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@fMRIstats

GLM Model Building 2: Linear basis sets for flexible hemodynamic modeling

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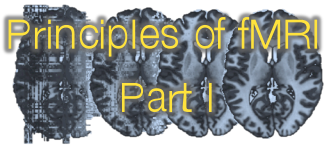
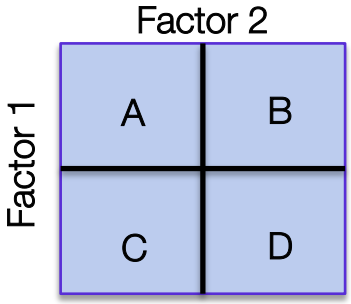
REVIEW: KEY CONCEPTS

@fMRIstats

Lindquist & Wager

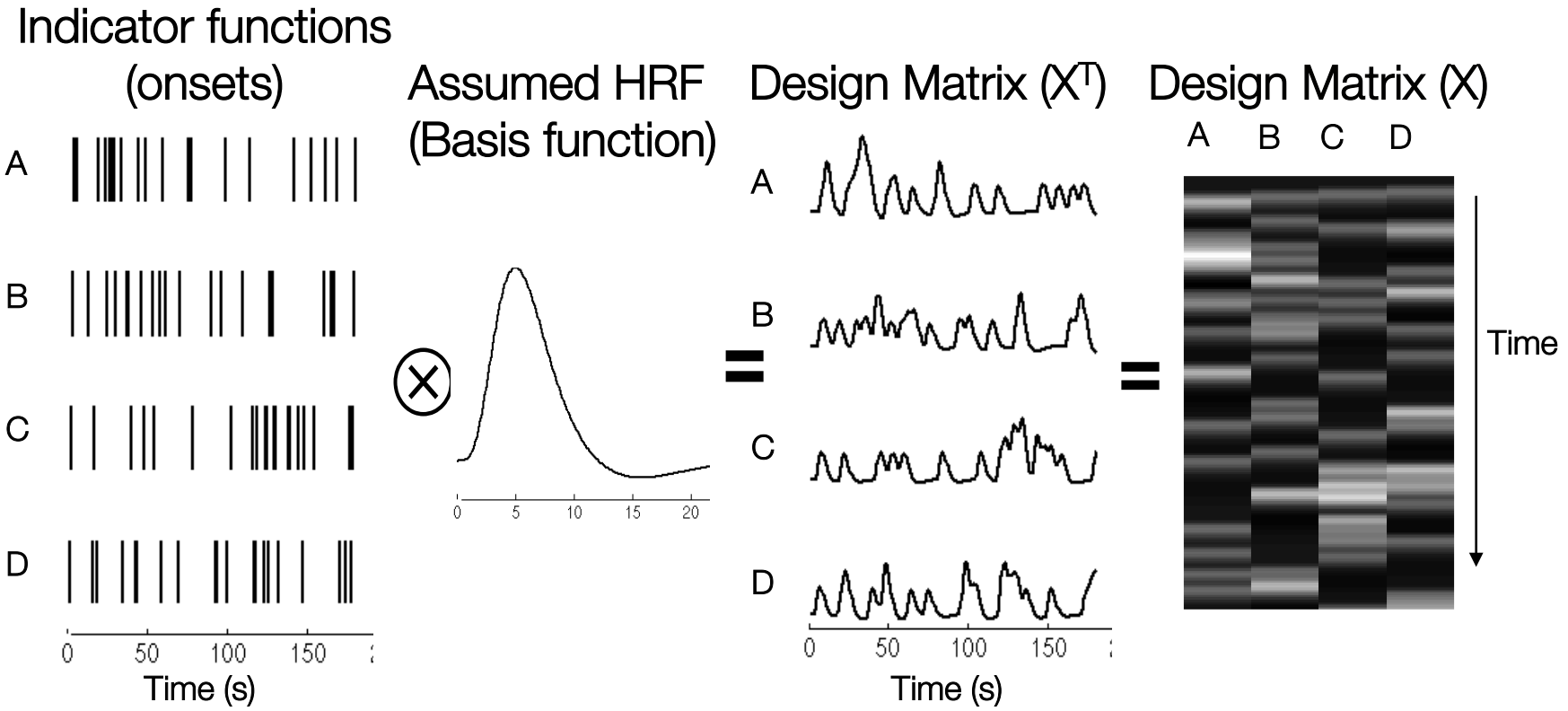
Model building and contrasts: multiple predictors



