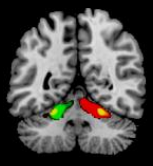
SPM8 for Basic and Clinical Investigators

Preprocessing



fMRI Preprocessing

- Slice timing correction
- Geometric distortion correction
- Head motion correction
- Temporal filtering
- Intensity normalization
- Spatial filtering

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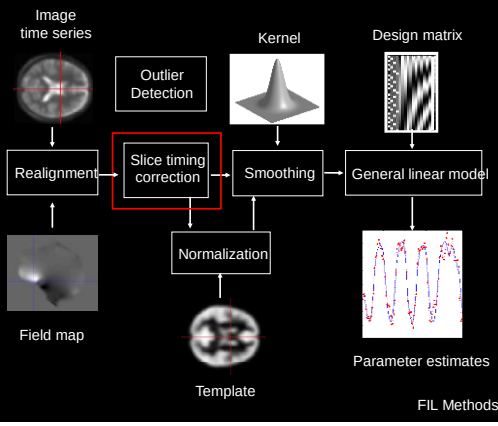
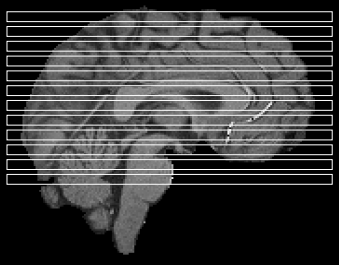


EPI Data Are Acquired Serially



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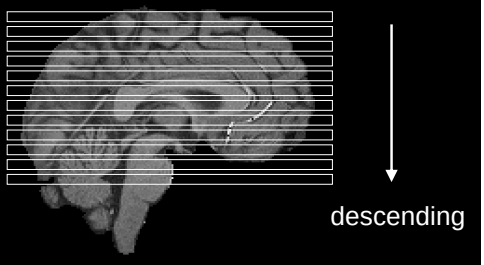

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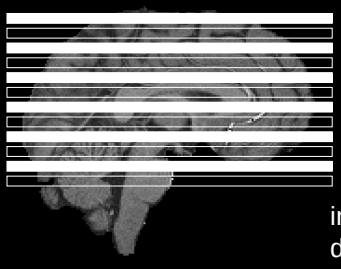
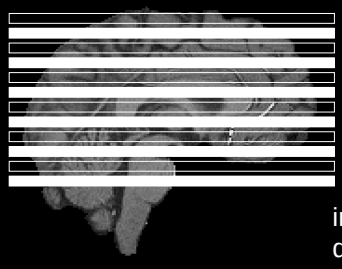


interleaved
descending

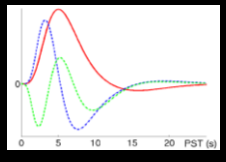
EPI Data Are Acquired Serially

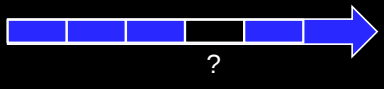


interleaved
descending

Two Approaches to Slice Timing Correction

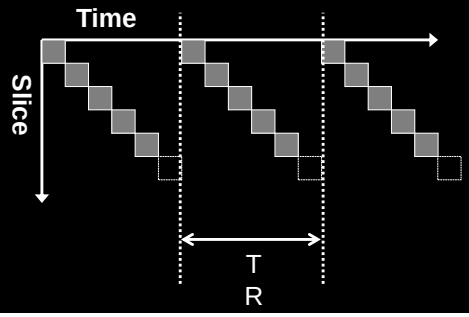
- Addition of temporal basis functions to the first-level statistical model
- Correction using temporal interpolation



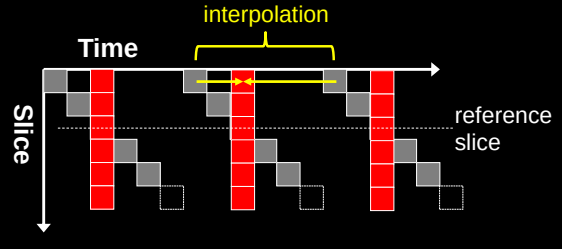


?

