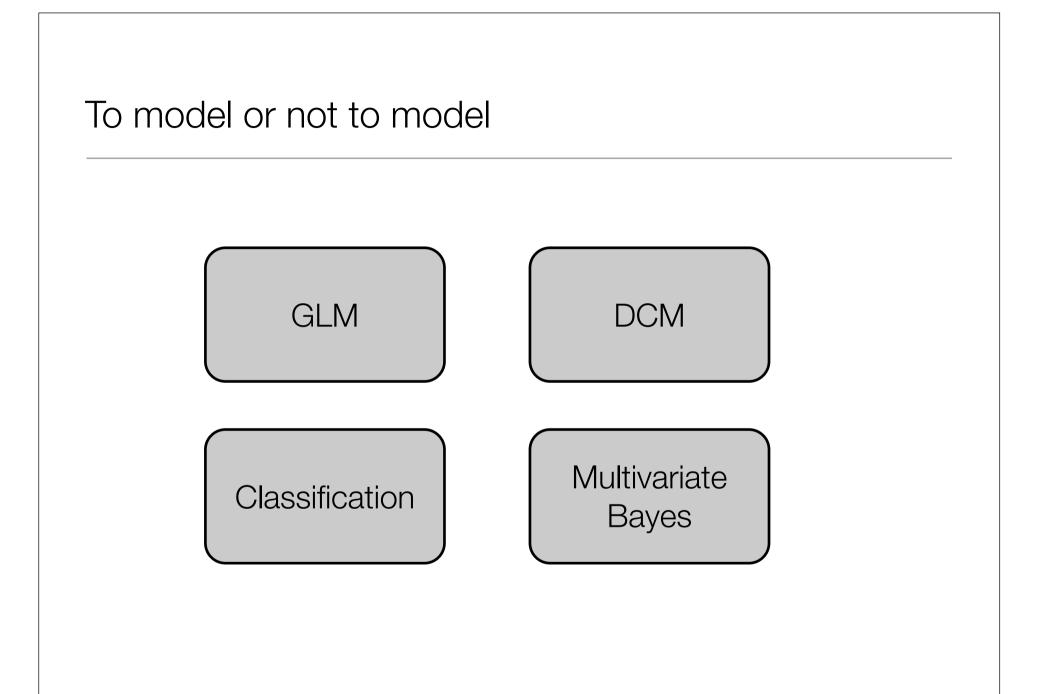
## Model-based fMRI

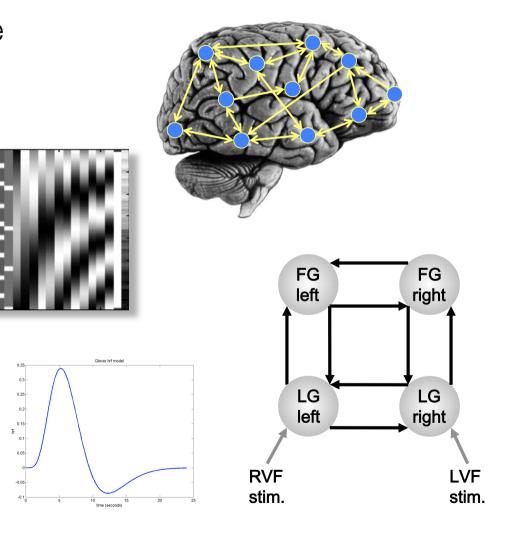
Zurich SPM Course February 18, 2011

Kerstin Preuschoff & Christoph Mathys



## fMRI

- hemodynamic response
- activation levels
- time courses
- connectivity
- t-tests

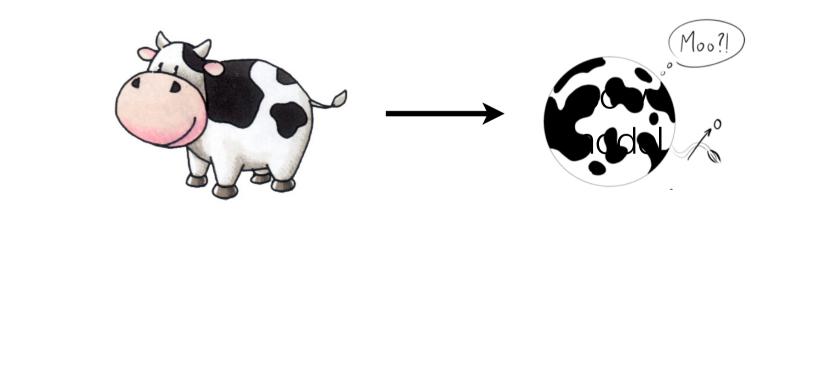


## Model-based fMRI

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

```
What is a good model?
```

The computer engineer, who, when asked to describe how he would write a computer program to recognize a cow, replied, "first, assume a spherical cow."...



# A good model (1)

## - clearly specified object of modeling

cow BOLD response expected value of a certain action

## - clearly specified purpose

recognize cows analyze fMRI data, inferences about neural processes model ventromedial frontal projections from the midbrain

## - tractable

computationally efficient

A good model (2)

#### - realistic

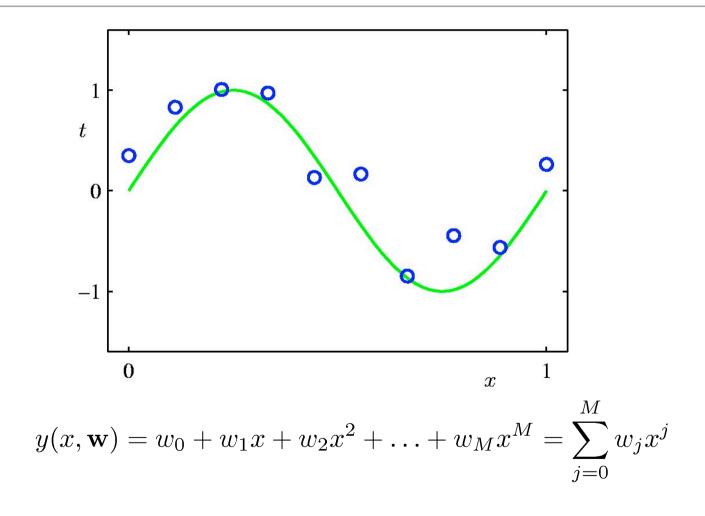
hrf beats spherical cow e.g., incorporate knowledge about brain anatomy and neuronal responses

