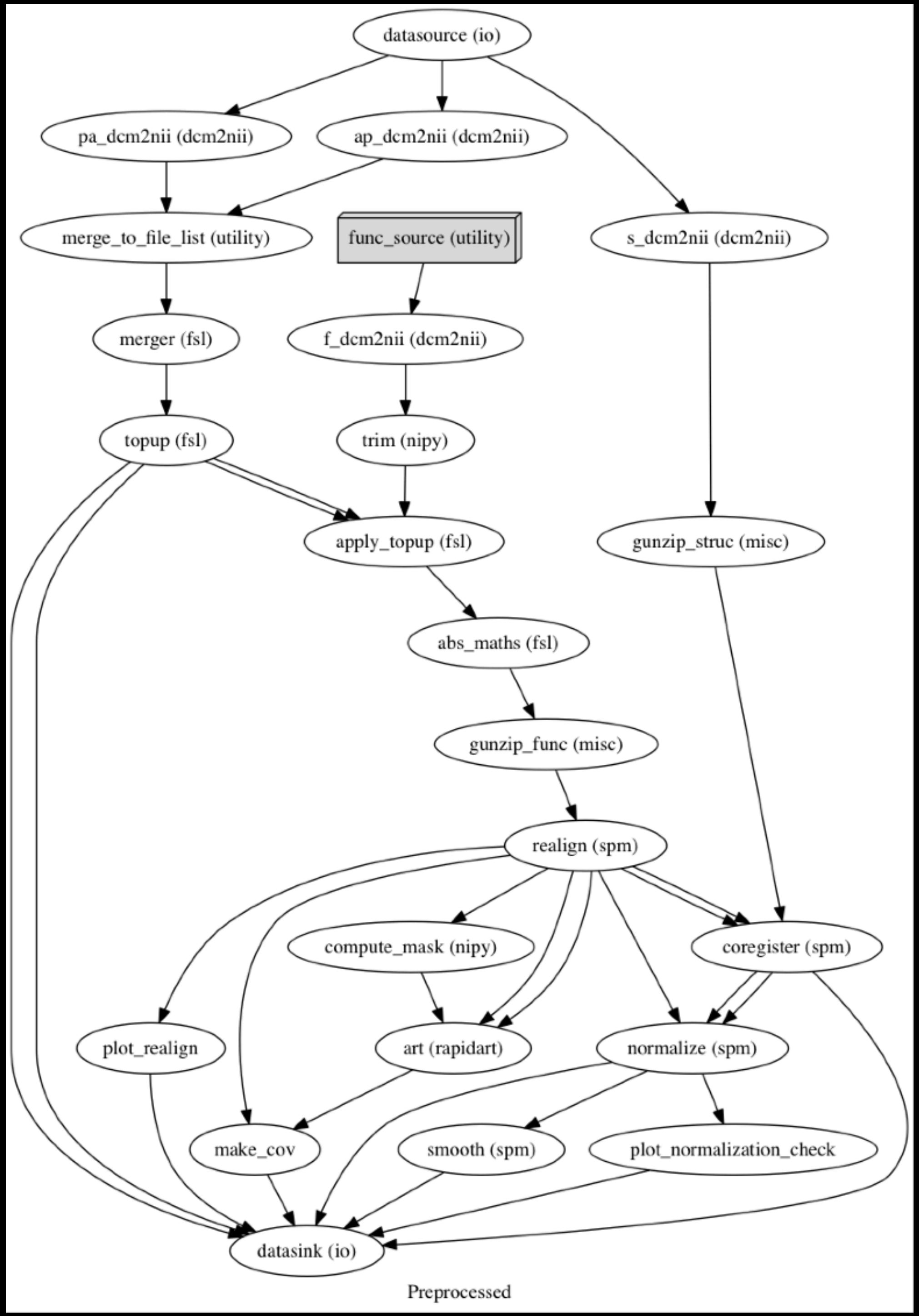
Preprocessing

Luke Chang

What are the steps to make the raw data ready to analyze?



fMRI Noise

- Thermal motion
- Gradient and magnetic field instability
- Head movement and its interactions with magnetic field
- Physiological effects (e.g., heartbeat & respiration)

Acquisition Artifacts

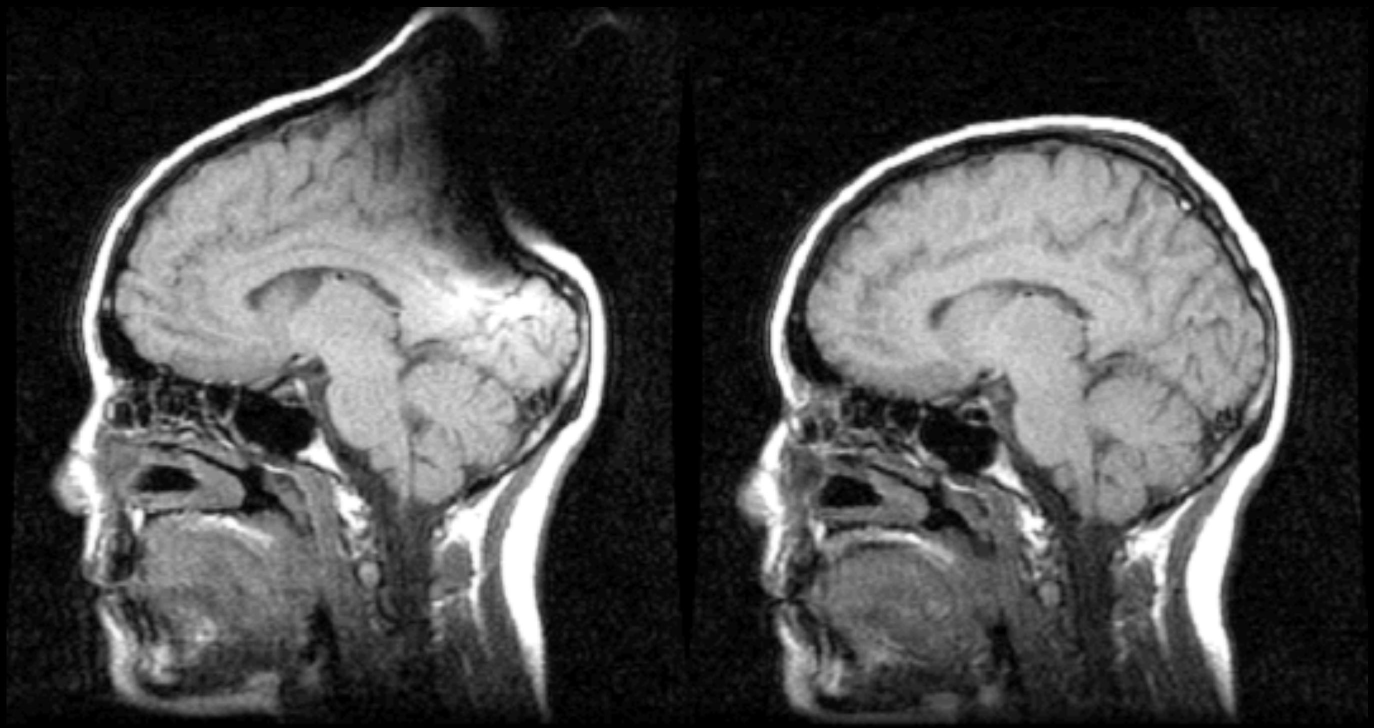
- Missing slices
- RF noise
- Transient gradient artifacts/spikes
- Ghosting
- Susceptibility artifacts/dropout
- Head motion

Acquisition Artifacts

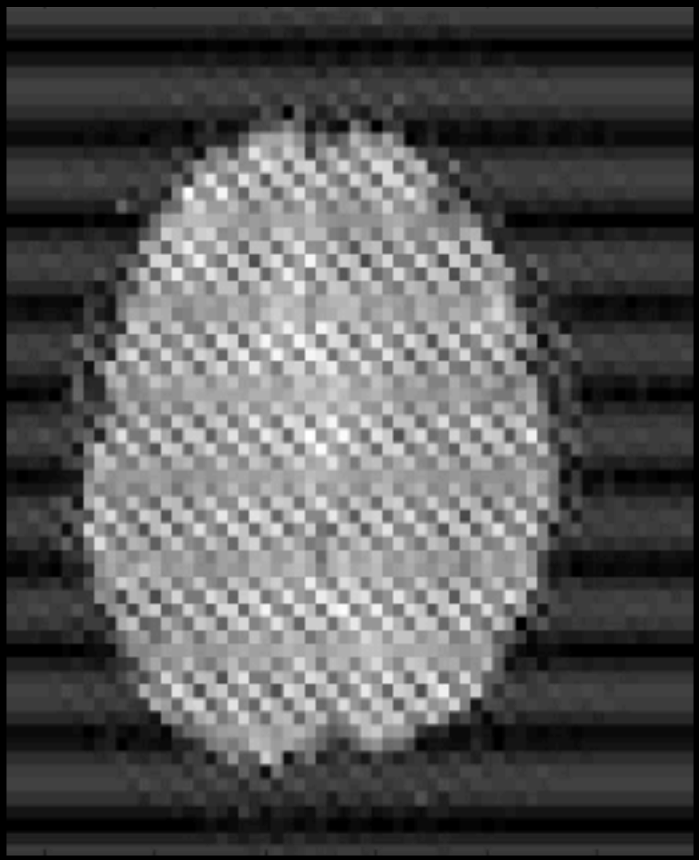
- Magnetic field
- Drift - slow changes in voxel intensity over time.
- Aliasing - signals that occur more rapidly than the sampling rate

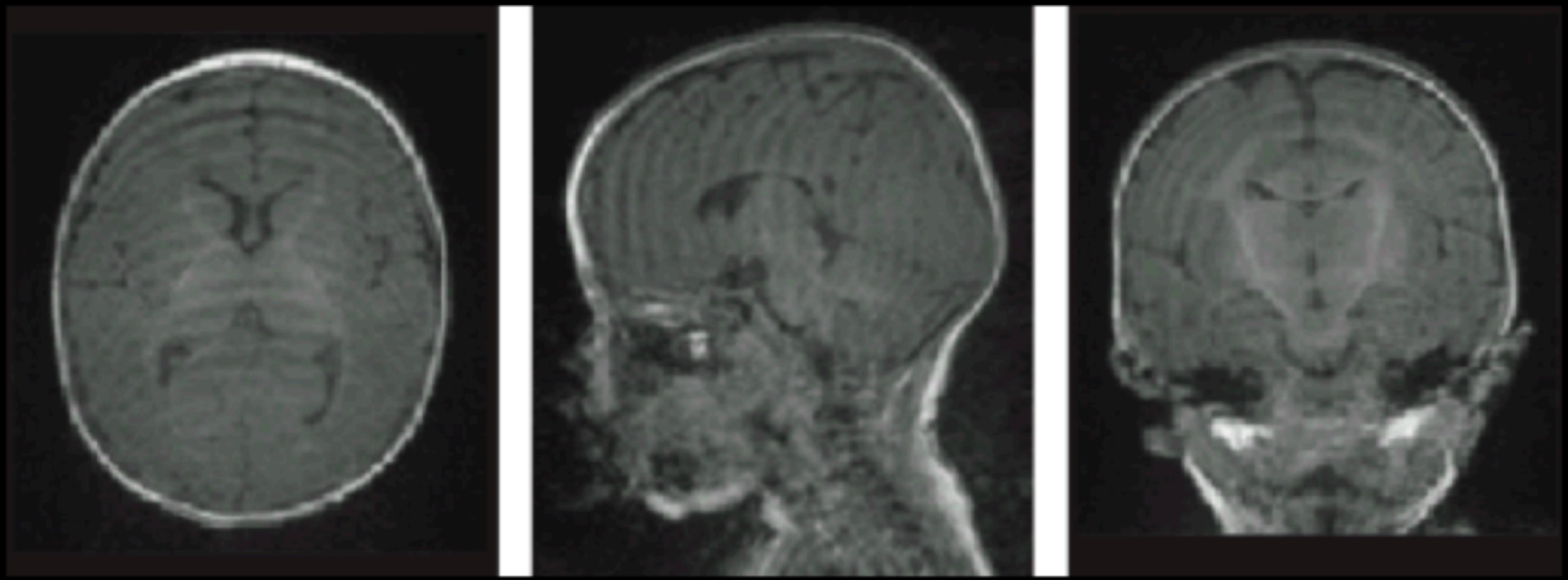
Metal

Hair ties distort the brain!