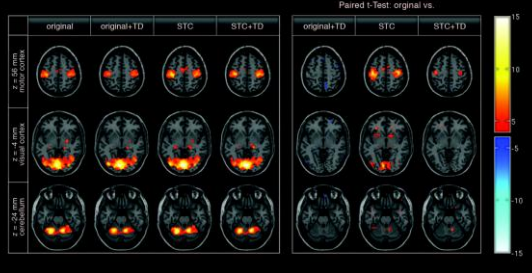
Slice Timing Correction



Slice Timing Correction



Slice Time Correction Improves Sensitivity Using a Visuomotor Task



Sladky et al., Neuroimage (2011)

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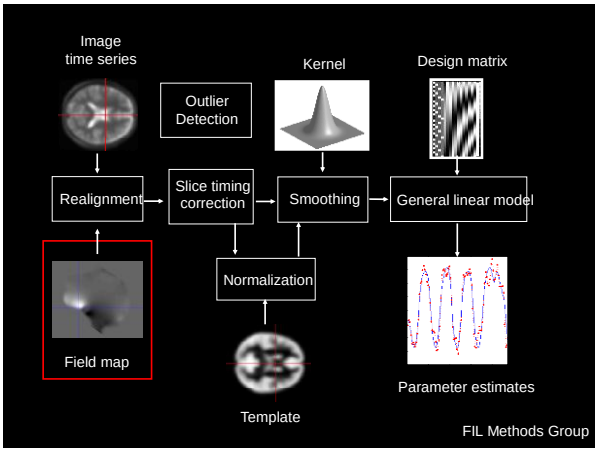
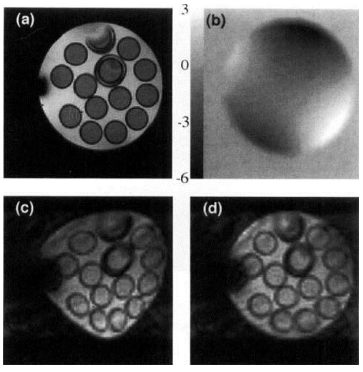
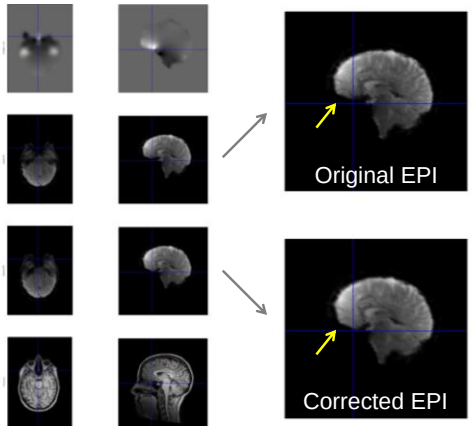


Signal Dropout and Geometric Distortion



Jezzard and Balaban, MRM (1995)



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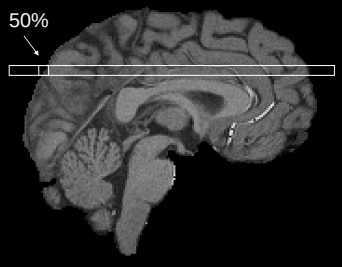
Head Motion in fMRI

- The goal is to compare brain locations across time
- Subjects move relative to the recording system
- Individual voxel time series are affected by this motion
- Motion effects on signal amplitude are non-linear and complex
- Motion therefore inflates the residual variance and reduces detection sensitivity
- Task correlated motion is particularly problematic

Head Motion Can Cause Partial Volume and Spin History Effects



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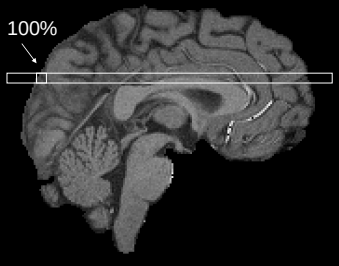

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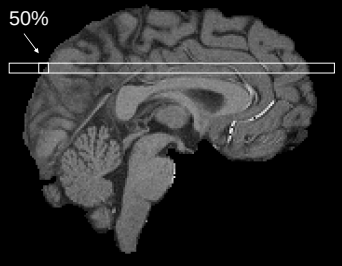

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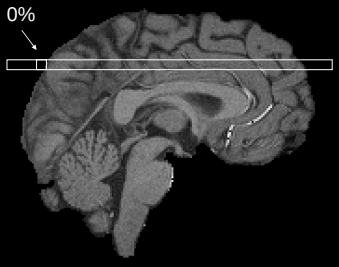

