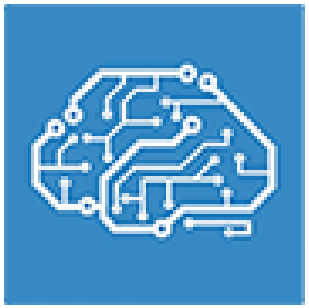
How to use decoding analyses to understand neural content and coding

Ethan Meyers

7/23/15



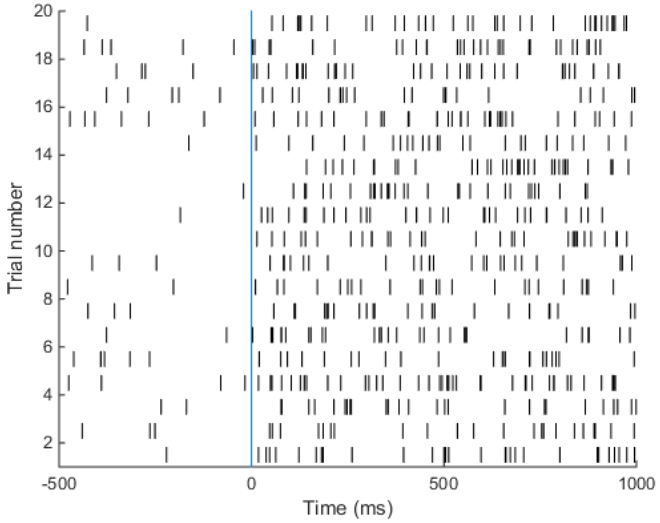
The Center for Brains, Minds & Machines

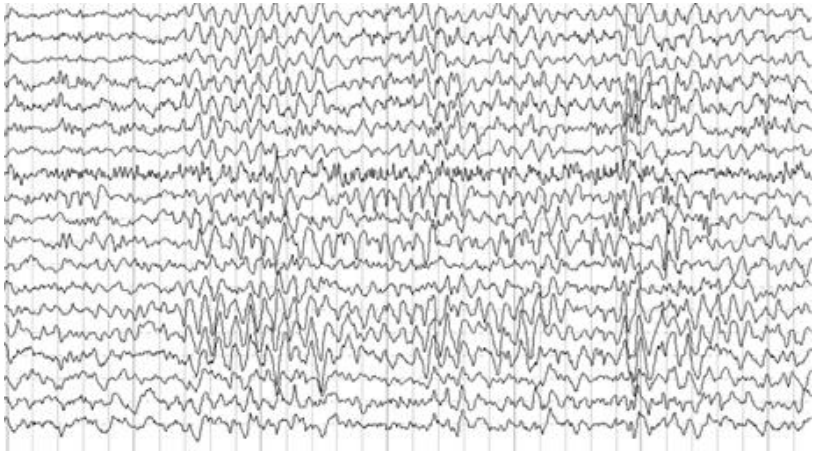
Motivation

We have some great theory about how the brain works

We run an experiment and make neural recordings

We get a bunch of data…





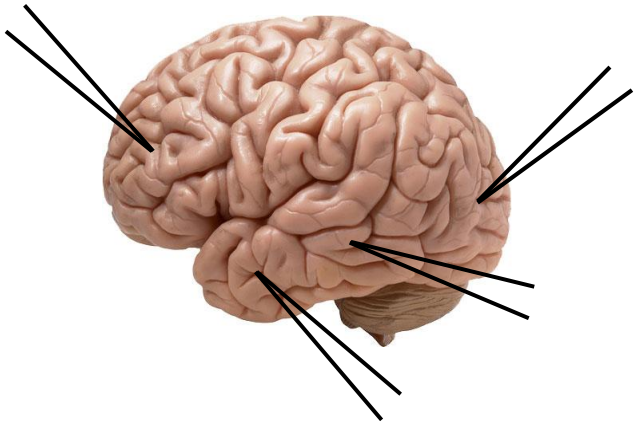
How can we convert data into answers?

What do I want from a data analysis method?

Clear answers to:

Neural content: What information is in a brain region?

Neural coding: What features of the activity contain information?



Talk Outline

What is population decoding?

Using decoding to understand **neural content**

Using decoding to understand **neural coding**

How to analyze your own data

Neural population decoding

Decoding: Predict stimulus/behavior from neural activity

f(neural activity) ⟶ stimulus

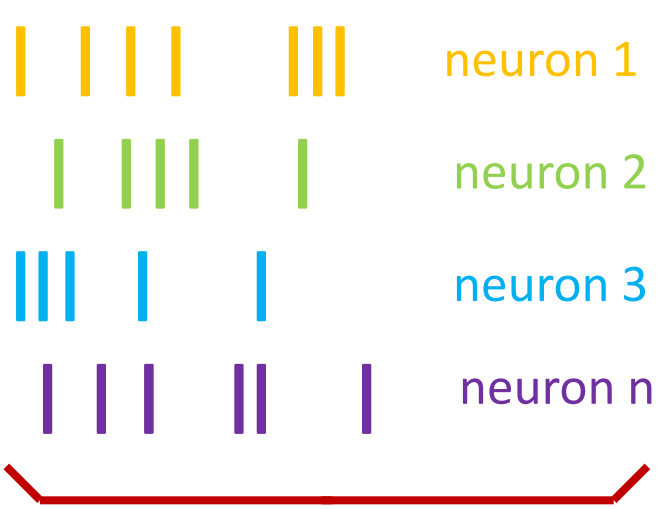
Decoding approaches have been used for 30 years

- Motor system: e.g., Georgopoulos et al, 1986
- Hippocampus: e.g., Wilson and McNaughton, 1993
- Computational work: e.g., Salinas and Abbott, 1994

Alternative names for decoding:

- Multivariate Pattern Analysis (MVPA)
- Readout

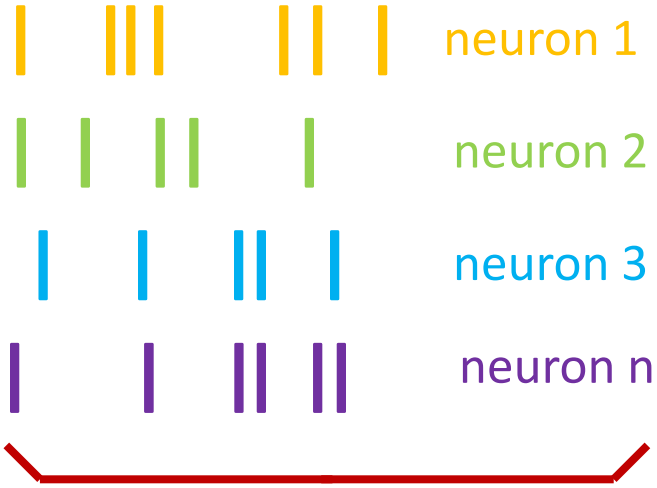
Training the classifier



Learning association between neural activity an image

Pattern Classifier

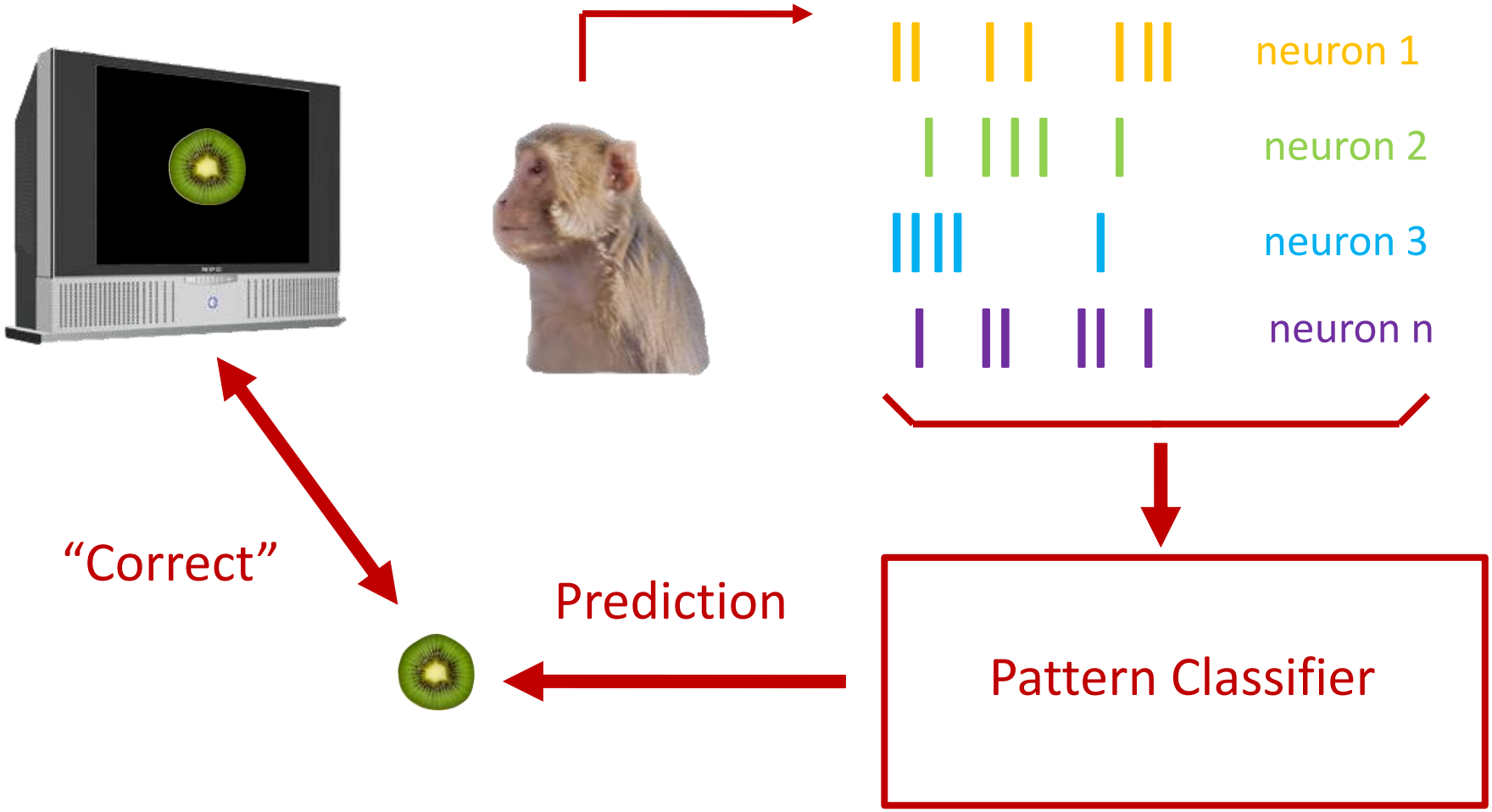
Training the classifier



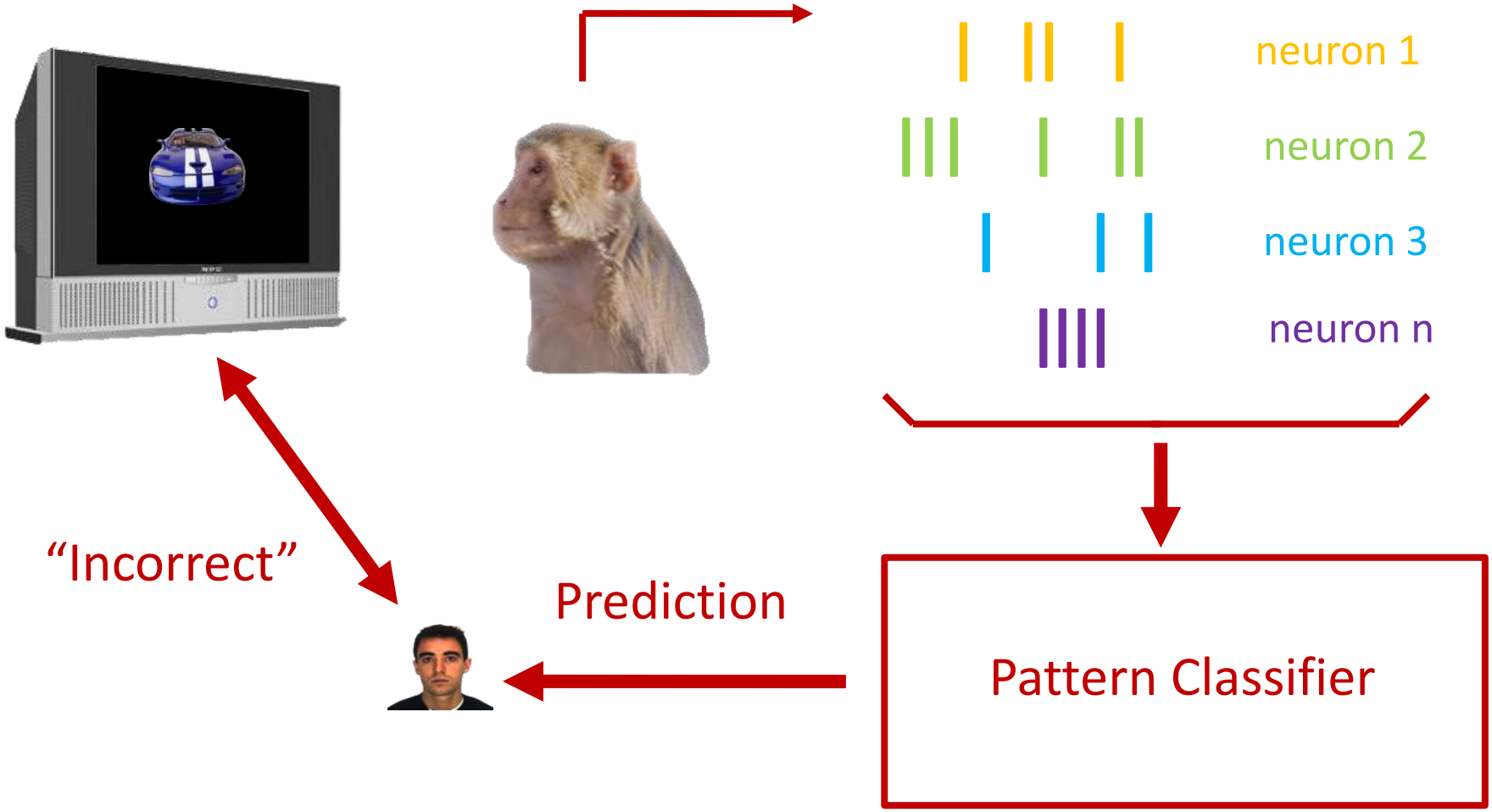
Learning association between neural activity an image

