

Image and Volume Registration with AFNI

- Goal: bring images collected with different methods and at different times into alignment
- Facilitates comparison of data on a voxel-by-voxel basis
 - ◇ Functional time series data will be less contaminated by artifacts due to subject movement
 - ◇ Can compare results across scanning sessions once images are properly registered
- Most (all?) image registration methods now in use do pairwise alignment:
 - ◇ Given a base image $J(x)$ and target image $I(x)$, find a geometrical transformation $T[x]$ so that $I(T[x]) \approx J(x)$
 - ◇ $T[x]$ will depend on some parameters
 - ↪ Goal is to find the parameters that make the transformed I a 'best' fit to J
 - ◇ To register an entire time series, each volume $I_n(x)$ is aligned to $J(x)$ with its own transformation $T_n[x]$, for $n=0, 1, \dots$
 - ↪ Result is time series $I_n(T_n[x])$ for $n=0, 1, \dots$
 - ◇ User must choose base image $J(x)$

- Most image registration methods make 3 algorithmic choices:
 - ◇ How to measure mismatch E (for error) between $I(T[x])$ and $J(x)$?
 - ◇ How to adjust parameters of $T[x]$ to minimize E ?
 - ◇ How to interpolate $I(T[x])$ to the $J(x)$ grid?
 - ↪ So can compare voxel intensities directly
- Existing AFNI programs match images by grayscale (intensity) values
 - ◇ $E =$ (weighted) sum of squares of differences $= \sum_x w(x) \cdot \{I(T[x]) - J(x)\}^2$
 - ↪ Only useful for registering ‘like images’:
 - SPGR↔SPGR, EPI↔EPI, but **not** SPGR↔EPI
 - ◇ Parameters in $T[x]$ are adjusted by “gradient descent”
 - ◇ Several interpolation methods are available:
 - ↪ Default method is Fourier interpolation
 - ↪ Polynomials of order 1, 3, 5, 7 (linear, cubic, quintic, and heptic)
- Alternative method would be to match features computed from grayscale images:
 - ◇ Brain outline
 - ◇ Edges (places where image intensity changes abruptly in 1–2 pixels)
 - ◇ Such techniques can be used to match SPGR↔EPI
 - ◇ Not in AFNI (yet)

- AFNI Program 3dvolreg is for aligning 3D volumes
 - ◇ T[x] has 6 parameters:
 - ↪ Shifts along x-, y-, and z-axes; Rotations about x-, y-, and z-axes
 - ◇ Generically useful for intra- and inter-session alignment
 - ◇ Motions that occur within a single TR (2–3 s) cannot be corrected this way, since method assumes a rigid movement of the entire volume
- AFNI program 2dImReg is for aligning 2D slices
 - ◇ T[x] has 3 parameters for each slice in volume:
 - ↪ Shift along x-, y-axes; Rotation about z-axis
 - ◇ Useful for sagittal EPI scans where dominant subject movement is a ‘nodding’ motion that may be faster than TR
 - ◇ It is possible and sometimes even useful to run 2dImreg to clean up nodding motion, followed by 3dvolreg to deal with out-of-slice motion
- Hybrid ‘slice-into-volume’ registration:
 - ◇ Put each separate 2D image slice into the target volume with its own 6 movement parameters (3 out-of-plane as well as 3 in-plane)
 - ◇ Has been tried (BD Ward of MCW; B Kim of Michigan)
 - ◇ Results not wildly better than volume registration; method often fails on slices near edge of brain ⇒ More work is needed (i.e., **send money**)

- Intra-session registration:

```
3dvolreg -base 'v1:time+orig[4]' -heptic -clipit -zpad 4 \  
        -prefix v1REG:time -dfile v1REG.dfile \  
        v1:time+orig
```