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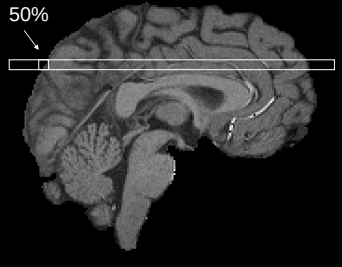

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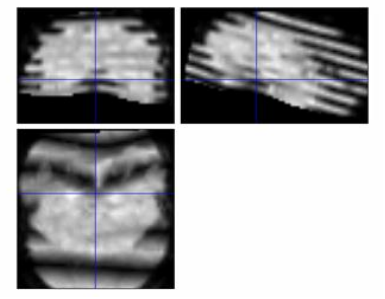


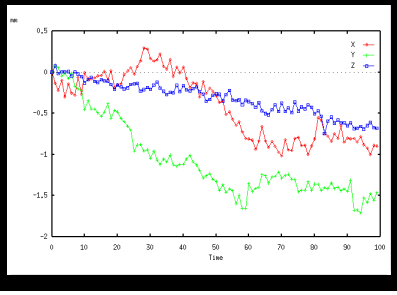
Whitfield-Gabrieli

Head Motion Detection

- compute time series center-of-intensity
- compute variance map of time series
- single-slice animation

Head Motion Detection

- compute time series center-of-intensity



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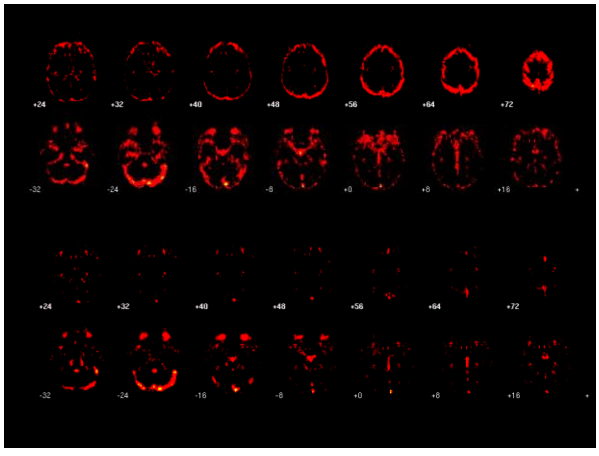

Mitigation of Head Motion Effects

- Prevention
- Prospective correction
- Realignment
- Covariate correction with head motion estimates
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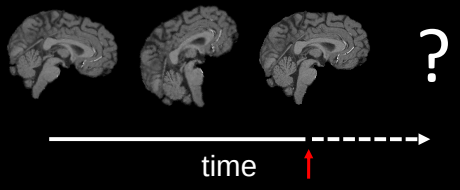
Prospective Motion Correction



Prospective motion correction makes predictions that may be dependent on outdated information.

Mitigation of Head Motion Effects

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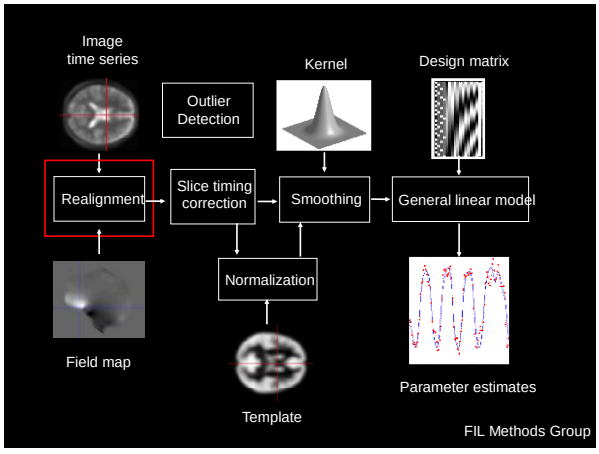
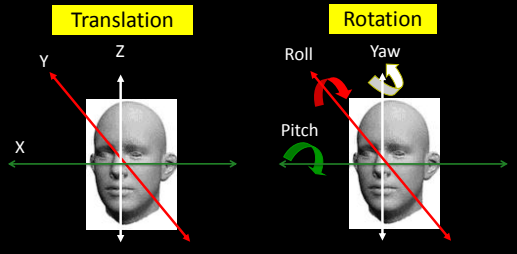


