Educational Course:

The Art and Pitfalls of fMRI Preprocessing

Fmri Spatial Processing

Ray Razlighi

Jun. 8, 2014

Spatial Processing

- Spatial Re-alignment
- Geometric distortion correction
- Spatial Normalization
- Smoothing

Why, When, How, Which

Why is it needed?

When is not needed?

How is it done?

Which method is the most suitable?

Agenda

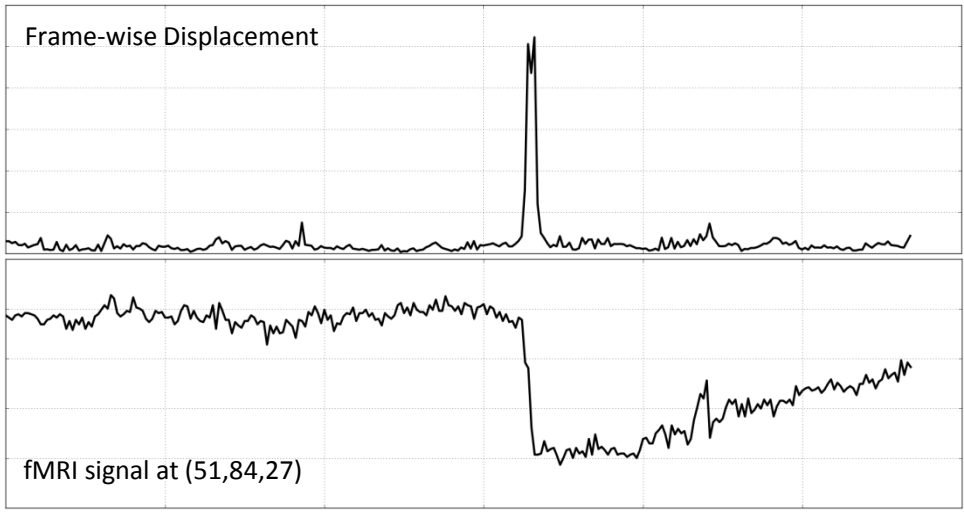
- Spatial Re-alignment
- Geometric distortion correction
- Spatial Normalization
- Smoothing

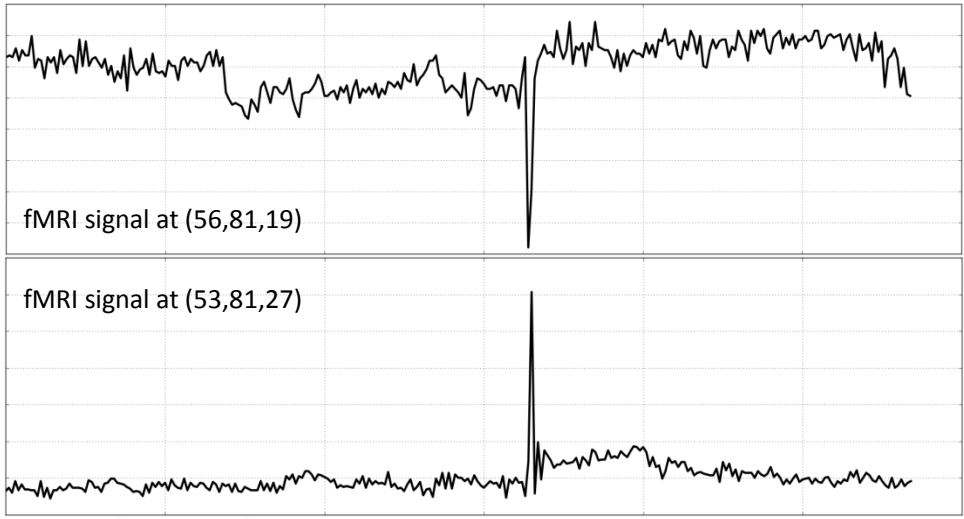
Why is it needed?

- Subject moves during the scanning either voluntary or involuntary but scanner doesn't
- The fMRI recording of a spatial coordinates (a voxel) will be from different anatomical regions of the brain
- Probably the most damaging and frustrating problem associated with fMRI data analysis is the motion
- Resting-state fMRI data are more vulnerable to motion than task-based fMRI
- Re-alignment is only a part of motion correction
- It does not correct all the artifacts caused by motion

Different artifacts of motion

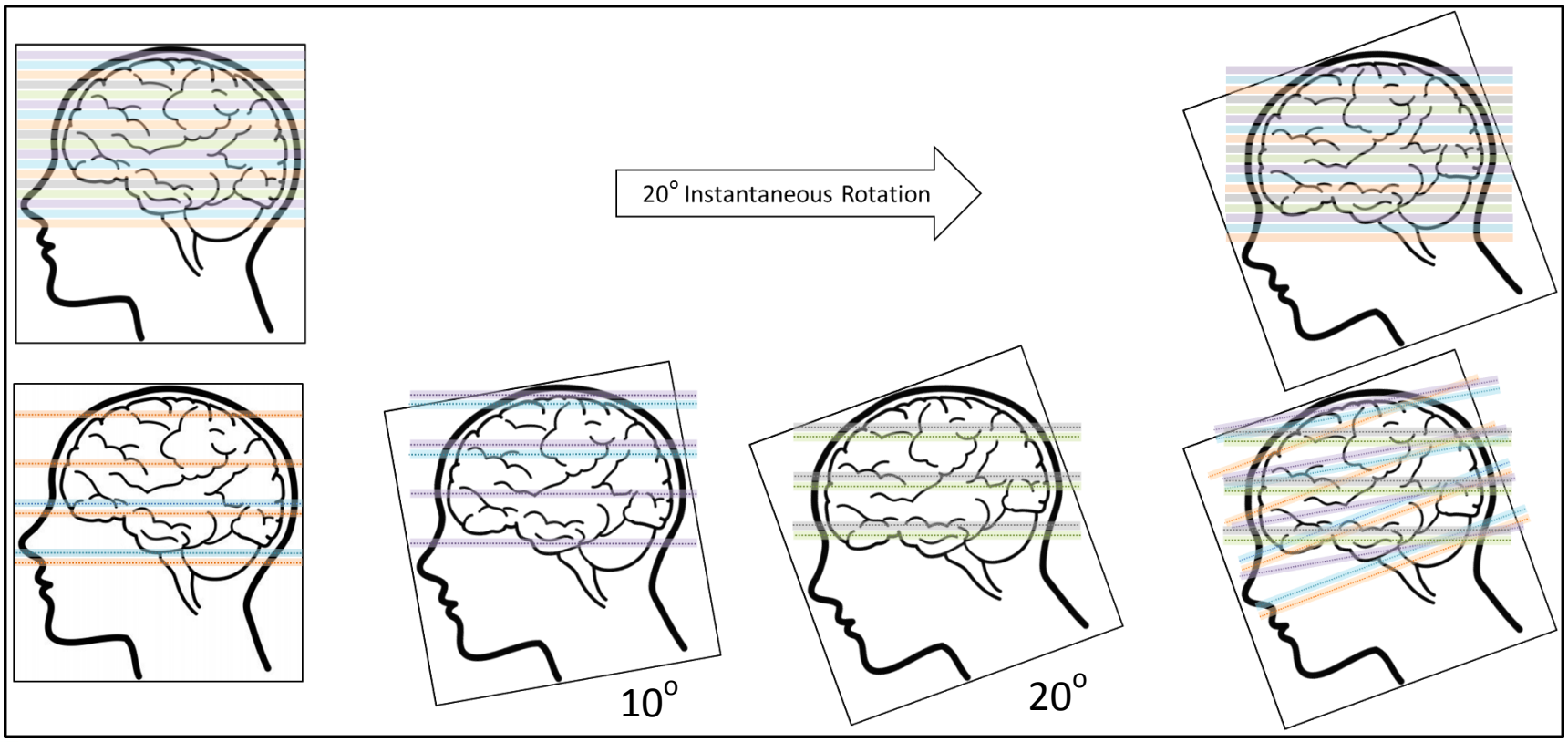
- It switches one voxel's signal with another
- It changes the slice orientation: some part of brain gets excited twice and others don't get excited at all
- Interaction with slice timing distributes the problem to the entire brain
- Distorts the homogeneity of the magnetic field





Slice timing and motion

- The effect of motion and interleaved slice acquisition on the measured fMRI signal is intertwisted which are extremely challenging to be separated
- There are lots of on-going studies to correct for motion and interleave simultaneously



When is not needed?

