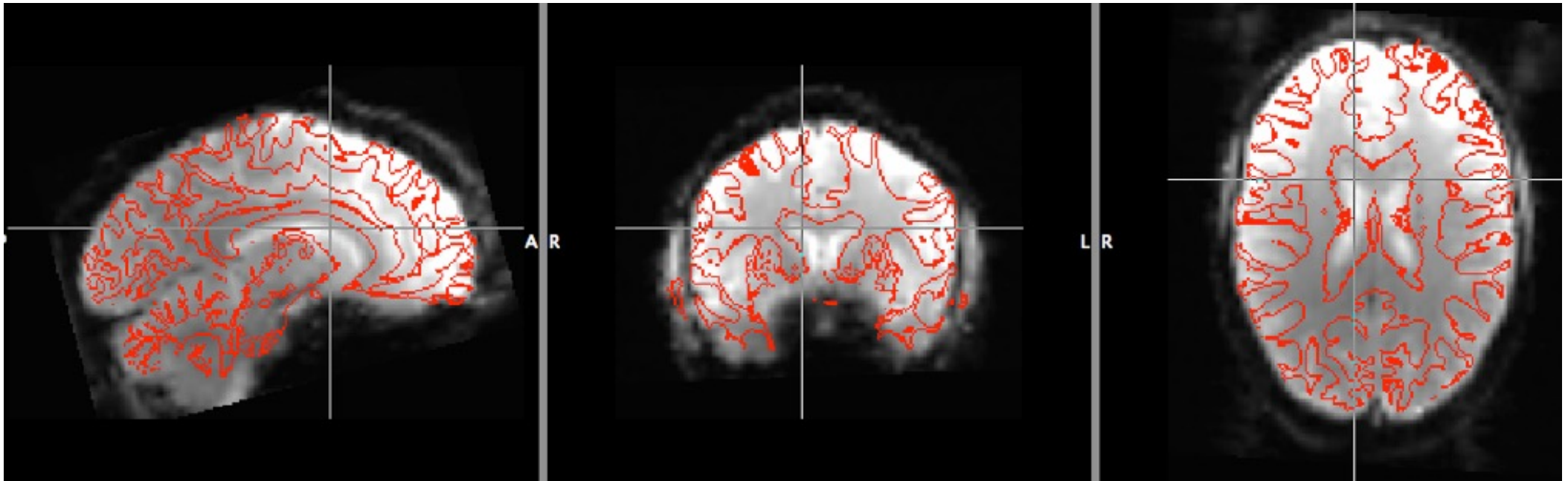
**BBR FLIRT
with Fieldmap**





BBR and Fieldmaps

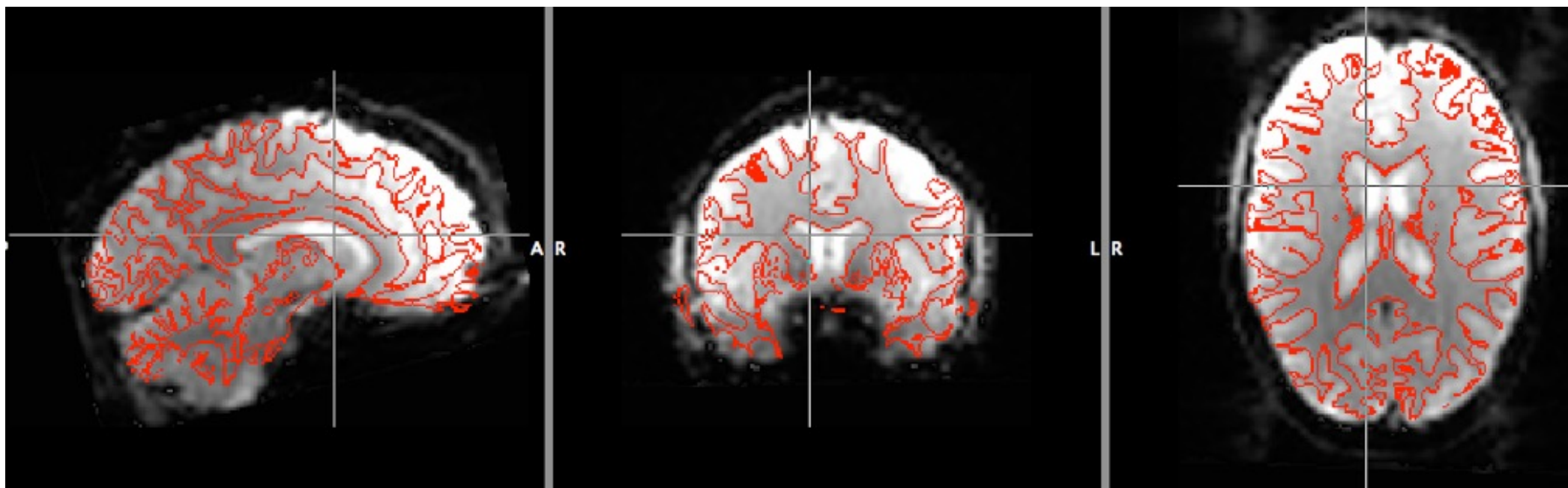
