Inferring mental states from imaging data: OpenfMRI and the Cognitive Atlas

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Two kinds of cognitive neuroscience questions

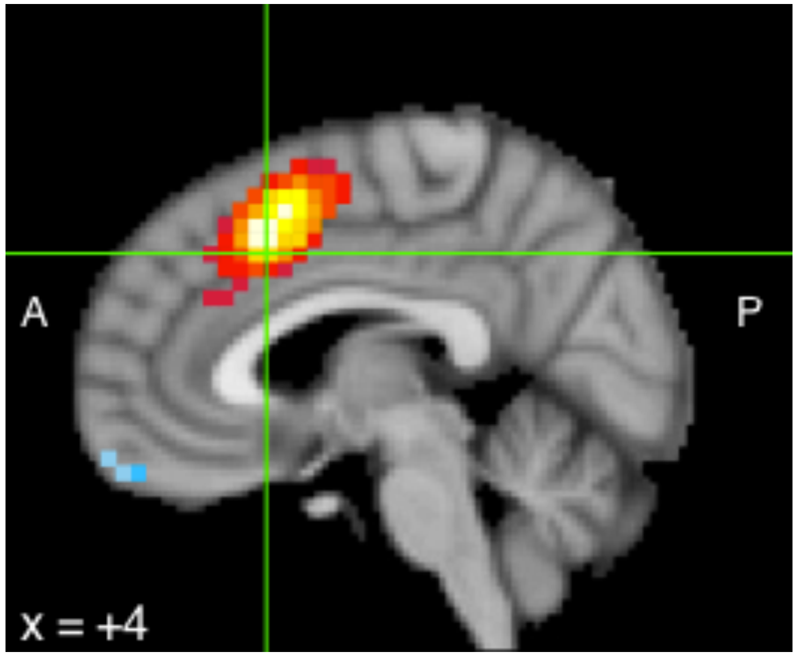
1. What are the neural correlates of mental process X?
2. What does area Z do?

Neural correlates

Manipulate some mental process

Observe associated brain activation

working memory maintenance →



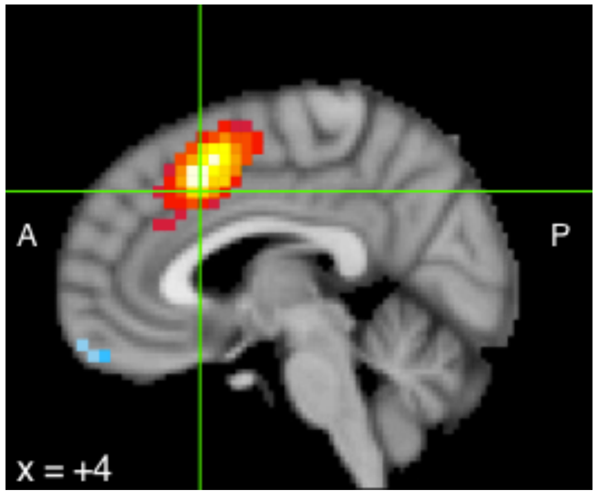
working memory is sufficient to activate ACC

~~working memory is necessary to activate ACC~~

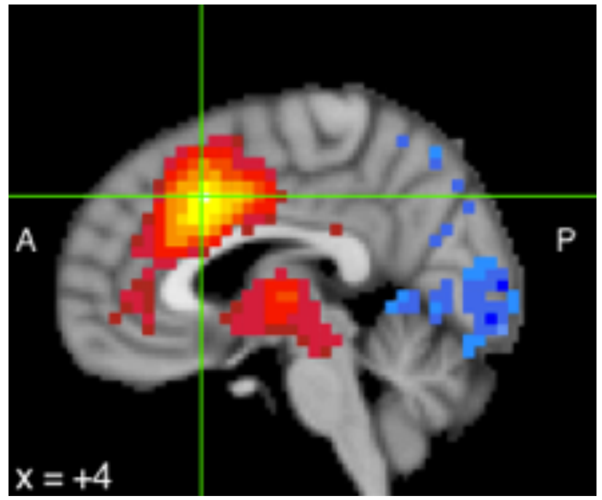
~~ACC is necessary or sufficient for working memory~~

What does the ACC do?

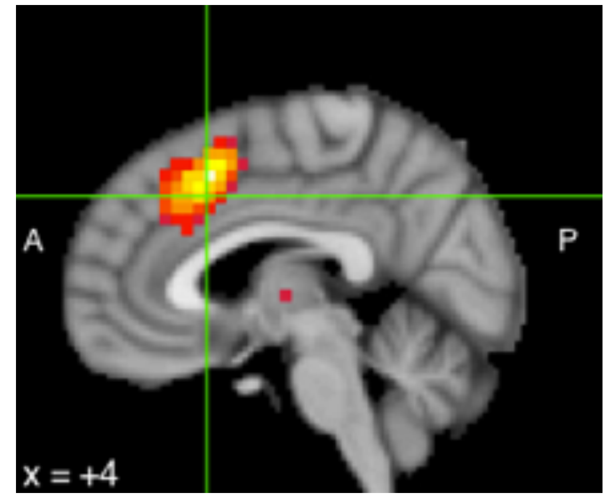
maintenance



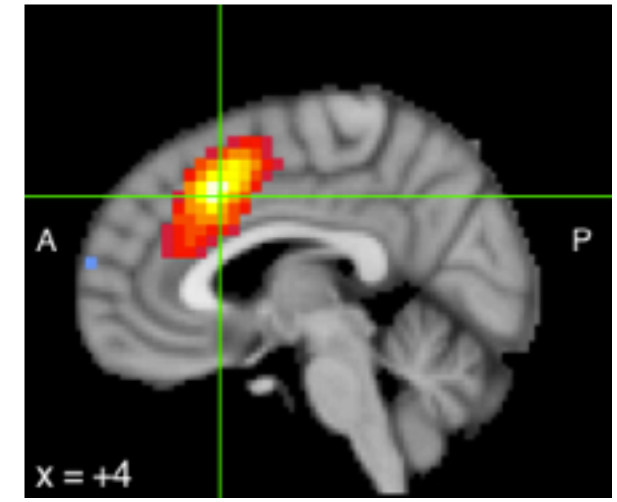
pain



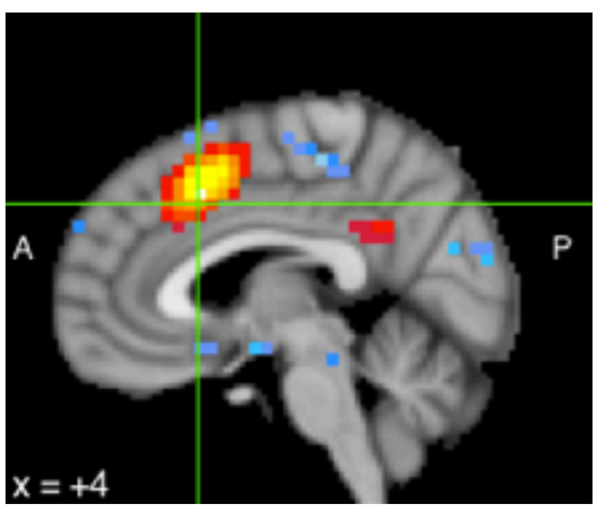
phonology



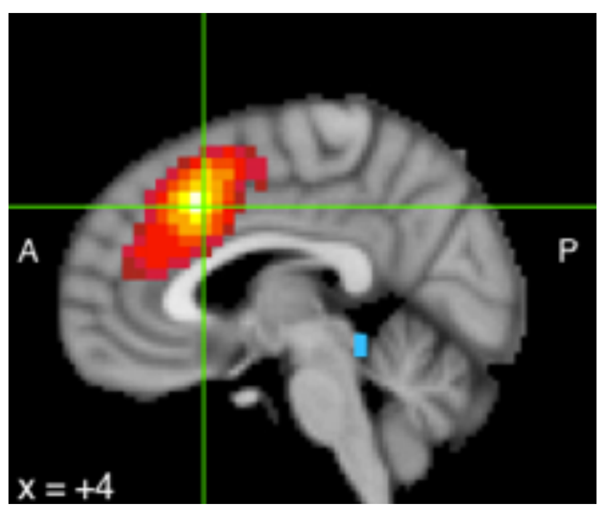
interference



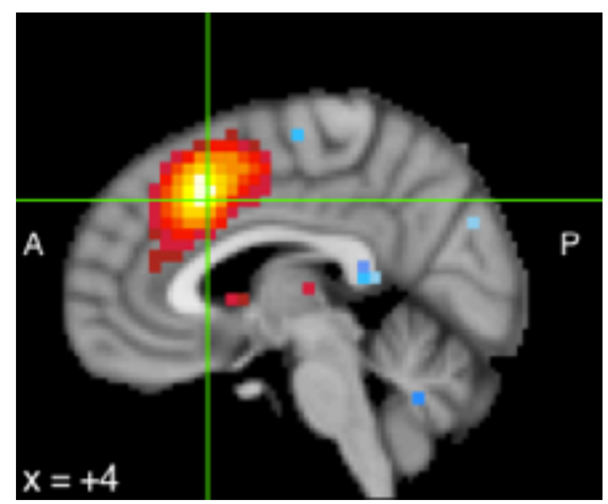
difficulty



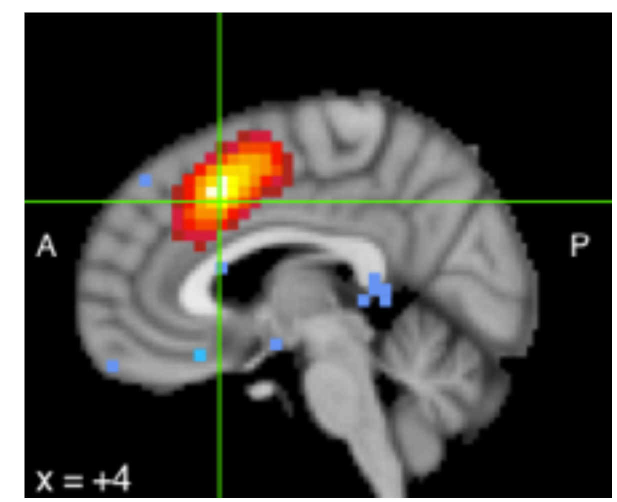
conflict



errors



attention



forward inference Z estimated using neurosynth.org

Some alternatives

- There is some confound driving all of these (such as autonomic arousal or breathing)
- These are all truly distinct functions performed by subsets of neurons in the ACC
- These are all truly distinct functions subserved by ACC in different neural contexts
- These are not truly distinct functions
    - We are chopping up mental function in the wrong way
    - Thought experiment: What if the phrenologists had fMRI?

What if the phrenologists had fMRI?

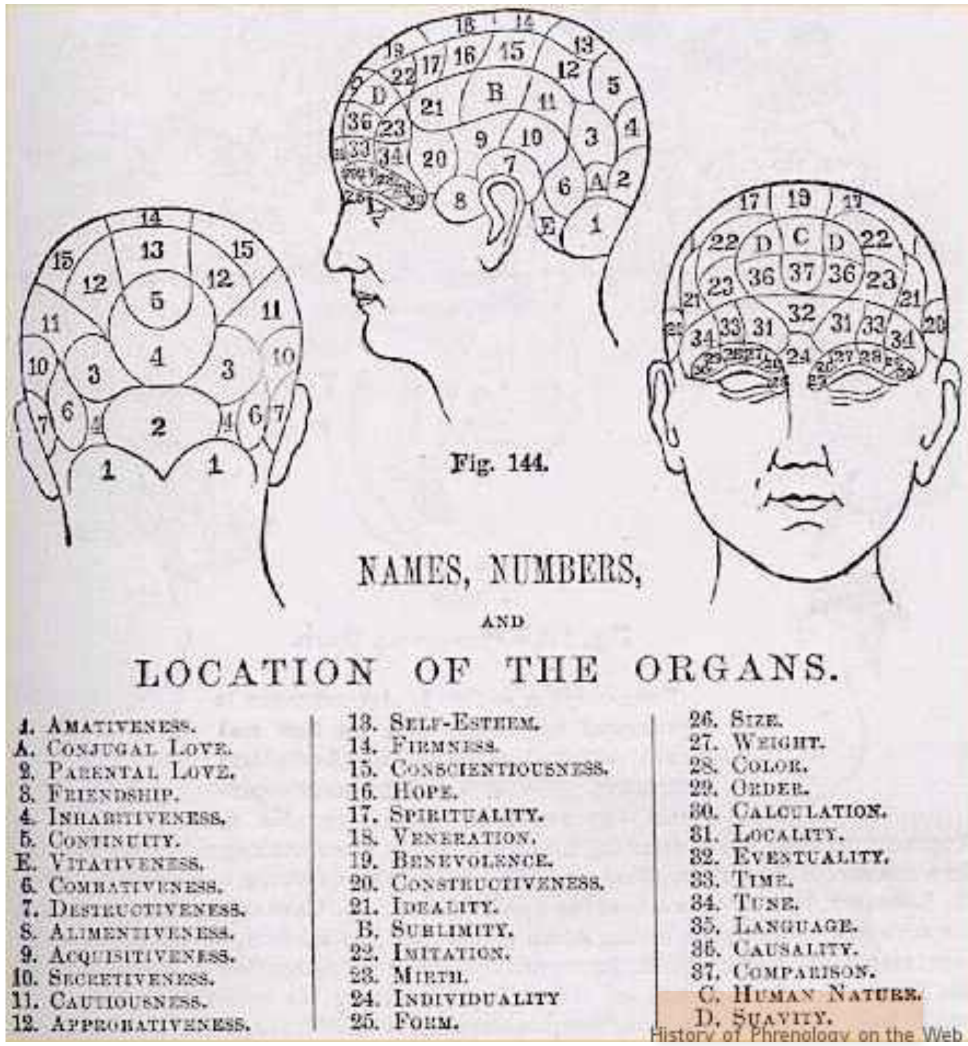


Fig. 144.

NAMES, NUMBERS,

AND

LOCATION OF THE ORGANS.

