Sunnybrook Neuroimaging Summer School

Structural module – Tutorial 1: Image viewers, file types, coordinate systems, and image registration

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Outline of topics

1. Image viewers
2. Imaging file types
3. Coordinate systems
4. Registration

Outline of format

- Presentation of concepts
- Demonstration with me (you can follow along)
- Exercises on your own (with help available)

1. Image viewers

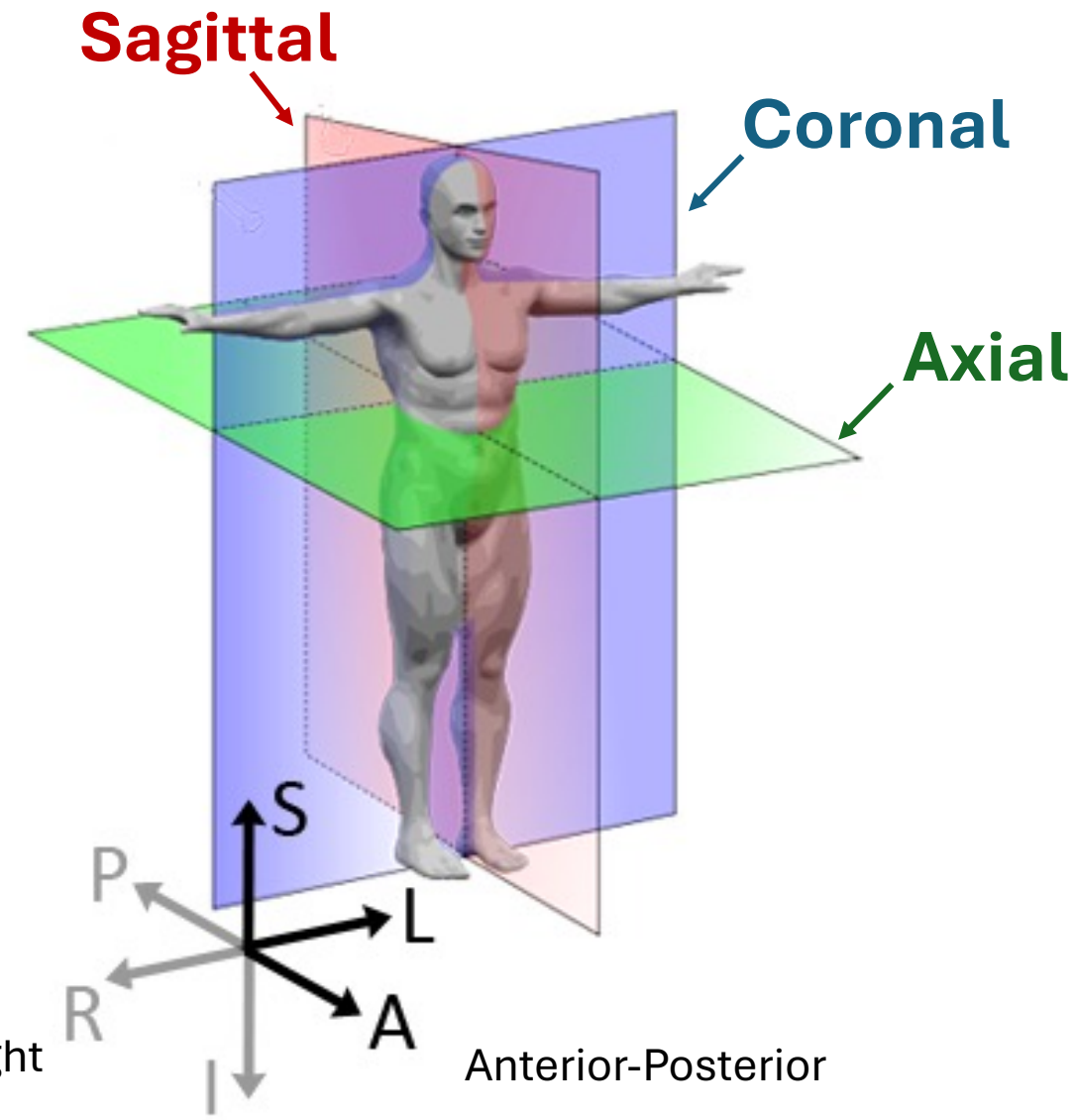
Image inspection

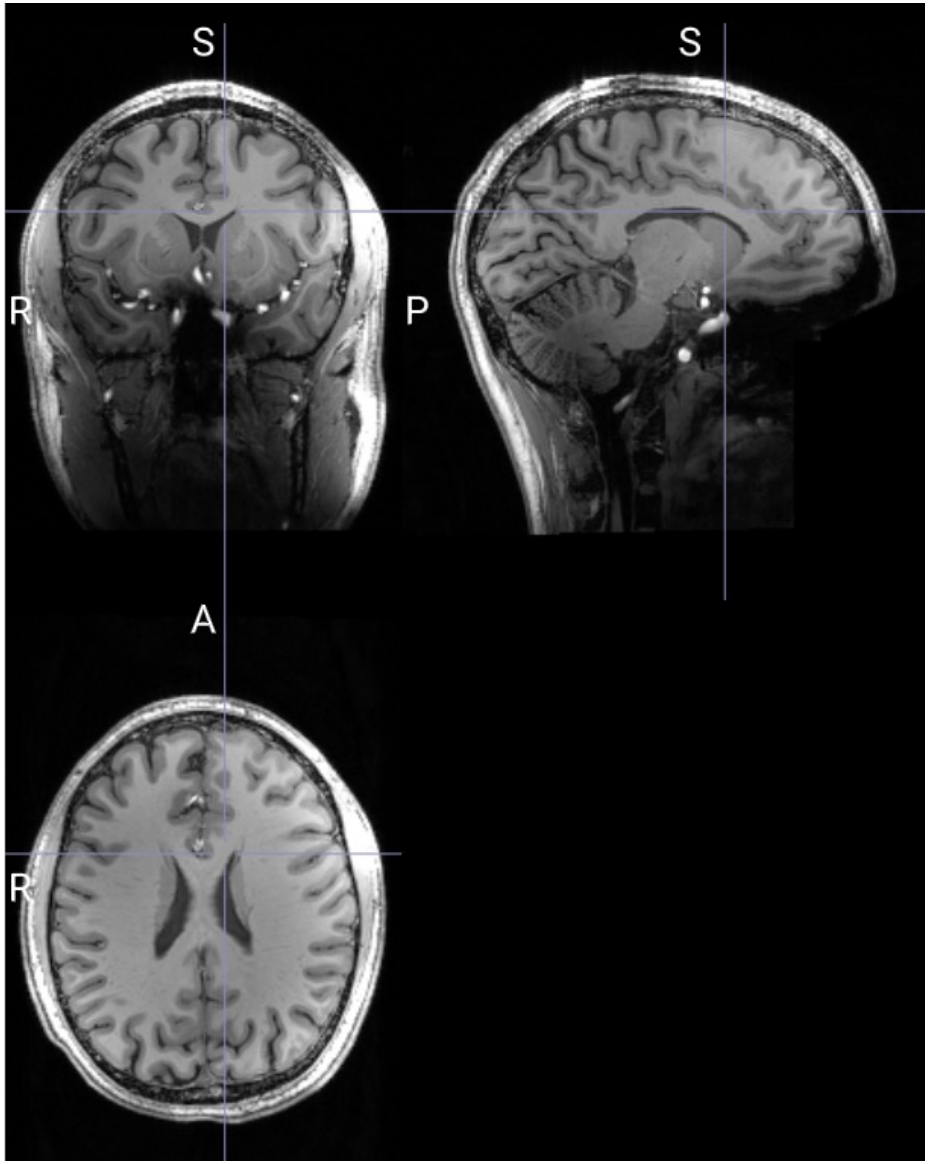
- Image = something you look at
- Therefore, look at your images before analyzing!
  - Is the image contrast correct?
  - Are there any artifacts?
  - Are different images of the same subject aligned?
  - Is my region-of-interest in the right location?

Image viewers

- MRIcroGL: https://www.nitrc.org/projects/mricrogl
- FSLeyes: https://open.win.ox.ac.uk/pages/fsl/fsleyes/fsleyes/userdoc/
- 3D Slicer: https://www.slicer.org
- ITKsnap: https://www.itksnap.org/pmwiki/pmwiki.php
- Many more…