Spatial Realignment

- **Realignment** (of *same-modality* images from *same subject*) involves two stages:
  - **Registration** - determining the 6 parameters that describe the rigid body transformation between each image and a reference image
  - **Reslicing** - re-sampling each image according to the determined transformation parameters

Henson

Spatial Realignment

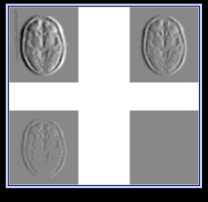


Henson

Spatial Realignment: Registration

- Determine the rigid body transformation that minimises the sum of squared difference between images
- Rigid body transformation is defined by:
  - 3 translations - in X, Y & Z directions
  - 3 rotations - about X, Y & Z axes
- Operations can be represented as affine transformation matrices:

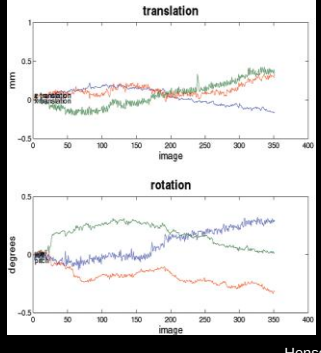
$$x_1 = m_{1,1}x_0 + m_{1,2}y_0 + m_{1,3}z_0 + m_{1,4}$$
$$y_1 = m_{2,1}x_0 + m_{2,2}y_0 + m_{2,3}z_0 + m_{2,4}$$
$$z_1 = m_{3,1}x_0 + m_{3,2}y_0 + m_{3,3}z_0 + m_{3,4}$$



Henson

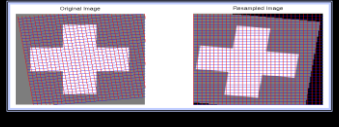
Spatial Realignment: Registration

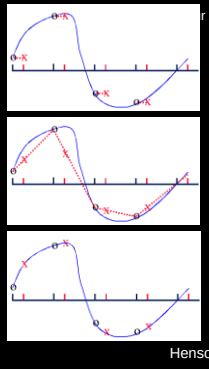
- Iterative procedure (Gauss-Newton ascent)
- Additional scaling parameter
- Nx6 matrix of realignment parameters written to file (N is number of scans)
- Orientation matrices in header of image file (data not changed until reslicing)



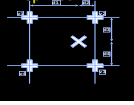
Henson

Spatial Realignment: Reslicing



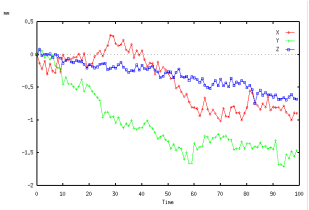


- Application of registration parameters involves re-sampling the image to create new voxels by interpolation from existing voxels
- Interpolation can be nearest neighbour (*0*-order), tri-linear (*1*st-order), (windowed) fourier/sinc, or *n*th-order "b-splines"

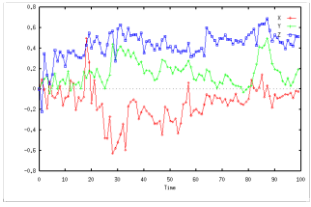


Henson

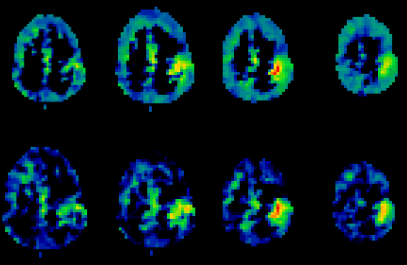
before correction



after correction



Effects of Realignment on Statistical Maps



before

after

Residual Error After Realignment

Even *after* realignment a considerable amount of the variance can be accounted for by movement

Causes:

1. Movement between and within slice acquisition
2. Interpolation artifacts due to resampling
3. Non-linear distortions and drop-out due to inhomogeneity of the magnetic field