1. Amativeness.
A. Conjugal Love.
2. Parental Love.
3. Friendship.
4. Inhabitiveness.
5. Continuity.
E. Vitativeness.
6. Combativeness.
7. Destructiveness.
8. Alimentiveness.
9. Acquisitiveness.
10. Secretiveness.
11. Cautiousness.
12. Approbativeness.
13. Self-Esteem.
14. Firmness.
15. Conscientiousness.
16. Hope.
17. Spirituality.
18. Veneration.
19. Benevolence.
20. Constructiveness.
21. Ideality.
B. Sublimity.
22. Imitation.
23. Mirth.
24. Individuality
25. Form.
26. Size.
27. Weight.
28. Color.
29. Order.
30. Calculation.
31. Locality.
32. Eventuality.
33. Time.
34. Tune.
35. Language.
36. Causality.
37. Comparison.
C. Human Nature.
D. Suavity.

History of Phrenology on the Web

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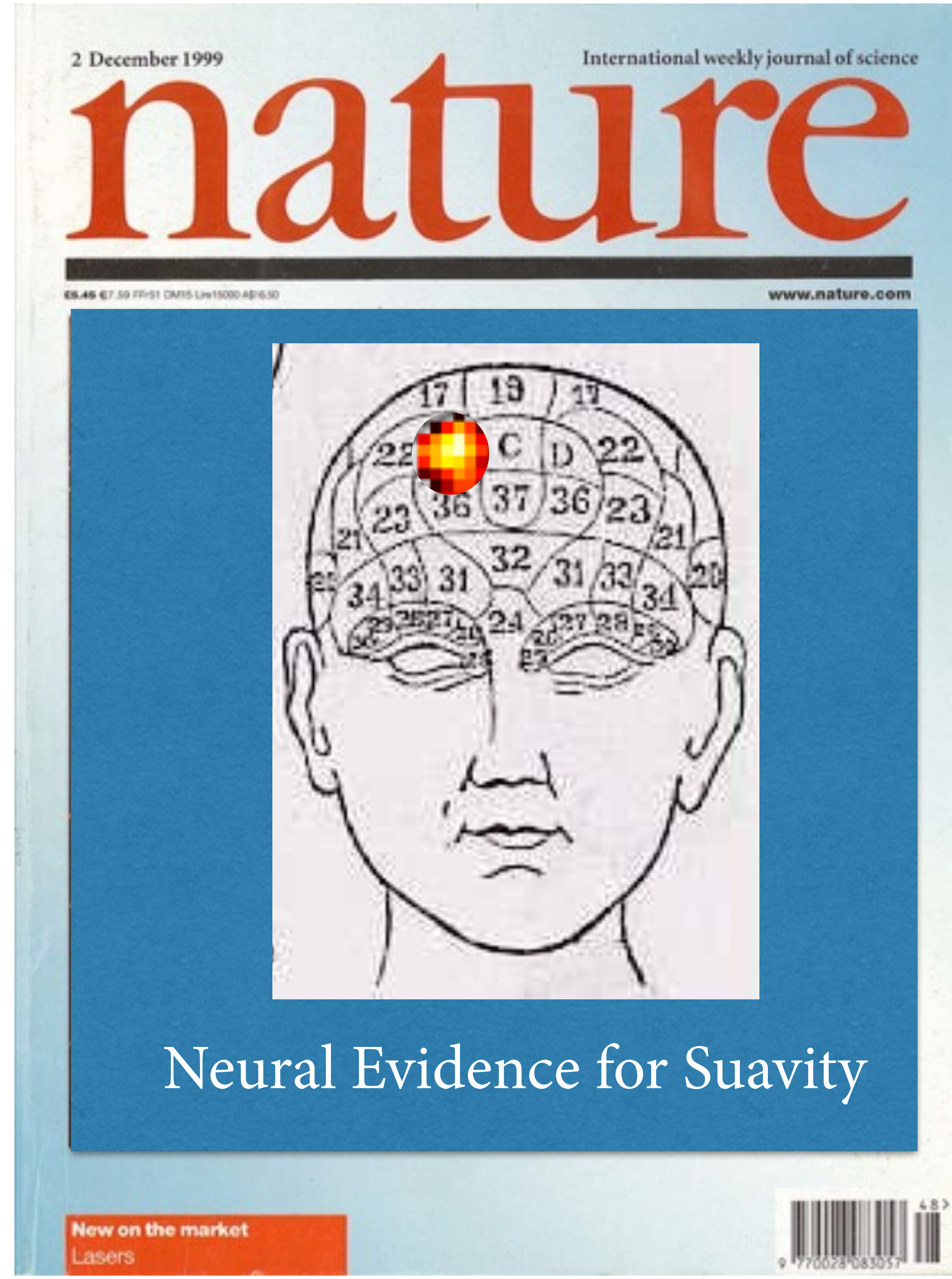
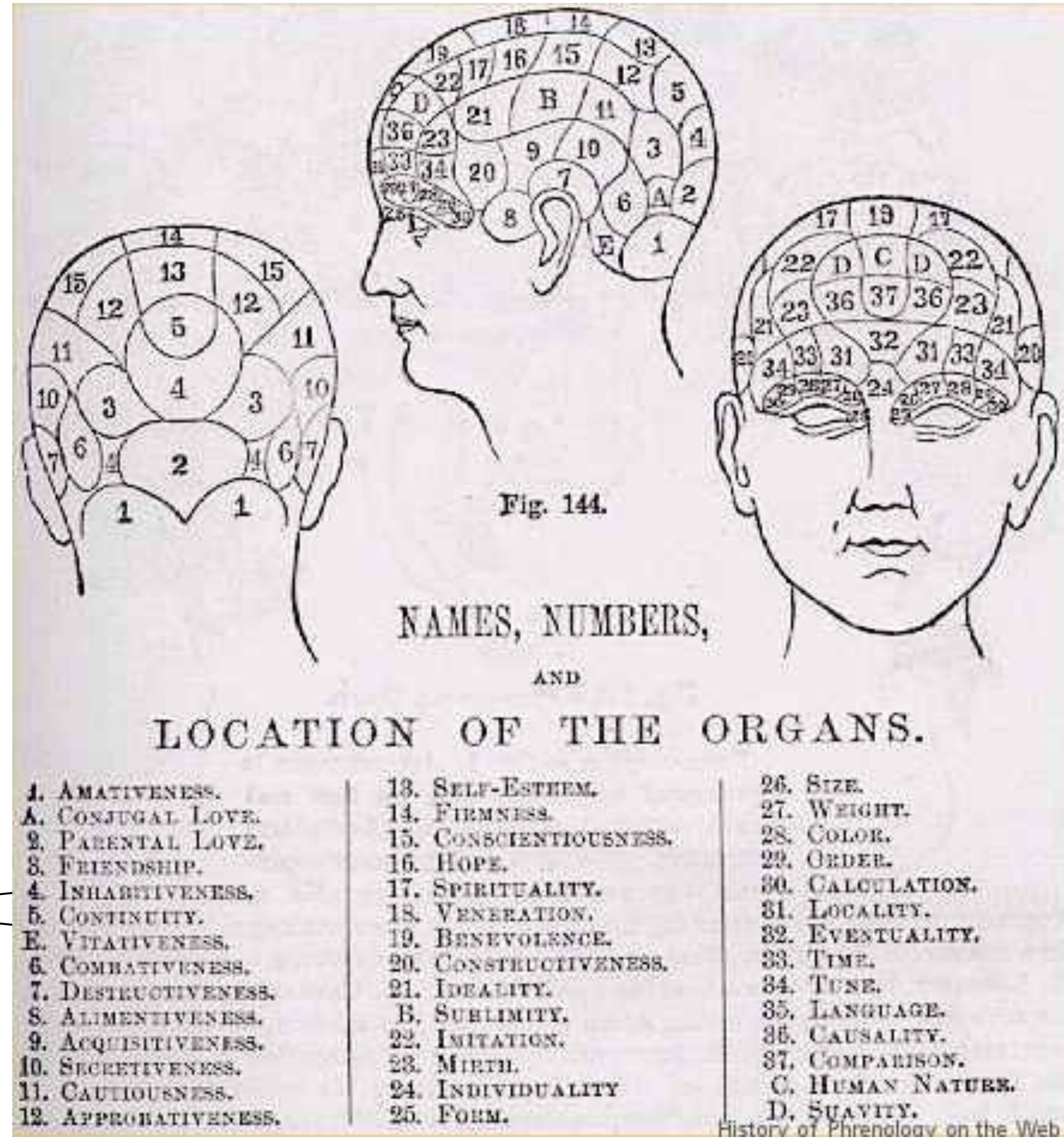
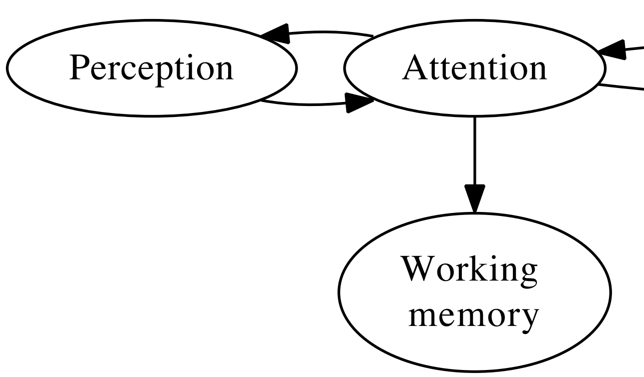
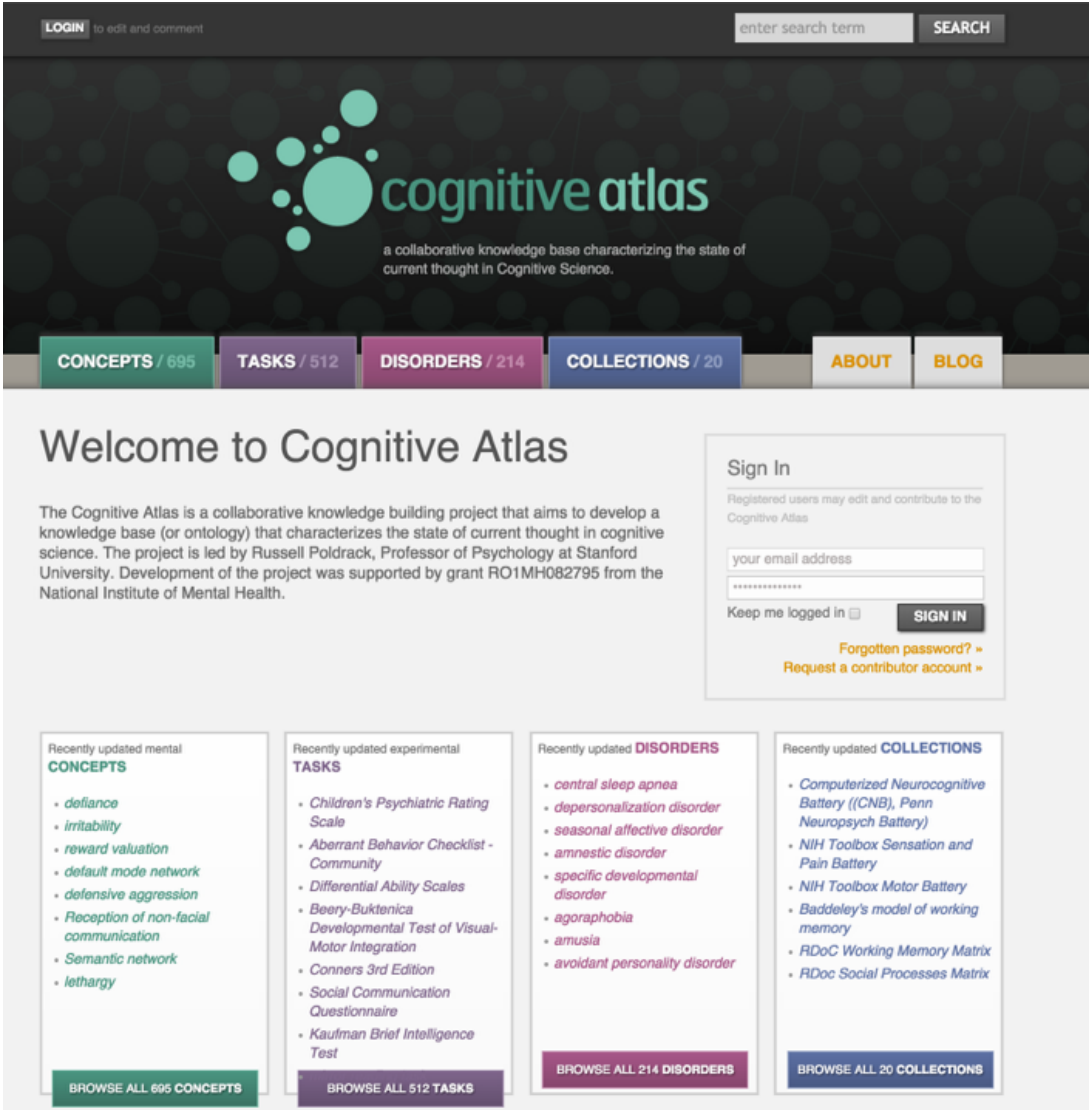


- What are the atoms of the mind?
- How are they related to one another?



