Model-based fMRI

Lausanne SPM Course
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To model or not to model

GLM

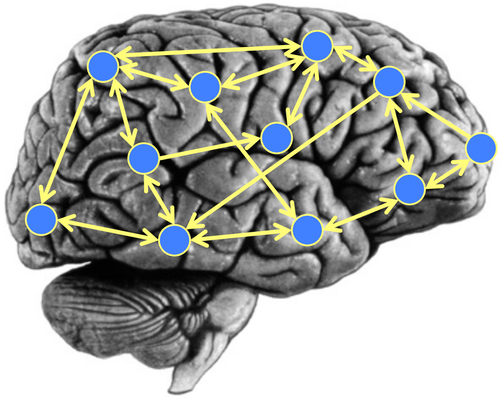
DCM

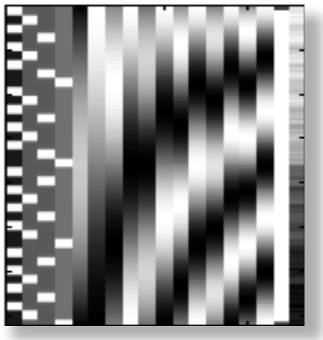
Classification

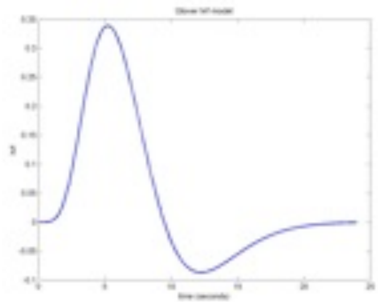
Multivariate Bayes

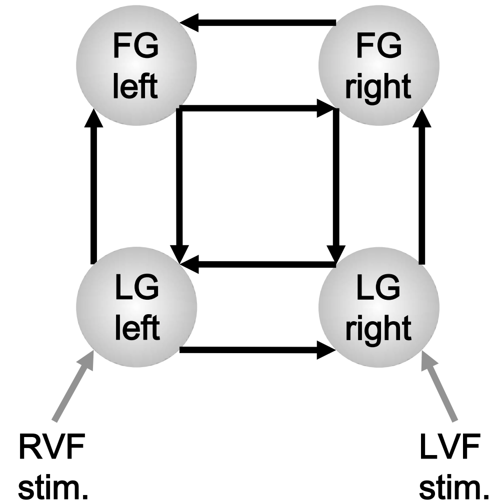
fMRI uses models at different stages

- Hemodynamic response (hrf)
- Activation levels
- Time courses
- Connectivity
- t-tests









Overview

- Categorical designs
  Subtraction - Pure insertion, evoked / differential responses
  Conjunction - Testing multiple hypotheses

- Parametric design
  Linear - Adaptation, cognitive dimensions
  Nonlinear - Polynomial expansions, neurometric functions

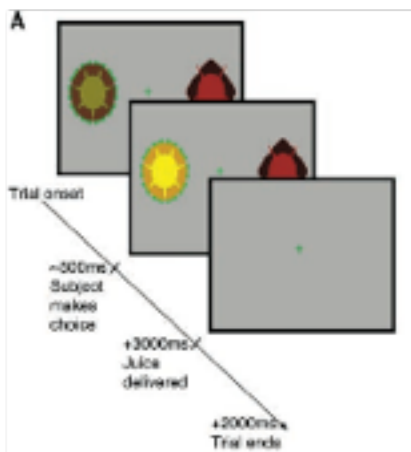
- Factorial designs
  Categorical - Interactions and pure insertion
  Parametric - Linear and nonlinear interactions
  - Psychophysiological Interactions

Parametric designs

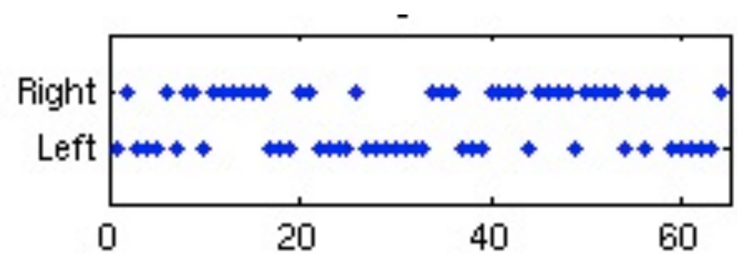
- Vary the stimulus-parameter of interest on a continuum, in more than 2 steps,
  - e.g., ratings on a scale of 1-7; amount of reward received
- Relate measured BOLD signal to this parameter
- Many possible tests for such relations:
  - Linear, Nonlinear: Quadratic/cubic/etc. (polynomial expansion)
- Model-based regressors (e.g., predictions from behavioral models)

Model-based fMRI

- Applying quantitative computational models to generate regressors of interest beyond stimulus inputs and behavioral responses



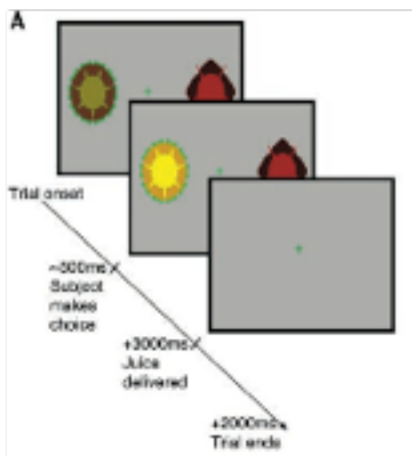
Participant response



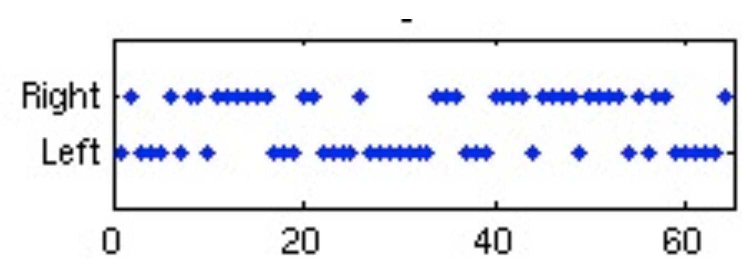
- Goal: uncover hidden variables or processes

Model-based fMRI: questions answered

- How (i.e., by activation of which areas) does the brain implement a particular cognitive process?



Participant response



Outline

1. Basic recipe for model-based fMRI

2. Using model-based regressors in the GLM

When ***not*** to decide on a model

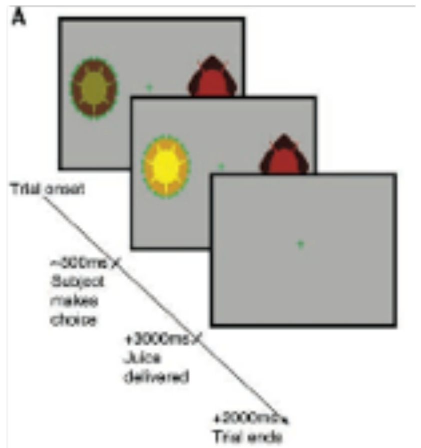
1. Hypothesis
2. Experimental design (e.g., event-related)
3. Data collection
4. No effect for event-related analysis :(
5. **Find a computational model to track hidden variables**

When to decide on a model

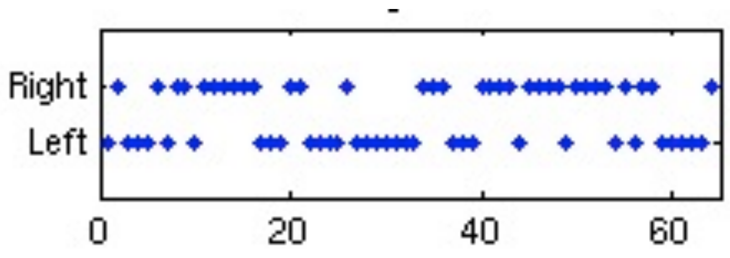
1. Hypothesis
2. **Find a computational model to track hidden variables**
3. Experimental design (e.g., event-related)
4. Data collection
5. ~~No effect for event-related analysis :(~~

Model-based fMRI

1. Decide on a model
   - This should happen *before* you run the experiment.
   - Start with a research question and choose a model that adequately addresses this question.
   - Design your experiment with this model in mind.
   - E.g., reinforcement learning model, hierarchical bayesian model.



