fMRI Data Analysis

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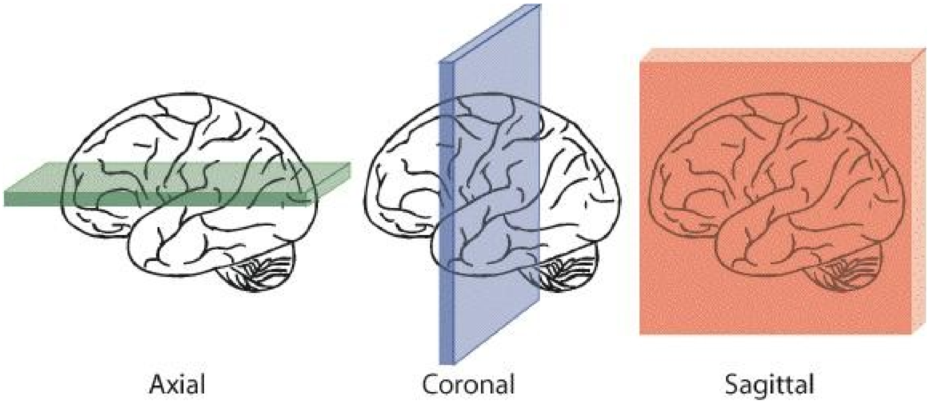
Neuroimaging

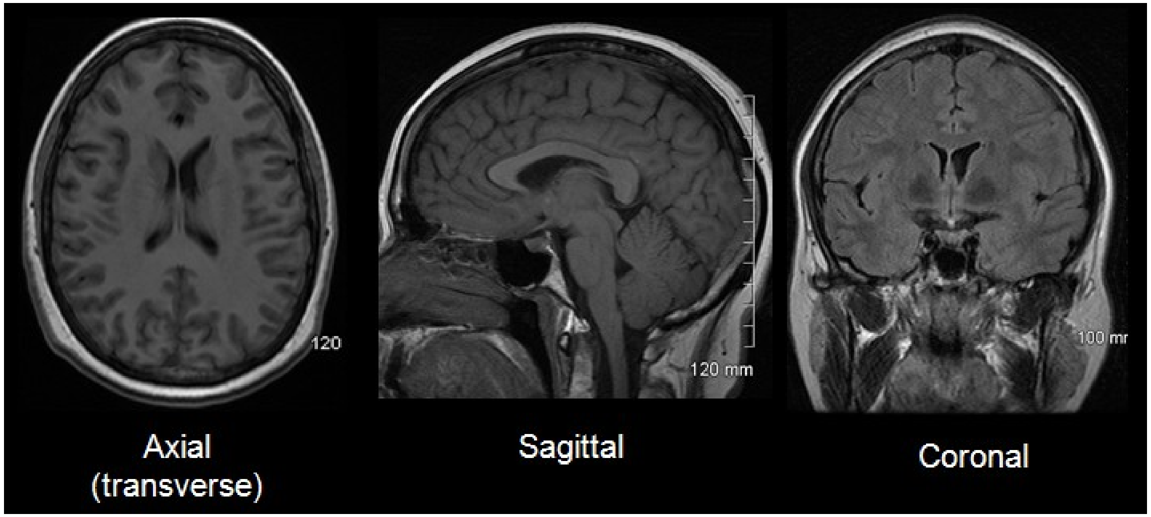
Neuroimaging can be separated into two major categories:

– Structural neuroimaging

– Functional neuroimaging

Some Terminology

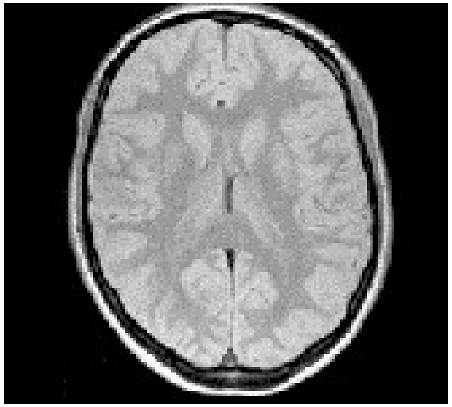


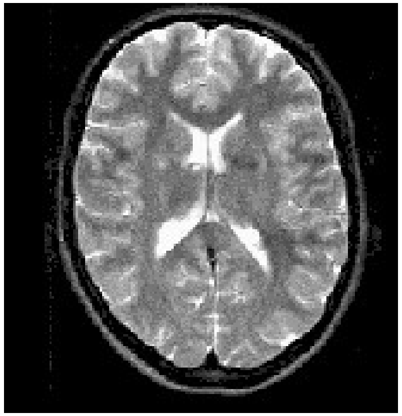


Structural Neuroimaging

- Structural neuroimaging deals with the study of brain structure and the diagnosis of disease and injury.

MRI



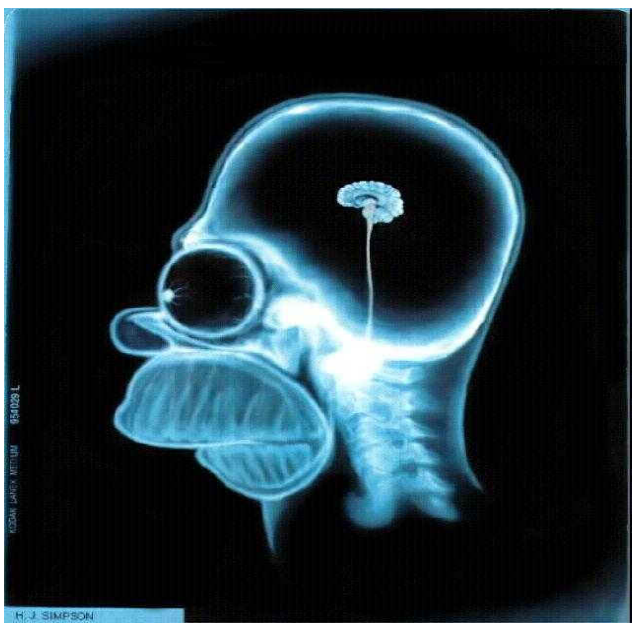


Functional Neuroimaging

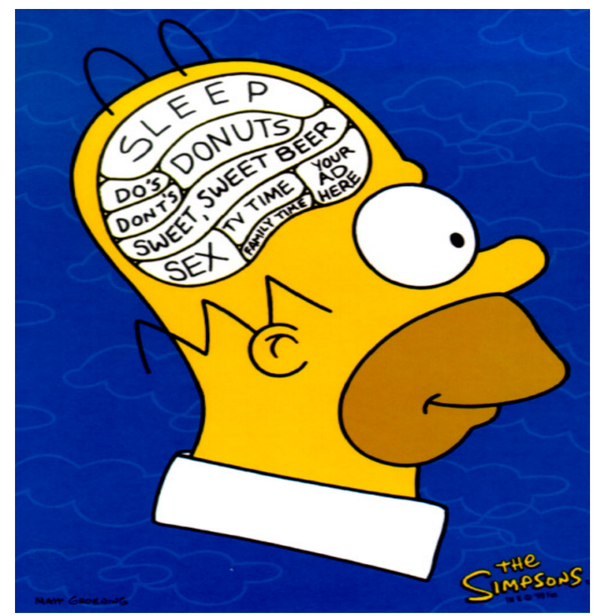
- Recently there has been explosive interest in using functional neuroimaging to study both cognitive and affective processes.

fMRI vs MRI

MRI studies brain anatomy.