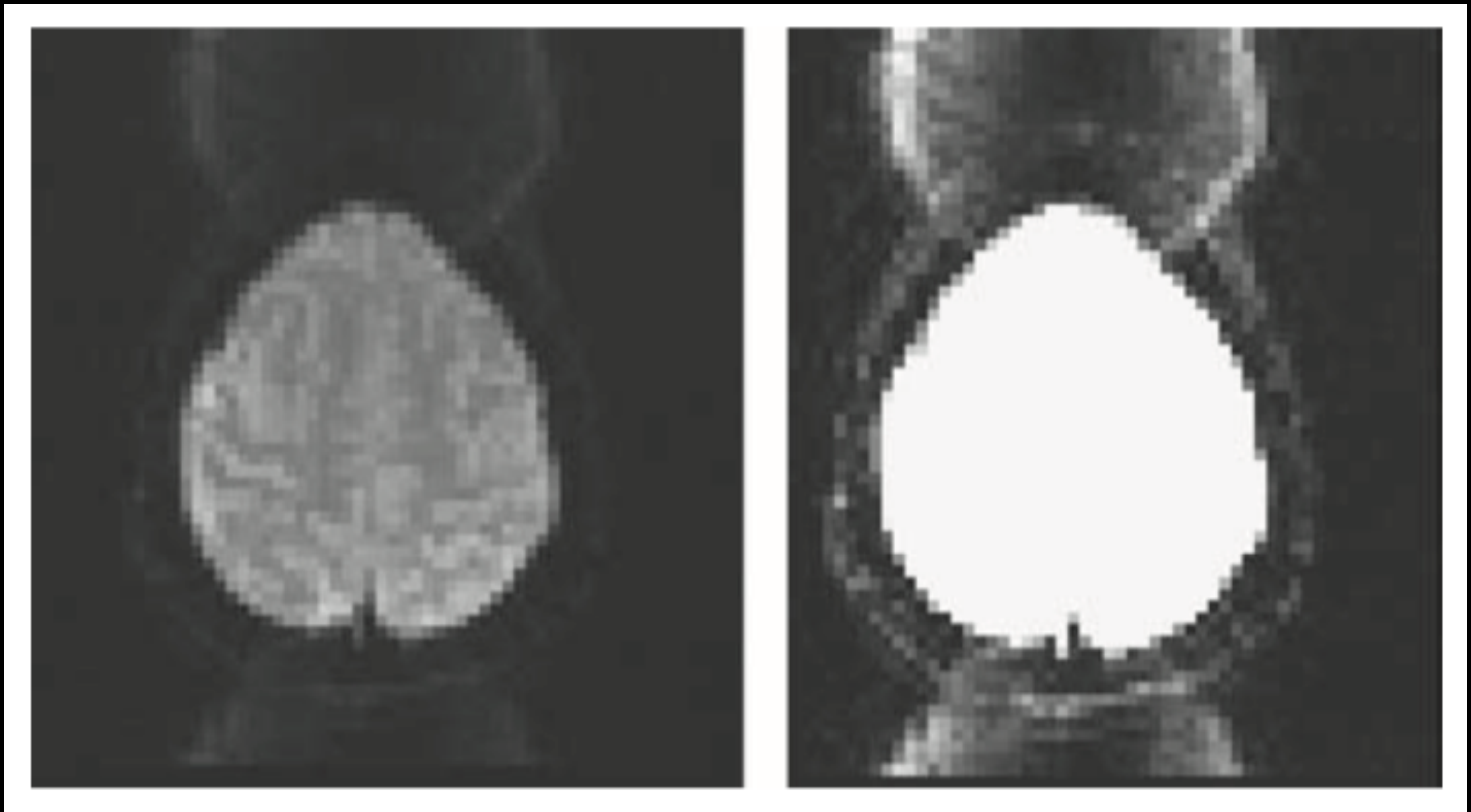
RF Noise





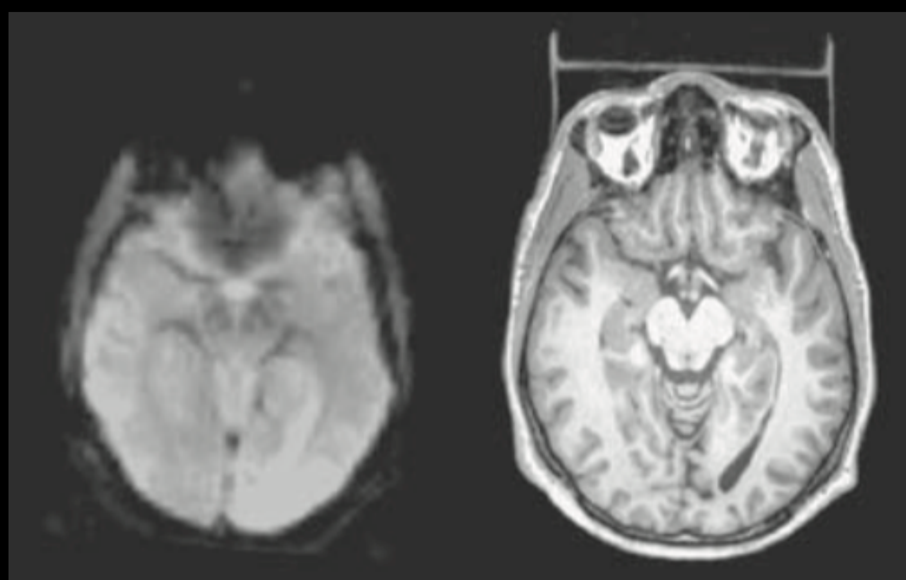
Ghosting

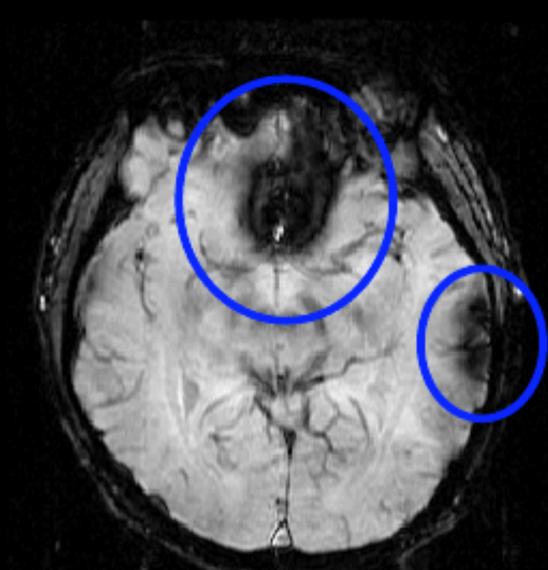
Phase offset between different lines of k-space
often from periodic motion (e.g., respiration, cardiac)



Susceptibility Artifact

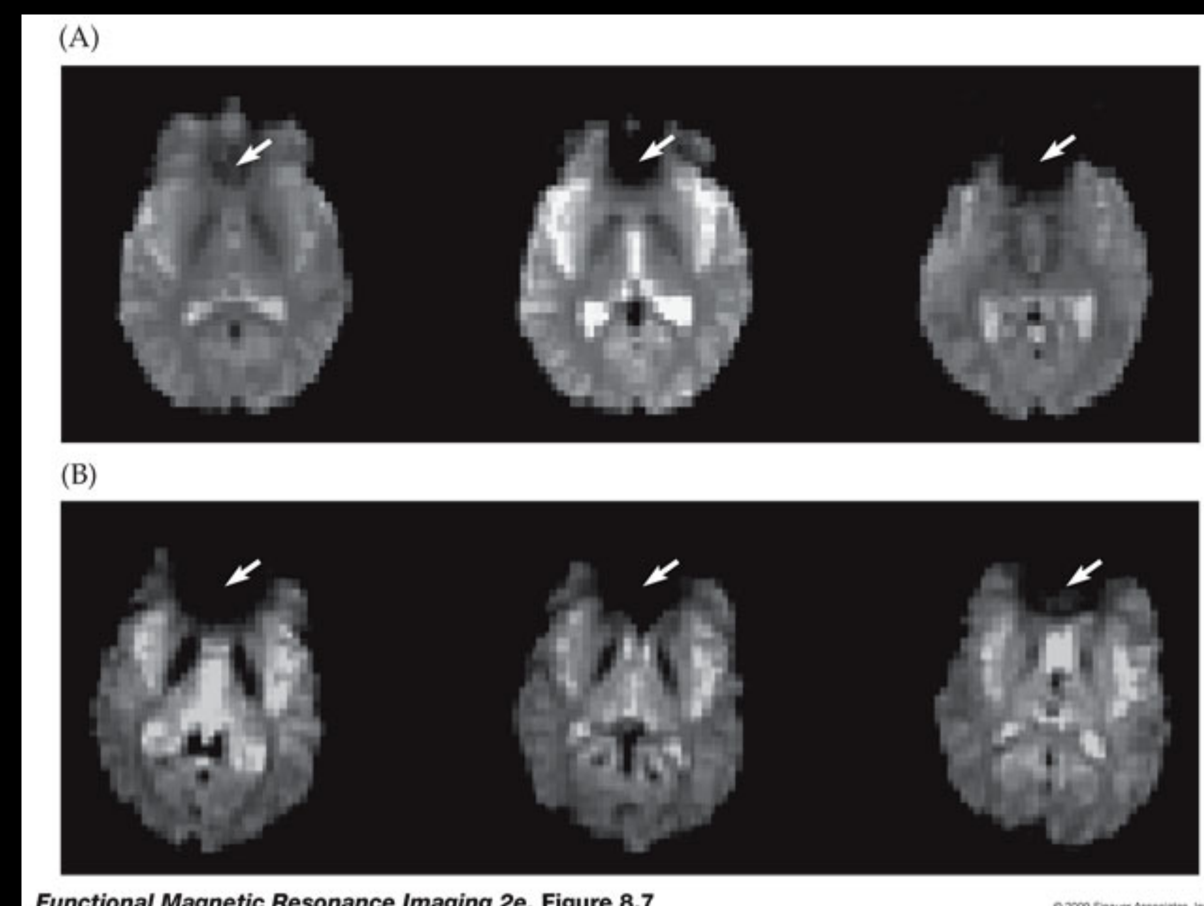
Distortion and signal loss where air meets tissue