Anatomical planes & axes



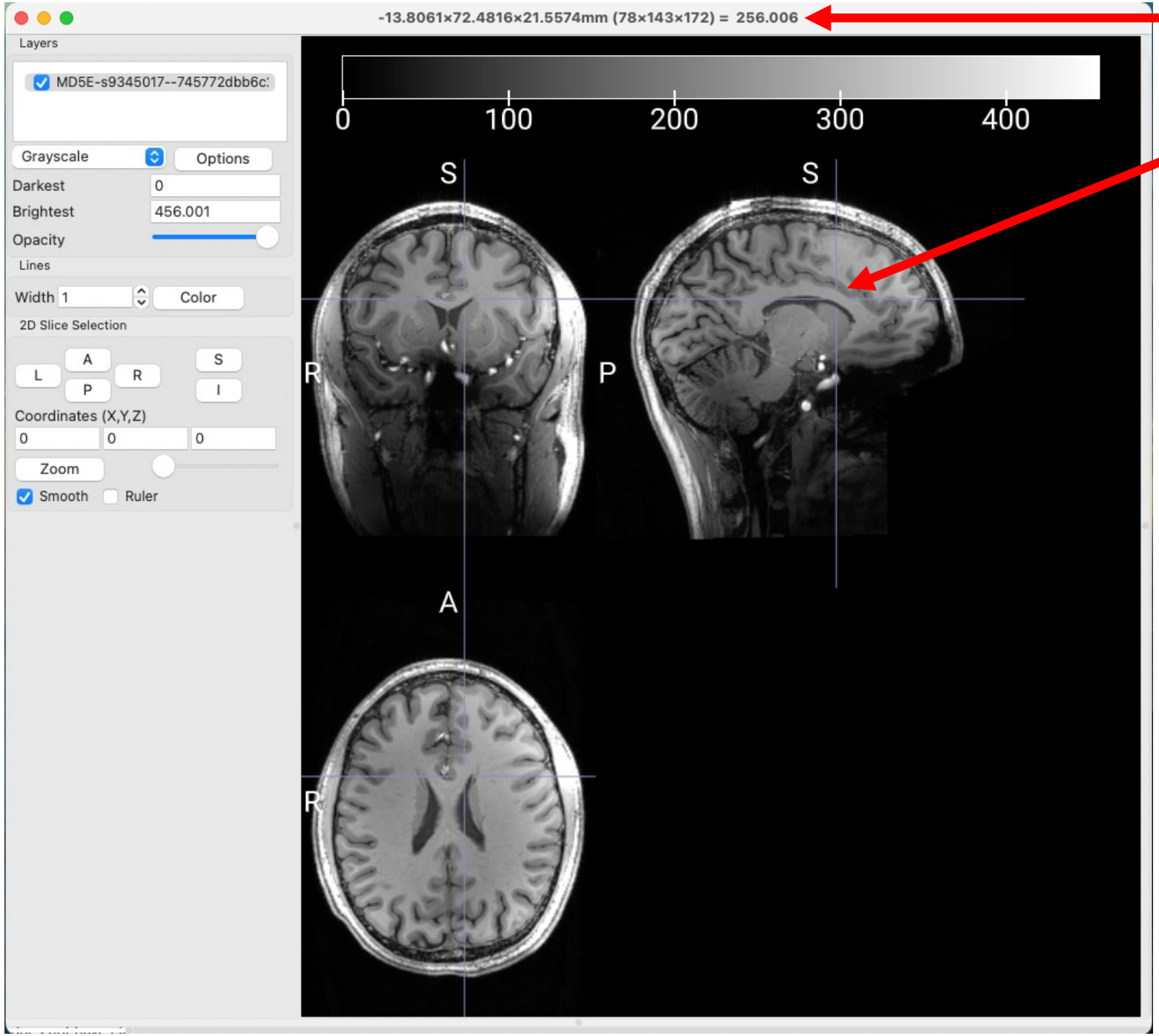


MRIcroGL basics

Layers, i.e., images displayed

Colourmap and colour scale

Slice selection, coordinates, and zoom



Coordinates & intensity at cursor

Cursor

Demo 1.1

- Opening a file
- Navigating a volume
- Changing the viewing planes
- Zooming and panning
- Changing the colourmap

Exercise 1.1

a) Open the volume “sub-001_ses-std_T1w.nii.gz”
b) Play with the settings “Darkest” and “Brightest”. What happens as you change each of these values?
c) Go to File > Add Overlay and select “sub-001_ses-fast_T1w.nii.gz”. What do you think this image is relative to the previous one? Try toggling the overlay on and off.
d) In “Coordinates”, enter the values 10, 10, 20. The coordinates label changes to a value very close to 10×10 ×20 mm. Beside it in parentheses is (96 ×79 ×163). What do you think that is?

Demo 1.2

- Displaying a mask overlaid on an image
- Creating and saving a region-of-interest (ROI) a.k.a. a volume-of-interest (VOI)

Exercise 1.2

a) Open the volume “sub-001_ses-std_T1w.nii.gz” and open the mask “sub-001_ses-std_T1w_brain_seg_2.nii.gz”. What do you think the mask covers?

b) Use the Draw toolbar to modify the mask. Erase one part and draw in a new part. Save your modified mask with a new filename.

c) Open some of the other files in this folder as overlays or masks and try to figure out what they are.

2. File types

Learning objectives

- Name the common image file types
- Describe the DICOM file type and header information
- Describe the NIfTI file type and header information
- Be able to convert DICOMs to NIfTIs

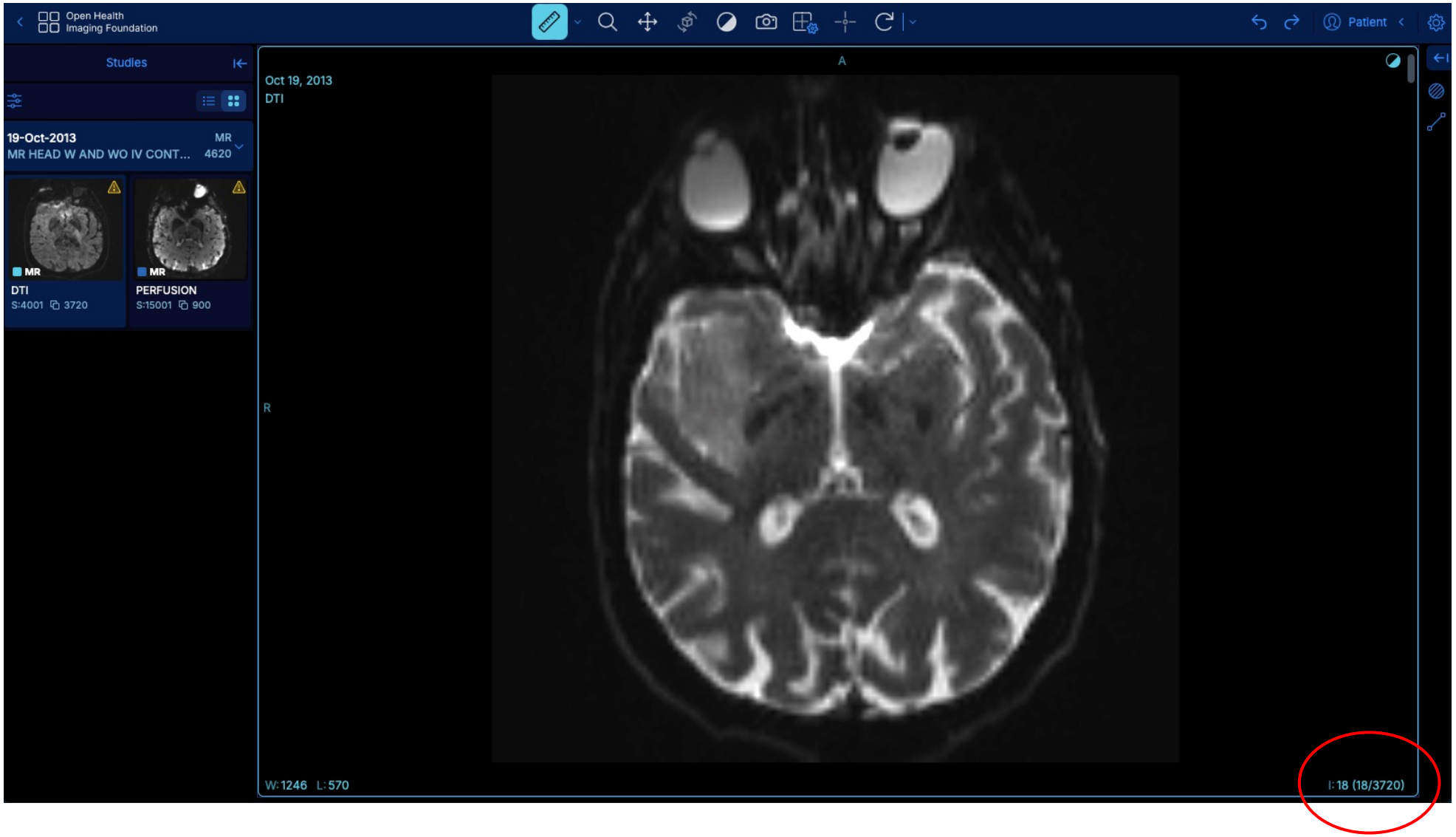
Imaging file types

- DICOM
- NIfTI
- MINC
- Analyze

DICOM

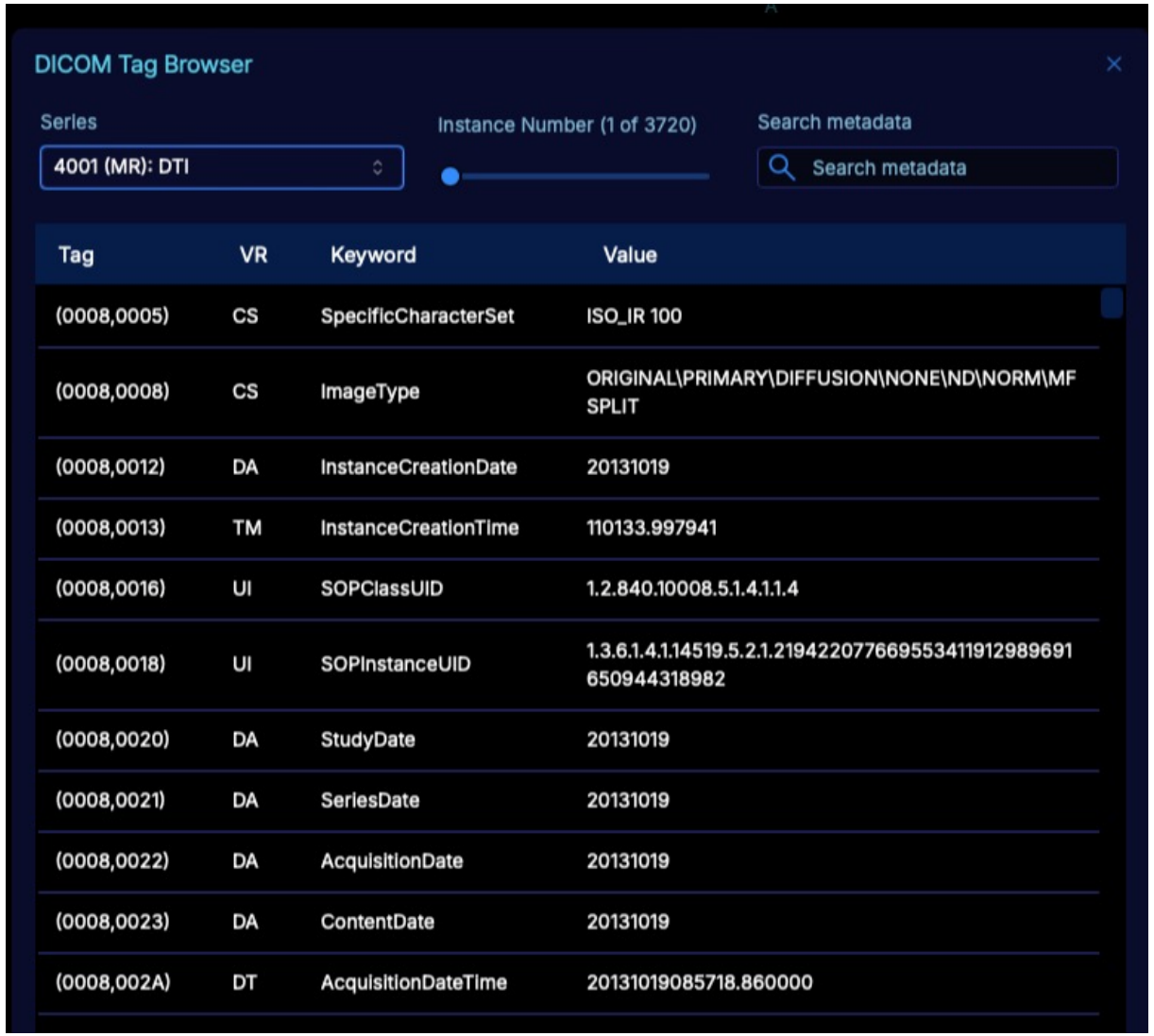
- “Digital Imaging and Communications in Medicine”
- Standard file type for medical imaging data including MRI
- Embedded attributes in the “header”
  - Patient name
  - Image modality
  - Acquisition parameters
  - Etc…
- Common export format for data from scanners

