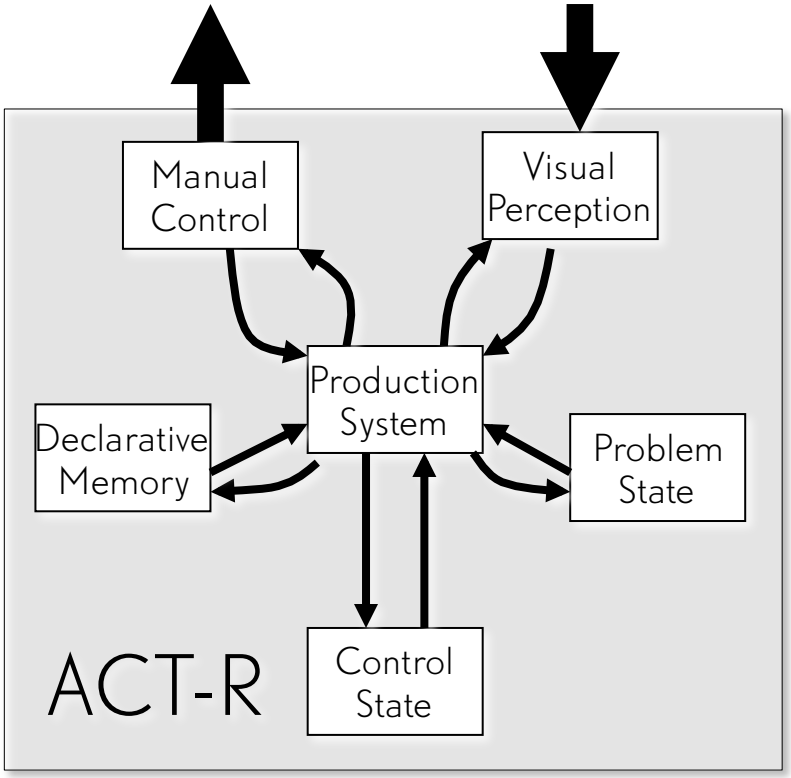
using Cognitive Models to Analyze fMRI data

Jelmer Borst

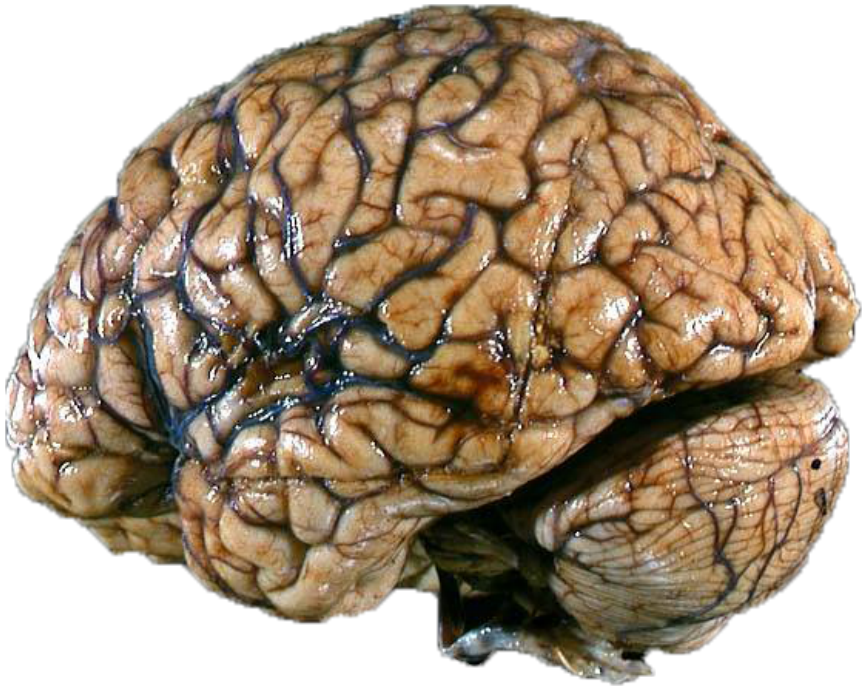
university of groningen

ACT-R Workshop

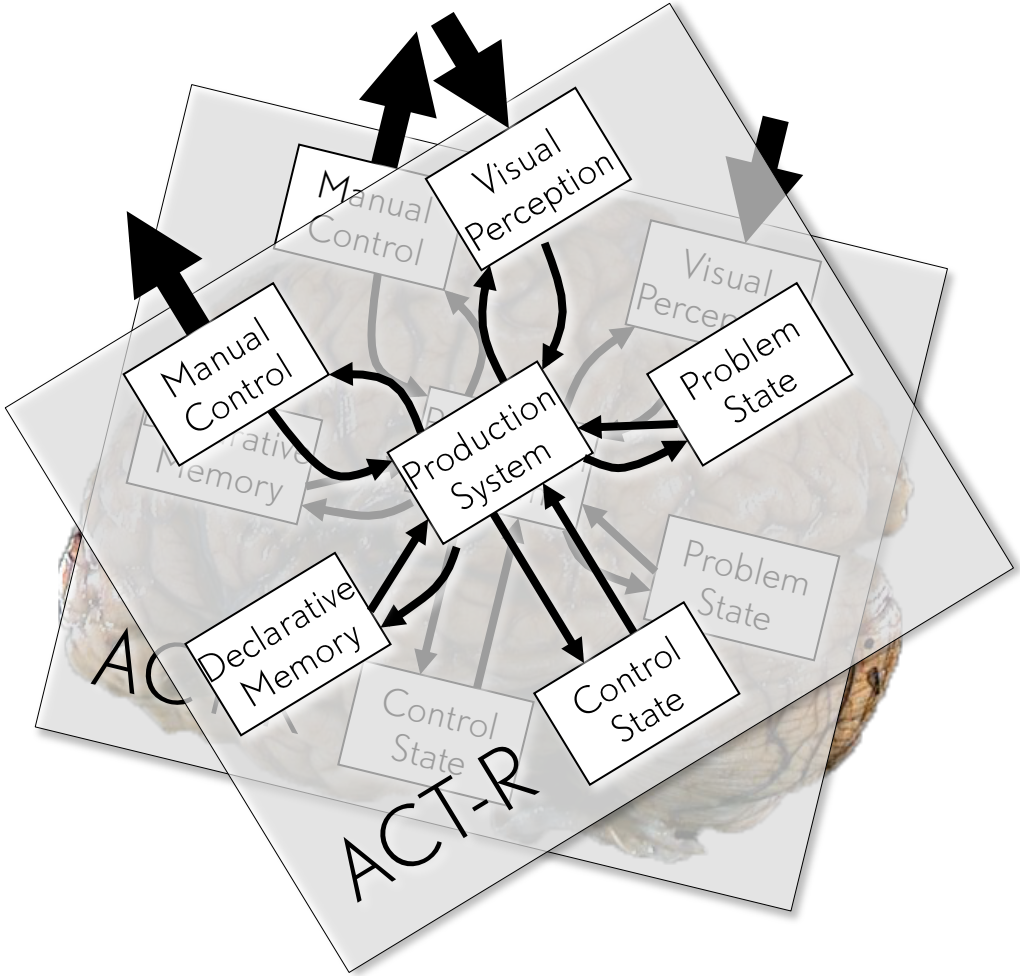
Philadelphia, August 5, 2010

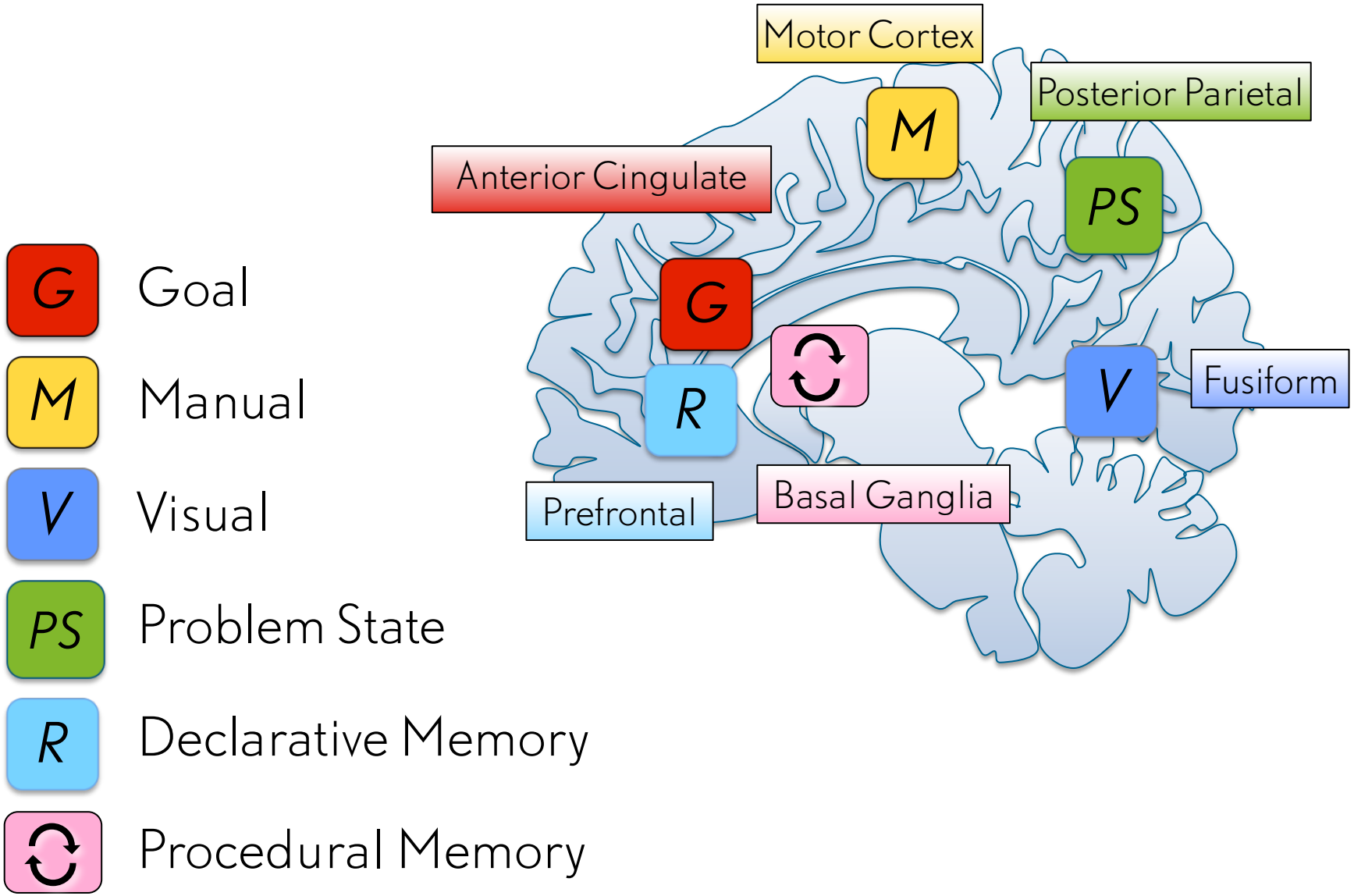


simulates cognition

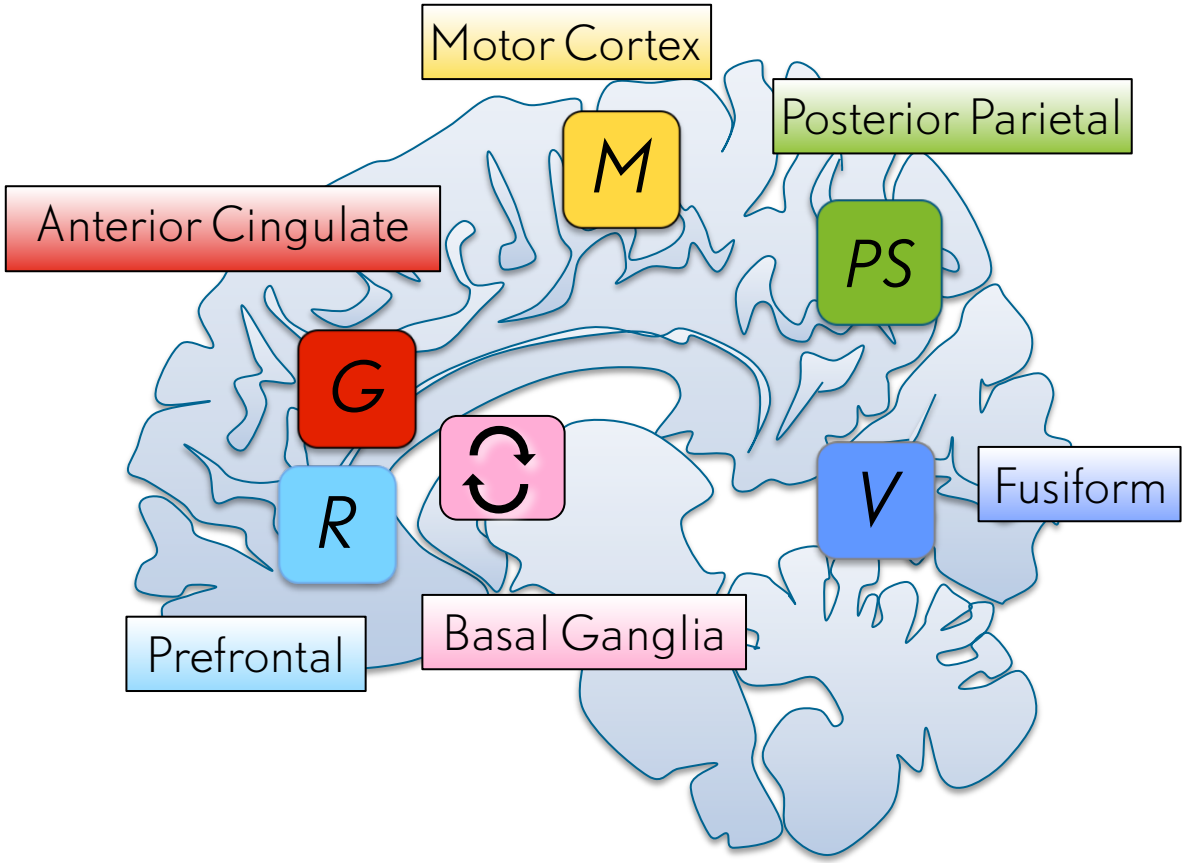


implements cognition


Manual Control
Visual Perception
Problem State
Production System
Declarative Memory
Control State
ACT-R



courtesy of Andrea Stocco



How to test this mapping?

