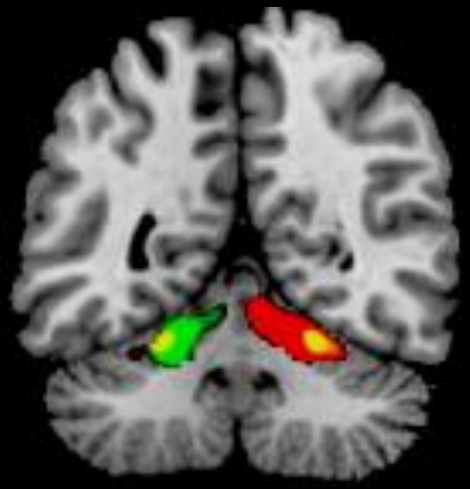
# SPM8 for Basic and Clinical Investigators

## Preprocessing



# fMRI Preprocessing

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

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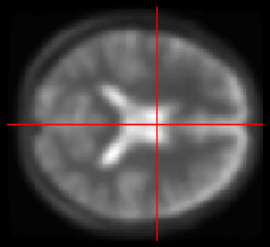
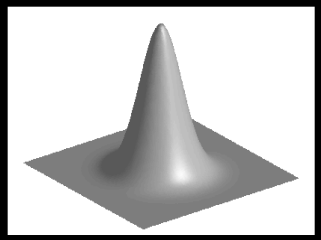
Image time series

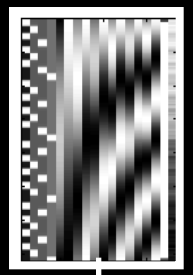


Outlier Detection

Kernel



Design matrix

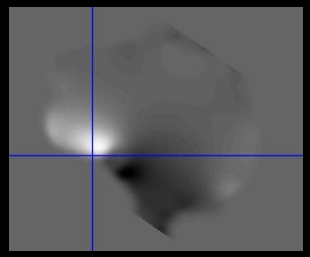


Realignment

Slice timing correction

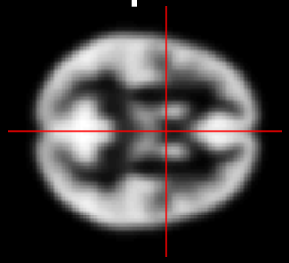
Smoothing

General linear model

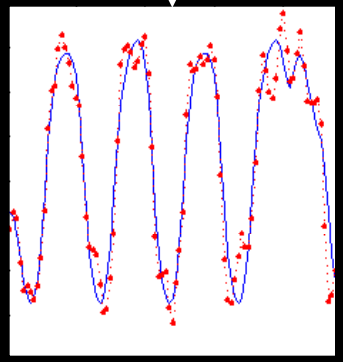


Field map

Normalization



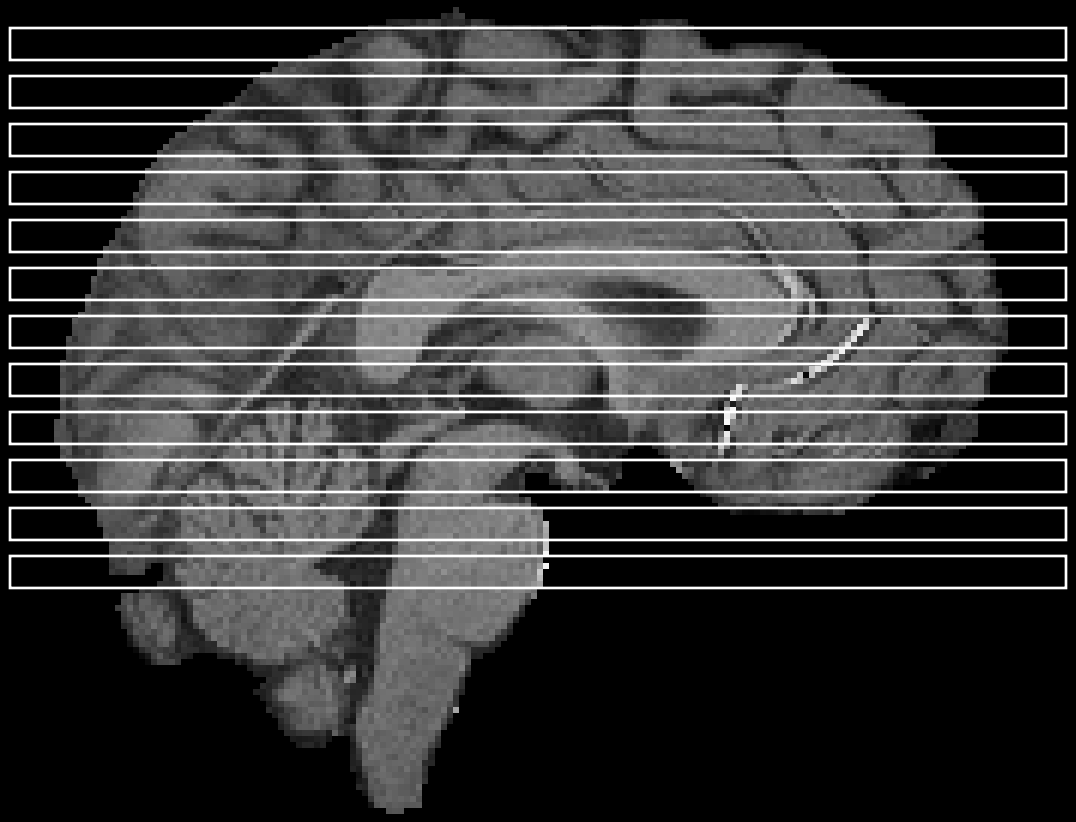
Template



Parameter estimates

FIL Methods Group

# EPI Data Are Acquired Serially



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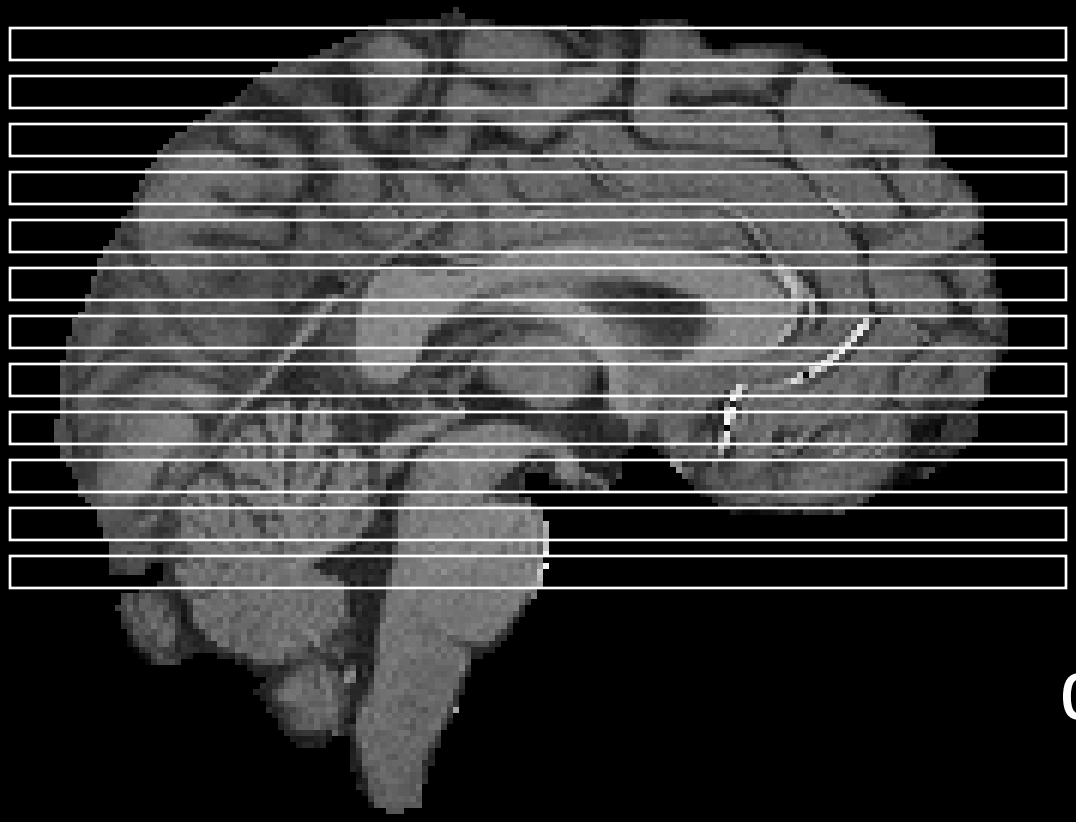

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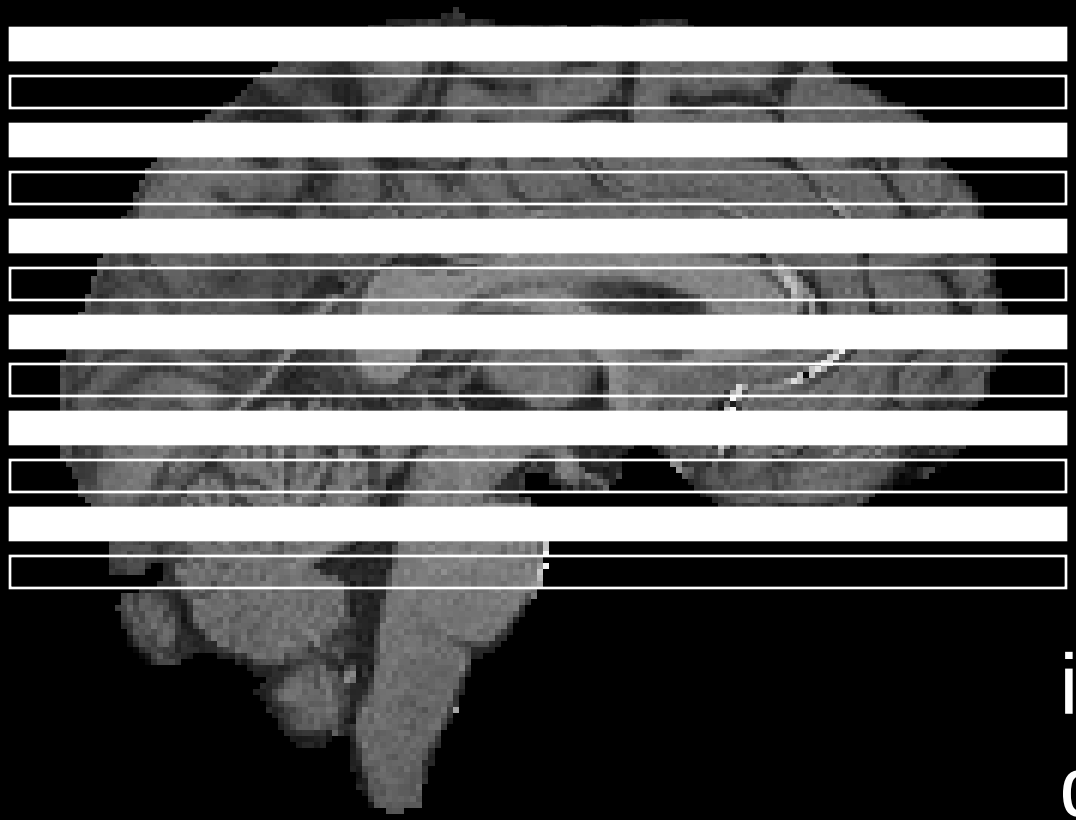

interleaved
descending

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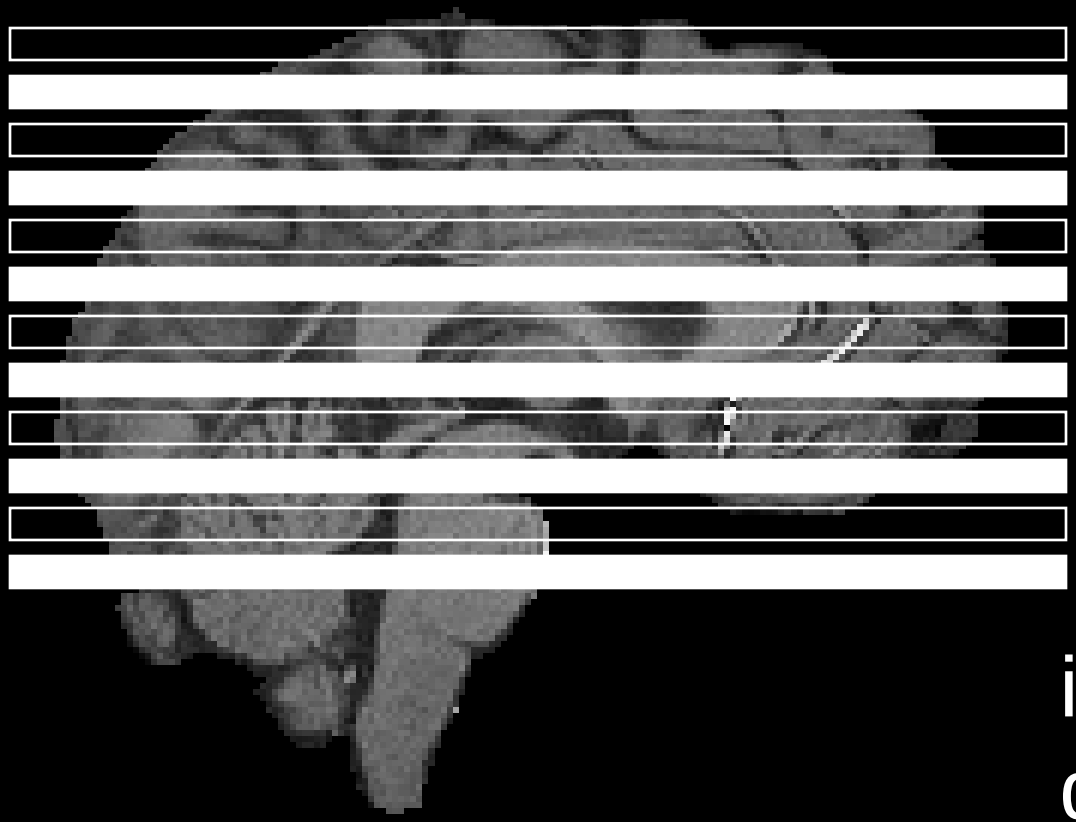
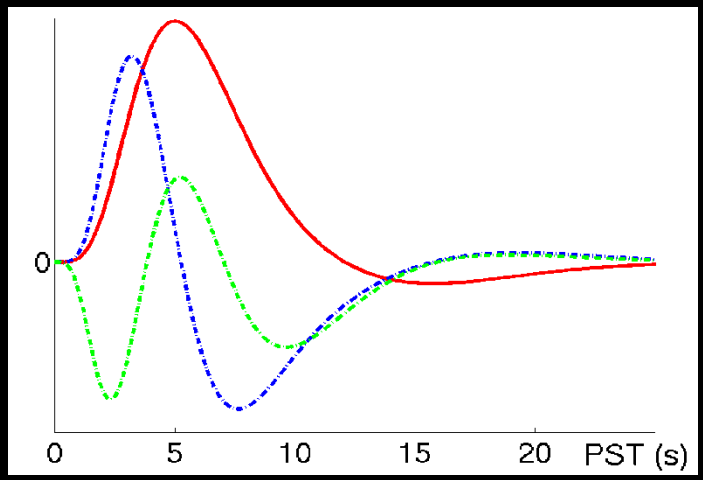
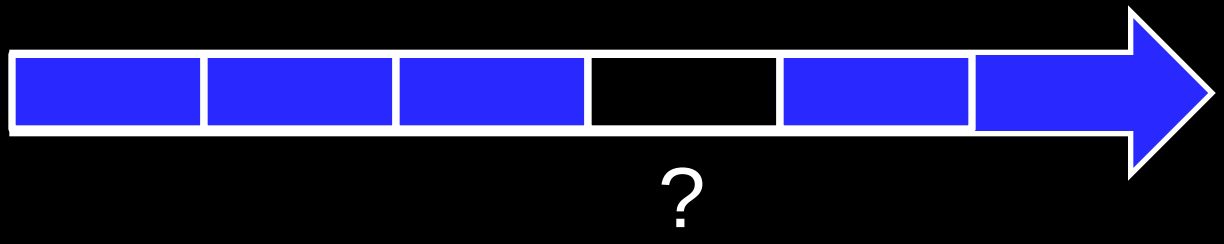


interleaved
descending

# Two Approaches to Slice Timing Correction

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



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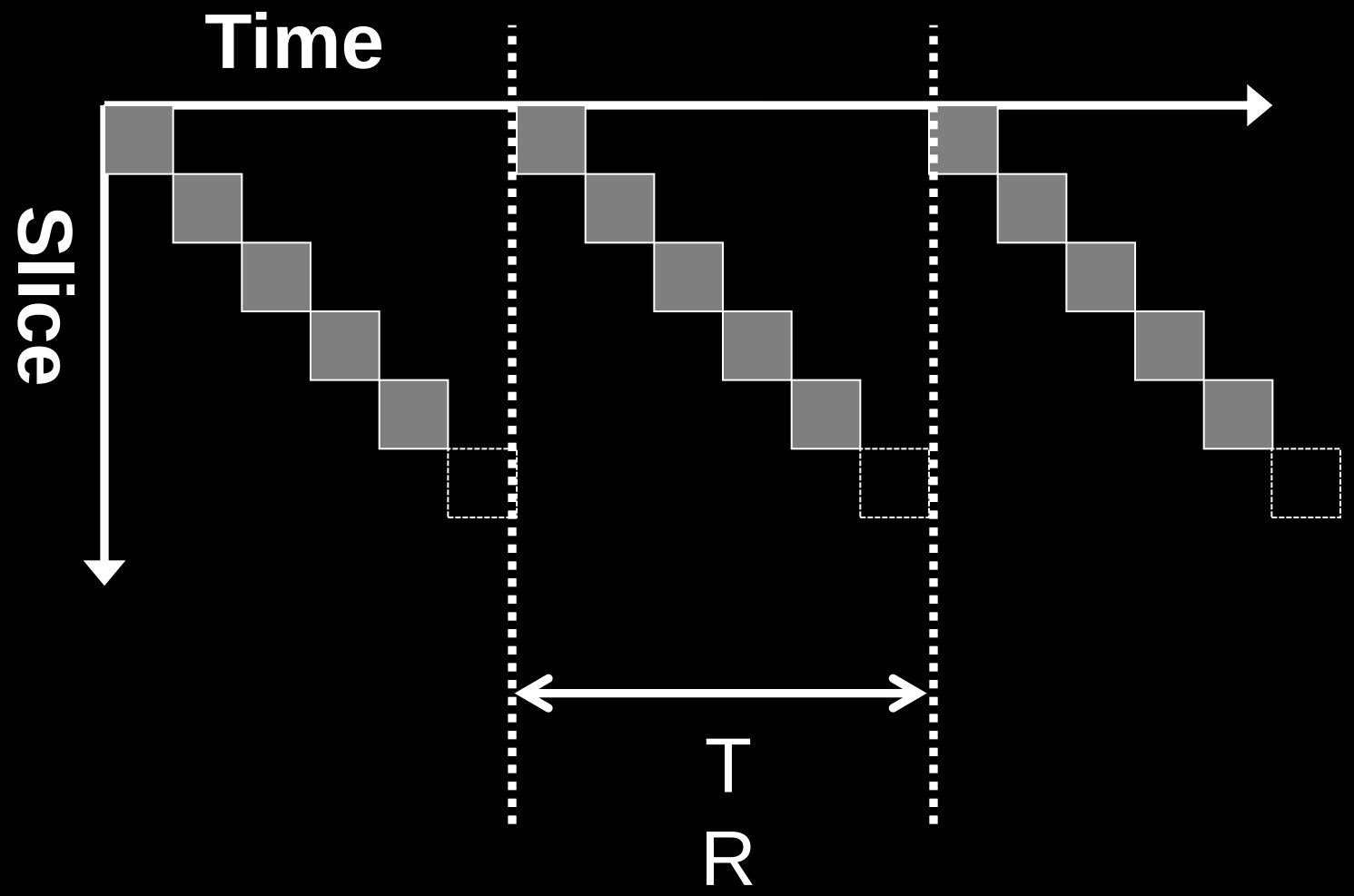