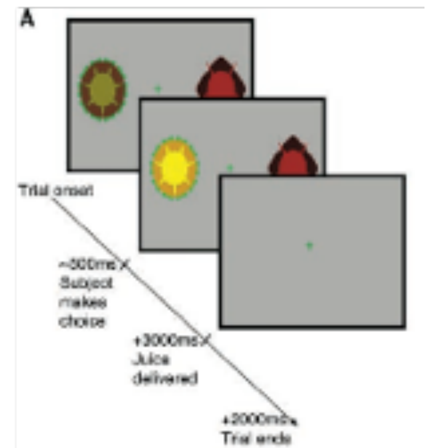
Participant response



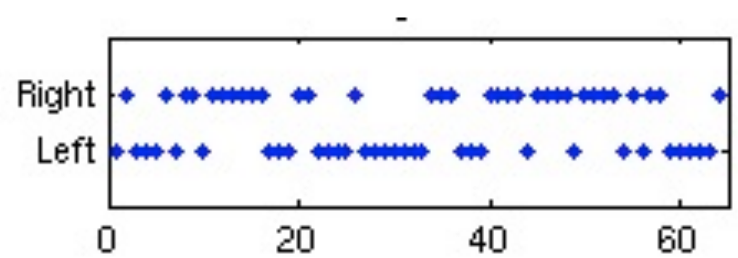
Model-based fMRI

1. Decide on a model

   - Reinforcement learning model

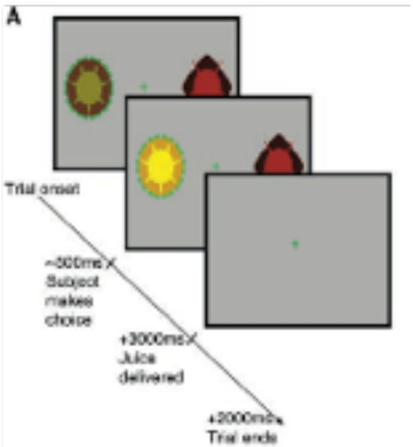


Participant response

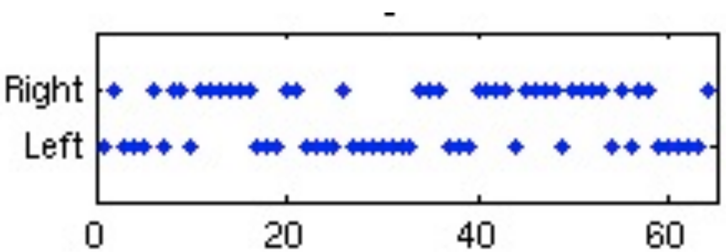


Model-based fMRI

2. Pass individual subject trial history to model



Participant response



$$\delta = R_{t+1} + \gamma V_{t+1} - V_t$$

$$V^A_{t+1} = V^A_t + \alpha\delta$$

Model-based fMRI

3. Find best-fitting parameters of the model (e.g., learning rate) to behavioral data

4. Generate

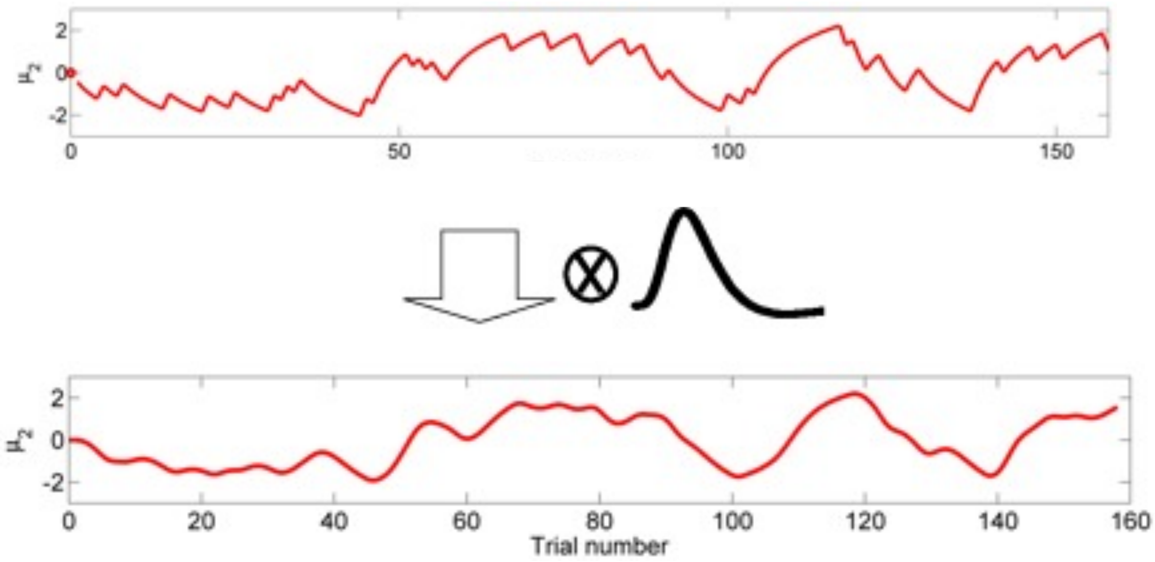
    a. parametric modulators (first level)

    b. model-based time series (first level)

    c. subject-specific parameters (e.g., second level, DCM)

Model-based fMRI

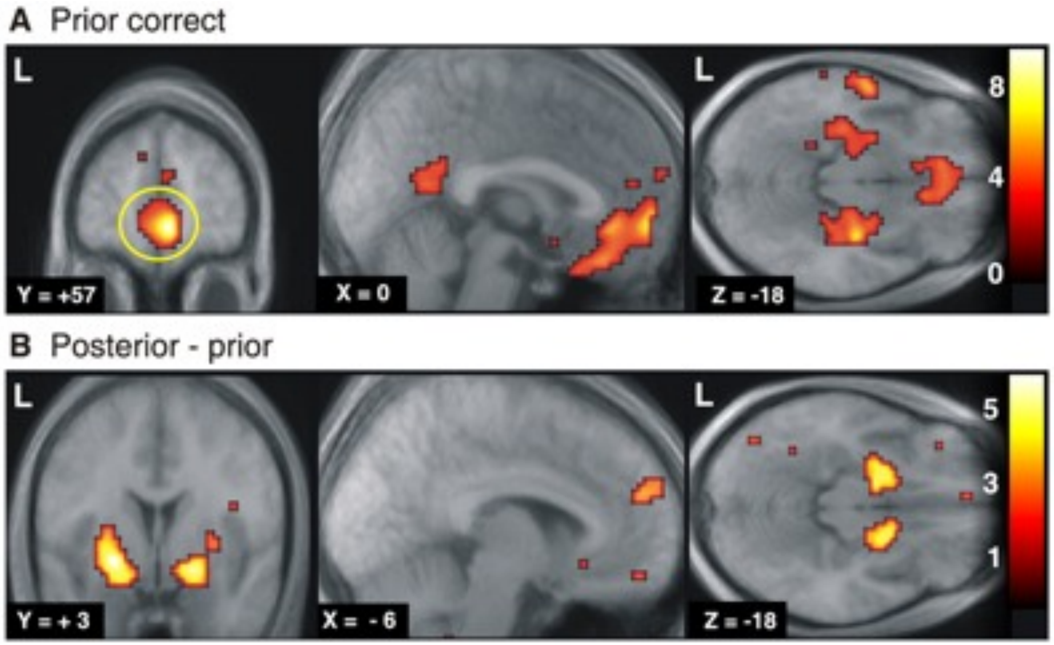
5. Convolve time series with hemodynamic response function



Adapted from O'Doherty et al., (2007)

Model-based fMRI

6. Regress against fMRI data



Hampton et al., (2006)

Model-based fMRI

1. Decide on a model
2. Pass individual subject trial history to model
3. Find best-fitting parameters of model to behavioral data

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4. Generate parametric modulators & model-based time series
5. Convolve time series with hemodynamic response function
6. Regress against fMRI data

