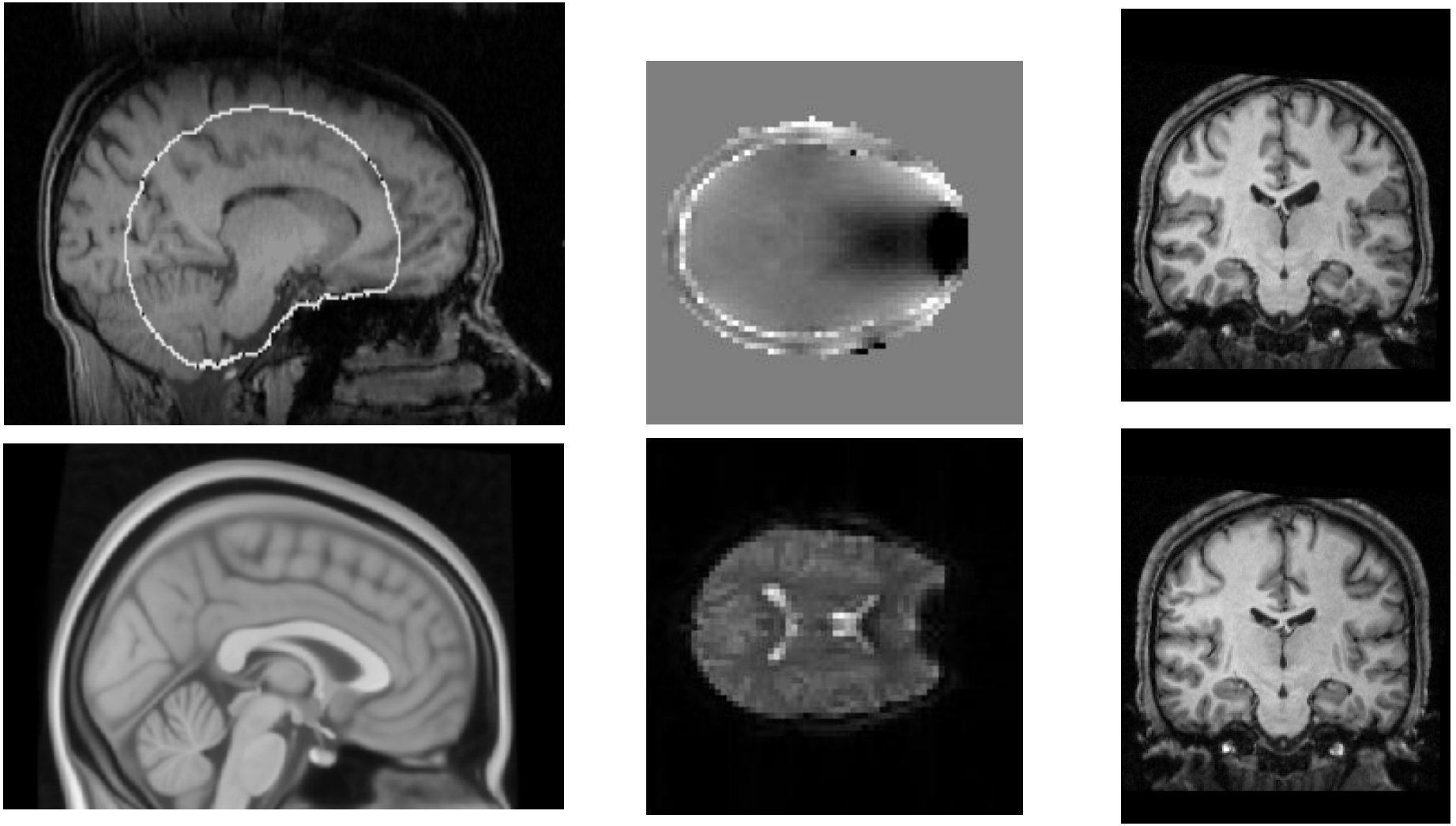
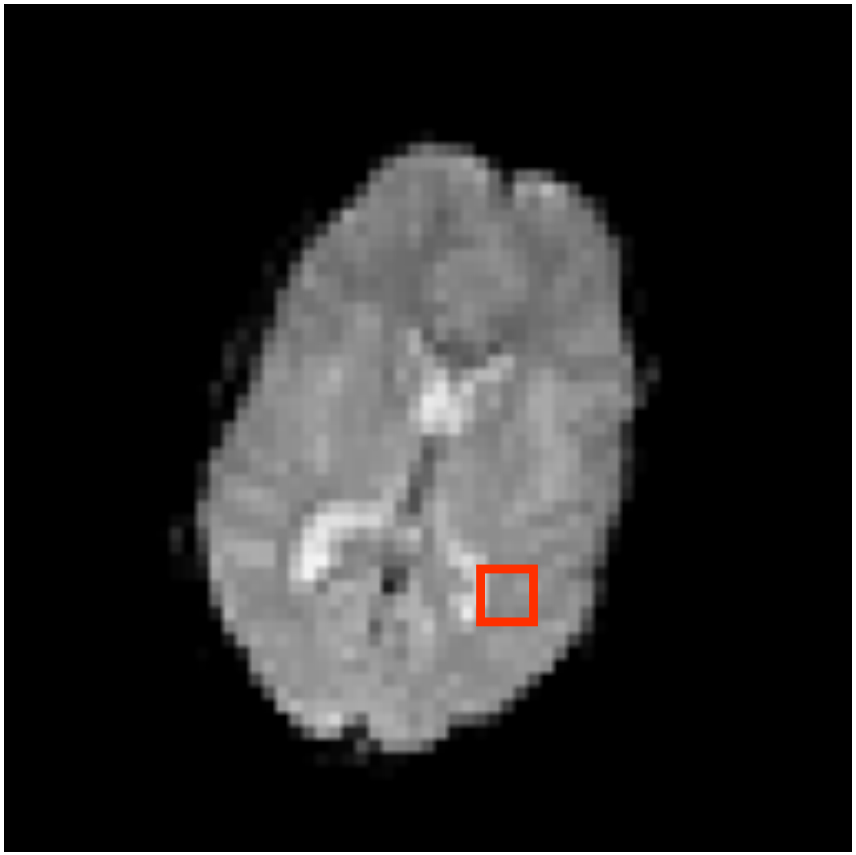
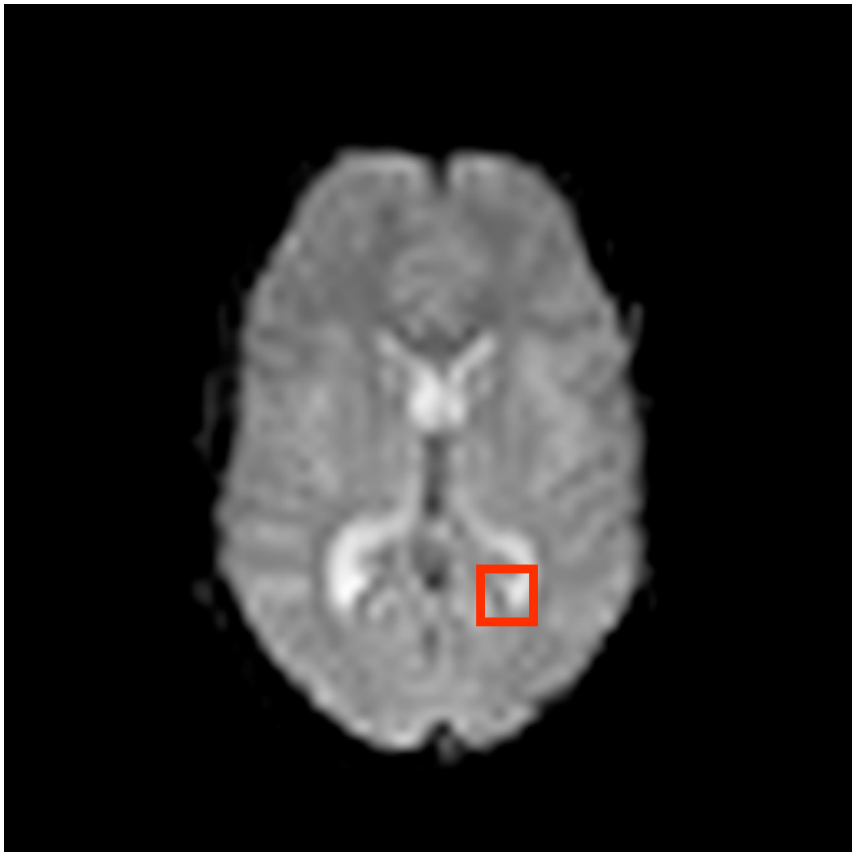
Introduction to Brain Extraction and Registration



What is Registration?



What is Registration?



Align images so that

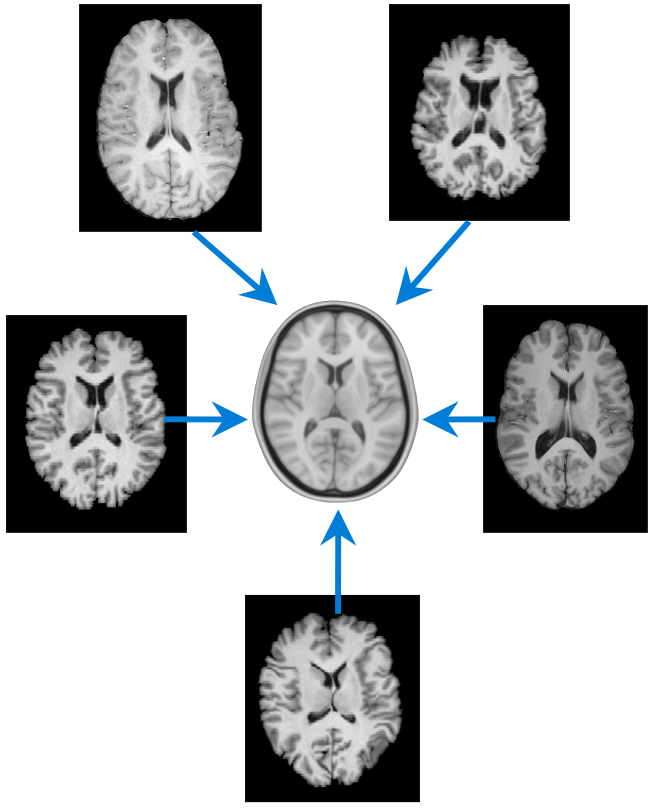
voxel location = anatomical location

with accurate intensity values

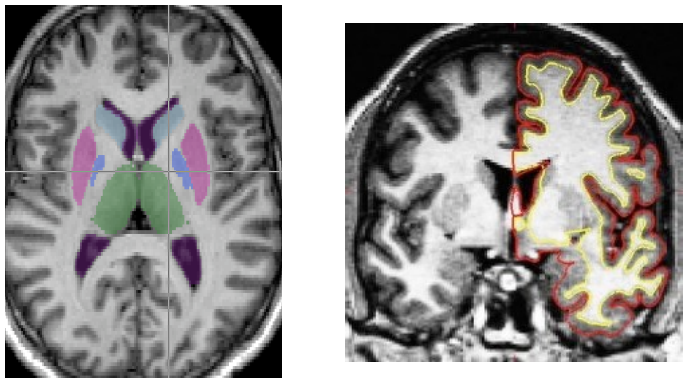
What use is Registration?