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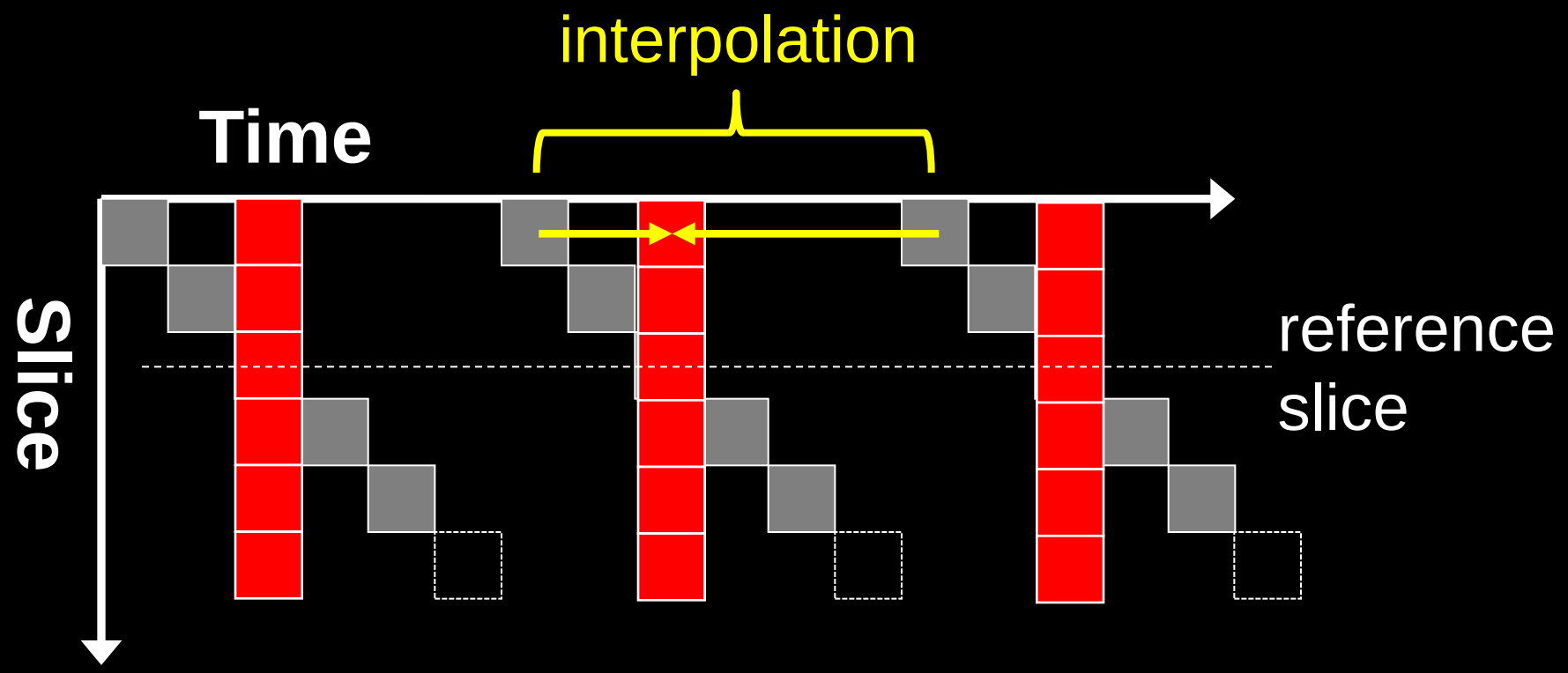

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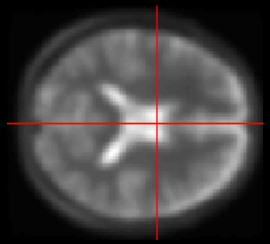
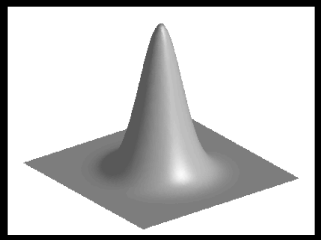


Outlier Detection

Kernel



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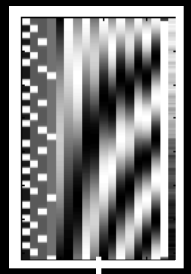
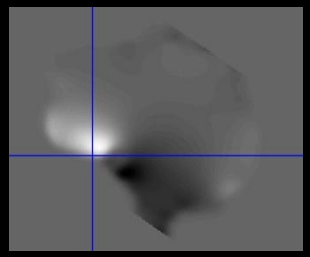


Realignment → Slice timing correction → Smoothing → General linear model



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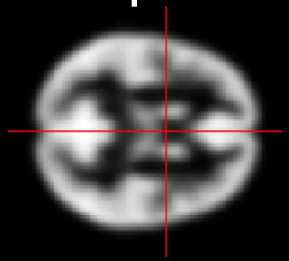
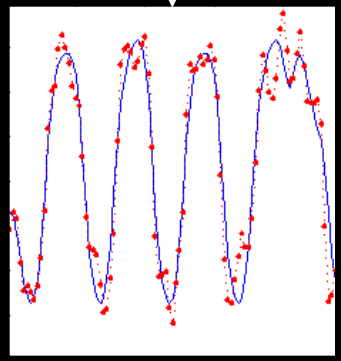


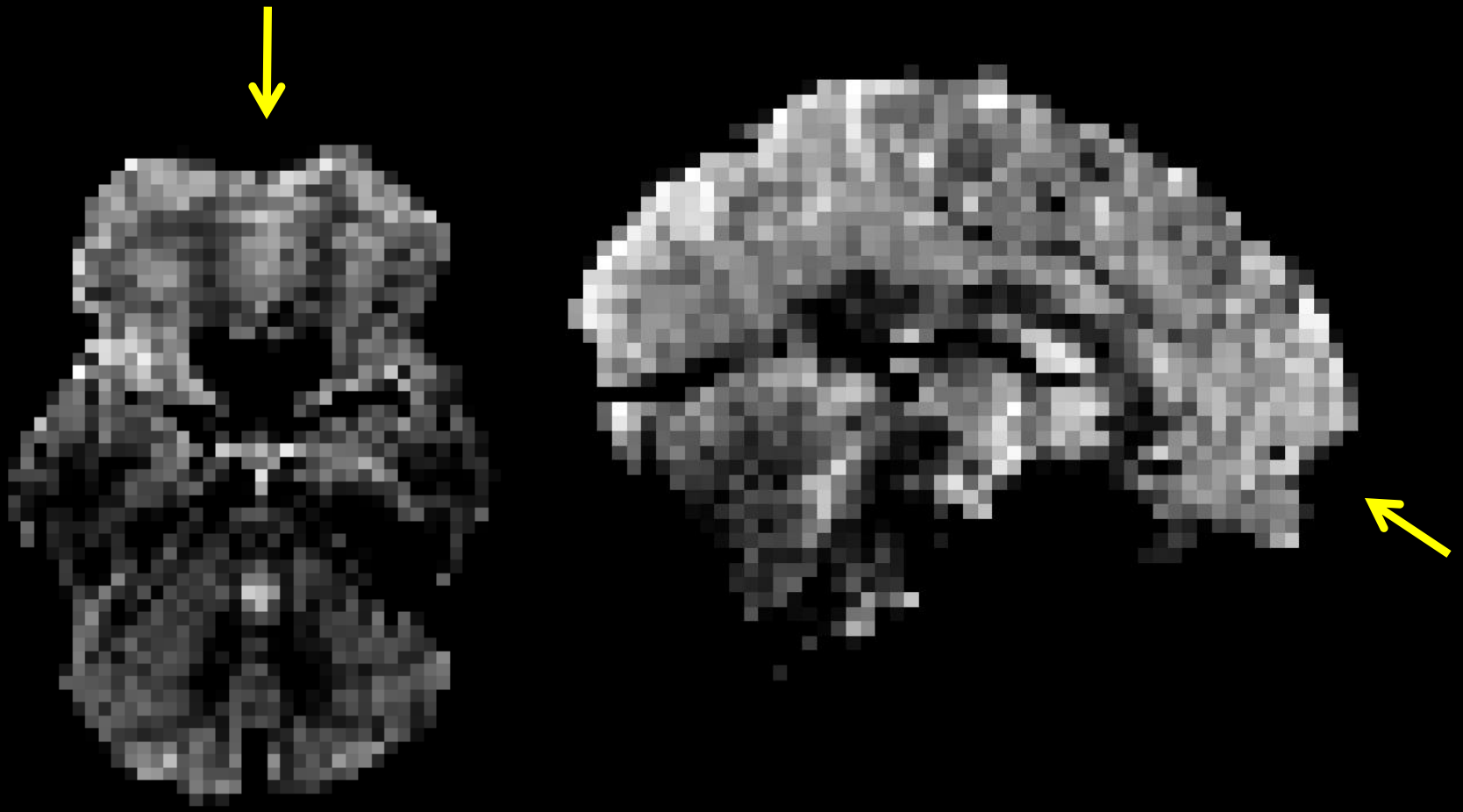
Template

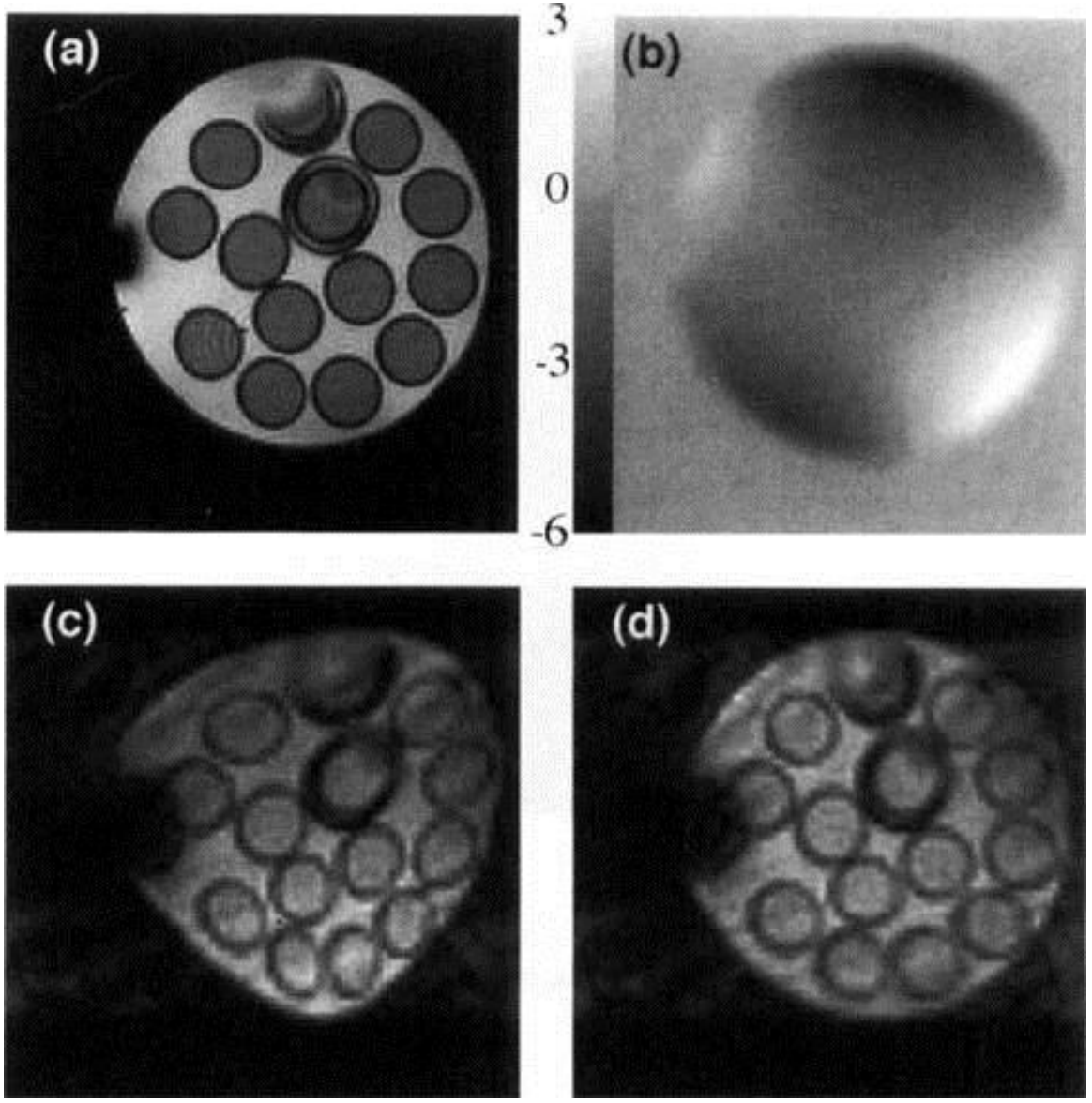


Parameter estimates

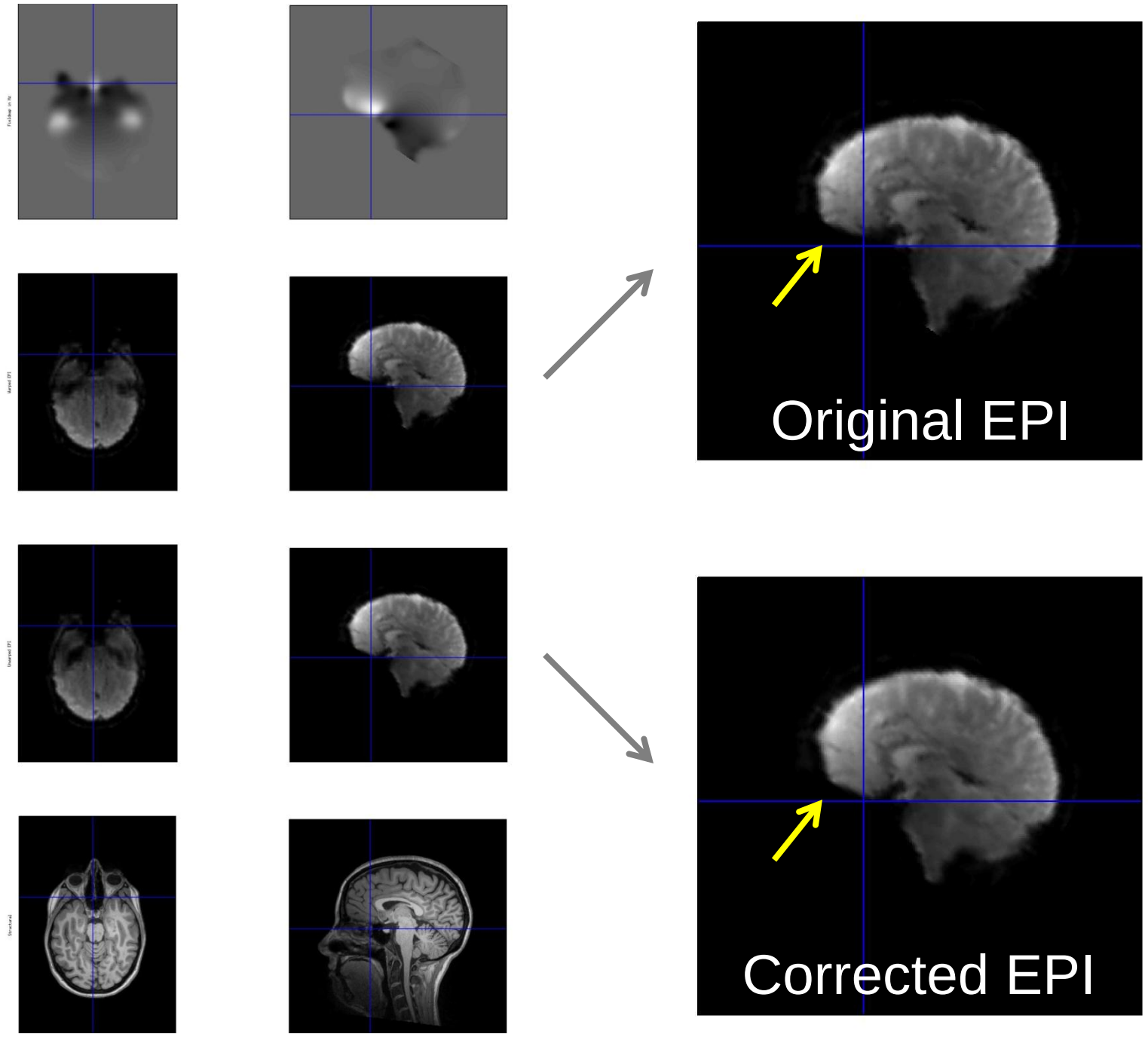
FIL Methods Group

# Signal Dropout and Geometric Distortion






Jezzard and Balaban, MRM (1995)


Original EPI
Corrected EPI

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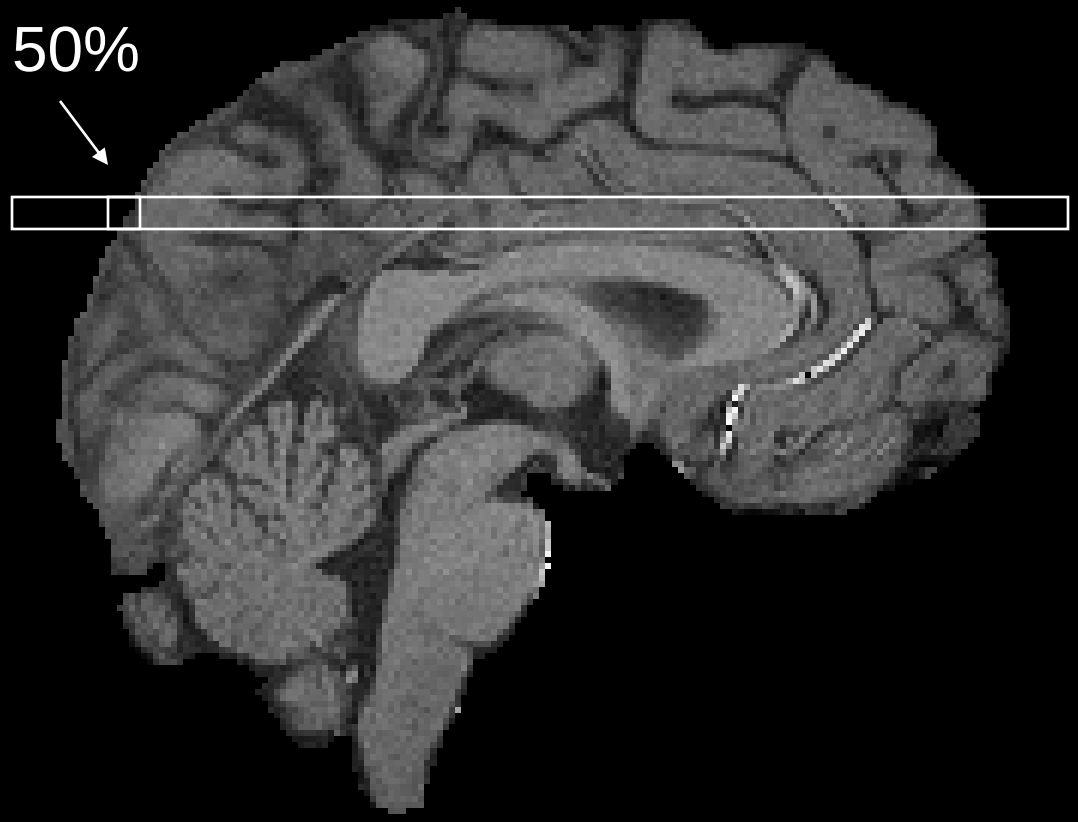
# Head Motion in fMRI

- 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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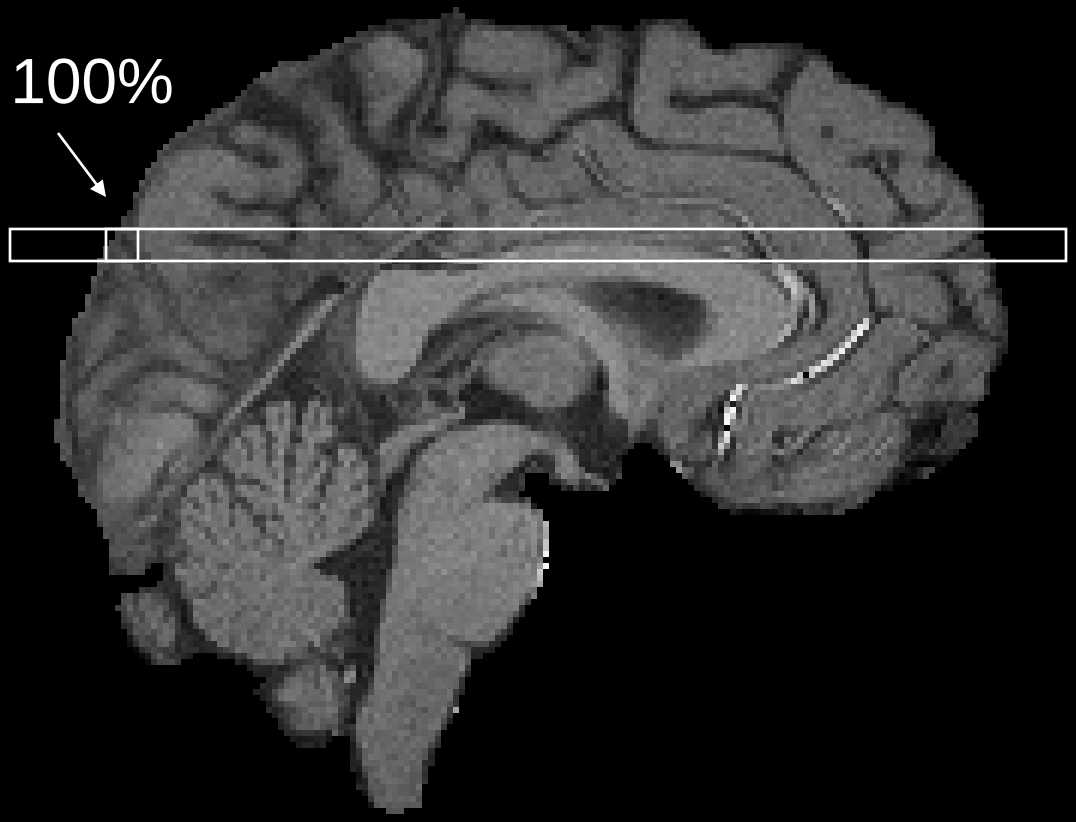