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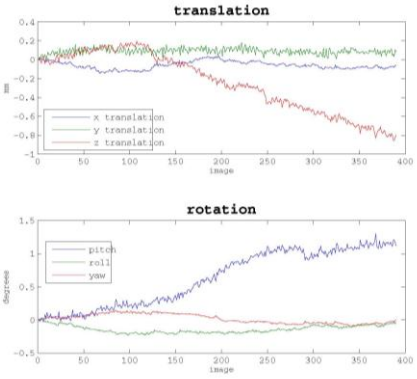
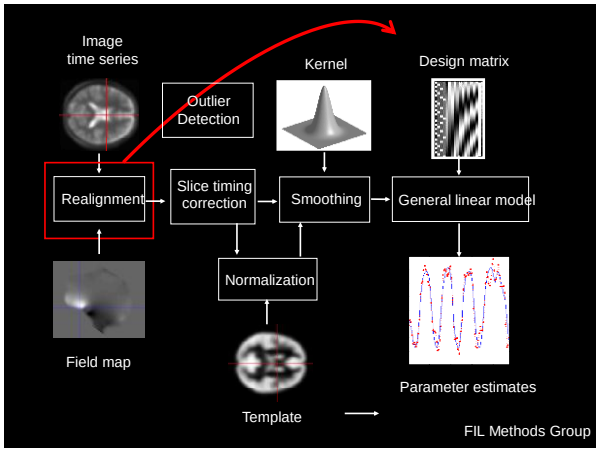


Realignment with Movement Covariates

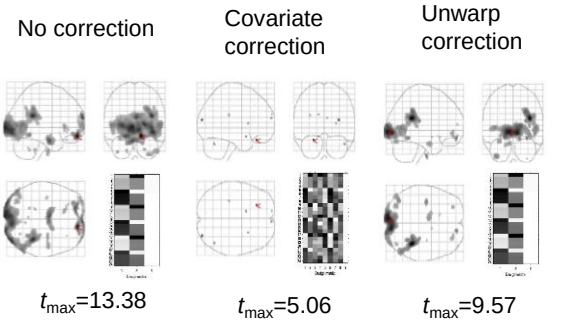
Friston et al., Movement-related effects in fMRI time series. Magn. Reson. Med. 35:346-355 (1996)

- estimate motion parameters

- use estimates as confounds in the statistical model



Movement Correction



FIL Methods Group

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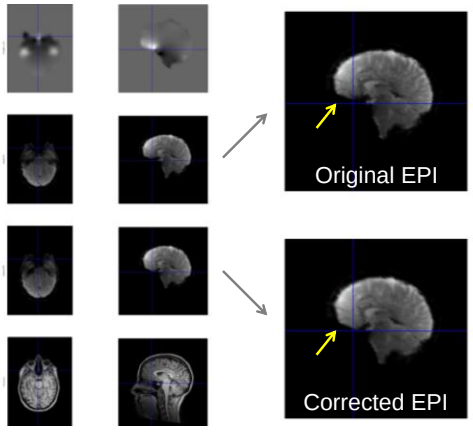
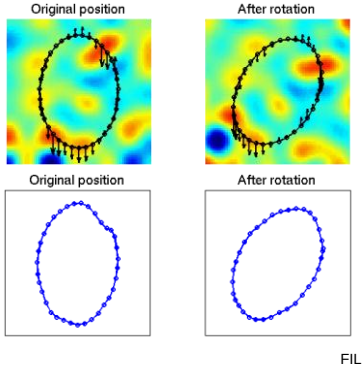


Movement-by-Distortion Interactions

Time dependent fMRI signal changes are dependent upon:

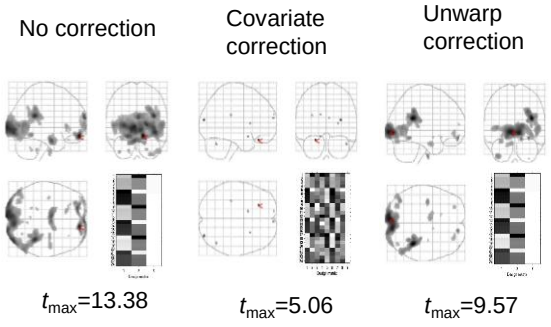
- position of the object in the scanner
  - geometric distortion
  - B_0 field effects
  - slice select gradient edge effects
- history of the position of the object
  - spin history effects