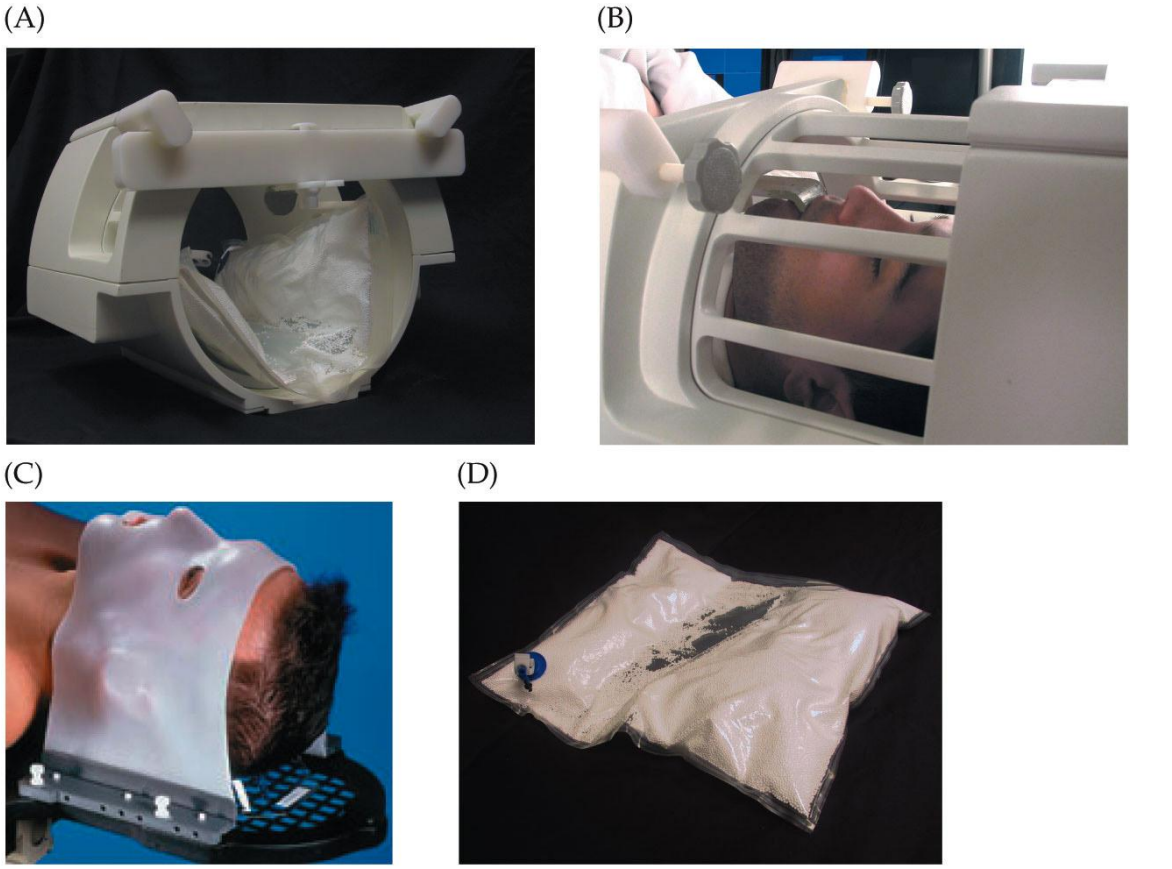
- Unless subjects are motionless it is always needed.
- Realignment assigns the correct signals to each voxel after motion; However, it doesn't correct the signal values during the motion
- Distorting magnetic field generates spatial distortion which often reduces the accuracy of rigid-body registration
- Realignment before slice timing correction may reduce its effectiveness
- Realignment itself may induce functional connectivity in resting-state fMRI data

Different types of motion

- Motions due to sudden head movement
- Motions due to respiration
  - Causes movement
  - Lung air volume variation changes the magnetic field
- Motions due to tremor in elders
- Task-related motion
  - Caused by periodic movement
  - Caused by periodic respiration

How is it done?

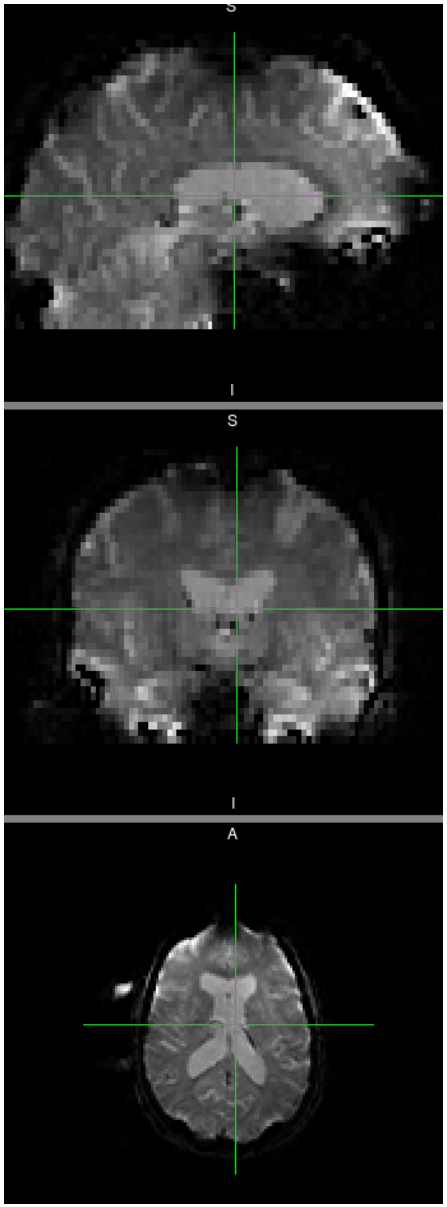
So far the most effective methods are the preventive ones



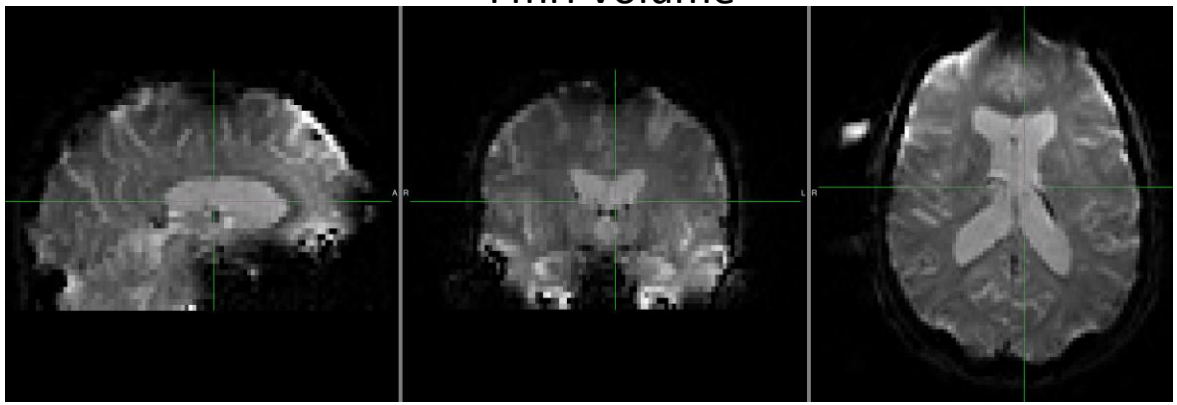
***Functional Magnetic Resonance Imaging 2e*, Figure 8.20**

Re-alignment

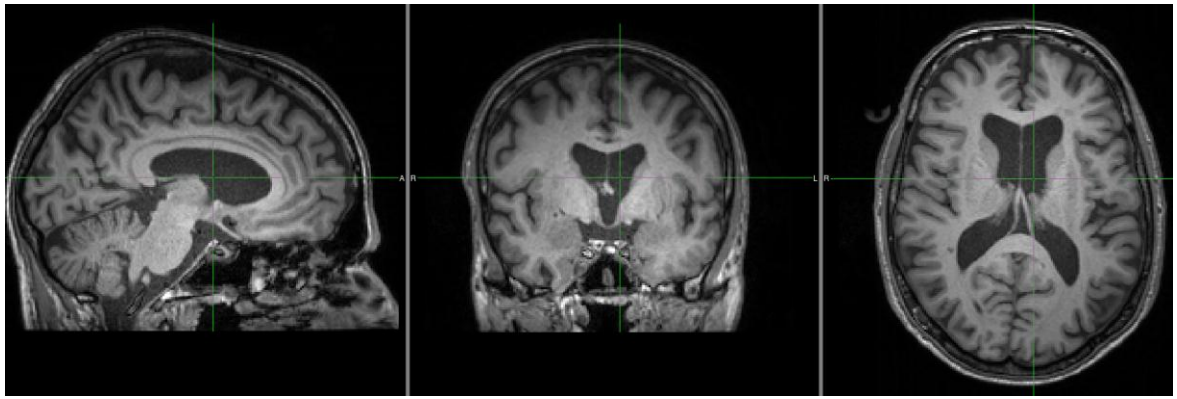
- It is almost always done by registering fMRI volumes to a reference volume.
  - Reference volume can be structural images (T1 or T2)
    - Use information theoretic similarity measures (MI, NMI, and etc)
    - Use 6 degree of freedom
  - one of the volumes in the fMRI data
    - Use 6 degree of freedom
    - Make sure reference volume is free of distortion
    - Spatial distortion may cause the rigid-body registration to fail