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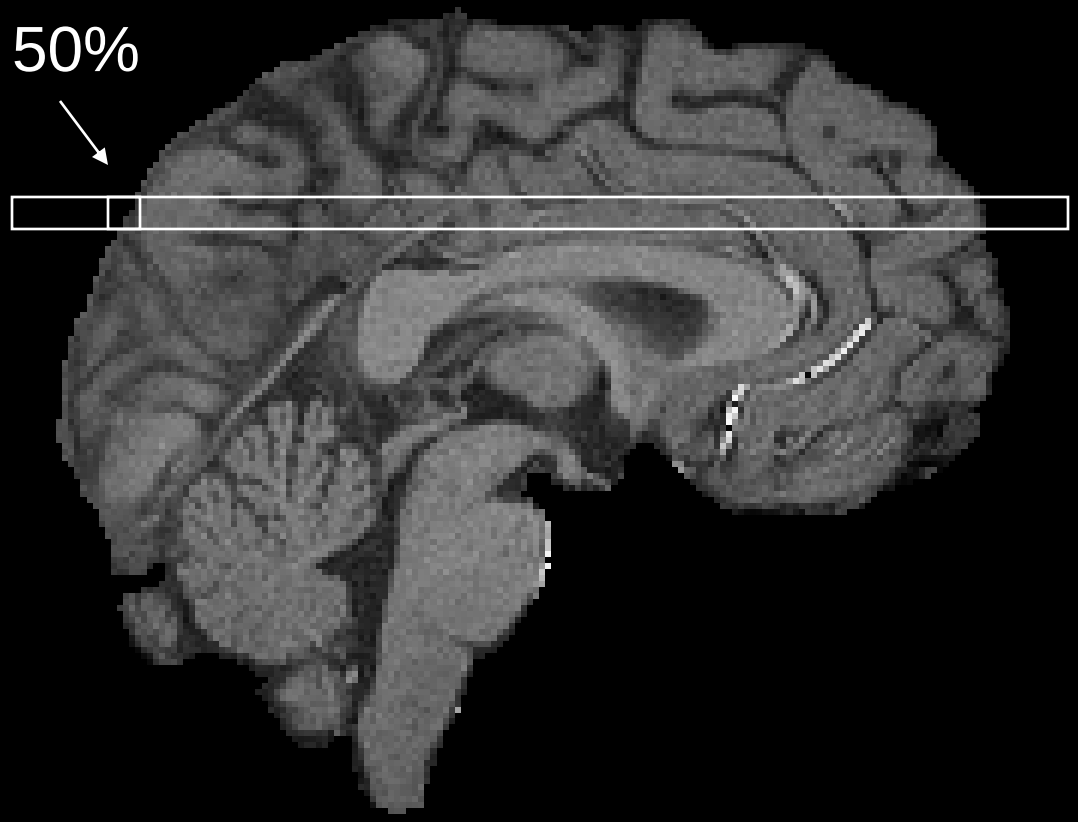

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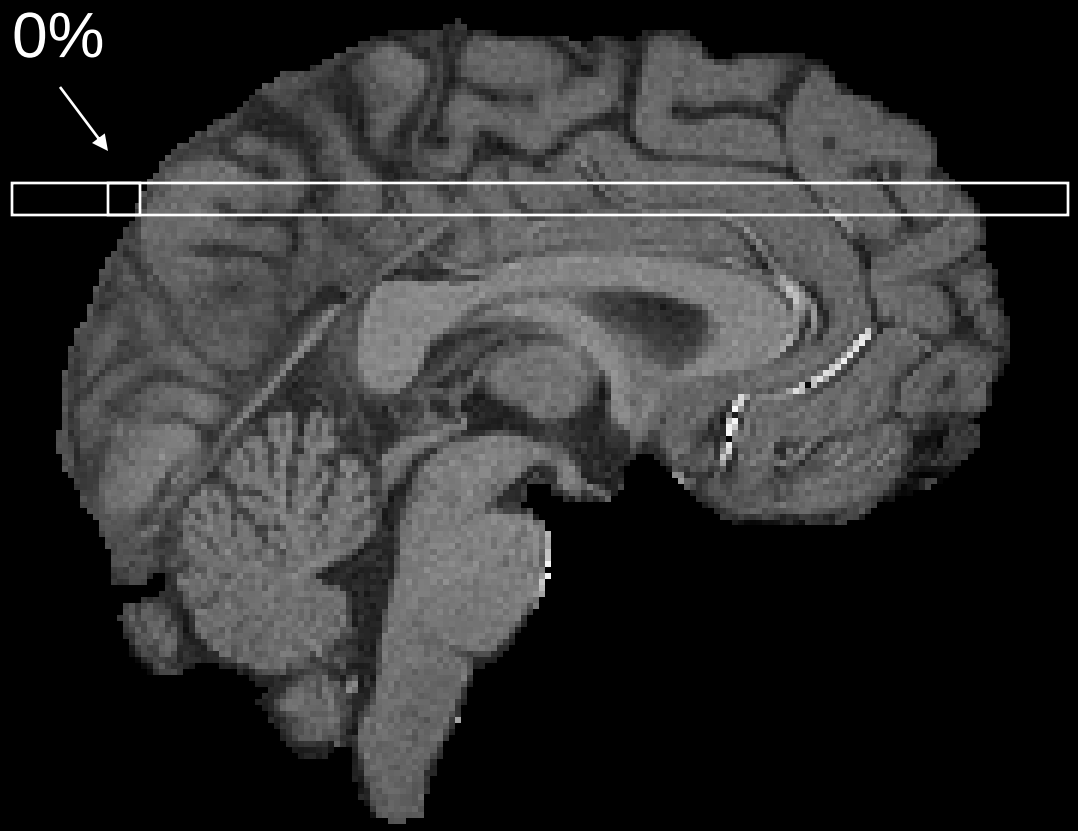

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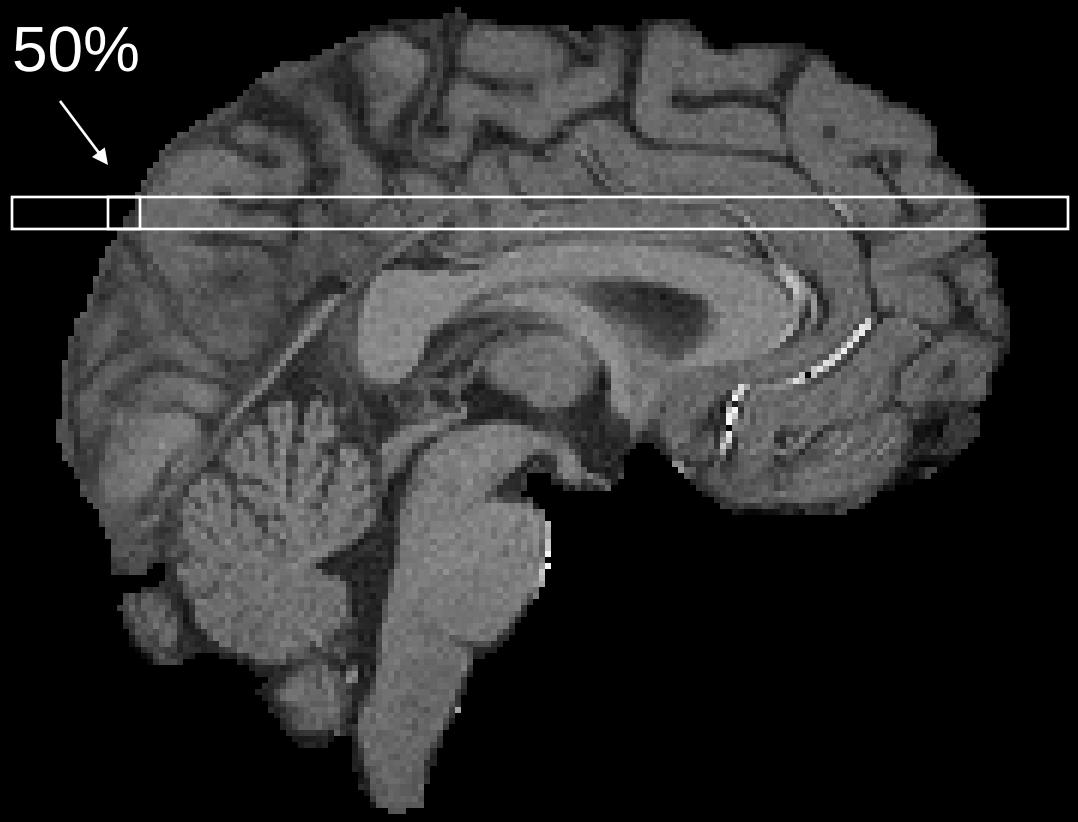

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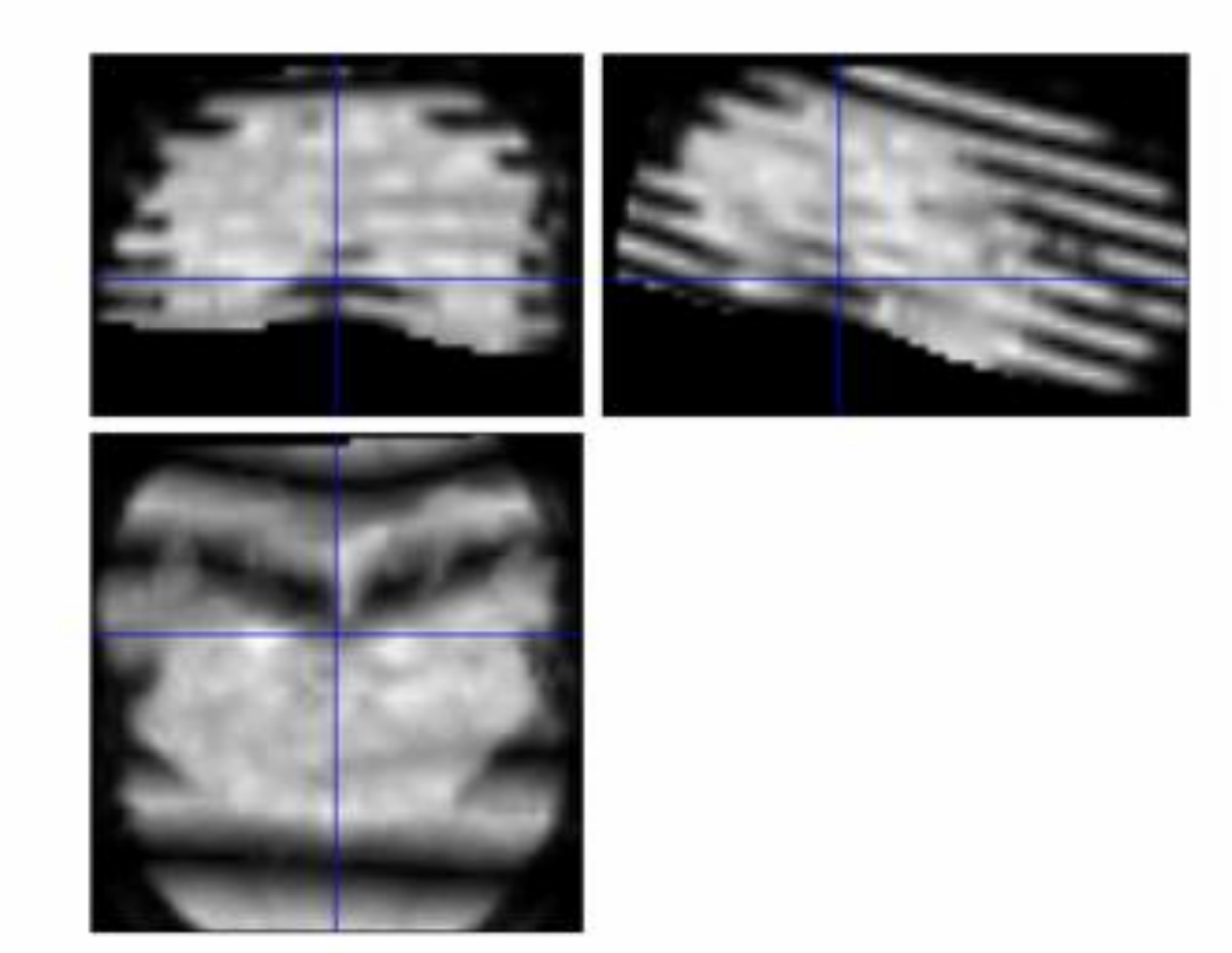


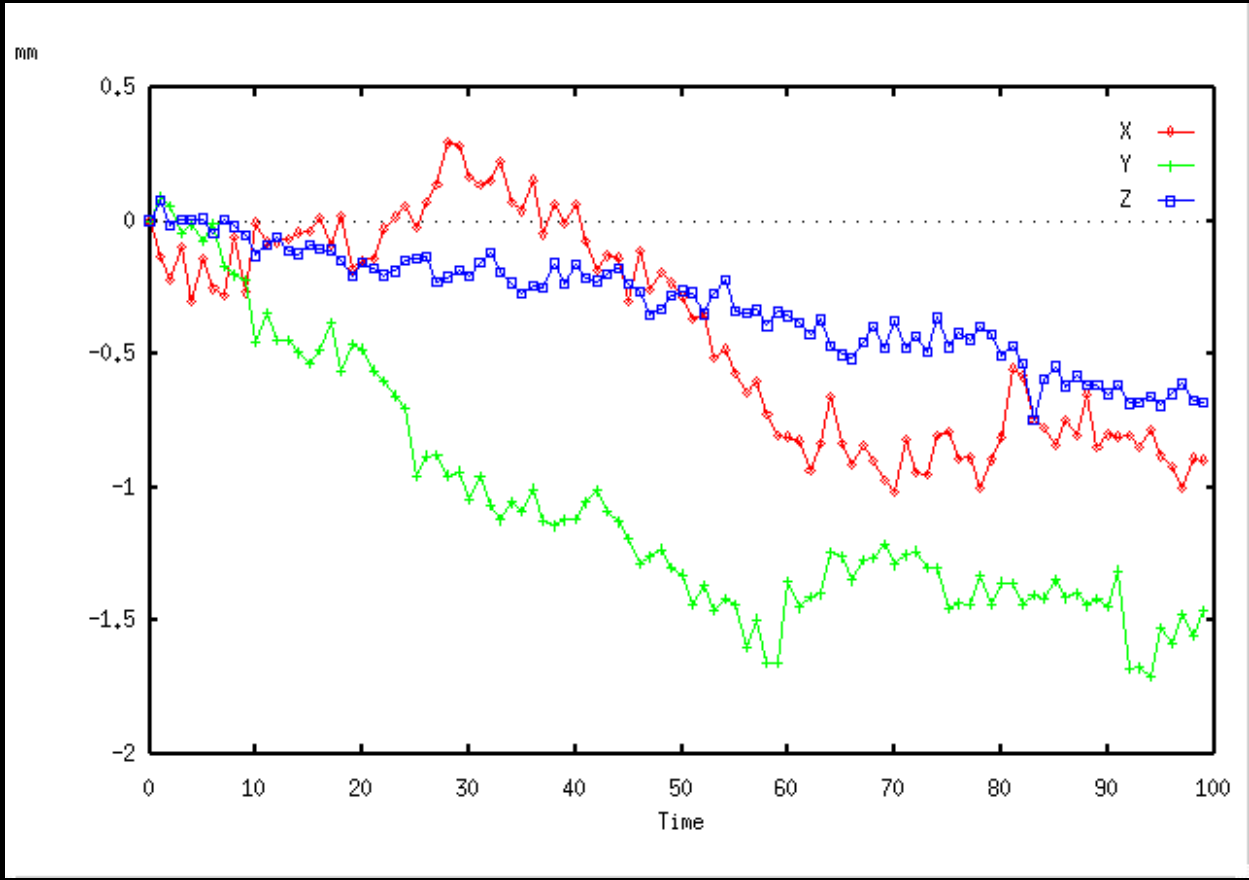
Whitfield-Gabrieli

# 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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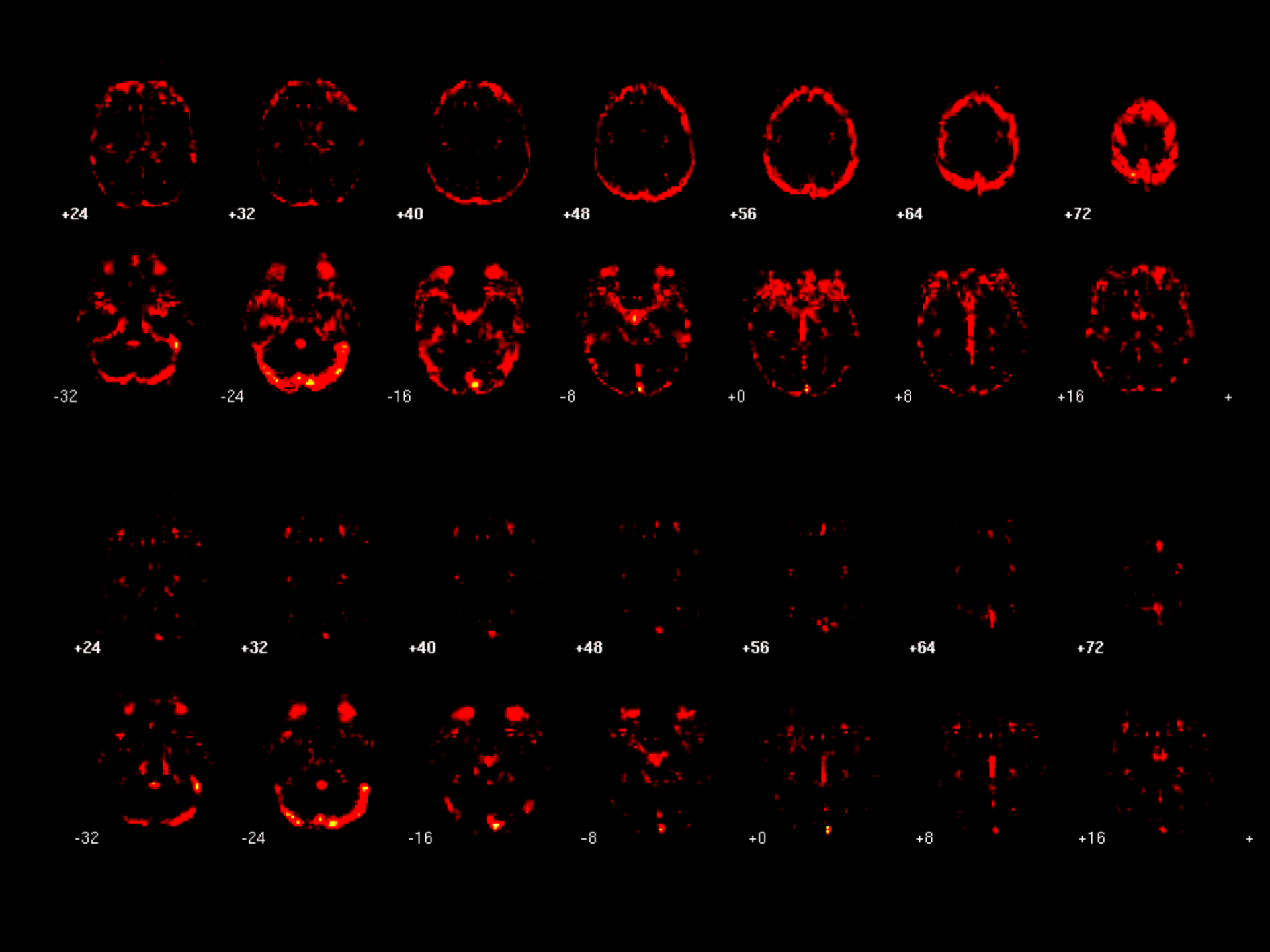
+24
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# Mitigation of Head Motion Effects

- Prevention
- Prospective correction
- Realignment
- Covariate correction with head motion estimates
- Movement by distortion effect correction with fieldmaps
- Covariate correction with outlier identification

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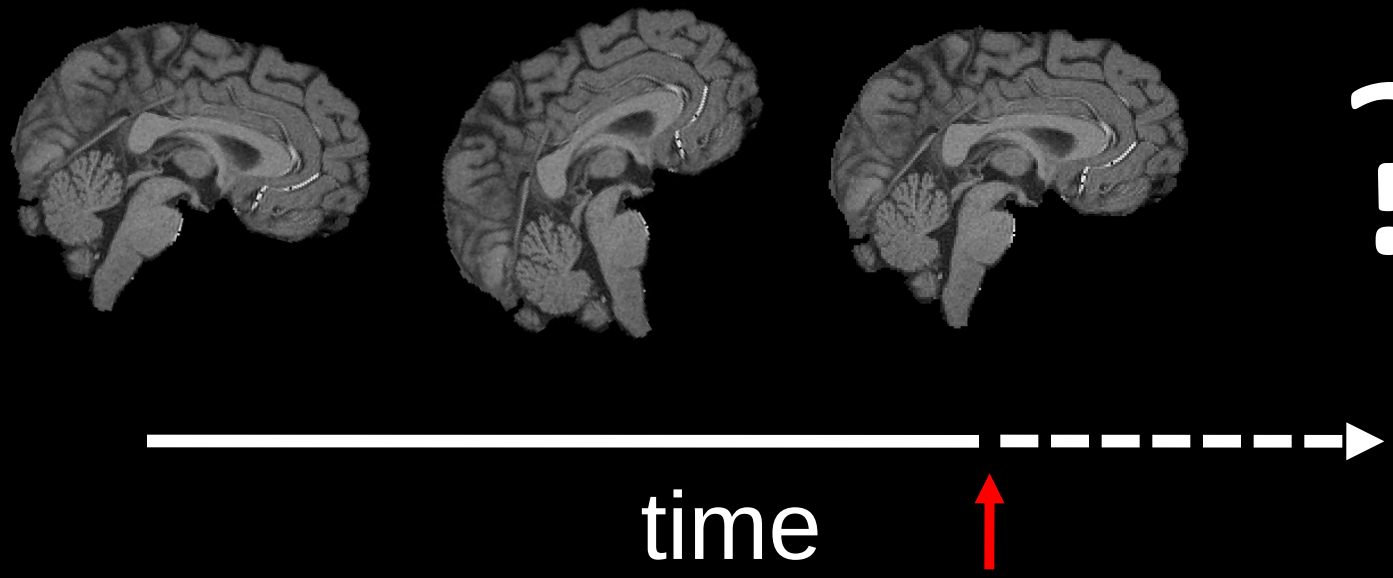
# Prospective Motion Correction




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


“We drive into the future using only our rearview mirror.” - Marshall McLuhan

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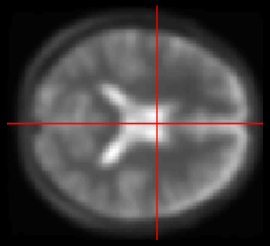
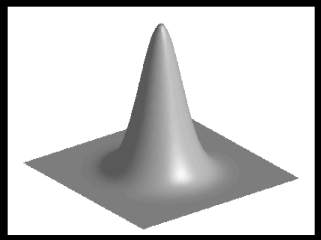
Image time series