Pattern Classifier

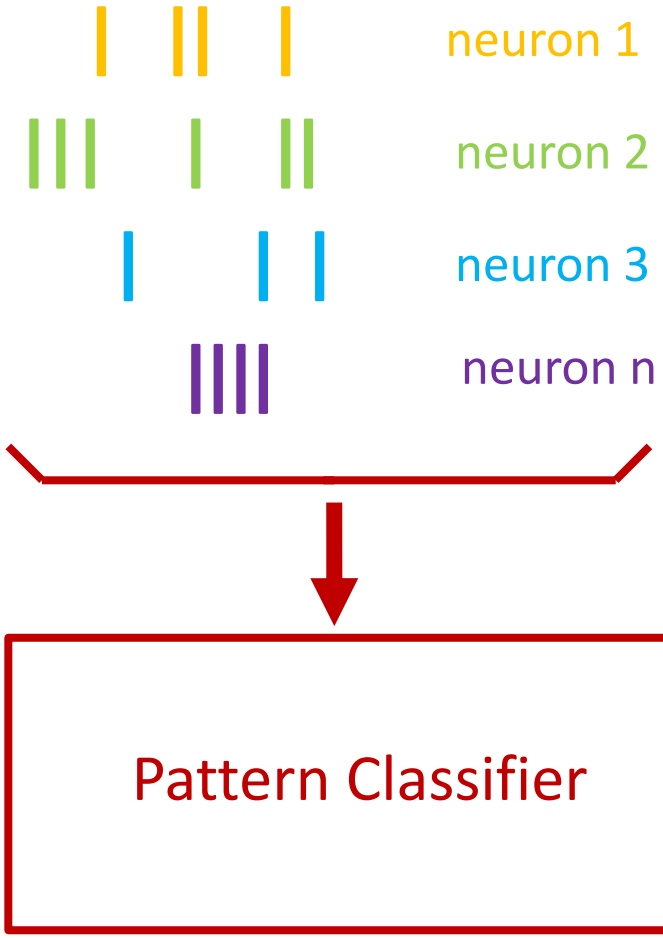
Using the classifier

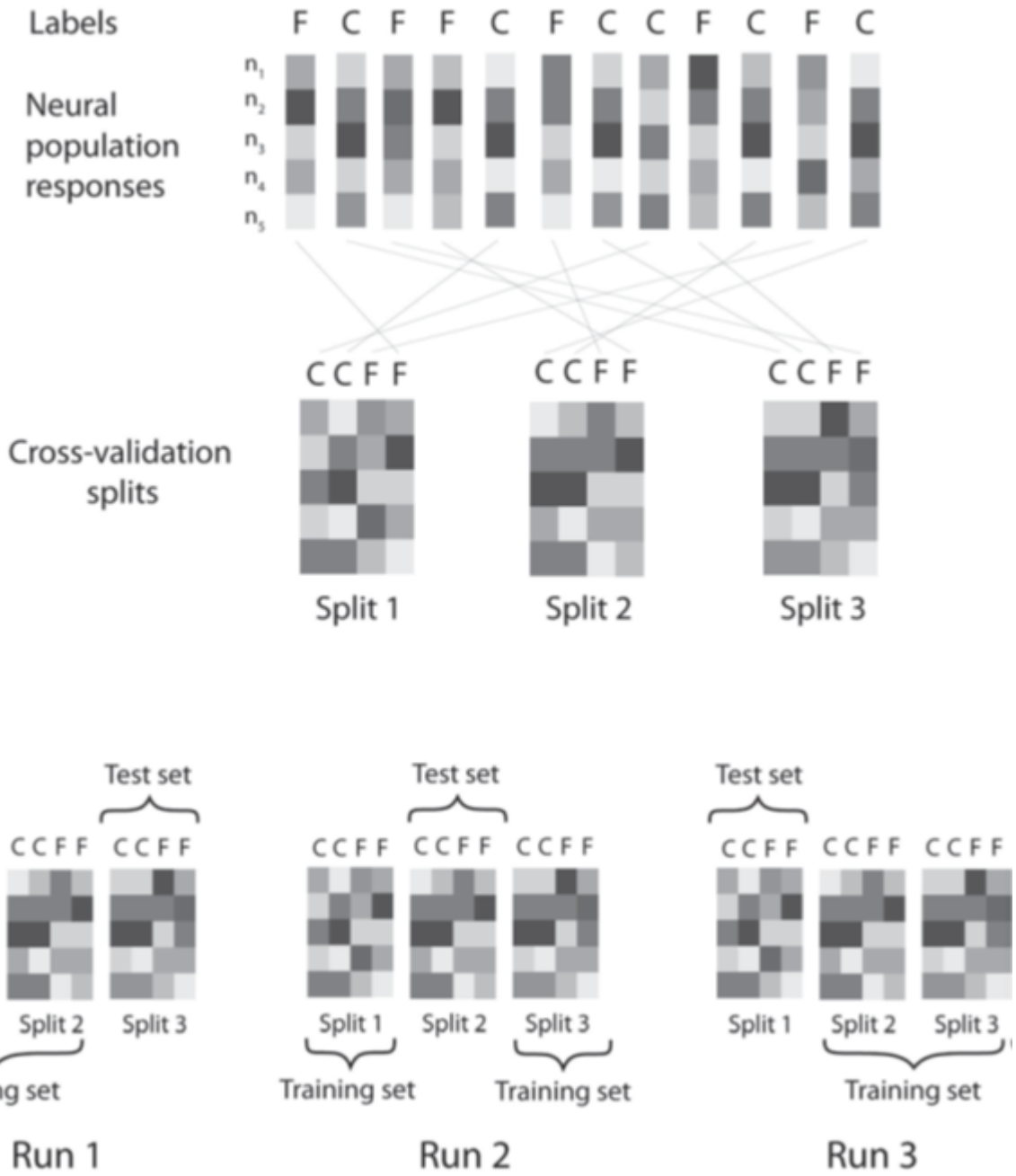


Using the classifier

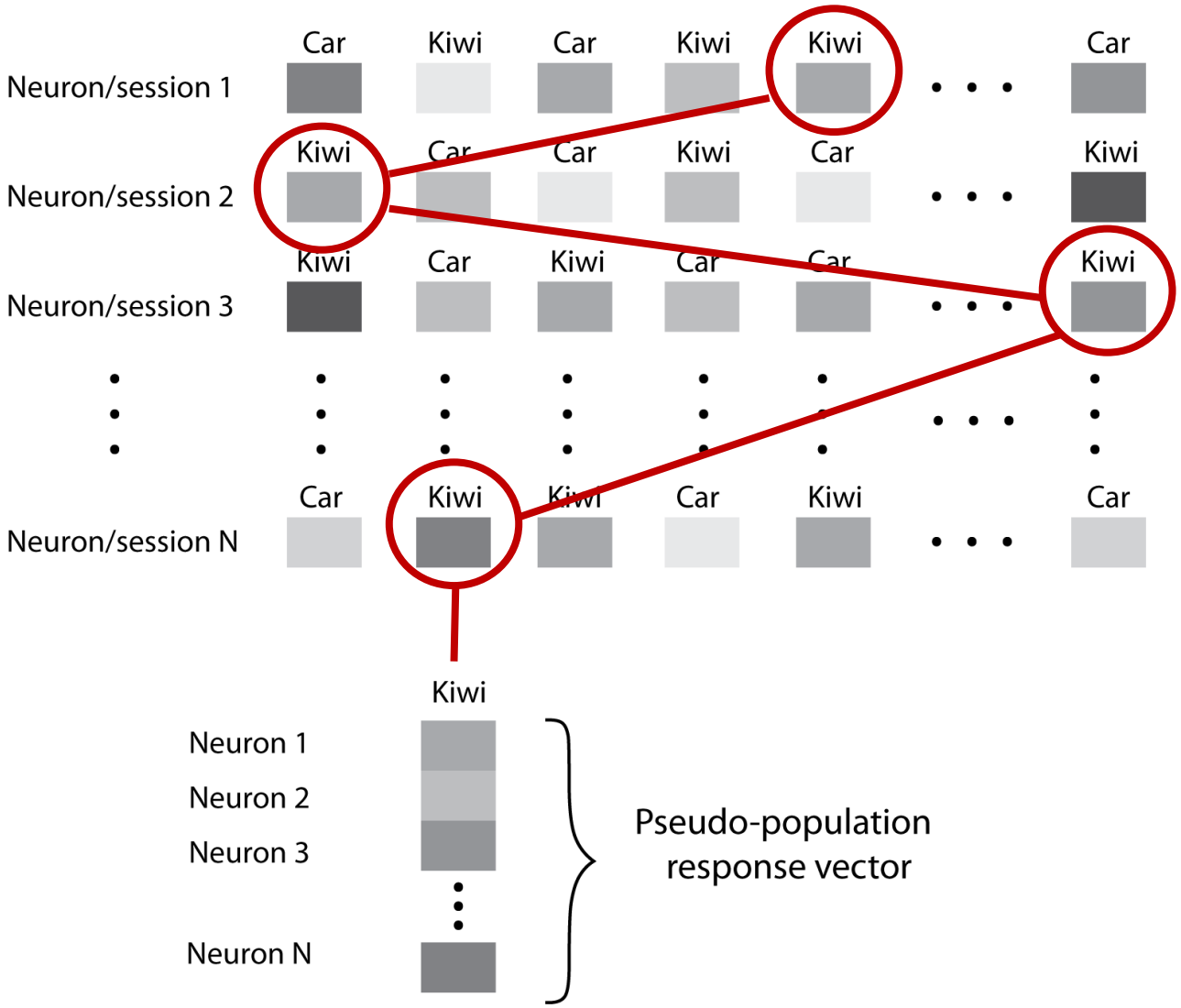


Using the classifier

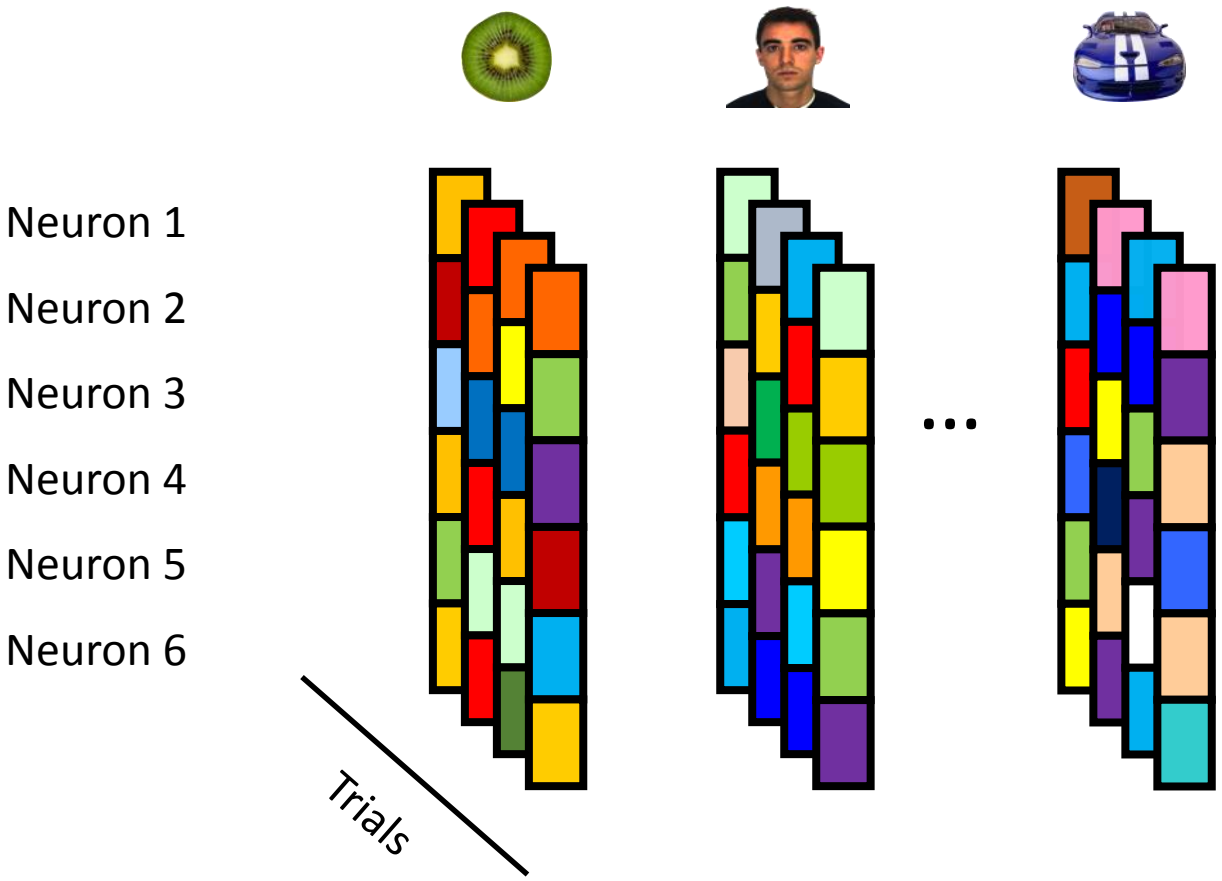



Labels
F C F F C F C C F C F C
Neural population responses
n1
n2
n3
n4
n5
Cross-validation splits
C C F F
C C F F
C C F F
Split 1
Split 2
Split 3
Test set
C C F F
C C F F
C C F F
Split 1
Split 2
Split 3
Training set
Run 1
Test set
C C F F
C C F F
C C F F
Split 1
Split 2
Split 3
Training set
Training set
Run 2
Test set
C C F F
C C F F
C C F F
Split 1
Split 2
Split 3
Training set
Run 3

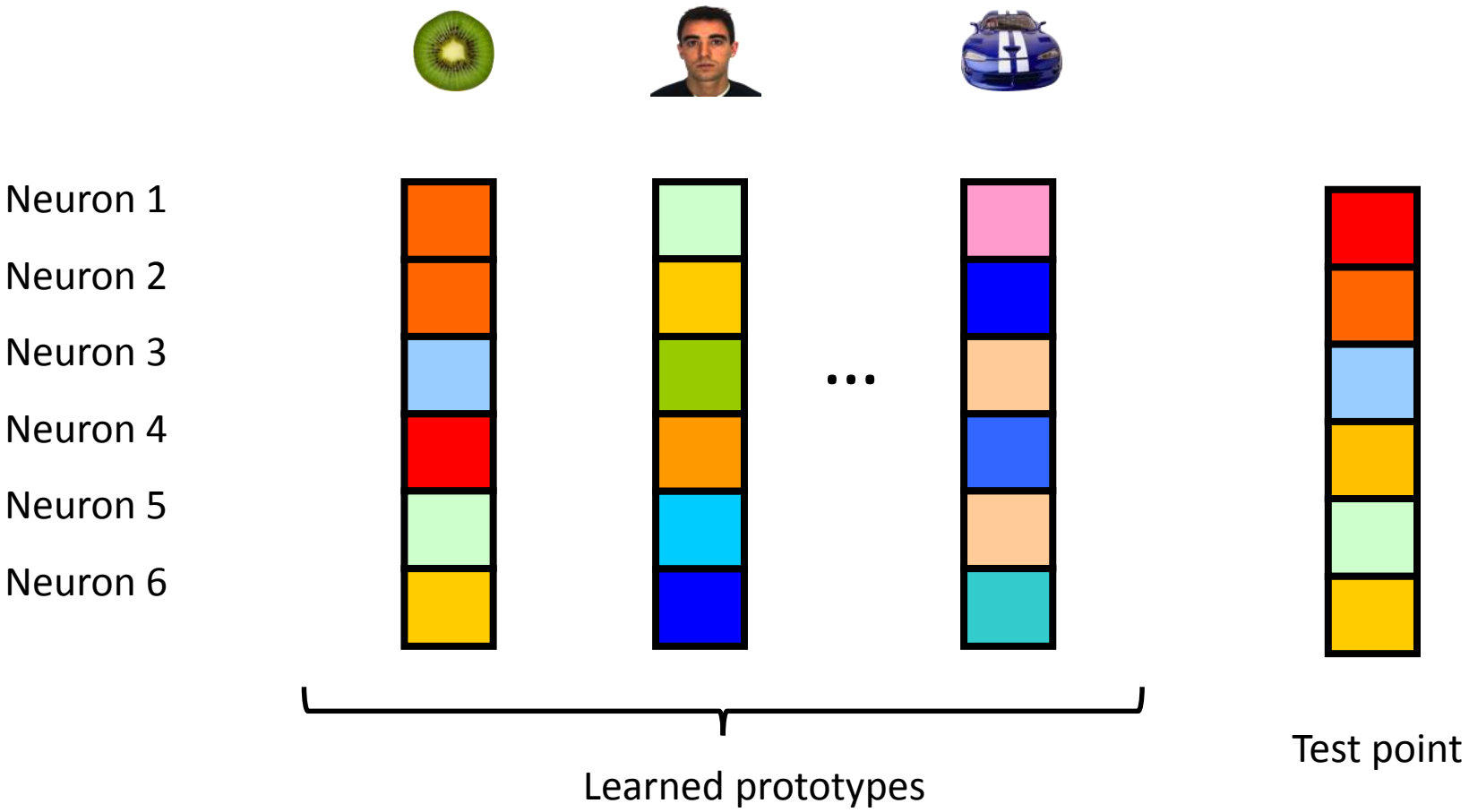
Pseudo-populations



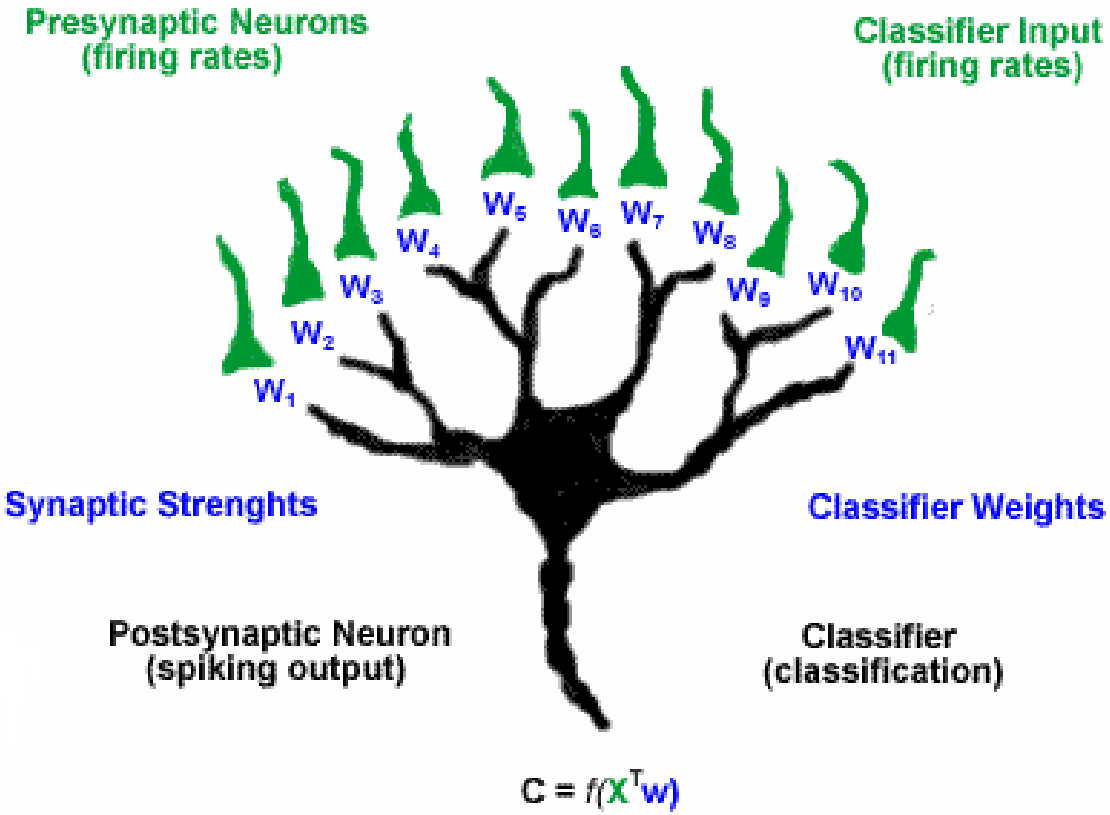
Maximum Correlation Coefficient Classifier



Maximum Correlation Coefficient Classifier

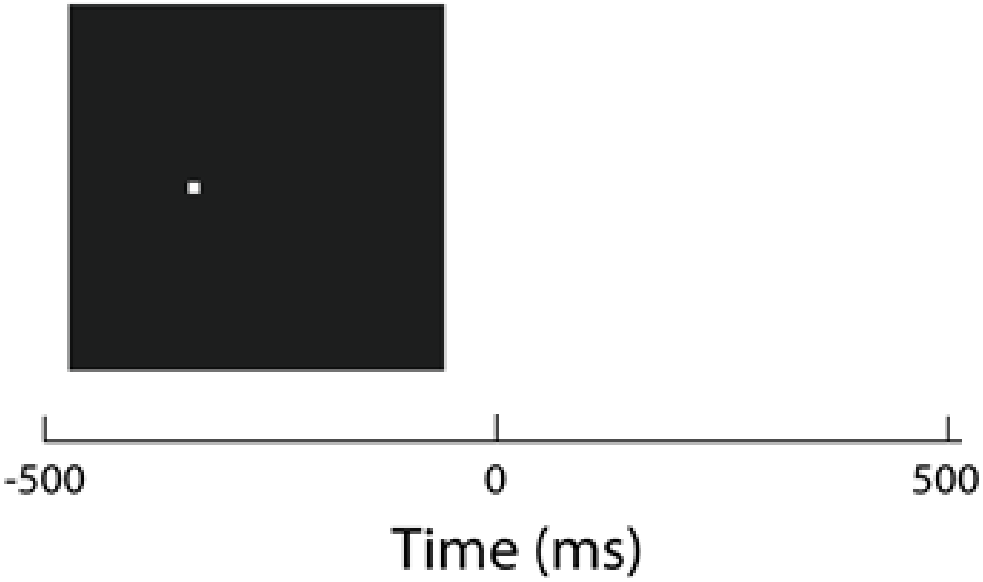


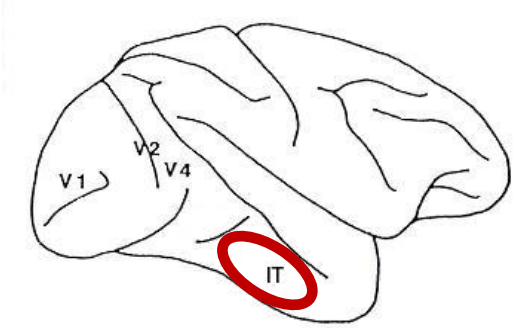
Decoding can be viewed as assessing the information available to downstream neurons



