NeuroImaging Training Program

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Preprocessing

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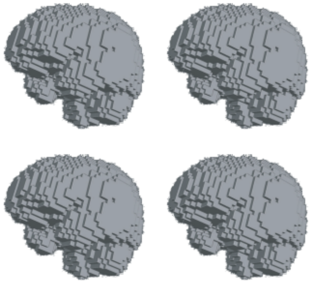
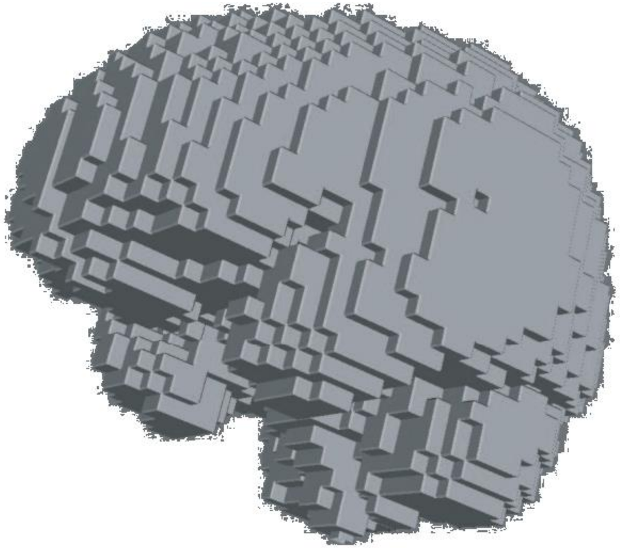
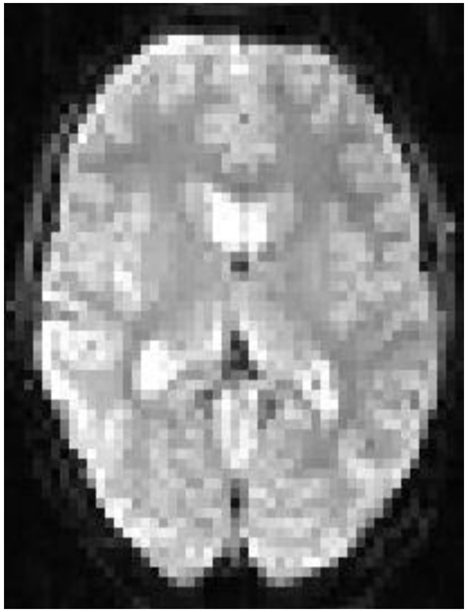
UCLA Psychology

NITP 2015

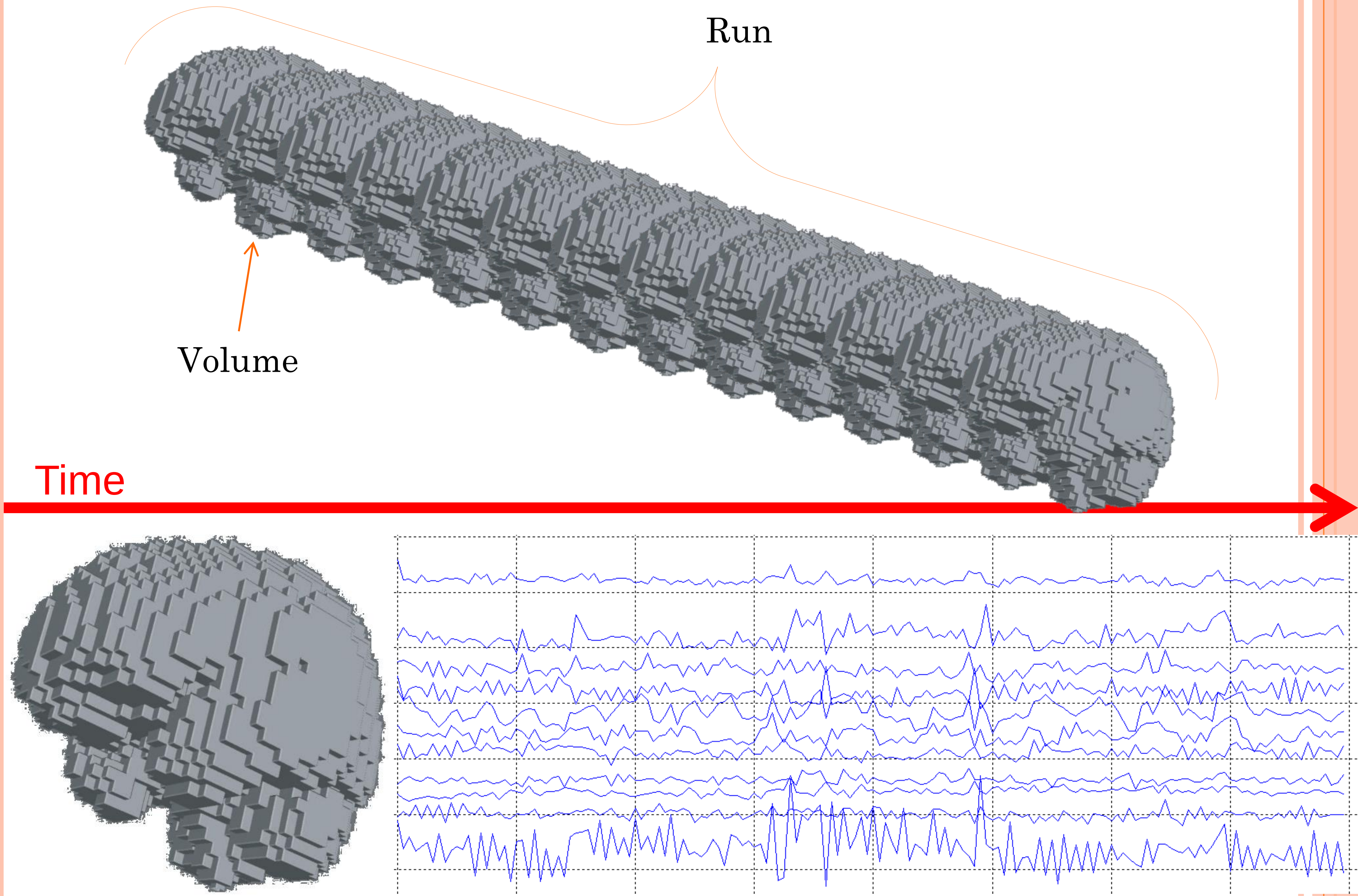
Typical dataset







TYPICAL DATASET



Typical fMRI analysis sequence

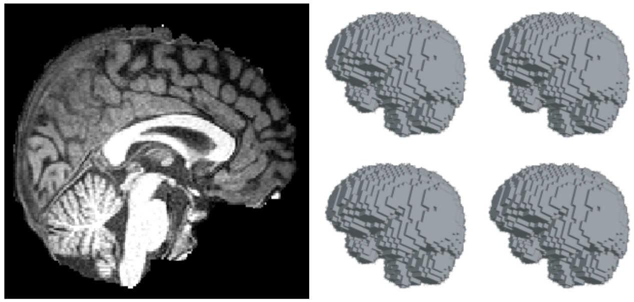
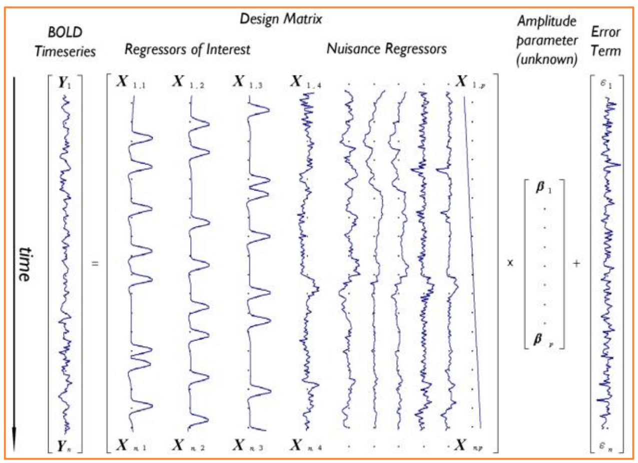
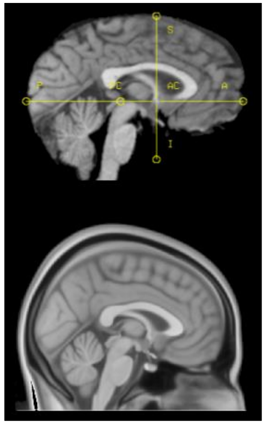


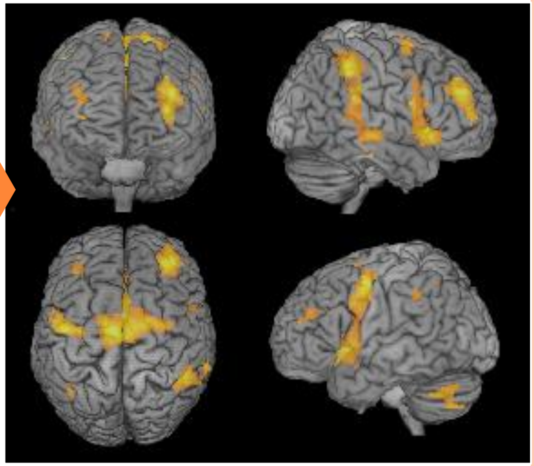
Image Pre-processing

Single Subject Analysis





Group Analysis



Preprocessing: what/why?

Preprocessing is a series of data transformations ("data conditioning") aimed at reducing sources of noise

Sources of noise in fMRI

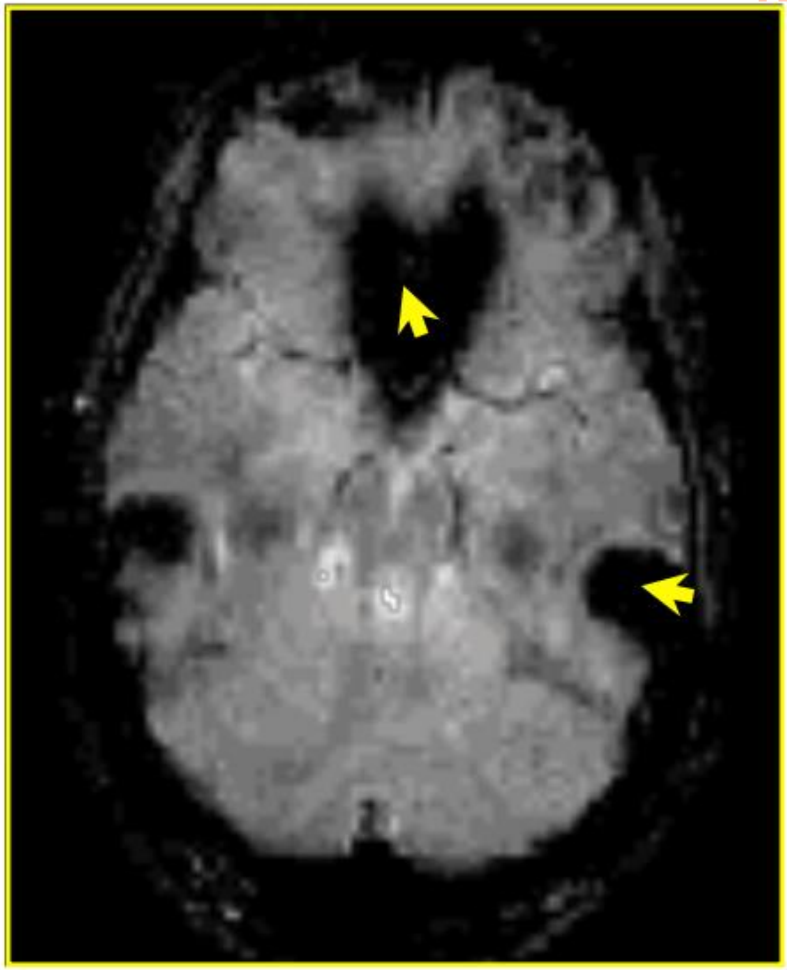
1. Hardware & acquisition related:
   - Thermal noise (intrinsic noise)
   - System noise
   - Field inhomogeneities
   - Slice acquisition timing
2. Subject related
   - Oscillatory physiological noise (heartbeat, respiration)
   - Field inhomogeneities
   - Head motion
   - Psychological (alertness, learning)
3. White noise

Correcting for noise in fMRI

1. Before scanning (maximize SNR):
   i. Choose good technology (field strength, coils, …)
   ii. Choose good sequence (TE, voxel size, …)
   iii. Be informed about the healthy of your scanner (QA)
2. After scanning (detect & correct):
   i. Look at your data (i.e., data quality check)
   ii. Look at your data (again and again)
   iii. Pre-processing ("standard", ICA)
   iv. Re-look at your data

Sequence Parameters: TE

Short TE



Long TE

S Clare

Correcting for noise in fMRI

1. Before scanning (maximize SNR):
   i. Choose good technology (field strength, coils, ...)
   ii. Choose good sequence (TE, voxel size, ...)
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2. After scanning (detect & correct):
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   iii. Pre-processing ("standard", ICA)
   iv. Re-look at your data

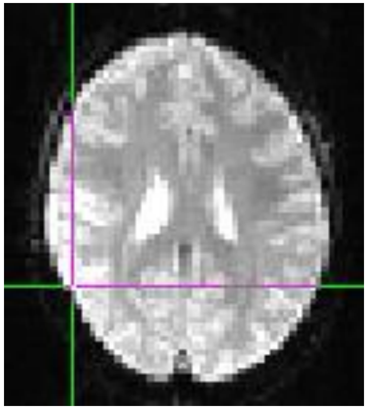
Preprocessing: what/why?

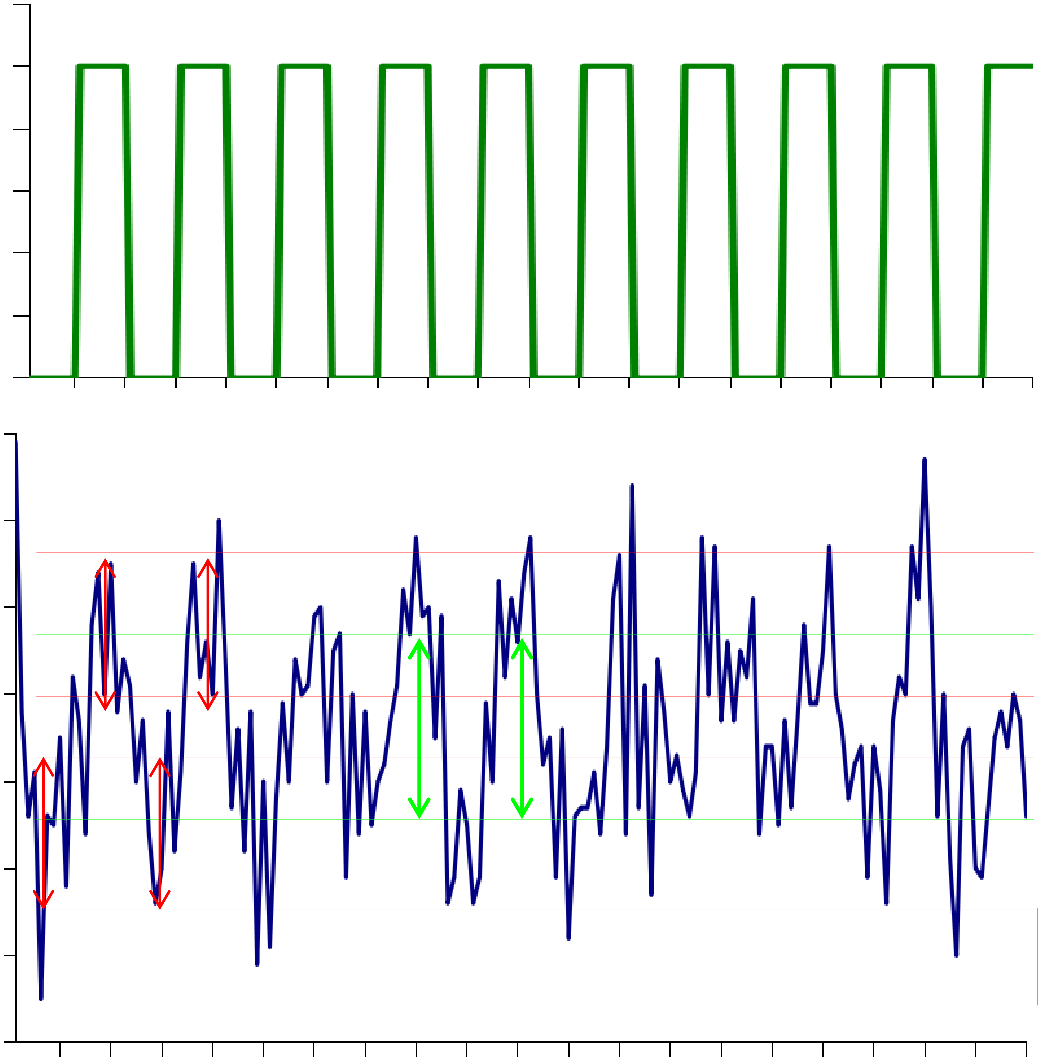
Preprocessing is a series of data transformations ("data conditioning") aimed at reducing sources of noise in order to:

1) Increasing sensitivity of analysis (SNR)
2) Ensuring validity of the statistical model

Sample Experiment: SNR

TR = 2s
Vols = 160
10 AB Cycles
Cycle = 8A + 8B





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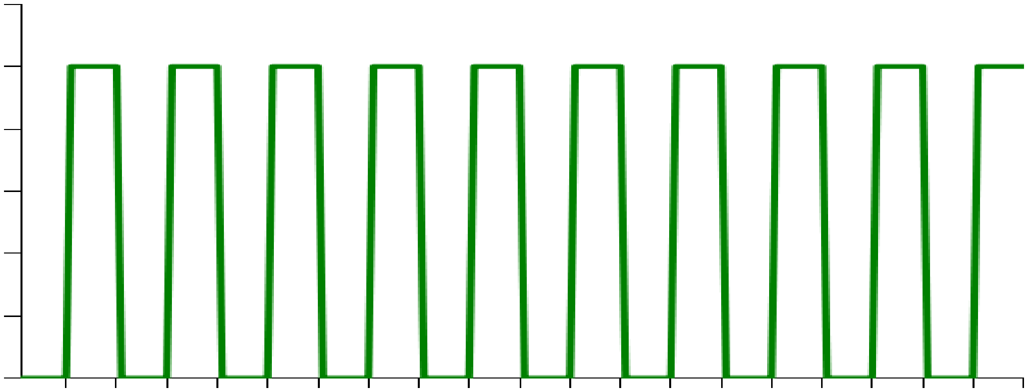