- ◇ -base 'v1:time+orig[4]' \Rightarrow Selects sub-brick #4 of dataset v1:time+orig as $J(x)$
- ◇ -heptic \Rightarrow Use 7th order polynomial interpolation (my personal favorite)
- ◇ -clipit \Rightarrow Clip off negative voxels to zero
 - \hookrightarrow Negative voxels are artifacts of high-order interpolation methods
- ◇ -zpad 4 \Rightarrow Pad each $I(x)$ with layers of zero voxels 4 deep on each face prior to shift/rotation, then strip them off afterwards
 - \hookrightarrow Zero padding is particularly desirable for -Fourier interpolation
 - \hookrightarrow Is also good for polynomial methods, since if there are large rotations, some data may get 'lost' when no zero padding is used (due to the 4-way shift algorithm used for fast rotation)
- ◇ -prefix v1REG:time \Rightarrow Save output dataset into a new dataset with the given prefix
- ◇ -dfile v1REG.dfile \Rightarrow Save estimated movement parameters into a 1D timeseries file with the given name
 - \hookrightarrow Can be plotted with command

```
1dplot -volreg -dx 5 -xlabel Time 'v1REG.dfile[1..6]'
```

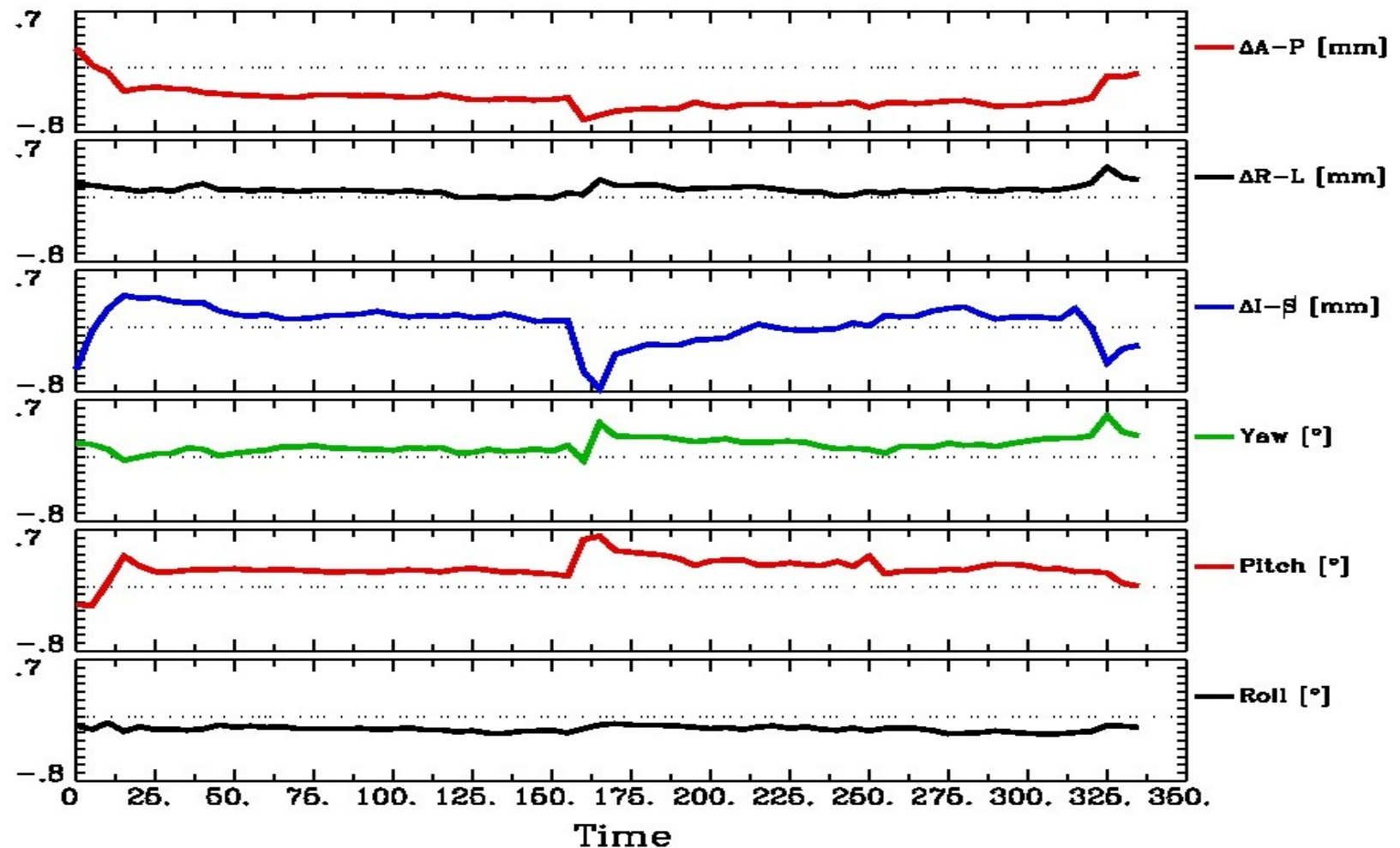
◇ Can now register second dataset from same session:

```
3dvolreg -base 'v1:time+orig[4]' -heptic -clipit -zpad 4 \  
-prefix v2REG:time -dfile v2REG.dfile v2:time+orig
```