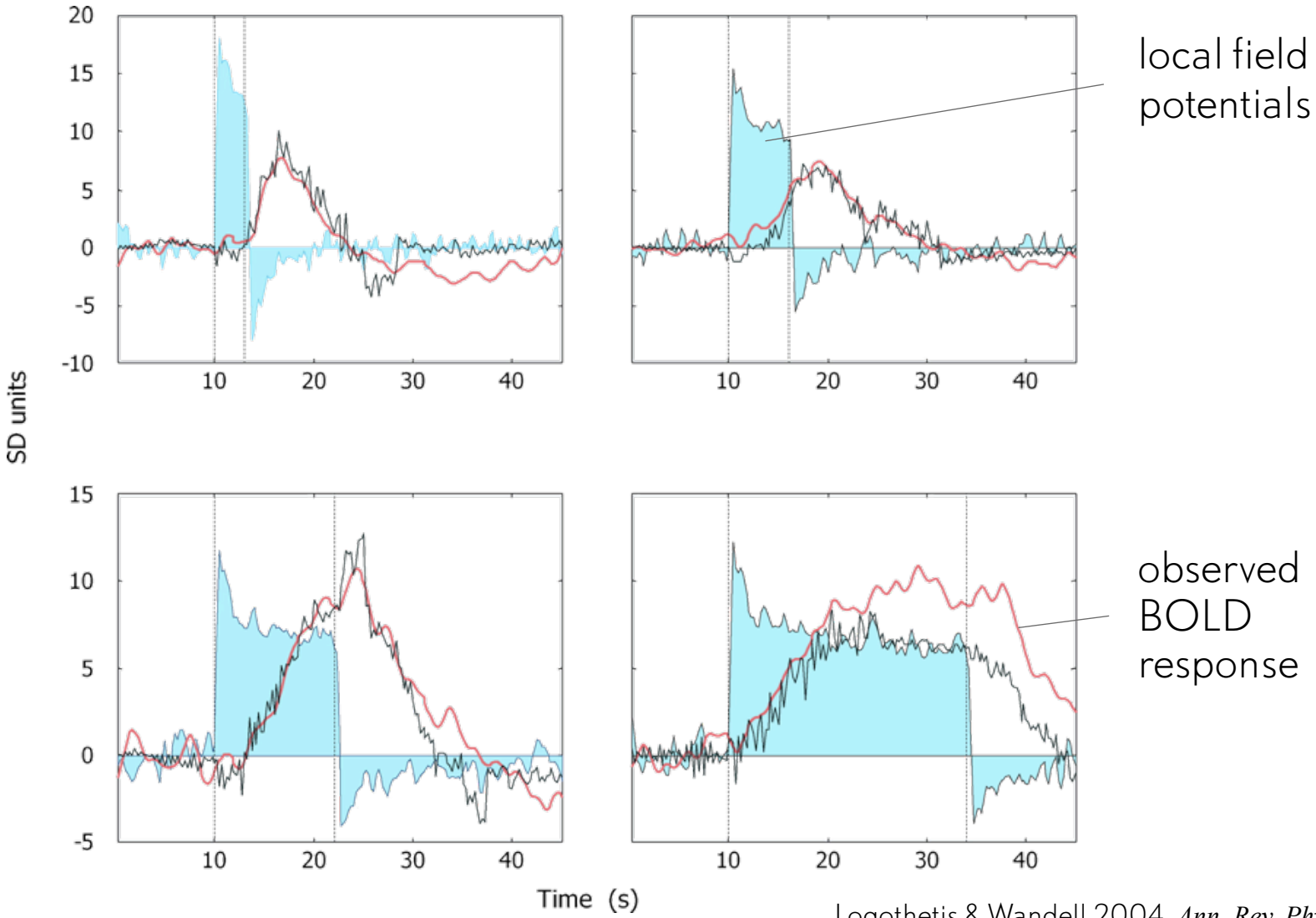
courtesy of Andrea Stocco

Model-Based fMRI Analysis

fMRI

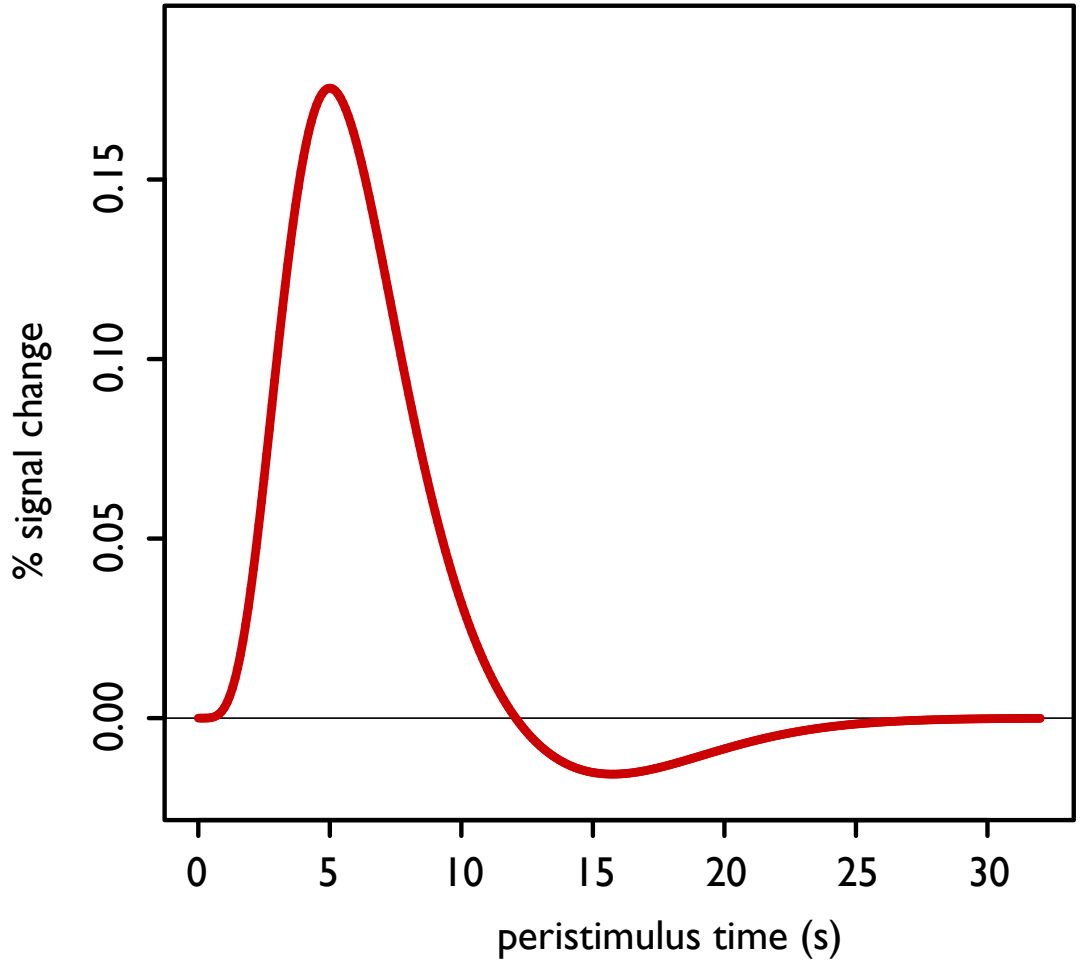
1. Neural activity
2. Increase of oxygenated blood
3. Oxygenated blood has different magnetic properties
4. fMRI scanner measures magnetic properties

BOLD response

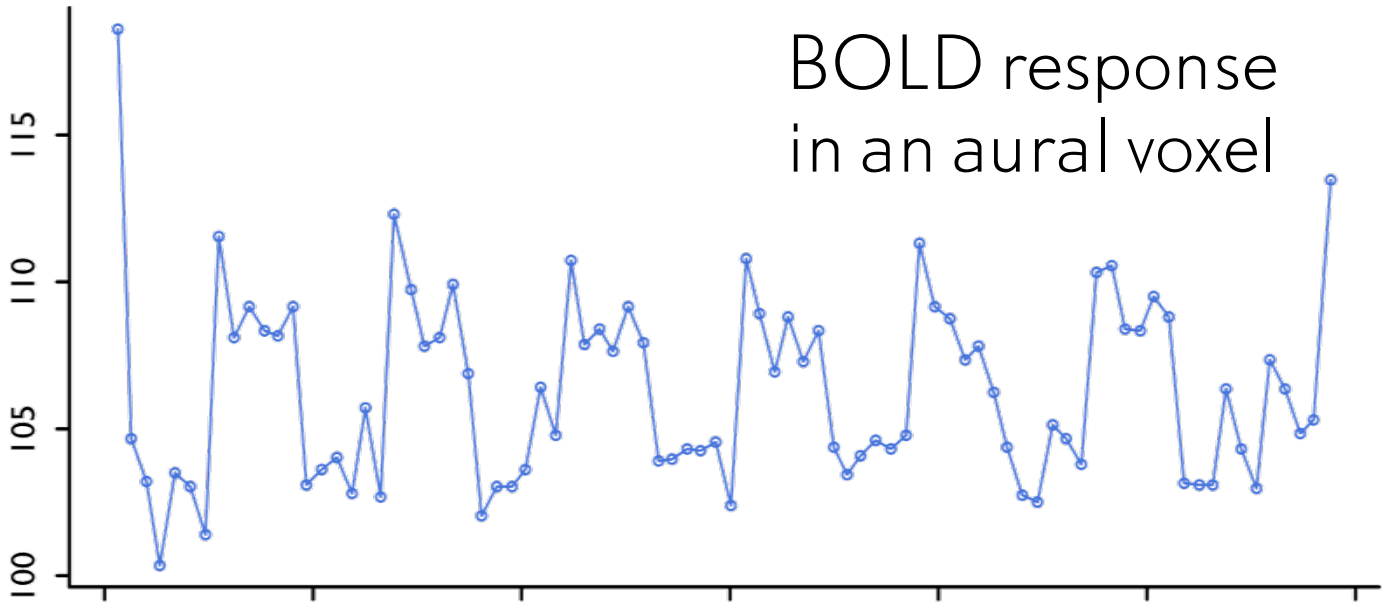


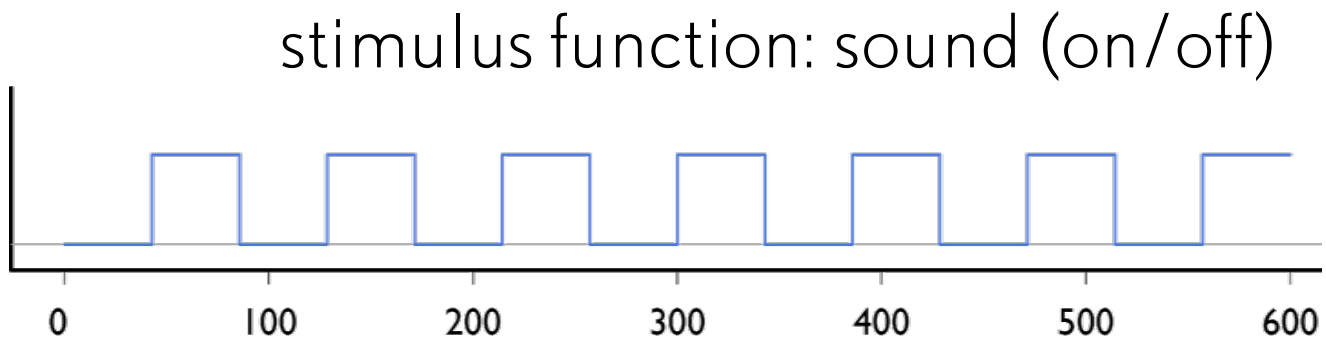
Logothetis & Wandell 2004, *Ann. Rev. Physiol.*