## - simple

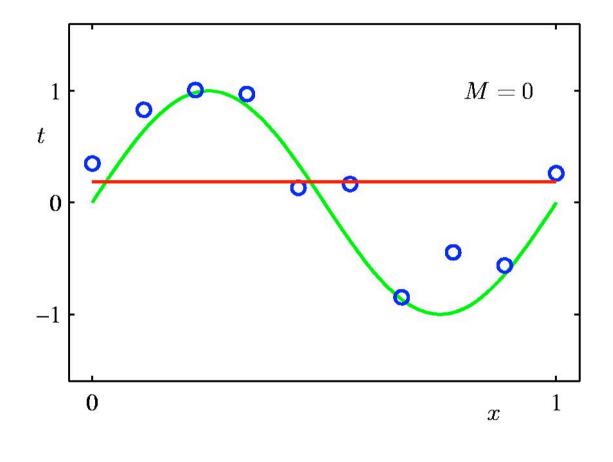
spherical cow beats hrf

 BUT Occam's razor: as simple as possible, as flexible as needed hrf beats spherical cow

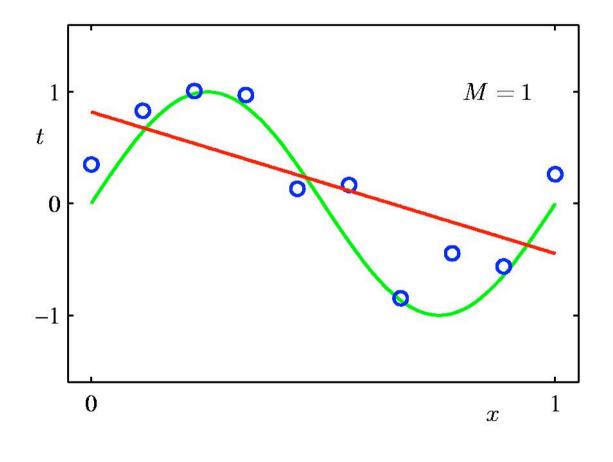
## Polynomial Curve Fitting



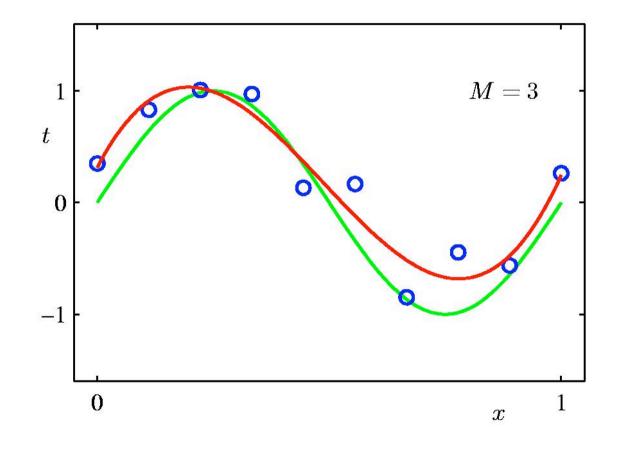
## Oth Order Polynomial



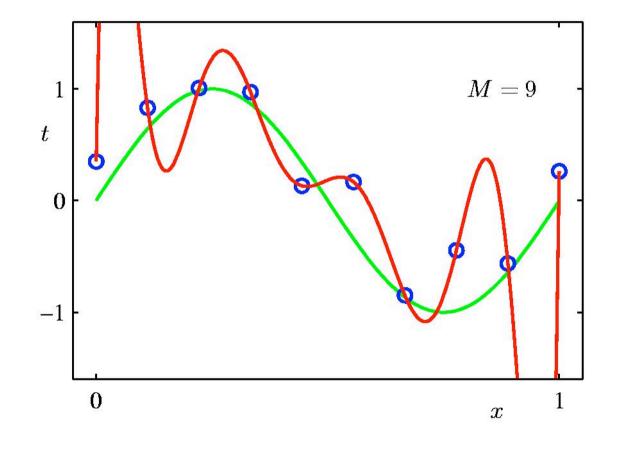
## 1st Order Polynomial



## 3rd Order Polynomial



## 9th Order Polynomial



A good model (2)

#### - realistic

hrf beats spherical cow e.g., incorporate knowledge about brain anatomy and neuronal responses

## - simple

spherical cow beats hrf

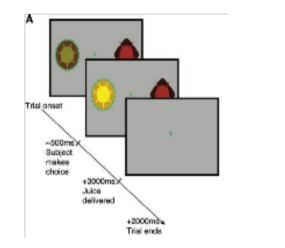
 BUT Occam's razor: as simple as possible, as flexible as needed hrf beats spherical cow A good model (3)

#### - extensible and reusable

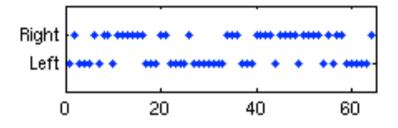
e.g., reward learning models, Rescorla-Wagner to TD learning to sophisticated versions



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



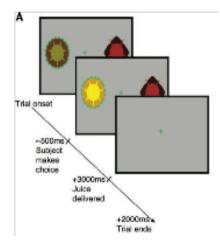
Participant response

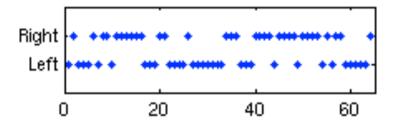


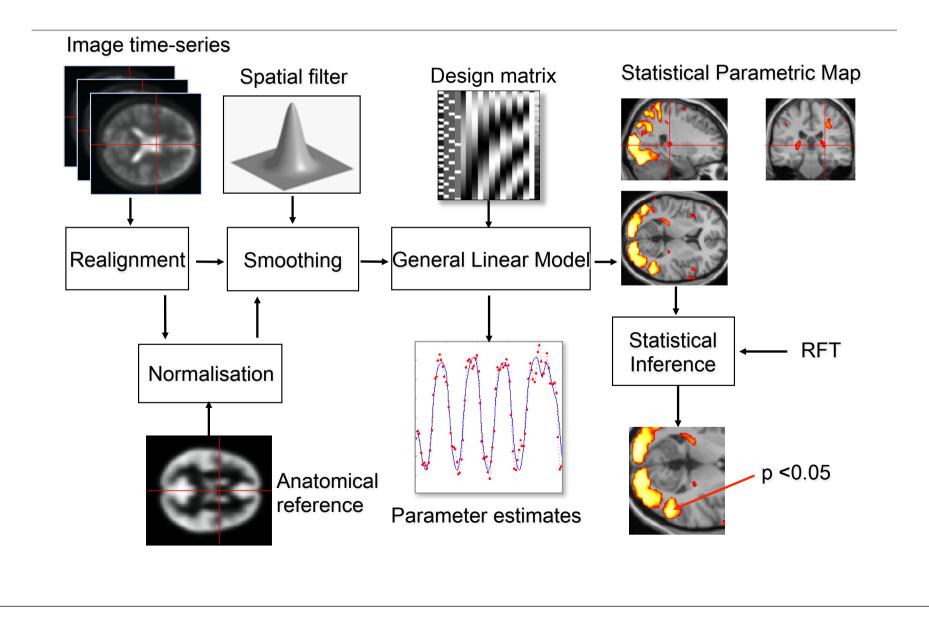
- goal: uncover hidden variables and/or processes

## Model-based fMRI: questions answered

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







Classic designs vs. model-based designs

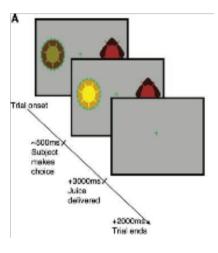
- Classic event and block related designs
  - Conditions are predefined by the experimental design or given by the participant's response and are limited to discrete values.
- Parametric designs
  - Continuous spectrum of levels and responses; leaves more degrees of freedom.
- Model-based
  - Access hidden variables and cognitive processes.

