Model-based fMRI

Lausanne SPM Course
April 24, 2014

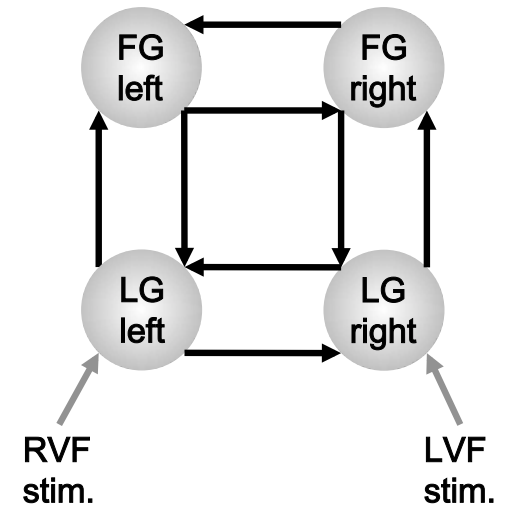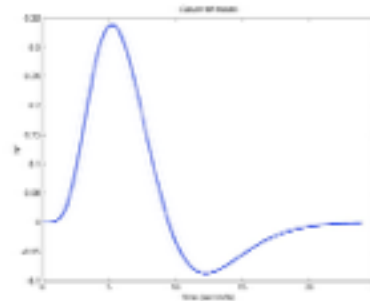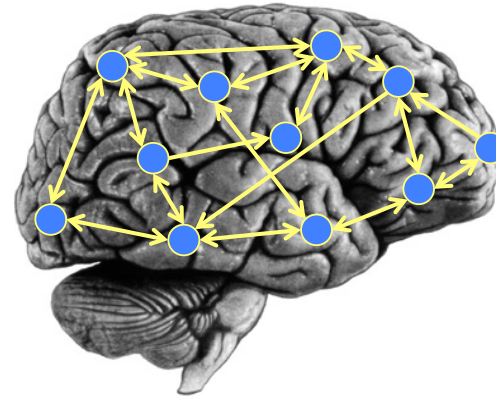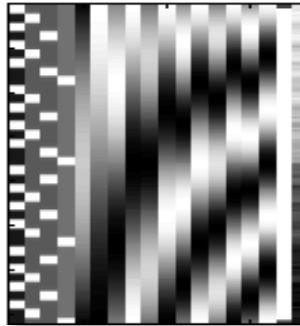Kerstin Preuschoff

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

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
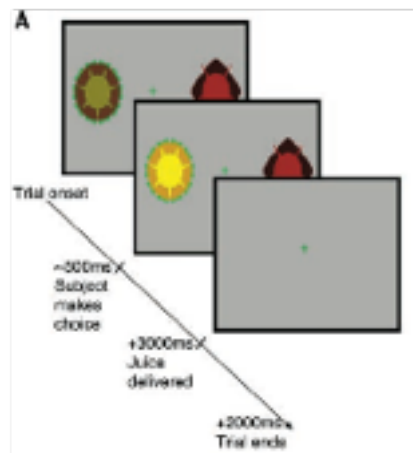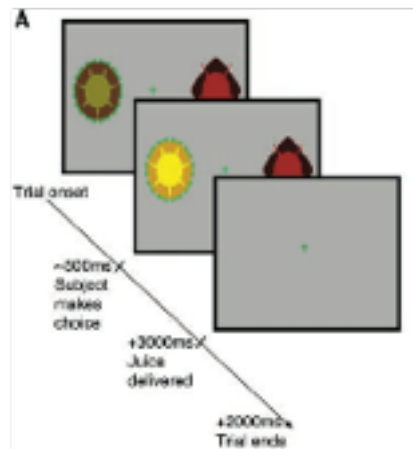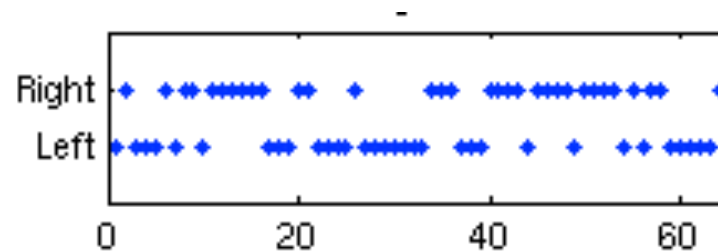

Participant response
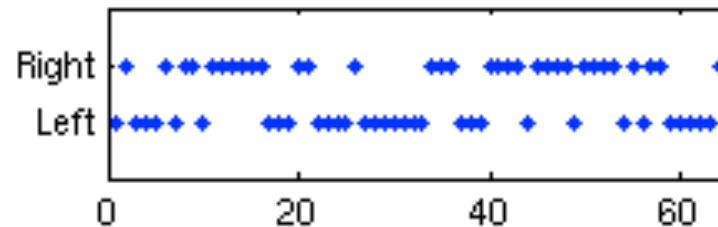
- Goal: uncover hidden variables or processes

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

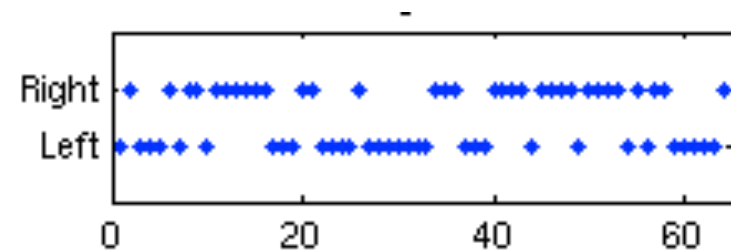5. ~~No effect for event-related analysis :(~~

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.

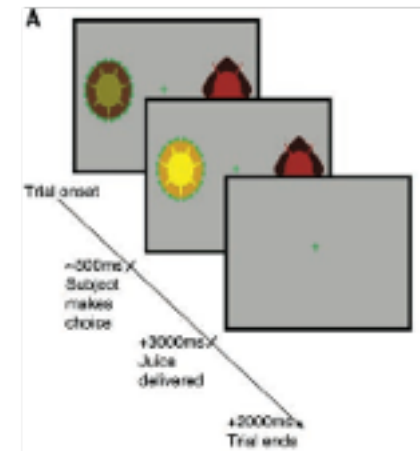   - E.g., reinforcement learning model, hierarchical bayesian model.
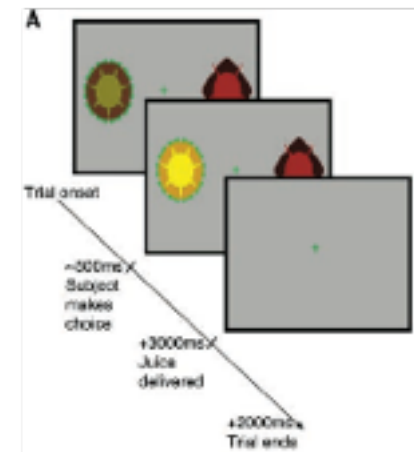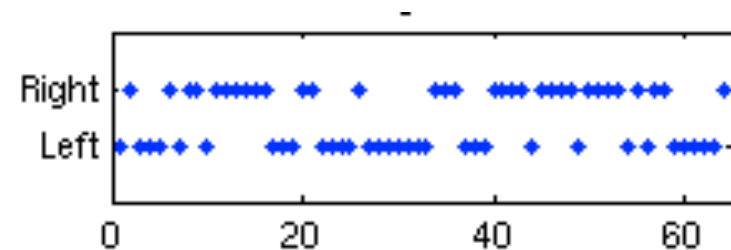