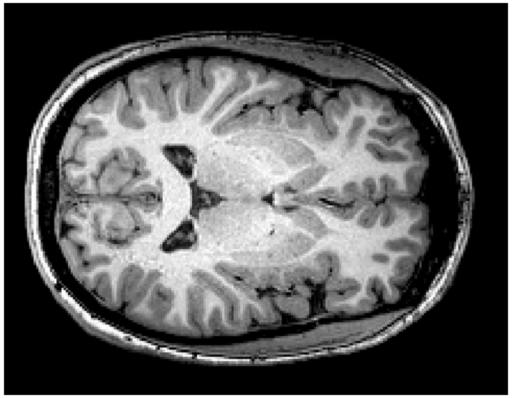


Functional MRI (fMRI) studies brain function.

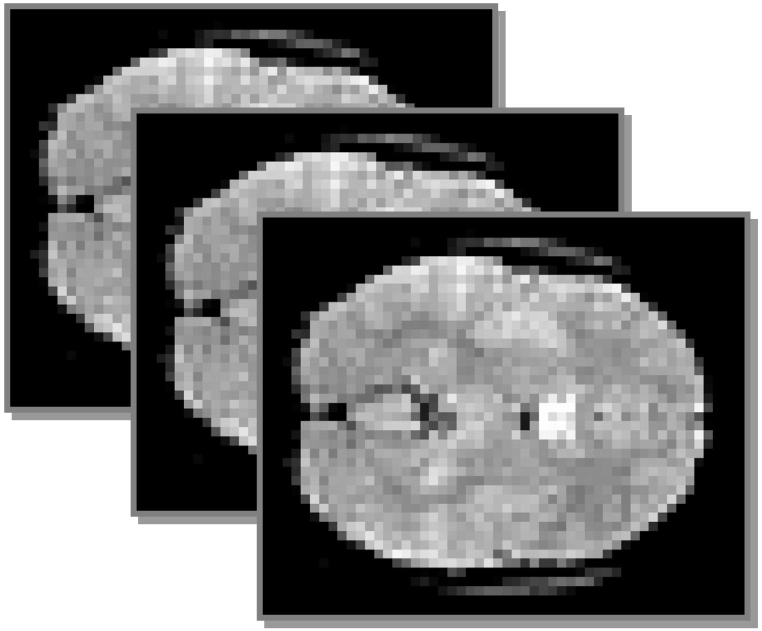


MRI vs fMRI

MRI



fMRI



MRI and fMRI

Structural images:

– High spatial resolution

– No temporal information

– Can distinguish different types of tissue

Functional images:

– Lower spatial resolution

– Higher temporal resolution

– Can relate changes in signal to an experimental task

- Spatial and temporal resolution
- Anatomical and functional imaging

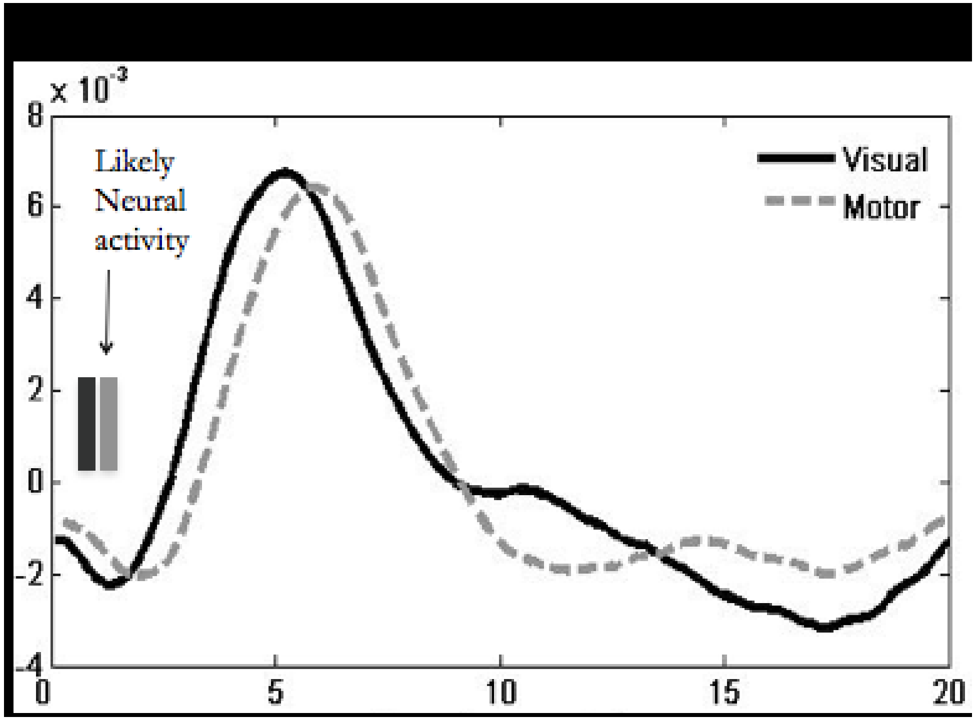
BOLD fMRI

- The most common approach towards fMRI uses the Blood Oxygenation Level Dependent (BOLD) contrast.
- It allows us to measure the ratio of oxygenated to deoxygenated hemoglobin in the blood.
- It doesn’t measure neuronal activity directly, instead it measures the metabolic demands (oxygen consumption) of active neurons.