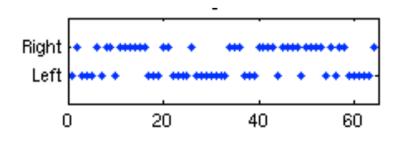
## Outline

- 1. Basic recipe for model-based fMRI
- 2. Using model-based regressors in the GLM
- 3. Generating model-based regressors: Examples from the literature

0. Find someone who knows a model

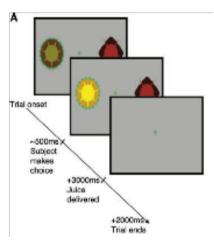
- Reinforcement learning model
- Hierarchical bayesian model
- Spherical cow model
- Hemodynamic response function

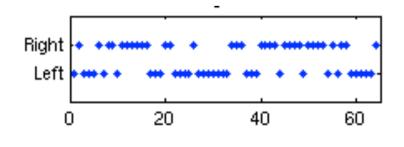




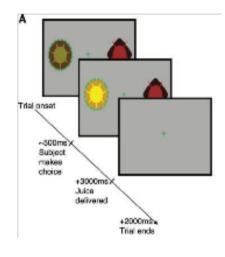
0. Find someone who knows a model

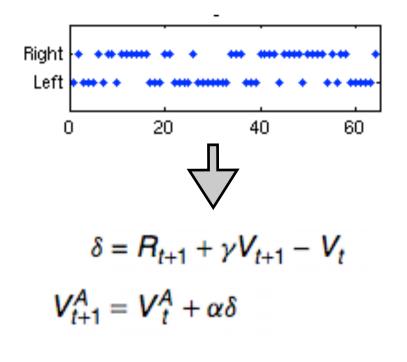
- Reinforcement learning model





1. Pass individual subject trial history to model



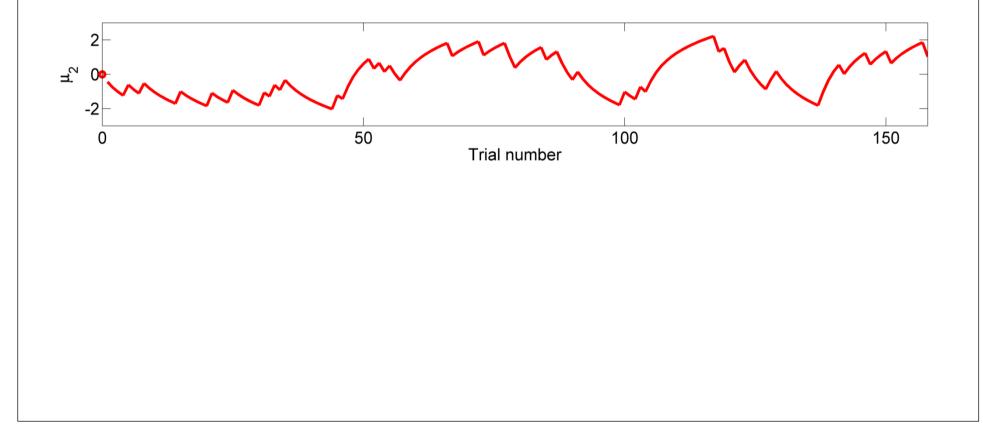


2. Find best-fitting parameters of model to behavioral data

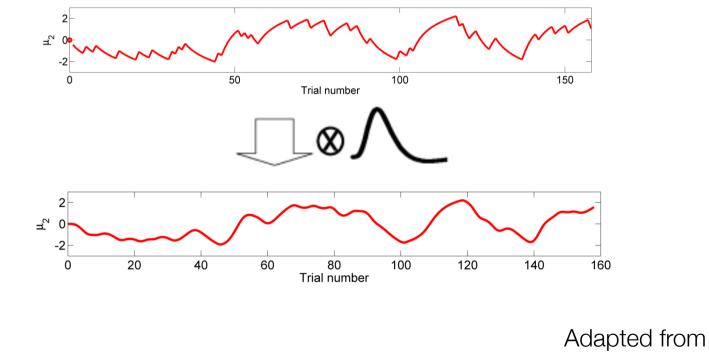
Model inversion:

>> est = bp\_sssr\_est(srdatal); Parameters: lamu0: 1.2107e-10 lasa0: 1.0000 lanu0: 3.4476e-10 latau0: 1.0000 ka: 0.9754 om: -15.7392 th: 0.4993 ze: 0.3319

3. Generate model-based time series



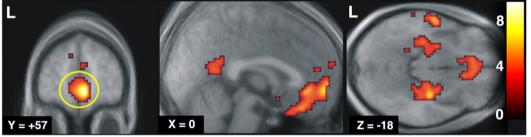
4. Convolve time series with hemodynamic response function



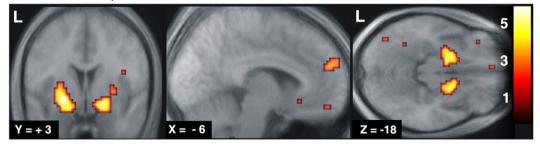
O'Doherty et al., (2007)

5. Regress against fMRI data

#### A Prior correct



B Posterior - prior



Hampton et al., (2006)

```
Model-based fMRI
```

1. Pass individual subject trial history to model

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

3. Generate model-based time series

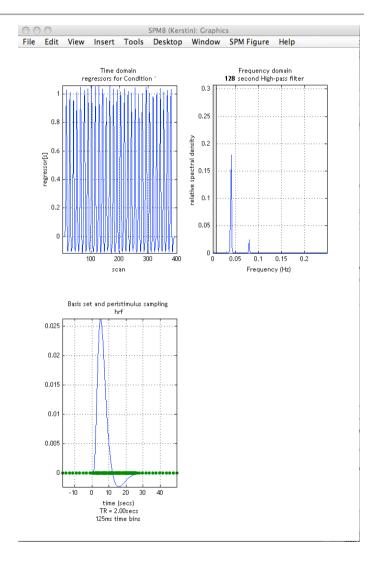
- 4. Convolve time series with hemodynamic response function
- 5. Regress against fMRI data

