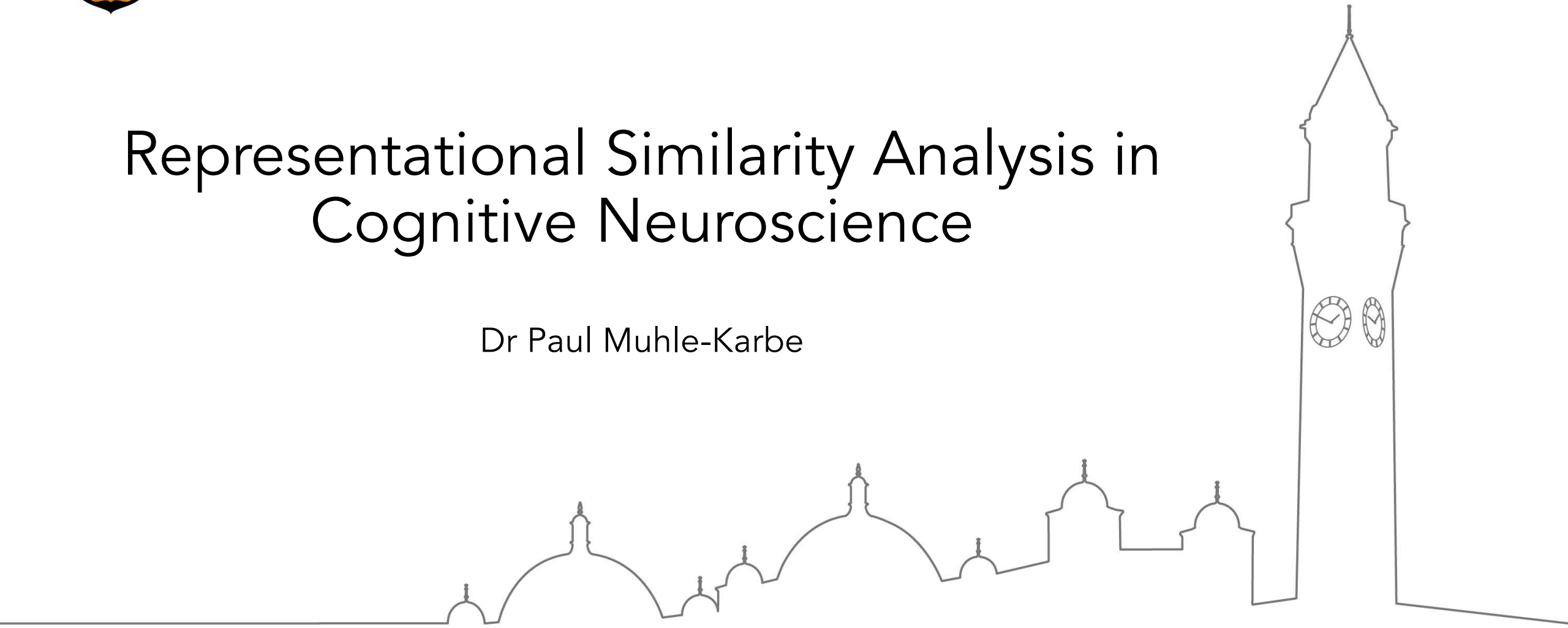
UNIVERSITY OF BIRMINGHAM

Representational Similarity Analysis in Cognitive Neuroscience

Dr Paul Muhle-Karbe



Overview

Session 1

- Recap: brain imaging modalities
- Problem space and concepts
- Basic principles of RSA
- Advanced forms of RSA

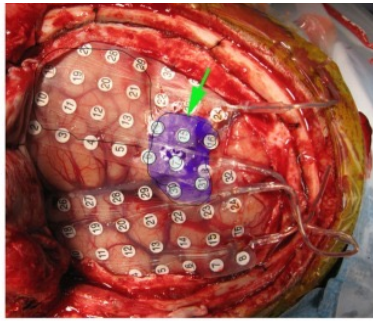
Session 2

- Recap: session 1
- Considerations for task design
- Considerations for analyses
- Practice

Brain Imaging: What do we measure?

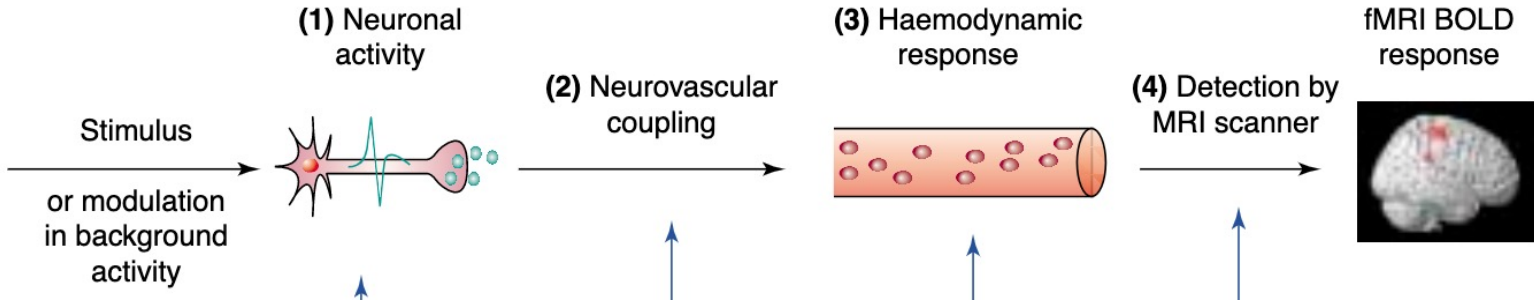
fMRI

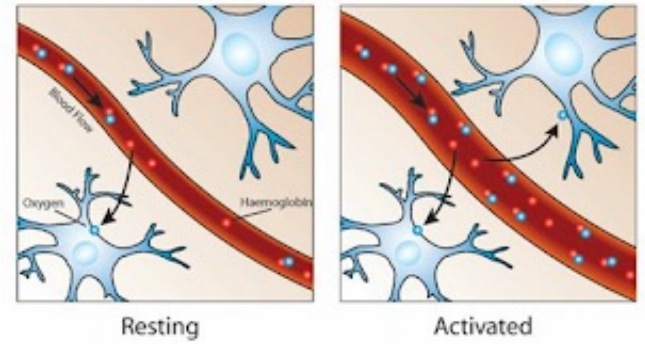
Electrophysiology

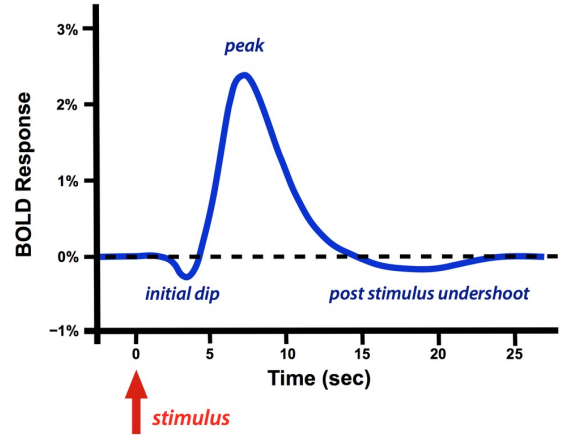


What does fMRI measure?

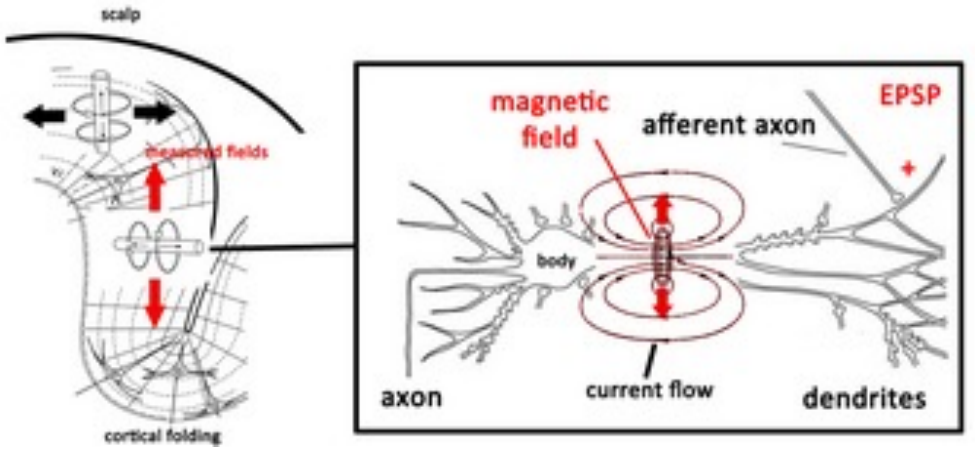
- BOLD signals indexes metabolic changes that are correlated with neuronal activity
- Spatial resolution at the level of millimeters, temporal resolution at the level of seconds
- Well-suited for questions about systems-level organization and sustained cognitive phenomena
- Not well-suited for circuit-level functions and questions about timing



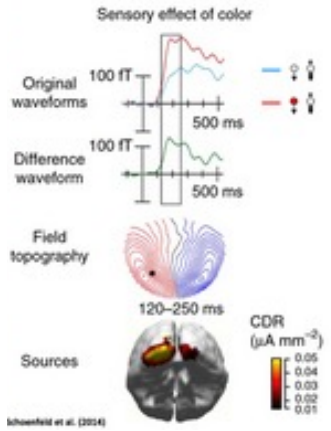


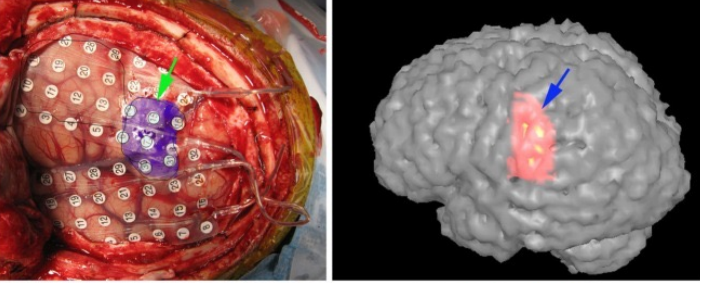


What does electrophysiology measure?