Participant response

Model-based fMRI

1. Decide on a model
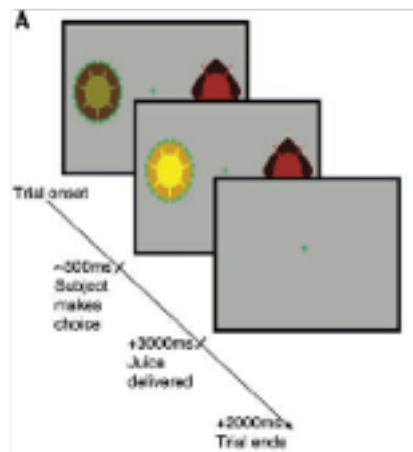
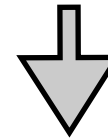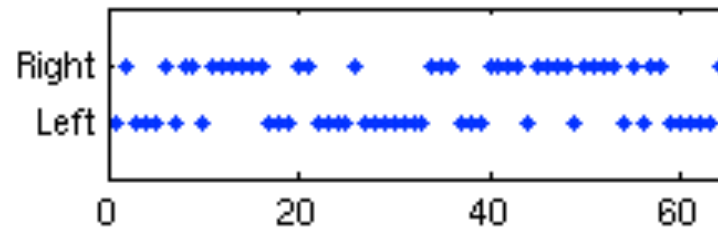   - Reinforcement learning model

Participant response

Model-based fMRI

2. Pass individual subject trial history to model

Participant response

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

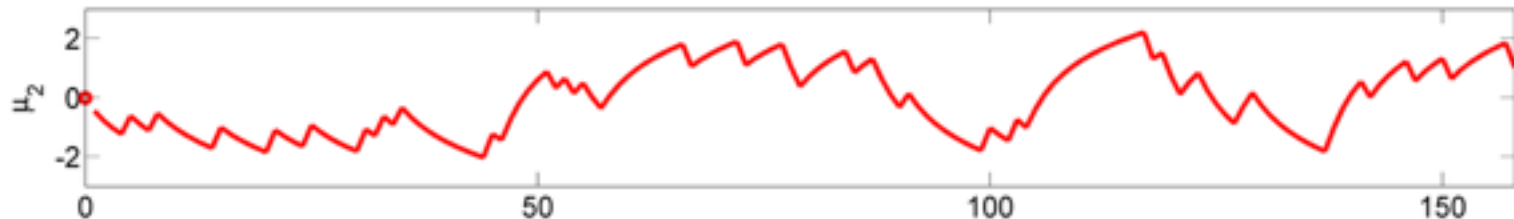$$V^A_{t+1} = V^A_t + \alpha \delta$$

Model-based fMRI

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

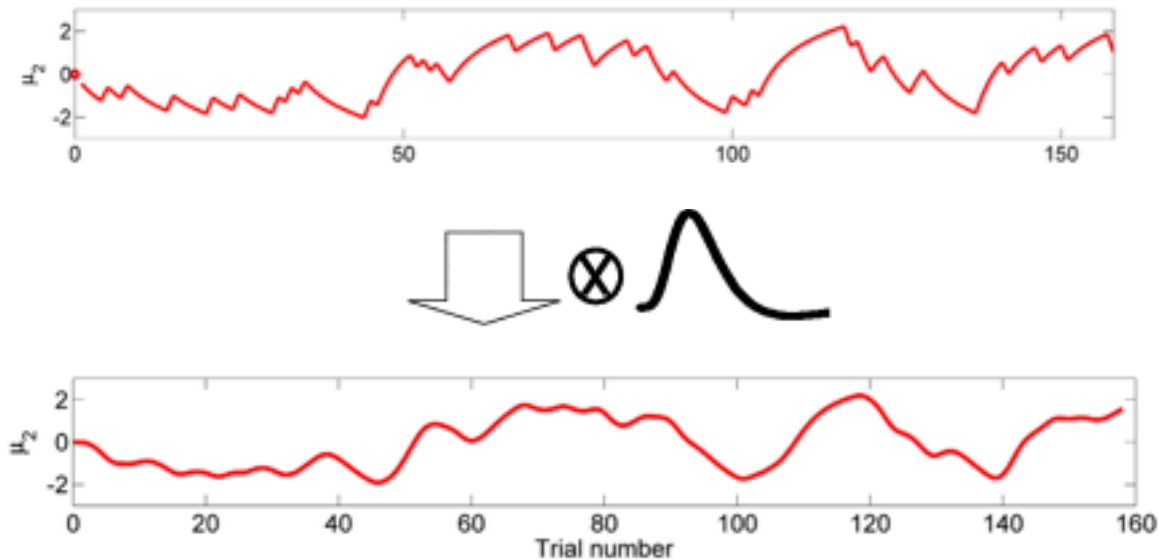4. Generate

    a. parametric modulators (first level)

    b. model-based time series (first level)

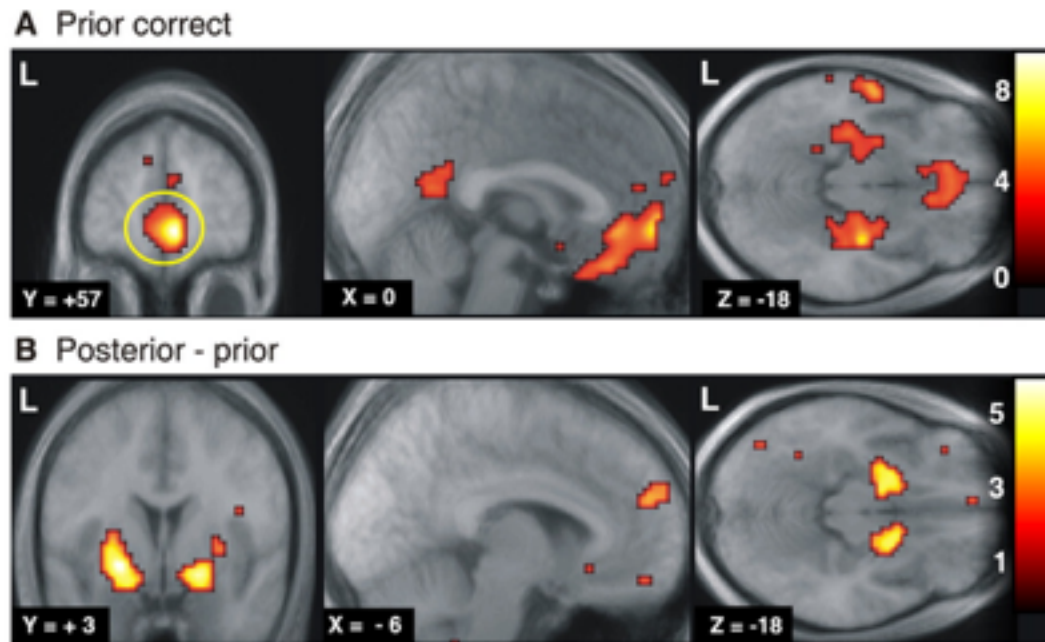   c. subject-specific parameters (e.g., second level, DCM)

