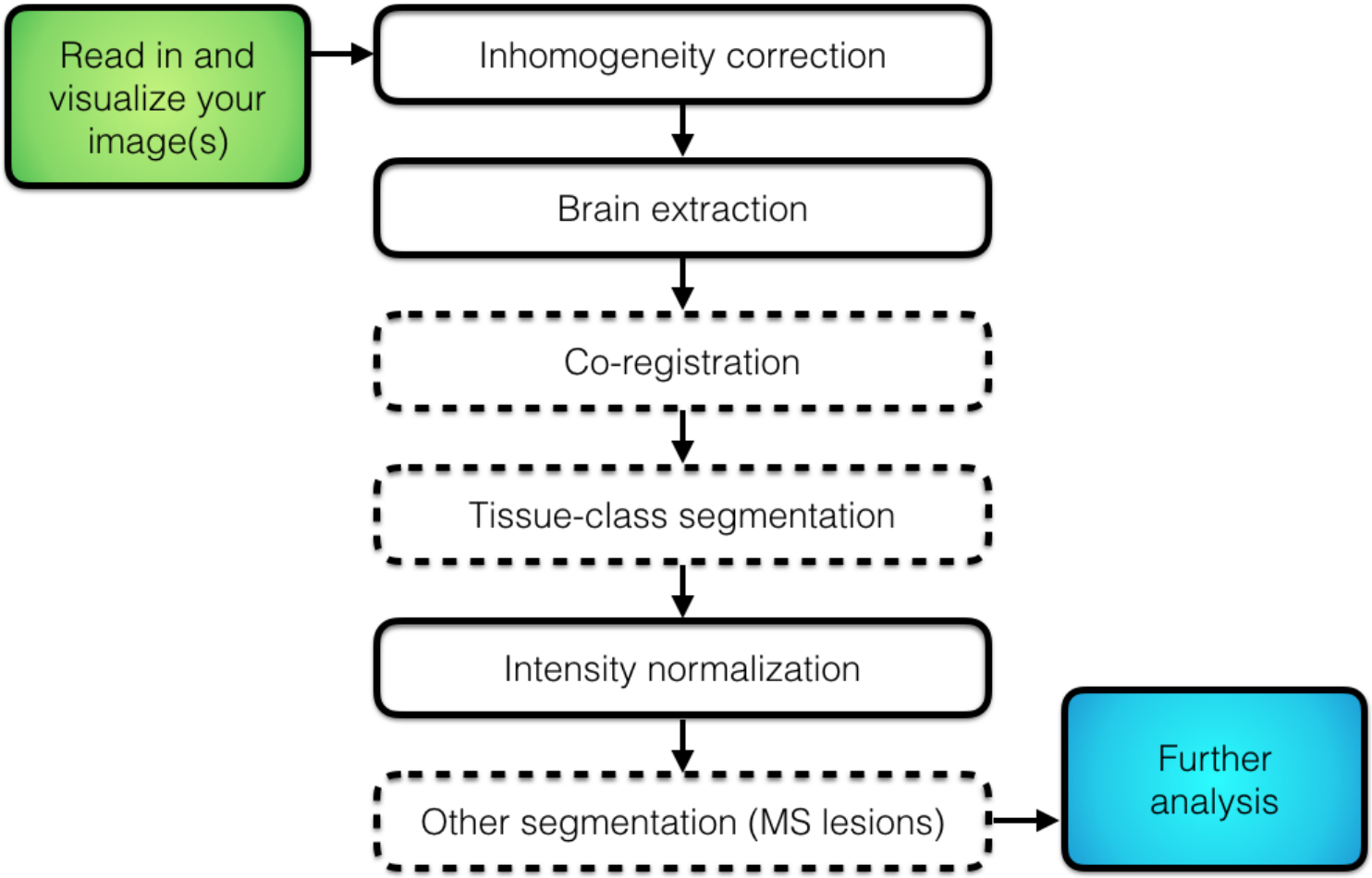
Image Registration

Overall Pipeline



Types of Registration

- Rigid-body registration (linear) - 6 degrees of freedom (dof)

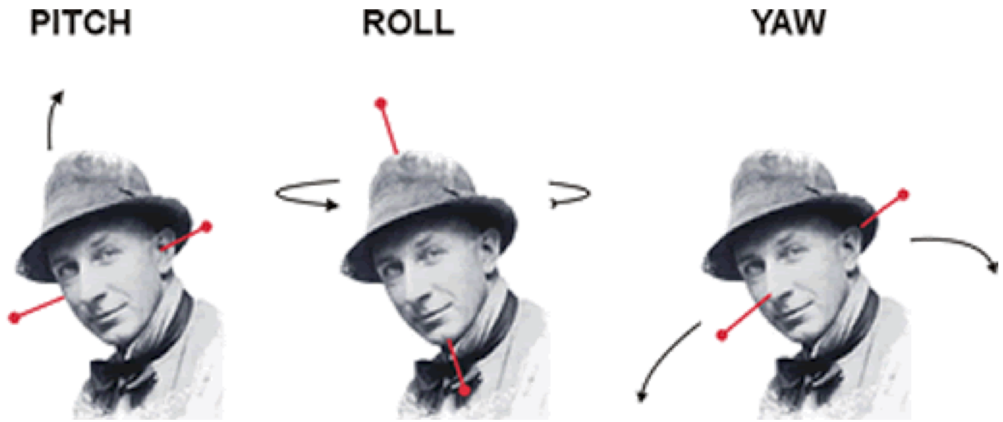


Image taken from http://cnl.web.arizona.edu/imageprops.htm

- Pitch - Think of nodding (“yes”)
- Yaw - Think of shaking head (“no”)
- Roll - Think of shoulder shrugging (“I don’t know”)
- x – left/right
- y – forward/backward
- z – jump up/down

