Lecture 14: Computational Cognitive Modeling

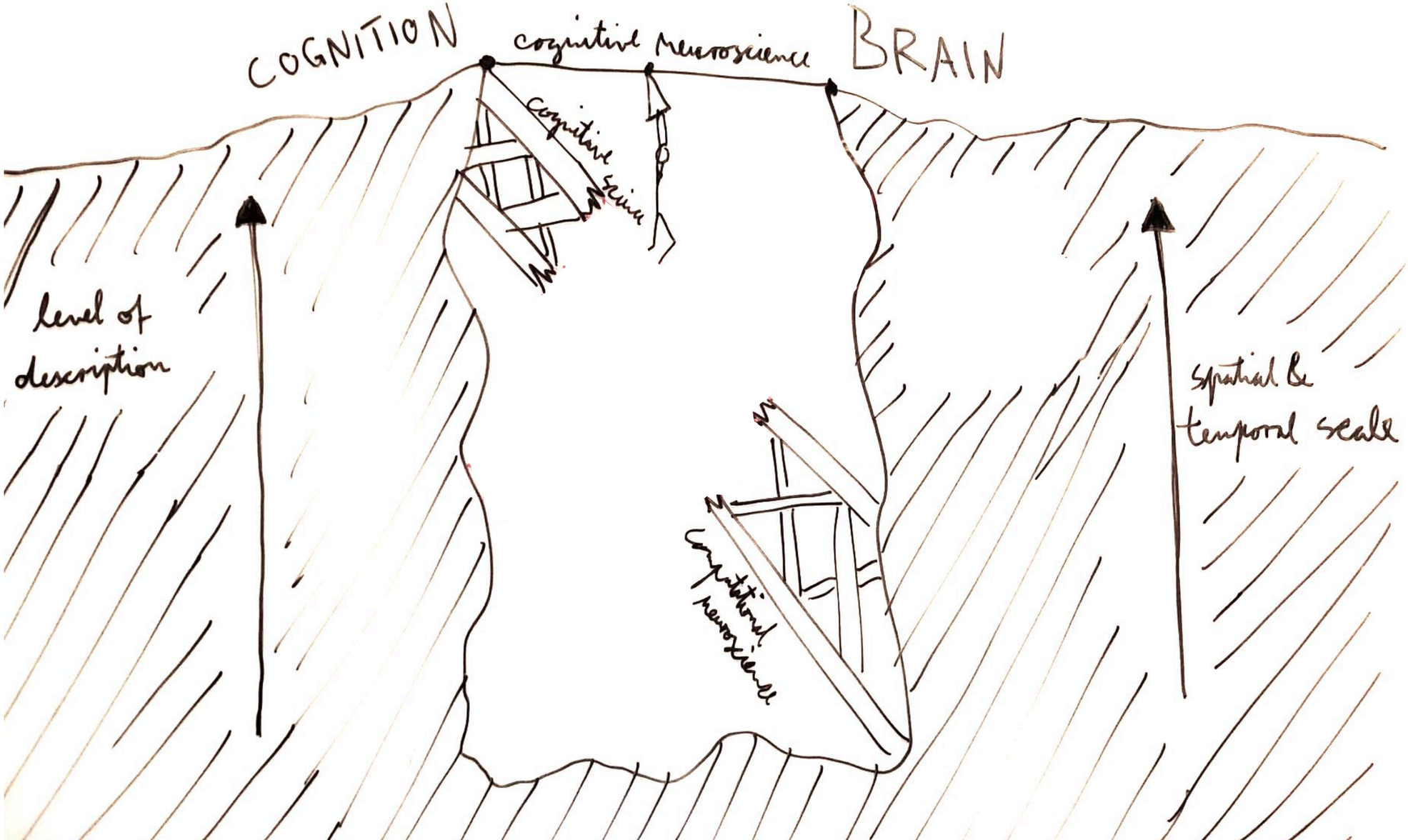
Computational Cognitive Neuroscience

email address for instructors:
instructors-ccm-spring2019@nyuccl.org

course website:
https://brendenlake.github.io/CCM-site/

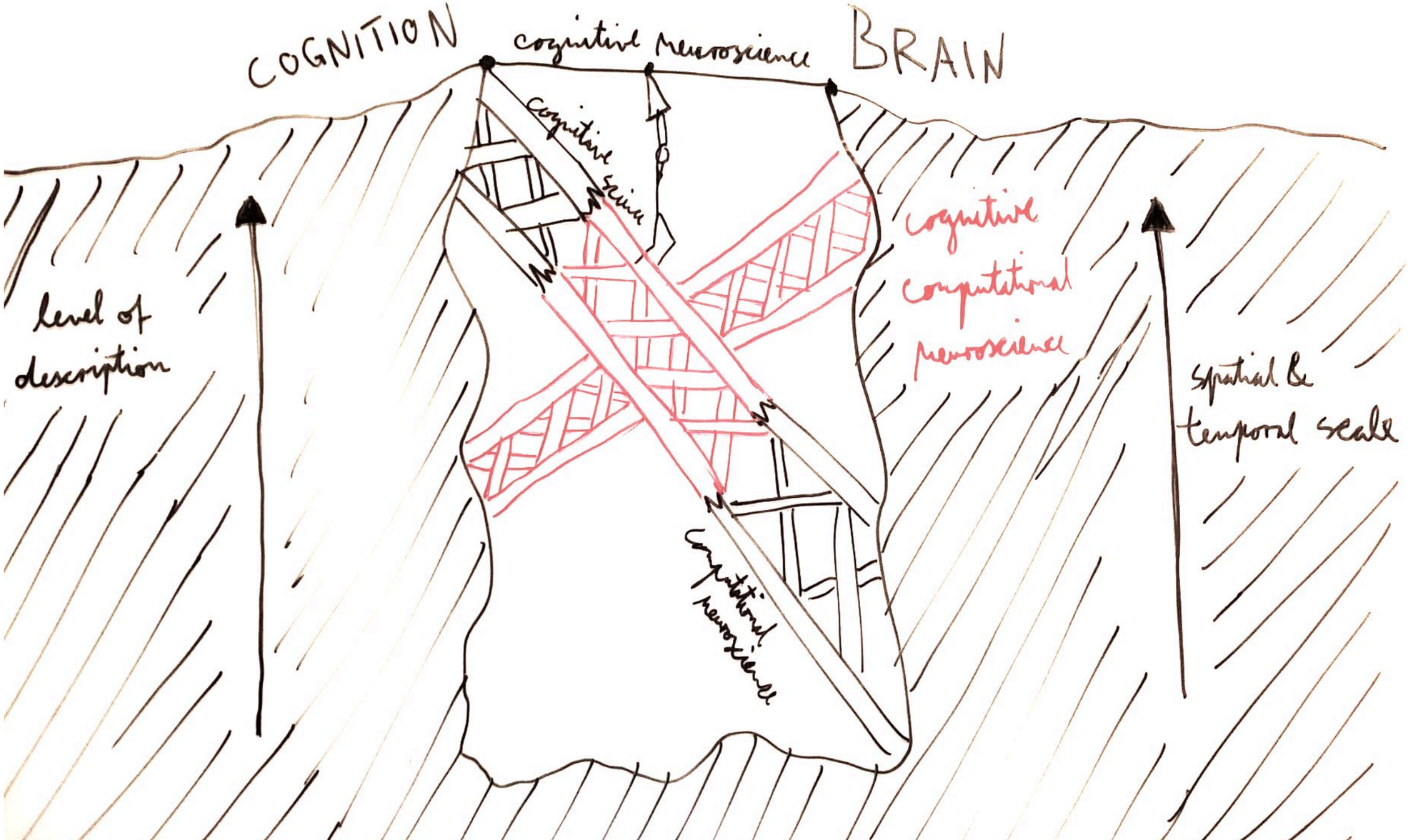
The “Chasm”