From classic design to model based fMRI

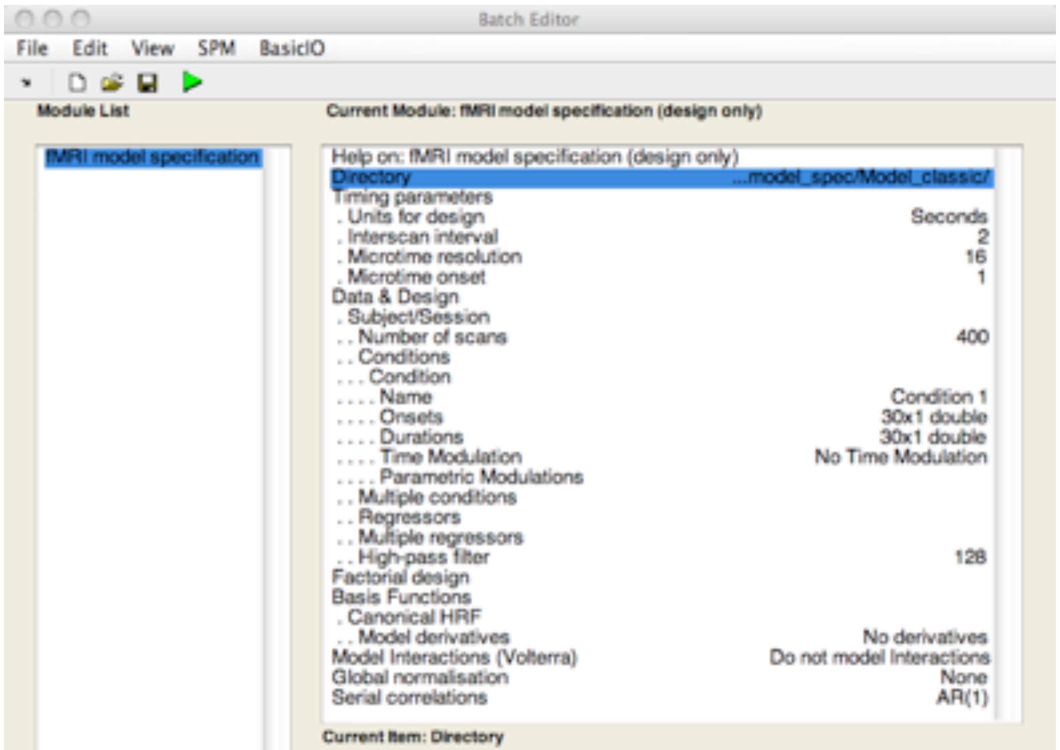
1. Classic event/block design

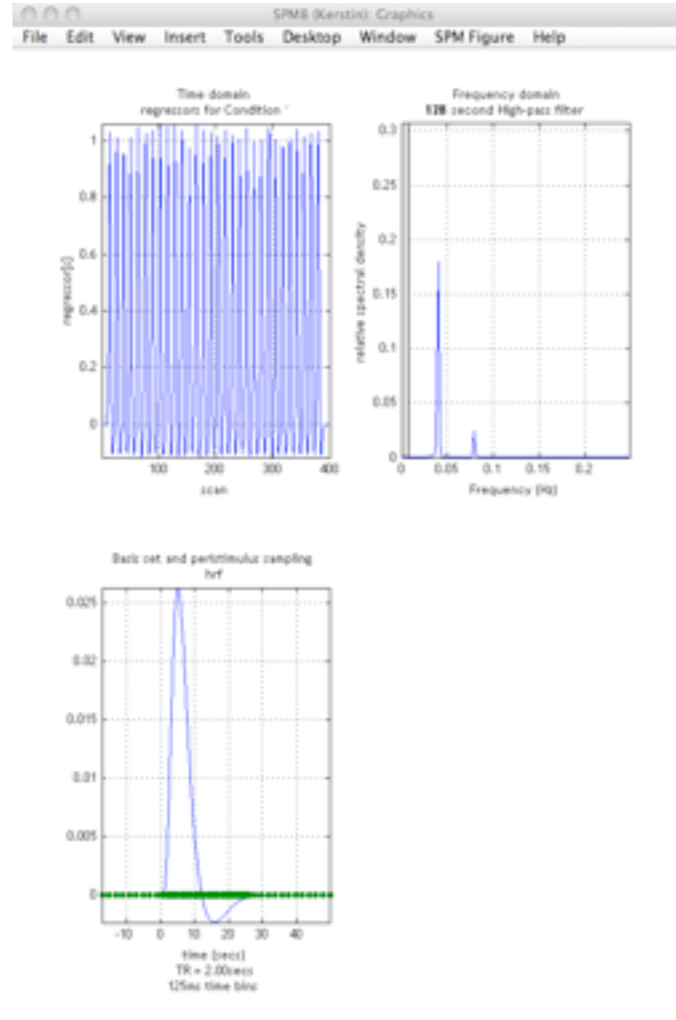
2. Adding parametric regressors

3. Model-based design

Model-based fMRI: comparisons

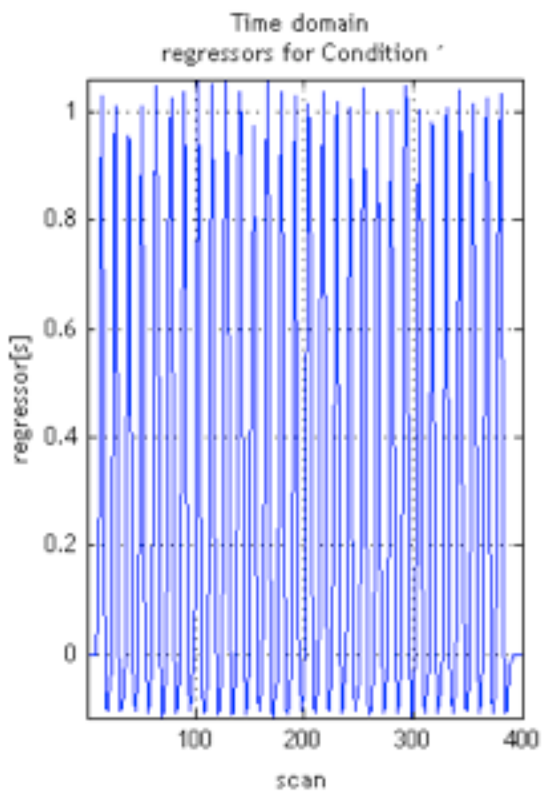
- Classical event/block design

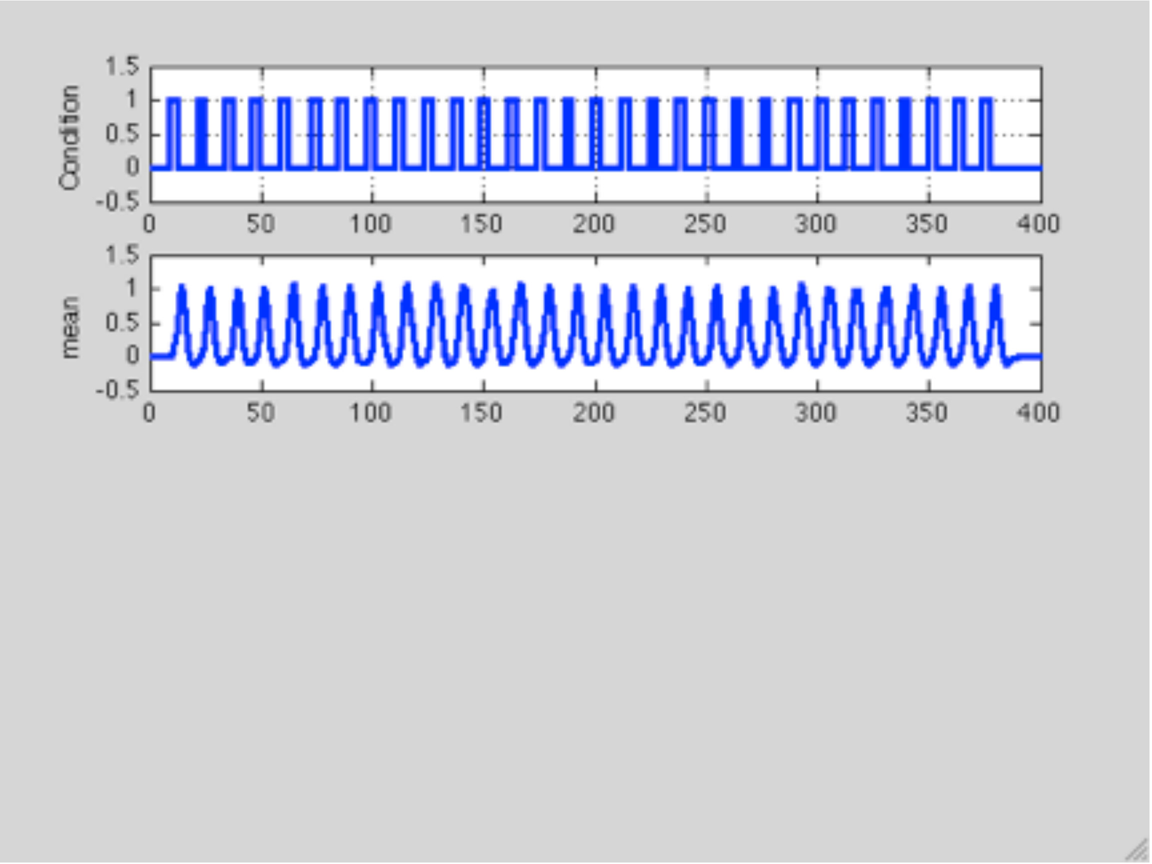




Model-based fMRI: comparisons