Types of Registration

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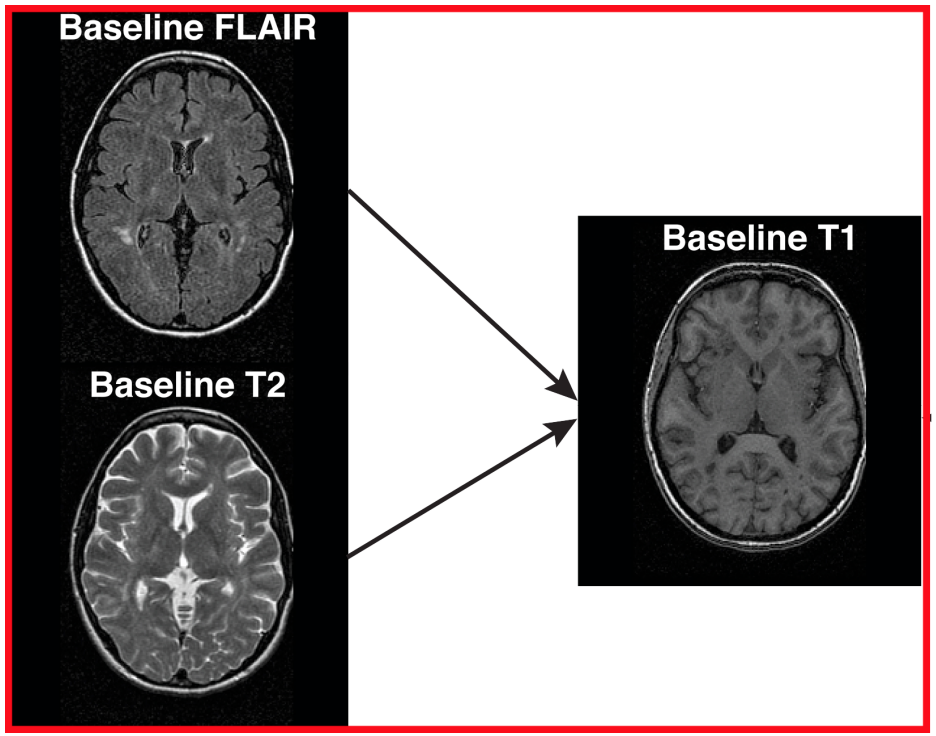
  - Co-registration (within the same person)
    - **Cross-sectional between-sequences**
    - Longitudinal between-sequences
    - Longitudinal within-sequence



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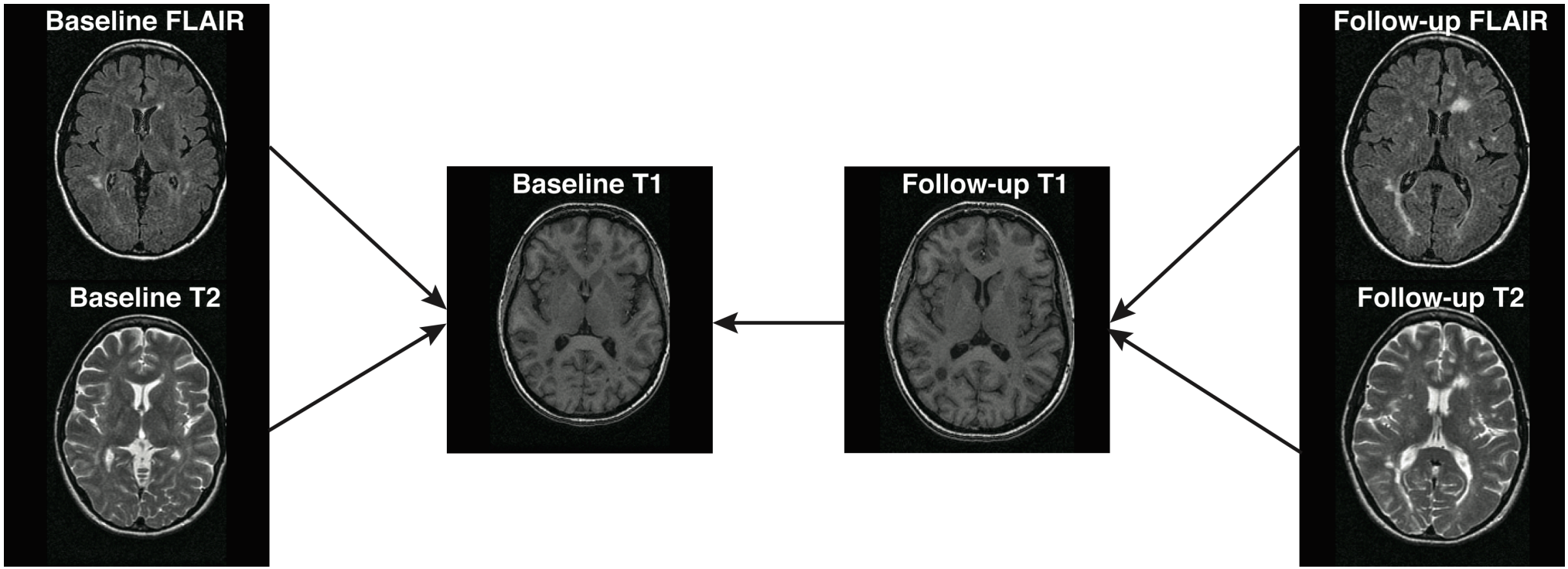