Hemodynamic Response Function

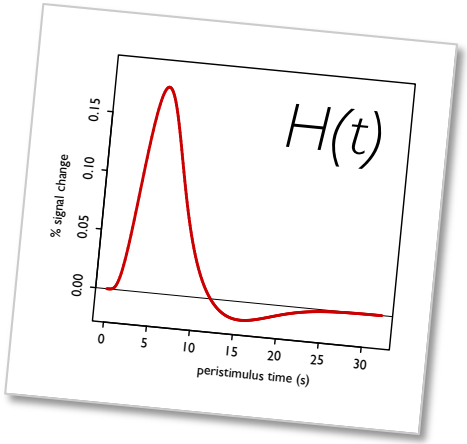


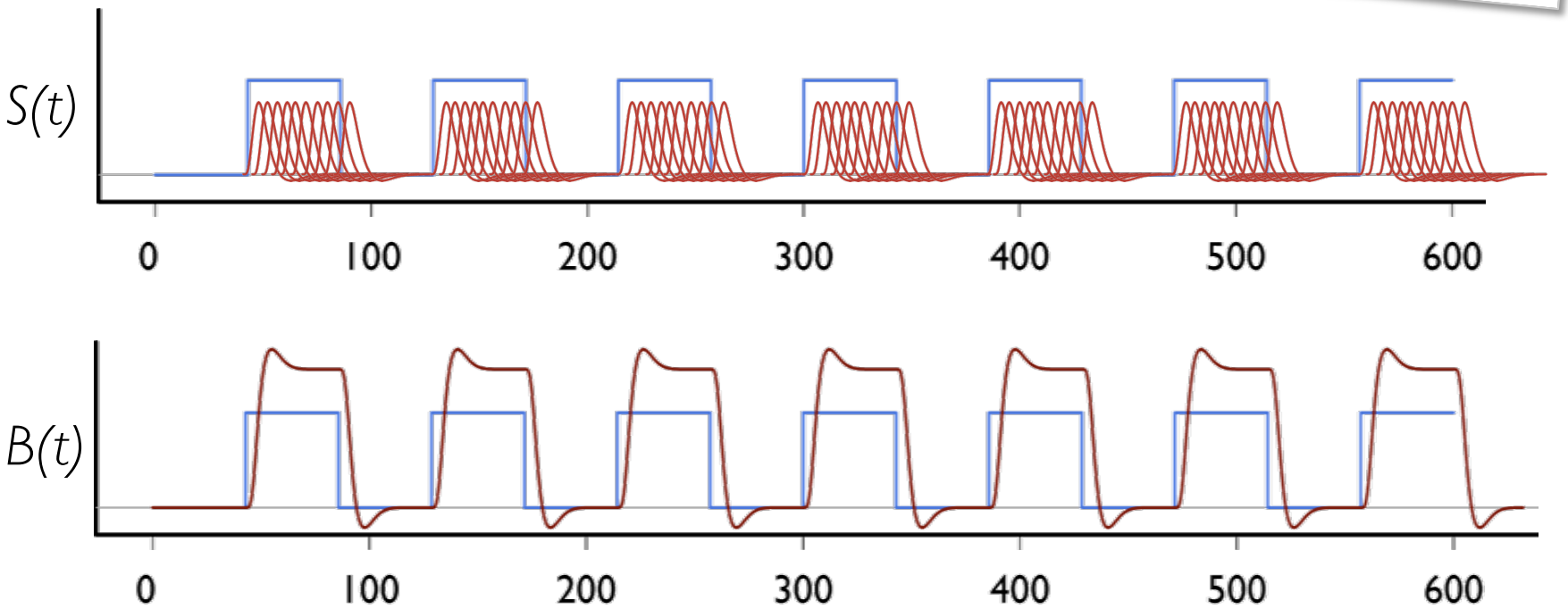
Classical fMRI analysis





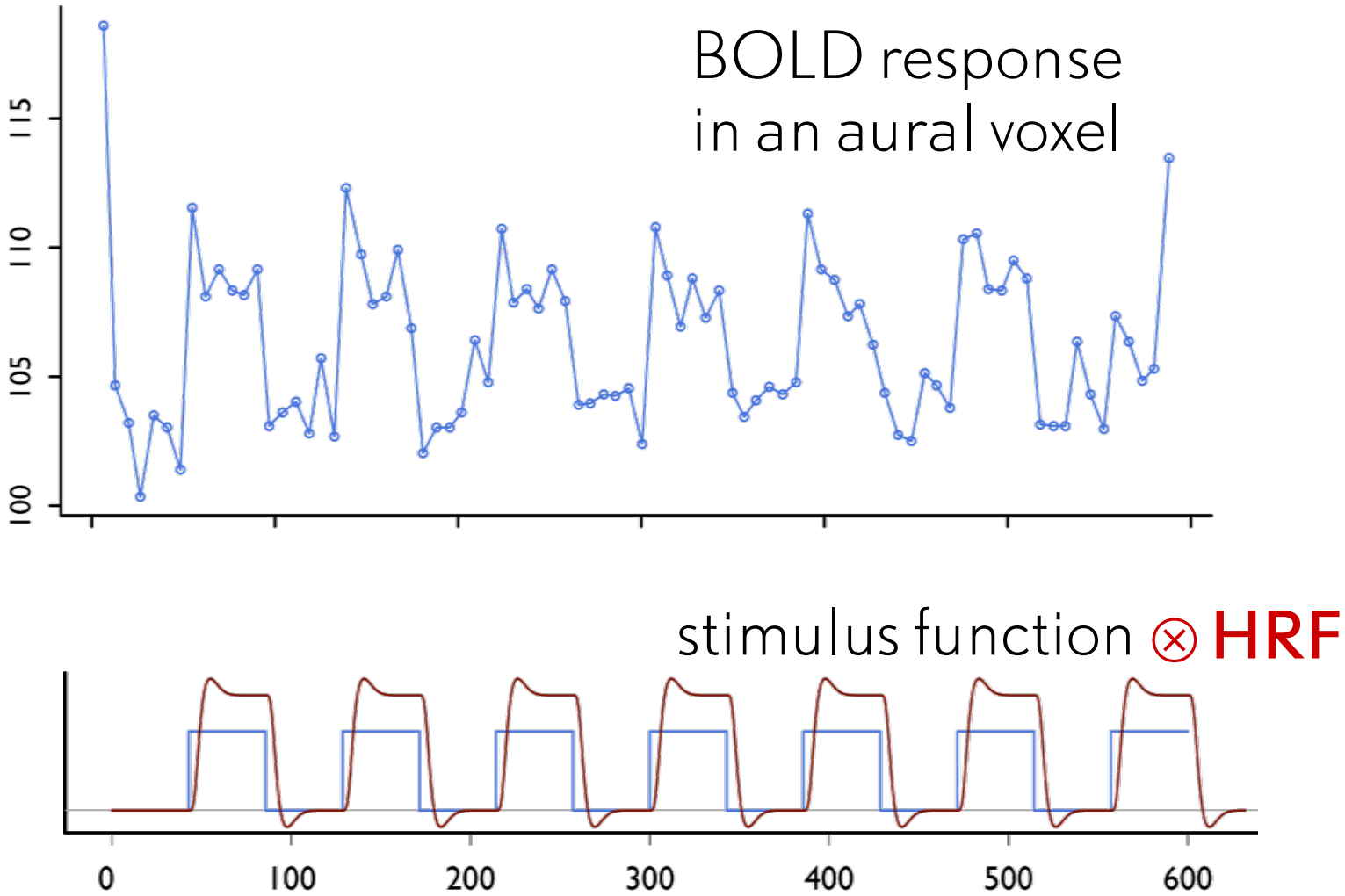
Convolution



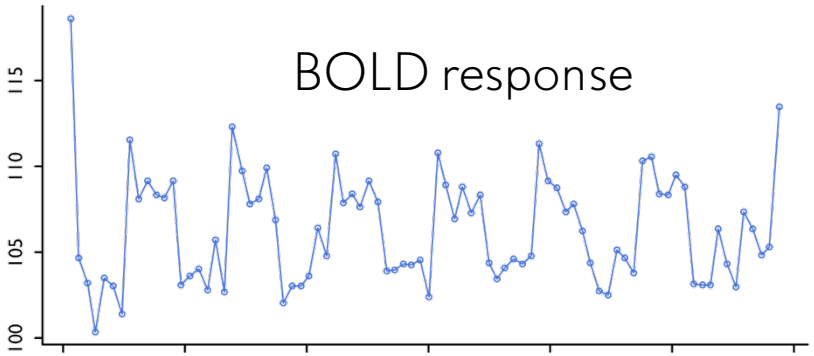


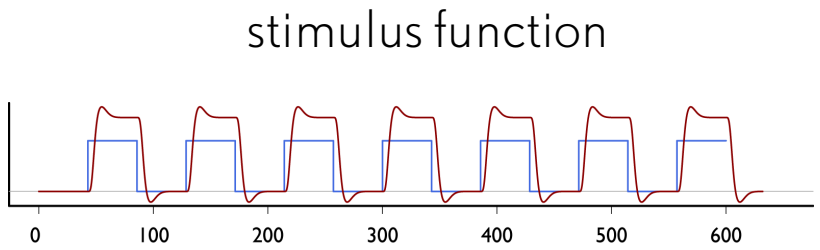
$$B(t) = S(t) \otimes H(t)$$

Classical fMRI analysis



Classical fMRI analysis

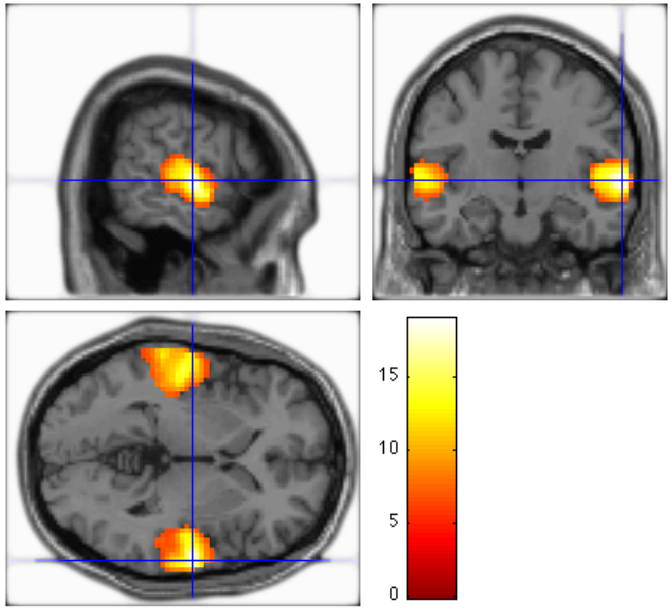




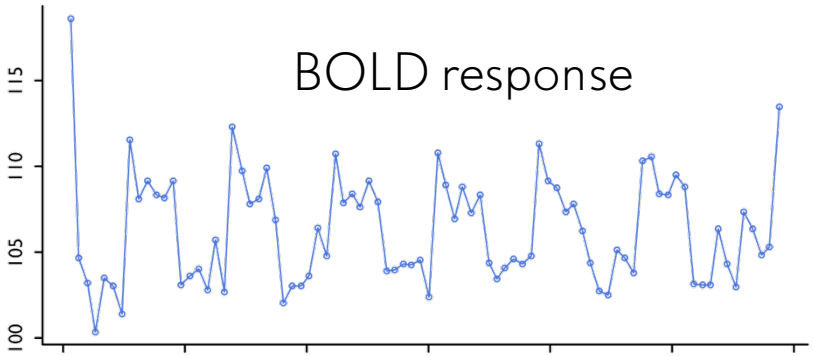
linear model
per voxel

which voxels correspond to
the stimulus function?