Some common uses of registration:

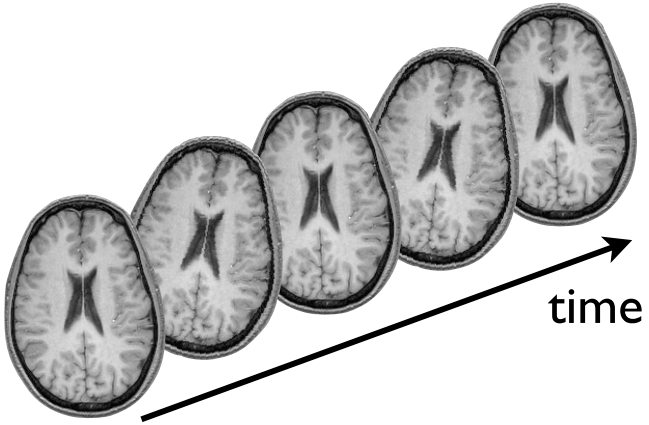
Combining across individuals in group studies: including fMRI & diffusion



Quantifying structural change



Correcting for motion

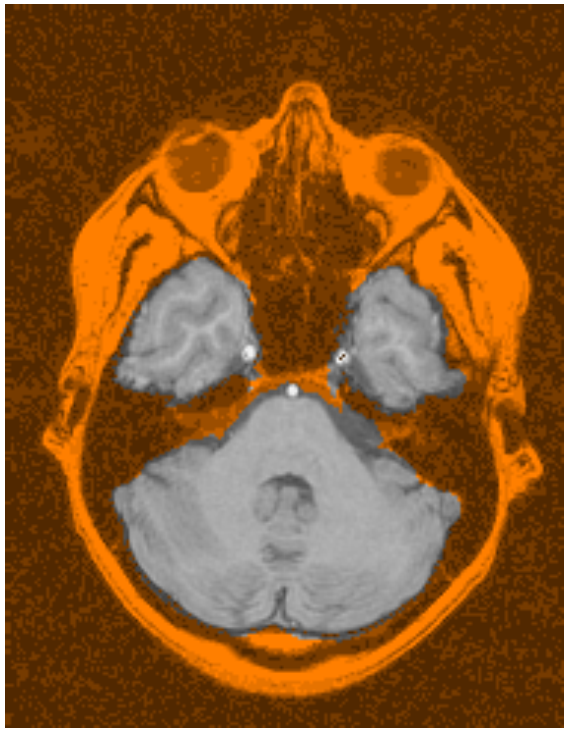


BET: Brain Extraction Tool

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



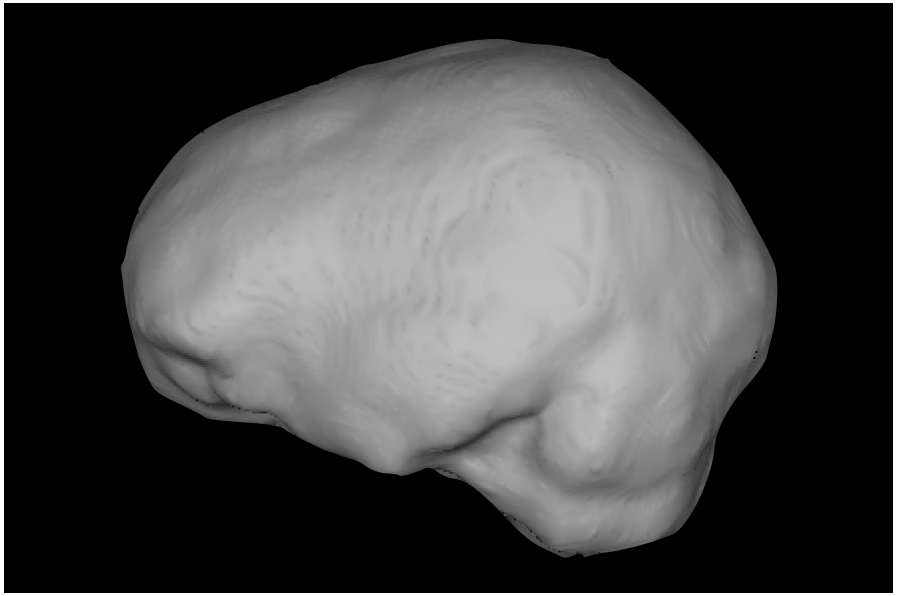
S.M. Smith; Fast robust automated brain extraction; HBM 17(3), 2002.

Robust to bias fields (by using local intensity changes)

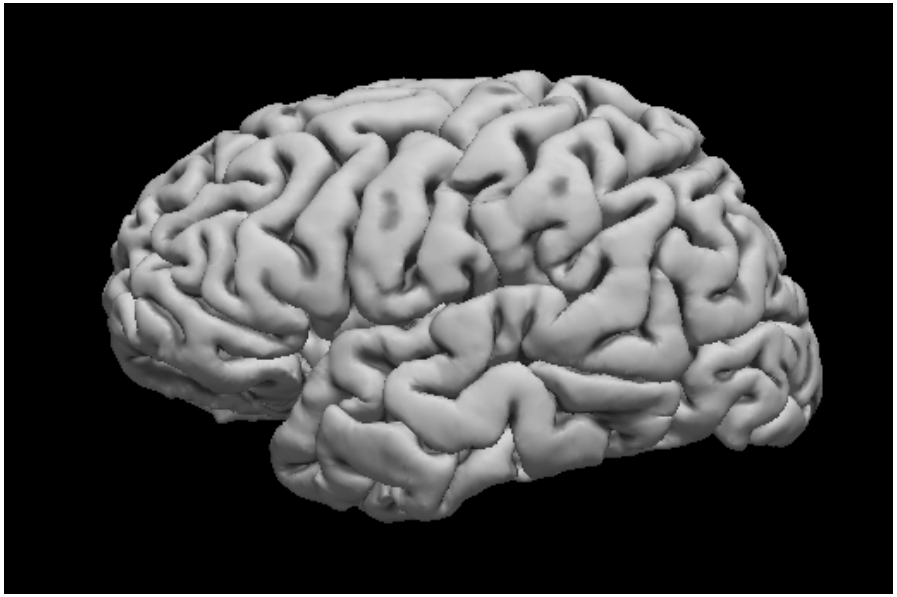
Works with a wide range of MRI sequences (T1, T2, etc.) and resolutions

Example Results

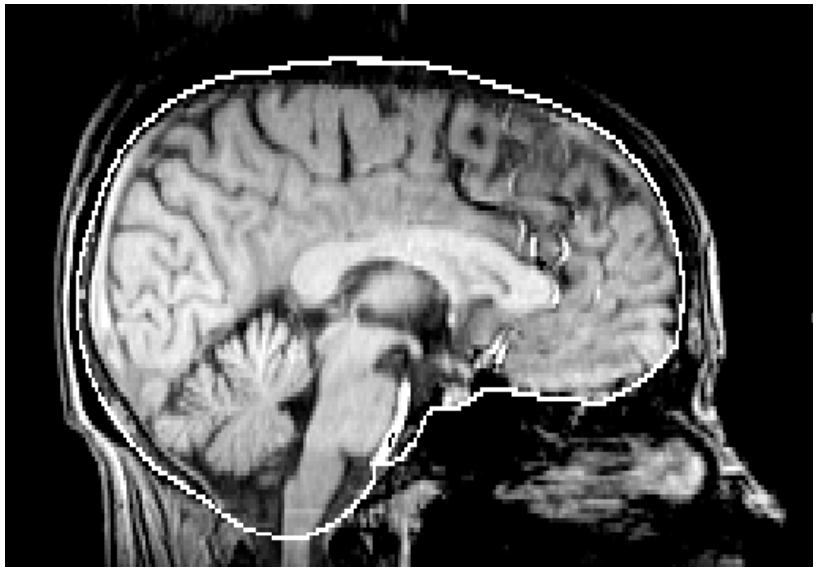
Brain Surface Model

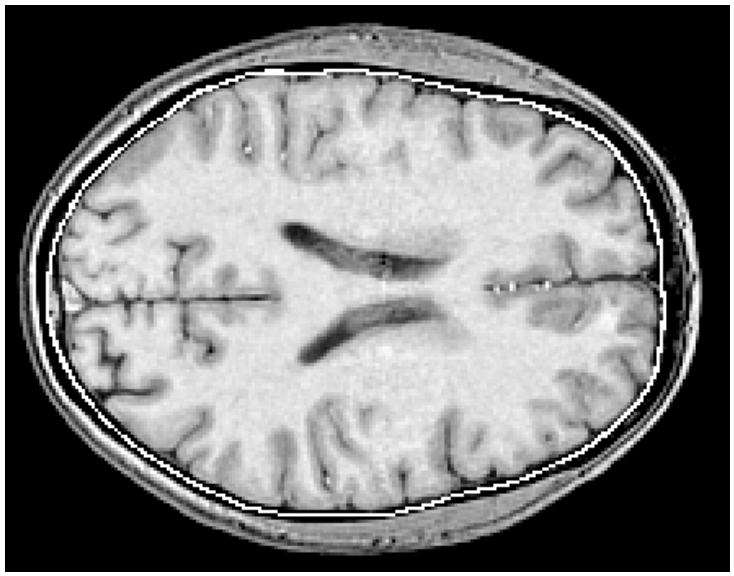


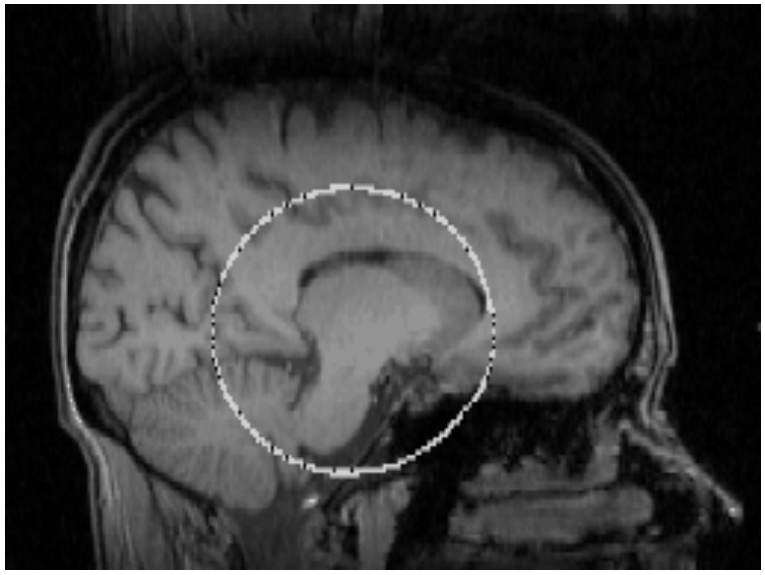
Extracted Brain Surface
(not what we aim for here)