Illustration by @NKriegeskorte



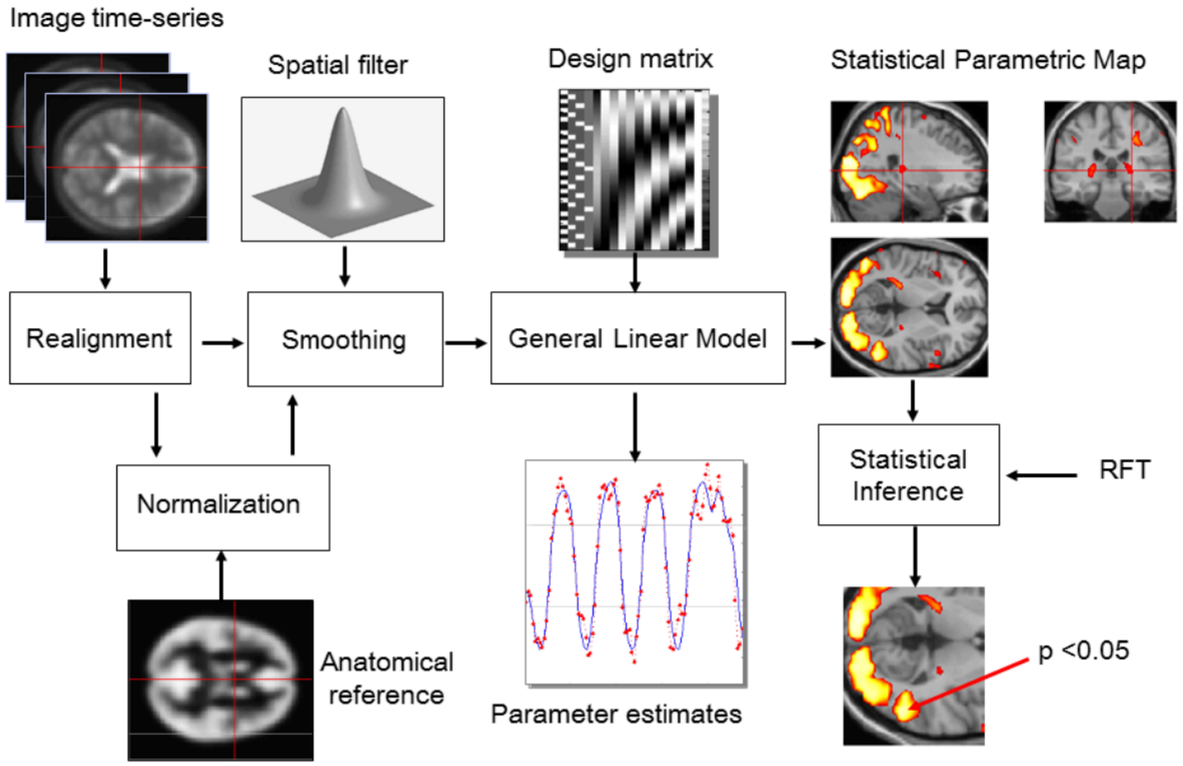
The “Chasm”

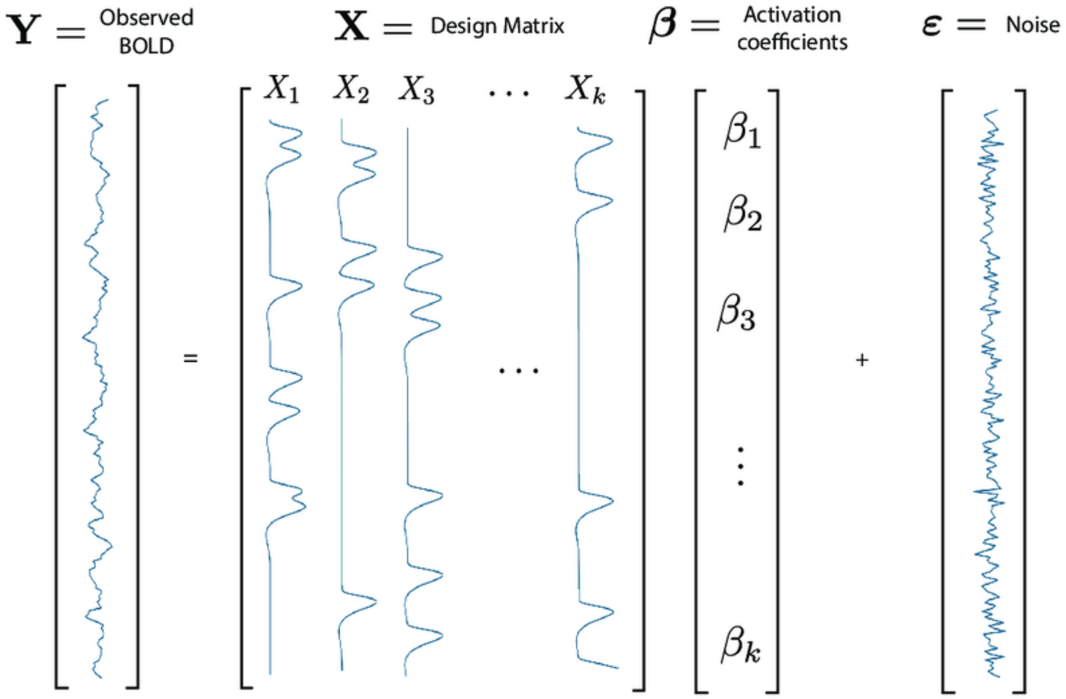
Illustration by @NKriegeskorte



Classic approach

Directly relate operational definitions of psychological constructs to the brain:





Model-based fMRI

Novelty and Reward

- Novelty bonuses (Kakade & Dayan, 2002)
- Daw Novelty study

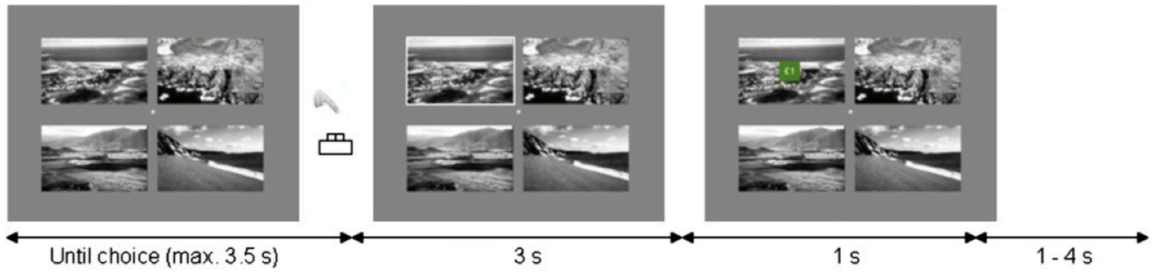


Figure 1. Experimental Design
Following a familiarization phase, participants were shown four pictures on each trial and asked to choose one. Both familiarized and novel pictures were presented at randomized locations that changed on each trial. Each picture was repeated for an average of 20 trials and then replaced. Participants were informed that each picture had been assigned a unique probability of winning £1 that would not change as long as that picture was repeated. They were given feedback at the end of each trial indicating whether they had won or received nothing.

Striatal Activity Underlies Novelty-Based Choice in Humans

Bianca C. Wittmann,[1,3,*] Nathaniel D. Daw,[2,3,4] Ben Seymour,[1] and Raymond J. Dolan[1]
[1]Wellcome Trust Centre for Neuroimaging, University College London, 12 Queen Square, London WC1N 3BG, UK
[2]Gatsby Computational Neuroscience Unit, University College London, 17 Queen Square, London WC1N 3AR, UK
[3]These authors contributed equally to this work
[4]Present address: Center for Neural Science and Department of Psychology, New York University, 6 Washington Place, New York, NY 10003, USA
*Correspondence: b.wittmann@ucl.ac.uk
DOI 10.1016/j.neuron.2008.04.027

Table 1. Parameter Estimates for the Behavioral Model, Shown as Mean (Over Subjects) ± 1 SE

Learning rate ν	0.23 ± 0.038
Softmax inv. temperature β	8.5 ± 1.2
Initial value, familiarized Q_f	0.37 ± 0.071
Initial value, novel Q_n	0.41 ± 0.076

Due to poor identification of β and ν, one subject is omitted from these averages.

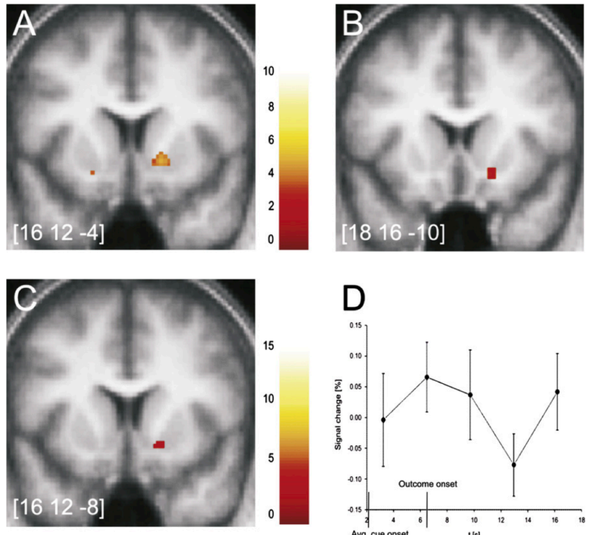
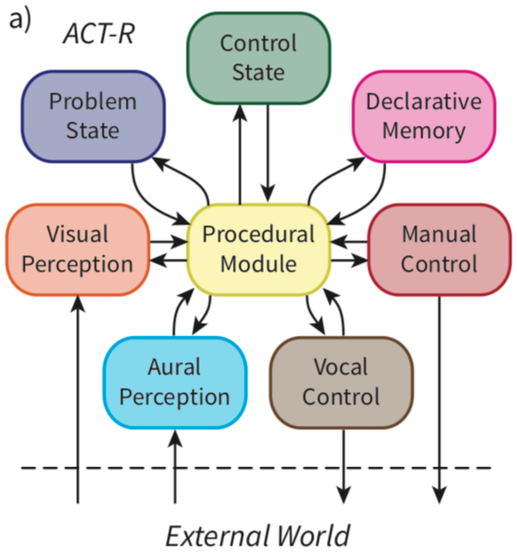
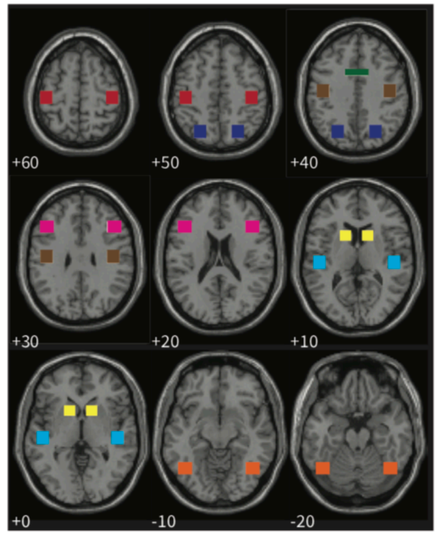
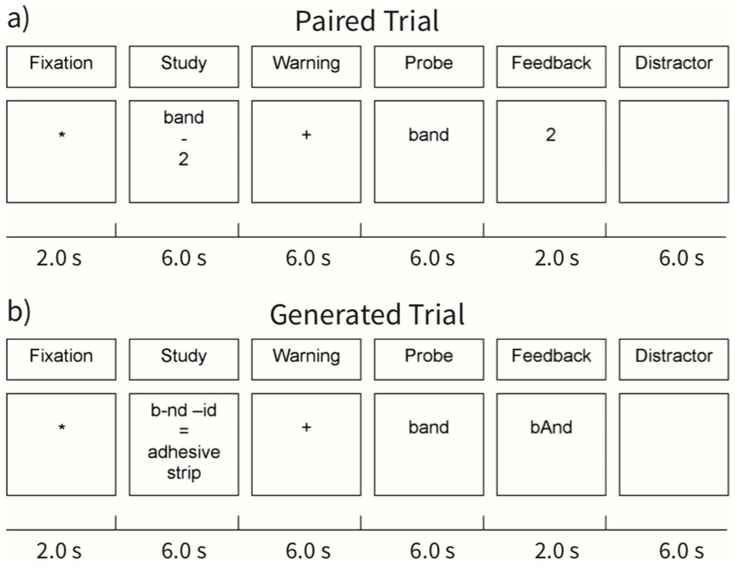


