Session I: Introduction to Multivariate Pattern Analysis (MVPA)

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NIMH

Neural Decoding of Visual Imagery During Sleep

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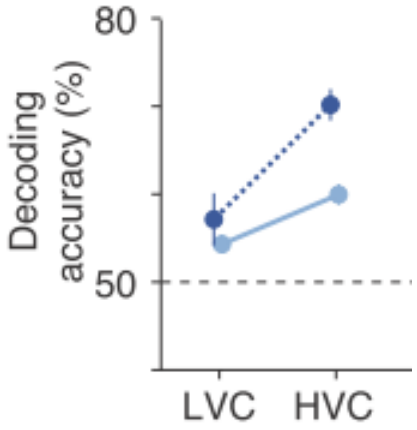
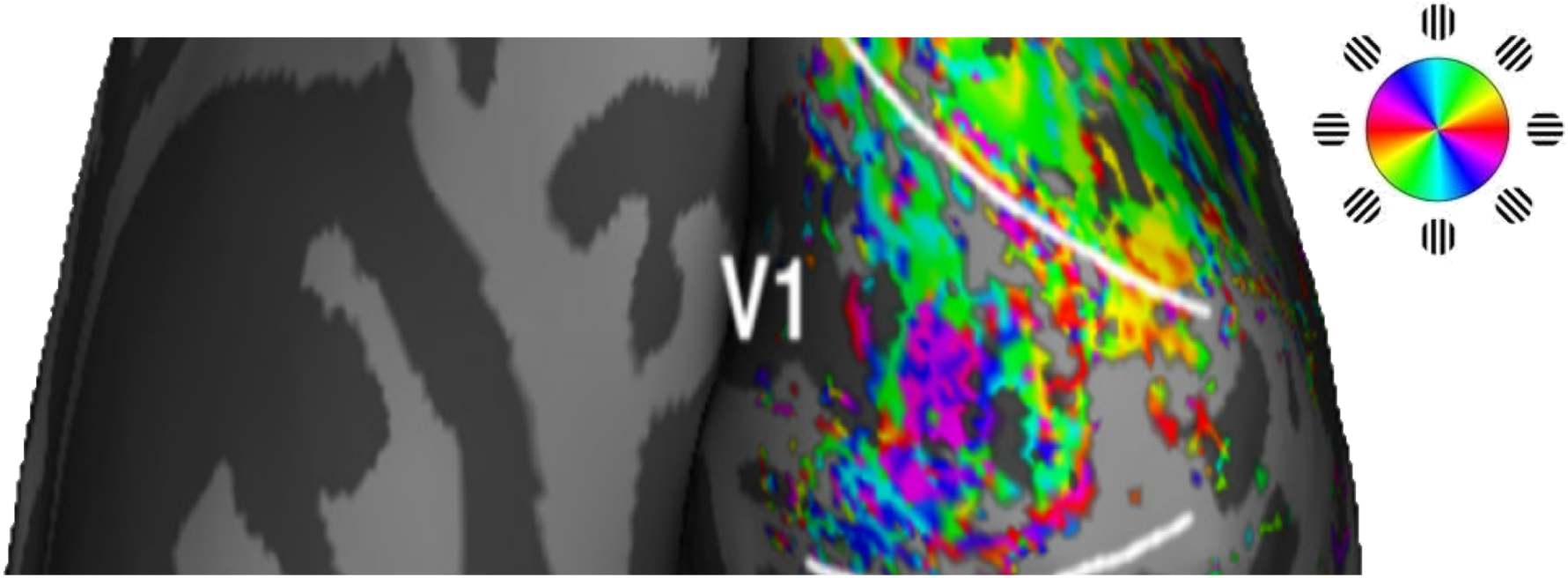


Image: David Castillo Dominici, http://www.freedigitalphotos.net

What is Multivariate Pattern Analysis?

Combined use of multiple variables measuring the brain (e.g. BOLD signal in multiple voxels) to predict or characterize states of the brain



Swisher et al. (2010) – J Neurosci

Overview

Why Multivariate Pattern Analysis?

How Does MVPA work?

Activity vs. Information

Encoding vs. Decoding

Prediction vs. Interpretation

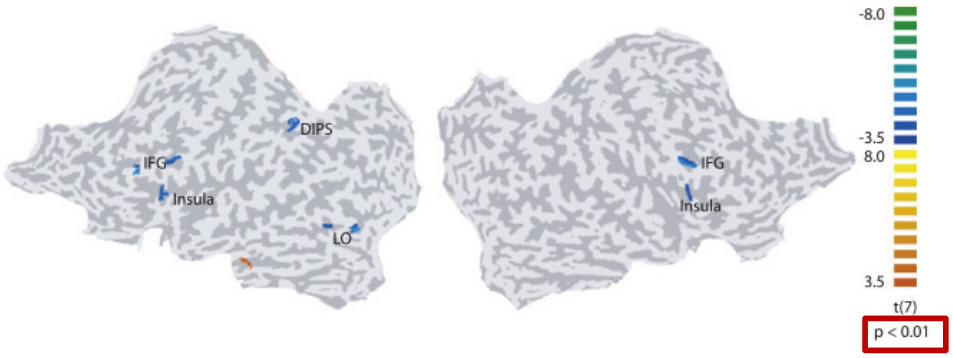
Neural Basis of MVPA

Why Multivariate Pattern Analysis?

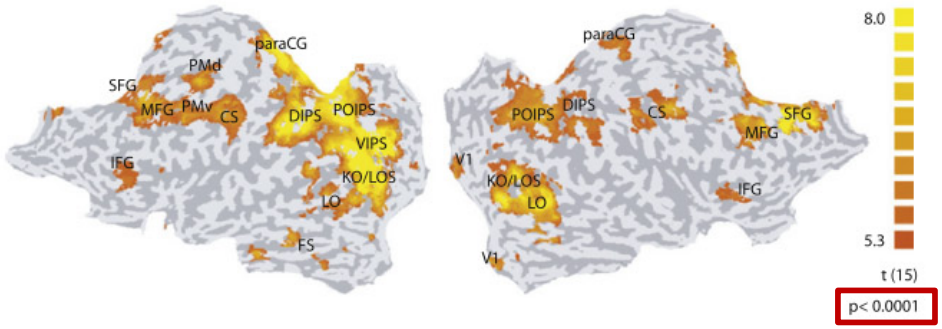
1. Often higher sensitivity compared to „normal“ univariate analyses

Example: Representation of perceptual choices

univariate



multivariate

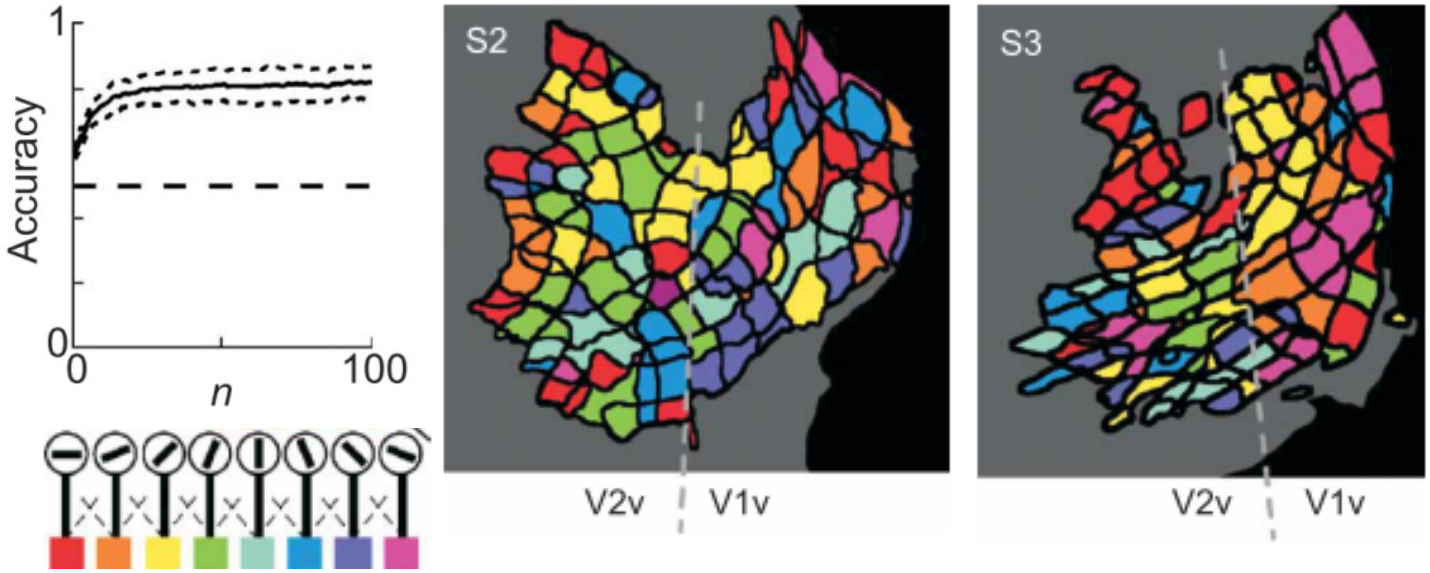


Li et al (2009) - Neuron

Why Multivariate Pattern Analysis?