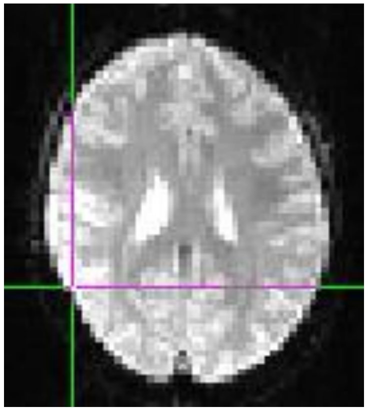

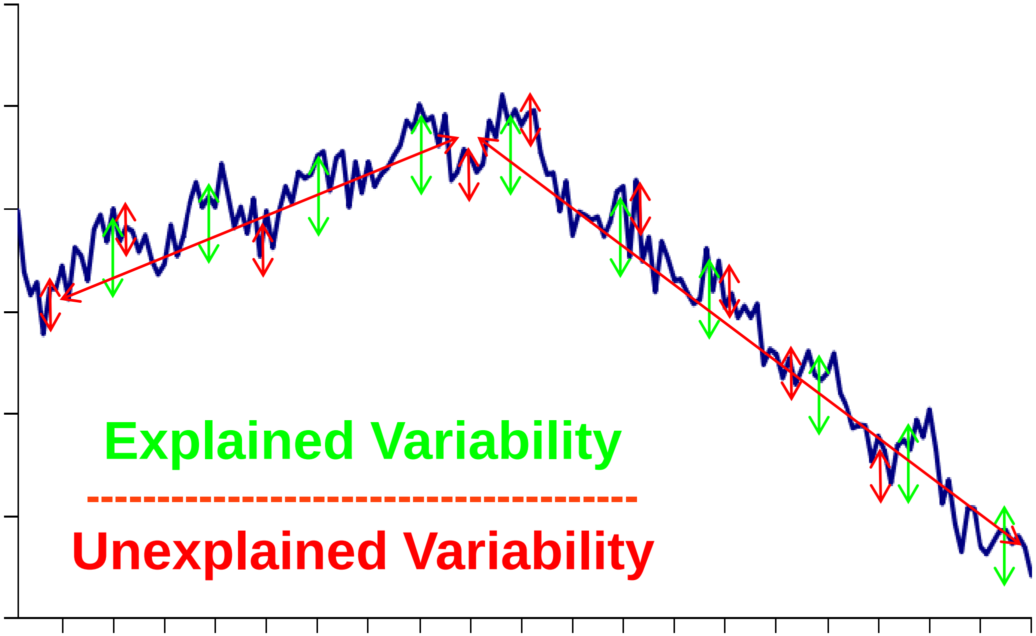

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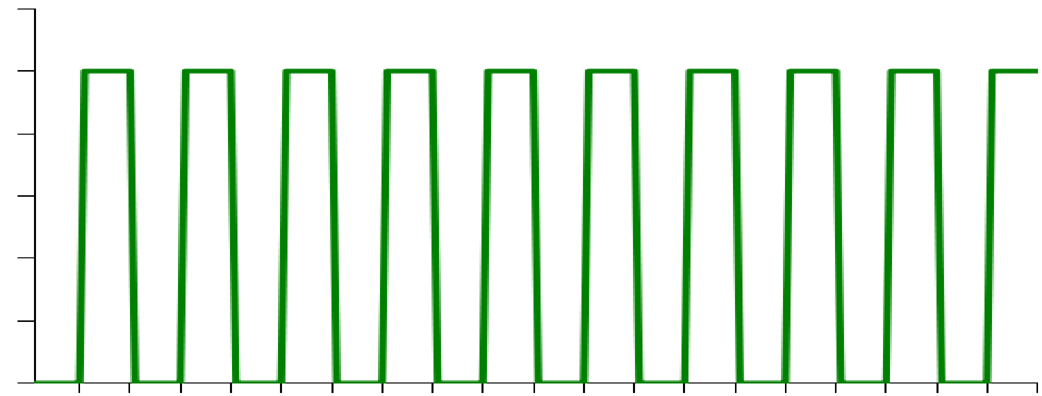

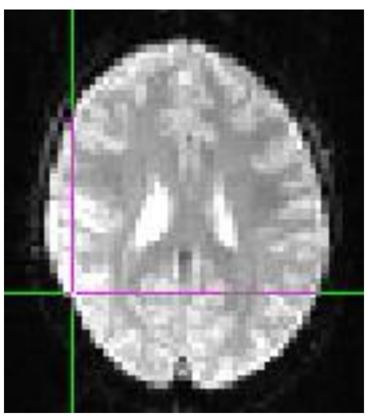

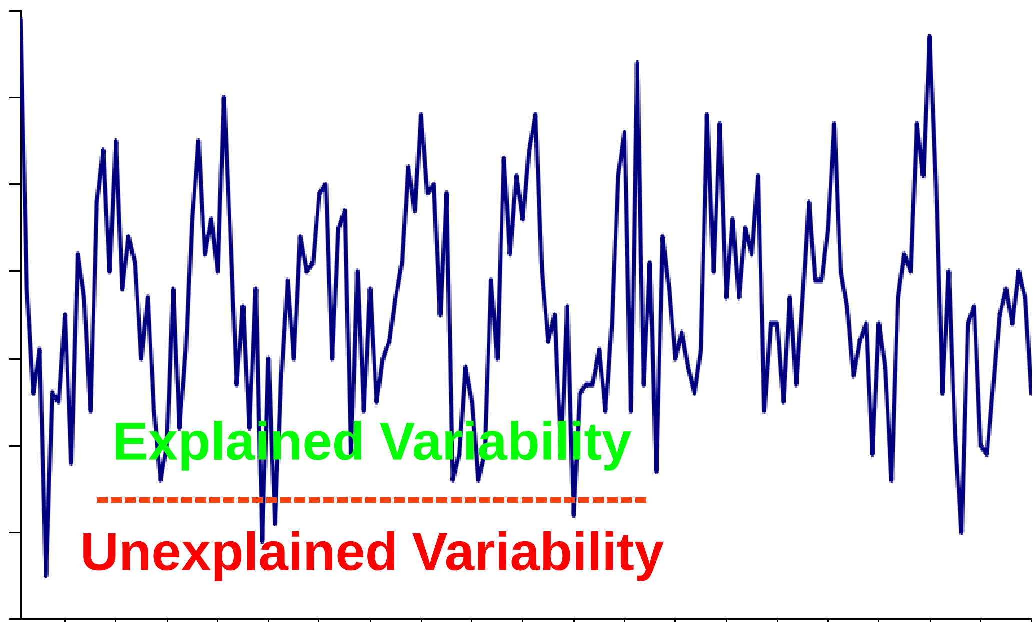

The General Linear Model (GLM)

$$y = X \times \beta + \varepsilon$$

fMRI Signal | Design Matrix | Parameter | Residuals

"our data" = "what we CAN explain" x "how much of it we CAN explain" + "what we CANNOT explain"

PREPROCESSING

i. Motion correction
ii. Slice timing correction
iii. Spatial filtering
iv. Temporal filtering
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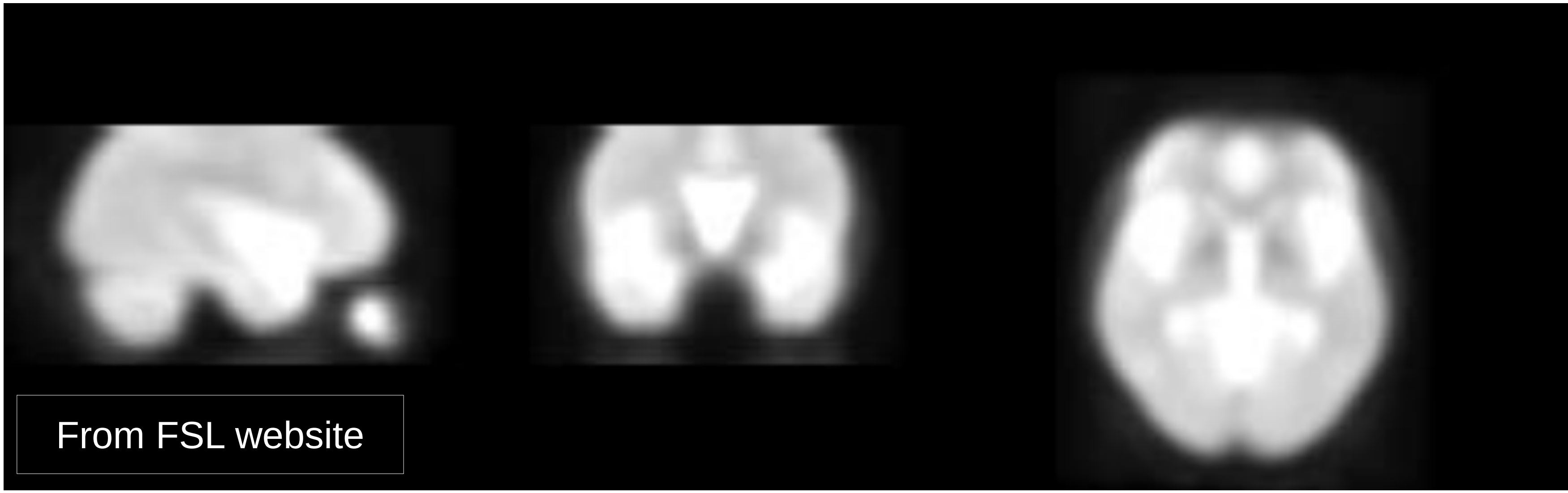
Subject Motion

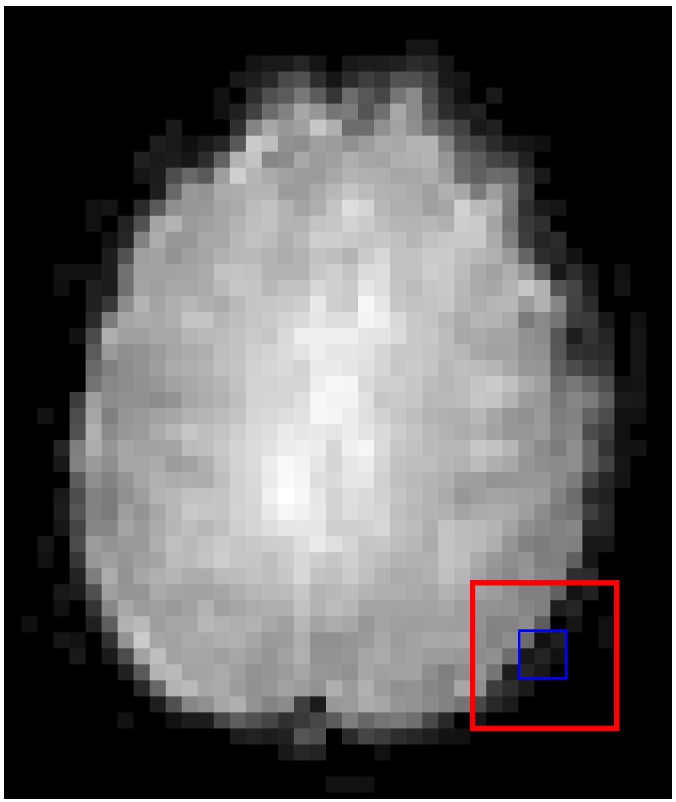


Motion within a time-series can have several unwanted consequences:

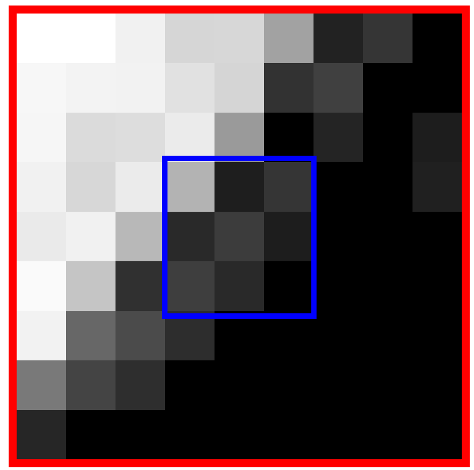
- Motion can produce signal changes of a greater magnitude than the BOLD signal
- Lose the correspondence between a voxel and anatomical location