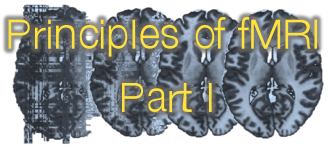


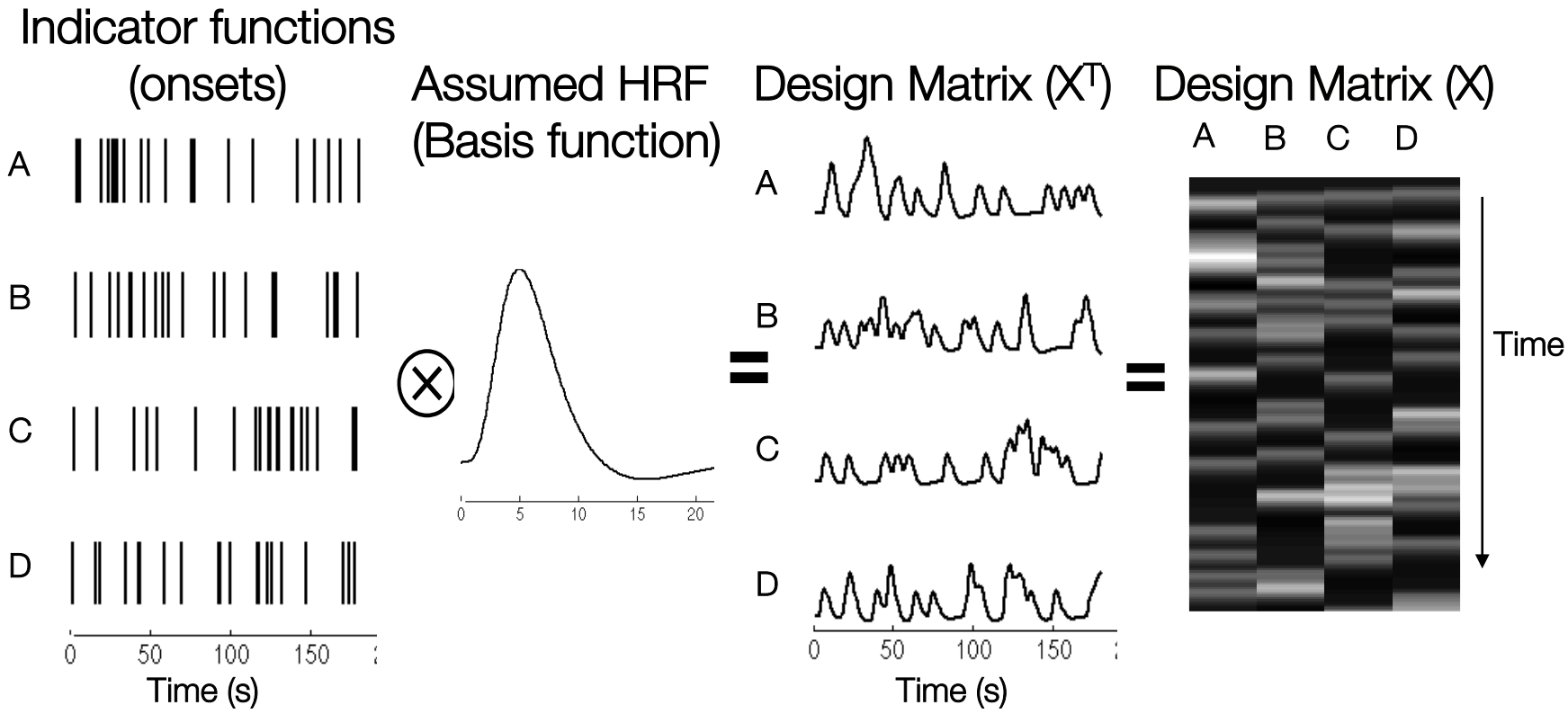
Example: Memory experiment
Four word types, grouped into two factors:

Factor 1: Visual vs. Auditory presentation (2 levels)
Factor 2: High vs. low imageability (2 levels)



Model building for multiple predictors





Assumptions!

Assume neural activity function is correct

Assume HRF is correct

Assume LTI system

We will look at how to relax these later

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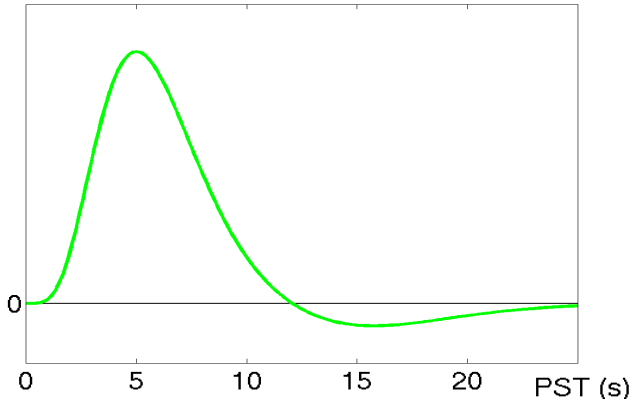
MODEL BUILDING: BASIS SETS

@fMRIstats

Lindquist & Wager

HRF Models

- Often a fixed canonical HRF is used to model the response to neuronal activity
  - Linear combination of 2 gamma functions.
  - Optimal if correct.
  - If wrong, leads to bias and power loss.
    - Unlikely that the same HRF is valid for all voxels.
    - True response may be faster/slower
    - True response may have smaller/bigger undershoot

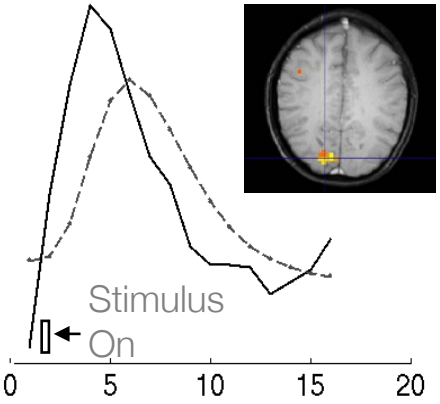


HRFs vary across brain regions and tasks
~~Problem for canonical model!~~

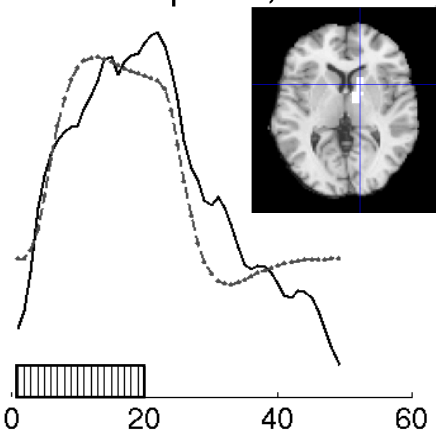
The HRF shape depends both on the vasculature and the time course of neural activity.

Assuming a fixed HRF is usually not appropriate.