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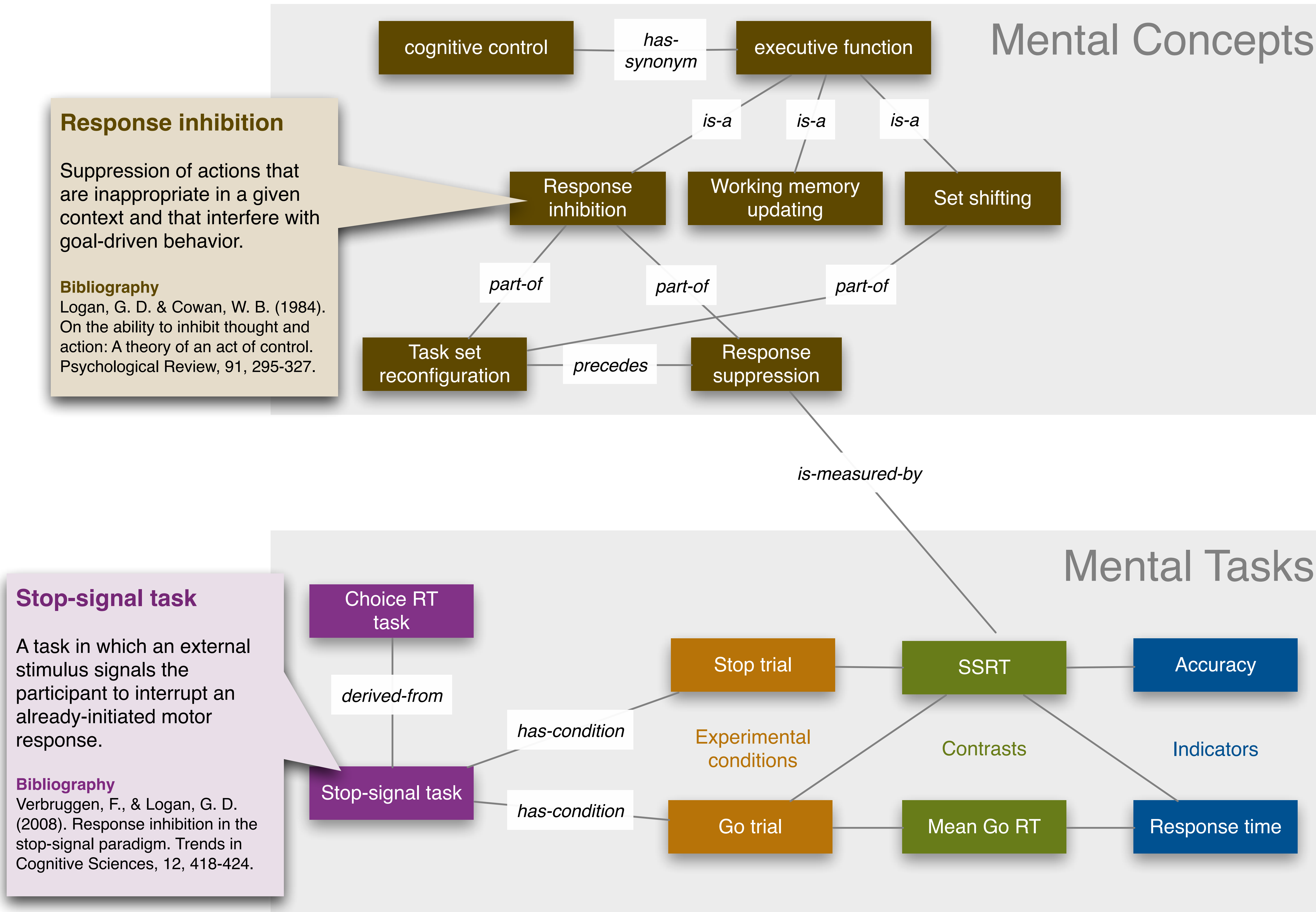
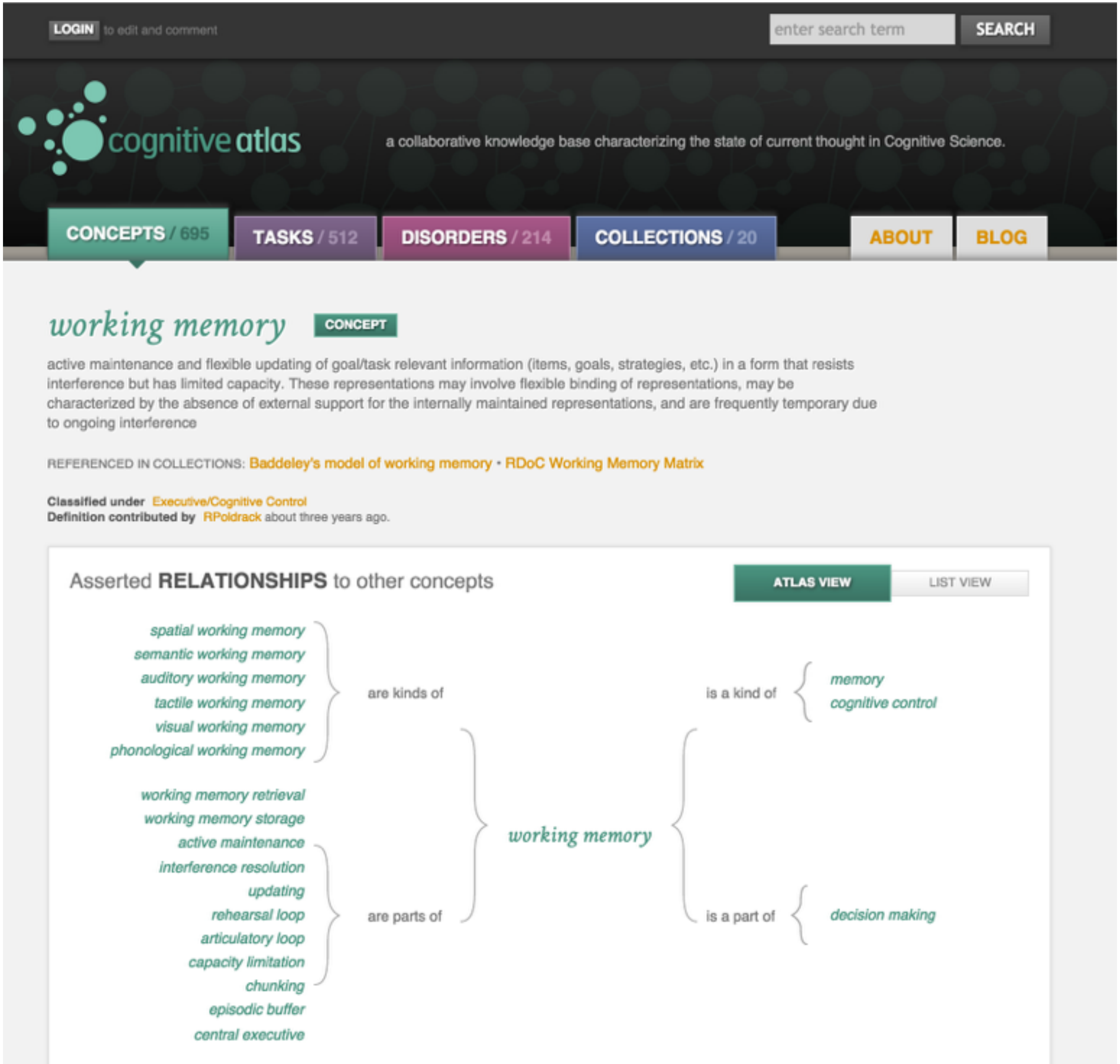
cognitive atlas
a collaborative knowledge base characterizing the state of current thought in Cognitive Science.
CONCEPTS / 695
TASKS / 512
DISORDERS / 214
COLLECTIONS / 20
ABOUT
BLOG
Welcome to Cognitive Atlas
The Cognitive Atlas is a collaborative knowledge building project that aims to develop a knowledge base (or ontology) that characterizes the state of current thought in cognitive science. The project is led by Russell Poldrack, Professor of Psychology at Stanford University. Development of the project was supported by grant RO1MH082795 from the National Institute of Mental Health.
Sign In
Registered users may edit and contribute to the Cognitive Atlas
your email address
Keep me logged in
SIGN IN
Forgotten password? »
Request a contributor account »
Recently updated mental CONCEPTS
defiance
irritability
reward valuation
default mode network
defensive aggression
Reception of non-facial communication
Semantic network
lethargy
BROWSE ALL 695 CONCEPTS
Recently updated experimental TASKS
Children's Psychiatric Rating Scale
Aberrant Behavior Checklist - Community
Differential Ability Scales
Beery-Buktenica Developmental Test of Visual-Motor Integration
Conners 3rd Edition
Social Communication Questionnaire
Kaufman Brief Intelligence Test
BROWSE ALL 512 TASKS
Recently updated DISORDERS
central sleep apnea
depersonalization disorder
seasonal affective disorder
amnestic disorder
specific developmental disorder
agoraphobia
amusia
avoidant personality disorder
BROWSE ALL 214 DISORDERS
Recently updated COLLECTIONS
Computerized Neurocognitive Battery ((CNB), Penn Neuropsych Battery)
NIH Toolbox Sensation and Pain Battery
NIH Toolbox Motor Battery
Baddeley's model of working memory
RDoC Working Memory Matrix
RDoc Social Processes Matrix
BROWSE ALL 20 COLLECTIONS


Mental Concepts
cognitive control
has-synonym
executive function
is-a
is-a
is-a
Response inhibition
Working memory updating
Set shifting
part-of
part-of
part-of
Task set reconfiguration
precedes
Response suppression
Response inhibition
Suppression of actions that are inappropriate in a given context and that interfere with goal-driven behavior.
Bibliography
Logan, G. D. & Cowan, W. B. (1984). On the ability to inhibit thought and action: A theory of an act of control. Psychological Review, 91, 295-327.
is-measured-by
Mental Tasks
Choice RT task
derived-from
Stop-signal task
has-condition
has-condition
Stop trial
Go trial
Experimental conditions
SSRT
Mean Go RT
Contrasts
Accuracy
Response time
Indicators
Stop-signal task
A task in which an external stimulus signals the participant to interrupt an already-initiated motor response.
Bibliography
Verbruggen, F., & Logan, G. D. (2008). Response inhibition in the stop-signal paradigm. Trends in Cognitive Sciences, 12, 418-424.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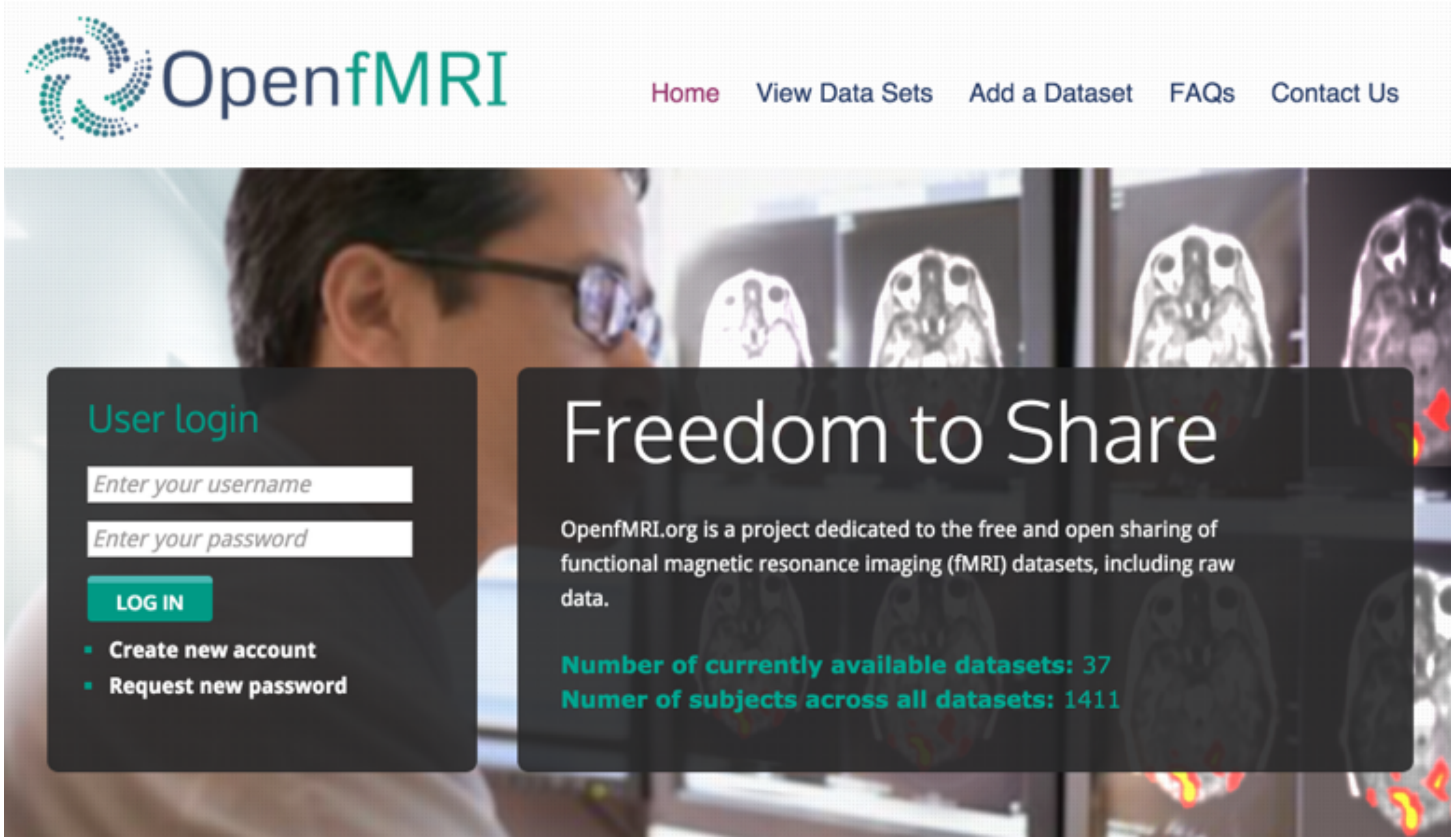
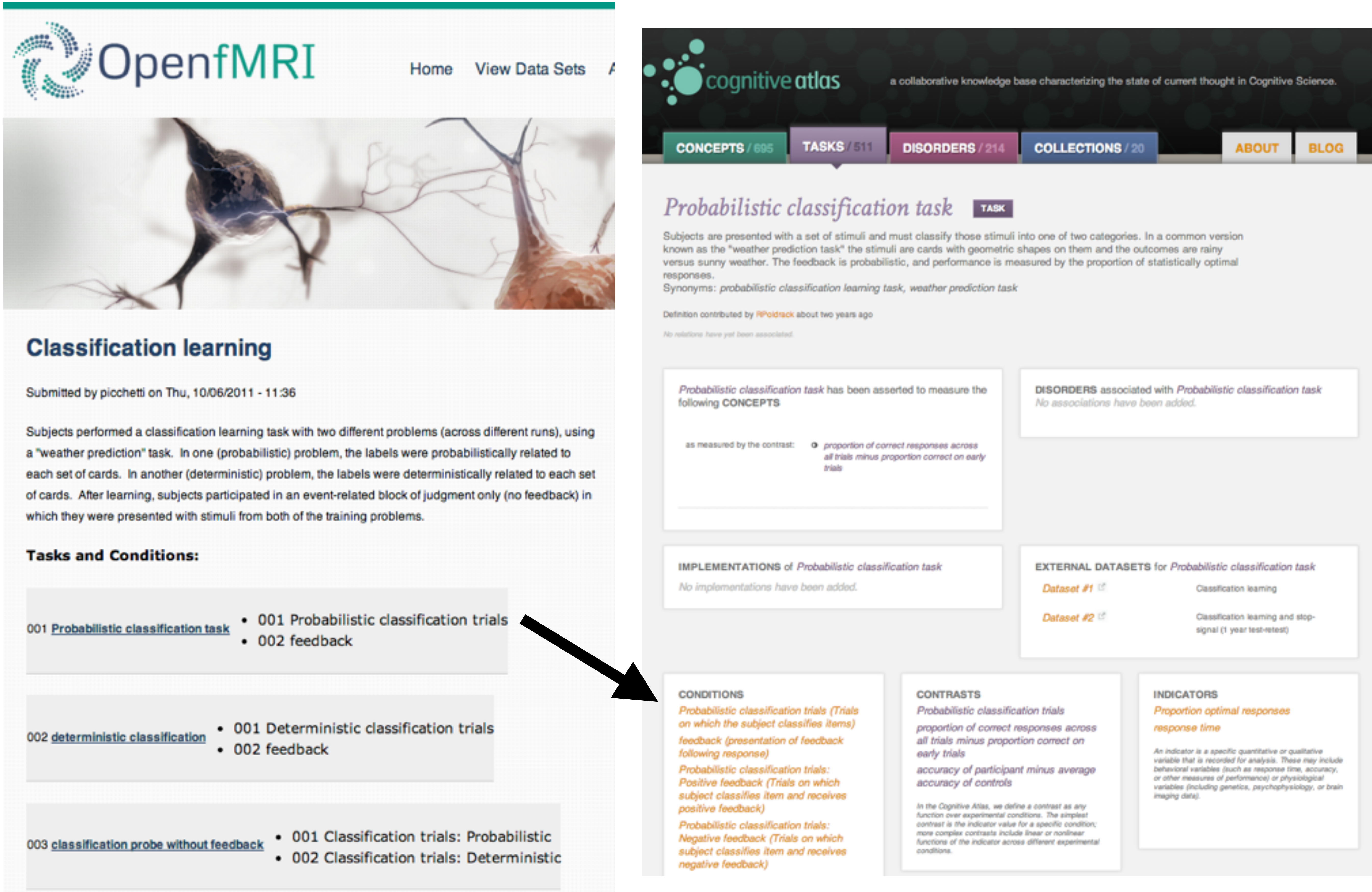
working memory
CONCEPT
active maintenance and flexible updating of goal/task relevant information (items, goals, strategies, etc.) in a form that resists interference but has limited capacity. These representations may involve flexible binding of representations, may be characterized by the absence of external support for the internally maintained representations, and are frequently temporary due to ongoing interference
REFERENCED IN COLLECTIONS: Baddeley's model of working memory • RDoC Working Memory Matrix
Classified under Executive/Cognitive Control
Definition contributed by RPoldrack about three years ago.
Asserted RELATIONSHIPS to other concepts
ATLAS VIEW
LIST VIEW
spatial working memory
semantic working memory
auditory working memory
tactile working memory
visual working memory
phonological working memory
are kinds of
is a kind of
memory
cognitive control
working memory retrieval
working memory storage
active maintenance
interference resolution
updating
rehearsal loop
articulatory loop
capacity limitation
chunking
episodic buffer
central executive
are parts of
working memory
is a part of
decision making