## From classic design to model based fMRI

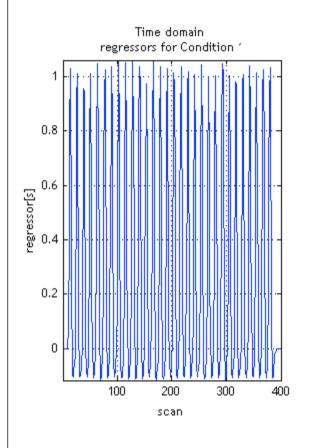
- 1. Classic event/block design
- 2. Adding parametric regressors
- 3. Model-based design

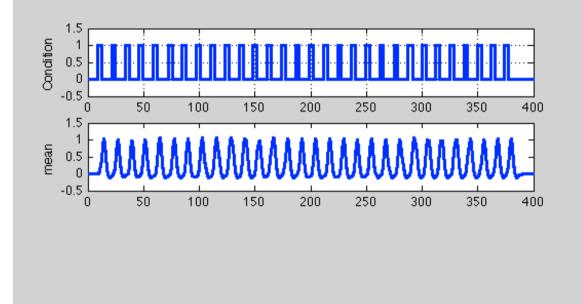
#### Classical event/block design

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	. Units for design	Seconds
	. Interscan interval	2
	. Microtime resolution	16
	. Microtime onset	1
	Data & Design	
	. Subject/Session	
	Number of scans	400
	Conditions	
	Condition	
	Name	Condition 1
	Onsets	30x1 double
	Durations	30x1 double
	Time Modulation	No Time Modulation
	Parametric Modulations	
	Multiple conditions	
	Regressors	
	Multiple regressors	
	High-pass filter	128
	Factorial design	
	Basis Functions	
	. Canonical HRF	
	Model derivatives	No derivatives
	Model Interactions (Volterra)	Do not model Interactions
	Global normalisation	None
	Serial correlations	AR(1)
	Current Item: Directory	



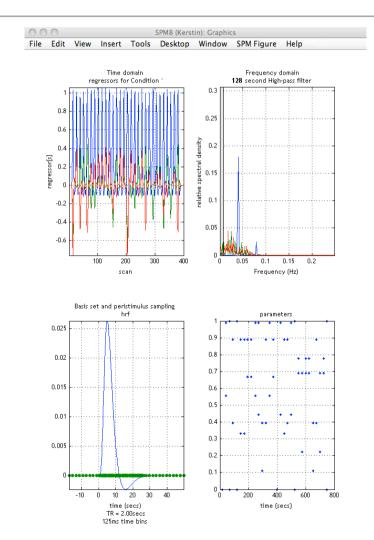
## - Classical event/block design



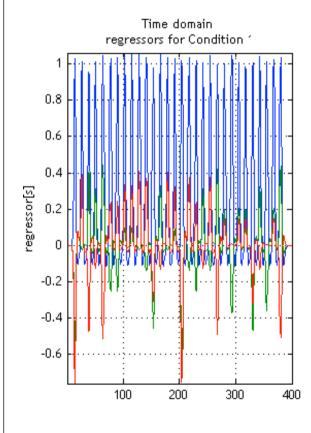


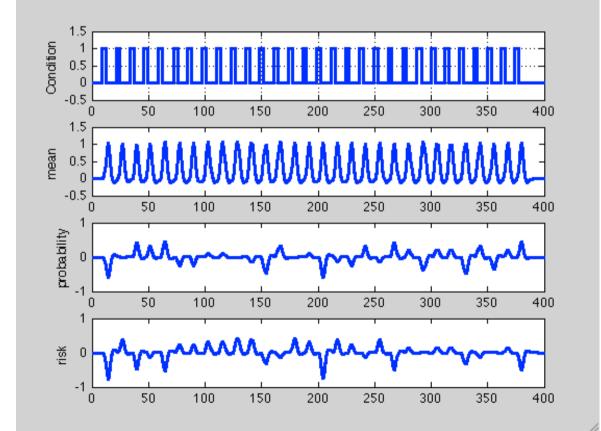
#### - Parametric regressors

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	. Units for design	Seconds
	. Interscan interval	2
	. Microtime resolution	16
	. Microtime onset	1
	Data & Design	
	. Subject/Session	
	Number of scans	400
	Conditions	
	Condition	
	Name	Condition 1
	Onsets	30x1 double
	Durations	30x1 double
	Time Modulation	No Time Modulation
	Parametric Modulations	
	Parameter	
	Name	Modulation 1
	Values	30x1 double
	Polynomial Expansion	1st order
	Parameter	
	Name	Modulation 2
	Values	30x1 double
	Polynomial Expansion	1st order
	Multiple conditions	
	Regressors	
	Multiple regressors	
	High page filter	100