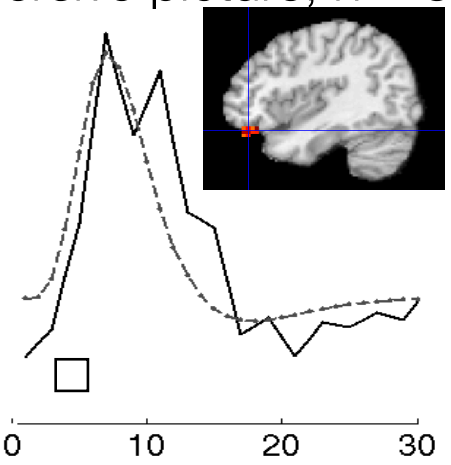
Checkerboard, n = 10



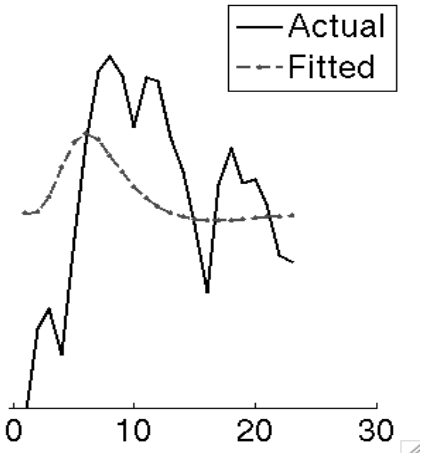
Thermal pain, n = 23



Aversive picture, n = 30

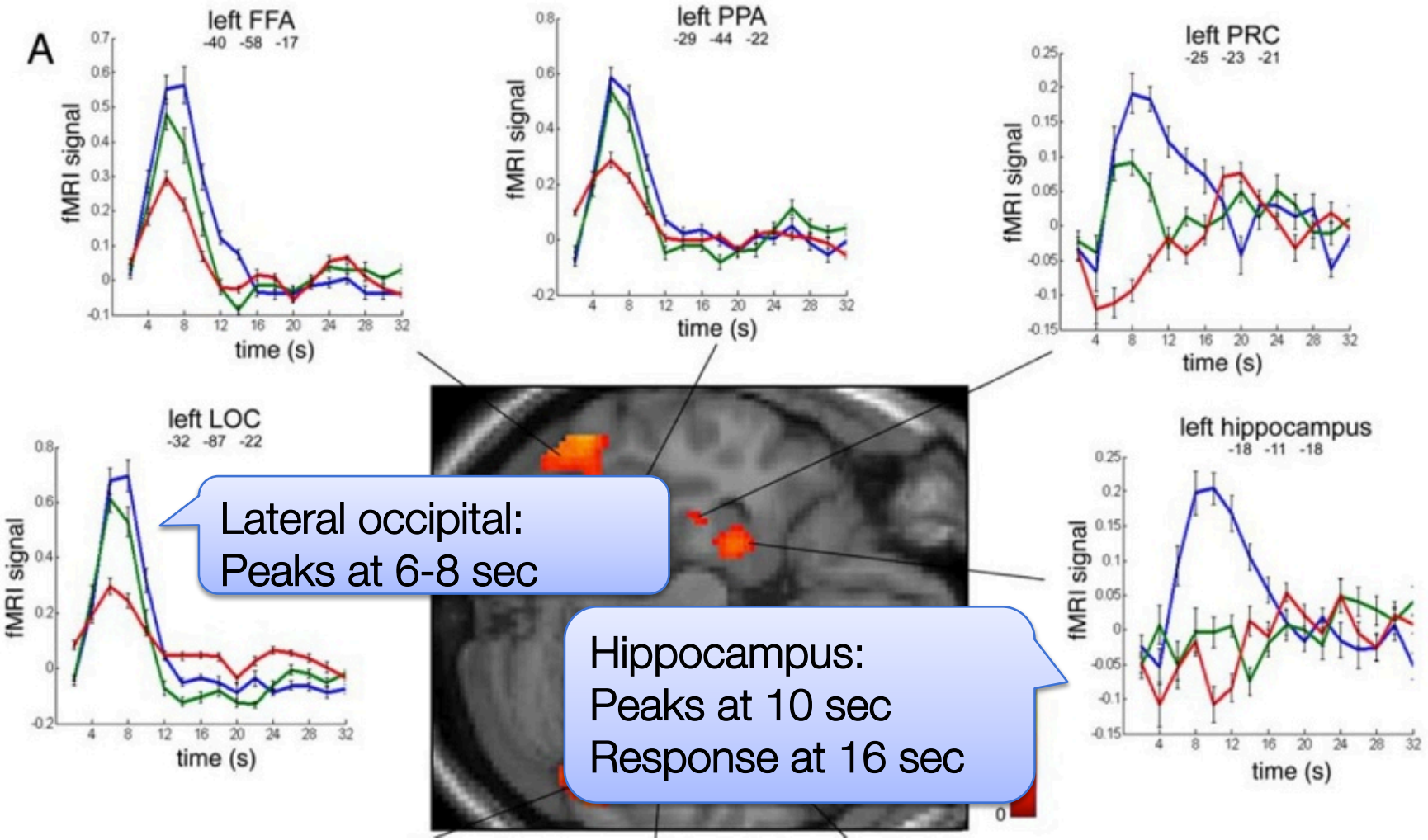


Aversive anticipation



Wager et al. 2008

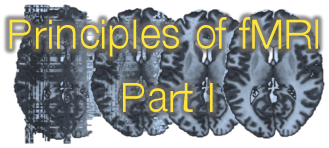
HRFs vary across brain regions and tasks
Problem for canonical model!



- HRF shape depends on:
- vasculature
- time course of neural activity

Summerfield et al (2006) PlOS Biology

Temporal Basis Functions



- The canonical HRF is a single basis function
- To allow for different types of HRFs in different brain regions, use temporal basis functions.
- Linear combination of pre-specified temporal functions: A linear model that allows for flexibility in the HRF shape
  - The stimulus function is convolved with each of the basis functions to give a set of predictors.
  - The parameter estimates are weights on the basis functions, so that the weighted average that best models the hemodynamic response
  - Usually fit for each trial type in each voxel for each person

Temporal Basis Functions

Model the HRF as a linear combination of temporal basis functions, $f_i(t)$, such that

$$h(t) = \sum \beta_i f_i(t)$$

Overall estimated HRF shape

A linear combination of 3 bases functions * 3 beta values, summed

$$h(t) = \beta_1$$

canonical

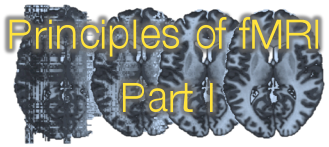
$$+\beta_2$$

Derivative (time)