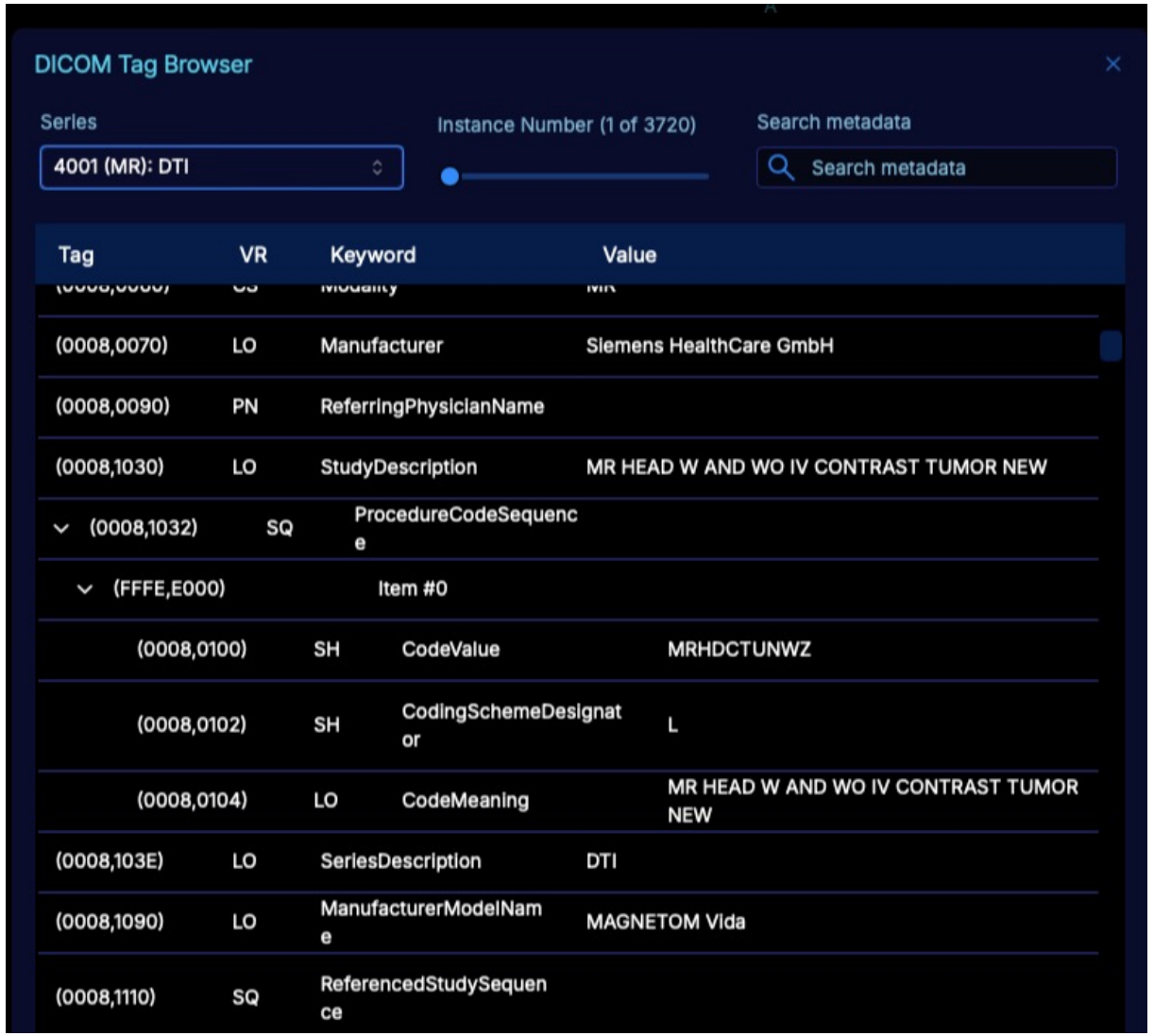
DICOM example – Image data



- Example of brain diffusion MRI
- 3720 DICOM files in this image series; screenshot shows #18

DICOM example - Metadata





- Each DICOM “tag” is associated with a unique piece of metadata

NIfTI

- “Neuroimaging Informatics Technology Initiative” format
- Minimalist file format
- Stores imaging data (like DICOM) alongside a small header
- Header mostly contains geometry and scaling information
  - Pixel size
  - Volume orientation
  - Etc…
- Commonly used for neuroimaging studies

Example of a NIfTI header

```
sizeof_hdr      348
data_type       INT16
dim0            3
dim1            400
dim2            400
dim3            182
dim4            1
dim5            1
dim6            1
dim7            1
vox_units       mm
time_units      s
datatype        4
nbyper          2
bitpix          16
pixdim0         1.000000
pixdim1         0.700000
pixdim2         0.700000
pixdim3         1.100000
pixdim4         0.008000
pixdim5         0.000000
pixdim6         0.000000
pixdim7         0.000000
```

Comparing DICOM and NIfTI

Property	DICOM	NIfTI
Image data format	2D slices	3D or 4D volumes
Header metadata	Extensive and flexible	Essential info only
Complexity	Large files, cumbersome	Simple and efficient
Common uses	Export format from scanner	Storage for neuroimaging studies

Converting from DICOM to NIfTI

- First image processing step is often DICOM ⇒ NIfTI conversion
- Many open-source tools for conversion
- We will use “dcm2niix”: https://github.com/rordenlab/dcm2niix
  - Command-line utility
  - MRIcroGL has an interface for dcm2niix

Demo 2.1

- Convert a DICOM to a NIfTI

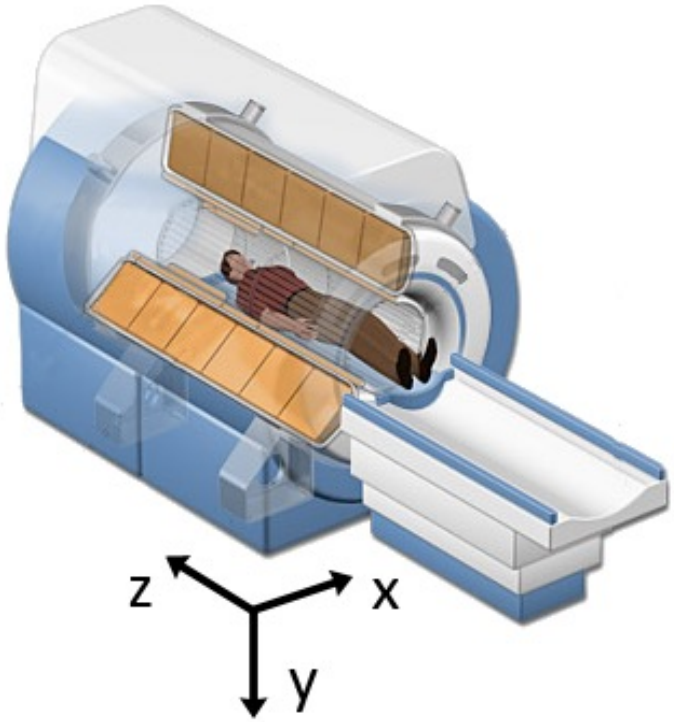
Exercise 2.1

a) Output the NIfTI into a different folder than the original DICOM
b) Customize the output file name for the DICOM
c) Look in the “BIDS Sidecar,” i.e., the .json file that is created alongside the .nii.gz file. You can use a standard text file viewer. What’s in there?