Current state of the Cognitive Atlas

- 771 mental constructs
- 610 tasks
- 214 disorders (inherited from Disease Ontology)
- 22 collections
- Formal ontology (OWL) available via BioPortal

Annotating data using the Cognitive Atlas




OpenfMRI
Home
View Data Sets
Classification learning
Submitted by picchetti on Thu, 10/06/2011 - 11:36
Subjects performed a classification learning task with two different problems (across different runs), using a "weather prediction" task. In one (probabilistic) problem, the labels were probabilistically related to each set of cards. In another (deterministic) problem, the labels were deterministically related to each set of cards. After learning, subjects participated in an event-related block of judgment only (no feedback) in which they were presented with stimuli from both of the training problems.
Tasks and Conditions:
001 Probabilistic classification task
• 001 Probabilistic classification trials
• 002 feedback
002 deterministic classification
• 001 Deterministic classification trials
• 002 feedback
003 classification probe without feedback
• 001 Classification trials: Probabilistic
• 002 Classification trials: Deterministic
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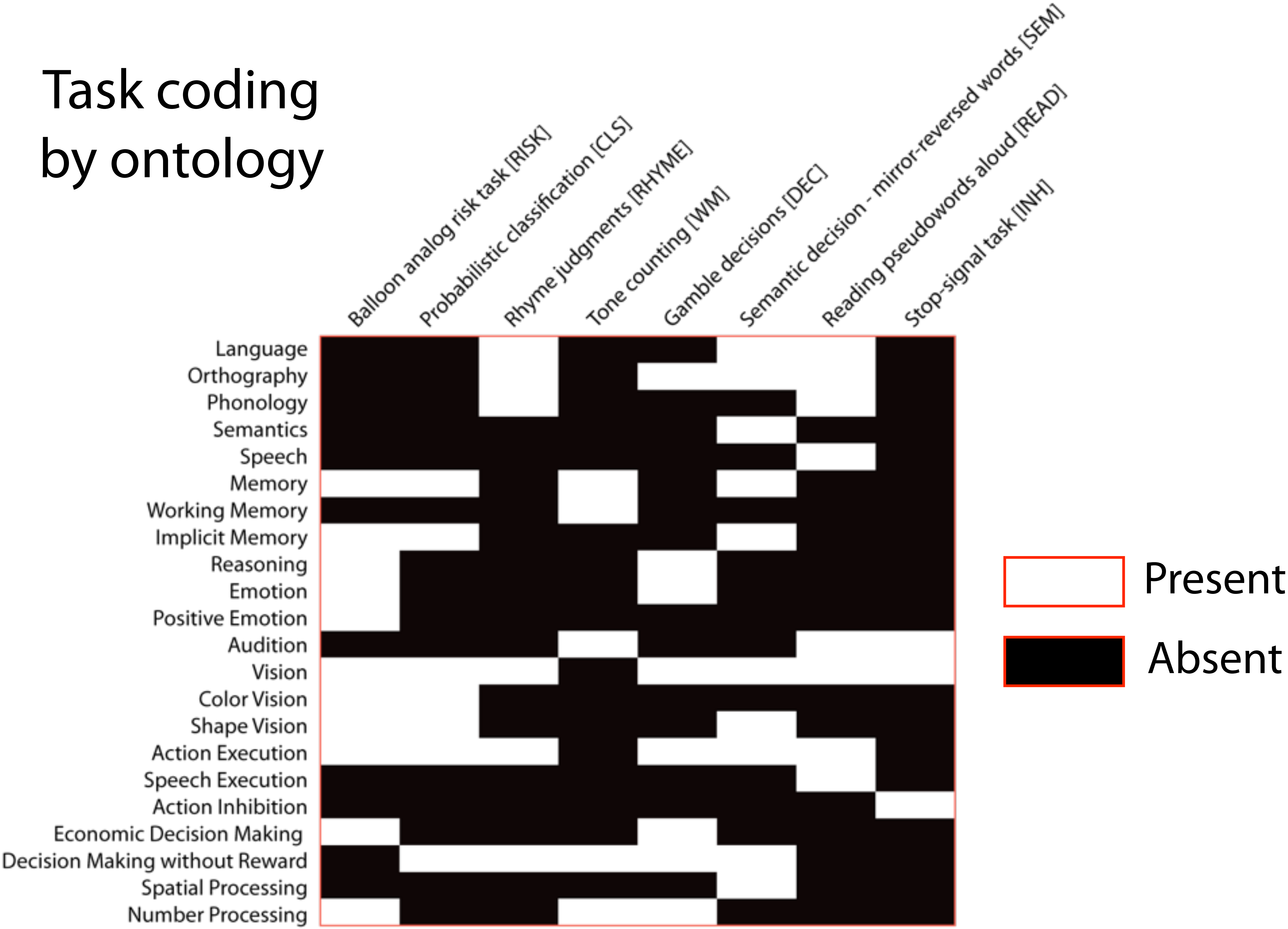
Probabilistic classification task
TASK
Subjects are presented with a set of stimuli and must classify those stimuli into one of two categories. In a common version known as the "weather prediction task" the stimuli are cards with geometric shapes on them and the outcomes are rainy versus sunny weather. The feedback is probabilistic, and performance is measured by the proportion of statistically optimal responses.
Synonyms: probabilistic classification learning task, weather prediction task
Definition contributed by RPoldrack about two years ago
No relations have yet been associated.
Probabilistic classification task has been asserted to measure the following CONCEPTS
as measured by the contrast:
proportion of correct responses across all trials minus proportion correct on early trials
DISORDERS associated with Probabilistic classification task
No associations have been added.
IMPLEMENTATIONS of Probabilistic classification task
No implementations have been added.
EXTERNAL DATASETS for Probabilistic classification task
Dataset #1
Classification learning
Dataset #2
Classification learning and stop-signal (1 year test-retest)
CONDITIONS
Probabilistic classification trials (Trials on which the subject classifies items)
feedback (presentation of feedback following response)
Probabilistic classification trials: Positive feedback (Trials on which subject classifies item and receives positive feedback)
Probabilistic classification trials: Negative feedback (Trials on which subject classifies item and receives negative feedback)
CONTRASTS
Probabilistic classification trials
proportion of correct responses across all trials minus proportion correct on early trials
accuracy of participant minus average accuracy of controls
INDICATORS
Proportion optimal responses
response time

An initial proof of concept

- Obtain brain imaging data from a broad range of mental tasks
  - In this case, 130 people doing one of 8 different tasks
- Code the the tasks using a preliminary cognitive ontology
- Map the brain systems onto the ontology

Task coding by ontology



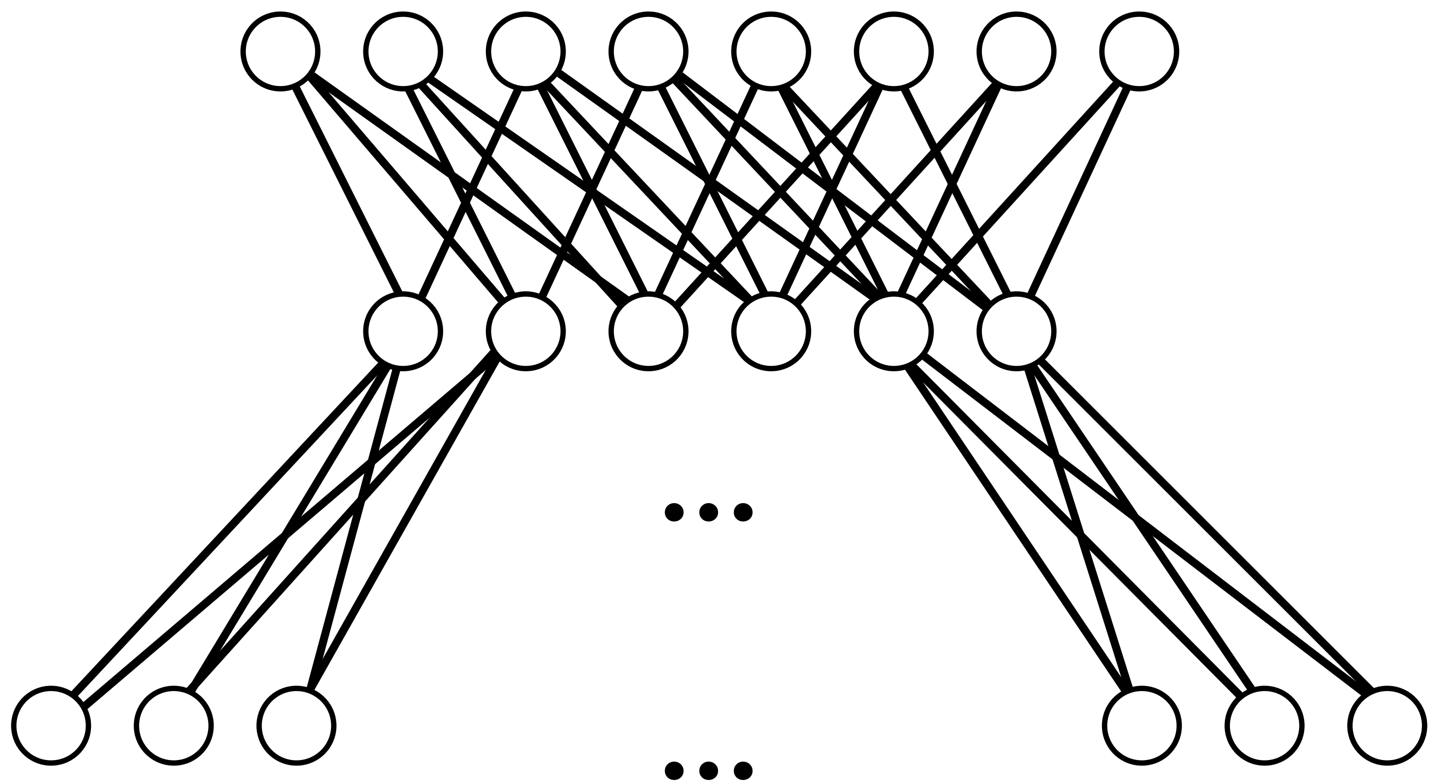
Poldrack, Halchenko, & Hanson, 2009

Artificial neural network classifier

Output: Which of the 8 tasks was the person performing?