Subject Motion

A

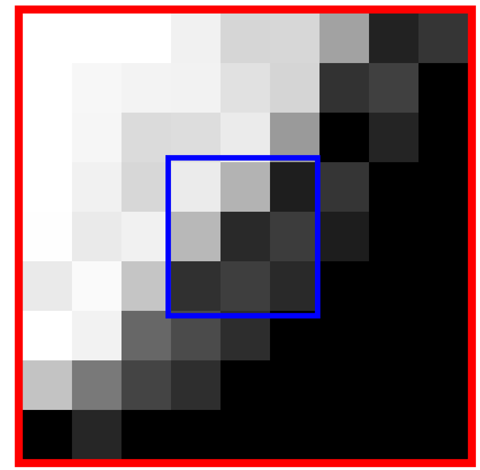


B



507	89	154
119	171	83
179	117	53

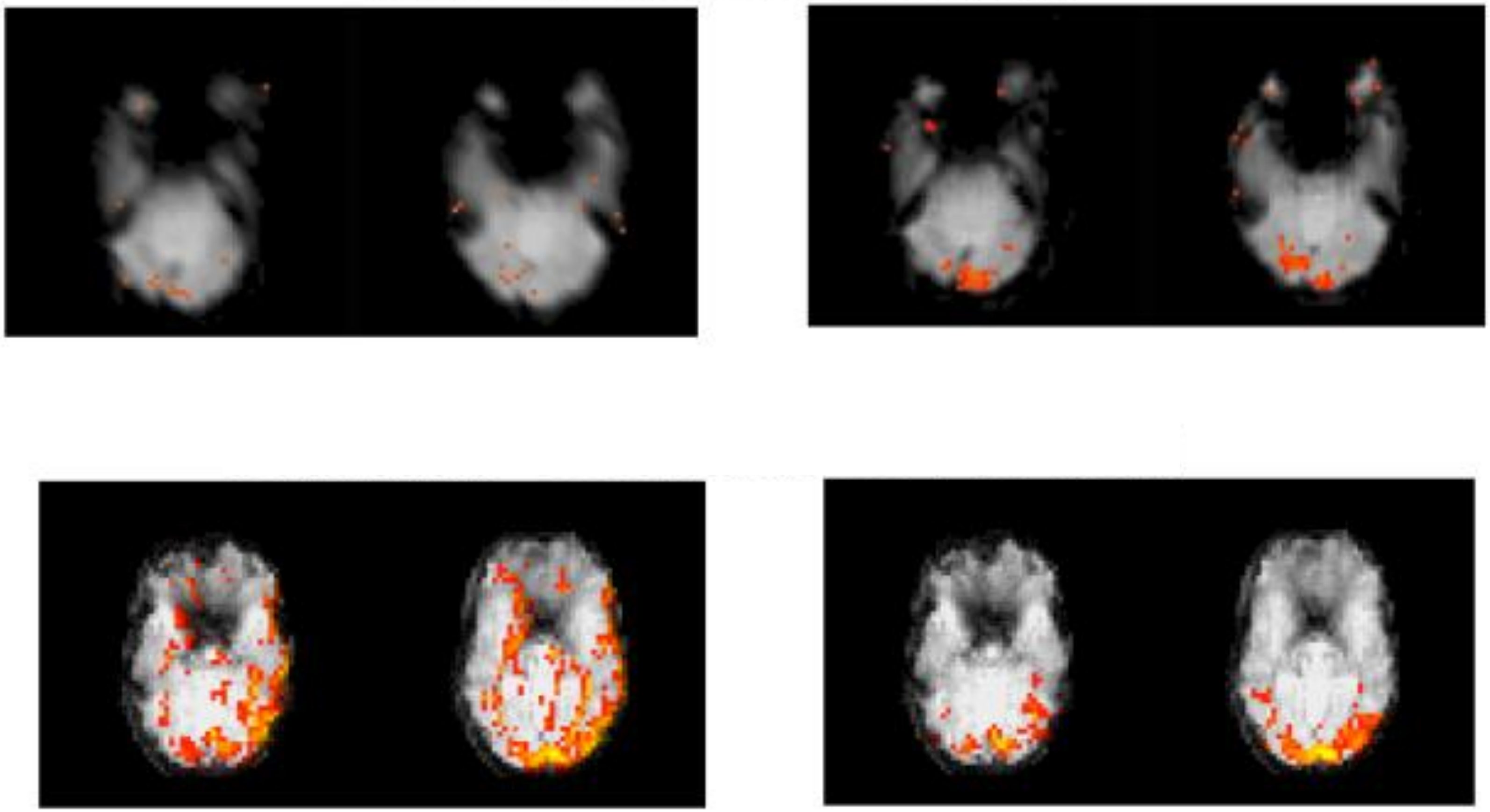
C



663	507	89
520	119	171
137	179	117

Huettel et al. Functional Magnetic ResonanceI Imaging

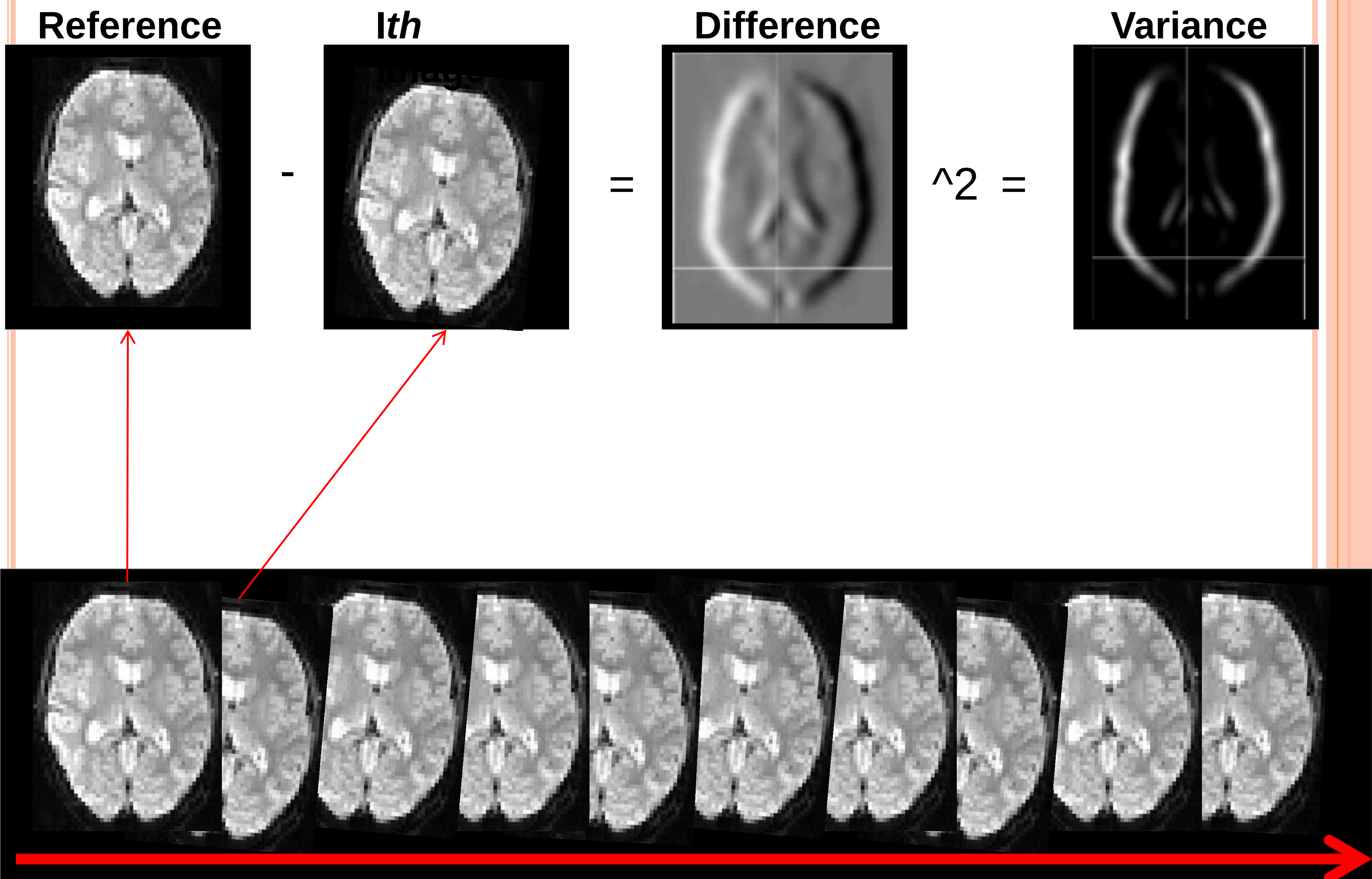
Effect of Motion Correction



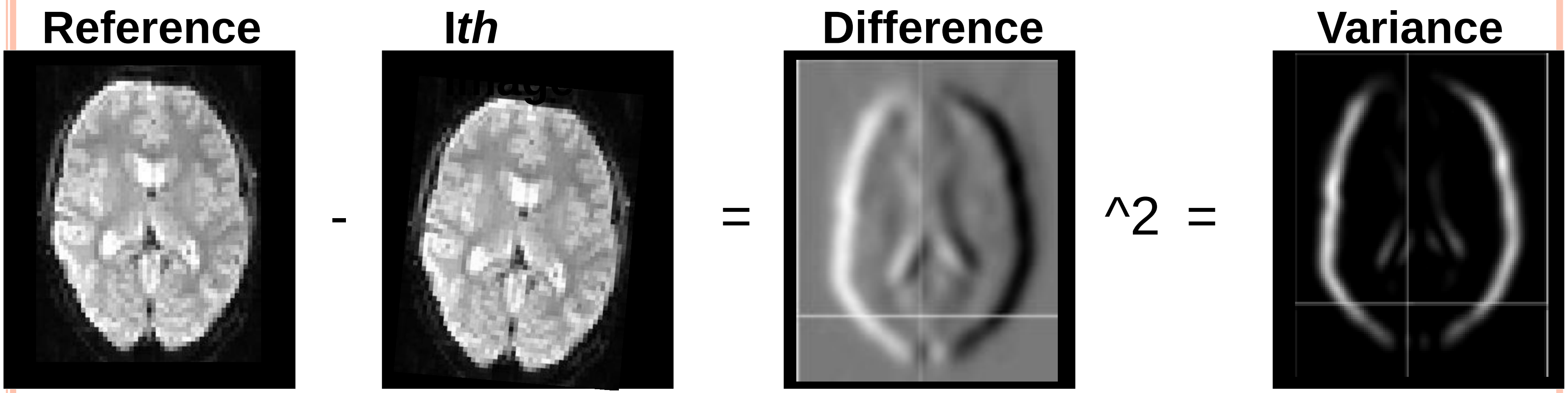
Without MC

With MC

Motion Correction



Motion Correction

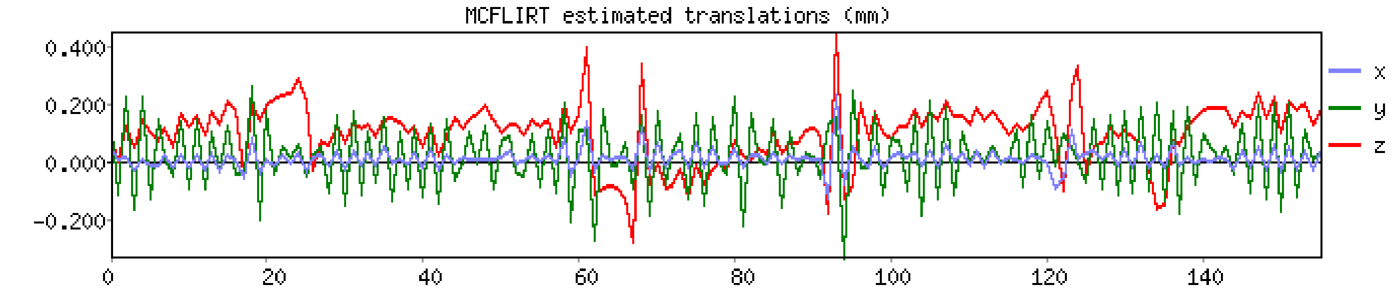


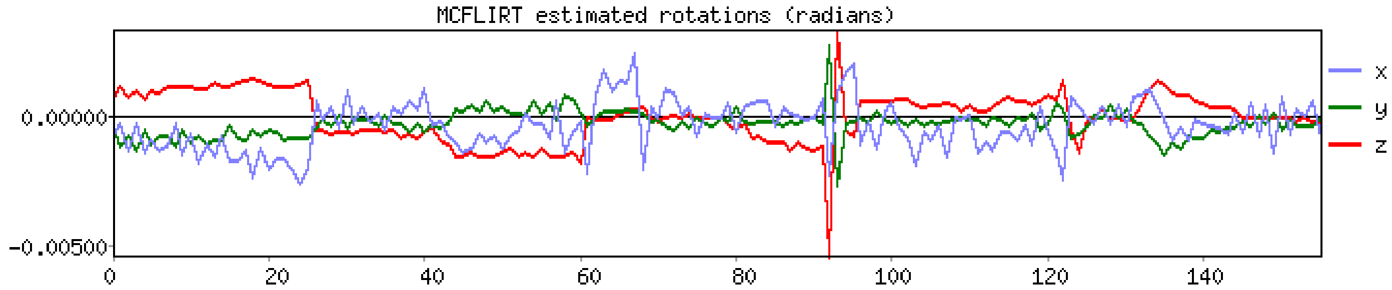
Rigid body (6dof)

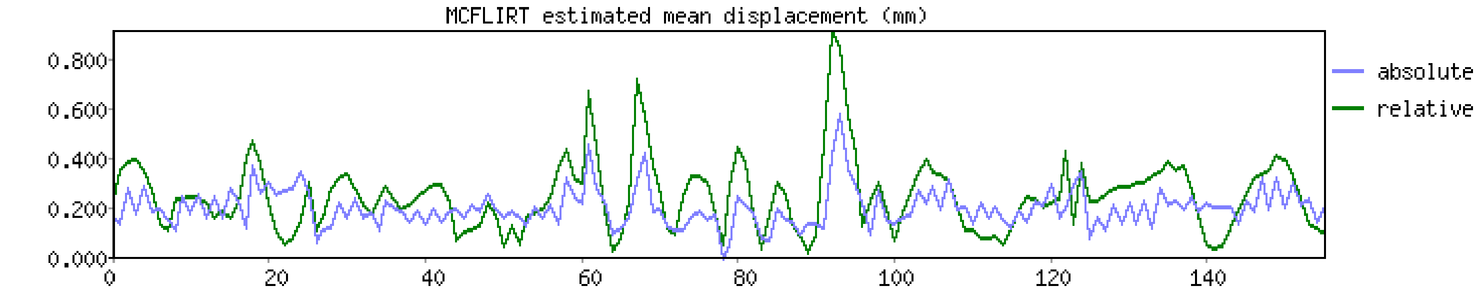
Rigid body transformations parameterised by:

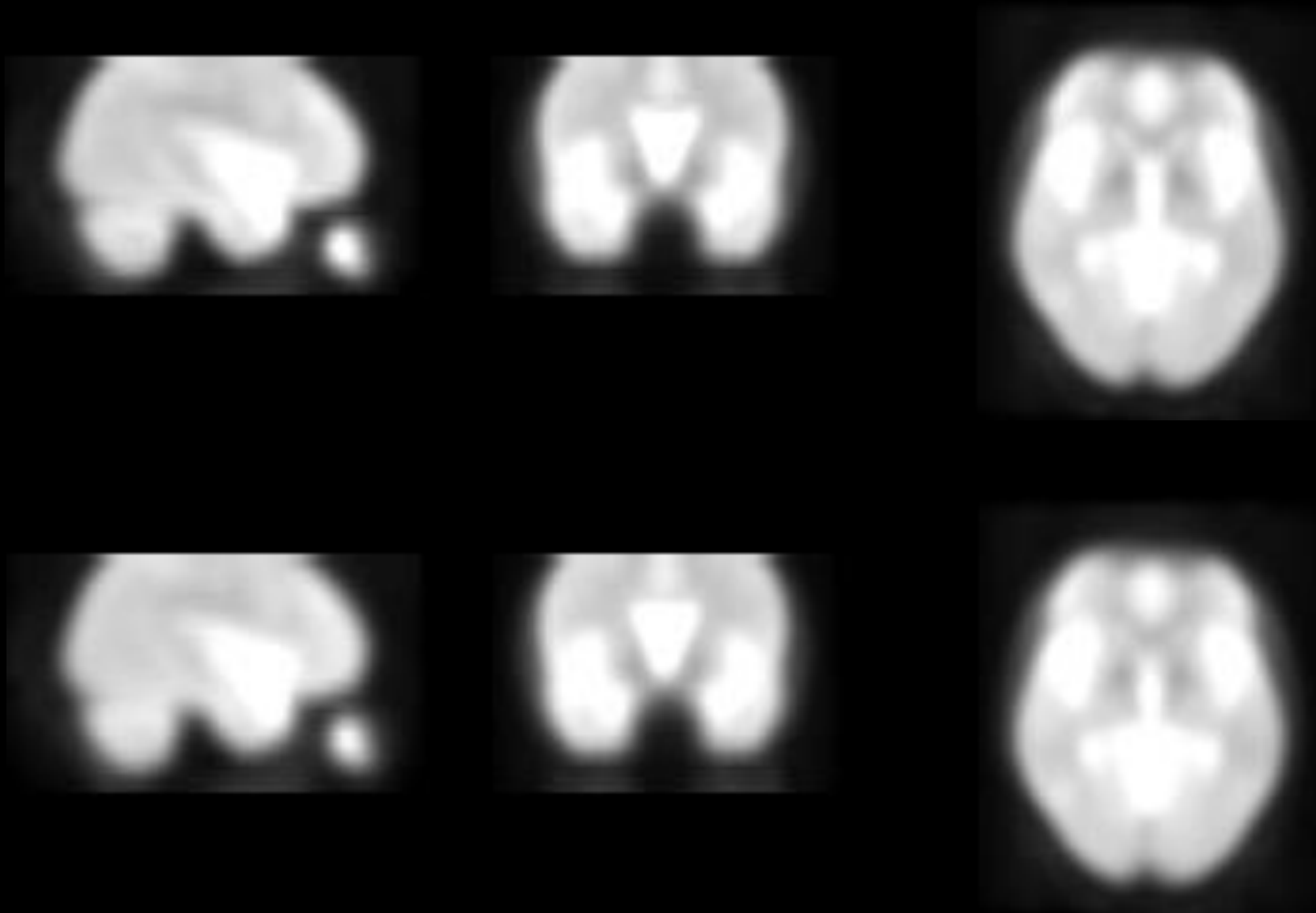
$$
\underbrace{\begin{pmatrix} 1 & 0 & 0 & X_{trans} \\ 0 & 1 & 0 & Y_{trans} \\ 0 & 0 & 1 & Z_{trans} \\ 0 & 0 & 0 & 1 \end{pmatrix}}_{\text{Translations}} \times \underbrace{\begin{pmatrix} 1 & 0 & 0 & 0 \\ 0 & \cos(\Phi) & \sin(\Phi) & 0 \\ 0 & -\sin(\Phi) & \cos(\Phi) & 0 \\ 0 & 0 & 0 & 1 \end{pmatrix}}_{\text{Pitch}} \times \underbrace{\begin{pmatrix} \cos(\Theta) & 0 & \sin(\Theta) & 0 \\ 0 & 1 & 0 & 0 \\ -\sin(\Theta) & 0 & \cos(\Theta) & 0 \\ 0 & 0 & 0 & 1 \end{pmatrix}}_{\text{Roll}} \times \underbrace{\begin{pmatrix} \cos(\Omega) & \sin(\Omega) & 0 & 0 \\ -\sin(\Omega) & \cos(\Omega) & 0 & 0 \\ 0 & 0 & 1 & 0 \\ 0 & 0 & 0 & 1 \end{pmatrix}}_{\text{Yaw}}
$$