Example Results

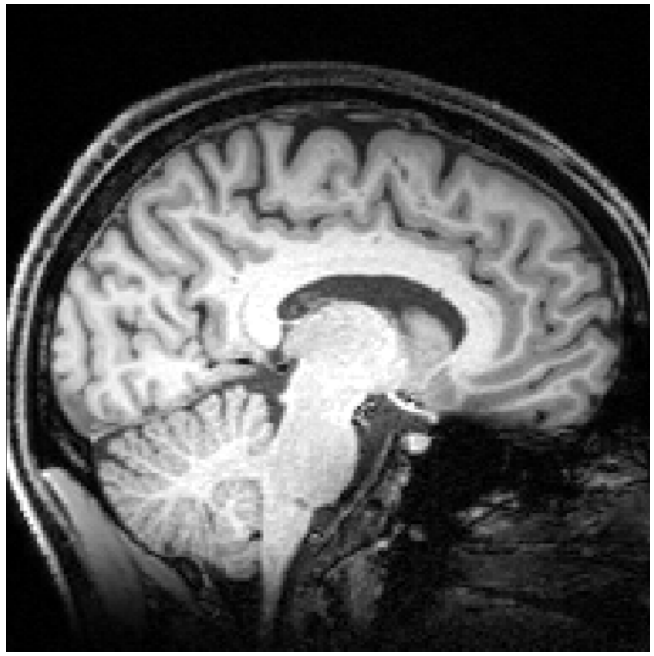




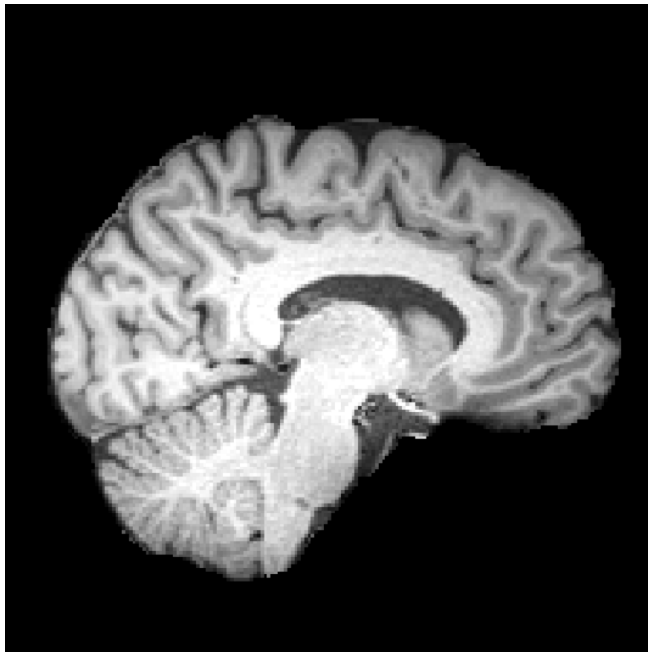


Example Results

Original

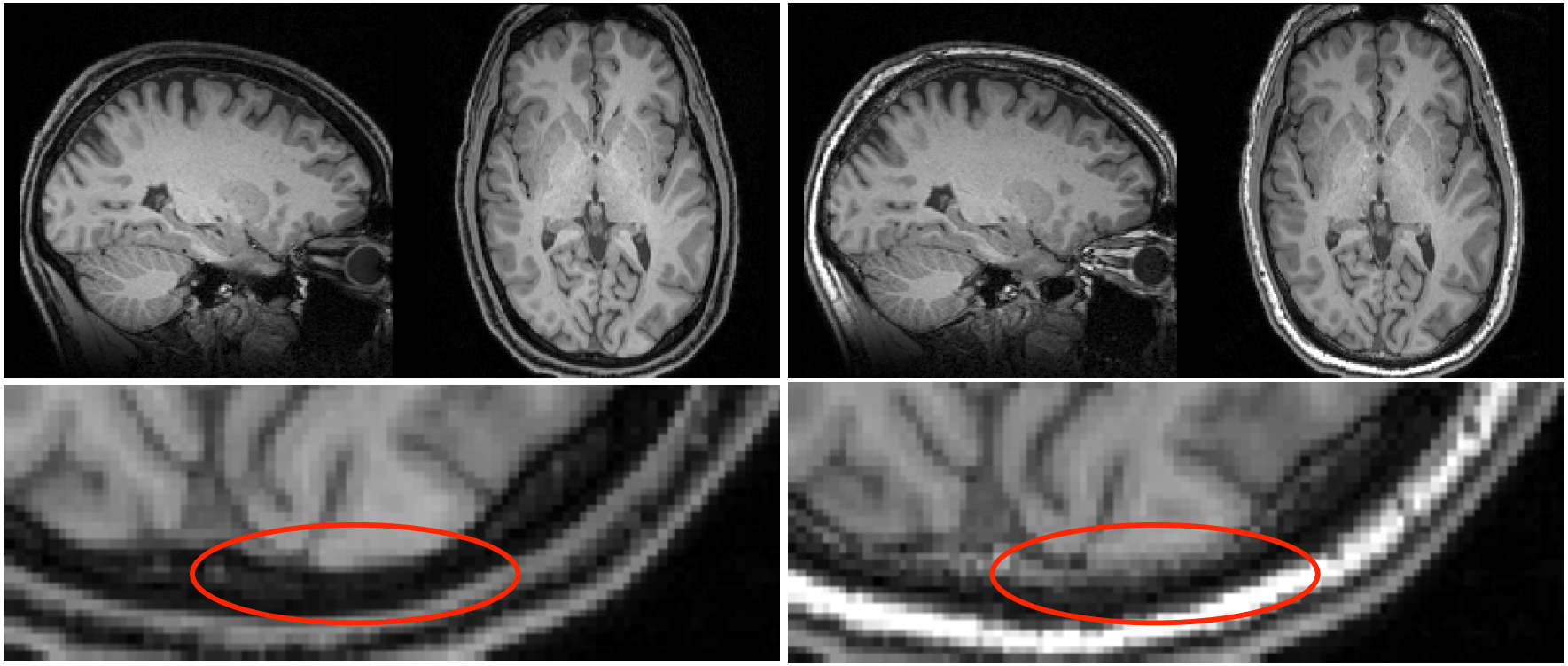


Brain Extracted

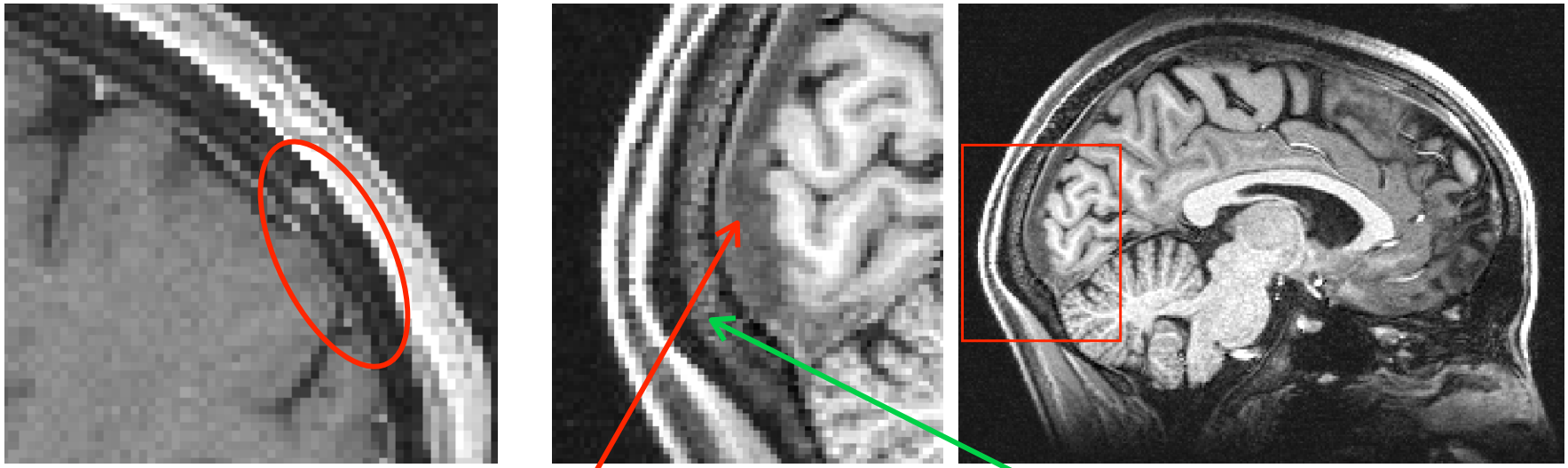


Brain Mask

Difficulties



Marrow



Membranes

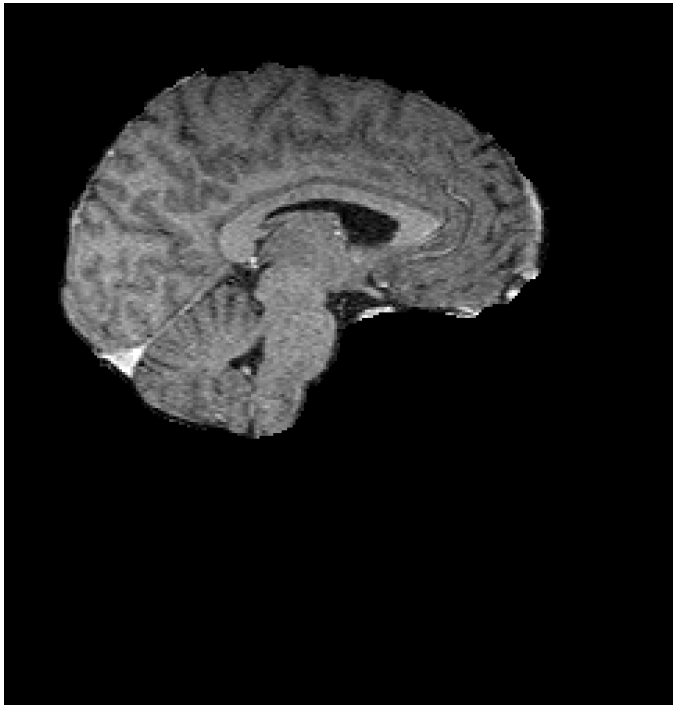
Blood (sinus)

Marrow

Example Results

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

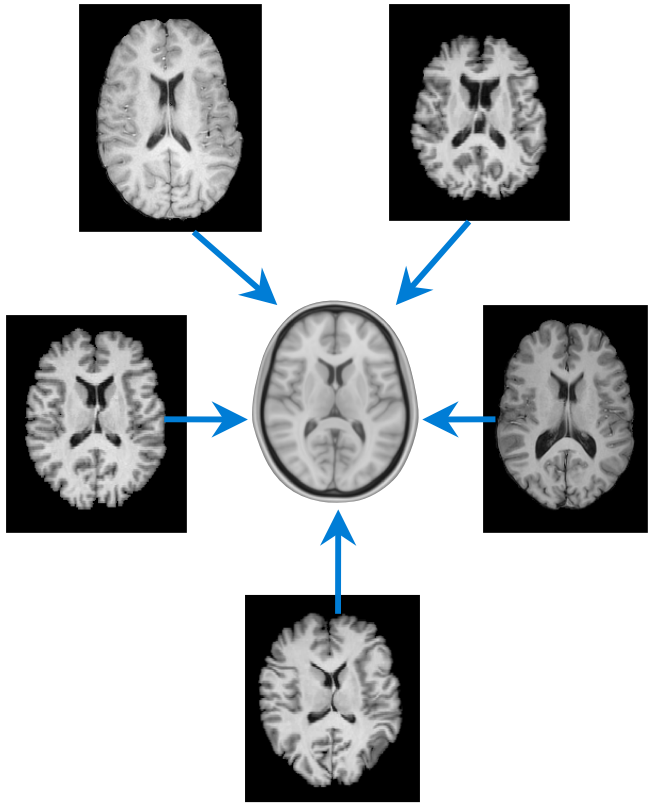
Leaving small pieces of non-brain is *unimportant for linear registration*, but it is important for segmentation.



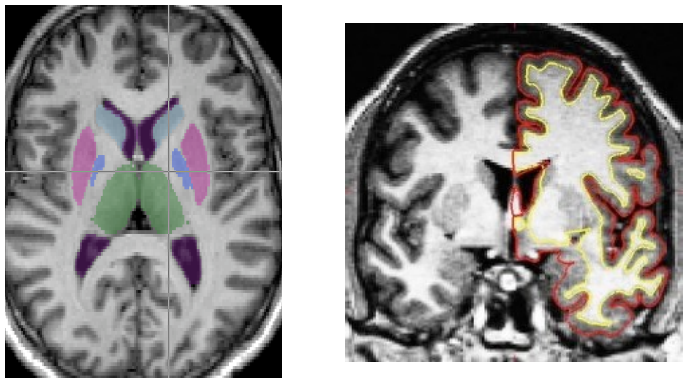
What use is Registration?