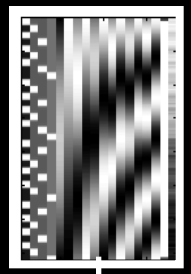


Outlier Detection

Kernel



Design matrix



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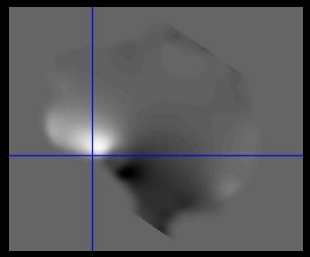
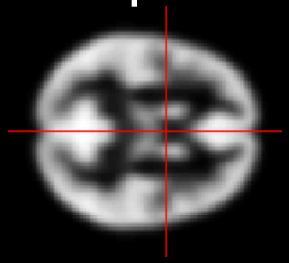
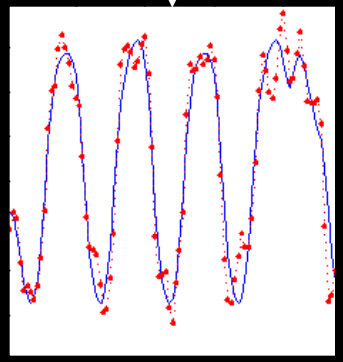


Field map

Normalization



Template



Parameter estimates

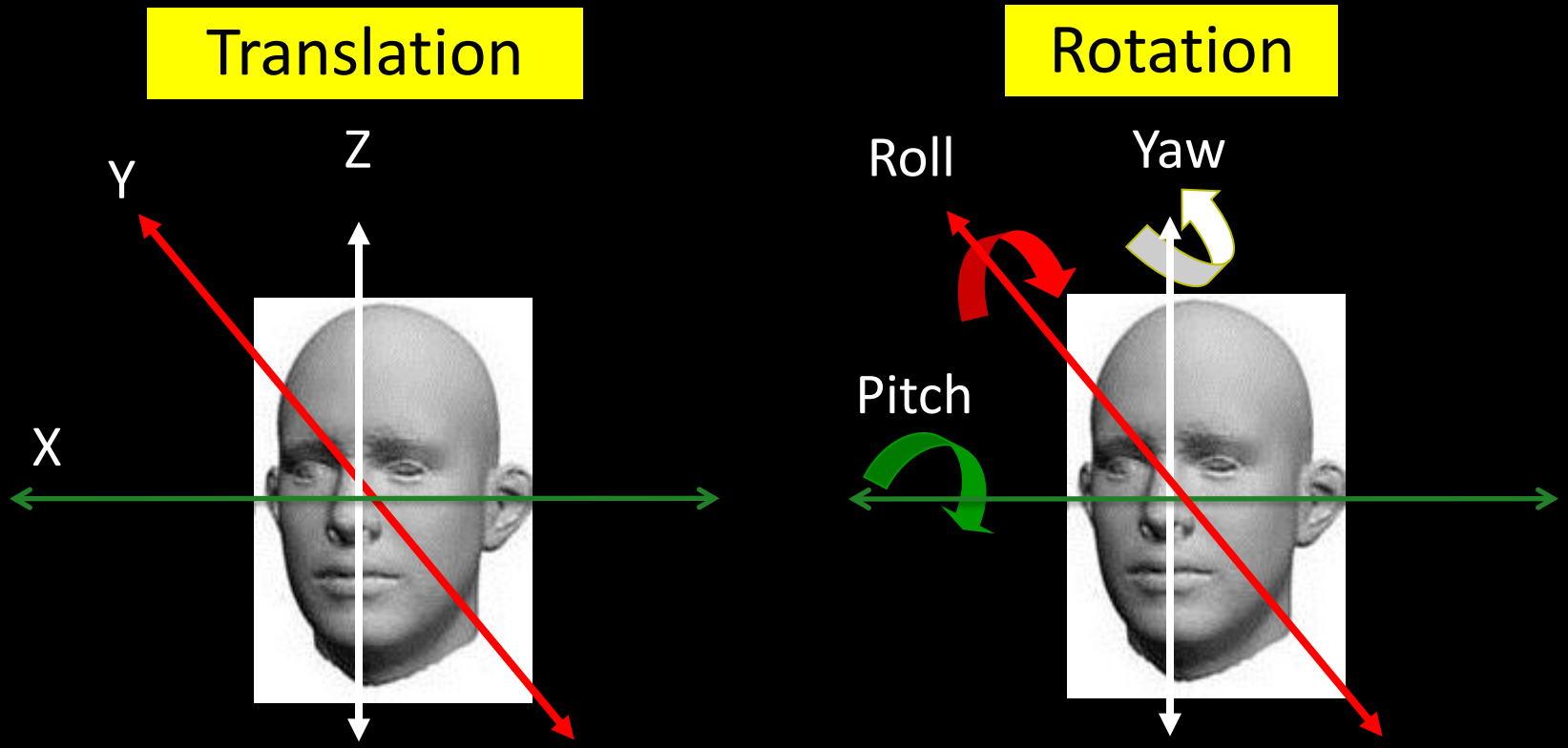
FIL Methods Group

# 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

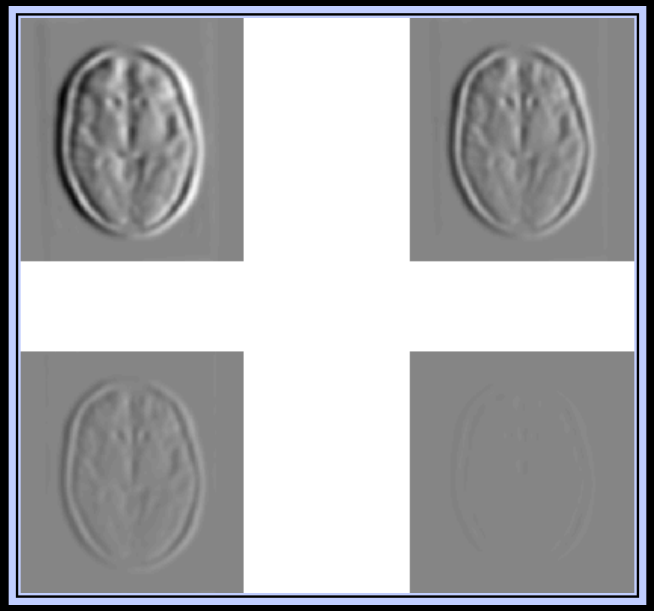
# Spatial Realignment: Registration

- 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:

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

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

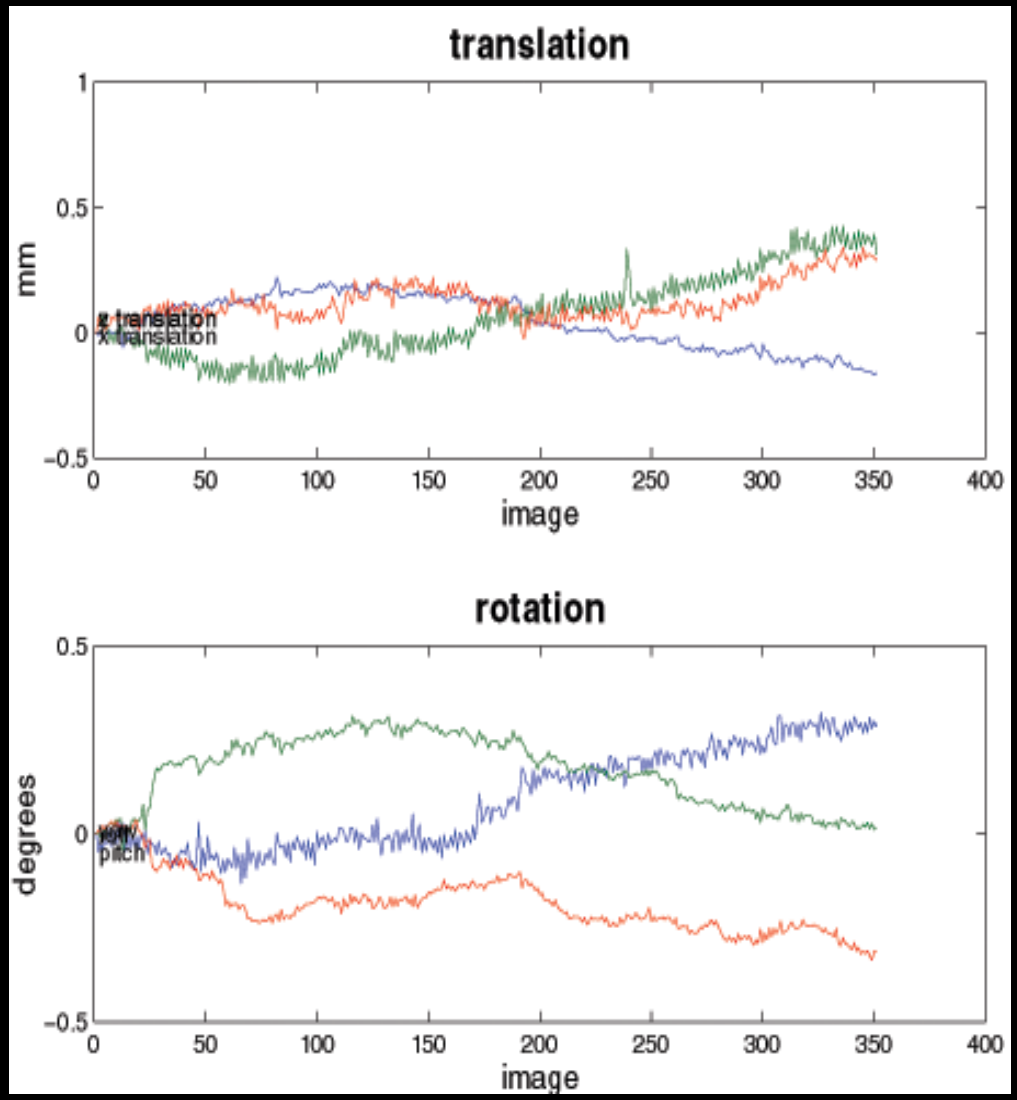
$$z_1 = m_{3,1}x_0 + m_{3,2}y_0 + m_{3,3}z_0 + m_{3,4}$$



Henson

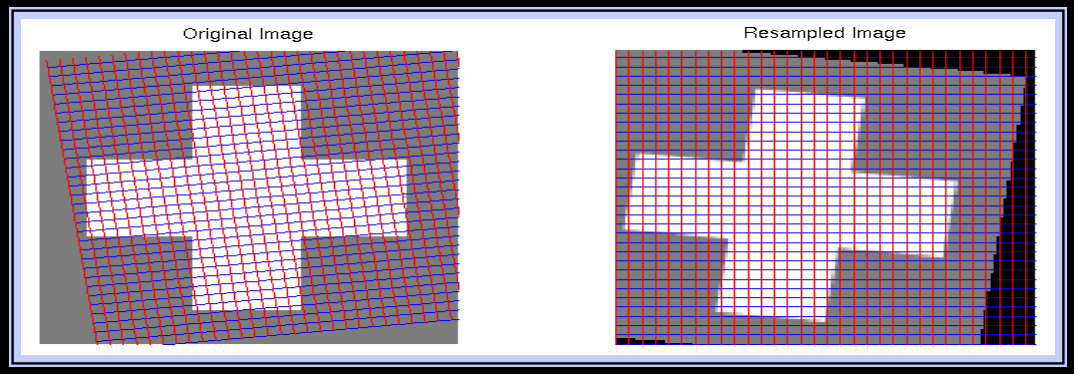
# Spatial Realignment: Registration

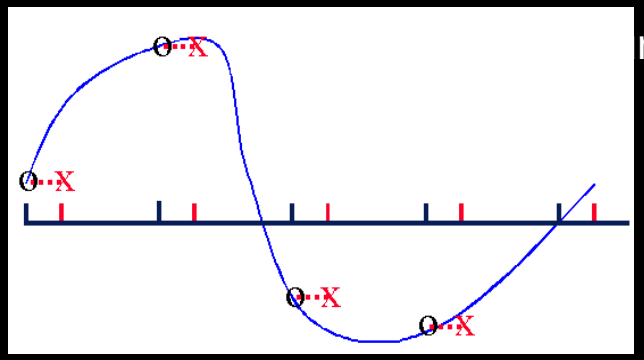
- Iterative procedure (Gauss-Newton ascent)
- Additional scaling parameter
- Nx6 matrix of realignment parameters written to file (N is number of scans)
- Orientation matrices in header of image file (data not changed until reslicing)

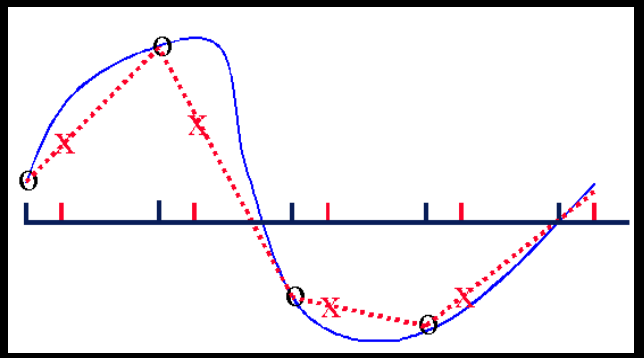


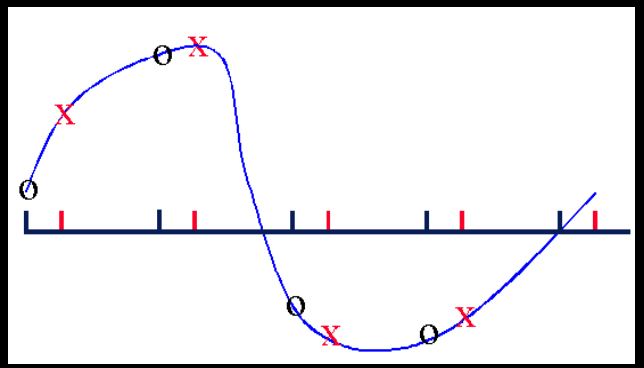

Henson

# Spatial Realignment: Reslicing

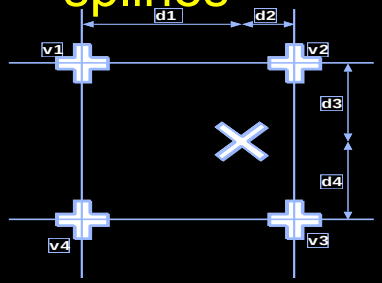


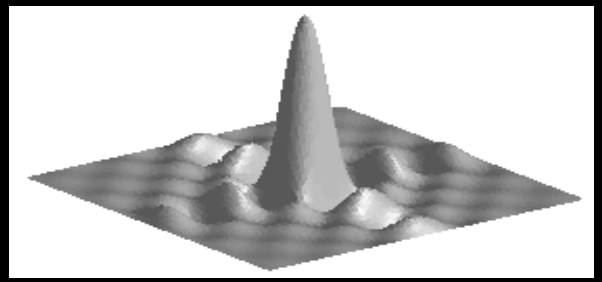







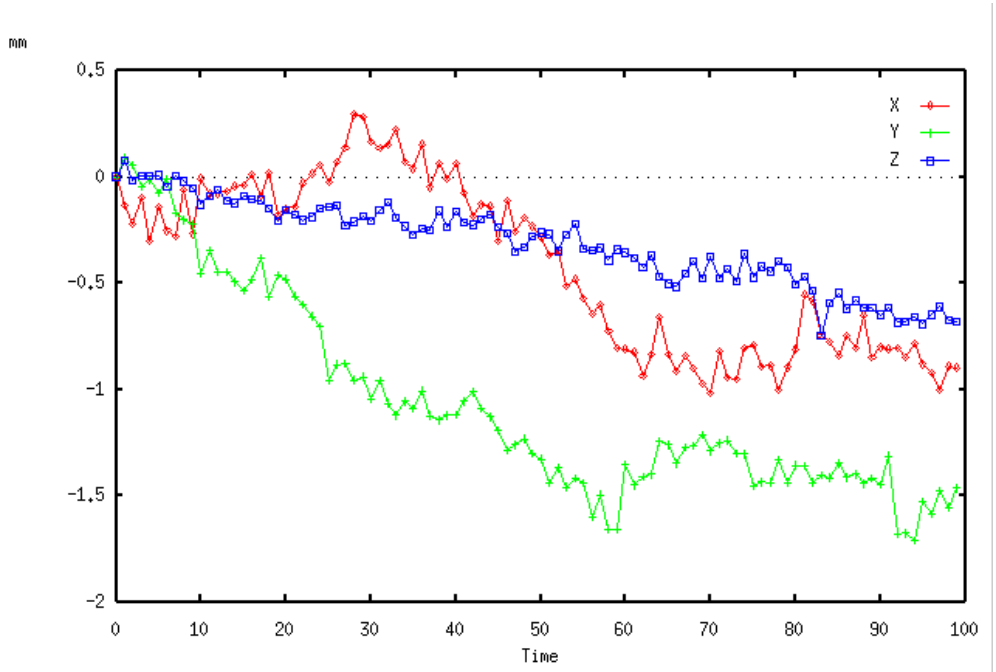
- Application of registration parameters involves re-sampling the image to create new voxels by interpolation from existing voxels
- Interpolation can be nearest neighbour (*0*-order), tri-linear (*1*st-order), (windowed) fourier/sinc, or *n*th-order "b-splines"