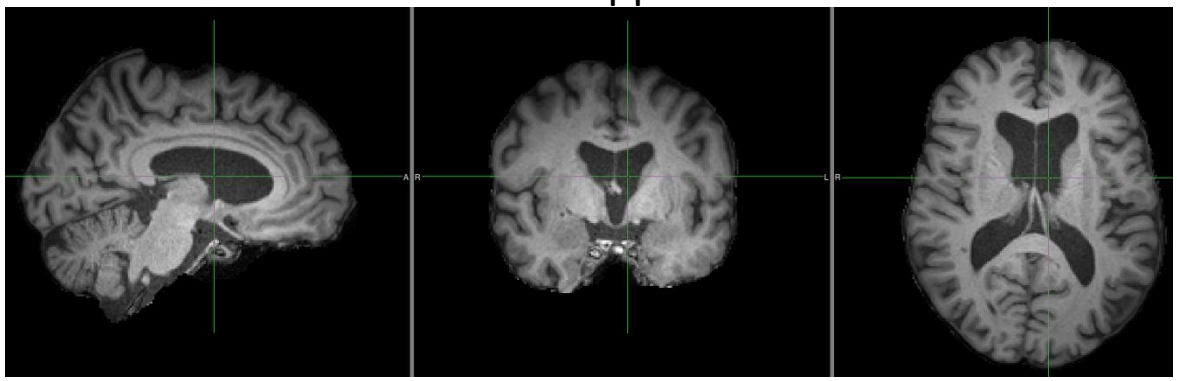
Fmri Volume



Structural T1



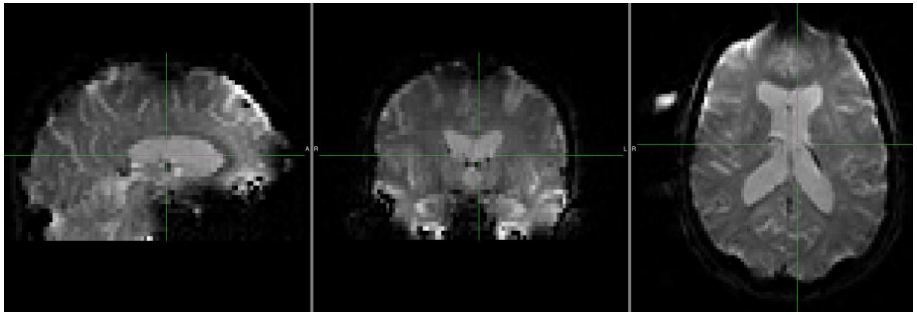
Skull Stripped T1



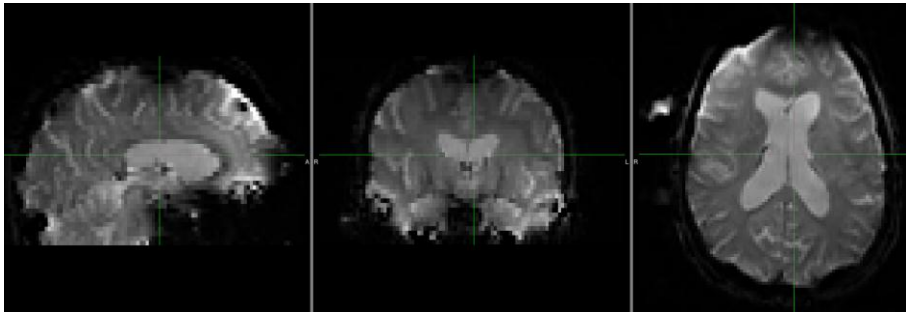
Which method to use?

- It is suggested to used fMRI temporal mean volume or a single volumes as the reference image
  - 6 degree of freedom,
  - Information theoretic similarity measures (MI, NMI, etc)
- No matter which method you use a visual check after re-alignment is necessary

Volume Zero

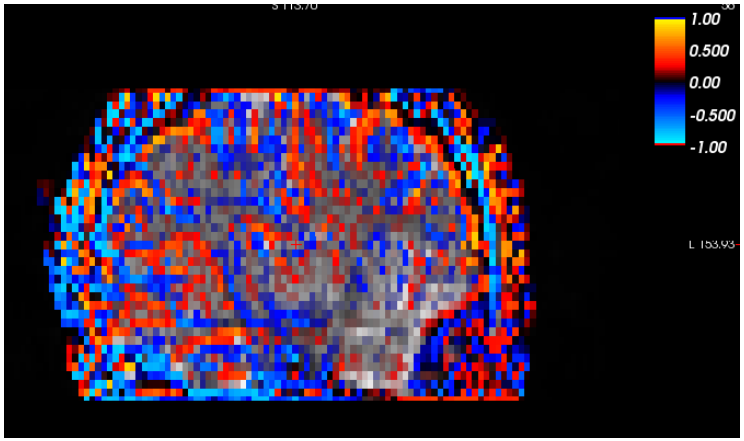


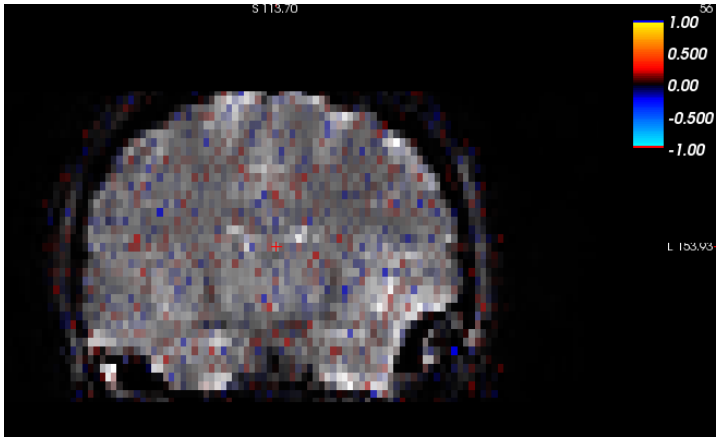
Mean Volume



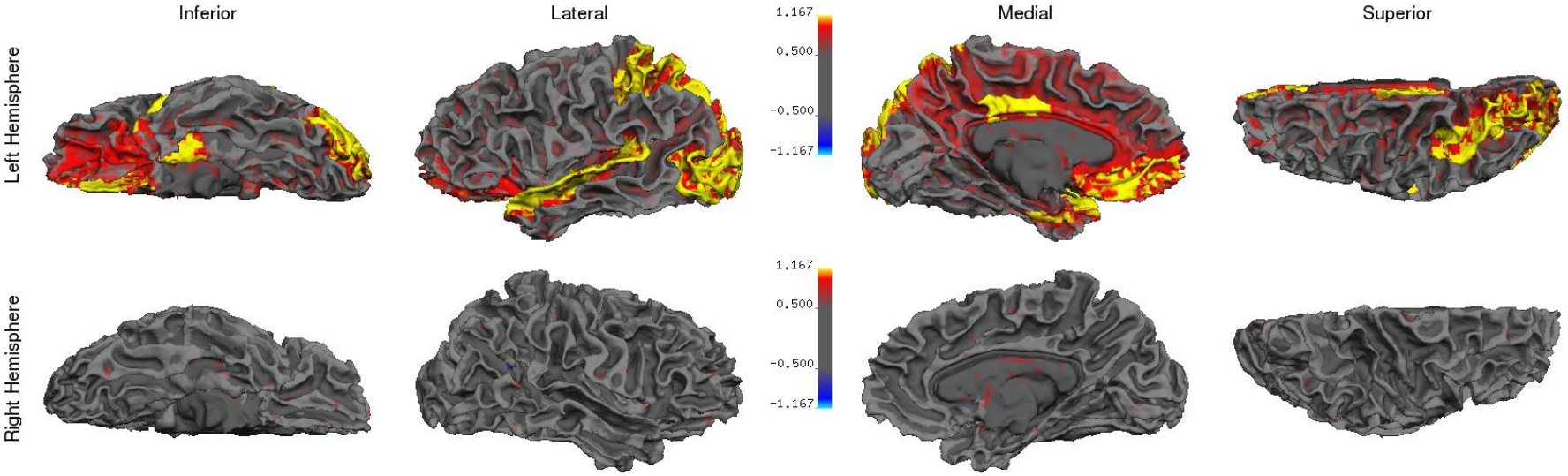
Which interpolation scheme to use?

- Any spatial transformation requires spatial interpolation
- Spatial interpolation introduce a slight spatial smoothing to the data
- However *Monte Carlo* simulation shows that for resting state fMRI tri-linear interpolation can introduce cluster of functional connectivity, thus nearest neighbor might be more suitable