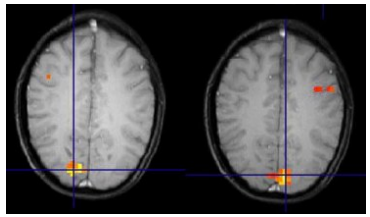
$$+\beta_3$$

Dispersion derivative

Model specification with basis sets

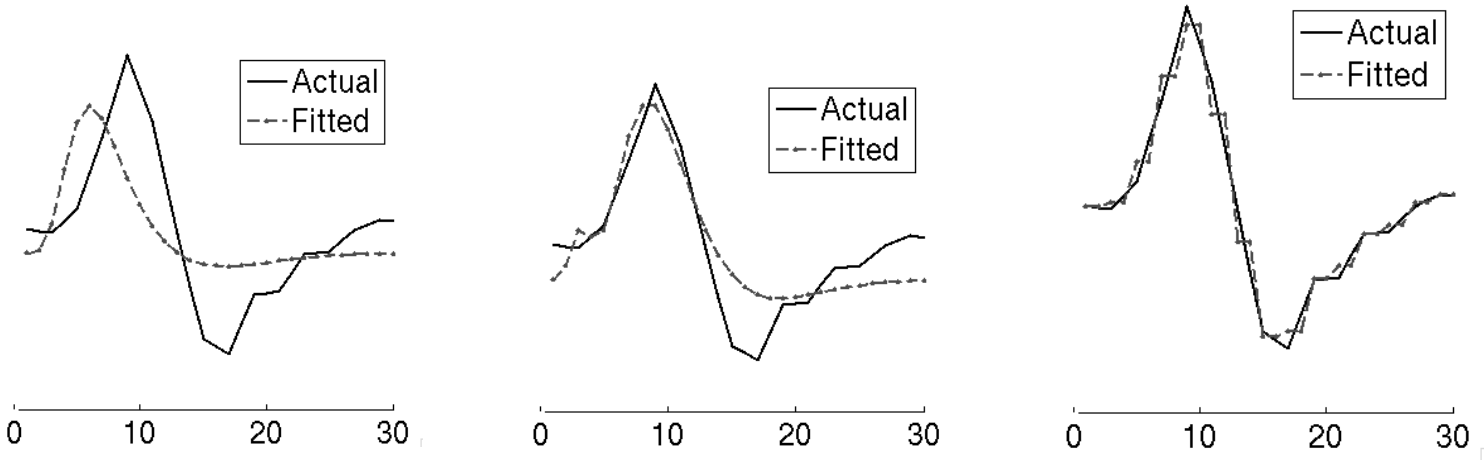


Basis sets vary in the degree they make *a priori* assumptions about the shape of the response, and the HRF shapes they can account for



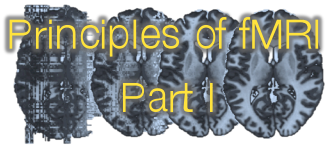
Visual evoked responses

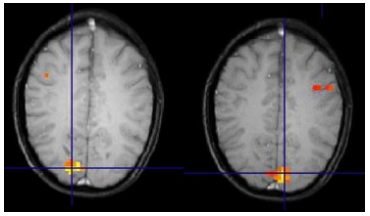
Data fit with three choices of basis set:



Data: Wager, T. D., Vazquez, A., Hernandez, l., Noll, D. C.. (2005). Accounting for nonlinear BOLD effects in fMRI: parameter estimates and a model for prediction in rapid event-related studies. Neuroimage, 25, 206-18.

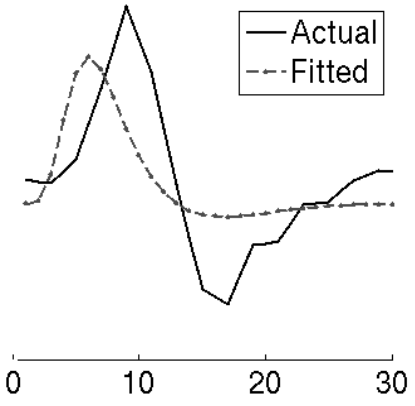
Different kinds of basis sets



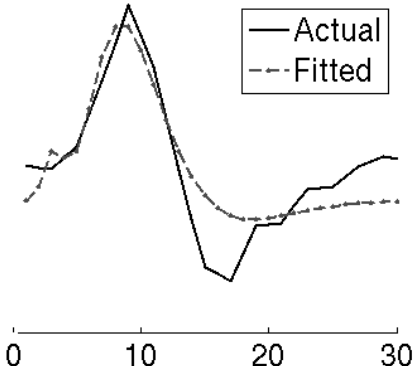


Visual evoked responses

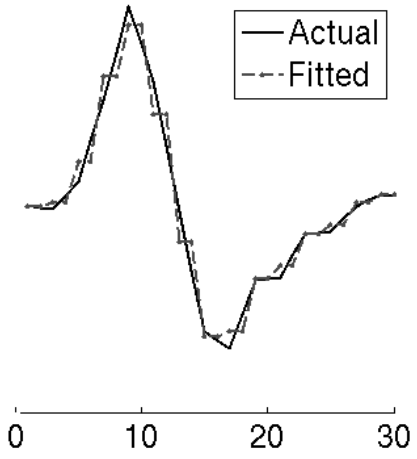
Data fit with three choices of basis set:
What are these basis sets?



Canonical HRF



3-parameter: HRF + derivatives



Finite Impulse Response (FIR) "deconvolution"

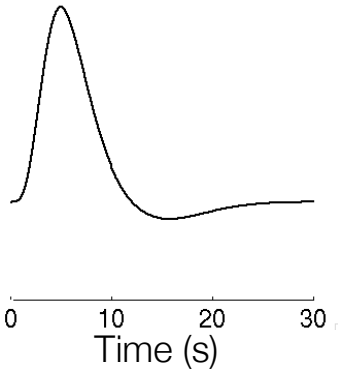
Basis sets

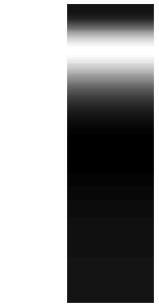
Model

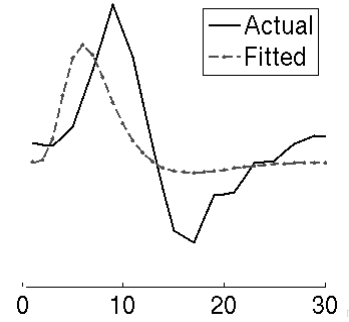
Image of predictors

Data & Fitted

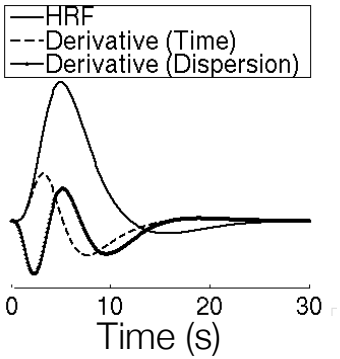
Canonical HRF

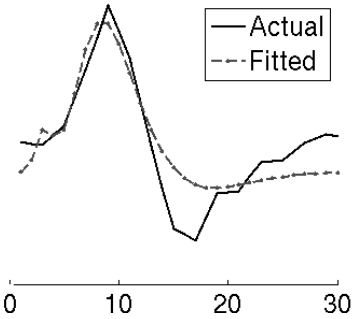




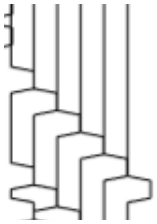


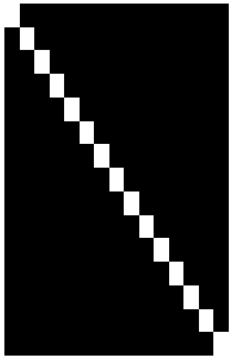
HRF + derivatives

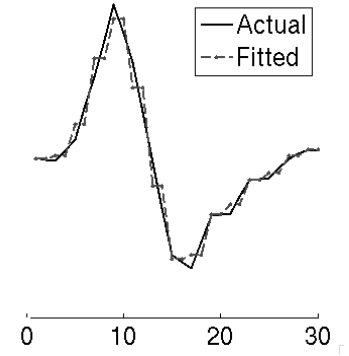




Finite Impulse Response (FIR)