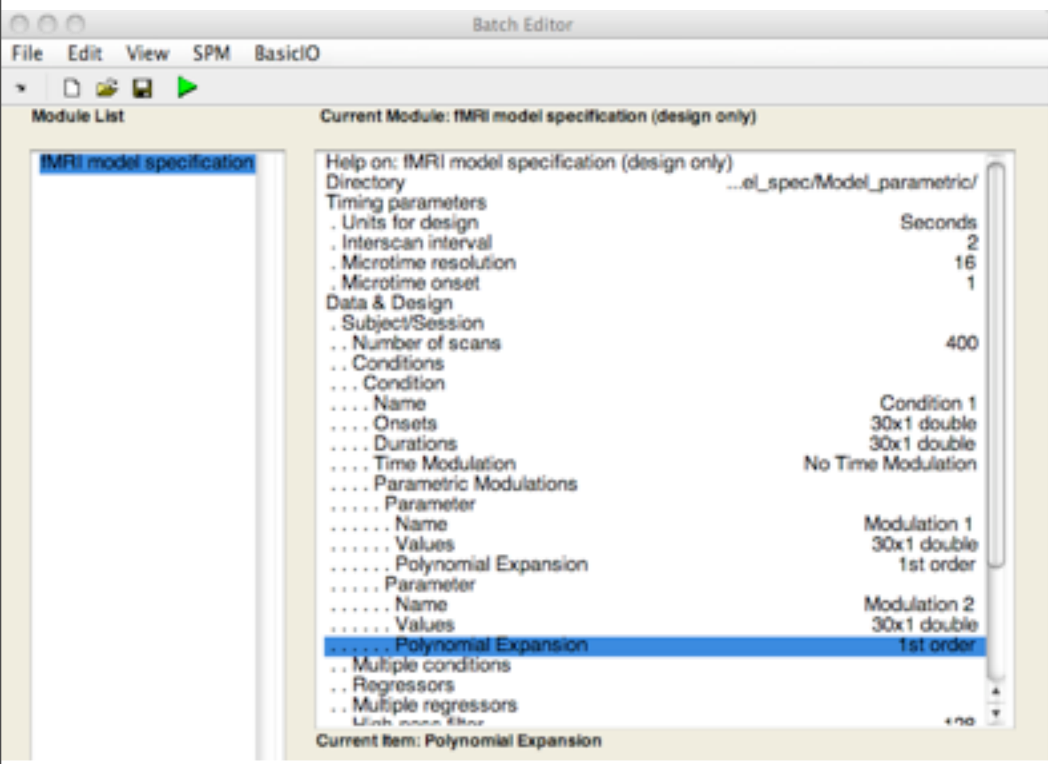
- Classical event/block design

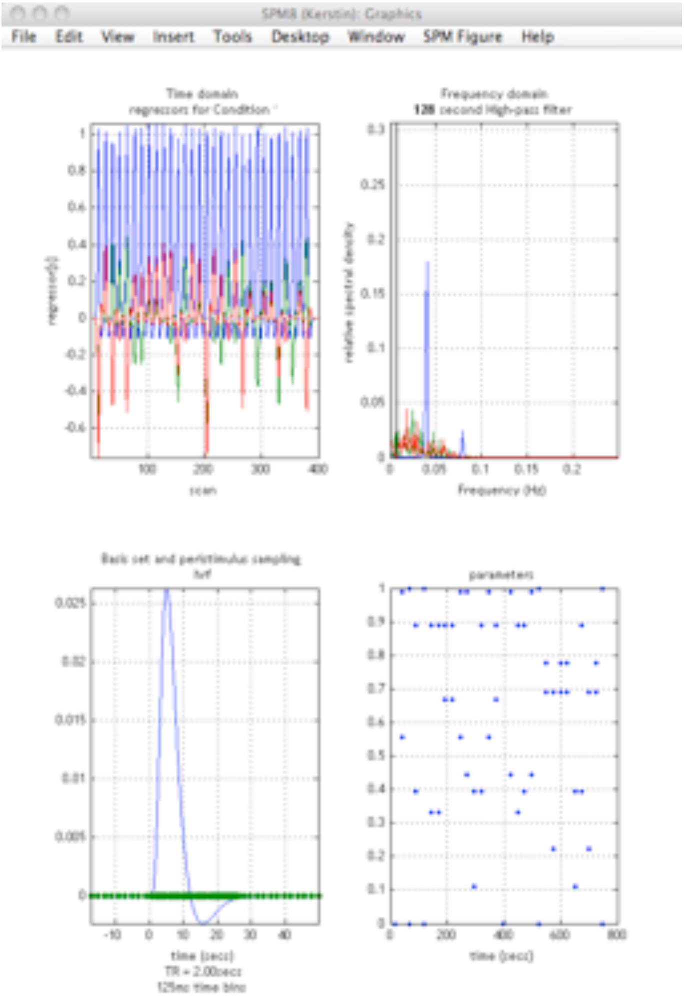




Model-based fMRI: comparisons

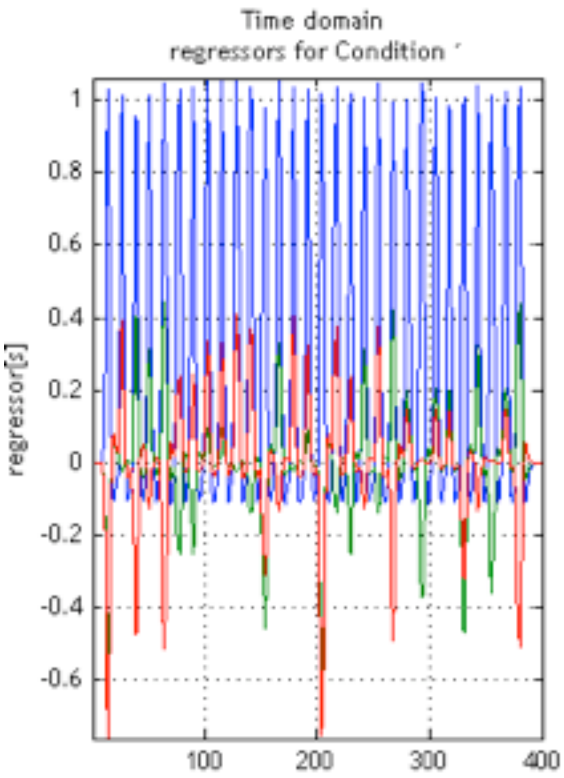
- Parametric regressors

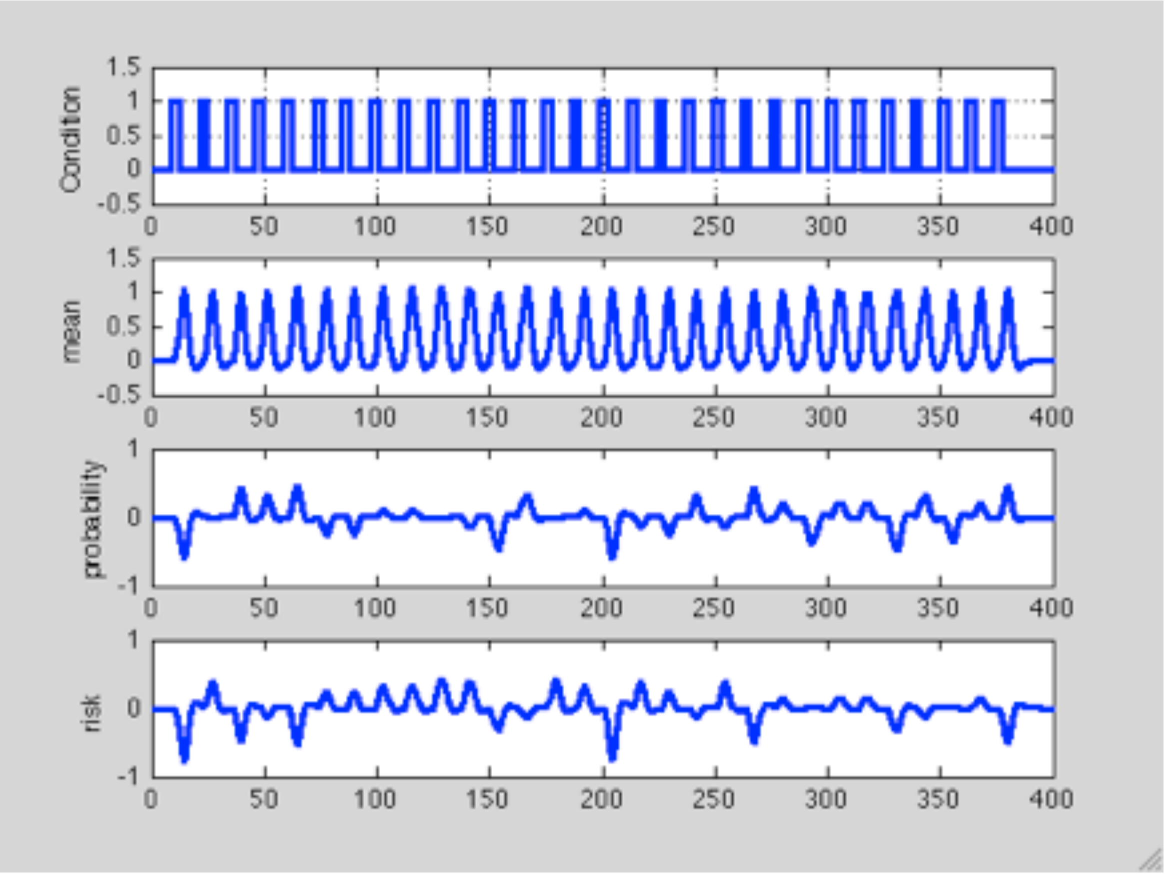




Model-based fMRI: comparisons

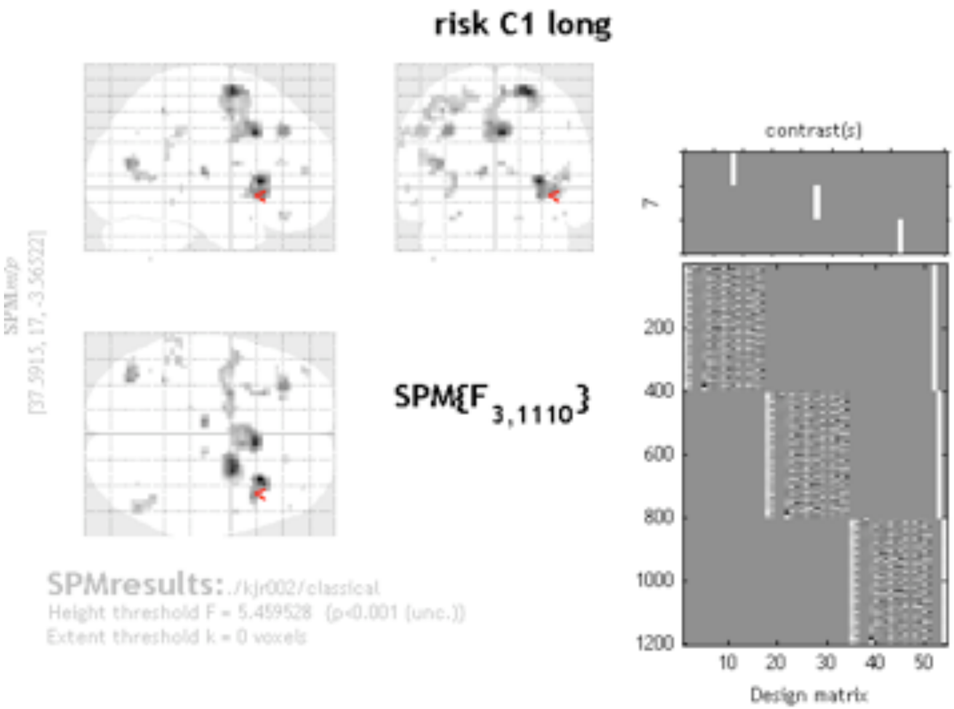
- Parametric regressors

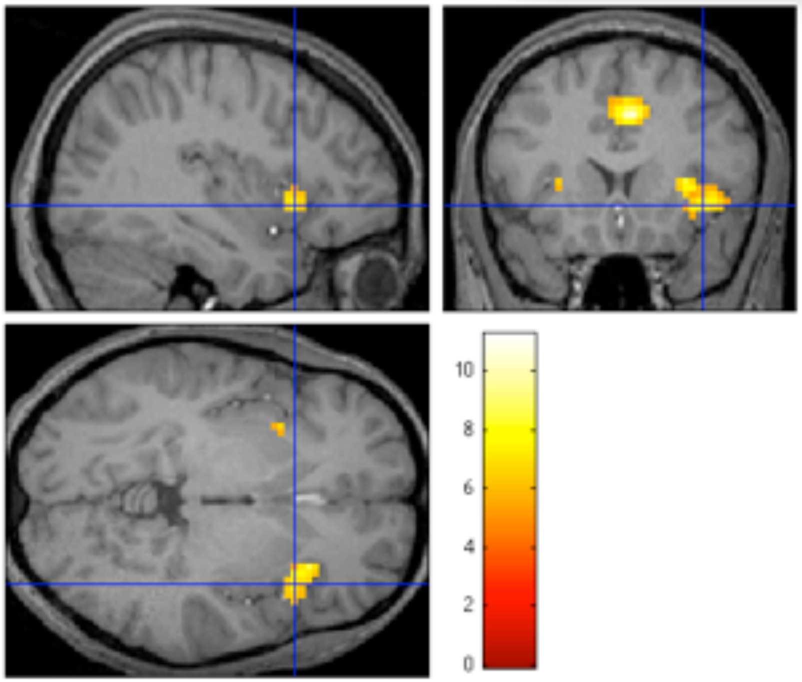