Standard FLIRT





BBR and Fieldmaps

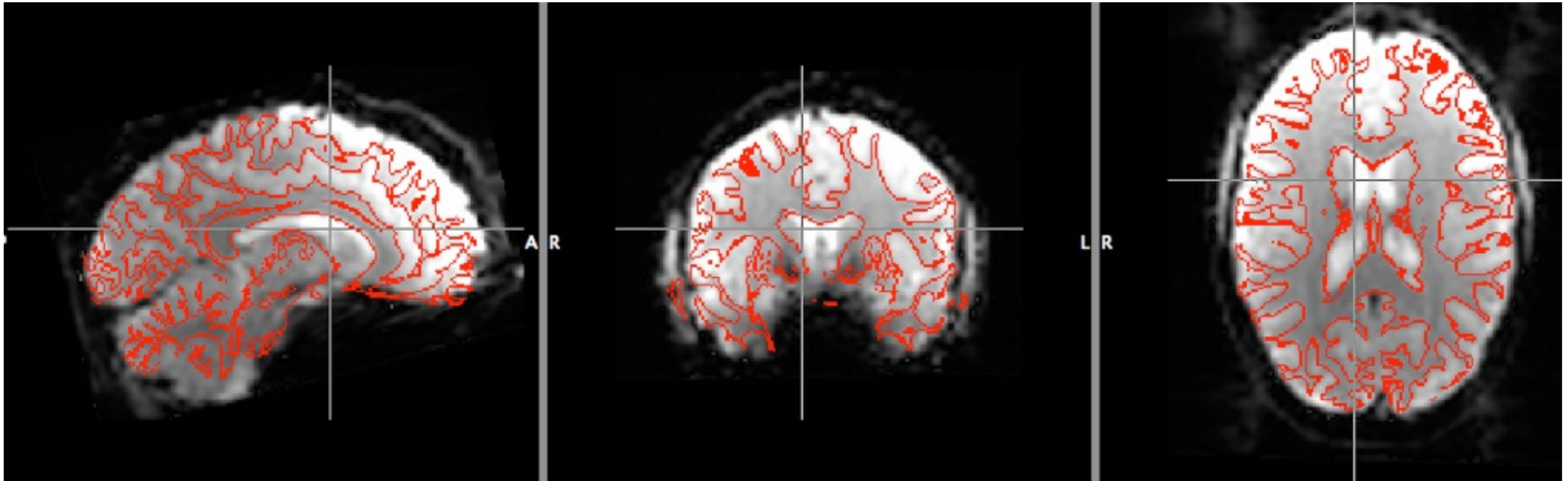
BBR FLIRT





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)