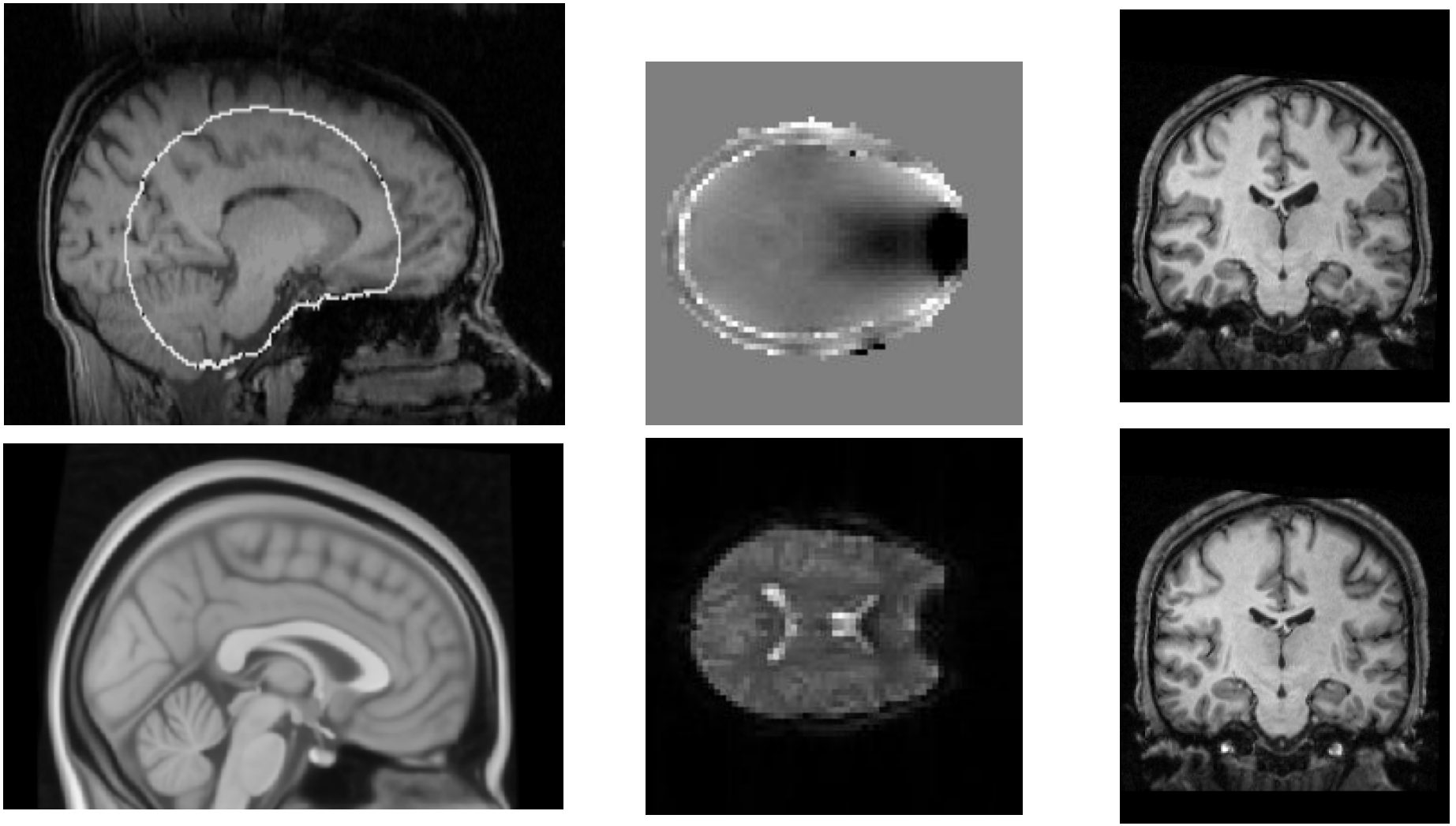
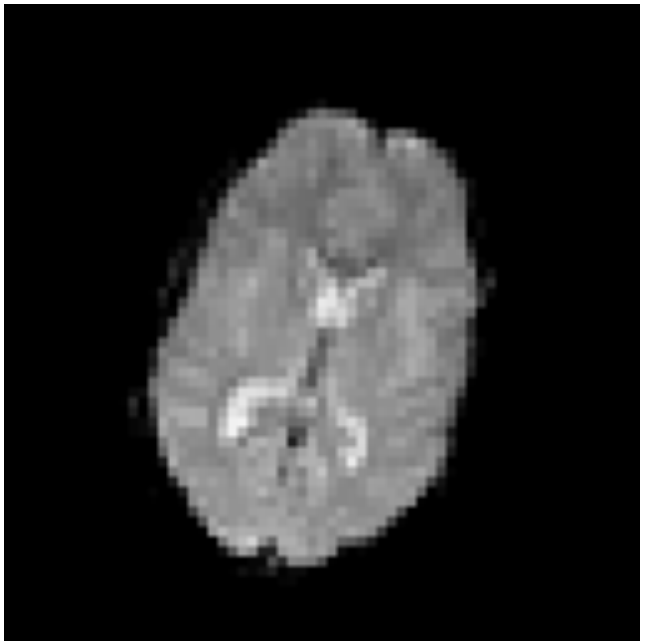
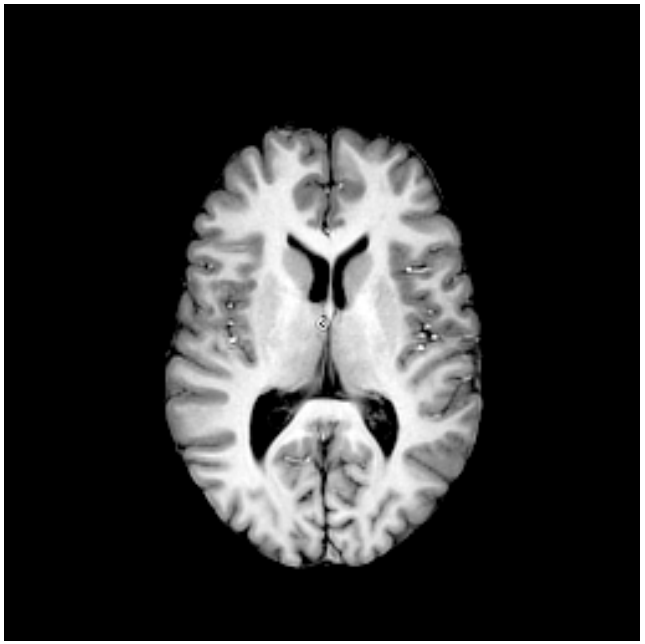
Registration: Image Spaces and Spatial Transformations