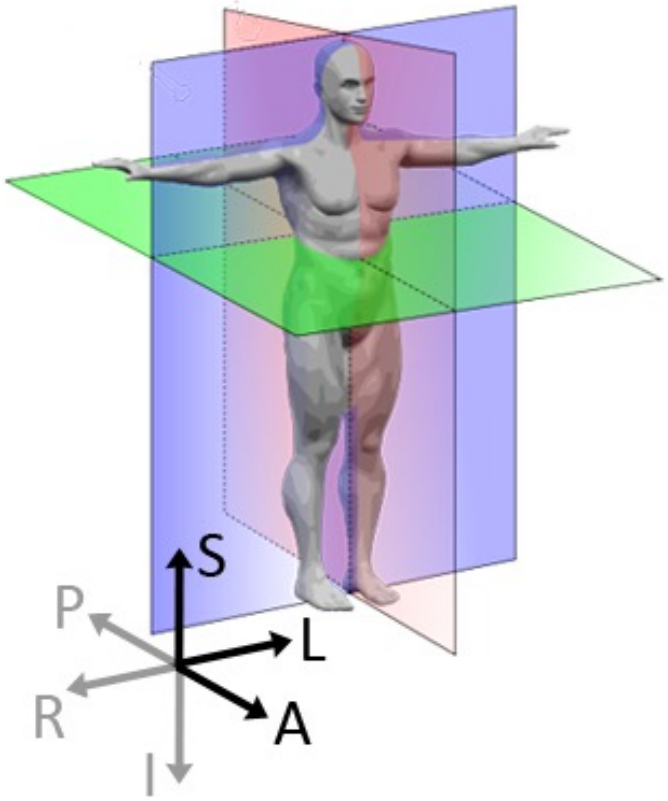
3. Coordinate systems

Types of coordinate systems

World



Anatomical



Image/Voxel

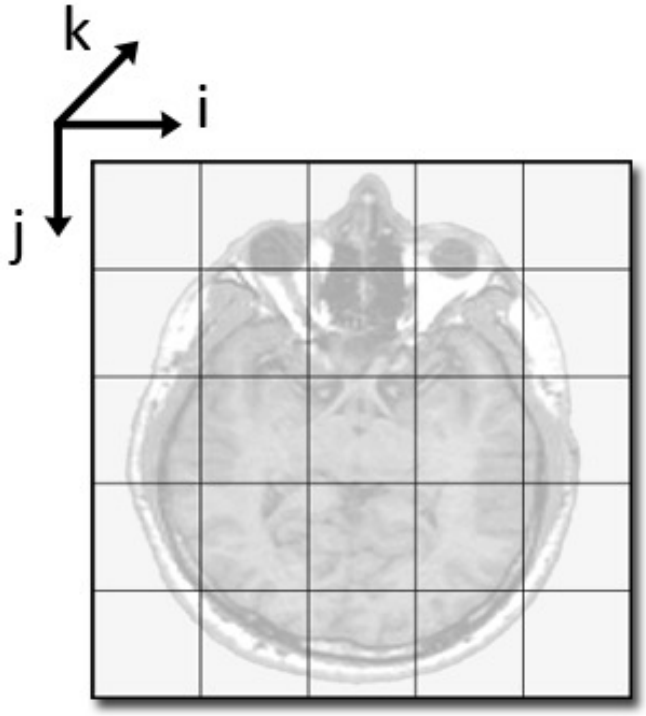


Image file types store spatial transformations from voxel coordinates to other coordinate systems

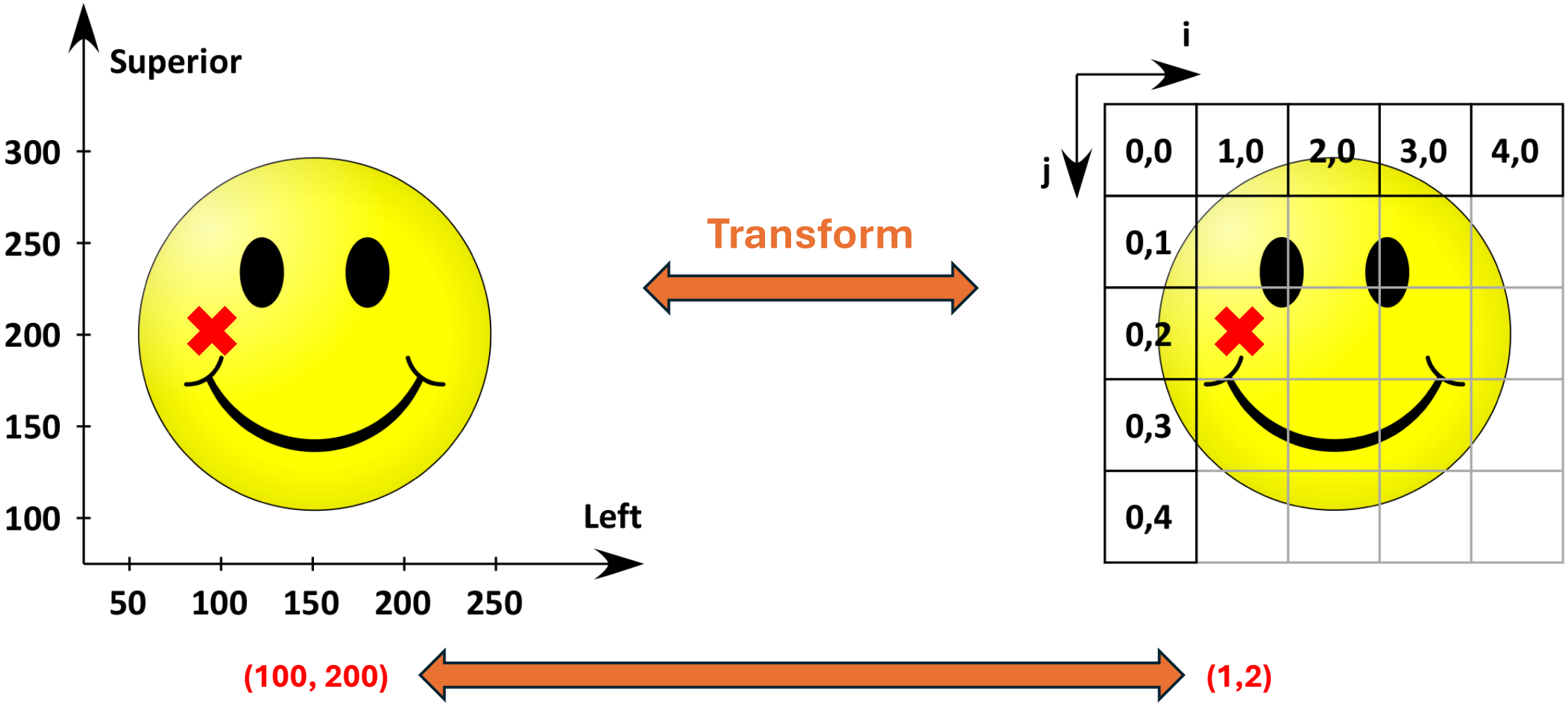
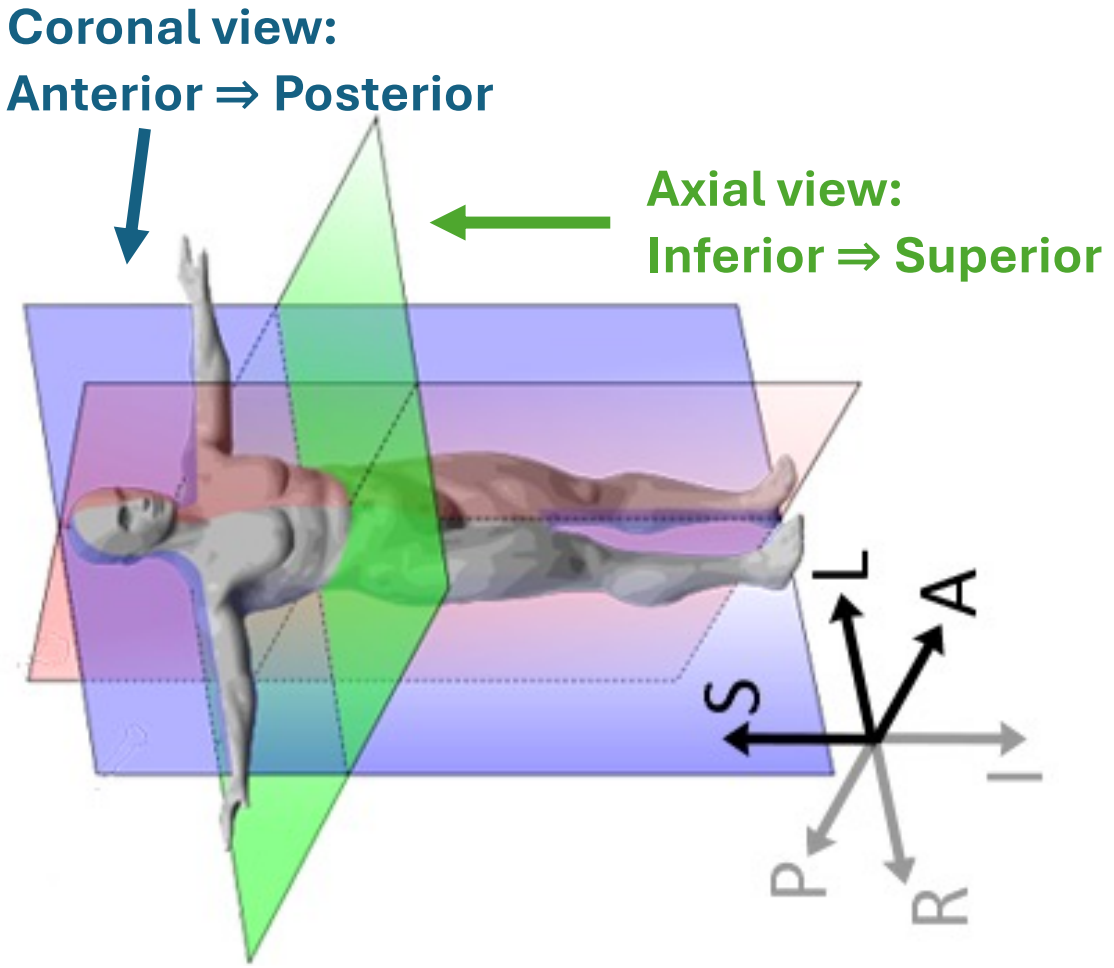
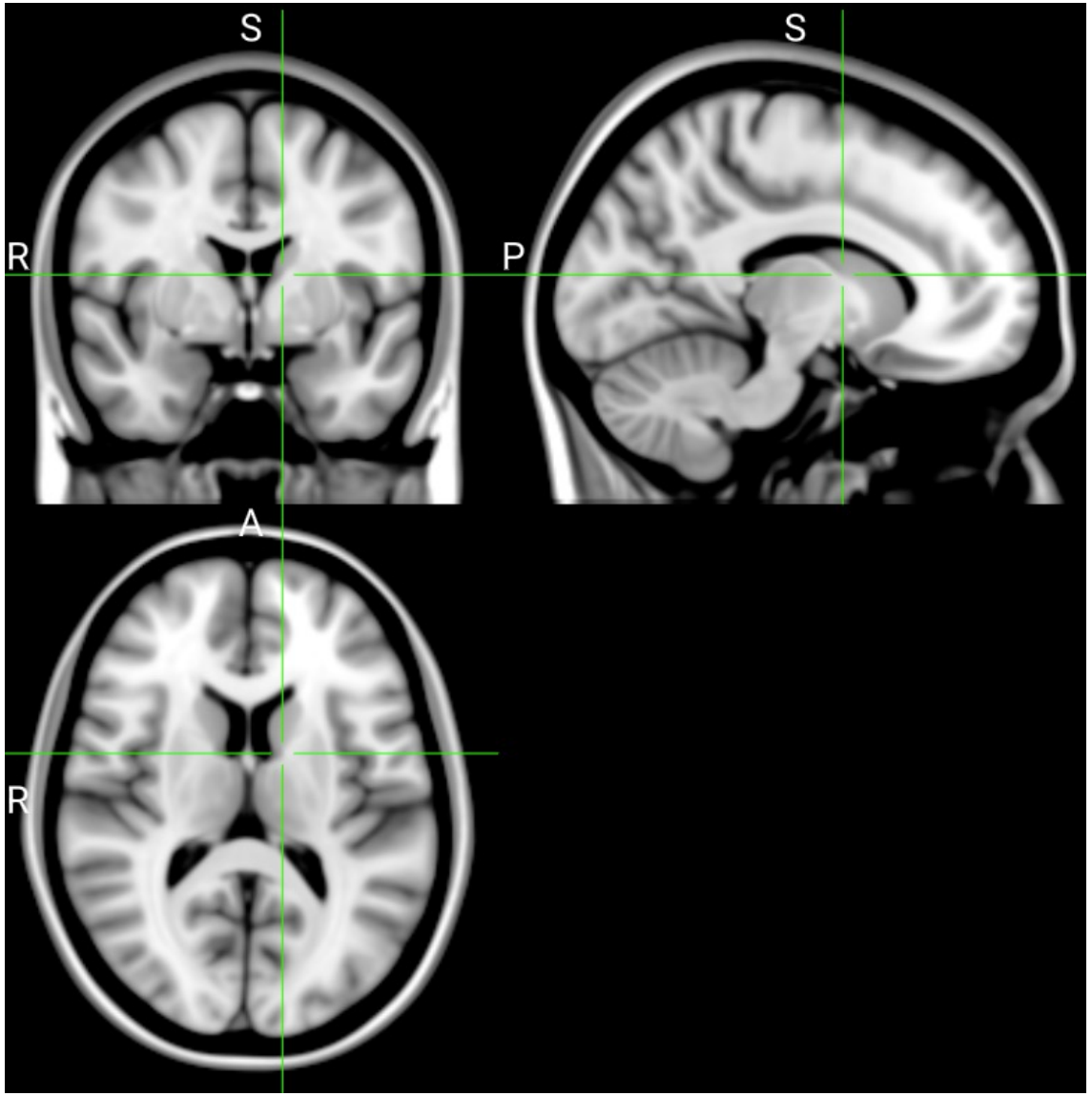