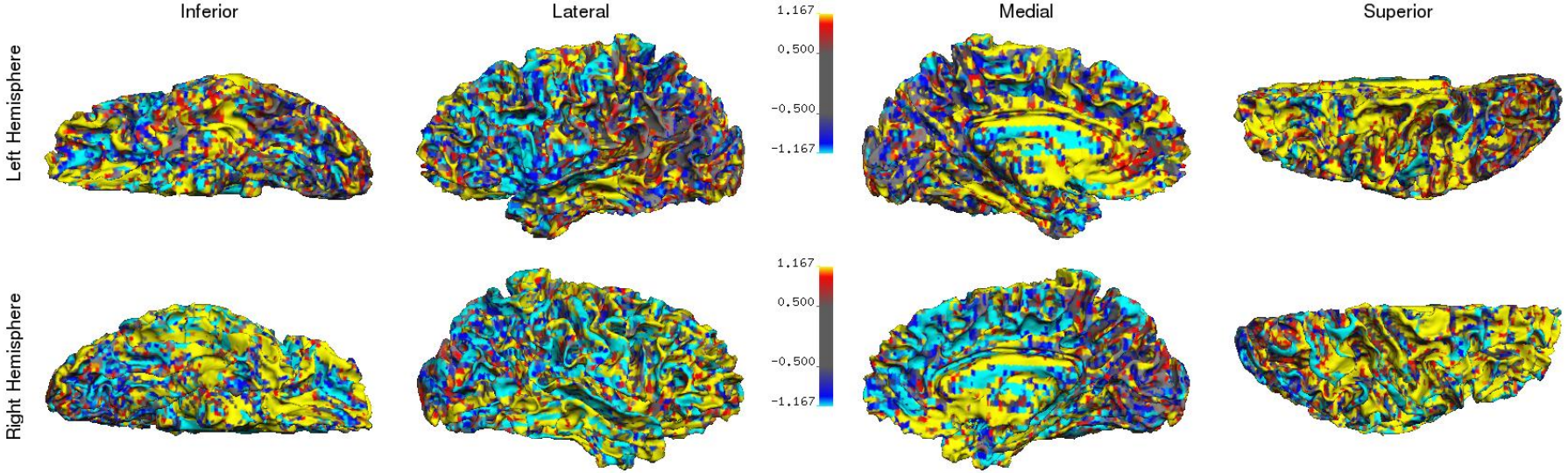




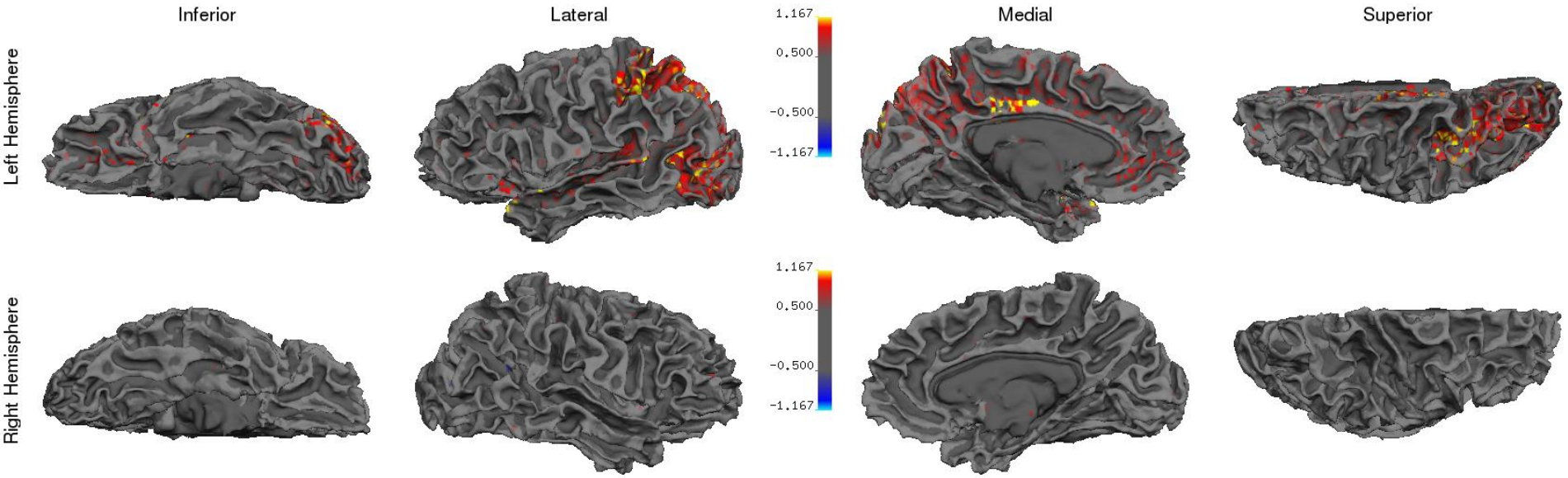
False-negative Original Activation



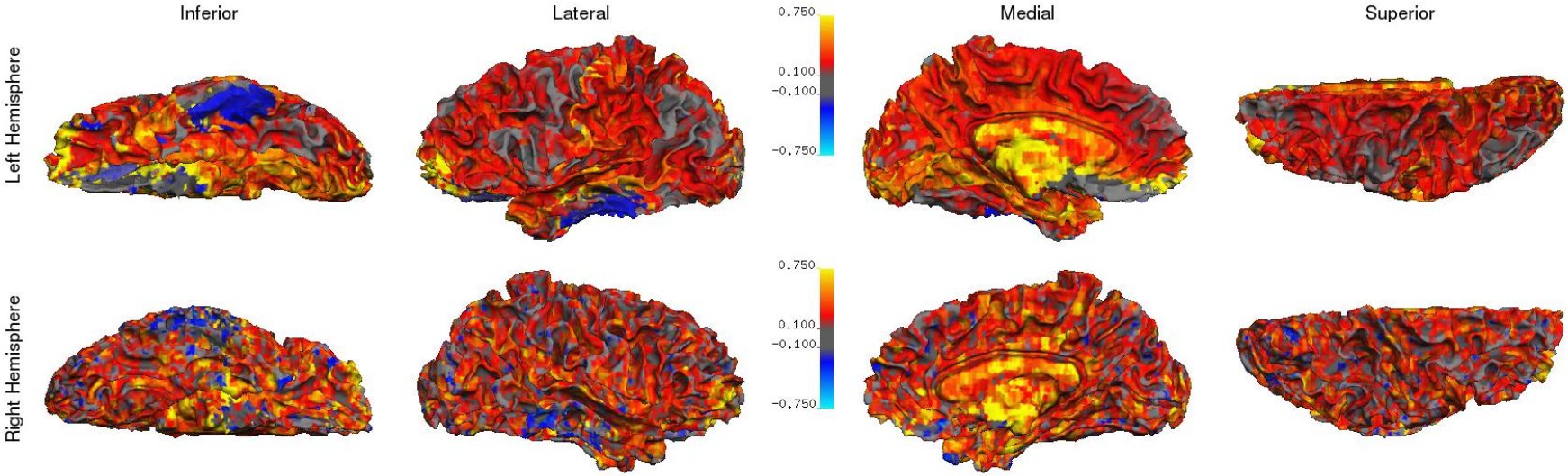
False-negative Activation Pattern After Motion



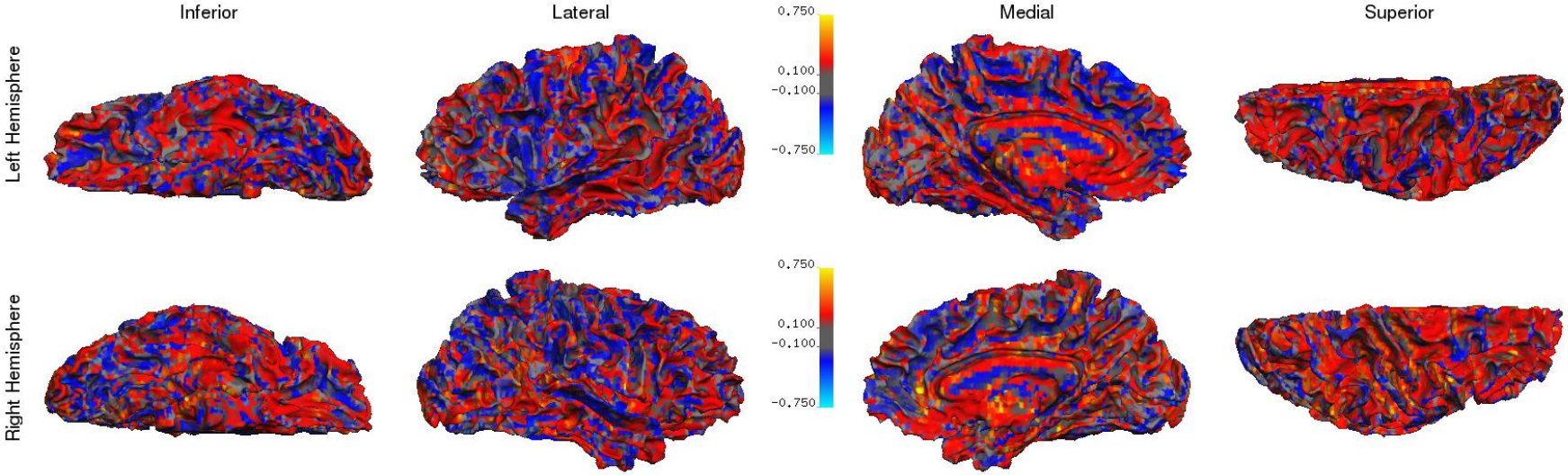
False-negative Activation Pattern After Motion Correction



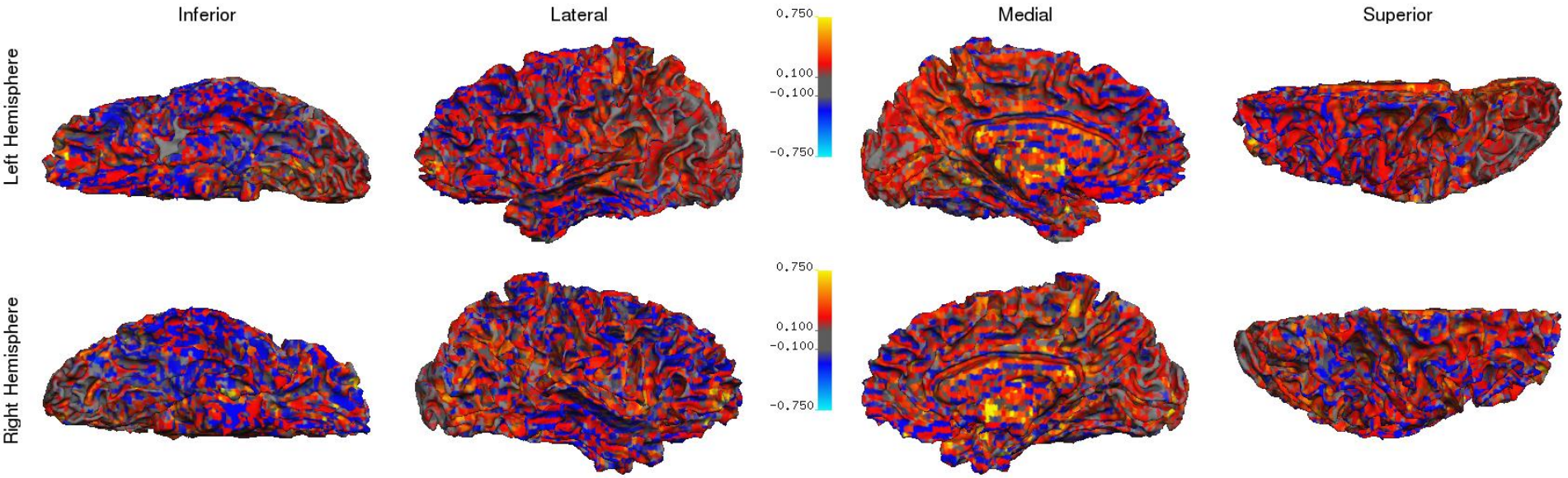
False-positive Original Activation Pattern