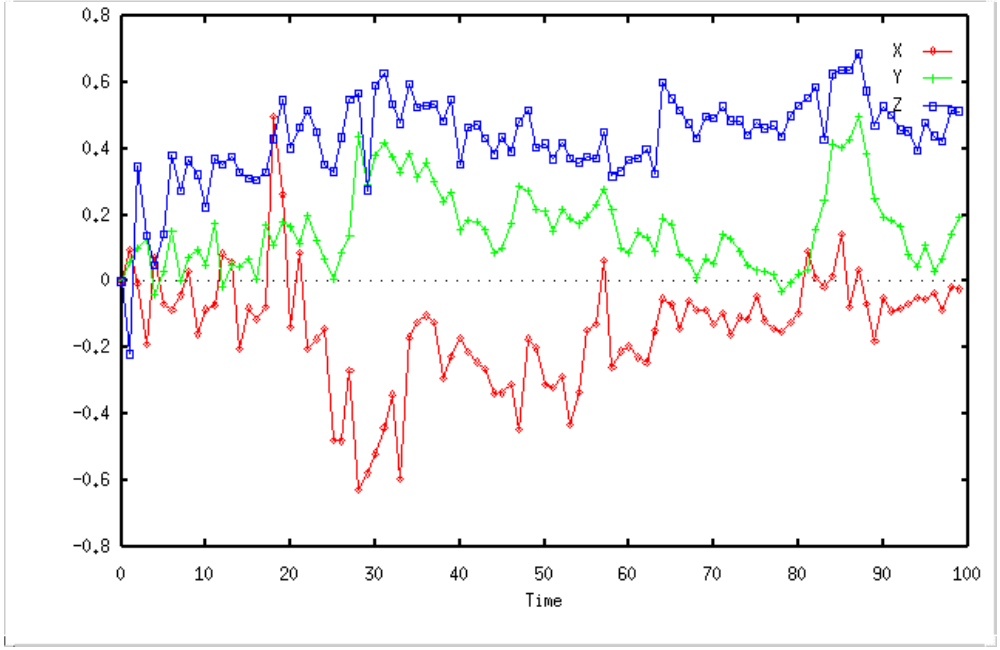



Henson

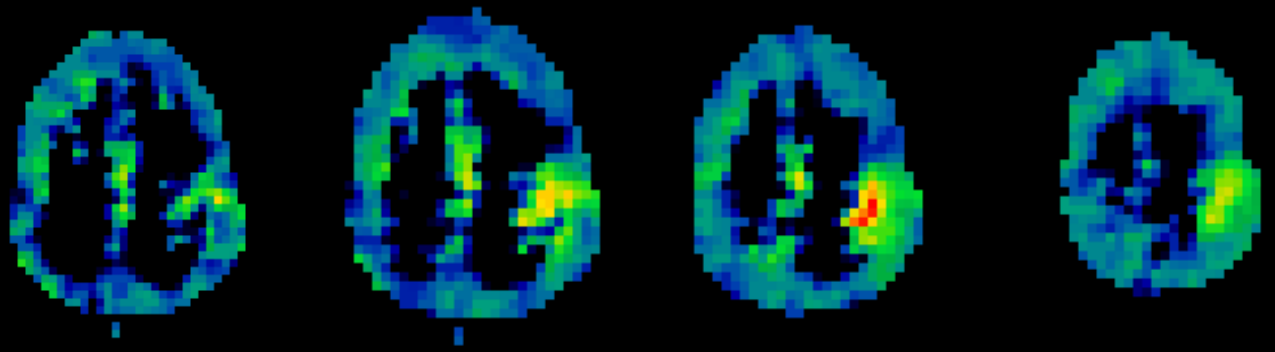
before correction



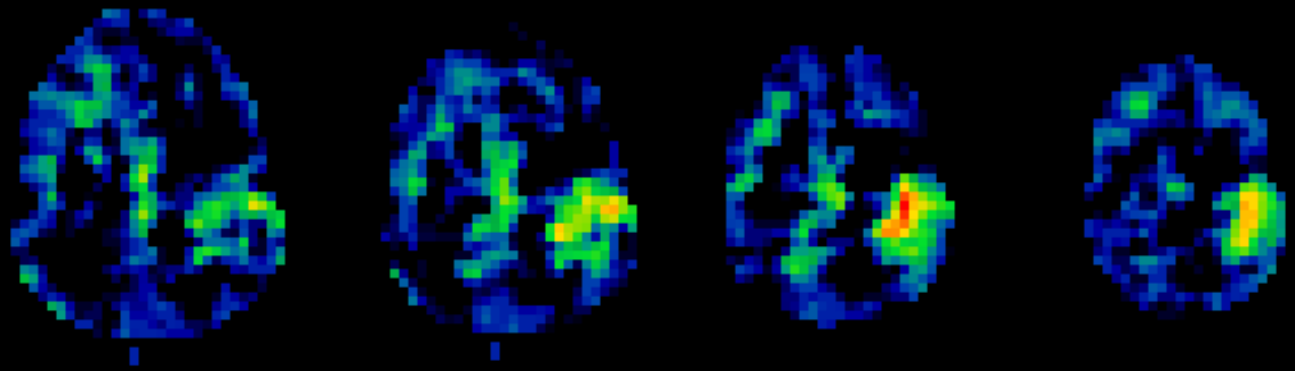

after correction



# Effects of Realignment on Statistical Maps



before



after

# Residual Error After Realignment

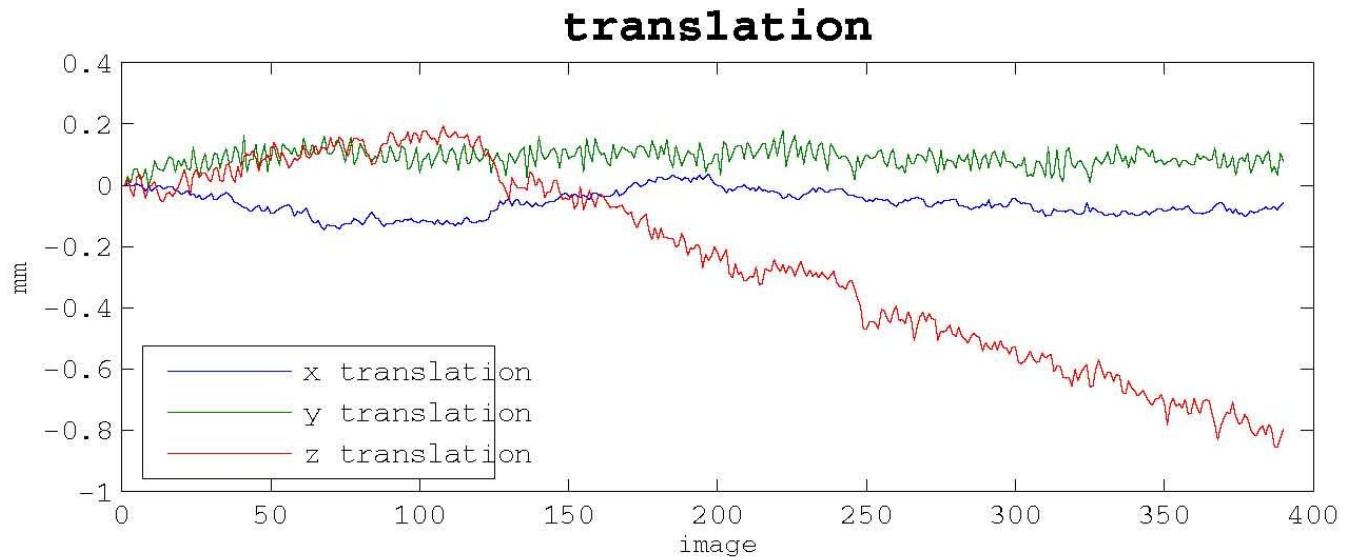
Even *after* realignment a considerable amount of the variance can be accounted for by movement

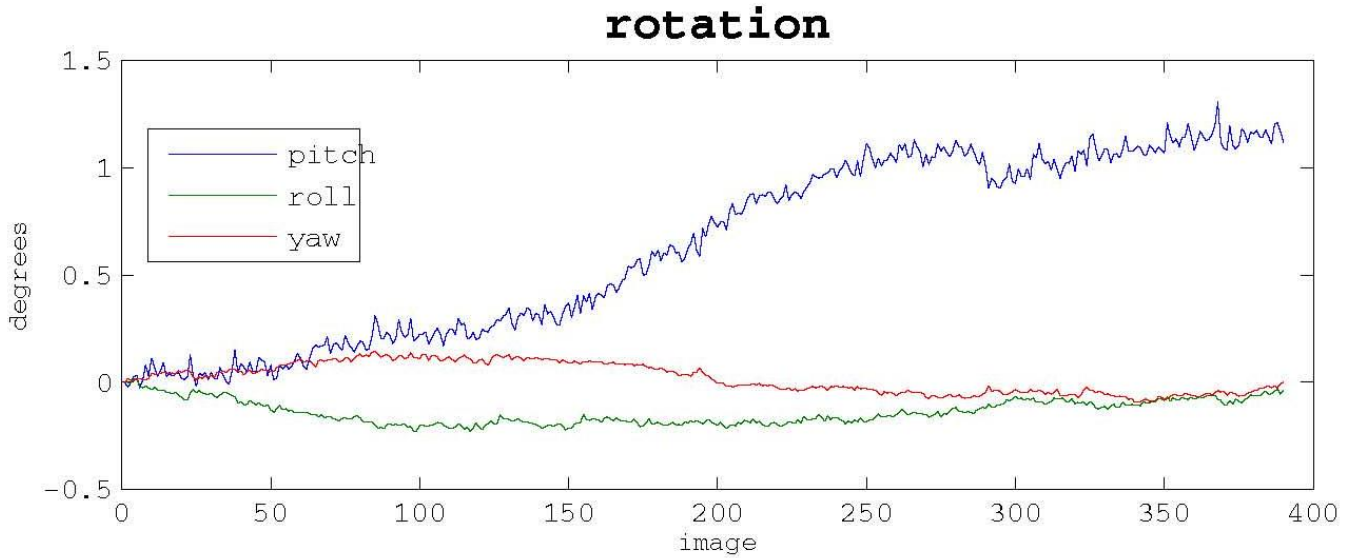
Causes:

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

# Mitigation of Head Motion Effects

- Prevention
- Prospective correction
- Realignment
- Covariate correction with head motion estimates
- Movement by distortion effect correction with fieldmaps
- Covariate correction with outlier identification


translation
0.4
0.2
0
-0.2
-0.4
-0.6
-0.8
-1
mm
0
50
100
150
200
250
300
350
400
image
x translation
y translation
z translation


rotation
1.5
1
0.5
0
-0.5
degrees
0
50
100
150
200
250
300
350
400
image
pitch
roll
yaw

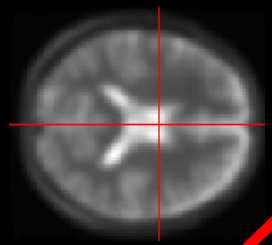
# Realignment with Movement Covariates

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

- estimate motion parameters

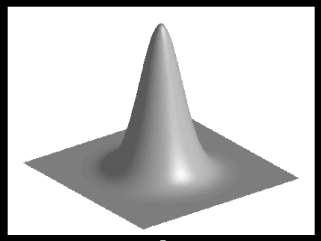
- use estimates as confounds in the statistical model

Image time series

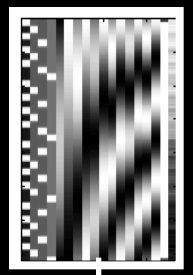


Outlier Detection

Kernel



Design matrix

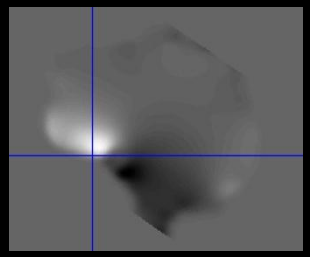


Realignment

Slice timing correction

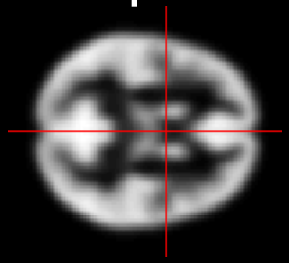
Smoothing

General linear model

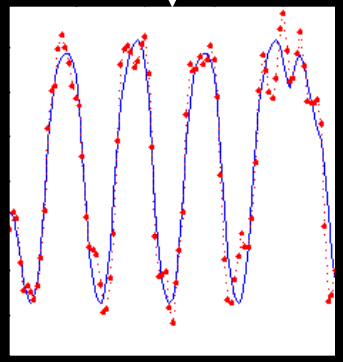


Field map

Normalization



Template



Parameter estimates

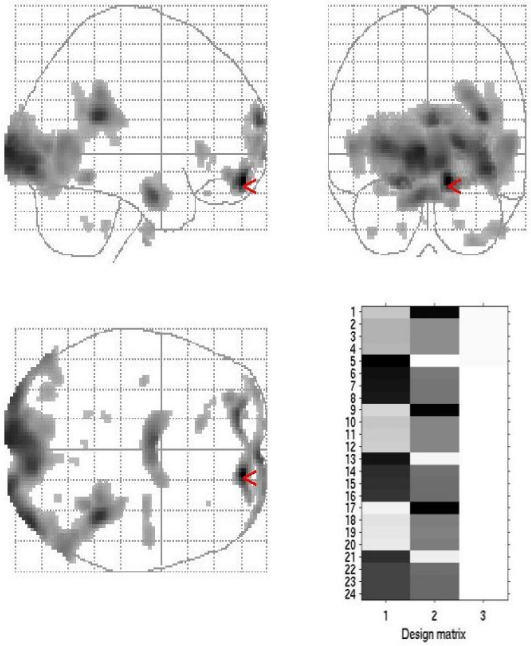
FIL Methods Group

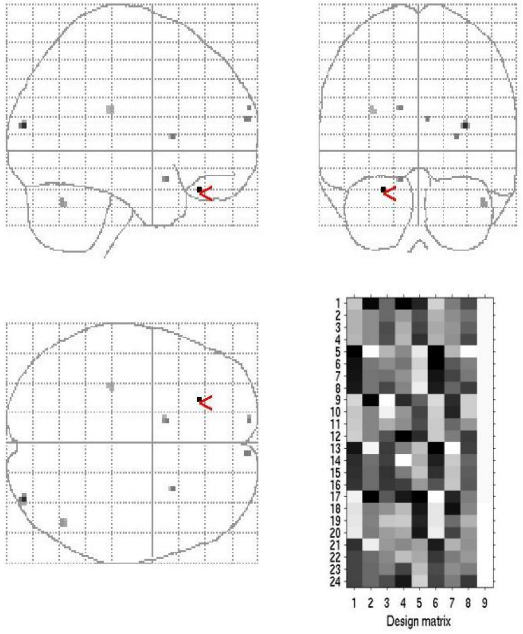
# Movement Correction

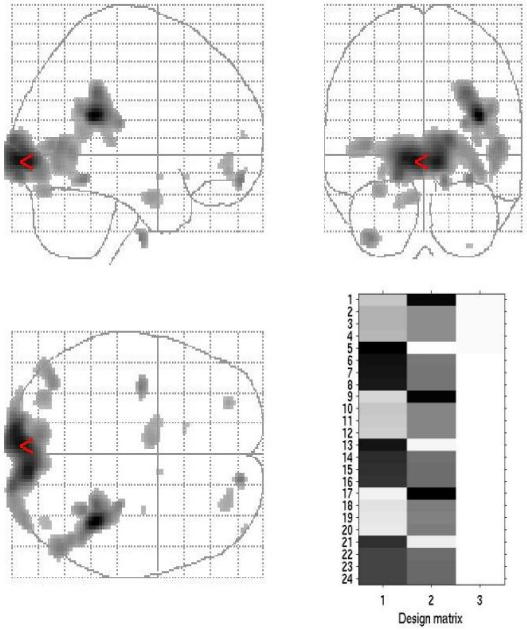
No correction

Covariate correction

Unwarp correction




$t_{max}$=13.38

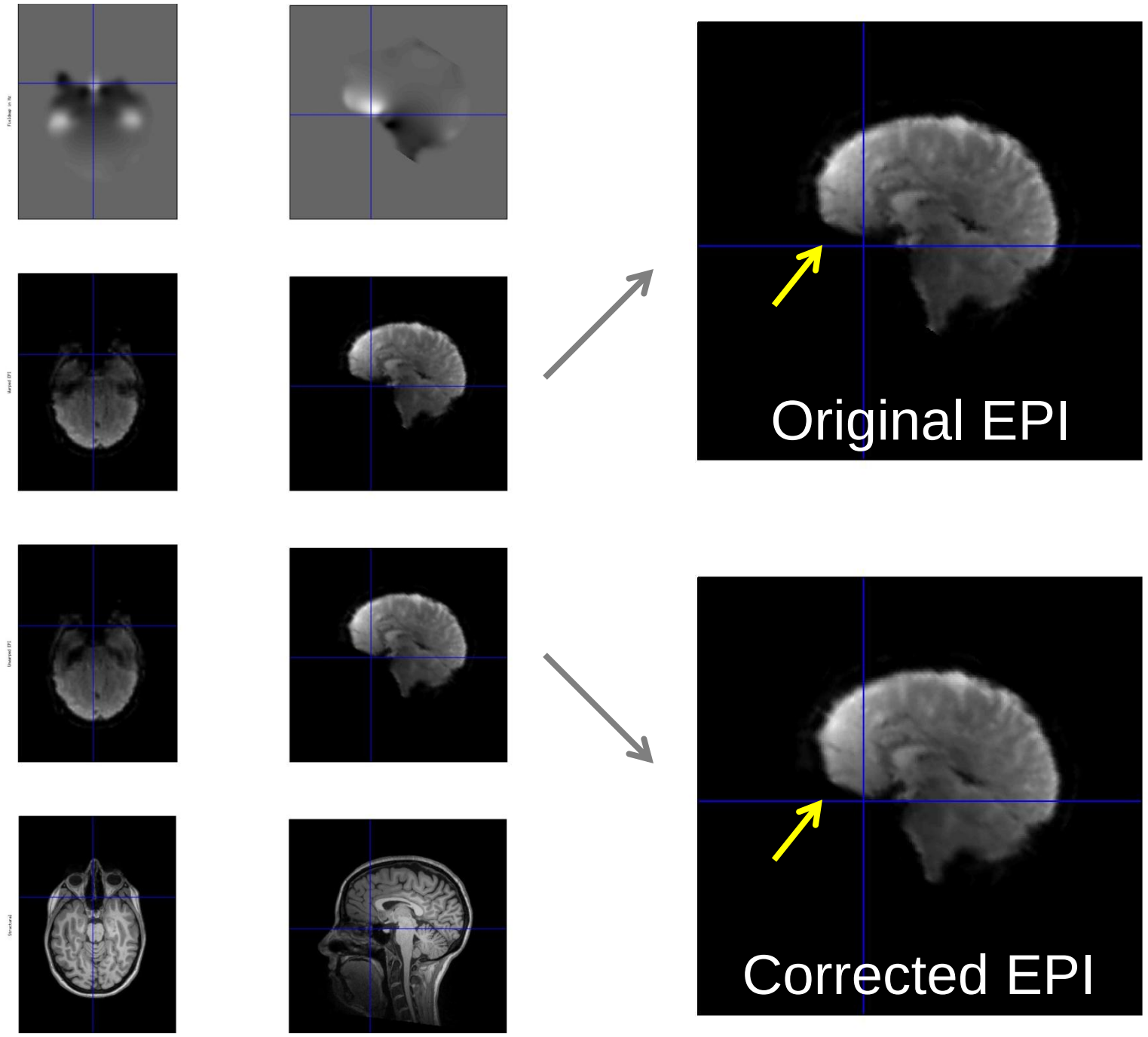
$t_{max}$=5.06

$t_{max}$=9.57

FIL Methods Group

# Mitigation of Head Motion Effects

- Prevention
- Prospective correction
- Realignment
- Covariate correction with head motion estimates
- Movement by distortion effect correction with fieldmaps
- Covariate correction with outlier identification


Original EPI
Corrected EPI

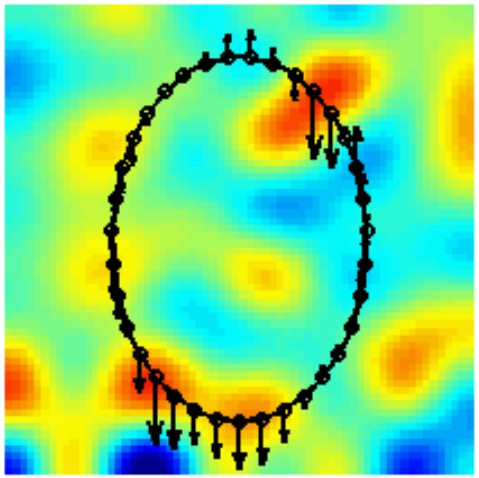
# Movement-by-Distortion Interactions

Time dependent fMRI signal changes are dependent upon:

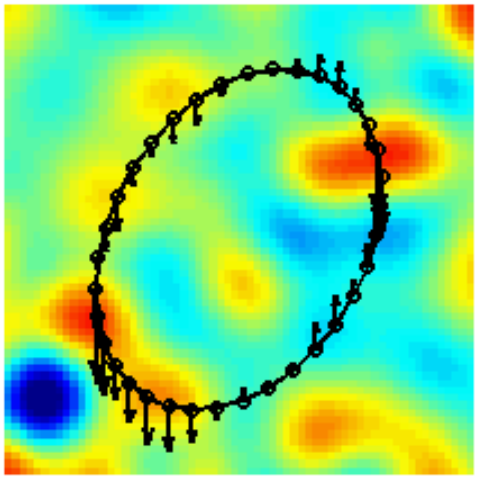
- position of the object in the scanner
  - geometric distortion
  - $B_0$ field effects
  - slice select gradient edge effects
- history of the position of the object
  - spin history effects

# Movement-by-Distortion Interactions

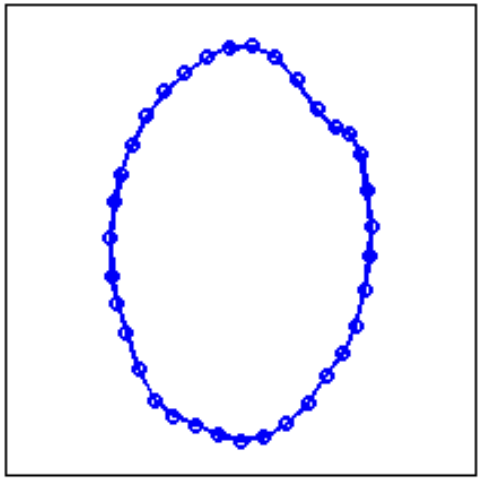
Original position



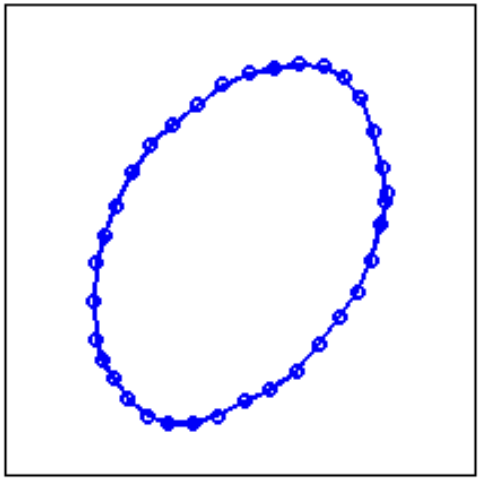
After rotation



Original position



After rotation



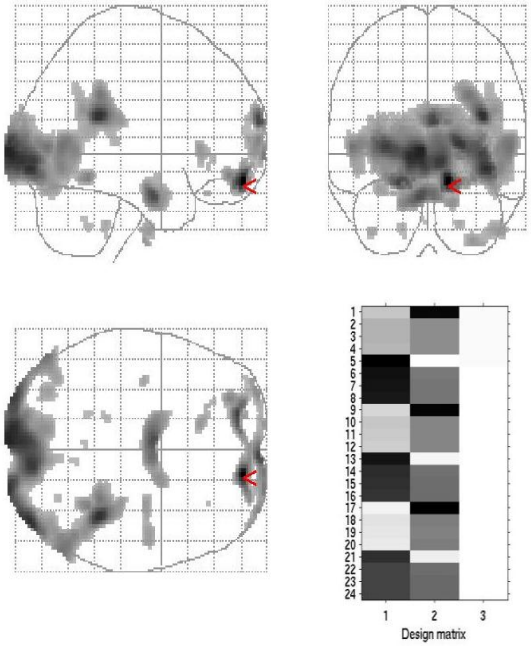
FIL Methods Group

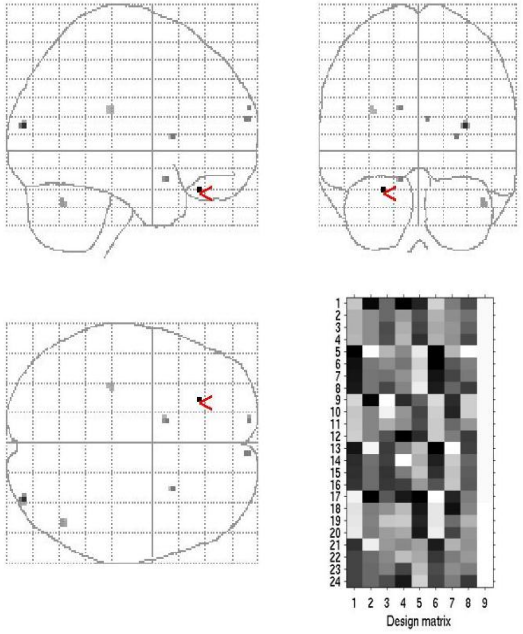
# Movement Correction

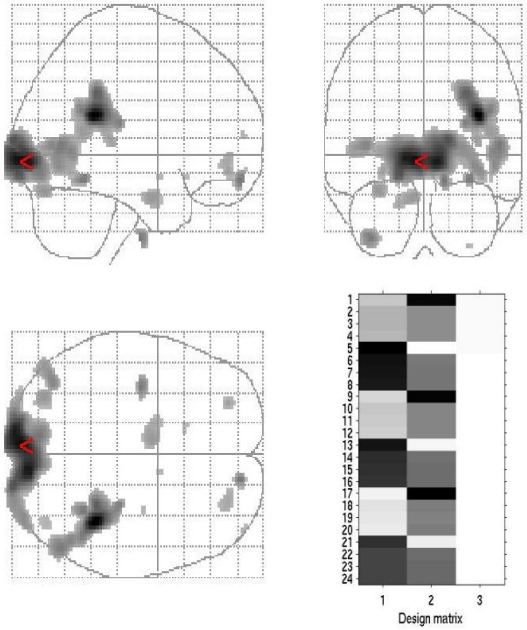
No correction

Covariate correction

Unwarp correction




$t_{max}$=13.38

$t_{max}$=5.06

$t_{max}$=9.57

FIL Methods Group

# Mitigation of Head Motion Effects

- Prevention
- Prospective correction
- Realignment
- Covariate correction with head motion estimates
- Movement by distortion effect correction with fieldmaps
- Covariate correction with outlier identification