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

A Prior correct

**B** Posterior - prior

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

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

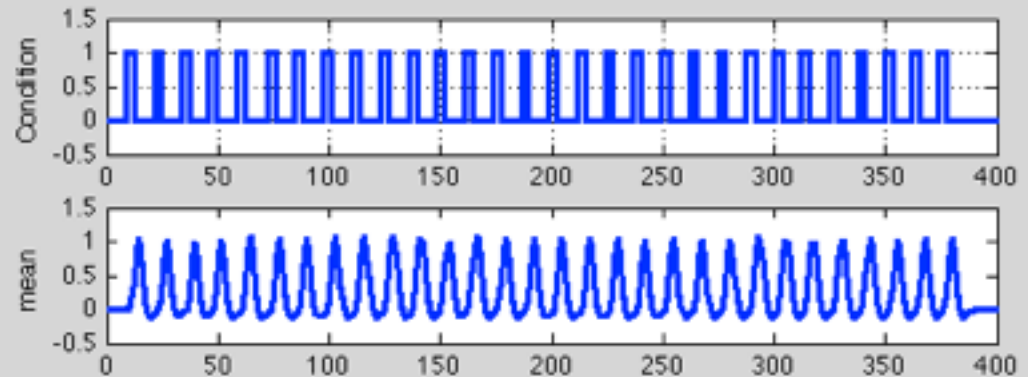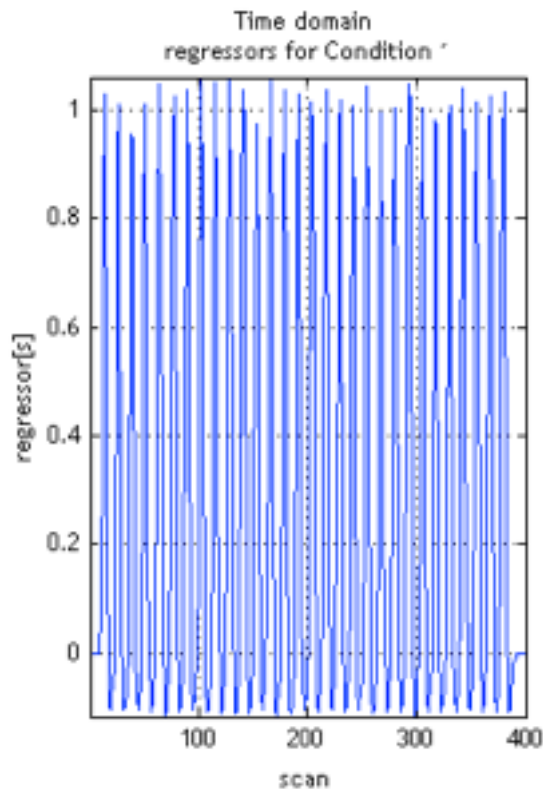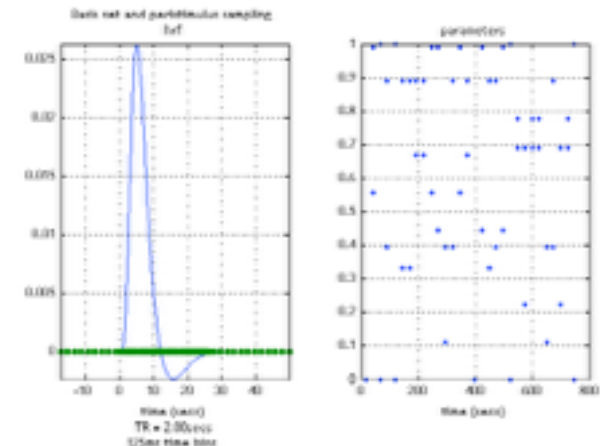2. Adding parametric regressors

