FMRI Pre-Statistics

FMRI pre-statistical image processing:

- Reconstruction from k-space data
- Motion correction
- Slice timing correction
- Spatial filtering
- Temporal filtering
- Global intensity normalisation

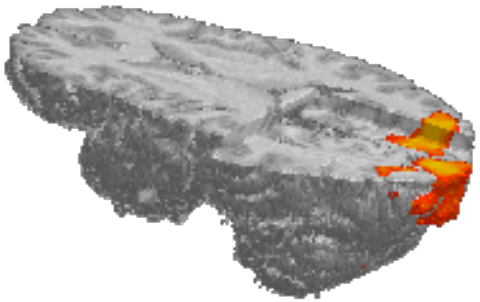
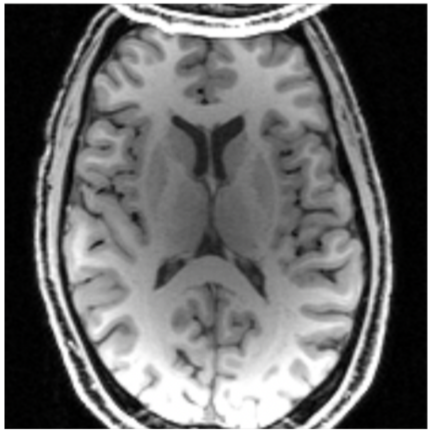
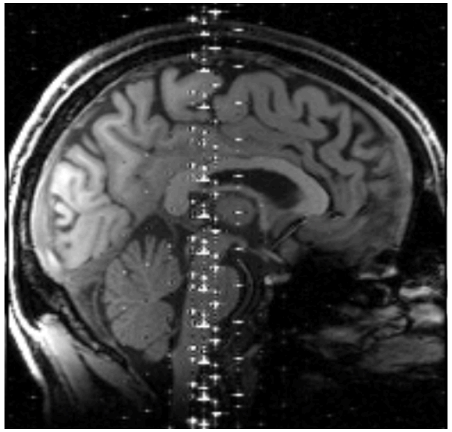


Image Reconstruction

- Convert k-space data to images:
    - reconstruction algorithms
- Occasionally get problematic data
    - e.g. RF spikes, wrap-around, RF interference

- Correct using custom-built initial analysis stages
- Scanner artefacts can be found by:

LOOK AT YOUR DATA!

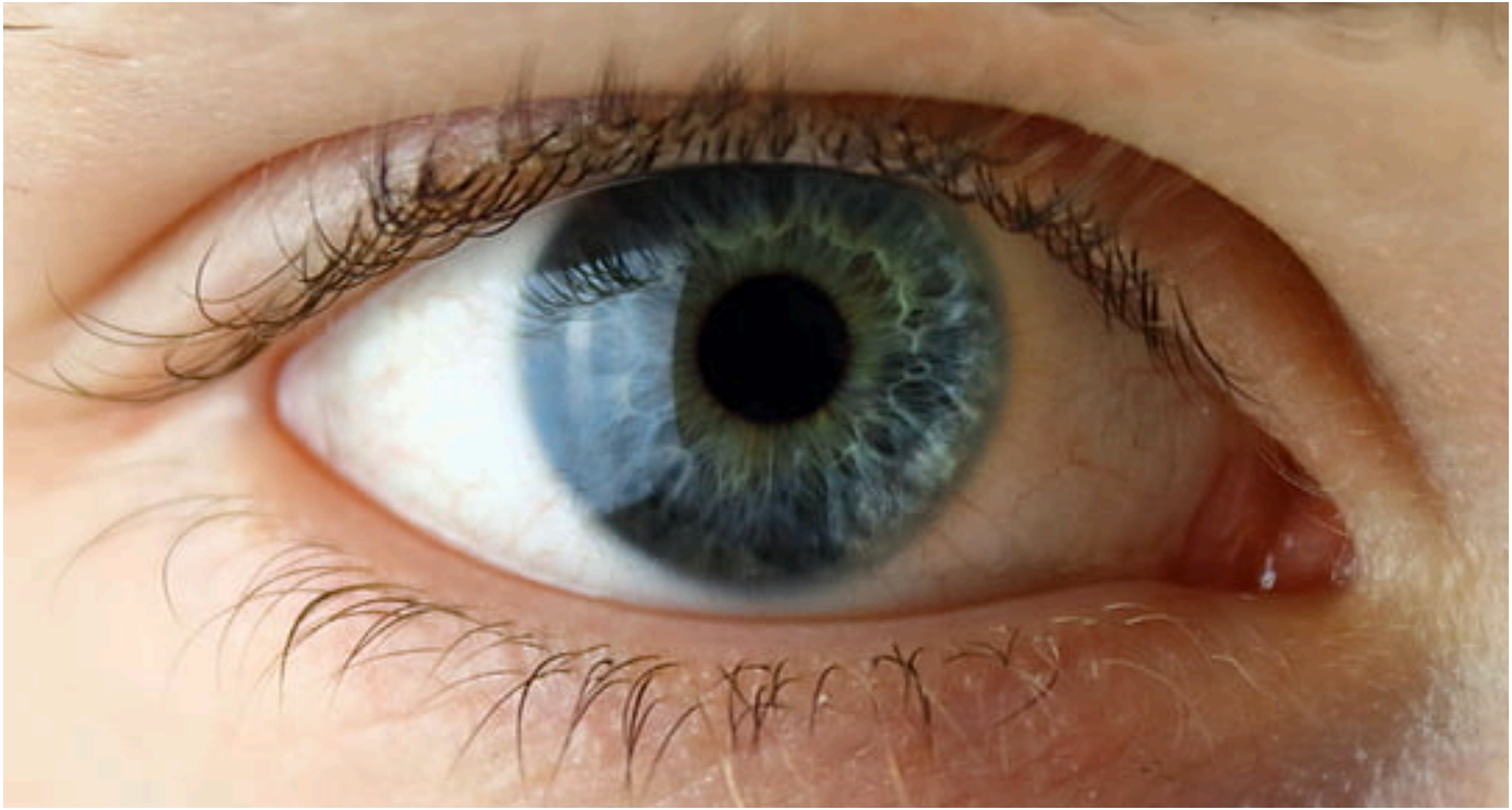


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Image Reconstruction

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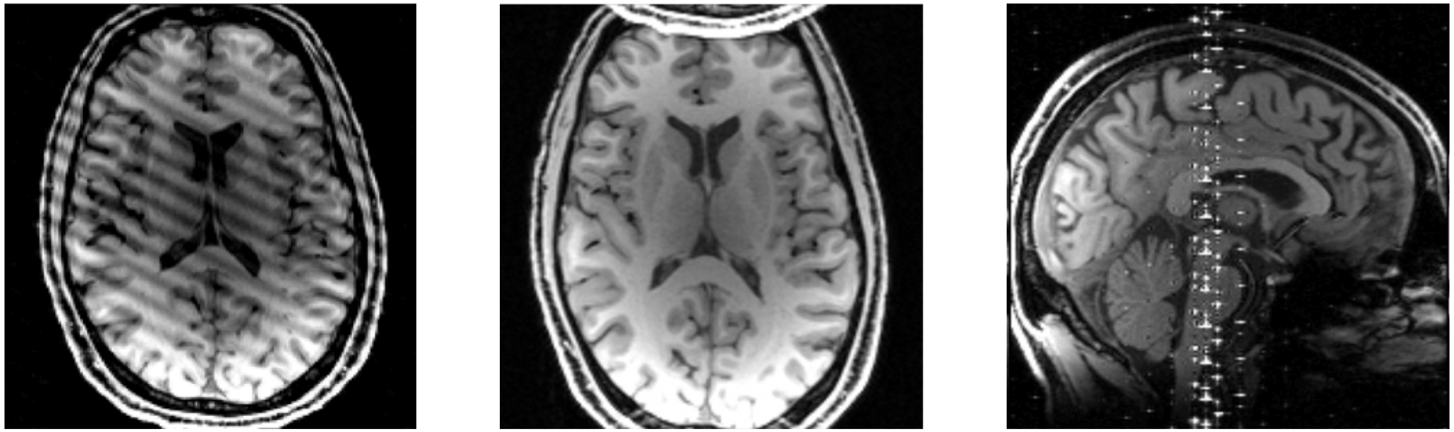

- Correct using custom-built initial analysis stages
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LOOK!
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Image Reconstruction

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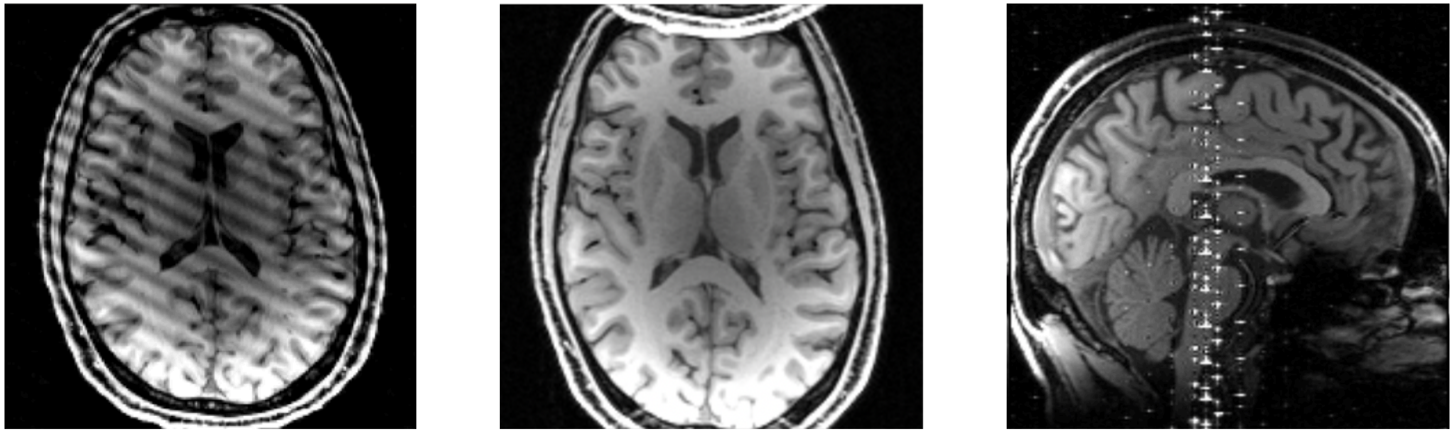

- Correct using custom-built initial analysis stages
- Scanner artefacts can be found by: **looking at data** exploratory analysis (ICA), **looking at data** , quality assessment software and ...