↪ Note base is from different dataset (v1:time+orig) than input (v2:time+orig)

▷ Aligning all EPI volumes from session to EPI closest in time to SPGR

↪ `1dplot -volreg -dx 5 -xlabel Time 'v2REG.dfile[1..6]'` gives:



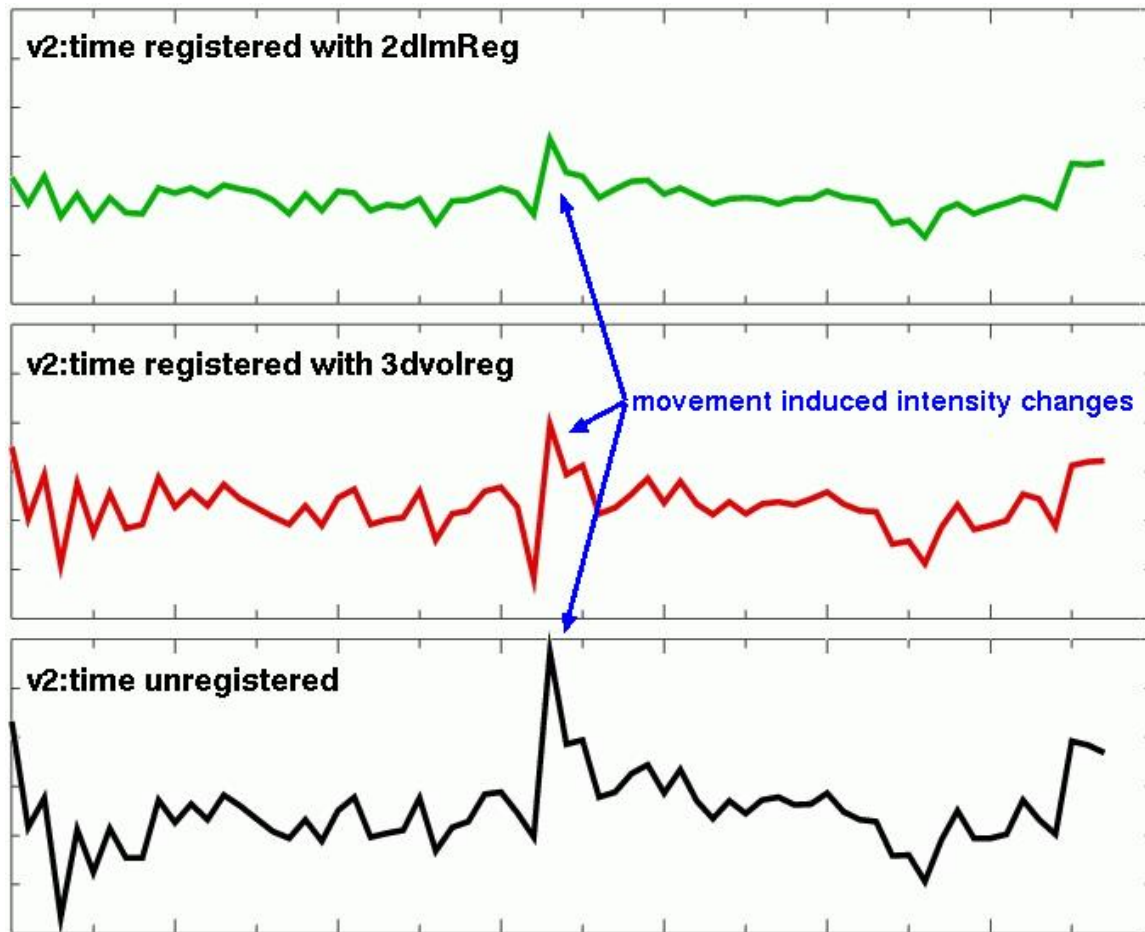
↪ Note motion peaks at time ≈ 160 s: subject jerked head up at that time