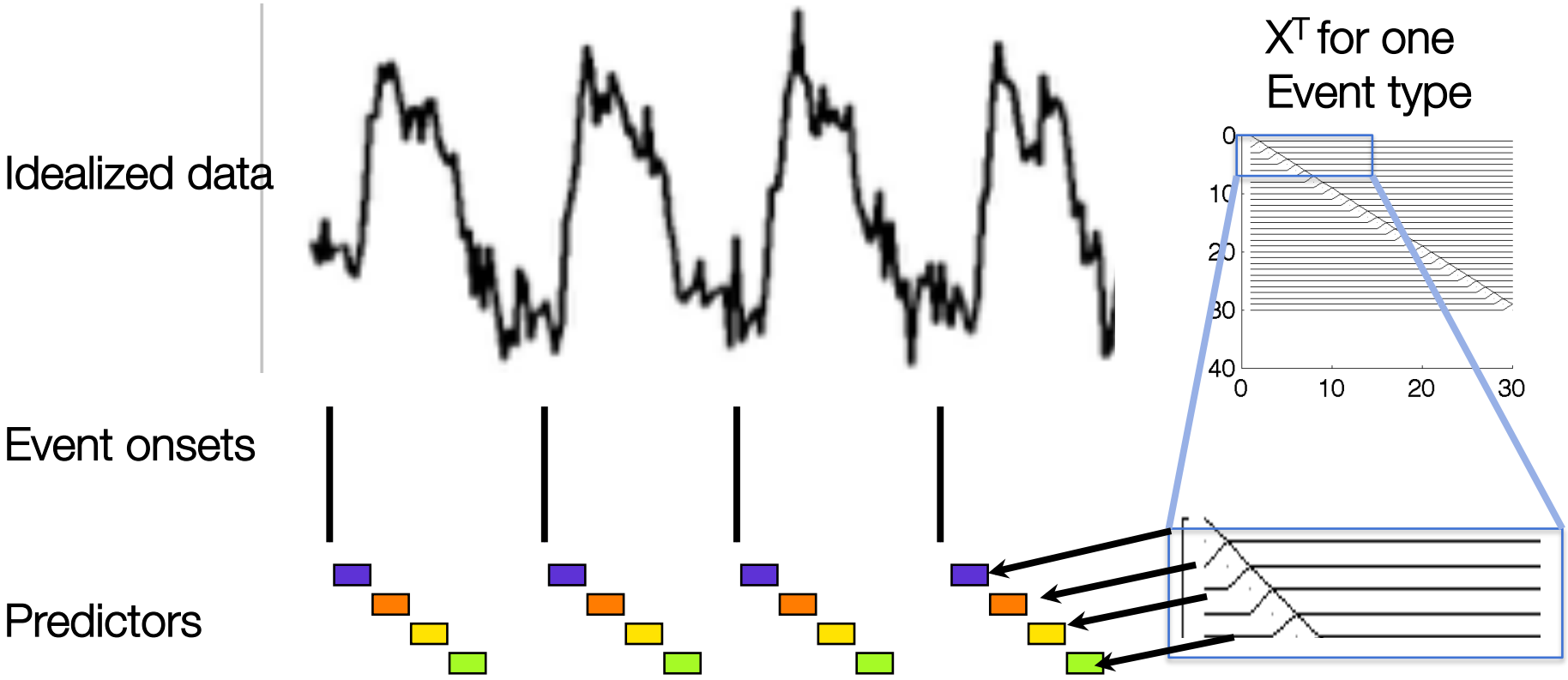






Time (s)

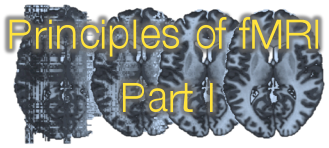
FIR model



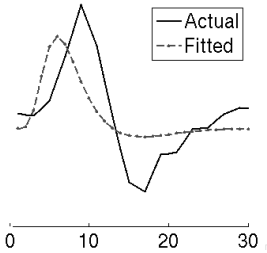
Four columns of X

(One column per time point locked to stimulus onset)

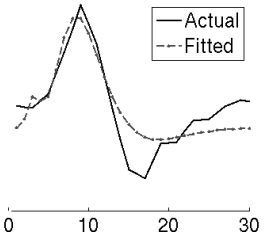
Basis sets: Multiple event types



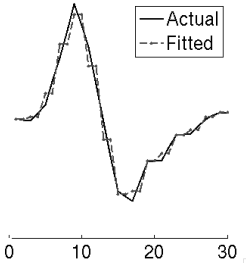
Design matrix has one predictor per event type (condition) per basis function



Canonical HRF

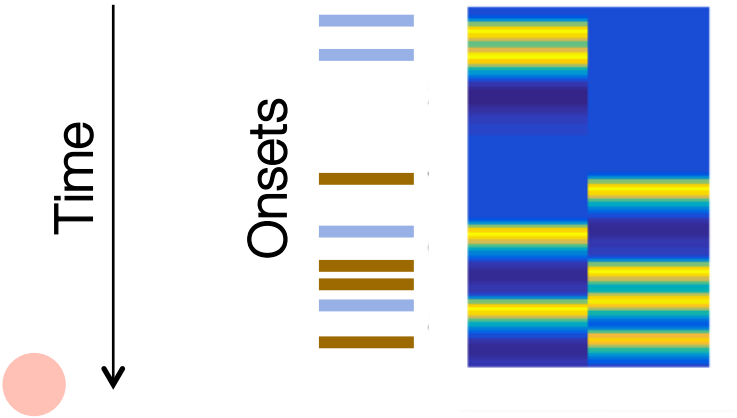


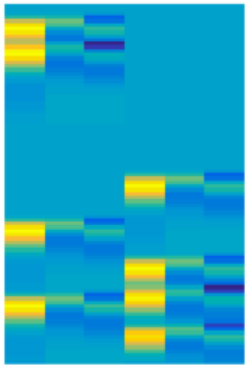
3-parameter: HRF + derivatives

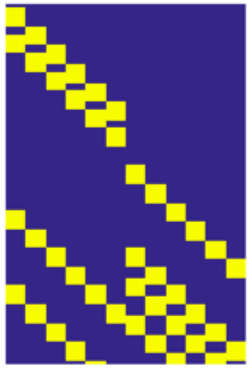


Finite Impulse Response (FIR) "deconvolution"