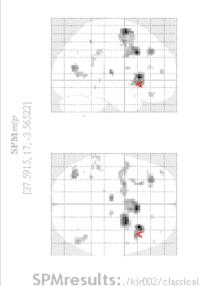


#### - Parametric regressors





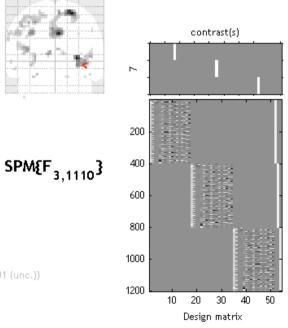
### - Parametric regressors

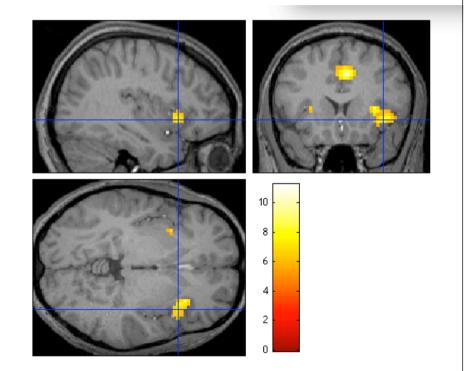


Extent threshold k = 0 voxels

Height threshold F = 5.459528 {p<0.001 (unc.)}

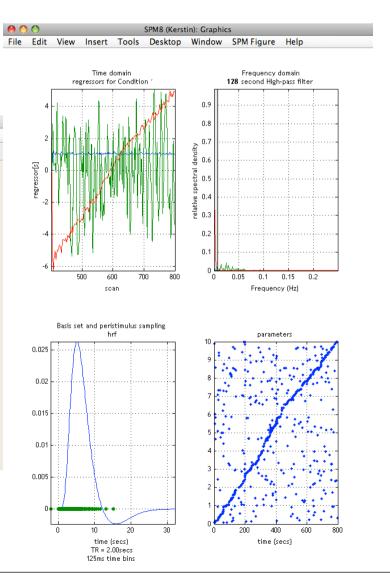
#### risk C1 long



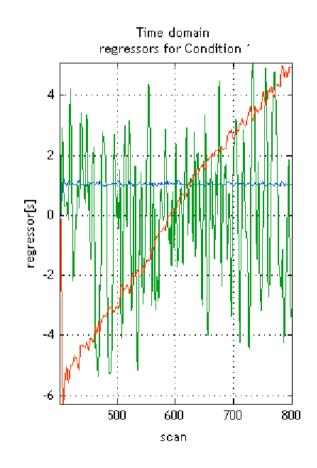


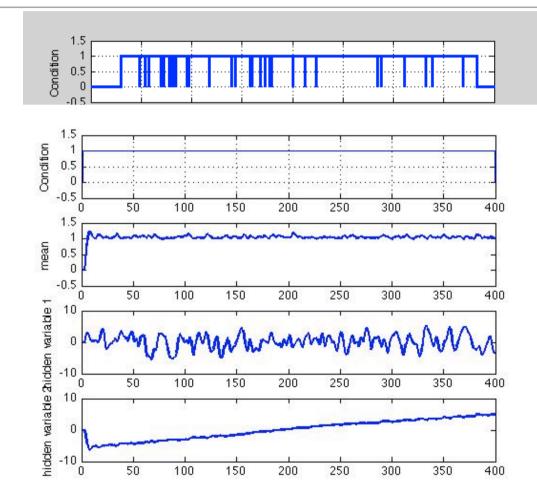
- Model based fMRI

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Module List	Current Module: fMRI model specification (design only)		
fMRI model specification	Help on: fMRI model specification (design Directory Timing parameters . Units for design . Interscan interval . Microtime resolution . Microtime onset Data & Design . Subject/Session Number of scans Condition Name Condition Name Onsets Durations Time Modulation Parameter	Hidden variable 30x1 double No Time Modulation	
	Values    Polynomial Expansion    Parameter    Values    Values    Polynomial Expansion    Multiple conditions    Regressors	Hidden variable 1 30x1 double 1st orde Hidden variable 2 30x1 double 1st orde	



- Model based fMRI





#### File Edit View Insert Tools Desktop Window SPM Figure Help - Model based fMRI Time domain Frequency domain regressors for Condition 128 second High-pass filter 0.6 0.5 000 Batch Editor File Edit View SPM BasiclO 0.4 × 🗋 🚔 🛃 0.3 Module List Current Module: fMRI model specification (design only) Help on: fMRI model specification (design only) fMRI model specification e 0.2 Directory ..I\_spec/Model\_modelbased/ -3 Timing parameters . Units for design Seconds 0.1 . Interscan interval 2 Microtime resolution 16 Microtime onset 1 0 Data & Design 0.1 0.15 100 200 300 400 0.05 0.2 0 . Subject/Session Frequency (Hz) sean . . Number of scans 400 . . Conditions ... Condition .... Name Hidden variable Basis set and peristimulus sampling 30x1 double .... Onsets hrf parameters 30x1 double .... Durations 0.025 .... Time Modulation No Time Modulation .... Parametric Modulations ..... Parameter 0.02 lidden variable Values 30x1 double ..... Polynomial Expansion 1st order .... Parameter 0.015 ..... Name Hidden variable 2 ..... Values 30x1 double ..... Polynomial Expansion 1st order 0.01 . . Multiple conditions ... Regressors . . Multiple regressors 100 7 0.005 Ligh page filter Current Item: Name

SPM8 (Kerstin): Graphics

time (secs) TR = 2.00secs 125ms time bins

20

30

200

400

time {secs}

600

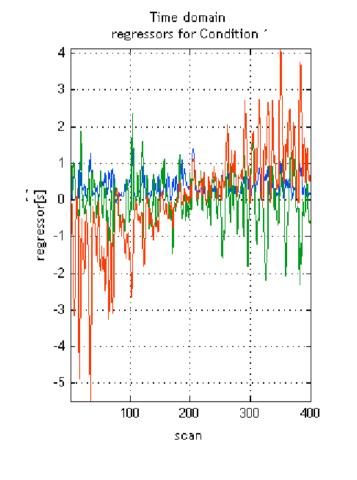
800

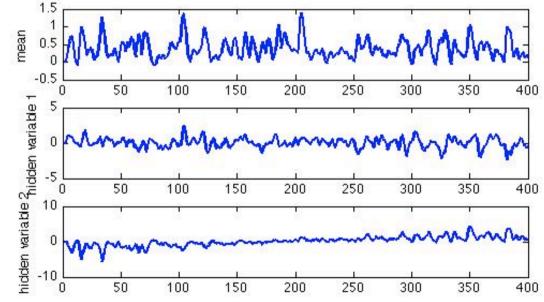
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### Model-based fMRI: comparisons