False-positive Activation Pattern after Motion



False-positive Activation Pattern after Motion

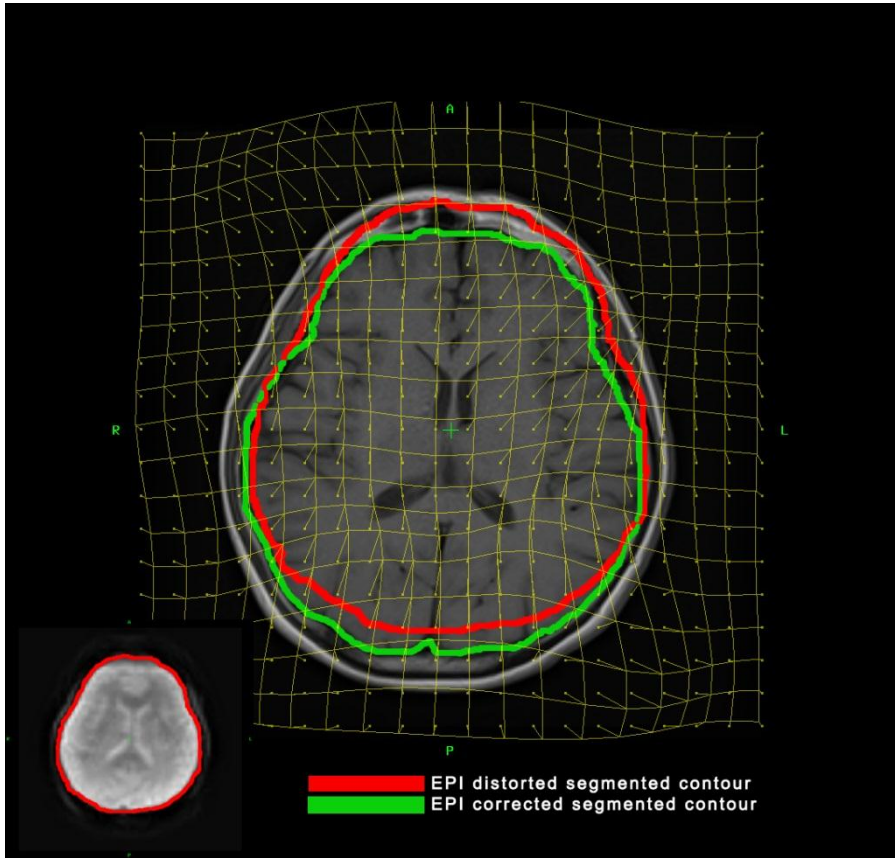


Agenda

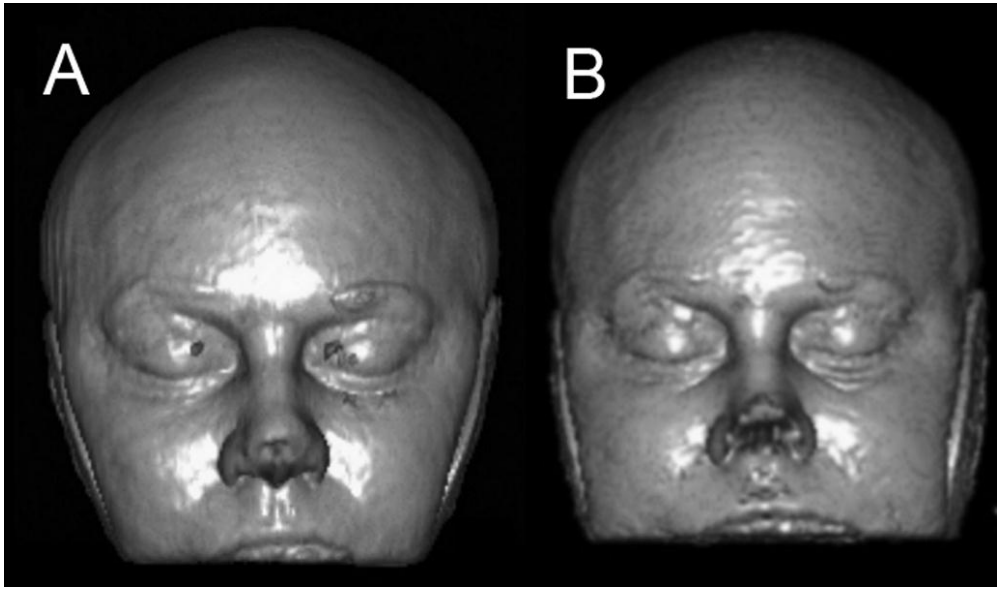
- Spatial Re-alignment
- Geometric distortion correction
- Spatial Normalization
- Smoothing

Why is it needed?

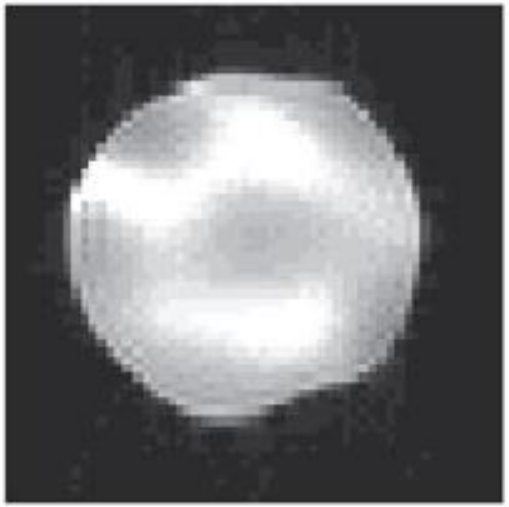
- Magnetic field inhomogeneity causes spatial distortion to the image
- EPI sequence are the most vulnerable to field inhomogeneity due to long readout period
- It is depend on the scanner quality and its calibration
- It will reduce the accuracy of co-registration of fMRI and structural image



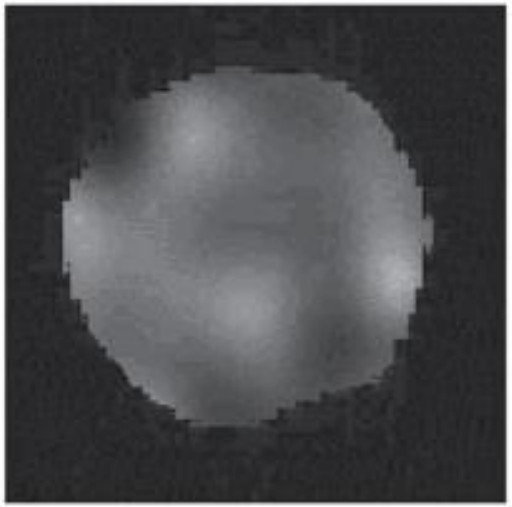
http://www.mauricioreyes.me/researchprojects.html



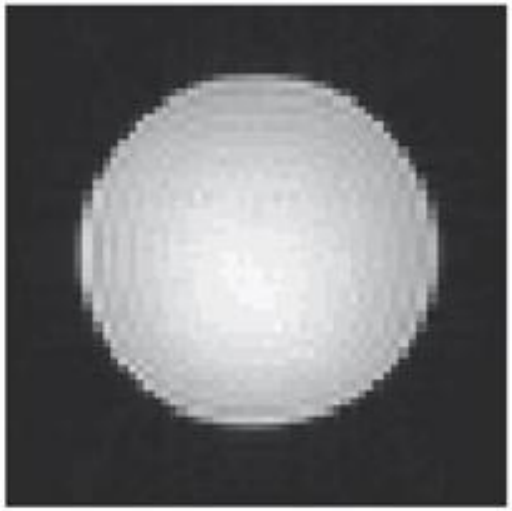
Phantom EPI image



Field Map

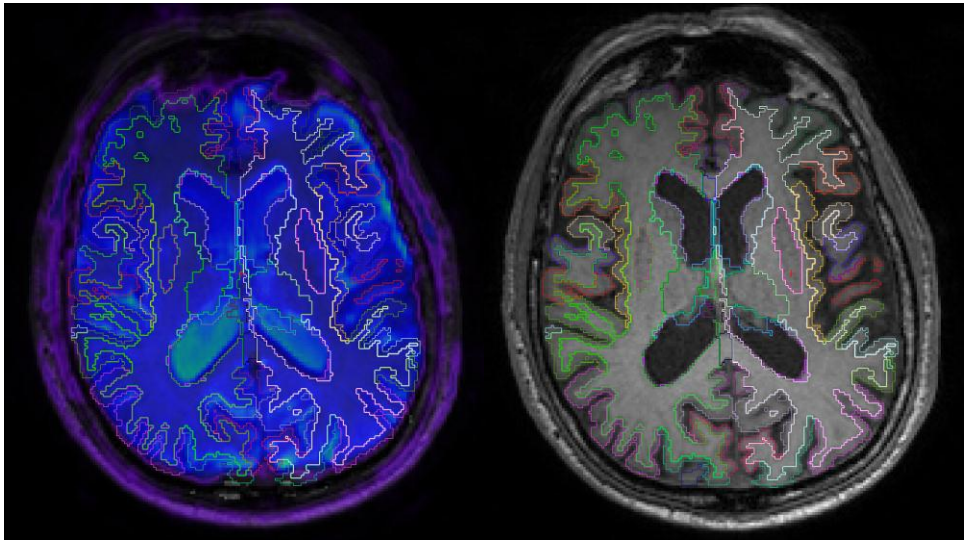


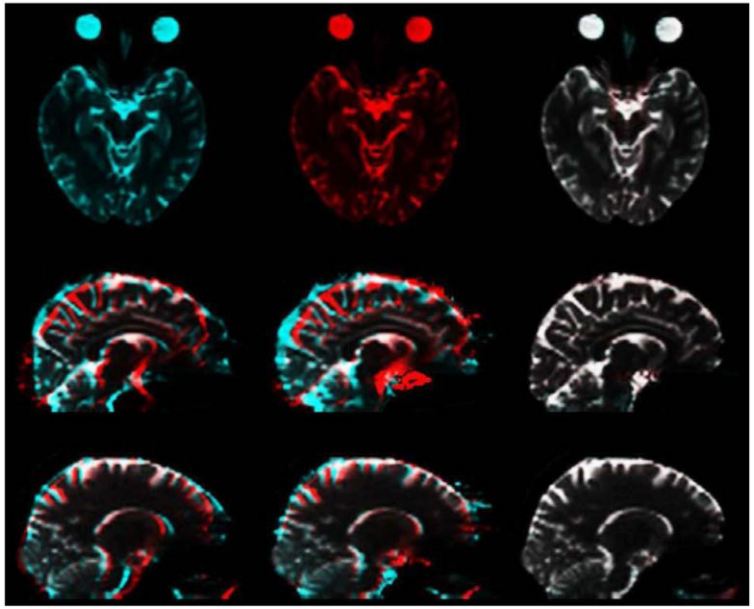
Distortion Corrected



When is not needed?