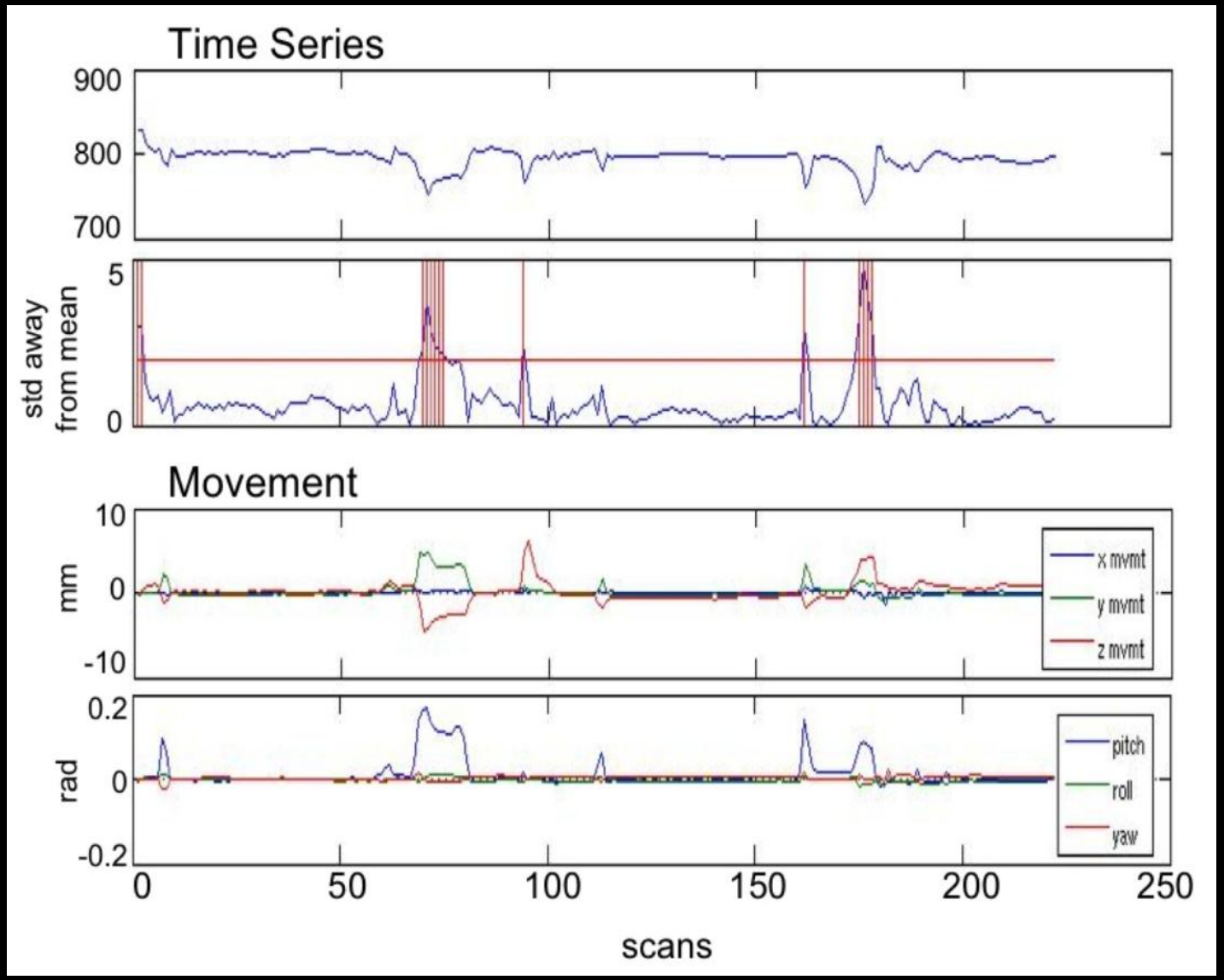
# Outlier Identification

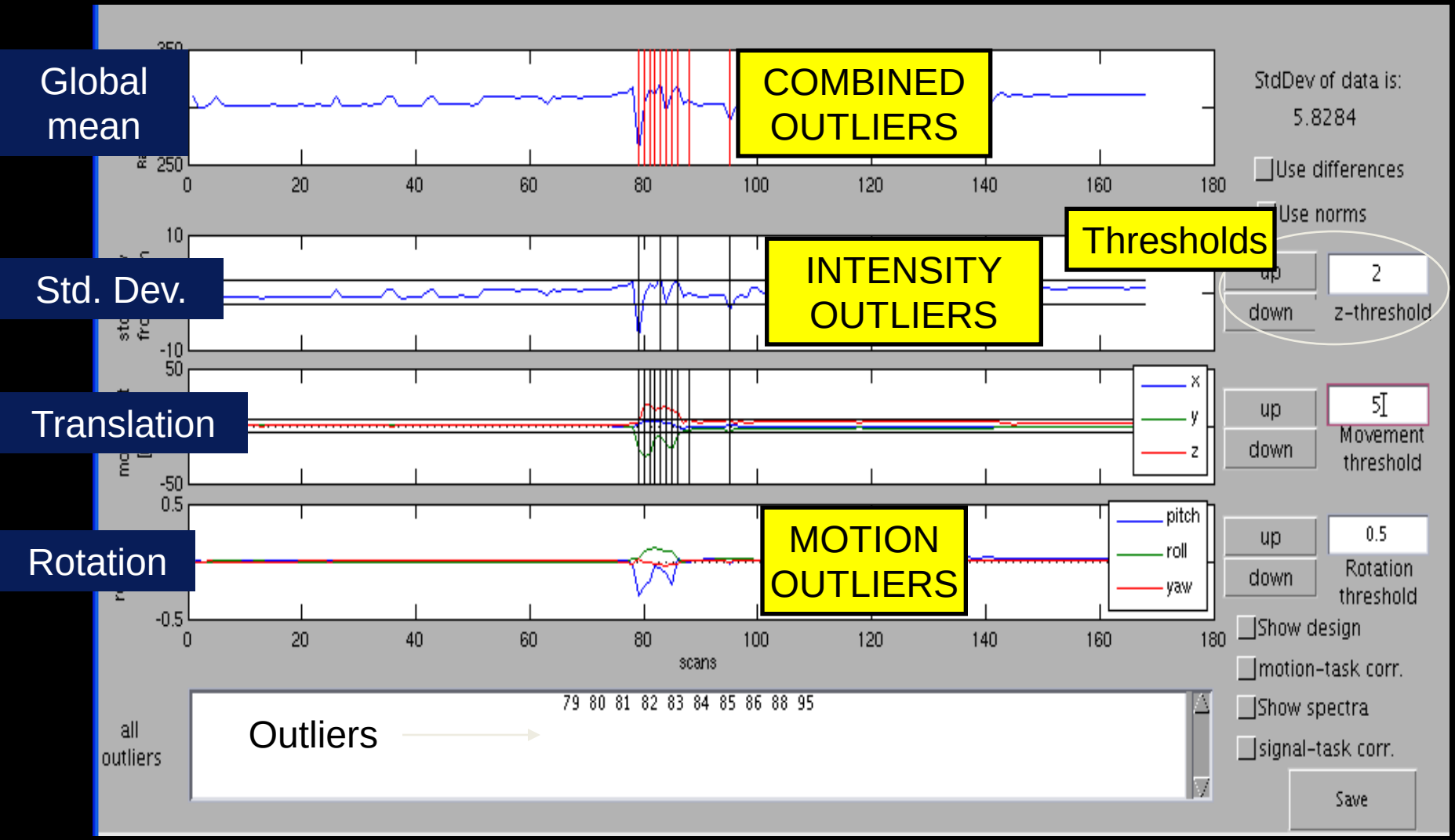
Global mean

Global Std. Dev.

Translation

Rotation




Global mean
Std. Dev.
Translation
Rotation
COMBINED OUTLIERS
INTENSITY OUTLIERS
MOTION OUTLIERS
Thresholds
StdDev of data is:
5.8284
Use differences
Use norms
up
down
2
z-threshold
5
Movement threshold
0.5
Rotation threshold
Show design
motion-task corr.
Show spectra
signal-task corr.
Save
x
y
z
pitch
roll
yaw
scans
all outliers
Outliers
79 80 81 82 83 84 85 86 88 95

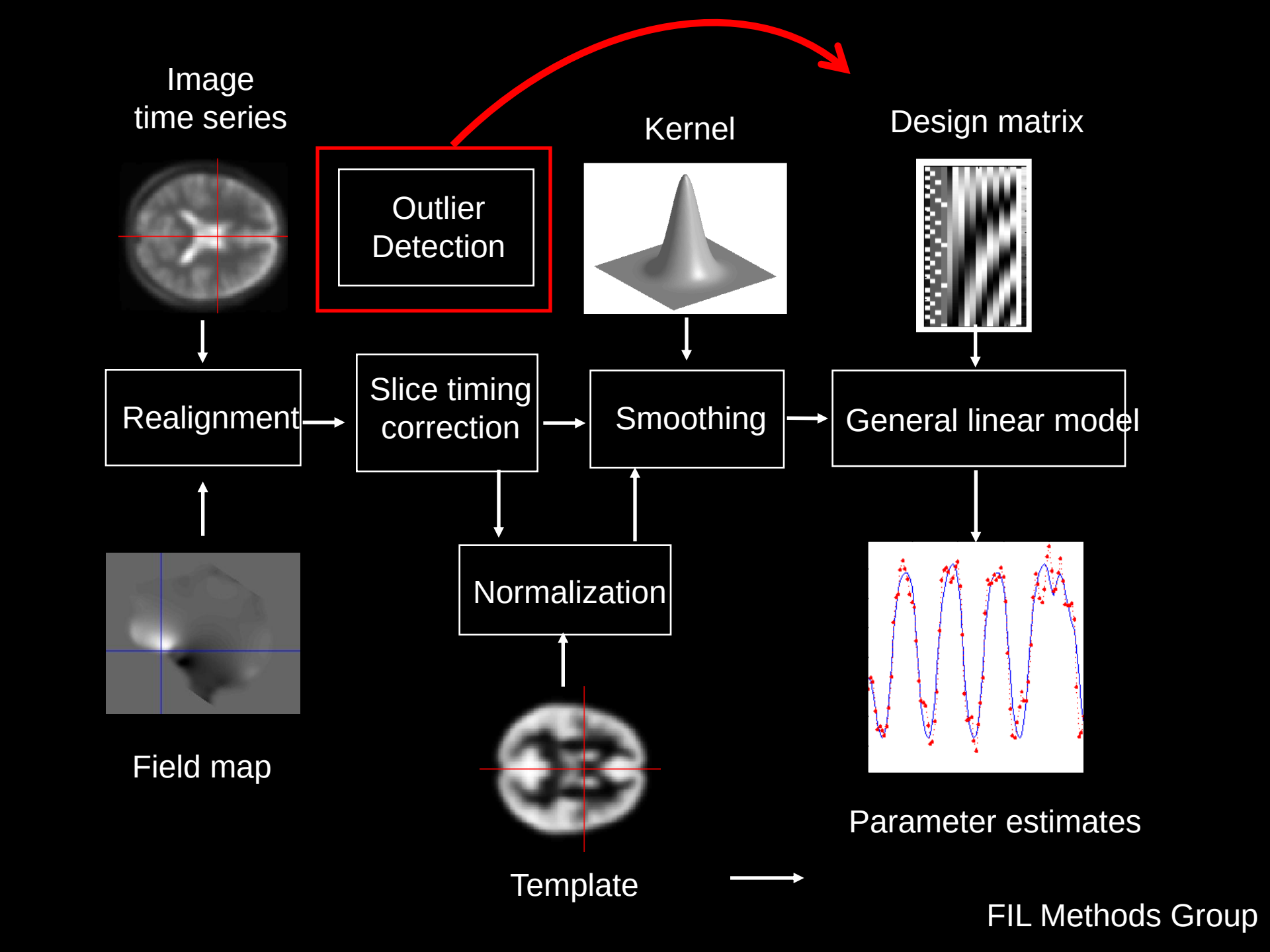
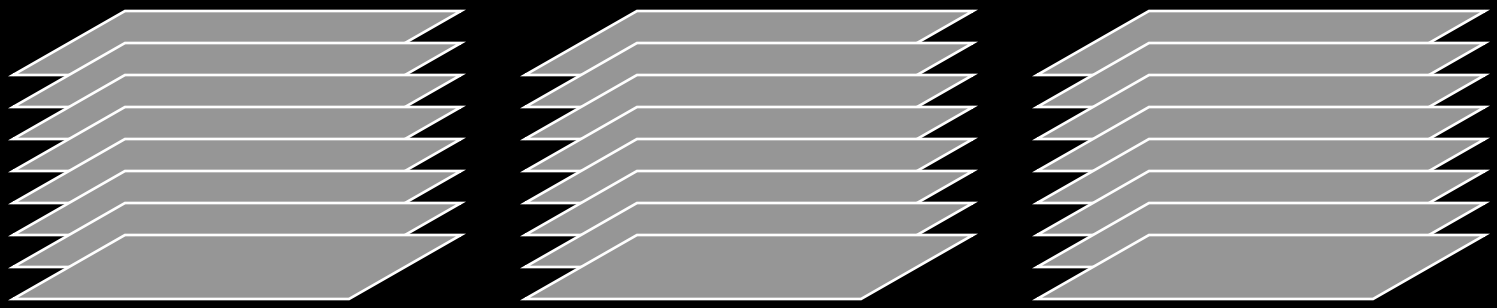


Image time series
Outlier Detection
Kernel
Design matrix
Realignment
Slice timing correction
Smoothing
General linear model
Normalization
Field map
Template
Parameter estimates
FIL Methods Group

# fMRI Preprocessing

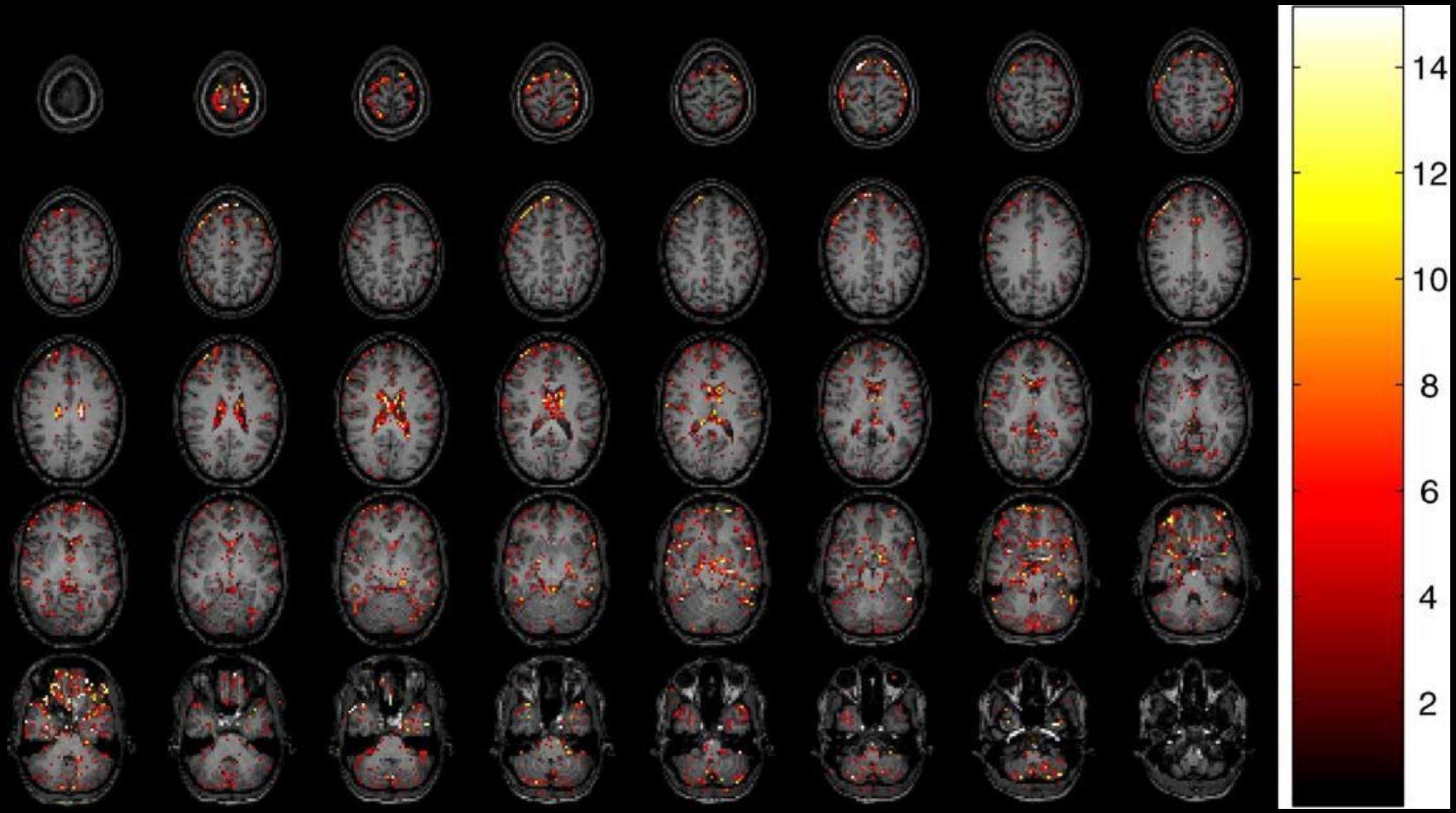
- Slice timing correction
- Geometric distortion correction
- Head motion correction
- Temporal filtering
- Intensity normalization
- Spatial normalization
- Spatial filtering