6 hidden units

Input: brain activity at ~2000 locations

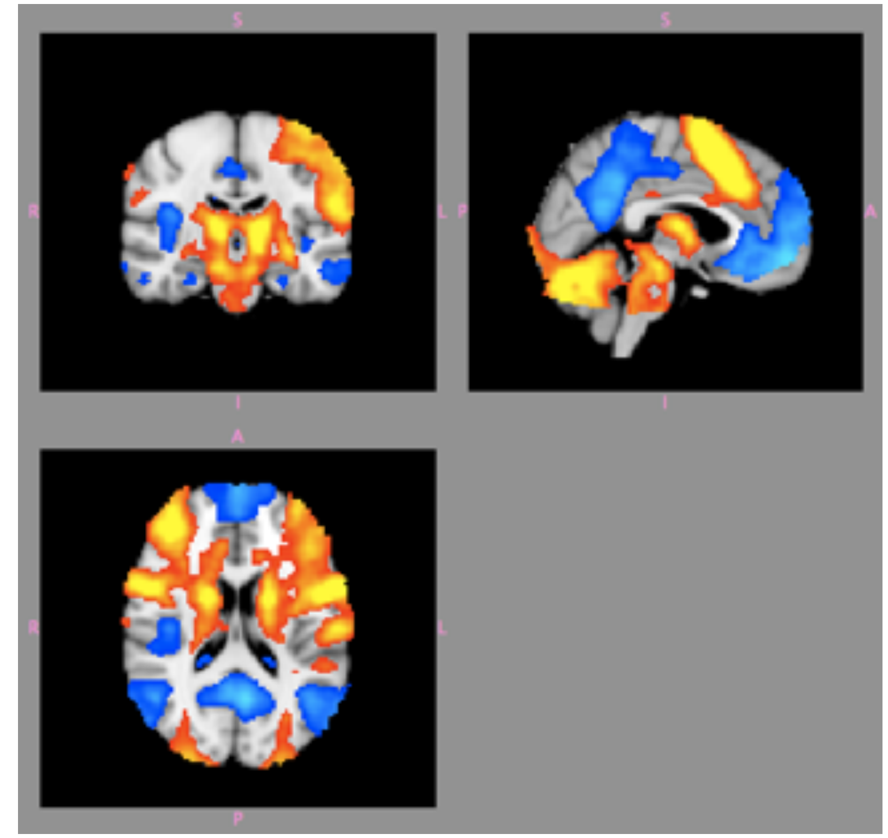


Use hidden unit patterns as low-dimensional representation for each subject

Poldrack, Halchenko, & Hanson, 2009

Analysis	Crossvalidated accuracy	# of voxels included
Union of all in-mask voxels across subjects (one-vs-one)	74%	417,231
Intersection of in-mask voxels across subjects (one-vs-many)	80.8%	214,940
Positively activated voxels only (across all 130 subjects, t > 3, p<. 002) (one-vs-many)	74.6%	83,825
Deactivated voxels only (t < -3, p<.002) (one-vs-many)	50.8%	23,736

Accuracy above 18.5% is significant at p<.05 by randomization

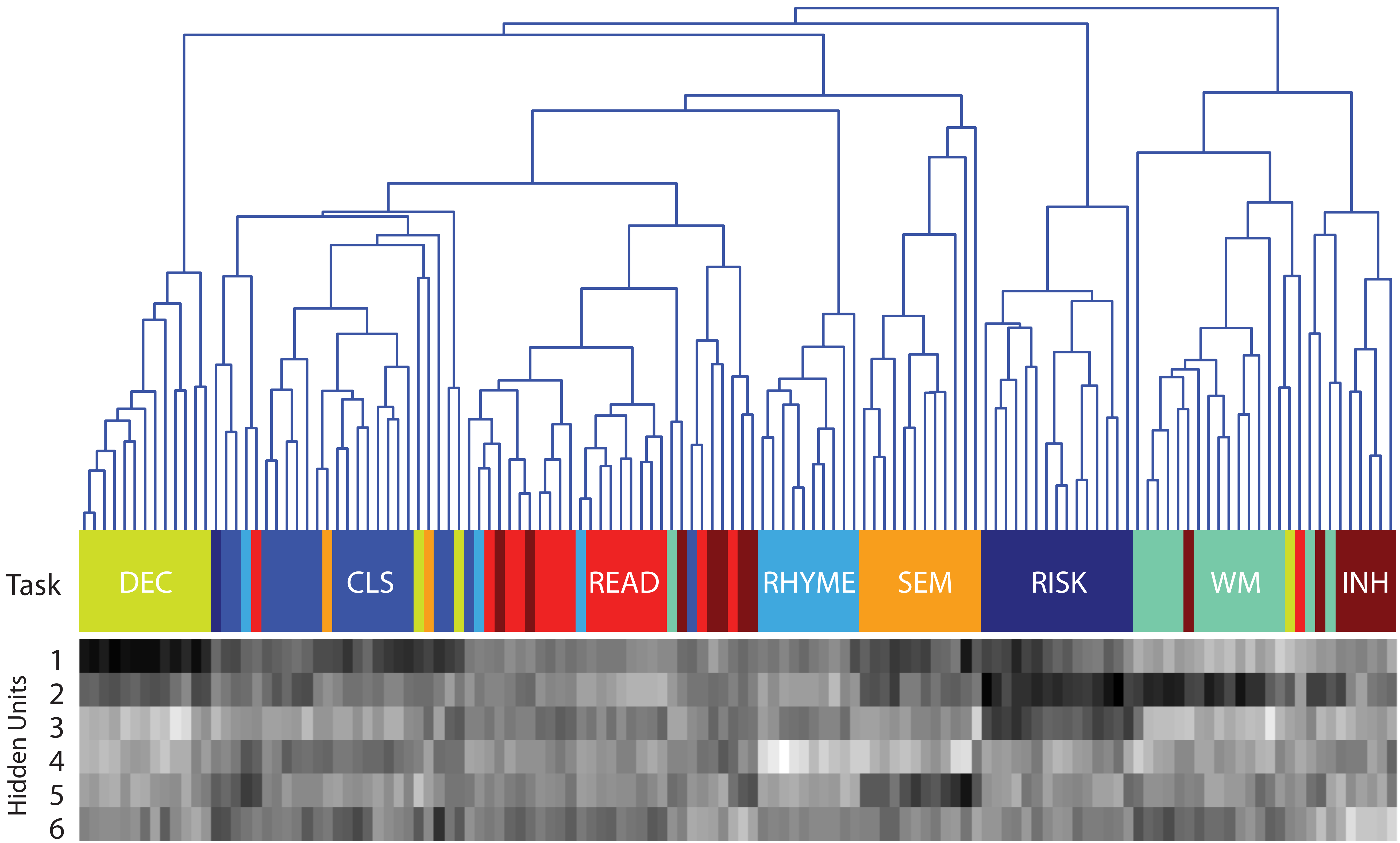


Task chosen by classfier

True task

	Task 1	Task 2	Task 3	Task 4	Task 5	Task 6	Task 7	Task 8
Task 1	**87.5**	6.0	0.0	0.0	6.0	0.0	0.0	0.0
Task 2	0.0	**90.0**	0.0	0.0	0.0	0.0	5.0	5.0
Task 3	8.0	23.0	**61.5**	0.0	0.0	8.0	0.0	0.0
Task 4	0.0	0.0	0.0	**82.4**	0.0	0.0	0.0	18.0
Task 5	0.0	38.0	0.0	0.0	**43.8**	18.2	0.0	0.0
Task 6	0.0	28.0	0.0	0.0	0.0	**71.4**	0.0	0.0
Task 7	0.0	11.0	0.0	0.0	0.0	0.0	**84.0**	5.0
Task 8	0.0	0.0	7.0	0.0	0.0	0.0	27.0	**63.0**

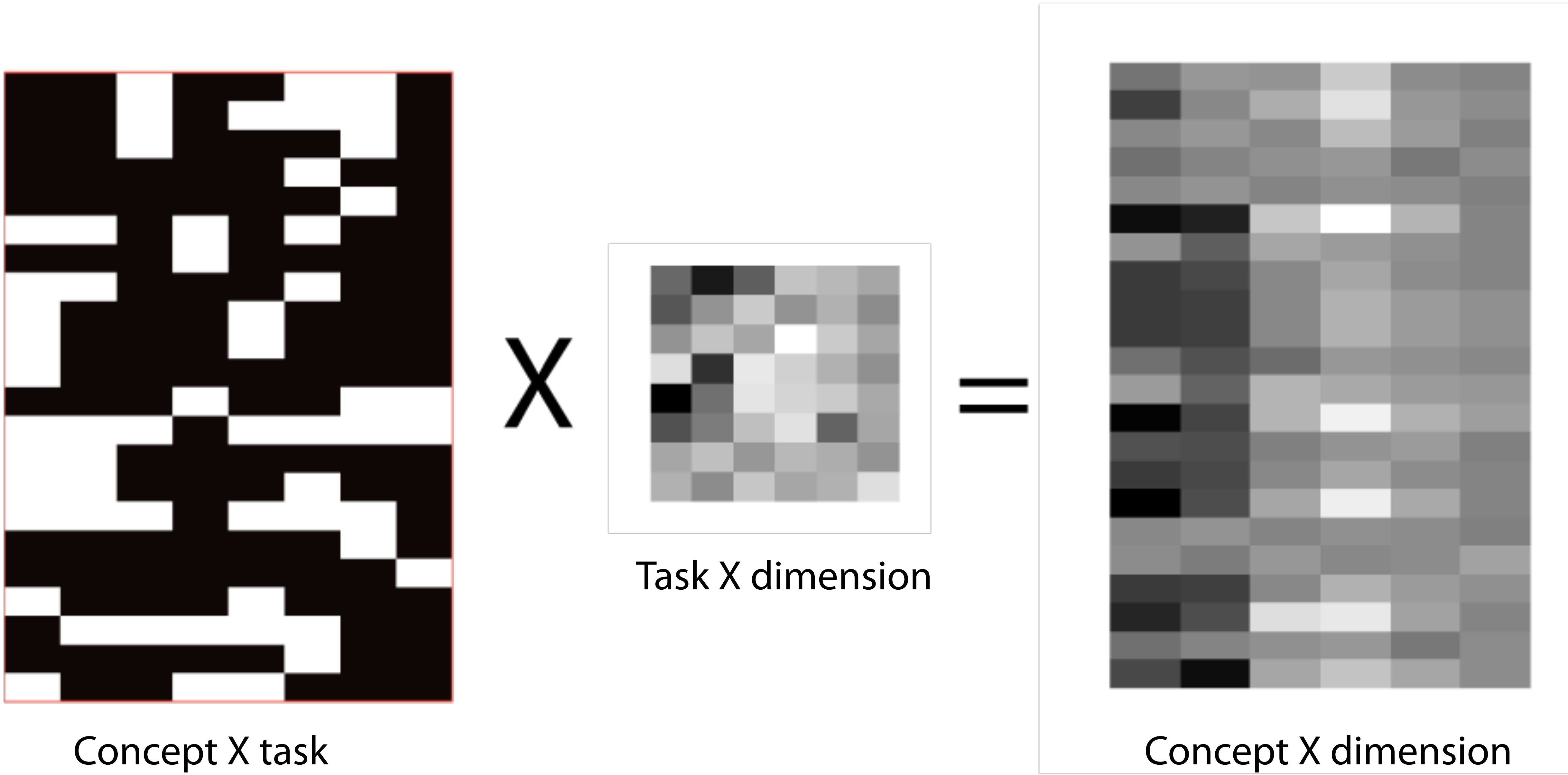
Poldrack, Halchenko, & Hanson, 2009



Hierarchical clustering on hidden unit values

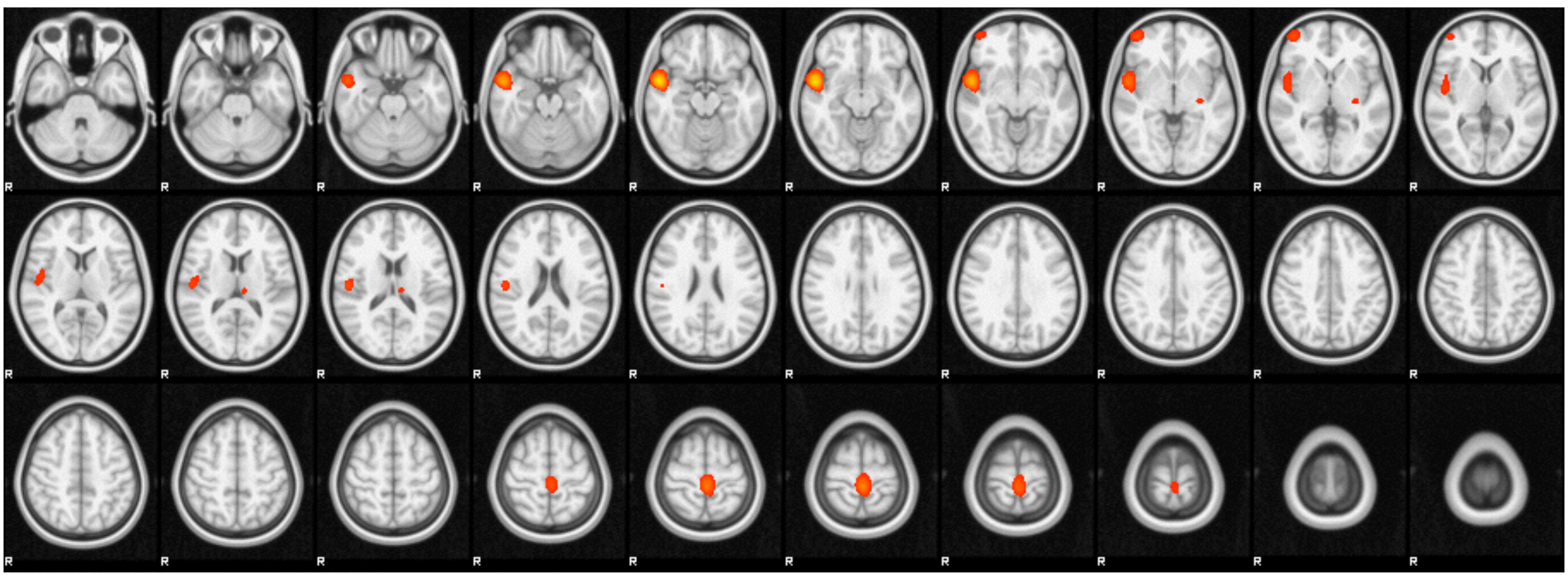
Poldrack, Halchenko, & Hanson, 2009

Mapping neural data into a cognitive ontology



Poldrack, Halchenko, & Hanson, 2009

actionexecution audition colorvision decisionmaking emotion implicitmemory
language memory numericprocessing orthography phonology
positiveemotion reasoning responseinhibition
reward semantics shapevision spatialprocessing speech vision
workingmemory