◇ Examination of time series v2:time+orig and v2REG:time+orig shows that head movement up and down happened within about 1 TR interval

↳ Assumption of rigid motion of 3D volumes is not good for this case

↳ Can do 2D slice-wise registration with command

```
2dImReg -input v2:time+orig -basefile v1:time+orig \  
-base 4 -prefix v2_2DREG
```



Graphs of a single voxel time series near the edge of the brain:

top \Rightarrow slice-wise alignment

middle \Rightarrow volume-wise alignment

bottom \Rightarrow no alignment

For this example, 2dImReg appears to produce better results. This is because most of the motion is 'head nodding' and the acquisition plane is sagittal.

You should also use AFNI to scroll through the images (using the Index control) during the period of pronounced movement, on all three datasets.

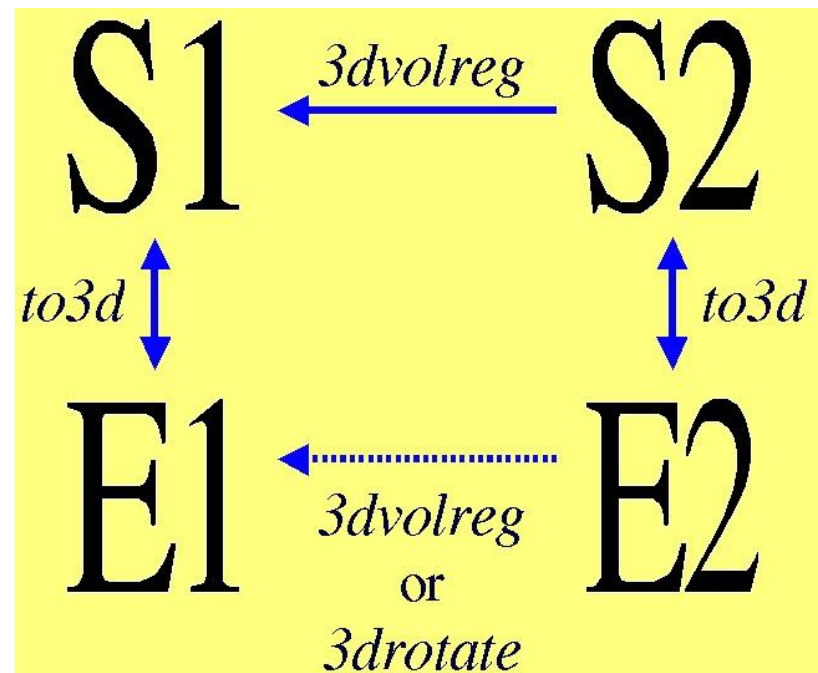
- Intra-subject, inter-session registration:

- ◇ Transformation between sessions is calculated by registering high-resolution anatomicals from each session

- ↳ to3d defines relationship between EPI and SPGR in each session

- ↳ 3dvolreg computes relationship between sessions

- ↳ So can transform EPI from session 2 to orientation of session 1



- ◇ Issues in inter-session registration:

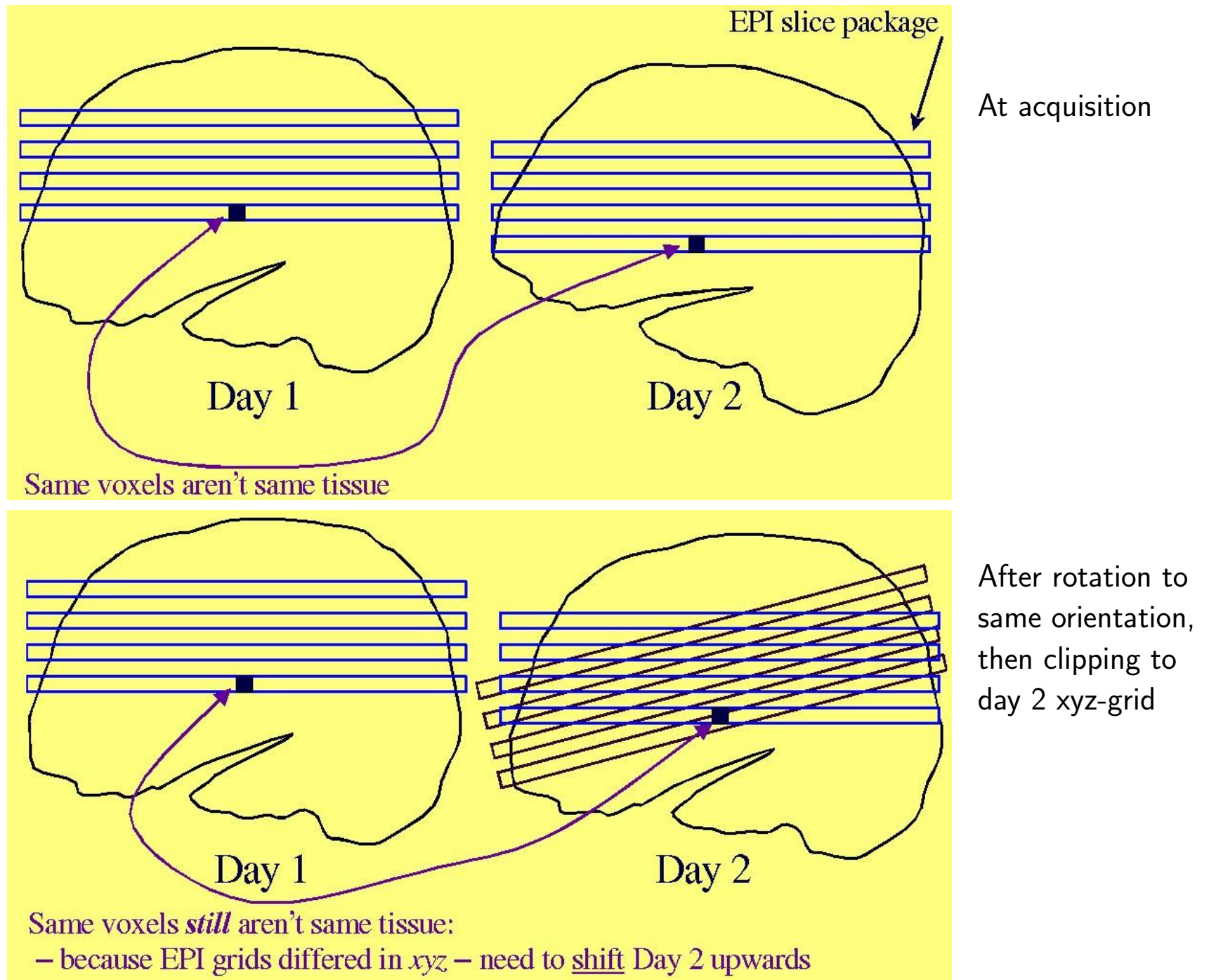
- ↳ Subject's head will be positioned differently (in orientation and location)
⇒ xyz-coordinates and anatomy don't correspond