Image orientation in brain MRI

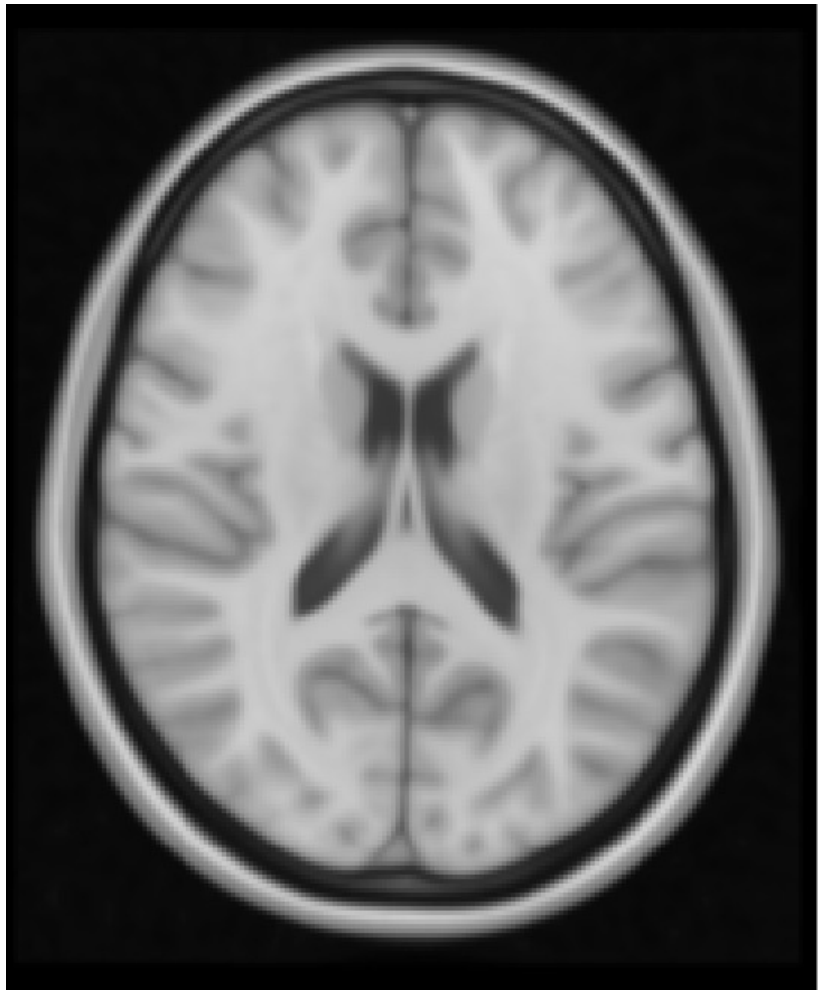


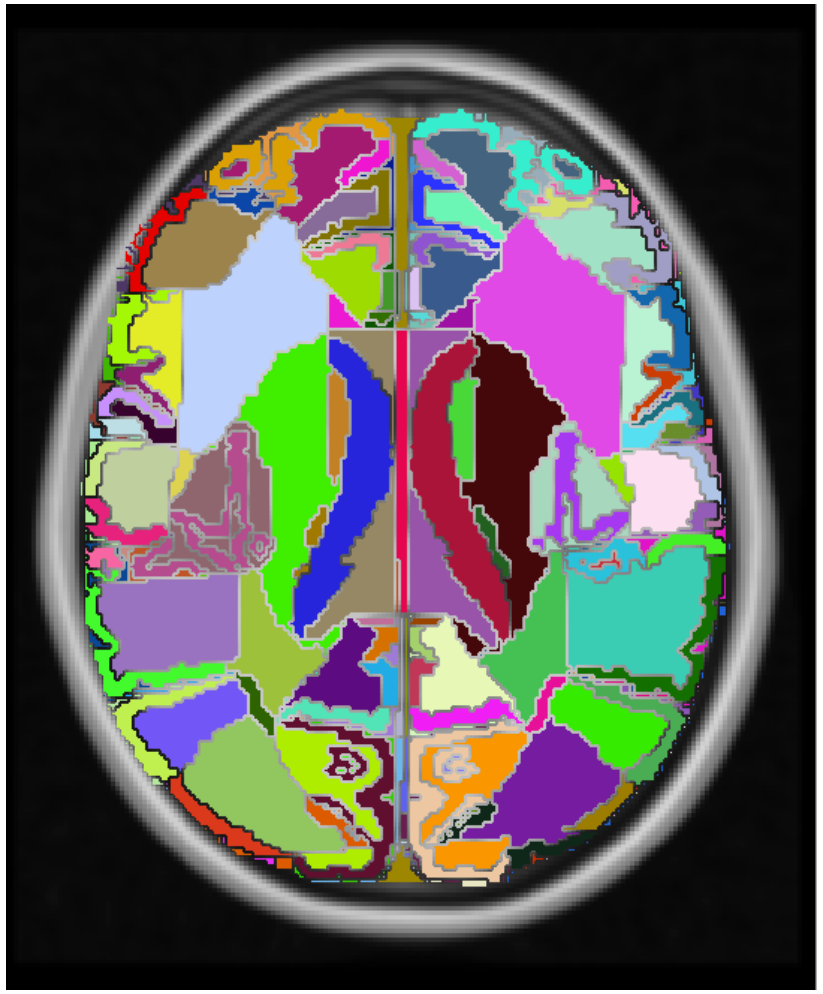
Standard space – MNI-152



- T_1-weighted image of human brain averaged from 152 healthy volunteers
- In a standardized coordinate system where (0,0,0) is the anterior commissure
- Many *atlases* defined in this space