Some common uses of registration:

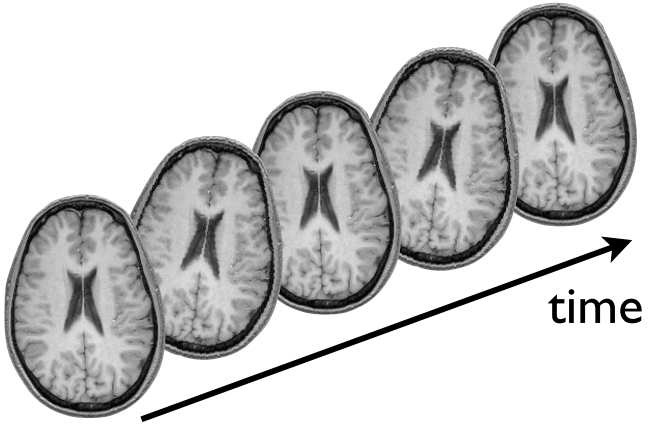
Combining across individuals in group studies: including fMRI & diffusion



Quantifying structural change



Correcting for motion

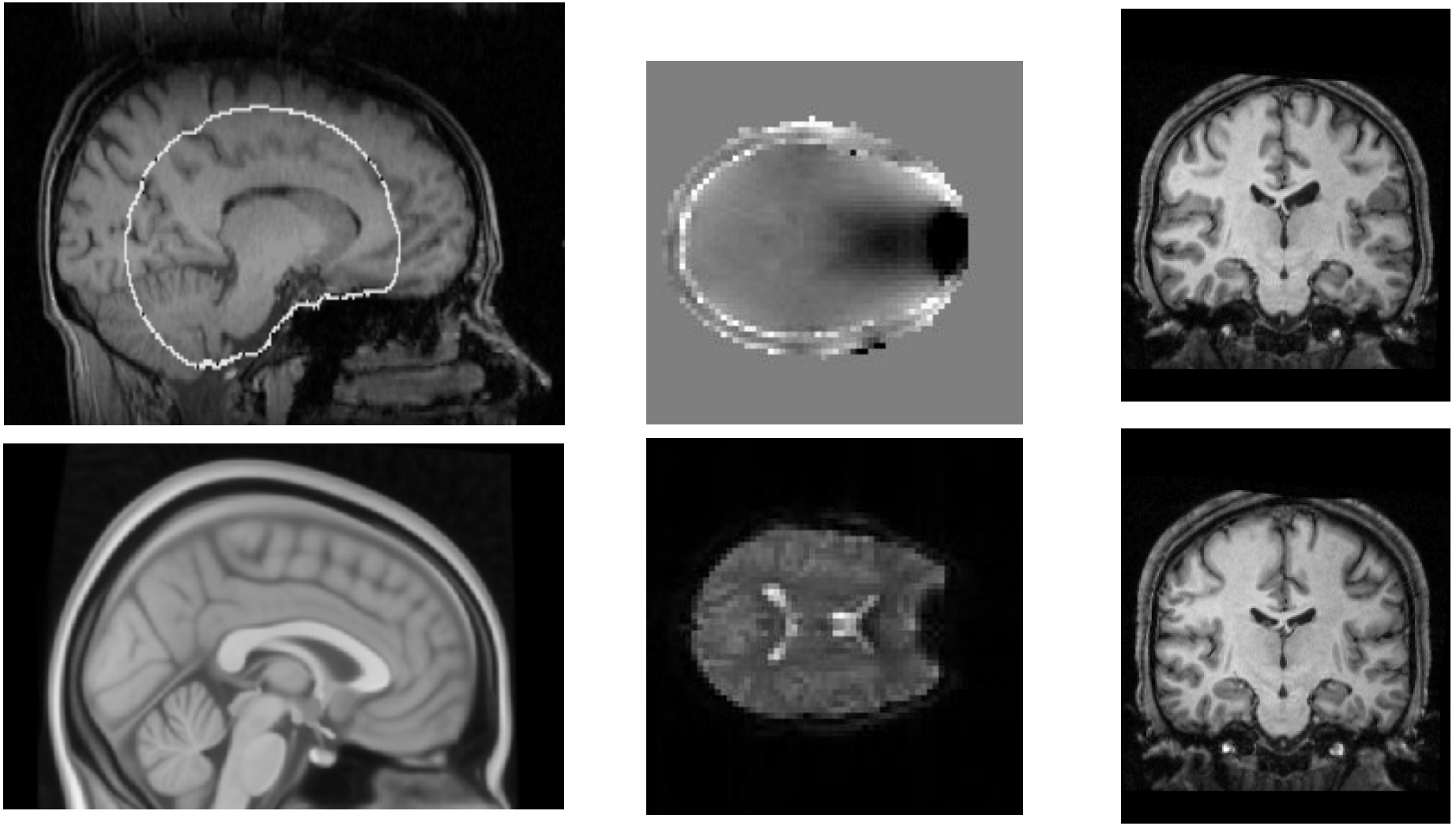


Brain Extraction and Registration

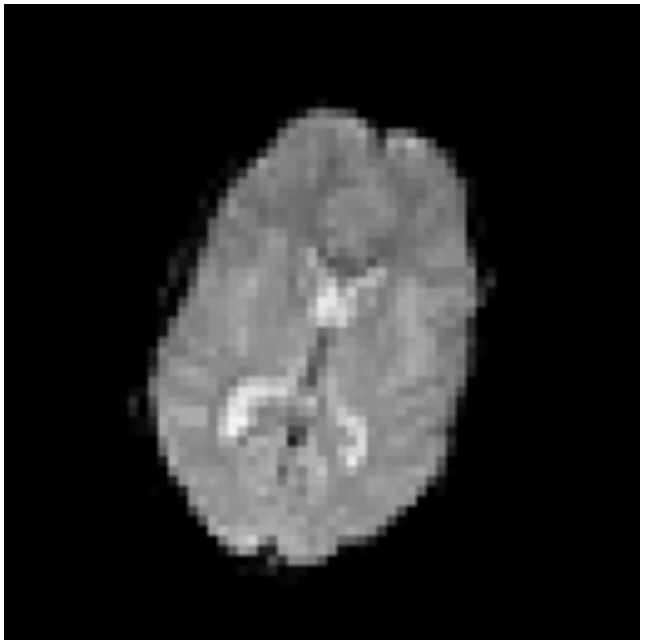
Summary:

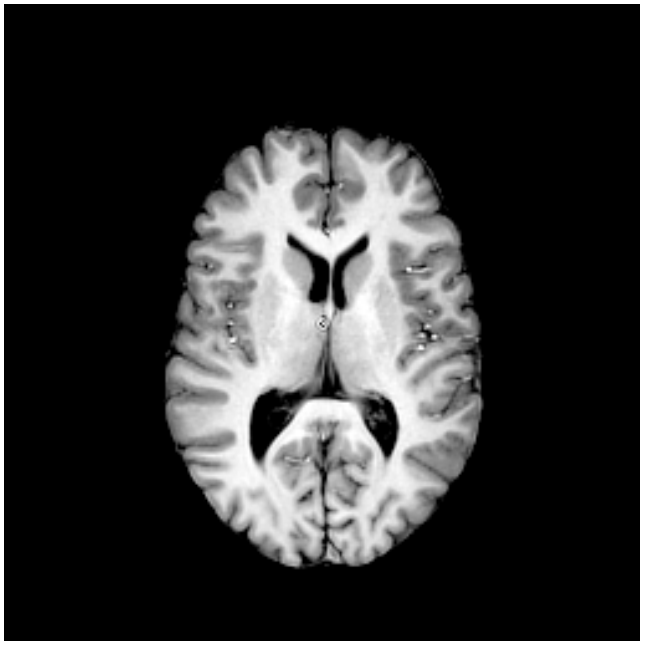
- Registration aims to align images/structures
- Can transform the image to match others
- Important component in *all* group studies
- Can measure motion or anatomical change
- Brain extraction removes bulk of non-brain
- Some errors are to be expected
- Small, isolated errors are not a problem *for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

Registration: Image Spaces and Spatial Transformations



Basic Registration Concepts

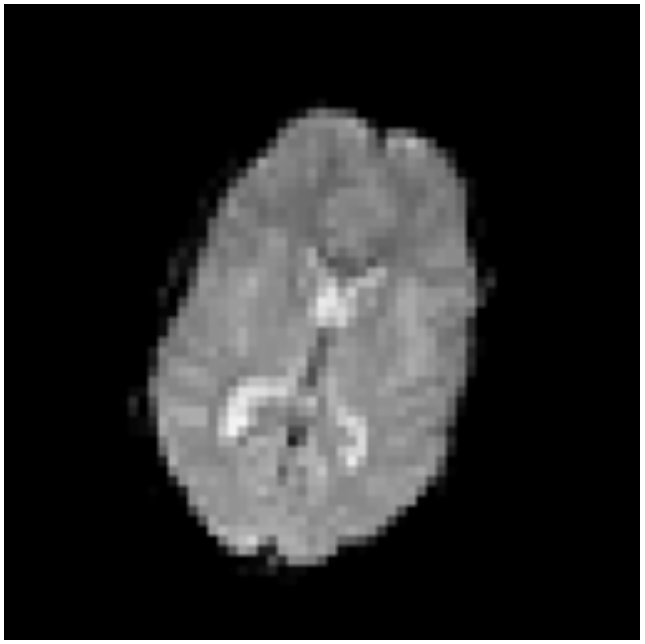


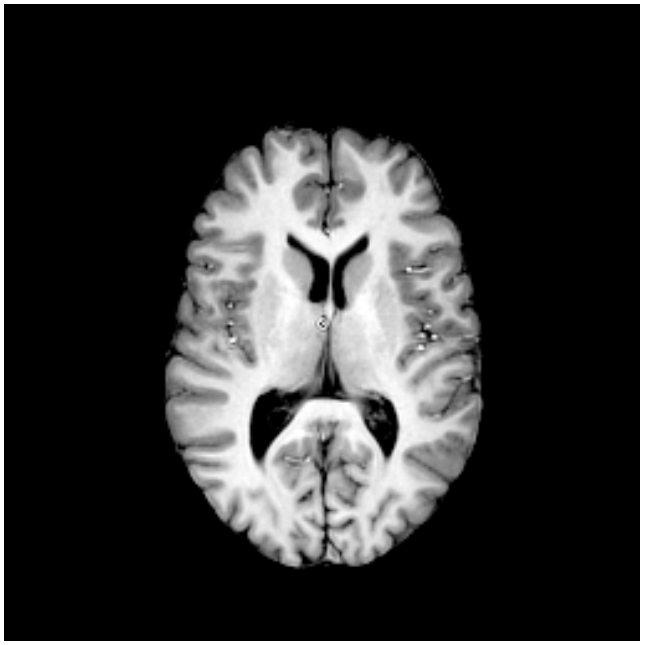


Need to understand:

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

Basic Registration Concepts



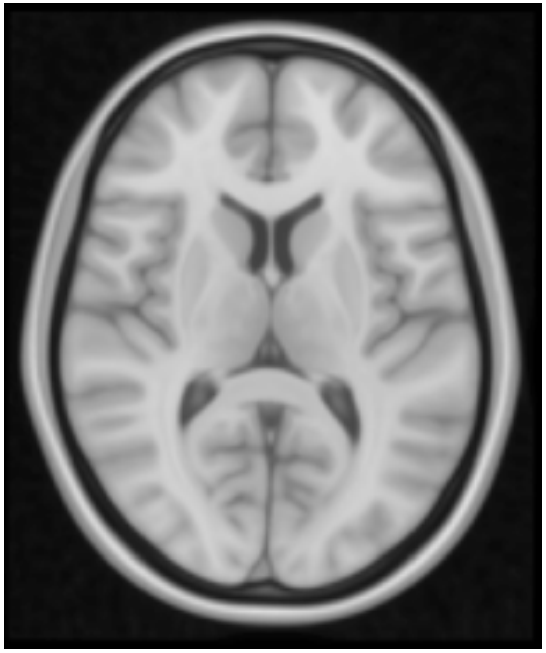


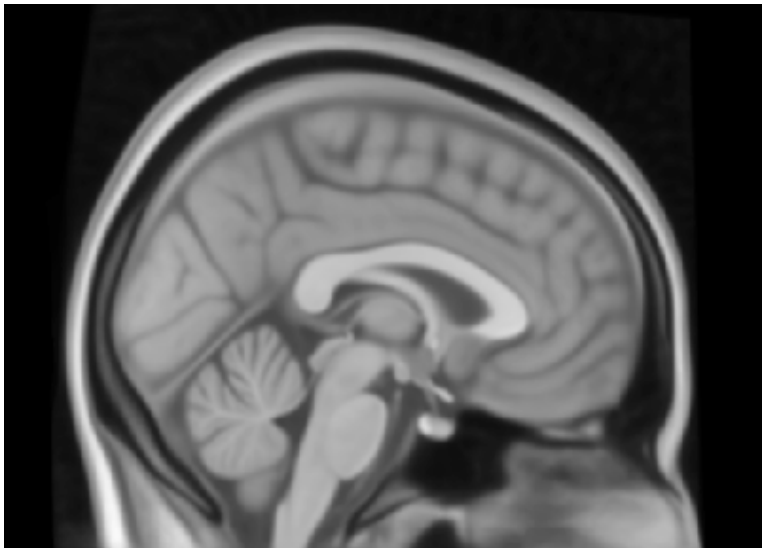
Need to understand:

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

Standard Space

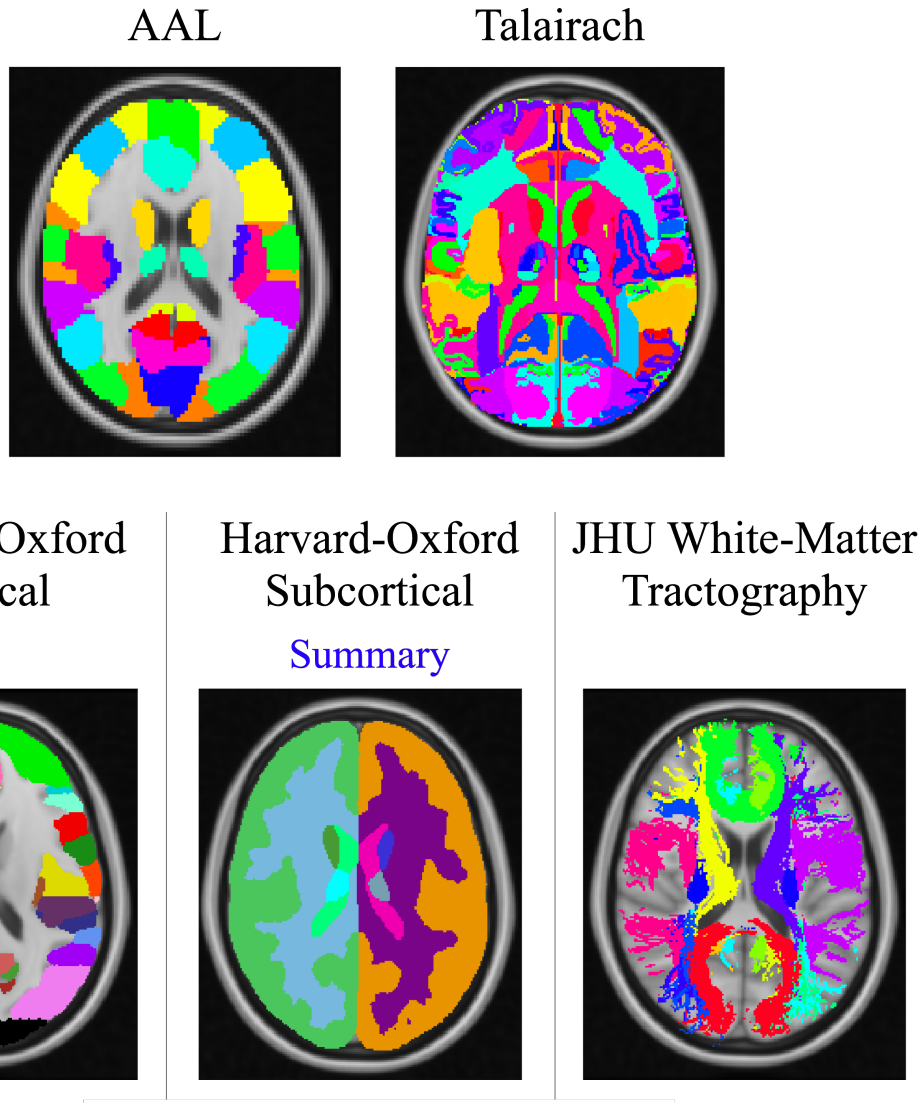
- Common reference coordinate system for reporting/describing
- Register all members of a group to this space for group studies
- Original Talairach & Tournoux coords based on one post-mortem brain
- Now use standard images based on non-linear group average (MNI152)
- MNI is not quite Talairach



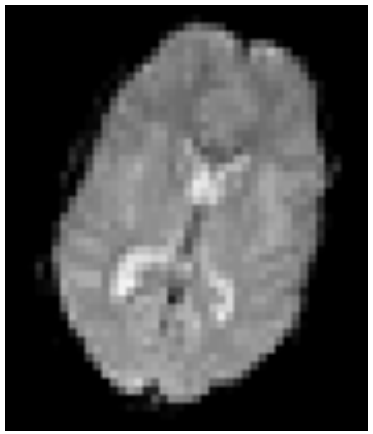


Standard Space: Atlases

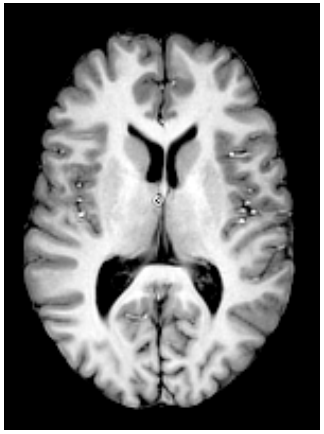
- Most atlases are in standard space (esp. MNI152)
- Information is derived from different sources, but in each case this has been brought into the standard space at some point
- To use atlas information for an individual (or group) study it is necessary to "get into" standard space



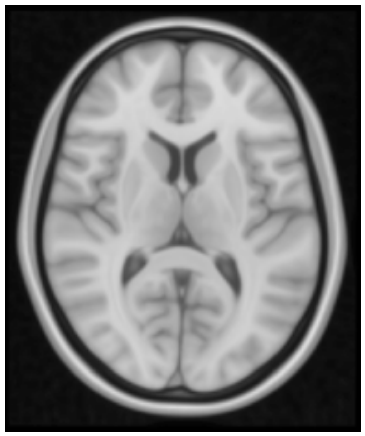
Other "Spaces"



FMRI



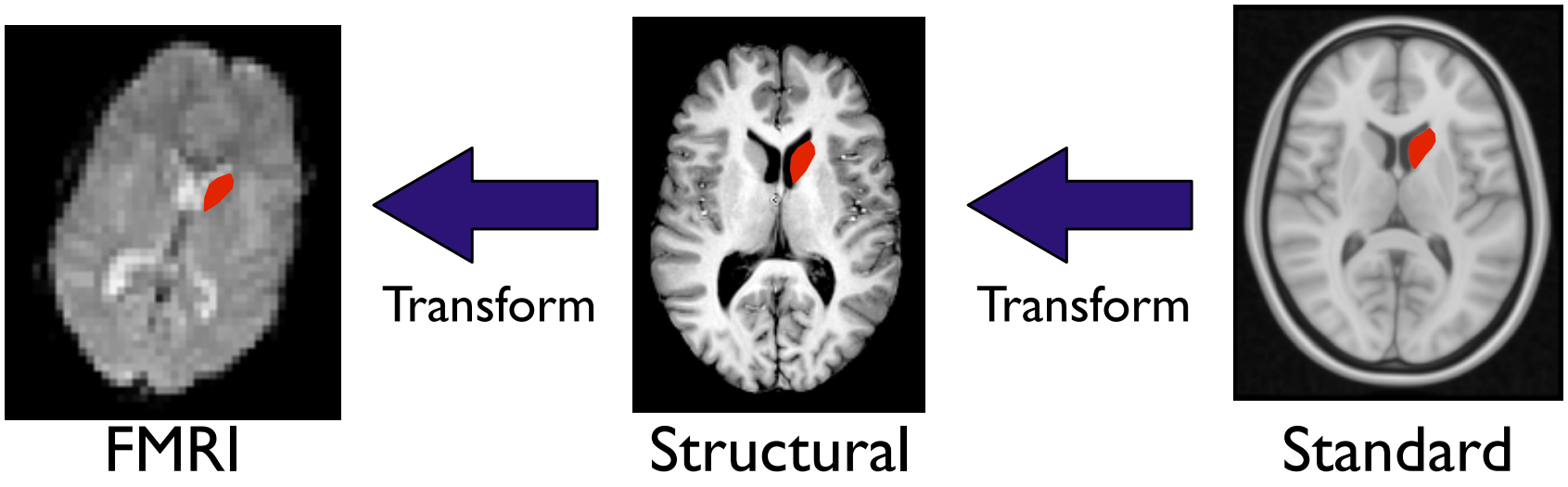
Structural



Standard

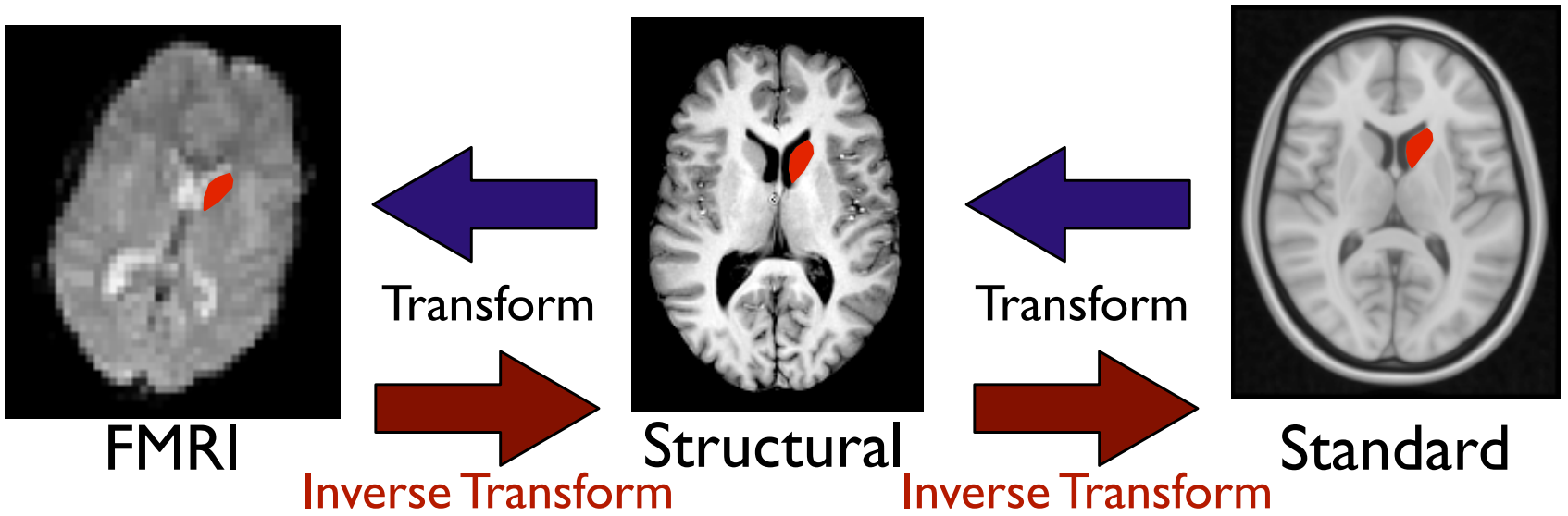
- All images in the same "space" are aligned
- Different images ⇒ different "spaces"
  e.g. standard space, structural space, functional space
- Can have different resolution images in the same space
  e.g. 1mm and 2mm versions of standard space images
- Want to move image-related info between spaces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

Other "Spaces"



- Need to *registration 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"