Classical fMRI analysis



Model-Based Analysis



[model predictions]

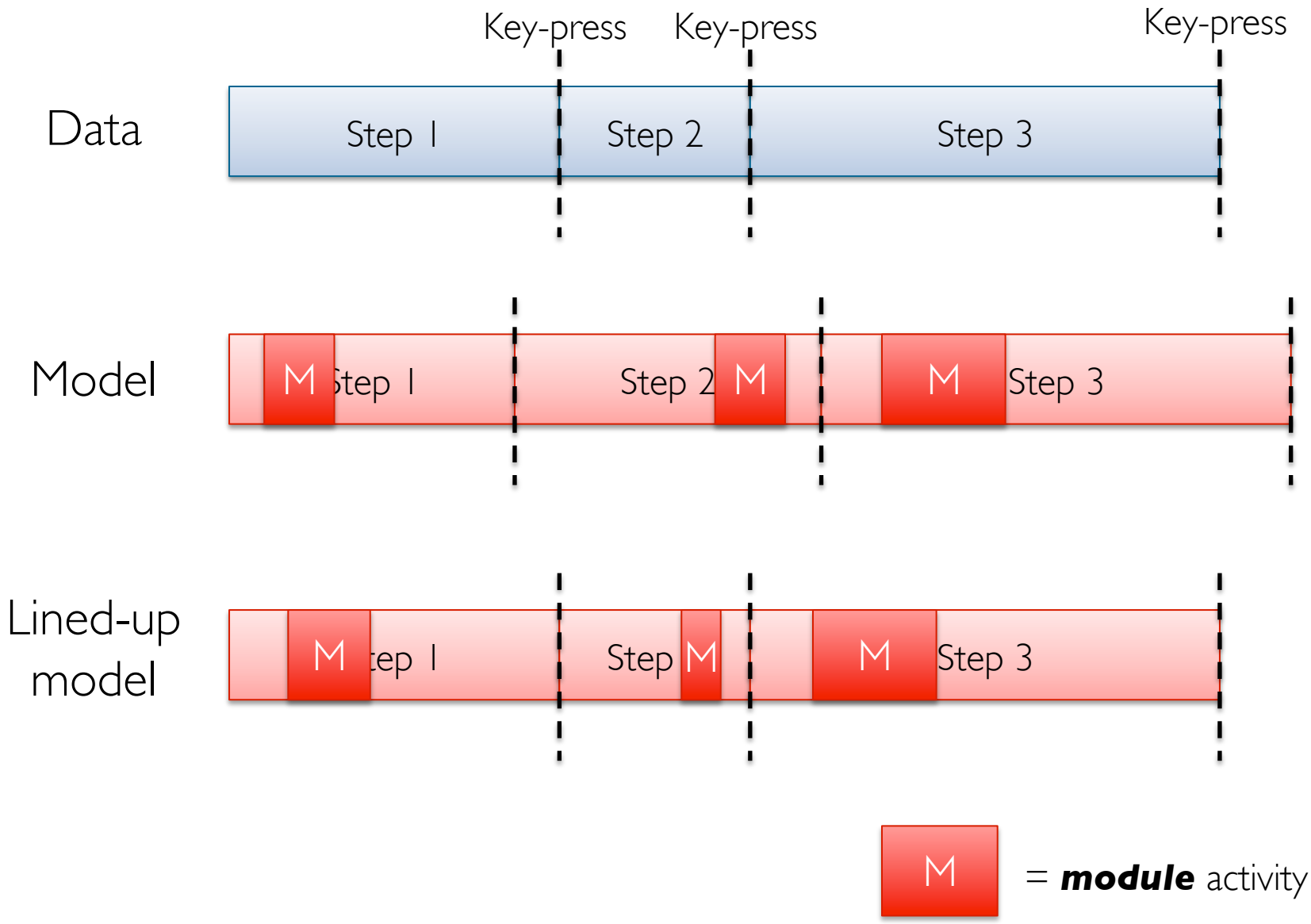
linear model
per voxel

which voxels correspond to
the **model predictions?**

Model Predictions

1. Let cognitive model do the exact same task as participants

2. Line up behavioral measurements


Key-press
Key-press
Key-press
Data
Step 1
Step 2
Step 3
Model
M
Step 1
Step 2
M
M
Step 3
Lined-up model
M
Step 1
Step
M
M
Step 3
M
= **module** activity

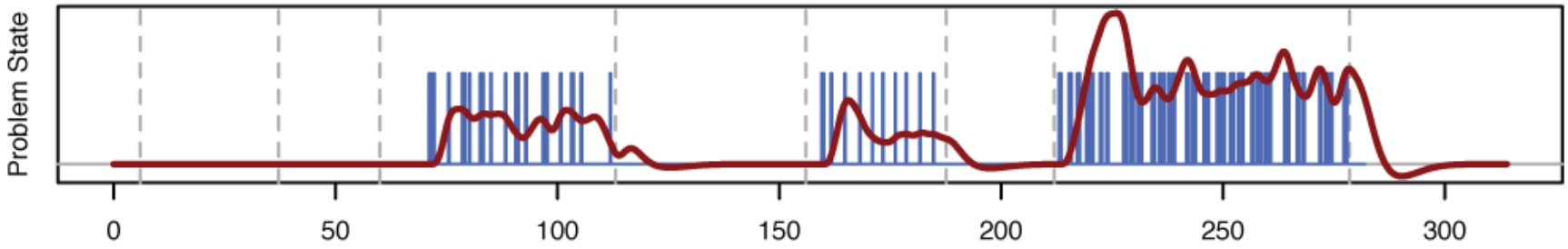
Model Predictions

1. Let cognitive model do the exact same task as participants

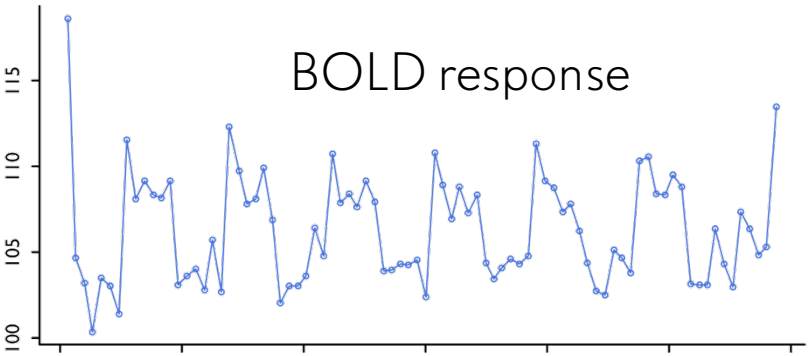
2. Line up behavioral measurements

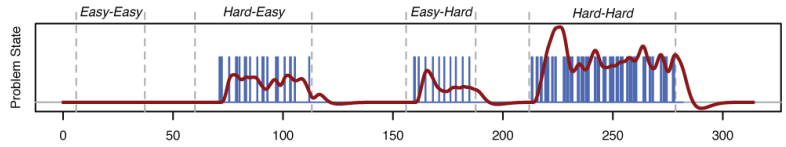
3. Take one module & convolve with HRF

Module activity $\otimes$ HRF



Model-Based Analysis





linear model
per voxel

which voxels correspond to
the **model predictions?**

Locating the problem state bottleneck

Punten: 100

Can **the problem state module** be used by **one** or by **multiple tasks** at the same time?

The Problem State

- Imaginal Module
- Intermediate results

The Problem State

- Imaginal Module
- Intermediate results

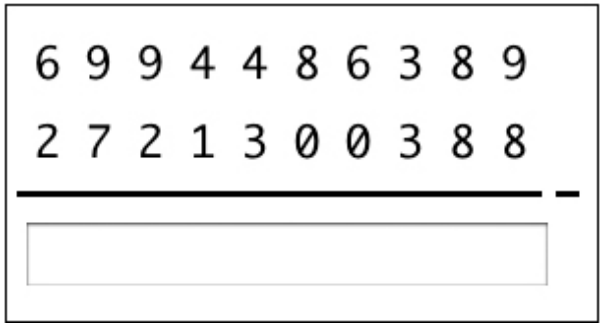
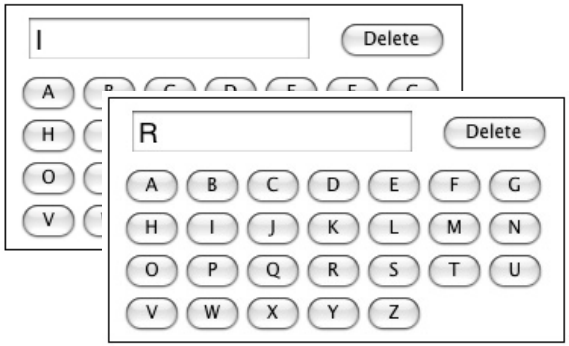
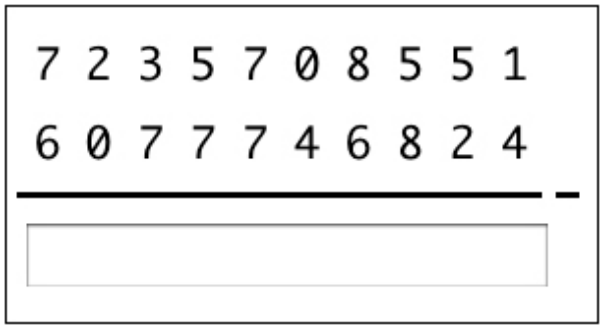
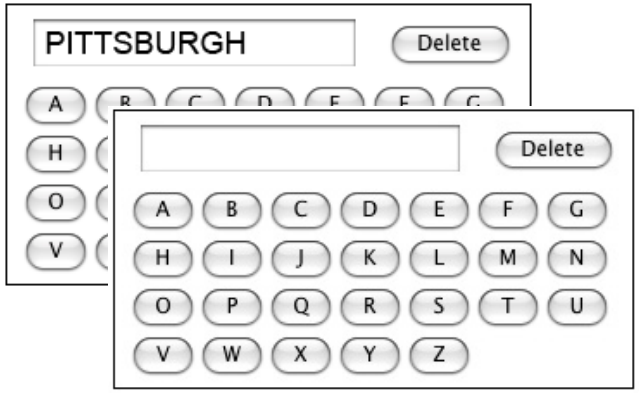
Solve:

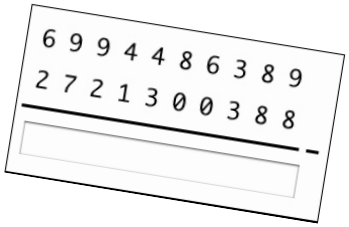
$3x - 5 = 10$

The Problem State

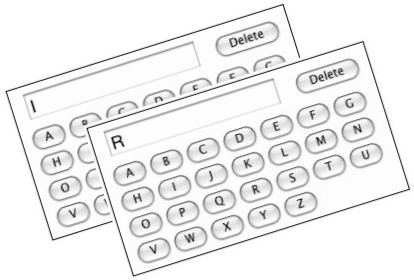
- Imaginal Module
- Intermediate results
- Directly accessible

- Threaded Cognition (Salvucci & Taatgen, 2008): maintains information for **one task**

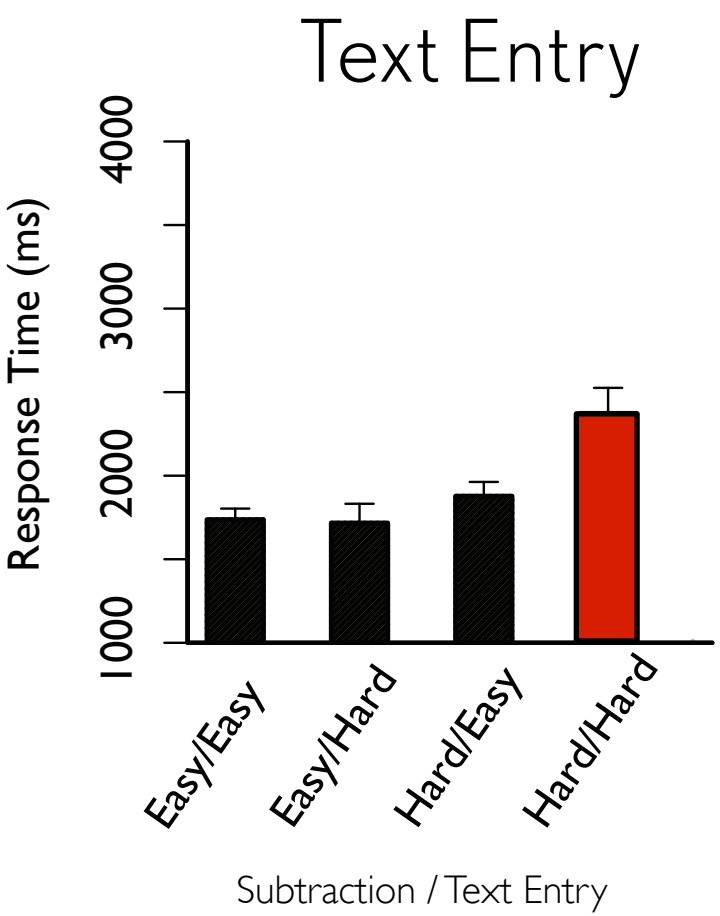
	Subtraction	Text Entry
Easy without Problem State		
Hard with Problem State		