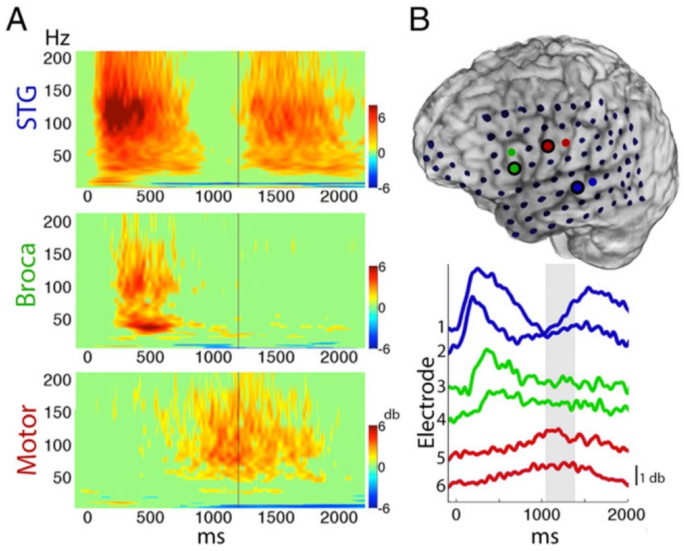
- Measures electrical potentials (EEG) or magnetic fields (MEG) at the scalp that result from coordinated neuronal activity (EPSP)
- Coarse spatial resolution, but very high temporal resolution at the level of milliseconds
- Well-suited for questions about temporal dynamics
- Not a good tool when the precise localization of neural activity is crucial

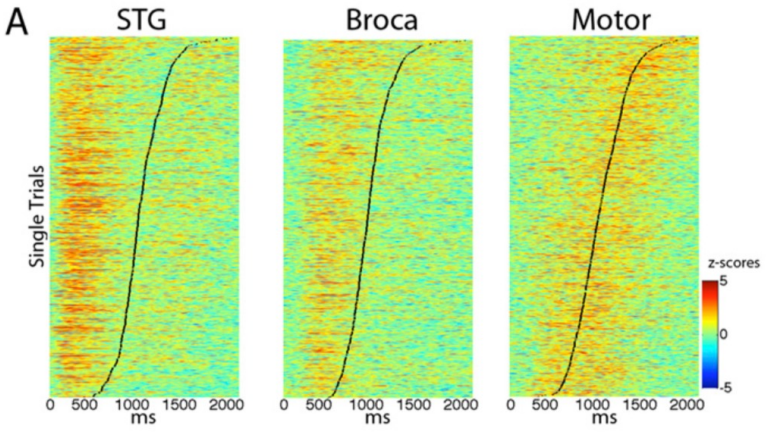




What do intracranial recordings measure?

- Direct measurement of brain activity
- High spatial resolution at the level of millimeters and very high temporal resolution at the level of milliseconds
- Very high signal-to-noise ratio (SNR)
- Problems: very limited brain coverage; still many neurons contributing to signal at each electrode; practical constraints
- Unique window for studying neural computation in the human brain, but clinical context places strong constraints





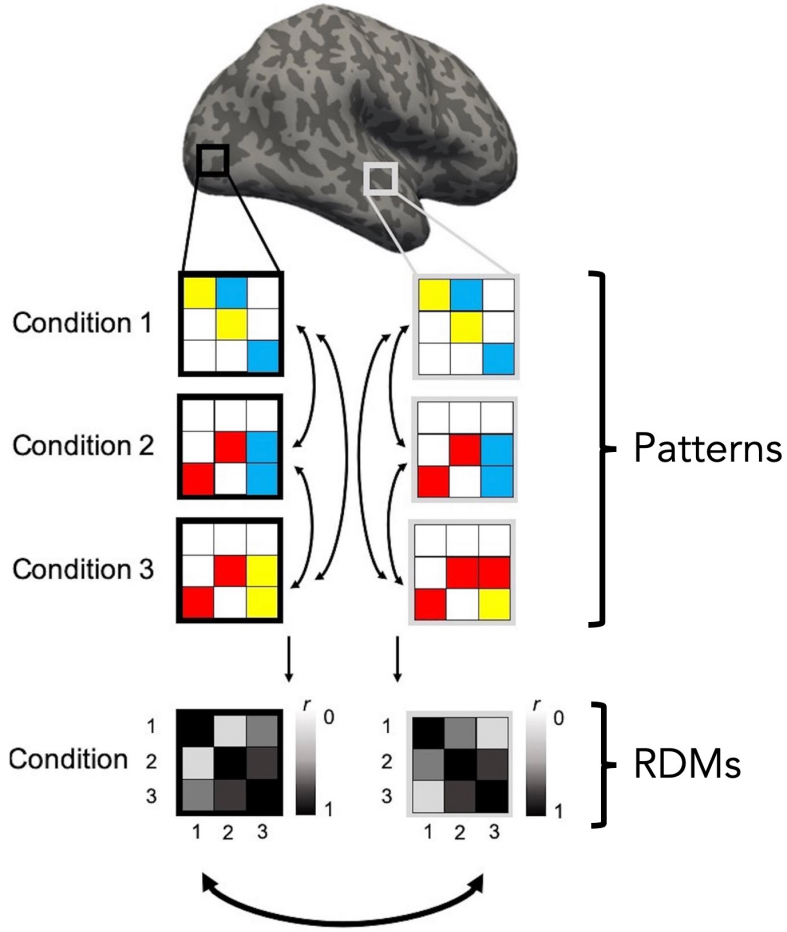
Flinker, 2015, PNAS

Challenges for Systems Neuroscience

- How to integrate brain signals across imaging modalities?
- How to examine brain signals encoded in population codes?
- How to integrate brain signals across subjects?
- How to integrate brain signals across species?
- How to integrate brain signals with behaviour?
- How to integrate brain signals with computational models?

Representational Similarity Analysis (RSA)

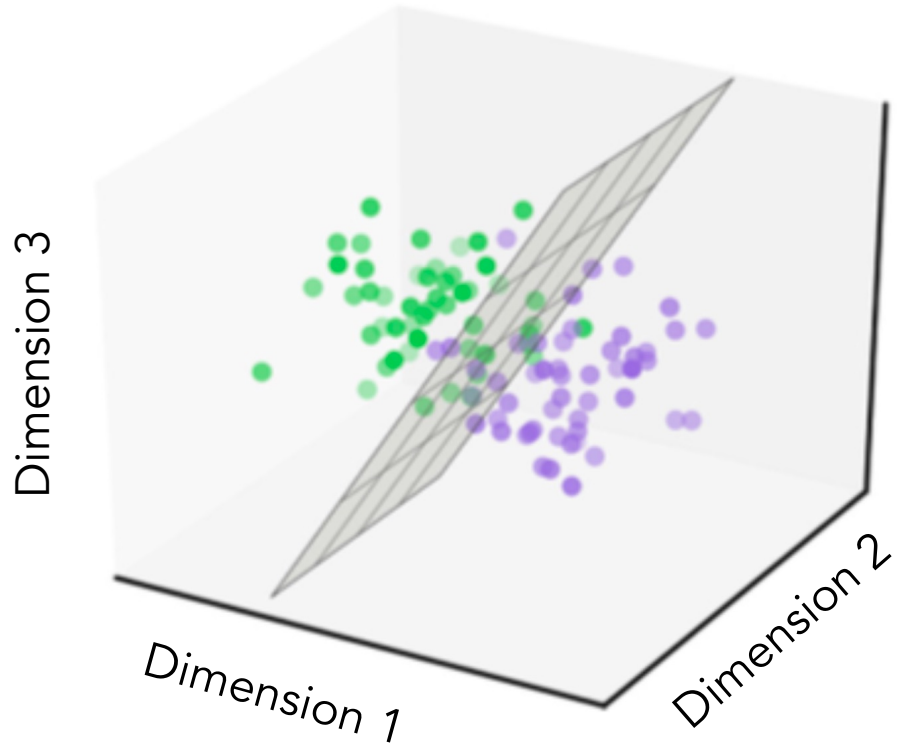
- Activity patterns associated with experimental conditions are interpreted as “representation”
- Comparing all pairs of patterns yields a representational dissimilarity matrix (RDM) that can be used to characterize the representation
- Indicates the extent to which different pairs of conditions are distinguished
- Abstracts from the spatial layout of the representation