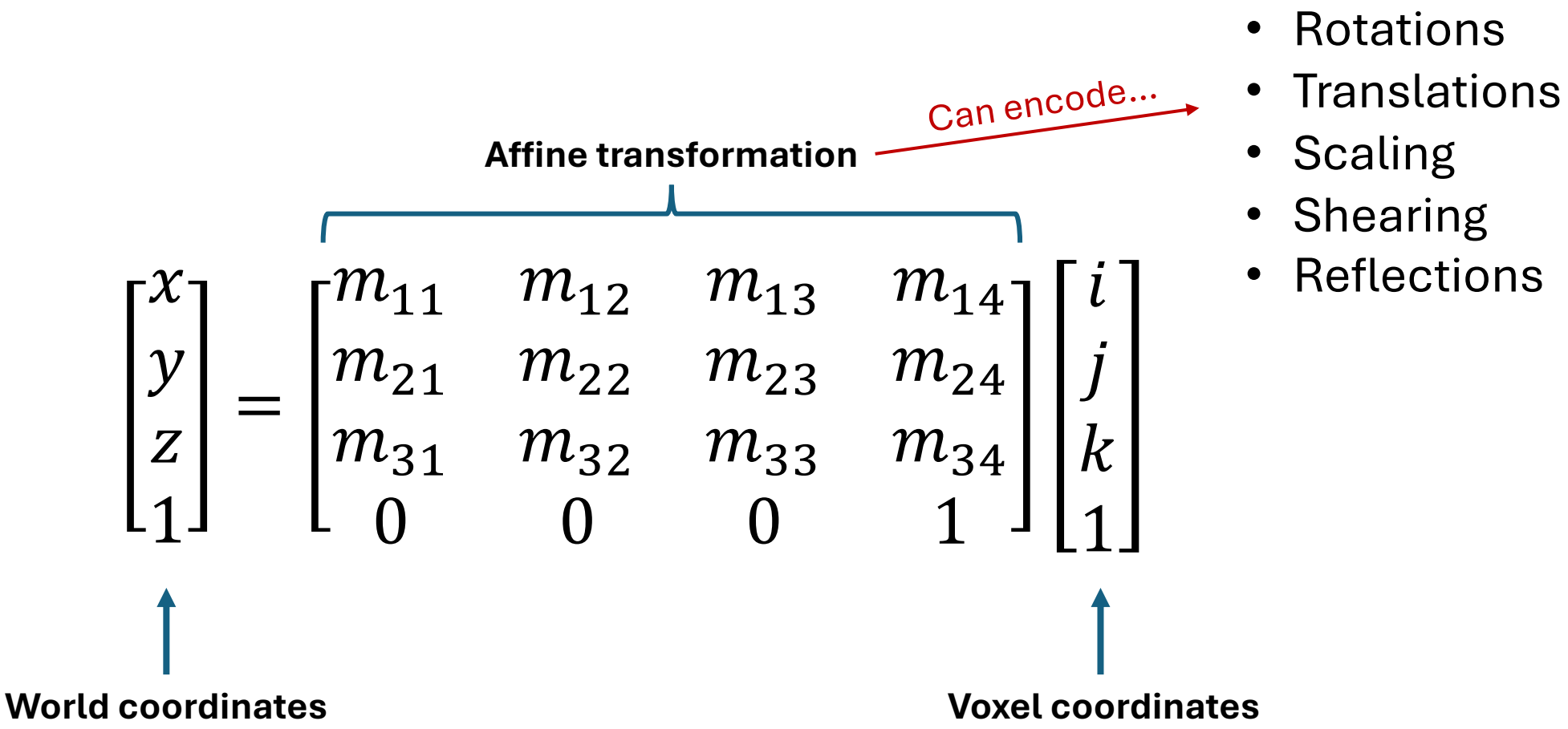
Atlas example: Talairach





- Set of brain structures defined in a standard space
- Need to align subject's brain to standard brain for analysis

The NIfTI affine (advanced)



- Rotations
- Translations
- Scaling
- Shearing
- Reflections

Demo 3.1

- Inspect the NIfTI header for the voxel size and orientation matrix

Exercise 3.1

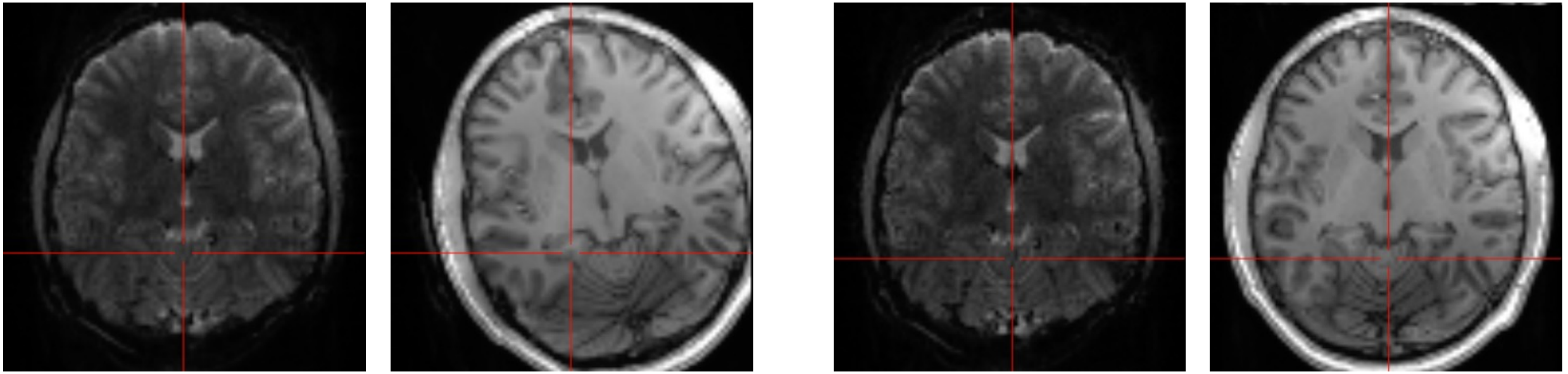
- Open “sub-001_ses-std_T1w_resampled_brain.nii.gz”
- What anatomical dimension (left-right, anterior-posterior, superior-inferior) does each voxel dimension (i,j,k) correspond to, roughly? (Hint: Try incrementing the cursor along each direction)

4. Image registration

Registration = Estimating a spatial transformation between two images to align the images

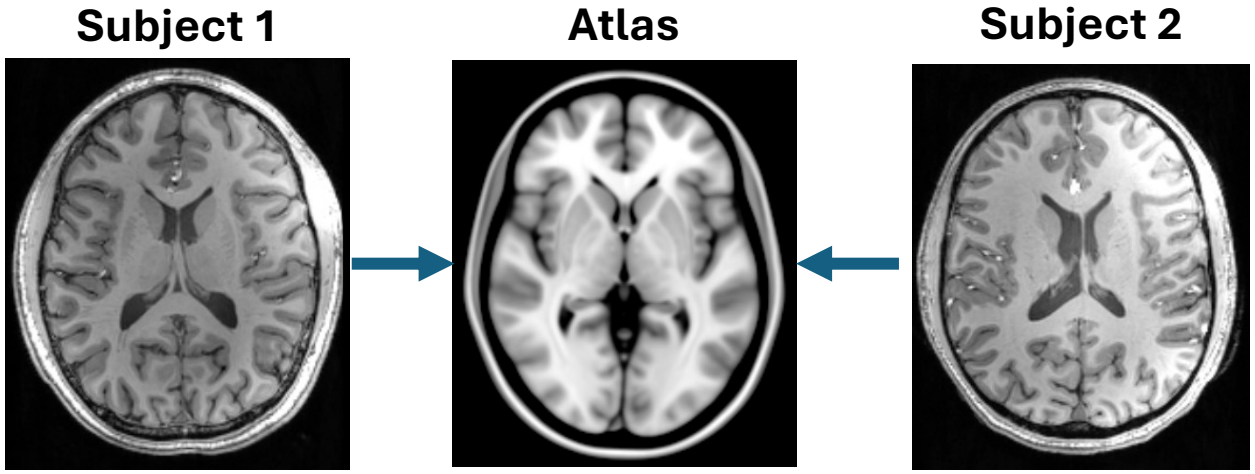
Before registration

After registration

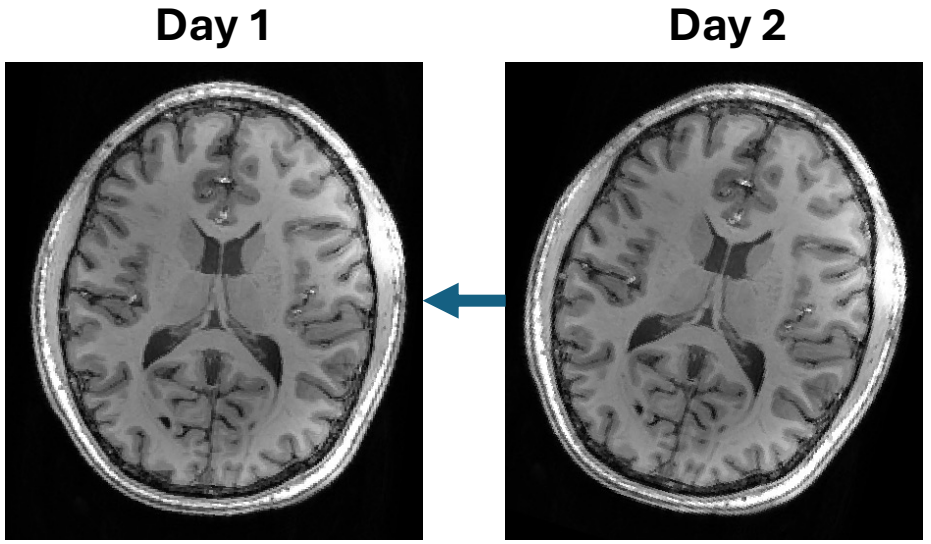


- “Aligned” means the relationship between the voxel coordinates and anatomical coordinates are the same
- Practically, when you flip between images in an image viewer, the subject should appear motionless

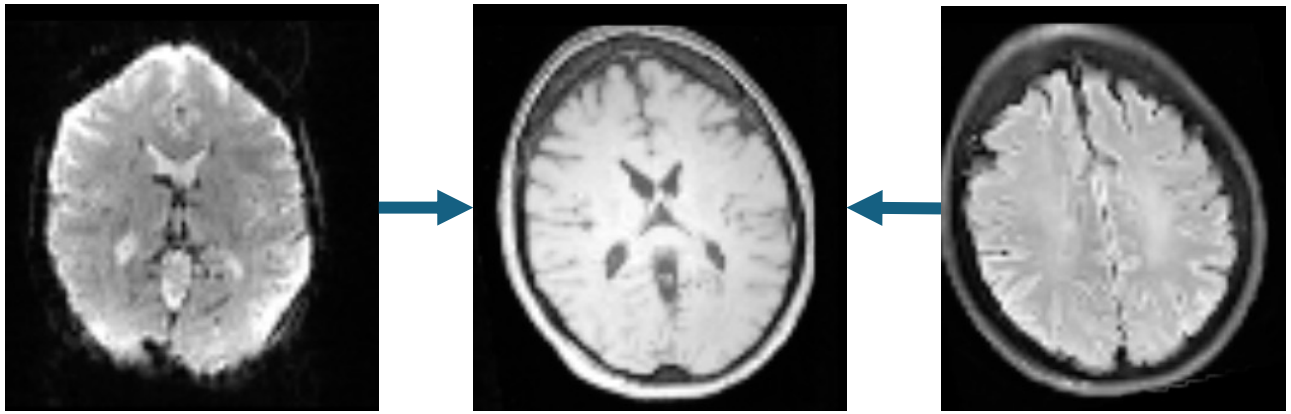
Common uses for registration



Align images from different subjects to an atlas



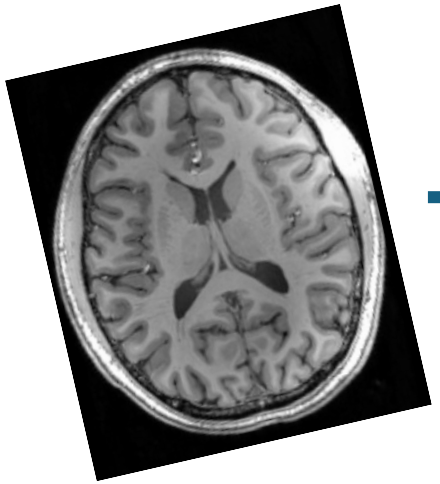
Align images from the same subject take on different days