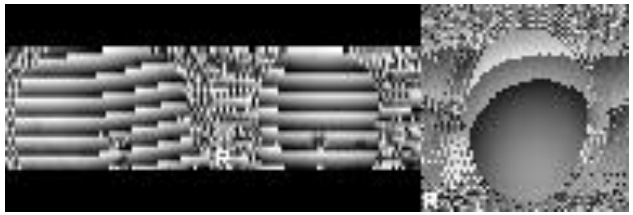
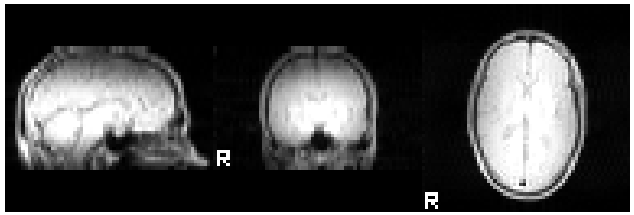
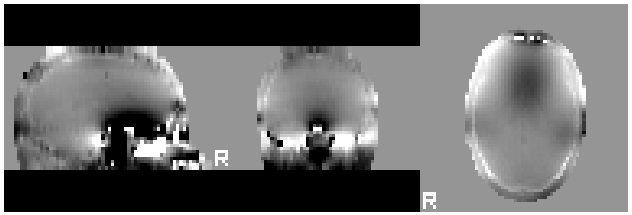
- It the study doesn't need a functional-structural images co-registration
- If distortion level is very low due to high quality of the scanner and its calibration/shimming





How is it done?

- Shimming Coils and Magnetic Field Mapping are two common method for correcting it
- Shimming coil produces a varying magnetic field which ideally compensate for inhomogeneity of the main magnetic field
- Shimming coils can be adjusted for each subject
- Field mapping is done be generating two images of signal phase with slightly different echo time, the difference between the two image is proportional to the change in the magnetic field inhomogeneity

Which method to use?

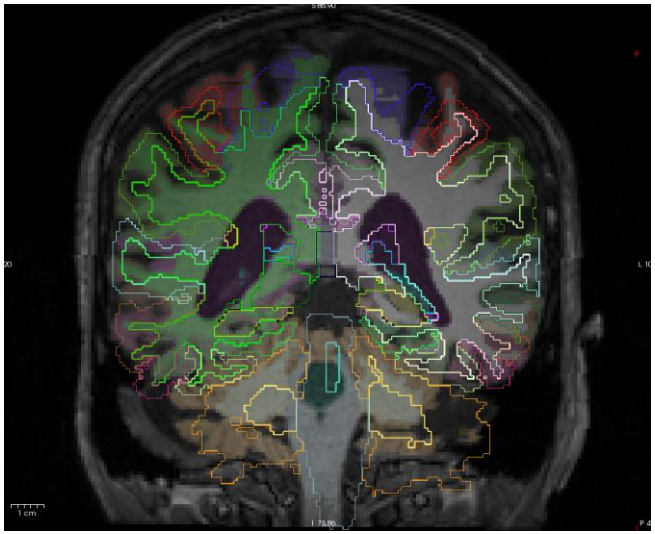
- If the field maps are acquired then all major software packages have a standard routine to correct for it
- B1 field maps are for intensity distortion and should not be used for geometric distortion correction
- The difference between two echo times, the direction of phase encoding, TE, and a registered magnitude image for this correction
- If it is applied the transformation needs to be combined with the other spatial transformation to reduce the interpolation error

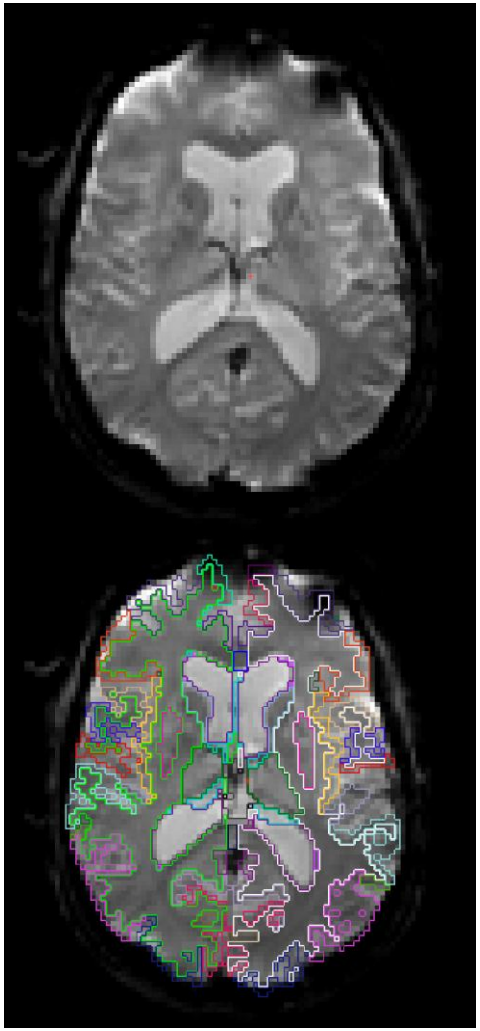
Agenda

- Spatial Re-alignment
- Geometric distortion correction
- Spatial Normalization
- Smoothing

Why is it needed?

1. **Localization:** Neuroanatomical regions are not completely visible in fMRI
2. **Normalization:** Voxel-wise group level comparison needs all subjects' voxels to correspond to the same neuroanatomical location





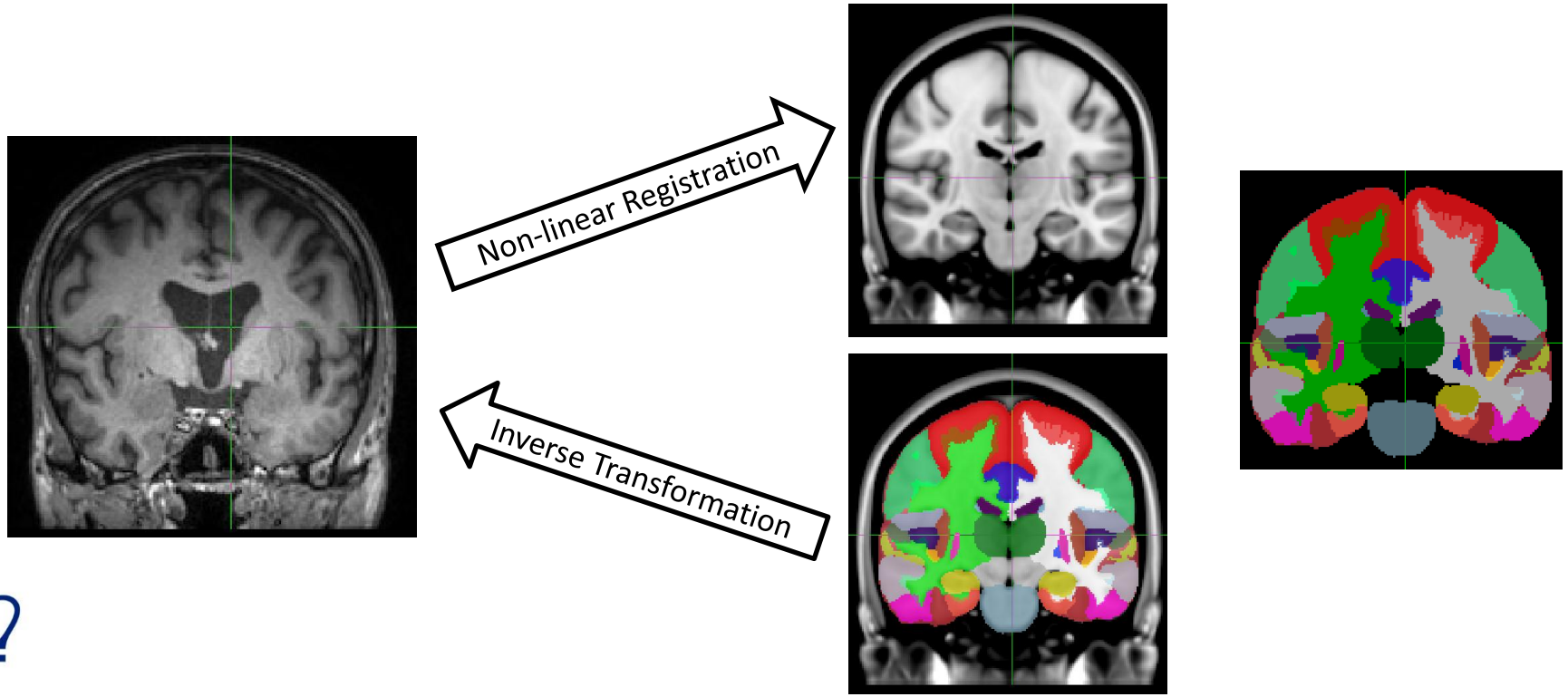
When is not needed?

- Spatial normalization can be excessively inaccurate specially in comparing different age-groups
- Thus it should be prevented as much as possible
- For localization, if segmented/parcellated structural images are available, then the normalization become a co-registration problem
- In the same way, in the case of ROI analysis, it is not required to be executed
- Even the perfect spatial normalization does not solve the issue associated with variation in brain cytoarchitecture

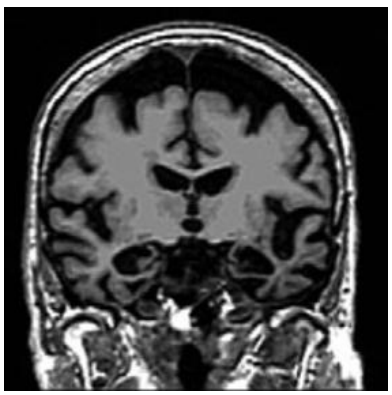
How is it done?