Kriegeskorte, 2008, Front Syst Neuro

Representational Spaces

- Population coding: information encoded in pattern of activity across many units
- Many combinations of possible activity states provide a rich representational space
- Representations exist in a multidimensional space



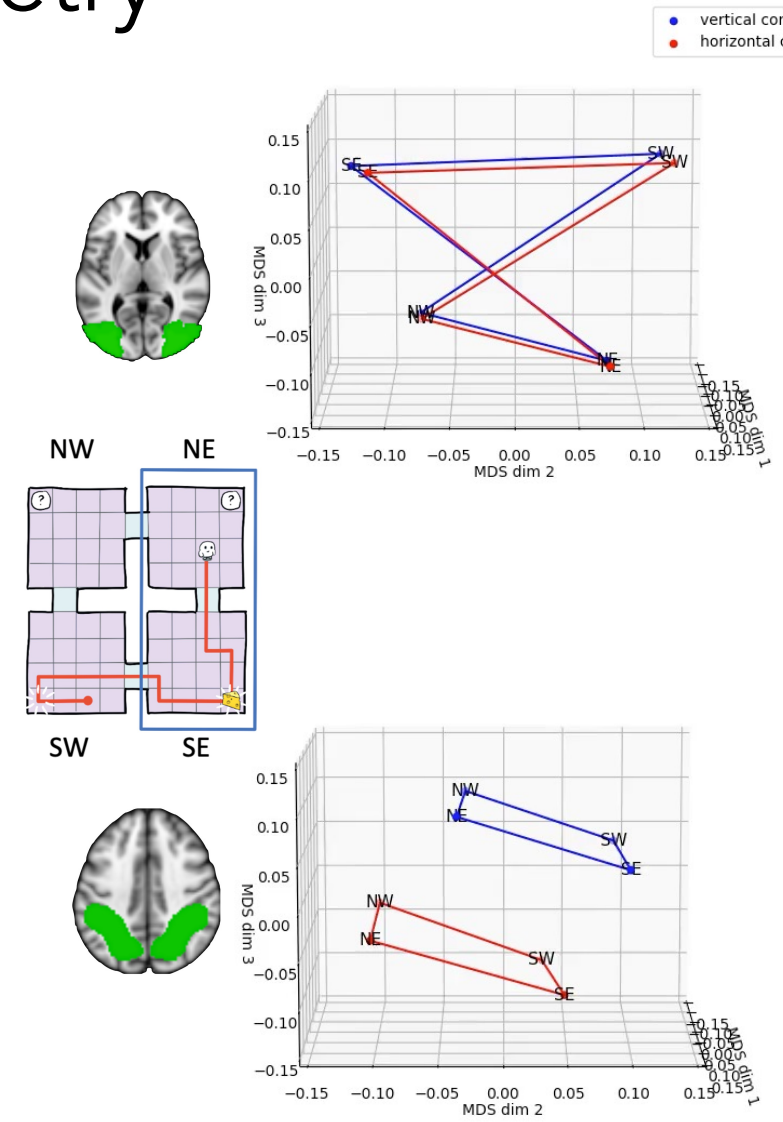
Representational Geometry

- Representational geometry describes what information is distinctly represented and what information is explicit (amenable to linear readout)

- Brain computation construed as transformation of representational geometries

No differentiation Clusters Parallel Lines

Kriegeskorte, 2013, Trends Cogn Sci



Muhle-Karbe, in prep

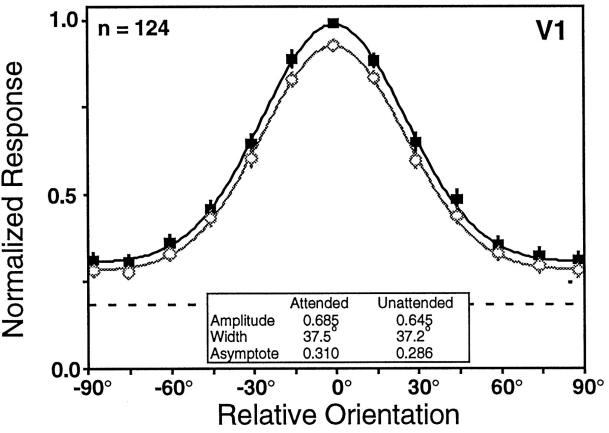
First-order and second-order isomorphisms

First-order isomorphism

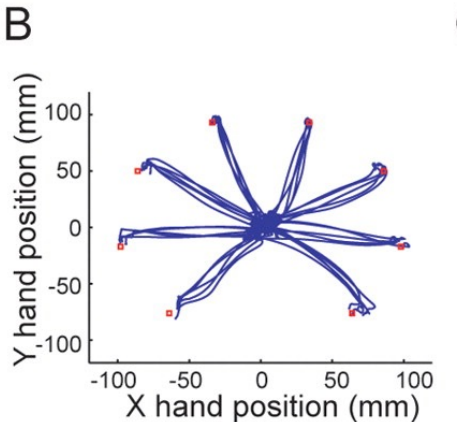
- Classic approach: relate properties of task conditions to properties of individual unit activity
- Examples: tuning for stimulus orientation or movement direction

Second-order isomorphism

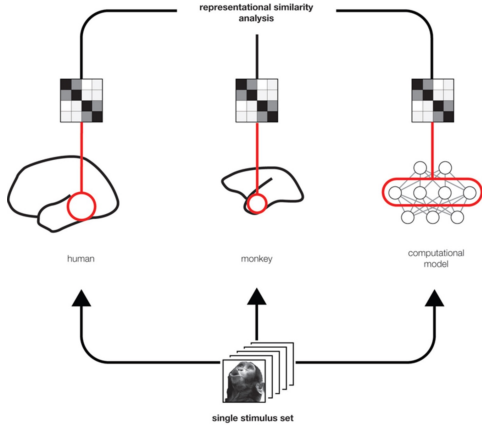
- RSA approach: establish correspondence between relations among task conditions and the relations among their representations
- Example: object representations in human and macaque IT area