# Temporal Filtering



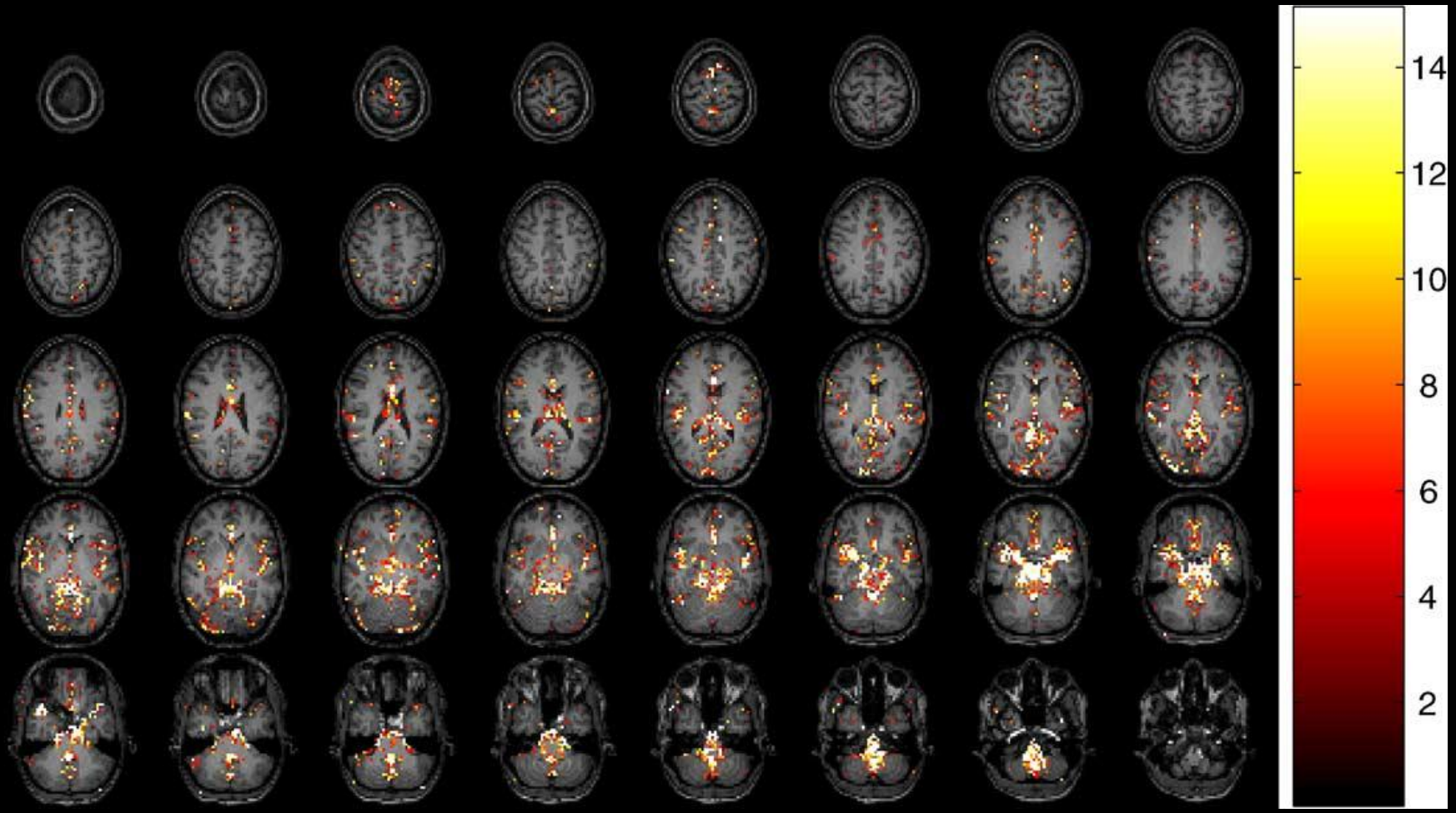
Time ⟶

# Respiration Modulates BOLD Contrast

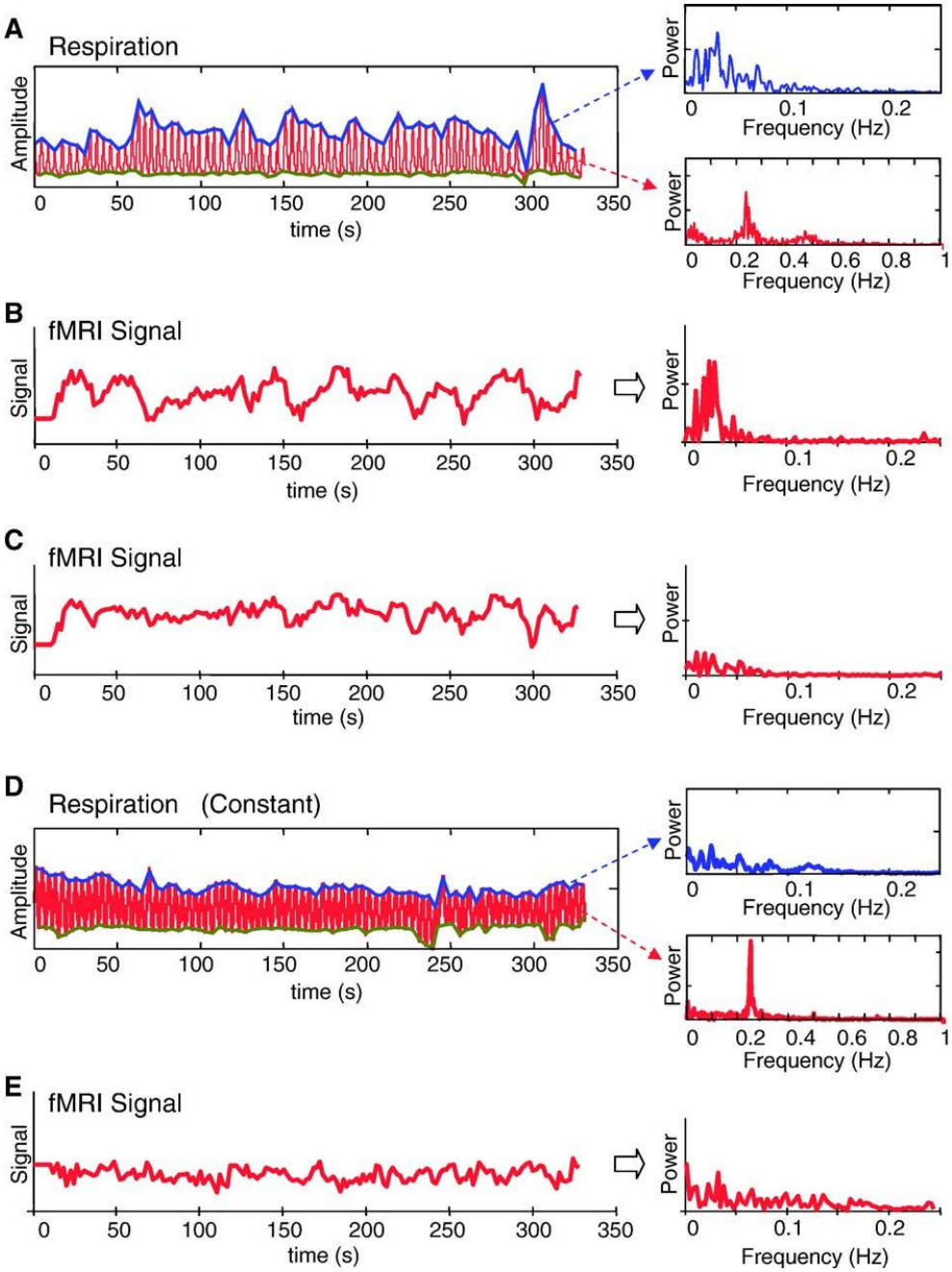



Lund et al., Neuroimage (2006)

# Cardiac Motion Modulates BOLD Contrast



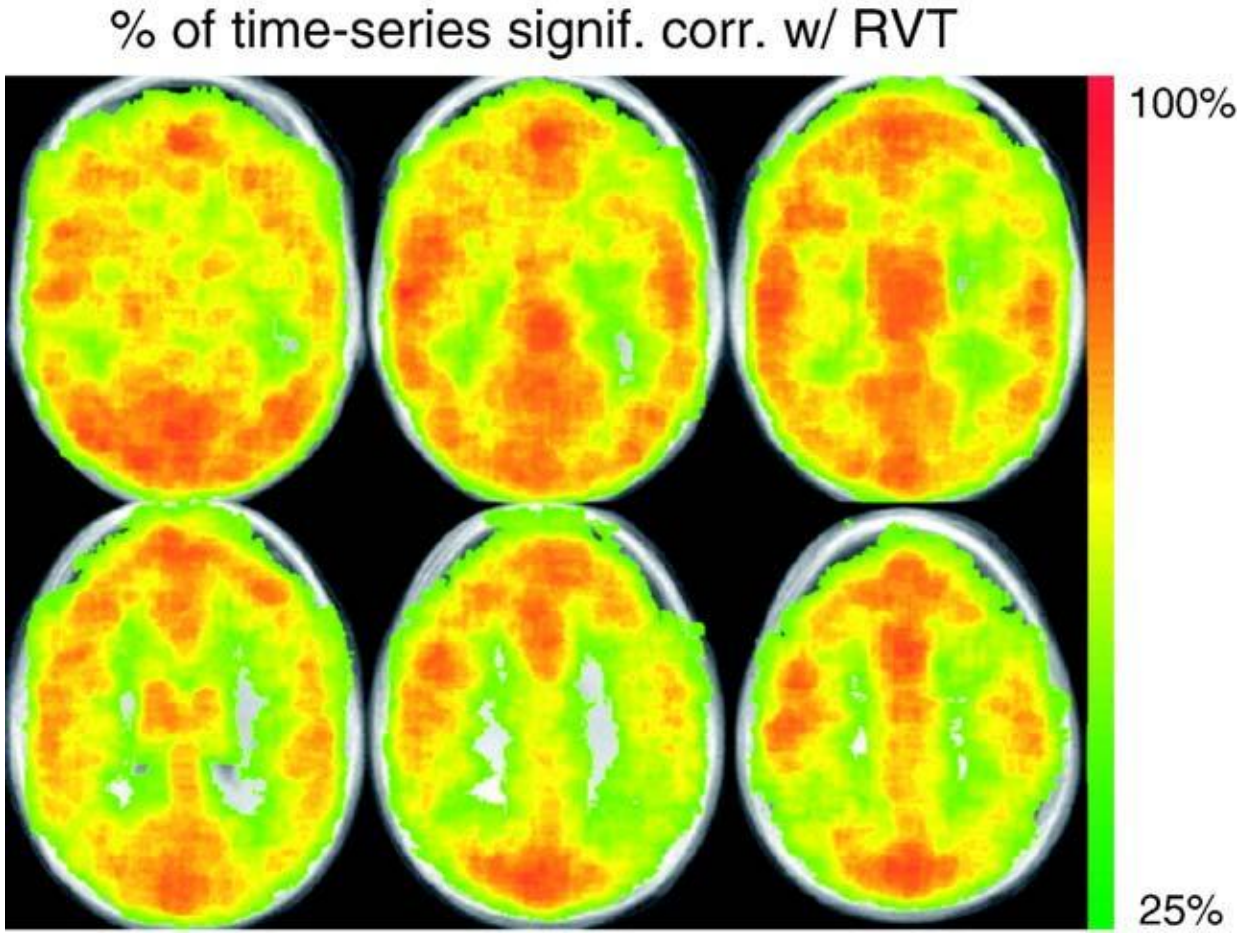

Lund et al., Neuroimage (2006)




# Respiration Modulates BOLD Contrast Time Series

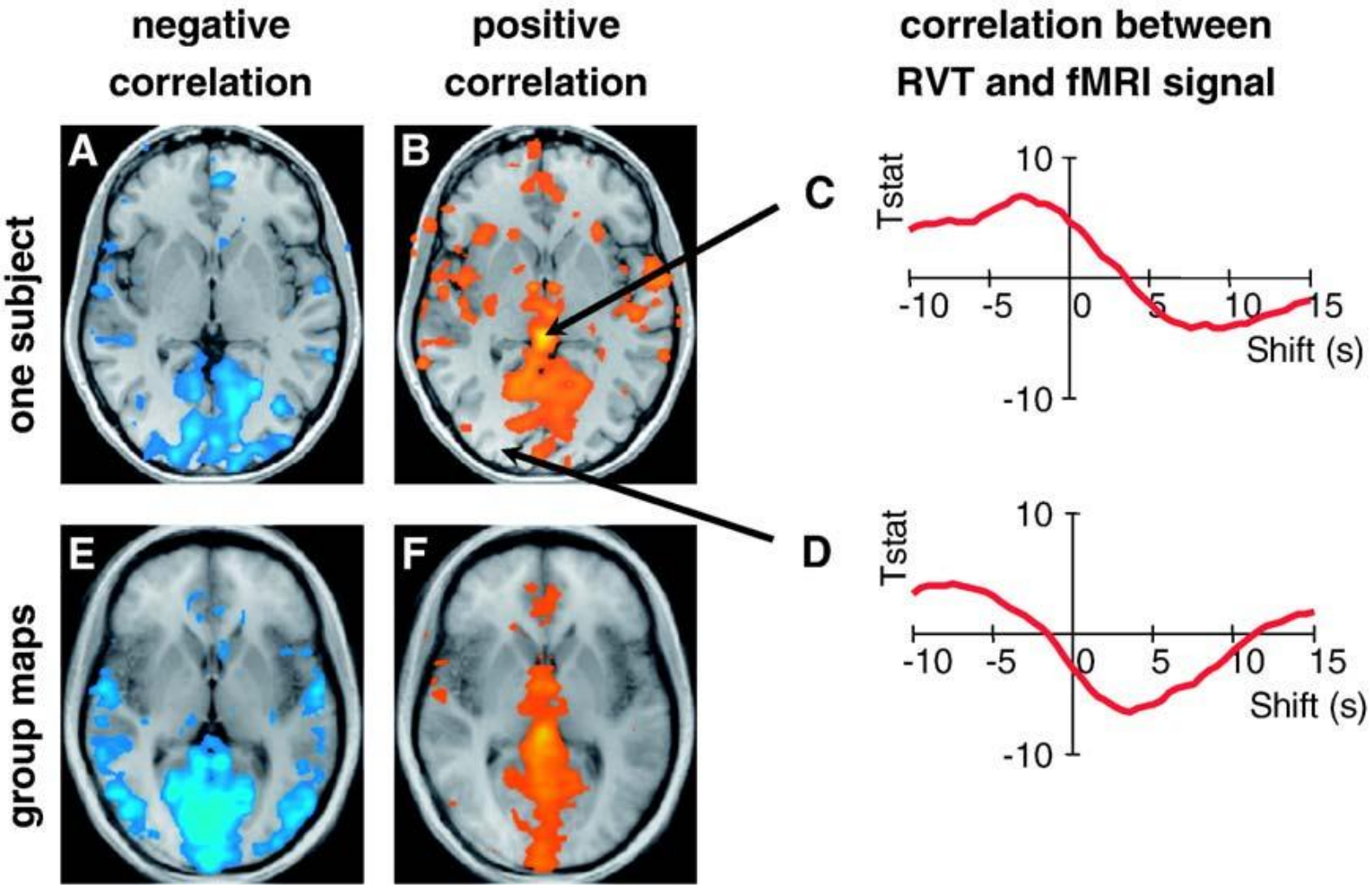
Birn et al., Neuroimage (2006)

# Respiration Modulates BOLD Contrast



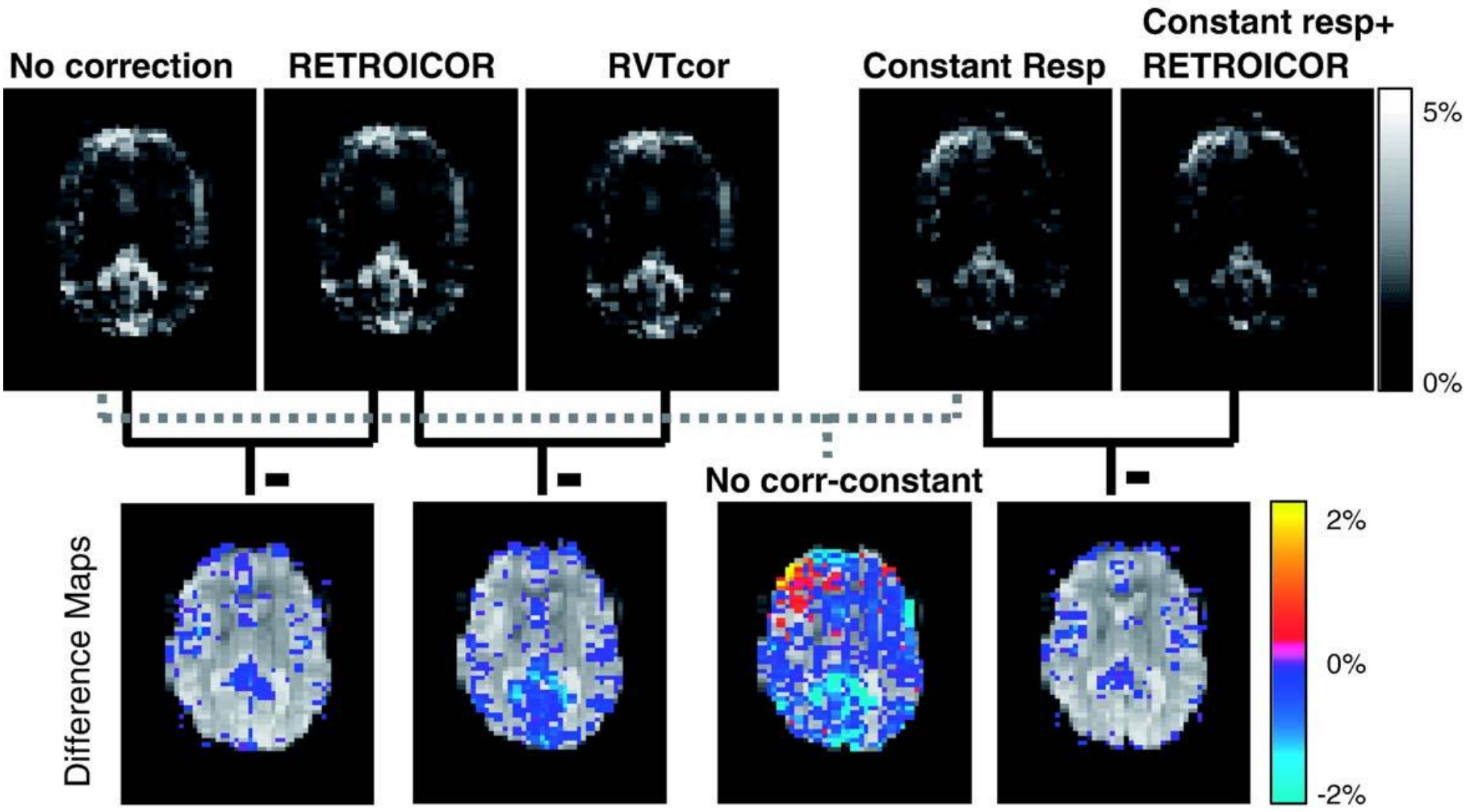

Birn et al., Neuroimage (2006)

# Respiration Modulates BOLD Contrast at Rest




Birn et al., Neuroimage (2006)

# Respiration Modulates BOLD Contrast at Rest




Birn et al., Neuroimage (2006)

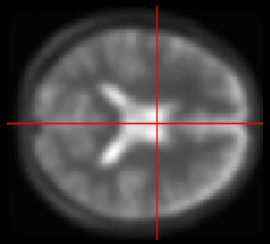
# Cardiovascular and Respiratory Artifacts

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).

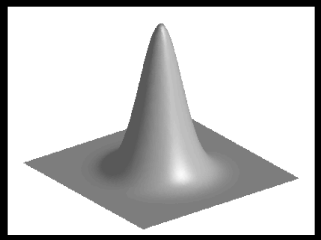
Hu et al., Retrospective estimation and correction of physiological fluctuation in functional MRI. Magn. Reson. Med. 34:201-212 (1995).