HRF

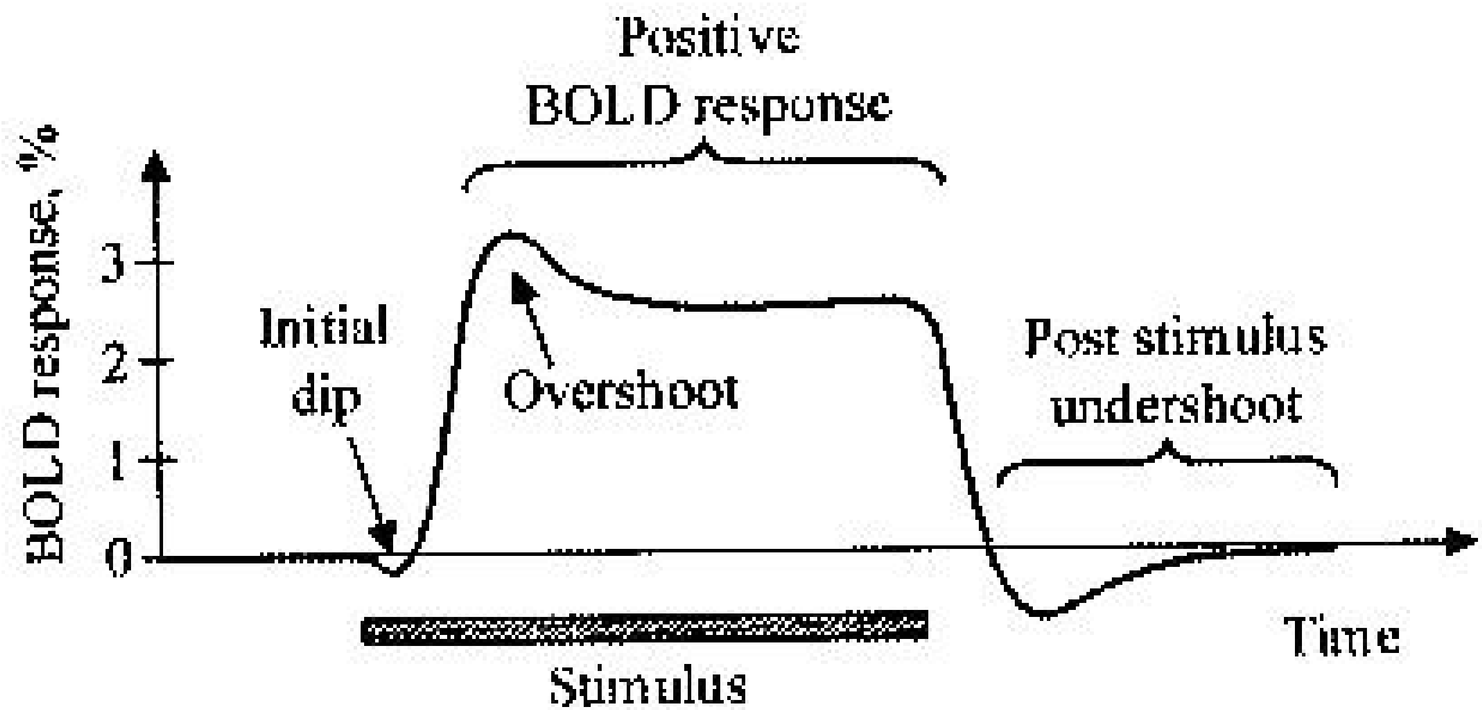
- The change in the MR signal triggered by instantaneous neuronal activity is known as the hemodynamic response function.

BOLD fMRI



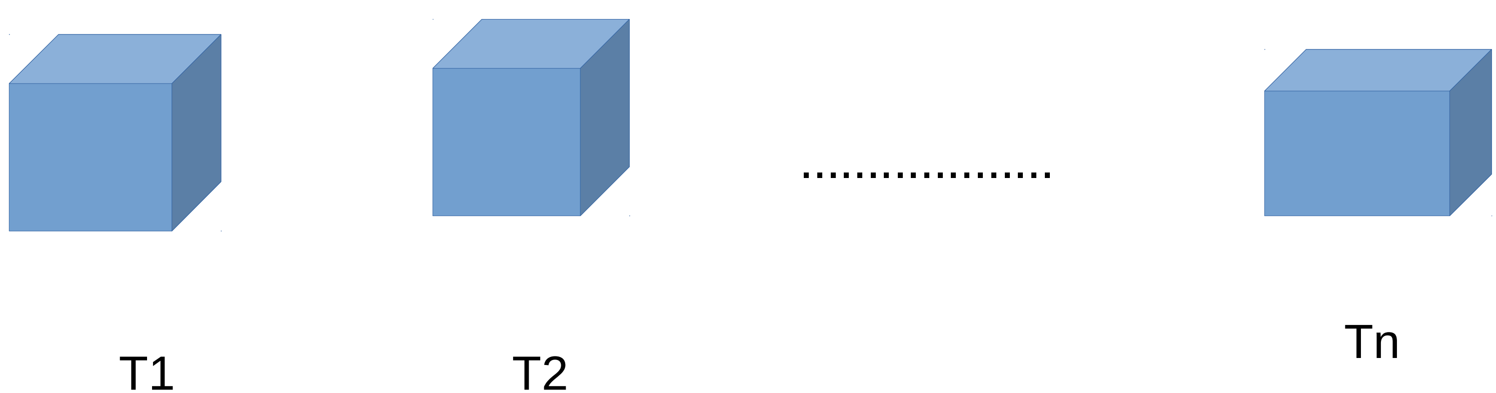
Time(sec)->

HRF for continuous stimulation



fMRI Data

- Each image consists of ~100,000 brain voxels.
- Several hundred images are acquired; typically one every 2s.
- Each voxel has a corresponding time course.



Goals:

- Localization:

  To identify the involved brain regions in the task.

- Prediction:

  To predict perception or behaviour, health prediction, etc.

- Connectivity:

  -Functional (seed based)

  -Effective (Path analysis, causality etc.)