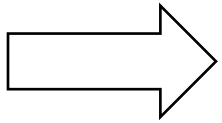
Atlas based spatial normalization

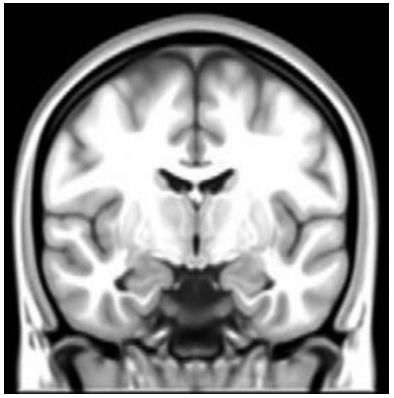
- Warping the fMRI image to a canonical brain template
- Transfer the brain template atlas labels to all the subjects in the group

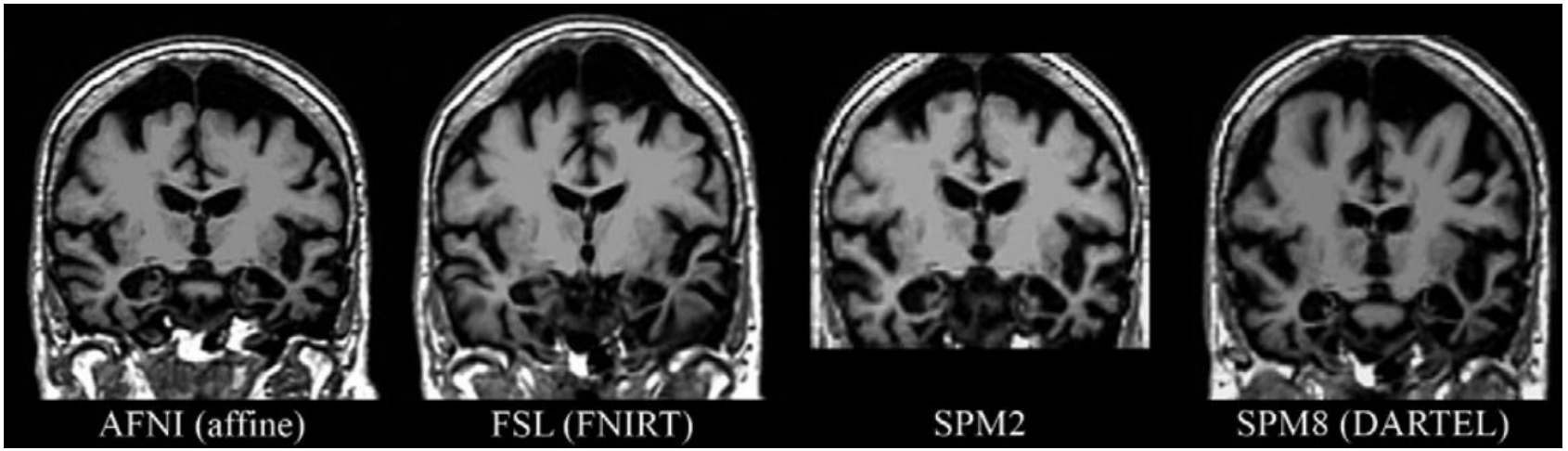


Inaccuracy in spatial normalization





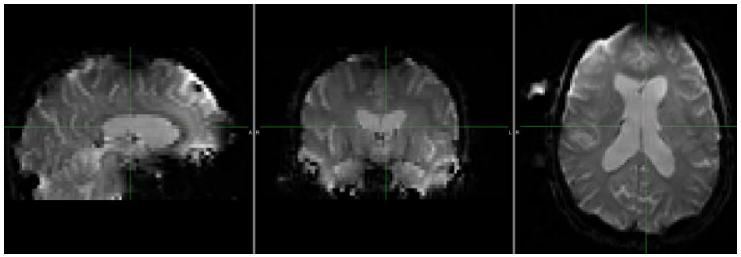




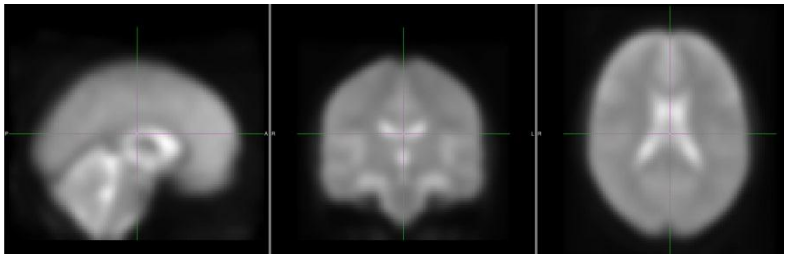
T.M. Seibert, J.B. Brewer / Journal of Neuroscience Methods 198 (2011) 301–311

How is it done?

- **Direct method:** registers/warps the fMRI data to EPI template
- **Indirect method:** registers/warps the accompanying structural image to structural template

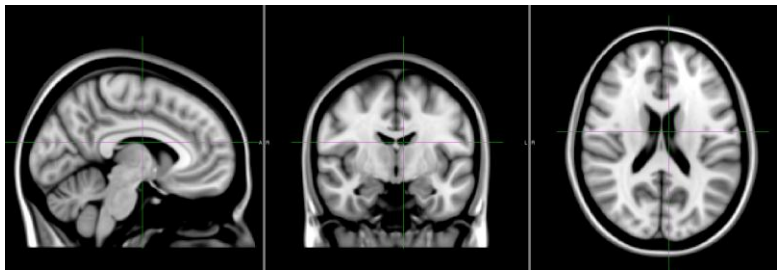


Direct



In-direct

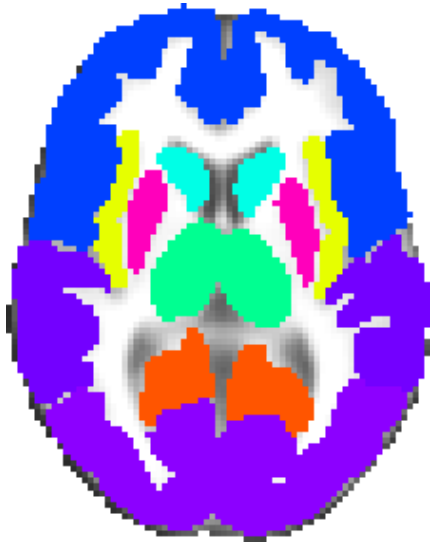
Indirect



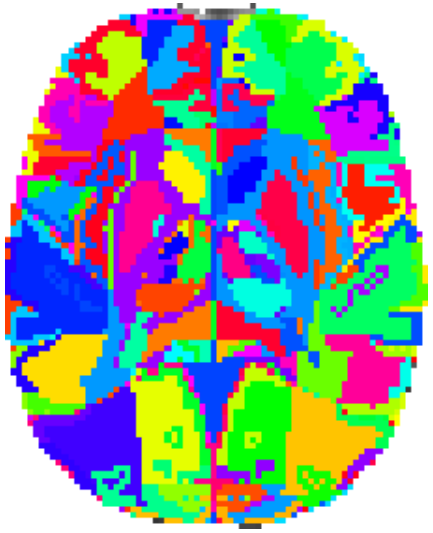
Which Template/Atlas

- There are different template/atlas that can be used for spatial normalization
- Subject driven templates/atlas can also be used