Basic Registration Concepts

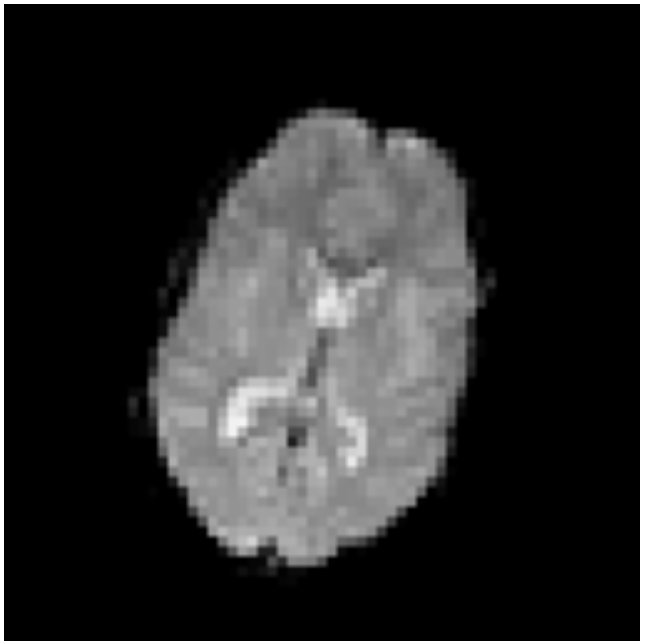


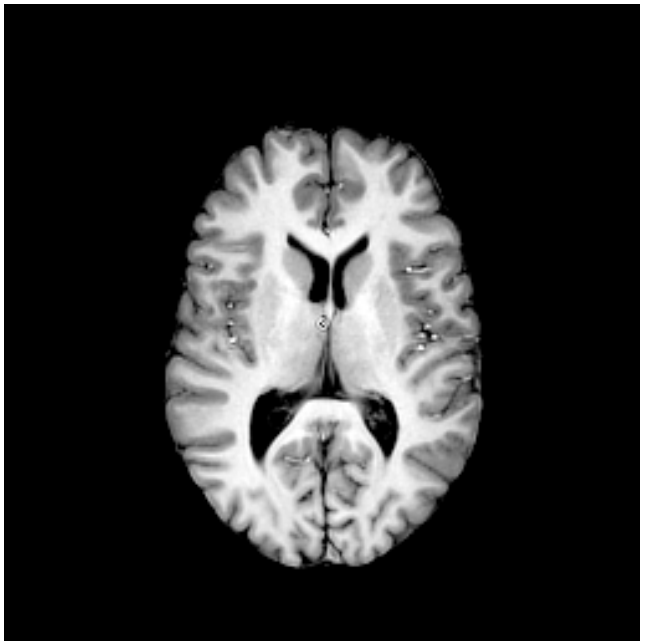


Need to understand:

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

Basic Registration Concepts





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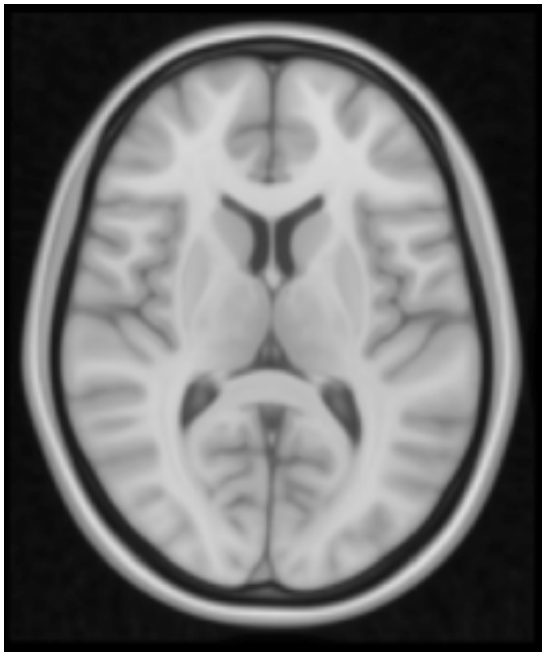
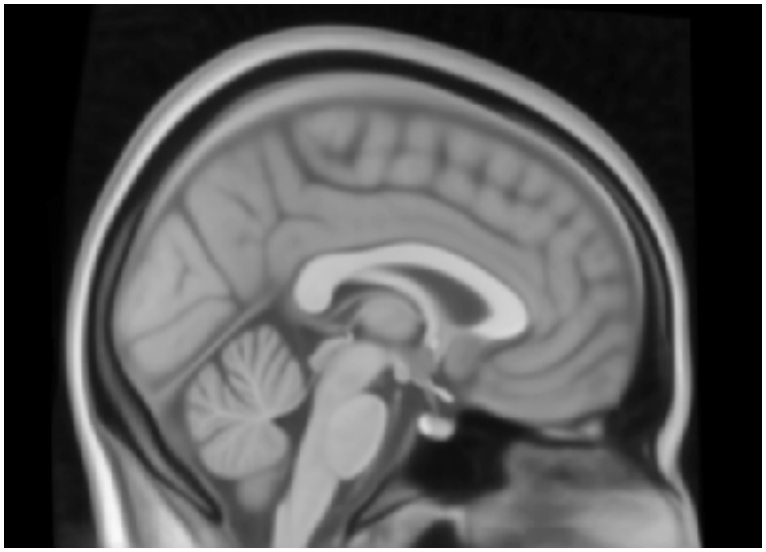
Standard Space

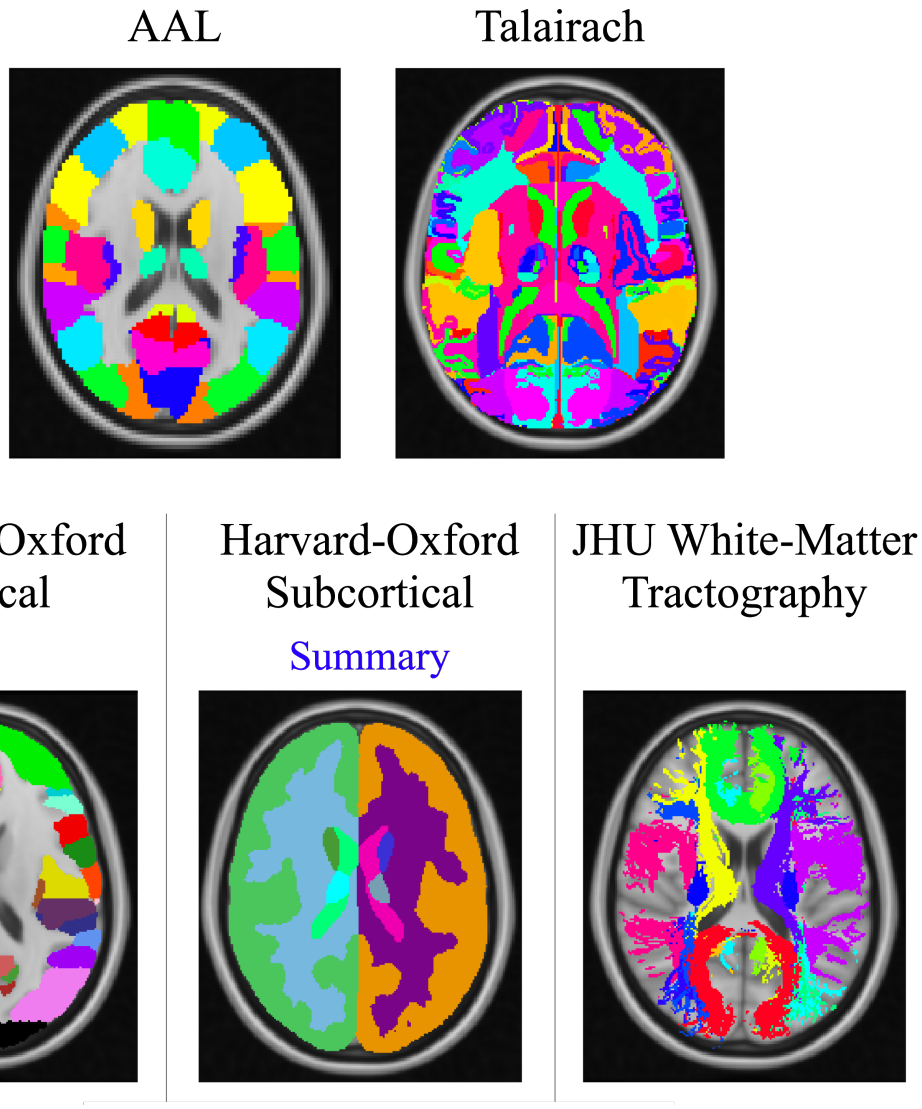
- Common reference coordinate system for reporting/describing
- Register all members of a group to this space for group studies
- Original Talairach & Tournoux coords based on one post-mortem brain
- Now use standard images based on non-linear group average (MNI152)
- MNI is not quite Talairach