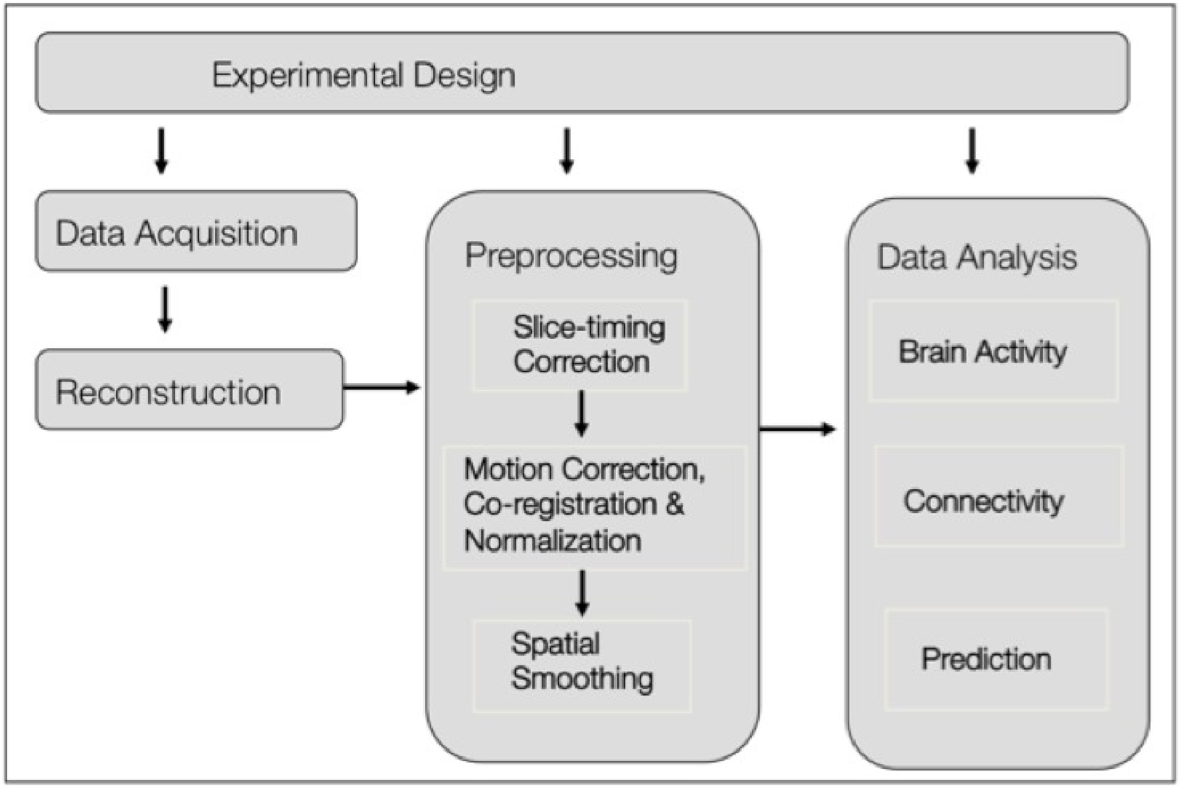
What Brain mapping is good for:

- Making inference of presence of activity in the region
- Testing a theory

What brain mapping isNOT good for:

- Reverse inference

Data Processing Pipeline



Experimental Design

fMRI Design Types:

- Blocked Designs
- Event-Related Designs

  -Periodic Single Trial

  -Jittered Single Trial

- Mixed Designs

  -Combination blocked/event-related

What are Blocked Designs?

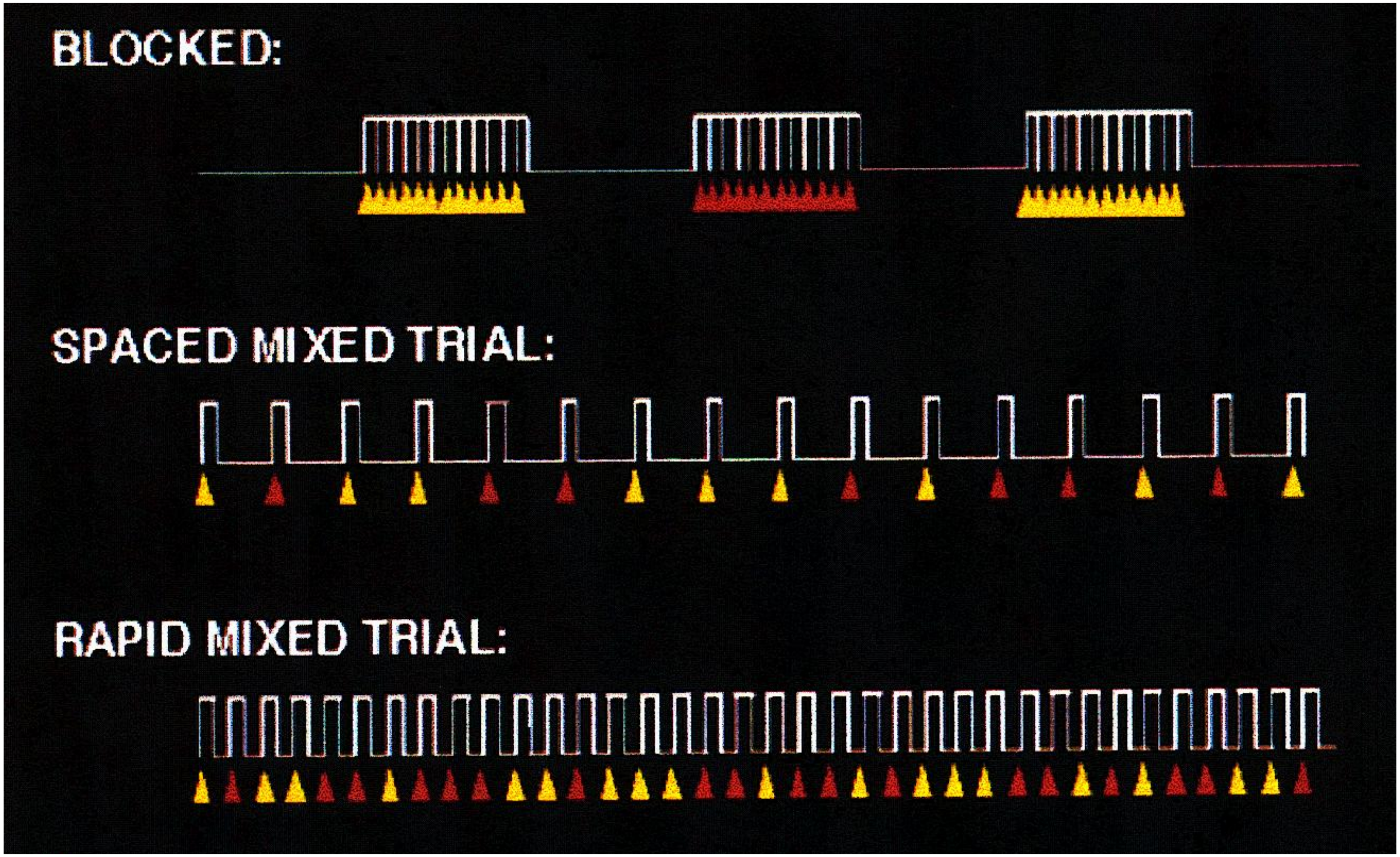
Blocked designs segregate different cognitive tasks into distinct time periods (blocks)

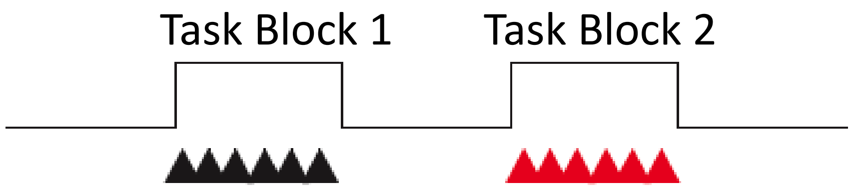
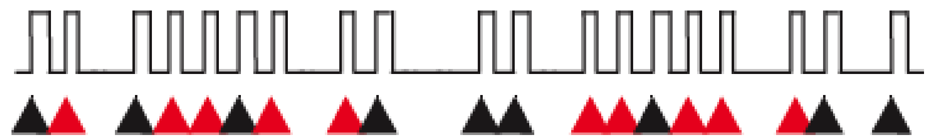
Task A	Task B	Task A	Task B	Task A	Task B	Task A	Task B
Task A	REST	Task B	REST	Task A	REST	Task B	REST

Limitations of Blocked Designs

- Sensitive to signal drift or MR instability
- Poor choice of conditions/baseline may preclude meaningful conclusions
- Many tasks cannot be conducted well repeatedly

What are Event-Related Designs?