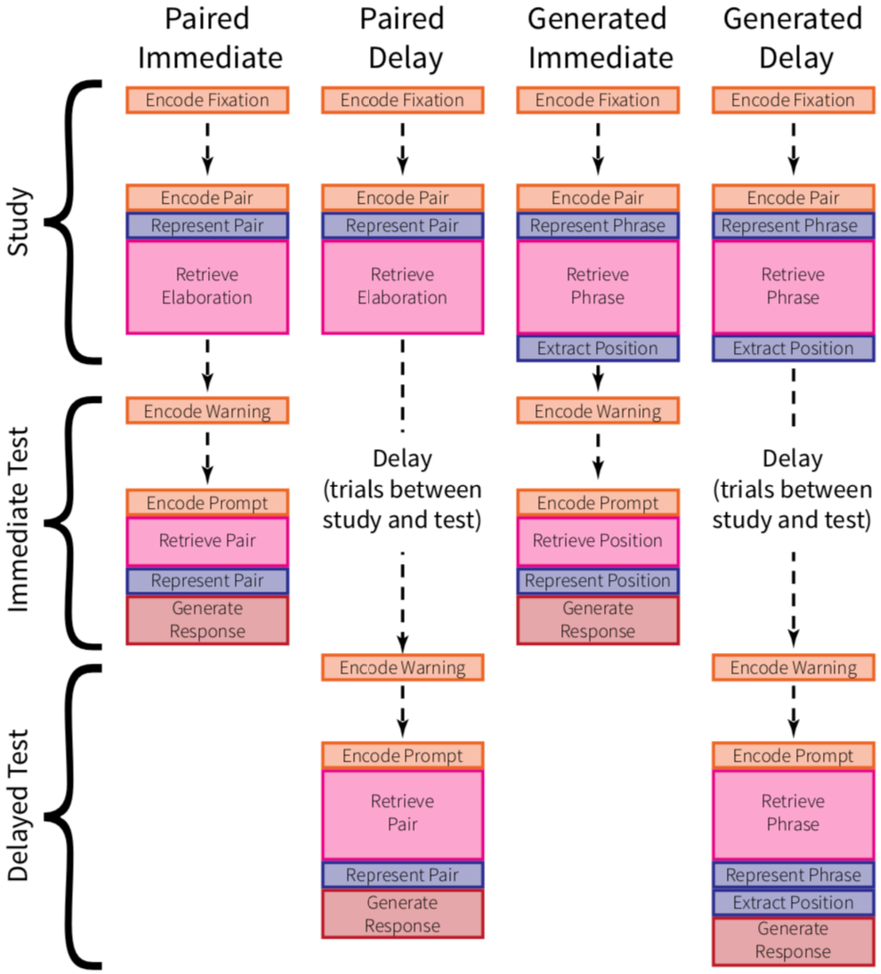
Figure 2. Ventral Striatal Response to Prediction Error and Novelty
Peak coordinates are given in MNI space on all images. Color bars indicate T values.
(A) Activation in right ventral striatum correlated significantly with reward prediction errors generated by the standard TD model ($p < 0.001$ uncorrected, $p < 0.05$ SVC, cluster > 5 voxels).
(B) Activation in right ventral striatum correlated significantly with additional prediction error due to inclusion of a novelty bonus ($p < 0.001$ uncorrected, $p < 0.05$ SVC, cluster > 5 voxels).
(C) Significant overlap between activation in right ventral striatum for the novelty bonus (see [B]) and activation obtained for standard model (see [A]) derived by inclusively masking (B) with (A) ($p < 0.005$, uncorrected, for both contrasts, cluster > 5 voxels).
(D) Striatal activation time courses calculated for the first two trials a novel stimulus is chosen minus the first two choices of familiar stimuli, shown for the peak voxel correlating with the novelty bonus (MNI coordinates: 14, 20, −10). Trials are aligned by the time of reward outcome at 6.5 s; the average stimulus onset time is also indicated. Error bars indicate SEM.