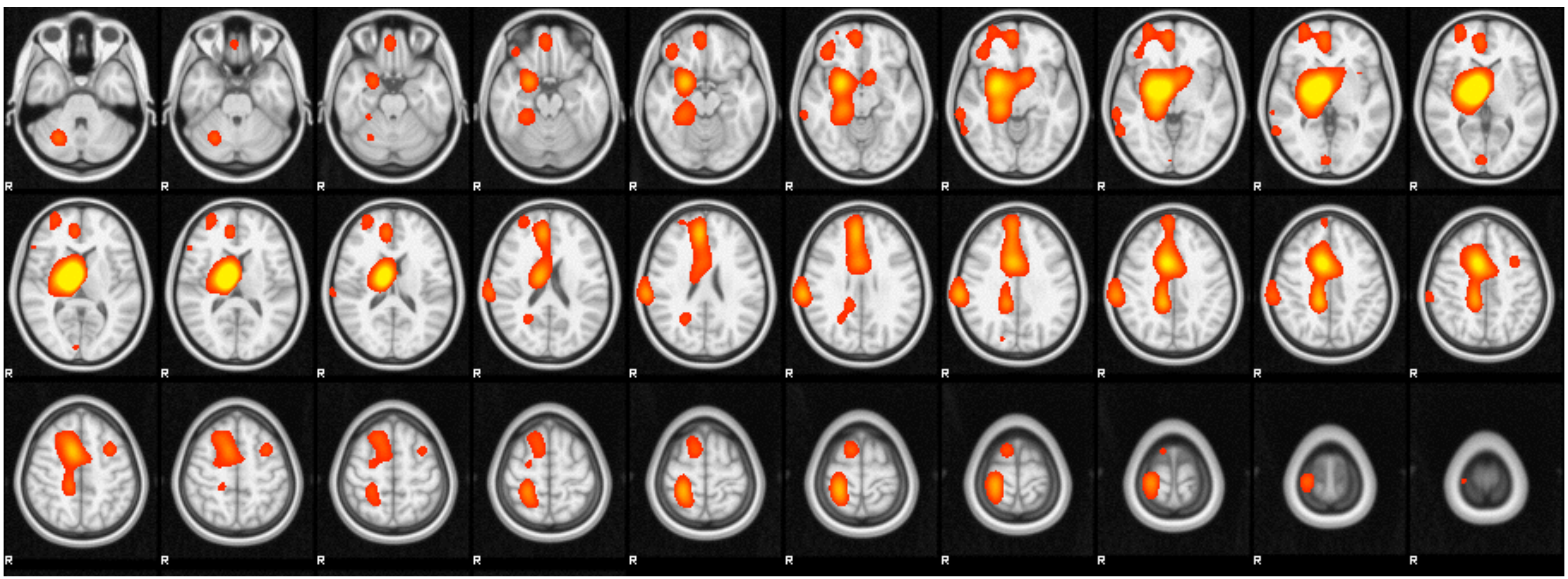


Poldrack, Halchenko, & Hanson, 2009

actionexecution audition colorvision decisionmaking

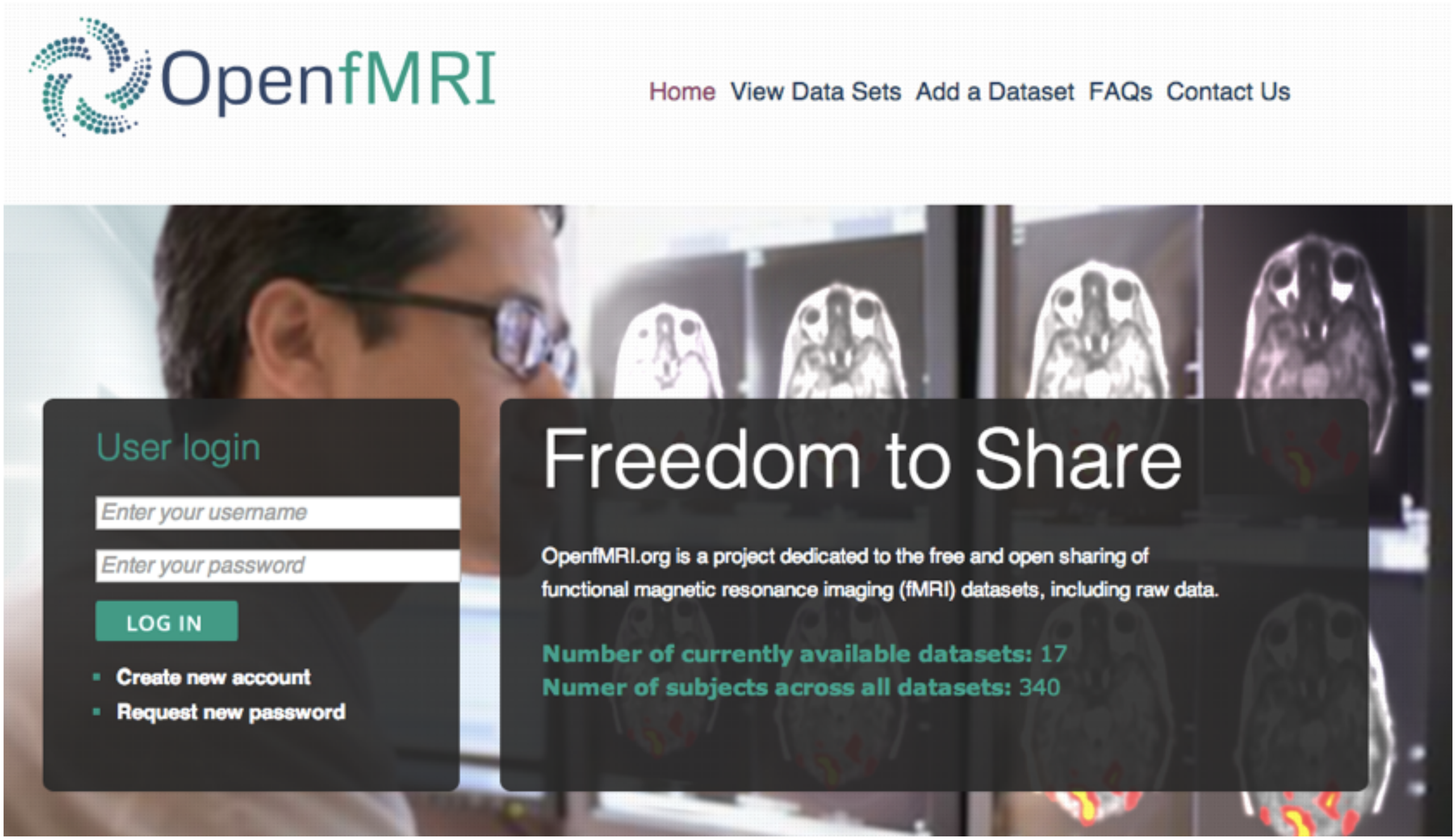
emotion implicitmemory language memory numericprocessing orthography phonology positiveemotion

reasoning responseinhibition reward semantics shapevision spatialprocessing speech vision workingmemory