	Block Design	Event-related Design
		
PROS	Achieve high efficiency by collapsing across many trials to attain an adequate signal-to-noise ratio. Suited for detecting regions of interest (ROI) for particular tasks. Good for experimental tasks that do not fit into a trial-by-trial framework.	Good at detecting trial/event related activity within a task, eg correct & incorrect trials, and different components within a trial, eg cue onset, decision, et al.
CONS	Can not distinguish between trial types within a block (e.g., correct versus error trials), nor can they identify interesting within trial or across trial events. Average both positive and negative response	Ignore the sustained activity that begins and ends with the performance of the task. Decrease of signal-to-noise. More dependent on accurate HRF modelling.

(Petersen & Dubis, 2012; Donaldson, 2004)

fMRI Artifacts

Sources of noise:

- thermal motion of forced electron in the system
- Gradient and magnetic field instability
- Head movements
- Physiological effects, eg- respiration, heartbeat etc.

Noise Artifact Mitigation

- Acquisition:

  using good scanner, no head movements

- Analysis:

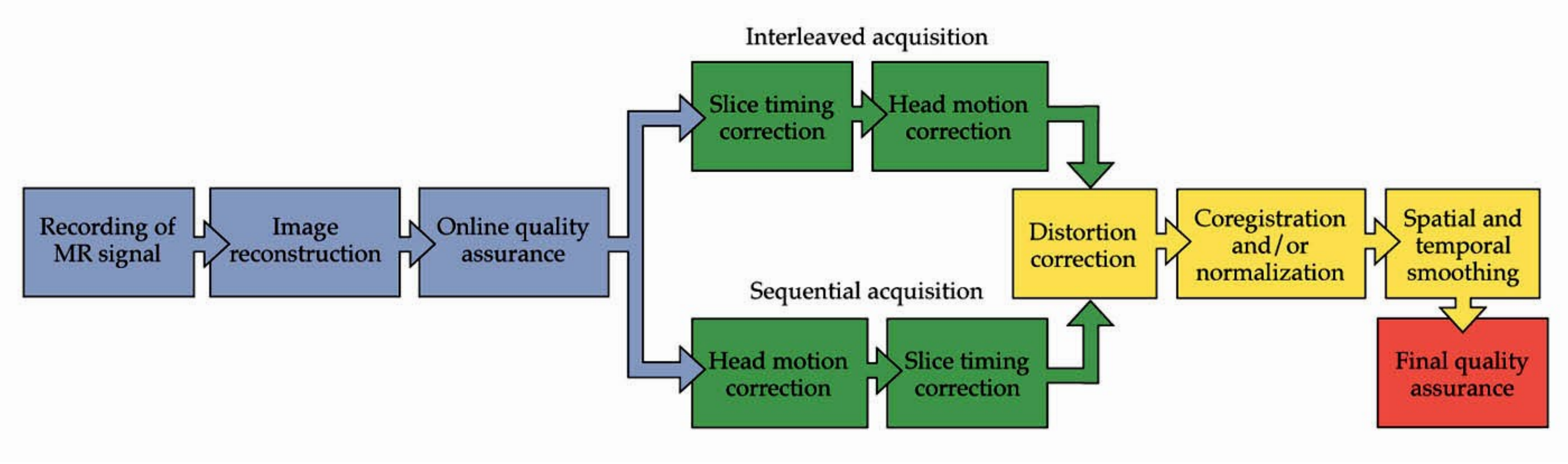
  -Look at the data

  -Outlier identification and correction

  -Periodic fluctuations

Preprocessing

Basic Preprocessing Chain



Goals of Preprocessing:

- Removing artifacts
- To minimize the influence of data acquisition and physical artifacts
- To transform the data into standard format
- To standardize the locations of brain regions across subjects