Neural content

A simple experiment



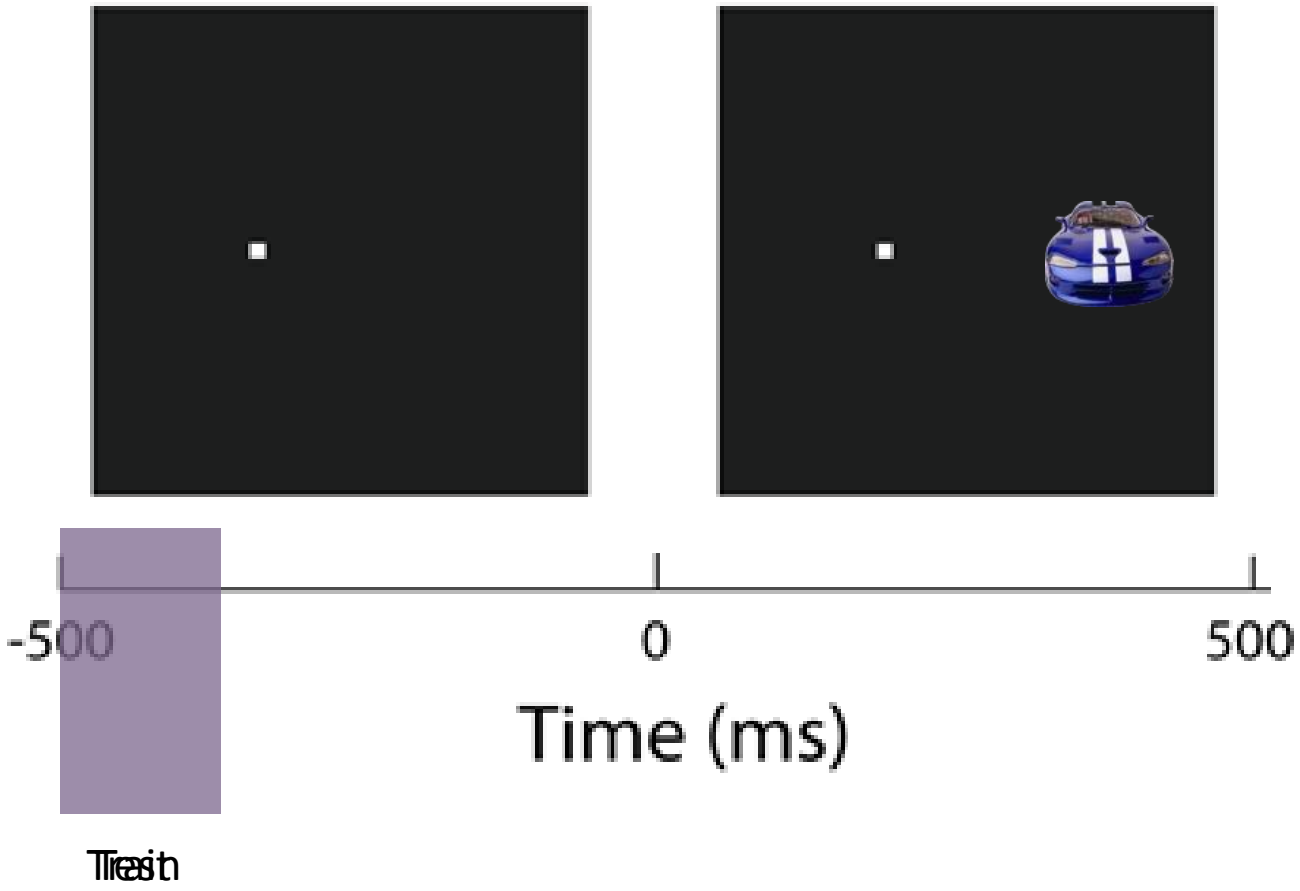


132 neurons recorded from IT

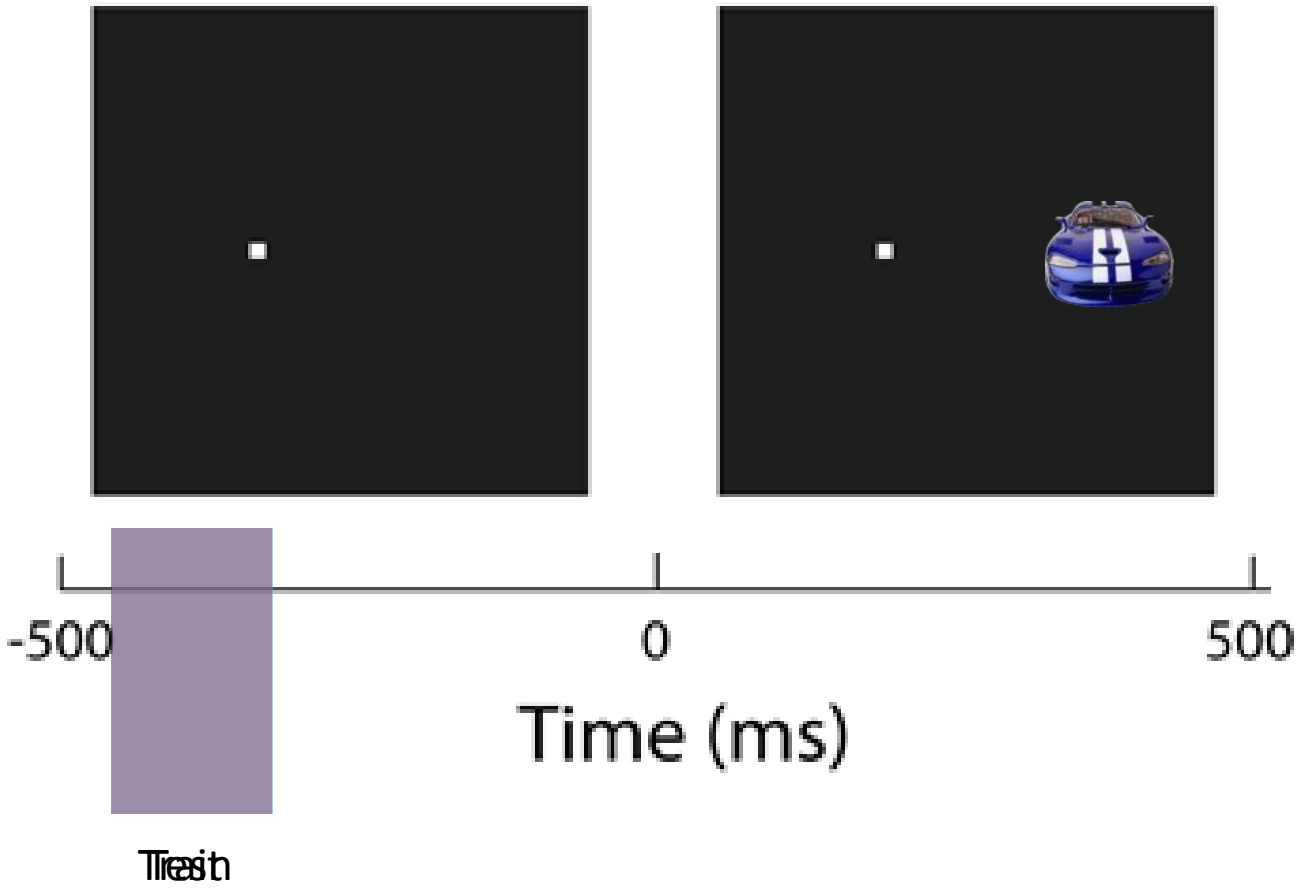
Seven objects:

Zhang, Meyers, Bichot, Serre, Poggio, and Desimone, PNAS, 2011

Applying decoding

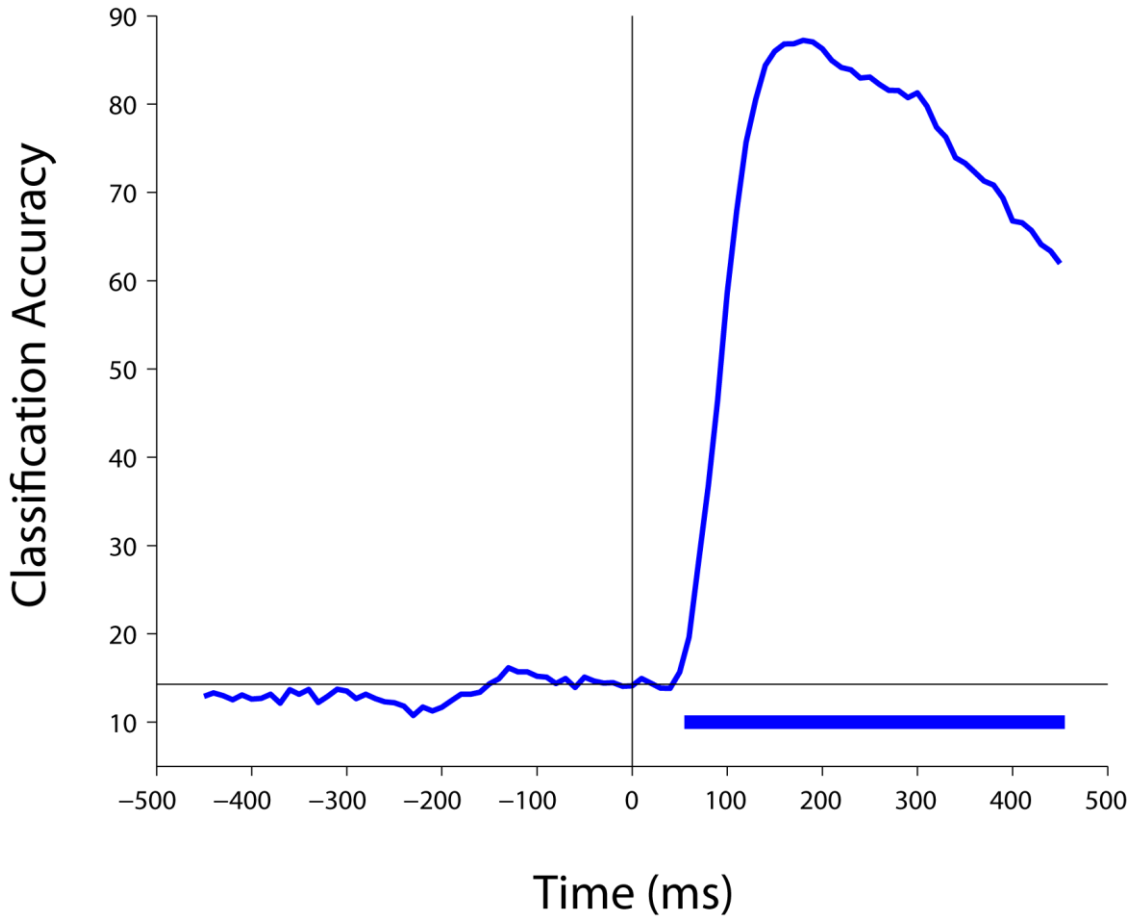


Applying decoding

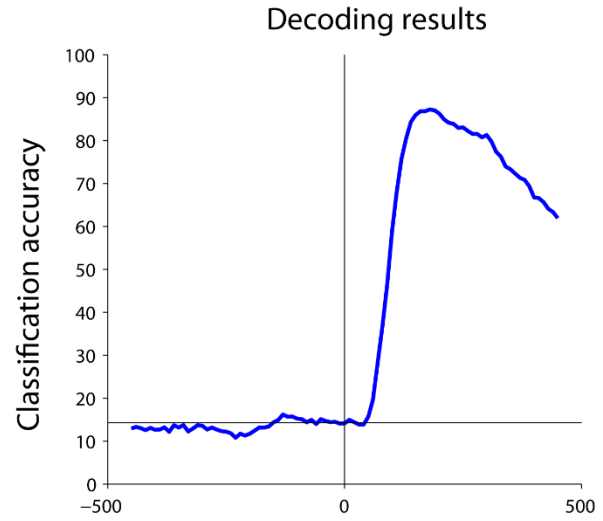


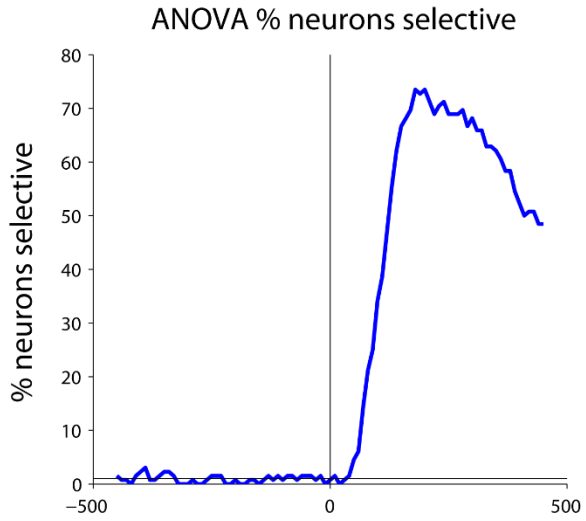
100 ms bins, sample every 10 ms

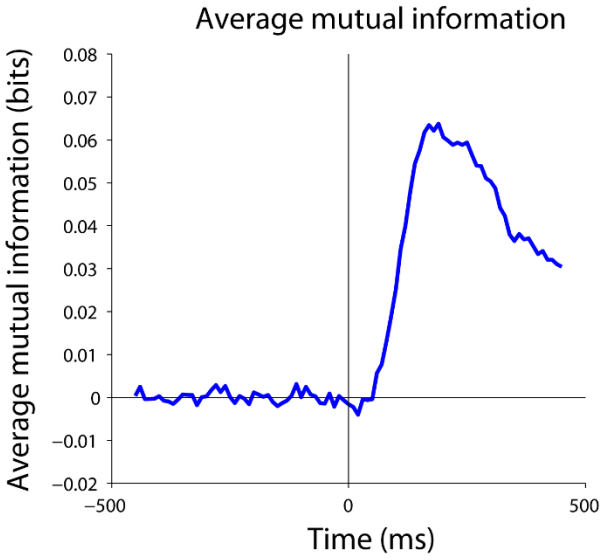
Basic decoding results

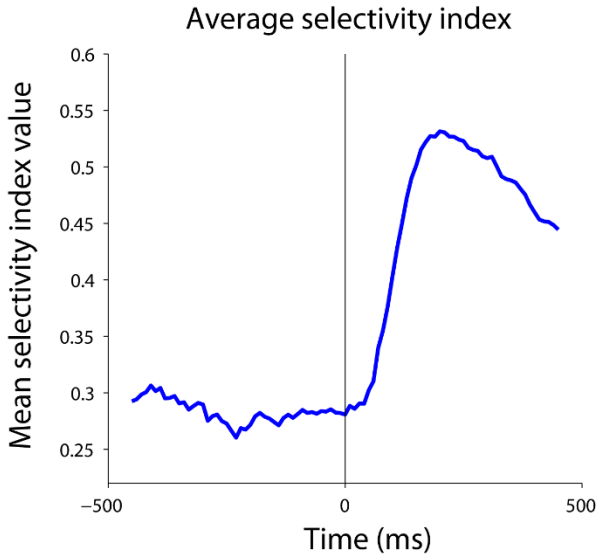


Basic results are similar to other methods

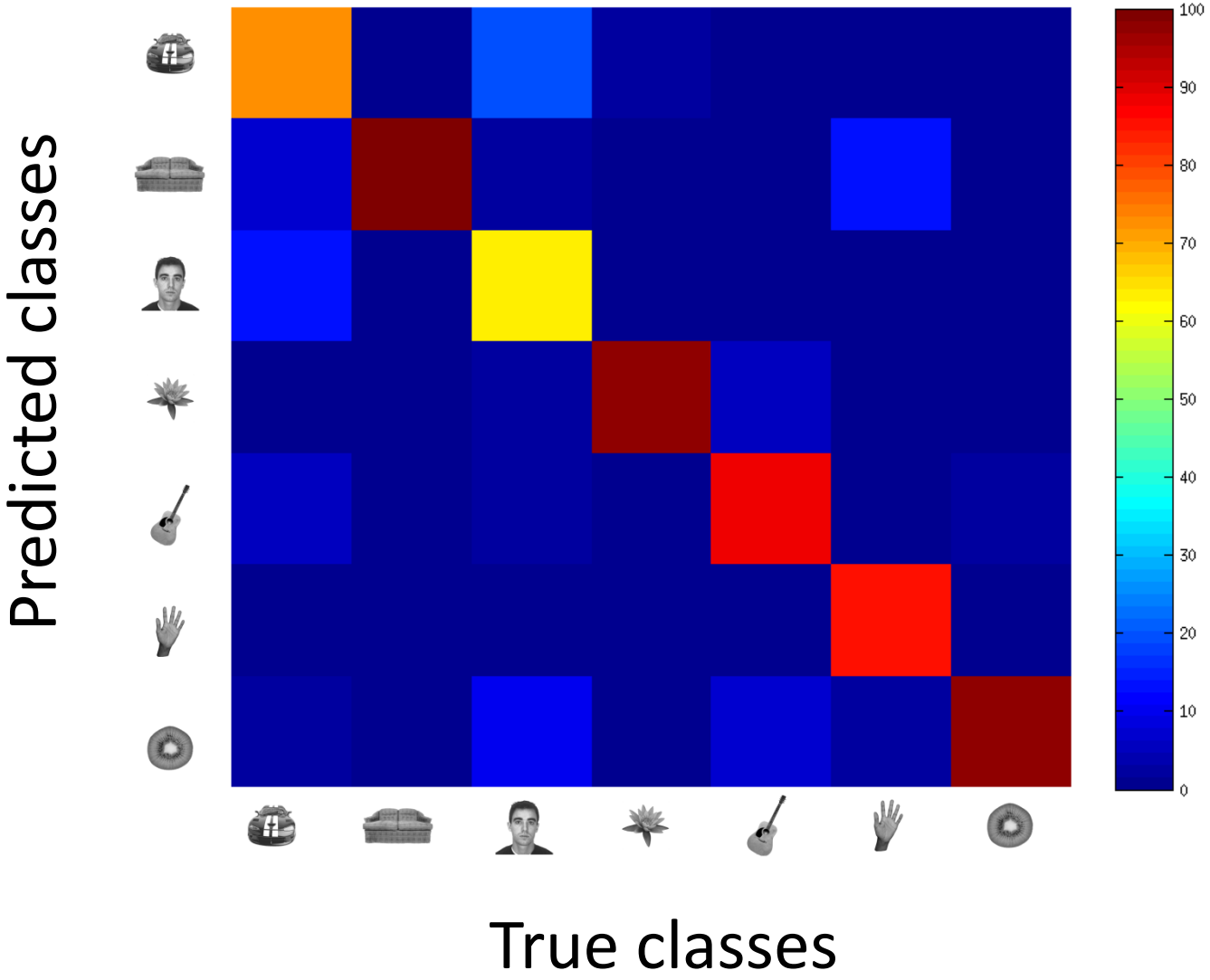




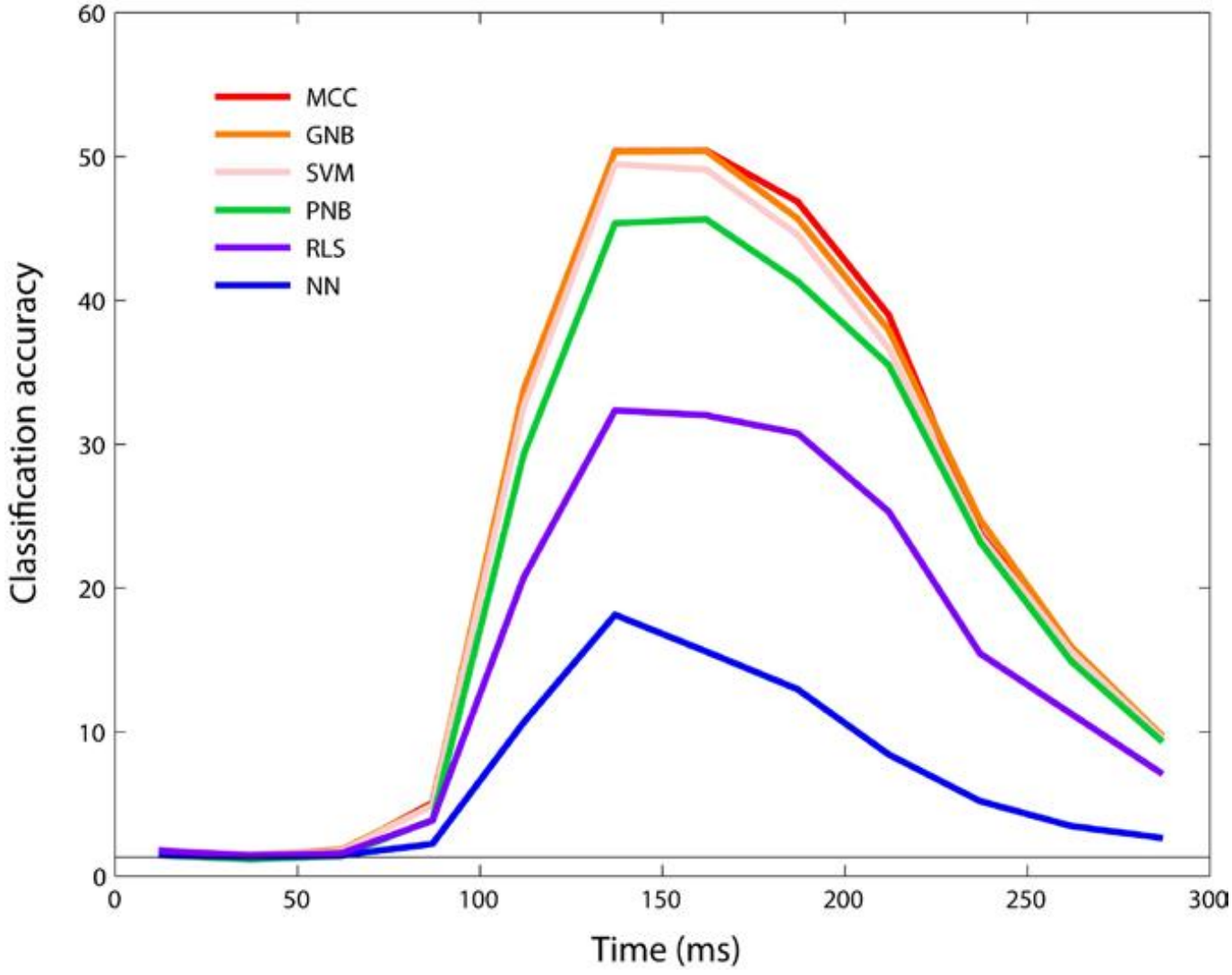




Confusion matrices



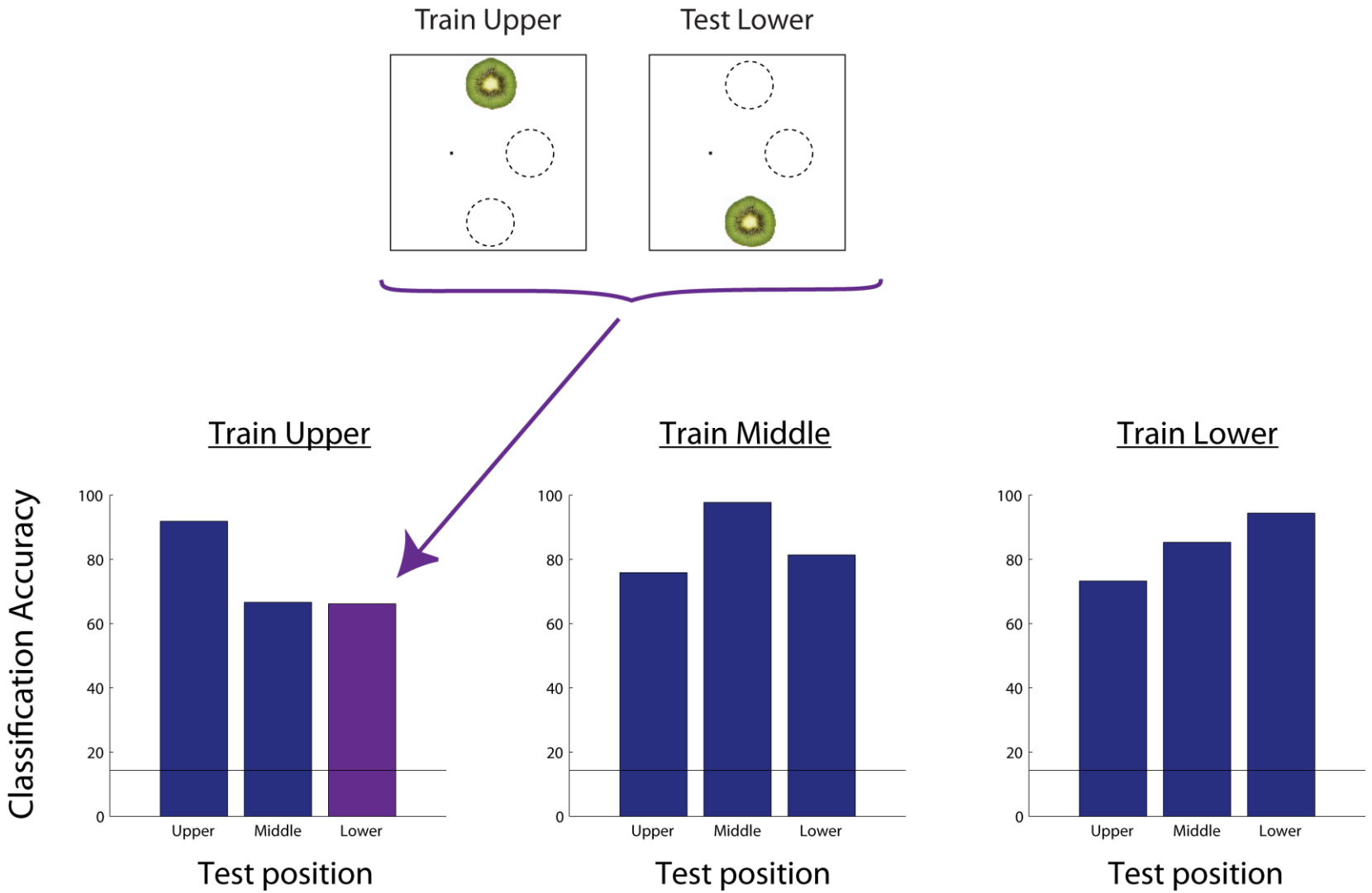
Generally robust to the choice of classifier



Abstract/invariant representations

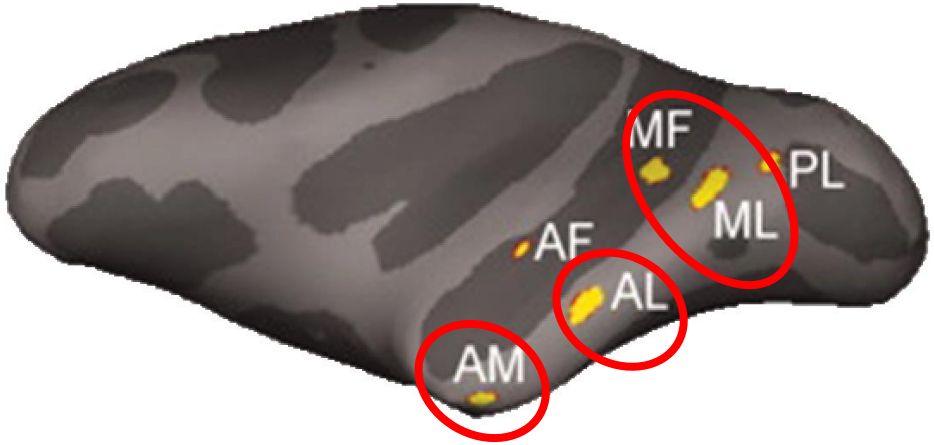
The ability to form abstract representations is essential for complex behavior

Example: position invariance



Hung, Kreiman, Poggio, and DiCarlo, Science, 2011

Face identification invariant to head pose



Stimulus set: 25 individuals, 8 head poses per individual

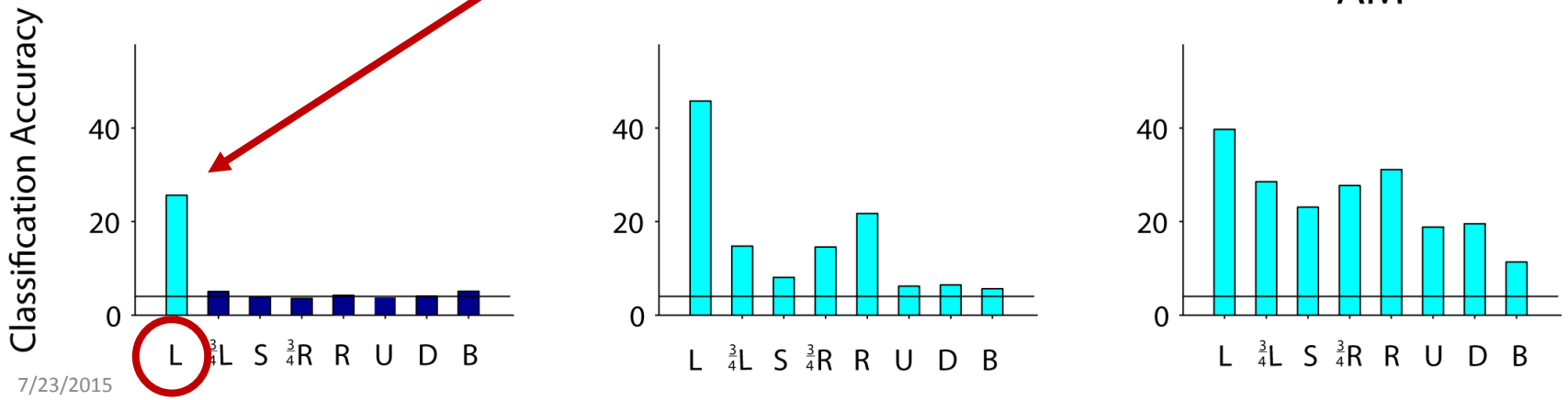
Meyers, Borzello, Freiwald, Tsao, J Neurosci, 2015

Face identification invariant to head pose

Train
Left Profile

Test
Same Pose

Test
Pose Invariance



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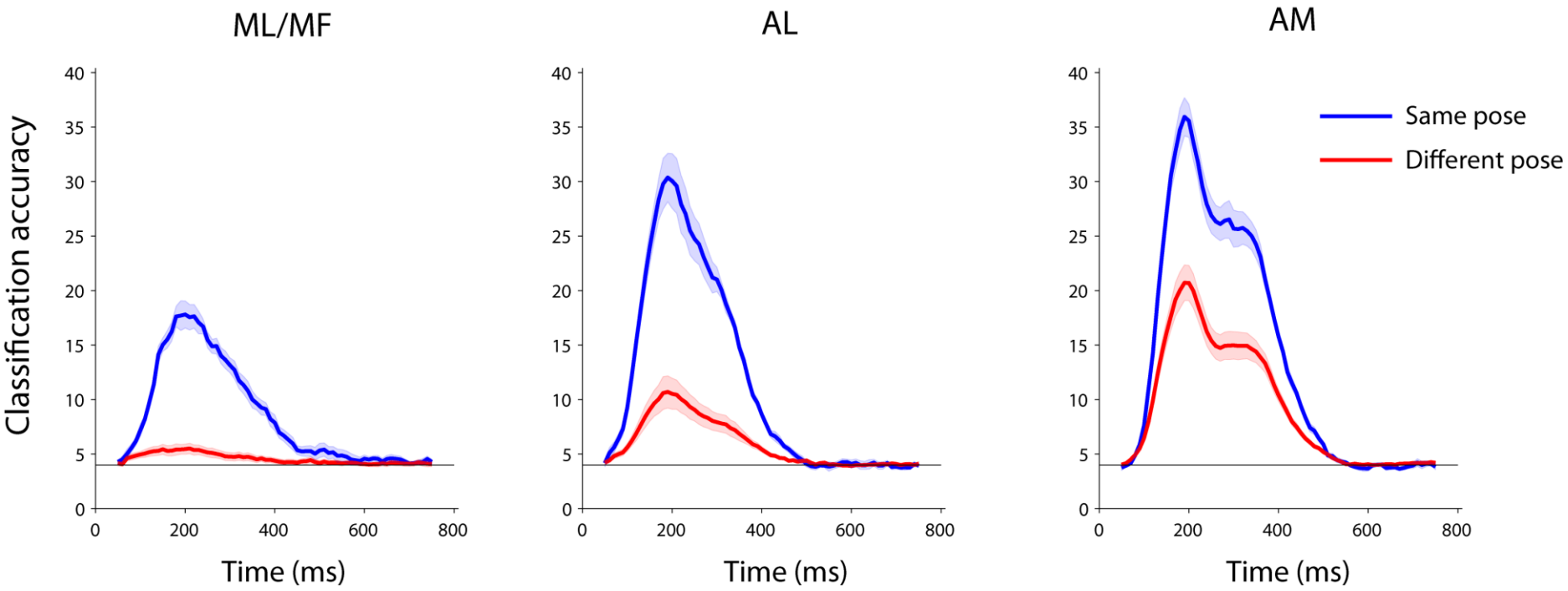
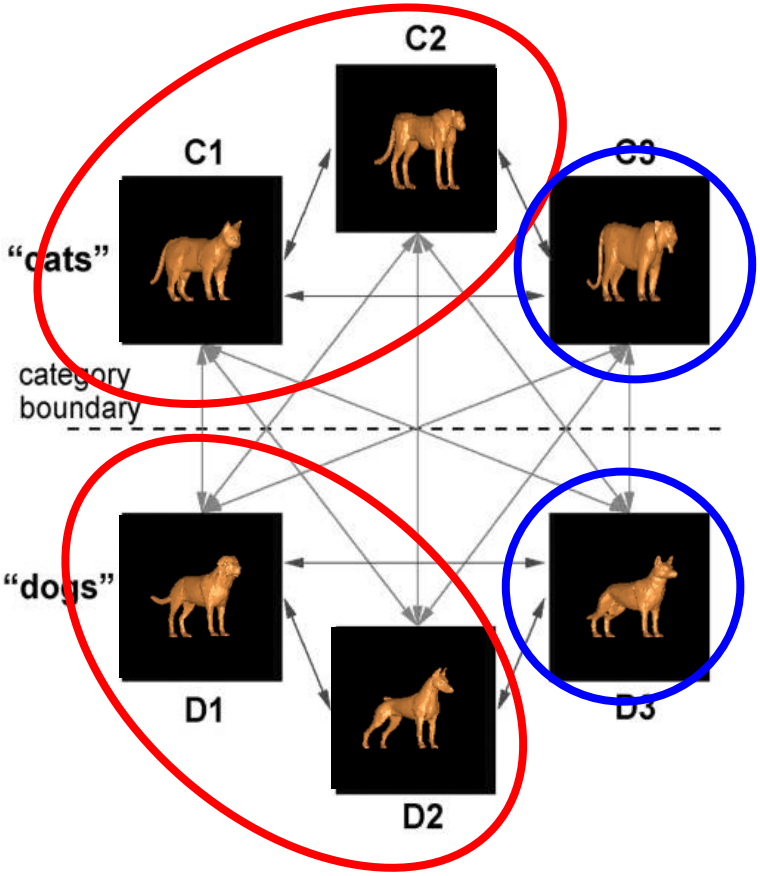
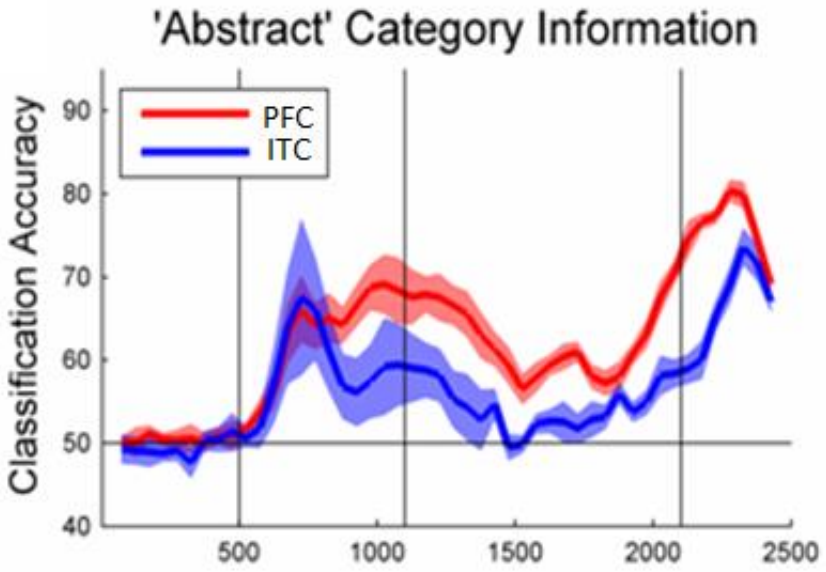


Learning abstract category information





Meyers, Freedman, Kreiman, Poggio, Miller, J Neurphys, 2008

Summary of neural content

Decoding offers a way to clearly see information flow over time

For assessing basic information, decoding often yields similar results as other methods

Decoding allows one to assess whether information is contained in an abstract/invariant format, which is not possible with other methods