3. Model-based design

Model-based fMRI: comparisons
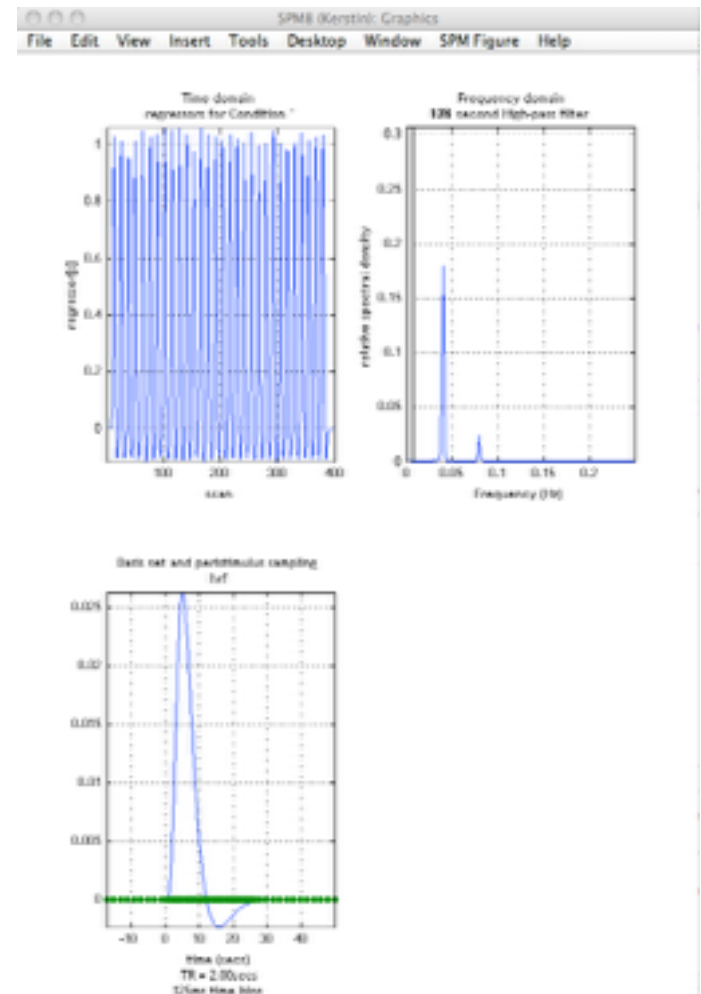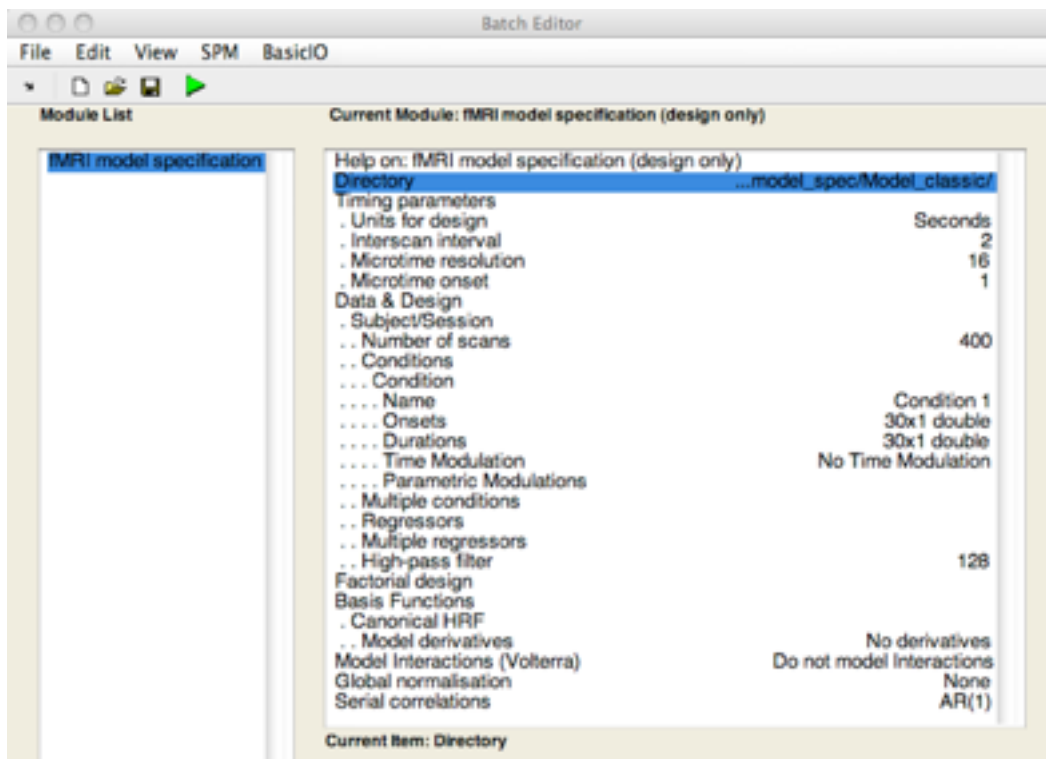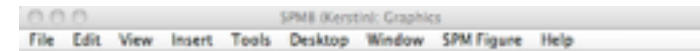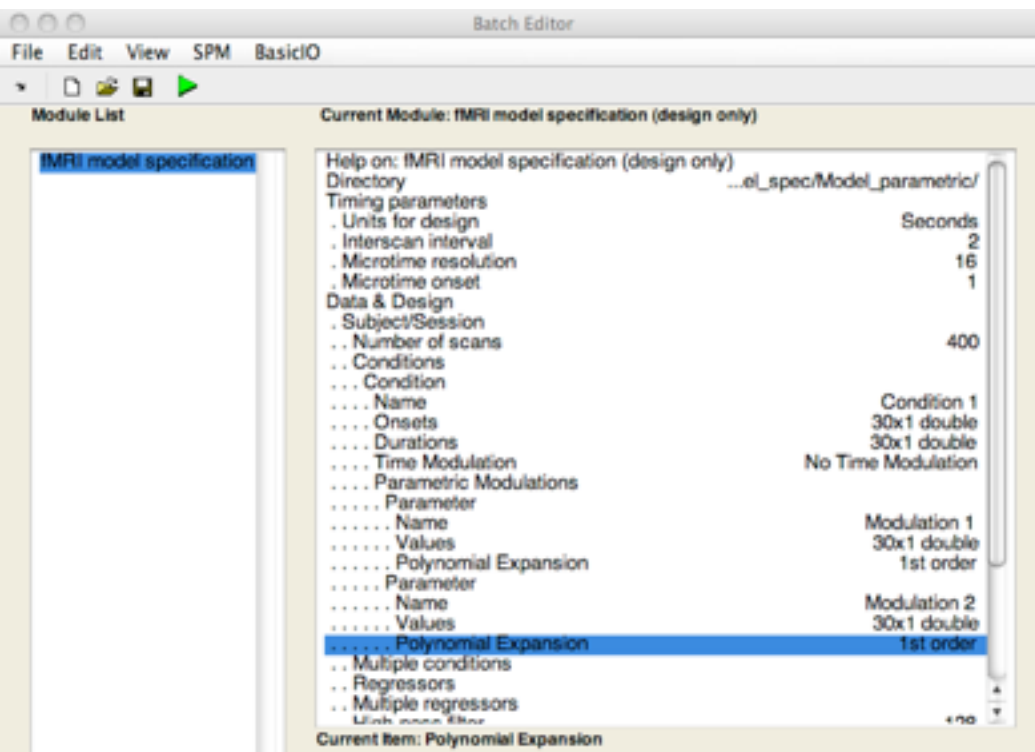
- Classical event/block design

Model-based fMRI: comparisons
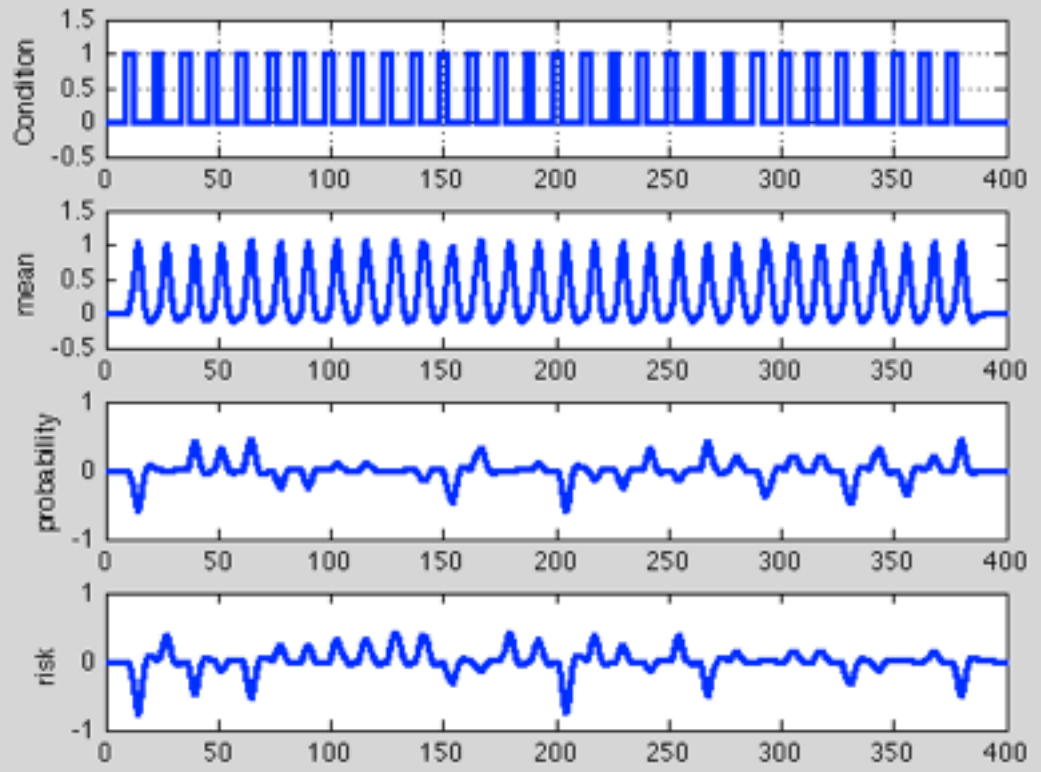
- Classical event/block design