MNI structural atlas



Talairach atlas

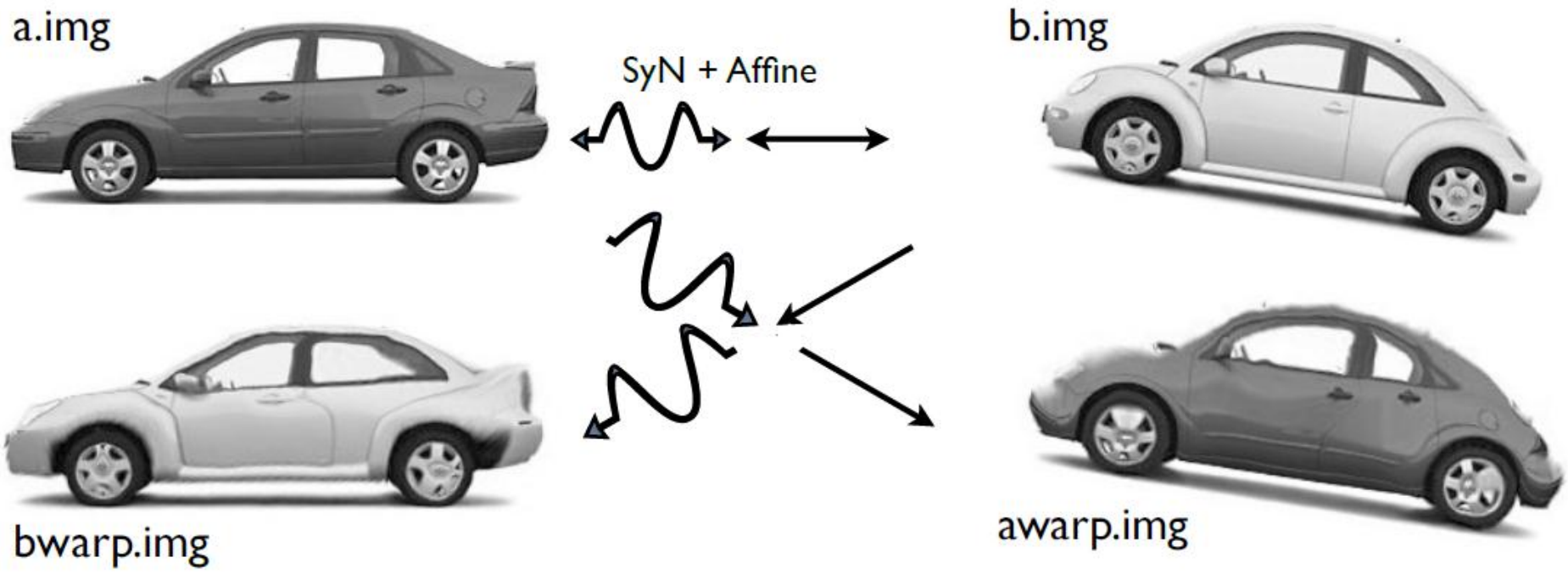


Harvard-Oxford atlases

http://fsl.fmrib.ox.ac.uk/fsl/fslwiki/Atlases

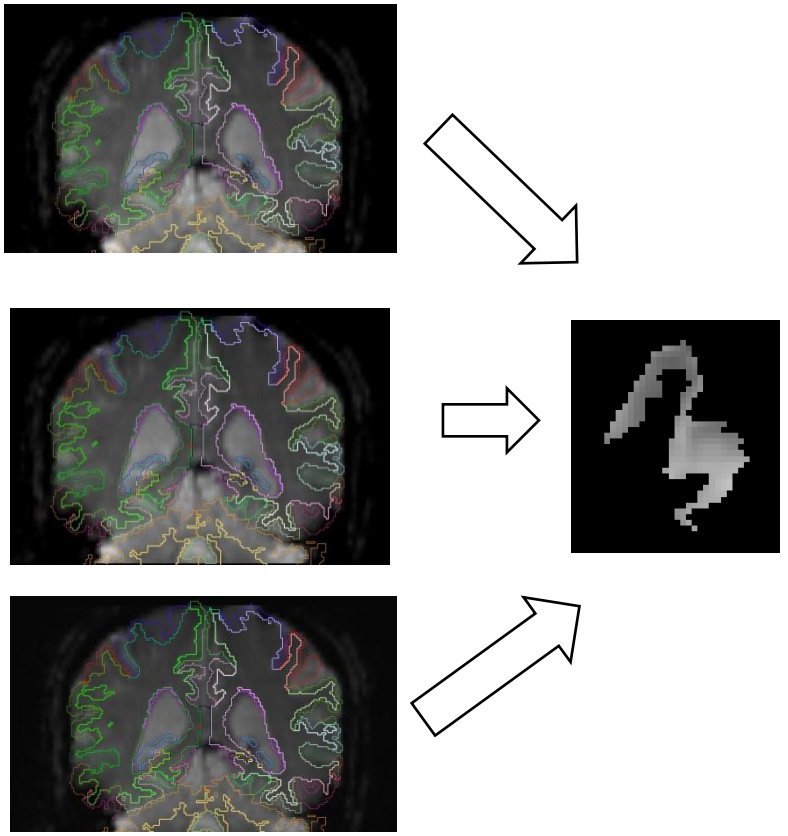
Over-fitting or Miss-fitting?

- How flexible the non-linear registration can get?
- What is the problem with perfect non-linear registration?
- Over-fitting or Mis-fitting?

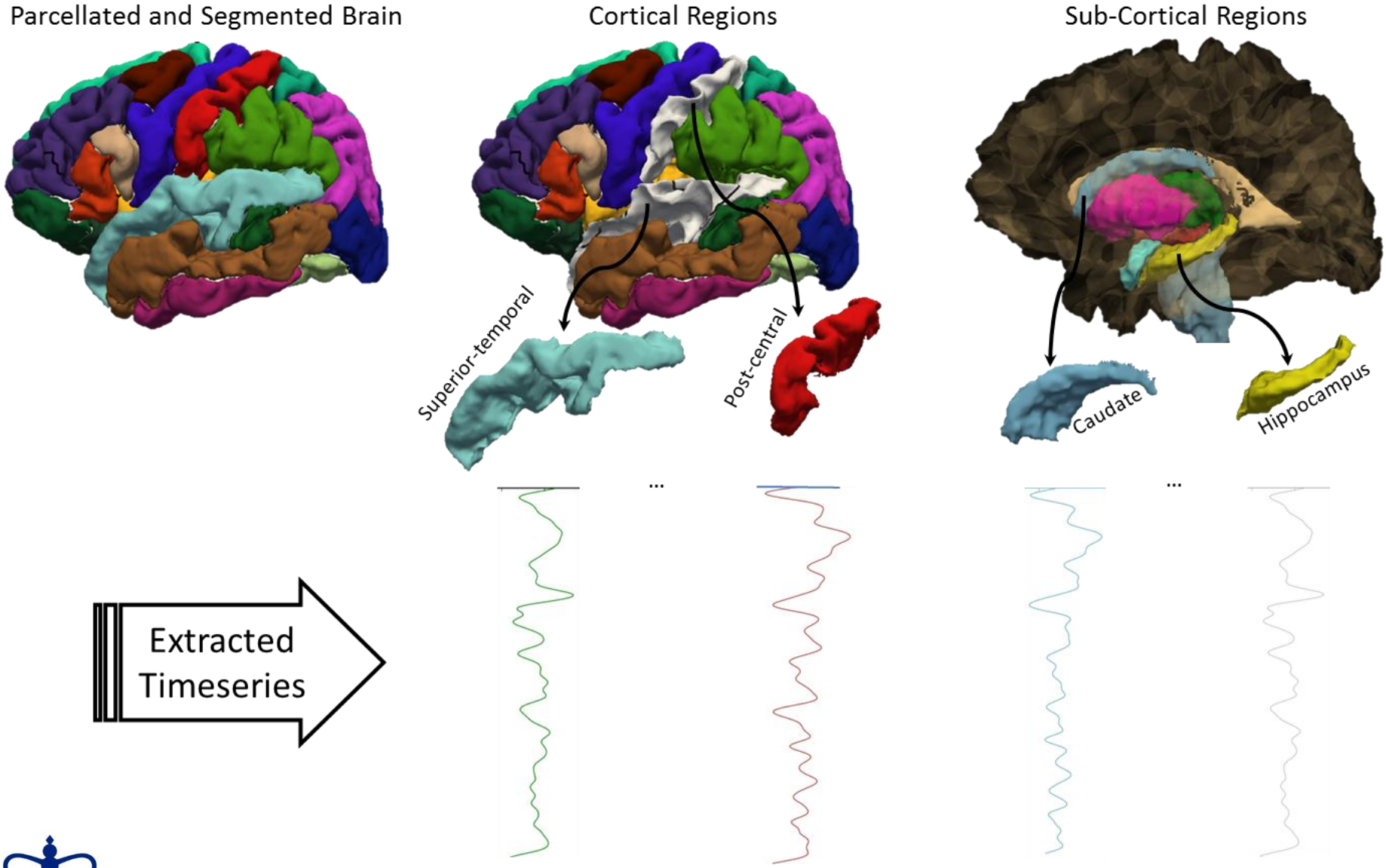


Native Space Analysis

- Only requires fMRI localization
- Circumvent the spatial normalization
- Has the highest level of fMRI localization accuracy
- Regional averaging gives a single time series for each region which makes the statistical analysis much easier
- Relies on pre assigned regions



Native Space Method



Agenda

- Spatial Re-alignment
- Geometric distortion correction
- Spatial Normalization
- Smoothing

Why is it needed?

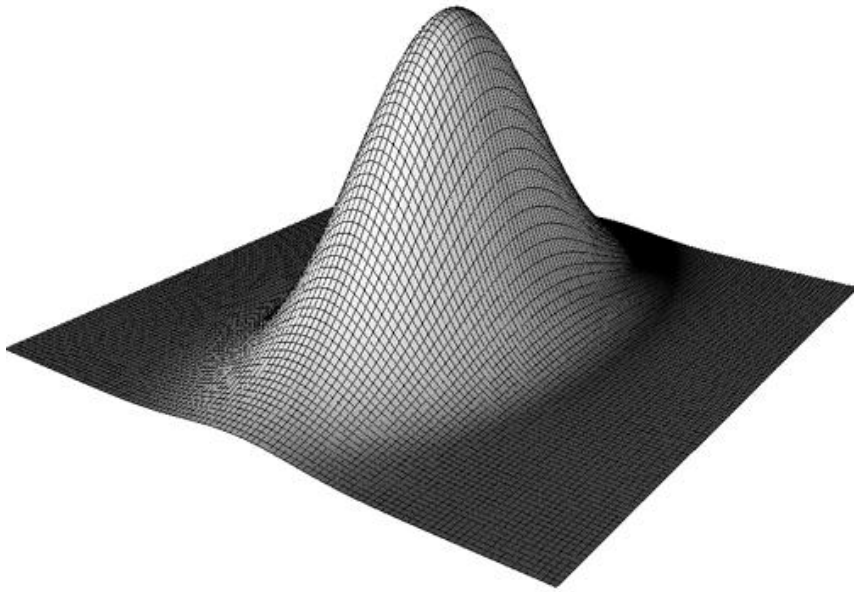
- Spatial filtering removes the mismatch between the voxel size and size of activation area
- fMRI data have spatial correlation
  - Blurring introduced by vascular system
  - Cortical gray matter have a thickness of about 5mm which often can fall within more than one voxel
  - Spatial extent of the MR signal are often larger than the expected area
- Across subject brain morphology mismatch also calls for spatial smoothing
- Increases the validity of statistical testing
  - Multiple comparison
  - Reduce false positive rate
  - Making the error distribution closed to normal

When is not needed?

- Depending on the voxel size and the extent of the activation area of interest spatial smoothing may increase to decrease the SNR of the fMRI data
- Smoothing only used in voxel-wise analysis and ROI analysis dose not need the smoothing
  - What will happen if we do spatial smoothing for ROI analysis?
- If spatial smoothing increases SNR it is in the cost of lowering spatial resolution
- Spatial smoothing can easily cause the activation of small regions to be eliminated
  - Why we don't care?

How is it done?

- Spatial filtering is often done by Gaussian kernel
  - Usually expressed in #mm FWHM
  - “Full Width – Half Maximum”
  - Typically ~2 times voxel size
  - FWHM of about 6 ~ 10 mm
- If we don’t know the size of activity, how can we set the FWHM?



Example