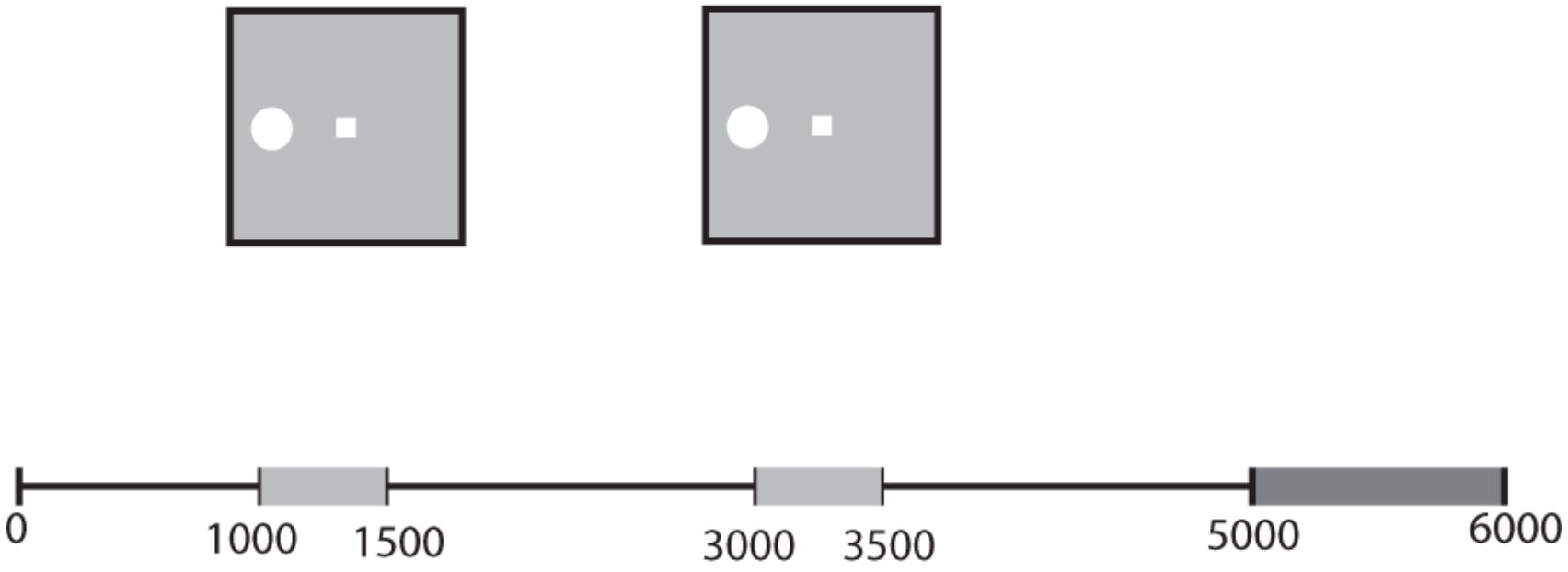
Neural coding

Motivating study

Meyers, Qi, Constantinidis, PNAS, 2012

Monkeys were first trained to passively fixate

Fixation 1st stimulus 1st delay 2nd stimulus 2nd delay Reward



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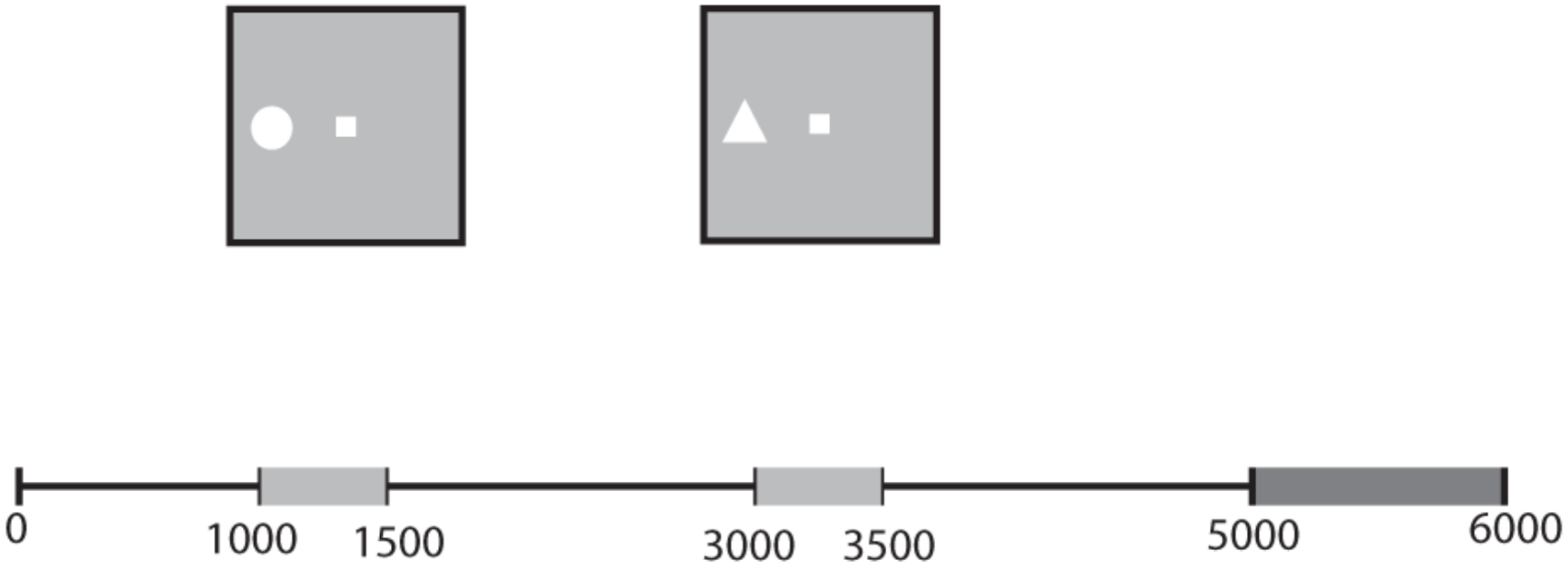
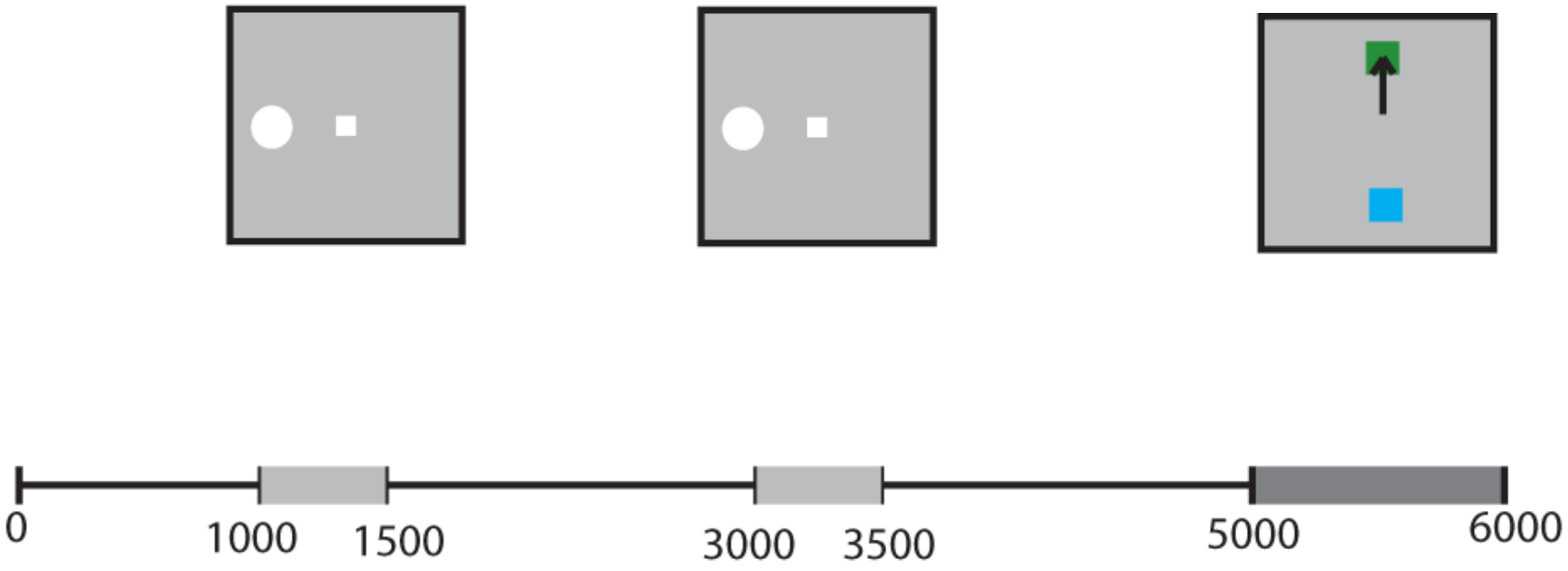


Monkeys then engaged in a delayed-match-to-sample task (DMS task)

Fixation | 1st stimulus | 1st delay | 2nd stimulus | 2nd delay | Choice targets/ saccade



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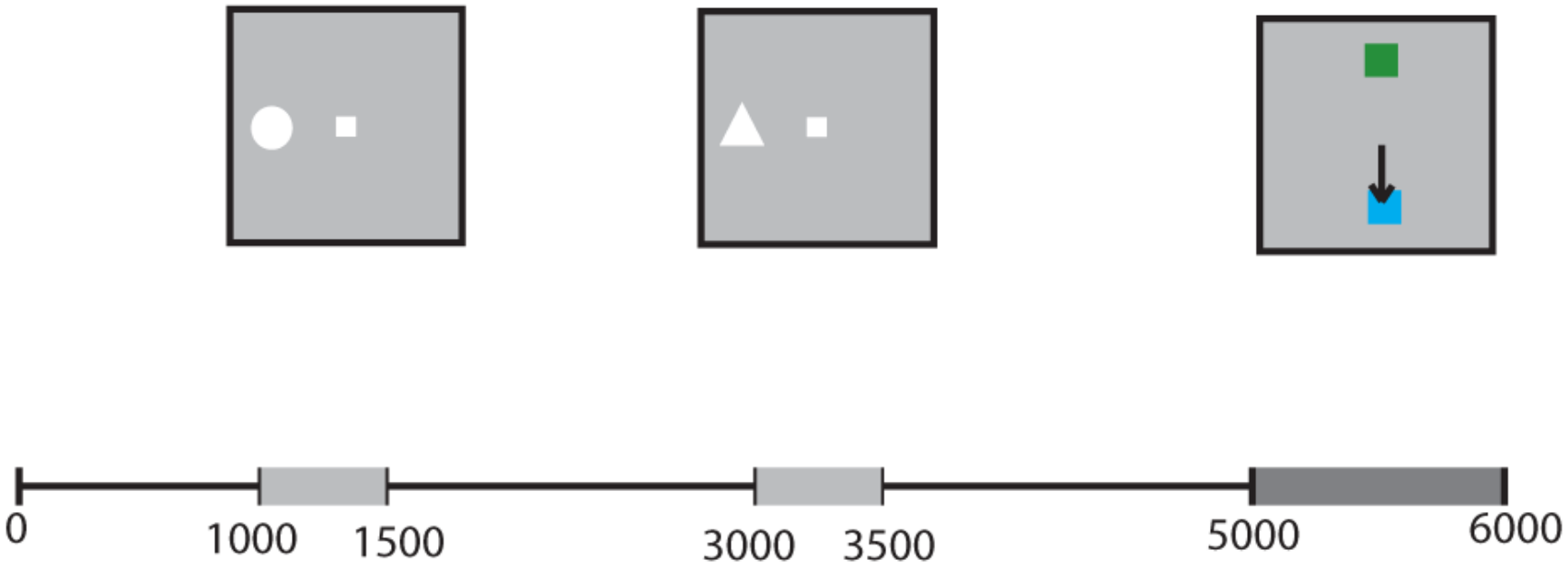
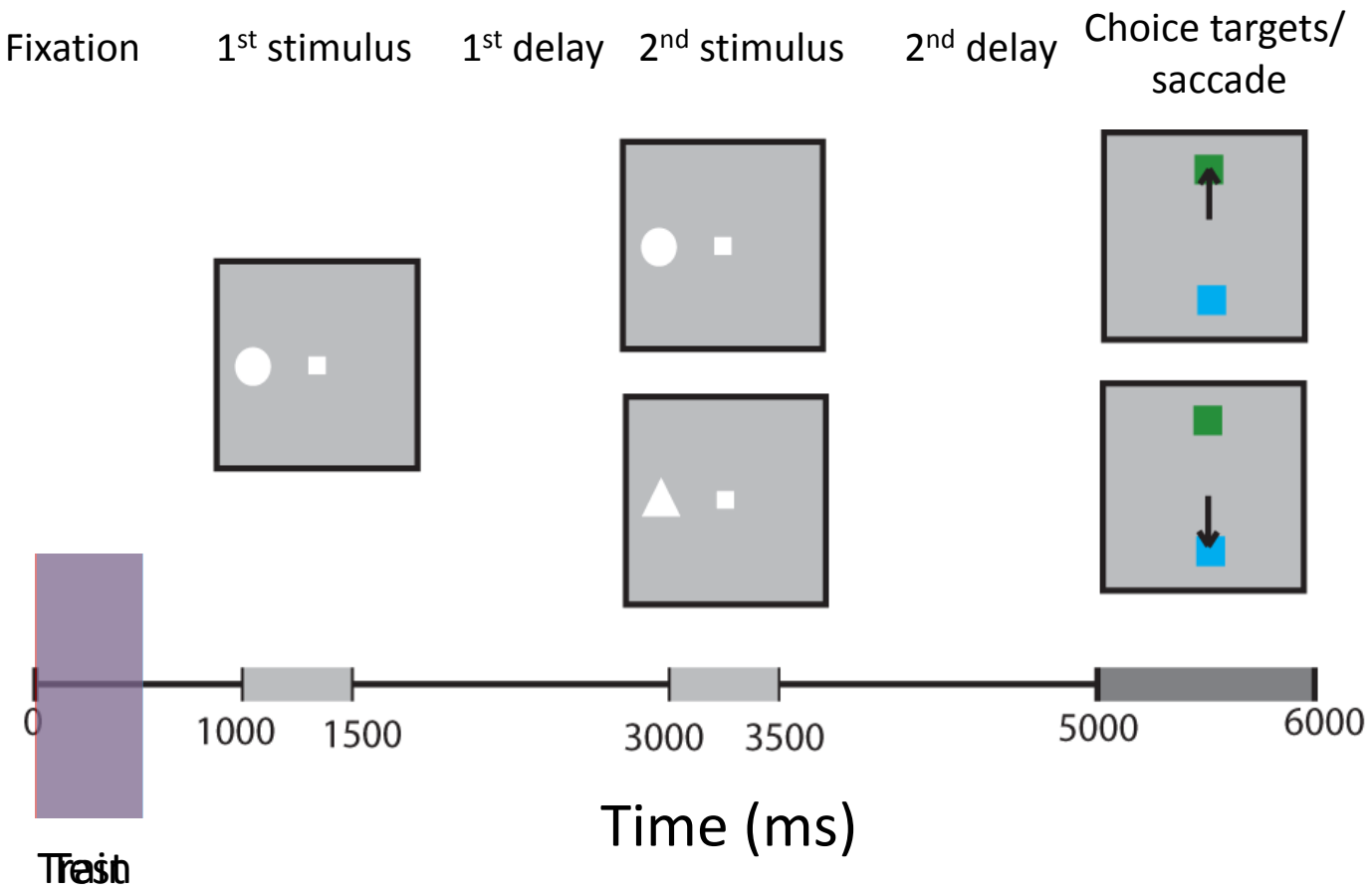