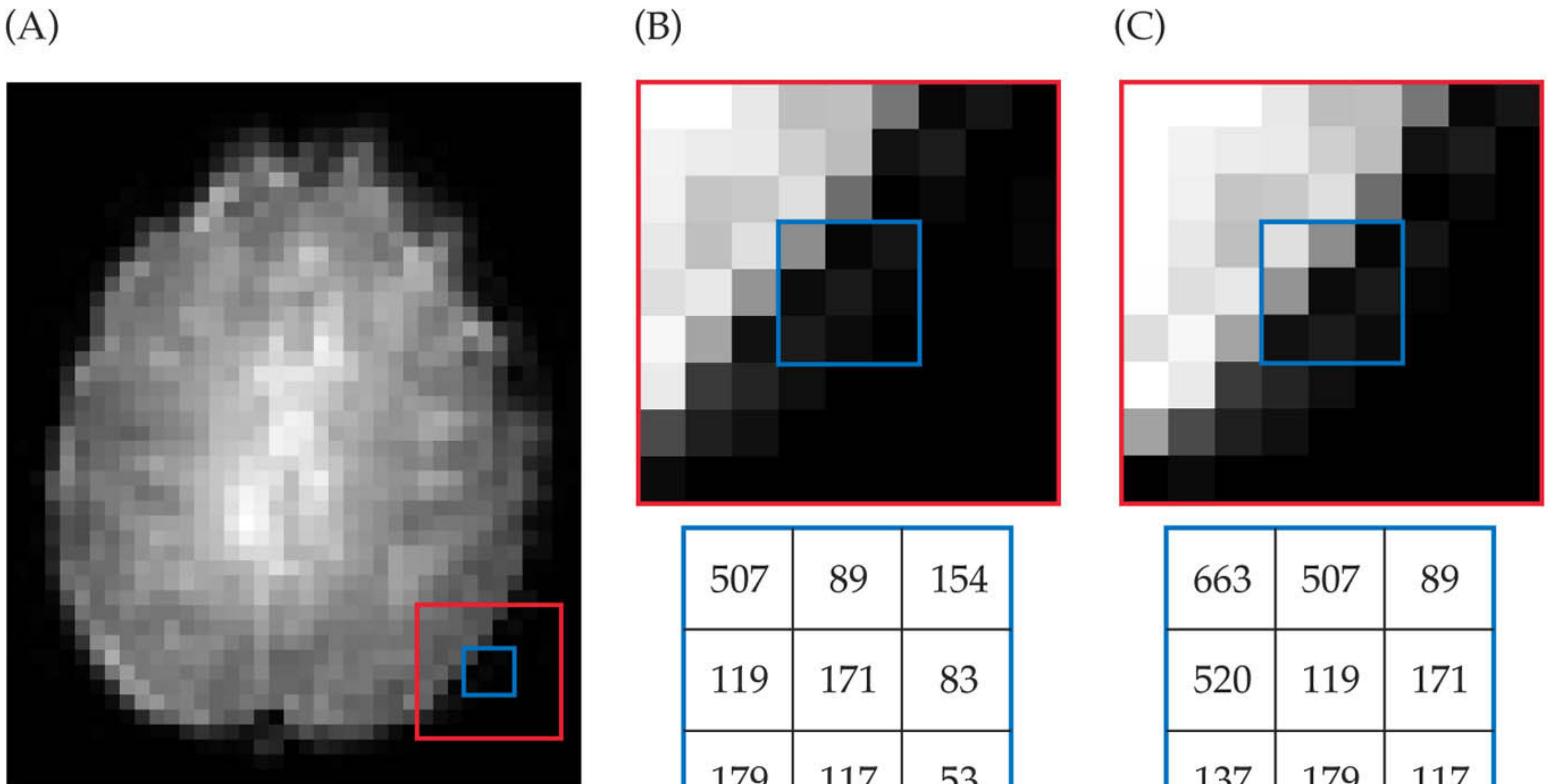
Steps for preprocessing

- Slice timing correction
- Head motion correction
- Distortion correction
- Co-registration
- Normalization
- Spatial and Temporal smoothing

Slice Timing Correction

- Uses temporal interpolation to make it appear as though all of the slices were acquired at the same time
- Thus, HRF across slices are aligned
- Generally more effective for short TR (1-2 secs) than longer TR (>3 secs)