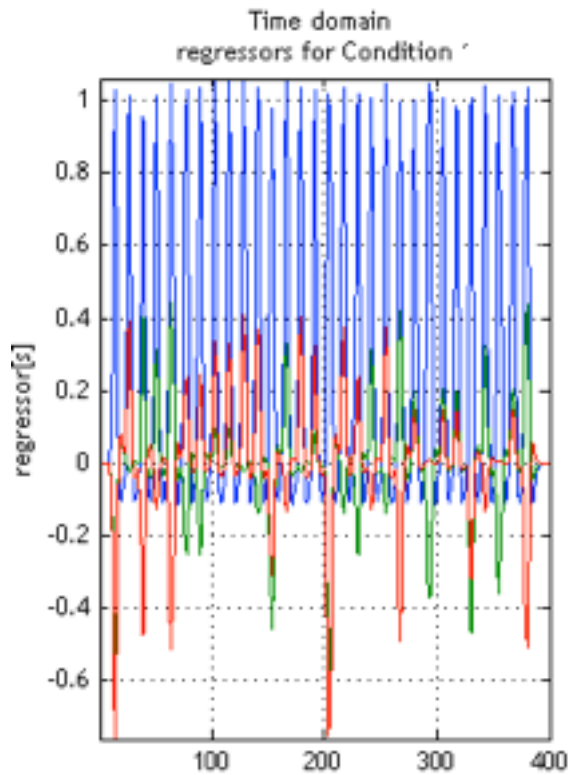# Model-based fMRI: comparisons

- Parametric regressors

Model-based fMRI: comparisons

- Parametric regressors
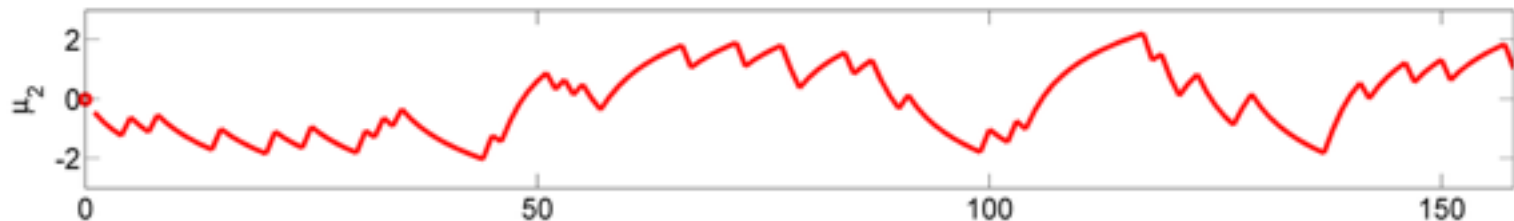
Model-based fMRI: comparisons

- Parametric regressors

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

4. Generate

    a. parametric modulators (first level)

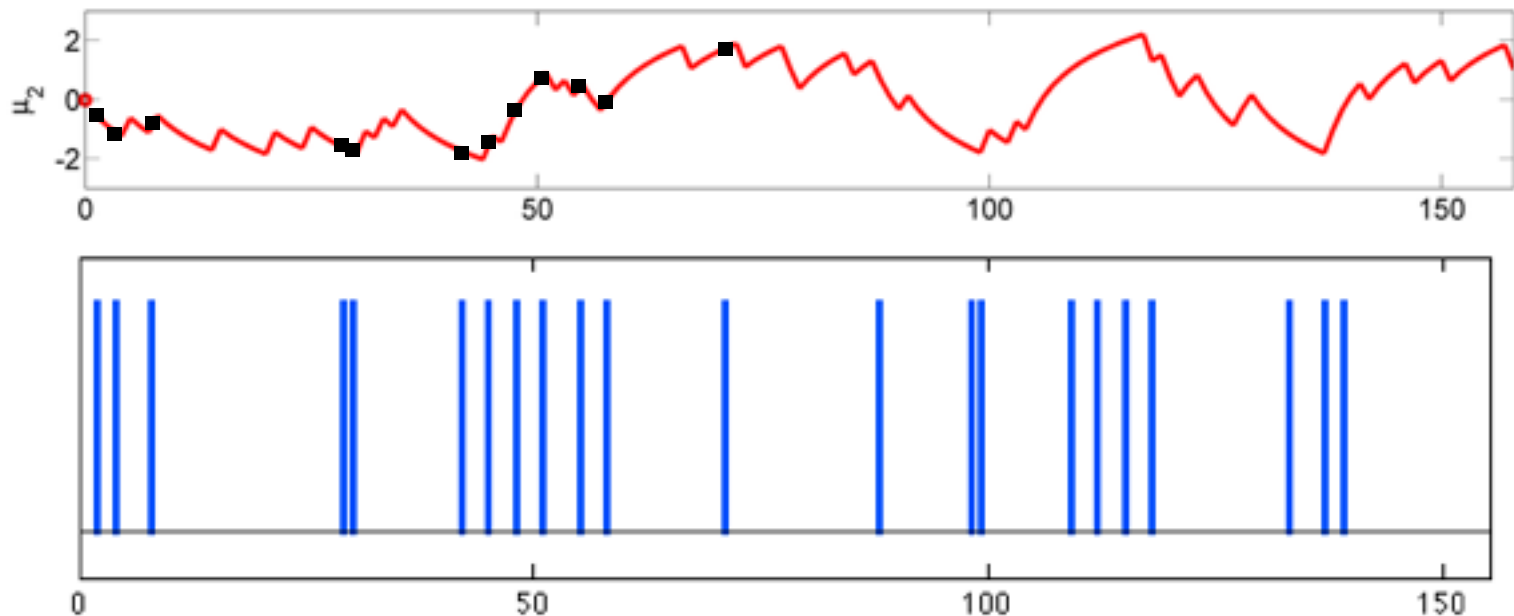   b. model-based time series (first level)