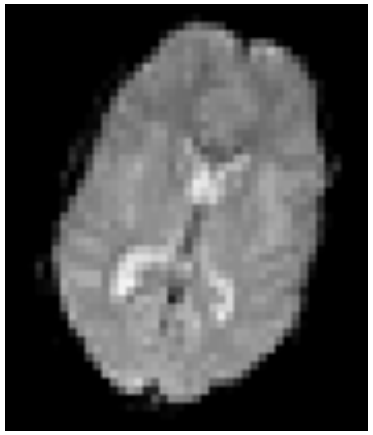


Standard Space: Atlases

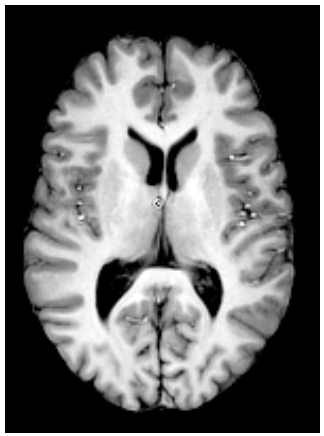
- Most atlases are in standard space (esp. MNI152)
- Information is derived from different sources, but in each case this has been brought into the standard space at some point
- To use atlas information for an individual (or group) study it is necessary to "get into" standard space



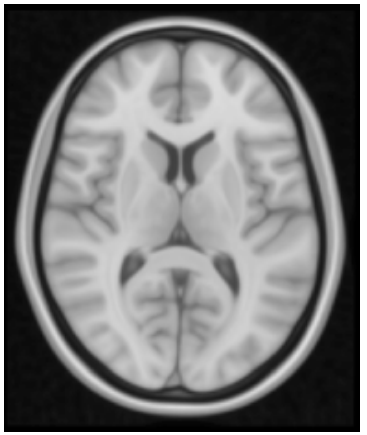
Other "Spaces"



FMRI



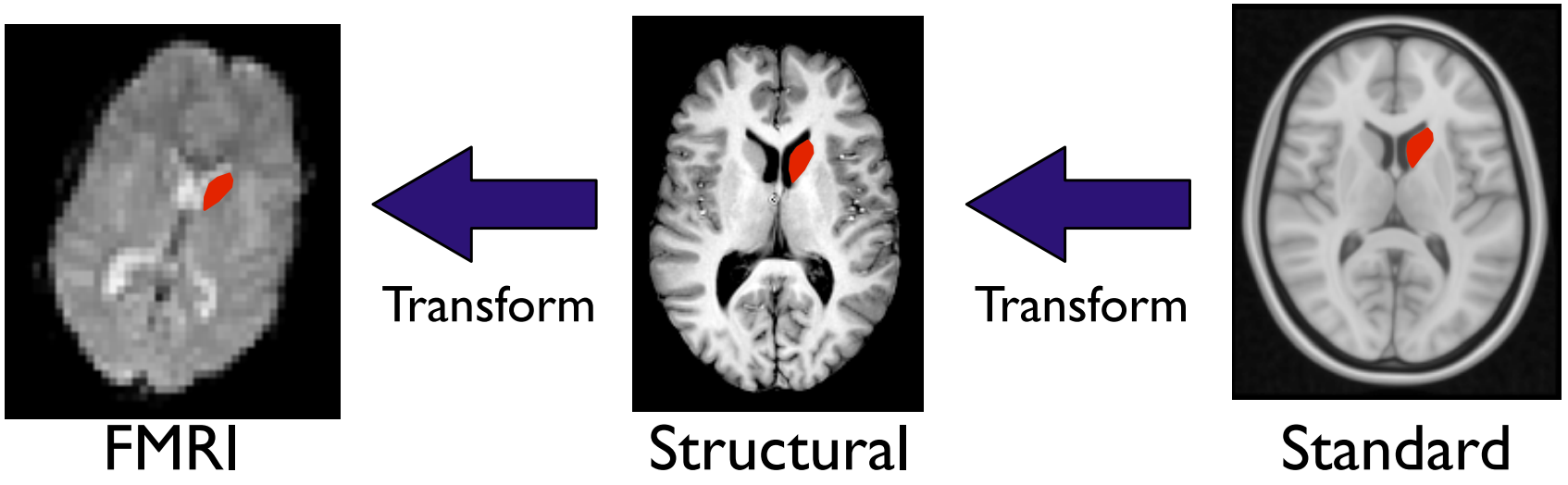
Structural



Standard

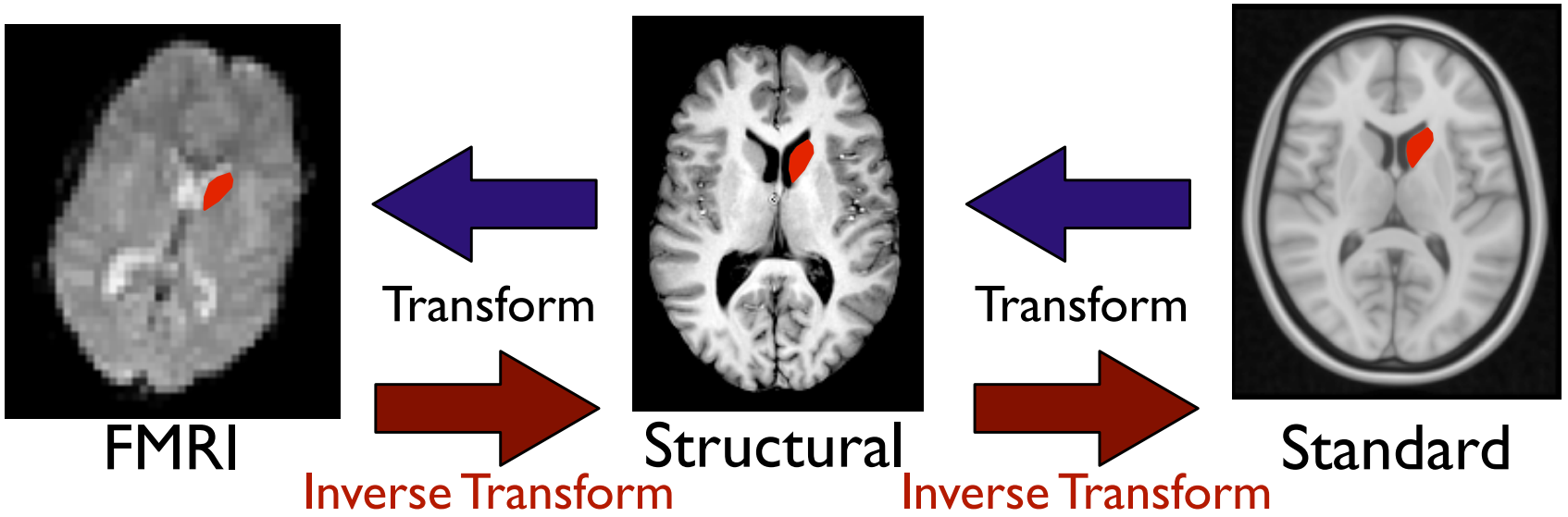
- All images in the same "space" are aligned
- Different images ⇒ different "spaces"
  e.g. standard space, structural space, functional space
- Can have different resolution images in the same space
  e.g. 1mm and 2mm versions of standard space images
- Want to move image-related info between spaces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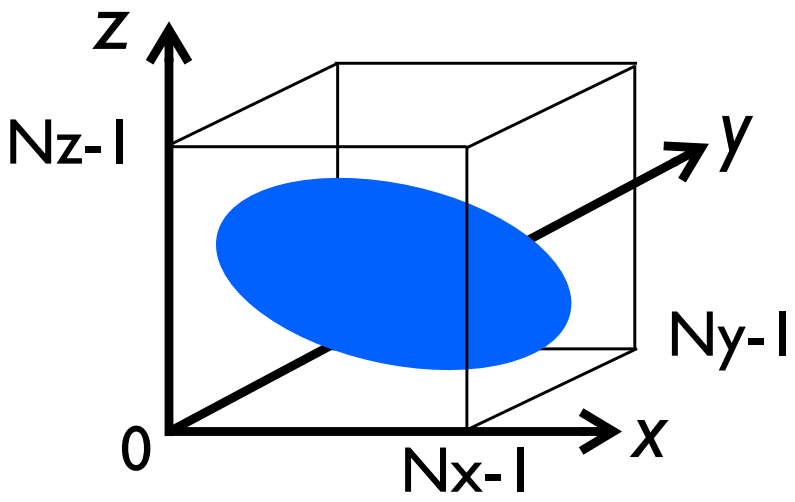
Image (Voxel) Coordinates