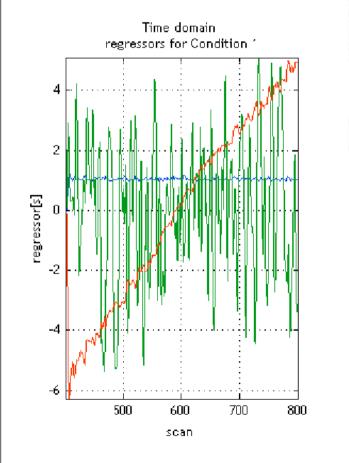
#### - Model based fMRI

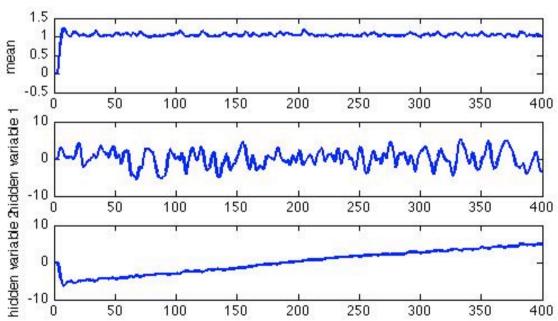




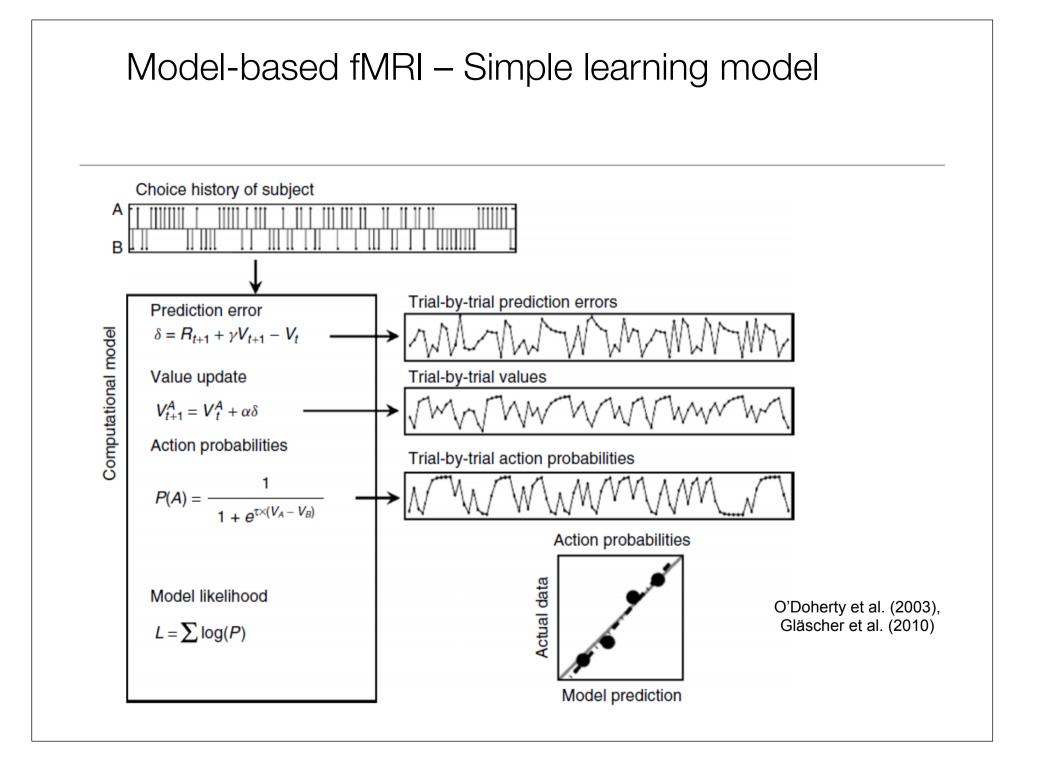
### Model-based fMRI: comparisons

- Model based fMRI

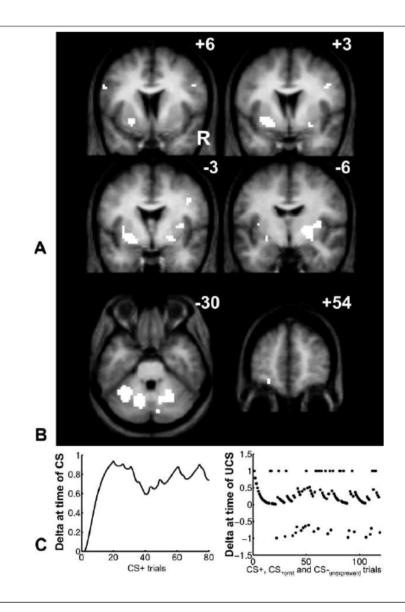




- 1. Simple learning model
  - O'Doherty et al Task, Model, Regressor, Result
- 2. Advanced Models
  - Behrens et al Task, Model, Regressor, Result
  - den Ouden et al Task, Model, Regressor, Result
  - Mathys et al Task, Model, Regressor, Result

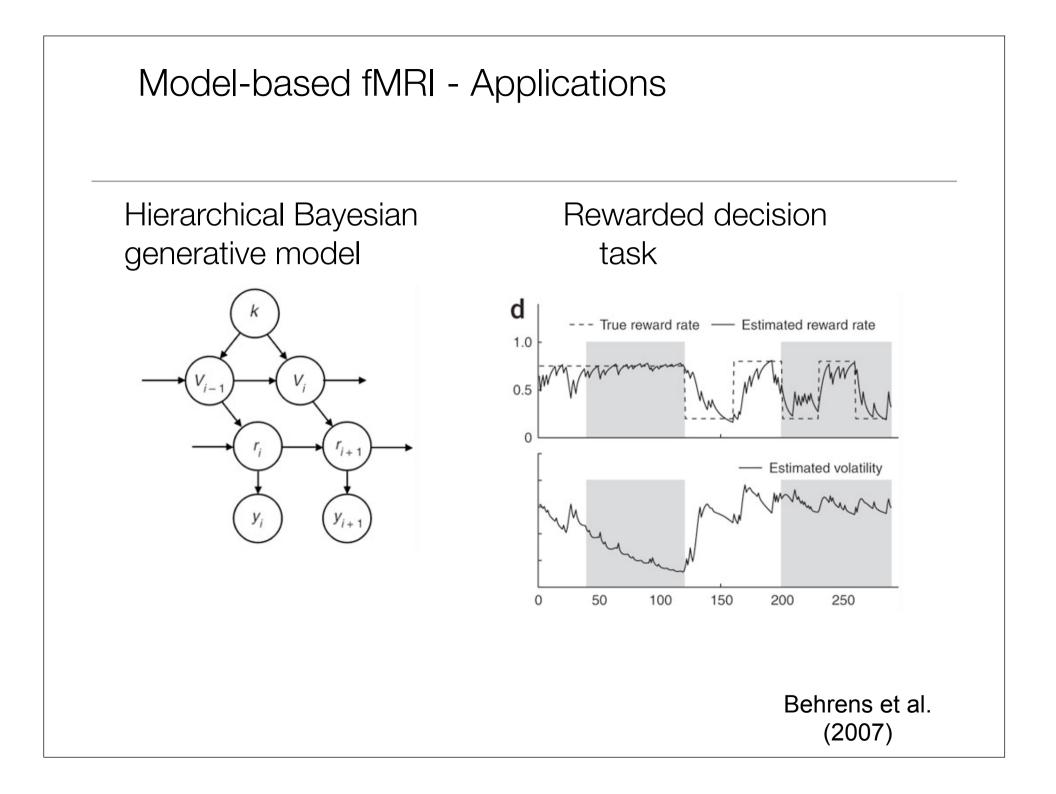


# Model-based fMRI – Simple learning model



Significant effects of prediction error with fixed learning rate

O'Doherty et al. (2003)