Event type 1
Event type 2







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MODEL BUILDING: CHOOSING A BASIS SET

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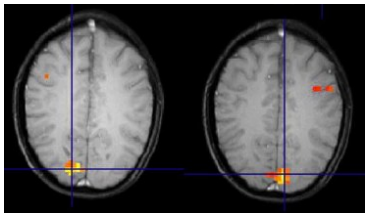
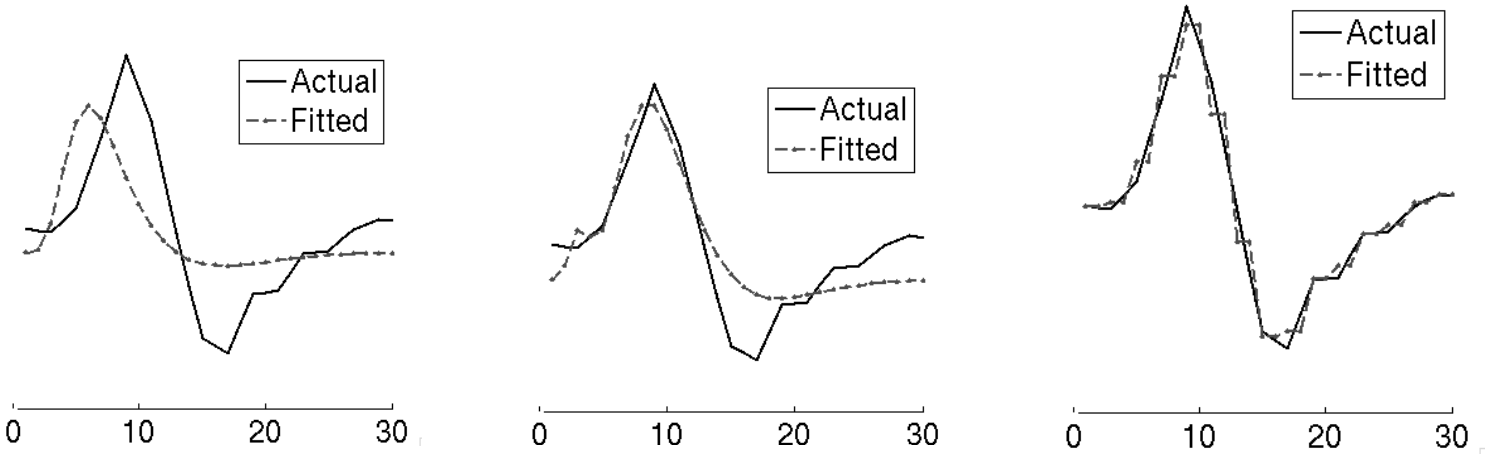
Lindquist & Wager

Choosing a basis set



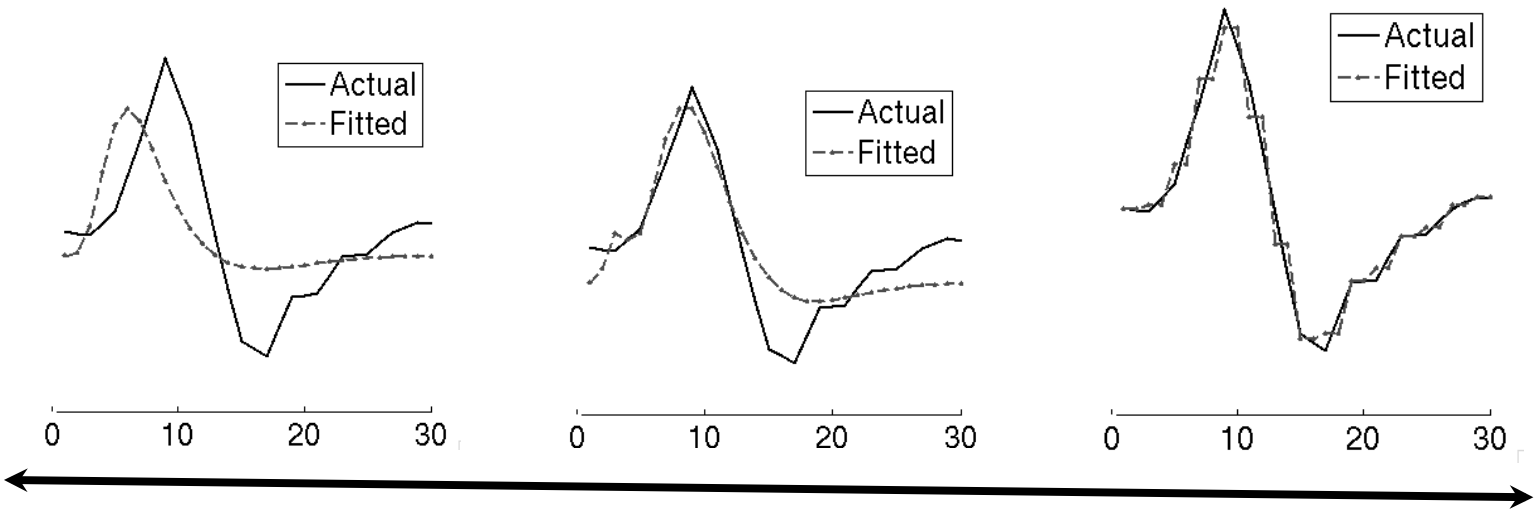
Visual evoked responses

Data fit with three choices of basis set:
Which one should we choose?



Data: Wager, T. D., Vazquez, A., Hernandez, l., Noll, D. C.. (2005). Accounting for nonlinear BOLD effects in fMRI: parameter estimates and a model for prediction in rapid event-related studies. Neuroimage, 25, 206-18.