Decoding applied



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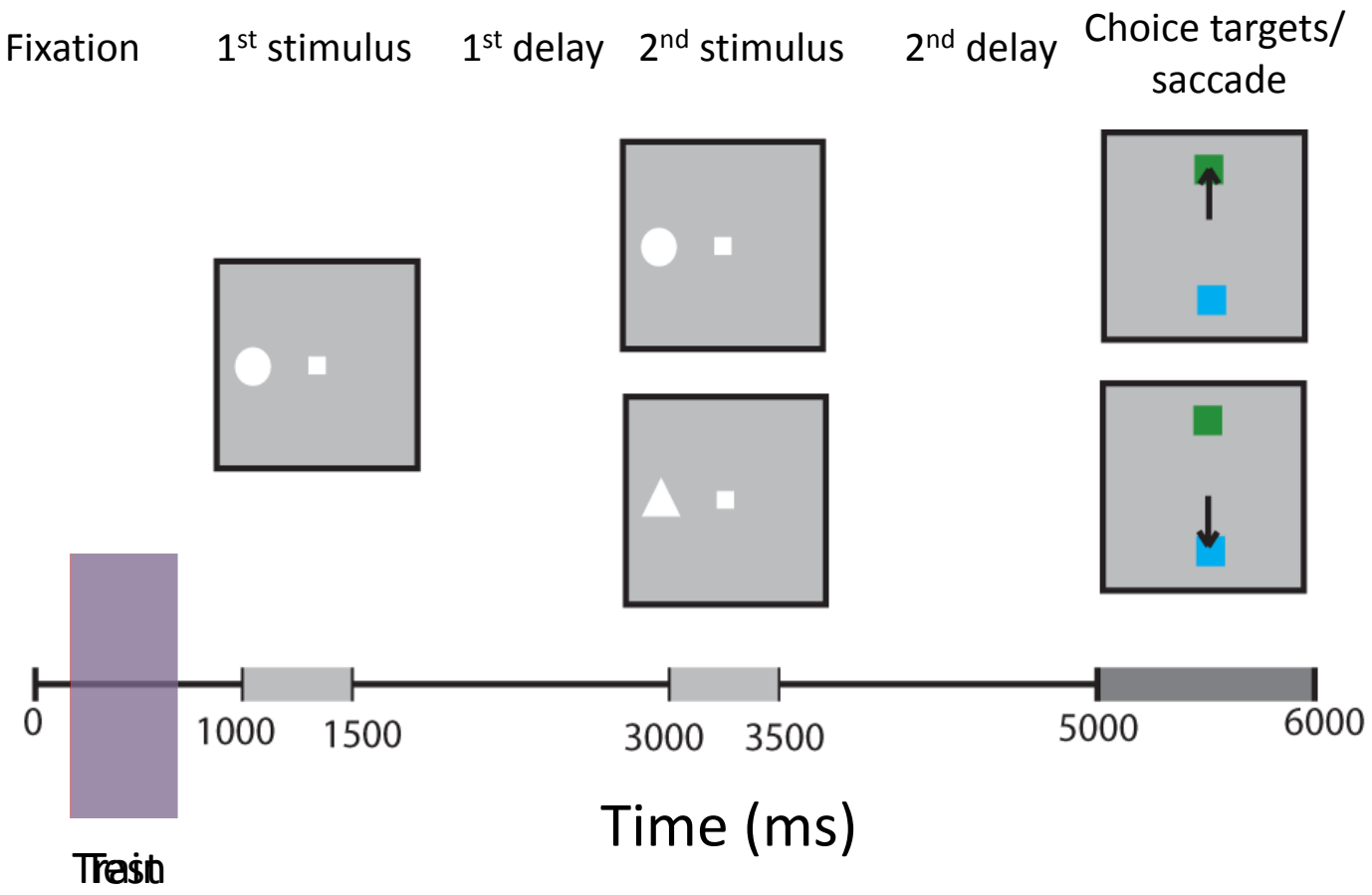
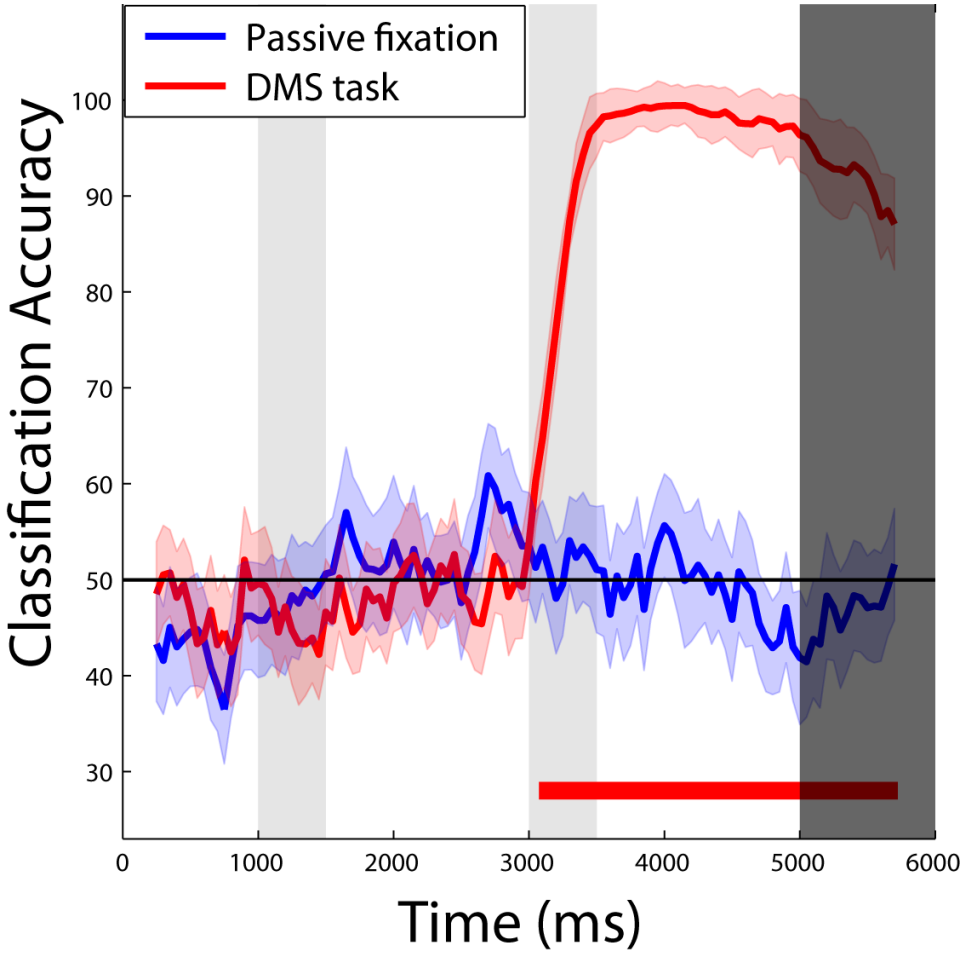
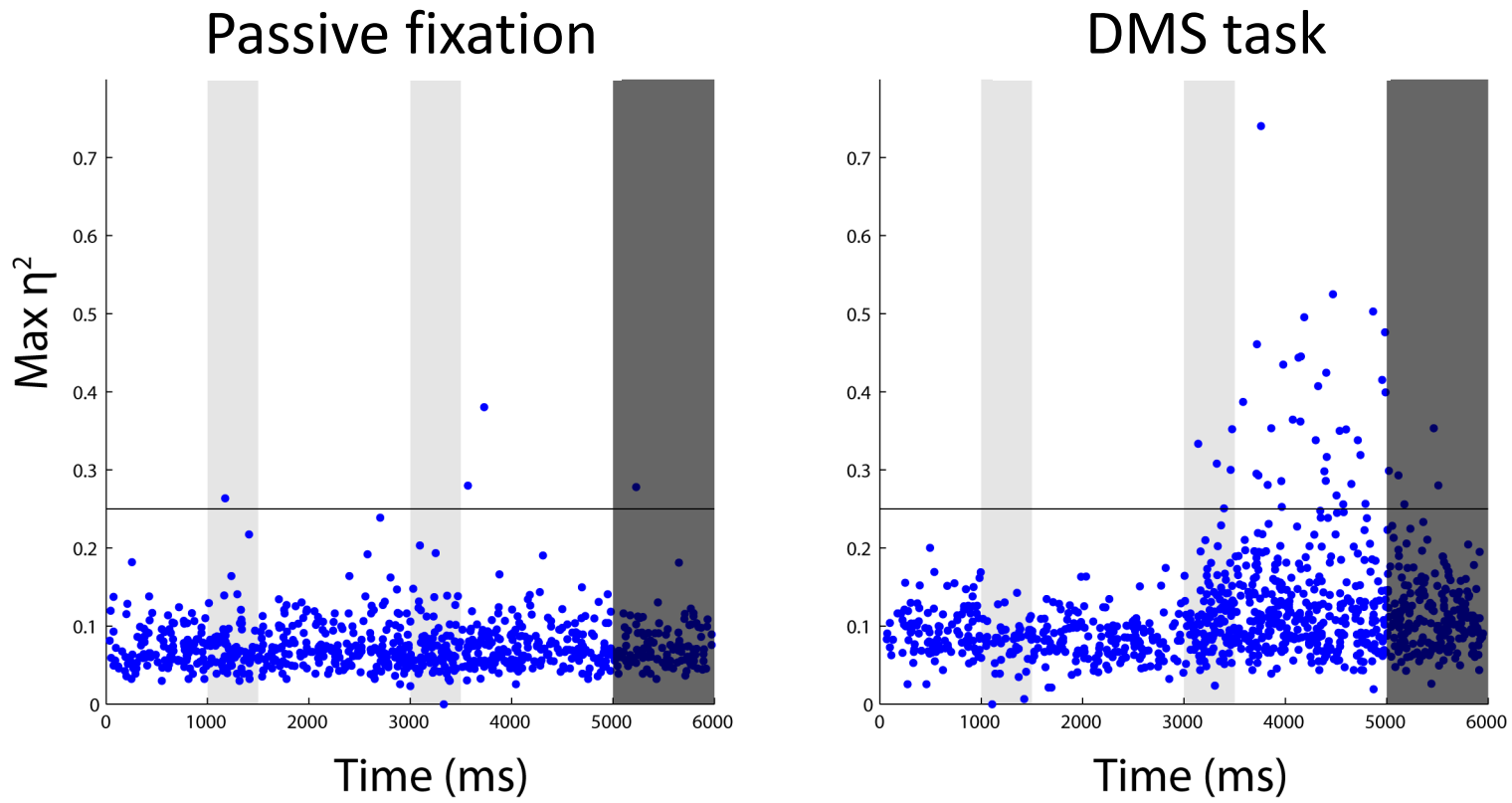


500 ms bins, sample every 50 ms
Decoding is based on 750 neurons

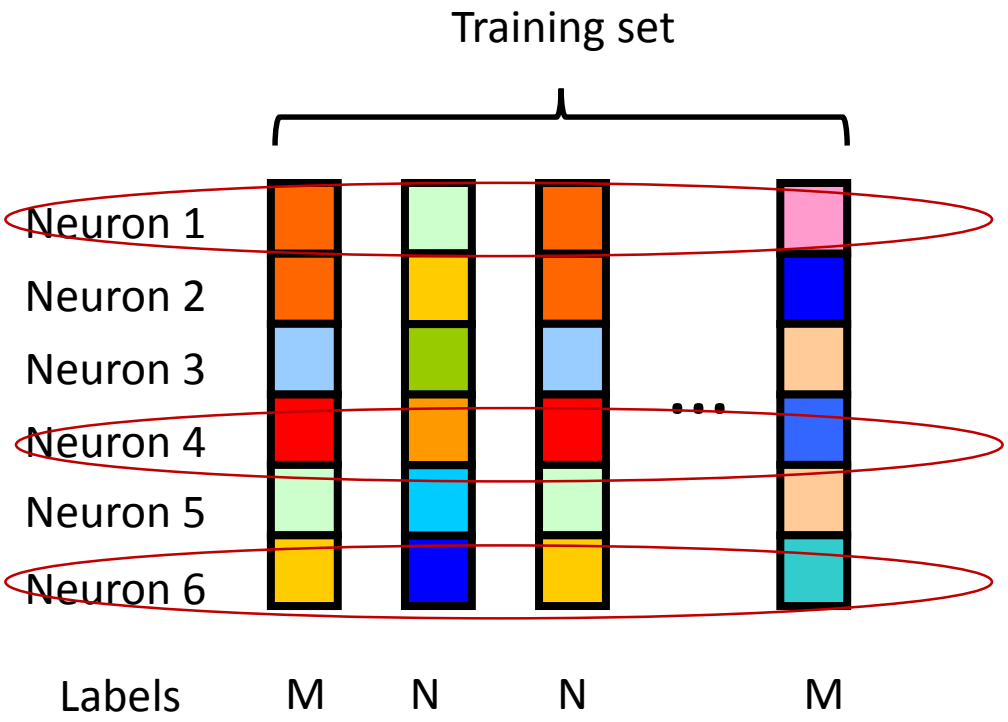
Decoding match/nonmatch information



Is the new information widely distributed?



Compact/sparse coding of information



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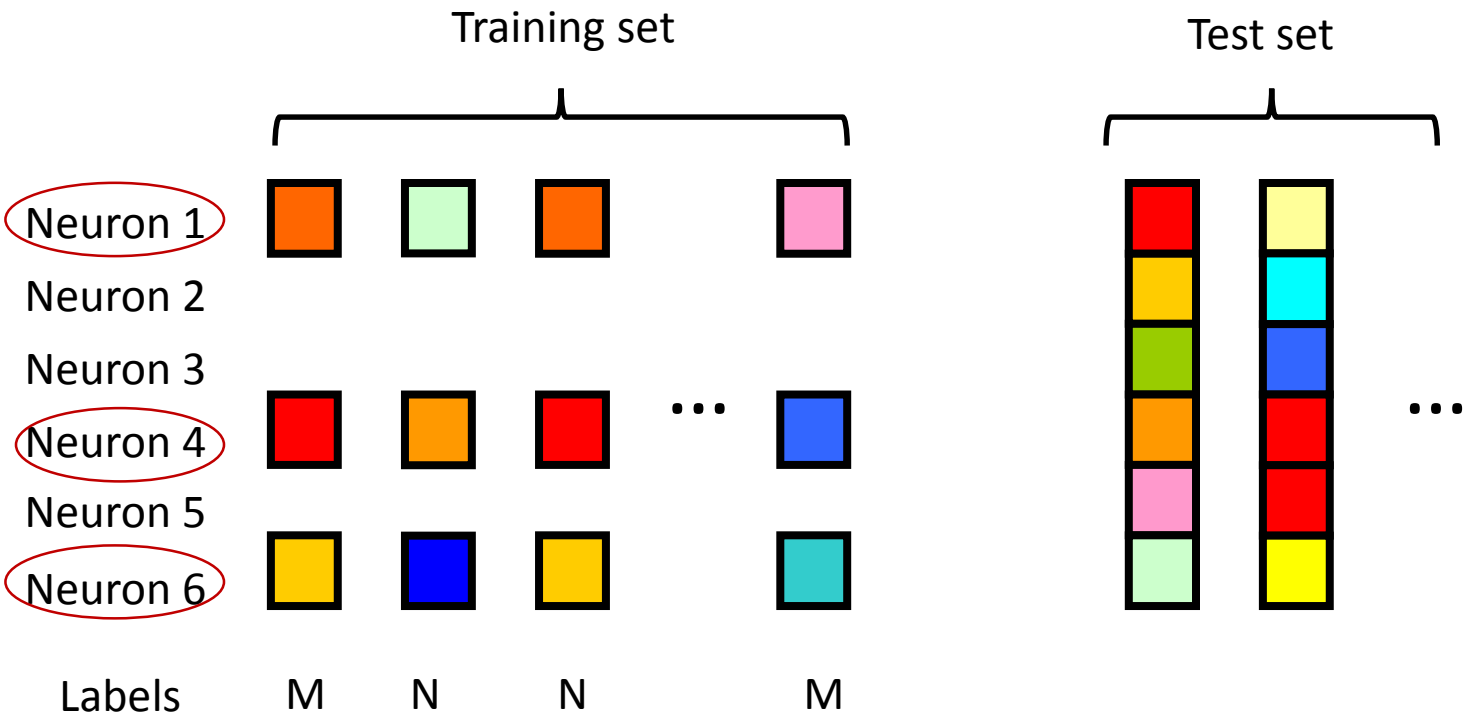

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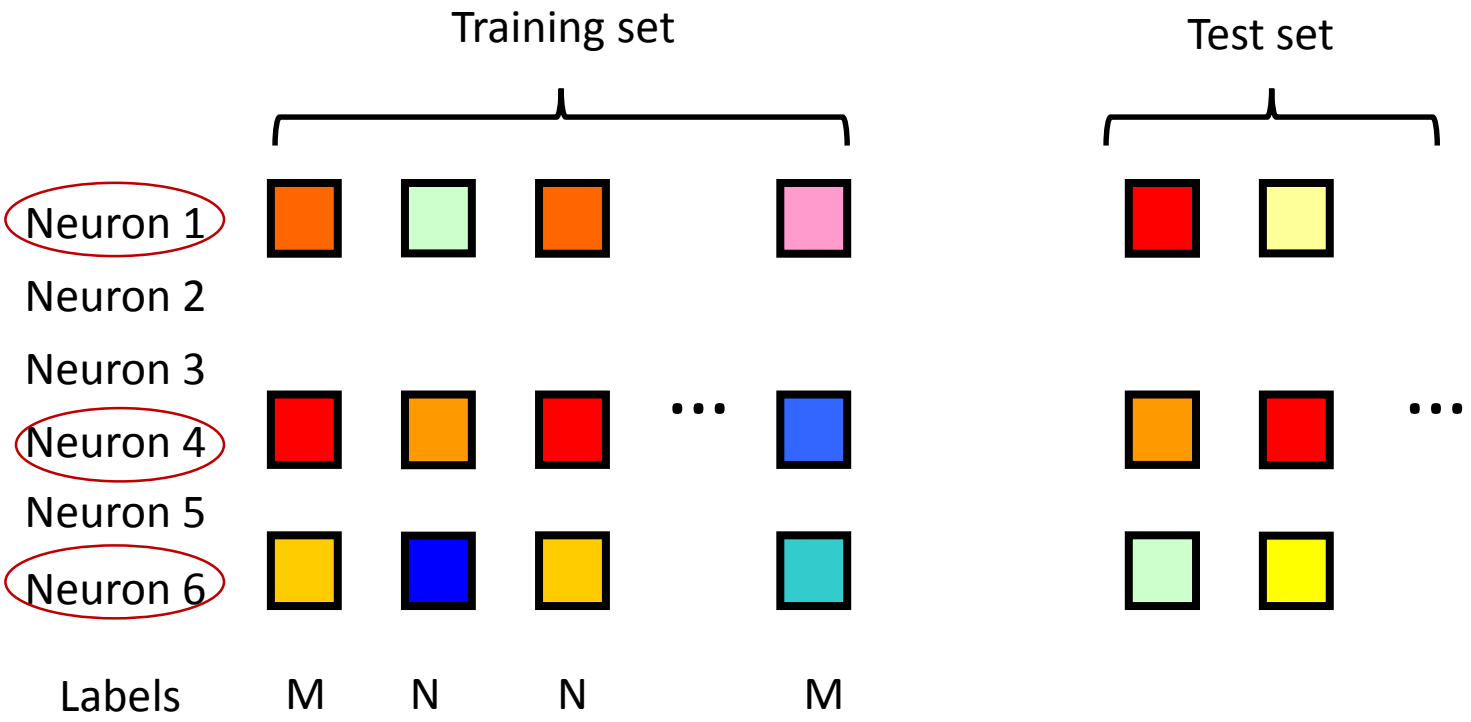

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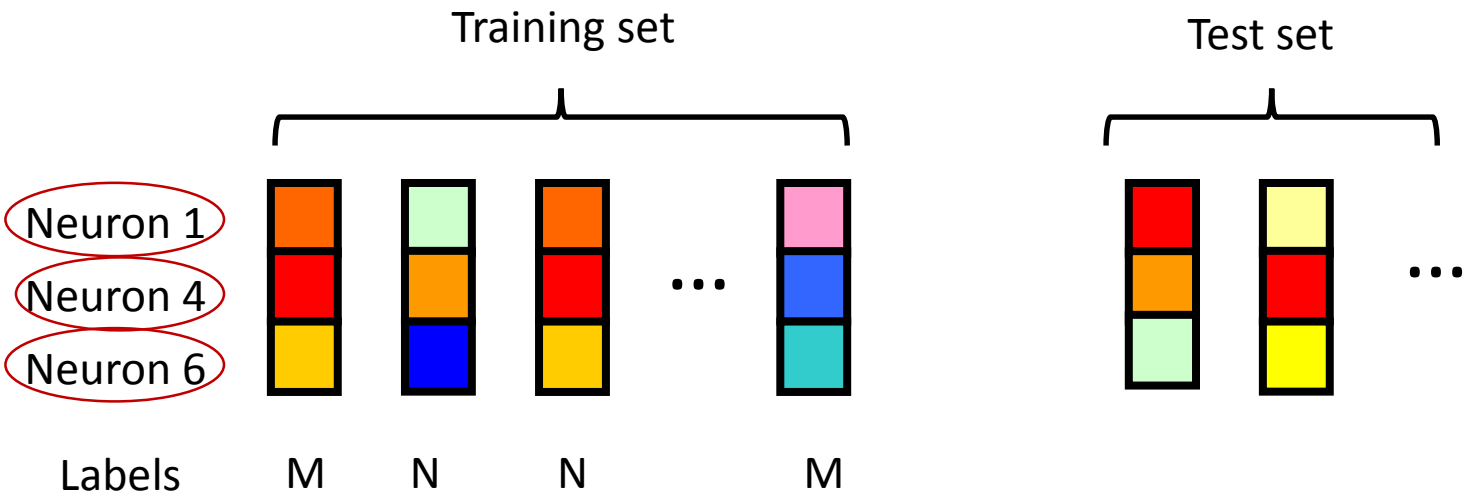
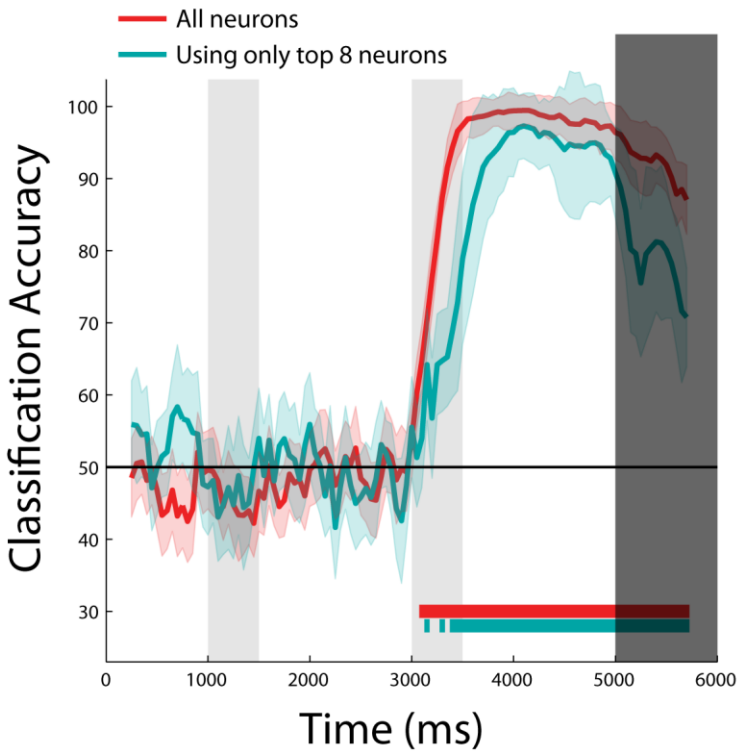


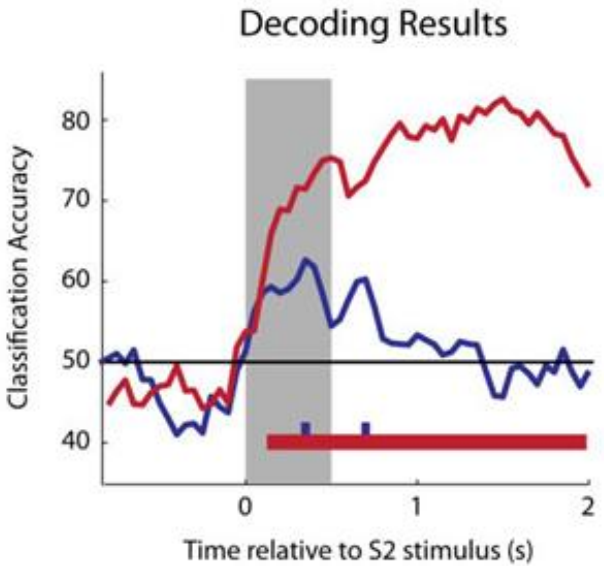
Is the new information widely distributed?