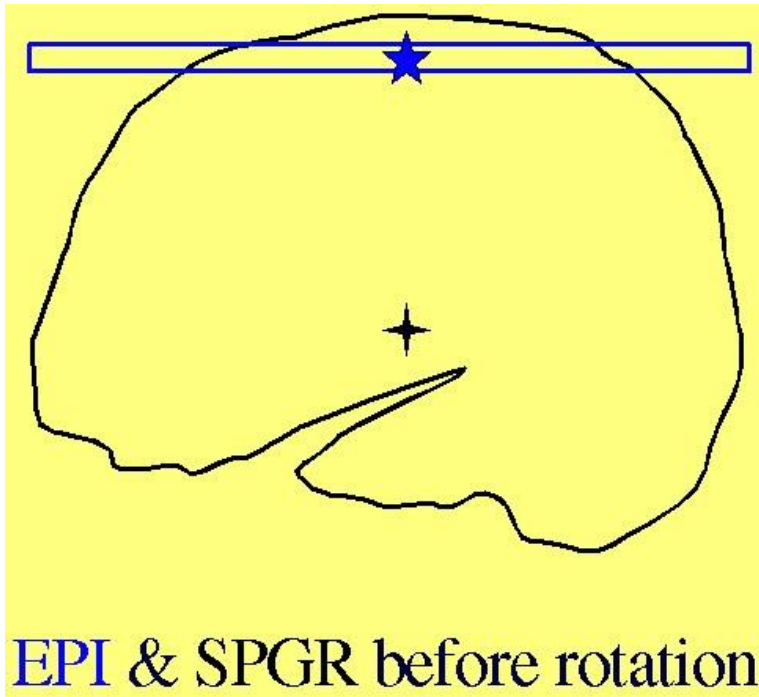
- ↳ Anatomical coverage of EPI slices will differ between sessions

- ↳ Geometrical relation between EPI and SPGR differs between session

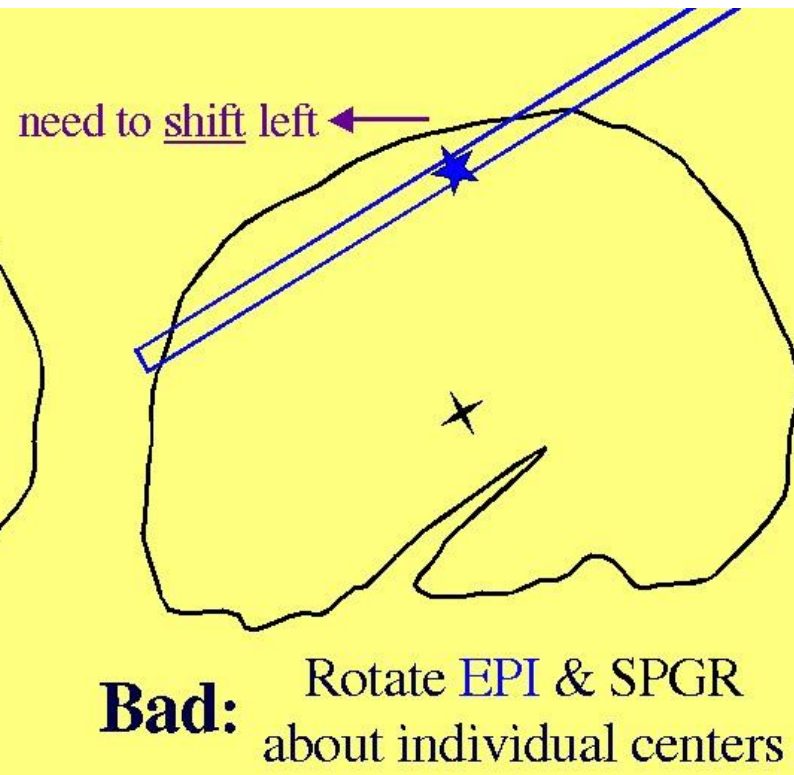
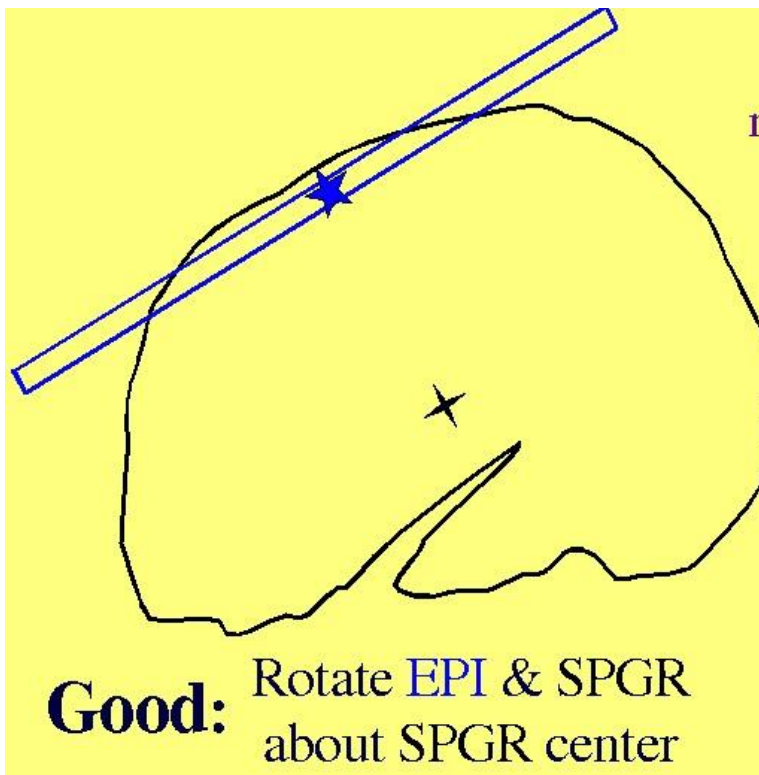
- ↳ Slice thickness may vary between sessions (try not to do this, OK?)