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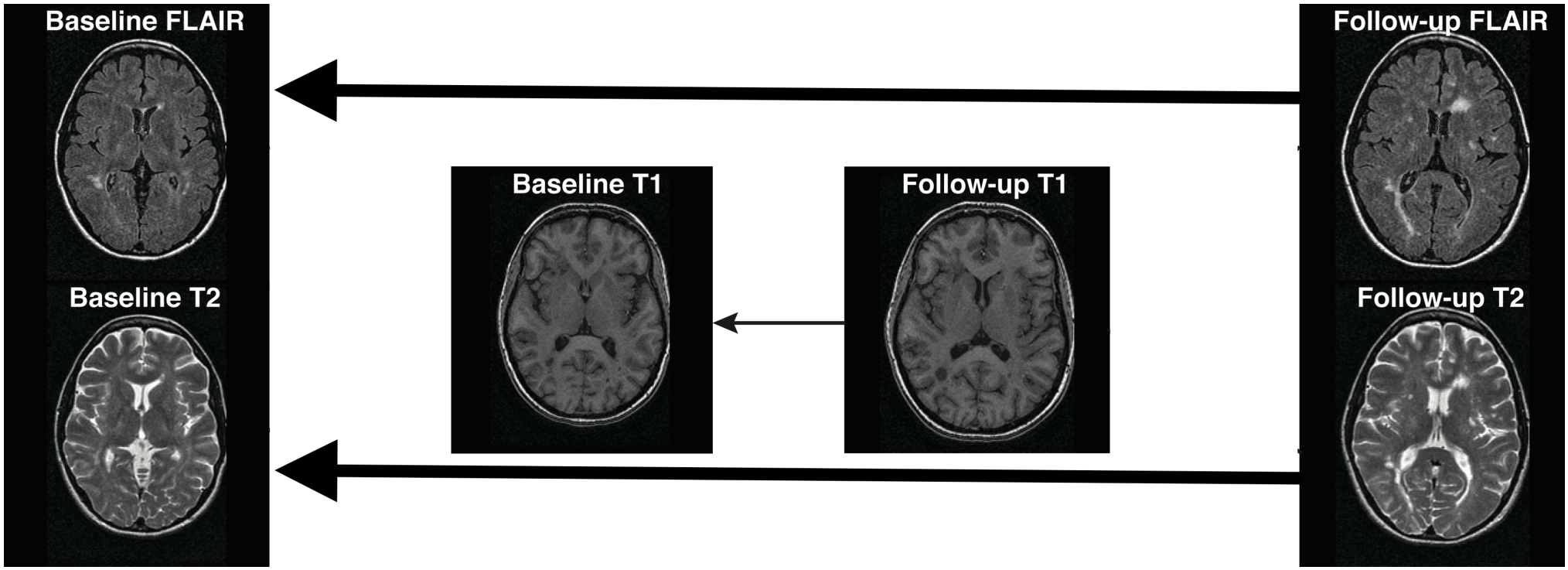
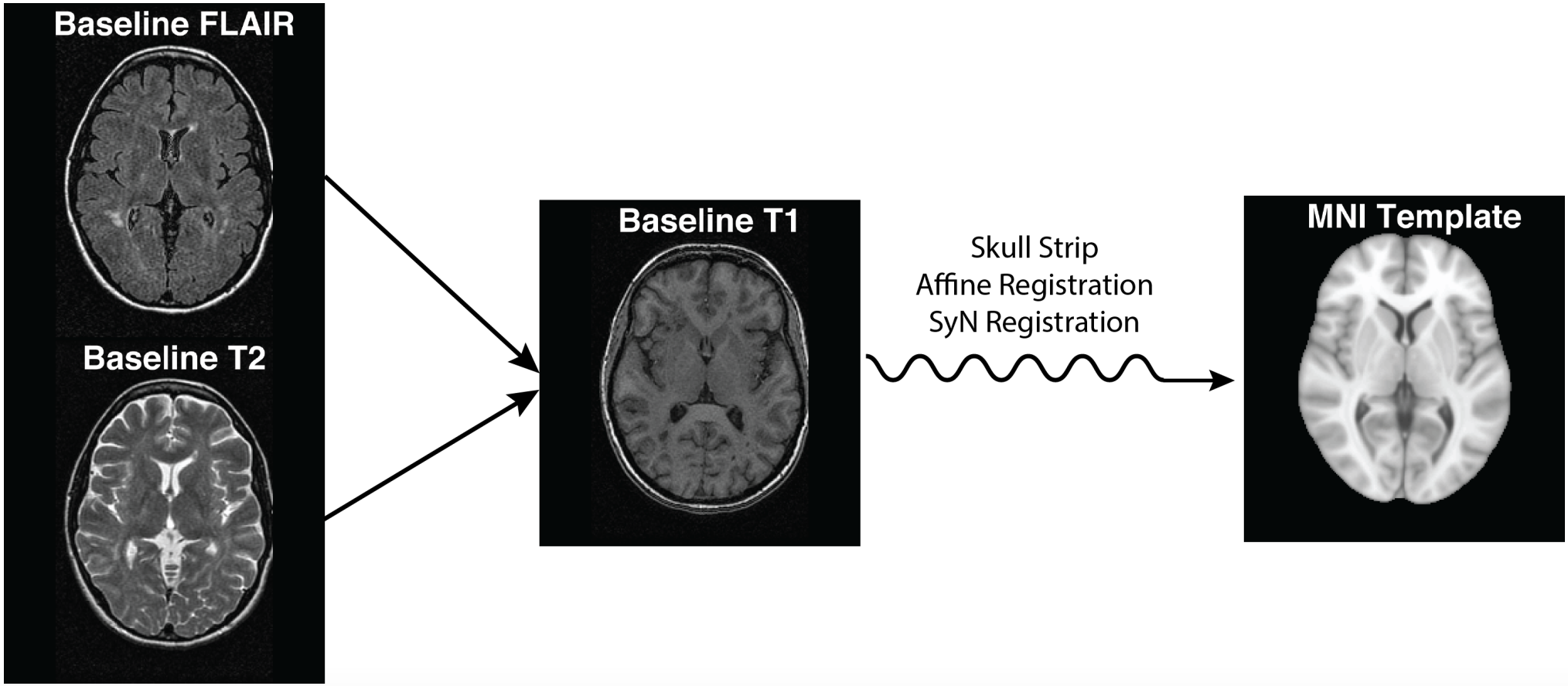