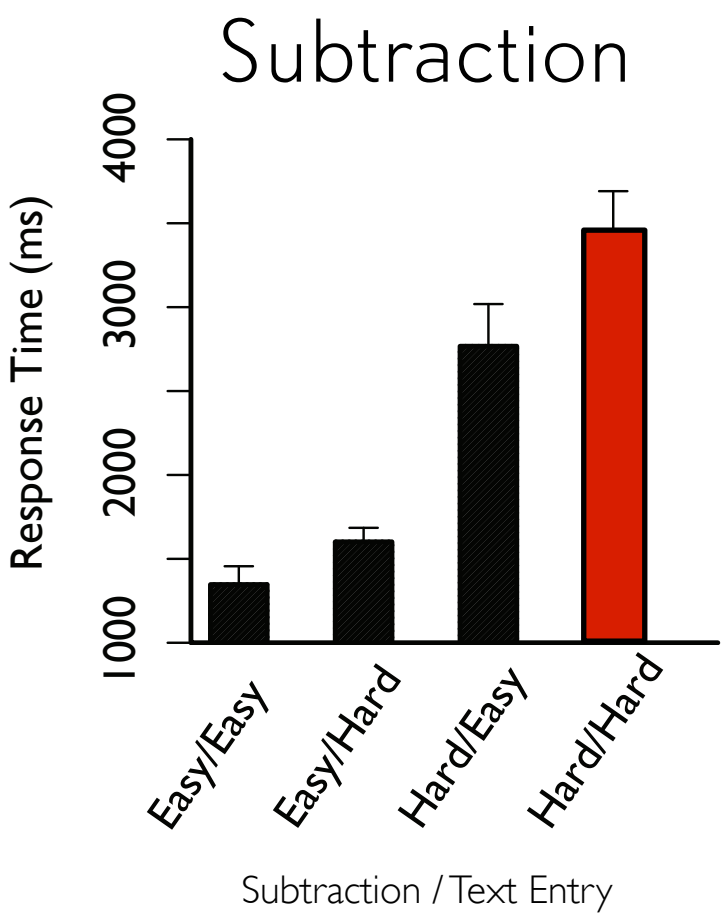


Text Entry	Subtraction: Easy *without* Problem State	Subtraction: Hard *with* Problem State
Easy	0 problem states	1 problem state
Hard	1 problem state	2 problem states



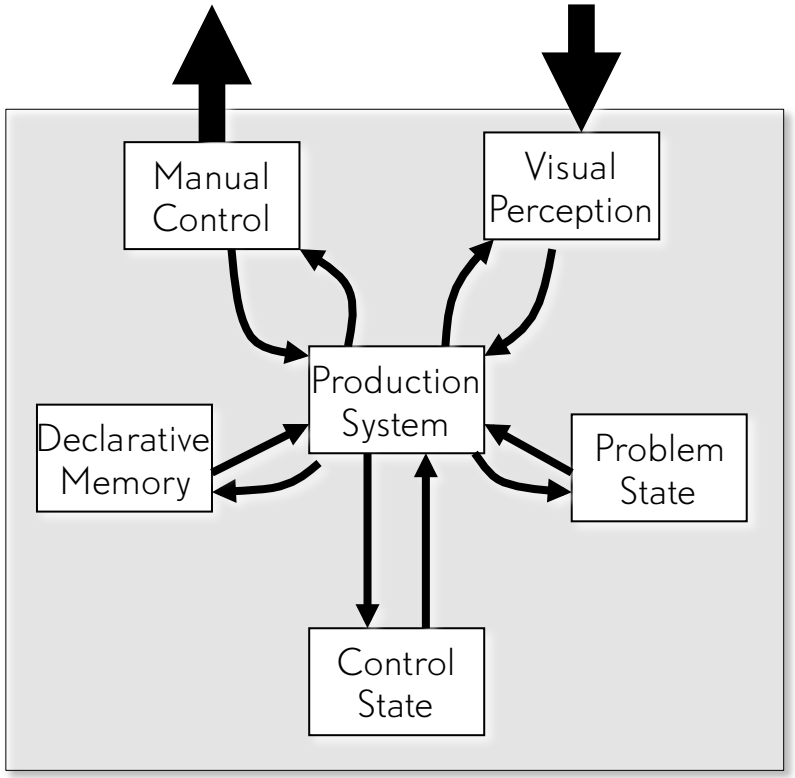
Interaction effects





Model

ACT-R

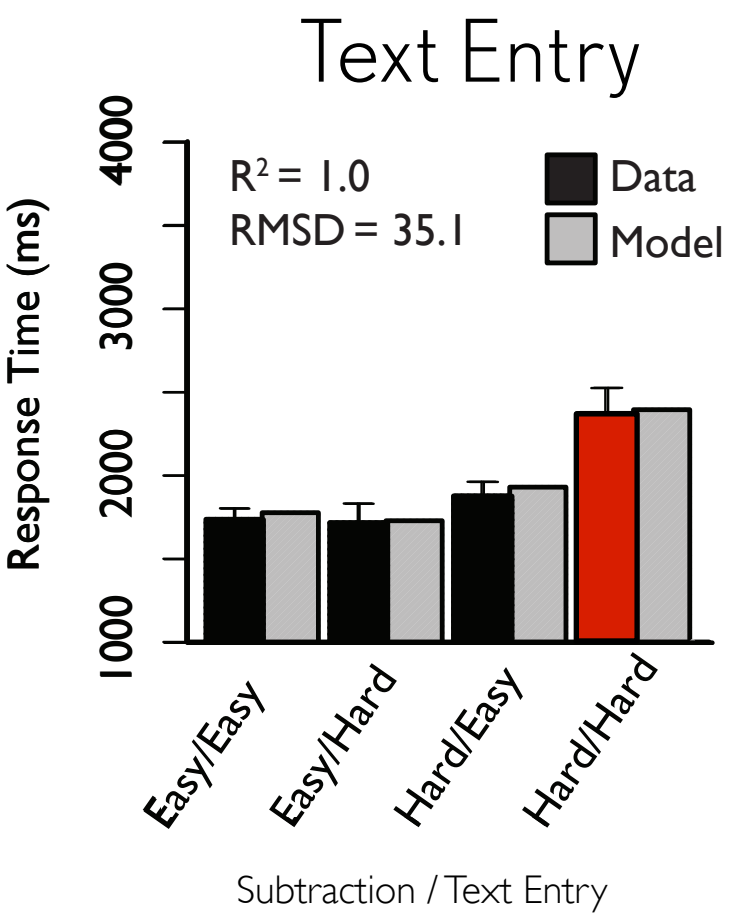


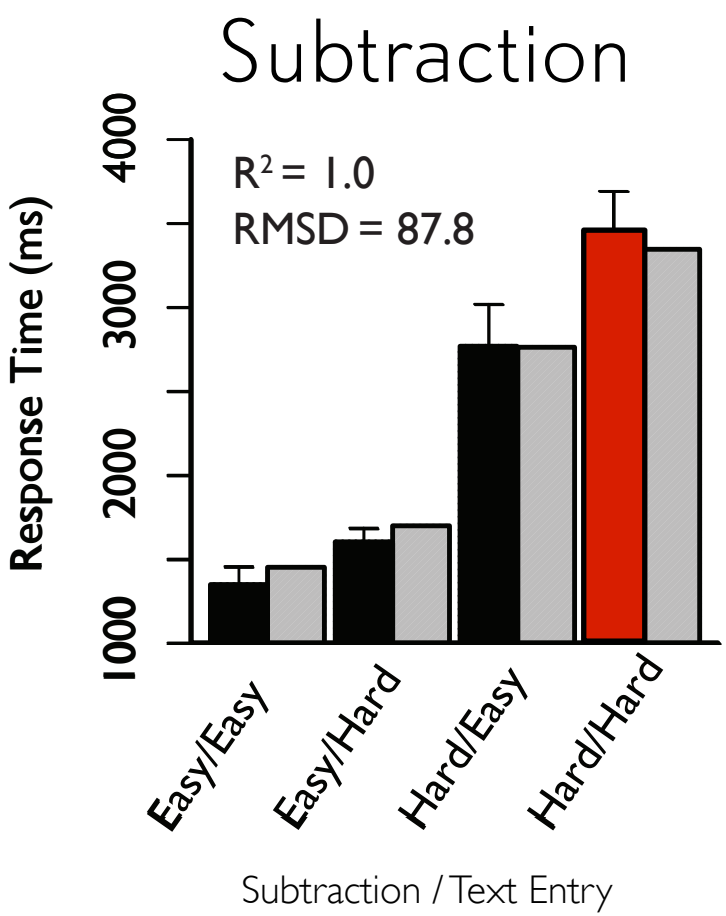
+

Threaded Cognition

problem state can be used for one task

Interaction effects

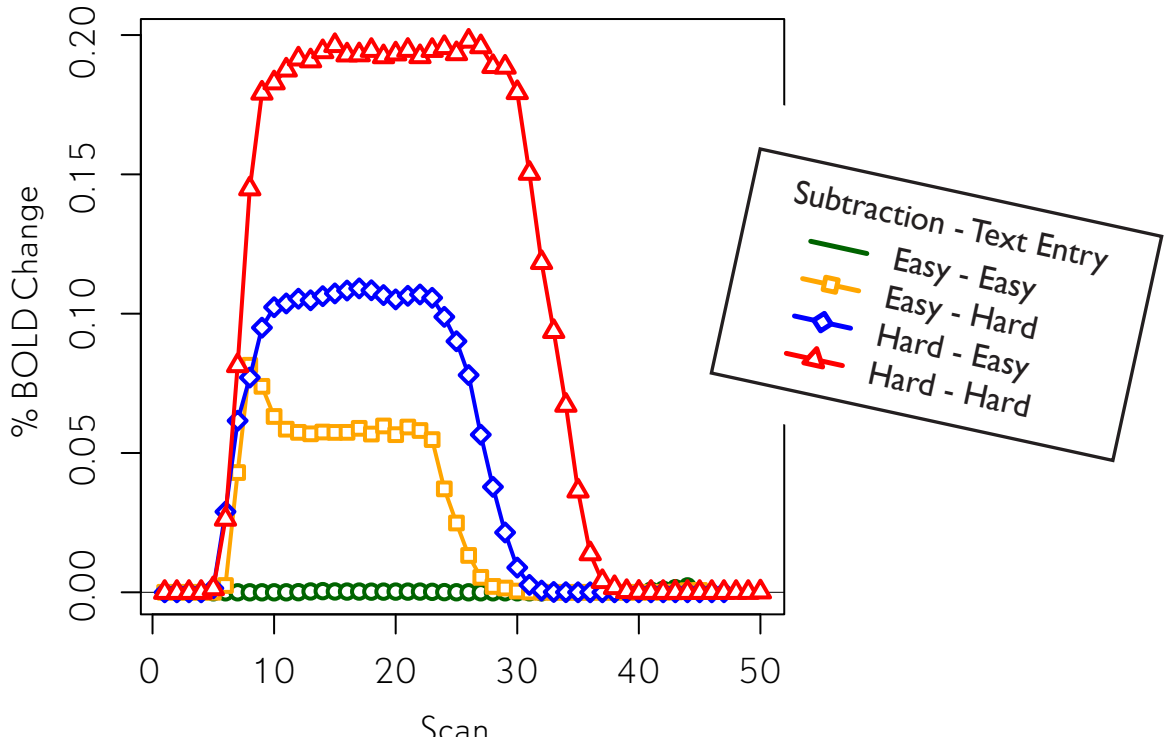


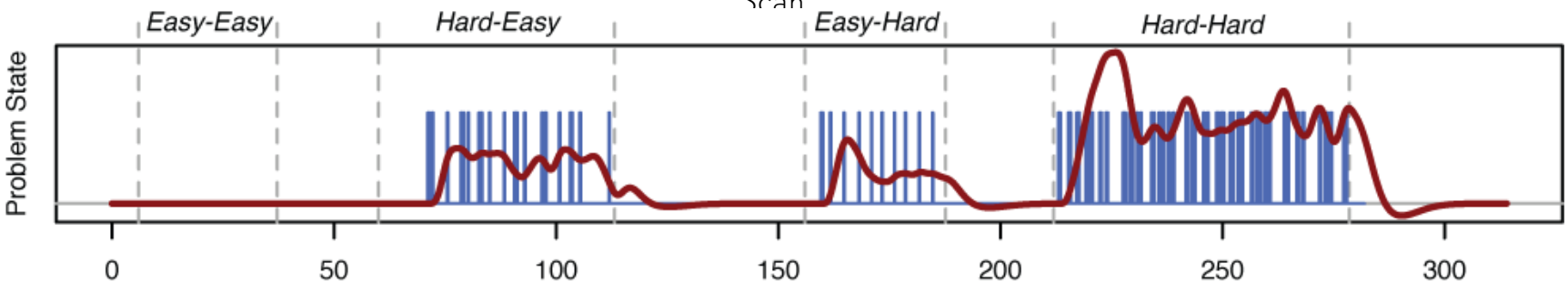


Model Explanation

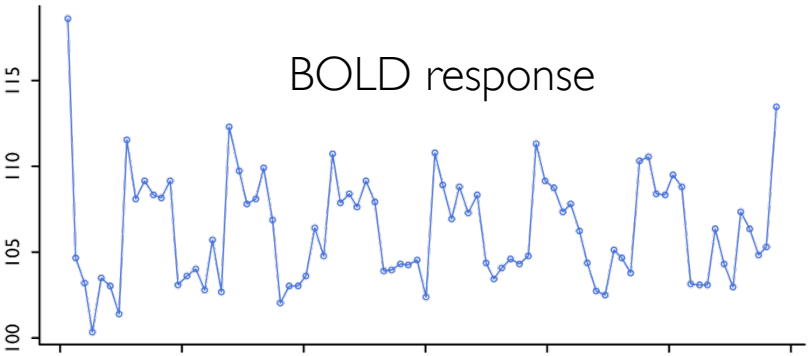
- The **hard/hard** condition:
  - problem state is required for **two** tasks
  - problem state resource holds **one**
  - it takes time to swap problem states via declarative memory