Poldrack, Halchenko, & Hanson, 2009

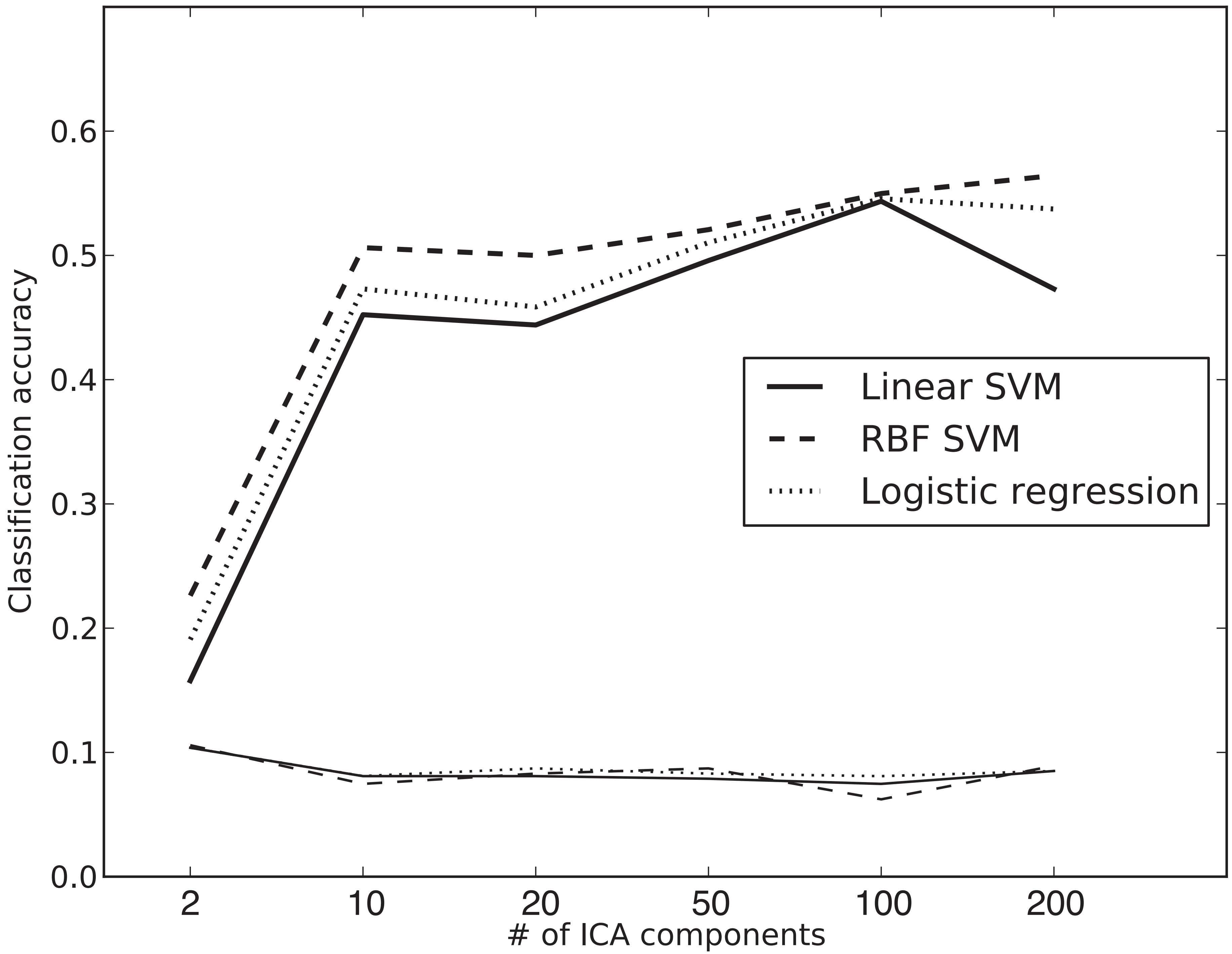
Larger-scale decoding



26 tasks, 482 images from 338 subjects

Larger-scale decoding

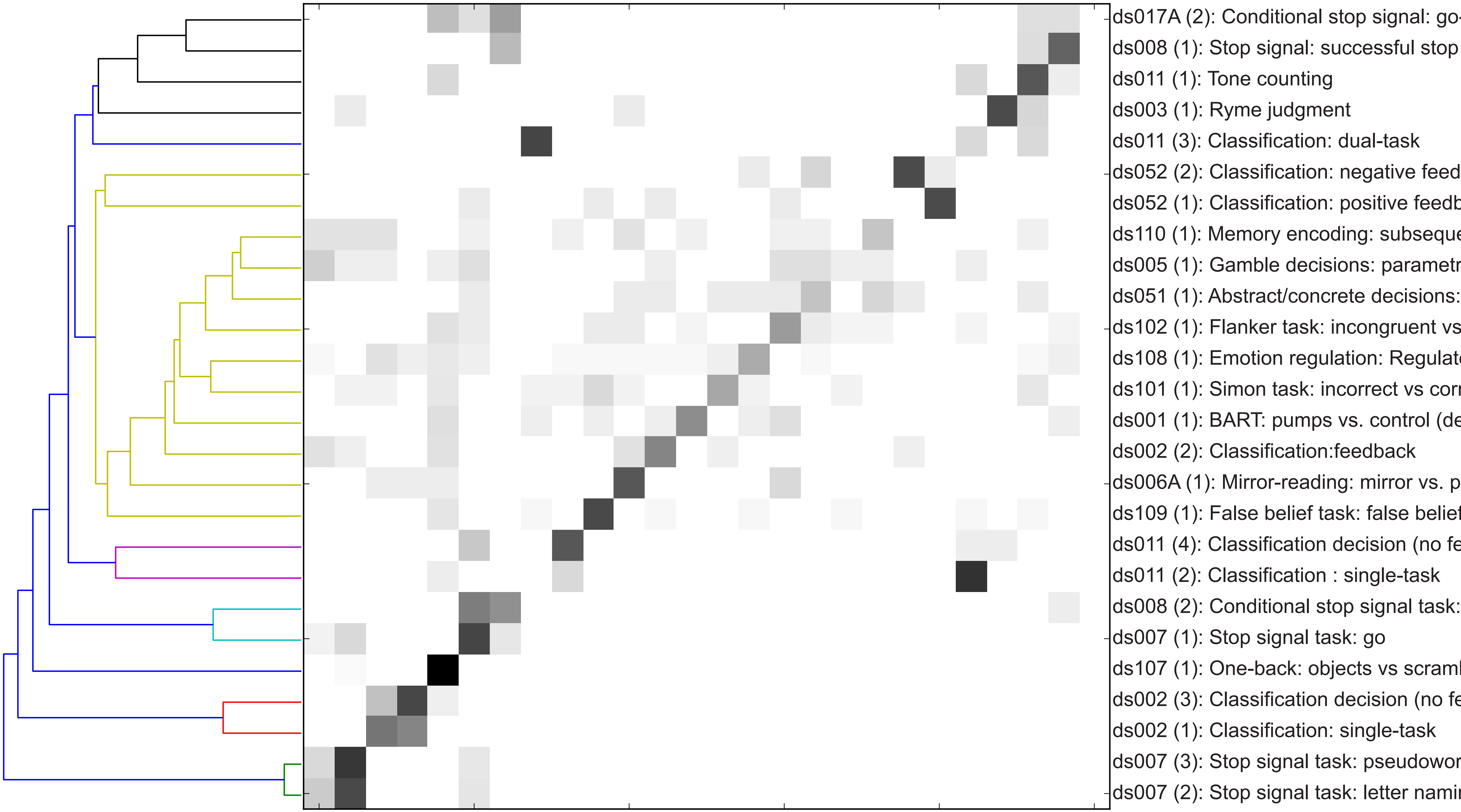
26 tasks, 482 images from 338 subjects



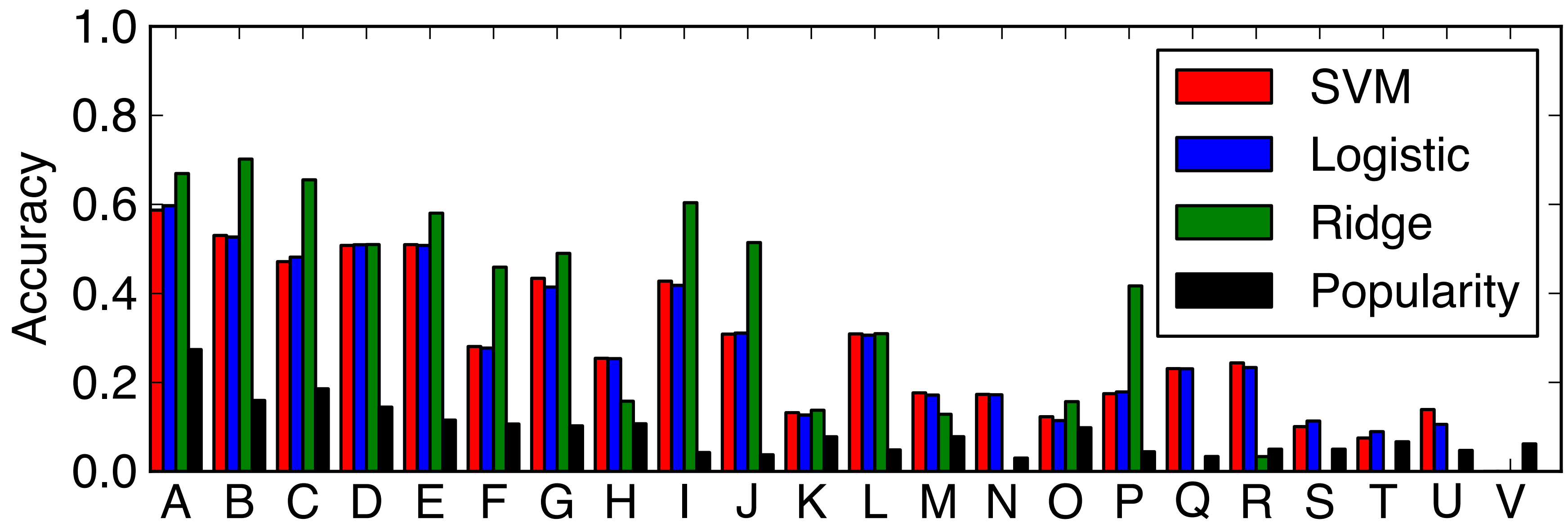
Whole-brain: 47% accuracy

Poldrack et al., submitted

Larger-scale decoding: Clustering



Decoding cognitive functions across subjects

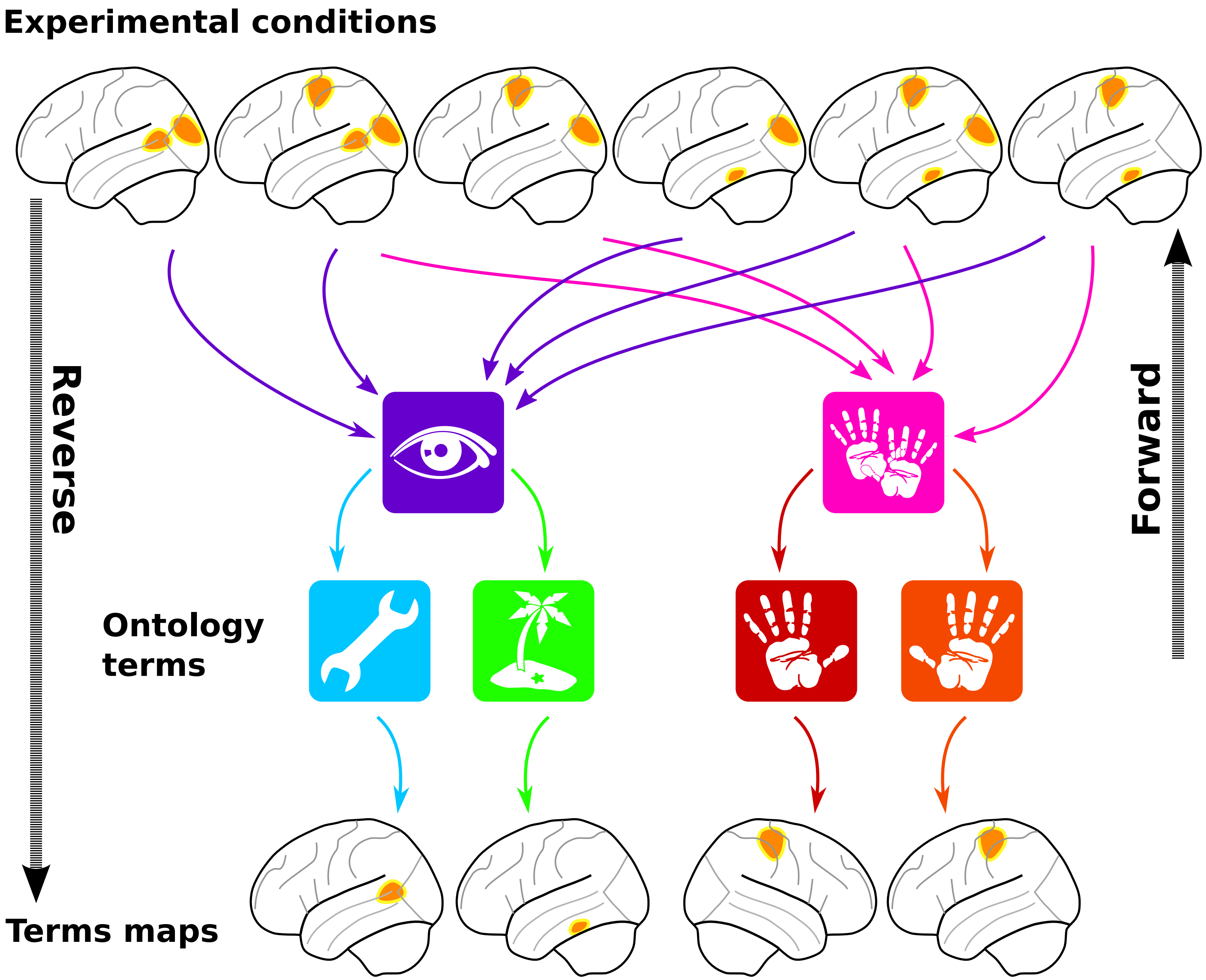


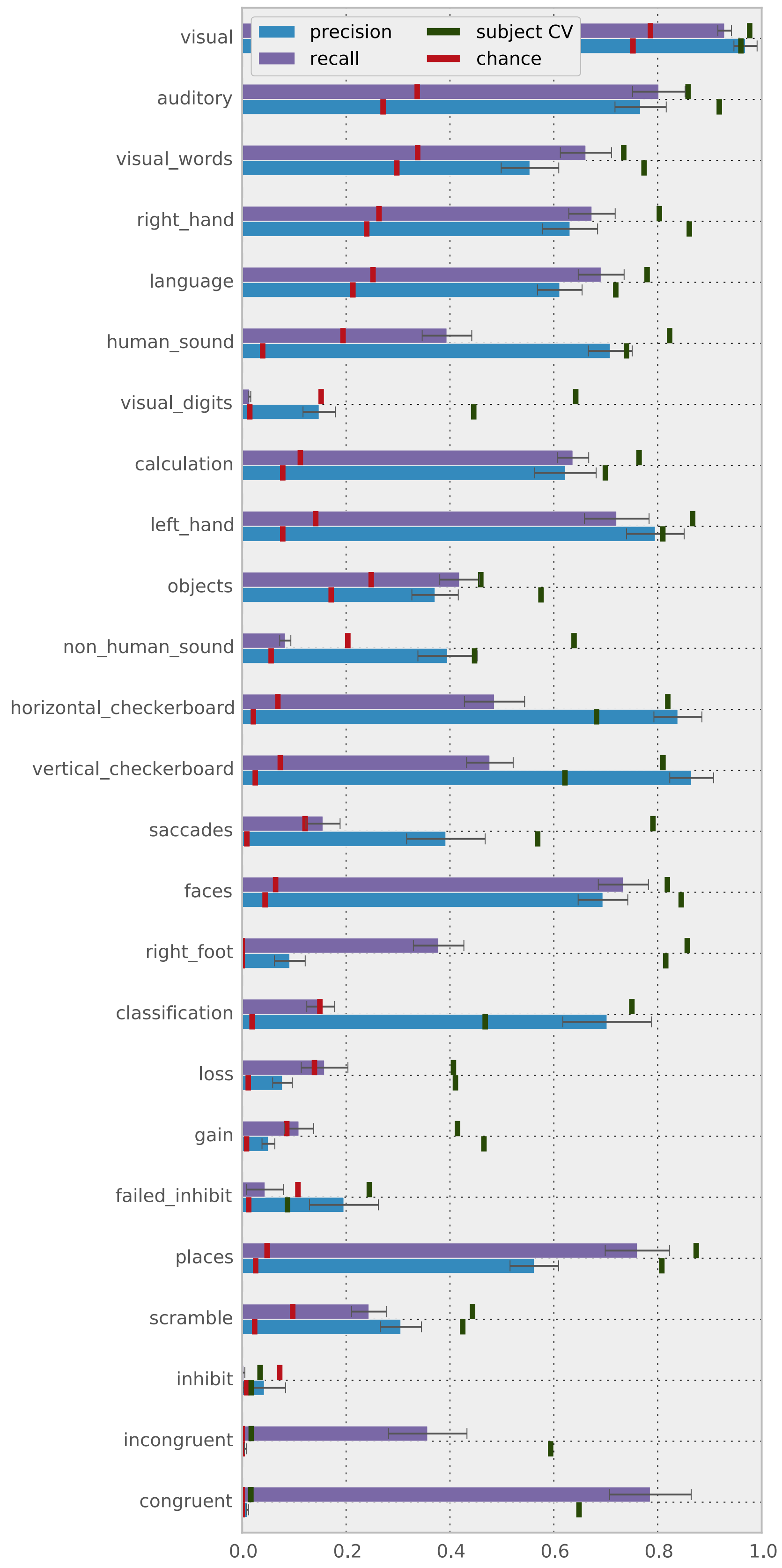
A Vision
B Action Execution
C Decision Making
D Orthography
E Shape Vision
F Audition
G Phonology
H Conflict
I Semantics
J Reinforcement Learning
K Working Memory
L Feedback
M Response Inhibition
N Reward
O Stimulus-driven Attention
P Speech
Q Emotion Regulation
R Mentalizing
S Punishment
T Error Processing
U Memory Encoding
V Spatial Attention

- Multilabel classifier trained using OpenfMRI data and Cognitive Atlas labels
- 26 task contrasts, 482 images from 338 subjects
- annotated with Cognitive Atlas