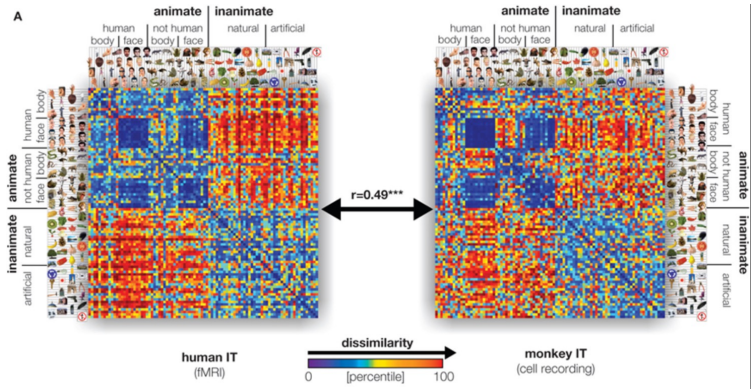


McAdams, 1999, J Neurosci



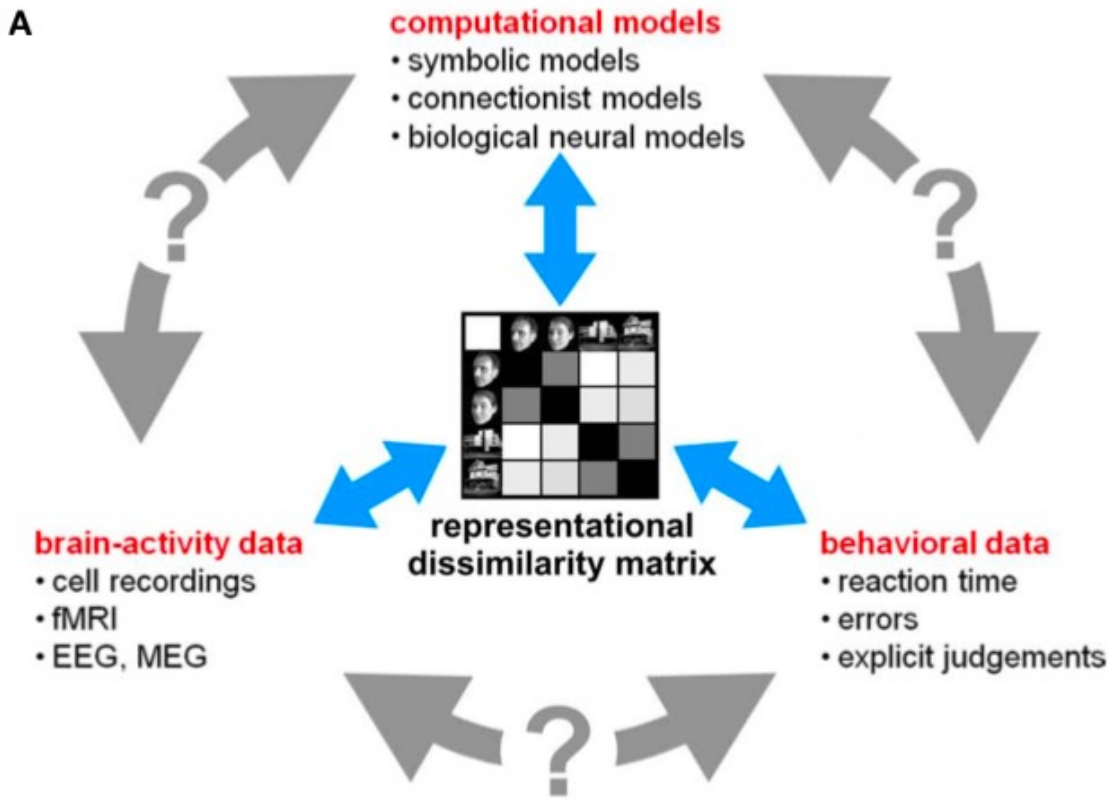
Chestek, 2007, J Neurosci

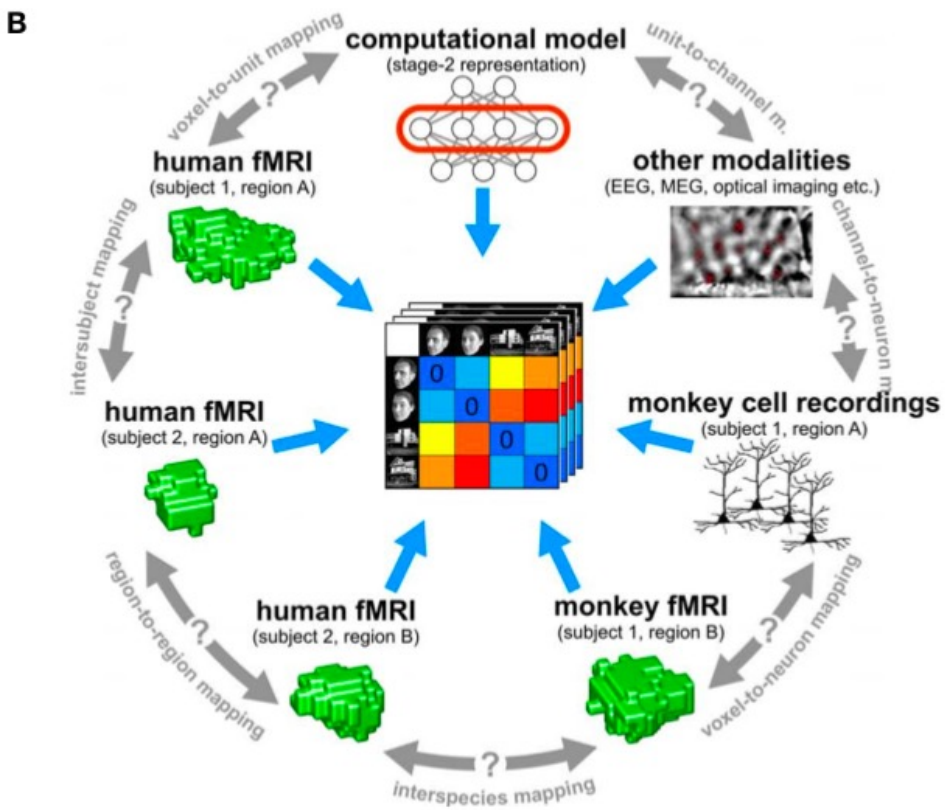




Kriegeskorte, 2008, Neuron

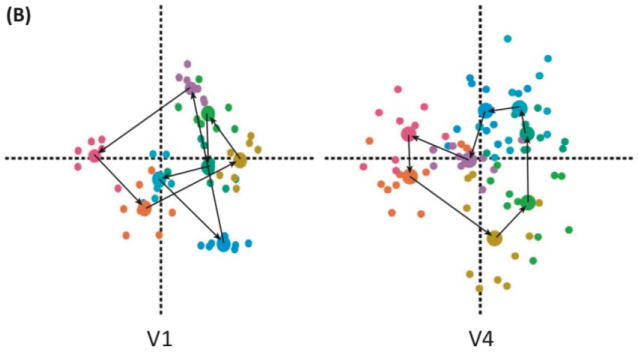
Connecting the branches of neuroscience





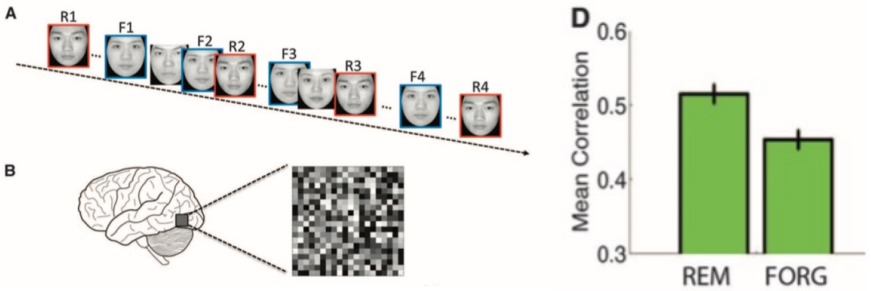
Kriegeskorte, 2008, Front Syst Neuro

RSA in action



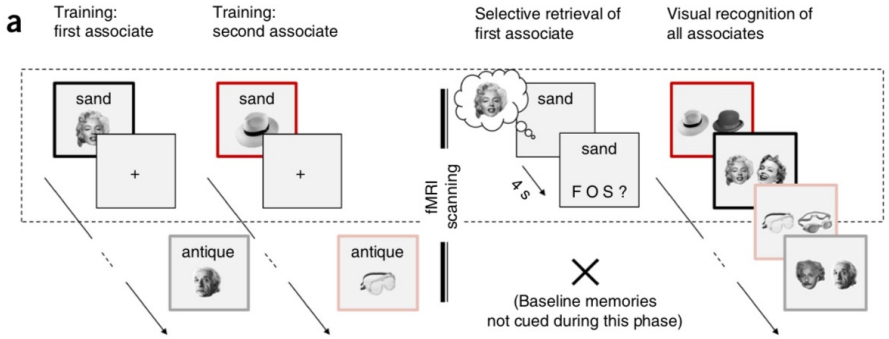
Color decoding works best in V1 but representational geometry in V4 best matches human color judgments