Confusingly, there are many types of coordinates

Voxel coordinates in FSL:

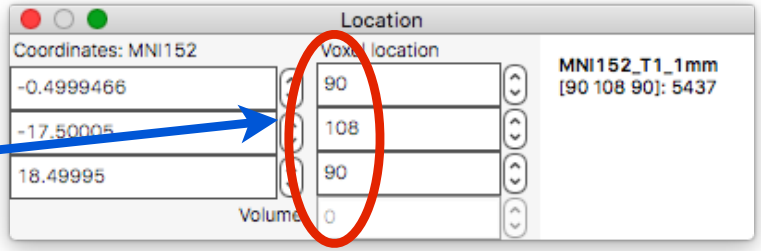
- Integers between 0 and N-1 inclusive
- Refer to the whole voxel
- Origin in the lower-left corner: (0,0,0)



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)

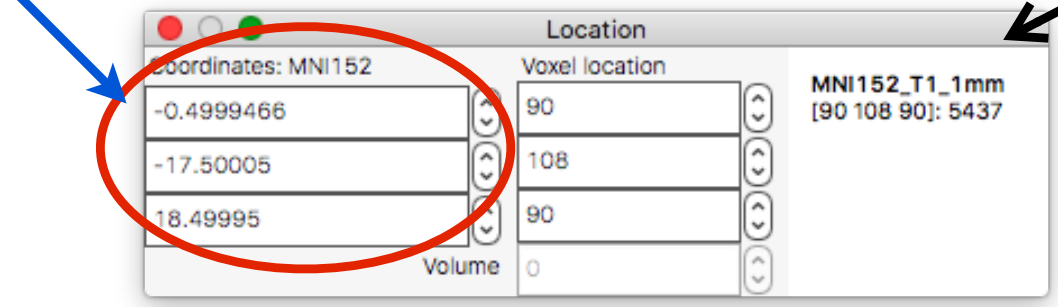
Axes aligned with anatomy

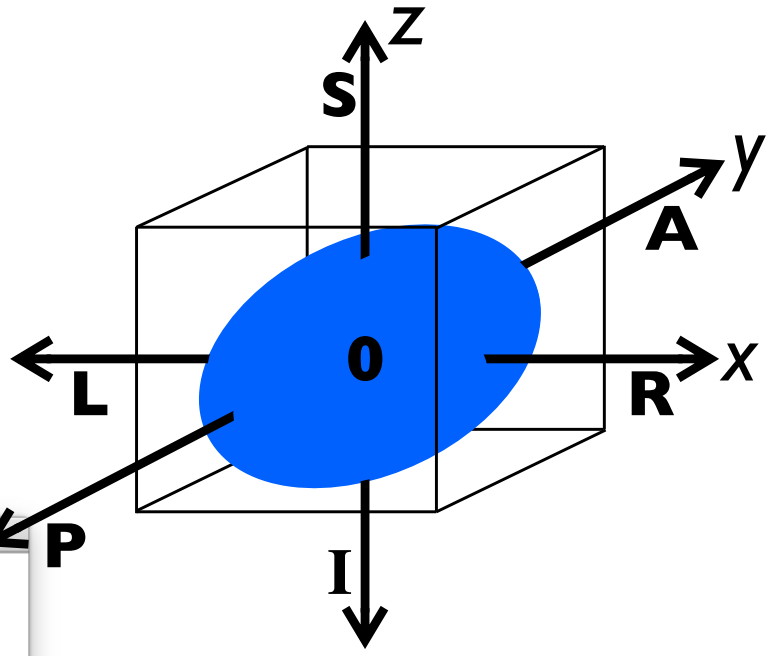
(left and right specified)

Several standard spaces exist:

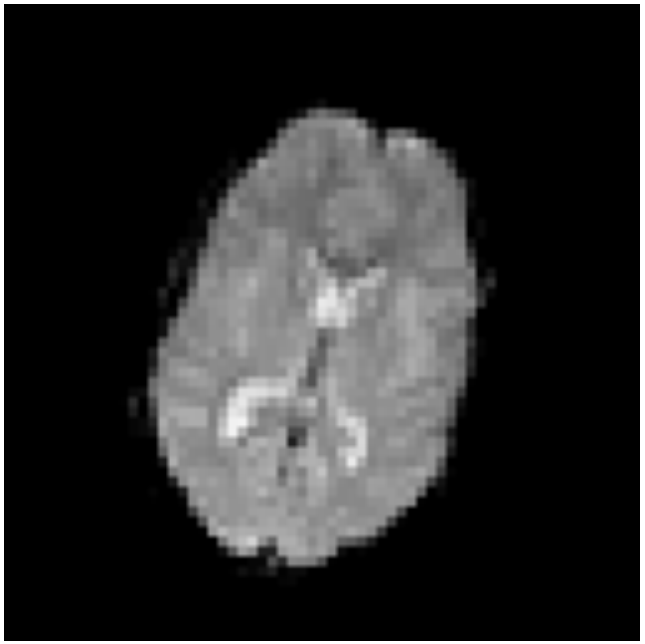
MNI, Talairach, BrainWeb, etc

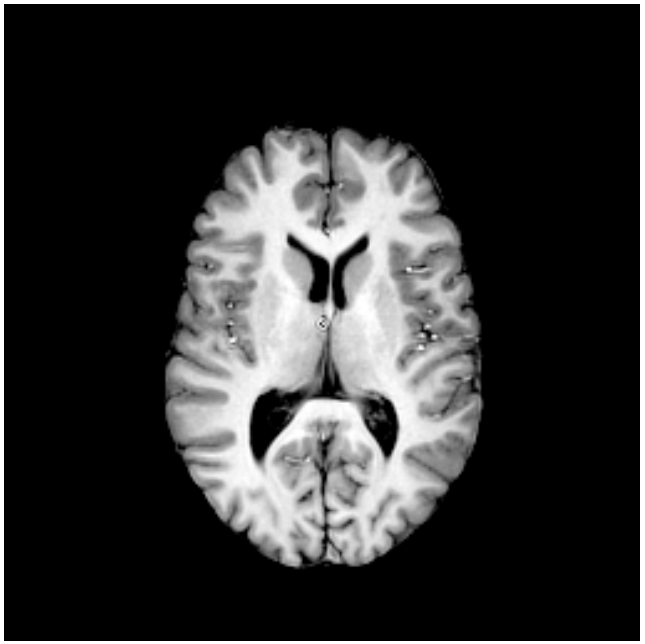
FSLeyes also reports these *when possible*





Basic Registration Concepts





Need to understand:

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

Spatial Transformations

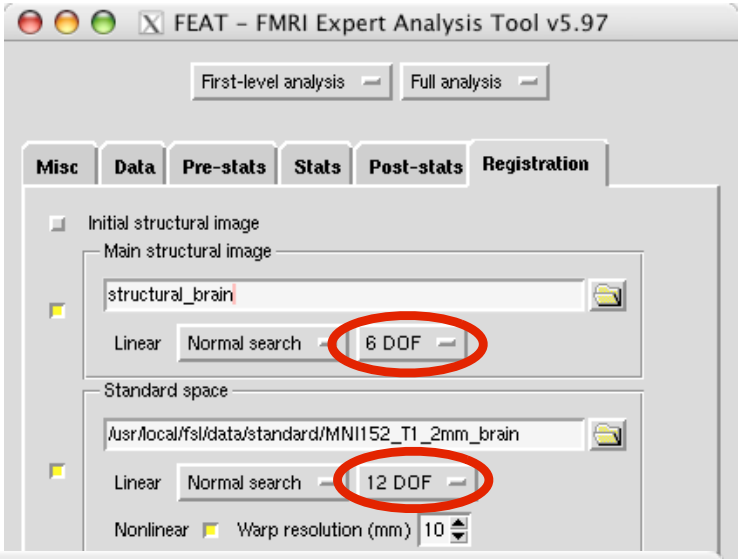
To align images must transform them

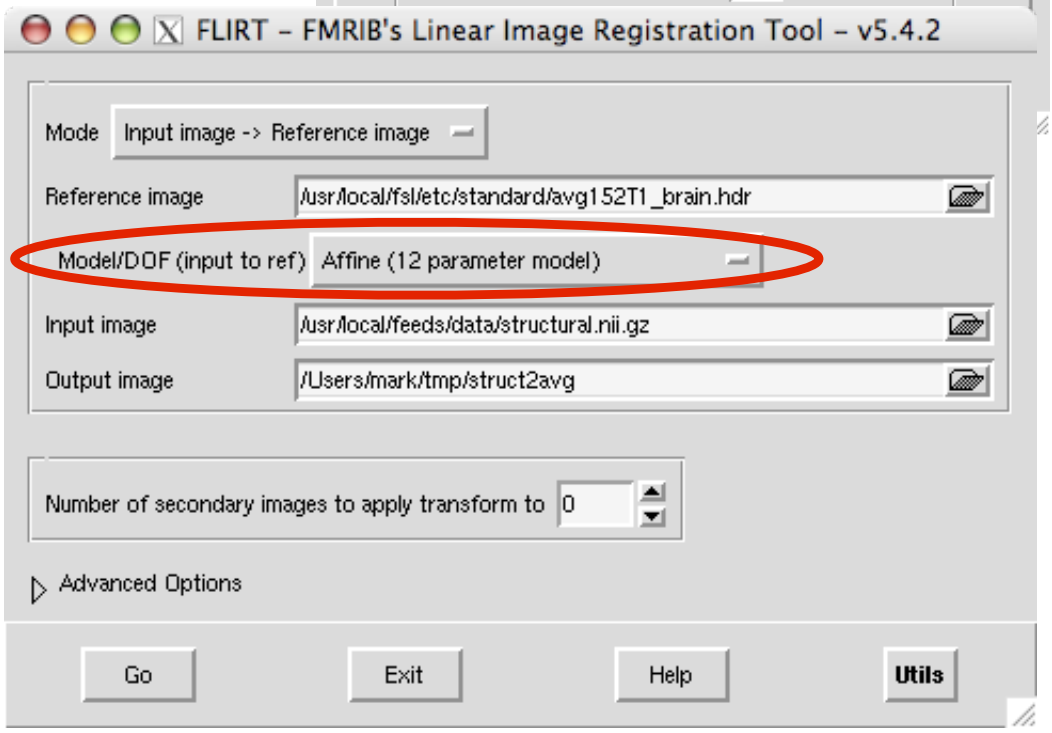
Many types of transformation

Degrees of Freedom (DOF) partially describe transform

Examples:

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



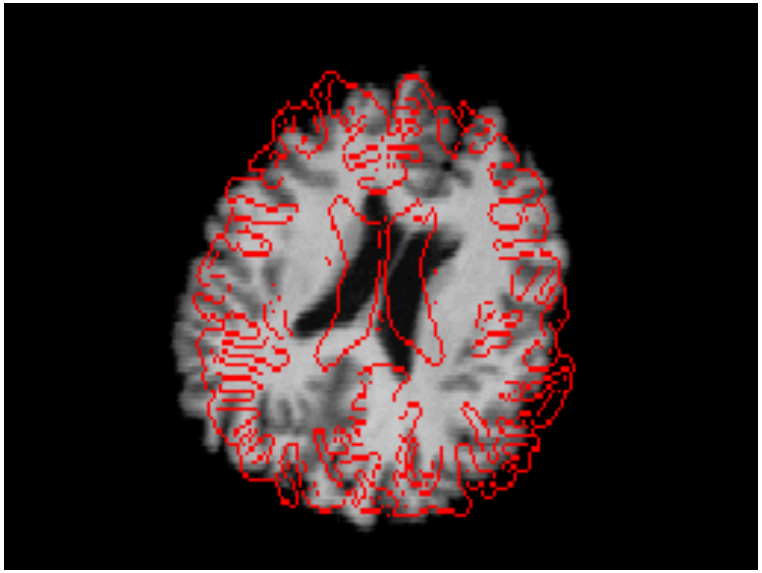


Rigid-Body Transformations

6 DOF in 3D

Includes:

- 3 Rotations



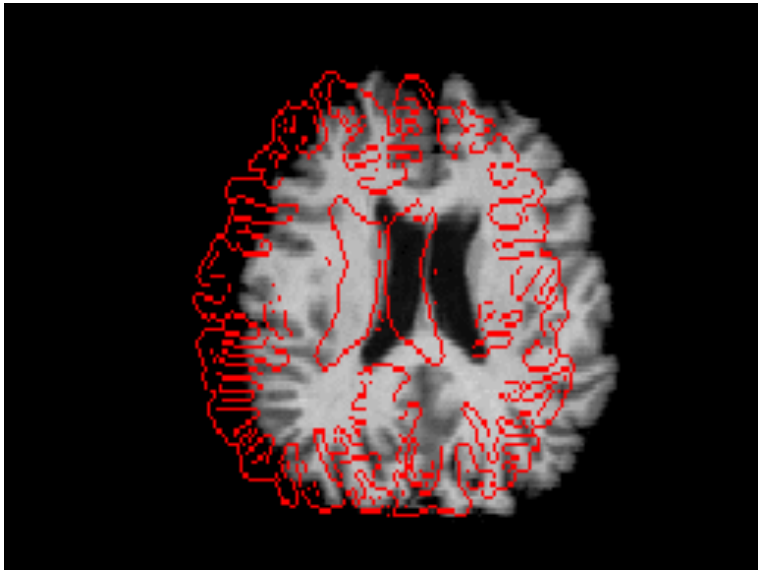
Rigid-Body Transformations

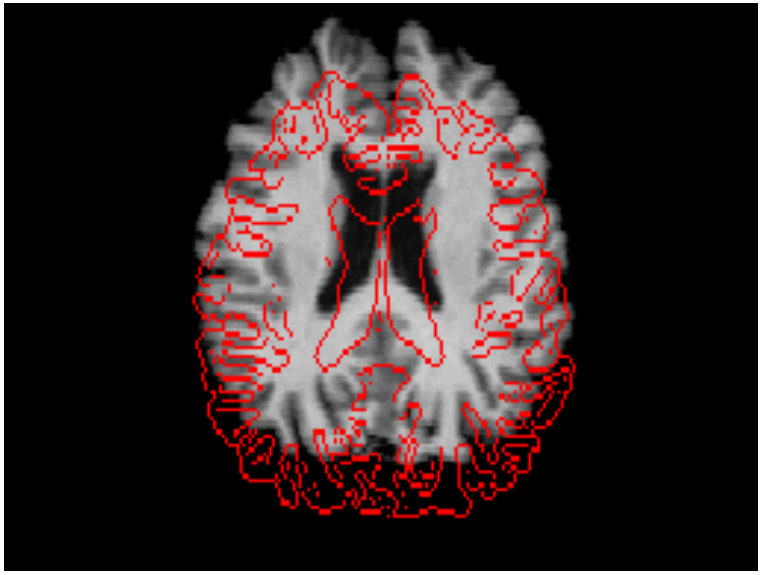
6 DOF in 3D

Includes:

- 3 Rotations
- 3 Translations

Used for **within-subject** registrations





Affine Transformations

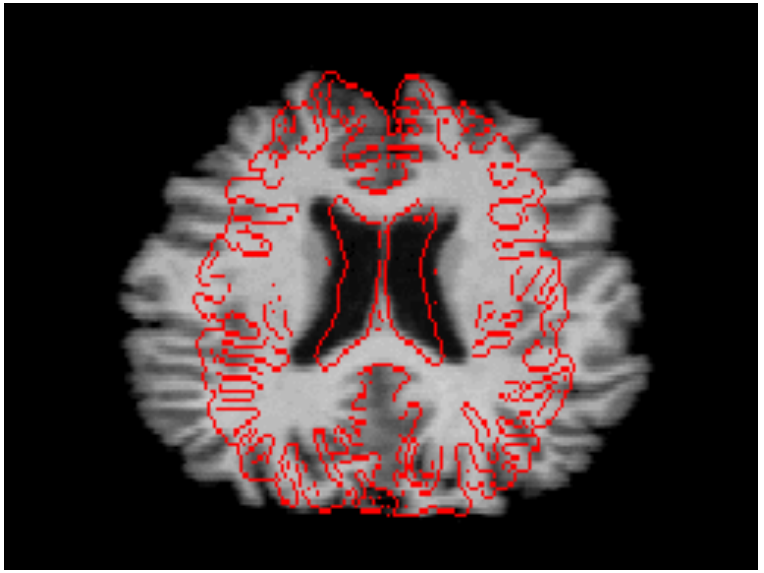
12 DOF in 3D

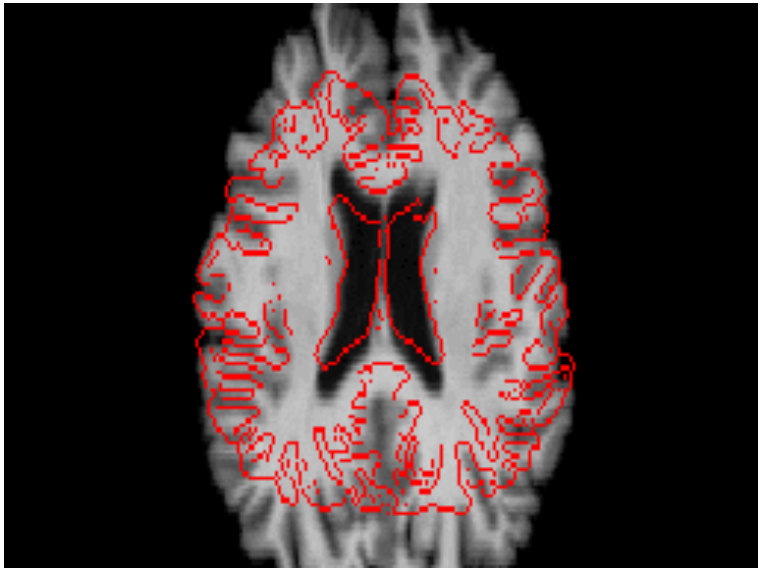
Linear Transf.

Includes:

- 3 Rotations
- 3 Translations

3 Scalings





Affine Transformations

12 DOF in 3D

Linear Transf.

Includes:

- 3 Rotations
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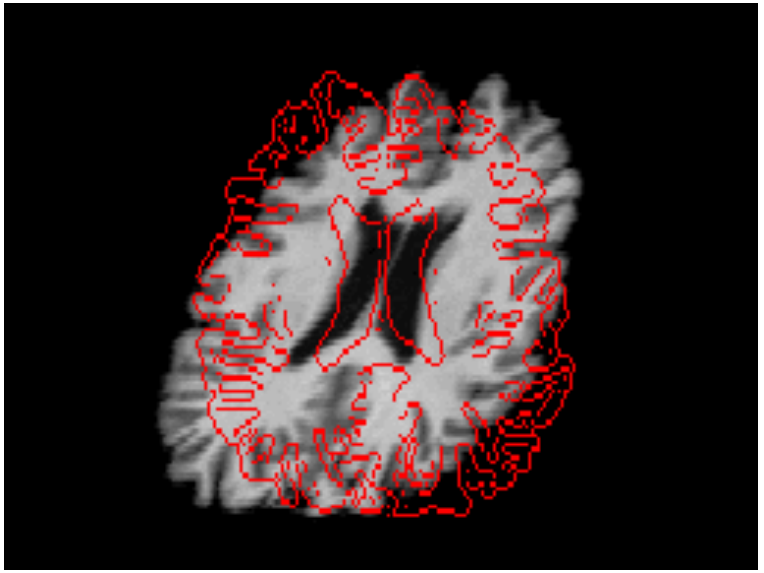