Movement-by-Distortion Interactions



FIL Methods Group

Movement Correction



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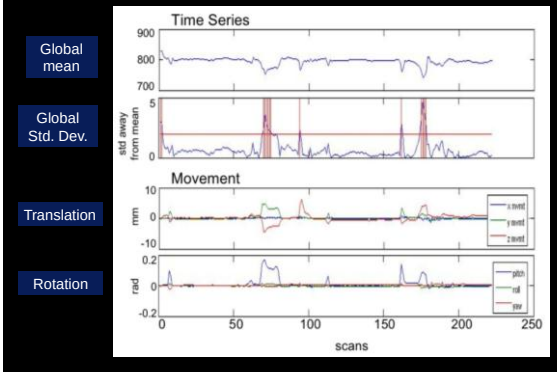
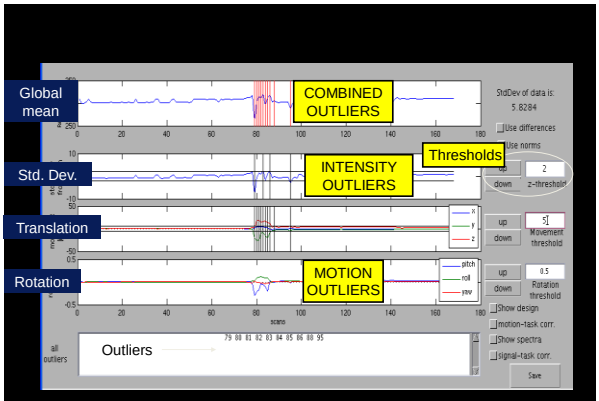
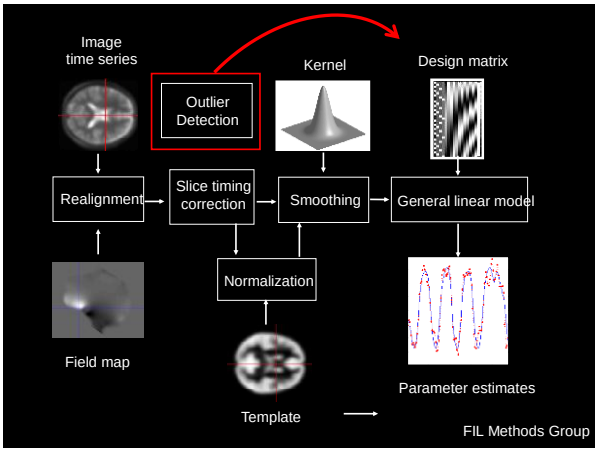
Outlier Identification







FIL Methods Group

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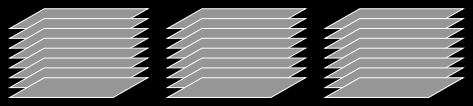
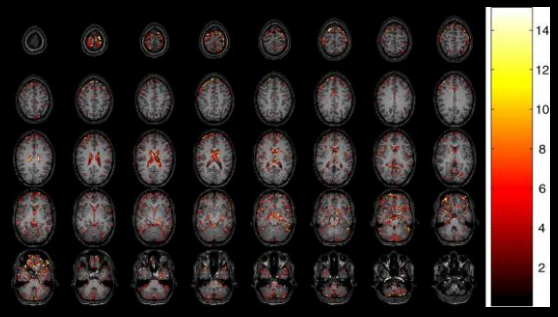
Temporal Filtering



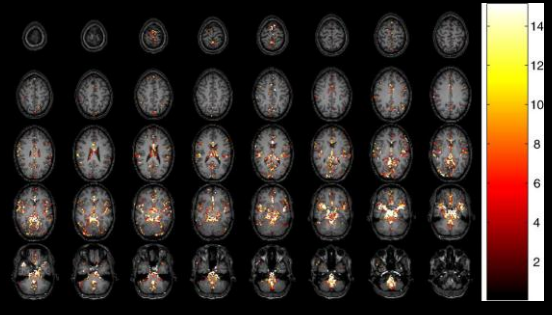
Time ⟶

Respiration Modulates BOLD Contrast

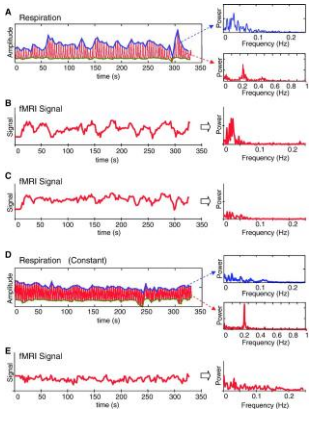


Lund et al., Neuroimage (2006)