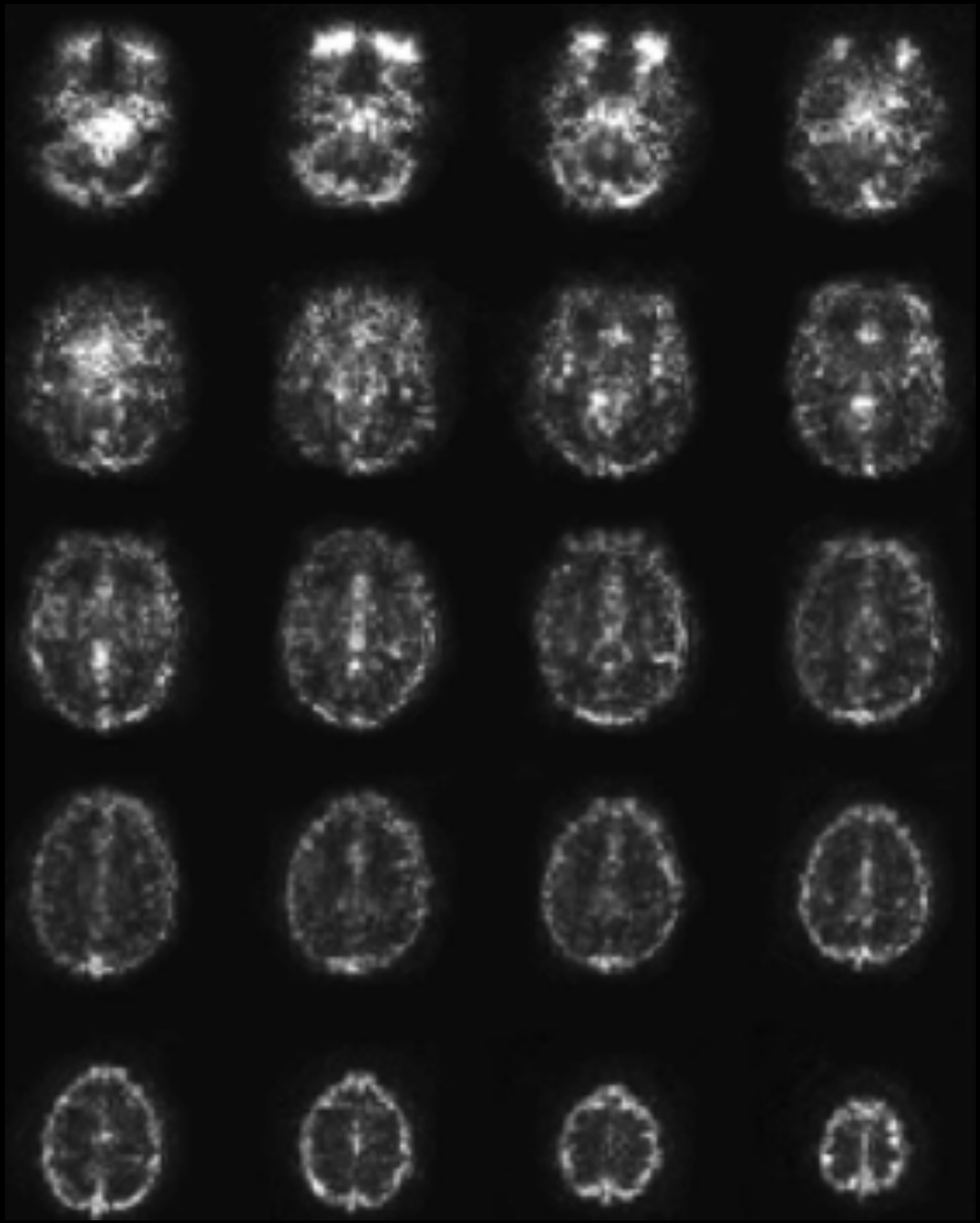


1.5 T

4 T

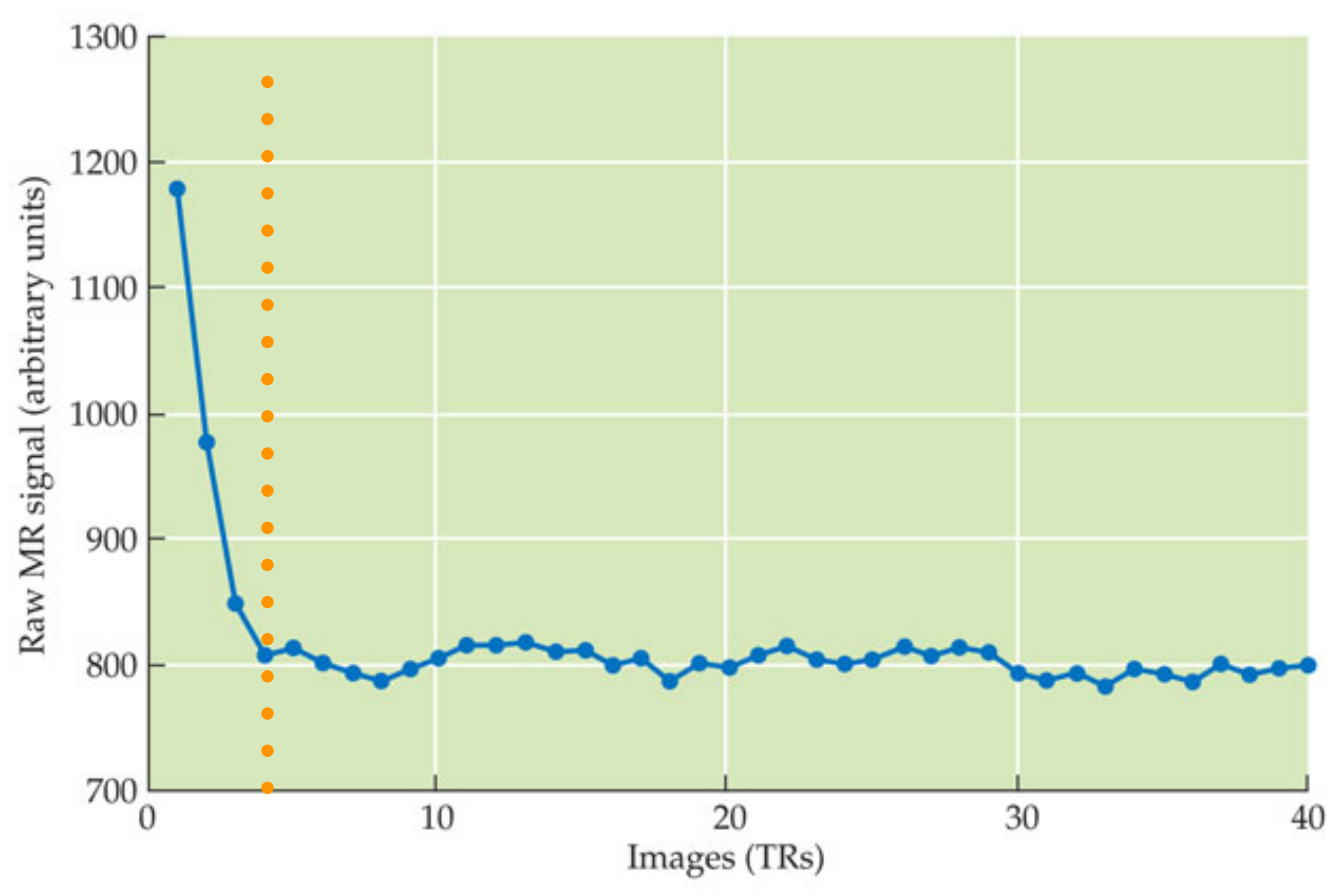


Variation in signal intensity over time

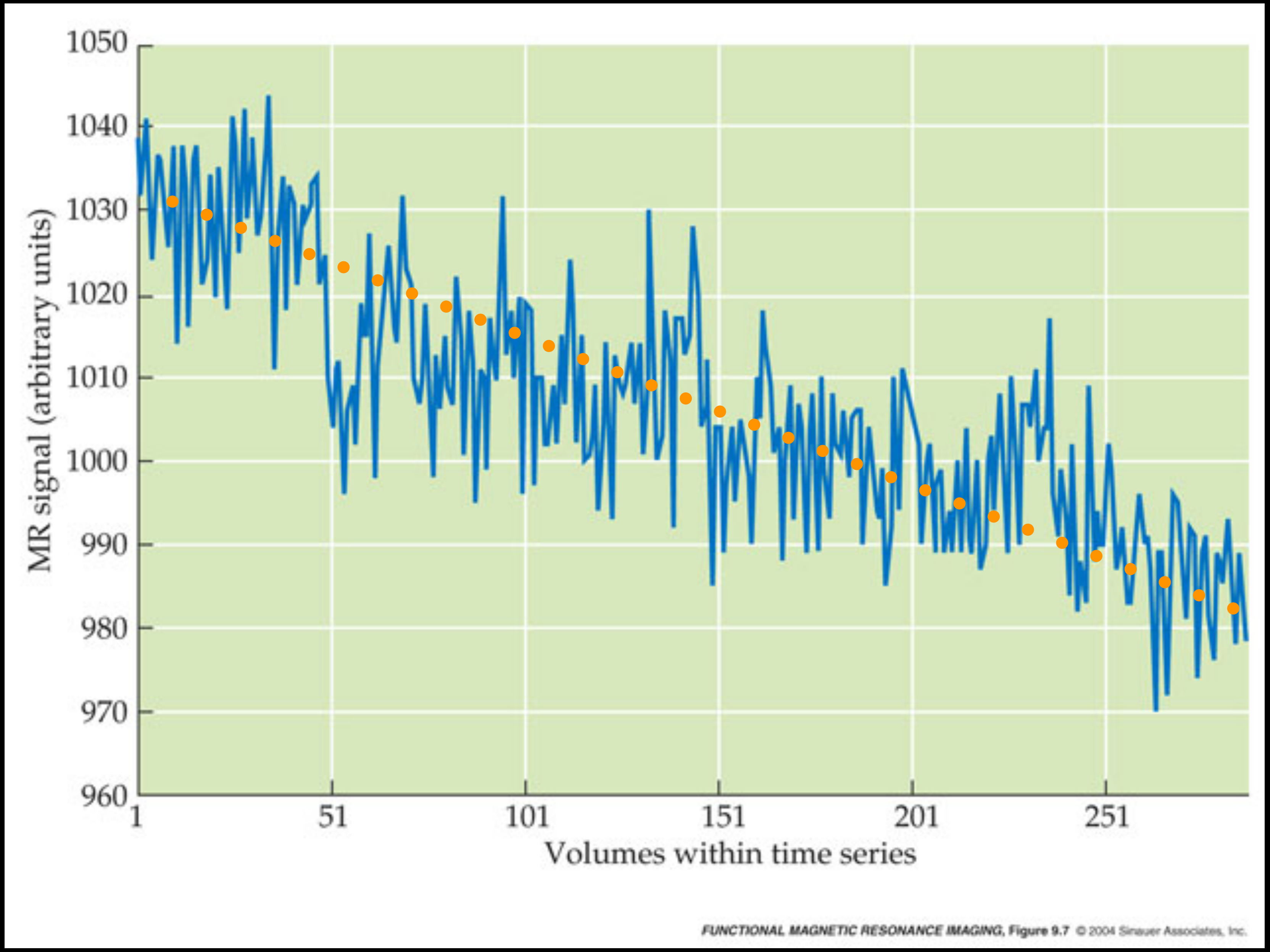


Steady State Equilibrium

Often we discard the first few TRs until the magnetic field reaches a steady state equilibrium
Ignoring this can cause huge problems with preprocessing and statistics
However, many modern scanners incorporate “dummy” scans by default.