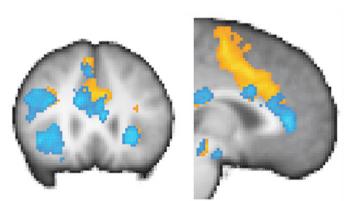


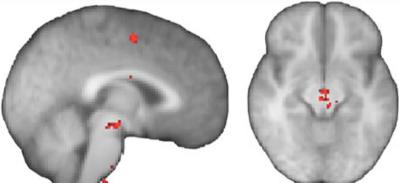
## **Correlation with volatility**

Orange: decide Blue: monitor

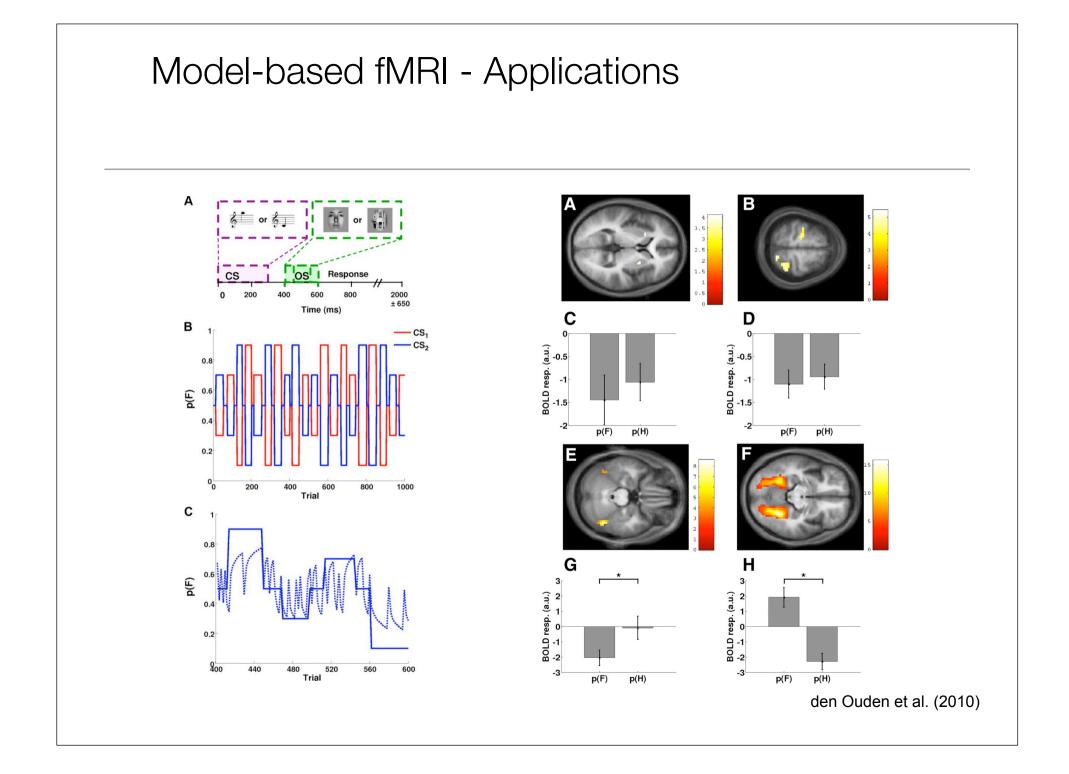
# Correlation with reward probability

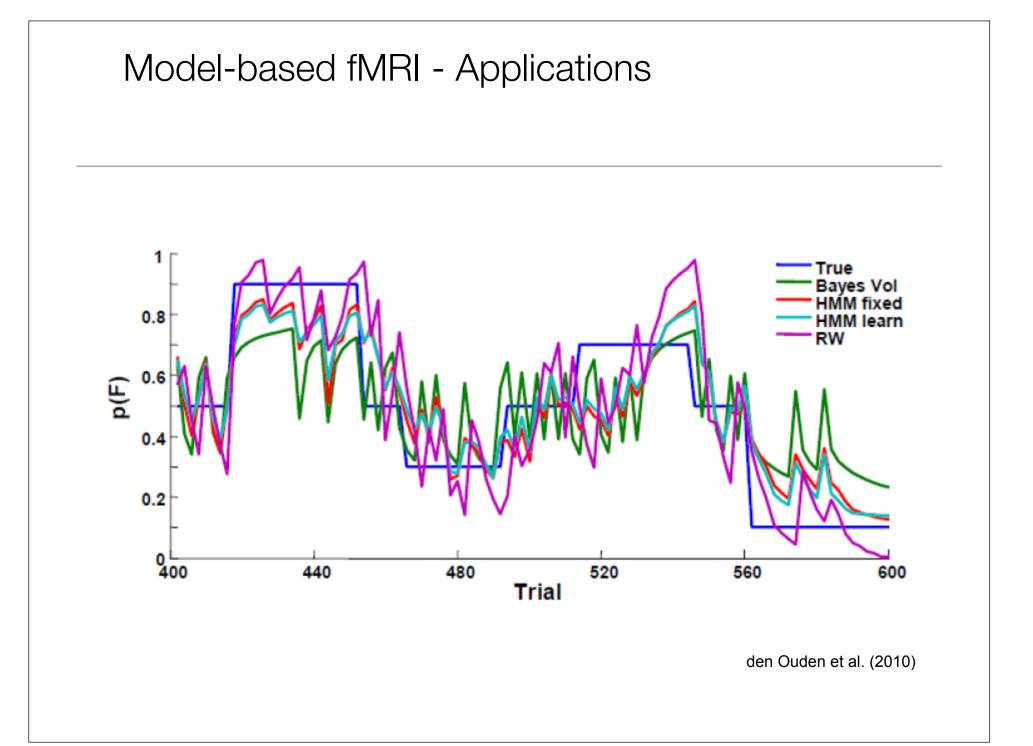
(Does not survive multiple comparison correction)



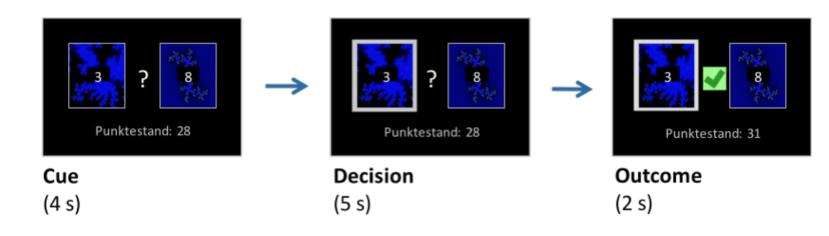


Behrens et al. (2007)