Model-based fMRI: comparisons

- Parametric regressors





How do we construct regressors that correspond to cognitive processes and use them in SPM?

4. Generate

a. parametric modulators (first level)

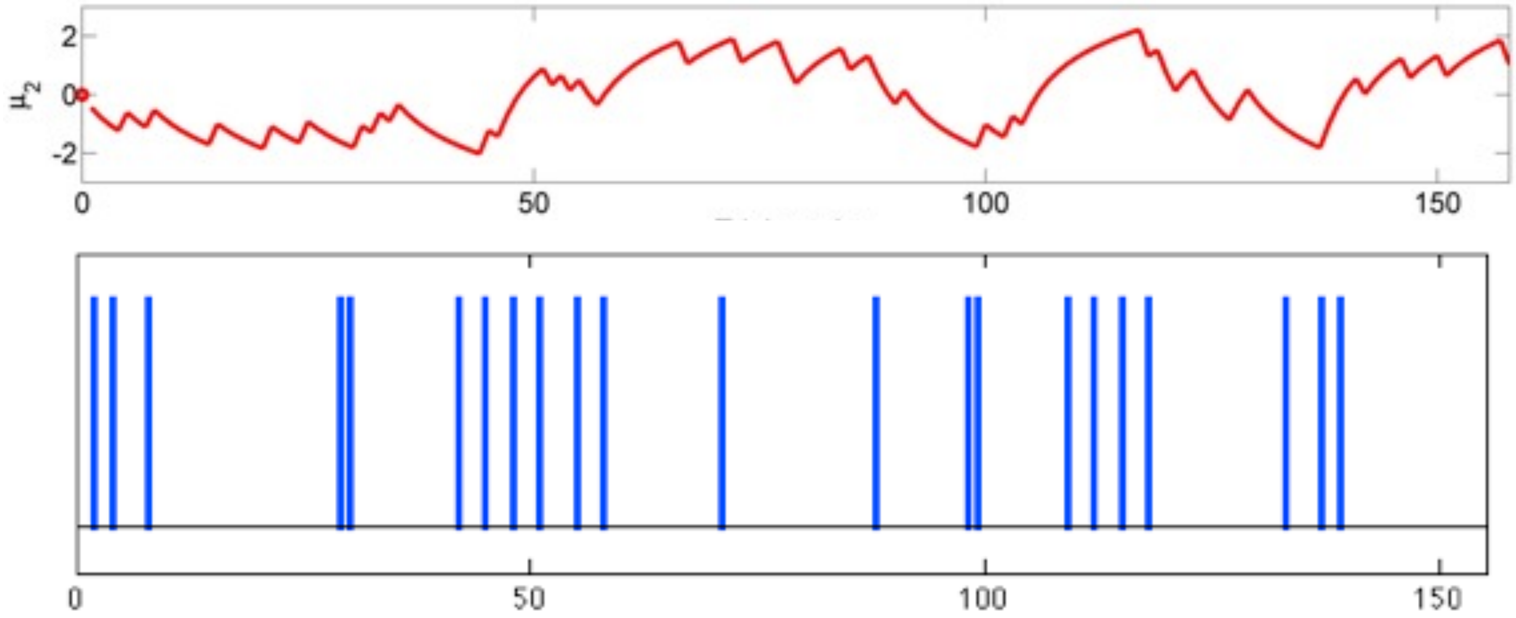
b. model-based time series (first level)

c. subject-specific parameters (e.g., second level, DCM)

How do we construct regressors from a time series and use them in SPM?