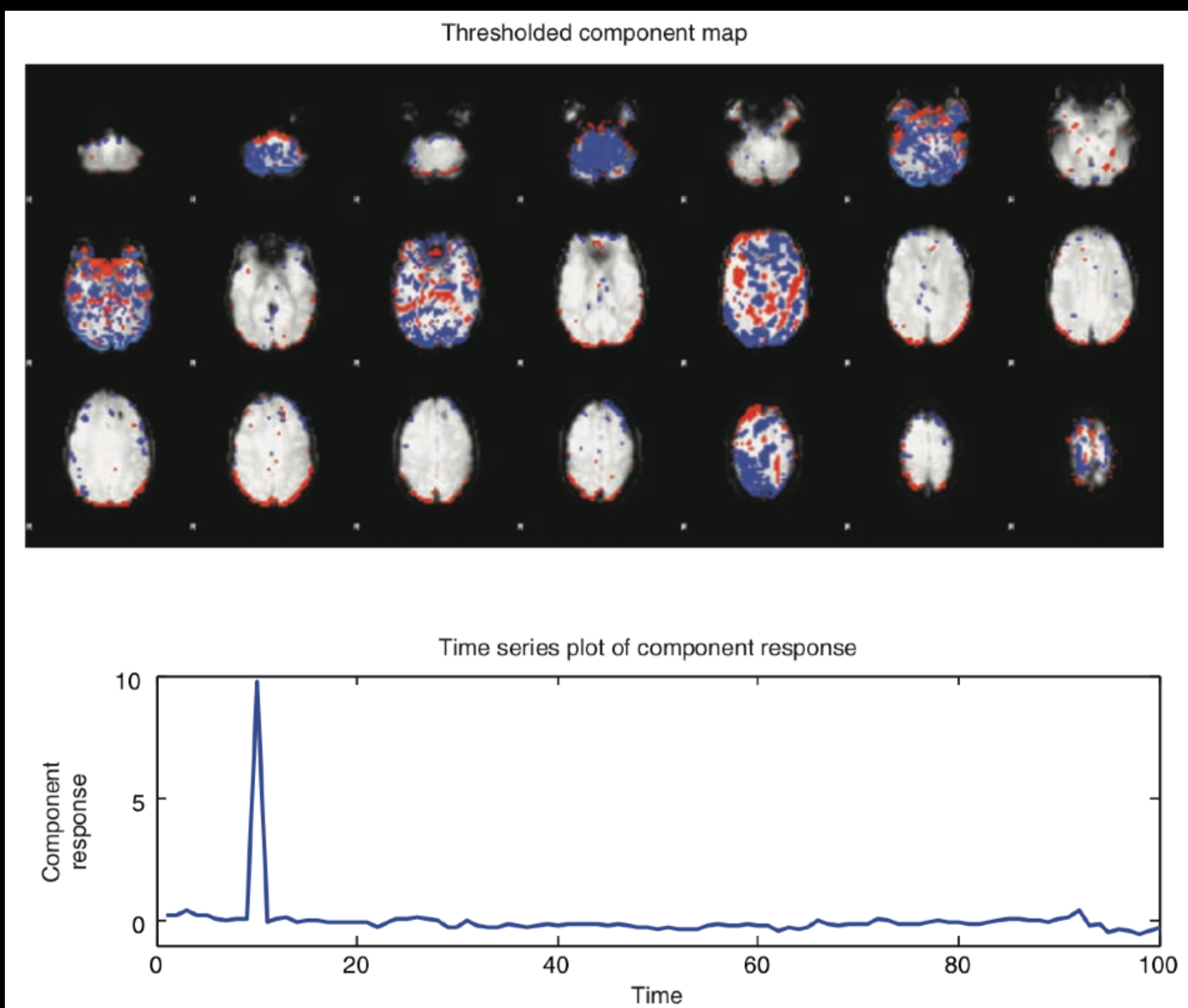


Scanner Drift



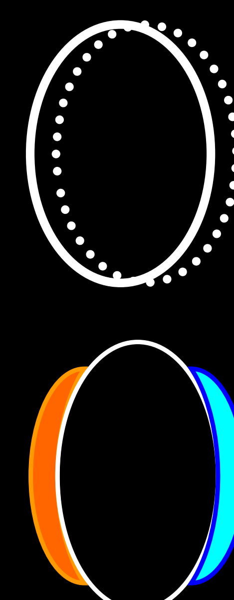
Movement Artifacts

Head motion can create pernicious spike artifacts



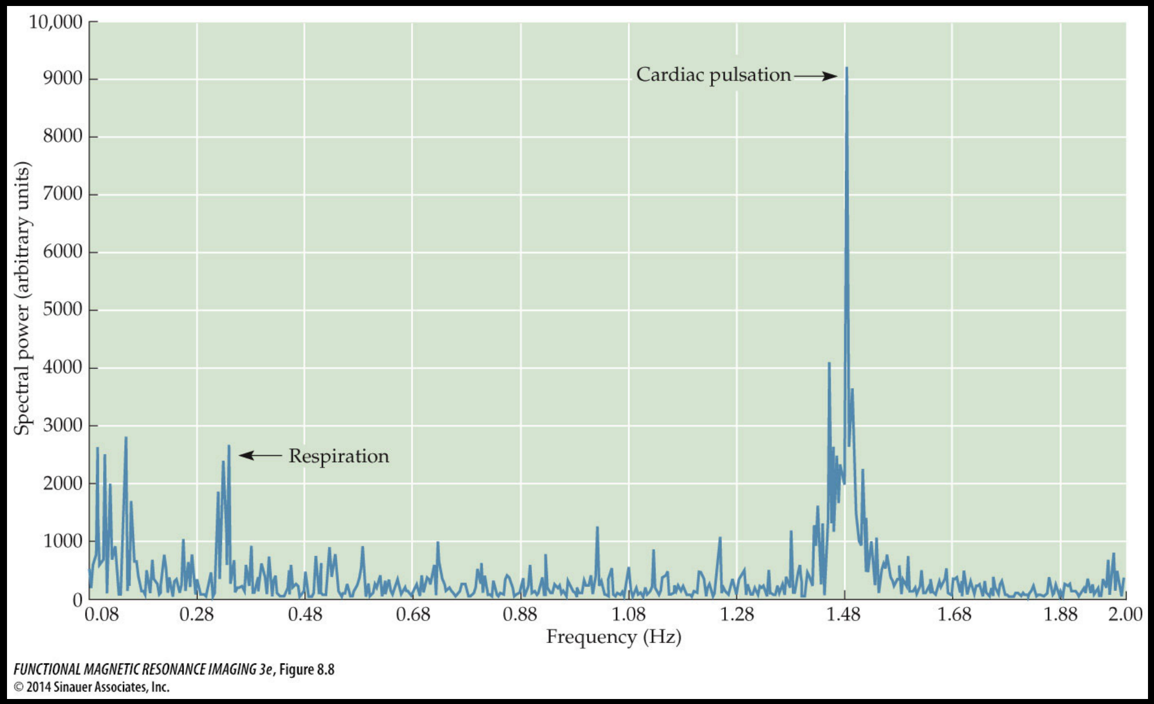
Ring artifact

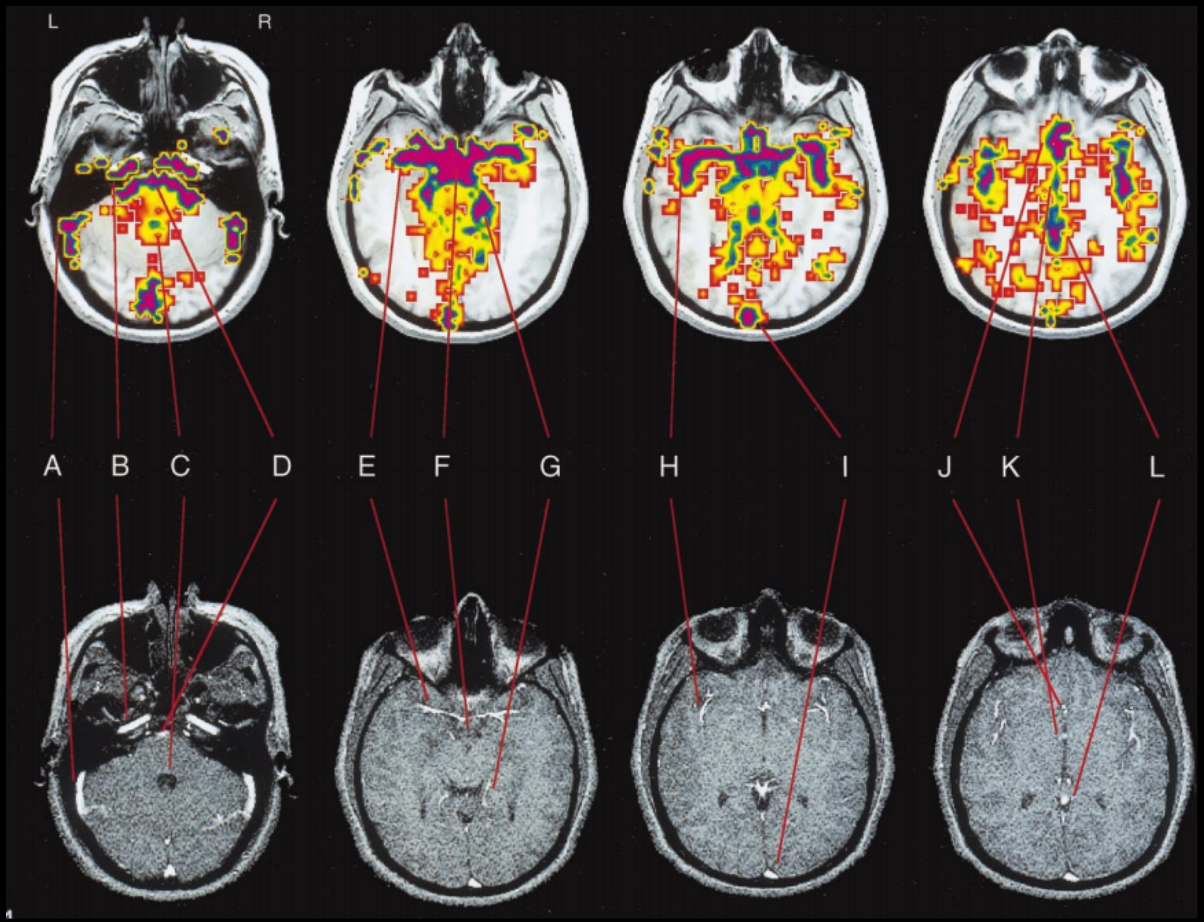
time1 → time2



Physiological Artifacts

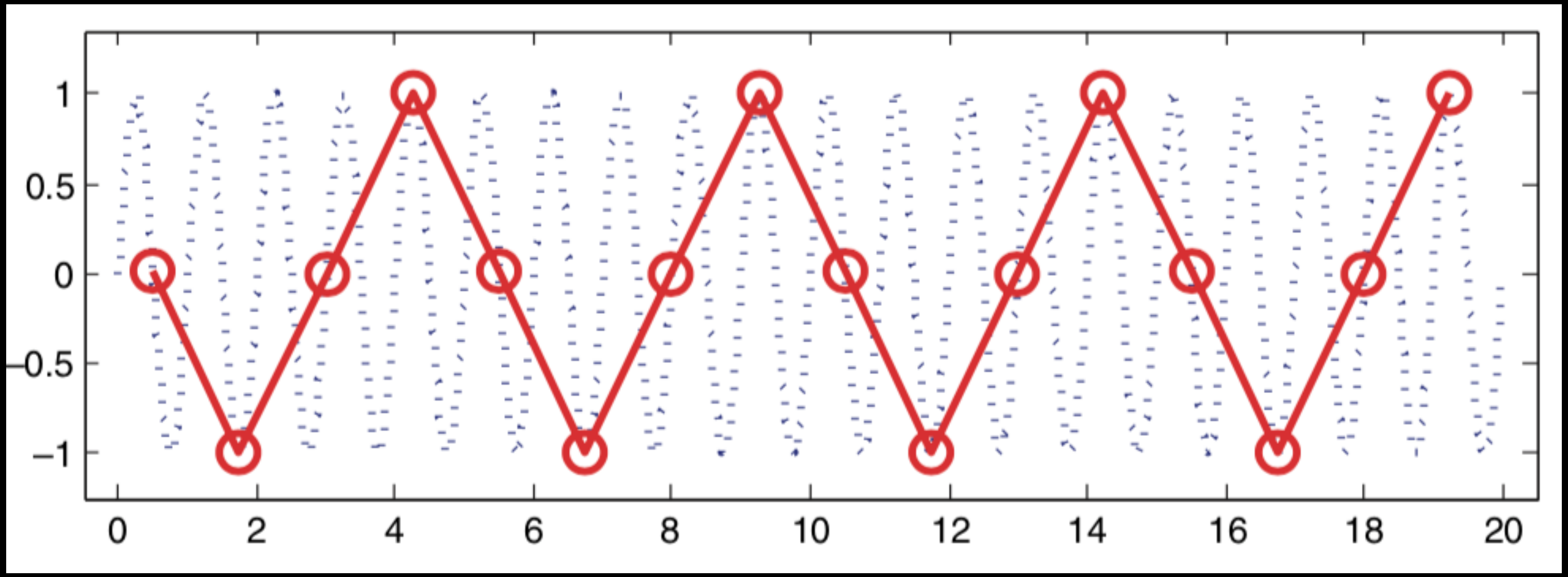
Relatively Consistent Frequencies



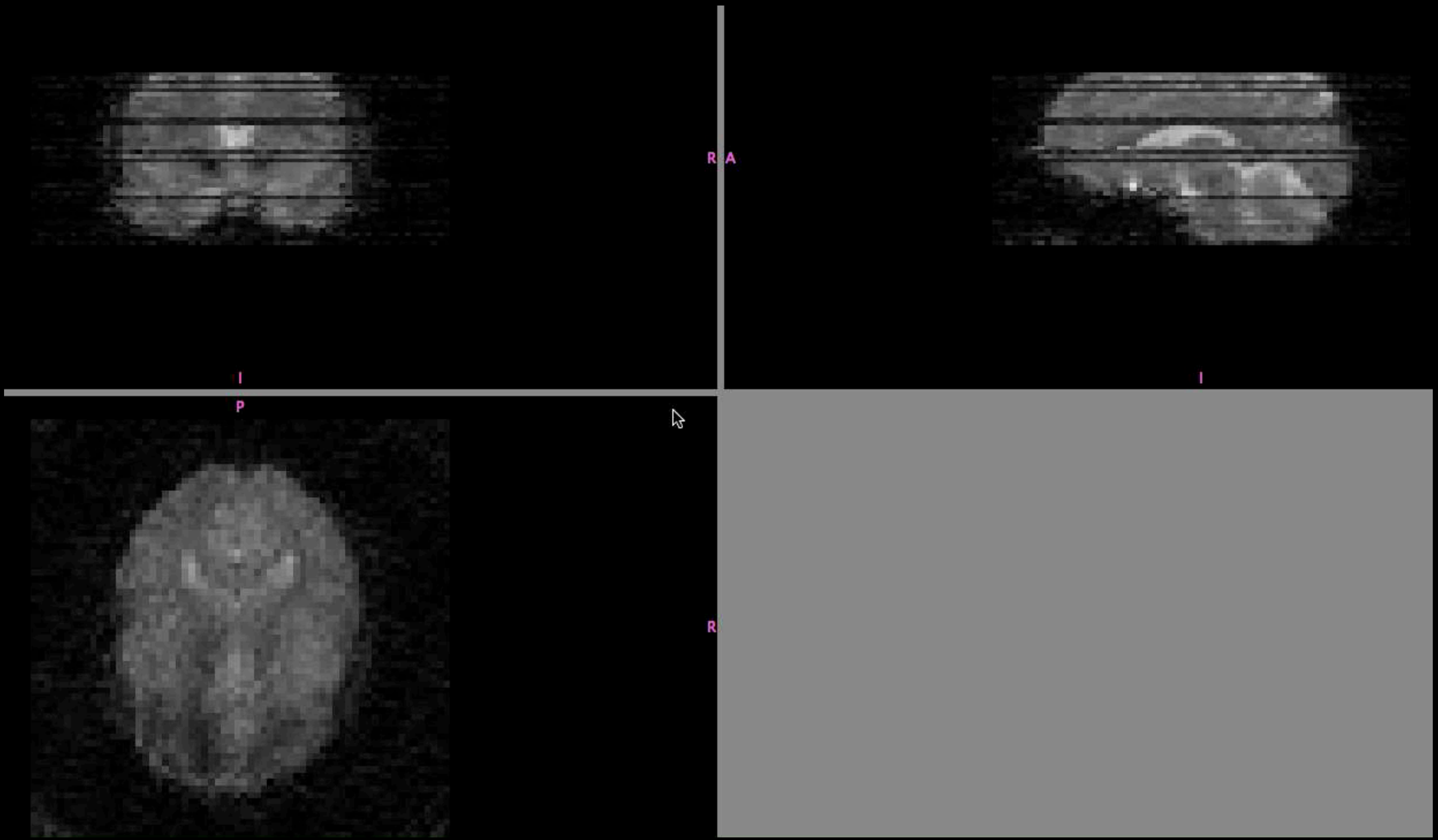


Dagli et al., 1999 Neuroimage

Aliasing

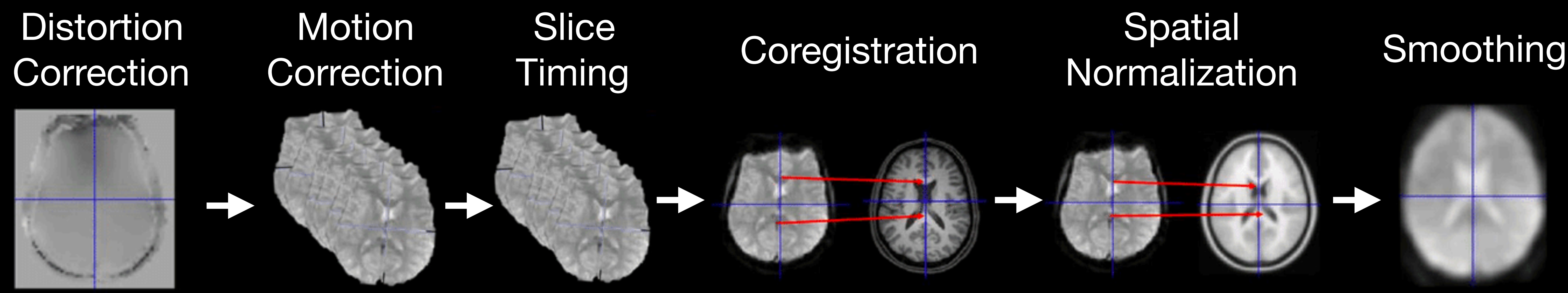


It gets bad…



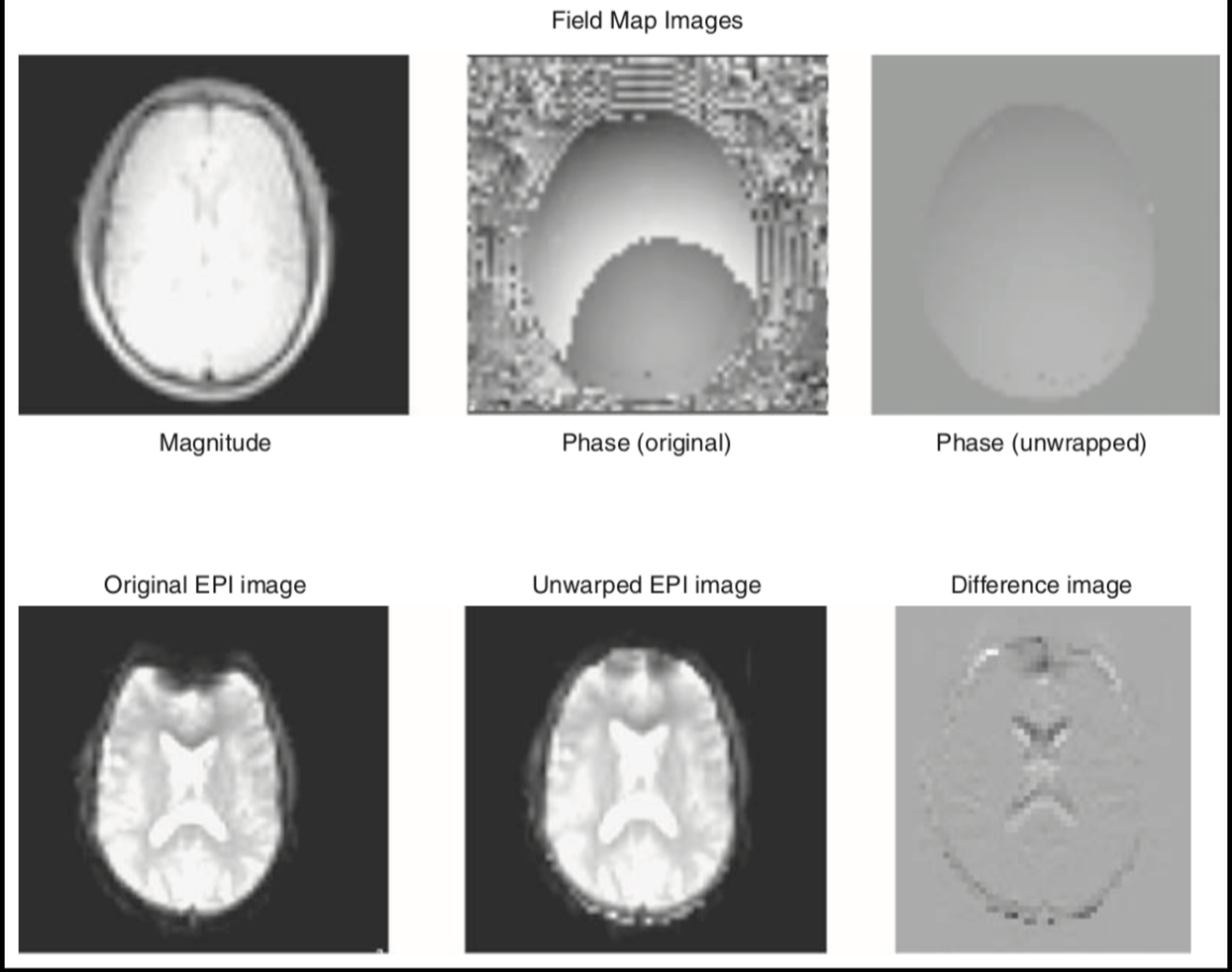
How do we fix it?

Preprocessing Overview



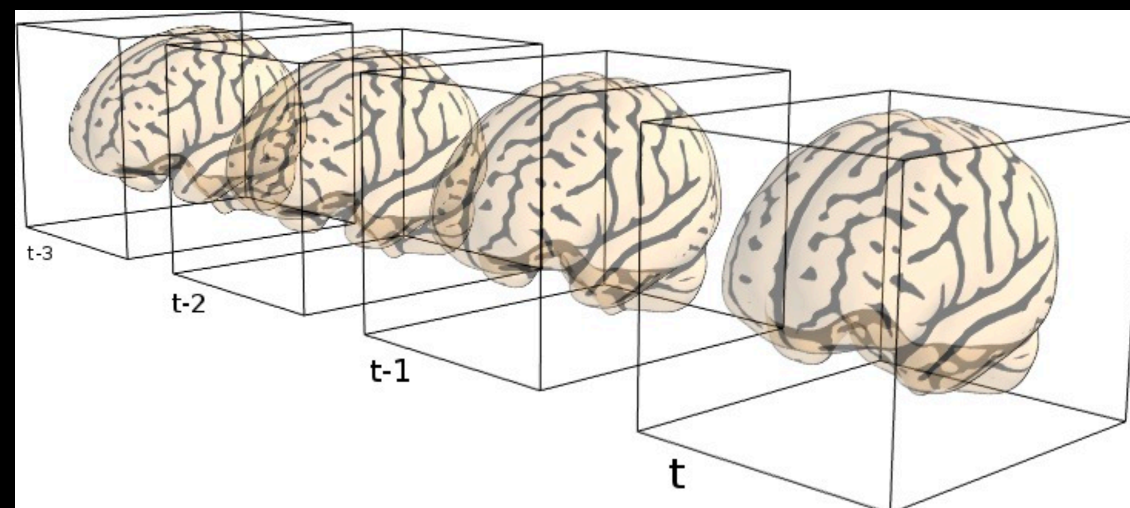
Distortion Correction

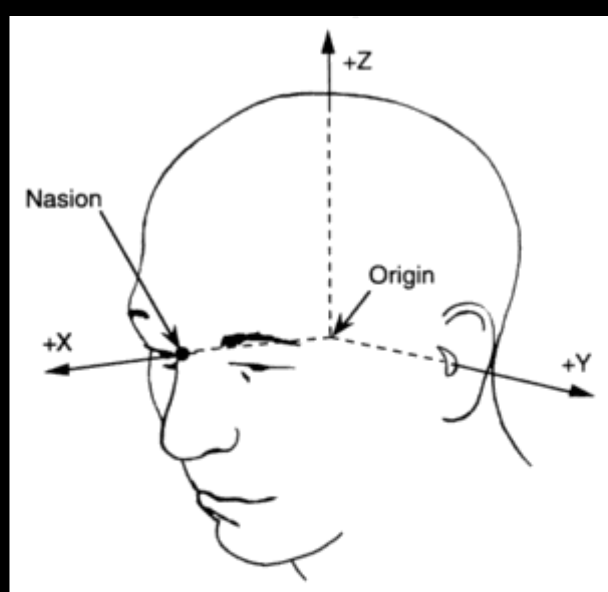
Can help reduce susceptibility artifact



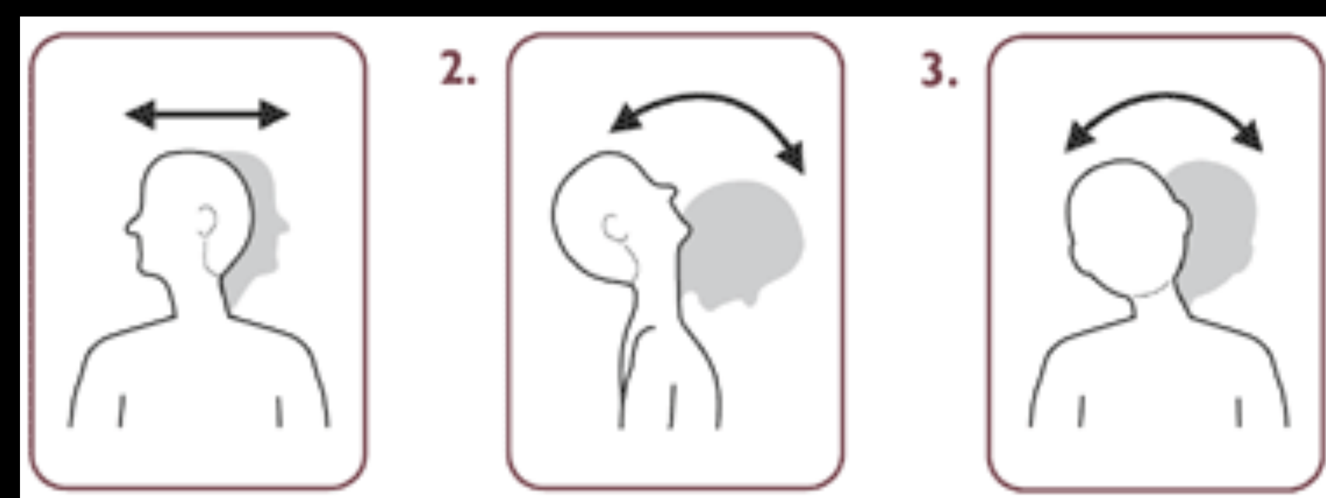
But can also introduce artifacts, particularly if subjects move in between field map and functional scans!