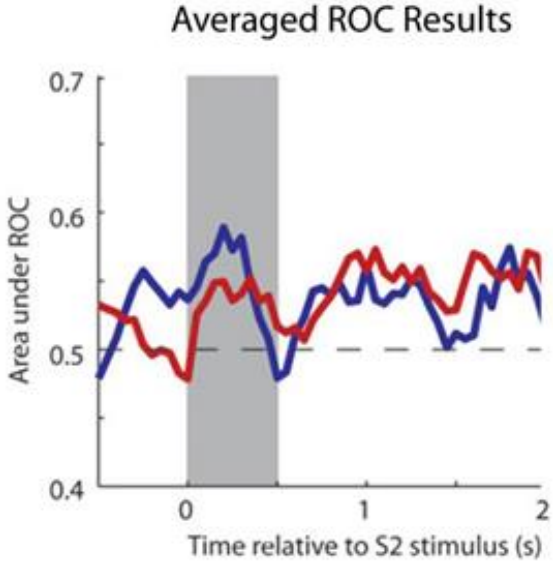
Using only the 8 most selective neurons

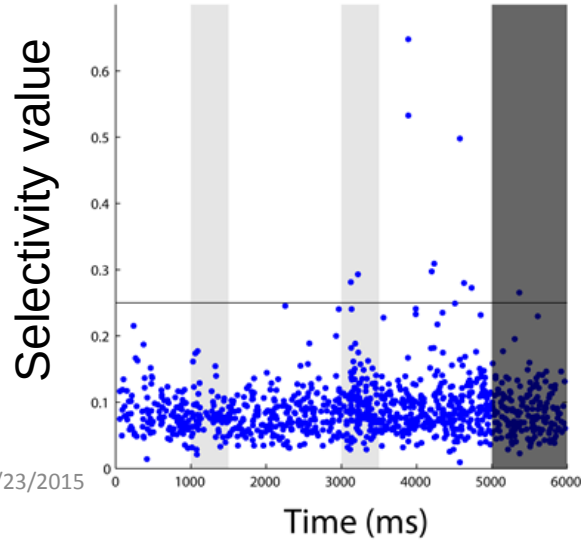


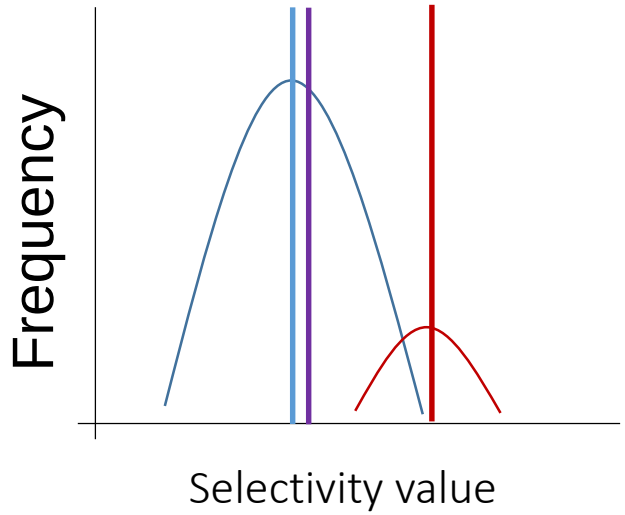
Excluding the 128 most selective neurons

Implications for analyzing data

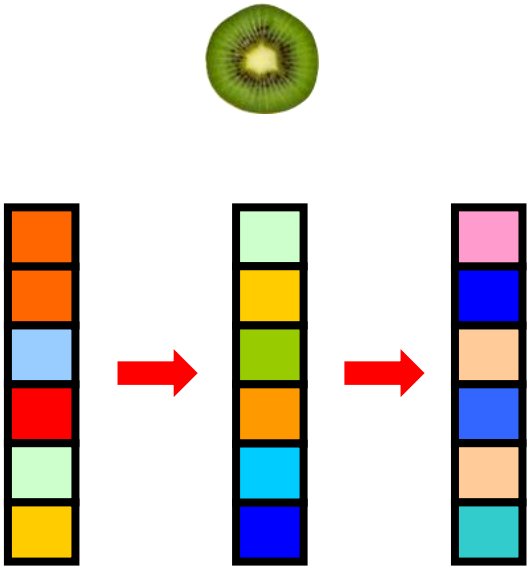




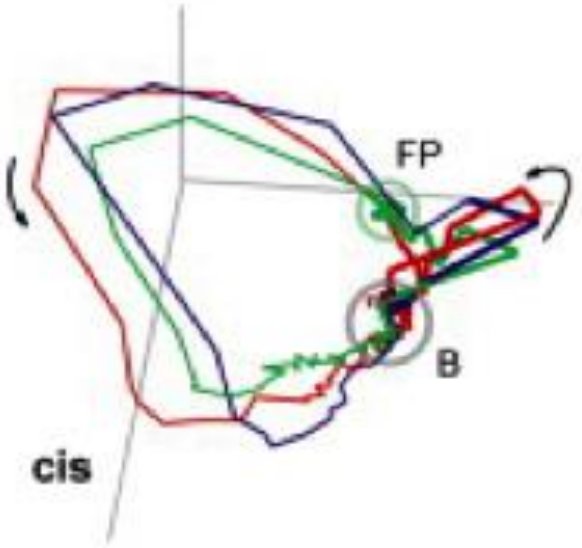




Is information contained in a dynamic population code?