- 3 Scalings

3 Skews/Shears

Used for **eddy current correction**
and initialising non-linear registration

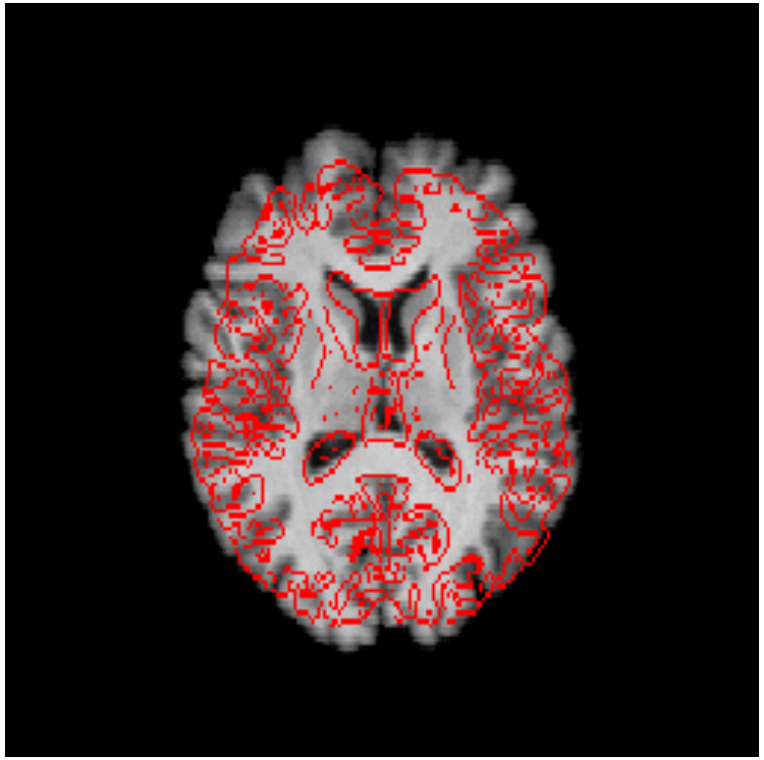
Non-Linear Transformations

More than 12 DOF

Can be purely local

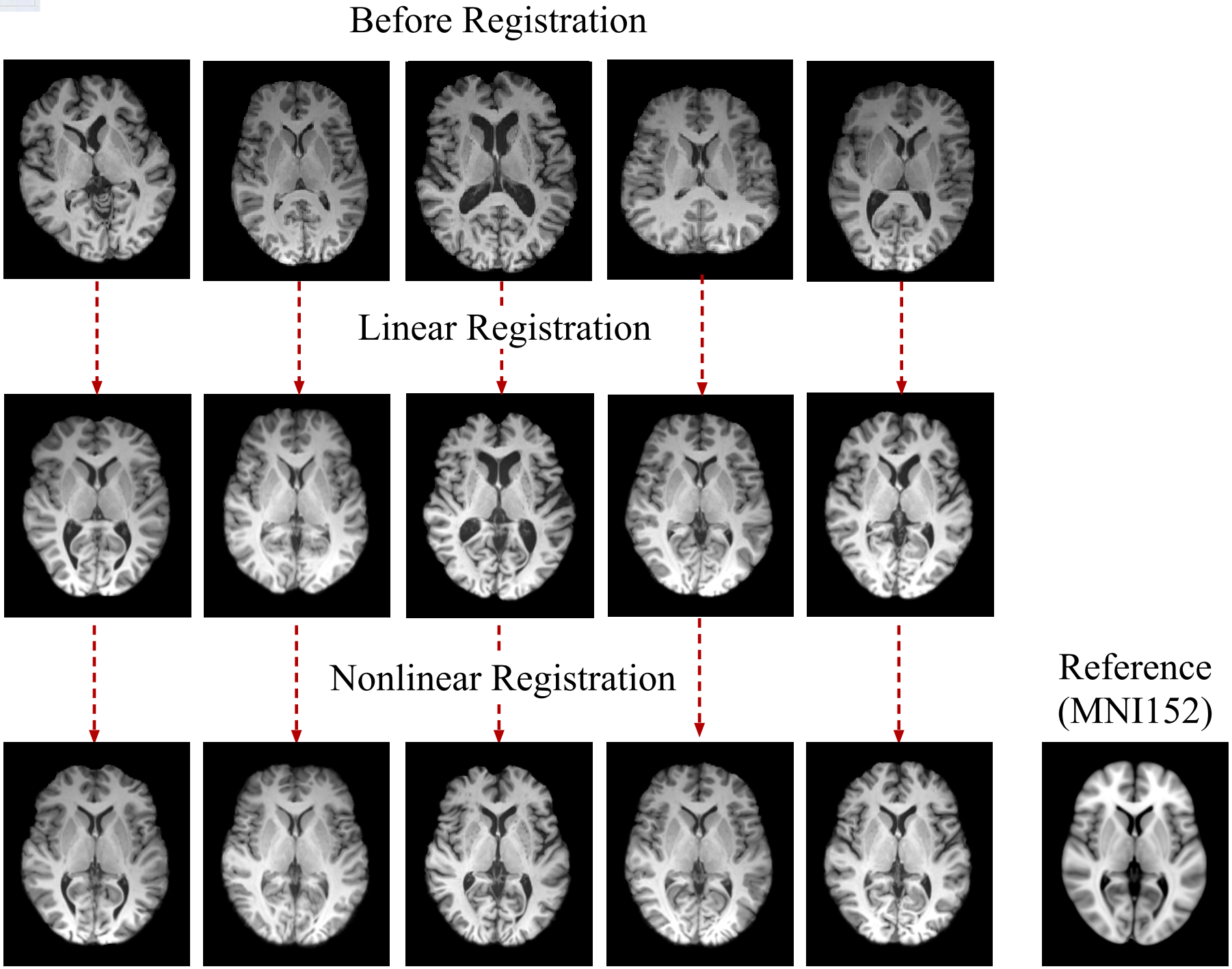
Subject to constraints:

- 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

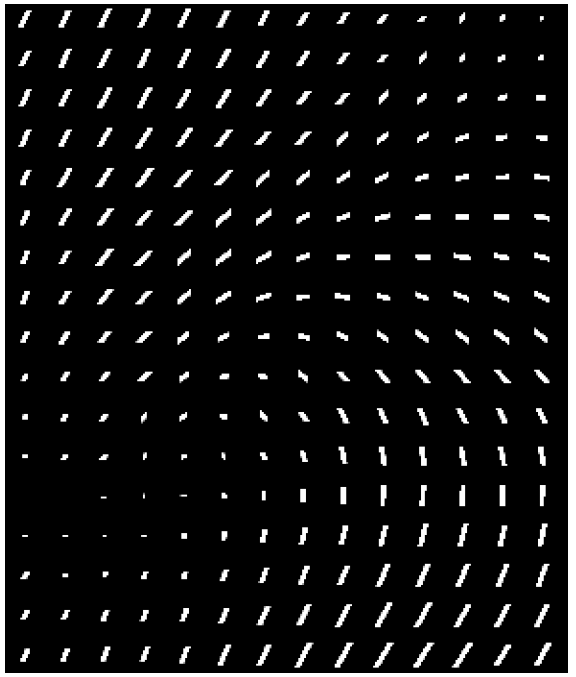
Global scaling (7 DOF)
- within-subject but with global scaling (equal in x,y,z)
- corrects for scanner scaling drift in *longitudinal studies*

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.