2. Representational content in brain region rather than general activation can be studied

Example: Representation of orientations

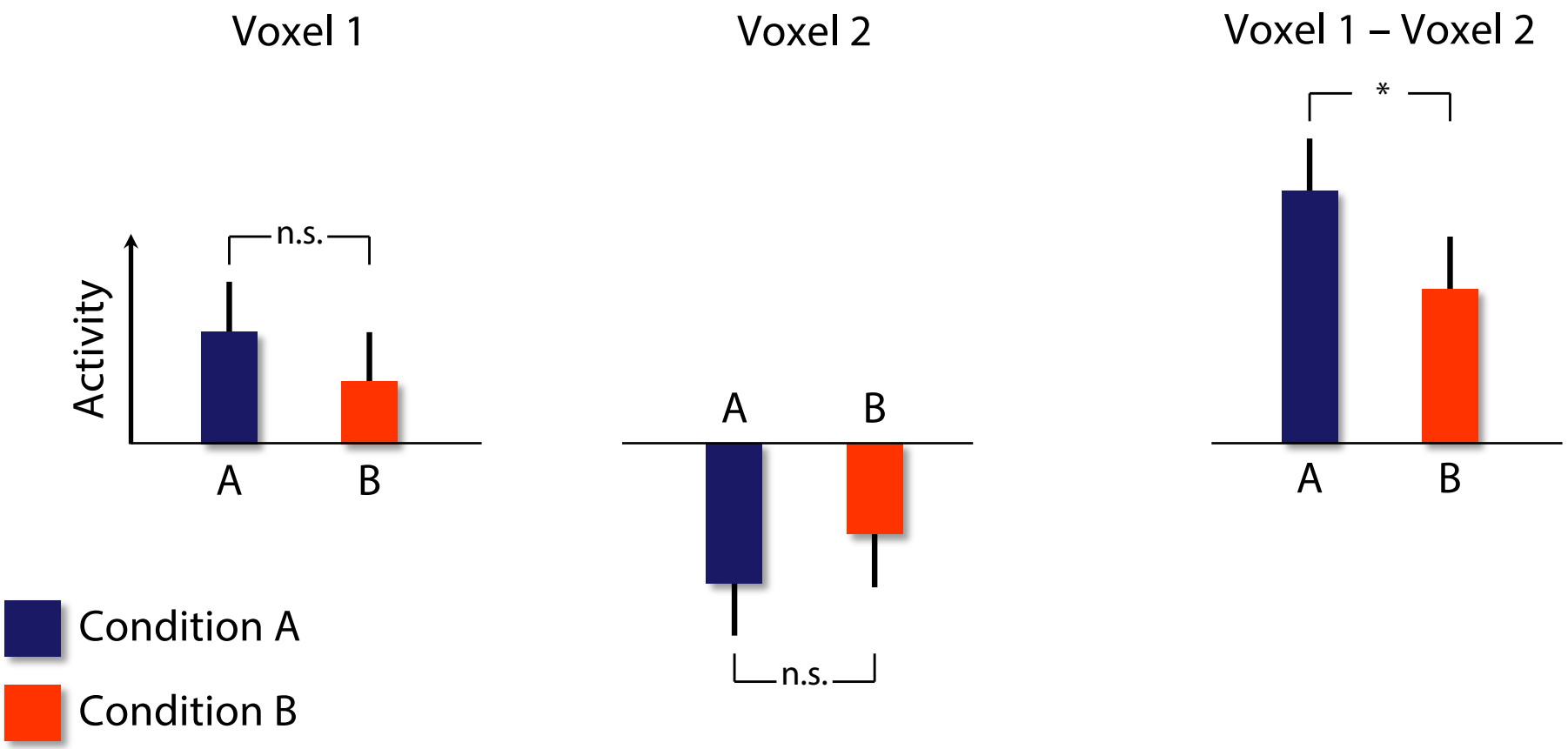


Kamitani & Tong (2005) – Nat Neurosci, Haynes & Rees (2005) – Nat Neurosci

How Does Multivariate Pattern Analysis Work?

1. Weak information can be combined across voxels

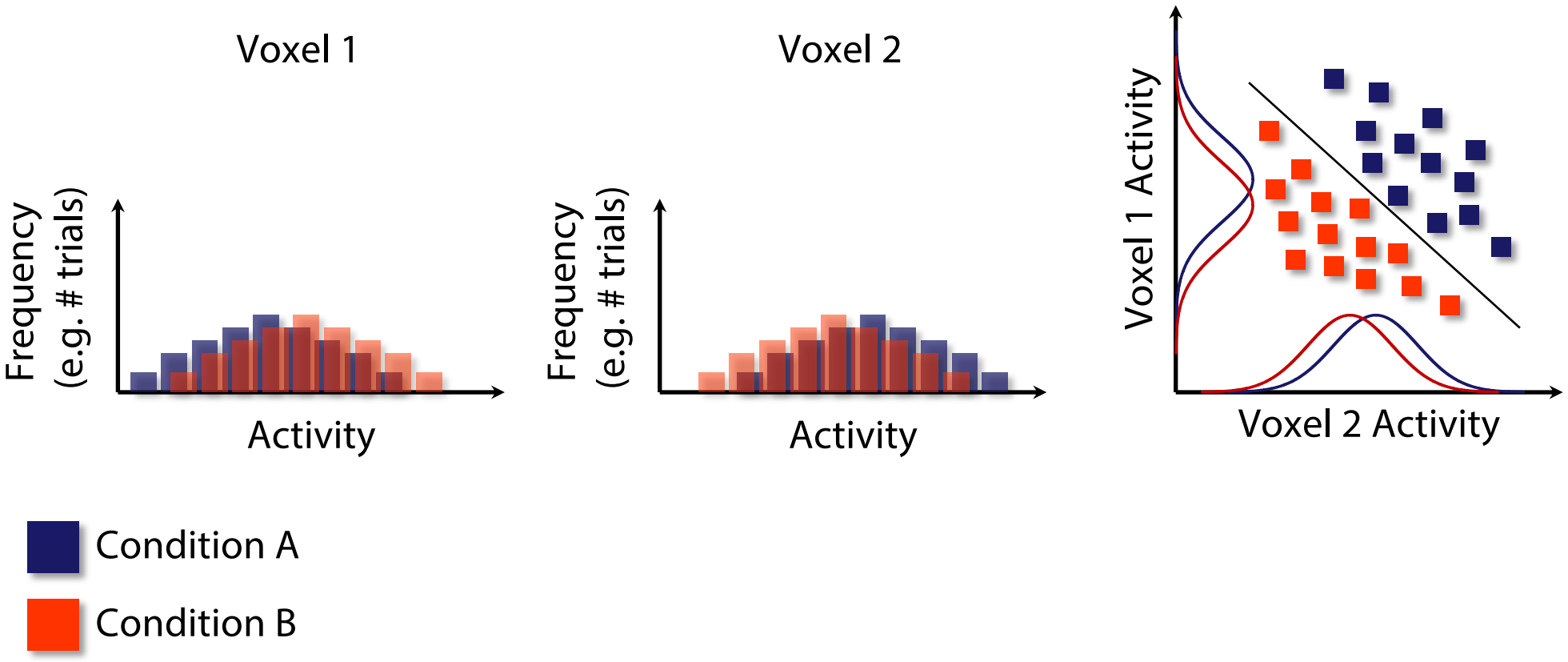
→ Multivariate analysis enhances signal



How Does Multivariate Pattern Analysis Work?