Process decoding









Process decoding

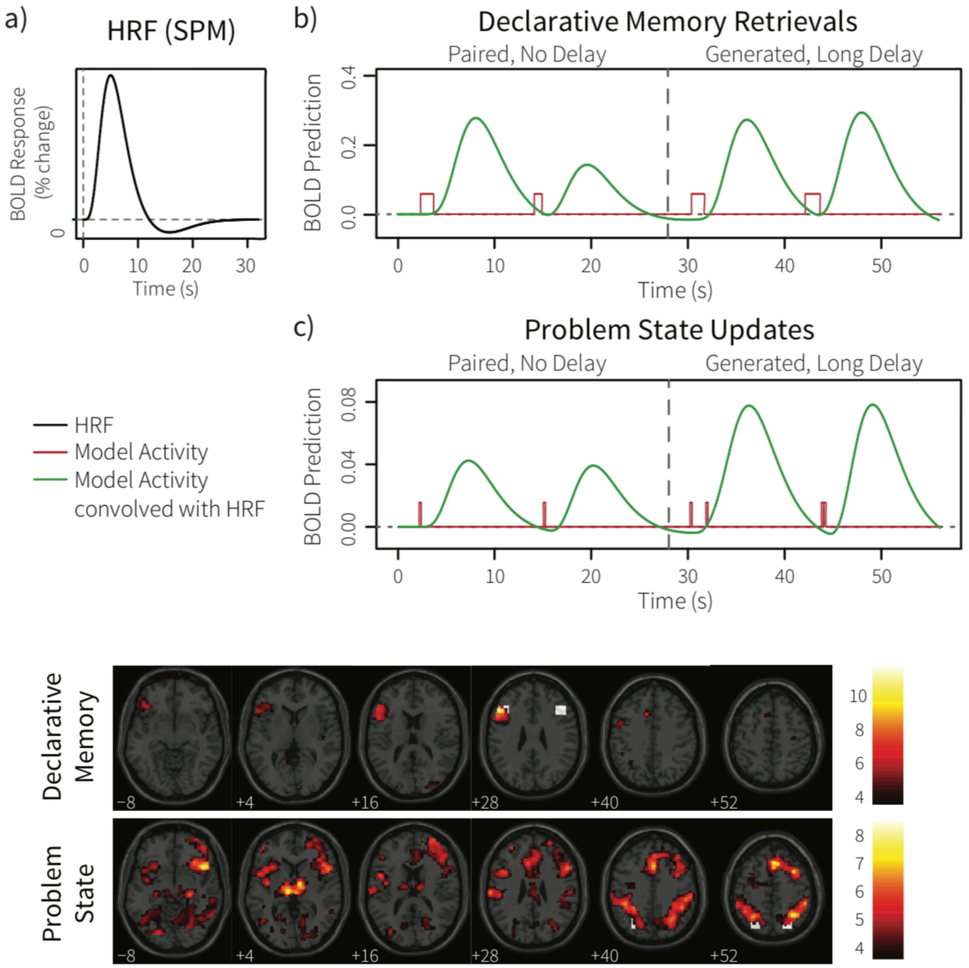


Figure 8. Model-based fMRI results. Statistical maps were thresholded at $p < .001$ (uncorrected). White squares indicate predefined ACT-R regions.

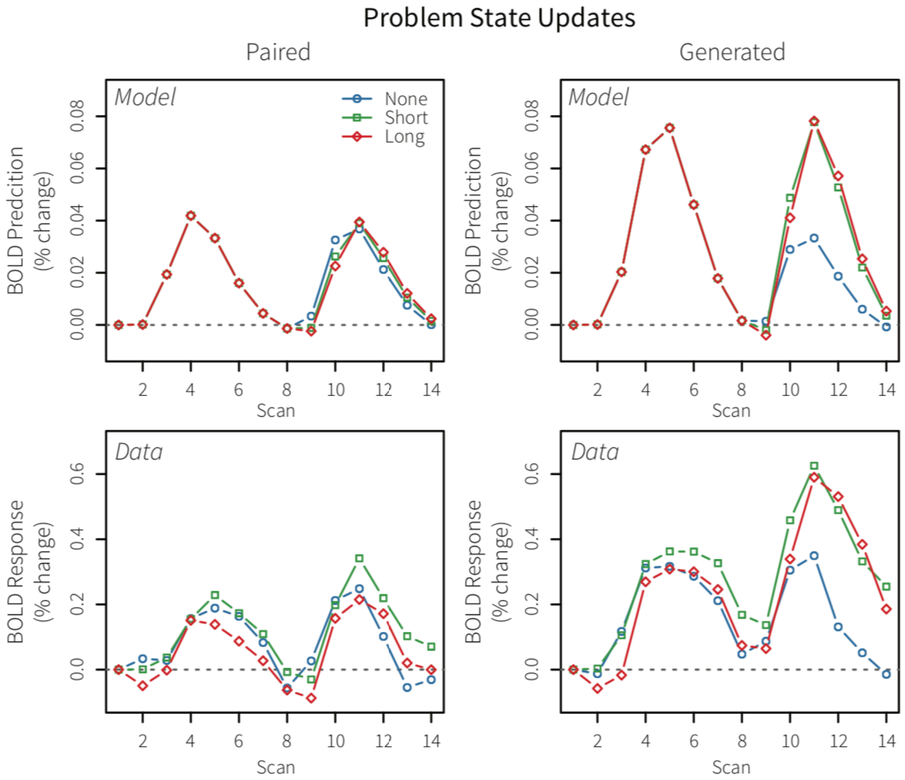
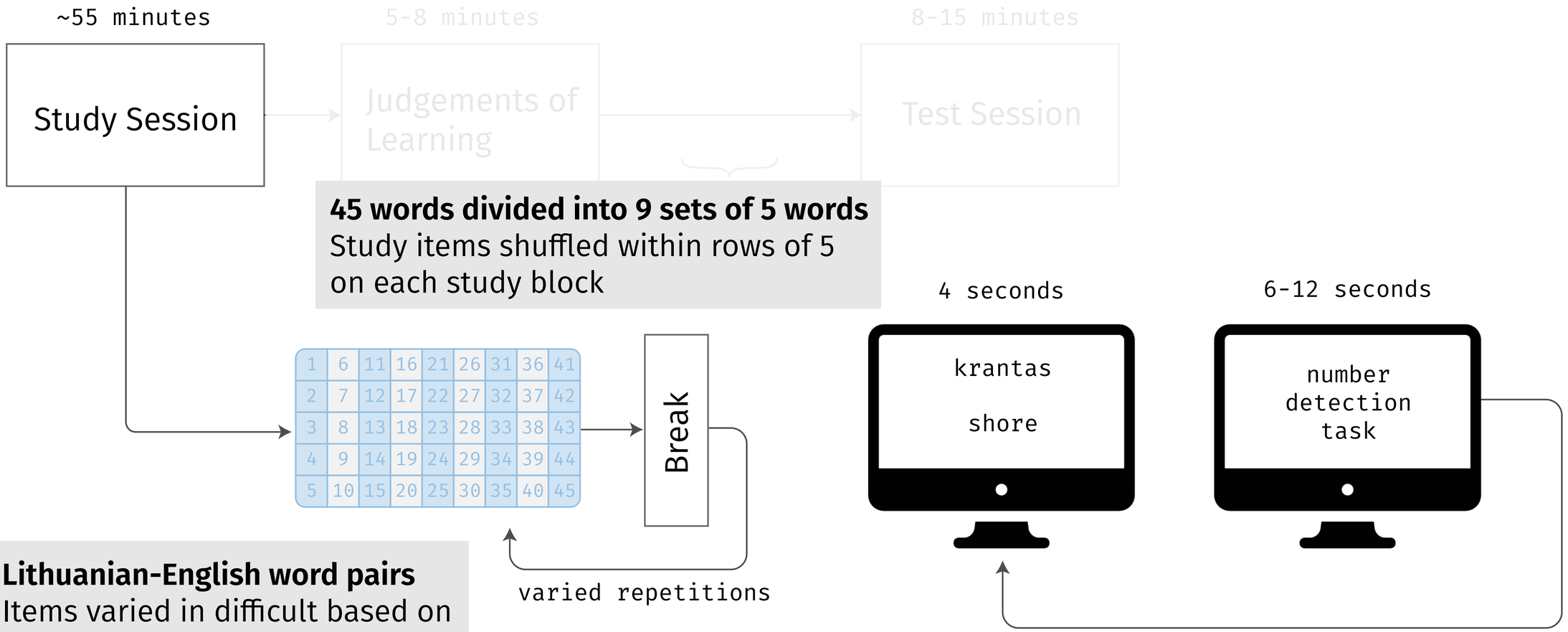