Image time series

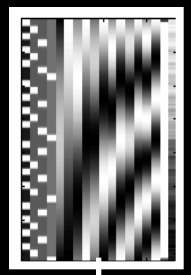


Outlier Detection

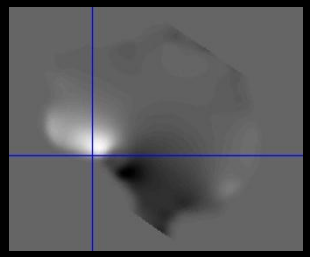
Kernel



Design matrix

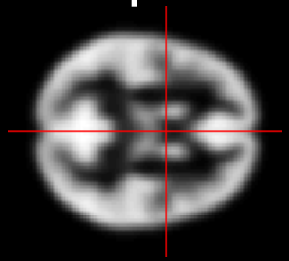


Realignment → Slice timing correction → Smoothing → General linear model

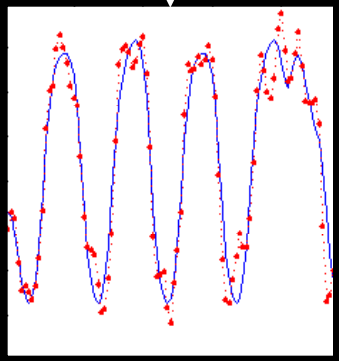


Field map

Normalization

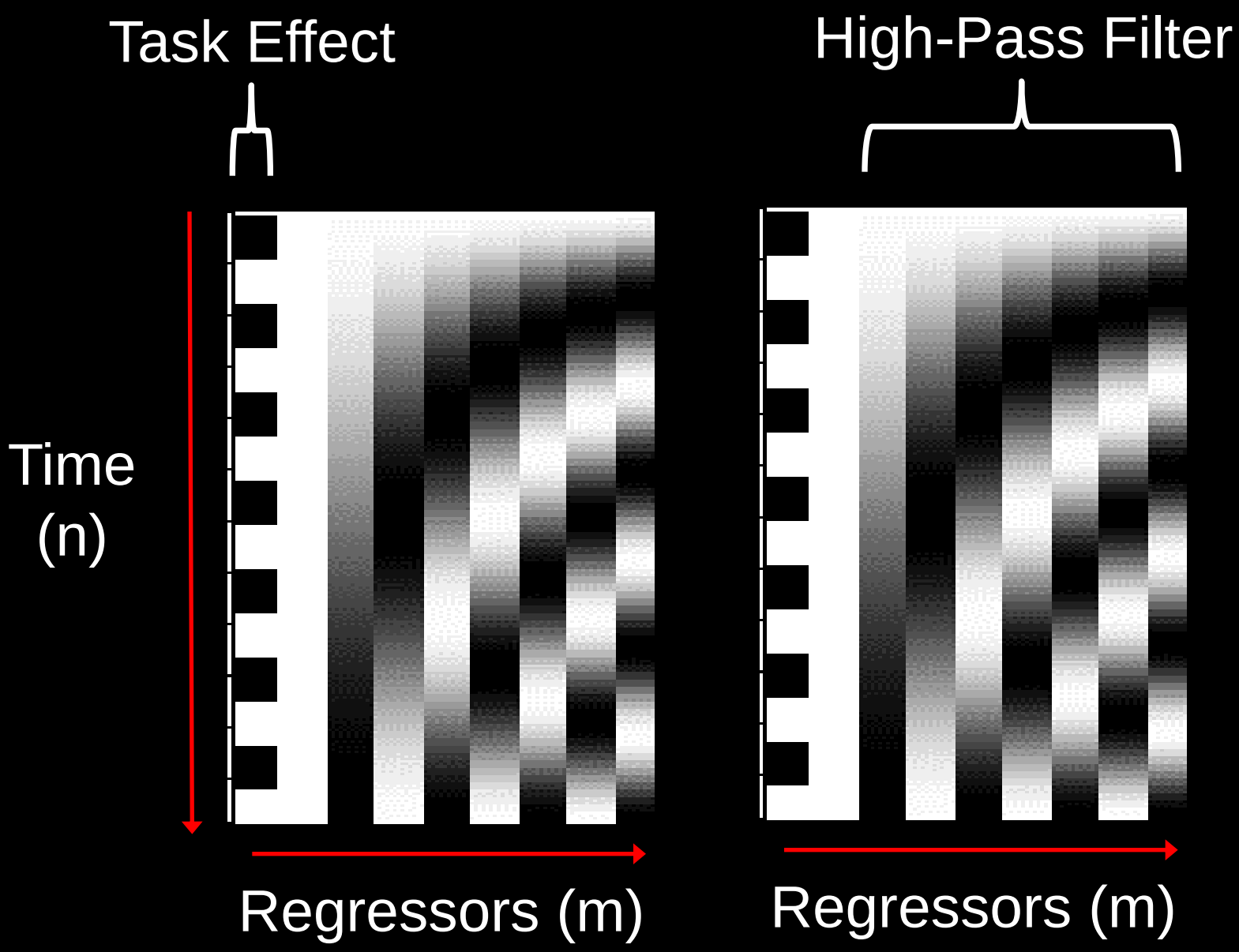


Template



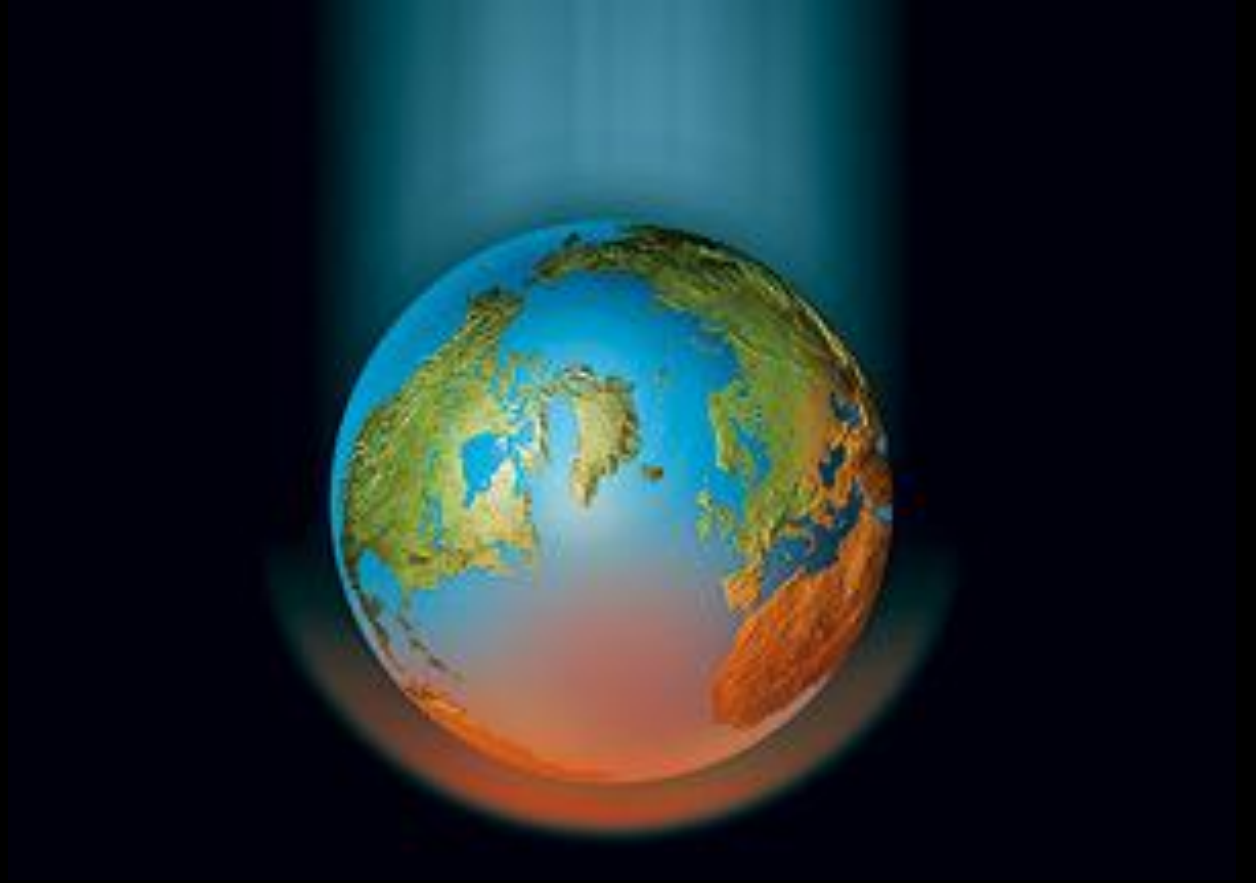
Parameter estimates

FIL Methods Group


Task Effect
High-Pass Filter
Time
(n)
Regressors (m)
Regressors (m)

# fMRI Preprocessing

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



# Global signal changes

# Global Intensity Variation

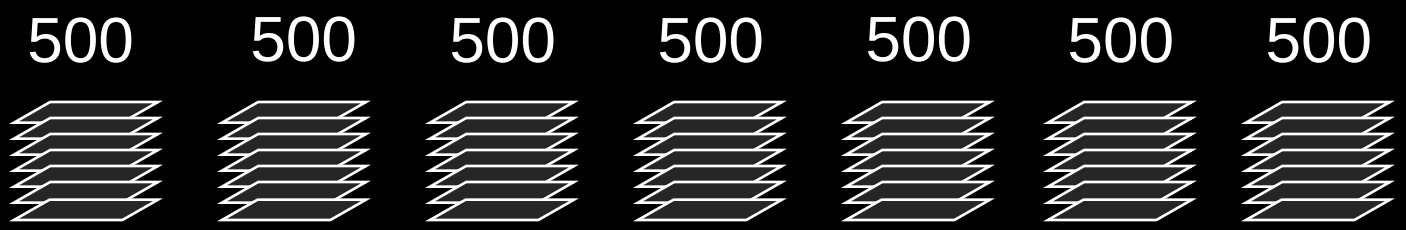
- machine instability
- global blood flow changes
  - arousal
  - respiratory effects
  - drug effects

# Global Intensity Normalization


Time ⟶

Intensity normalization per time point

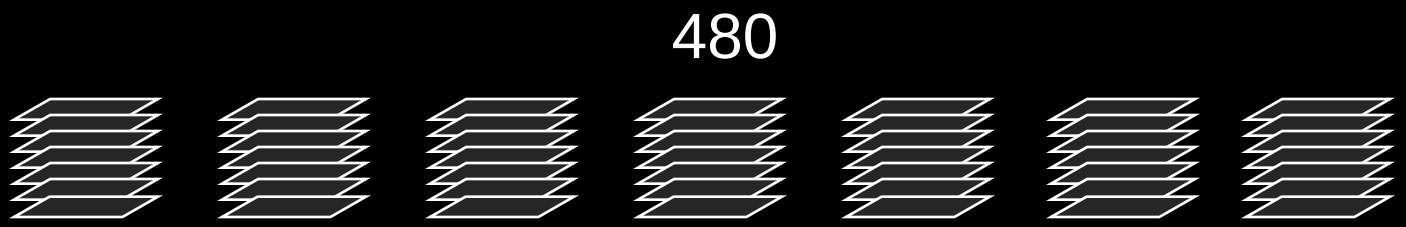
# Global Intensity Normalization



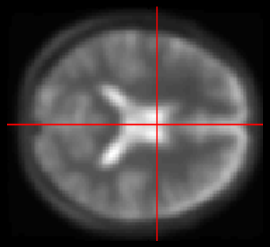

Time ⟶

Intensity normalization per time point

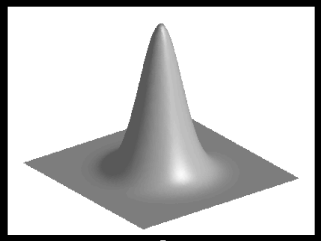
# Global Intensity Normalization

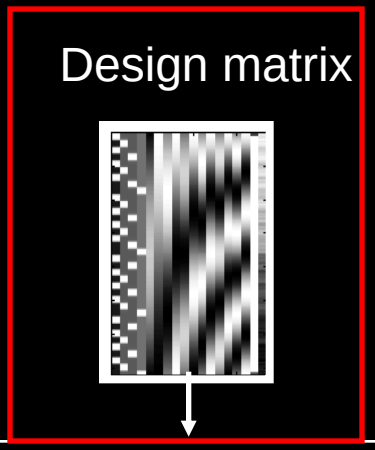



Intensity normalization per session




Outlier Detection



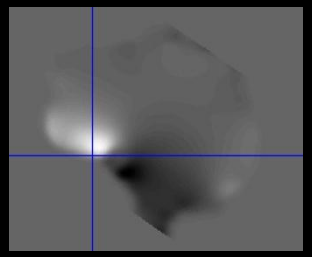




Realignment

Slice timing correction

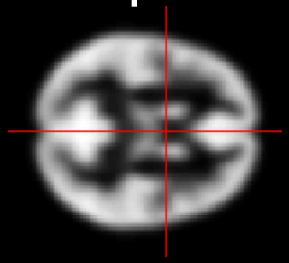
Smoothing

General linear model

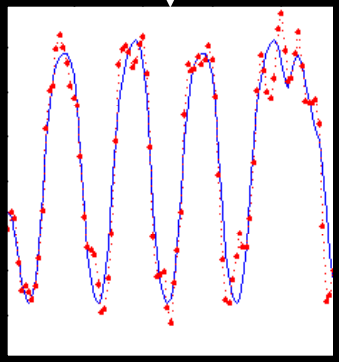


Field map

Normalization



Template



Parameter estimates

FIL Methods Group

# fMRI Preprocessing

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# fMRI Preprocessing

- Slice timing correction
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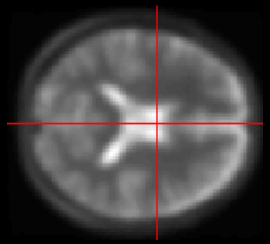
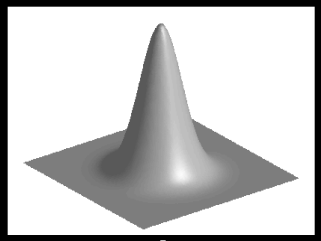
# Spatial filtering

Image time series

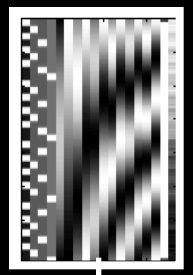


Outlier Detection

Kernel



Design matrix



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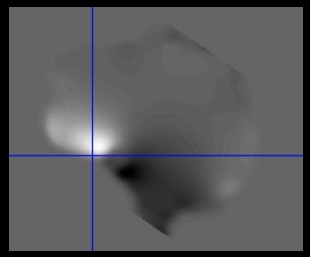
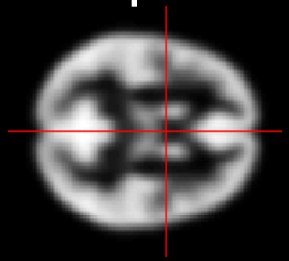
General linear model

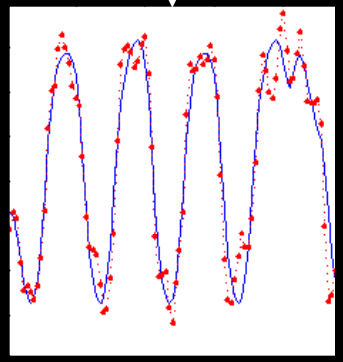


Field map

Normalization



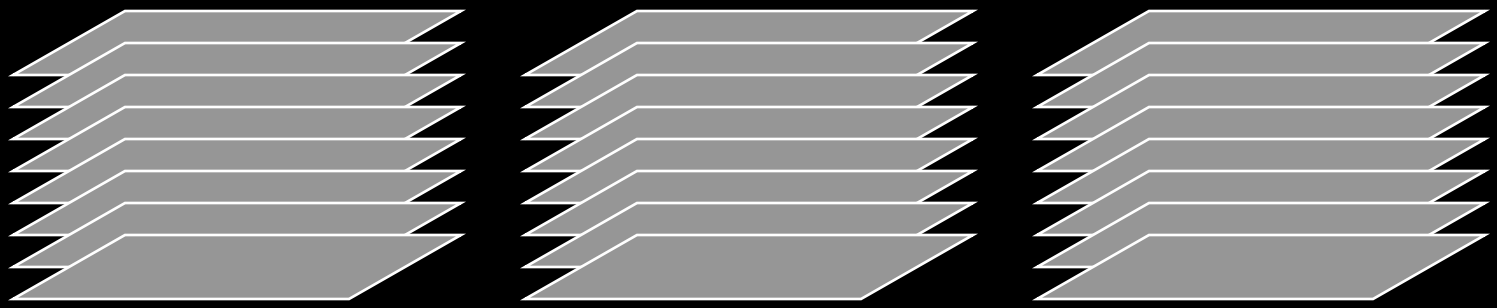
Template



Parameter estimates

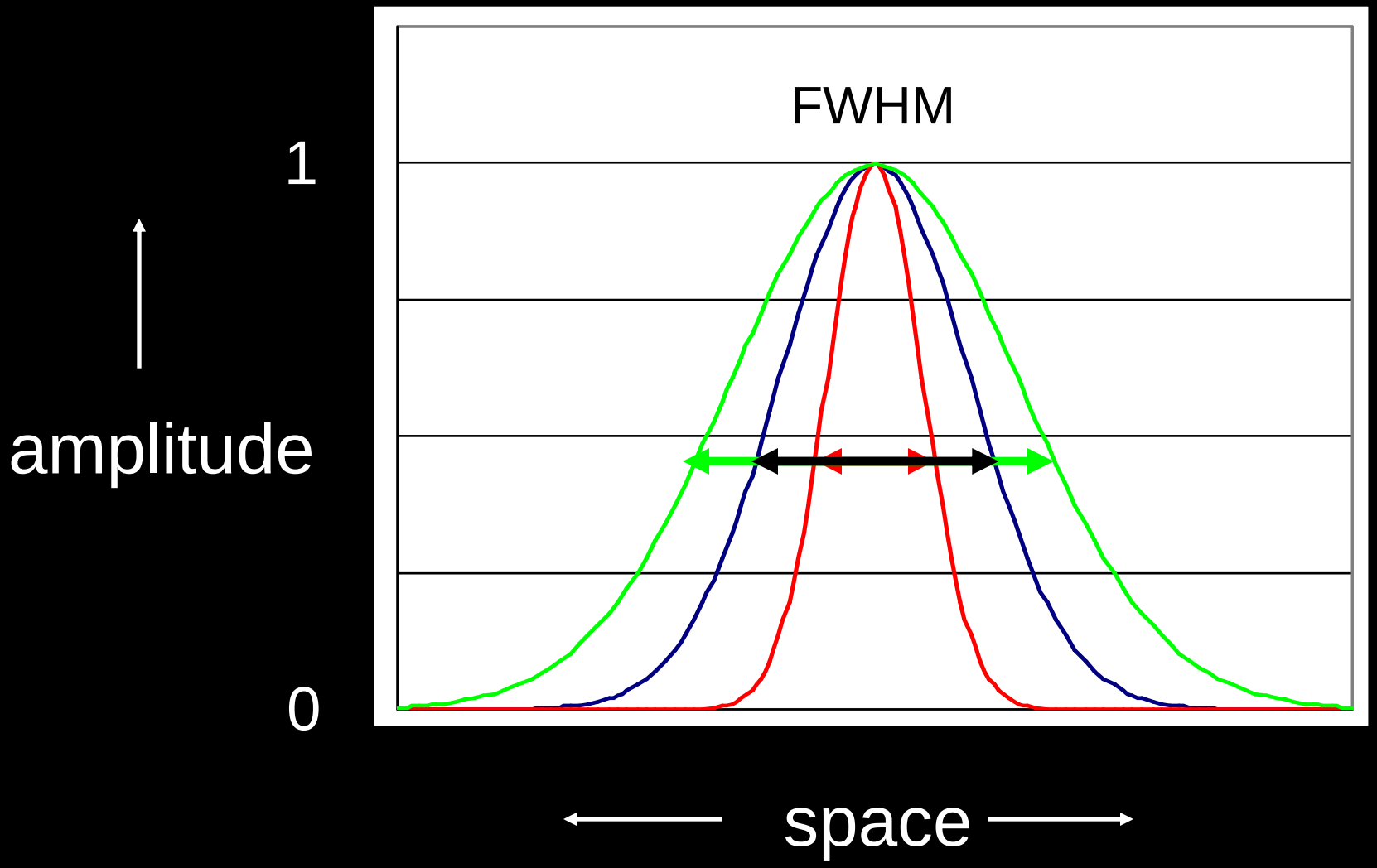
FIL Methods Group

# Spatial Filtering

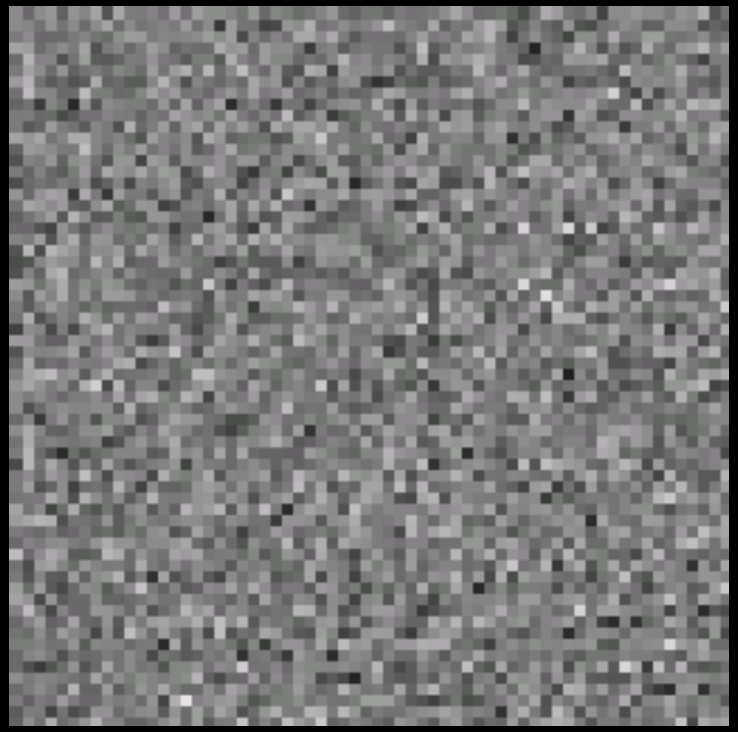


Time ⟶

# 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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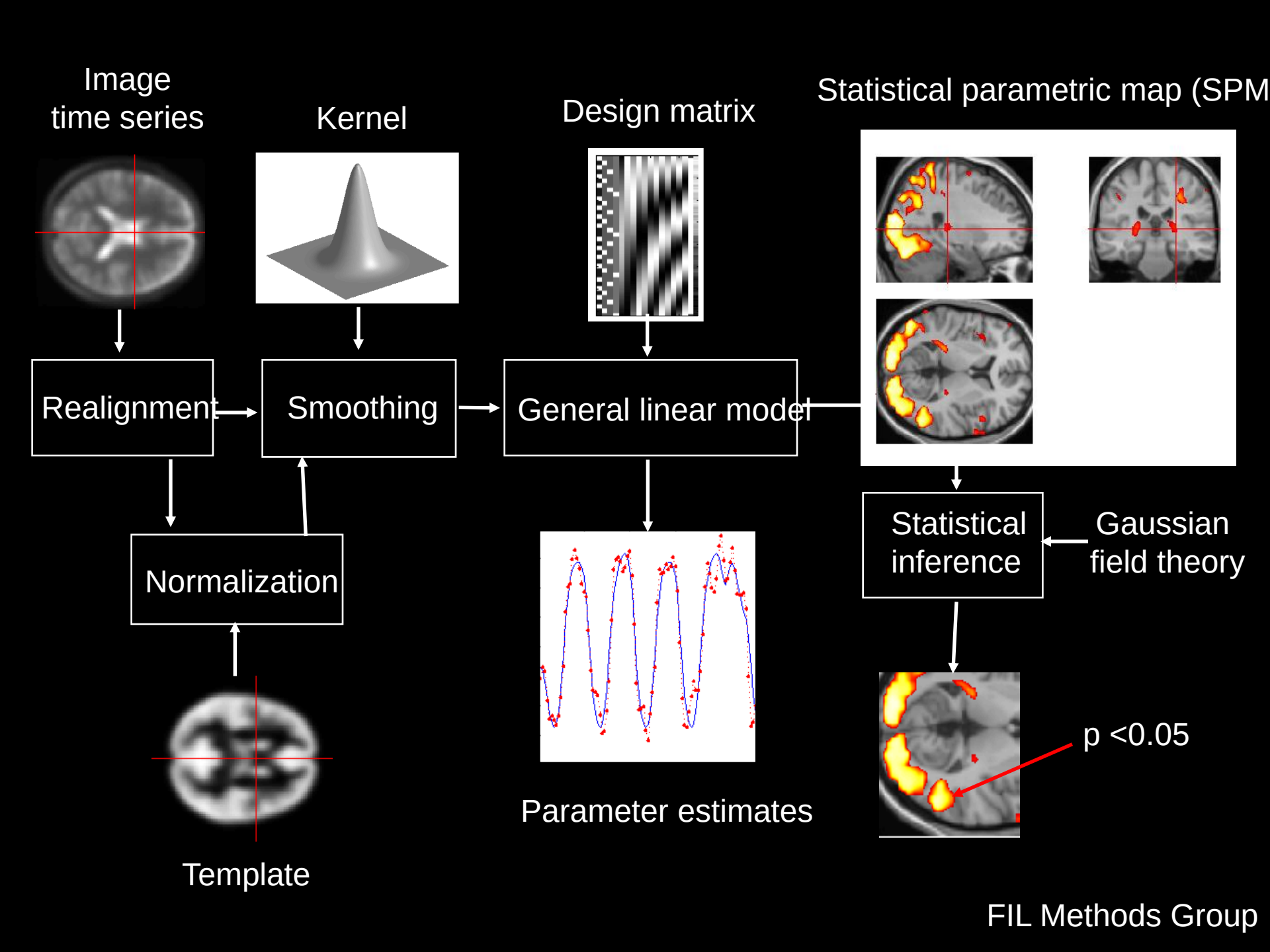
Image time series
Kernel
Design matrix
Statistical parametric map (SPM
Realignment
Smoothing
General linear model
Normalization
Statistical inference
Gaussian field theory
p <0.05
Parameter estimates
Template
FIL Methods Group

# Further Information

References for the material covered in the lecture and additional material are available at:

www.neurometrika.org

Contact: zeffiro@neurometrika.org