2. Covariation of voxel information can be used

→ Multivariate analysis suppresses noise



How Does Multivariate Pattern Analysis Work?

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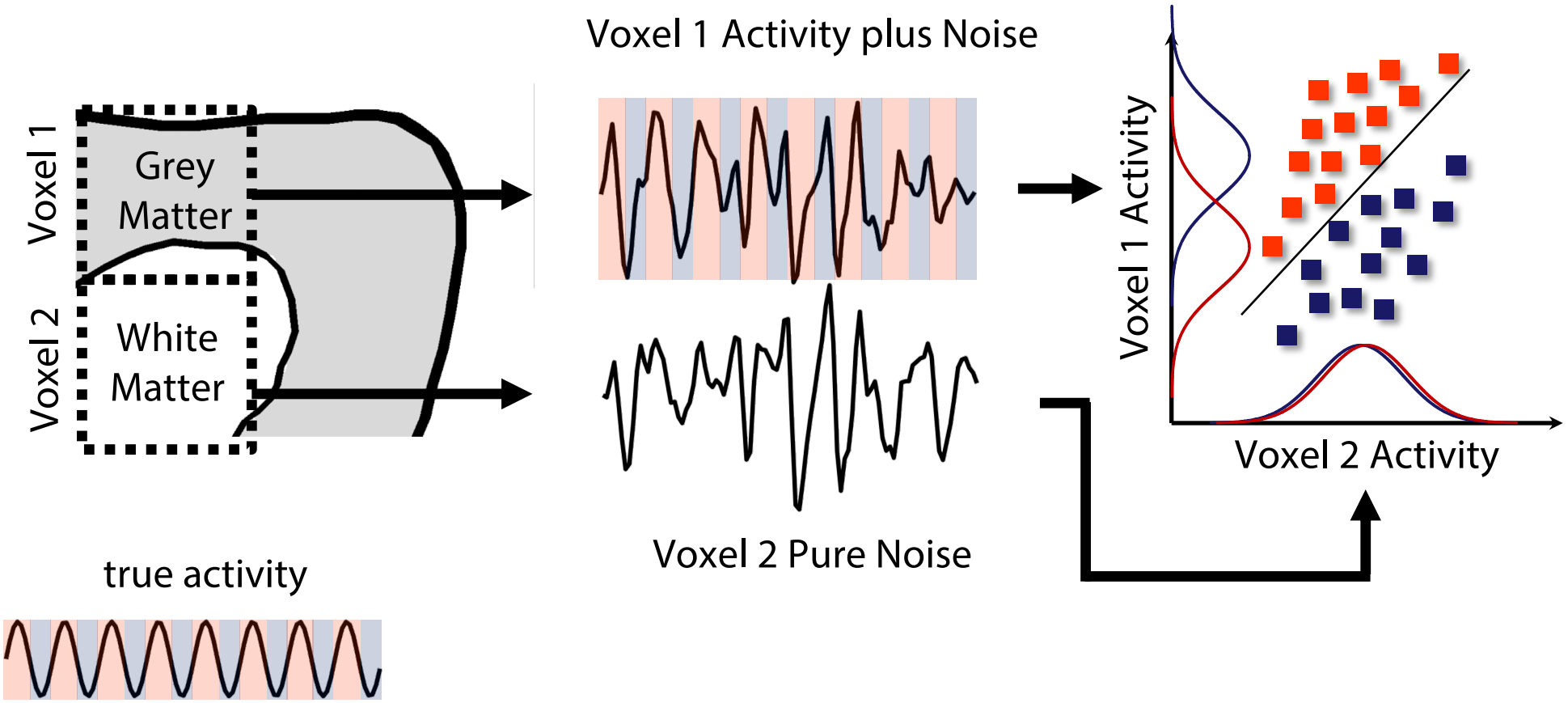
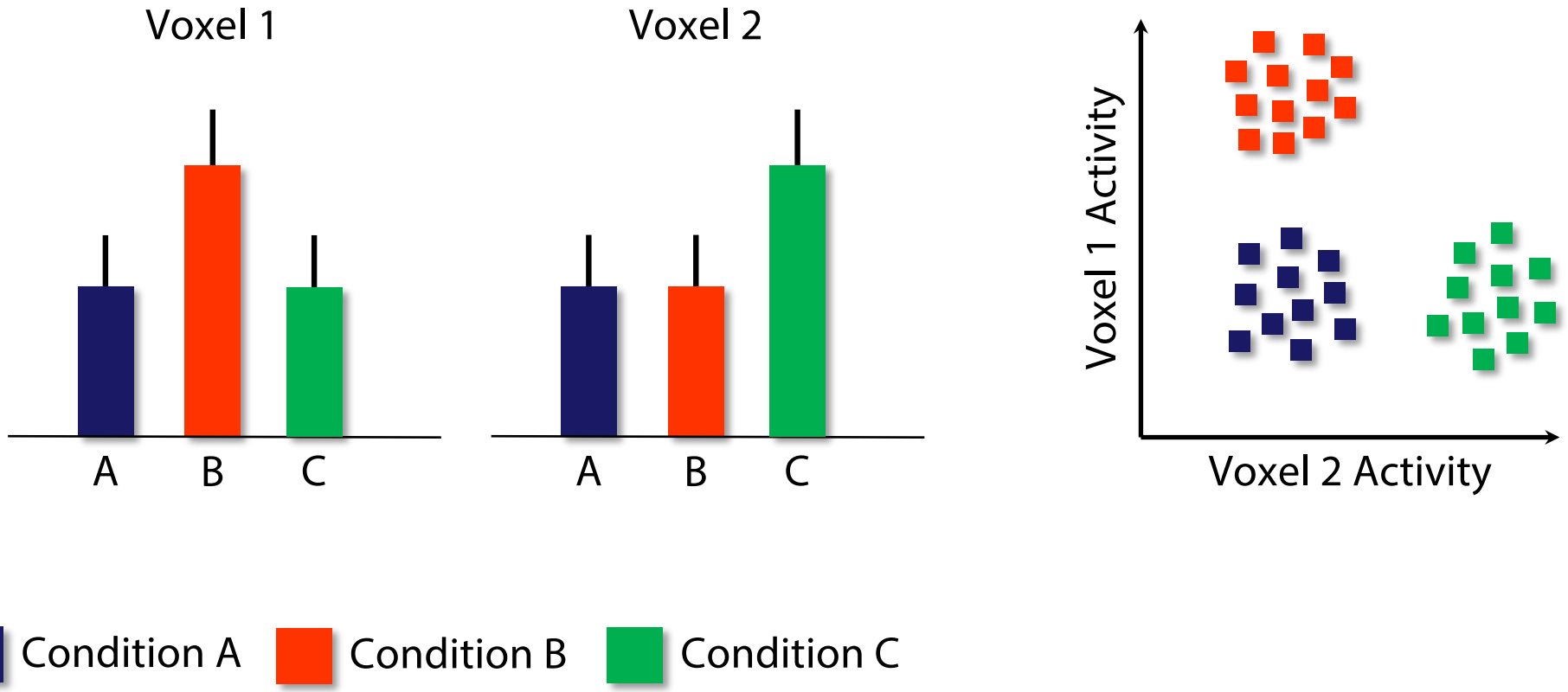


How Does Multivariate Pattern Analysis Work?