Koyejo & Poldrack, 2013

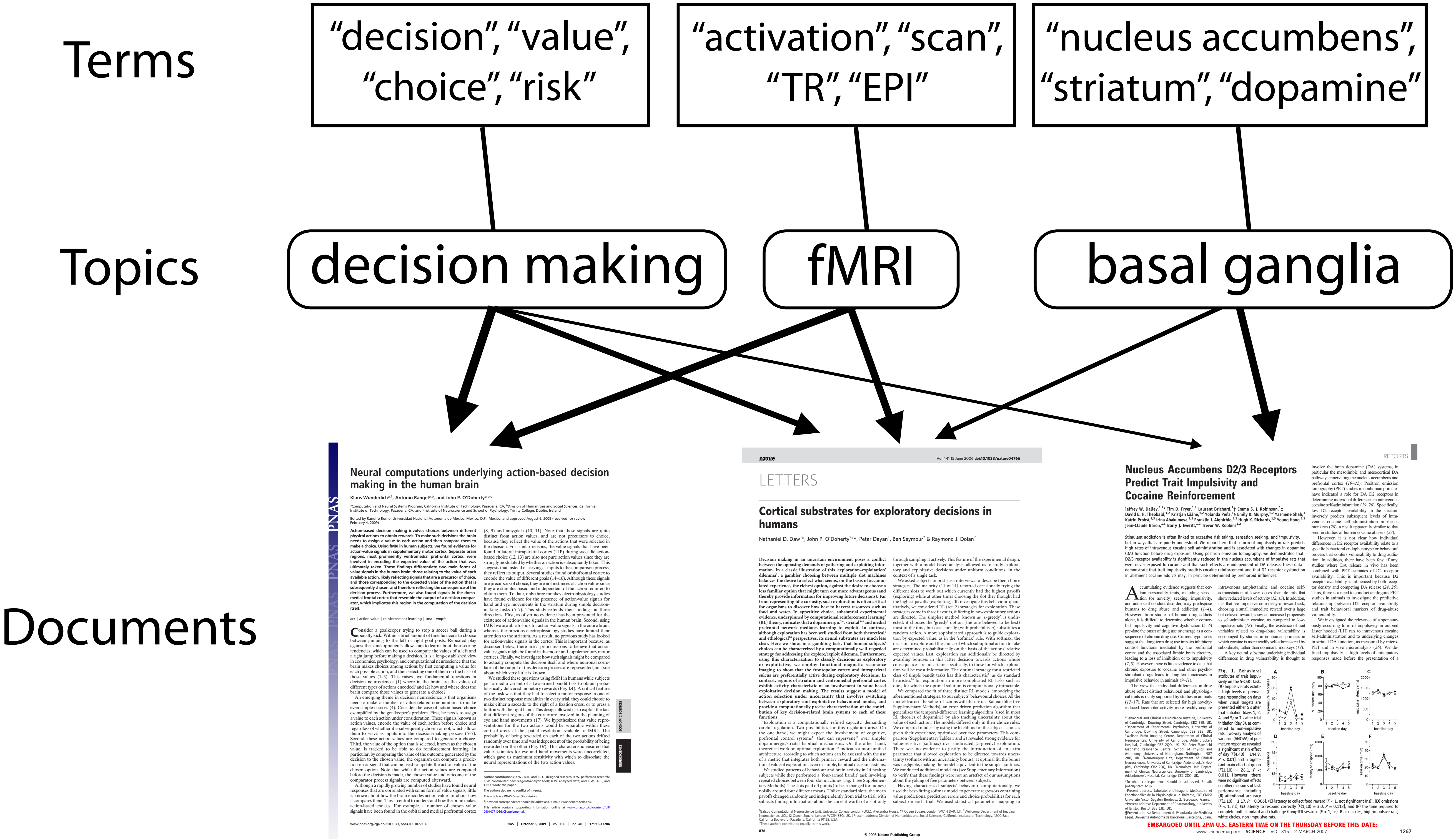
Ontology-based decoding





Schwartz et al., in prep

Mining text using topic modeling



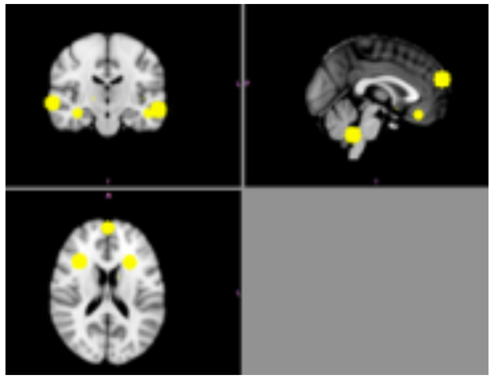
Topic Mapping

- Perform topic modeling using latent Dirichlet allocation with Cognitive Atlas terms
- Each document has a loading on each topic
  - On average, each document loads on ~6.5 topics
- Extract activation coordinates for 5,809 papers in NeuroSynth
- Perform voxelwise chi-square test with FDR correction to examine association between topics and activation

Topic — Documents — Activation Coordinates

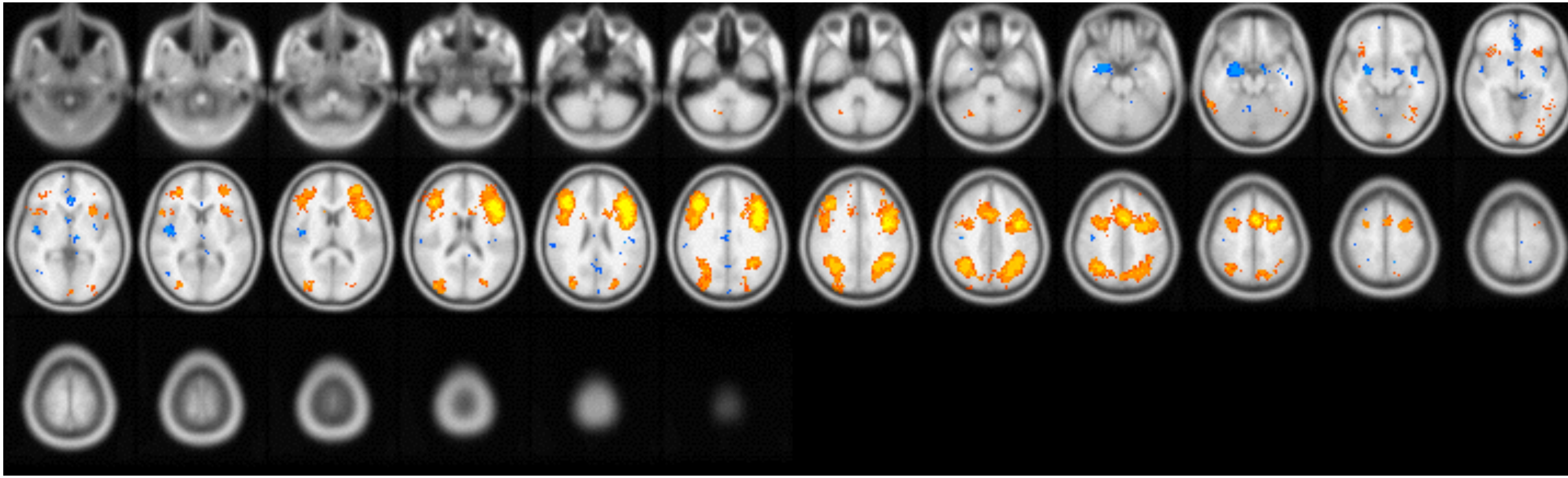
emotion
negative
unpleasant

"...amygdala...emotion...negative..."



Poldrack et al., 2012, *PLOS Comp Biology*

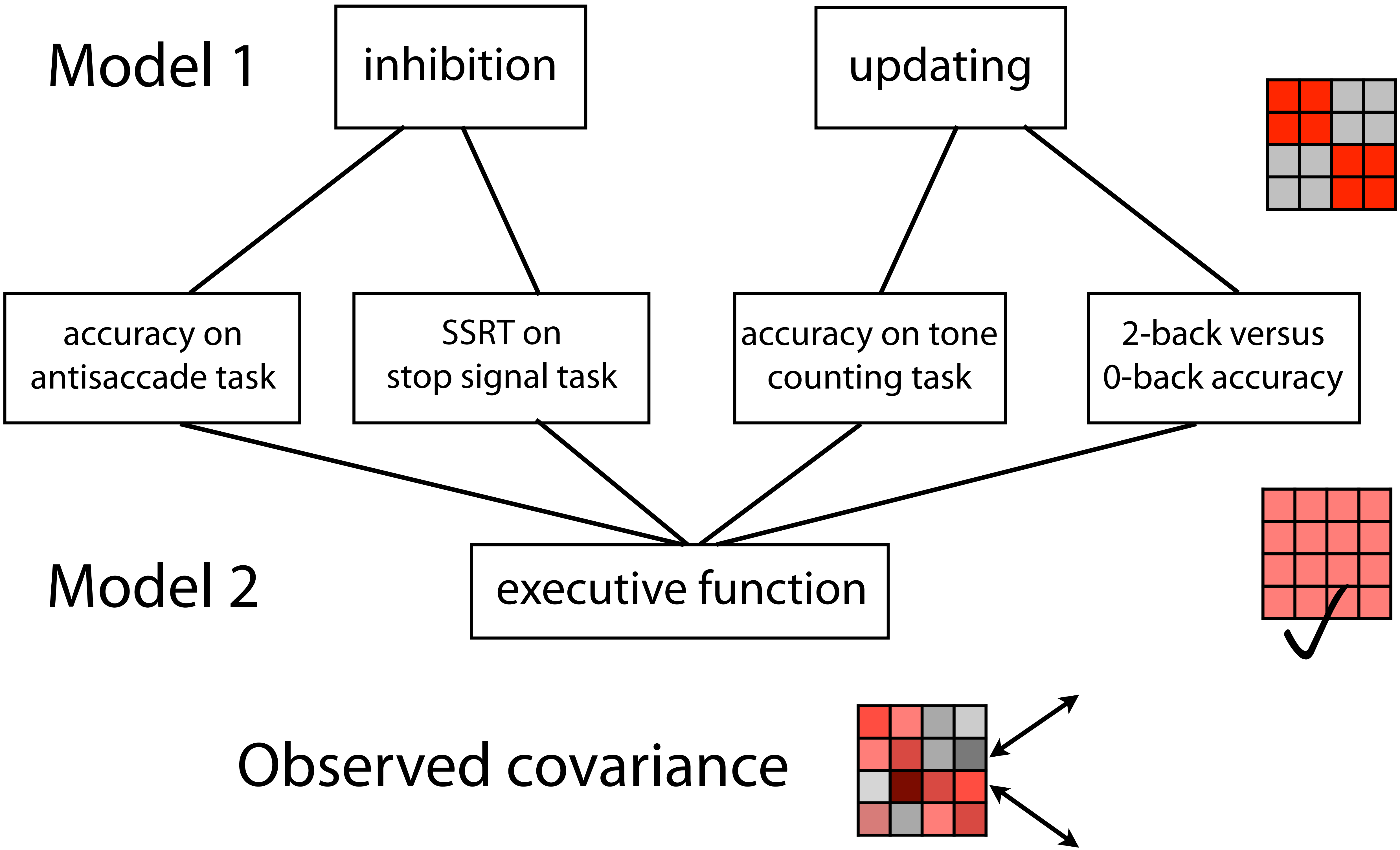
Meta-analysis using Cognitive Atlas terms



Topic 61 (442 docs): memory working_memory maintenance visual_working_memory spatial_working_memory manipulation episodic_buffer retention rehearsal retrieval

Poldrack et al., 2012, *PLOS Comp Biology*

Towards meta-analytic testing of cognitive frameworks



Conclusion

- Cognitive ontologies can provide a more formal definition of cognitive functions
- Ontologies plus meta-analysis may provide the means to test between different conceptual frameworks

Acknowledgments

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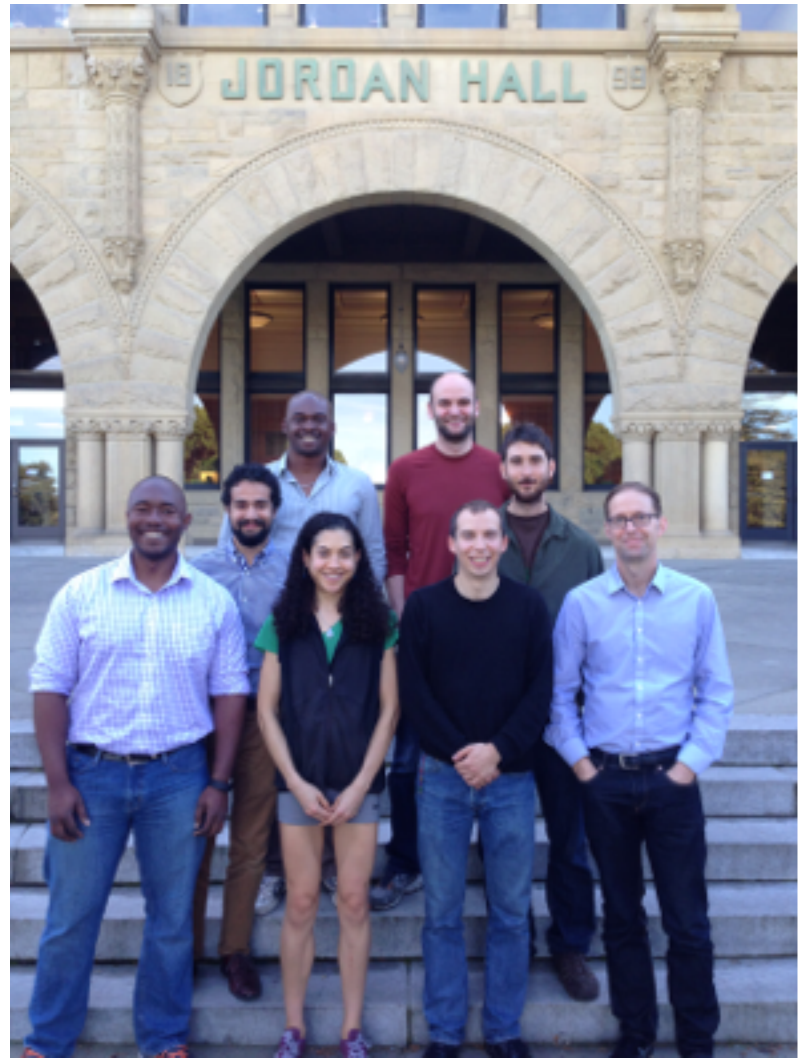

The Poldrack Lab @ Stanford

Visit:
www.openfmri.org
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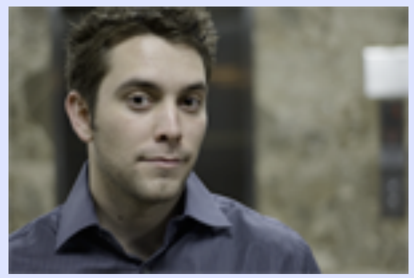
UCLA

Robert Bilder



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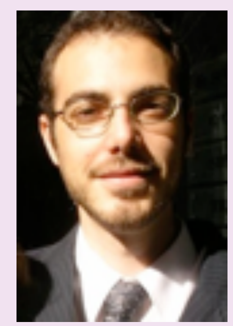
D. Stott Parker

UT Austin

Jeanette Mumford



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