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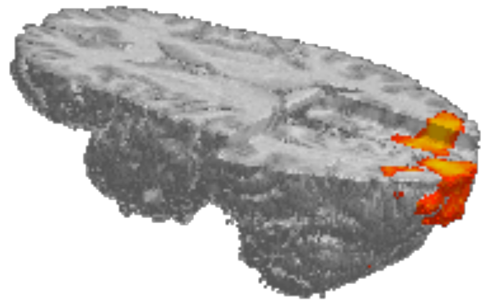
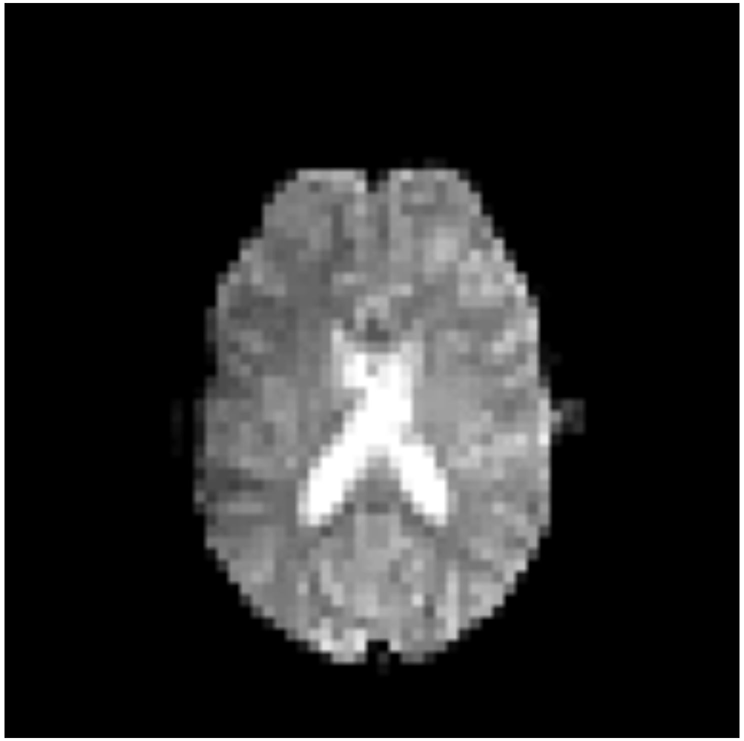


Motion Correction: Why?

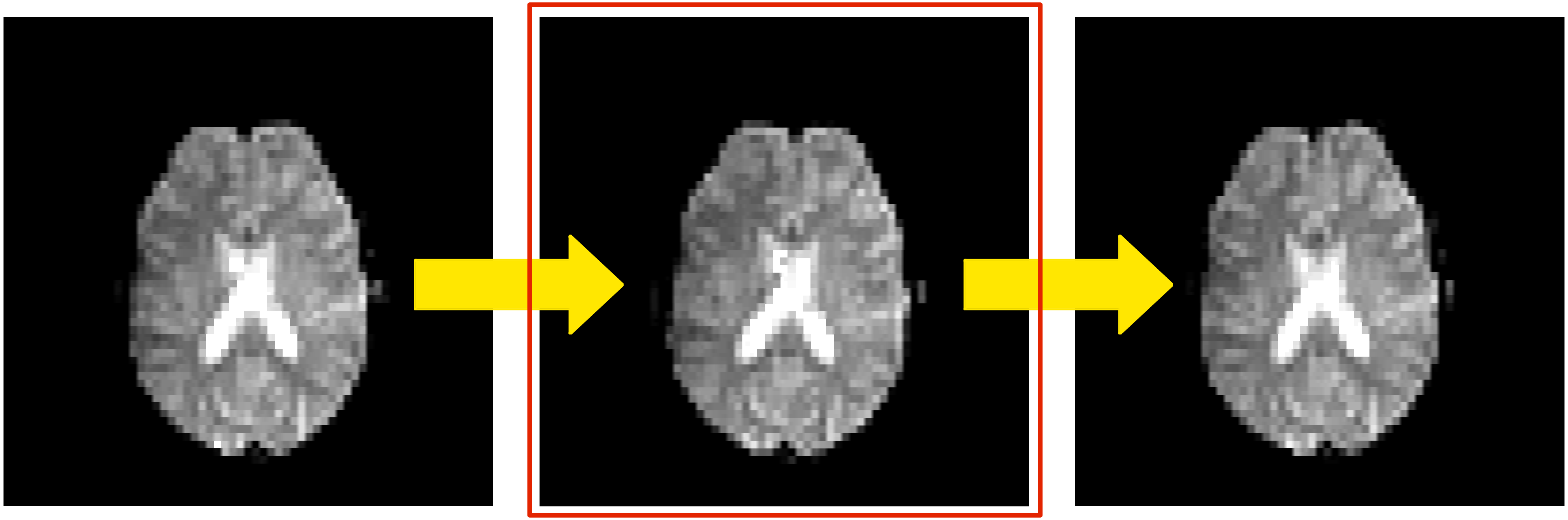
- People always move in the scanner



- Even with padding around the head there is still some motion
- Need each voxel to correspond to a consistent anatomical point for each point in time
- Motion correction realigns to a common reference
- Very important correction as small motions (e.g. 1% of voxel size) near strong intensity boundaries may induce a 1% signal change > BOLD

Motion Correction

= multiple registration



Select a MC target (reference) for all FMRI volumes.

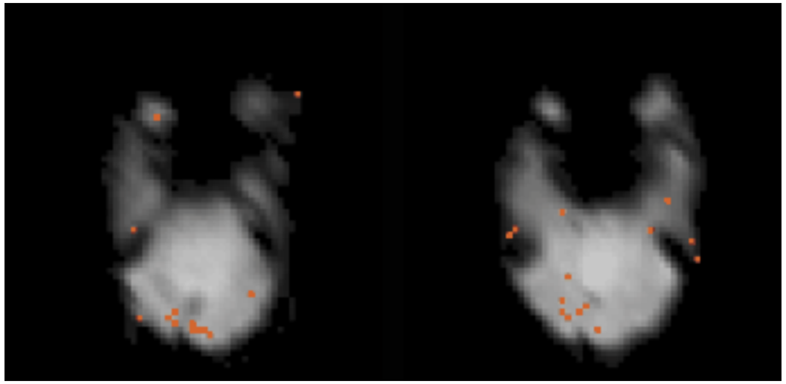
Can use either one original volume, mean of several, standard space image etc.

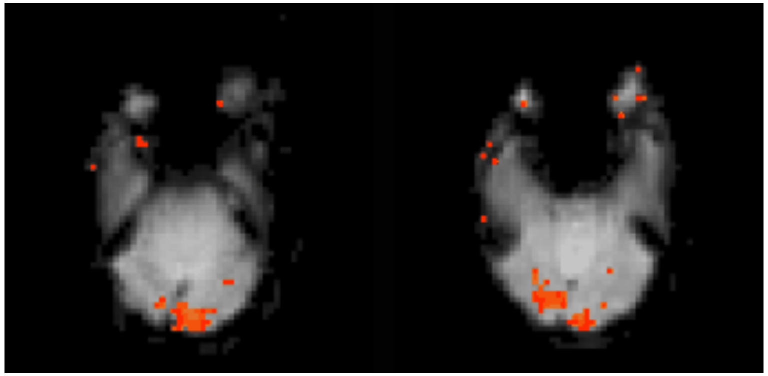
Register each FMRI volume to target separately

Use rigid body (6 DOF)

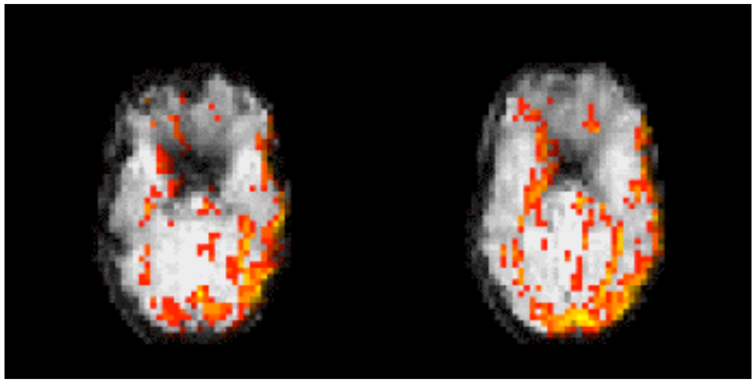
Effect of Motion Correction

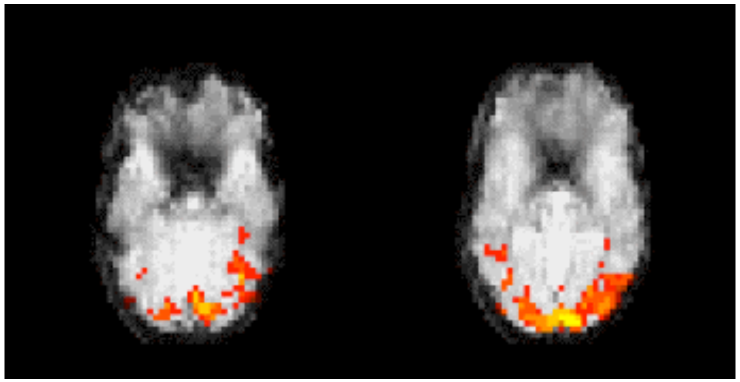
Uncorrelated Motion





Stimulus Correlated Motion

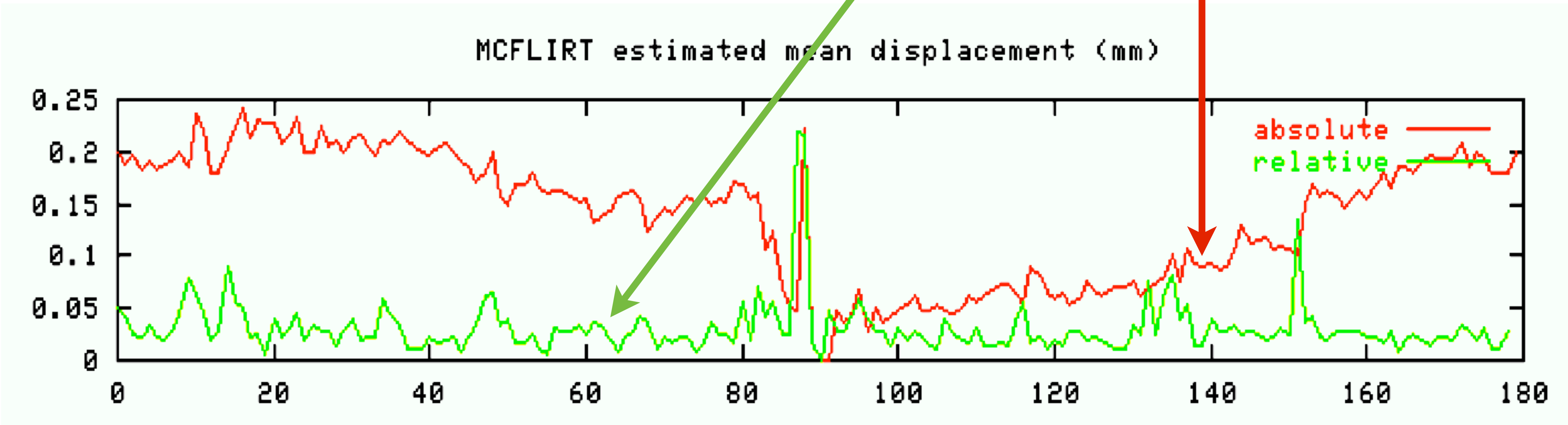




Without MC With MC

Motion Parameter Output

Summary of total motion (relative and absolute)