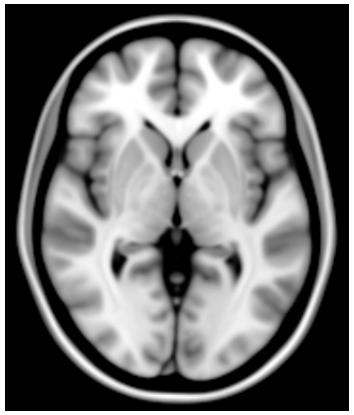
Align different image contrasts from the same subject taken the same day

Overview of registration steps

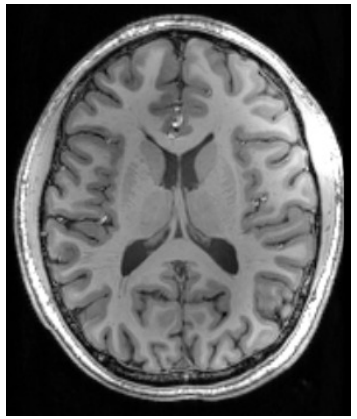
Moving image

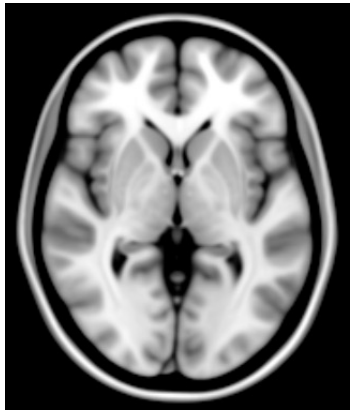


Reference image



Transformed image



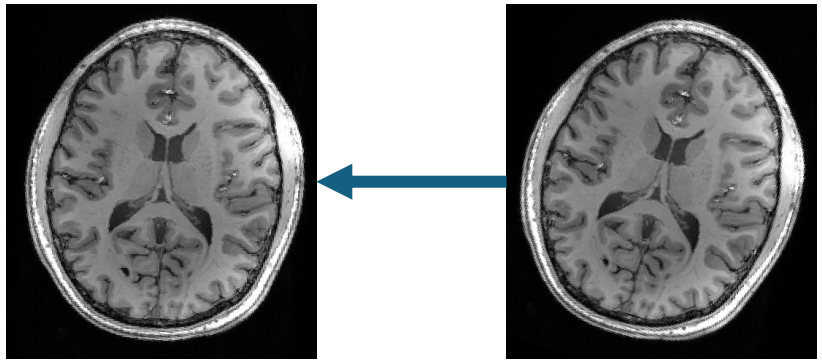


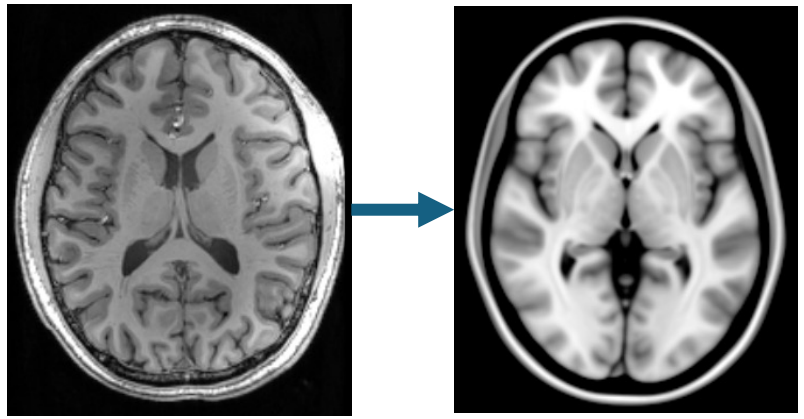
1. Estimate a *transformation* that minimizes a *cost function*

2. Apply the transformation and *interpolate* the image intensities

Linear versus non-linear registration

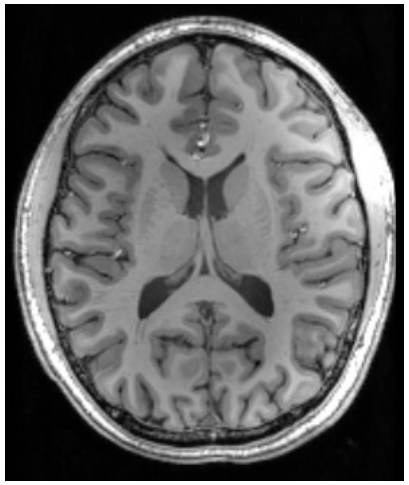
Type	Example software	Number of parameters	Example use
Linear	FLIRT, ANTs Rigid	1-12	Align images of the same subject (different days or different contrasts)
Non-linear	FNIRT, ANTs Symmetric Normalization	12-millions	Align images of different subjects to a common atlas