Model fMRI Prediction: Interaction Effect

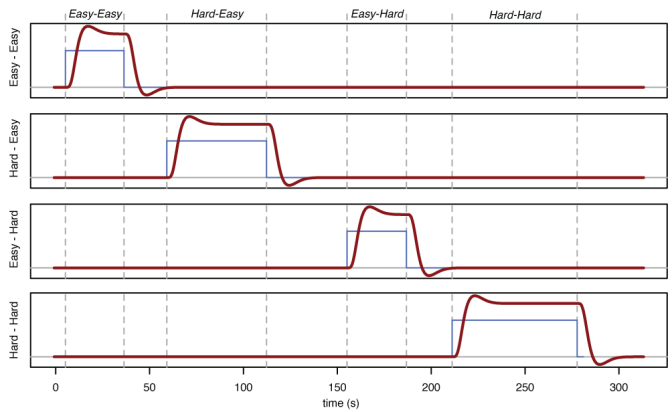




Classical fMRI analysis



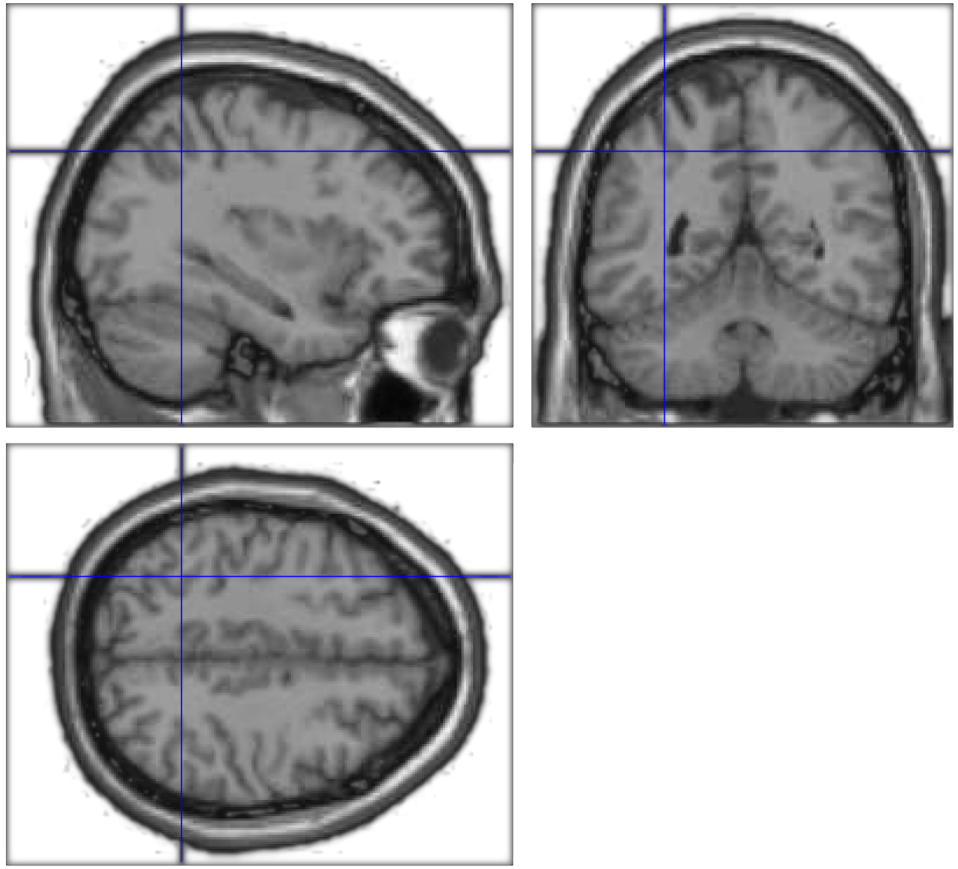
stimulus functions



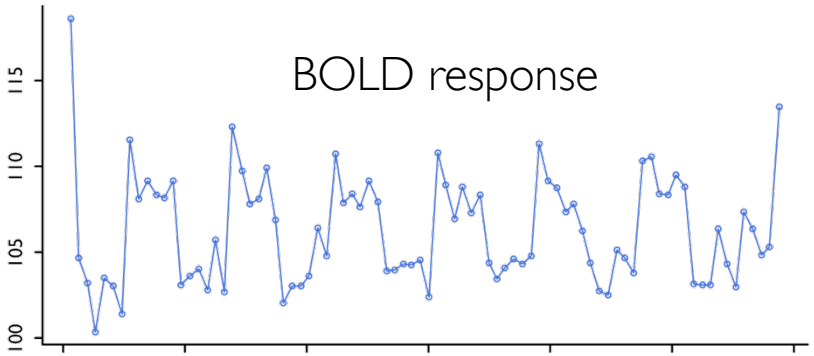
linear model
per voxel

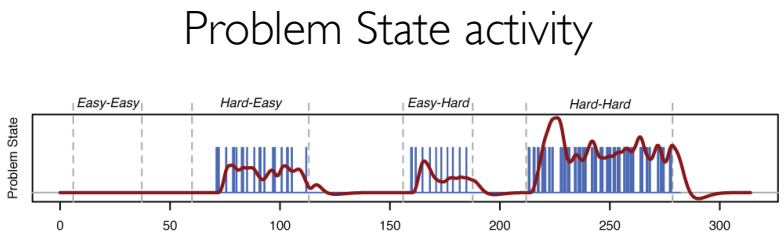
which voxels show an interaction effect of the stimulus functions?

Classical fMRI analysis



Model-Based Analysis

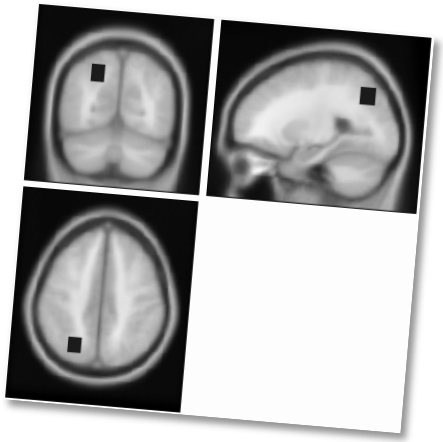


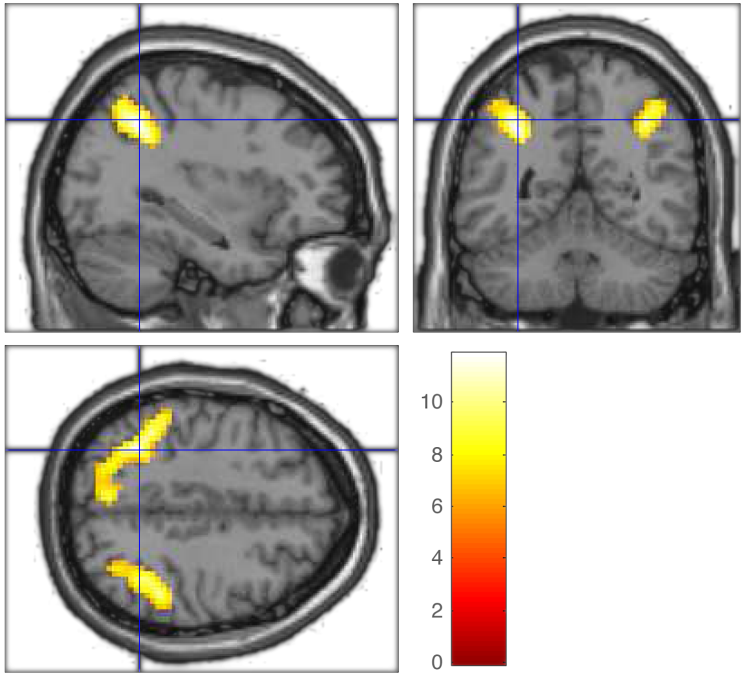


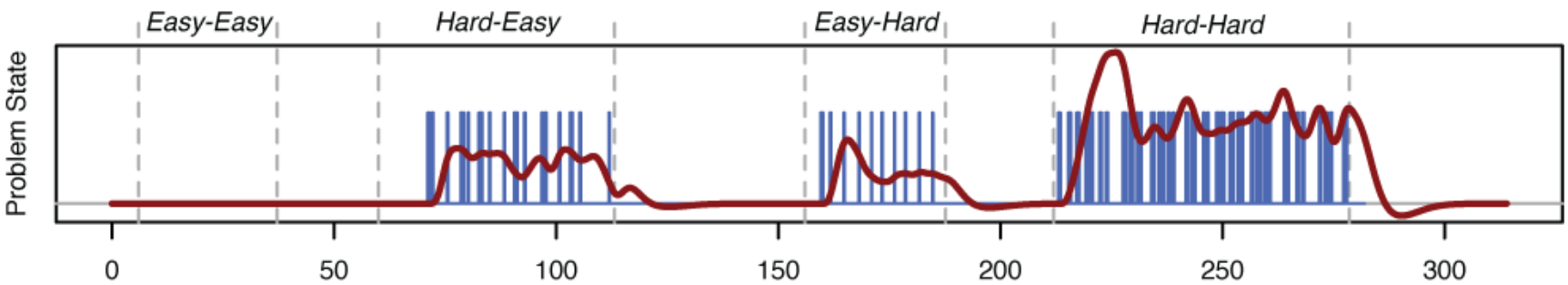
linear model
for each voxel

which voxels correspond to the model predictions?