Relative = time point to next time point - shows jumps
Absolute = time point to reference - shows jumps & drifts

Note that large jumps are more serious than slower drifts, especially in the relative motion plot

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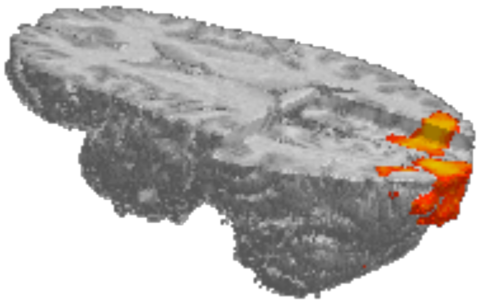
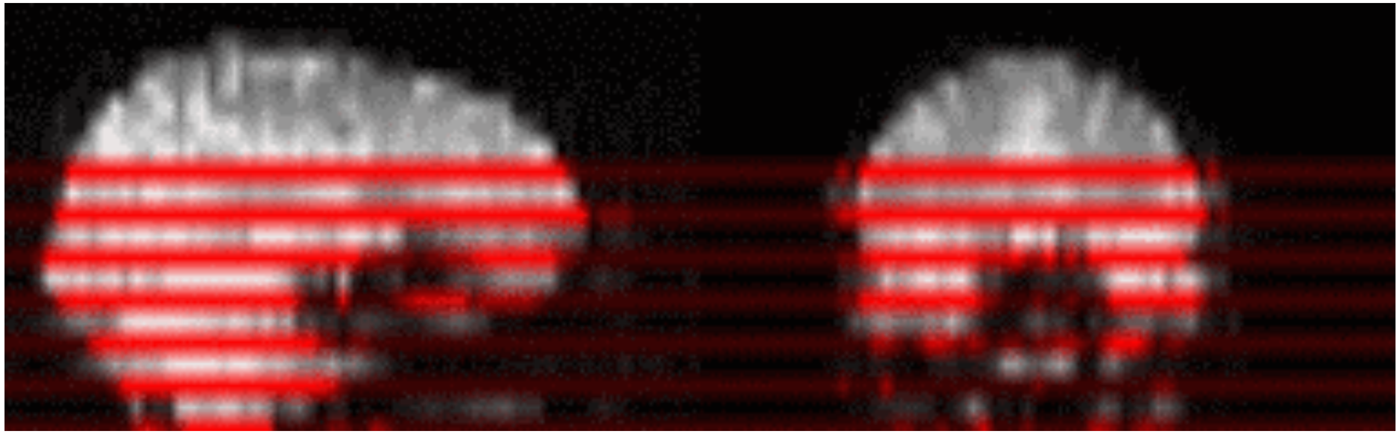


Slice Timing Correction



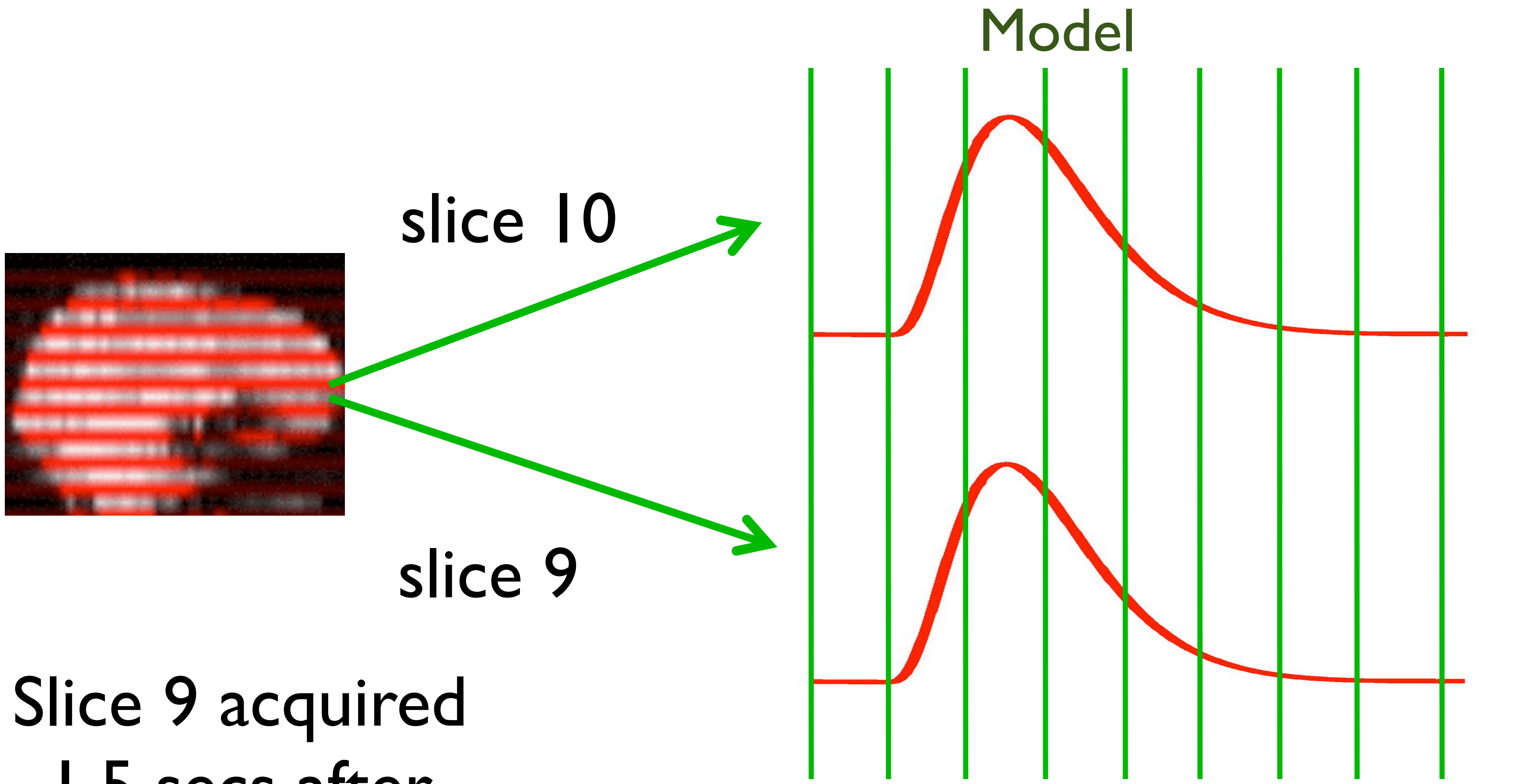
Almost all FMRI scanning takes each slice separately

Each slice is scanned at a slightly different time

Slice order can be interleaved (as shown) or sequential (up or down)

Slice Timing

Without any adjustment, the model timing is always the same

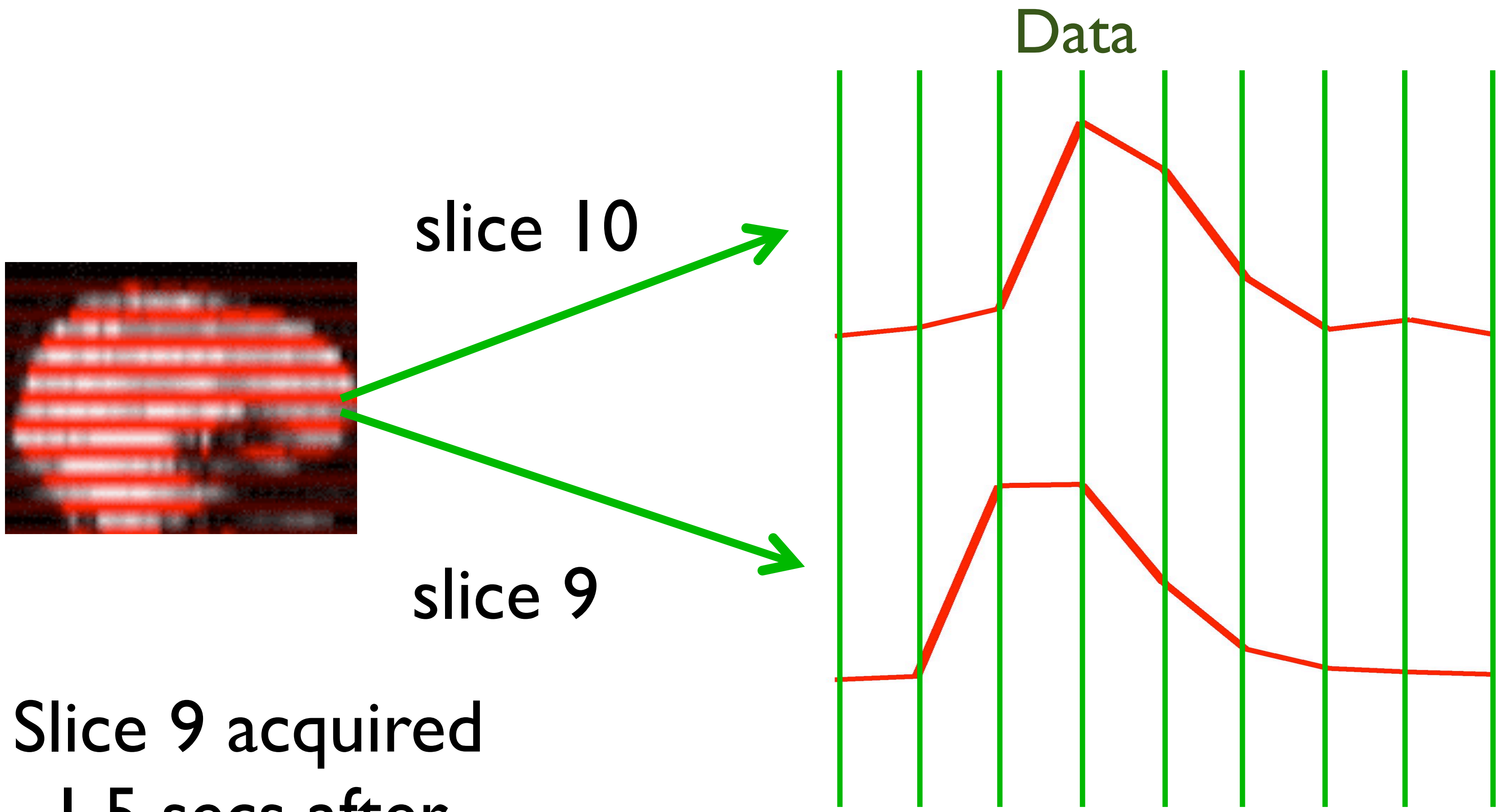


Slice 9 acquired 1.5 secs after slice 10

acquisition timing (TRs)