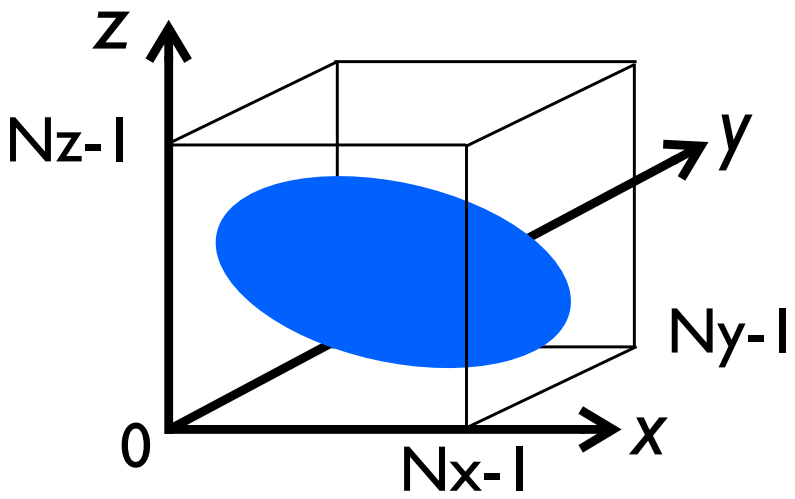
- Need to *registration between spaces* (via images) and get the transformations before transforming/moving/resampling any image-related info (like masks or atlas ROIs)
- Can have versions of the same "image" (e.g. a mask) in several different spaces
- FSL tools (e.g. FEAT) often move things between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

Image (Voxel) Coordinates

Confusingly, there are many types of coordinates

Voxel coordinates in FSL:

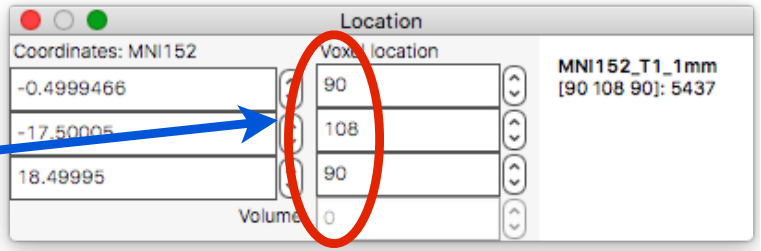
- Integers between 0 and N-1 inclusive
- Refer to the whole voxel
- Origin in the lower-left corner: (0,0,0)



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:

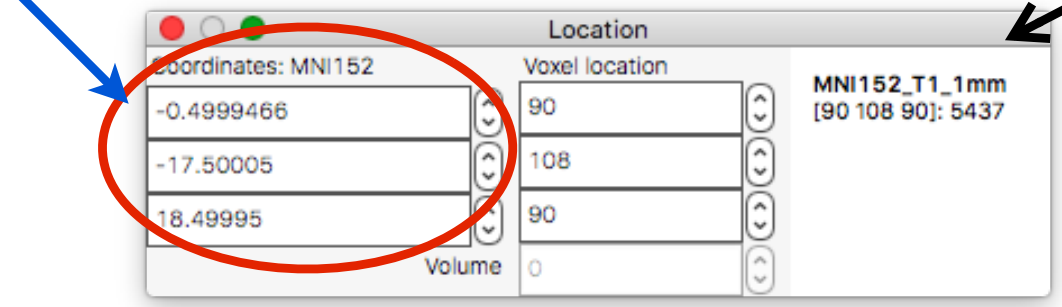
Real numbers, in units of *mm*

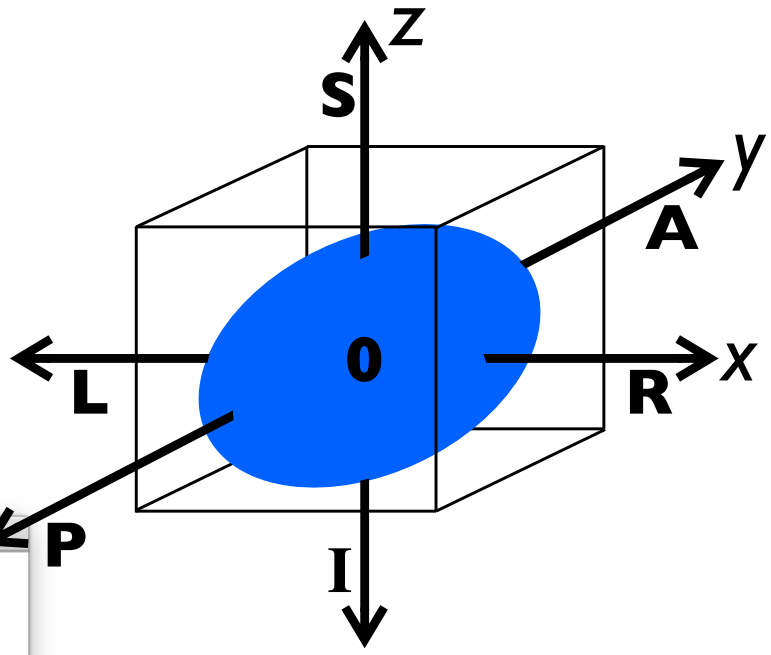
Origin (0,0,0) near centre of image
(anatomical landmark; e.g. anterior commisure)

Axes aligned with anatomy
(left and right specified)

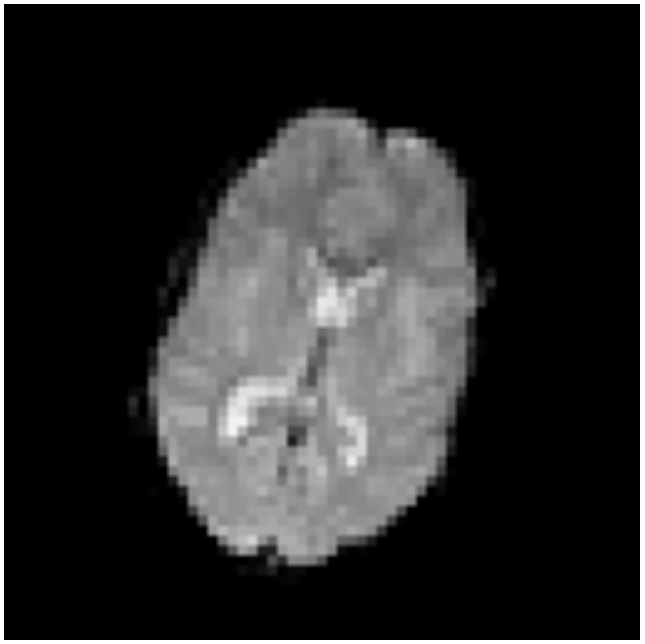
Several standard spaces exist:
MNI, Talairach, BrainWeb, etc

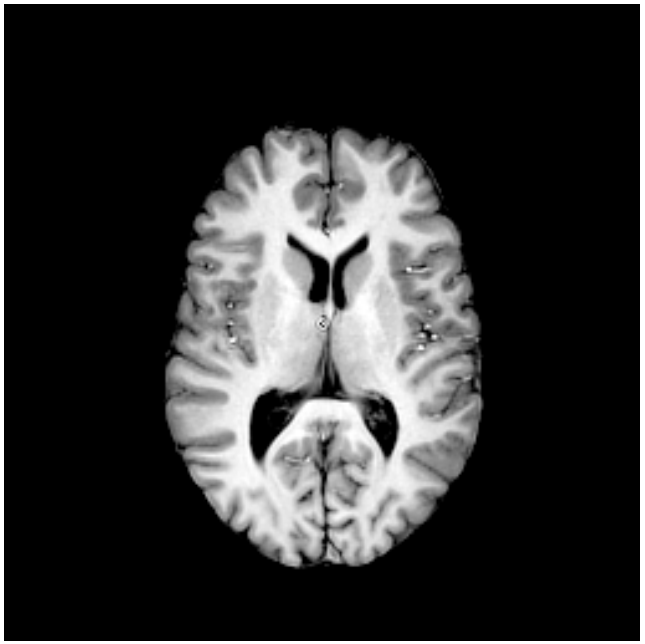
FSLeyes also reports these *when possible*





Basic Registration Concepts





Need to understand:

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

Spatial Transformations

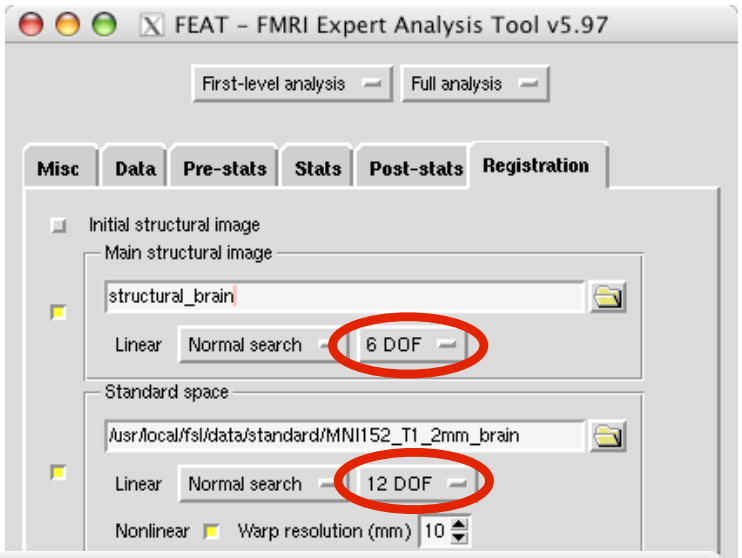
To align images must transform them

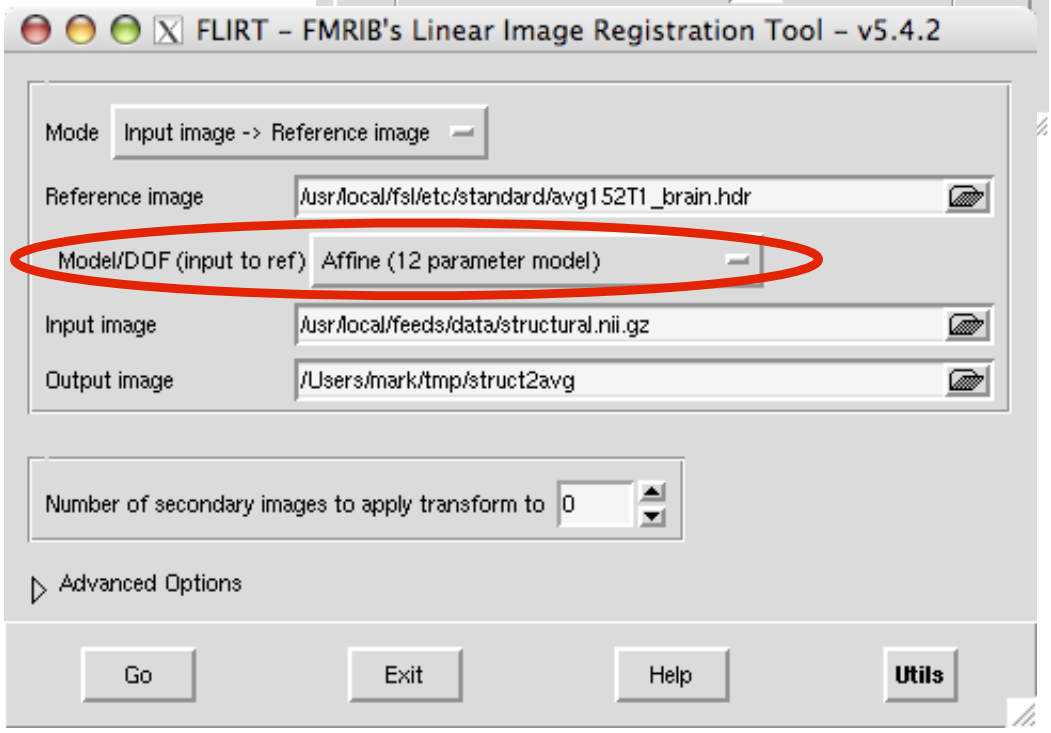
Many types of transformation

Degrees of Freedom (DOF) partially describe transform

Examples:

- Rigid Body (6 DOF)
- Affine (12 DOF)
- Non-linear (12 - millions DOF)