Head Motion





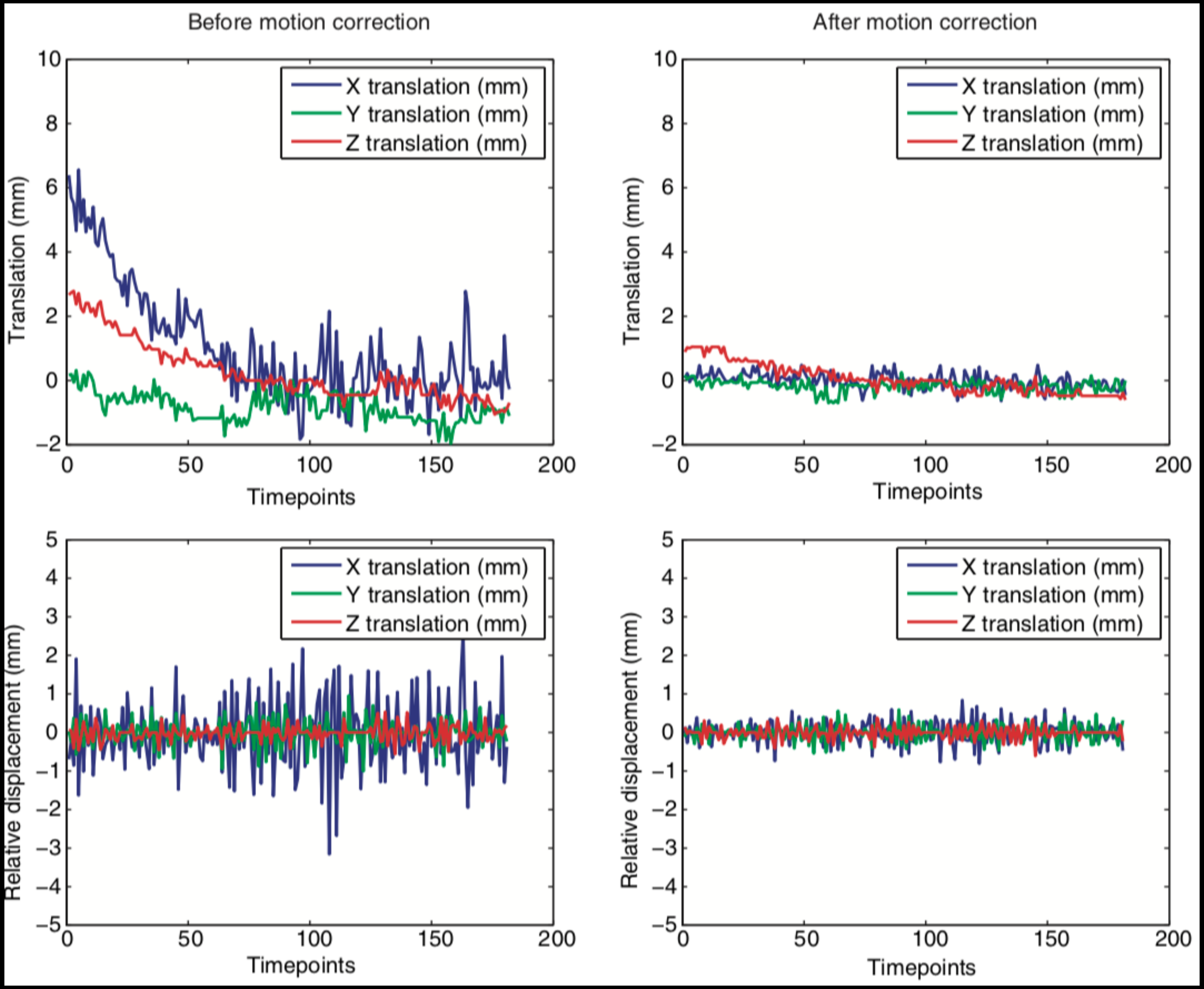
Yaw Pitch Roll



Head motion can be realigned with 6 parameters

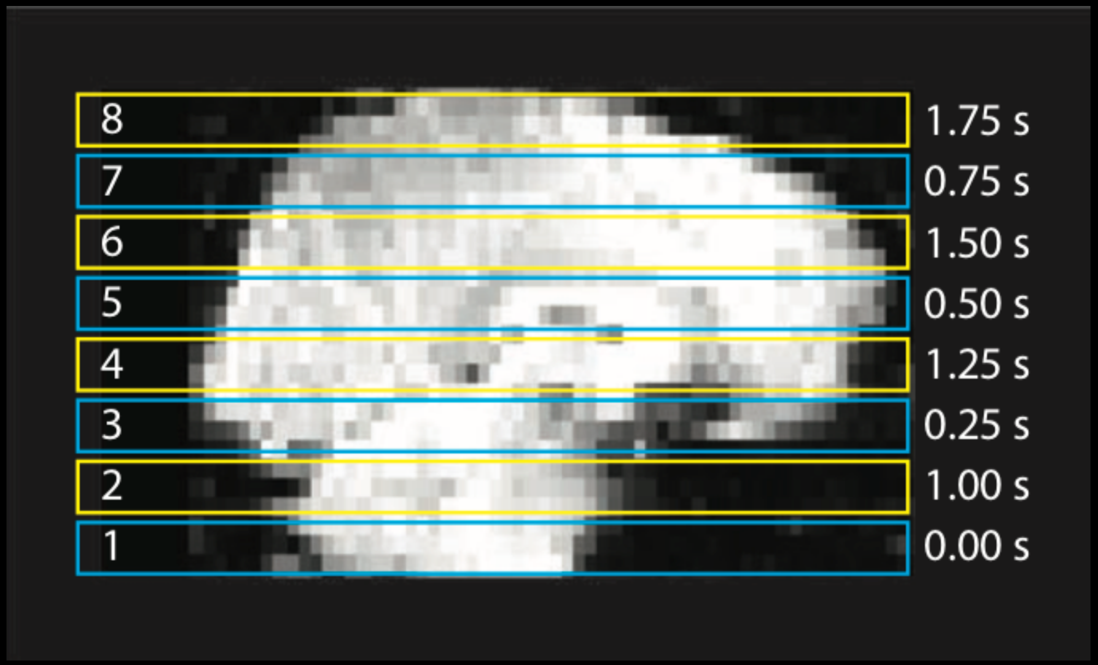
- x, y, z translations
- pitch, roll, yaw rotations

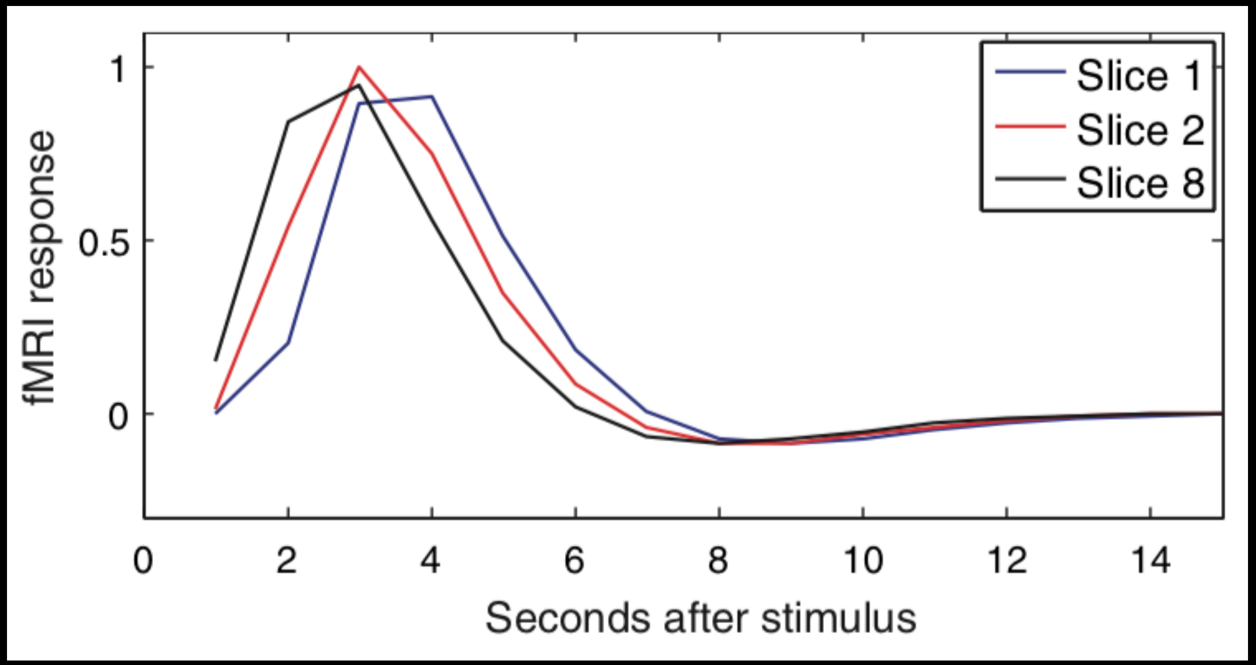
Realignment Parameters



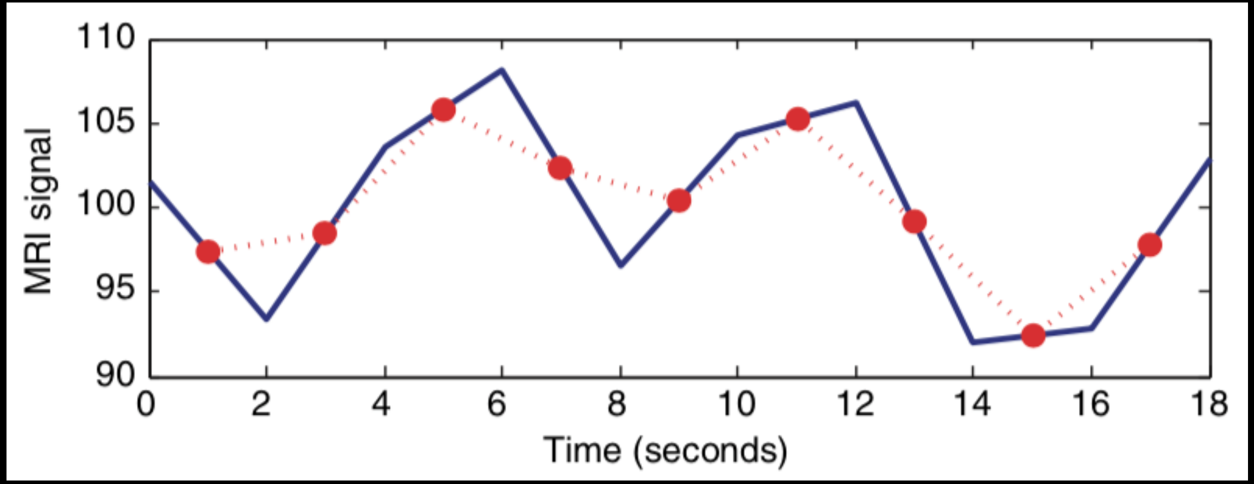
Slice Timing

How do we account for the fact that slices are not acquired simultaneously?





Slice timing correction interpolates signal across scans to attempt to align timing

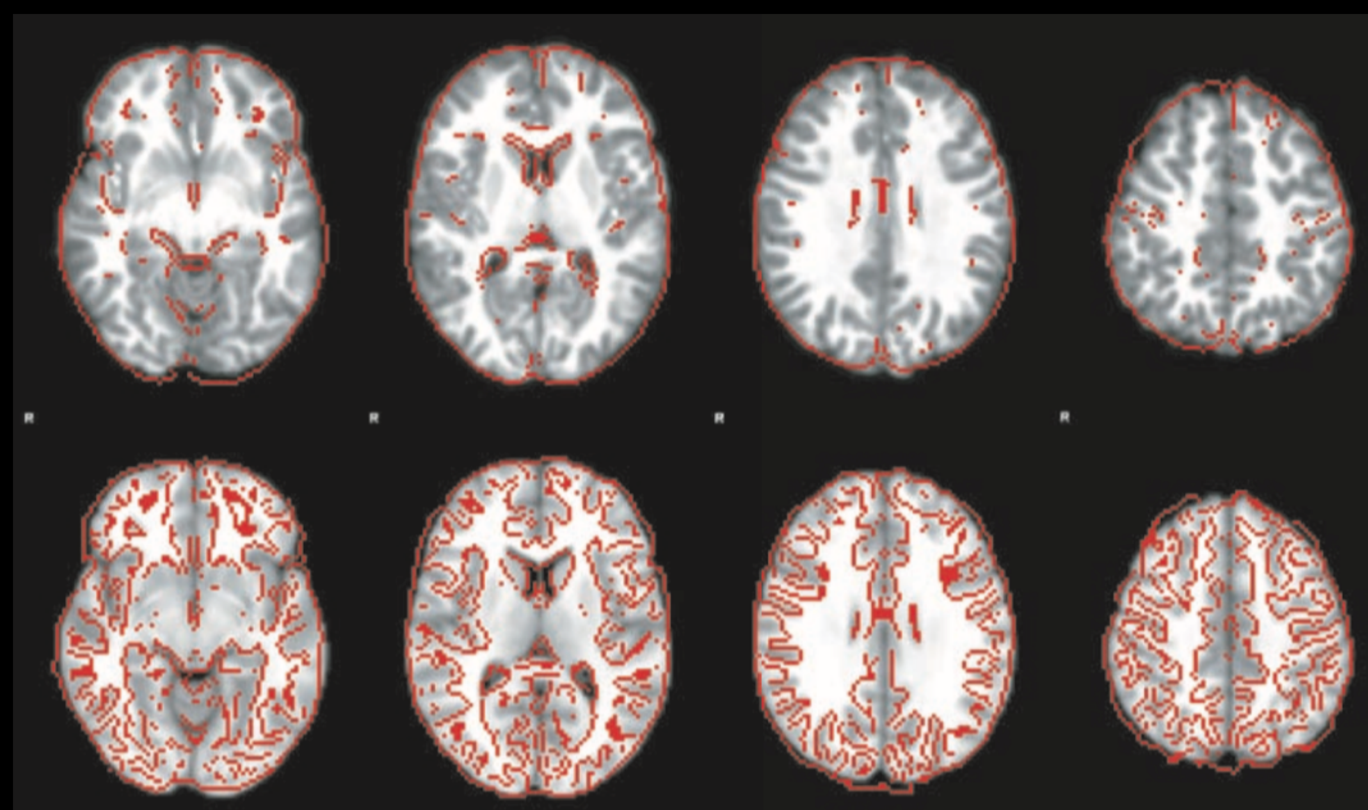


- Generally not recommend if TR <= 2s
- Can be minimized if using interleaved vs ascending slice acquisition
- Definitely do not recommend if using multi band

Spatial Normalization

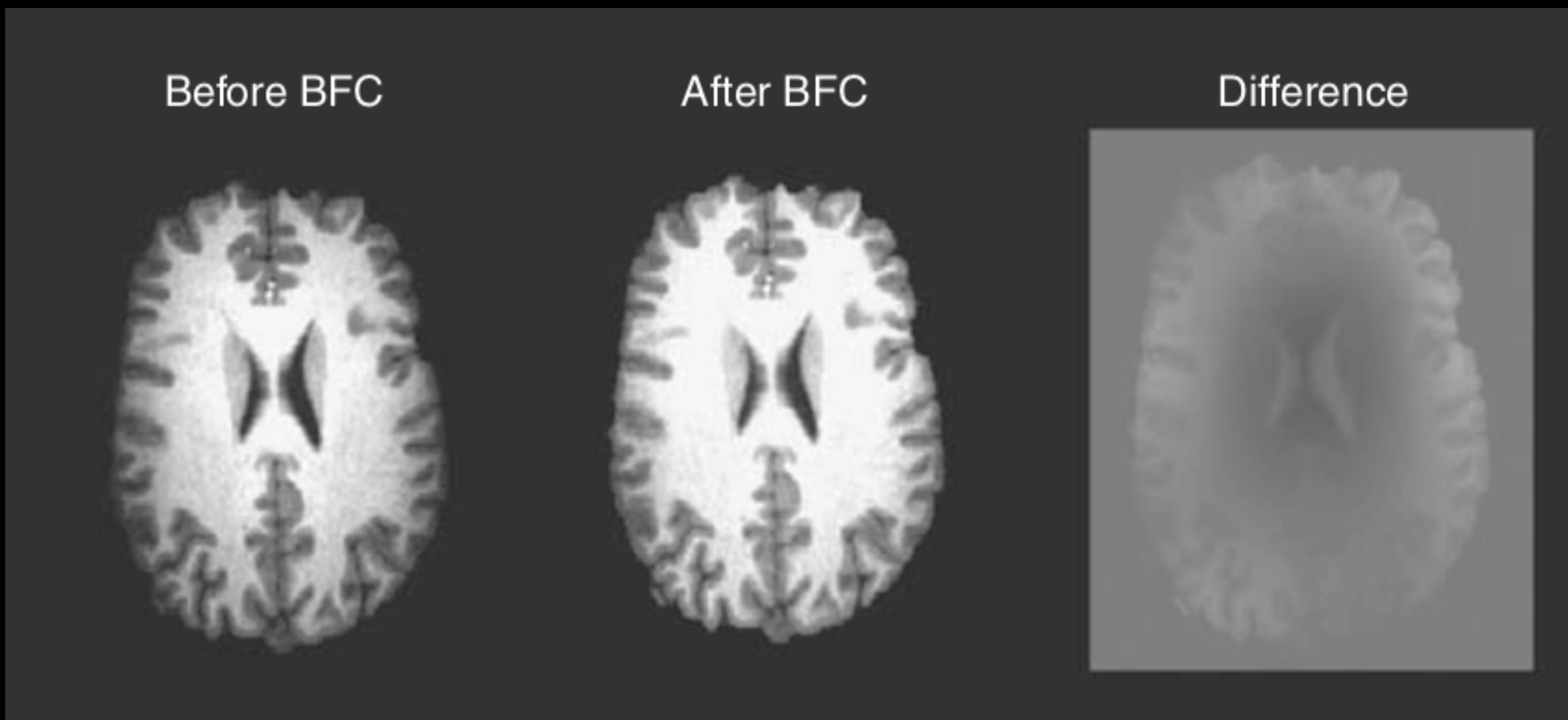
How can we compare uniquely shaped brains?