Viewing motion correction



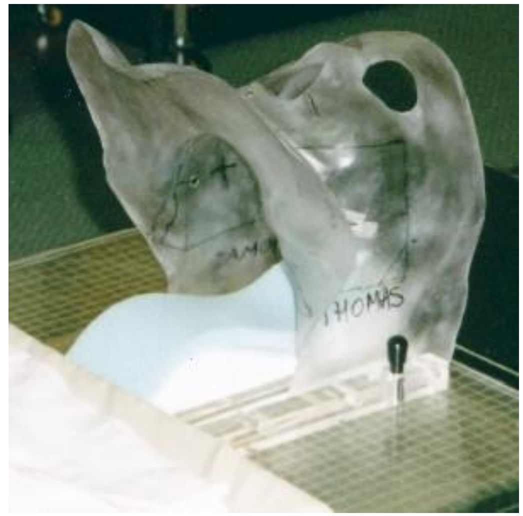


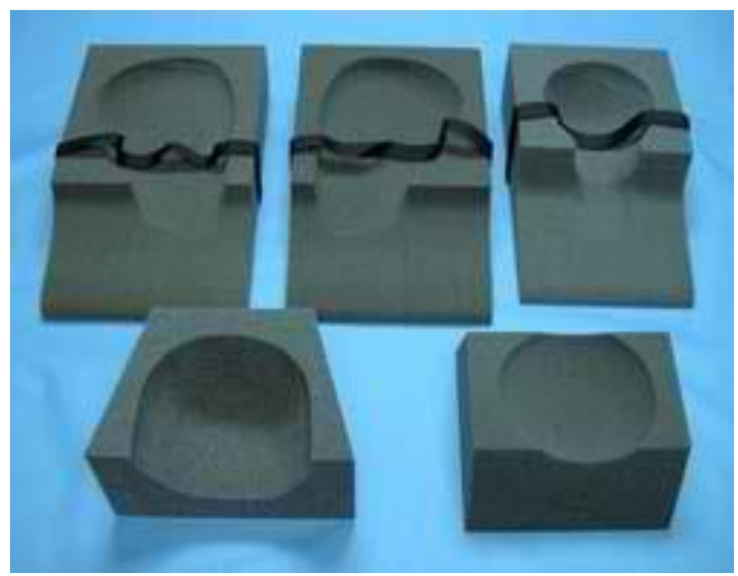




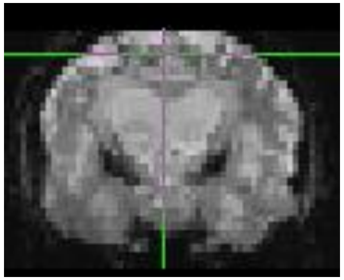
From FSL website

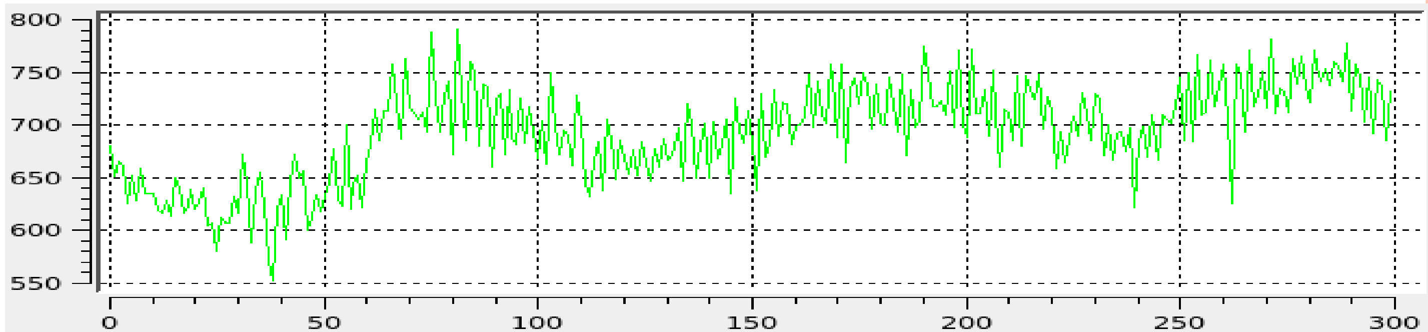
Coping with motion I: prevent it

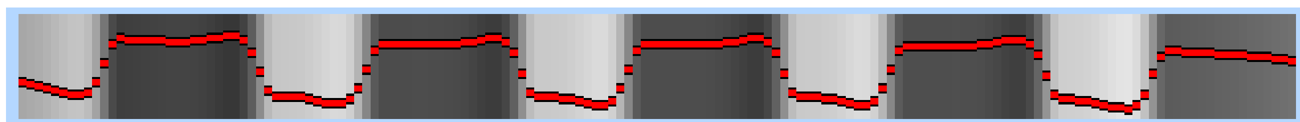




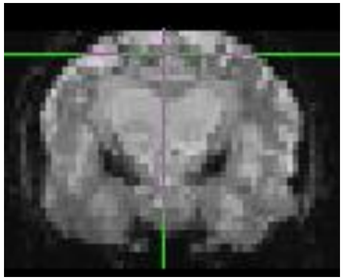
Coping with motion II(a): model it

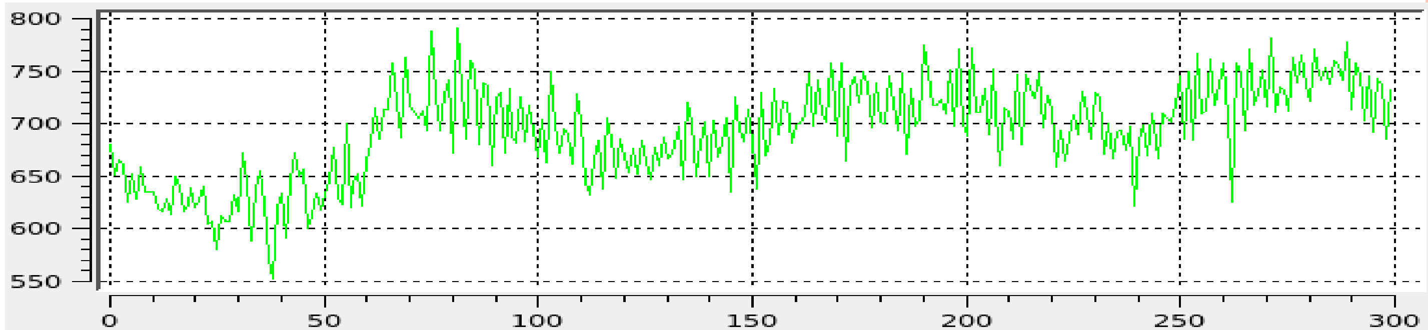


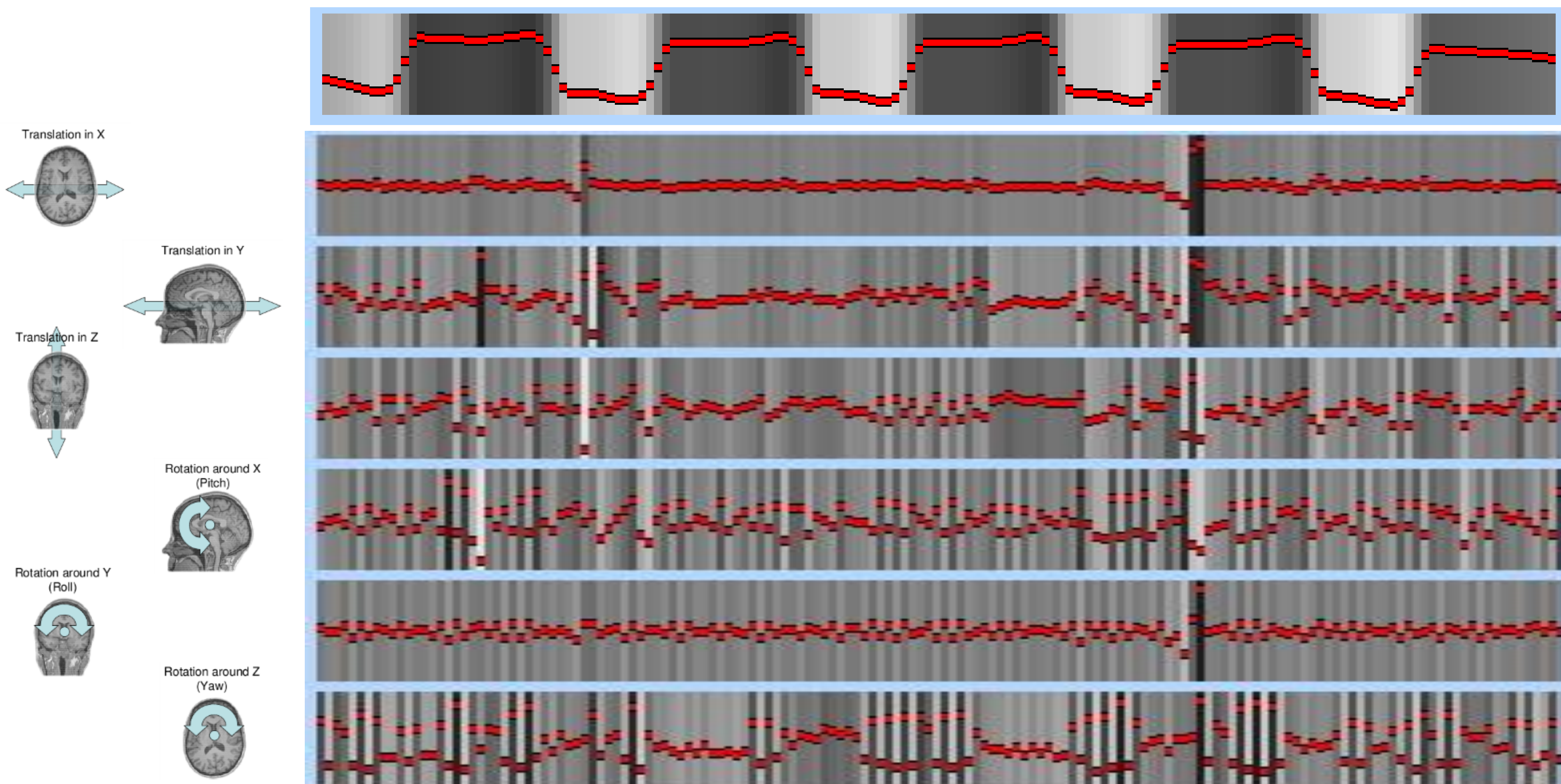




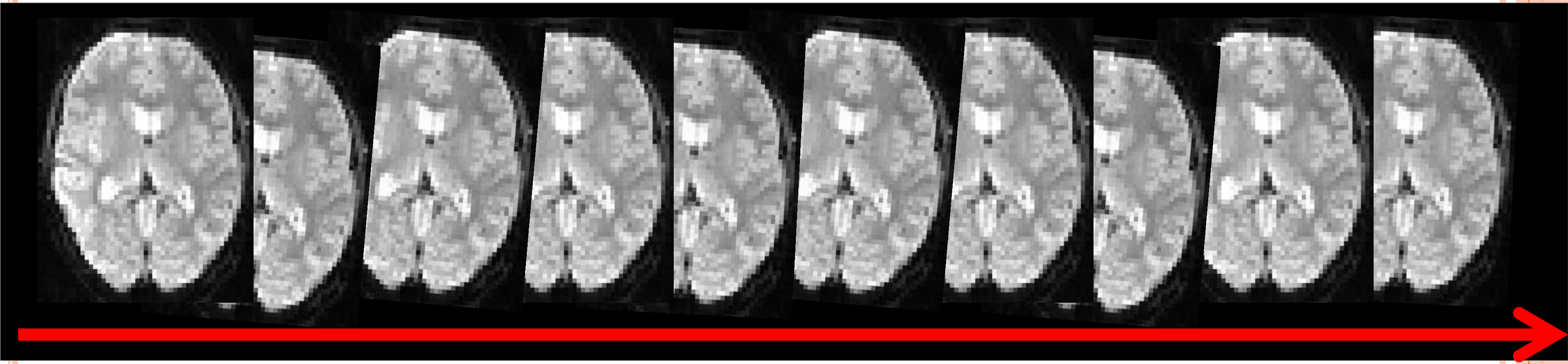
Coping with motion II(b): model it

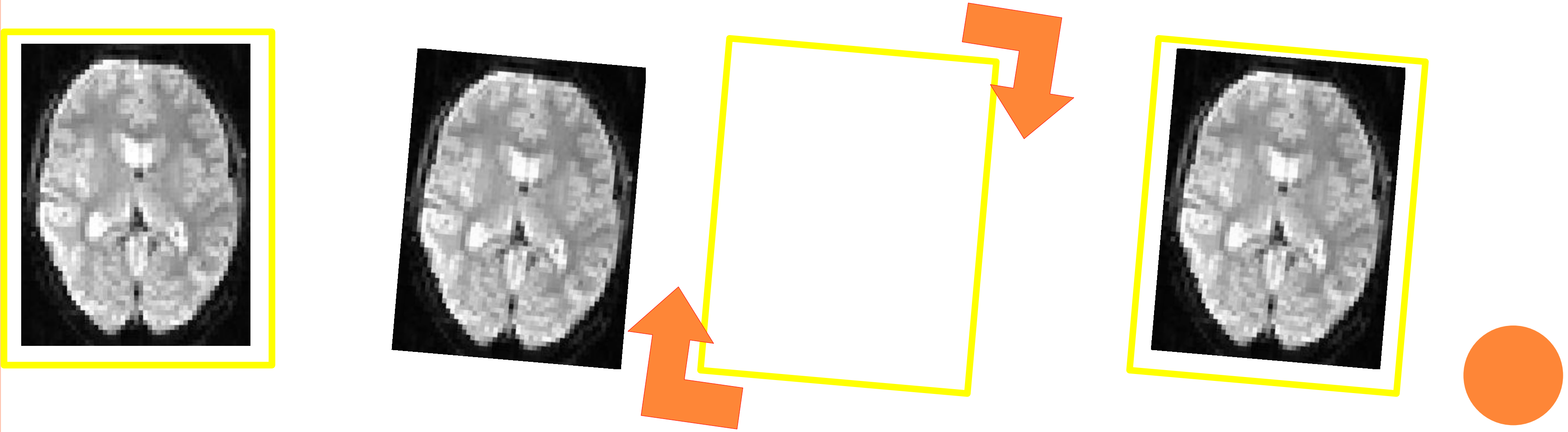




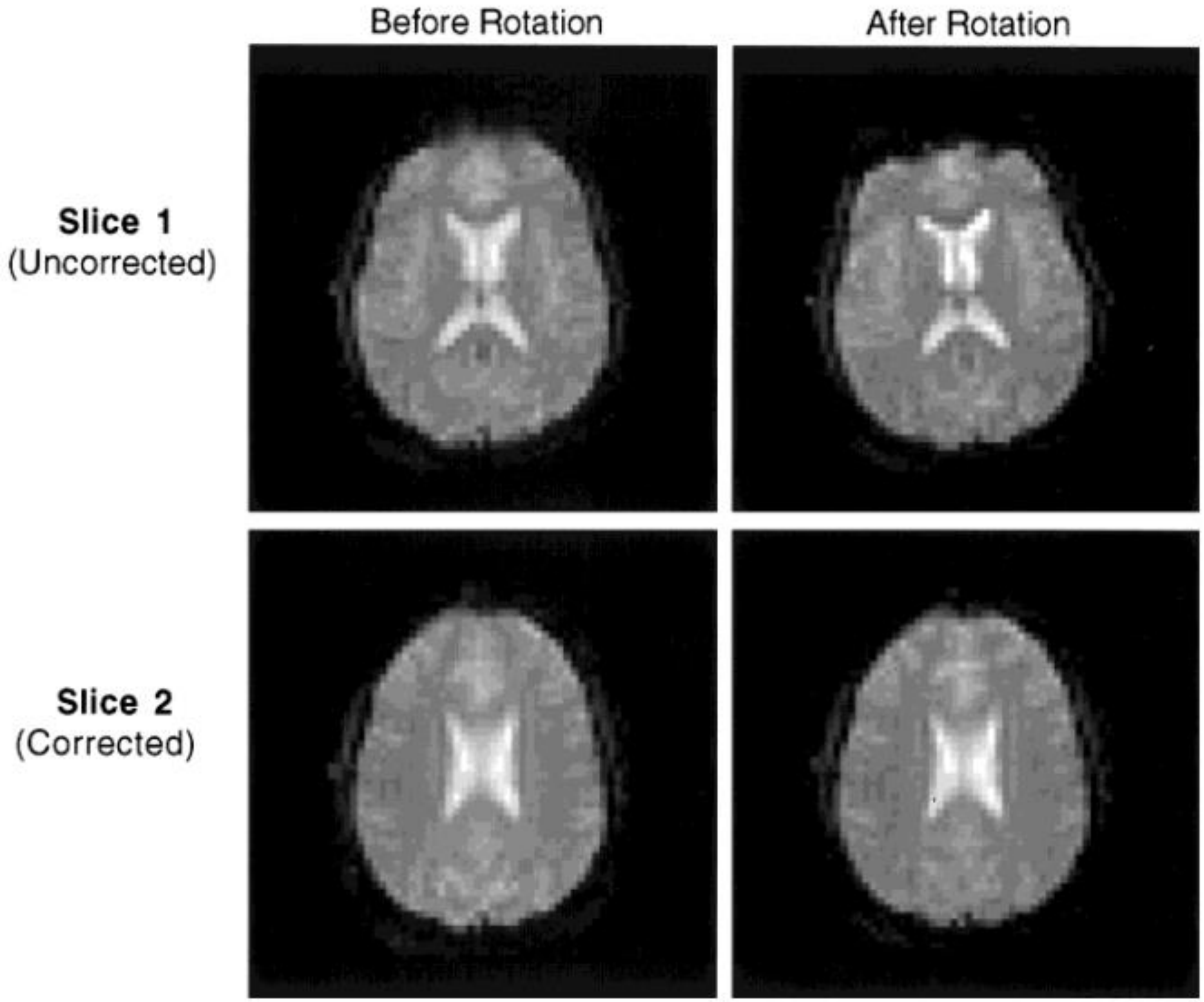


Coping with motion III: Prospective MC





Prospective motion correction



Ward et al 2000 MRM

Motion correction is good, however:

- Even after all this, movement artefacts still remain
  - Residual (uncorrected) motion
  - There's no way of detecting rapid movements within a scan
  - Spin history effects*
  - Task correlated motion

The moral of the story…

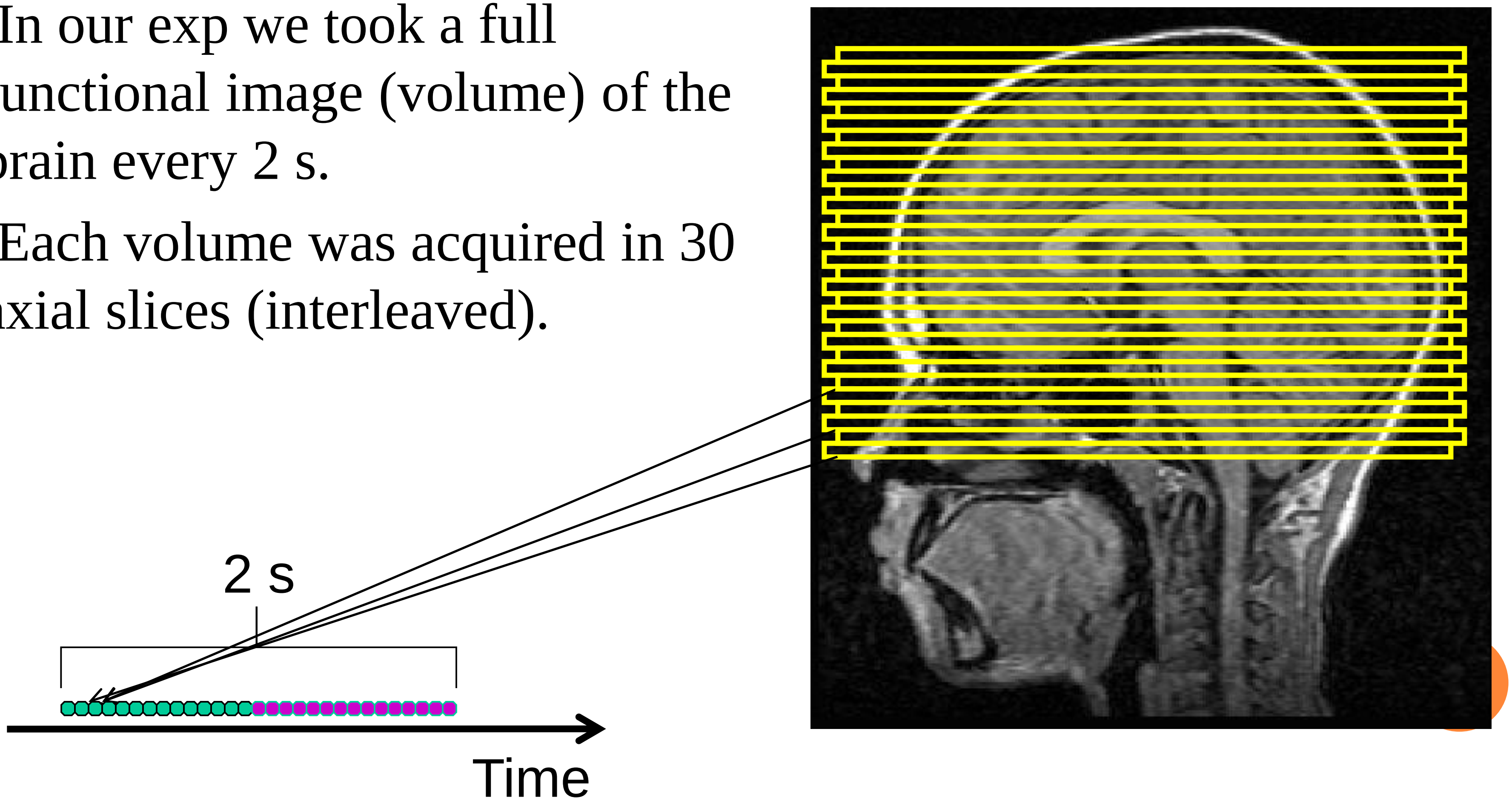
- ***Stop people from moving***
  - Make sure they're comfortable to begin with
  - Tell them that motion is a big problem
  - Train subjects?
  - Reward them?
- Decouple motion-prone tasks from cognitive event of interest
- Model motion out
- Reject run/subject

Preprocessing

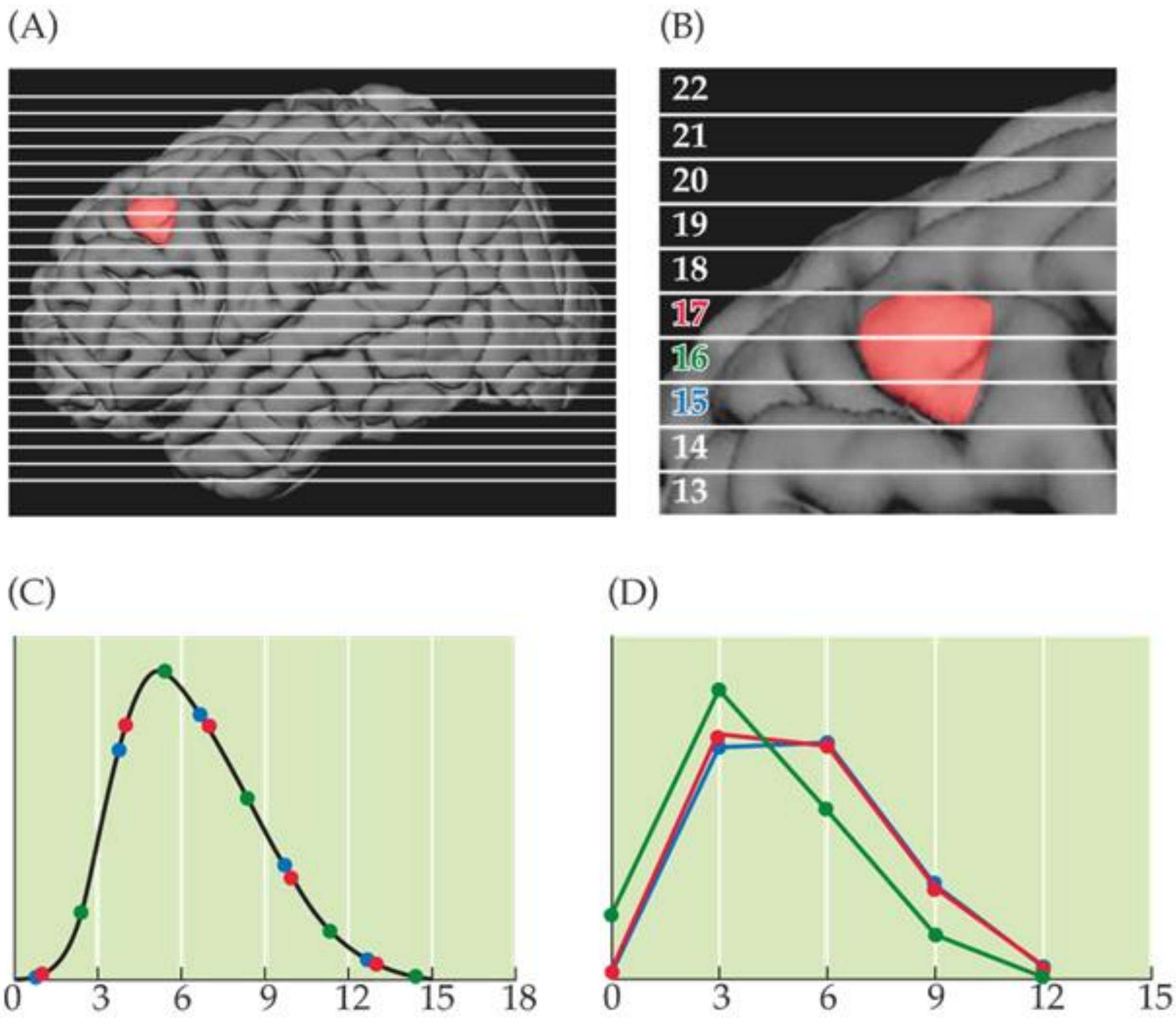
i. Motion correction
ii. Slice timing correction
iii. Spatial filtering
iv. Temporal filtering
v. Intensity normalization

Slice timing correction

- In our exp we took a full functional image (volume) of the brain every 2 s.
- Each volume was acquired in 30 axial slices (interleaved).



Slice timing correction



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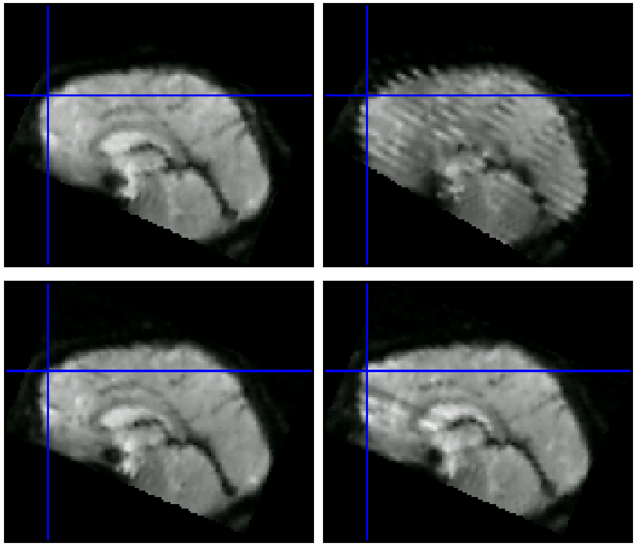
Slice timing correction

Most people now suggest not to do it

- Not all that helpful & requires interpolation
- It may worsen artefacts (e.g., smearing spikes)
- Interacts in unpredictable ways with motion correction
- We spatially smooth across proximal slices
- Mismatching TR and task
- Include temporal derivative of HRF



- What order? Ascending, descending, contiguous, interleaved.

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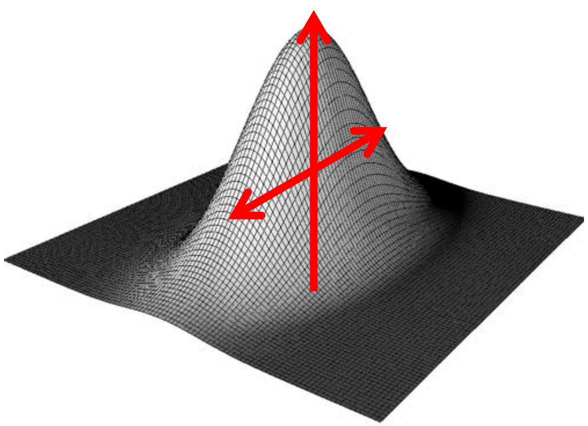
Spatial Filtering

Replace each voxel's value with a weighted average of its value and the value of it's neighbouring voxels.