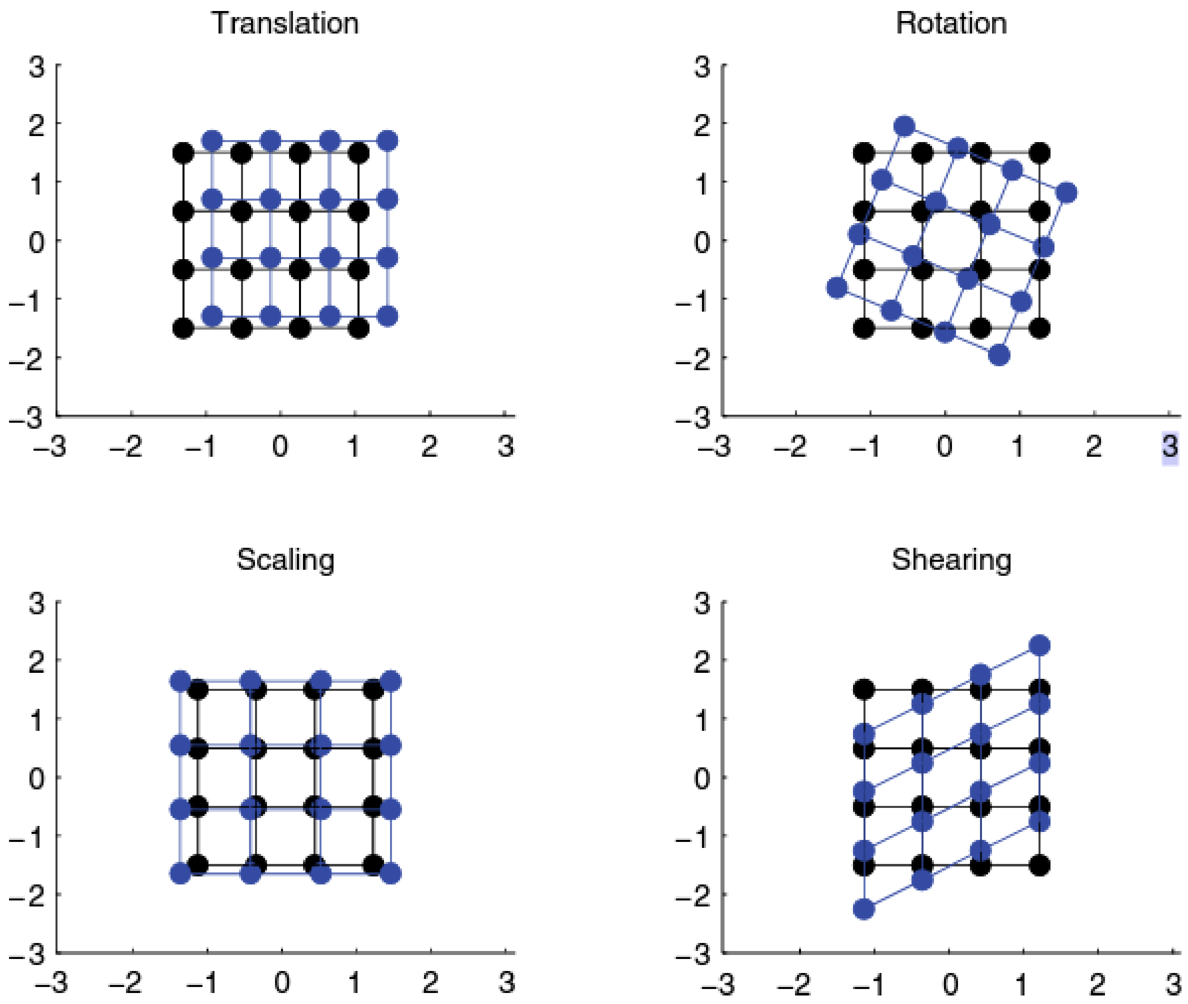
Effect of Head Motion



507	89	154
119	171	83
179	117	53

663	507	89
520	119	171
137	179	117

Motion Correction



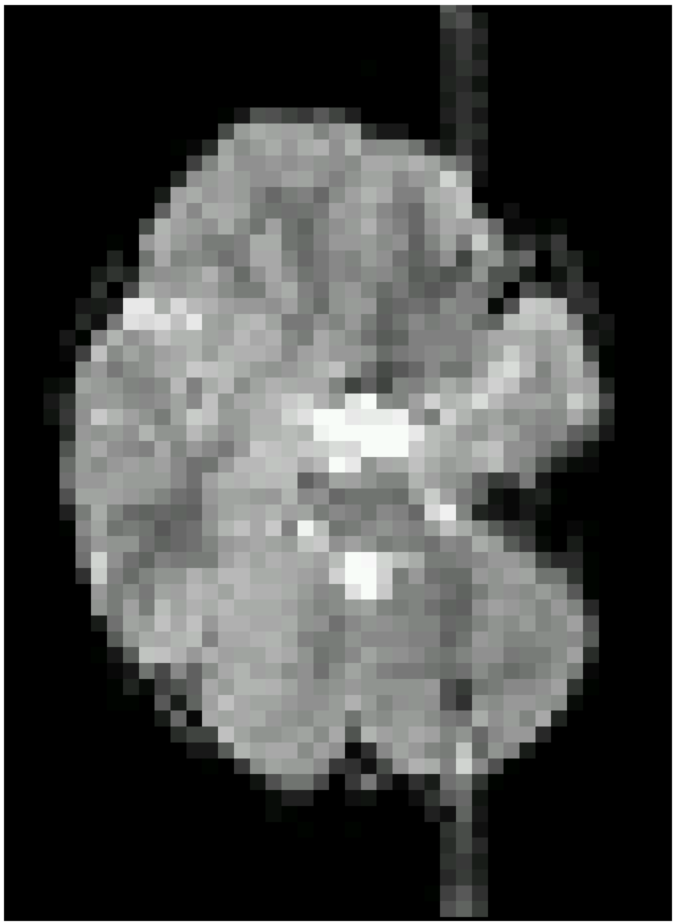
Spatial Normalization

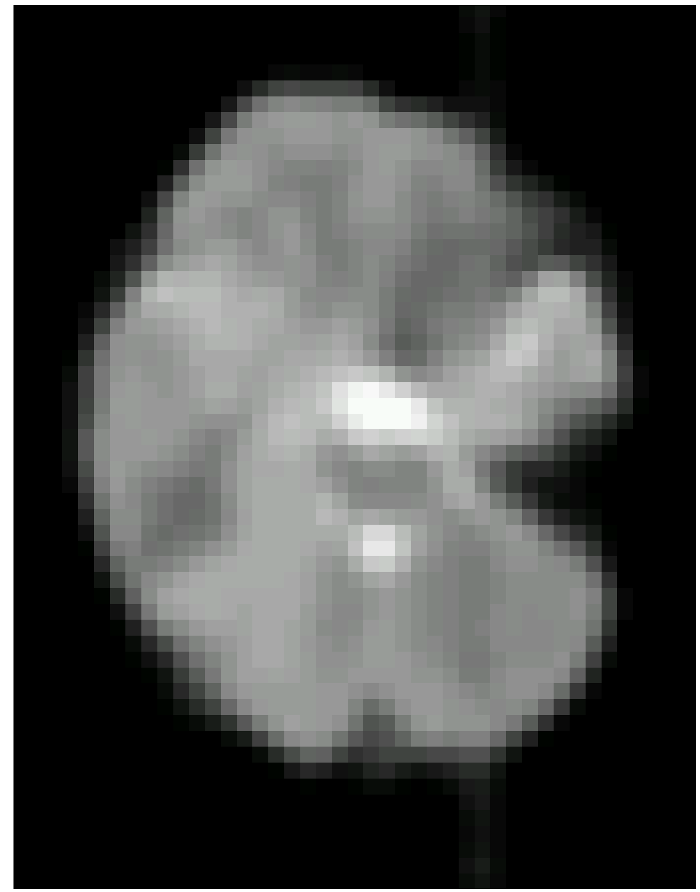
- Variations between individual brains is large
- Spatial normalization warps individual brains into a common reference space
- Allows for examination of fMRI signal changes across individuals within a group or between groups of subjects
- Most commonly used reference space is based on the Talairach atlas.

Smoothing

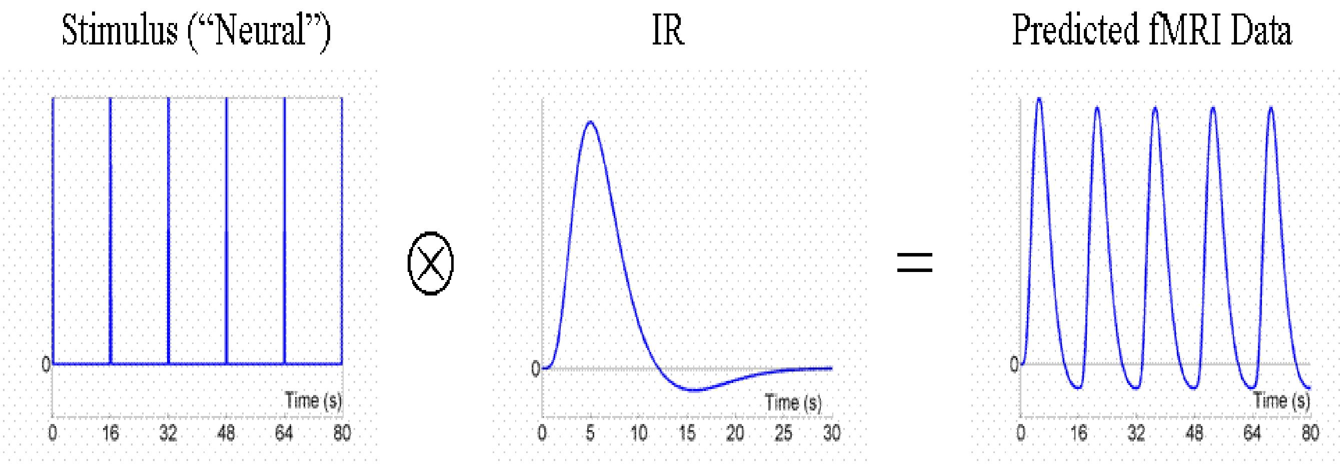
- Low pass filtering
- High pass filtering
- Neighborhood operation
- New pixel value based on weighted sum of a pixel and its neighbors