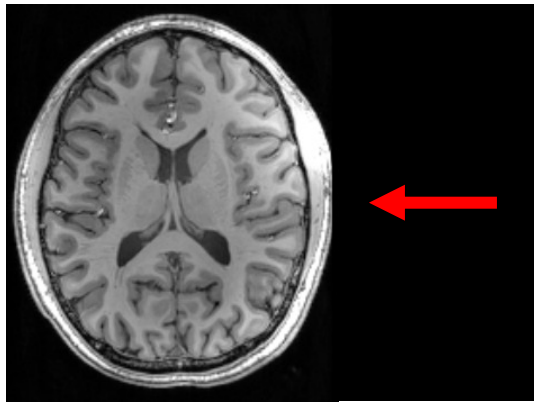


Examples of linear transformations

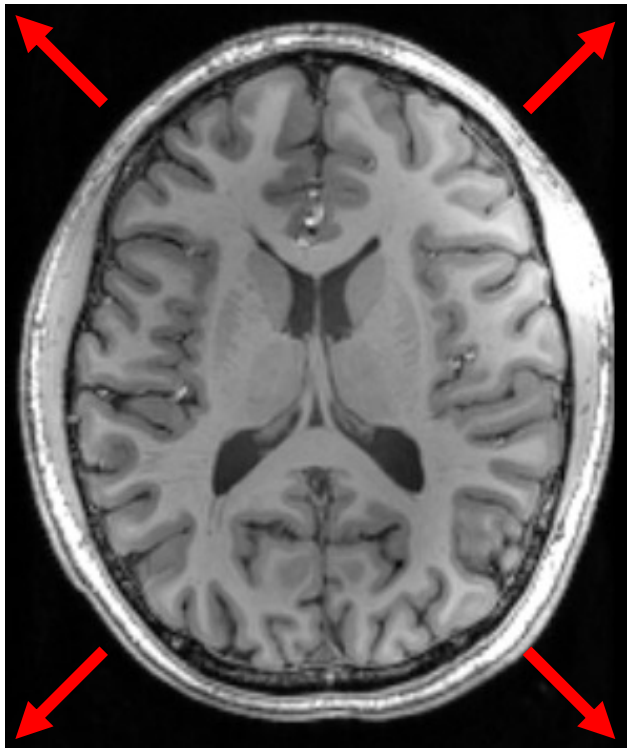
Original image



Translation

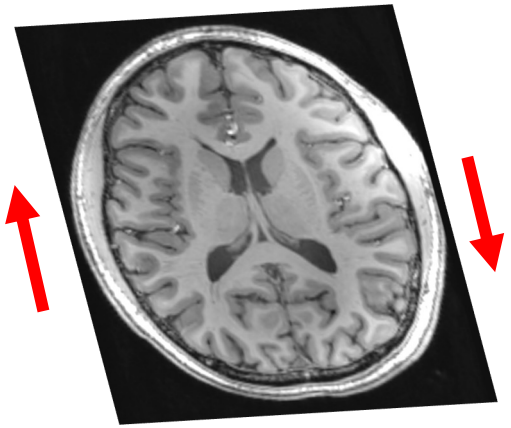


Scale



Rotation

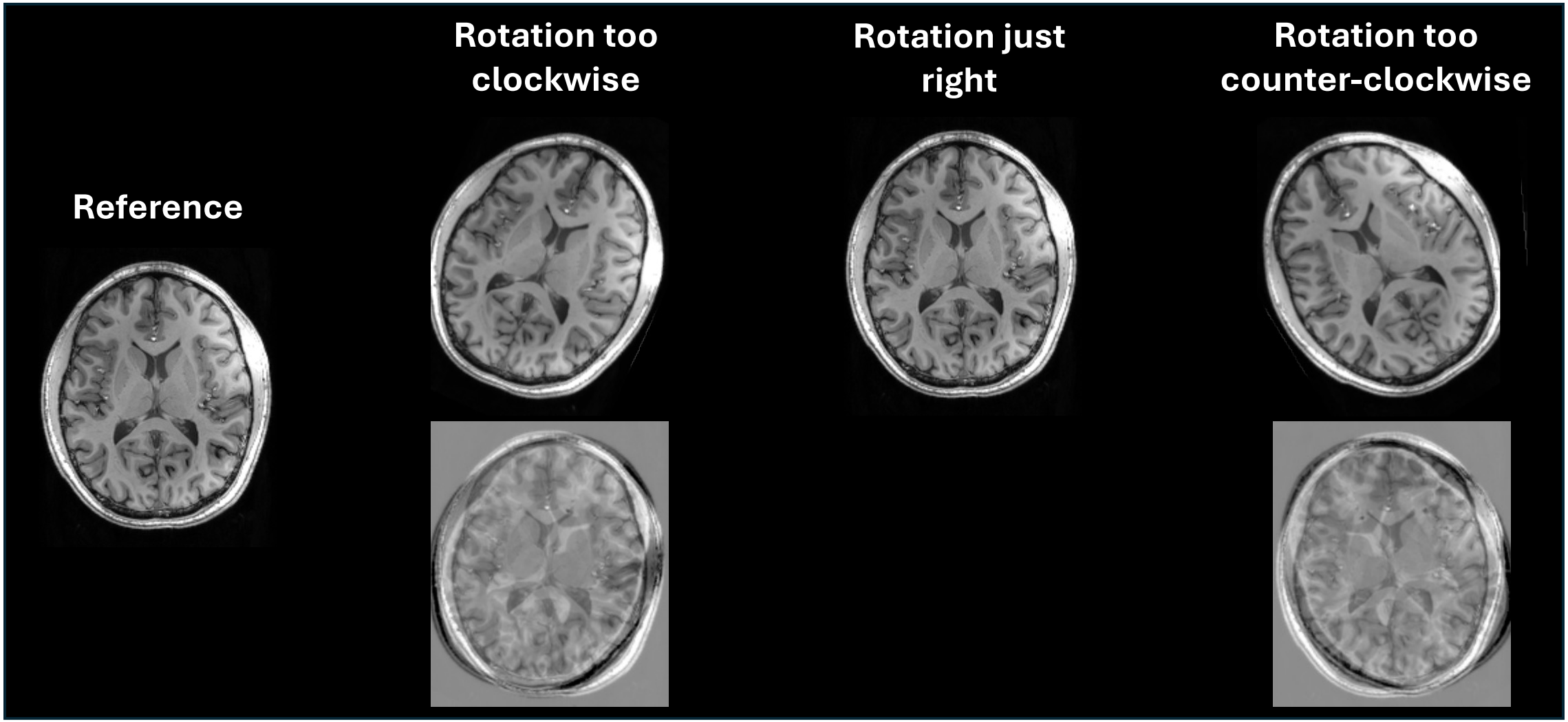
Shear



Linear transformation types available in FMRIB's Linear Image Registration Tool (FLIRT)

Model	DOF	Description
Translation only	3	Translation in 3 dimensions
Rigid body	6	Translations (3) and rotations (3)
Global rescale	7	Rigid body (6) + uniform scale (1)
Traditional	9	Rigid body (6) + anisotropic scaling (3)
Affine	12	Traditional (9) + anisotropic shearing (3)

Cost functions

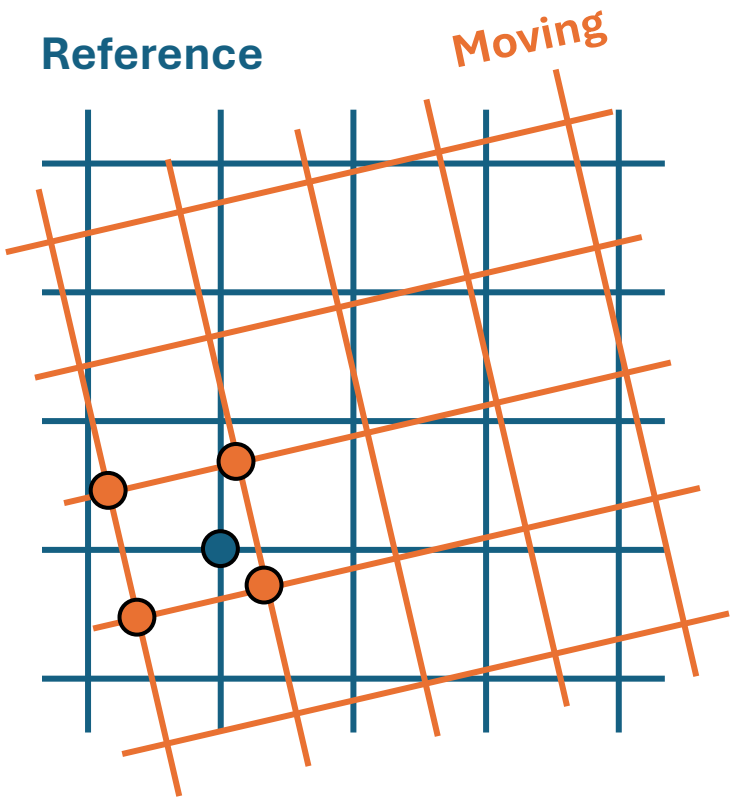


- Input: Moving and reference images
- Output: Single scalar measurement of alignment quality

Cost functions available in FLIRT

Cost function	Use
Correlation ratio	Any two MRI contrasts
Mutual Information	Any contrasts (incl. non-MR)
Normalised Mutual information	Any contrasts (incl. non-MR)
Normalised Correlation	Same contrast
Least Squares	Same contrast & sequence parameters

Interpolation



- Estimate intensities on reference image grid from intensities on moving image grid
- Can choose intensity of nearest neighbour
- Can use intensities from multiple neighbours to calculate an estimate

Interpolation methods available in FLIRT

Interpolation method	Properties
Nearest Neighbour	Fast but “blocky” images result; good for regions-of-interest
Tri-Linear	Fast but blurs the image
Spline	Decently fast and less blurring
Sinc	Slower but less blurring

Demo 4.1

- Rigidly register two T1-weighted images of the same subject on different days (ses-fast ⇒ ses-std) using the default settings in FLIRT
- Check the registration with MRIcroGL

Exercise 4.1

a) Rigidly register the low-resolution “sub-010001_ses-02_acq-lowres_FLAIR_misaligned.nii.gz” to “sub-010001_ses-02_acq-mp2rage_T1w” using the default settings. Check the registration quality with MRIcroGL. How does it look?

b) Try changing the cost function from the default to fix the problem in (a).

c) Do the registration again but change the interpolation option. What happens if you choose “Nearest neighbour”?

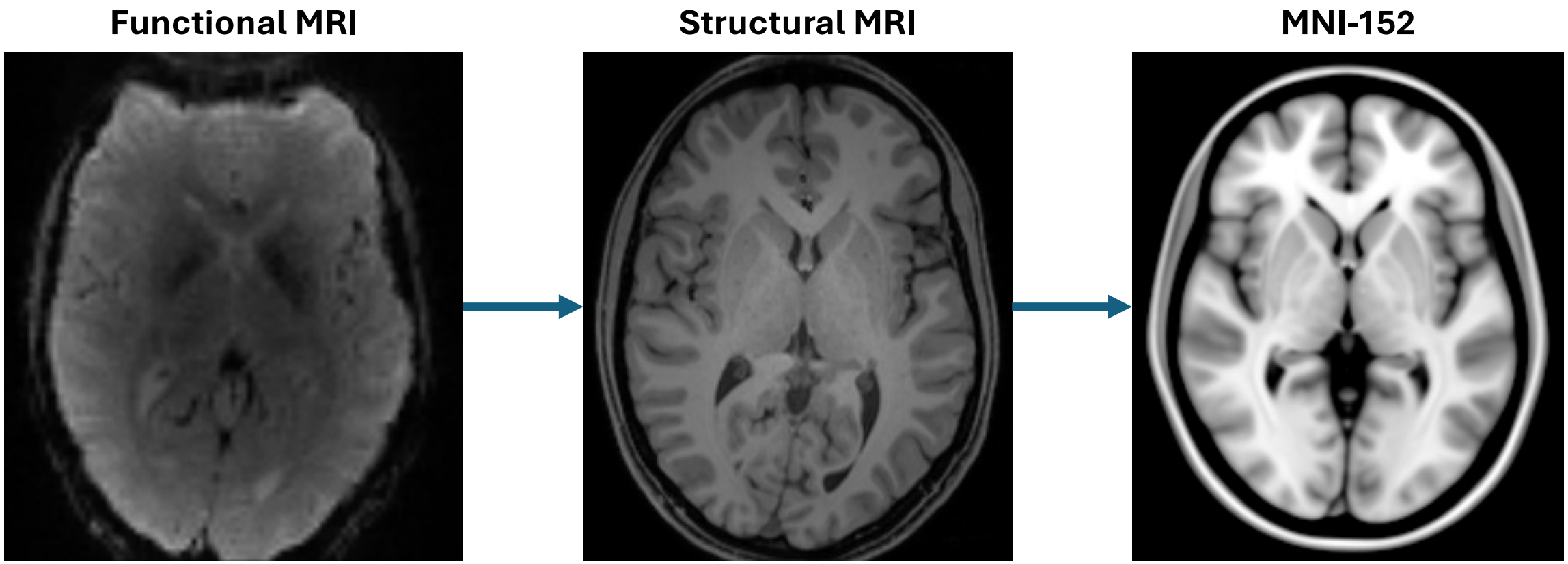
Exercise 4.2

a) Register “sub-010001_ses-02_inv-1_mp2rage_misaligned.nii.gz” to “sub-010001_ses-02_acq-mp2rage_T1w.nii.gz”. Check the .mat file once the registration is complete. What’s in this file?

b) Open FSL FLIRT then go to Utils > Apply FLIRT transform. Apply the saved transformation to “sub-010001_ses-02_inv-2_mp2rage_misaligned.nii.gz”

c) Check that both inv-1 and inv-2 are correctly co-registered

Multi-stage registration to align to an atlas



- Requires multiple types of registration including non-linear registration
- Frequently used to align functional scans from many subjects to an atlas

Demo 4.2

- Align “FUNC.nii.gz” and “STRUCT.nii.gz” to the MNI-152 atlas using FSL FEAT