Normalize to a common anatomical space

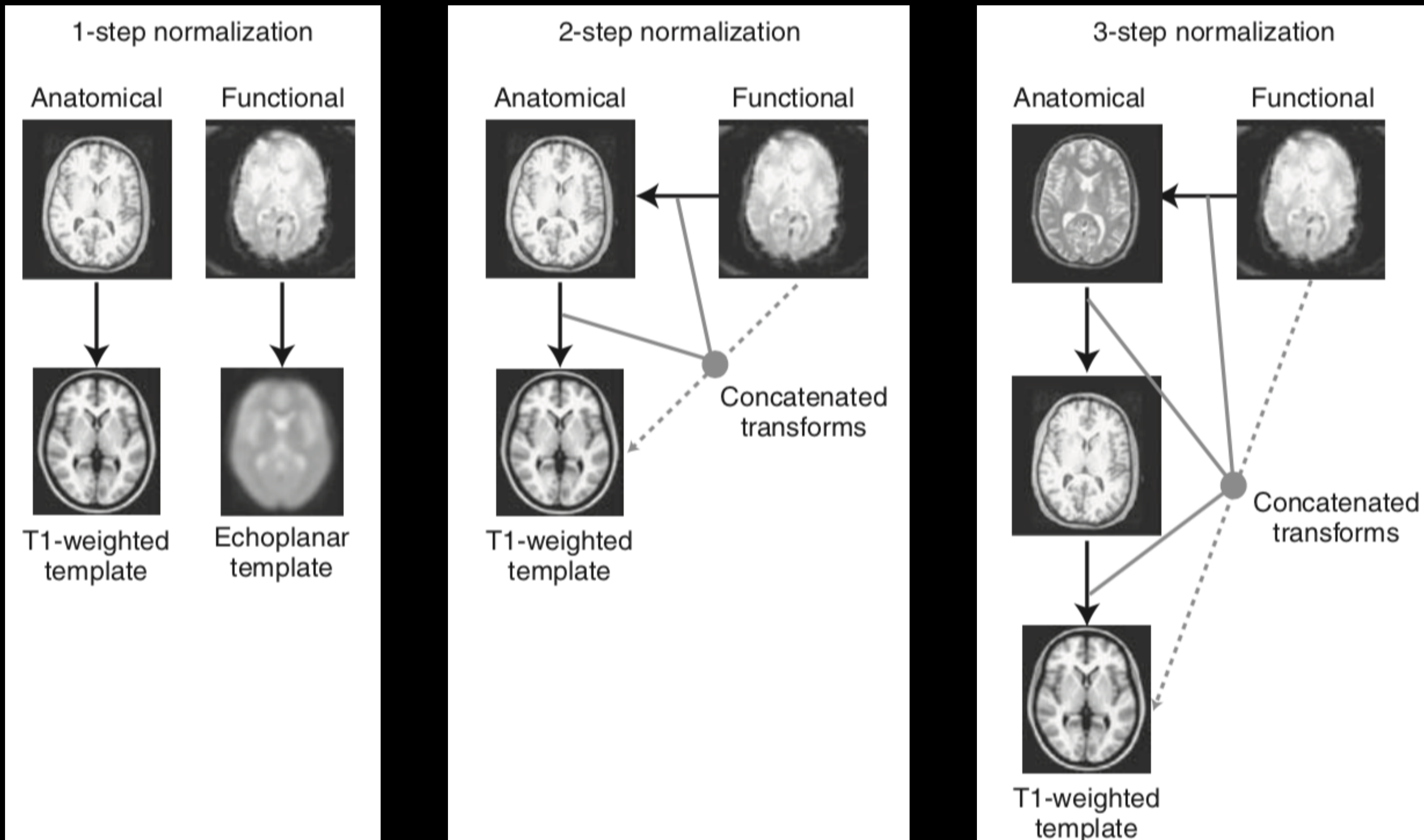


Alternative techniques are to align based on function
(Hyperalignment - James Haxby)

Bias Field Correction

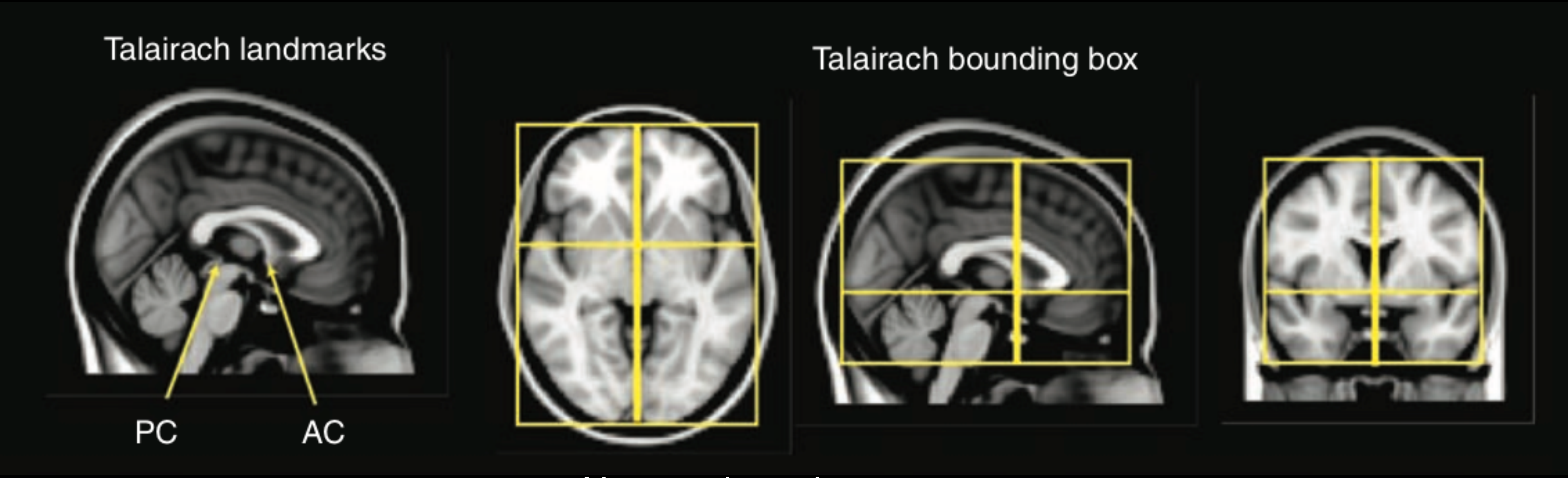


Normalization processing streams



Landmark Based Normalization

Normalize based on identifying landmarks (AC/PC) and bounding box

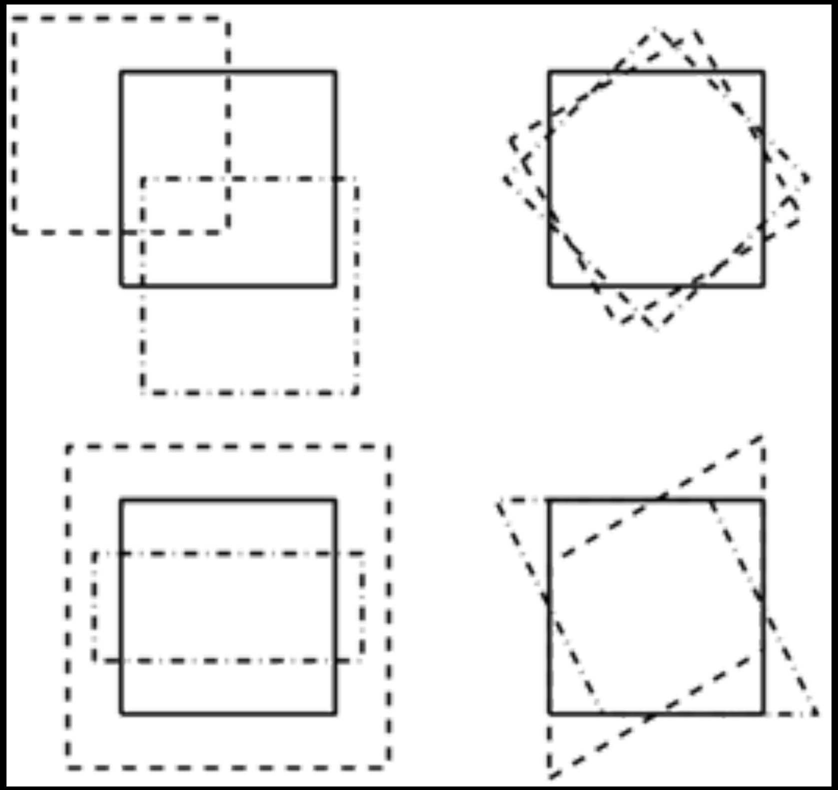


Not used much anymore
Software: Brainvoyager

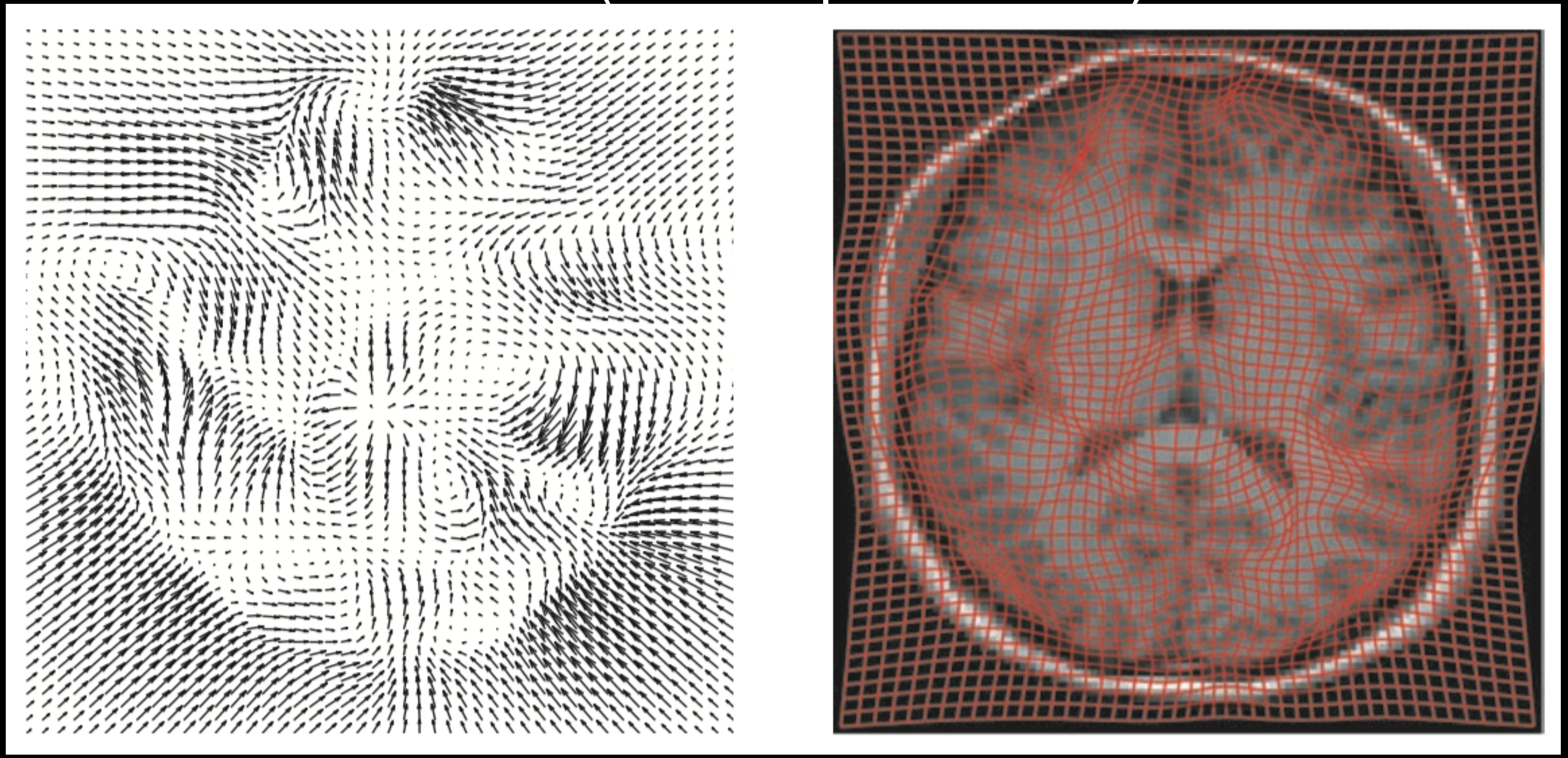
Volume Based Normalization

Normalize based on transforming one 3D volume into another

Linear Affine Transformations
(12 parameters)



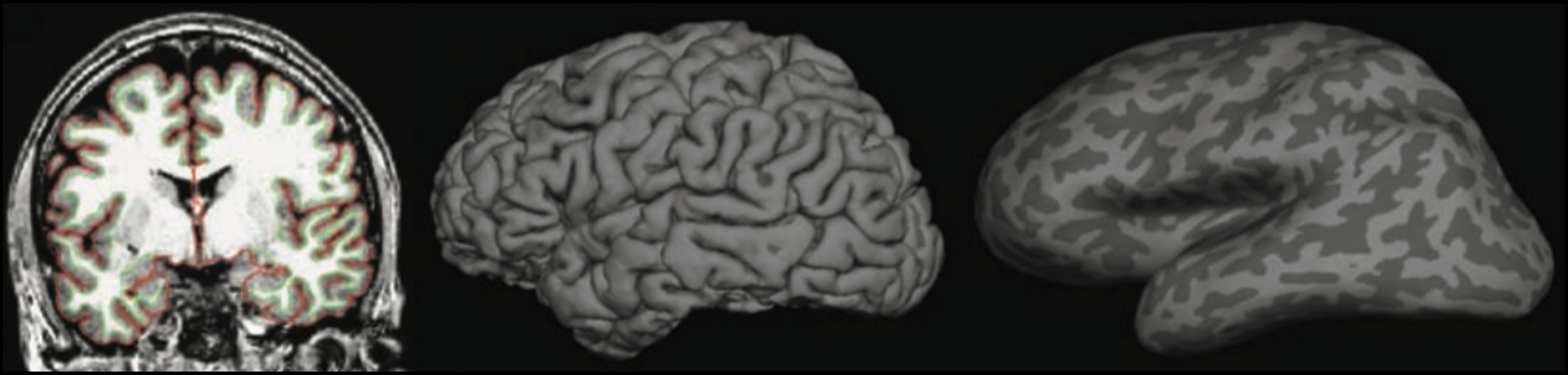
Nonlinear Transformations
(Lots of parameters)