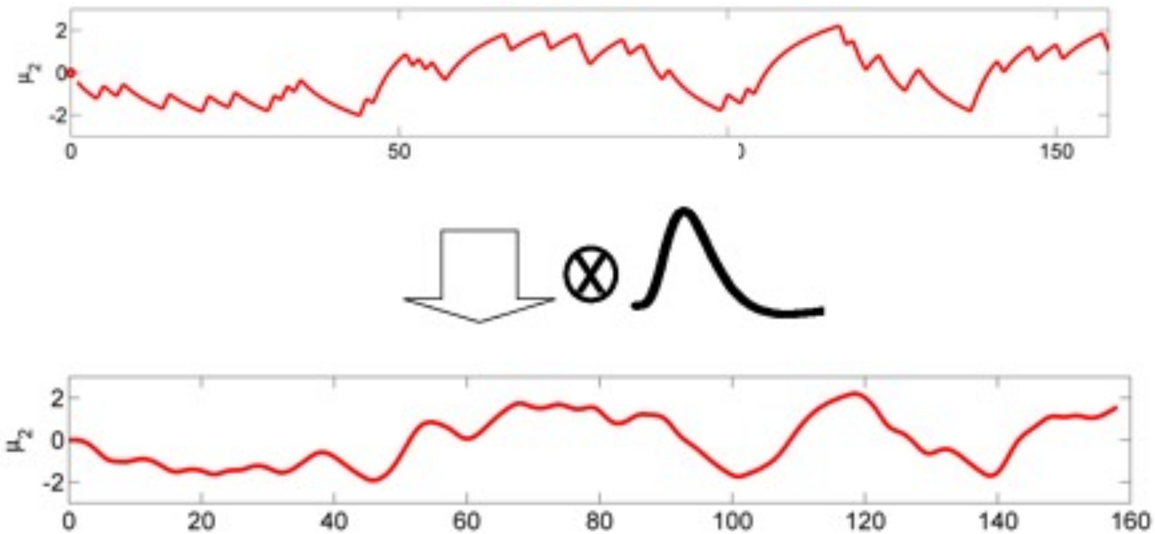
Sample time-series at points of interest (e.g., participant response)

Enter as parametric modulation for condition ‘participant response’



How do we construct regressors from a time series and use them in SPM?

Convolve time series with hemodynamic response function

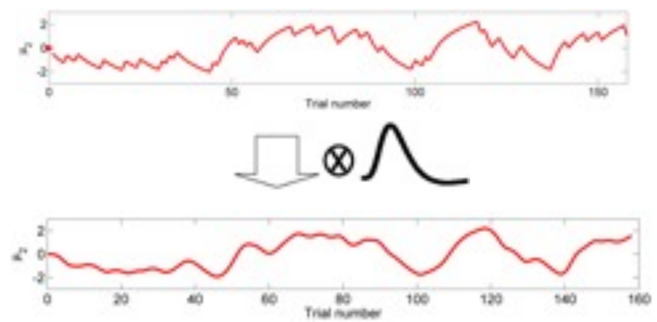


Adapted from O'Doherty et al., (2007)

How do we construct regressors from a time series and use them in SPM?

Convolve time series with hemodynamic response function

- sample time series at the same rate as the basis functions

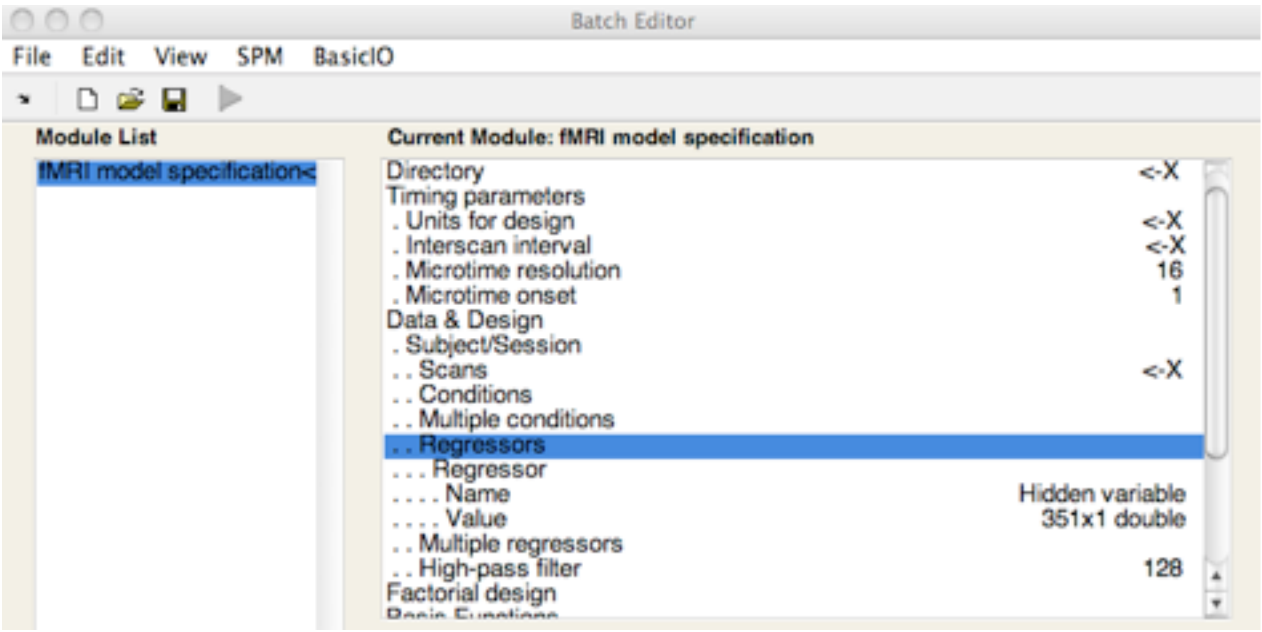


- convolve with the basis functions **`SPM.xBF.bf`**
- sample at TR (i.e., one sample per functional volume)
- add to design matrix as (multiple) regressor(s)

How do we construct regressors from a time series and use them in SPM?

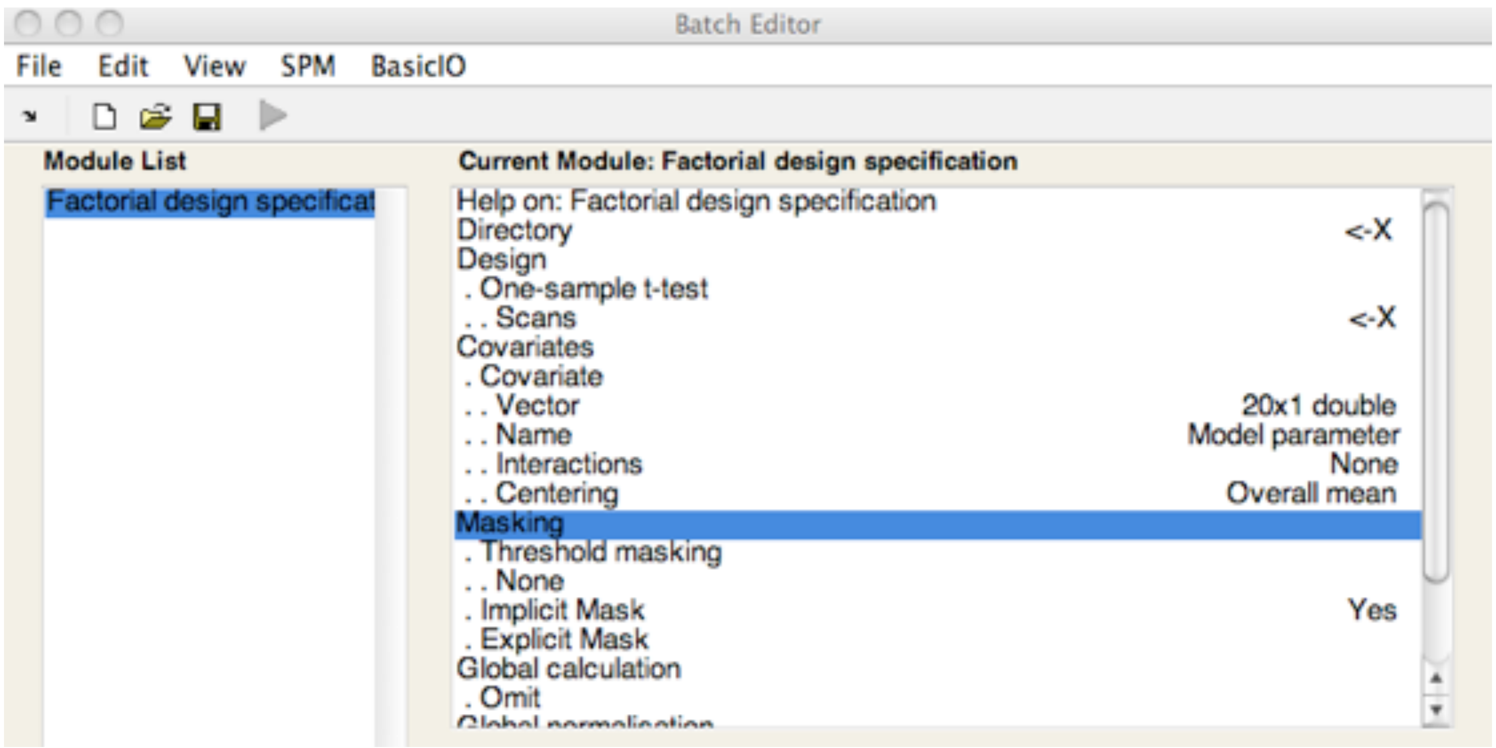
Convolve time series with hemodynamic response function