Slice Timing

... but the timing of each slice's data is *different*

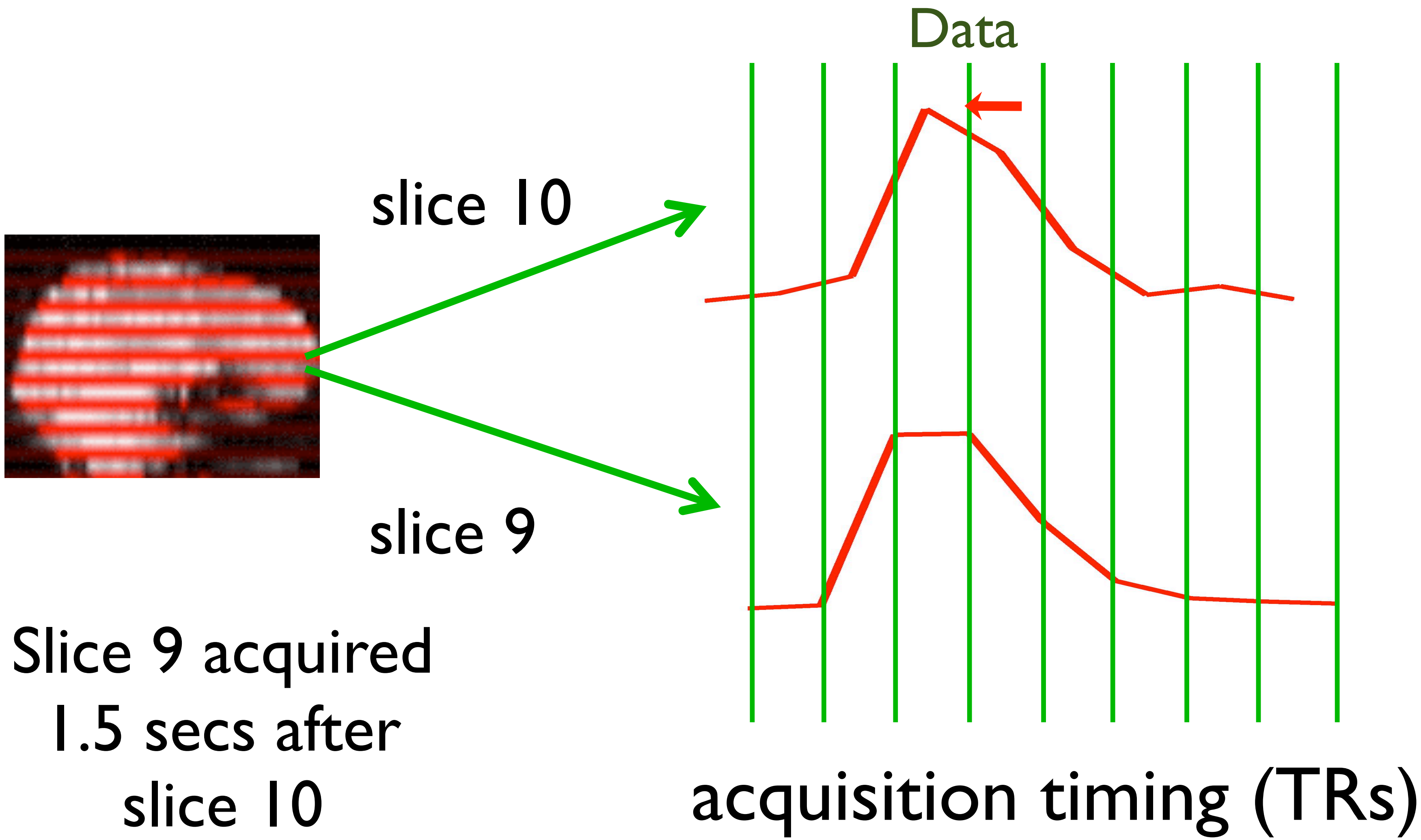


acquisition timing (TRs)