Choosing a basis set



Accuracy

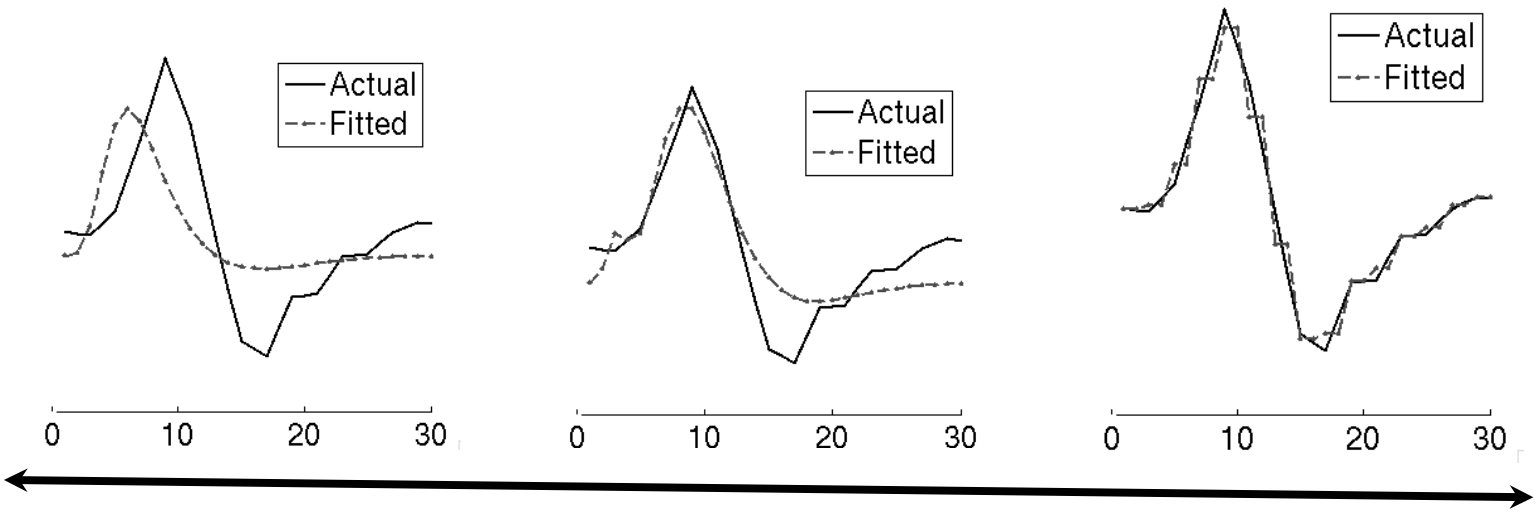
Can the model capture the true response (in this participant, voxel, and condition) without systematic bias?

Precision

Are the model parameters (and thus the shape) estimated with little error variance?

- Bias/variance or accuracy/precision tradeoff:
  A fundamental tradeoff in statistics

Choosing a basis set



Accuracy

Strong assumptions about shape, more bias

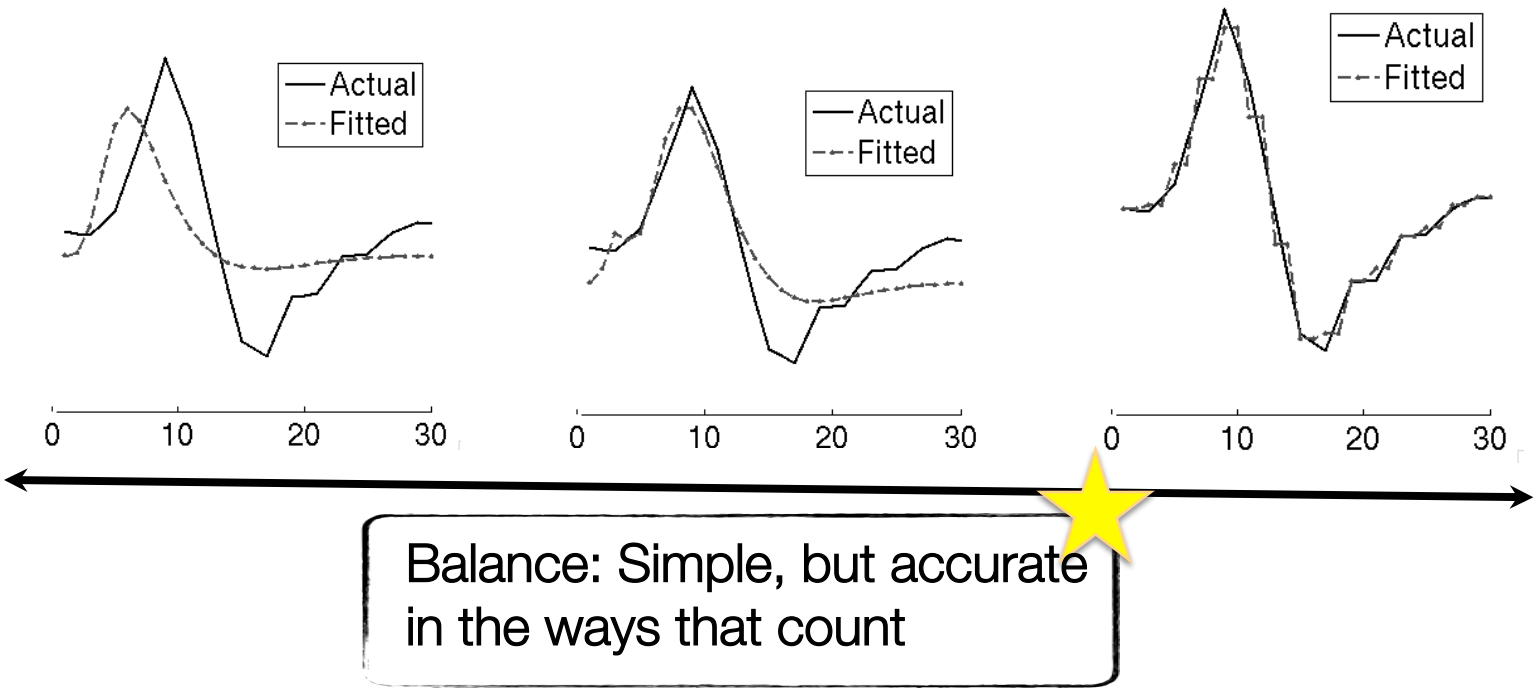
Weak assumptions about shape, less bias

Precision

Few parameters, high precision (and reliability)

Many parameters, low precision (noisy!)