Types of Registration

- Affine registration – 12 dof (scaling)
- Non-linear (> 12 dof): sually requires a prior affine registration
  - Across-subject registration
  - Registration to a template: There are many different templates



Rigid Registration: The Math

For a voxel v, the rigid transformation can be written as:

$T_{rigid}(v) = Rv + t$ where $R =$

$$\begin{bmatrix} \cos\beta\cos\gamma & \cos\alpha\sin\gamma + \sin\alpha\sin\beta\cos\gamma & \sin\alpha\sin\gamma - \cos\alpha\sin\beta\cos\gamma & -\cos\beta\sin\gamma & \cos\alpha\cos\gamma - \sin\alpha\sin \\ \beta\sin\gamma & \sin\alpha\cos\gamma + \cos\alpha\sin\beta\sin\gamma\sin\beta & -\sin\alpha\cos\beta & \cos\alpha\cos\beta \end{bmatrix}$$

- 6 degrees of freedom
- 3 associated with the translation vector: $t = (t_x, t_y, t_z)$
- 3 associated with the rotation parameters: $\theta = (\alpha, \beta, \gamma)$.

Aside into Lists

- Initialize an empty list and add two elements to it

```
l = list()
l[[1]] = c(1, 2, 4, 5)
l[[2]] = matrix(1:10, nrow = 2)
print(l)
```

```
[[1]]
[1] 1 2 4 5

[[2]]
     [,1] [,2] [,3] [,4] [,5]
[1,]    1    3    5    7    9
[2,]    2    4    6    8   10
```

- Subsetting uses double brackets:

```
print(l[[1]])
```

```
[1] 1 2 4 5
```

Subsetting by name

If a `vector` has names, you can also put the - Initialize an empty list and add two elements to it

```
x = c(one = 1, three = 14, two = 5)
print(x)
```

```
  one three   two
    1    14     5
```

```
x[c("three")]
```

```
three
   14
```

If a `list` has names, you can subset with the `$`

- Subsetting with double brackets:

```
names(l) = c("V", "m"); l[["V"]]
```

```
[1] 1 2 4 5
```

Subsetting by name

If a `list` has names, you can also subset with the `$`

```
l$v
```

```
[1] 1 2 4 5
```

Reading in more than the T1: `ms.lesion` package

- `get_image_filenames_list_by_subject` - returns a list, each element is a subject, and each subject has a vector of filenames, named for each modality

```
library(ms.lesion)
all_files = get_image_filenames_list_by_subject()
class(all_files); names(all_files)
```

```
[1] "list"
```

```
[1] "test01"     "test02"     "test03"     "training01" "training02"
[6] "training03" "training04" "training05"
```

```
files = all_files$training01; class(files); names(files)
```

```
[1] "character"
```

```
[1] "T1"    "T2"    "FLAIR"
```

```
t1_fname = files["T1"]
t1 = readnii(t1_fname)
rt1 = robust_window(t1, probs = c(0, 0.975))
```

Image Registration

The `registration` function from `extrantsr` can register 2 images. The main arguments are:

- `filename` - either `nifti` object or filename of image to be registered (moving)
- `template.file` - either `nifti` object or filename of target image (fixed)
- `typeofTransform` - transformation of moving to fixed image (Rigid/Affine/SyN)
- `interpolator` - how are voxels averaged in `fixed` space (Linear/NearestNeighbor/LanczosWindowedSinc)

It can also perform bias correction if `correct = TRUE`.