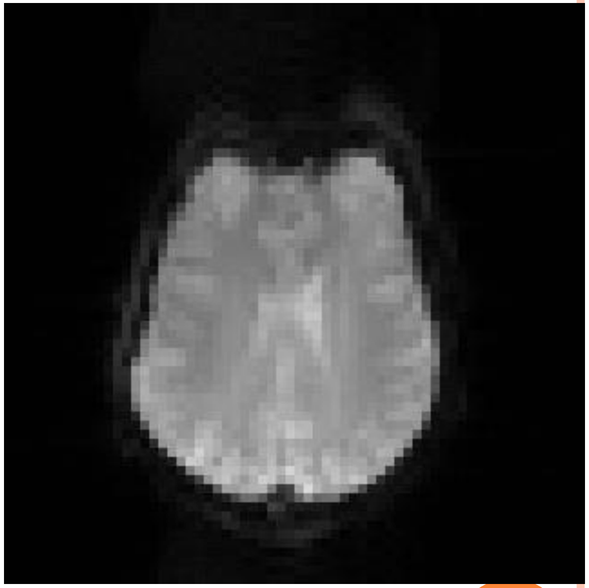
- Gaussian kernel (mm FWHM)



Weights

0.1	0.3	0.4	0.3	0.1
0.3	0.6	0.8	0.6	0.3
0.4	0.8	1.0	0.8	0.4
0.3	0.6	0.8	0.6	0.3
0.1	0.3	0.4	0.3	0.1

FWHM



Spatial Filtering

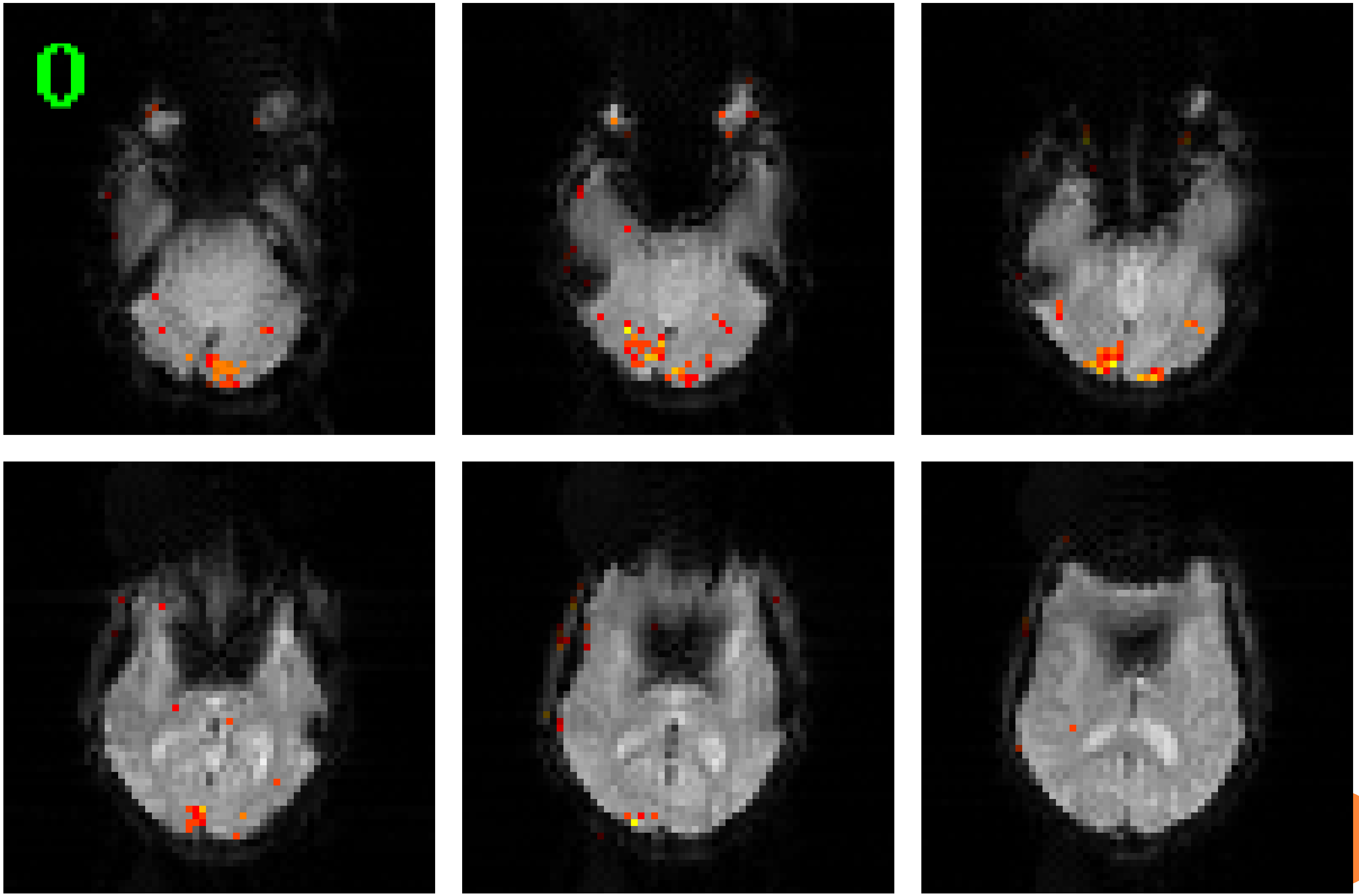
Advantages

- Increases Signal to Noise Ratio (SNR)
  - *Matched Filter Theorem*: Maximum increase in SNR by filter with same shape/size as signal
- Allows application of Gaussian Field Theory
- May improve comparisons across subjects

Disadvantages

- Reduces spatial resolution
- May reduce your signal if smaller than your filter size!

Spatial Filtering



Source FSL website

Preprocessing

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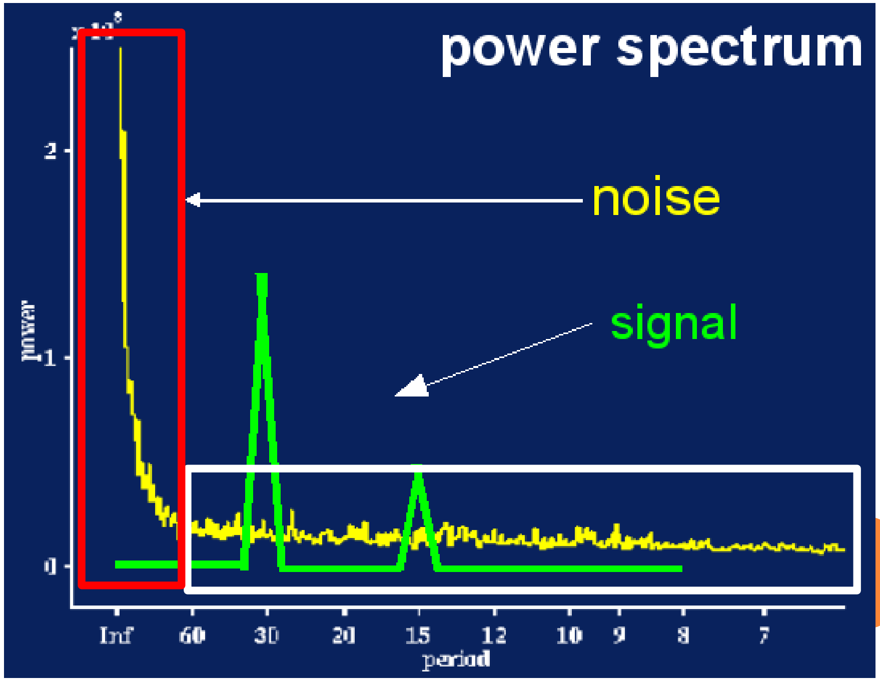
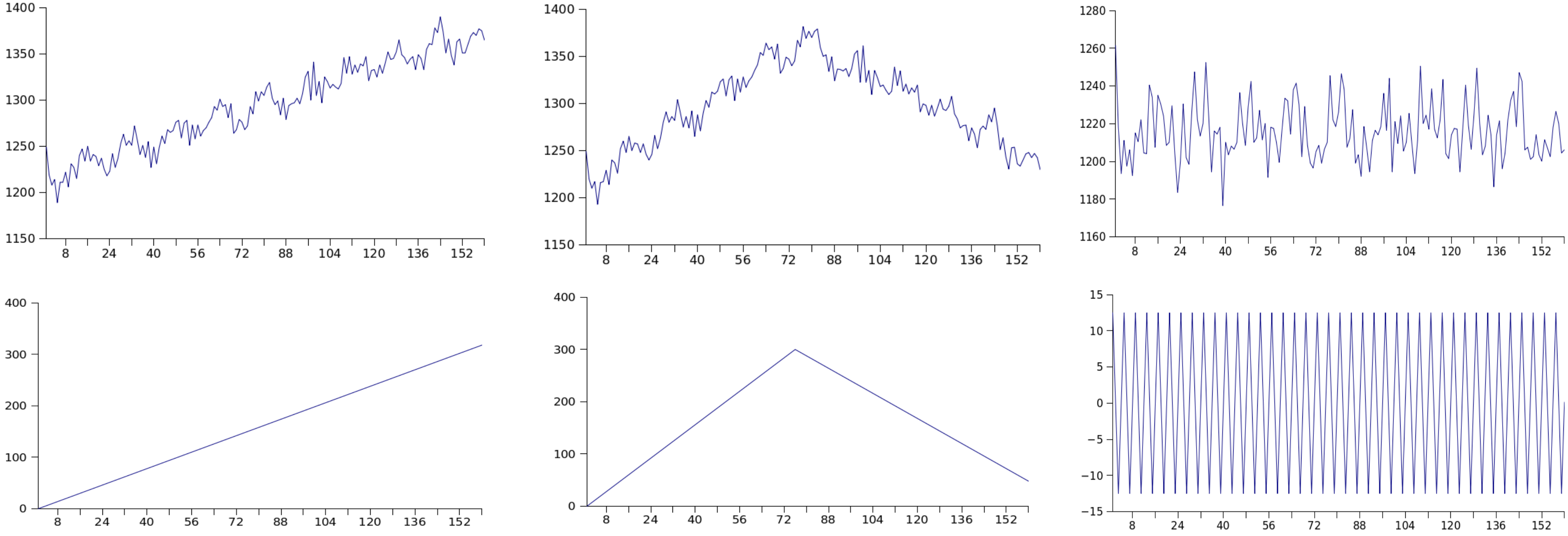
Temporal Filtering

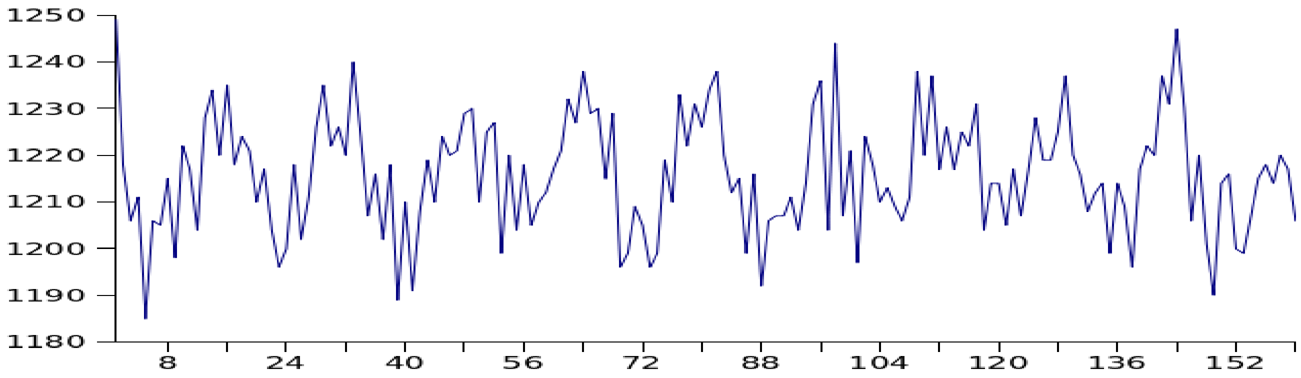
- You are interested in the signal fluctuations that have to do with your task, and thus are at a specific frequency

- But there is a lot of activity at many other frequencies (particularly at low ones: 1/f):
  - Thermal noise
  - Heart beat
  - Respiration
  - Alertness
  - Learning



Signal & Noise



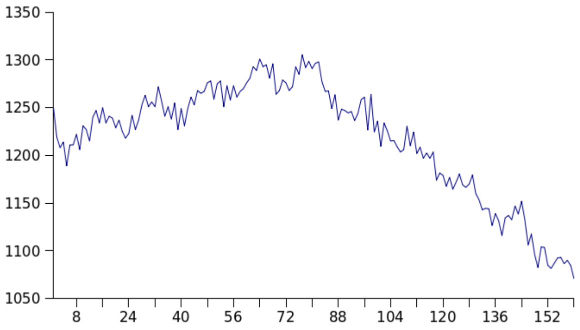


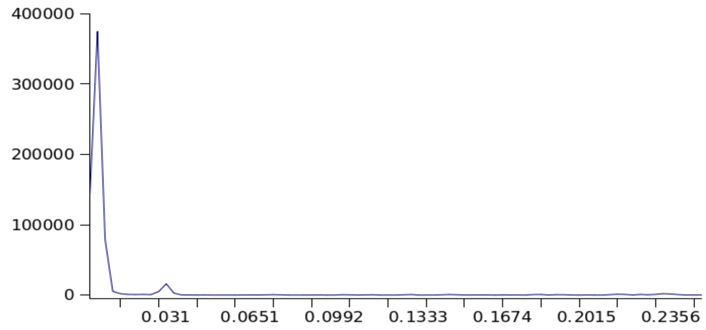
High-Pass Filtering

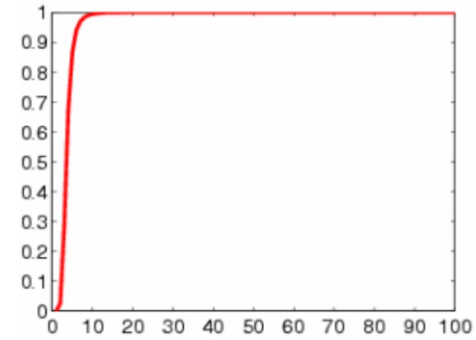
Timecourse

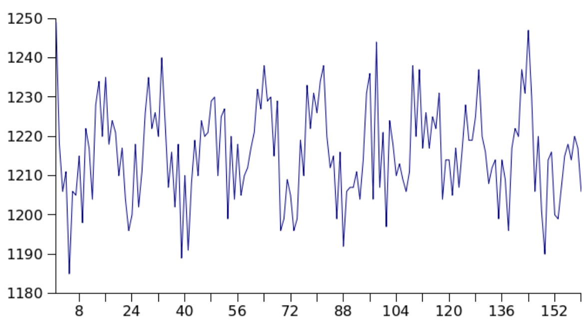
Power Spectrum

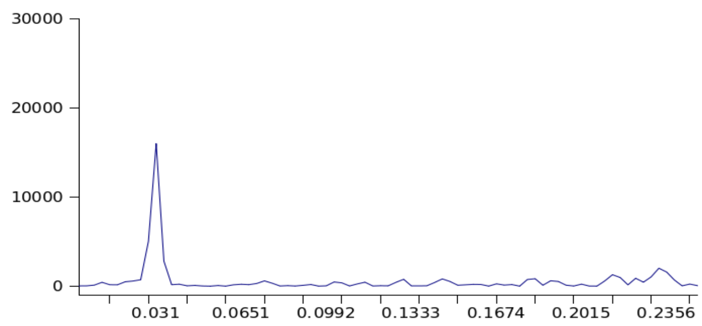
HP Filter











High-Pass Filtering

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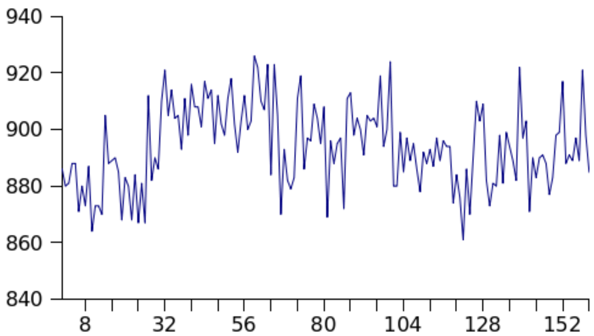
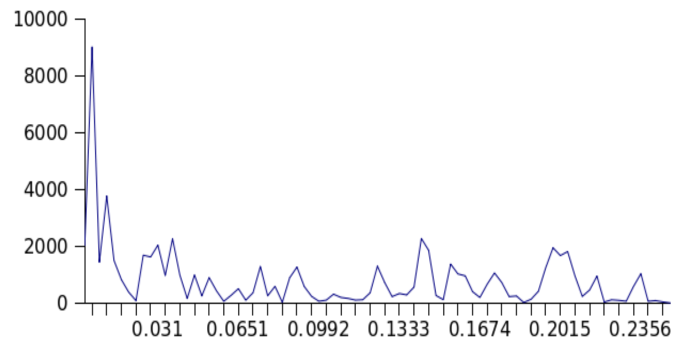
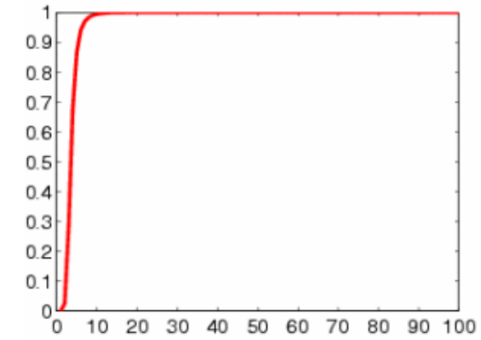
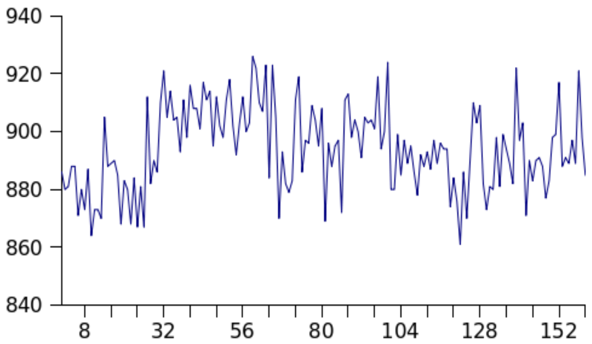
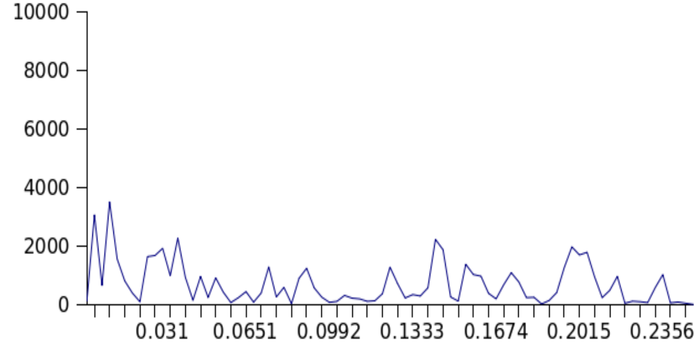