Cardiac Motion Modulates BOLD Contrast



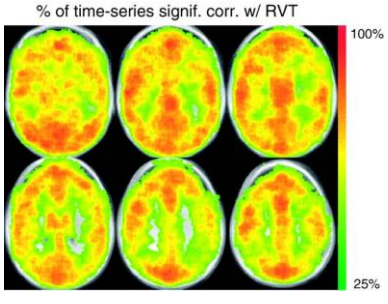
Lund et al., Neuroimage (2006)



Respiration Modulates BOLD Contrast Time Series

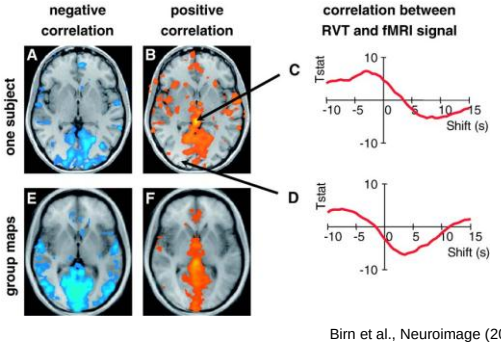
Birn et al., Neuroimage (2006)

Respiration Modulates BOLD Contrast



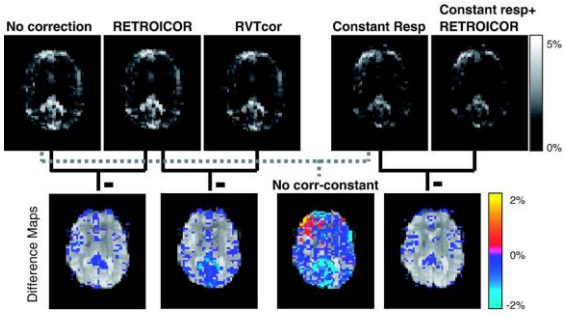
Birn et al., Neuroimage (2006)

Respiration Modulates BOLD Contrast at Rest



Birn et al., Neuroimage (2006)

Respiration Modulates BOLD Contrast at Rest



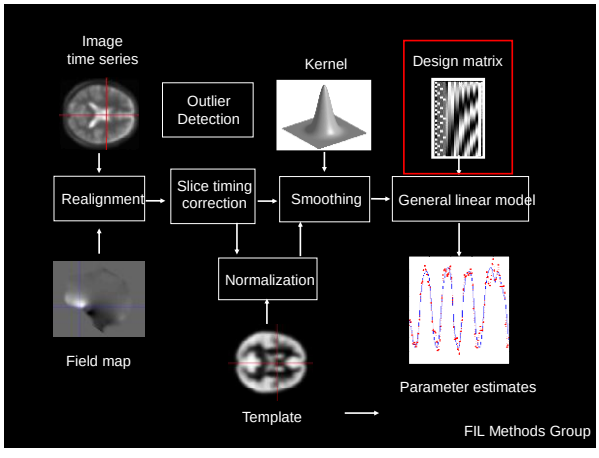
Birn et al., Neuroimage (2006)

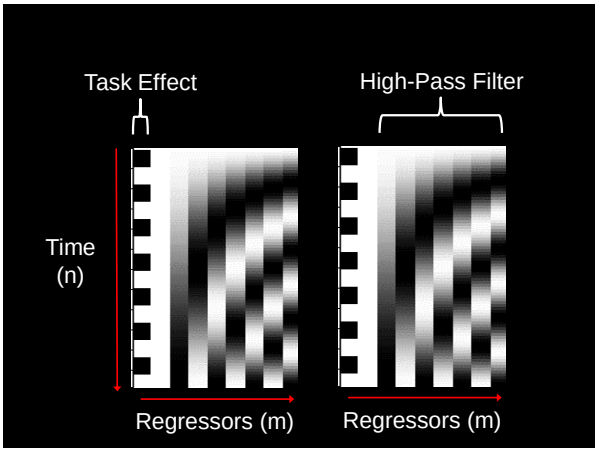
Cardiovascular and Respiratory Artifacts

Poncelet et al., Brain parenchyma motion: measurement with cine echo-planar MR imaging. Radiology 185:645-651 (1992).

Biswal et al., Reduction of physiological fluctuations in fMRI using digital filters. Magn. Reson. Med. 35:107-113 (1996).