Choosing a basis set



(1) Simple = few parameters (high precision)

(2) Simple = Parameters are interpretable measures of neuroscientific interest (e.g., response amplitude)

(3) Accurate in ways that count = captures true response amplitude in physiological range Depends on your task and brain region!!

End of Module

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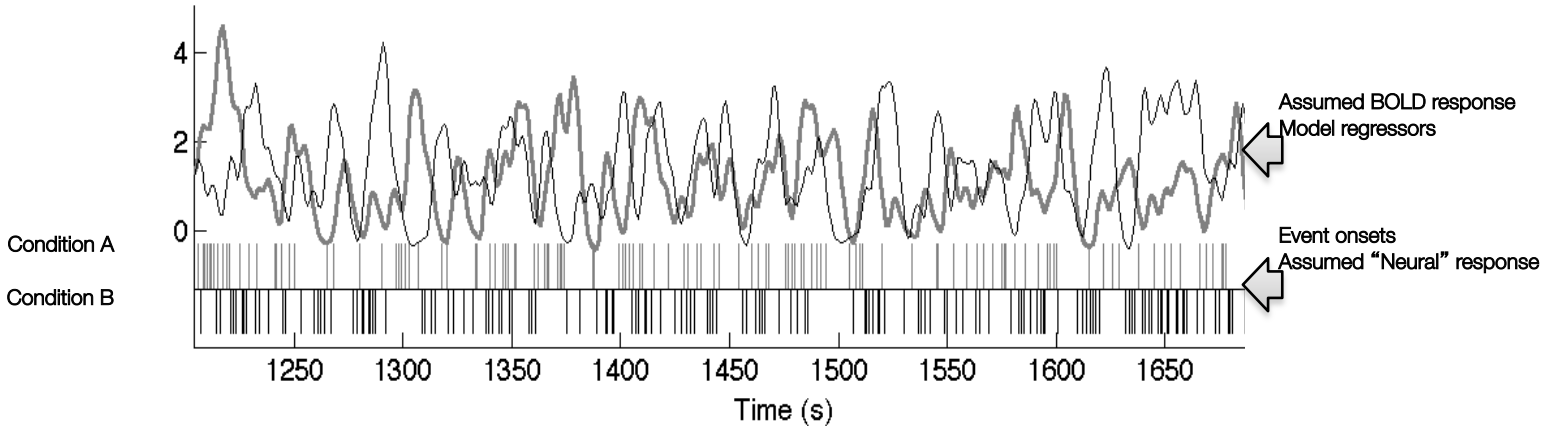
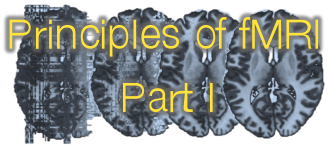
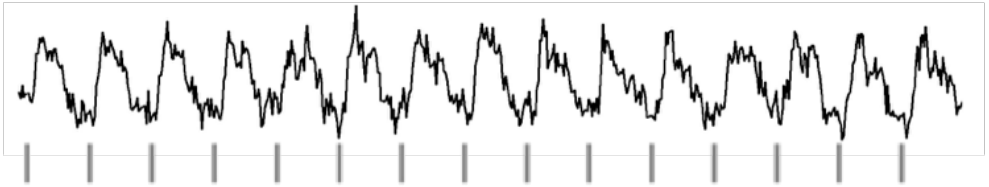

4
2
0
Condition A
Condition B
1250
1300
1350
1400
1450
1500
1550
1600
1650
Time (s)
Assumed BOLD response
Model regressors
Event onsets
Assumed "Neural" response

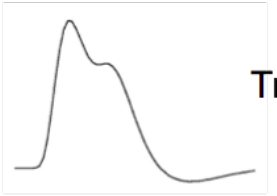
Basis sets: Example for a series of trials



Idealized data

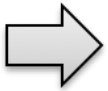


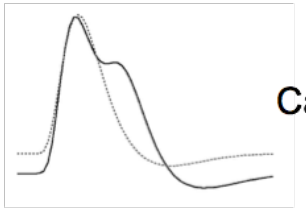
Hemodynamic response



True (simulated)

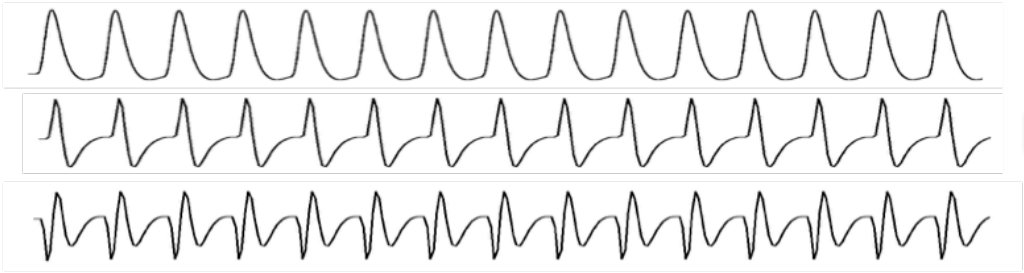
Model predictor: canonical

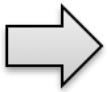


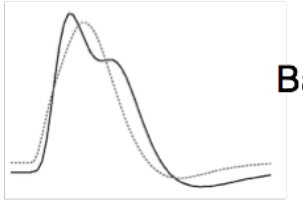


Canonical fit

Model predictors: Basis set

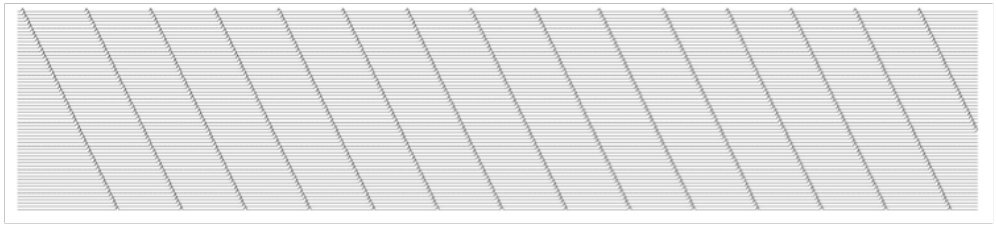


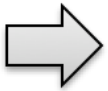


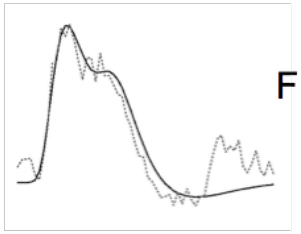


Basis set fit

Model predictors: Finite Impulse Response (FIR)







FIR model fit