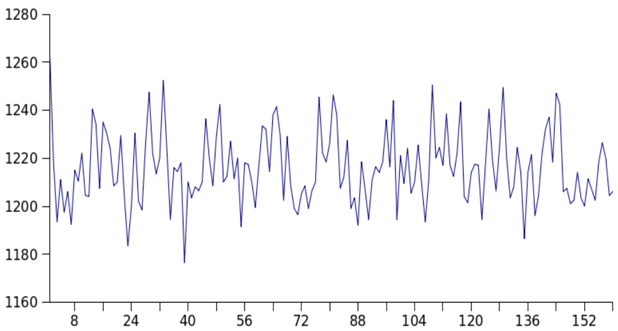


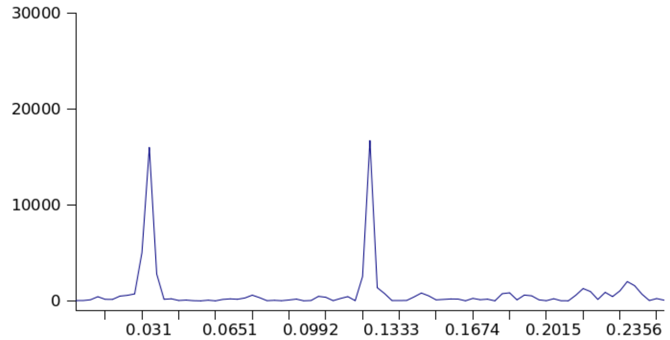
LOW-PASS FILTERING

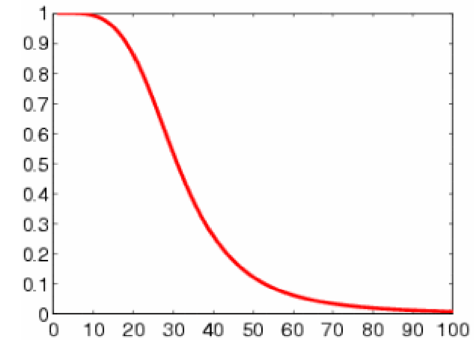
Timecourse

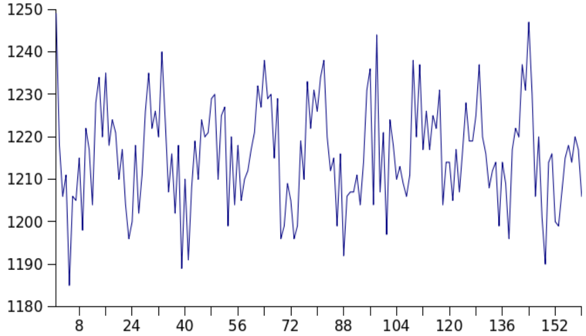
Power Spectrum

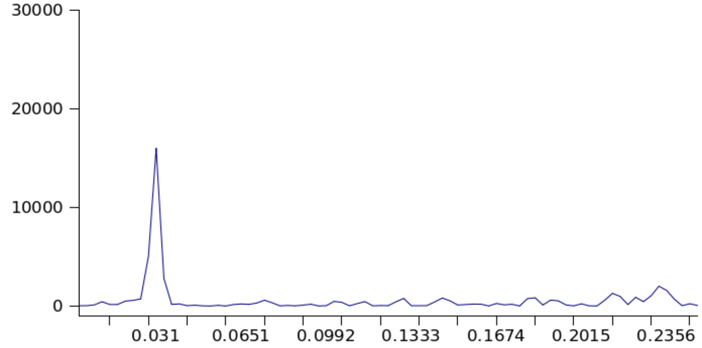
LP Filter





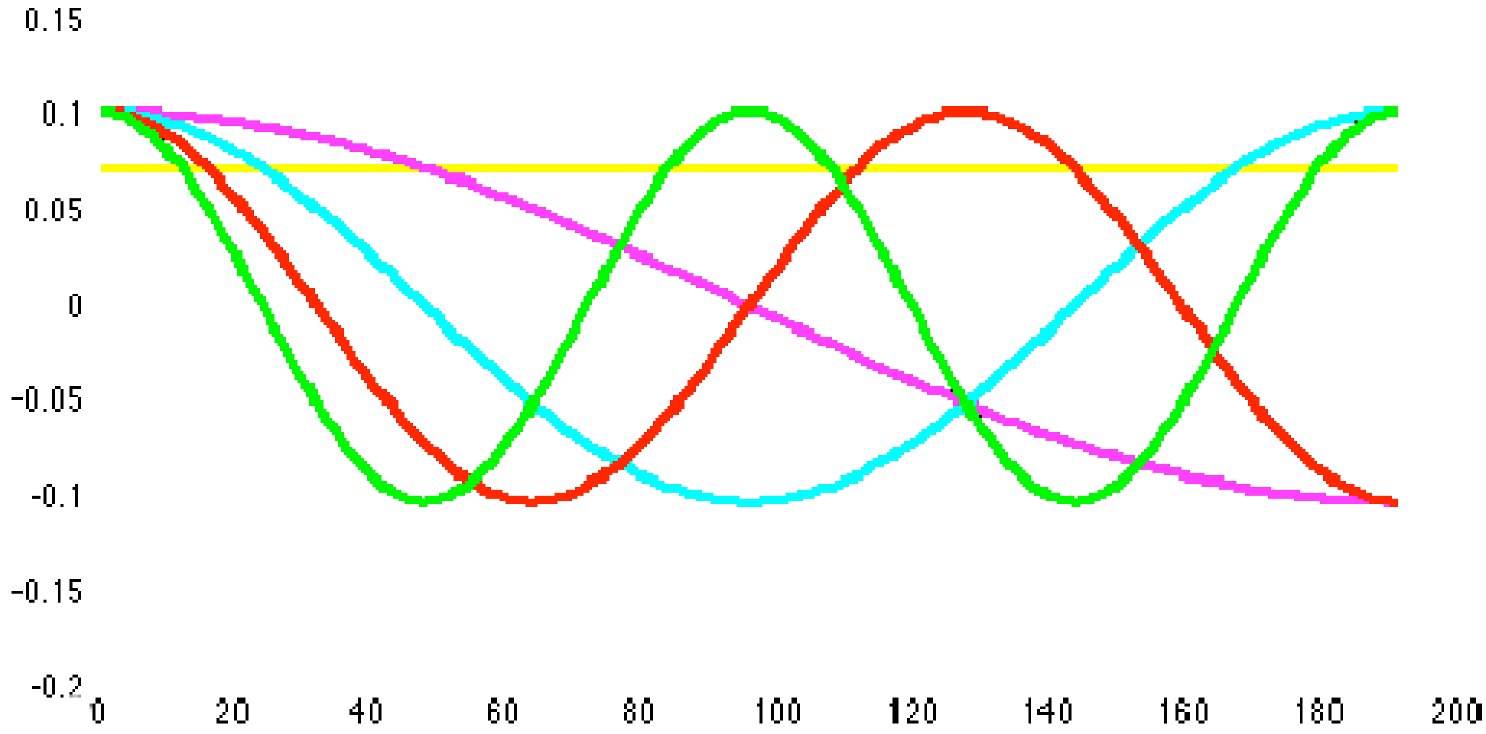






HP Filtering Strategy I: SPM

- Model low drifts to "soak up" their variance (using a discrete cosine transform basis set).



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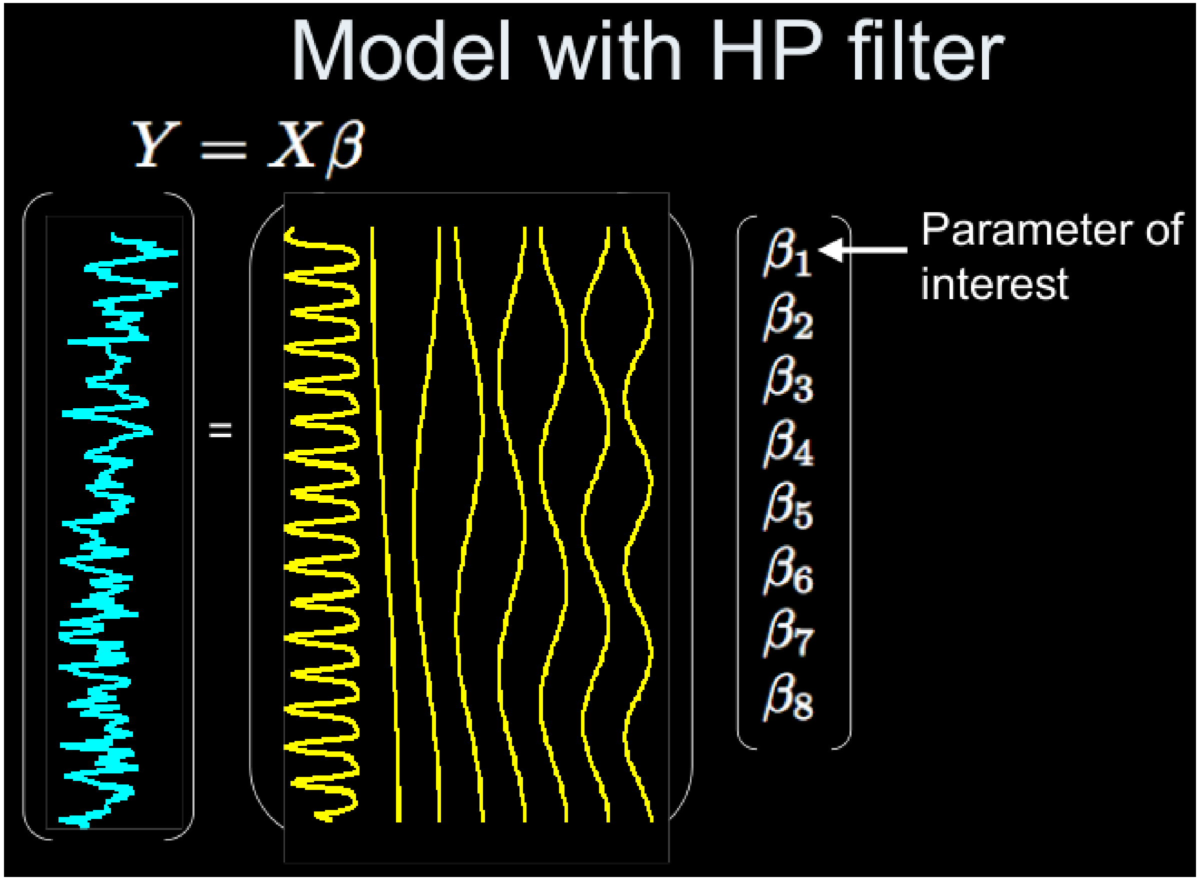
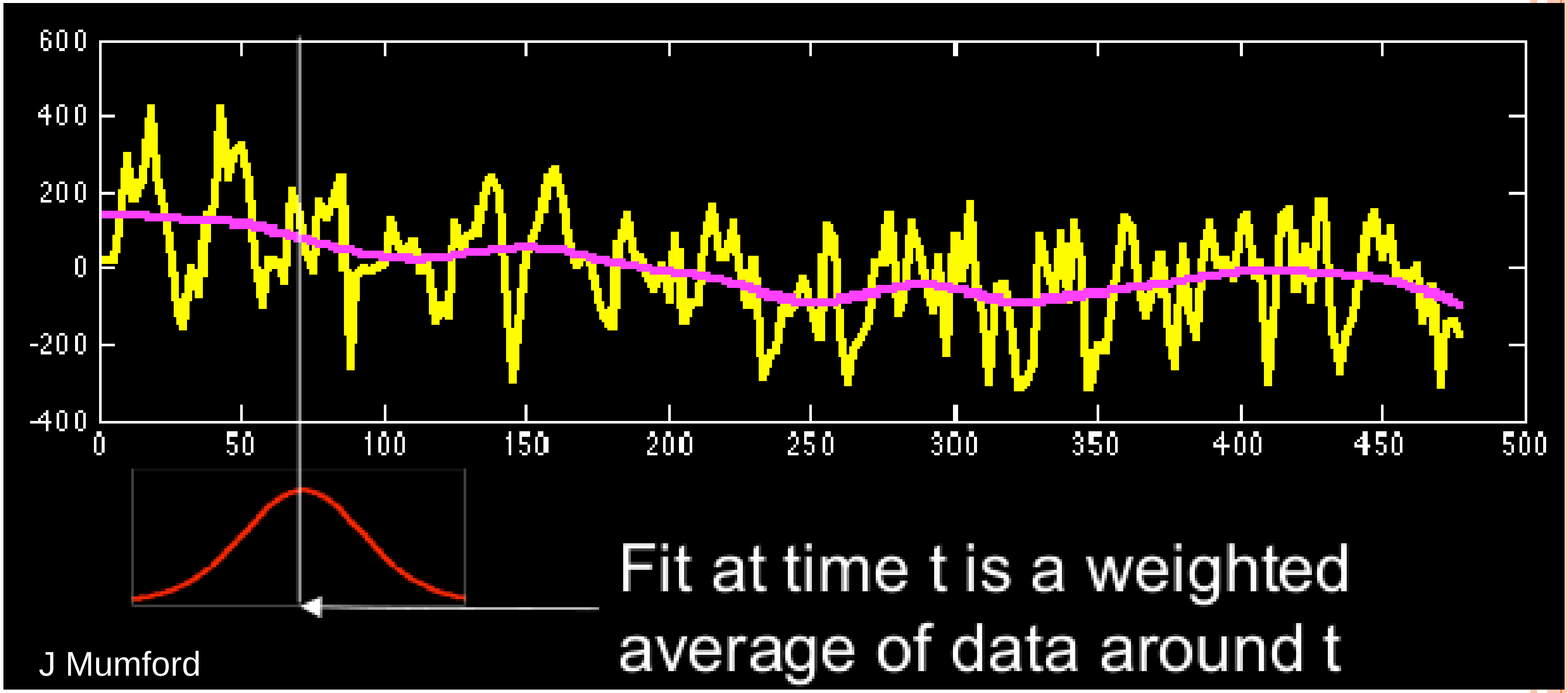


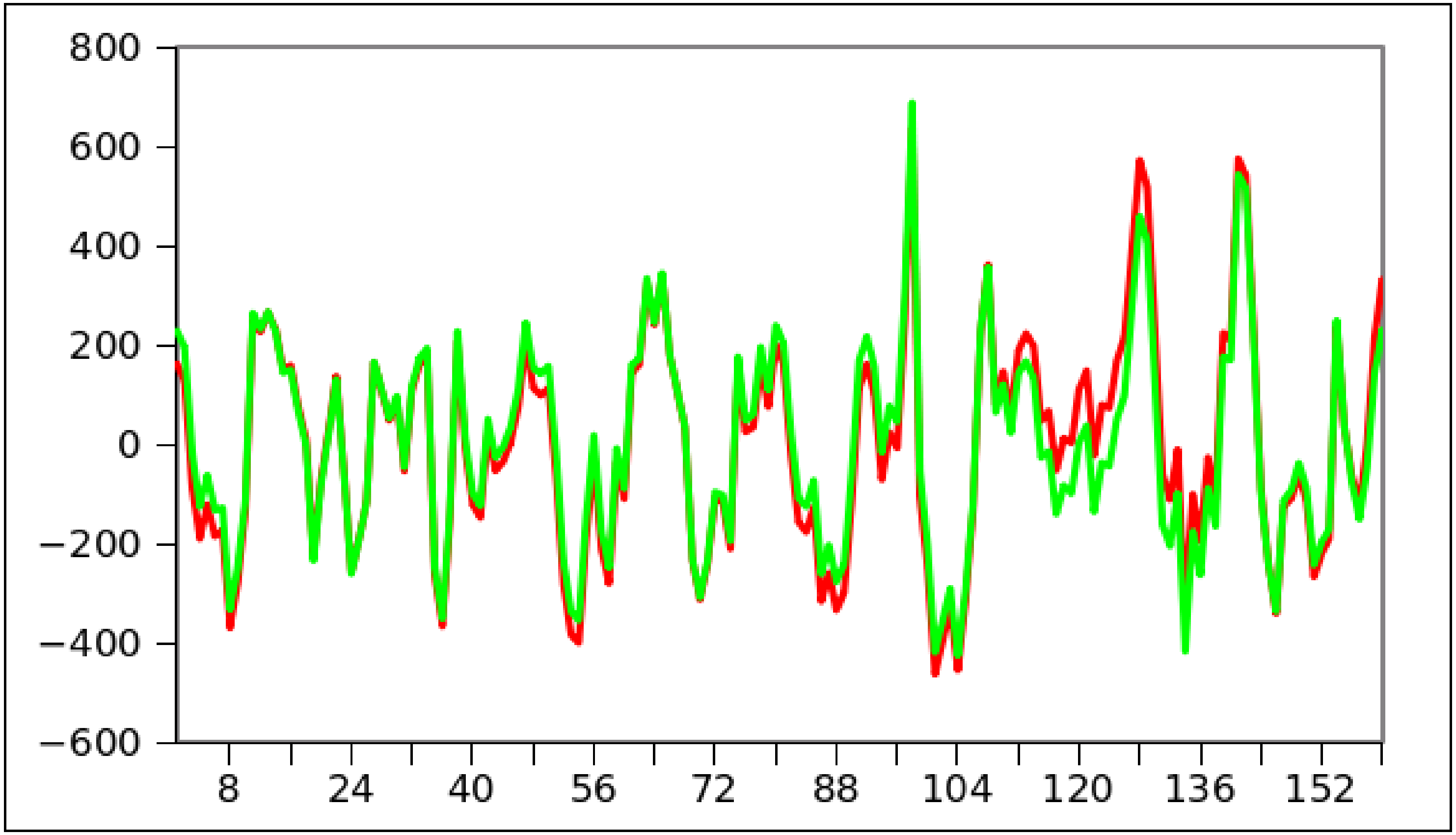
HP Filtering Strategy II: FSL

- Remove low drifts from the signal:
  i. Fit a Gaussian-weighted running line



HP Filtering Strategy II: FSL

- Remove low drifts from the signal:
  i. Fit a Gaussian-weighted running line
  ii. Subtract from data (red is pre-HPF, green is post-HPF)



PREPROCESSING

i. Motion correction

ii. Slice timing correction

iii. Spatial filtering

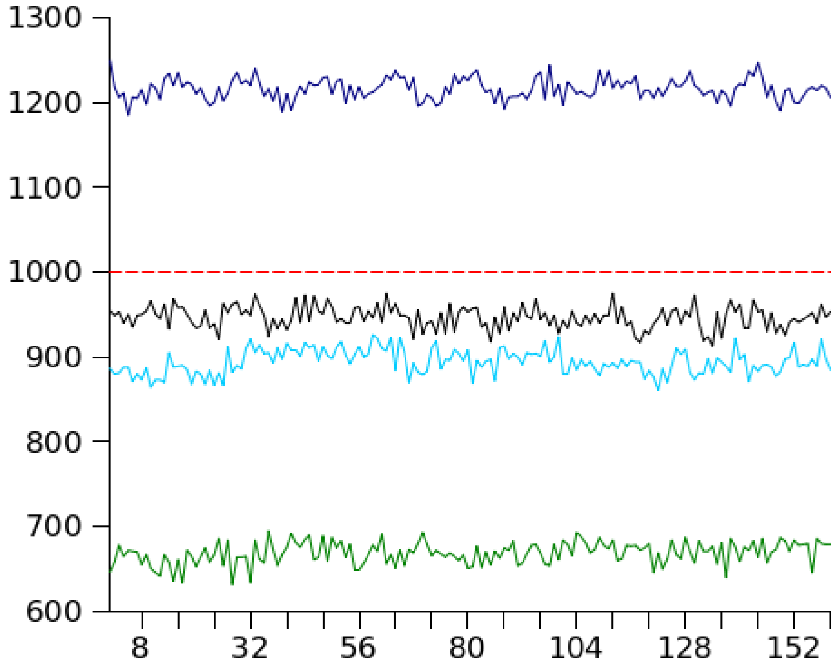
iv. Temporal filtering

v. Intensity normalization

INTENSITY NORMALIZATION I (GMS)

Between-session (grand mean scaling)

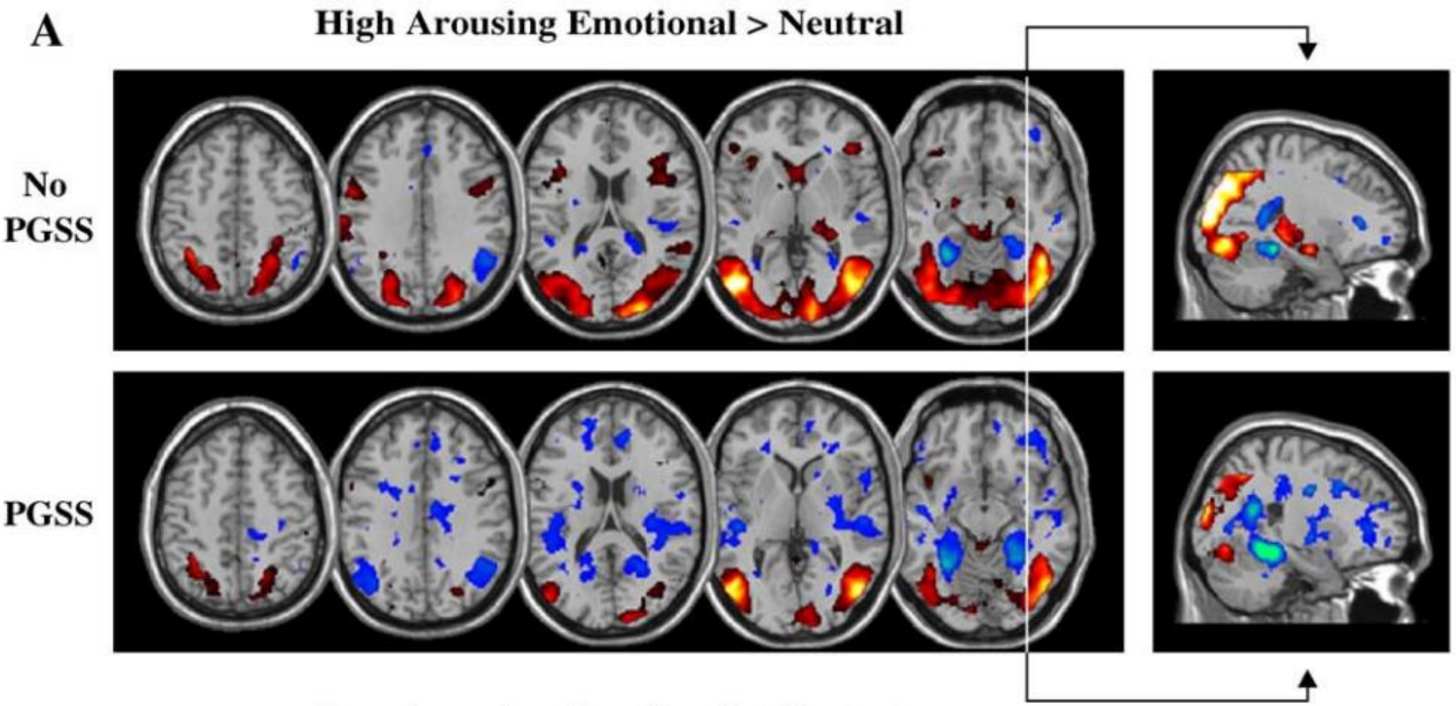
- The mean intensity of each 4D dataset varies for non-experimentally interesting reasons.
- Scale each 4D time-series by a single factor.
- Time-series from different runs are now centred around the same mean.