- add to design matrix as (multiple) regressor(s)



How do we include individual model parameters?

e.g., enter as covariates at the second level



Model-based fMRI recipe

1. Decide on a model (*before* finishing your experimental design)

2. Pass individual subject trial history to model

3. Find best-fitting parameters of model to behavioral data

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4. Generate parametric modulators & model-based time series

5. Convolve time series with hemodynamic response function

6. Regress against fMRI data

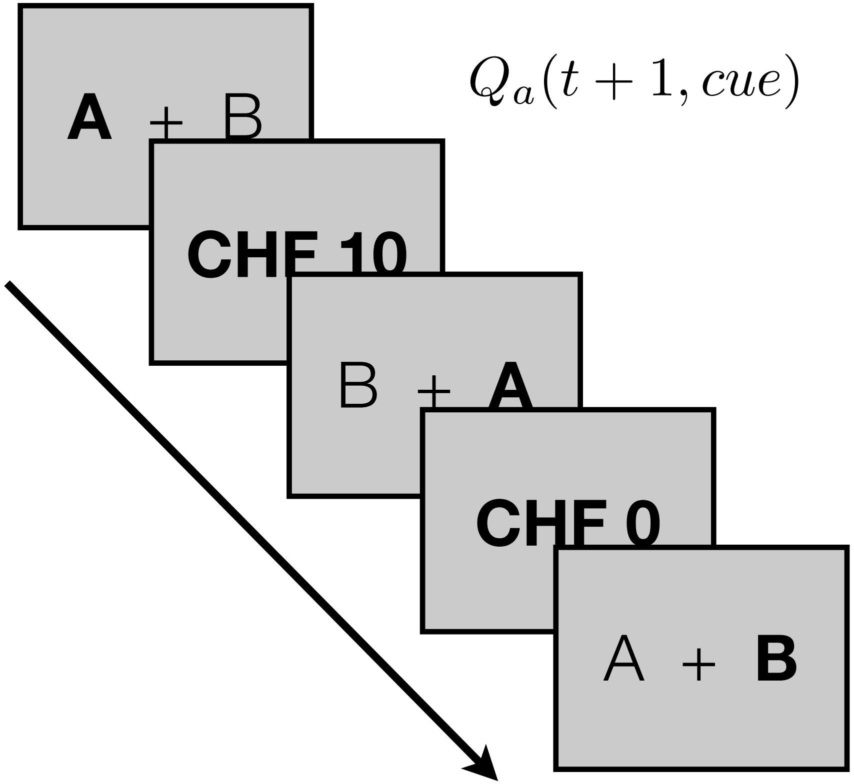
Design efficiency

- Regressors and design matrix not fully specified before data collection.
- To estimate design efficiency:
  - Simulate behavioral data, conduct behavioral pilot study
  - Obtain simulated/pilot time course from the model
  - Optimize design efficiency

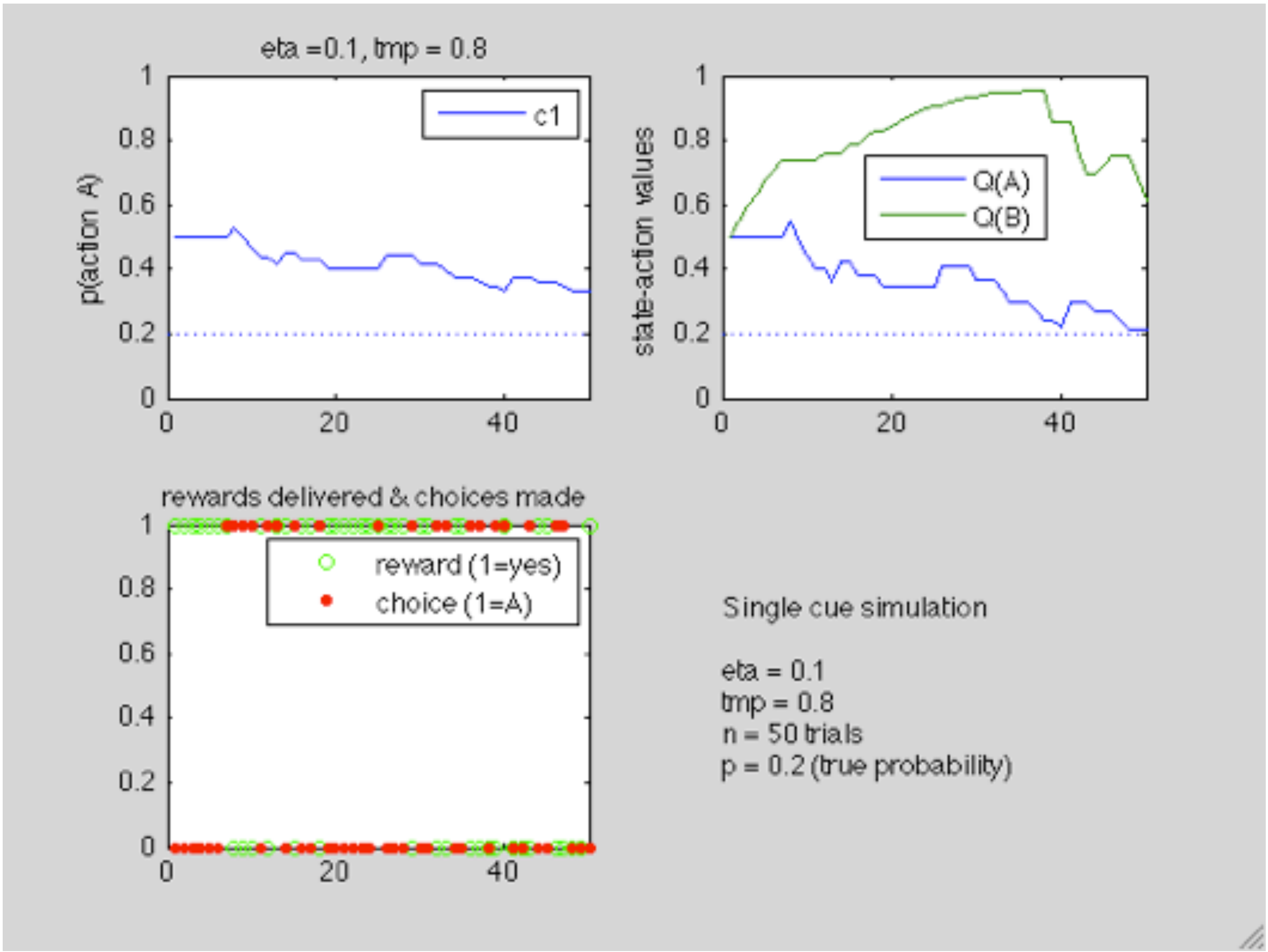
Simulated data for estimating design efficiency

$$p_a(t, cue) = \frac{e^{Q_a(t,cue)/\beta}}{e^{Q_a(t,cue)/\beta} + e^{Q_b(t,cue)/\beta}}$$