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

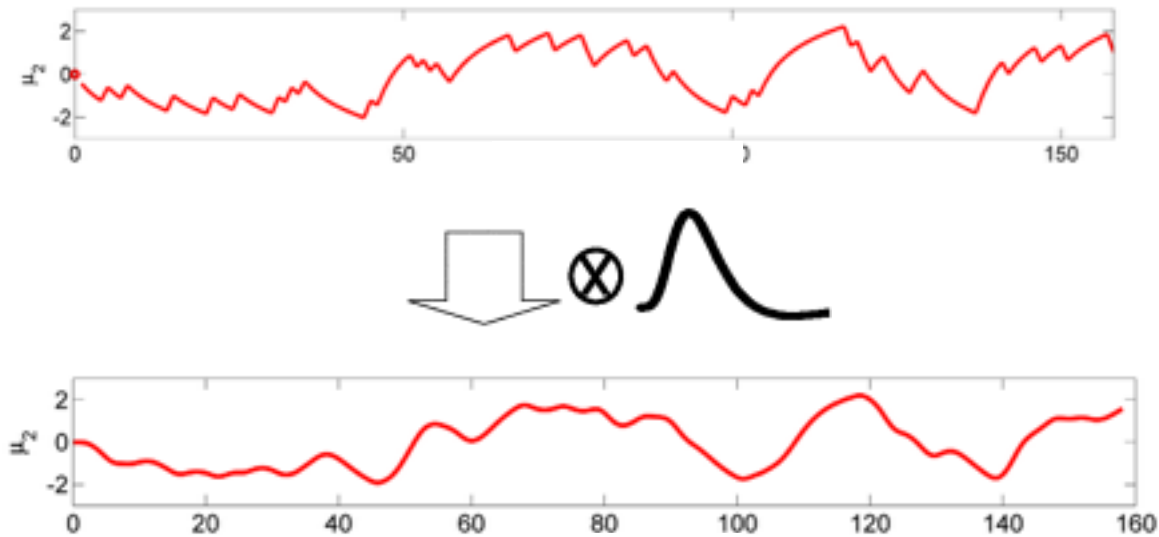# How do we construct regressors from a time series and use them in SPM?

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
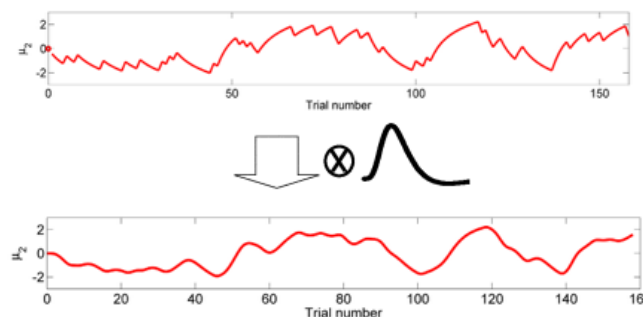

Adapted from O'Doherty et al., (2007)

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

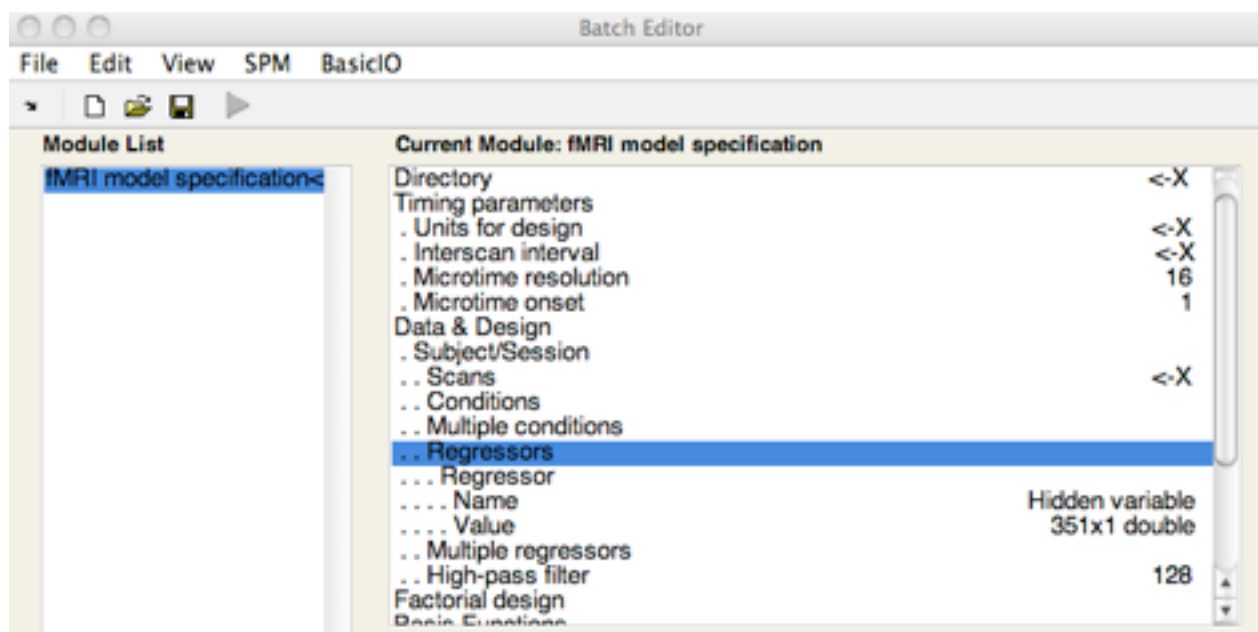- convolve with the basis functions `SPM.xBF.bf`

- sample at TR (i.e., one sample per functional volume)

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

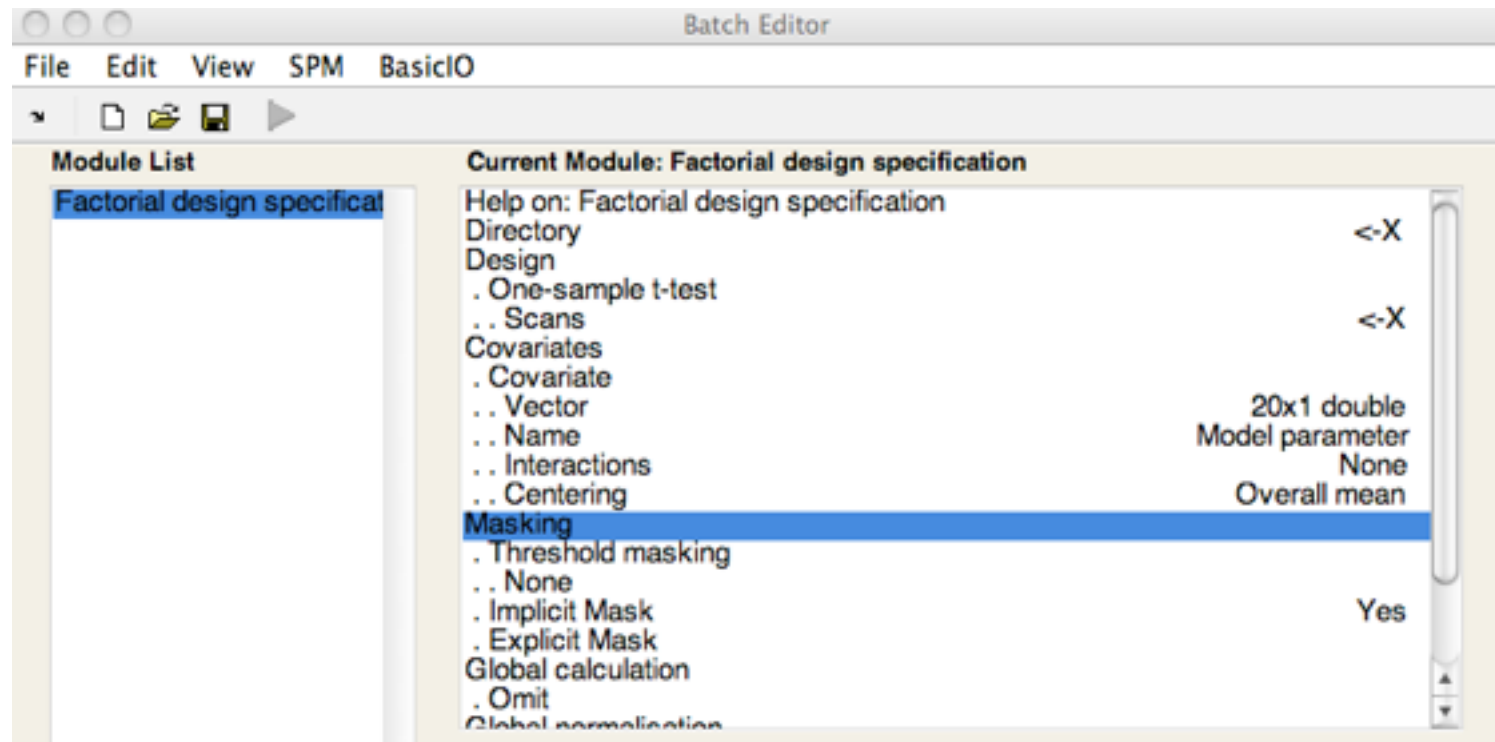# How do we construct regressors from a time series and use them in SPM?