Intensity Normalization II

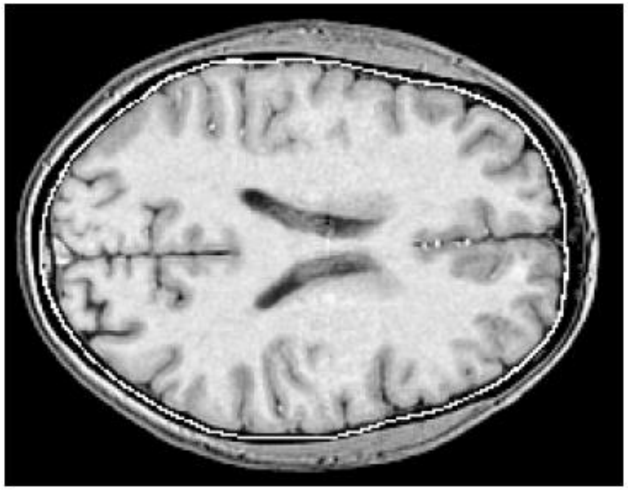
Within-session

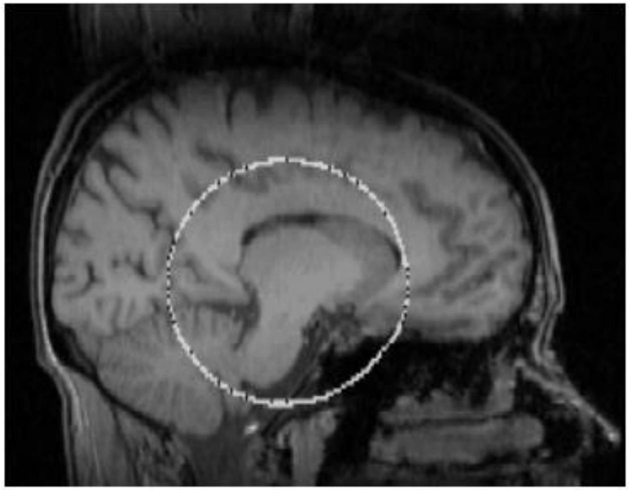
- Forces each volumes (***within a run***) to have the same mean intensity.



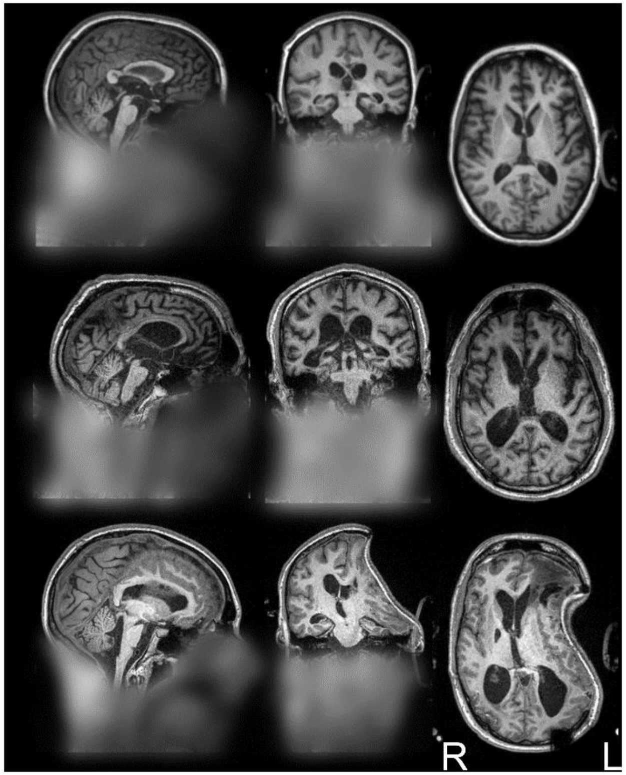
Junghofer et al, 2005, neuroImage

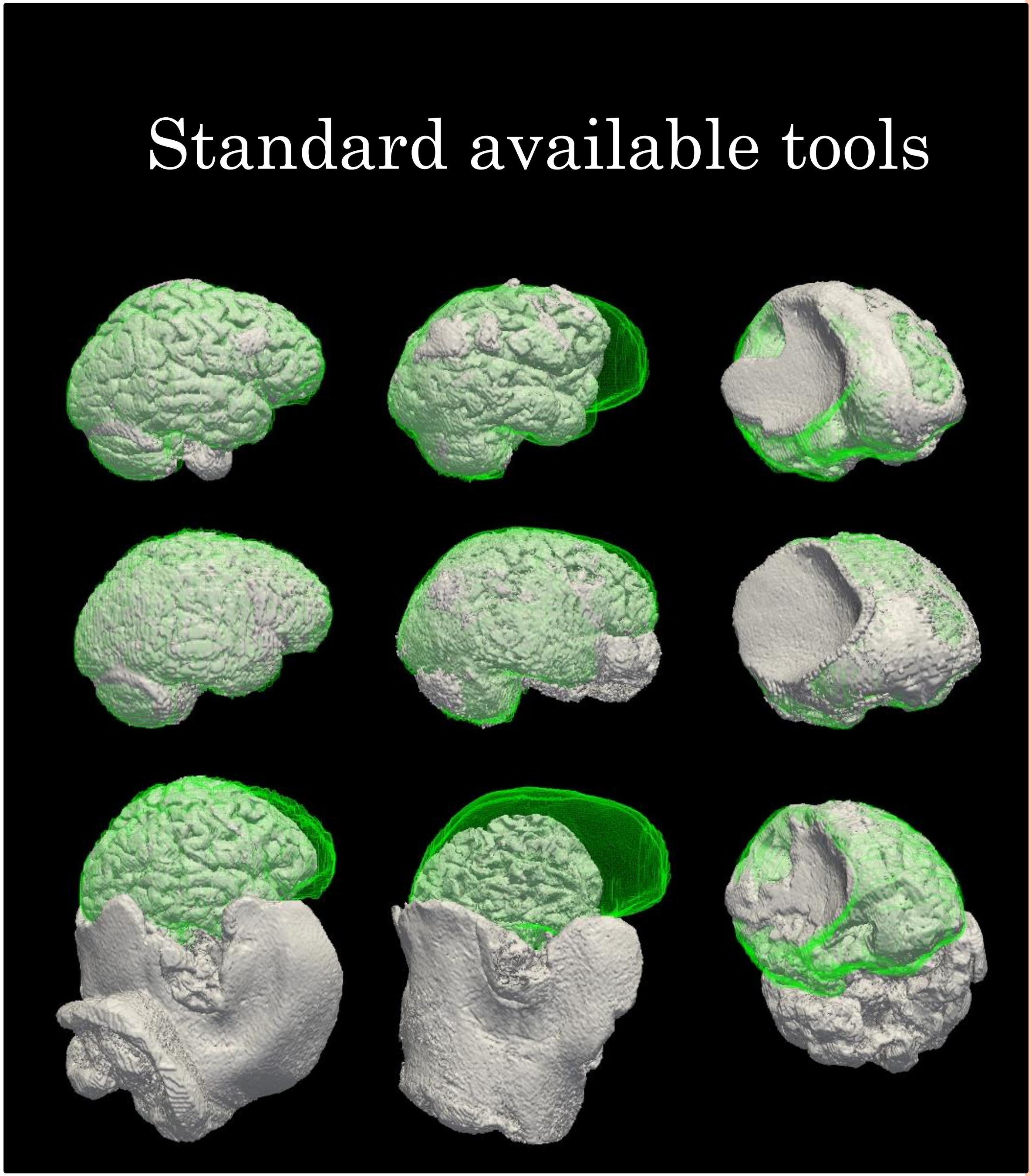
Brain extraction



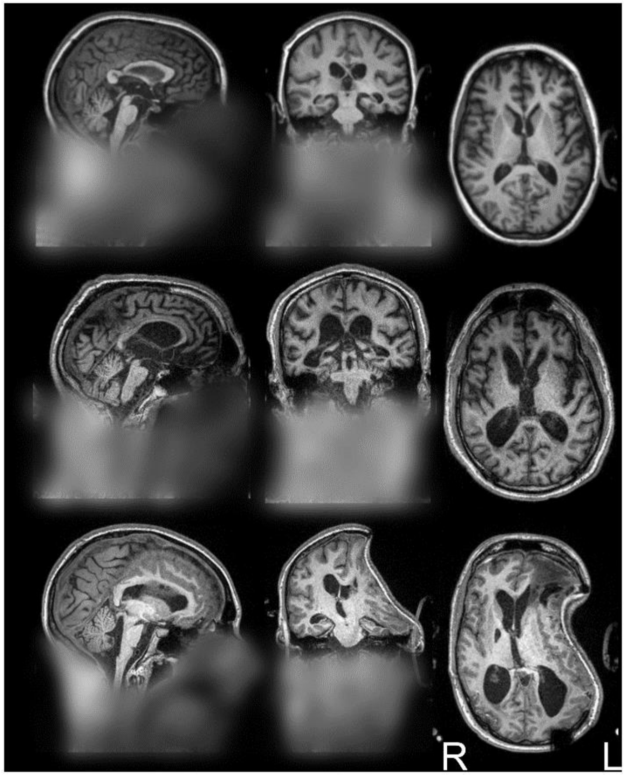
OPTIBET

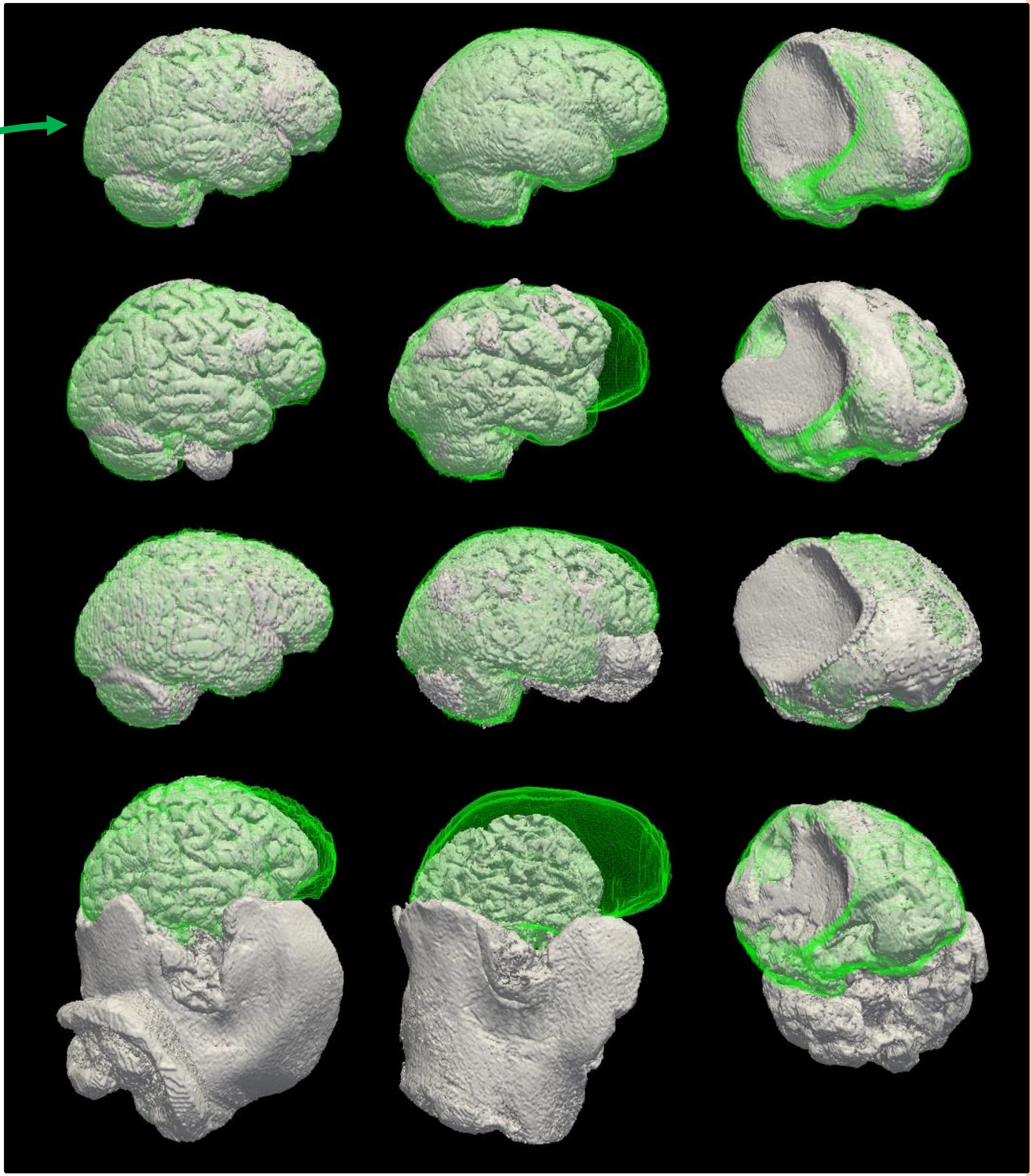




http://montilab.psych.ucla.edu/fmri-wiki/optibet

OPTIBET





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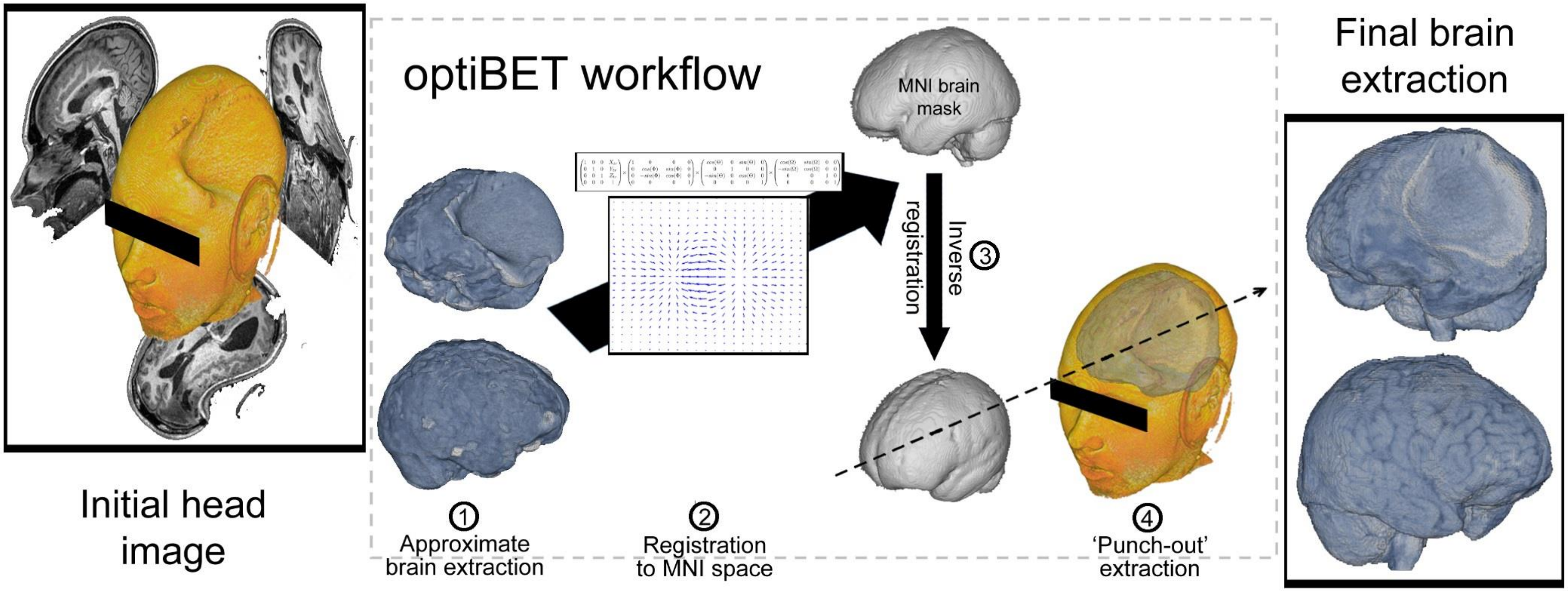
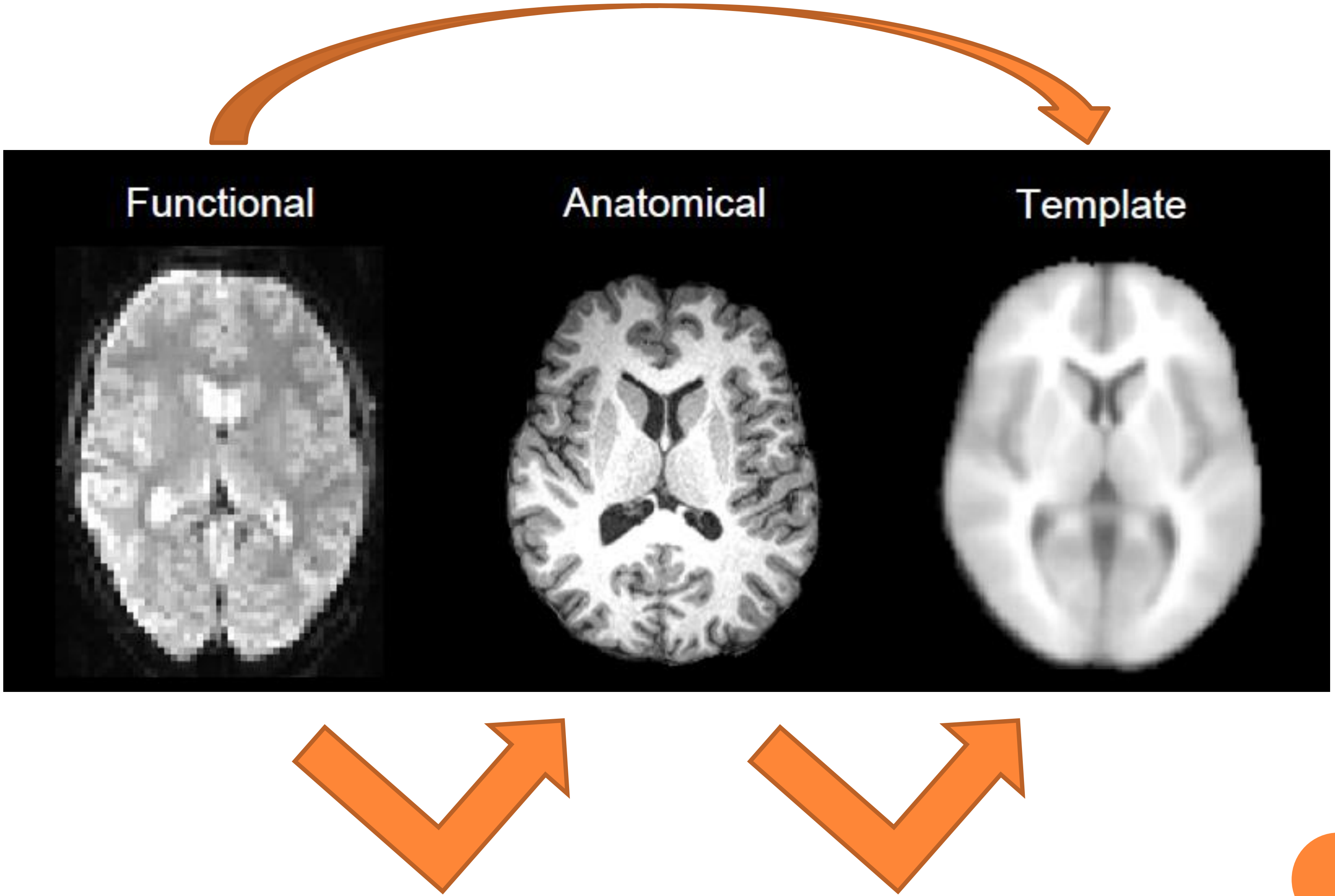
optiBET