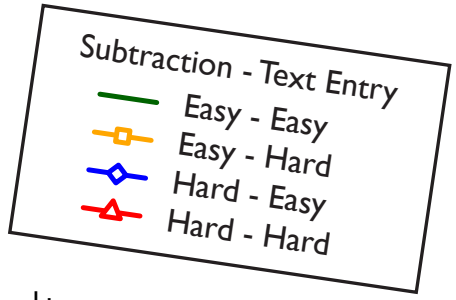
Problem State



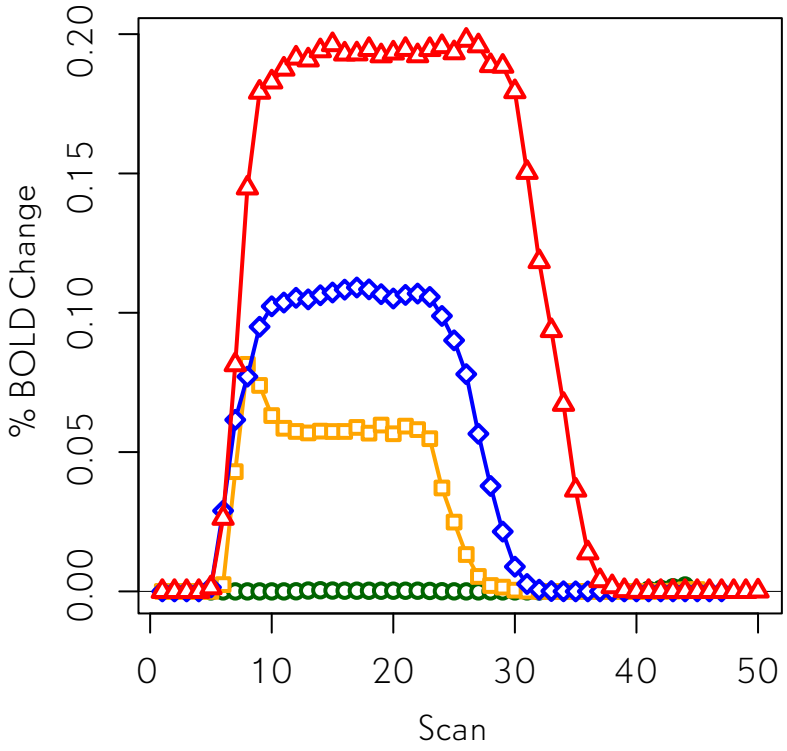




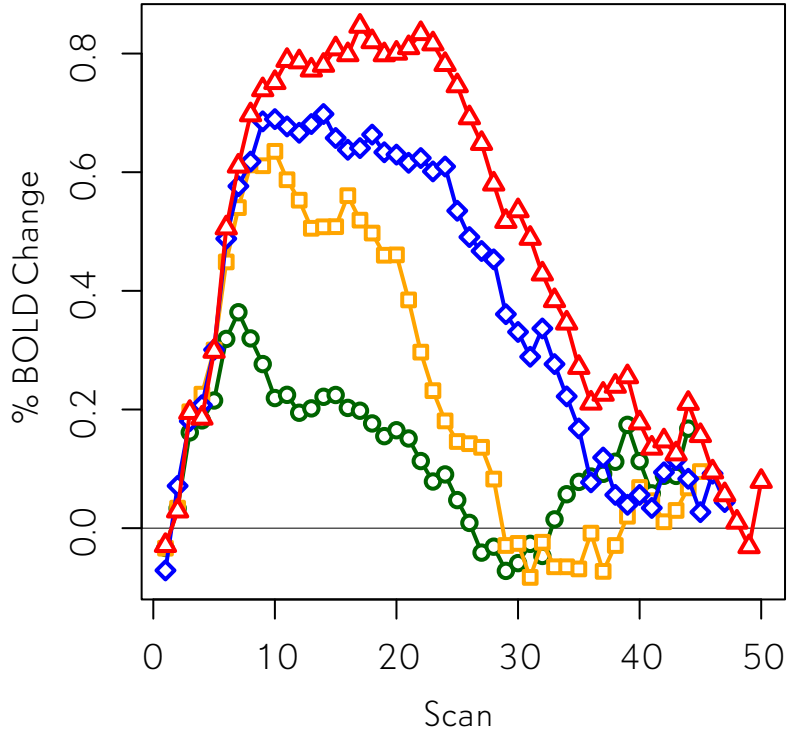
Problem State

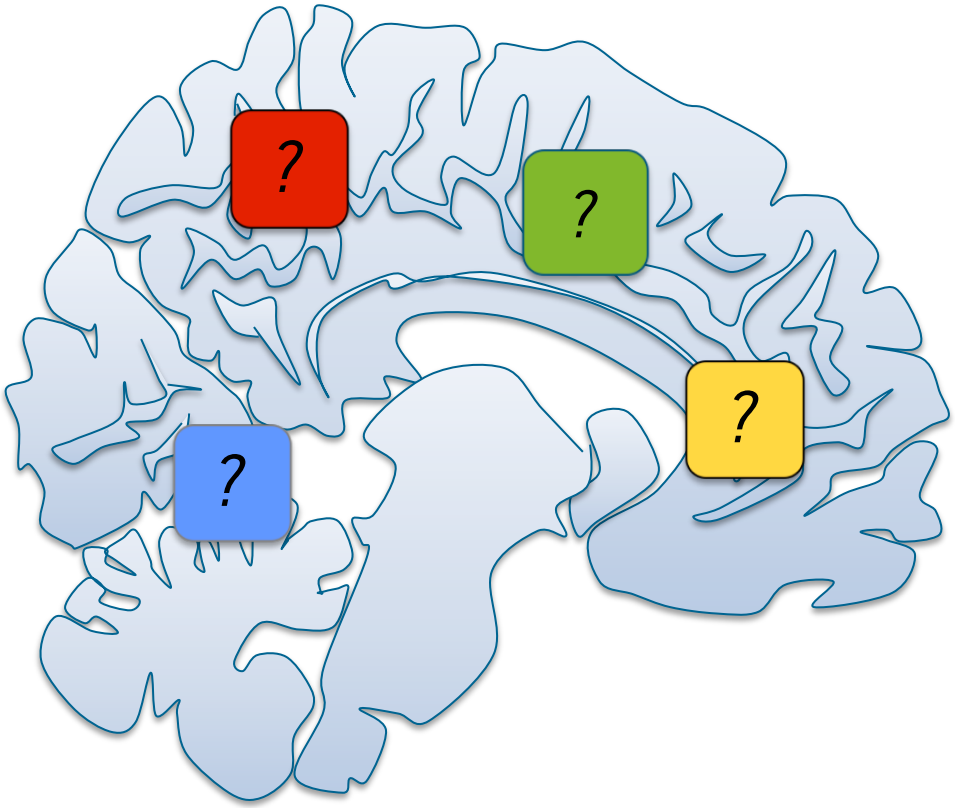


Prediction



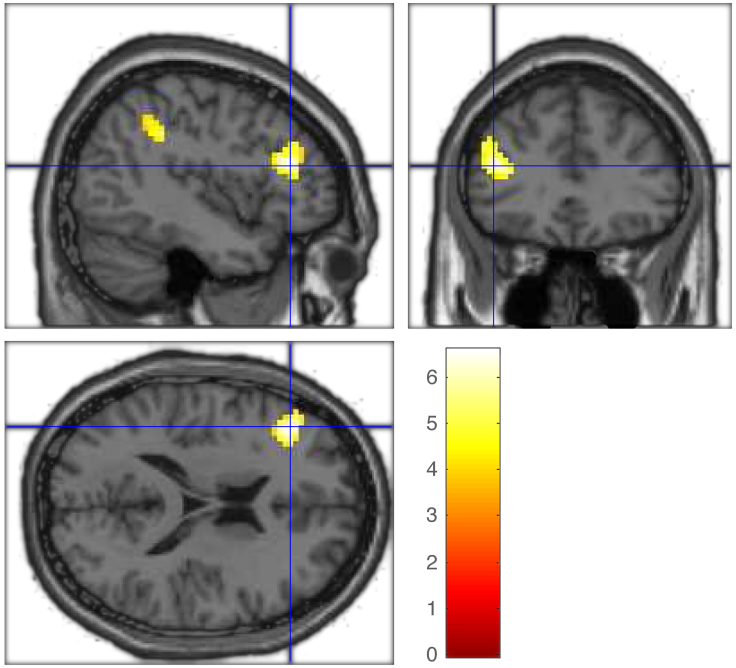
Results

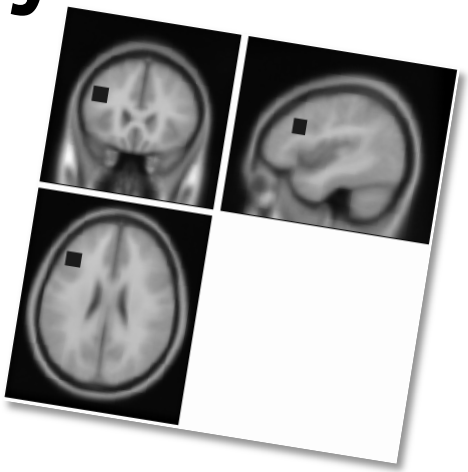


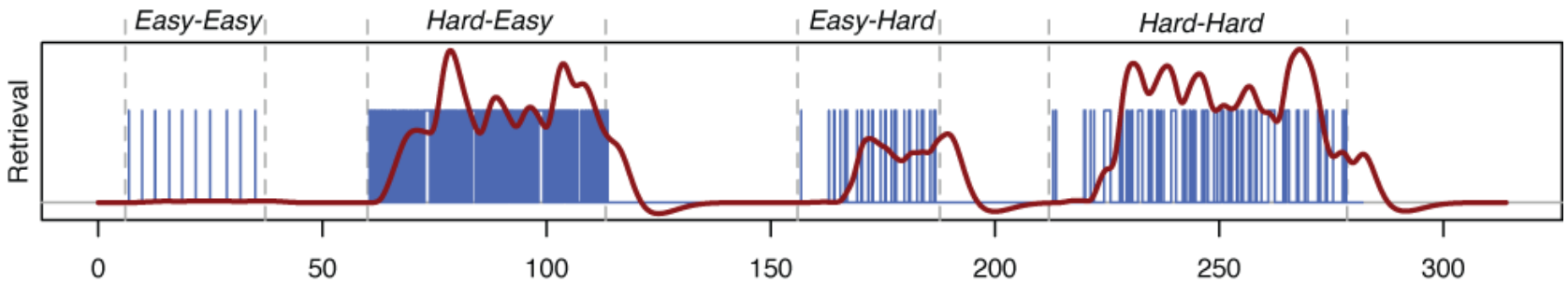


So, where are those other modules?