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

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
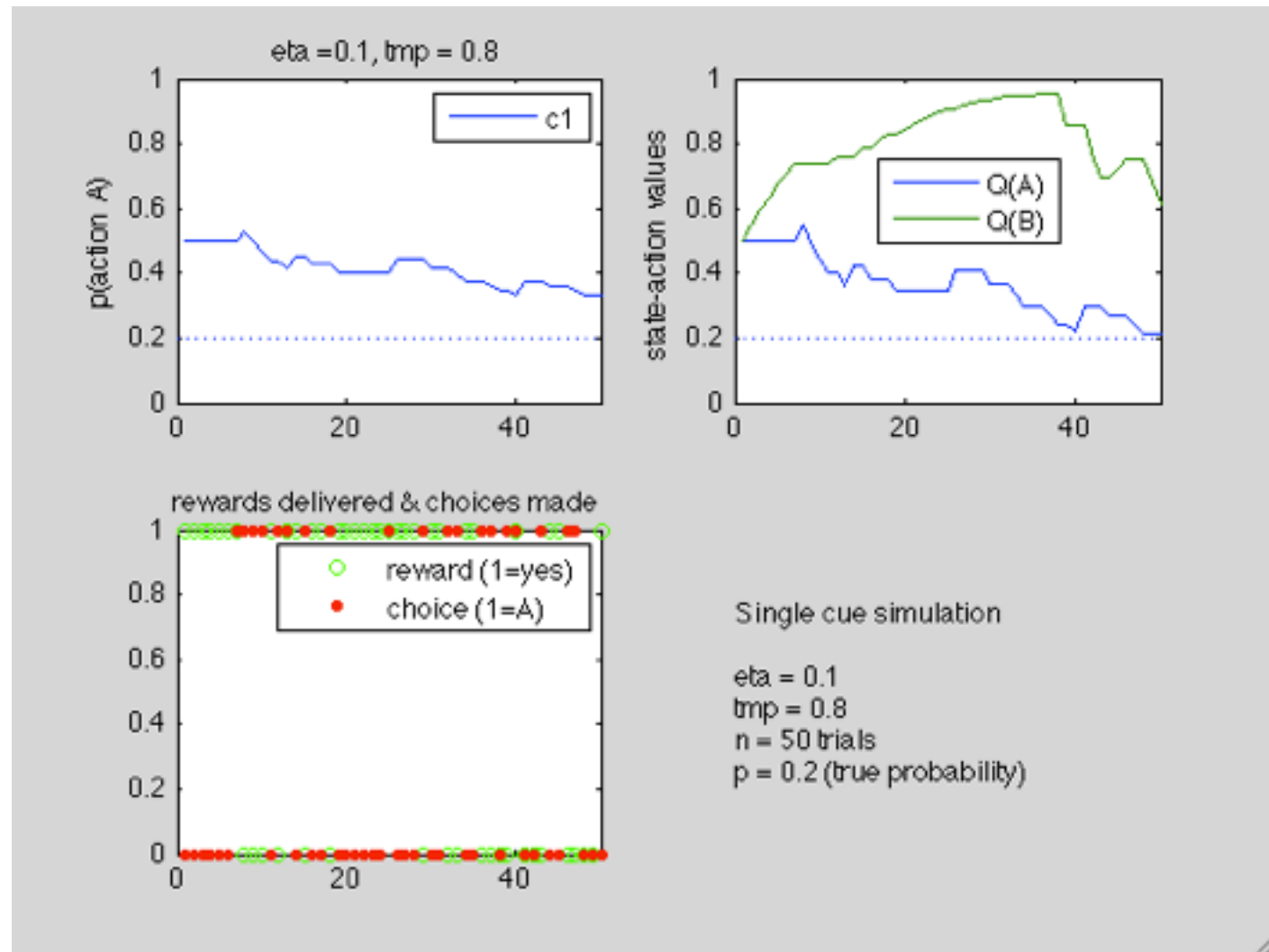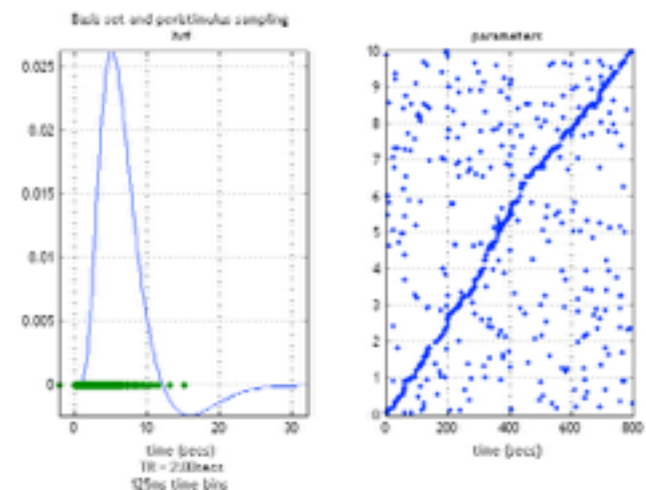
  - Optimize design efficiency