◇ Anatomical coverage differs



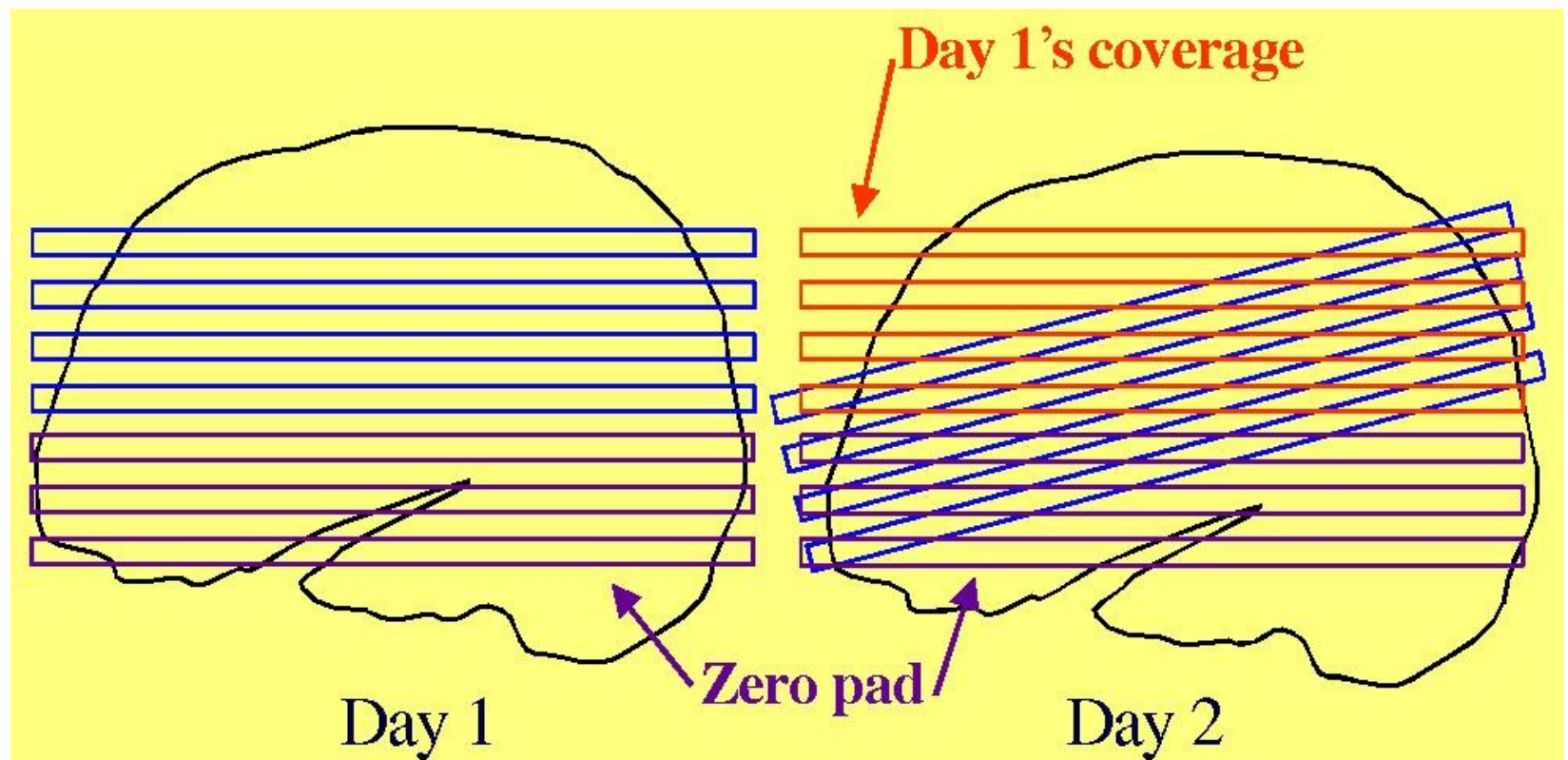


- ◇ Another problem: rotation occurs around center of individual datasets



◇ Solutions to these problems:

- ↪ Add appropriate shift to E2 on top of rotation
 - ▷ Allow for xyz shifts between days (E1-E2), and center shifts between EPI and SPGR (E1-S1 and E2-S2)
- ↪ Pad EPI datasets with extra slices of zeros so that aligned datasets can fully contain all data from all sessions
- ↪ Zero padding of a dataset can be done in to3d (at dataset creation time), or later using program 3dZeropad
- ↪ 3dvolreg and 3drotate can zero pad to make the output match a “grid parent” dataset in size and location



◇ Recipe for intra-subject inter-session registration:

1. Compute S2-to-S1 transformation:

```
3dvolreg -twopass -twodup -clipit -zpad 4 -base S1+orig \  
-prefix S2reg S2+orig
```

↪ Rotation/shift parameters are saved in S2reg+orig.HEAD

2. If not done before (e.g., in to3d), zero pad E1 datasets:

```
3dZeropad -z 4 -prefix E1pad E1+orig
```

3. Register E1 datasets within the session:

```
3dvolreg -clipit -base 'E1pad+orig[4]' -prefix E1reg \  
E1pad+orig
```

4. Register E2 datasets within the session, at the same time executing larger rotation/shift to session 1 coordinates that was saved in S2reg+orig.HEAD:

```
3dvolreg -clipit -base 'E2+orig[4]' \  
-rotparent S2reg+orig \  
-gridparent E1reg+orig \  
-prefix E2reg E2reg+orig
```