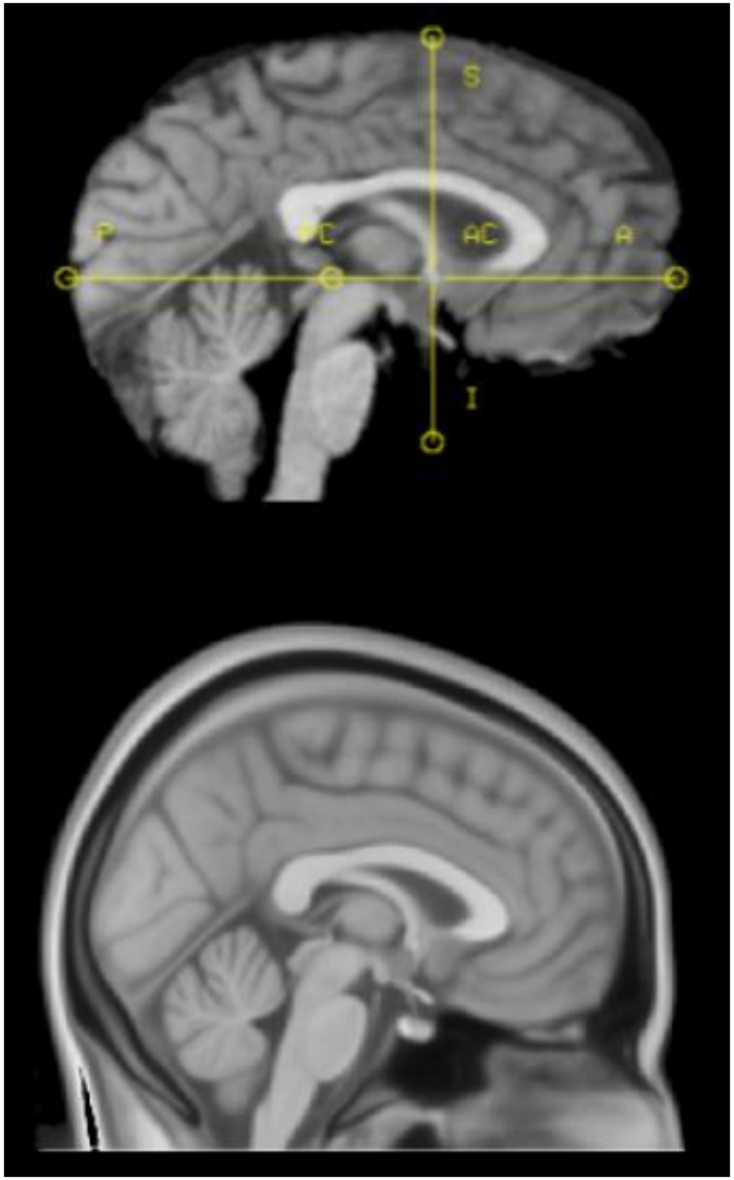
http://montilab.psych.ucla.edu/fmri-wiki/optibet

Registration

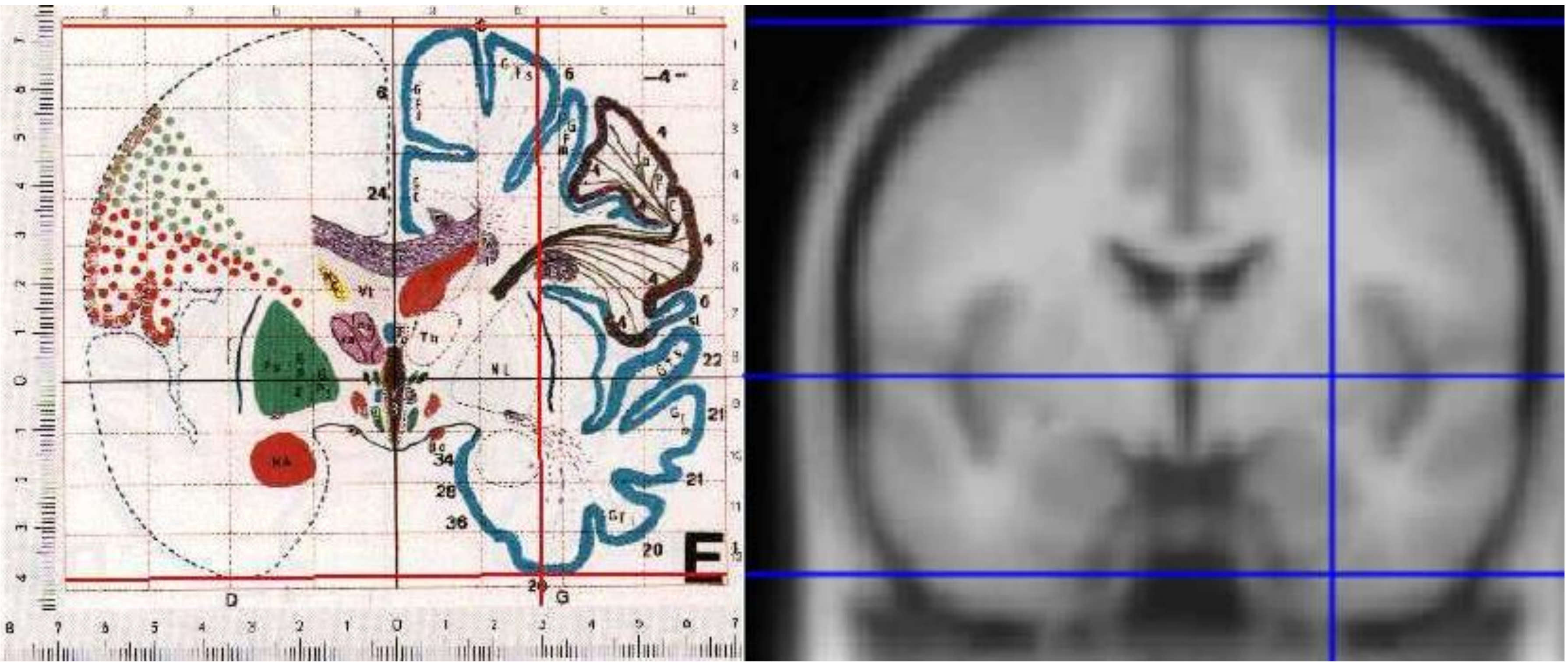


Standard Space

- Common reference frame
  - Talairach & Tournoux 1988, based on post mortem dissection of 1 brain
  - MNI (152) non linear average of multiple individuals



STANDARD SPACE



Registration

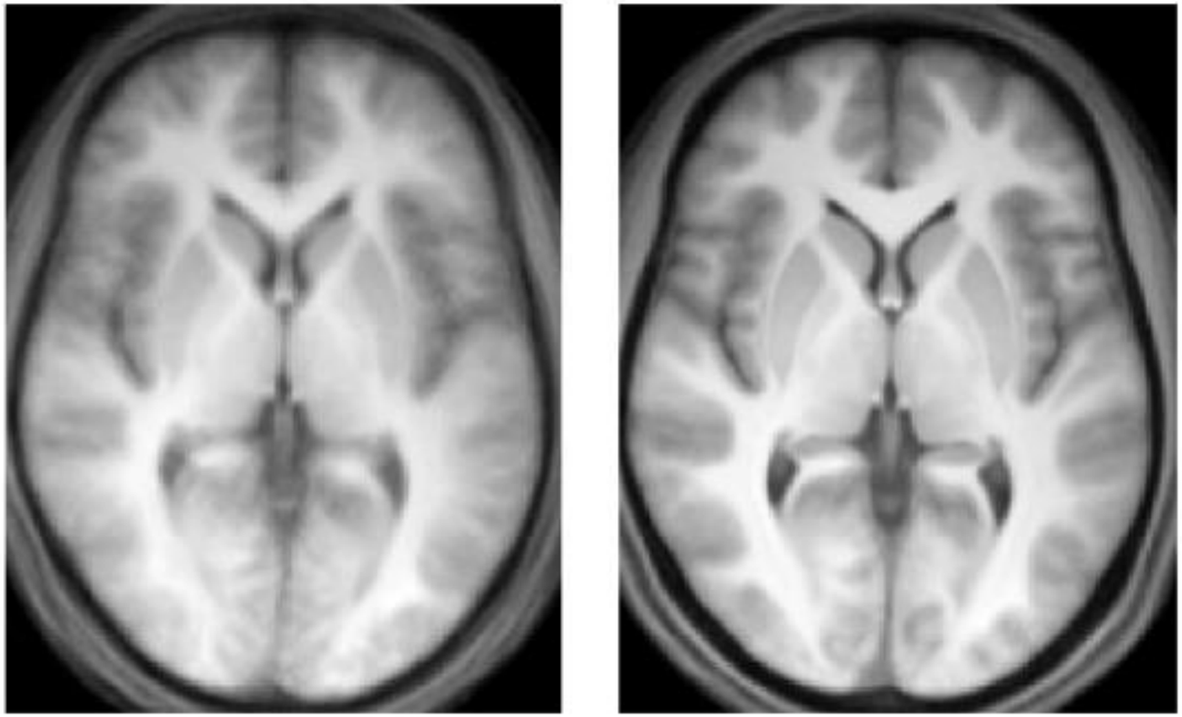
1. **Transformation:** How to manipulate an image to fit it from its native space into a different space?
2. **Cost function:** How to assess the quality of the manipulation?
3. **Interpolation:** How create the intensity values to be assigned to the new "grid"?

Transformation

- Rigid body (6dof):
  - 3 rotations, 3 translations
  - Typically used for intra-subject registration
- Rigid body + global scaling (7dof)
  - 3 rotations, 3 translations, global scaling
  - Typically used for within subject/between modalities (i.e., functional to structural)
- Affine (12dof)
  - 3 rotations, 3 translations
  - 3 scalings, 3 sheers/skews
  - Typically used for registering a subject to the template

Transformation

- Non linear (>12dof):
  - Can be local
  - Can be constrained (e.g., regularization, topology preservation)



Transformation

- Non linear (>12dof):
  - Can be local
  - Can be constrained (e.g., regularization, topology preservation)

$$A = \begin{pmatrix} a_{11} & a_{12} & a_{13} & a_{14} \\ a_{21} & a_{22} & a_{23} & a_{24} \\ a_{31} & a_{32} & a_{33} & a_{34} \\ 0 & 0 & 0 & 1 \end{pmatrix}$$

An affine transformation is represented by these 12 numbers.
This matrix multiplies coordinate vectors to define the transformed coordinates.

FLIRT: Cost Functions

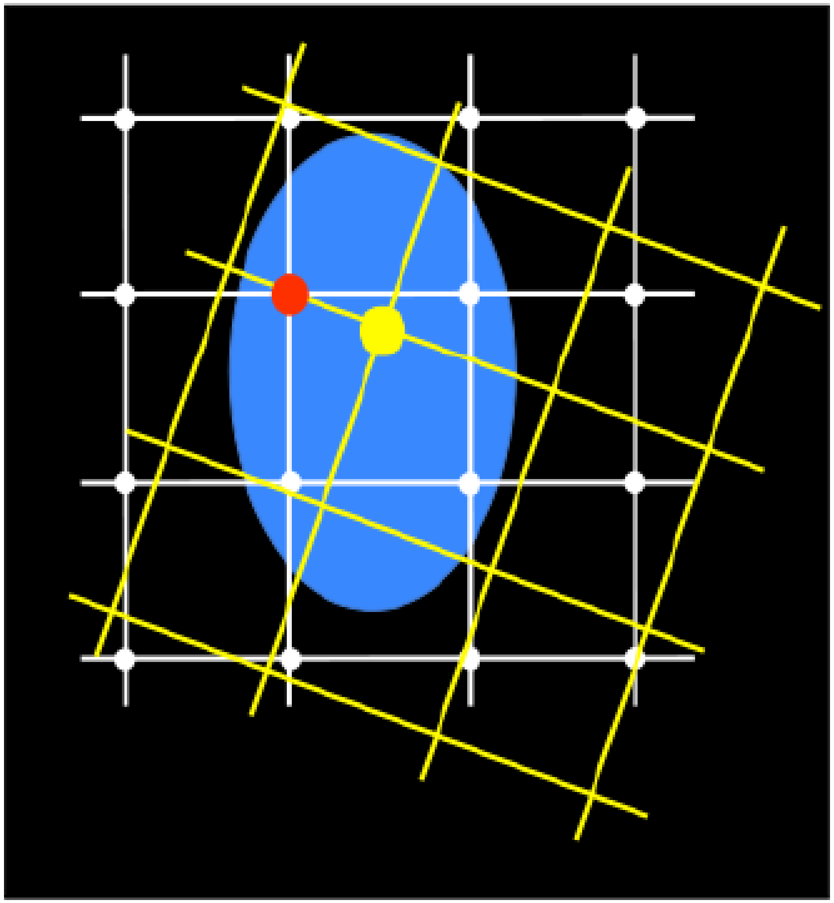
Important: Allowable image modalities

Less important: Details

Least Squares	*Same modality* (exact sequence parameters)
Normalised Correlation	*Same modality* (can change brightness & contrast)
Correlation Ratio	*Any MR modalities*
Mutual Information	*Any modalities* (including CT, PET, etc.)
Normalised Mutual Info.	*Any modalities* (including CT, PET, etc.)

Interpolation

Finds intensity values between grid points



Various types include

- Nearest Neighbour
- Trilinear
- Sinc
- Spline
- k-Space methods

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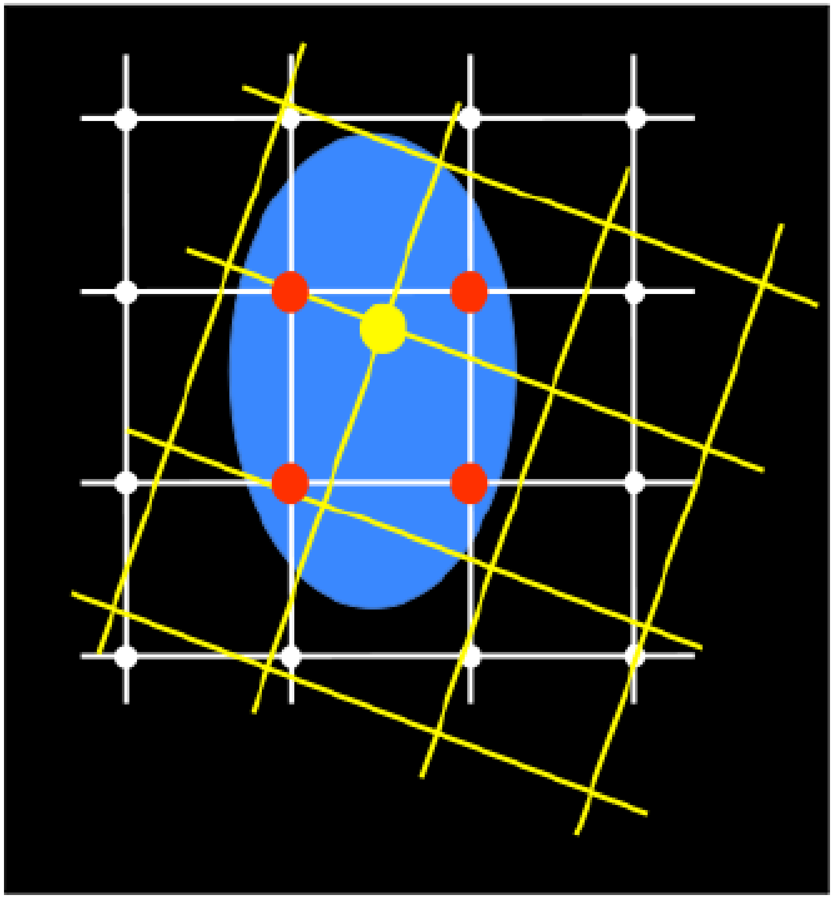

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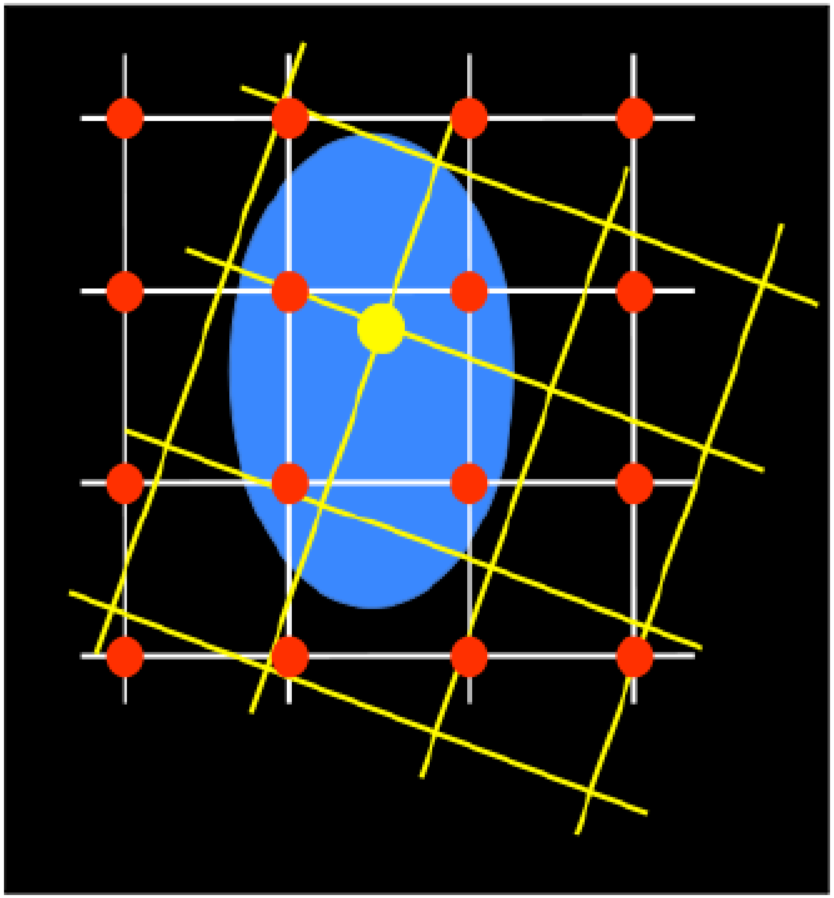

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Considerations: speed, accuracy, stability