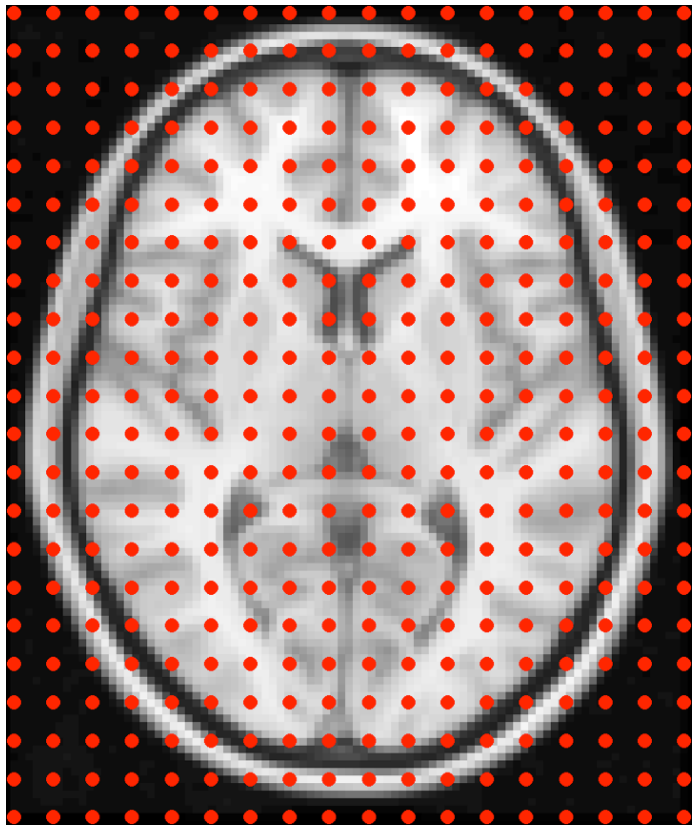
A non-linear transformation can be represented by a ***deformation field***.

Non-linear deformation

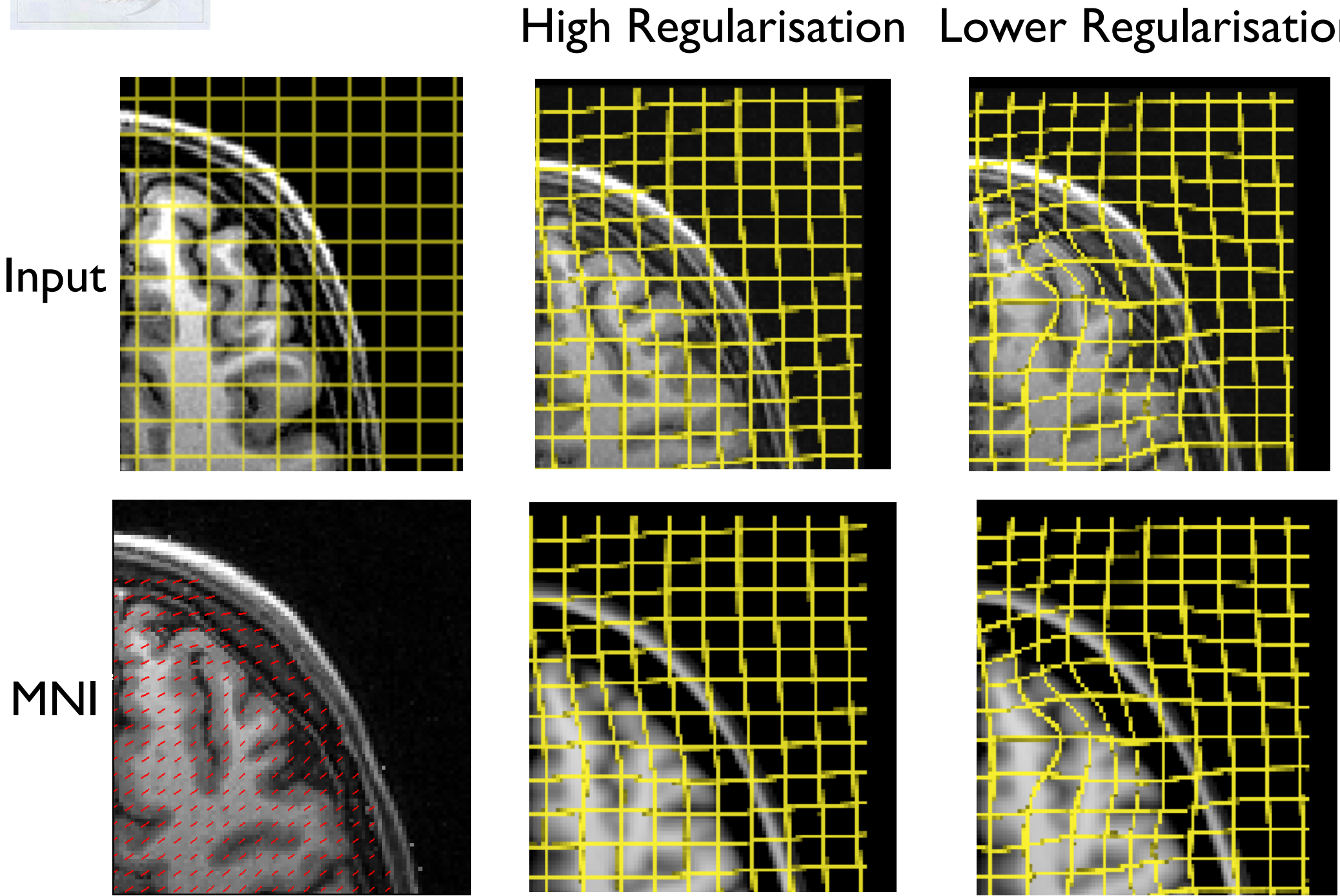
Regularisation, Warp Resolution and DOF

- 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

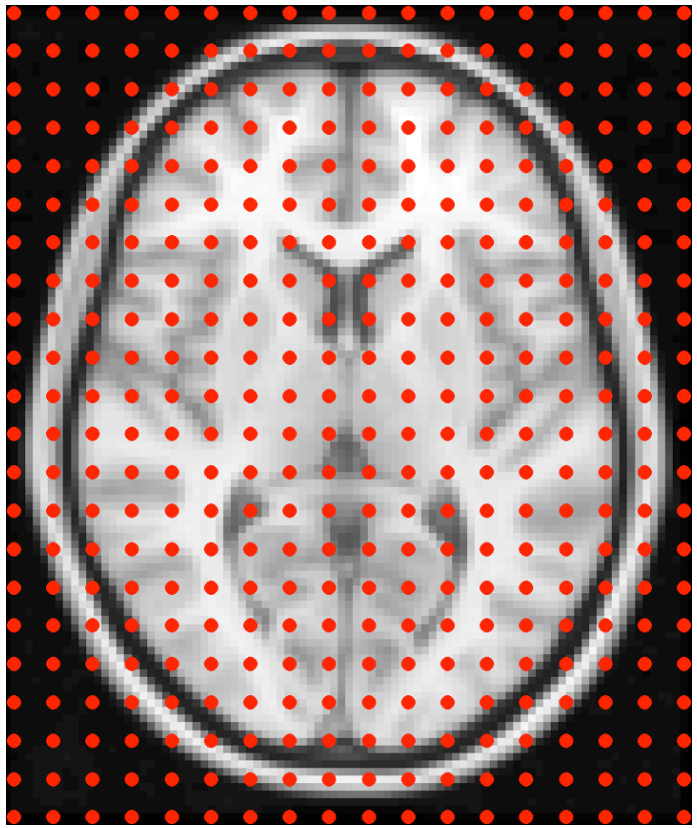


Non-linear deformation

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