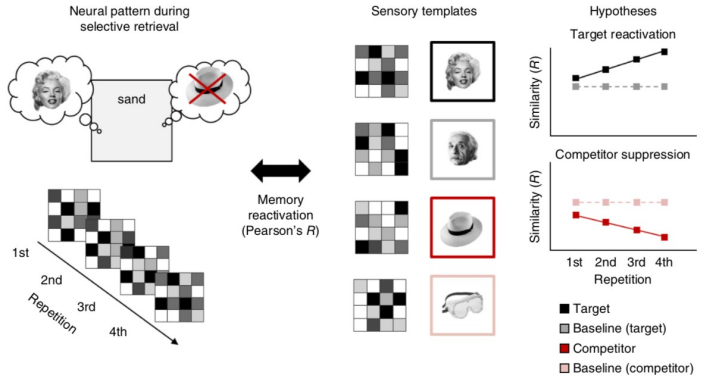
Brouwer, 2009, JNeurosci



Patterns from memory encoding are reinstated during (successful) retrieval

Xue, 2010, Science



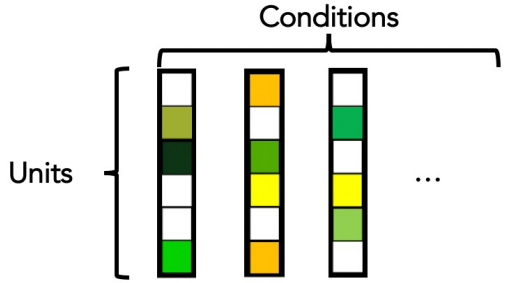


Selective memory retrieval produces inhibition of competing associates

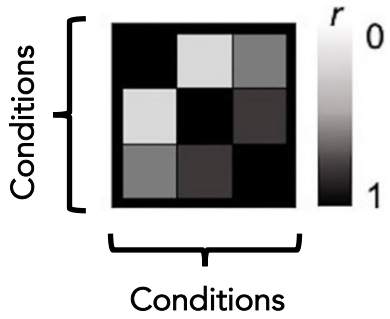
Wimber, 2014, Nat Neurosci

Steps involved in RSA

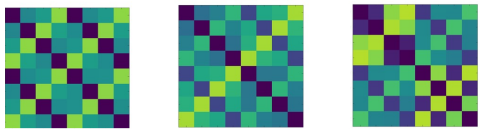
Estimate activity patterns



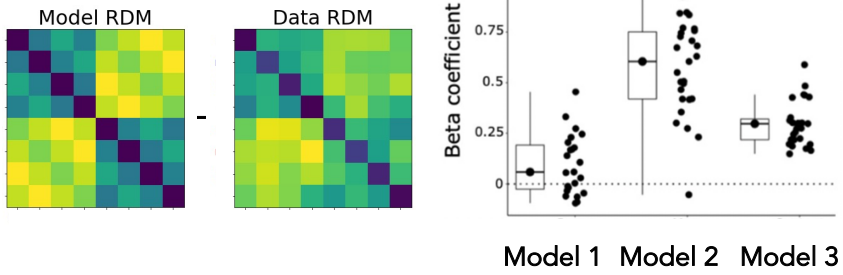
Compute pattern dissimilarity



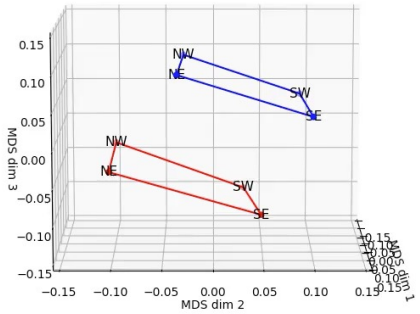
Predict pattern similarity with models



Compare brain and model dissimilarity matrices

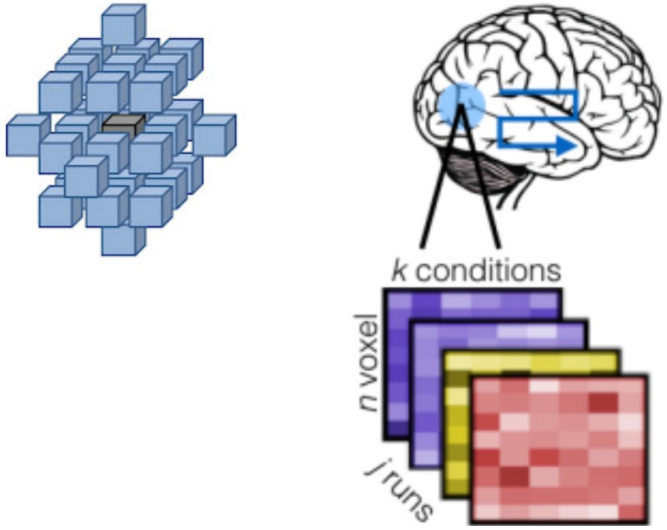


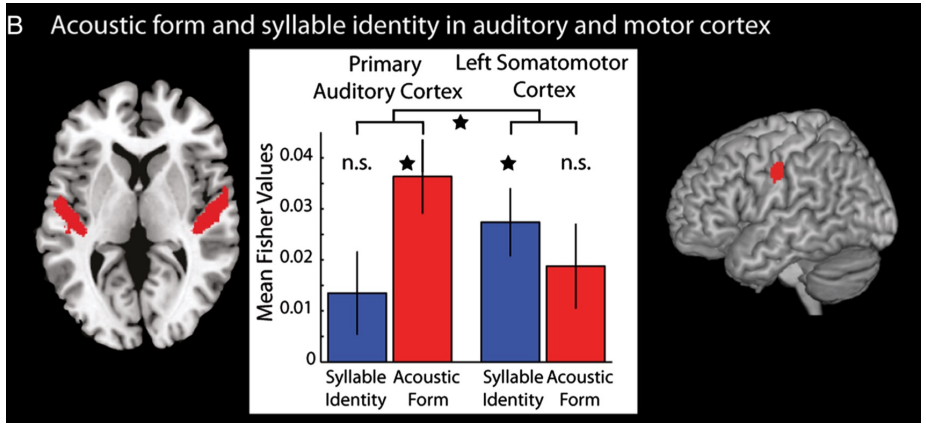
Visualise similarity structures



Advanced forms: searchlight analysis

- Move spherical searchlight through the brain volume and select a contiguous set of voxels to perform RSA at each point
- Find brain regions whose activity profiles match a specific model
- Yields continuous statistical map showing how well models match across locations

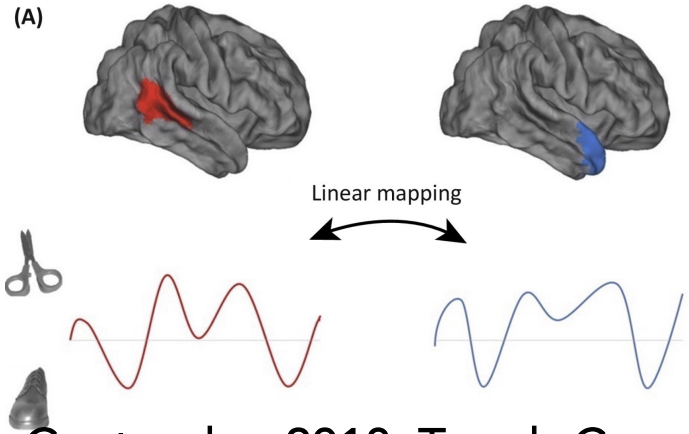




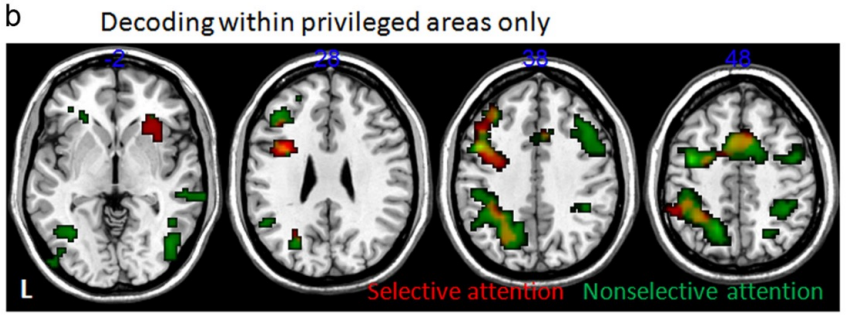
Evans, 2015, Cereb Cortex

Advanced forms: representational connectivity

- Compare representations of two regions in the same subject
- Can be done either via conditions or via time course
- Relate representations in one region to univariate effects in another region (integrate processes and representations)