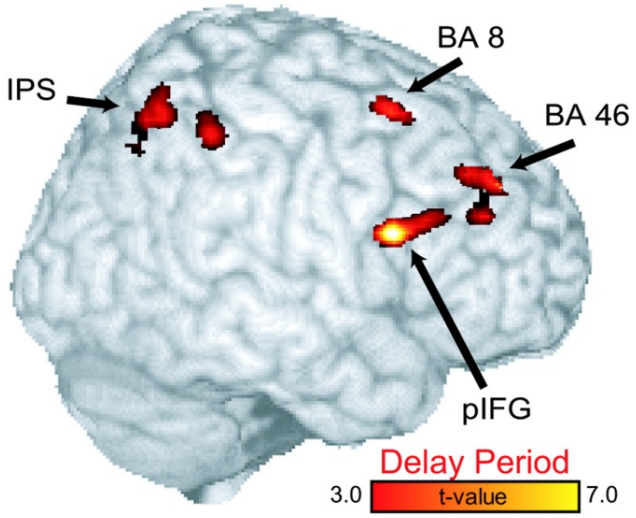
3. Information becomes accessible that is encoded only in distributed activity patterns

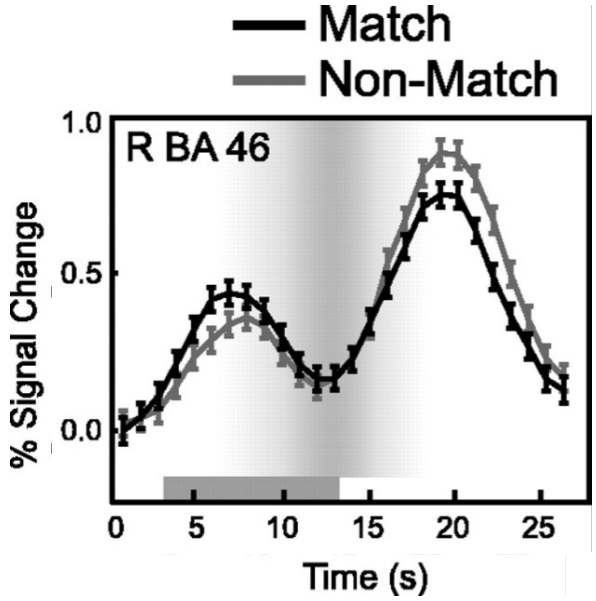


ACTIVITY VS INFORMATION

Activity vs. Information

Activity: Tells us about general involvement in cognitive function (e.g. working memory)

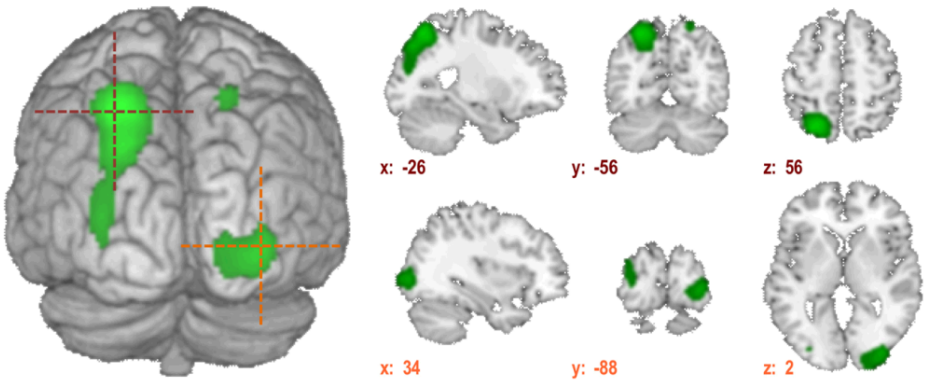


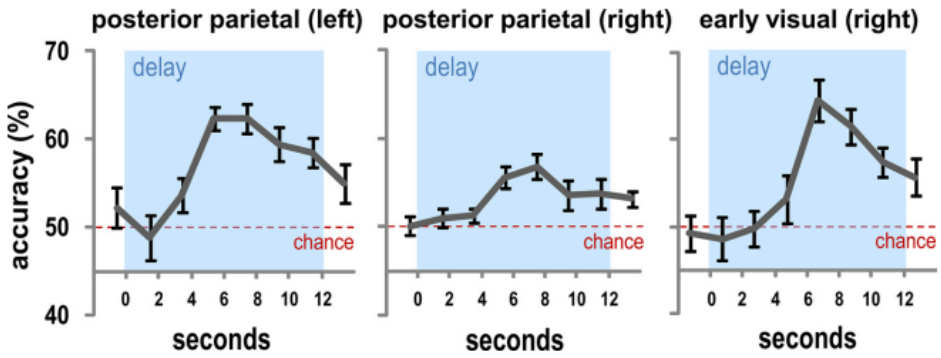


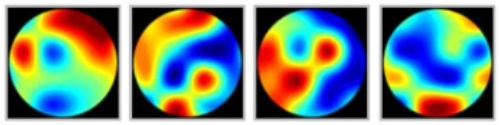
Curtis et al. (2004) – J Neurosci

Activity vs. Information

Information: Tells us about representational content (e.g. memory trace of A vs. memory trace of B)







Christophel, Hebart, & Haynes (2012) – J Neurosci, but see Ester et al. (2015) – Neuron