Slice 9 acquired 1.5 secs after slice 10

Slice Timing

Can get consistency by shifting the ***data***

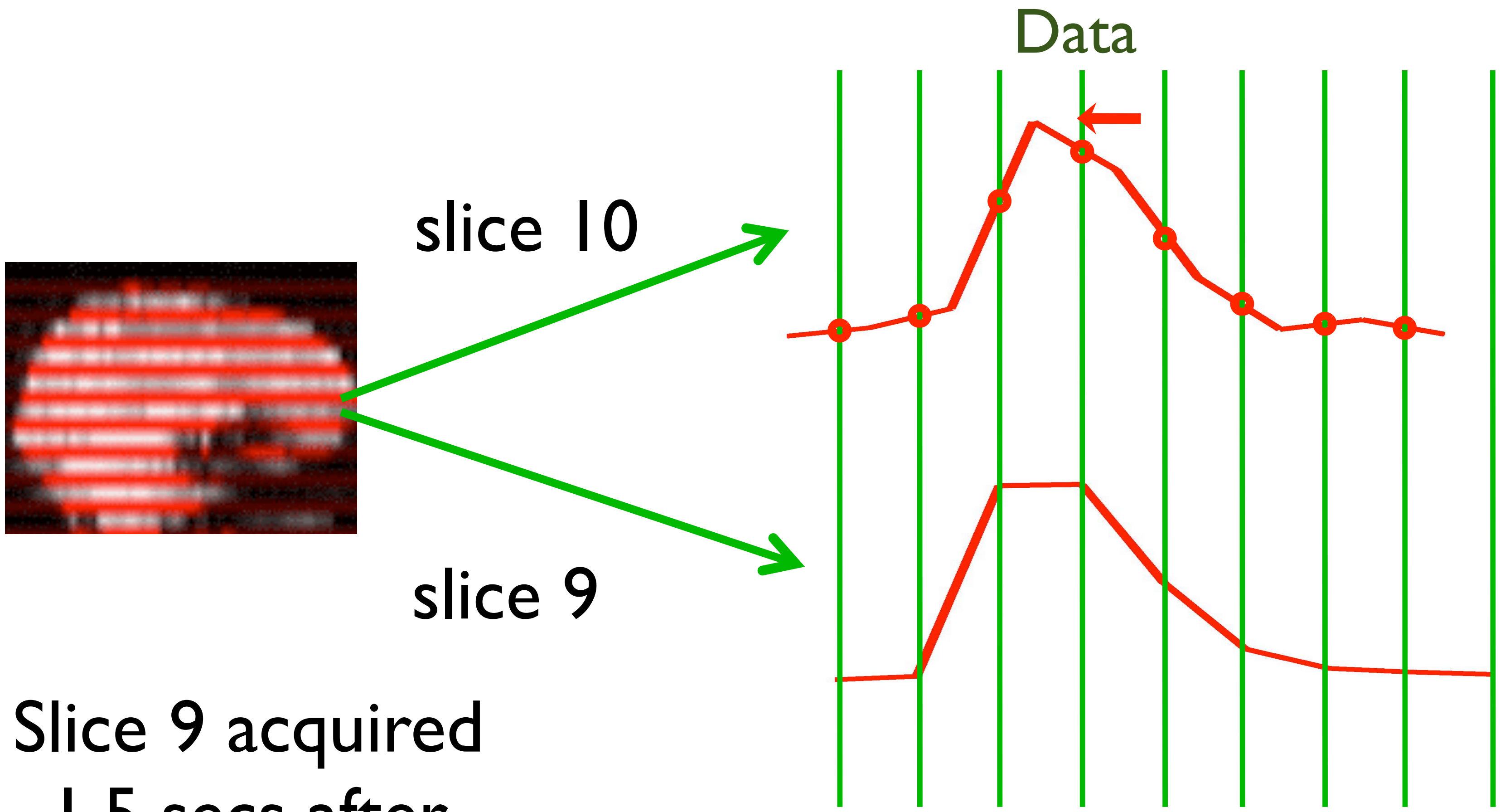


Slice 9 acquired 1.5 secs after slice 10

Slice Timing

... and then interpolating the data

= ***slice timing correction***



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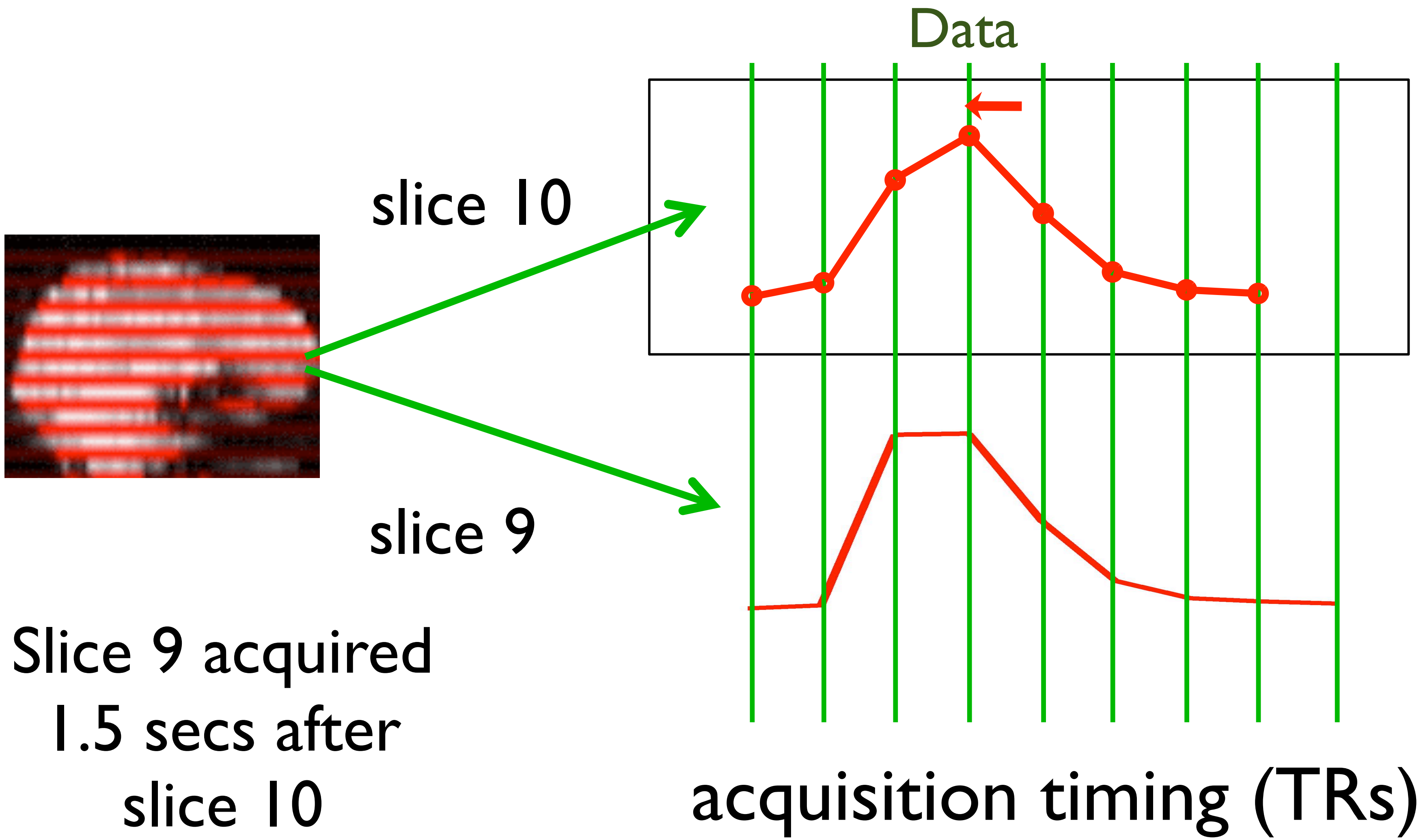
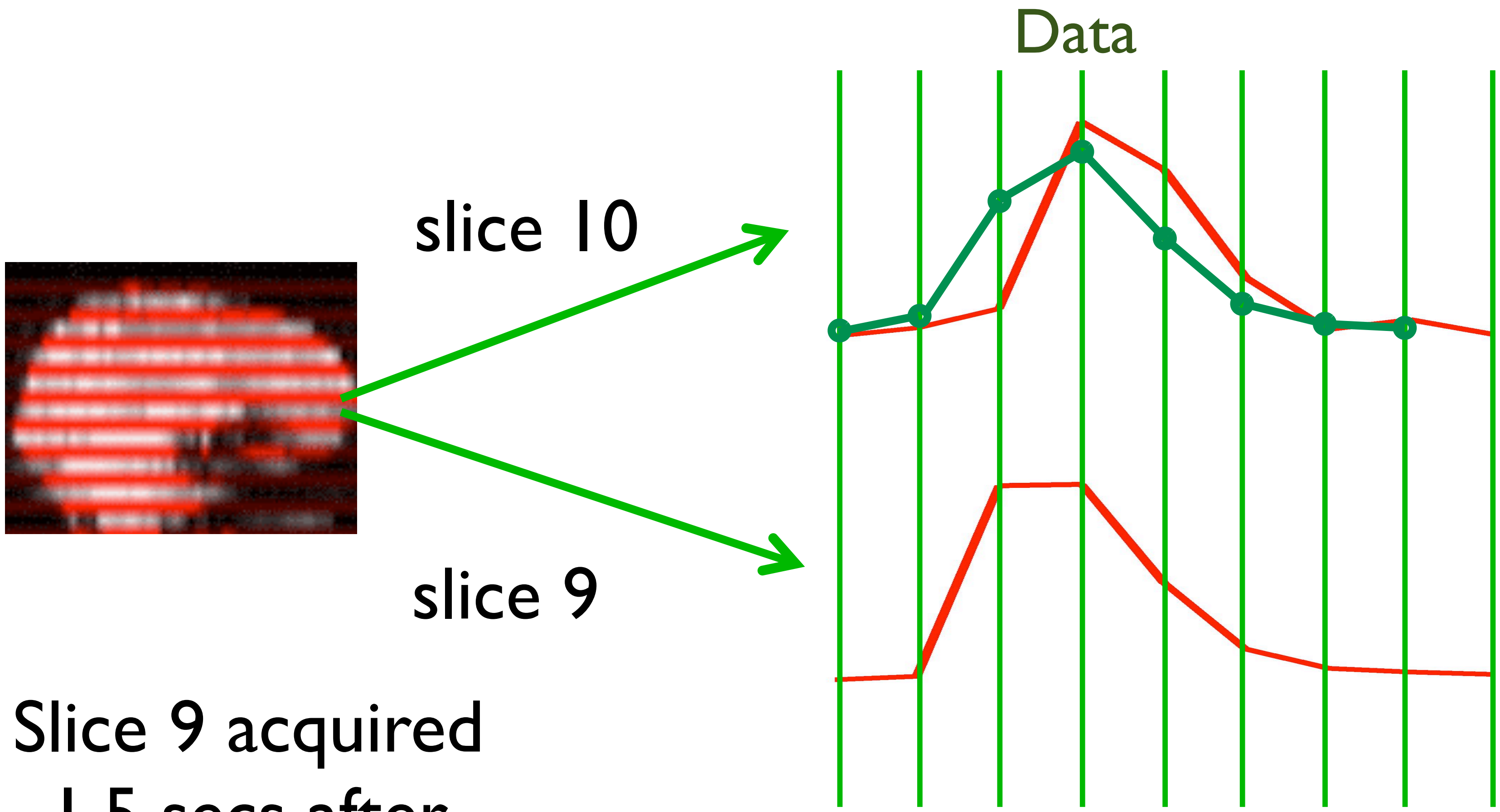


Slice 9 acquired
1.5 secs after
slice 10

Slice Timing

The result of slice timing correction is that the data is changed (degraded) by interpolation

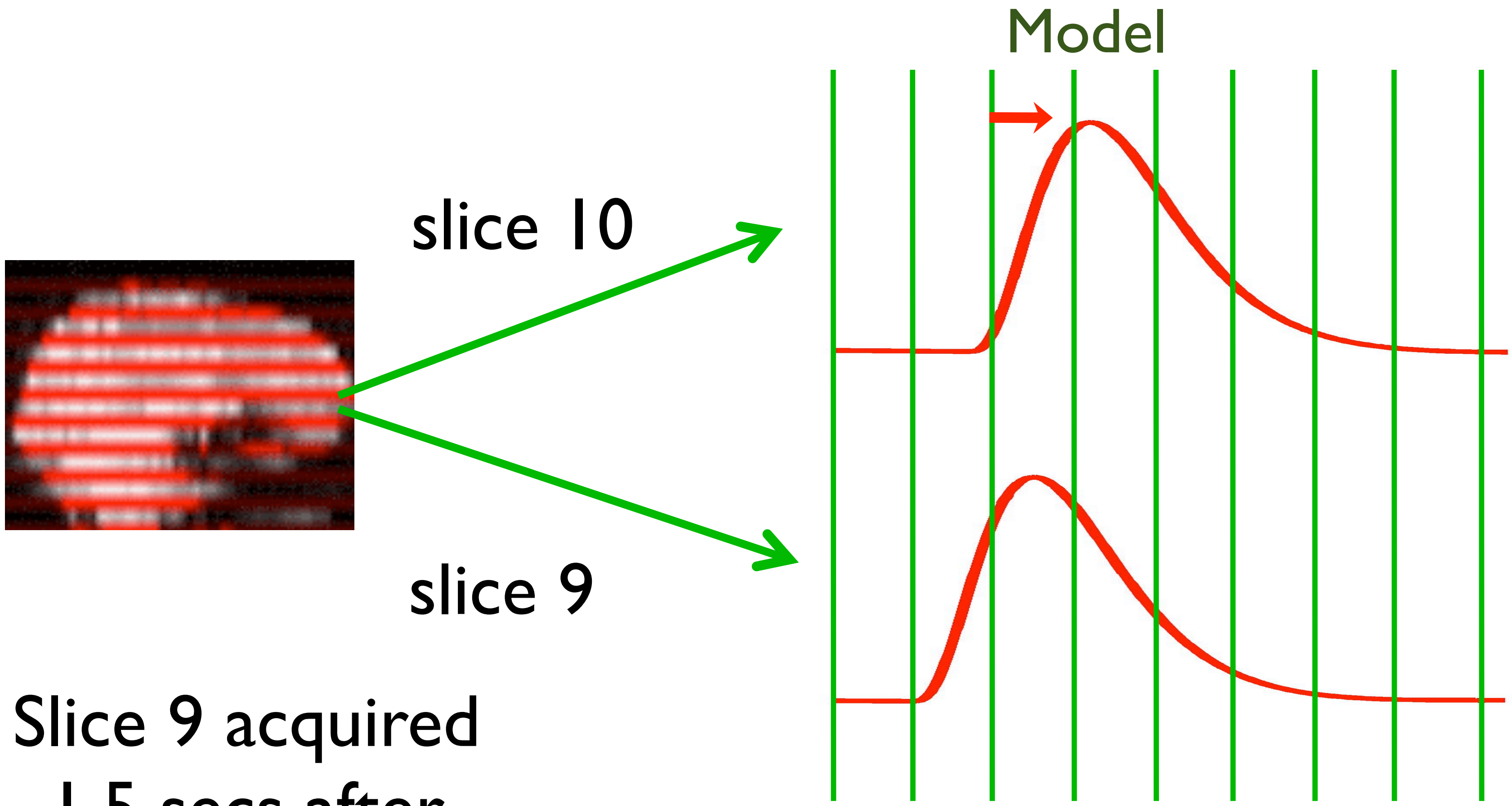


Slice 9 acquired
1.5 secs after
slice 10

acquisition timing (TRs)

Slice Timing

Alternatively, can get consistency by shifting the ***model***



Slice 9 acquired 1.5 secs after slice 10

acquisition timing (TRs)

Slice Timing

One way to shift the model is to use the ***temporal derivative in the GLM***

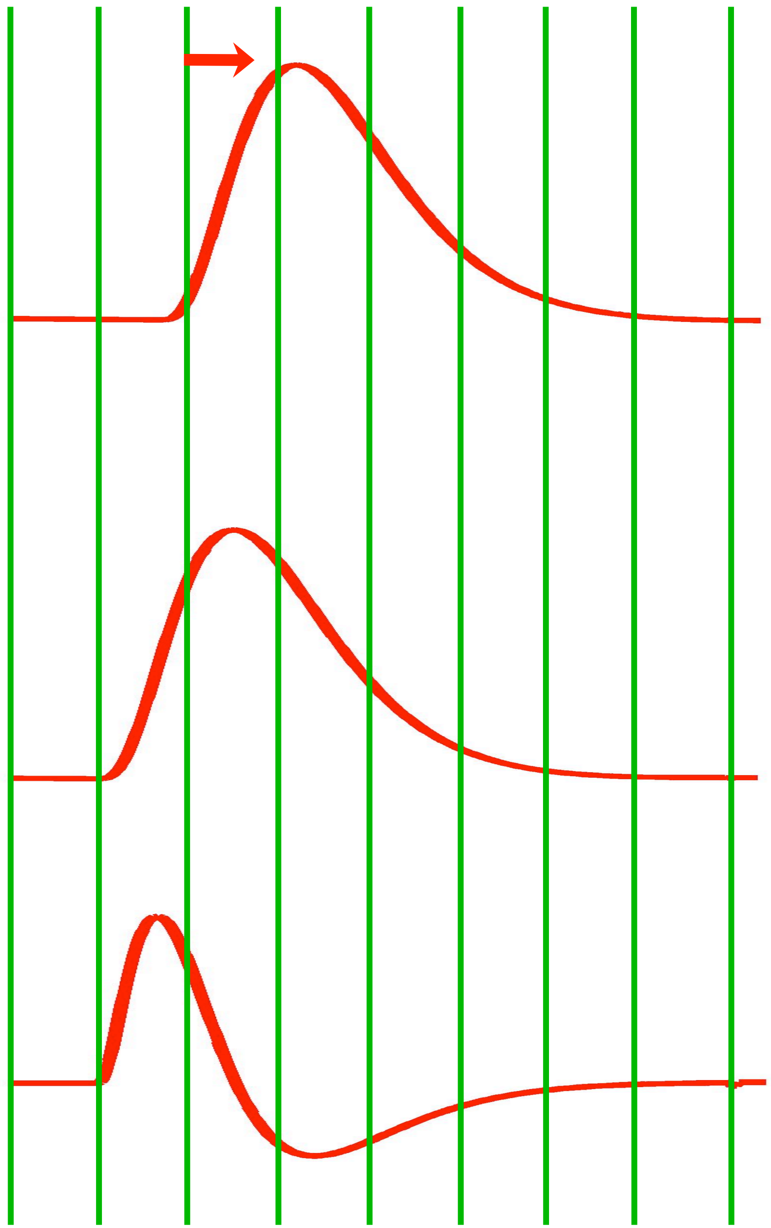
Shifted Model

=

Original Model

-

Temporal Derivative



Based on Taylor approx:

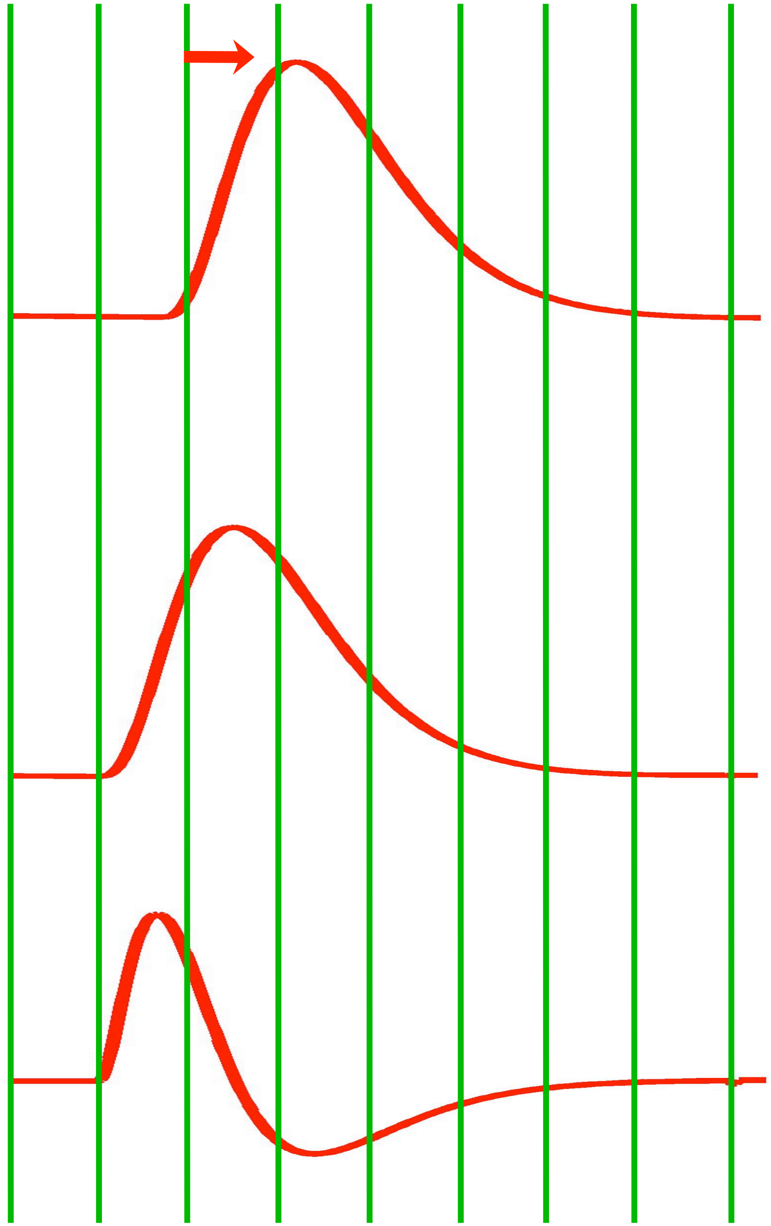
$m(t+a) = m(t) + a.m'(t)$

Slice Timing

Shifting the model also accounts for variations in the HRF delay

- as the HRF is known to vary between subjects, sessions, etc.

This is the recommended solution for slice timing



Motion Problems

Motion correction eliminates gross motion changes but assumes *rigid-body motion* - not true if slices acquired at different times

Other motion artefacts persist including:
Spin-history changes, B_0 (susceptibility) interactions &
Interpolation effects

Such artefacts can severely degrade functional results
Severity usually worse for *stimulus-correlated* motion

Motion Problems

For persistent motion artefacts, acquisition solutions can be good

Motion Problems

Motion correction eliminates gross motion changes but assumes *rigid-body motion* - not true if slices acquired at different times

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Such artefacts can severely degrade functional results
Severity usually worse for *stimulus-correlated* motion

Some *potential* analysis remedies for motion artefacts include:

- including motion parameter regressors in GLM
- removing artefacts with ICA denoising
- outlier timepoint detection and exclusion (via GLM)
- rejection of subjects displaying "excessive" motion

No simple rule of thumb defining "too much" motion

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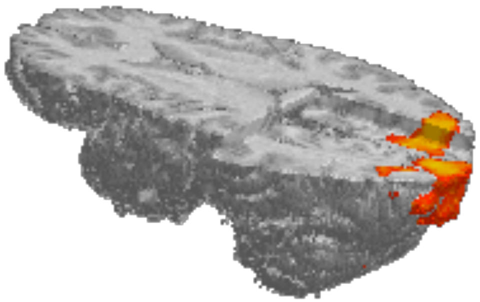
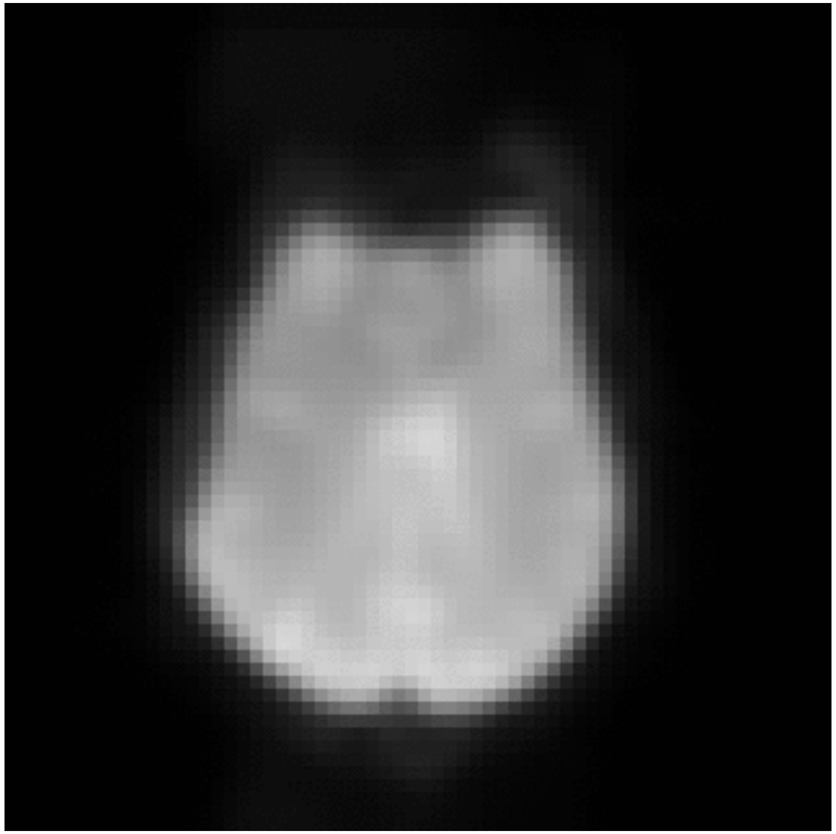


Spatial Filtering

Why do it?

1. Increases signal to noise ratio if size of the blurring is less than size of activation

2. Need minimum "smoothness" to use *Gaussian random field theory* for thresholding



However:

- Reduces small activation areas
- Safest option is to do a small amount of smoothing
- Alternative thresholding/stats eliminates the need for smoothing (e.g. randomise, TFCE)

Spatial Filtering: How?

Spatial filtering done by a 3D convolution with a Gaussian (cf. 1D convolution with HRF for model)

Each voxel intensity is replaced by a *weighted* average of neighbouring intensities

A Gaussian function in 3D specifies weightings and neighbourhood size

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

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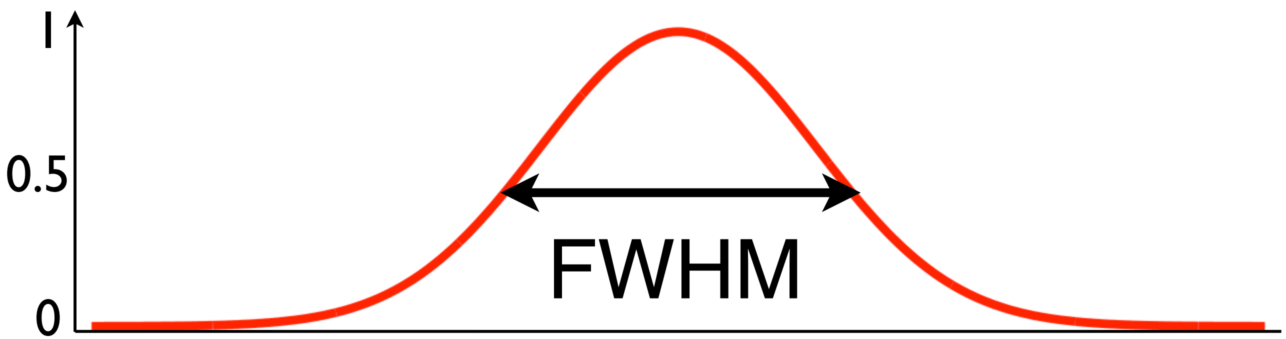