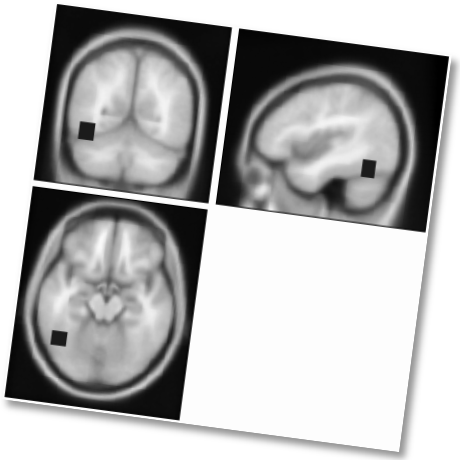
Declarative Memory

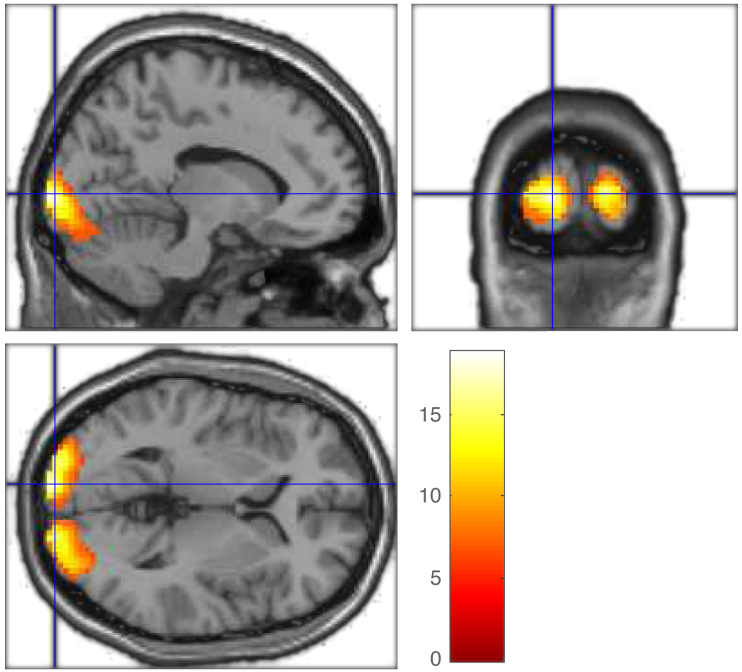


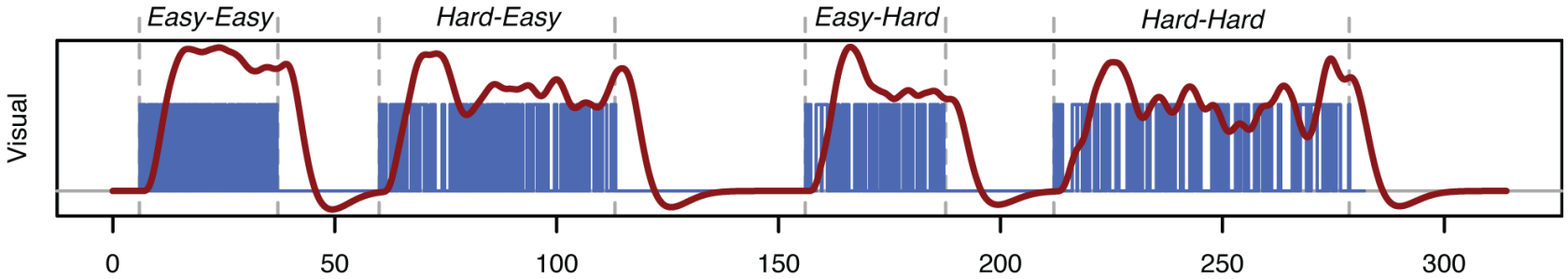




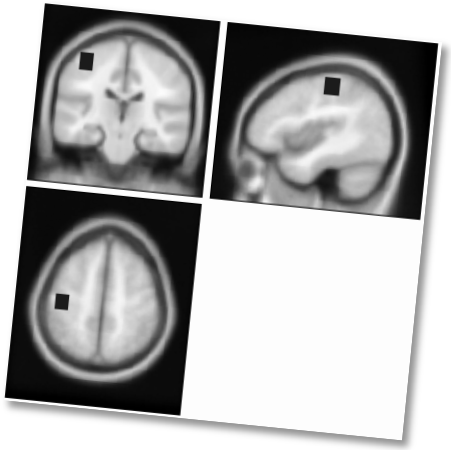
Visual

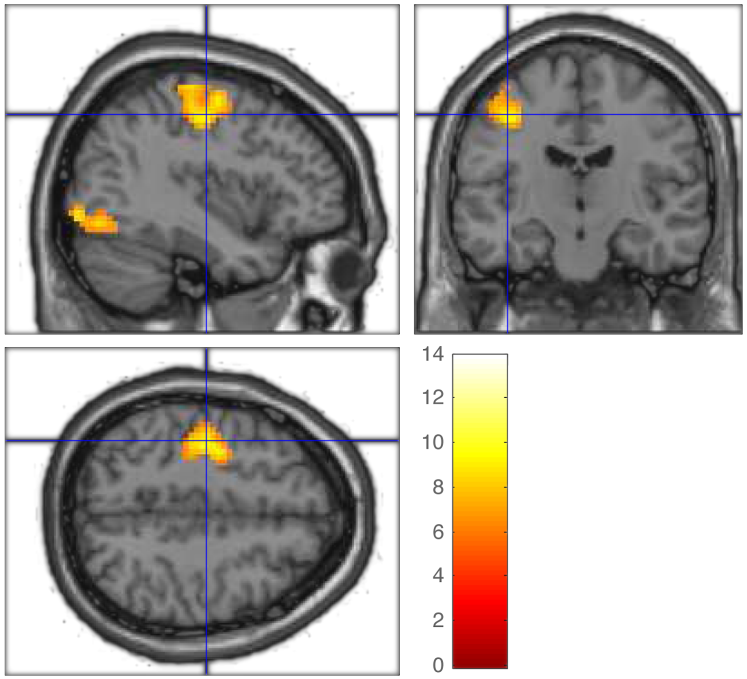


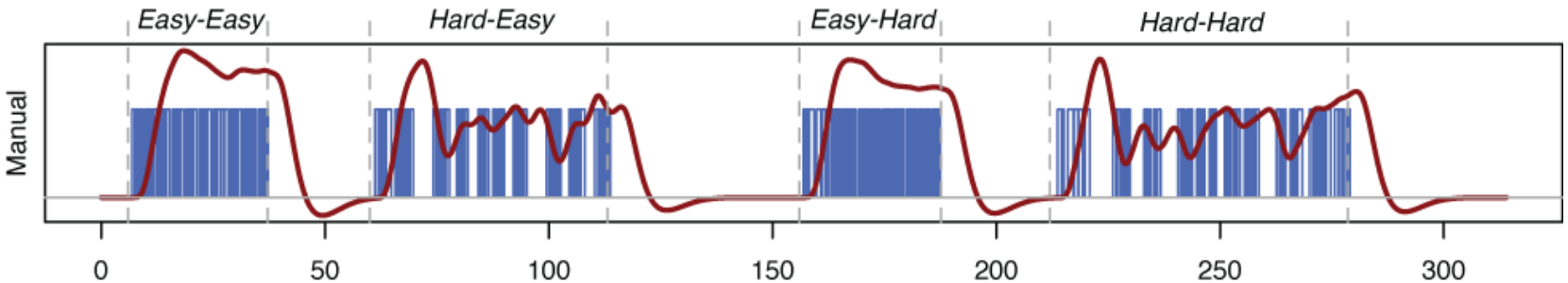

15
10
5
0

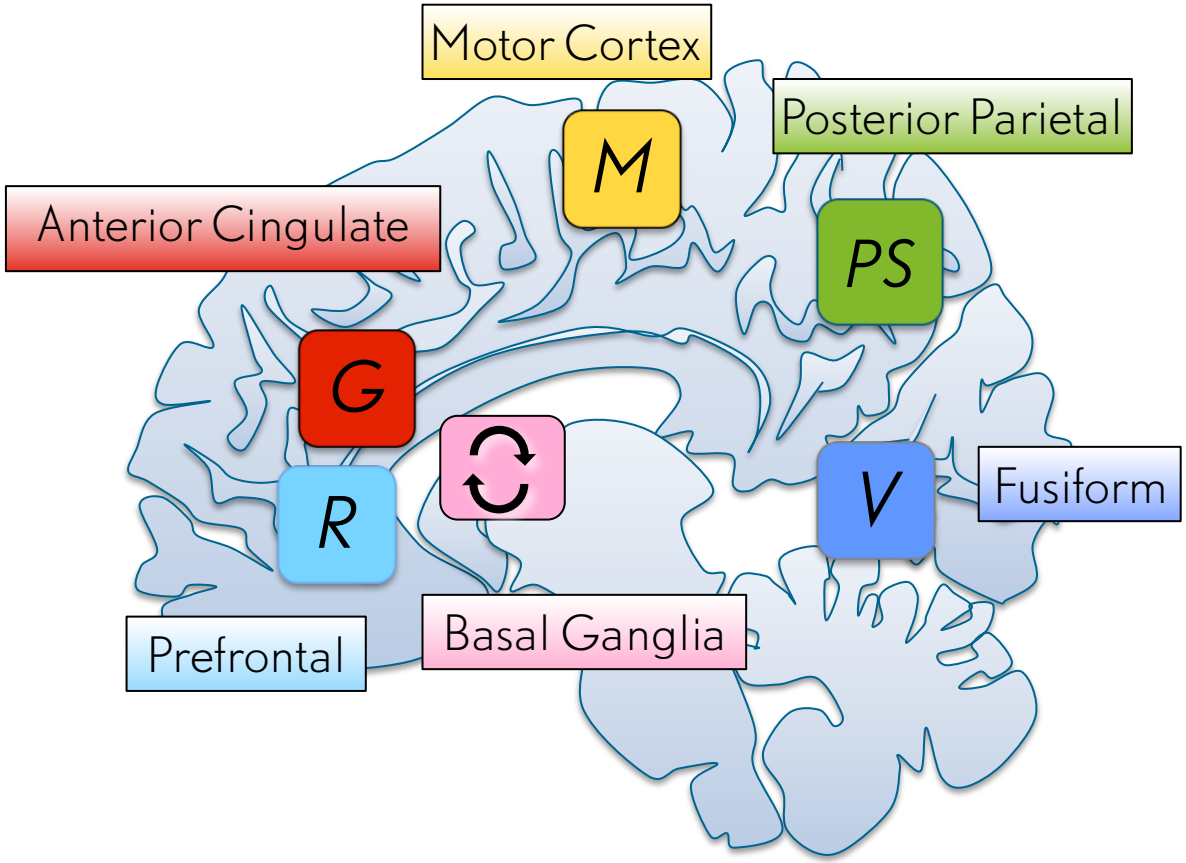

Easy-Easy
Hard-Easy
Easy-Hard
Hard-Hard
Visual
0
50
100
150
200
250
300

Manual



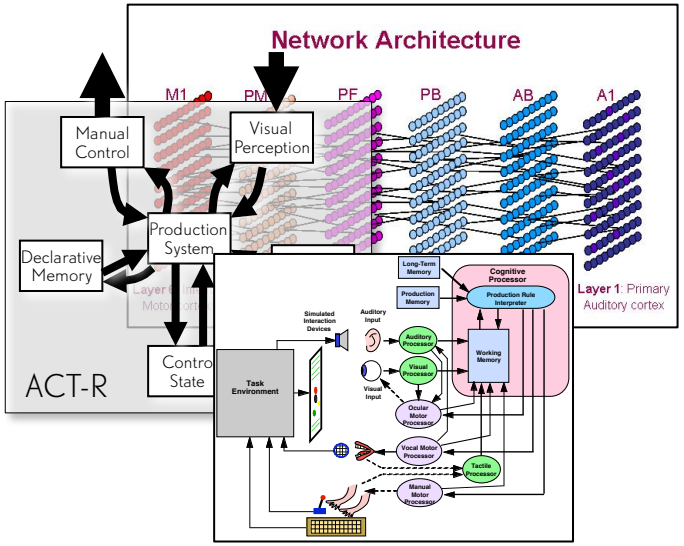

14
12
10
8
6
4
2
0


Easy-Easy
Hard-Easy
Easy-Hard
Hard-Hard
Manual
0
50
100
150
200
250
300

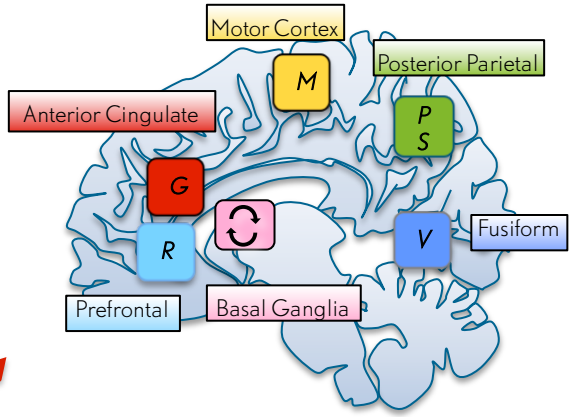

Motor Cortex
M
Posterior Parietal
PS
Anterior Cingulate
G
R
V
Fusiform
Prefrontal
Basal Ganglia

The Bigger Picture

Models

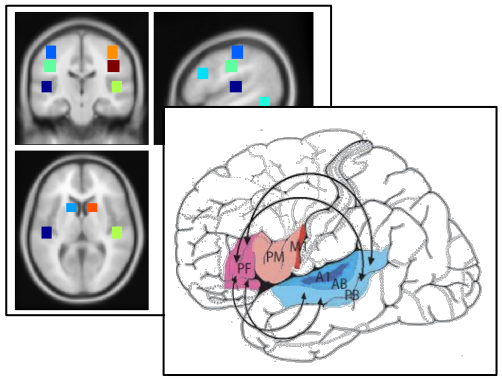


ROI Analysis

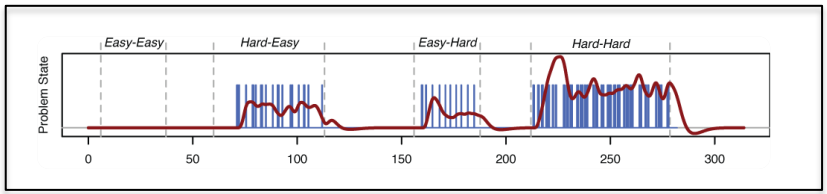


Model validation

Model-Brain Mappings

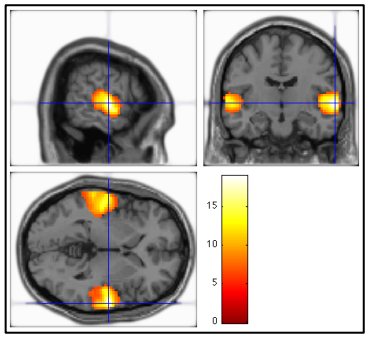


Model-Based Analysis



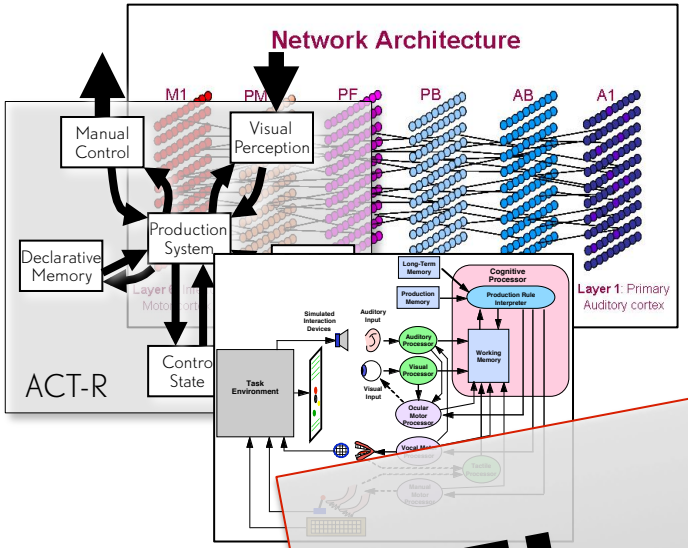
Checks plausibility

Classical Analysis



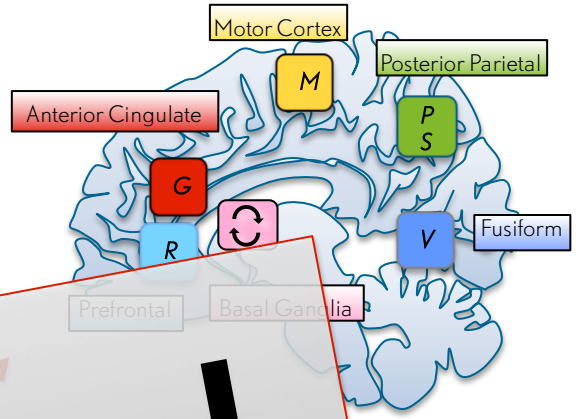
Thank you!

Models

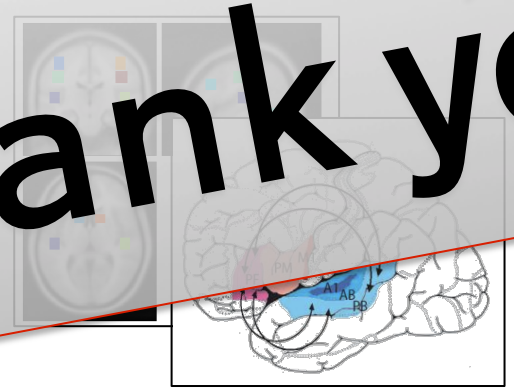


Model validation

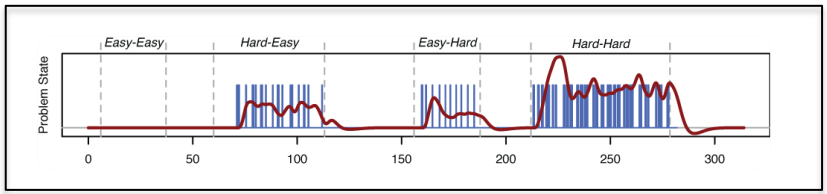
ROI Analysis

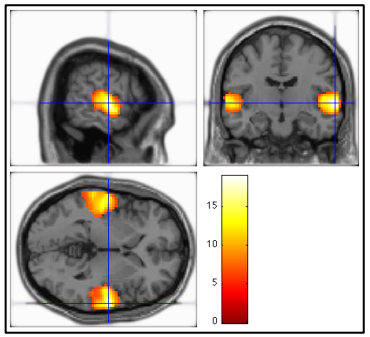


Model-Brain Mappings



Model-Based Analysis



Checks plausibility

Classical Analysis