ENCODING VS DECODING

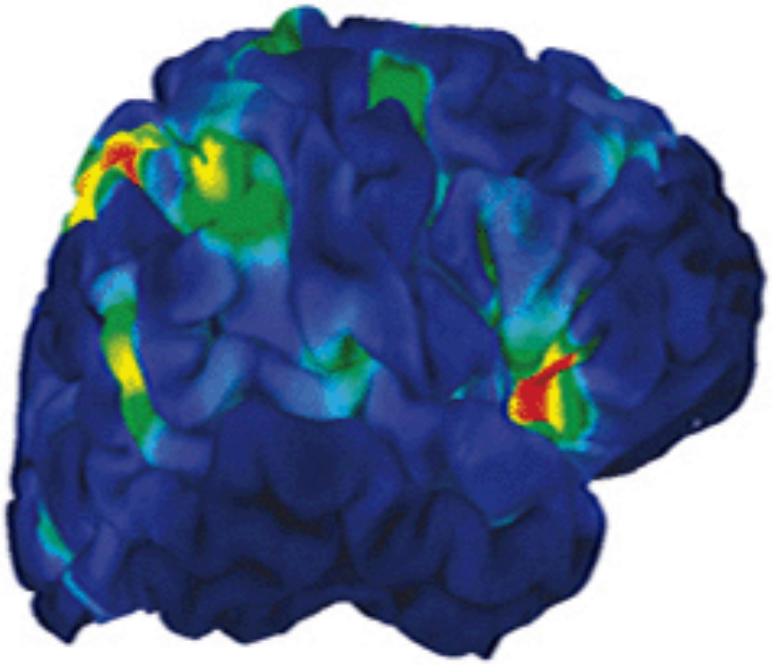
Encoding vs. Decoding

what we normally do
in univariate analyses

Encoding g: X → Y

Cognitive Function

Decoding h: Y → X



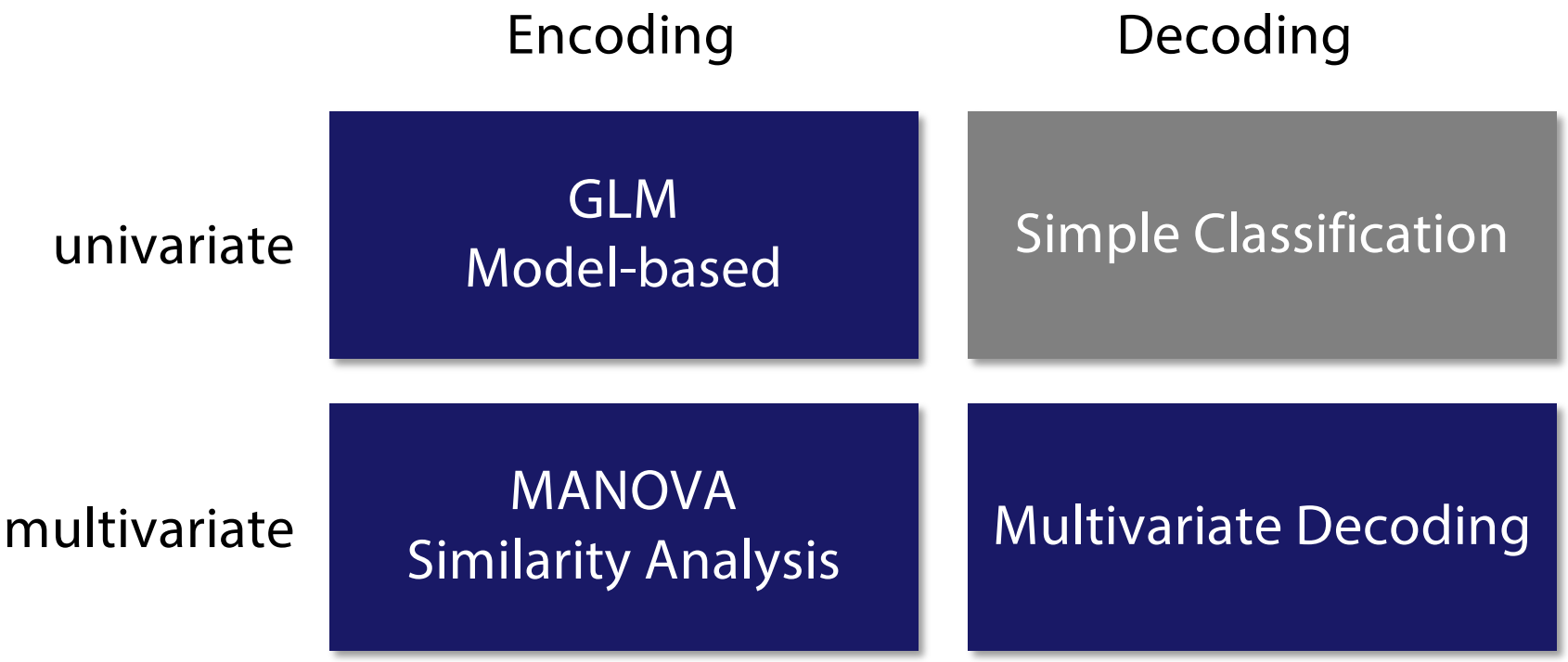
X: Explaining variable

Example: Stimulus, response, cognitive condition

Y: Measured data

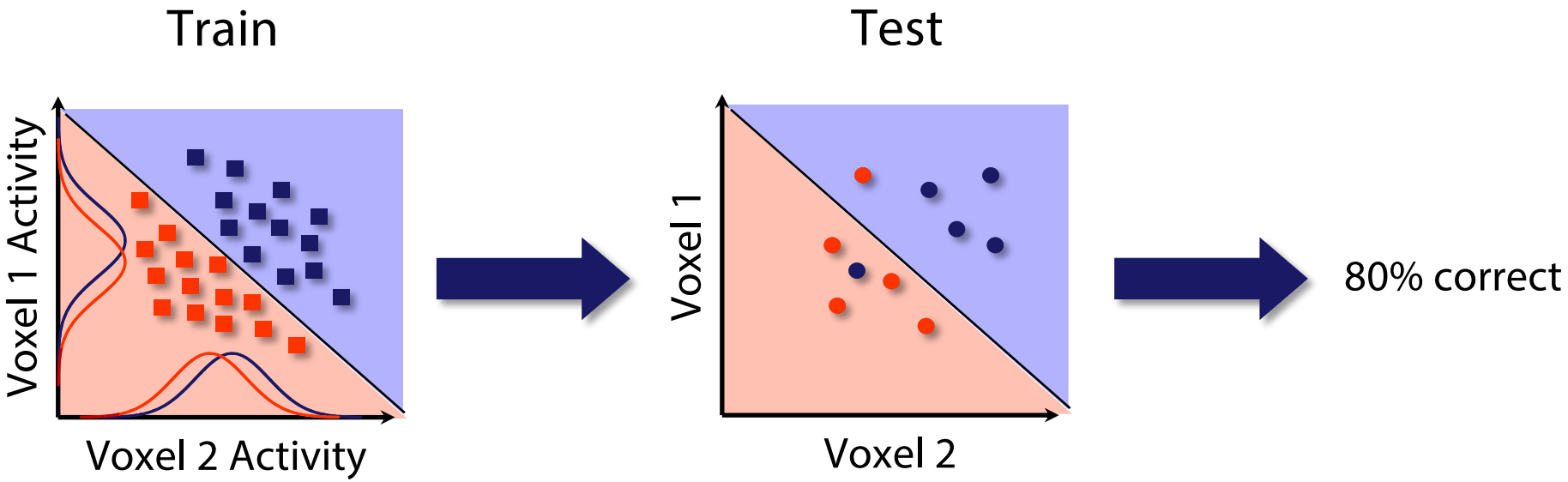
Example: BOLD signal, EEG signal, VBM intensity

Overview Over Analysis Methods



Multivariate Decoding Approach (the big picture)

1. Separate data in training and test data
2. “Train” a classifier (i.e. find a good separating line)
3. Apply this classifier (i.e. the line) to test data
4. Result: Accuracy of test data (i.e. % correct prediction)



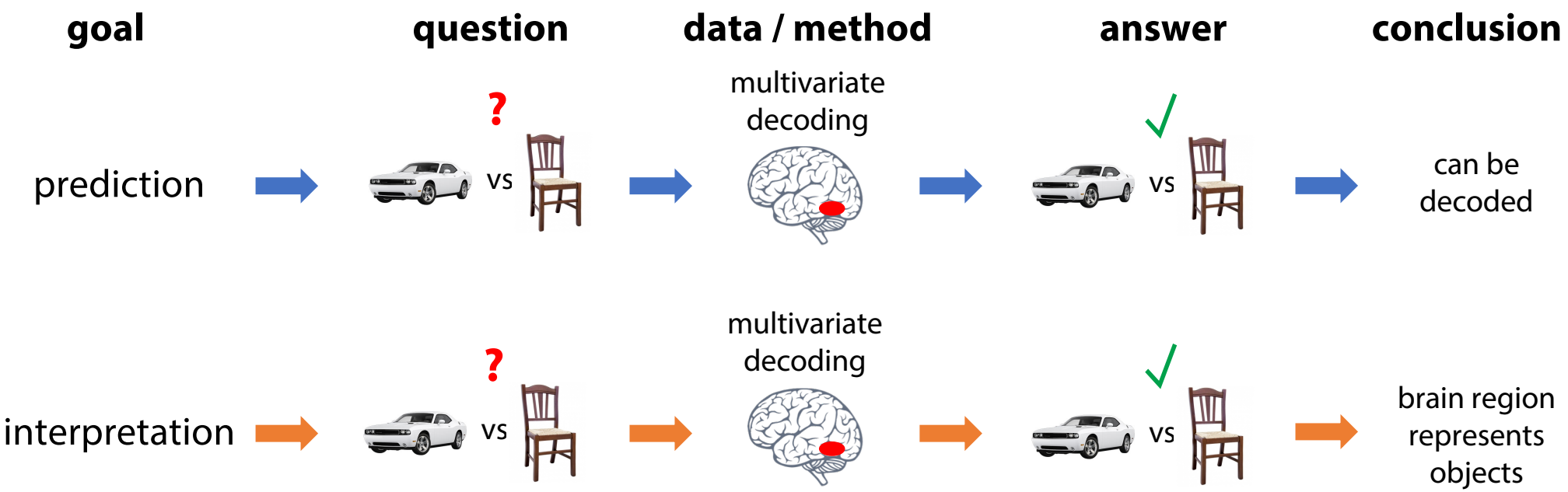
Why Decoding?