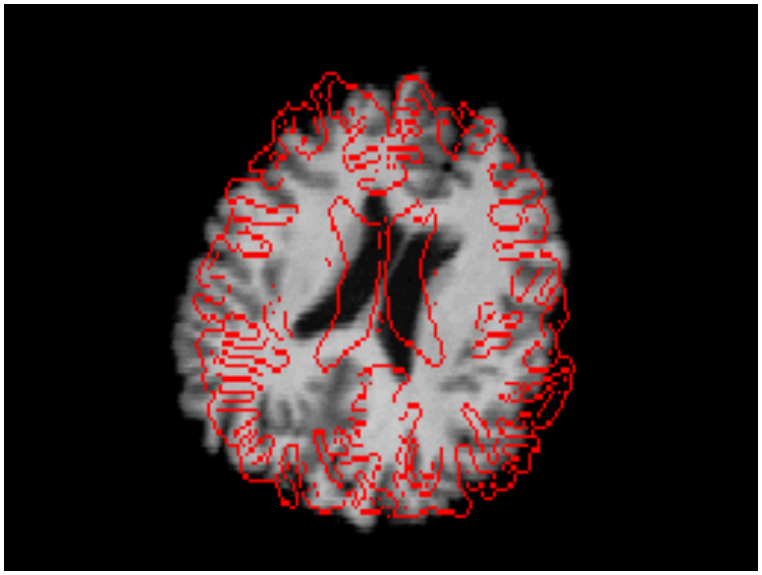


Rigid-Body Transformations

6 DOF in 3D

Includes:

- 3 Rotations

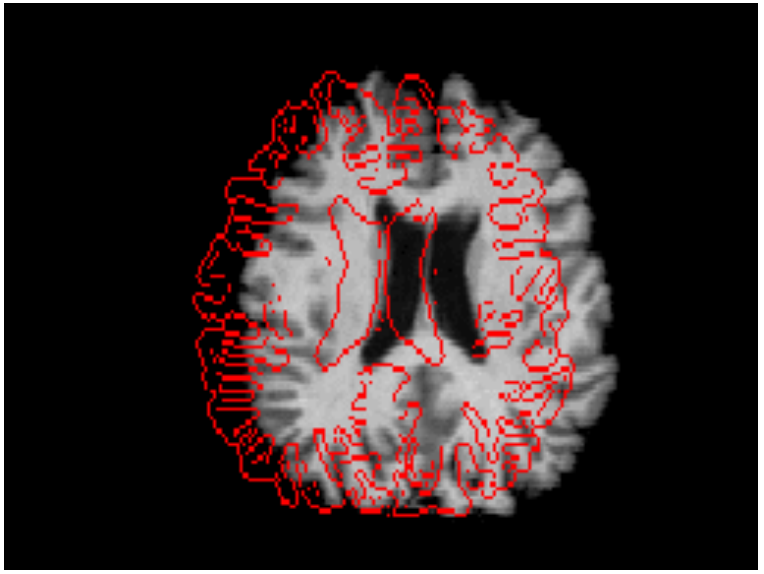


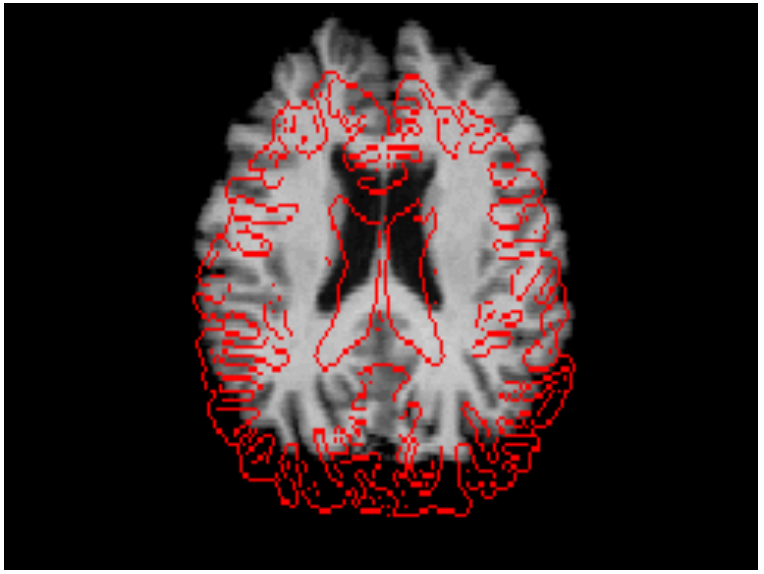
Rigid-Body Transformations

6 DOF in 3D

Includes:

- 3 Rotations
- 3 Translations





Used for **within-subject** registrations

Affine Transformations

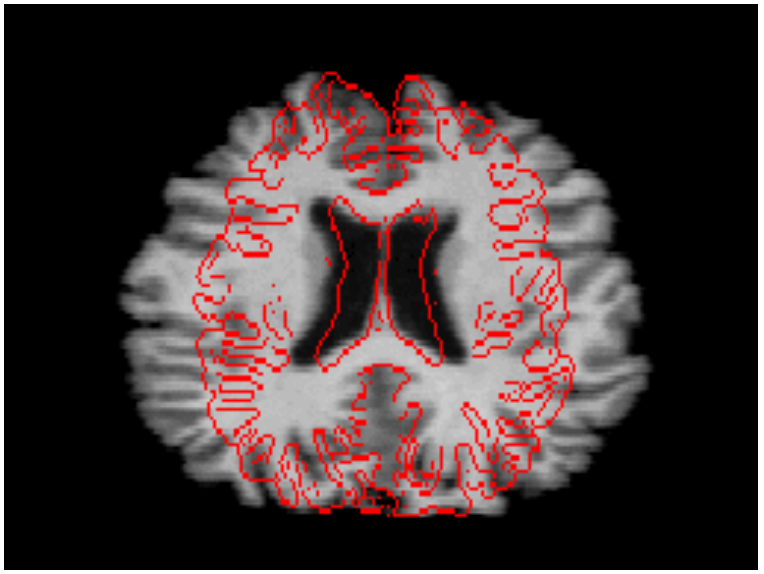
12 DOF in 3D

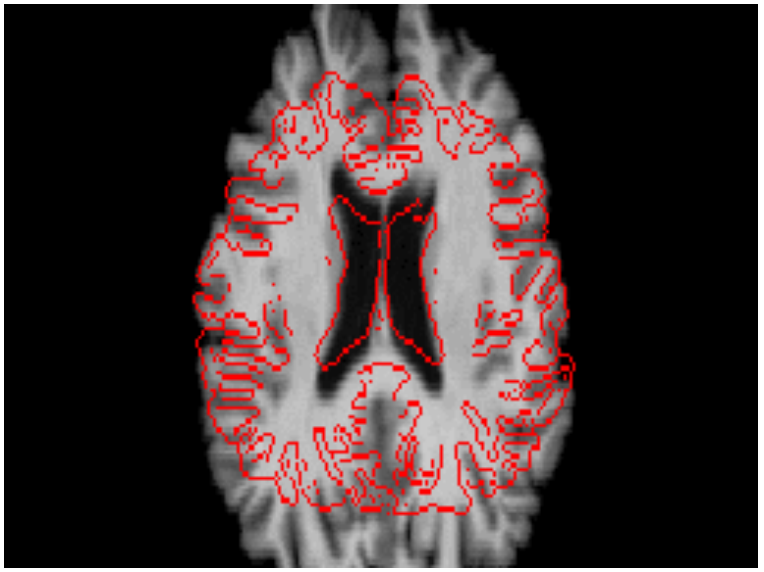
Linear Transf.

Includes:

- 3 Rotations
- 3 Translations

3 Scalings





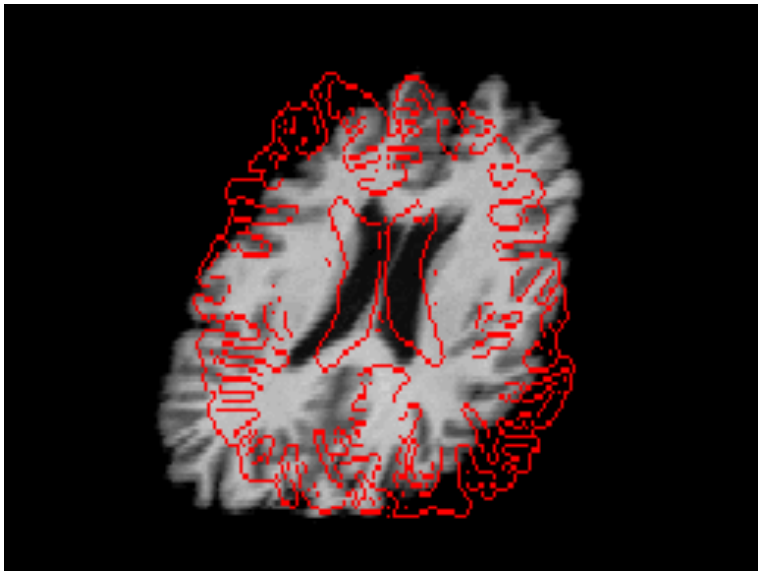
Affine Transformations

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

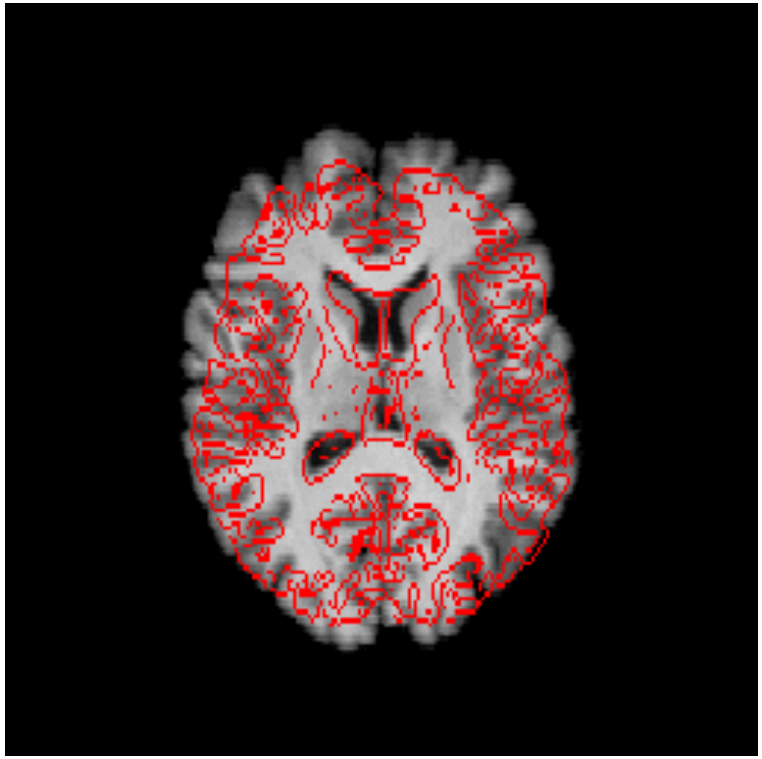
Non-Linear Transformations

More than 12 DOF

Can be purely local

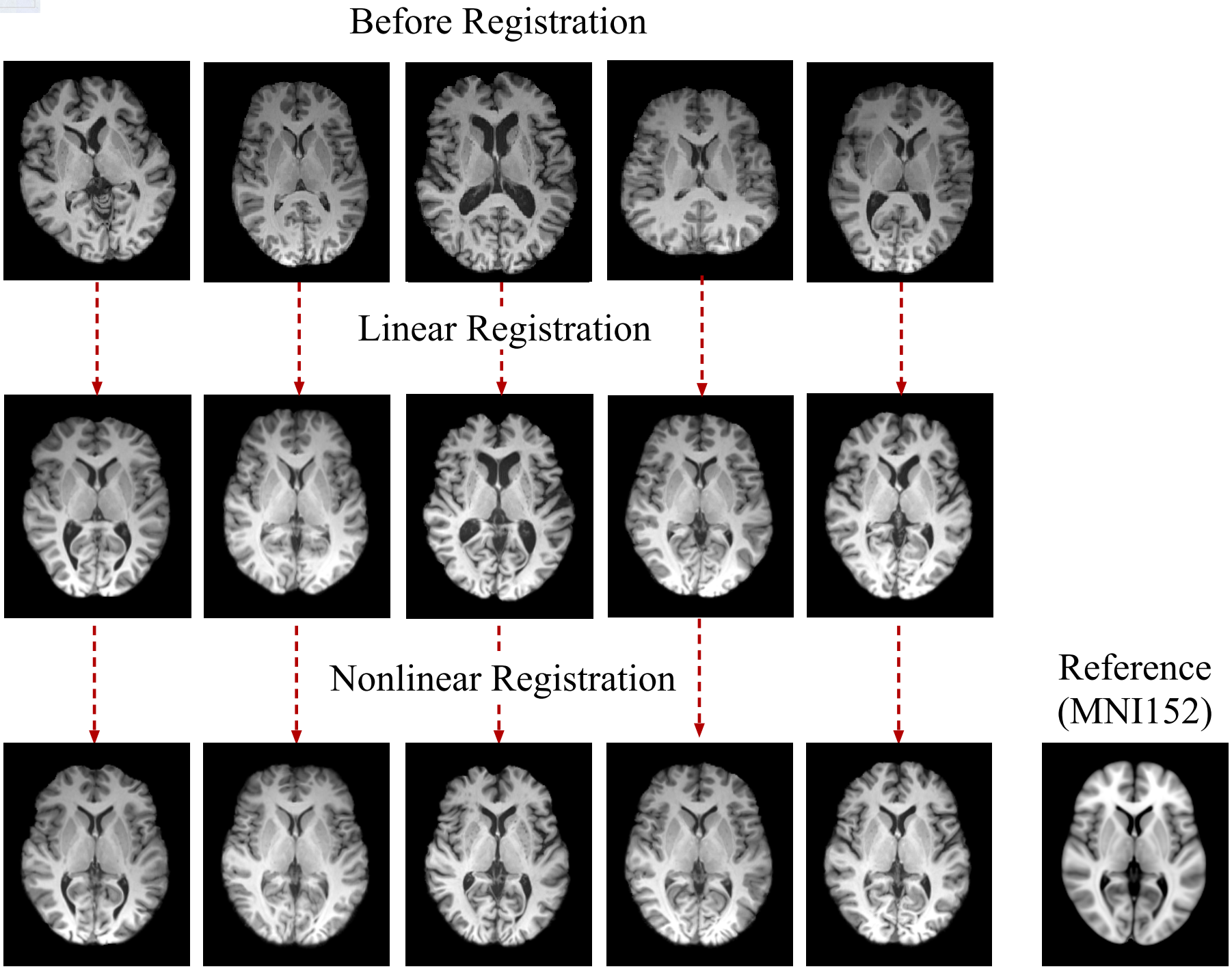
Subject to constraints:

- 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

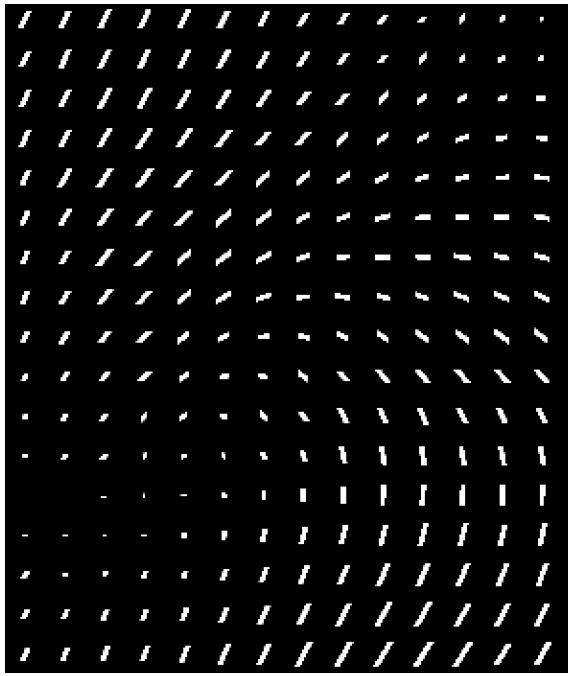
Global scaling (7 DOF)
- within-subject but with global scaling (equal in x,y,z)
- corrects for scanner scaling drift in *longitudinal studies*

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.



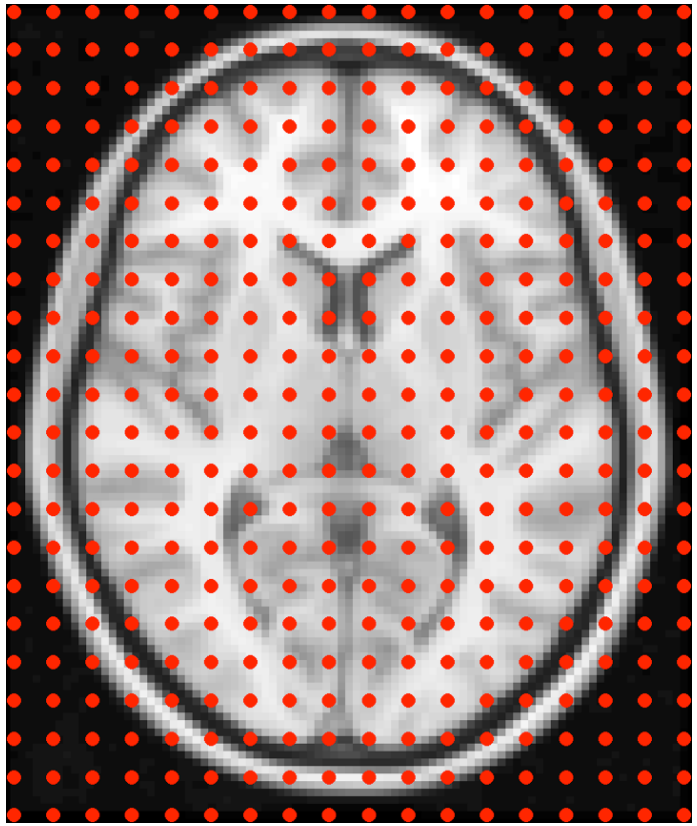
A non-linear transformation can be represented by a ***deformation field***.

Non-linear deformation

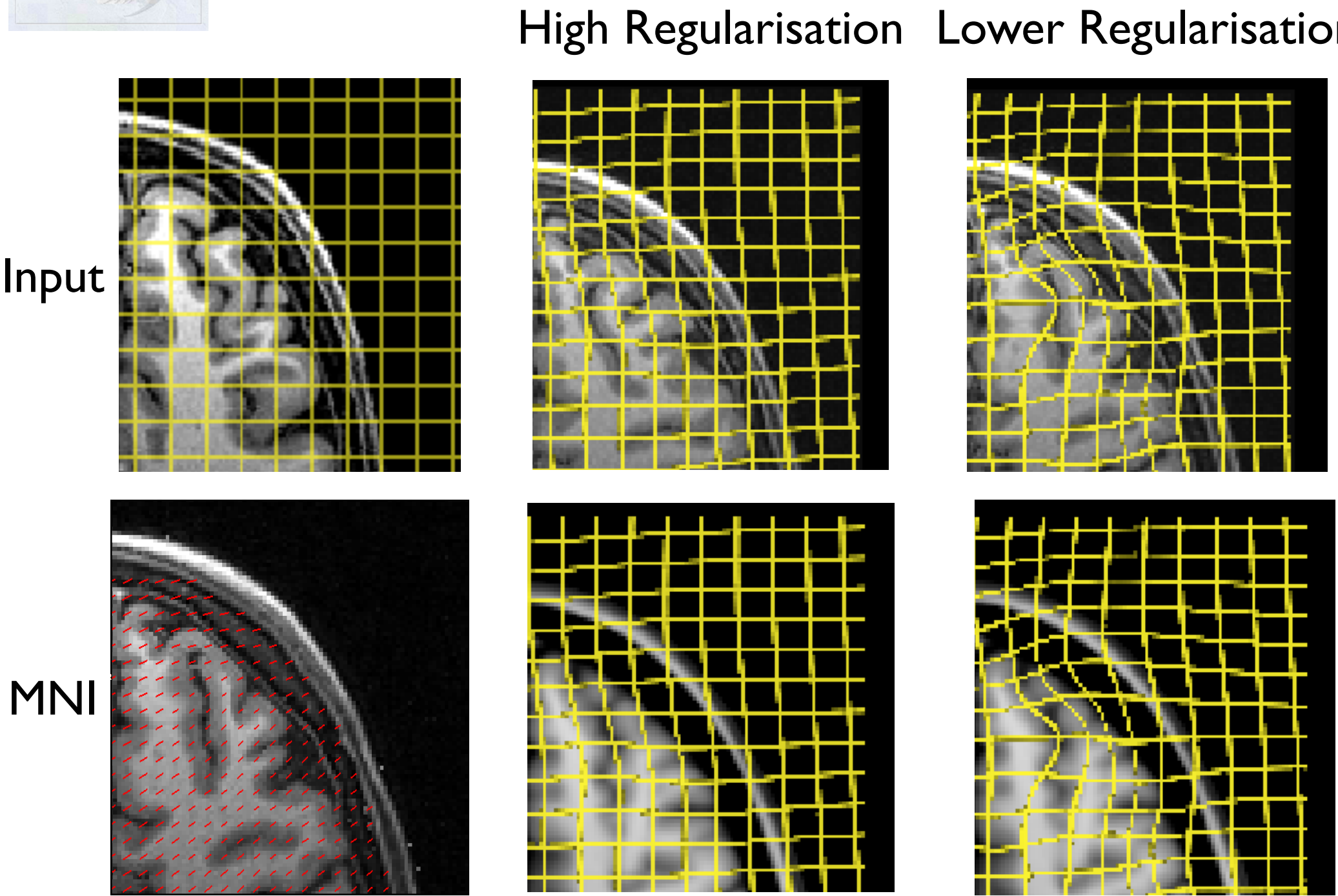
Regularisation, Warp Resolution and DOF

- 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

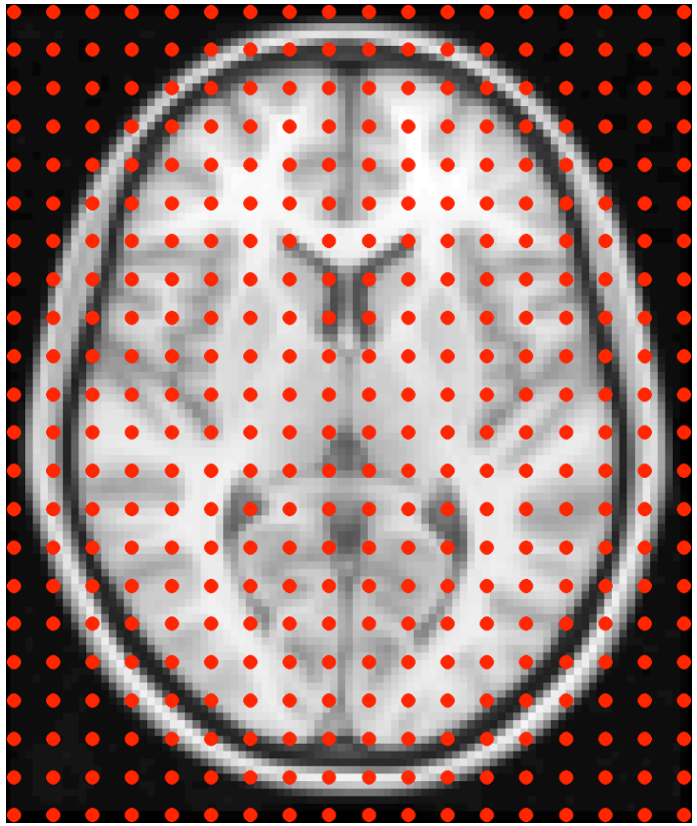


Non-linear deformation

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