$$Q_a(t+1, cue) = Q_a(t, cue) + \eta(R(t) - Q_a(t, cue))$$

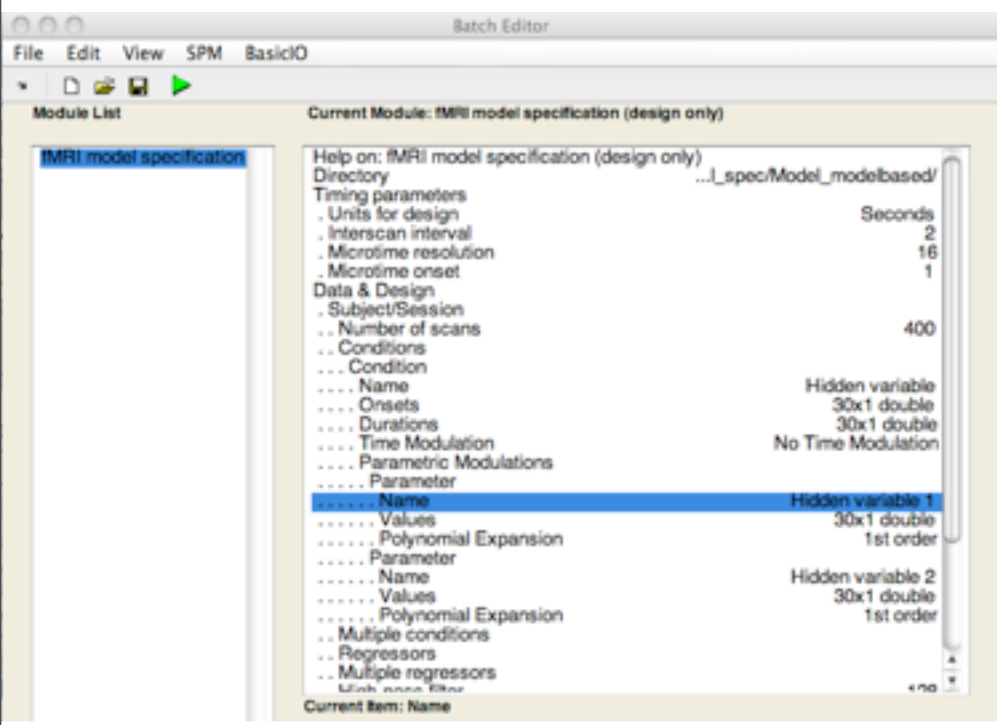


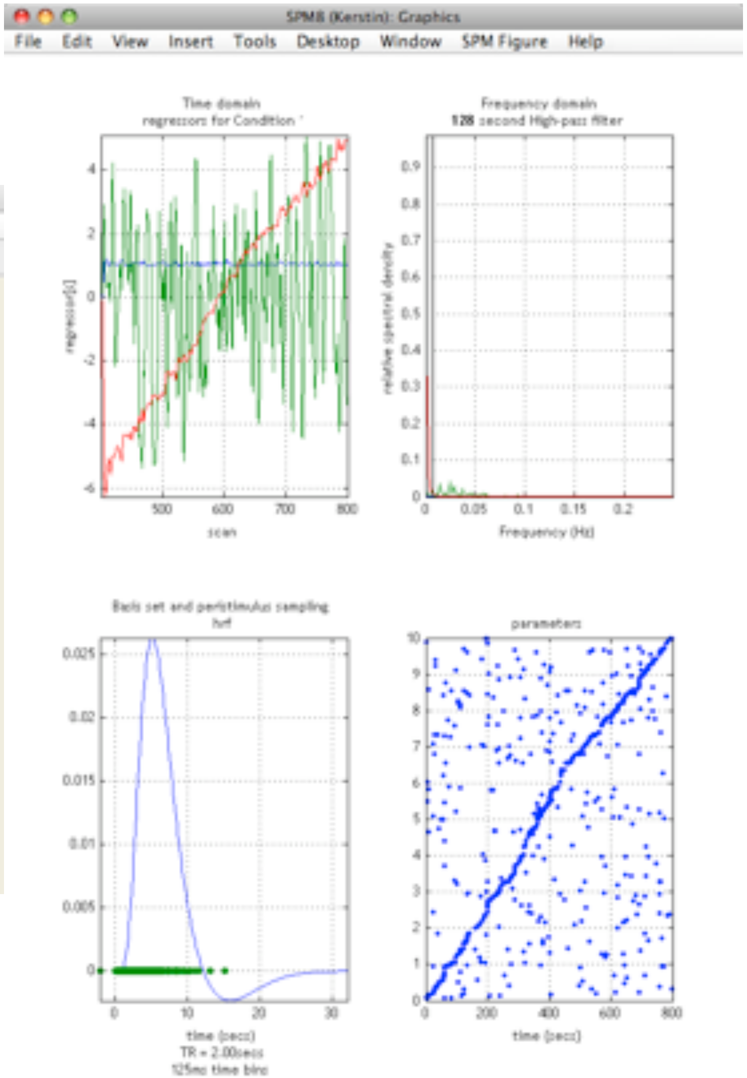
Simulated data for estimating design efficiency



Model-based fMRI: design efficiency

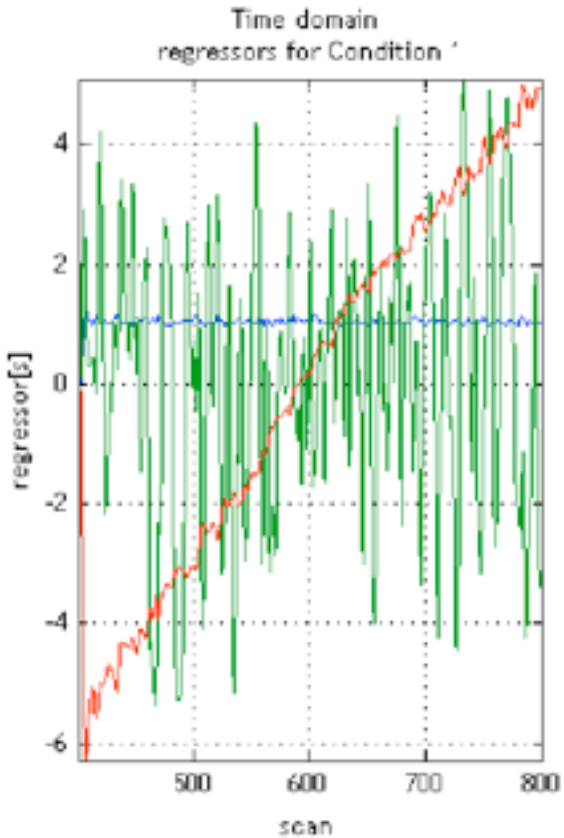
- Model based fMRI

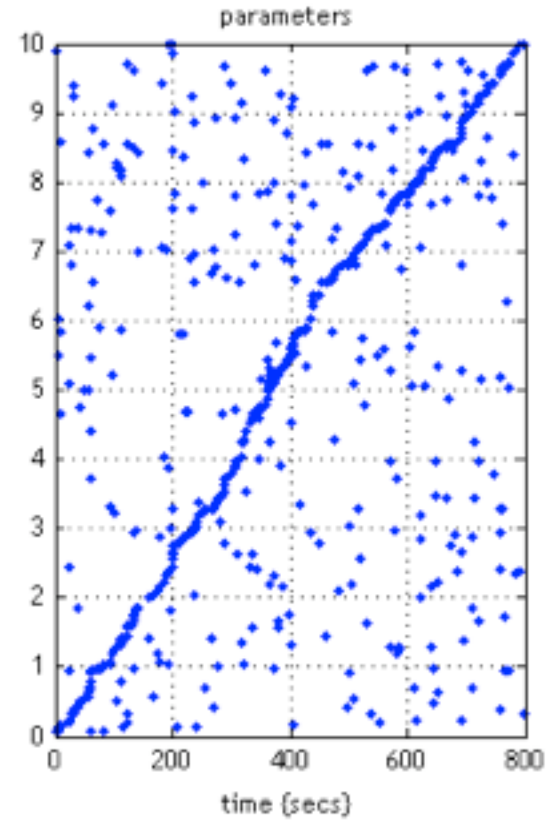




Model-based fMRI: comparisons

- Model based fMRI





Model-based fMRI recipe

1. Decide on a model

2. Pass individual subject trial history to model

3. Find best-fitting parameters of model to behavioral data

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4. Generate model-based time series

5. Convolve time series with hemodynamic response function

6. Regress against fMRI data