Image registration

For example, if we wanted to register the FLAIR to the T1 image, we would run:

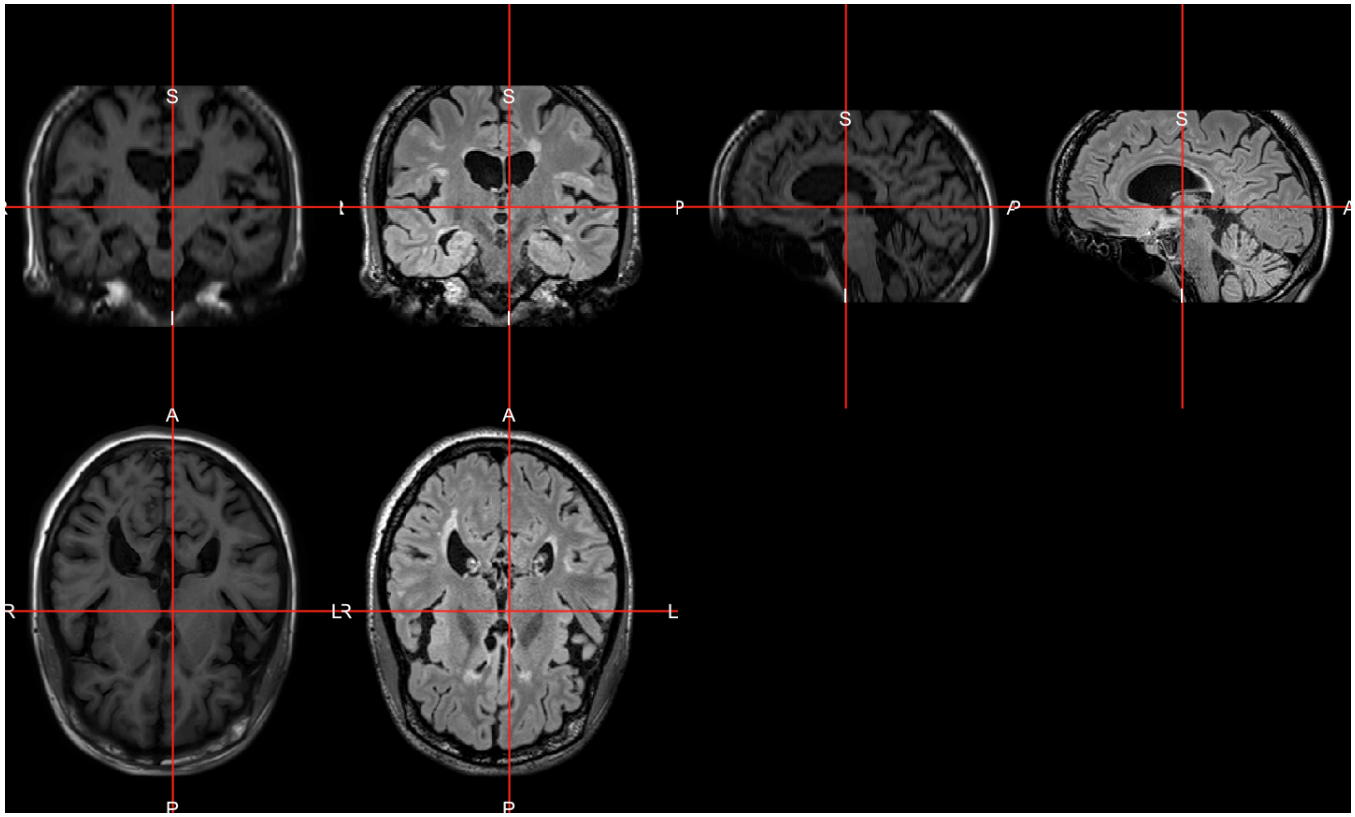
```
library(extrantsr)
reg = registration(
  filename = files["FLAIR"], template.file = files["T1"],
  typeofTransform = "Rigid", interpolator = "Linear", verbose = FALSE)
names(reg)
```

```
[1] "outfile"             "fwdtransforms"       "invtransforms"
[4] "interpolator"        "other_interpolator"  "invert_interpolator"
[7] "typeofTransform"     "retimg"
```

The output in `reg` would contain the transformed image and paths to the estimated transformations.

FLAIR comparison

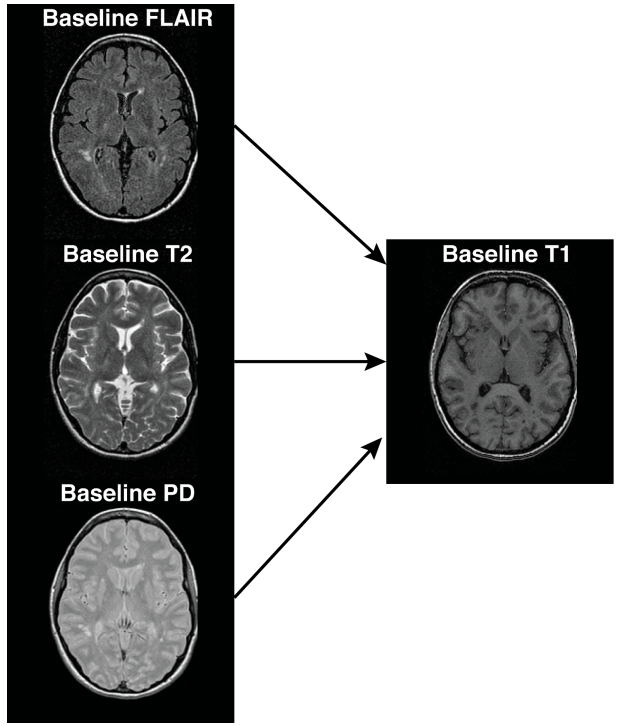
```
double_ortho(rt1, reg$outfile)
```



Wrapper function to perform preprocessing

We would like to perform registration within a visit for all modalities. The `extrantsr` function `within_visit_registration` will do the following steps:

1. Inhomogeneity correction (N3 or N4): could also use images from previous lecture
2. Registration to a fixed image (T1)



Registration within a visit

The function `within_visit_registration` arguments take in:

- `fixed` image - the image to be registered to
- `moving` images - images to register to the `fixed`
- `typeofTransform` - transformation of moving to fixed image (Rigid/Affine)
- `interpolator` - how are voxels averaged in `fixed` space
- `correct` - should correction be done, if so, specify `correction = "N4"`

and outputs a list of transformations (`fwdtransforms`) and output filenames (`outfile`)

Lists: `lapply`

With `lists` and vectors, there are `apply` functions. These apply a function to every element of the list. In this course, we will use:

- `lapply` - apply function and return the elements as a `list`
  - `lapply(LIST, FUNCTION, OTHER_ARGUMENTS_TO_FUNCTION)`
- `sapply` - apply function and return a "simplified" version
  - if all elements returned are a one-element vector, return a `vector`
  - if element 1 is a vector of length 3 and element 2 is a vector of length 1, return a `list`

Register to the T1 image

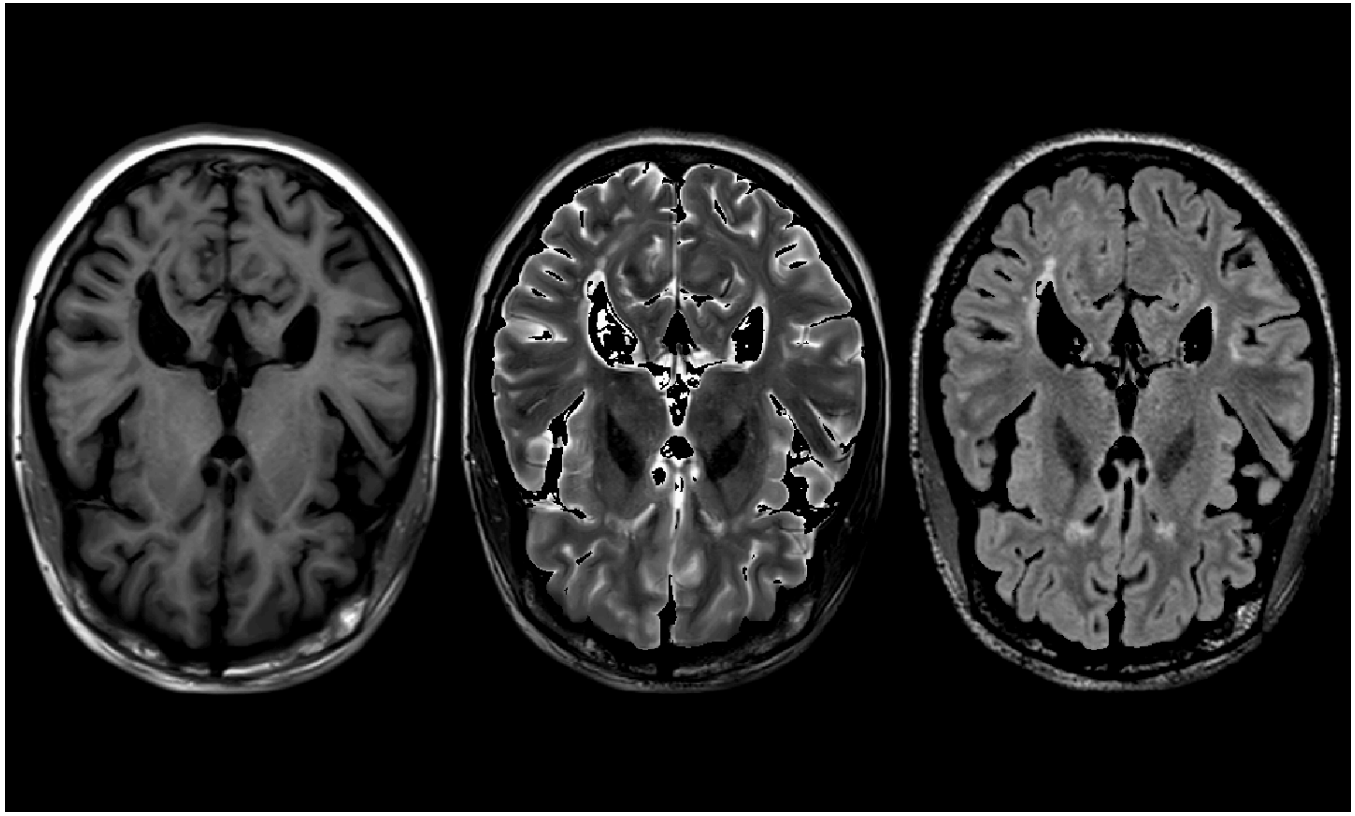
```
res = within_visit_registration(
  fixed = files["T1"], moving = files[c("T2", "FLAIR")],
  correct = TRUE, correction = "N4",
  typeofTransform = "Rigid", interpolator = "Linear")
output_imgs = lapply(res, function(x) x$outfile)
out = c(T1 = list(t1), output_imgs)
```

```
# Running Bias-Field Correction on file

# Running Registration of file to template

# Applying Registration output is

$fwdtransforms
[1] "/var/folders/1s/wrtqcpxn685_zk570bnx9_rr0000gr/T//RtmpN4MXsP/file12bc91f0b4b400G

$invtransforms
[1] "/var/folders/1s/wrtqcpxn685_zk570bnx9_rr0000gr/T//RtmpN4MXsP/file12bc91f0b4b400G

$prev_transforms
character(0)

# Applying Transformations to file

 [1] "-d"
 [2] "3"
 [3] "-i"
 [4] "<pointer: 0x7fdb04b572c0>"
 [5] "-o"
 [6] "<pointer: 0x7fdb04a70fa0>"
```