Most common due to accuracy vs computational time tradeoff
Software: SPM-Dartel, FSL-fNIRT, ANTs

Surface Based Normalization

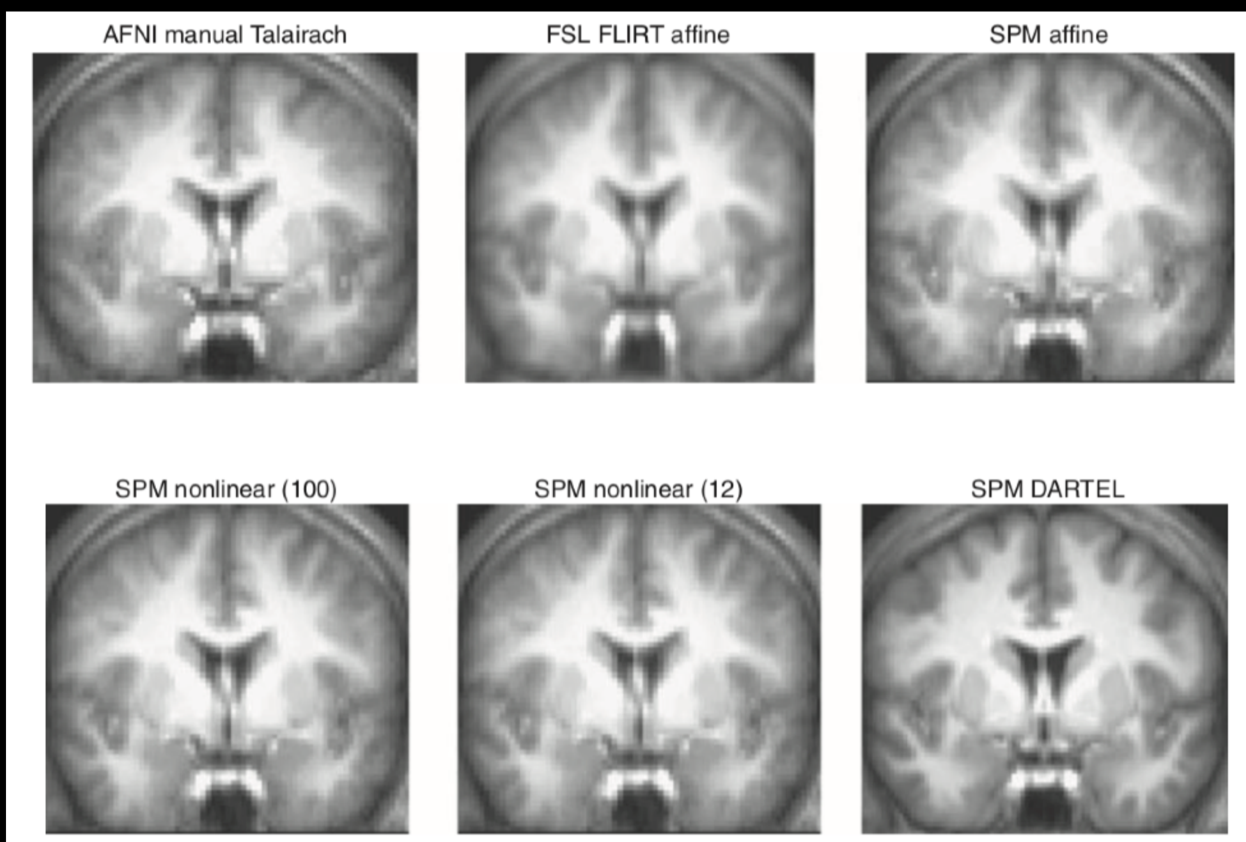
Normalize based on inflating cortical surface and aligning sulcal patterns

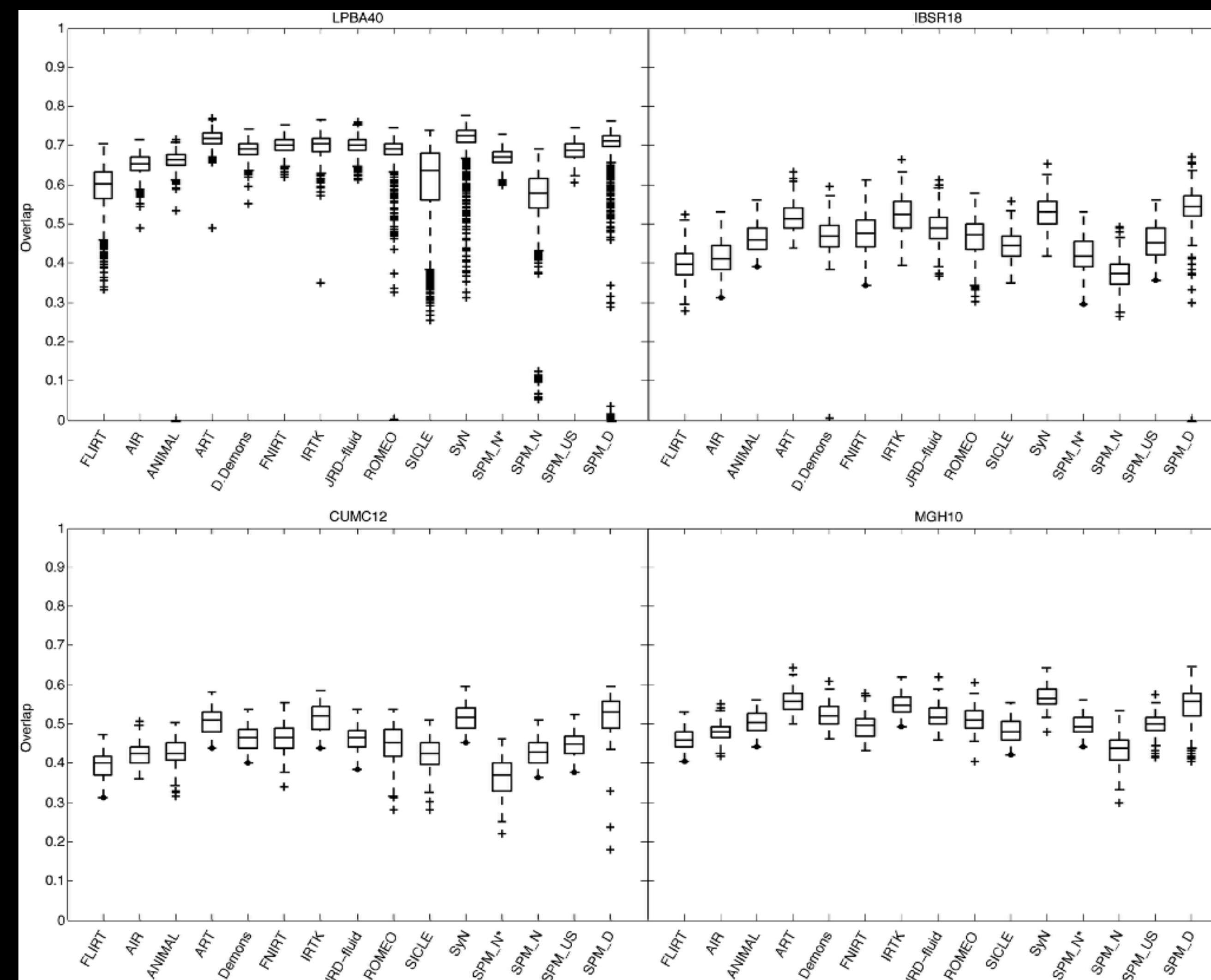


Computationally expensive (very slow), some people strongly prefer

Software: Freesurfer

Nonlinear Normalization

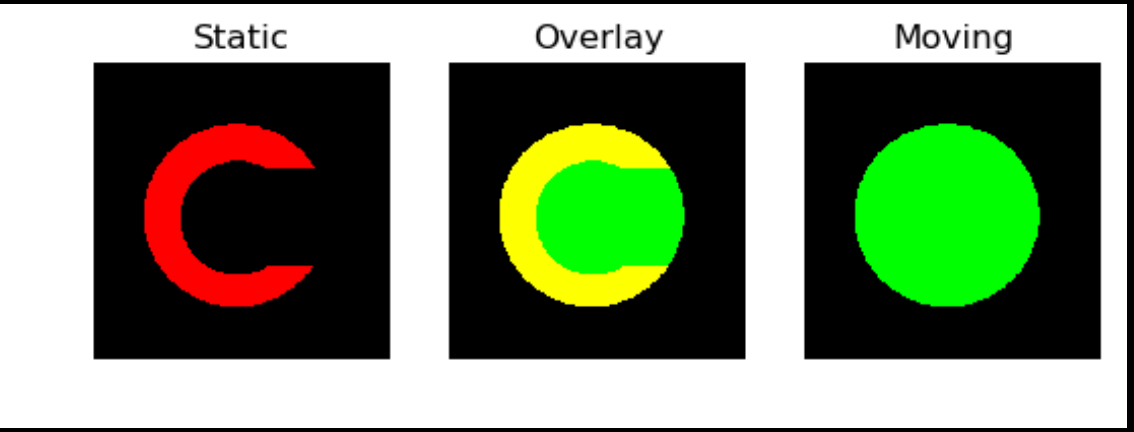


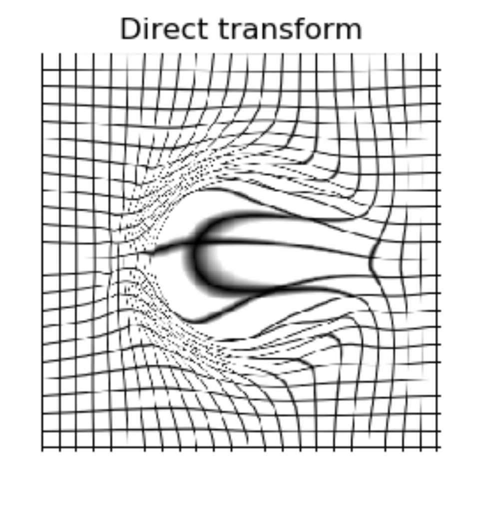


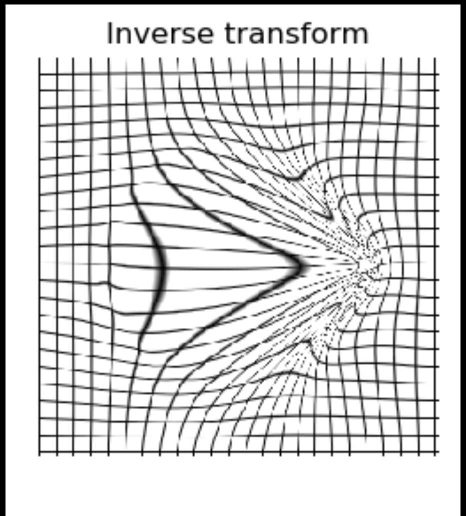
Klein et al., 2009 Neuroimage

Diffeomorphic Registration

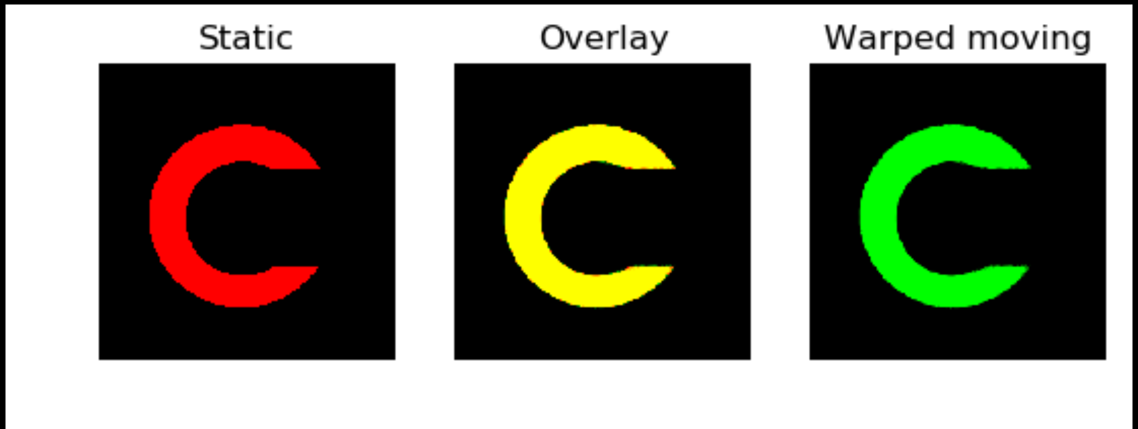
Widely used nonlinear registration algorithm