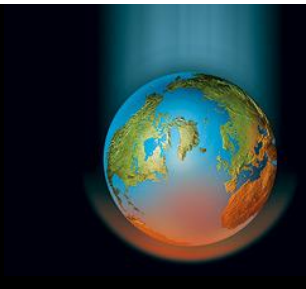
Hu et al., Retrospective estimation and correction of physiological fluctuation in functional MRI. Magn. Reson. Med. 34:201-212 (1995).





fMRI Preprocessing

- Slice timing correction
- Geometric distortion correction
- Head motion correction
- Temporal filtering
- Intensity normalization
- Spatial filtering

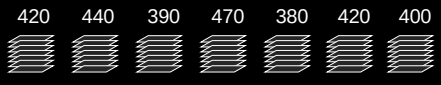


Global signal changes

Global Intensity Variation

- machine instability
- global blood flow changes
  - arousal
  - respiratory effects
  - drug effects

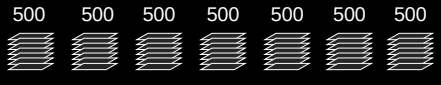
Global Intensity Normalization



Time ⟶

Intensity normalization per time point

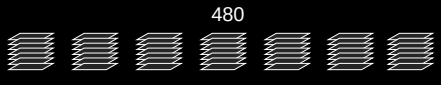
Global Intensity Normalization



Time ⟶

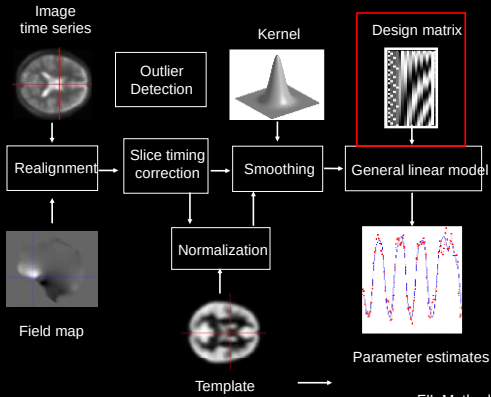
Intensity normalization per time point

Global Intensity Normalization



Time ⟶

Intensity normalization per session



fMRI Preprocessing

- Slice timing correction
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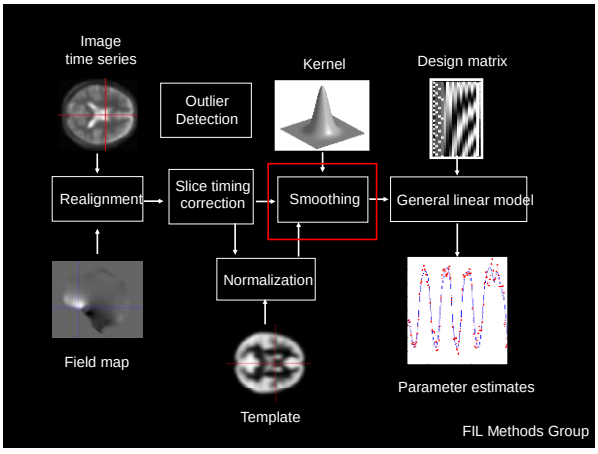
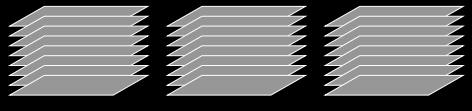
- Spatial filtering

Spatial filtering

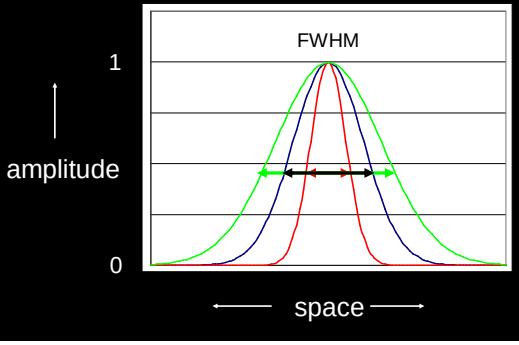


Spatial Filtering

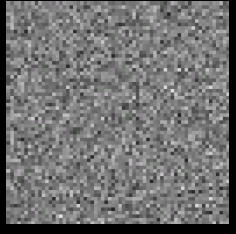


Time ⟶

Gaussian Kernel



Spatial Filtering



Slice from nonsmoothed noise volume

voxel size 1mm^3

Same slice after 8mm isotropic smoothing

How much smoothing?

- Noise reduction
- Spatial normalization compensation
- Matched filter theorem

fMRI Preprocessing

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