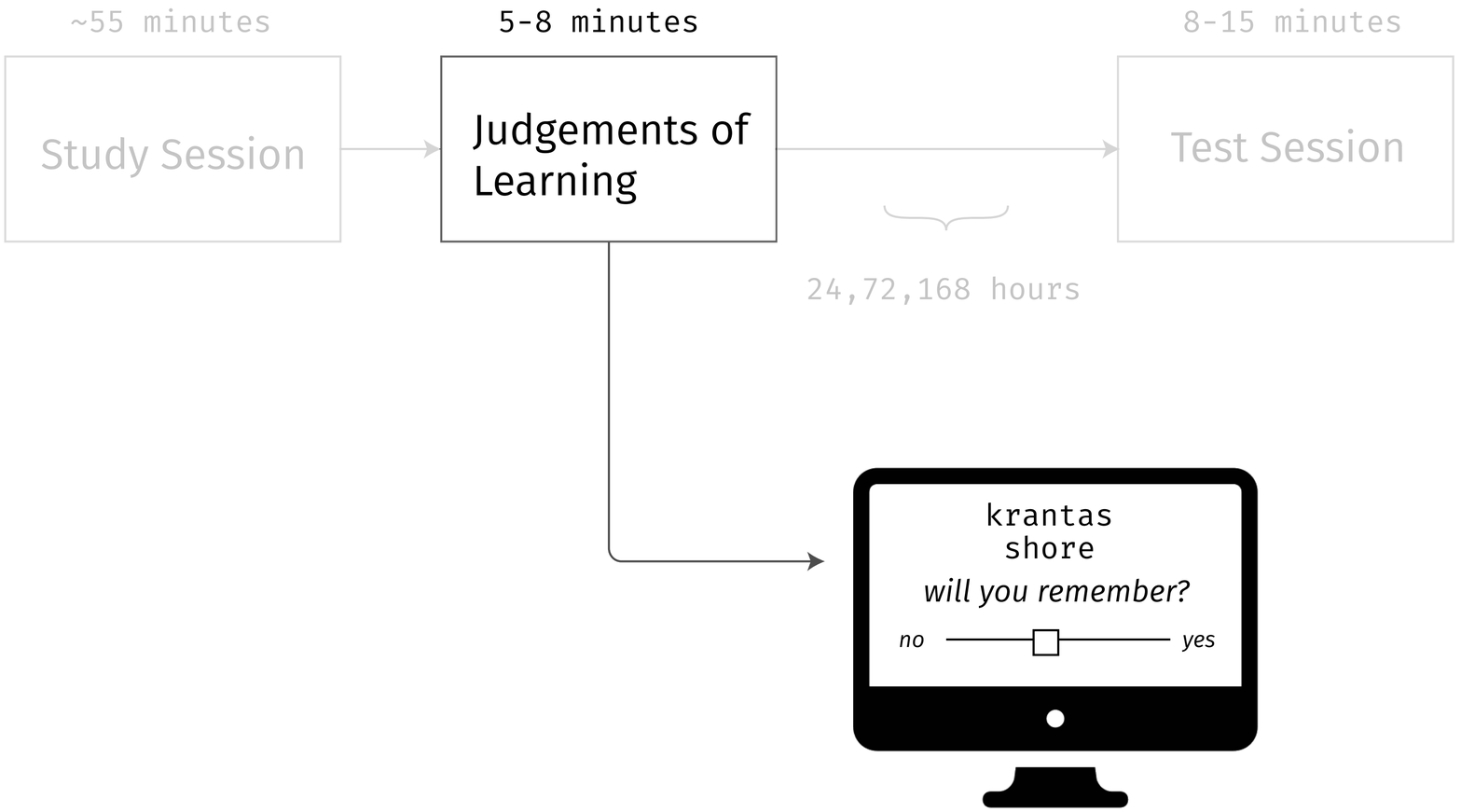
Figure 7. ROI results for problem state updates. Top panels show model predictions; bottom panels data. 1 scan = 2 seconds.

Experiment Design



Lithuanian-English word pairs
Items varied in difficult based on piloting and Grimaldi et al. (2010)