- Decoding sounds cool
- Methods readily available from machine learning
- The principle is relatively easy to understand
- Model-based univariate approaches and RSA are typically limited to condition-rich designs (i.e. few repetitions, many conditions)
- CV-MANOVA has only been developed more recently and is not widely popularized

- Decoding for reverse inference: Poldrack (2011) – Neuron
- Decoding for causal inferences: Weichwald et al (2015) – Neuroimage

PREDICTION VS INTERPRETATION

Goals of Decoding: Prediction vs. Interpretation



Hebart & Baker (2017) – Neuroimage

Goals of Decoding: Prediction

Prediction: Goal is to maximize future correct predictions

→ Any information is useful as long as it increases accuracy

Medical Diagnosis

Brain-Computer-Interface

Lie Detection

Goals of Decoding: Prediction

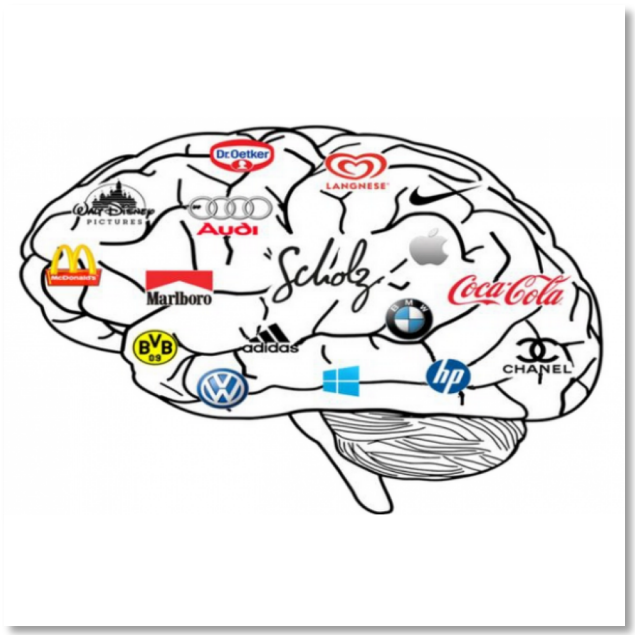
Prediction: Goal is to maximize future correct predictions

→ Any information is useful as long as it increases accuracy

Medical Diagnosis

Brain-Computer-Interface

Neuromarketing

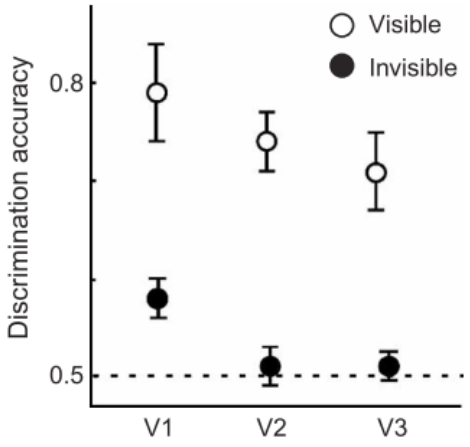


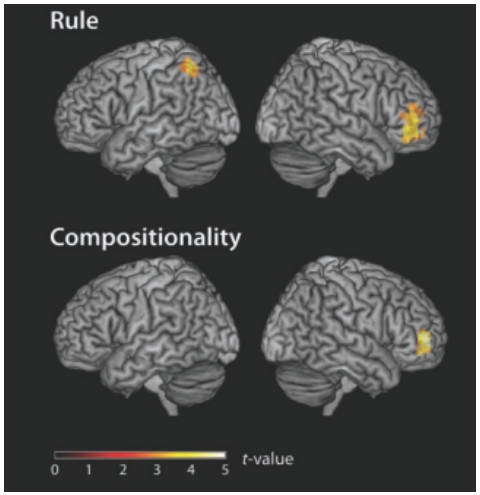
Goals of Decoding: Interpretation

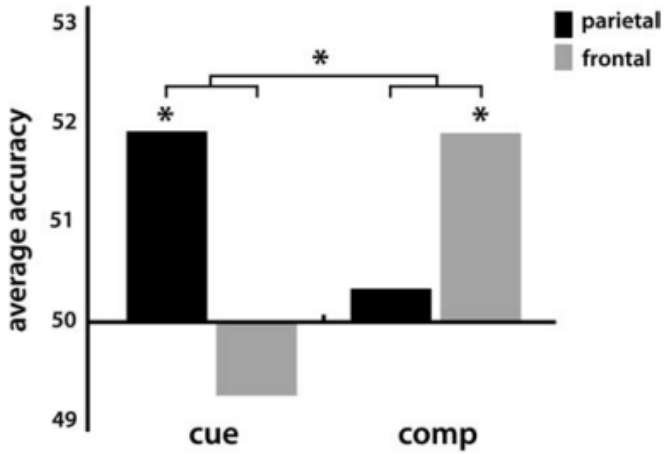
Interpretation: Is there information about XYZ?

→Sufficient to show above chance accuracy (statistically!)

→Not all information sources ok, need to rule out confounds







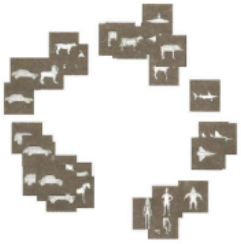
Haynes & Rees (2005) – Nat Neurosci; Reverberi, Görgen, & Haynes (2012) – Cereb Cortex

Prediction vs. Interpretation

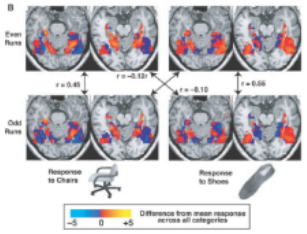
- Machine learning methods have been developed for prediction, but we are using them for the inference that there is information present about XYZ
- This alternative use of these methods has far reaching consequences that are underappreciated
- Many misunderstandings in MVPA originate from this, e.g.:
  - Too strong restrictions for interpretation studies (related to non-independence)
  - False sense of certainty when high decoding in study → High decoding can arise from confounds and should not be trusted more than activation studies (see Ritchie et al (2017) – bioRxiv)

Milestones of MVPA

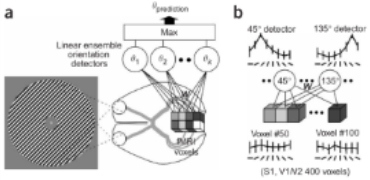
Edelman et al (1998)



Haxby et al (2001)

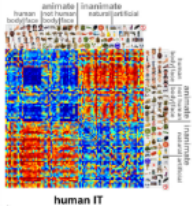


Kamitani & Tong (2005)
Haynes & Rees (2005)

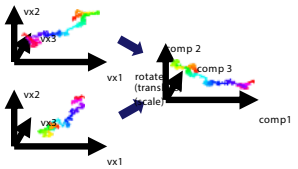


Kriegeskorte et al (2006)

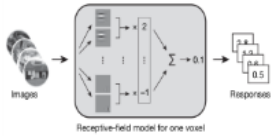
Kriegeskorte et al (2008)



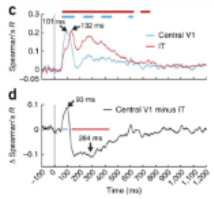
Haxby et al (2011)



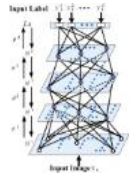
Kay & Gallant (2008)