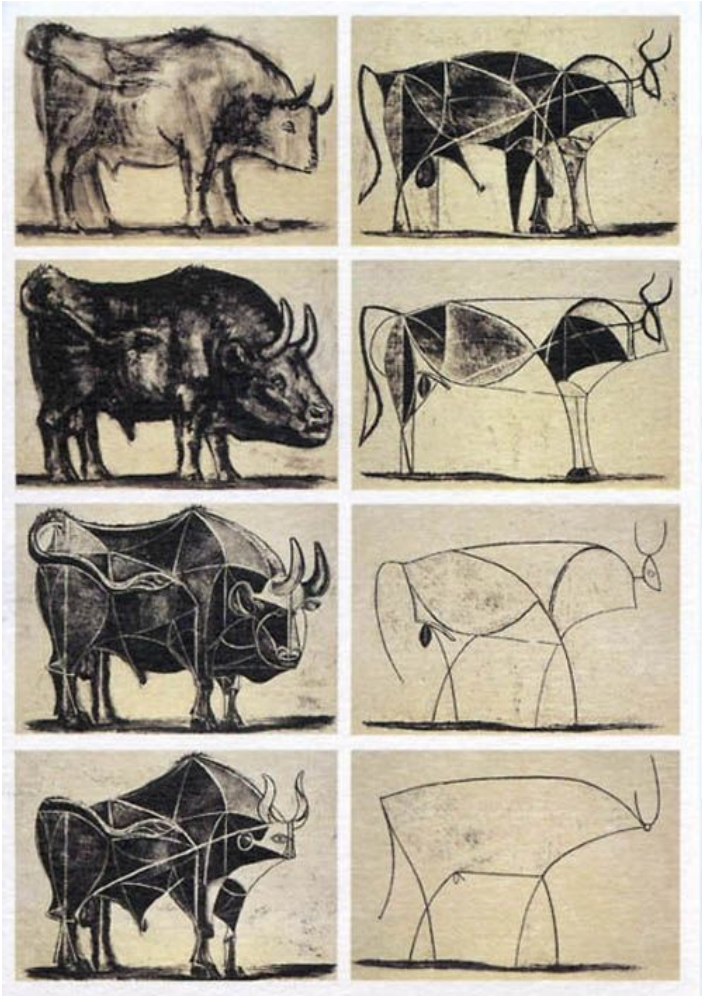


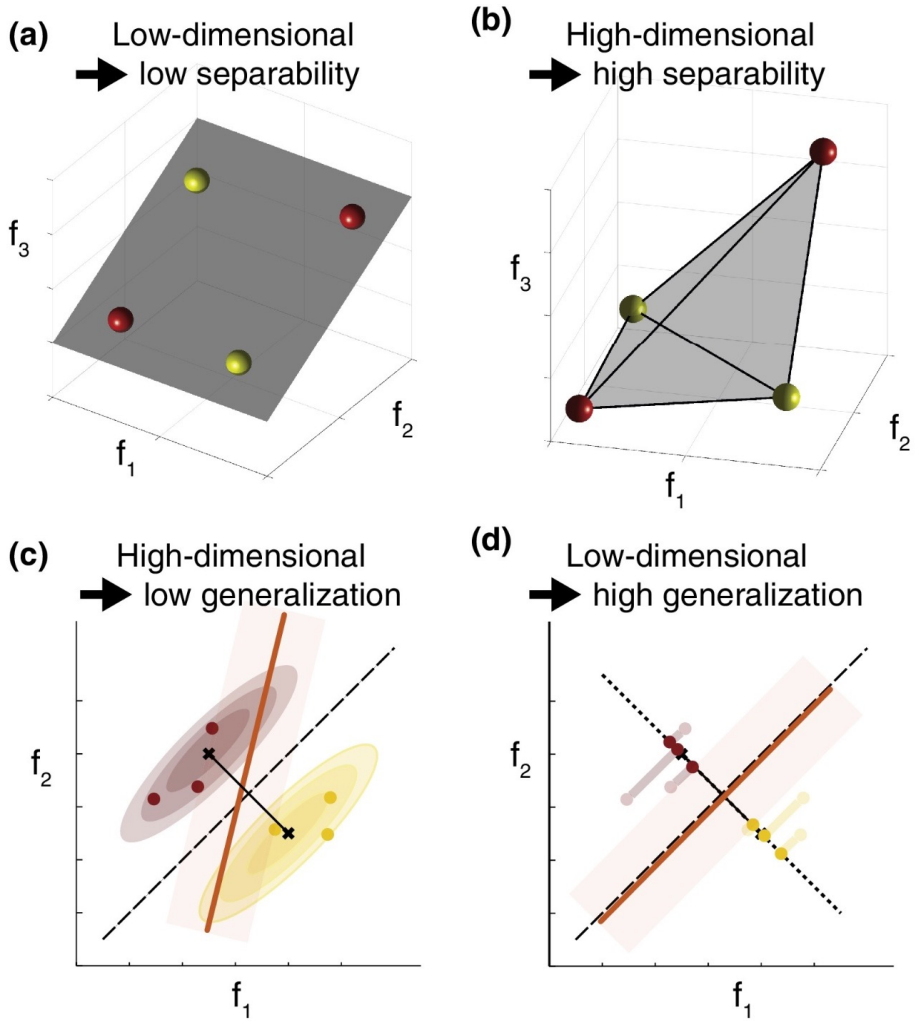
Coutanche, 2018, Trends Cogn Sci



Nelissen, 2013, J Neurosci

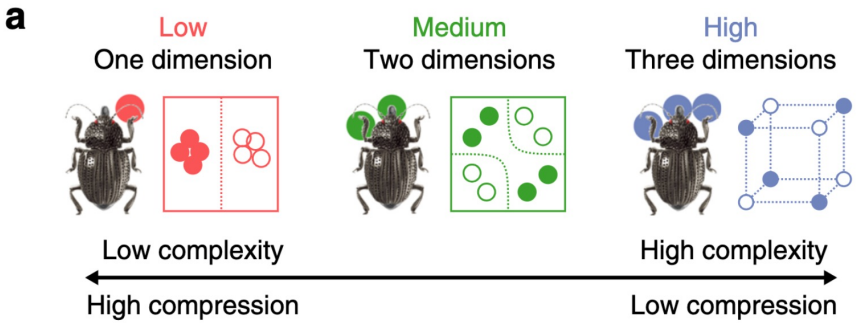
Advanced forms: dimensionality estimation

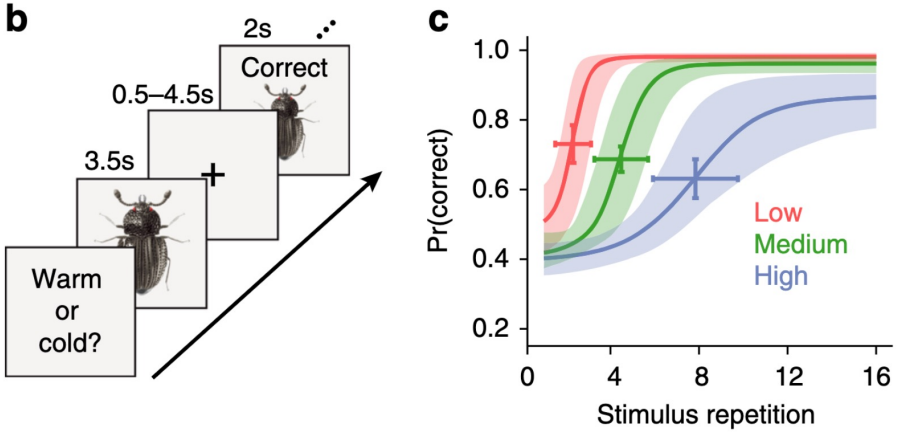




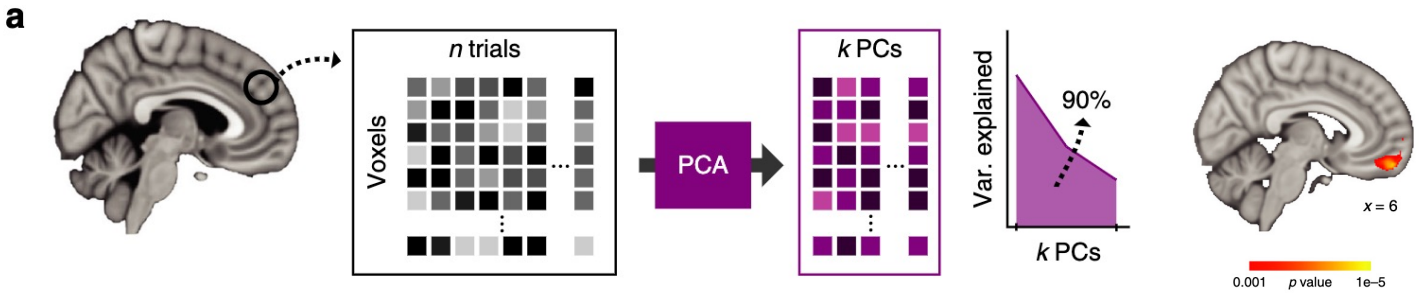
Rigotti, 2016, Curr Opin Neurobiol

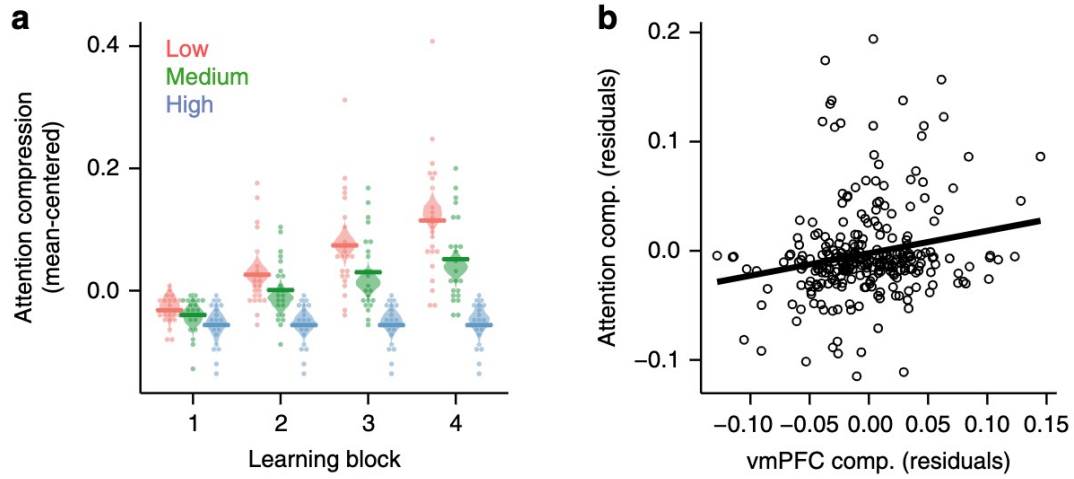
Advanced forms: dimensionality estimation





Speed of concept learning scales with the complexity of the learning problem





Dimensionality of mPFC activity adapts to task demands

Mack, 2020, Nat Comms

Time-resolved RSA

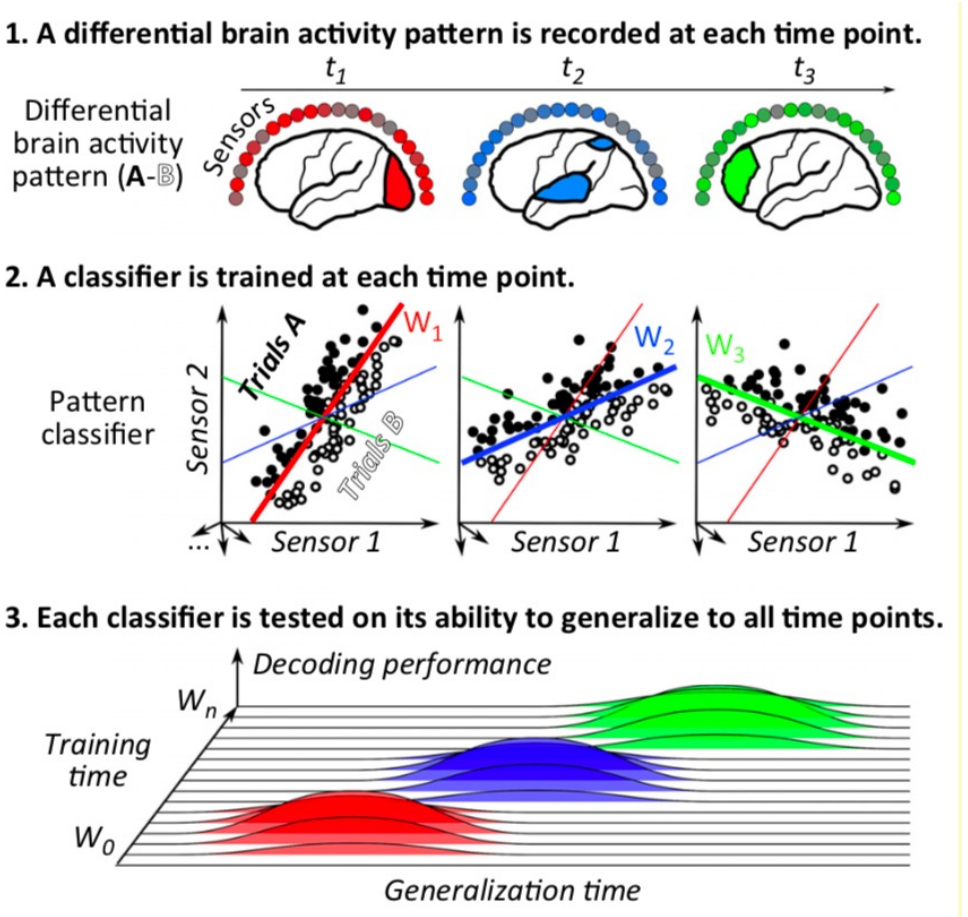
- Leverage the high temporal resolution of electrophysiology

- Sheds light on different questions than RSA applied to fMRI:
  - At which moment in time is specific mental content available?
  - How do classifiers generalize in time?
  - How do classifies generalize across task conditions?