Experiment Design



Experiment Design

~55 minutes

Study Session

5-8 minutes

Judgements of Learning

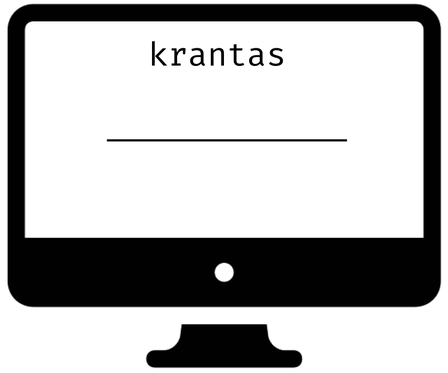
24,72,168 hours

8-15 minutes

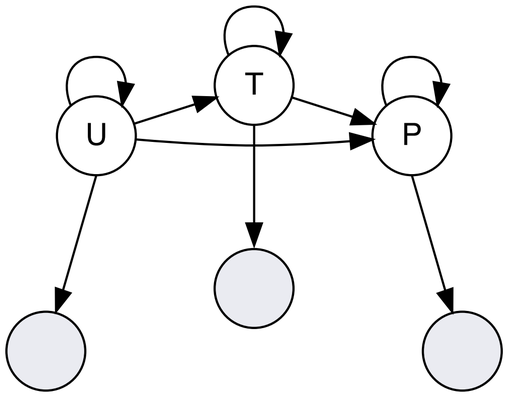
Test Session

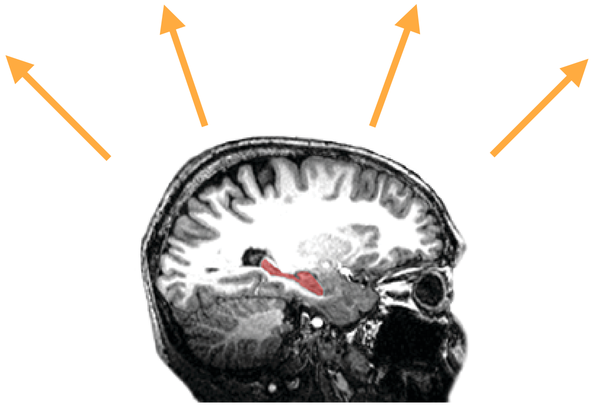
Delay between study and test varied
Different subjects came back on different days, all > 24 hours.

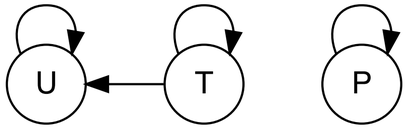
Cued Recall Test
Type out response with keyboard within 12 seconds