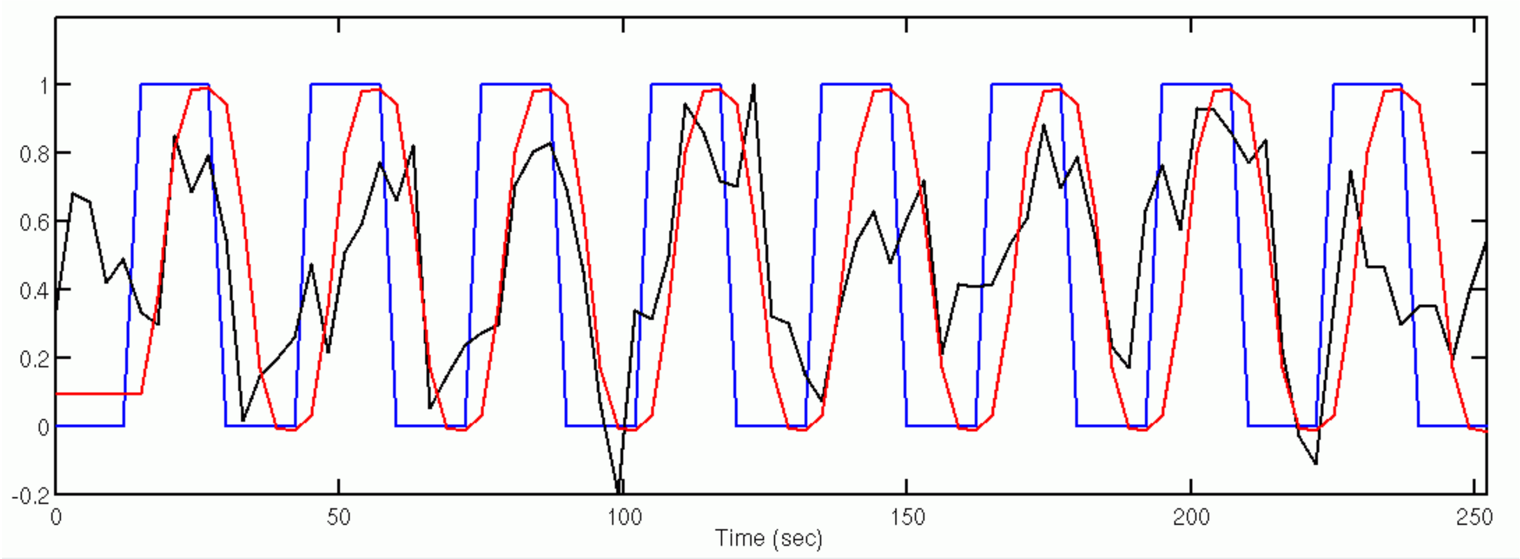
Example Reduced Noise Using Smoothing





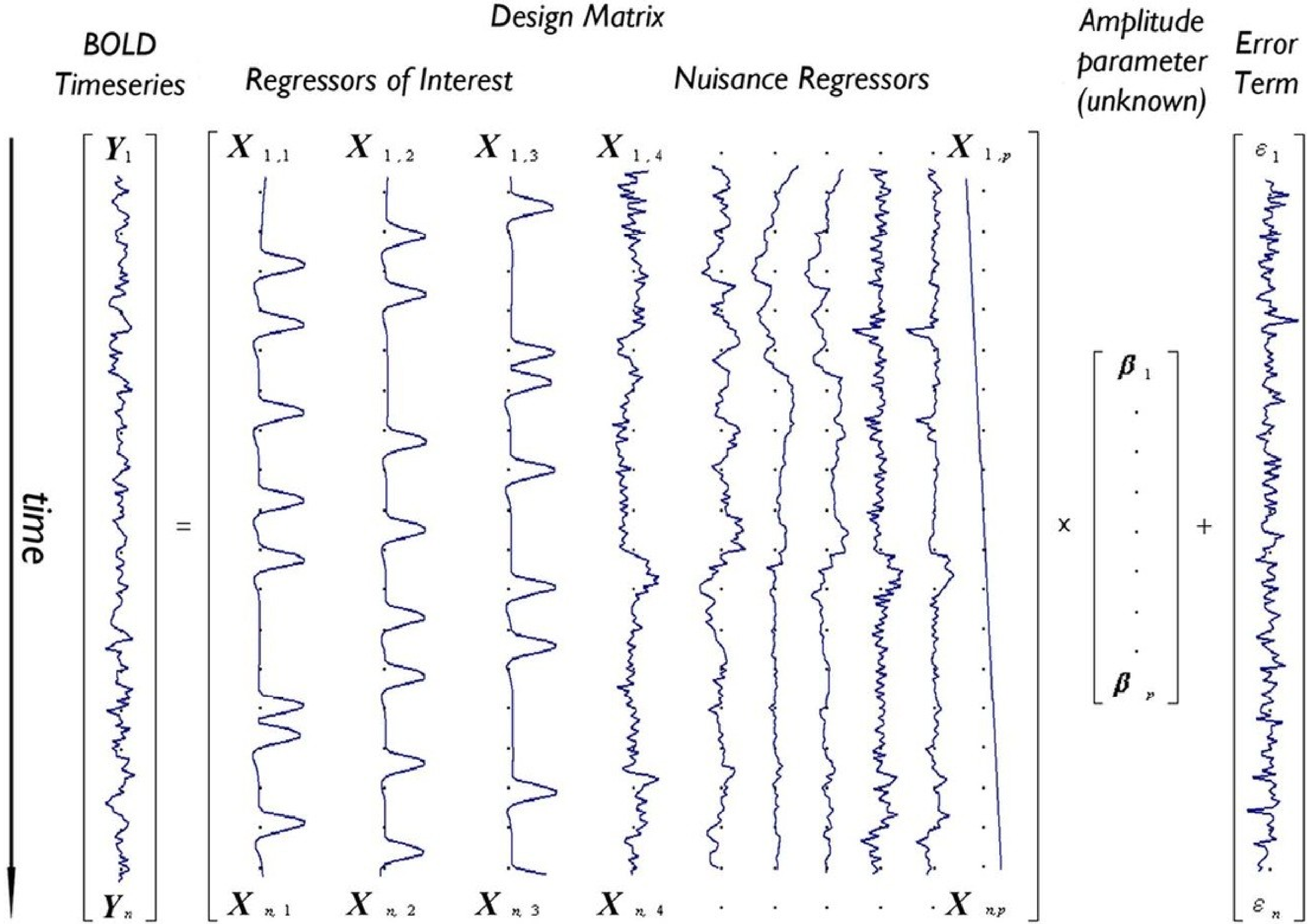
Convolution with HRF (Getting Design Matrix)





Overview of GLM

$$\begin{bmatrix} y_1 \\ \vdots \\ \vdots \\ \vdots \\ y_n \end{bmatrix} = \begin{bmatrix} 1 & X_{11} & \cdots & \cdots & \cdots & X_{1k} \\ \vdots & \vdots & \vdots & \vdots & \vdots & \vdots \\ \vdots & \vdots & \vdots & \vdots & \vdots & \vdots \\ \vdots & \vdots & \vdots & \vdots & \vdots & \vdots \\ 1 & X_{n1} & \cdots & \cdots & \cdots & X_{nk} \end{bmatrix} \begin{bmatrix} b_0 \\ \vdots \\ \vdots \\ b_k \end{bmatrix} + \begin{bmatrix} e_1 \\ \vdots \\ \vdots \\ \vdots \\ e_n \end{bmatrix}$$


Design Matrix
BOLD Timeseries
Regressors of Interest
Nuisance Regressors
Amplitude parameter (unknown)
Error Term
time
Y_1
Y_n
=
$X_{1,1}$ $X_{1,2}$ $X_{1,3}$ $X_{1,4}$ . . . . . $X_{1,p}$
$X_{n,1}$ $X_{n,2}$ $X_{n,3}$ $X_{n,4}$ . . . . . X_{np}
x
β_1
β_p
+
ε_1
ε_n

Thank You