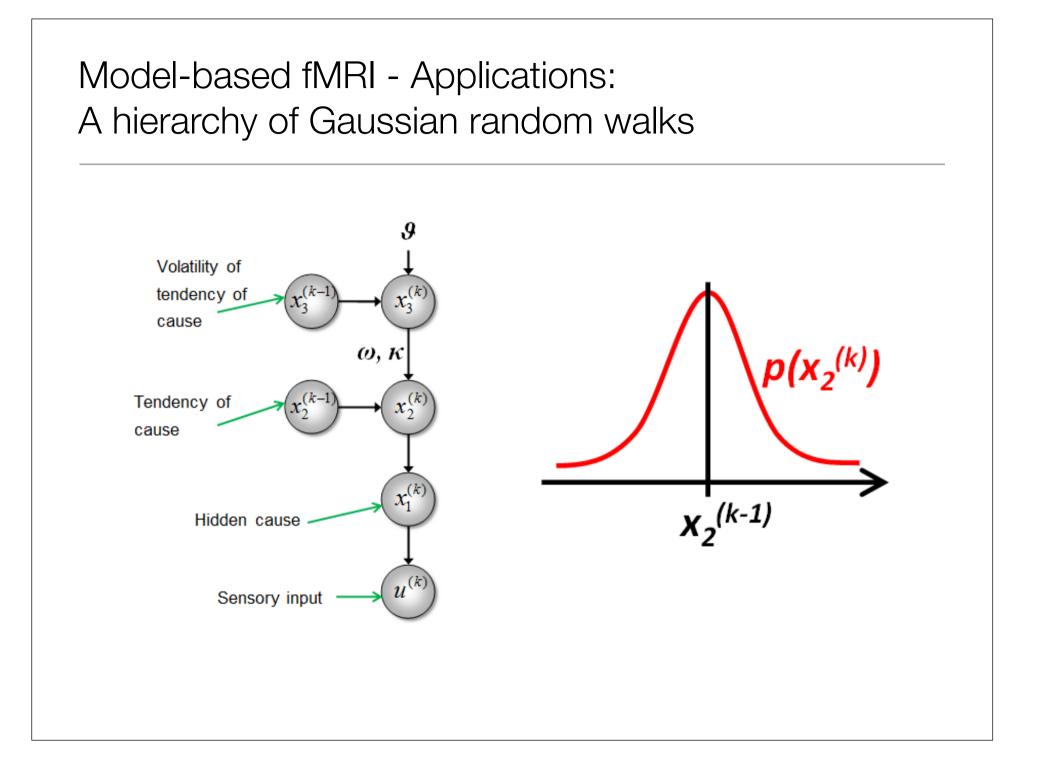




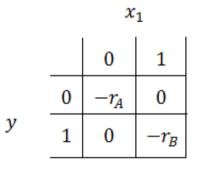
- Behavioral task



- 160 trials
- Changing stochastic association of cue with monetary reward
- Stochastic association varies over time
- Subjects: prodromal schizophrenics and healthy controls



- Loss Function



y: Decision (0=A, 1=B)

*x*<sub>1</sub>: Outcome (0=A, 1=B)

r<sub>A</sub>, r<sub>B</sub>: Rewards associated with A and B

- Expected Loss

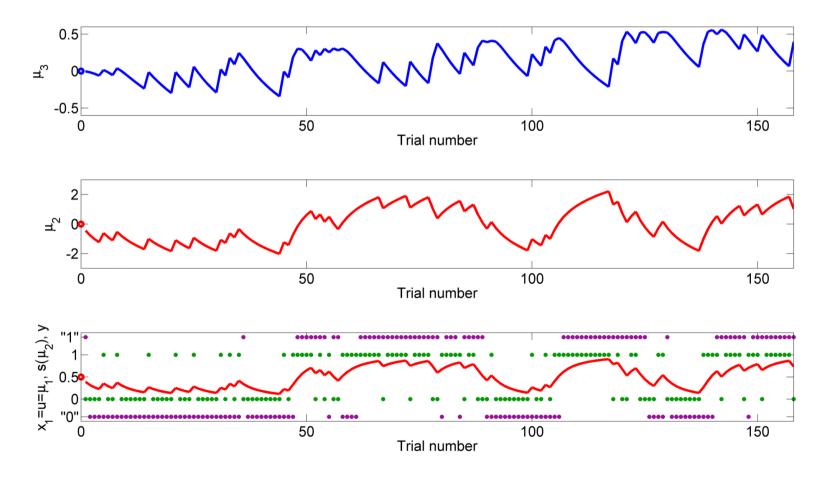
$$Q(y; \lambda) = \begin{cases} -r_B \mu_1 & \text{for } y = 1\\ -r_A(1 - \mu_1) & \text{for } y = 0 \end{cases}$$
$$\mu_1 = p(x_1 = 1)$$

Decision model

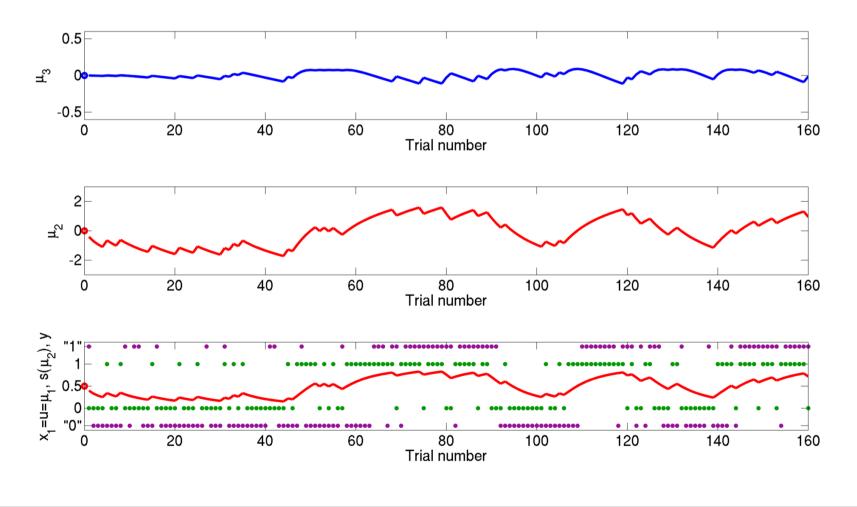
$$p(y^{(k)} = 1 | \lambda^{(k)}, \chi, u) = \frac{1}{1 + \exp\left(-\zeta \left(\mu_1^{(k)} r_B^{(k)} - \left(1 - \mu_1^{(k)}\right) r_A^{(k)}\right)\right)}$$

- Logistic sigmoid of difference in expected loss between options A and B
- Parameter ζ determines shape of sigmoid (exploration <-> exploitation)
- Inversion leads to estimates for parameters  $\vartheta$ ,  $\omega$ ,  $\kappa$ , and  $\zeta$

- Healthy control subject:



#### - Prodromal schizophrenic:



# Summary

- Model-based fMRI:
  - Application of quantitative computational models to generate regressors of interest beyond stimulus inputs and behavioral responses.
  - Serves to uncover hidden variables and cognitive processes
- A model may be realistic but it is never correct.
- In most cases, hrf beats