Checking registration: new visualization!

The `multi_overlay` function takes in a list of images and then plots one slice across modalities (assumes center slice):

```
multi_overlay(out)
```



Coregistration within a visit results

- Overall, there seems to be good overlap after registration
- It is usually beneficial to do inhomogeneity correction before registration.
    - just set `correct = TRUE` or pass in the bias-corrected images

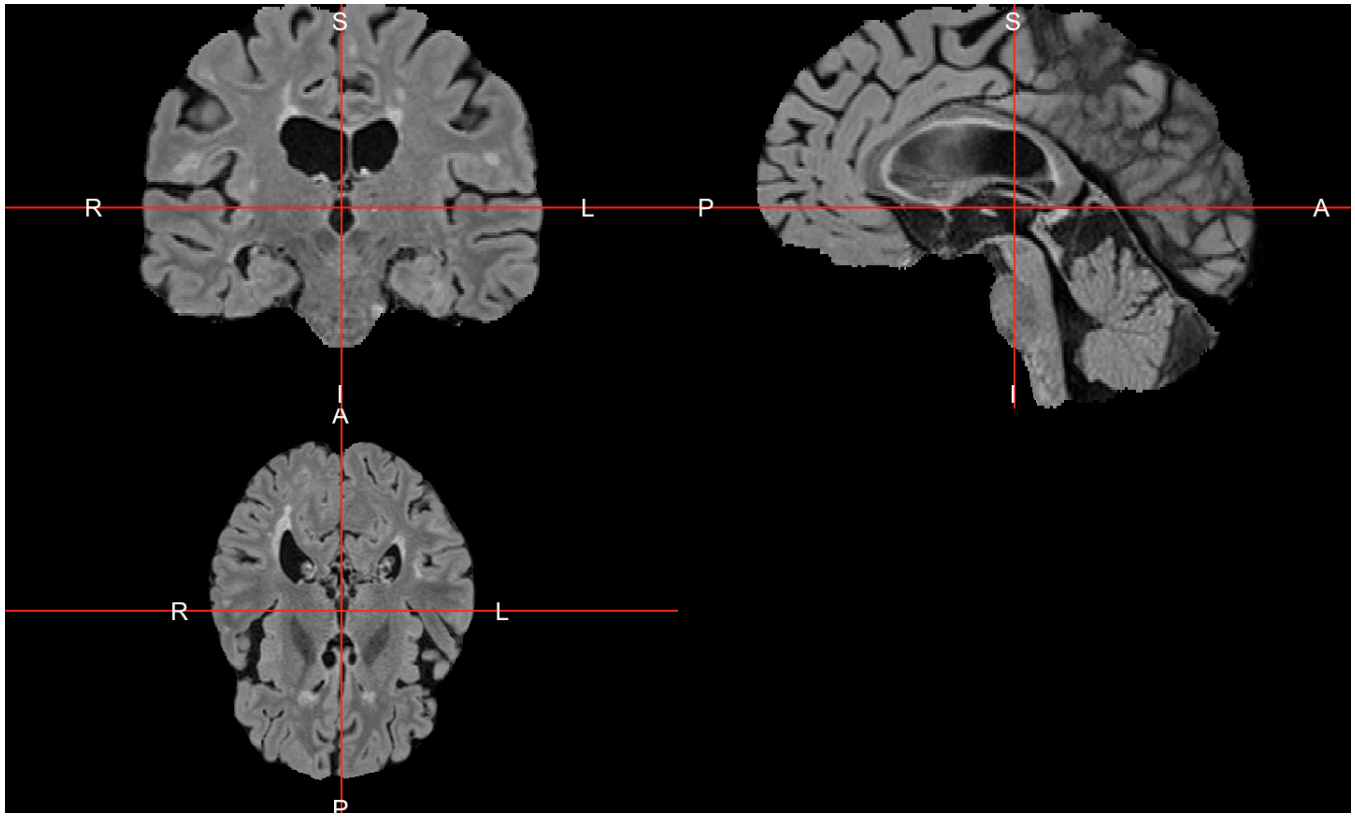
Applying a Brain mask to all registered images