Simulated data for estimating design efficiency

$$p_a(t, cue) = \frac{e^{Q_a(t,cue)/\beta}}{e^{Q_a(t,cue)/\beta} + e^{Q_b(t,cue)/\beta}}$$
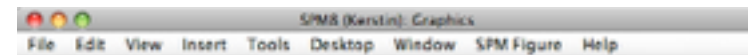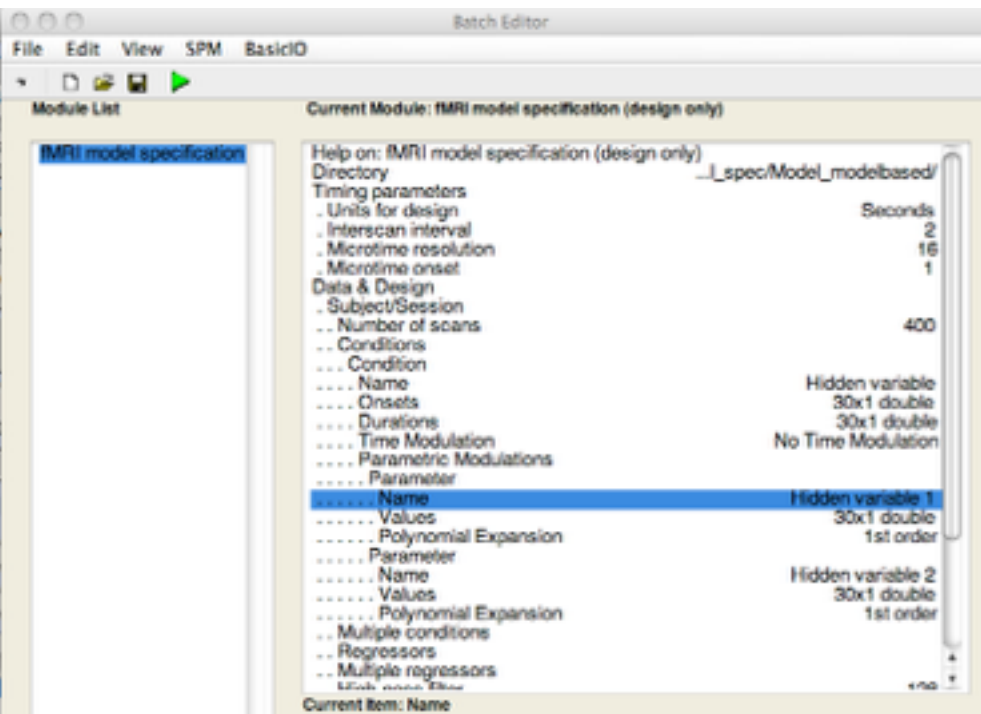
$$Q_a(t+1, cue) = Q_a(t, cue) + \eta(R(t) - Q_a(t, cue))$$
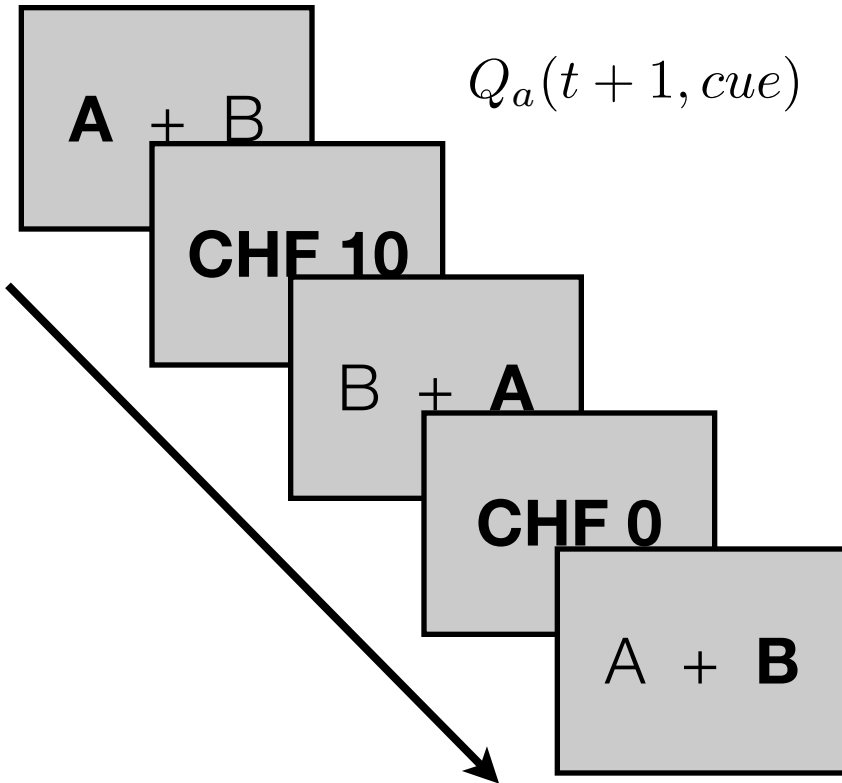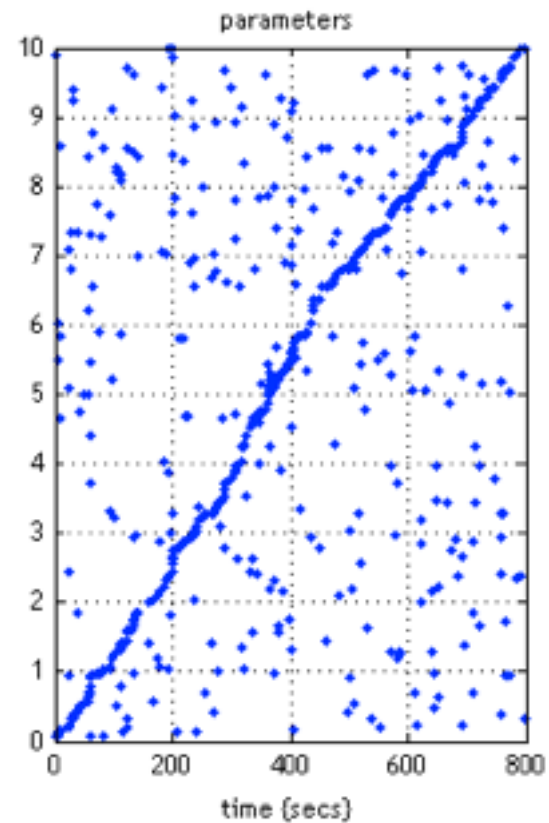
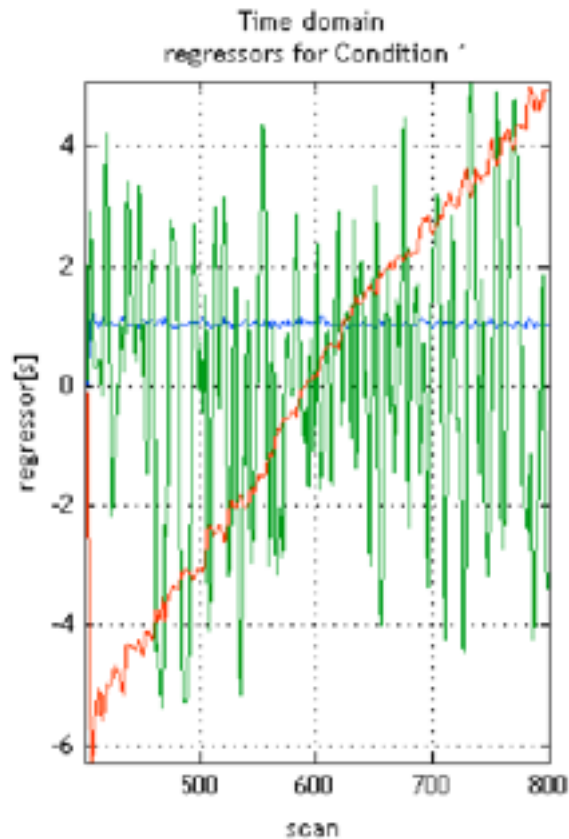# Simulated data for estimating design efficiency

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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