↪ -rotparent tells where the inter-session transformation comes from

↪ -gridparent defines the output grid location/size of new dataset

▷ Output dataset will be shifted and zeropadded as needed to lie on top of E1reg+orig

- ◇ Recipe above does not address problem of having different slice thicknesses (EPI and/or SPGR) in different sessions
 - ↪ Best solution: pay attention when you are scanning, and always use the same slice thickness for the same type of image
 - ↪ OK solution: use 3dZregrid to linearly interpolate datasets to a new slice thickness
- ◇ Recipe above does not address issues of slice-dependent time offsets stored in data header from to3d (e.g., 'alt+z')
 - ↪ After interpolation to a rotated grid, voxel values can no longer be said to come from a particular time offset, since data from different slices will have been combined
 - ↪ Before doing this spatial interpolation, makes sense to time shift dataset to a common temporal origin
 - ↪ Time shifting can be done with program 3dTshift
 - ▷ Or by using the -tshift option in 3dvolreg, which first does the time shift to a common temporal origin, then does the 3D spatial registration
- Further reading at the AFNI web site:
 - ◇ File **README.registration** (plain text) has more detailed instructions and explanations about the usage of 3dvolreg
 - ◇ File **regnotes.pdf** has some background information on issues and methods used in FMRI registration packages