- Temporal organization of information processing stages

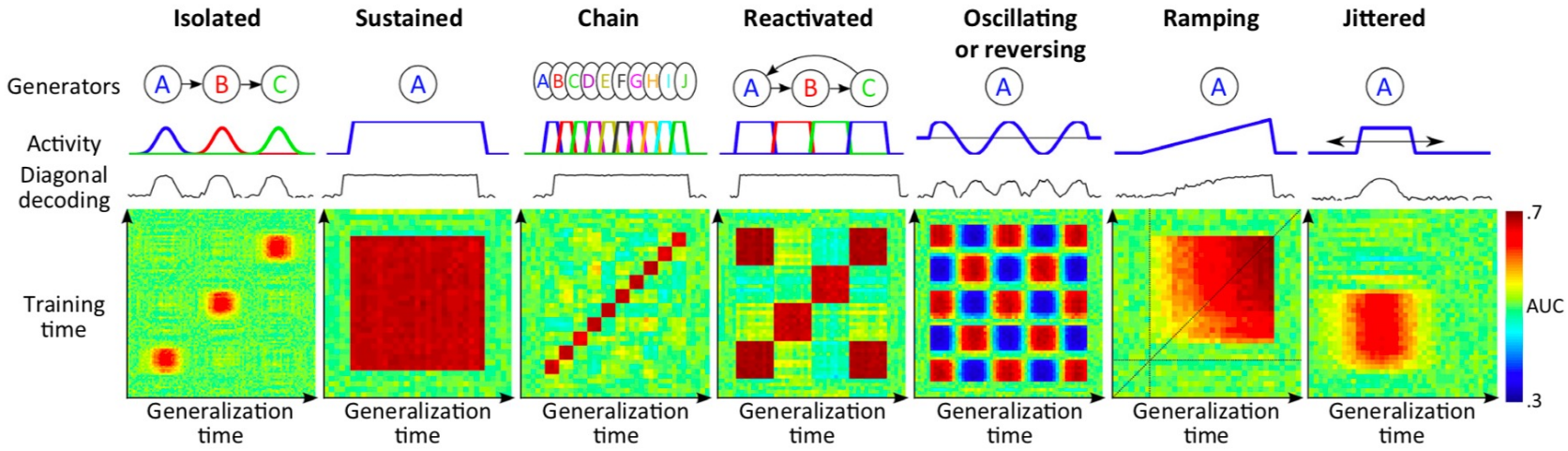
Time-resolved RSA

- Time as additional data dimension
- Analysis can be repeated for each time point to reveal processing stages
- Cross-temporal generalisation can show how representations are transformed
- Surprisingly, spatial resolution of EEG/MEG might be sufficient for mental state decoding

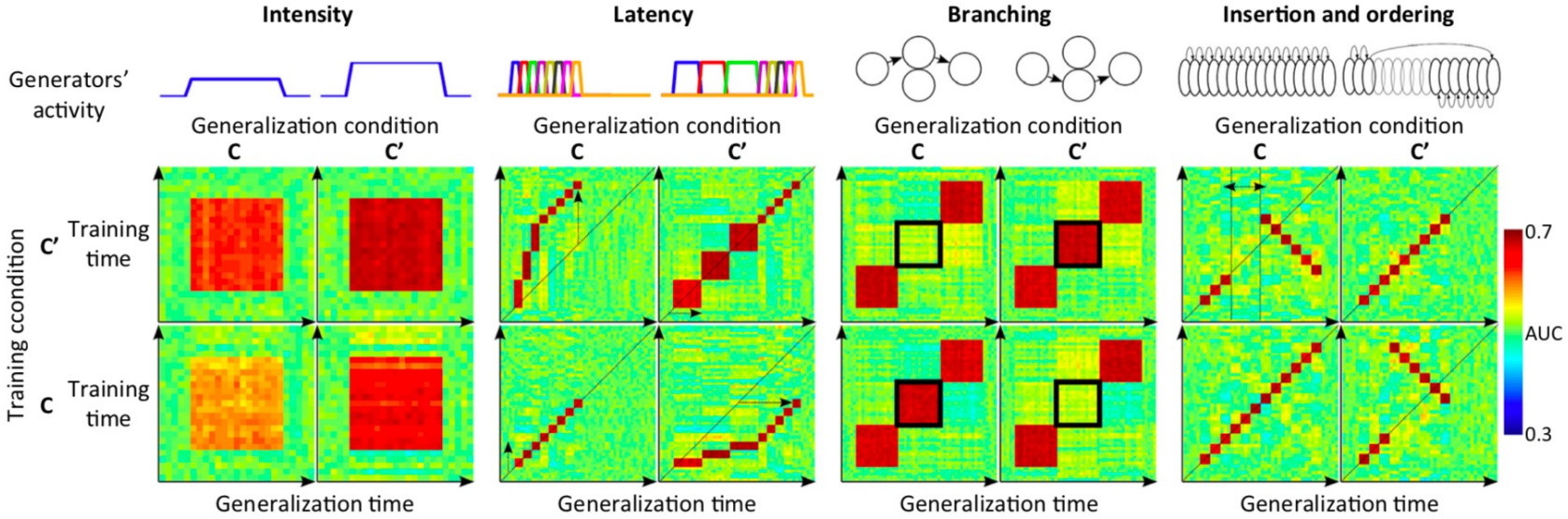


King, 2014, Trends Cogn Sci

Possible coding schemes (hypothetical)

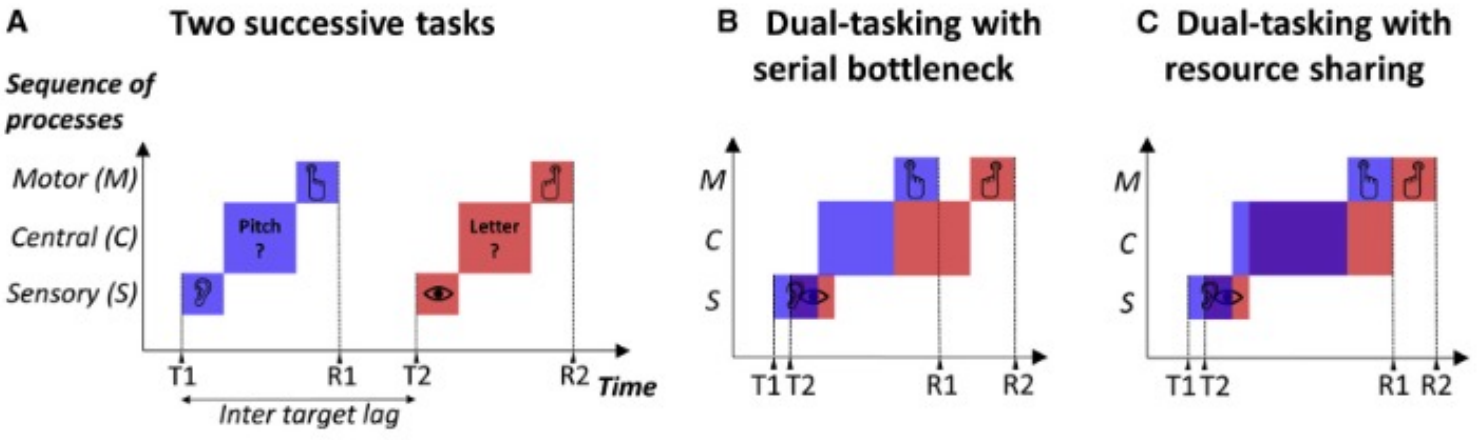


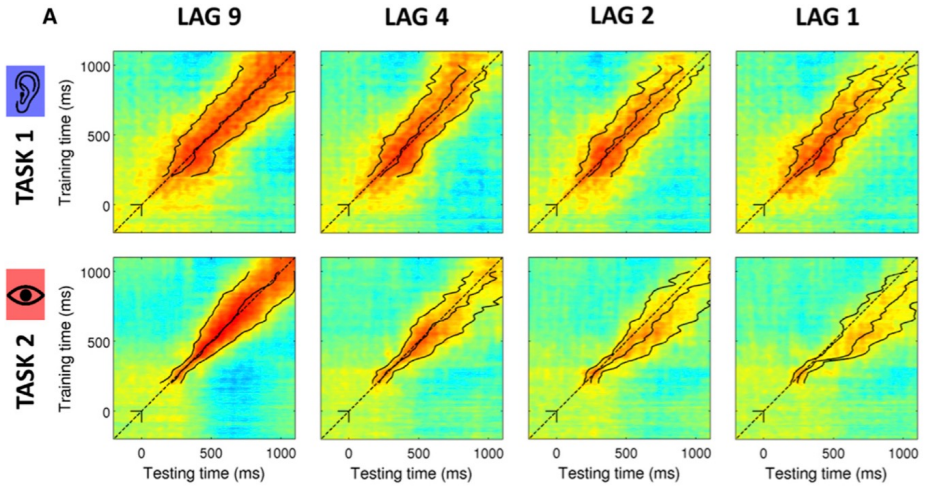
Effects of task manipulations (idealized)