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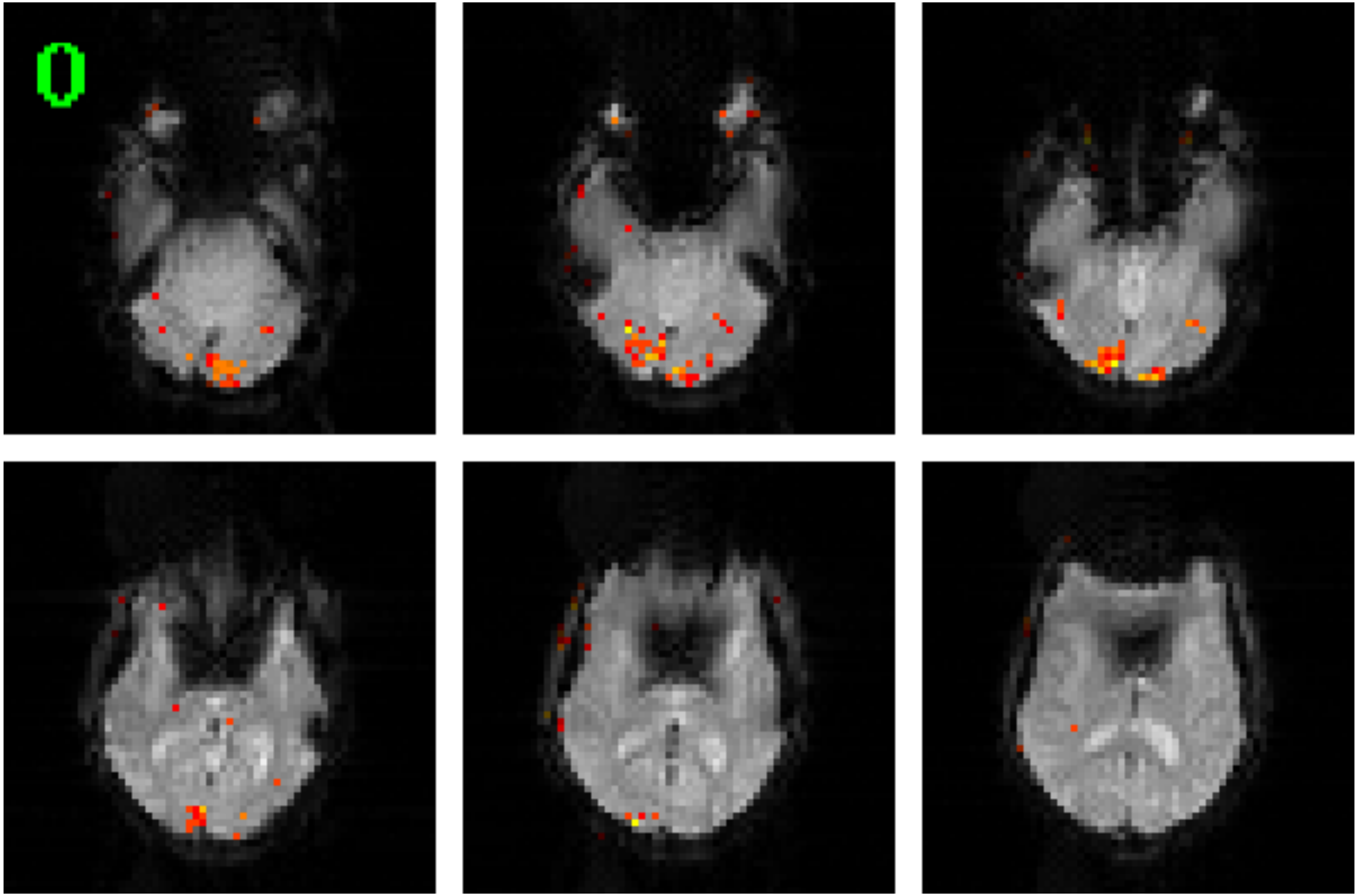
0.1	0.3	0.4	0.3	0.1

FWHM

Specify amount by Full Width Half Maximum (FWHM)
= distance between 0.5 values

Spatial Filtering: Results at Different FWHM



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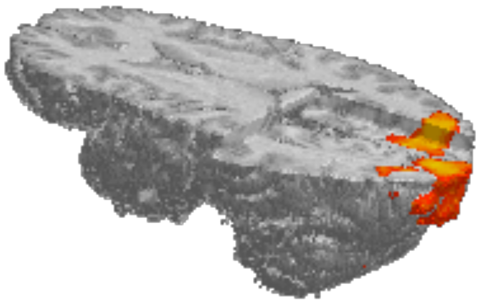
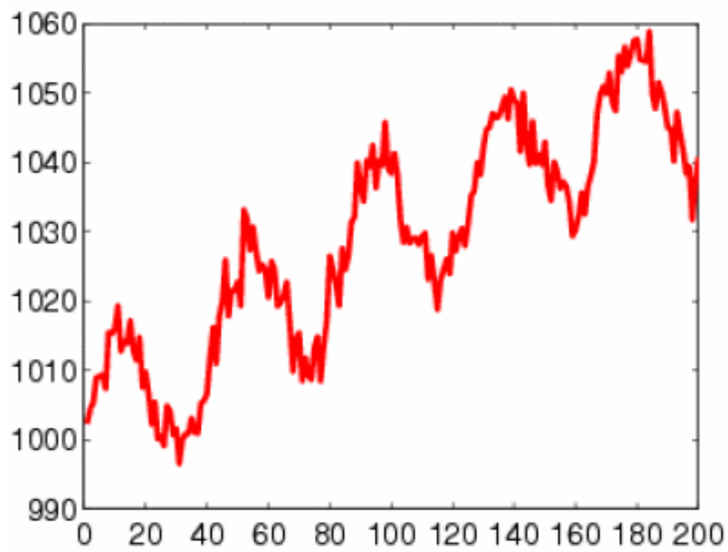


Temporal Filtering: Why?

- Time series from each voxel contain scanner-related and physiological signals + high frequency noise
- Scanner-related and physiological signals (cardiac cycle, breathing etc) can have both high and low frequency components
- These signals + noise hide activation

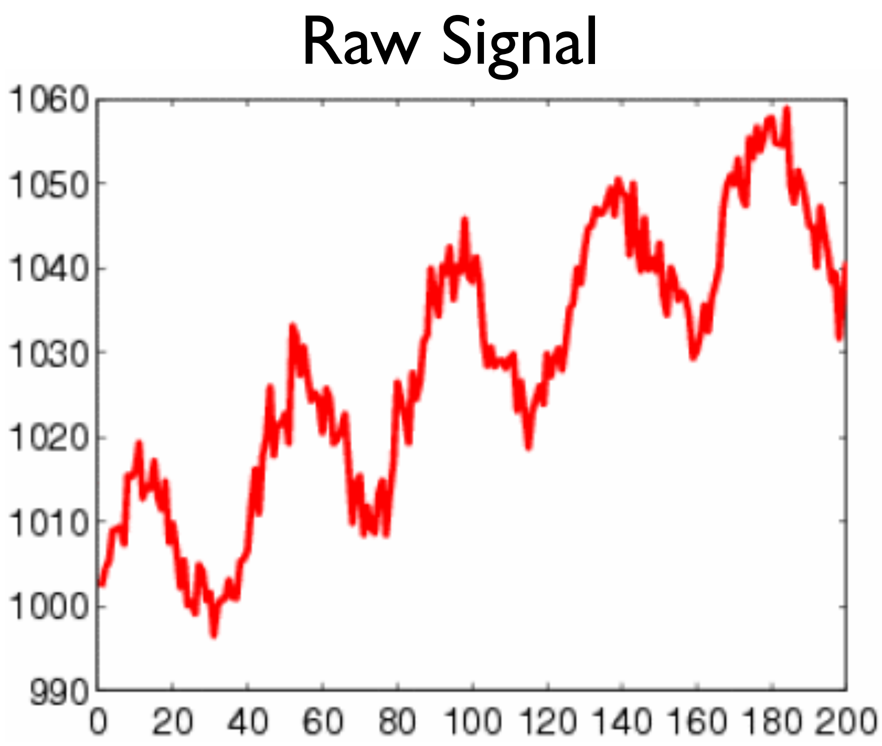
Raw Signal

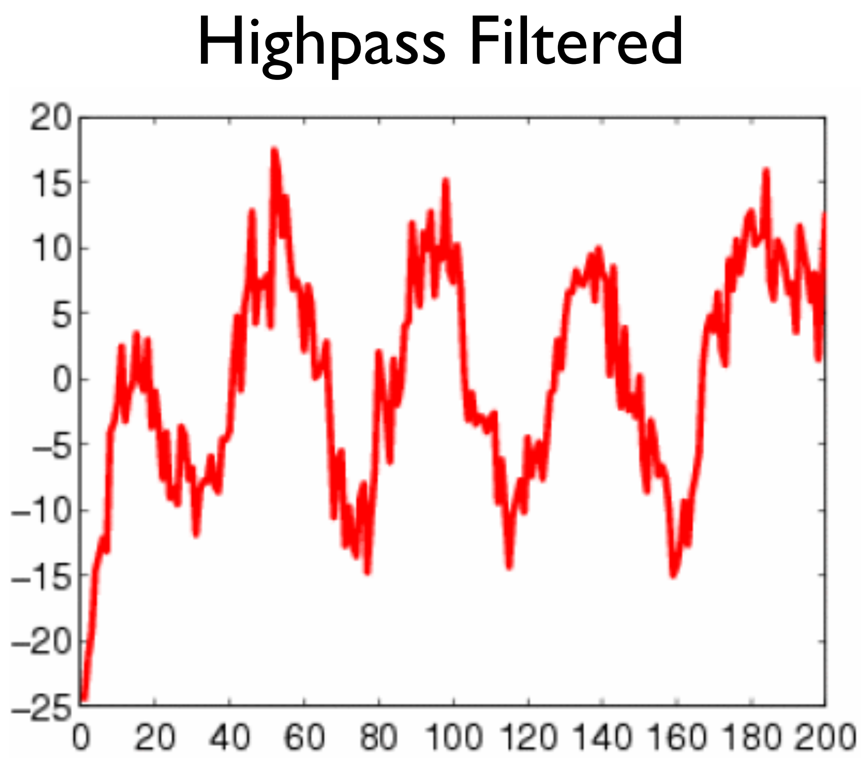


What is temporal filtering?

- Removal of high frequencies, low frequencies or both, *without removing signals of interest*

Temporal Filtering: Highpass

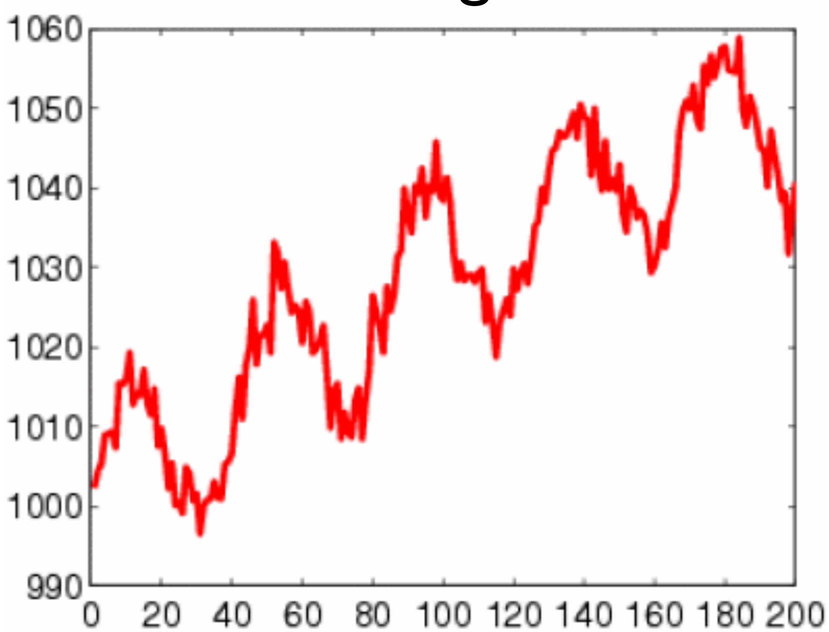




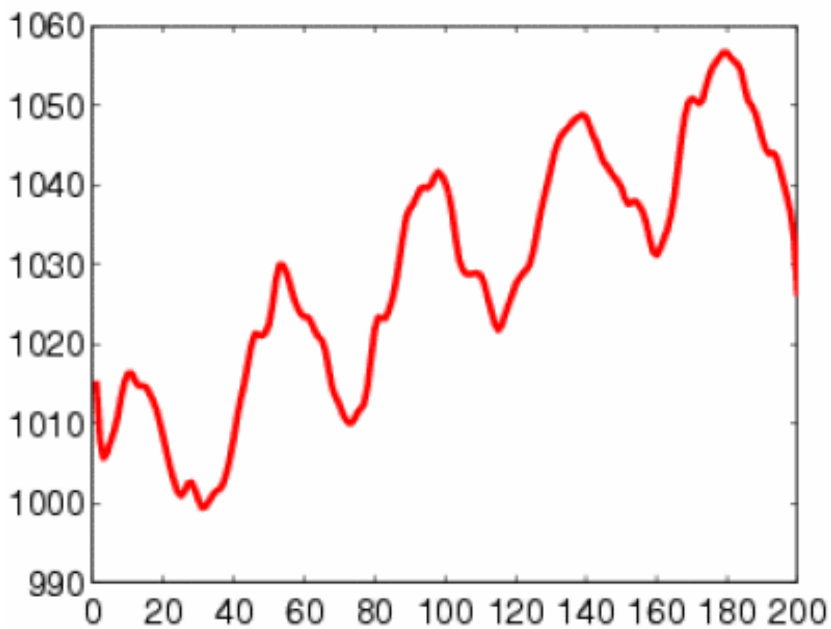
- Removes low frequency signals, including linear trend
- Must choose cutoff frequency carefully (lower than frequencies of interest = longer period)