Cichy et al (2014)



e.g. Di Carlo



1998 2001 2005 2006 2008 2011 2014 2015/2016

"first" MVPA study

first multivariate decoding study

popularization of multivariate decoding

searchlight approach

representational similarity analysis

model-based encoding methods

hyperalignment

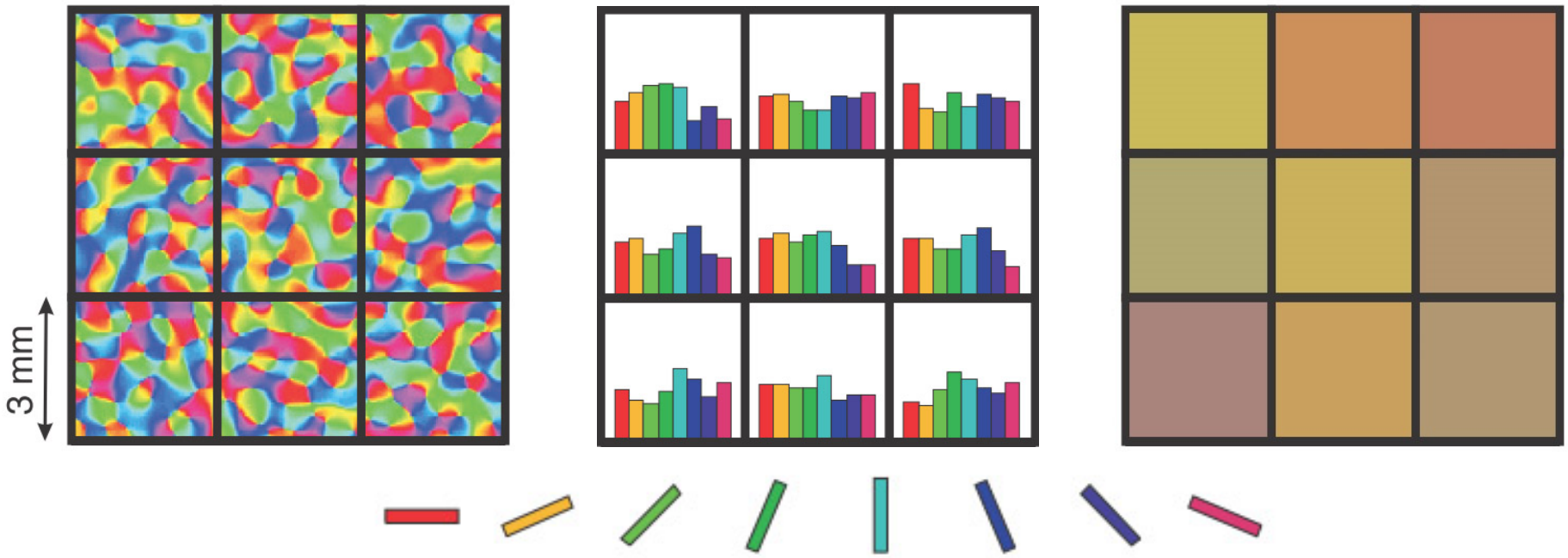
combination of fMRI and MEG using RSA

use of artificial neural networks as models for cognition

NEURAL BASIS OF MVPA

Neural Basis of MVPA

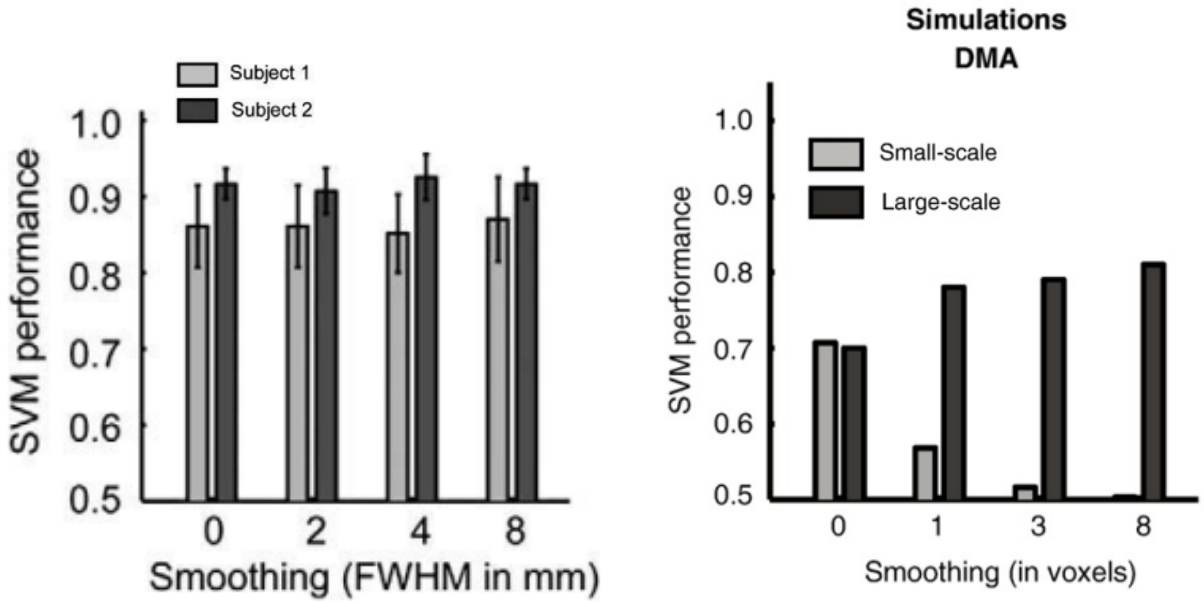
Popular Idea: Small random sampling bias in orientation retains orientation information in voxel



Boynton (2005) – Nat Neurosci

Neural Basis of MVPA: Fine-scale patterns?

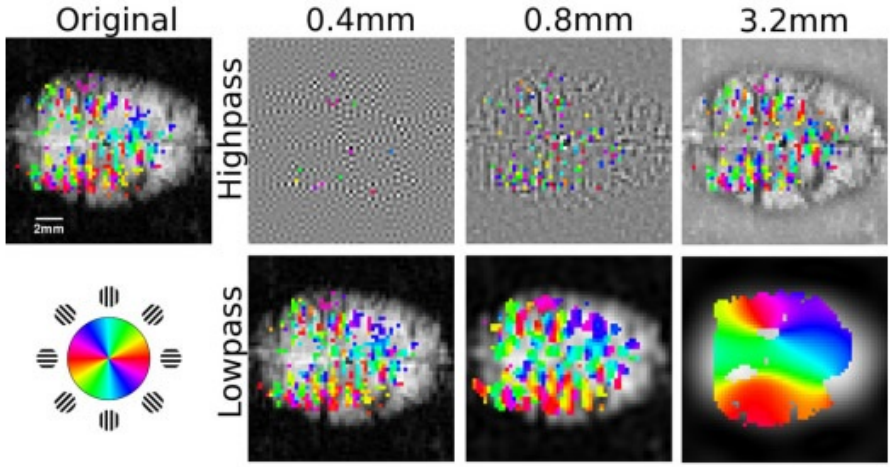
Does smoothing hurt decoding accuracy?



Neuroimage: Op de Beeck (2010a,b) ; Kamitani & Sawahata (2010); Kriegeskorte (2010); Shmuel et al (2010); Chaimow et al (2011)

Neural Basis of MVPA: Sampling Bias?

Dominance of fine scale (evidence for „hyperacuity“)



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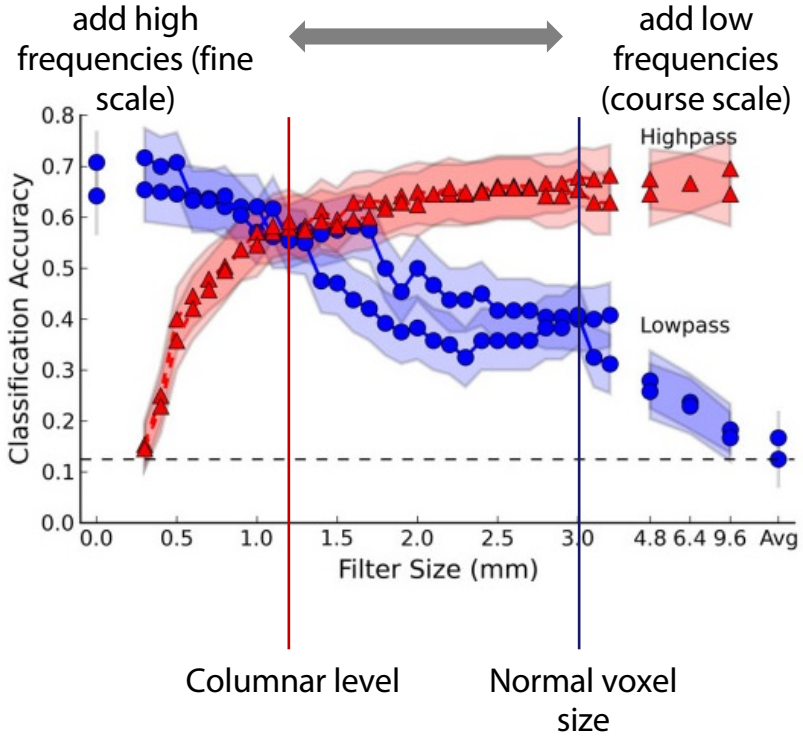
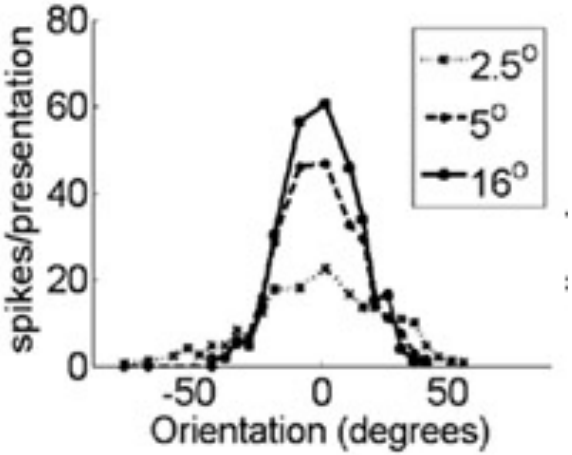