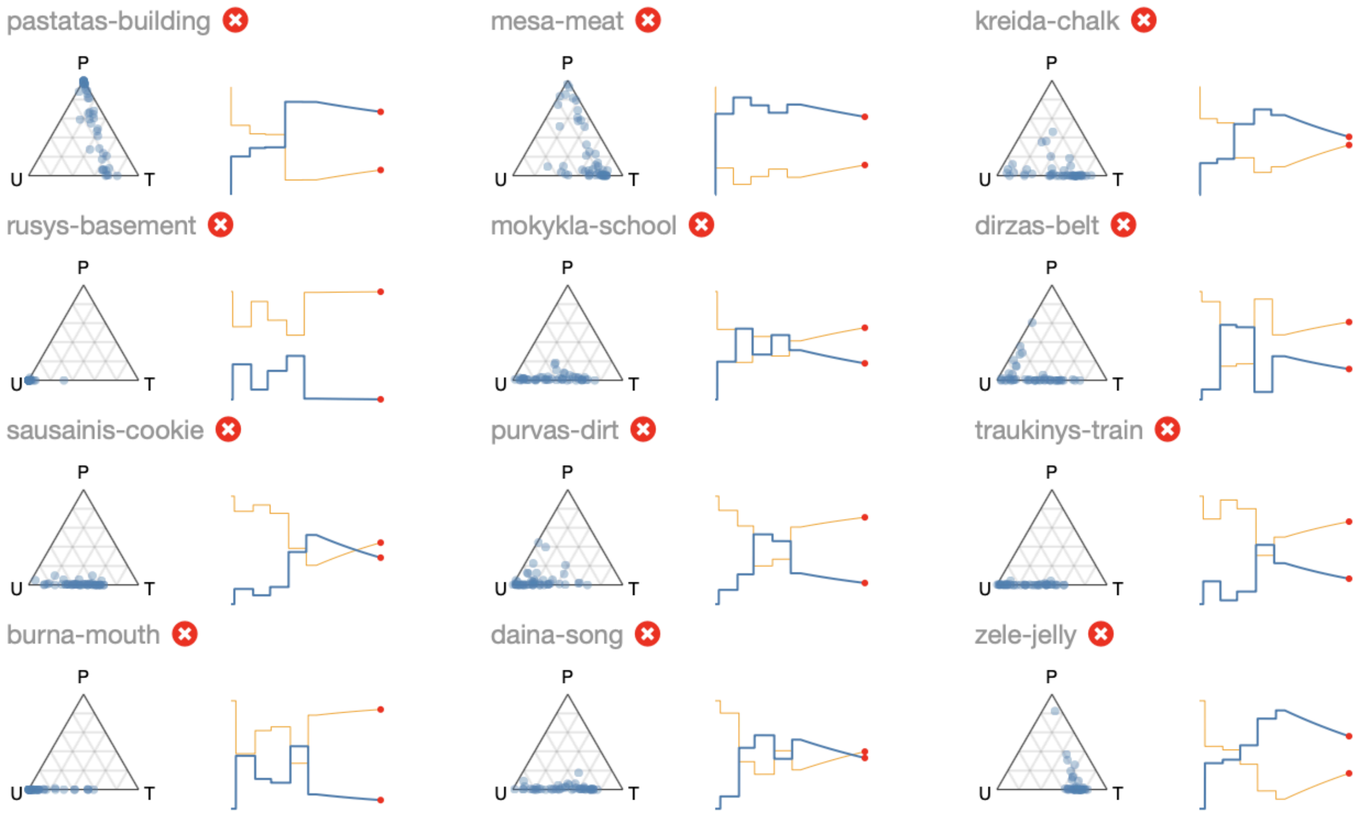
Process decoding





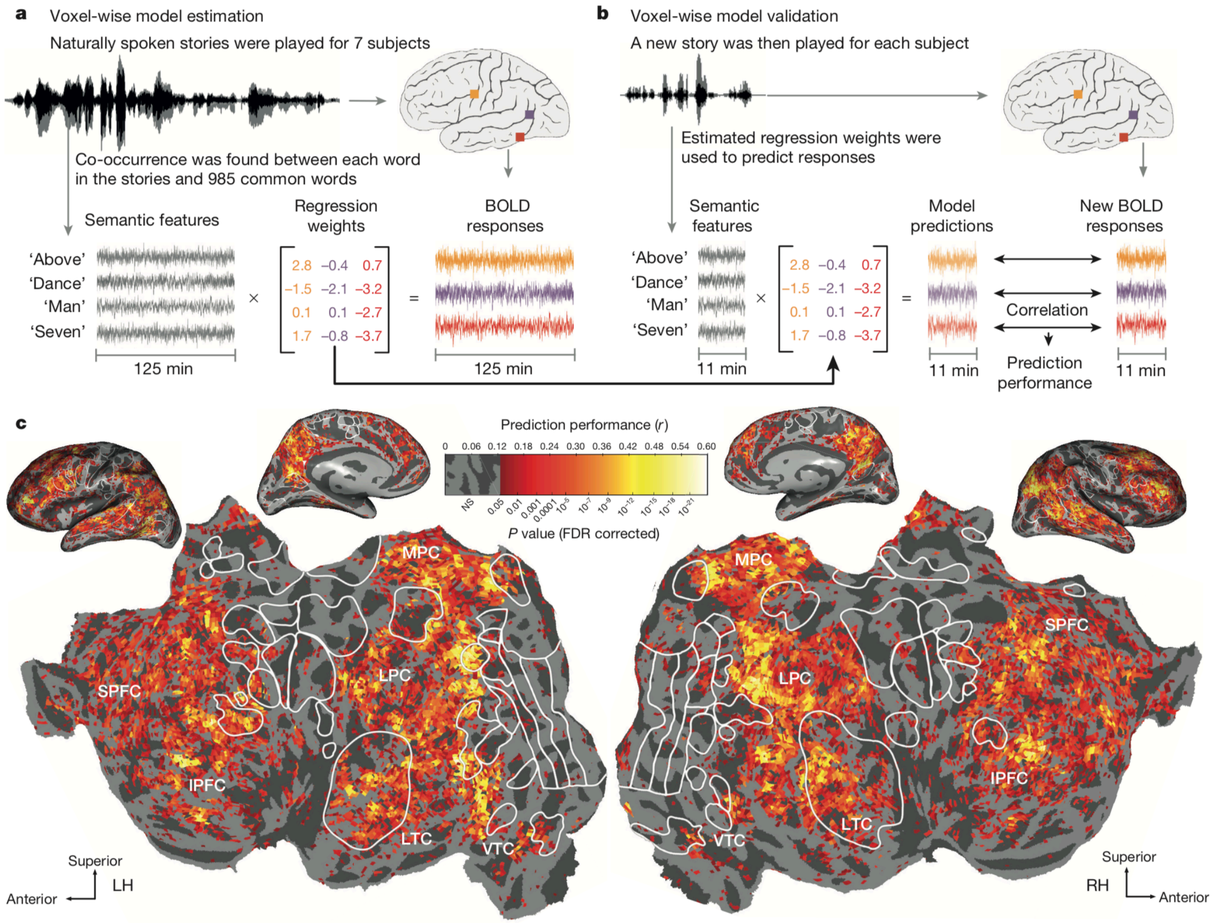


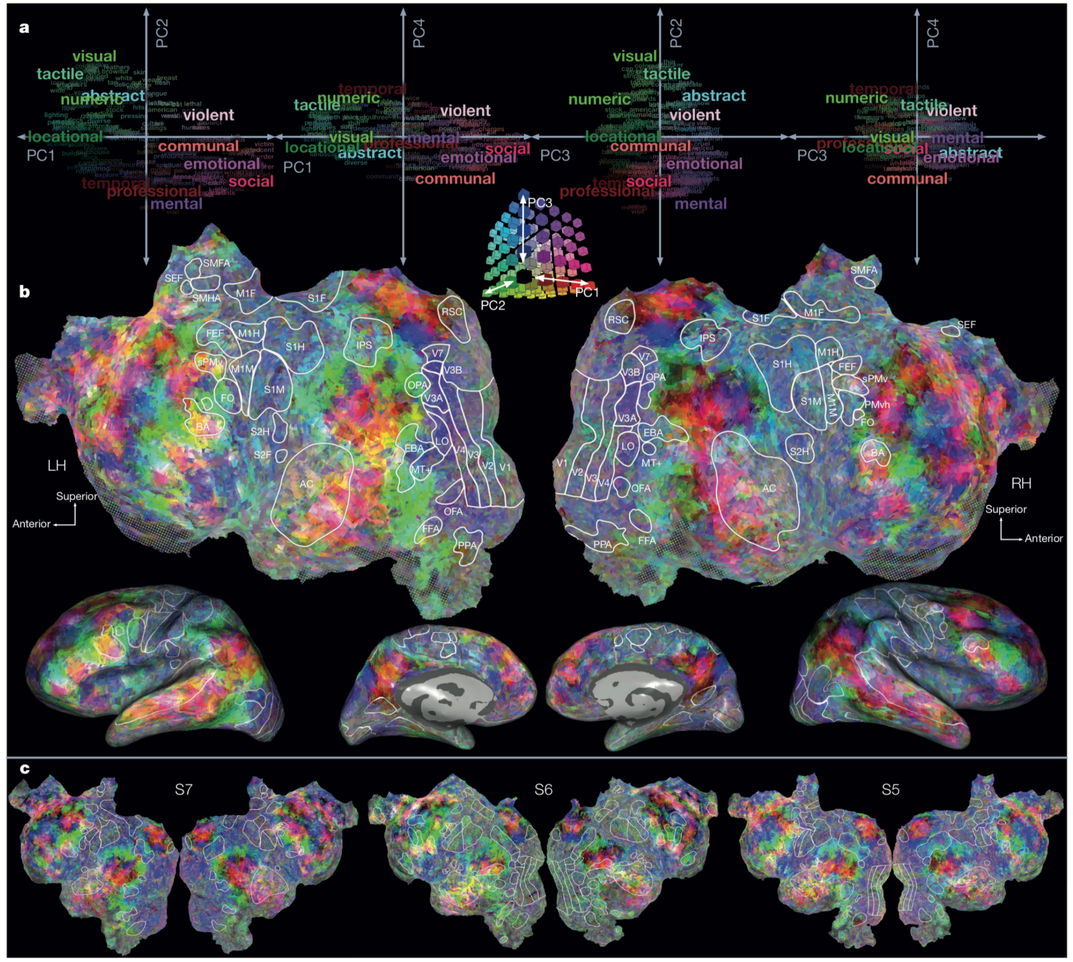
gureckislab.org/omni



Halpern, D., Tubridy, S., Wang, H.Y., Gasser, C., Popp, P.J.O., Davachi, L., & Gureckis, T.M. (2018). Knowledge Tracing Using the Brain. Educational Data Mining 2018. Buffalo, NY.

Brain mapping of semantic space





Natural speech reveals the semantic maps that tile human cerebral cortex

Alexander G. Huth[1], Wendy A. de Heer[2], Thomas L. Griffiths[1,2], Frédéric E. Theunissen[1,2] & Jack L. Gallant[1,2]

Summary

- Cognitive models might provide the bridge between Marr's levels of analyses
- Cognitive models are able to account of behavior (e.g., choices, reaction time) and thus provide strong targets for localizing and interpreting brain data
- Can possibly use brain data to adjust predictions of behavior for individual subjects
- Large scale mapping studies provide insight into the organization of semantic memory in the brain