Temporal Filtering: Lowpass

Raw Signal



Lowpass Filtered



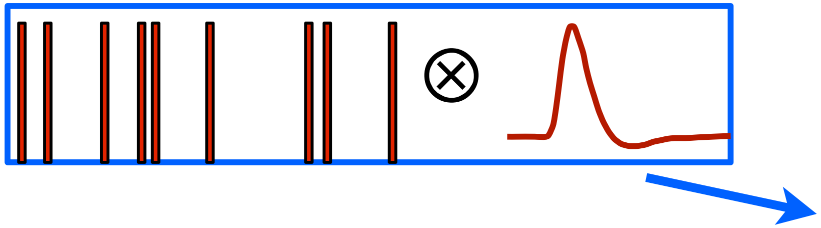
Removes high frequency noise

Only useful if the predicted model does not also contain high frequencies...

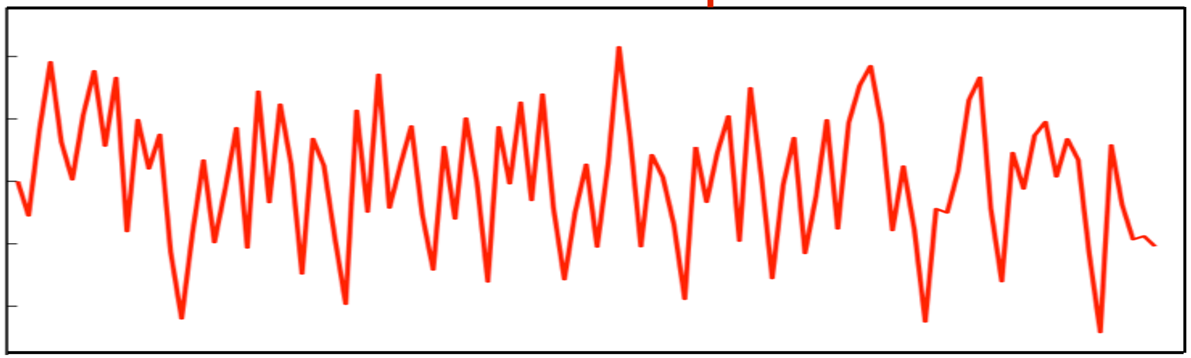
Filtering & Temporal Autocorrelation

Some designs also contain high frequency content *in the model*

e.g. Dense Single-Event Model:



Spectrum of model



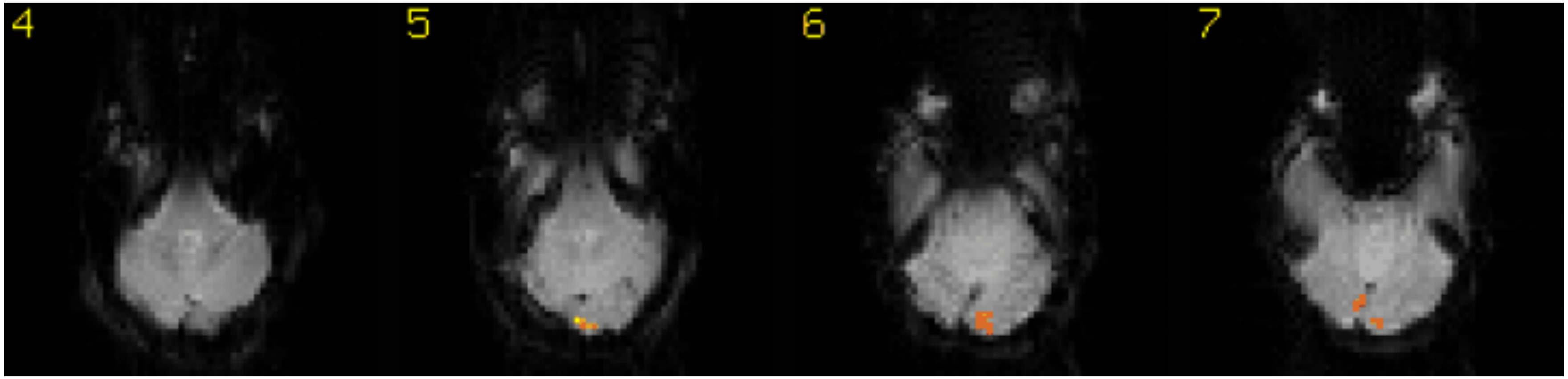
- In these cases, lowpass filtering removes too much signal
- Also, need noise data to correctly estimate autocorrelation (to make statistics valid - see later) ➜ avoid lowpass filtering

Recommendations:

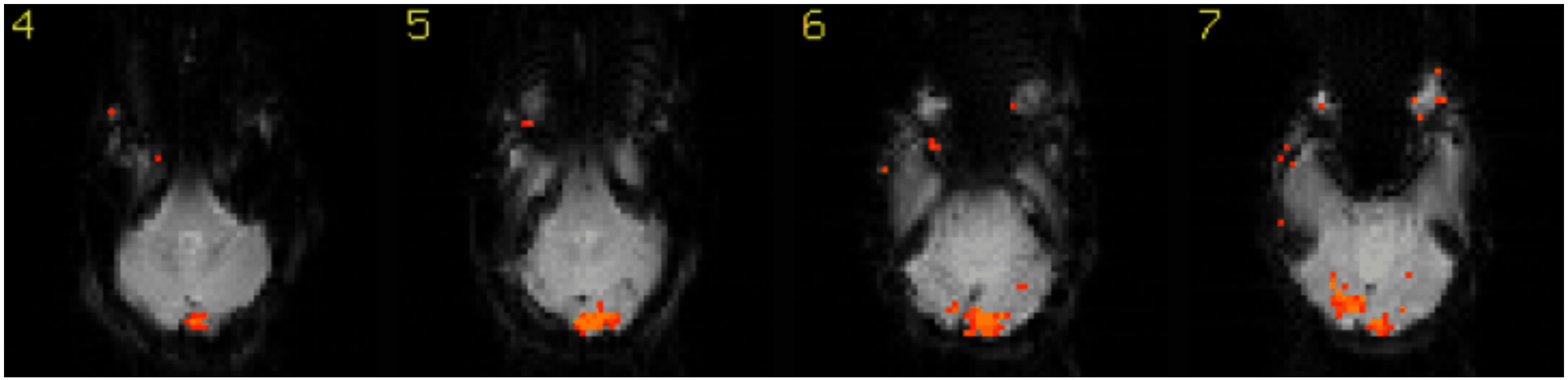
- Use ***Highpass only***
- Ensure cutoff frequency higher than model frequencies
  (can use the Estimate button in the GUI - see practical)
- Lower limit on cutoff frequency for good autocorrelation
  estimation (e.g. for TR=3s, cutoff period > 90s)

Effect of Temporal Filtering

No Temporal Filtering



Highpass Temporal Filtering



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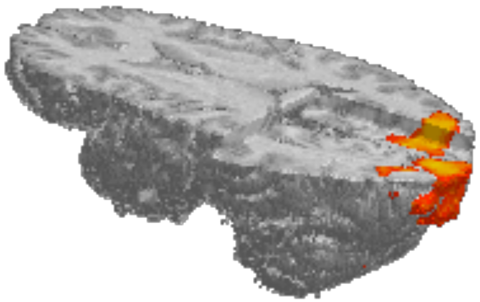
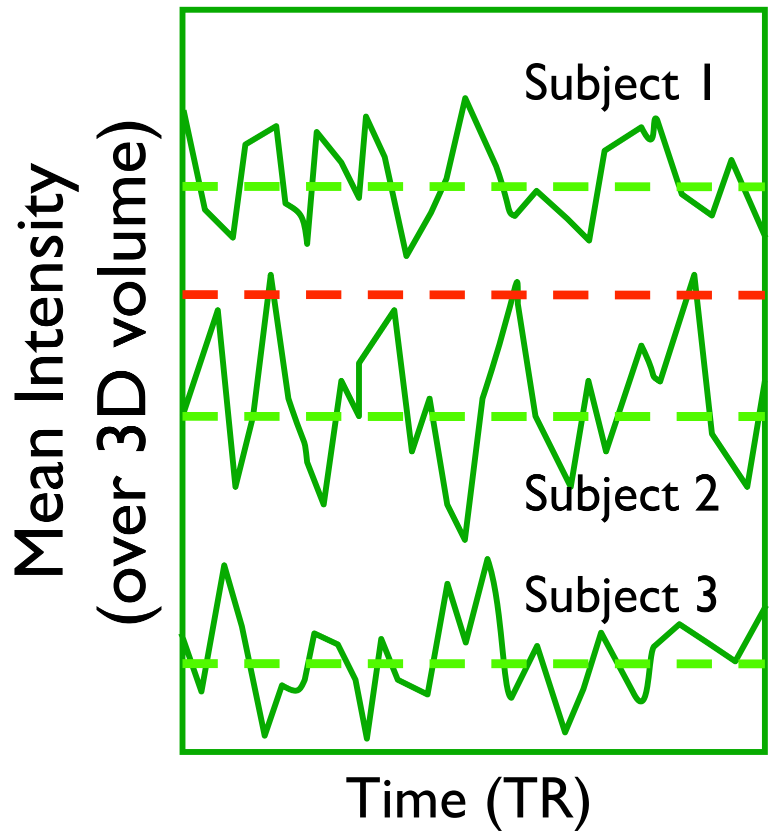


Global Intensity Normalisation

- Mean intensity of the whole dataset changes between subjects and sessions
  - due to various uninteresting factors (e.g. caffeine levels)
- Want the same mean signal level for each subject (taken over all voxels and all timepoints: i.e. 4D)
- Scale each 4D dataset by a *single value* to get the overall 4D mean (dotted line) to be the same
- Automatically done within FEAT



Summary

Reconstruction	Create image and remove gross artefacts
Motion Correction	Get consistent anatomical coordinates (always do this)
Slice Timing	Get consistent acquisition timing (use temporal derivative instead)
Spatial Smoothing	Improve SNR & validate GRF
Temporal Filtering	Highpass: Remove *slow* drifts Lowpass: Avoid for autocorr est.
Intensity Normalisation	4D: Keeps overall signal mean constant across sessions