Swisher et al (2010) – J Neurosci

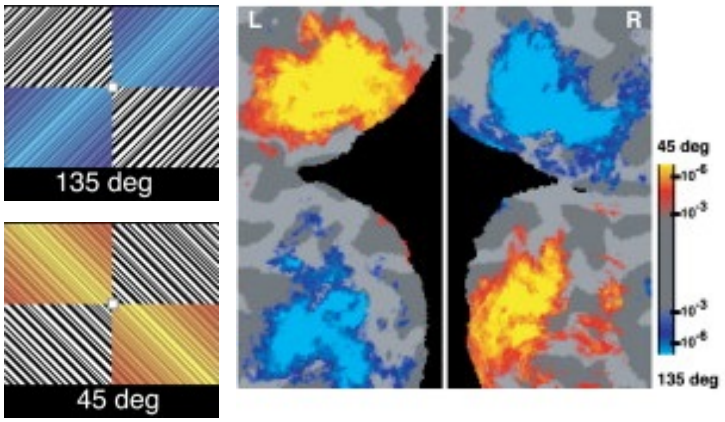
Neuronal Basis of MVPA

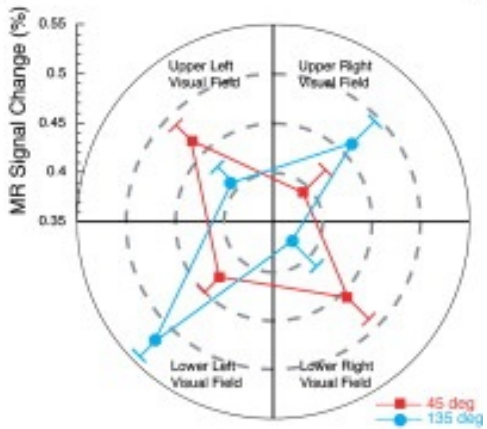
Bias maps instead of columns in V1?

Oblique effect



Radial bias

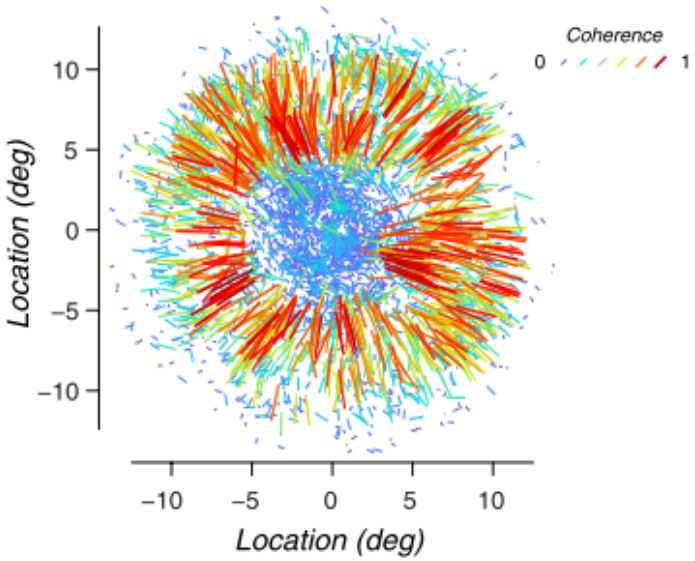


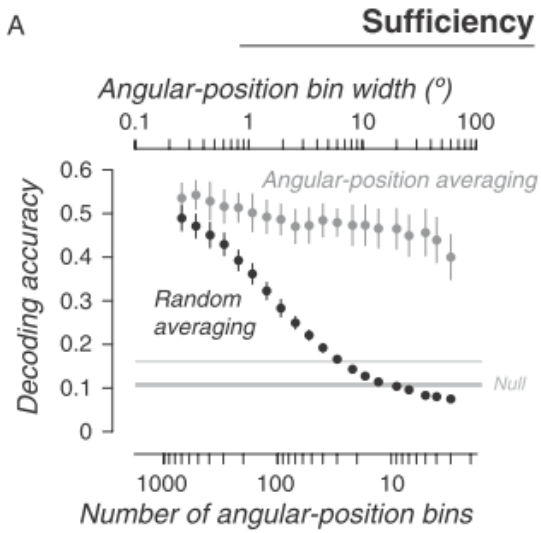


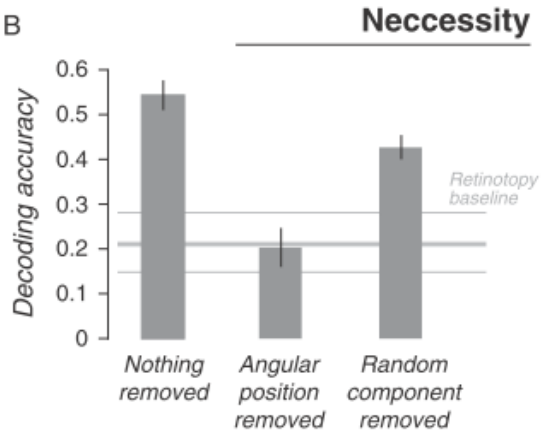
Orban et al (1979) – J Neurophysiol; Sasaki et al (2006) – Neuron

How does MVPA work – revisited

Radial bias maps, not columns explain „hyperacuity“







Freeman et al (2011) – J Neurosci; Beckett et al (2012) - Neuroimage

How does MVPA work – revisited

The debate continues…

- Chaimow et al (2011) – Neuroimage
- Beckett et al (2012) – Neuroimage
- Freeman et al (2013) – J Neurosci
- Alink et al (2013) – Front Hum Neurosci
- Carlson (2014) – J Neurosci
- Clifford & Mannion (2015) – Neuroimage
- Carlson & Wardle (2015) – Neuroimage
- Cichy et al (2015) – Neuroimage
- Maloney (2015) – J Neurophysiol
- Wardle et al (2017) – J Neurosci
- Alink et al (2017) – Scientific Reports

Neural Basis of MVPA – Summary

- Both course and fine-grained responses can contribute to decoding results
- Orientation decoding in V1 probably does not work with „hyperacuity“
- This property may also hold for other brain regions where the coarse-scale „maps“ are unknown
- **But:** In general decoding based on course-scale signals is fine as long as effects not driven by different feature of the results (e.g. radial bias and not orientation)

Summary

- MVPA is more sensitive than classical univariate approaches and can reveal representational content
- MVPA works by combining signal across voxels and suppressing correlated noise between voxels
- Investigating brain activity vs. informational content are two different approaches
- Encoding methods predict brain data from categories, decoding methods predict categories from brain data
- Decoding for prediction and decoding for interpretation are very different approaches
- MVPA likely relies strongly on course-scale signals

Study Questions

"A colleague comes by to ask for your methodological expertise. She studies action perception with fMRI and got a reviewer comment saying that she should distinguish brain regions that represent perceived actions from brain regions generally involved in perceiving actions."

Question 1: What does this difference mean?

Question 2: How would you tell her to do the analysis (without details, just in general)?

Question 3 (difficult): Can you think of a way of designing an experiment that addresses this issue without decoding? Can you think of a downside to this approach?