Now that the images are in the same space as the T1, if we skull-strip the T1 image (we did with MALF), we can apply this mask to those images to extract brain tissues using the `neurobase::mask_img` command:

```
mask = readnii("../output/training01_01_t1_mask.nii.gz") # MALF mask
masked_imgs = lapply(out, mask_img, mask)
```

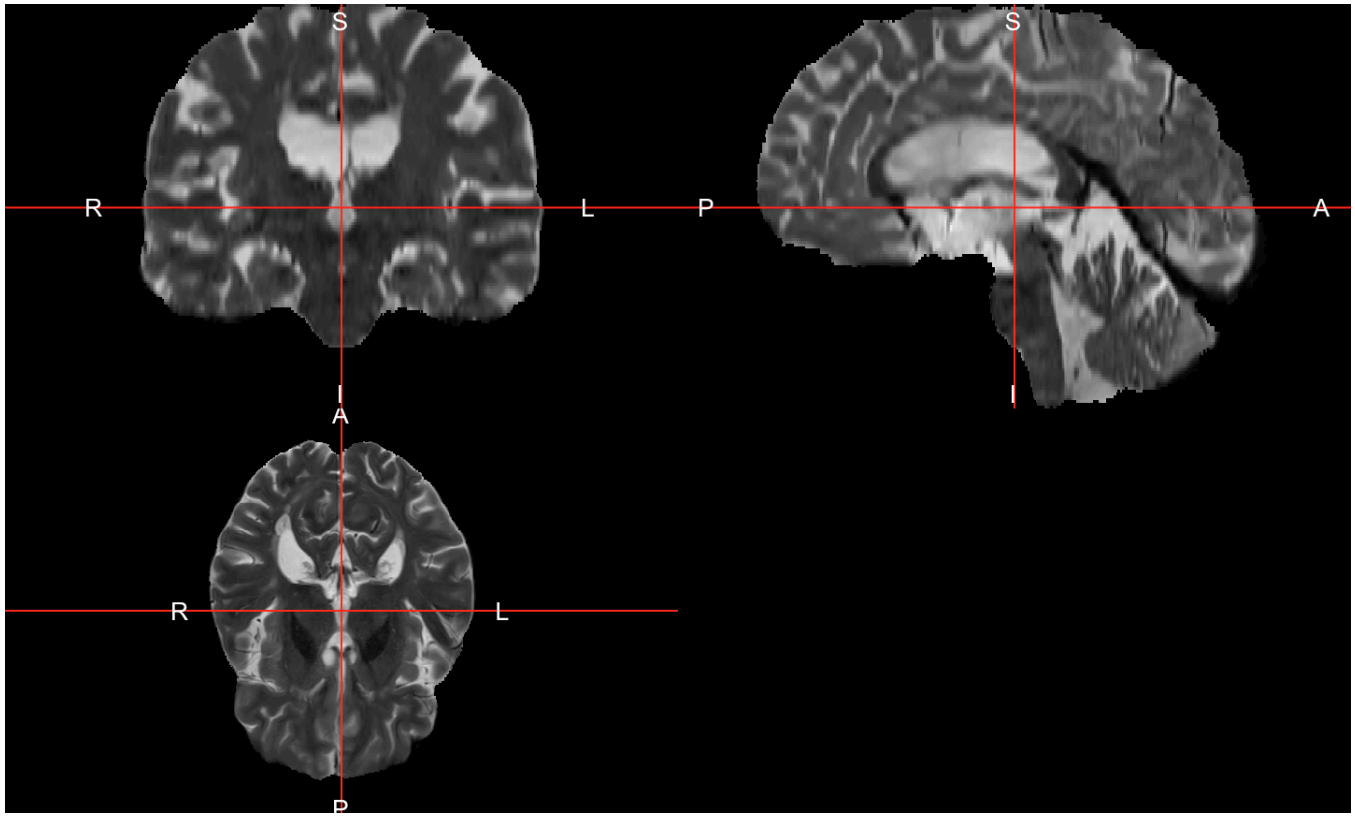
Masked FLAIR Result

```
ortho2(masked_imgs$FLAIR)
```



Masked T2 Result

```
ortho2(masked_imgs$T2)
```



Overview of functions

- Registration within a subject can be done in R
  - `registration` wraps around the reading/writing of images and applying transformations (uses `ANTsR` functions)
  - `double_ortho`, `ortho2`, and `multi_overlay` can provide some basic visual checks to assess registration quality
  - `within_visit_registration` is a registration wrapper function
  - `preprocess_mri_within` - wraps multiple steps above (inhomo, reg, extract)
- Once images are registered in the same space, operations can be applied to all the images, such as:
  - Masking with a brain mask
  - Transforming images to new spaces with one modality

Co-registration overview

- Co-registration requires a few degrees of freedom (usually 6)
  - sequences from the same individual/brain are more alike than images from different subjects
- Example analyses that do not require a reference template
  - Identify location-specific longitudinal changes within an individual
  - Tissue class or structural segmentation
  - Analysis of indvidual-subject change in intensities

Population template registration

We have only done registration within a subject, but many times you want to perform a population-level analysis. This requries registration to a **template**:

- The `registration` can be done for this as well, just the `template.file` is now the template image and `filename` is the subject image.
  - other files (in the same space) can be transformed using the `other.files` and `other.outfiles` arguments. Or:
  - `ants_apply_transforms` can be used to apply this transformations to the other files

Website

http://johnmuschelli.com/imaging_in_r