King, 2014, Trends Cogn Sci

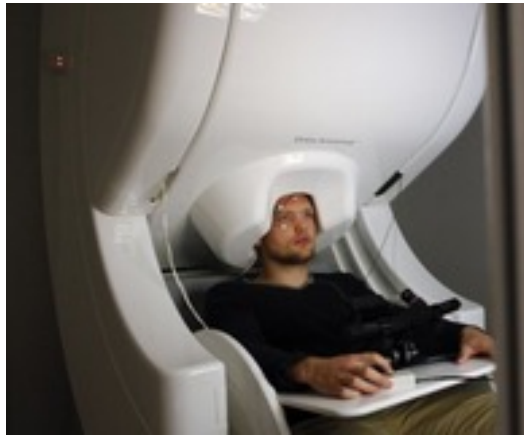
Time-resolved RSA in action



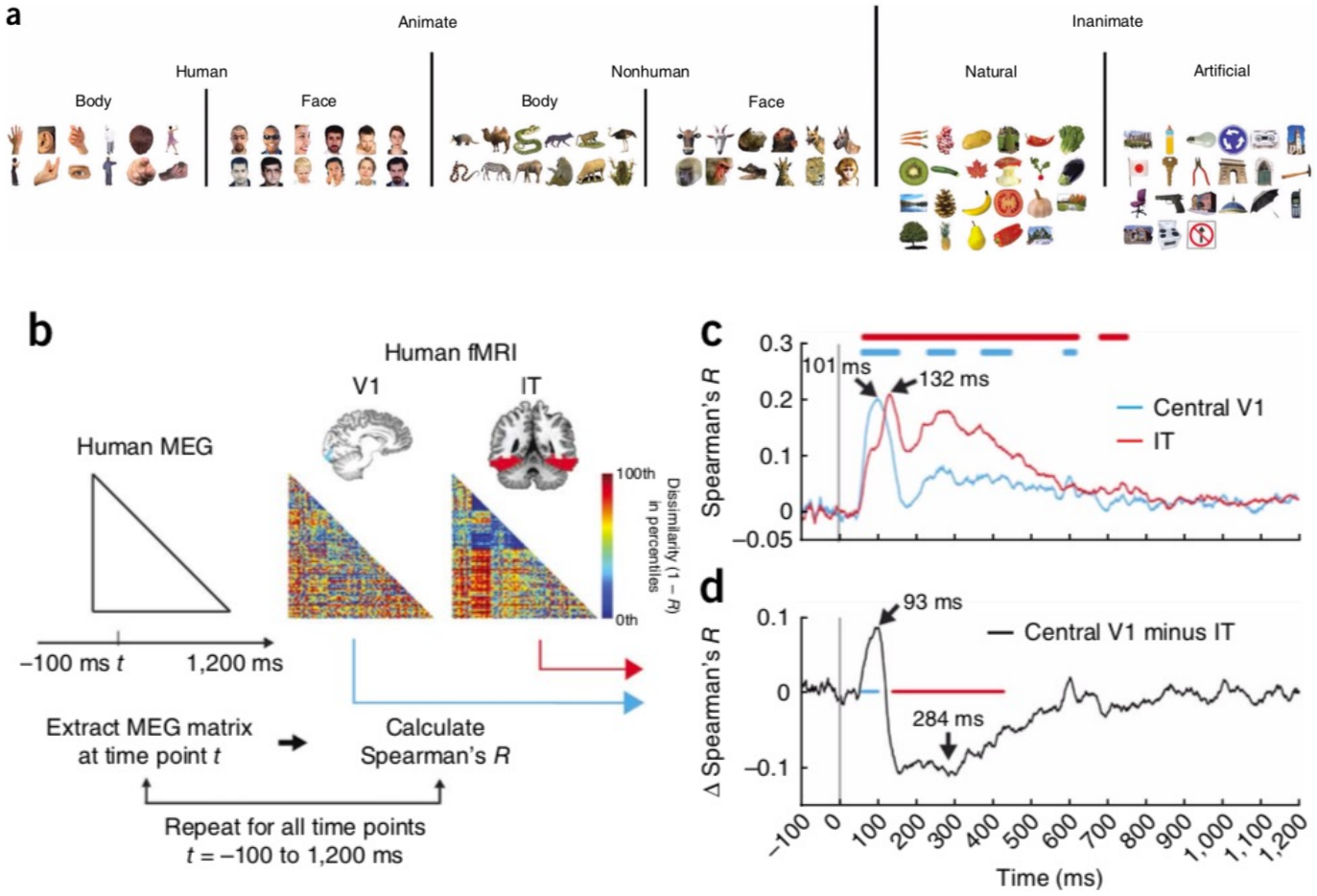


Marti, 2015, Neuron

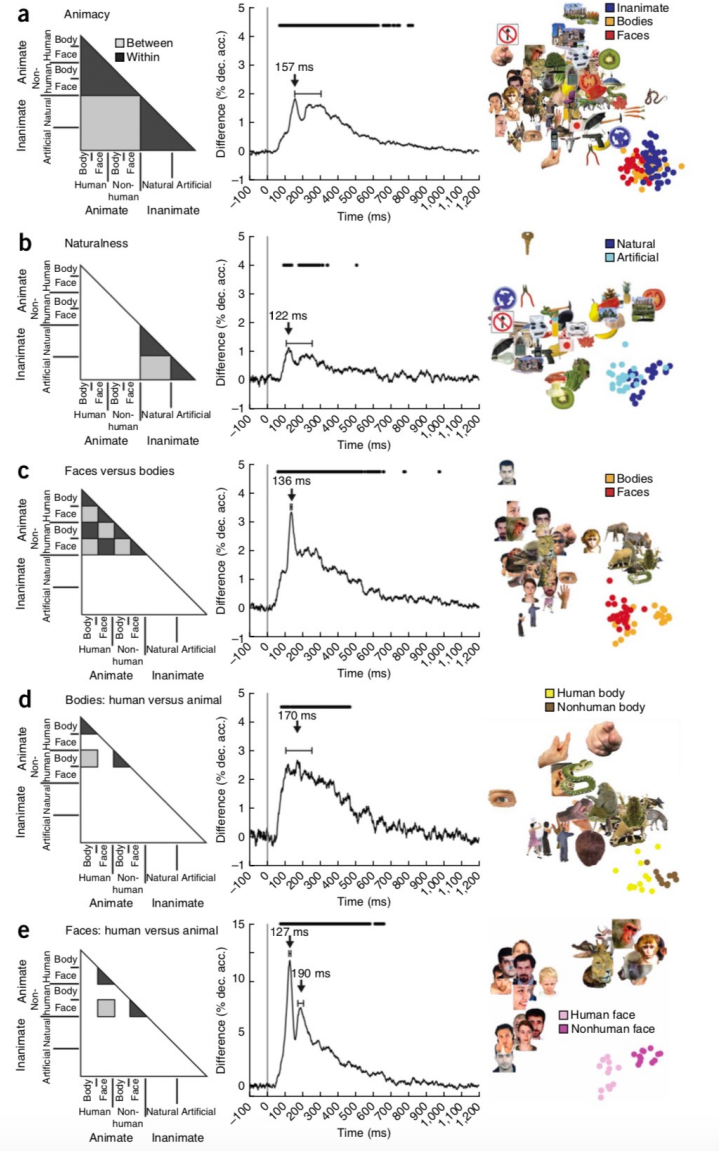
Modality fusion: integrating information in time and space



Modality fusion: integrating information in time and space



Cichy, 2014, Nat Neurosci



Summary

- RSA provides a compact second-order metric that can be used to characterize the content and structure of neural population codes
- This facilitates integration of results across brain regions, subjects, modalities, species, etc., and comparisons with computational models
- Time-resolved RSA provides additional insights into the temporal organization of information processing stages and the effects of task manipulations
- Powerful framework to make neuroscience more useful for cognitive science

References

- Brouwer, 2009, J Neurosci
- Chestek, 2007, J Neurosci
- Cichy, 2014, Nat Neurosci
- Coutanche, 2018, Trends Cogn Sci
- Evans, 2015, Cereb Cortex
- Flinker, 2015, PNAS
- King, 2014, Trends in Cogn Sci
- Kriegeskorte, 2008, Front Syst Neurosci
- Kriegeskorte, 2013, TiCS
- Kriegeskorte, 2008, Neuron
- Mack, 2020, Nat Comms
- Marti, 2015, Neuron
- McAdams, 1999, J Neurosci
- Nelissen, 2013, J Neurosci
- Rigotti, 2016, Curr Opin Neurobiol
- Wimber, 2015, Nat Neurosci
- Xue, 2010, Science