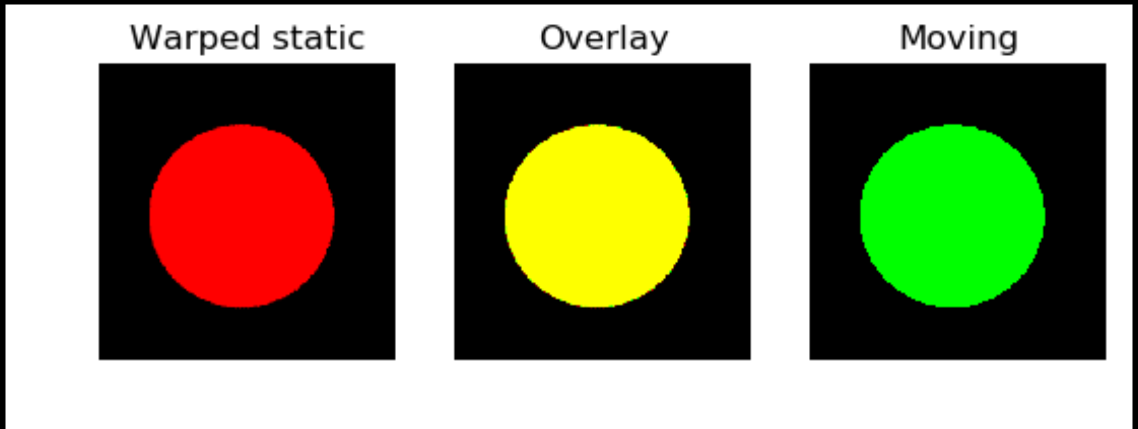




Apply Transformation

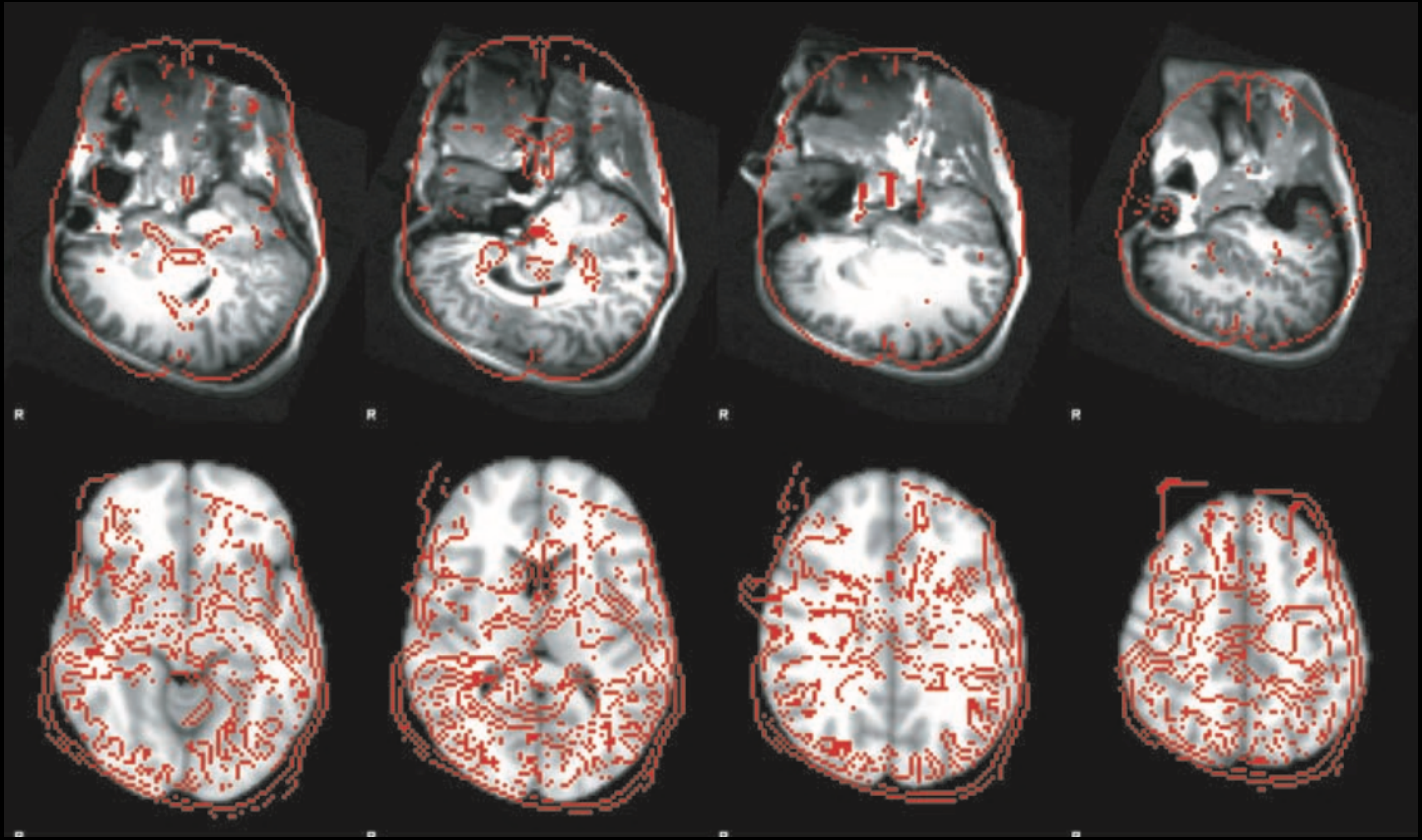


Apply Inverse Transformation



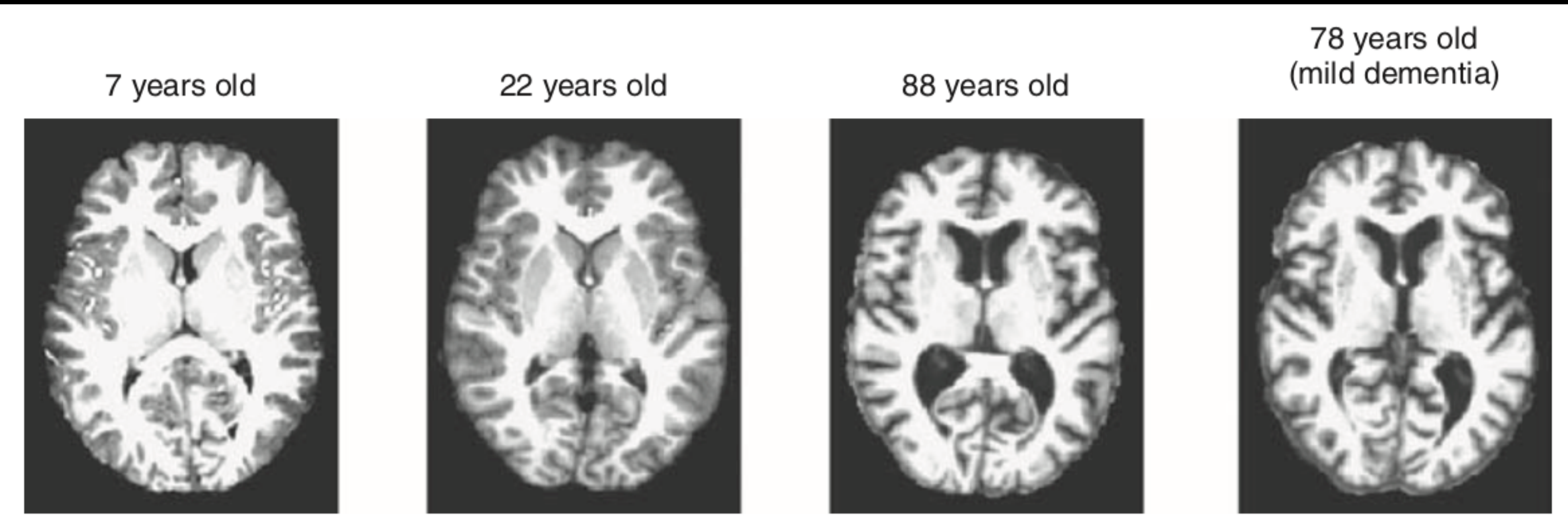
http://nipy.org/dipy/examples_built/syn_registration_2d.html

Normalization Errors

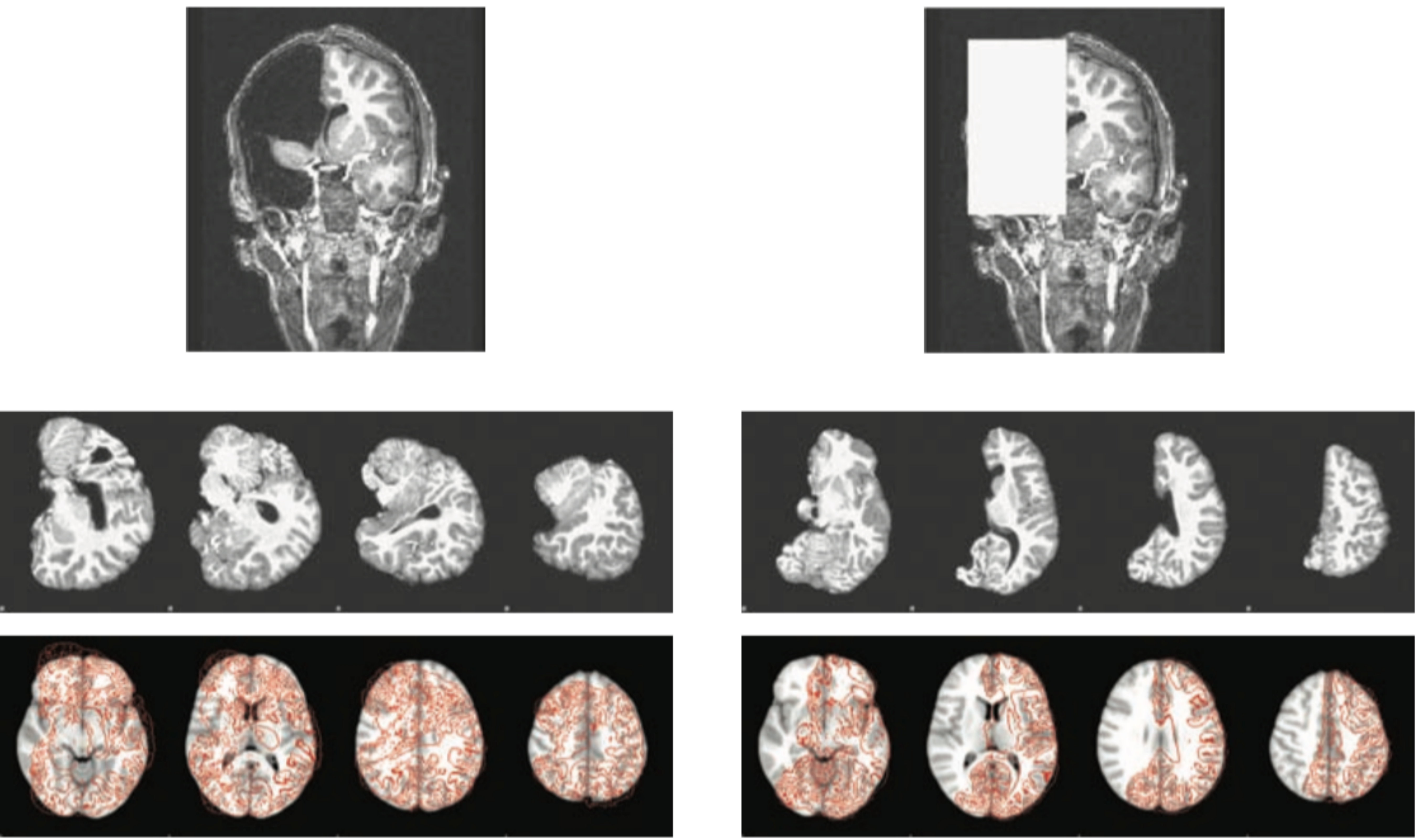


What about special populations?

Aging


7 years old
22 years old
88 years old
78 years old
(mild dementia)

Lesions



Spatial Smoothing

Benefits

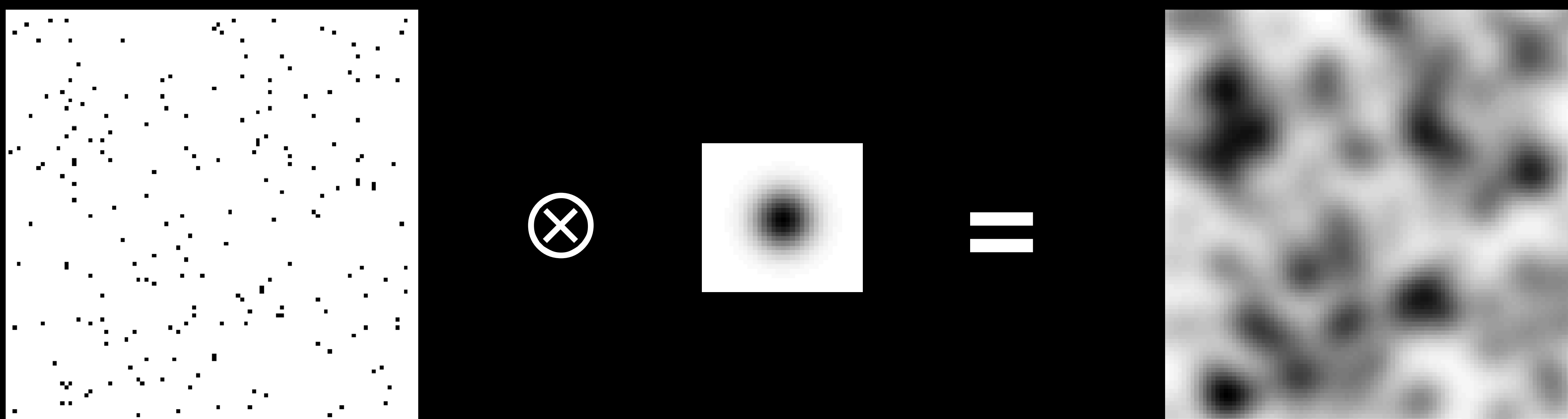
1. Increases signal to noise
2. Minimizes anatomical alignment issues
3. Can help meet assumptions for certain statistics (gaussian random field theory)

Costs

1. Decreases spatial resolution
2. Unclear how much to smooth (e.g., 6mm)
3. Should different regions be smoothed with different sizes?

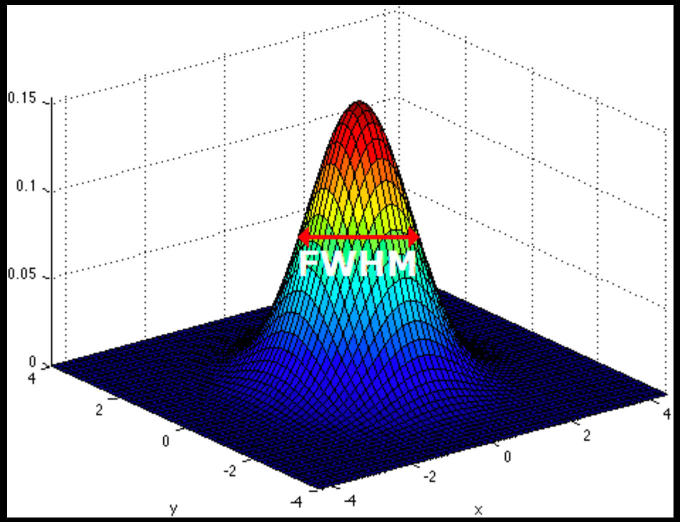
Convolve with Gaussian Kernel

2D Example



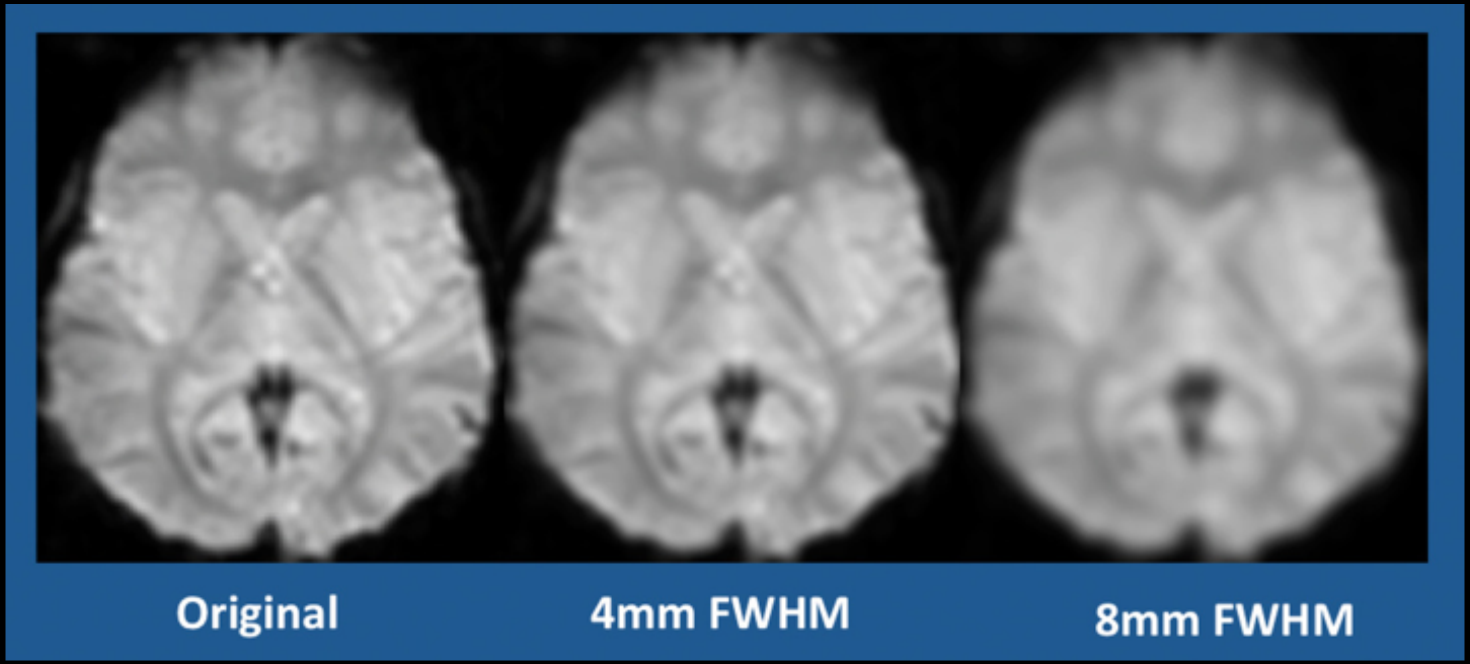
Spatial Smoothing

3D Gaussian Kernel



Full width at half maximum (mm)

Spatial blurring



Impacts statistics