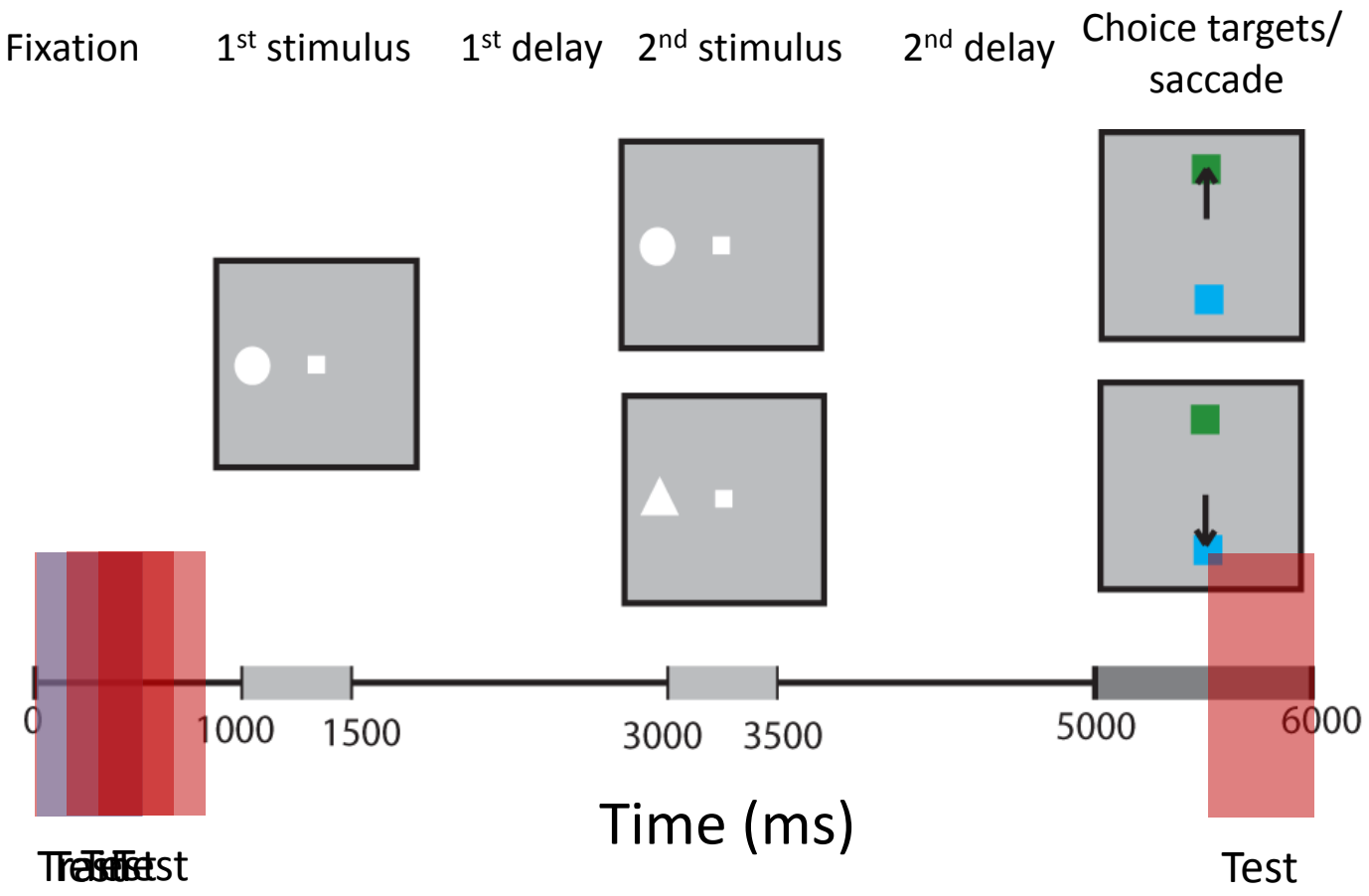


Time

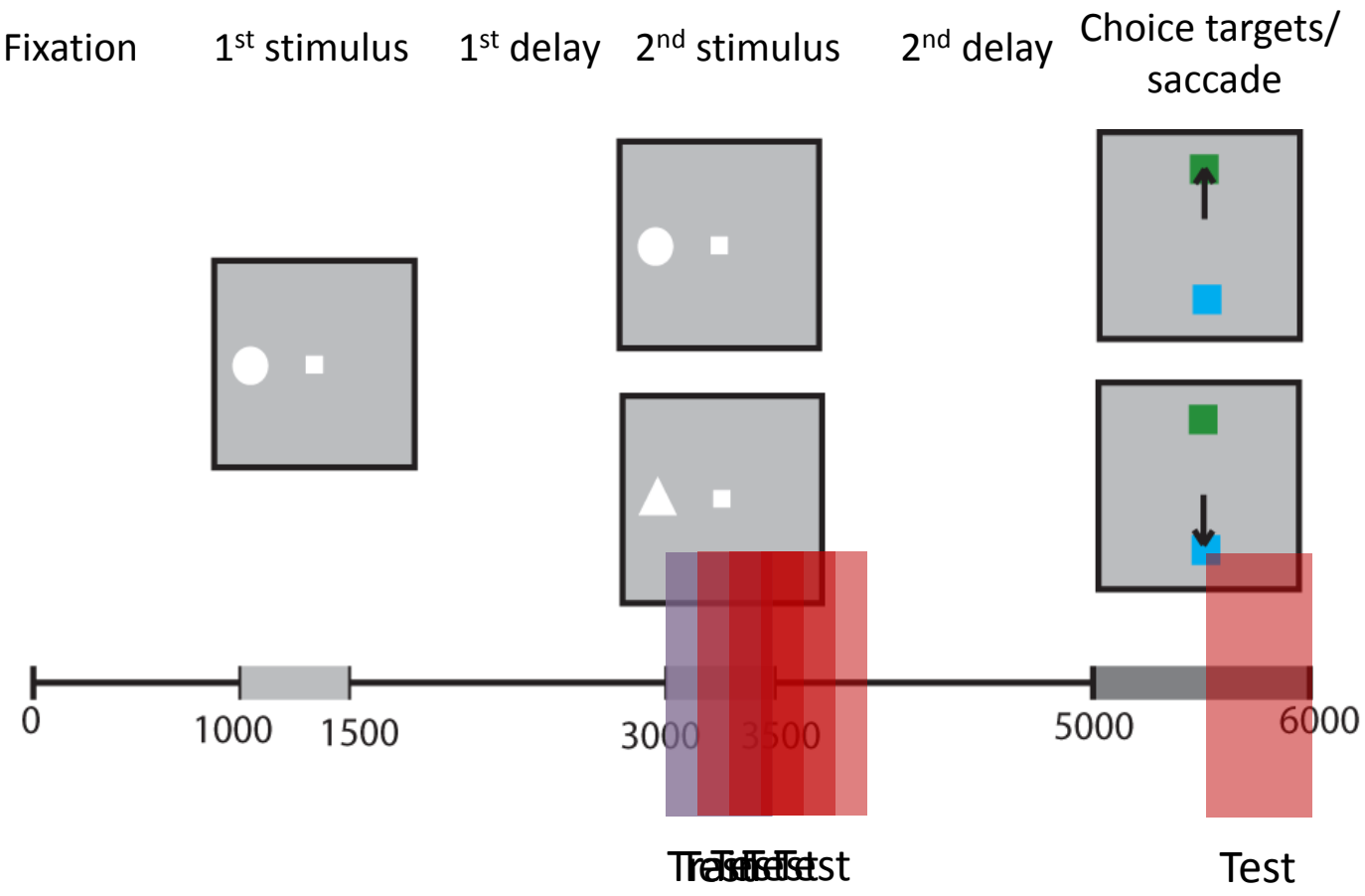


Mazor and Laurent 2005; Meyers et al, 2008; King and Dehaene 2014

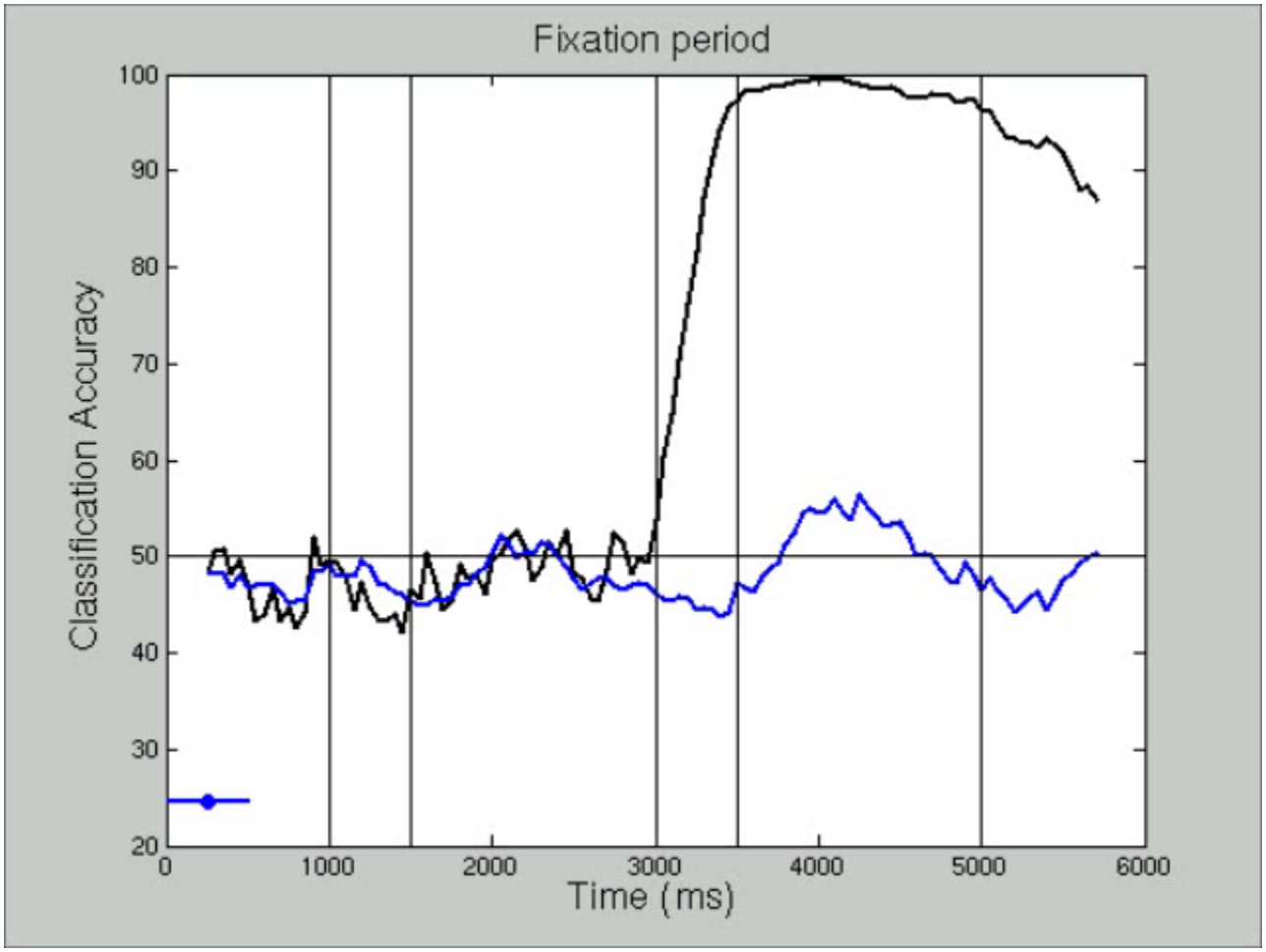
Decoding applied



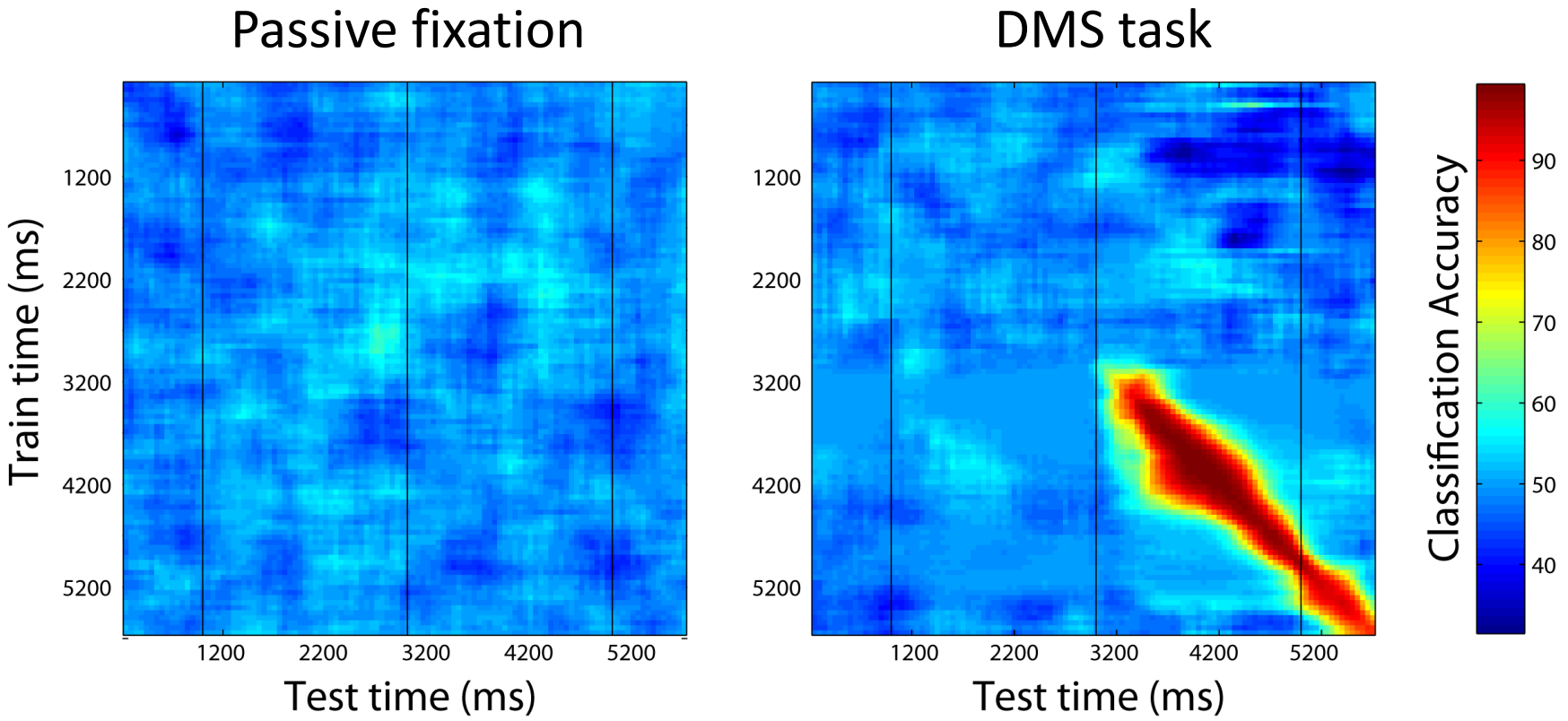
Decoding applied



Dynamic population coding

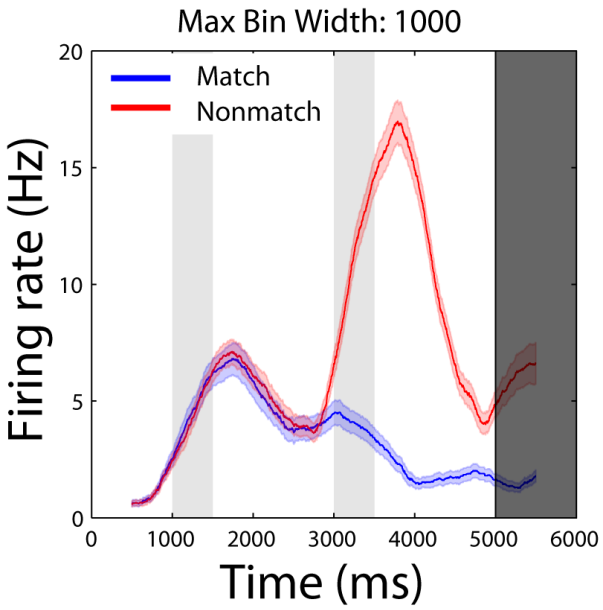


Dynamic population coding

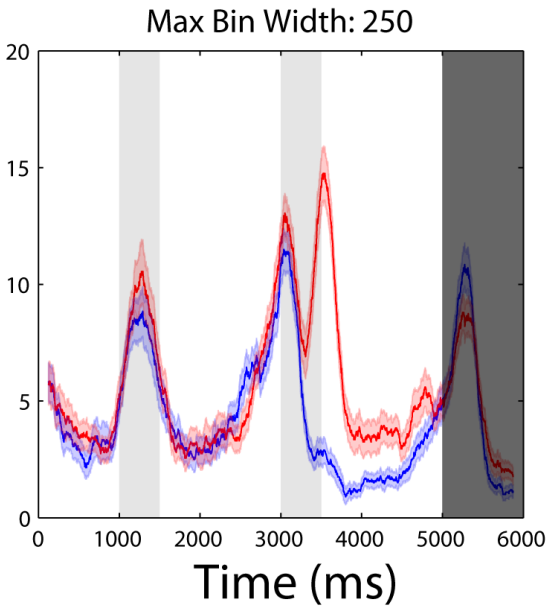


The dynamics can be seen in individual neurons

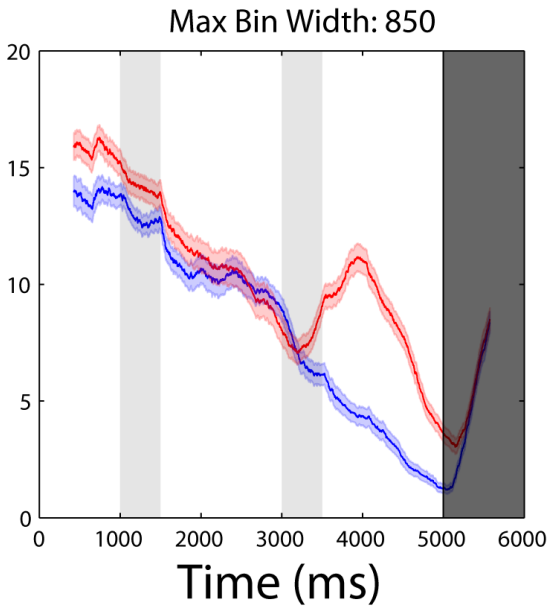
Neuron 1



Neuron 2



Neuron 3



Is information coded in high firing rates or patterns?

Decision Rule

Poisson Naïve Bayes Classifier

Total activity and pattern

$$\arg\max_c \ \log(\mathbf{w_c})^T\mathbf{x} - n\overline{w}_c$$

Minimum Angle Classifier

Pattern only

$$\arg\max_c \ \frac{\mathbf{w_c}^T\mathbf{x}}{\|\mathbf{w_c}\|\|\mathbf{x}\|}$$

Total Population Activity Classifier

Total activity only

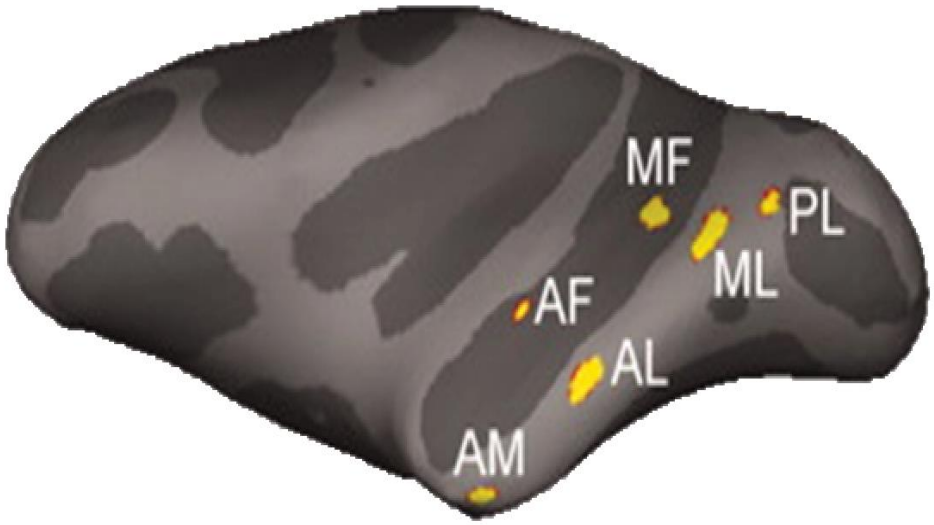
$$\arg\max_c \ |\overline{w}_c - \overline{x}|$$

$\mathbf{w_c}$ are the classification weights for class c

x is the test point to be classifier

Is information coded in high firing rates or patterns?

Pose specific face identification



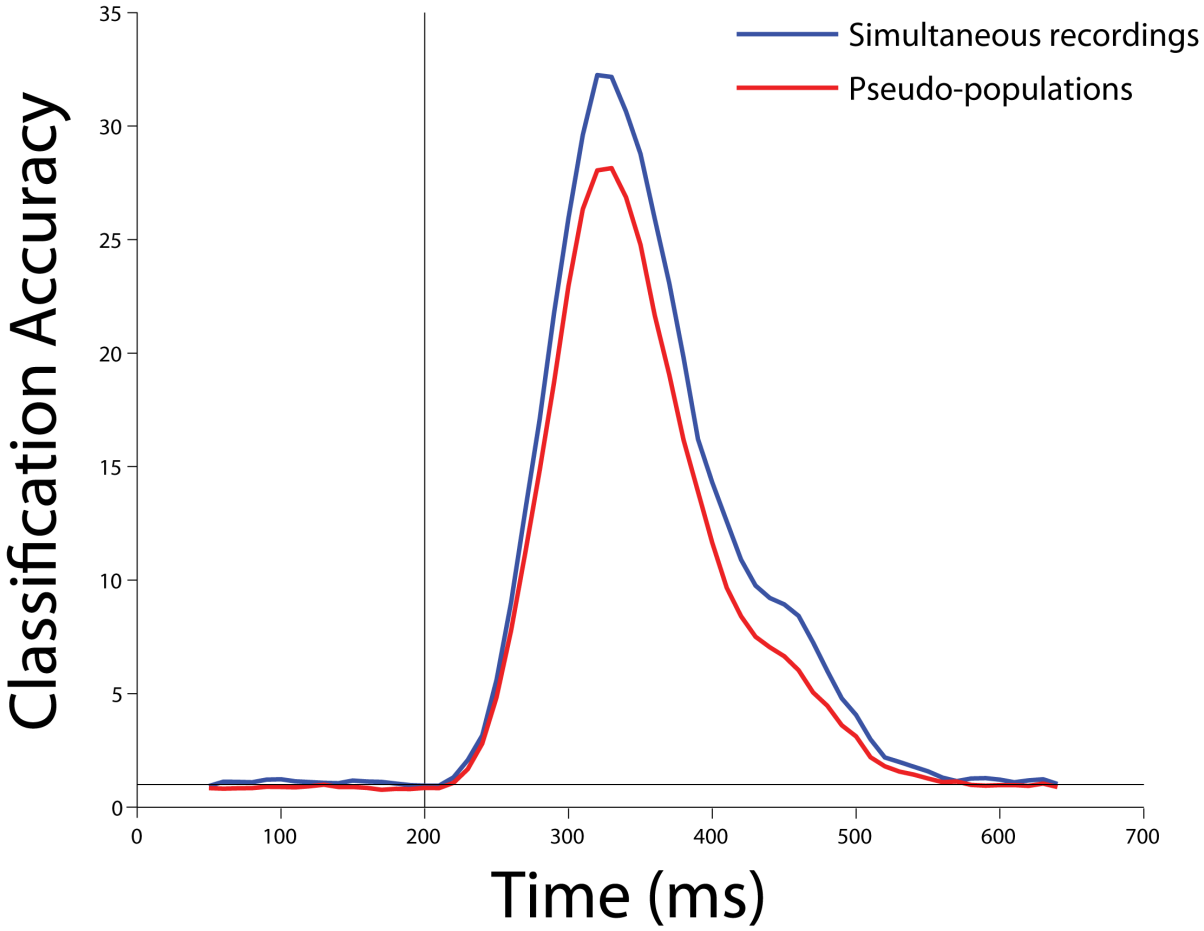
Poisson Naïve Bayes – Total activity and pattern

Minimum Angle – Pattern only

Total Population Activity - Total activity only

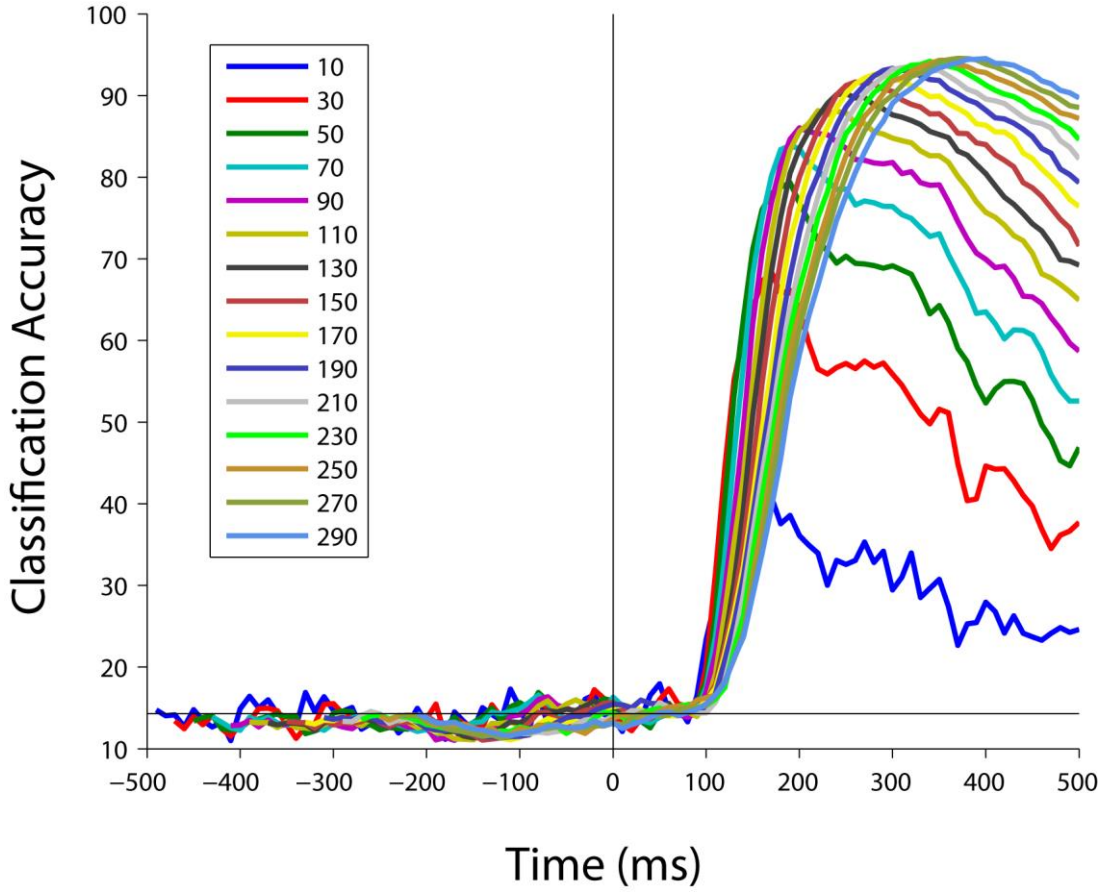
Meyers, Borzello, Freiwald, Tsao, 2015

Independent neuron code?



Data courtesy of the DiCarlo lab; see Ami Patel's MEng thesis

Precision of the neural code (temporal coding)



(basic results – clearly room to explore this further)

See Meyers et al, COSYNE, 2009

Summary of neural coding

Decoding allows you examine many questions in neural coding including:

- Compact/sparse coding
- Dynamic population coding
- Independent neural code
- Temporal precision/temporal coding

Decoding can be applied to other types of data

MEG/EEG (LFPs, ECog)

- New tutorial on readout.info

fMRI

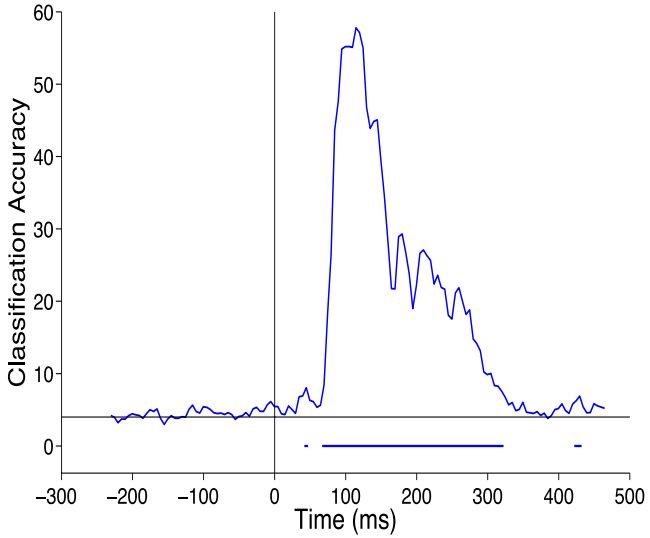
- [Princeton-mvpa-toolbox]
- [PyMVPA]
- [The decoding toolbox]

Continuous decoding

- [nSTAT]

MEG Decoding

A	B	C	D	E
F	G	H	I	J
K	L	M	N	O
P	Q	R	S	T
U	V	W	X	Y



Isik, Meyers, Liebo, Poggio, J. Neurophys, 2014

Limitations of decoding

Hypothesis based – could be overlooking information that is not explicitly tested for

Just because information is present, doesn't mean it's used

Decoding focuses on the computational and algorithmic/representational levels, does not give a mechanistic explanation of the phenomena

Decoding methods can be computationally intensive, analyses can be slow to run

The Neural Decoding Toolbox (NDT)

Makes it easy to do decoding in MATLAB:

```
1   binned_file = 'Binned_data.mat';
2   ds = basic_DS(binned_file, 'stimulus_ID', 20);
3   cl = max_correlation_coefficient_CL;
4   fps{1} = zscore_normalize_FP;
5   cv = standard_resample_CV(ds, cl, fps)
6   DECODING_RESULTS = cv.run_cv_decoding;
```

Open Science philosophy: open source for reproducible results

- The code open source for reproducible results
- Hope to encourage open science culture, so please share your data

www.readout.info

Meyers, Font Neuroinfo, 2013

The Neural Decoding Toolbox Design

Toolbox design: 4 abstract classes

1. Datasource: creates training and test splits

- E.g., can examine the effects from different binning schemes

2. Preprocessors: learn parameters from training data apply them to the training and test data

- E.g., can examine sparse/compact coding

3. Classifiers: learn from training data and make predictions on test data

- E.g., can examine whether information is in high firing rates or patterns

4. Cross-validators: run the training/test cross-validation cycle

Getting started with your own data

You can use the NDT on your own data by putting your data into 'raster format'

raster_data

	Time 1	Time 2	Time 3	Time 4	Time 5	Time 6	...
Trial 1	0	0	1	0	0	0	
Trial 2	0	0	0	1	0	0	
Trial 3	0	1	0	0	0	1	
Trial 4	0	0	1	0	0	0	
Trial 5	0	0	0	0	0	0	
⋮							

raster_labels

.stimulus_ID	.stimulus_position
'flower'	'middle'
'face'	'upper'
'couch'	'upper'
'couch'	'middle'
'hand'	'lower'
⋮	⋮

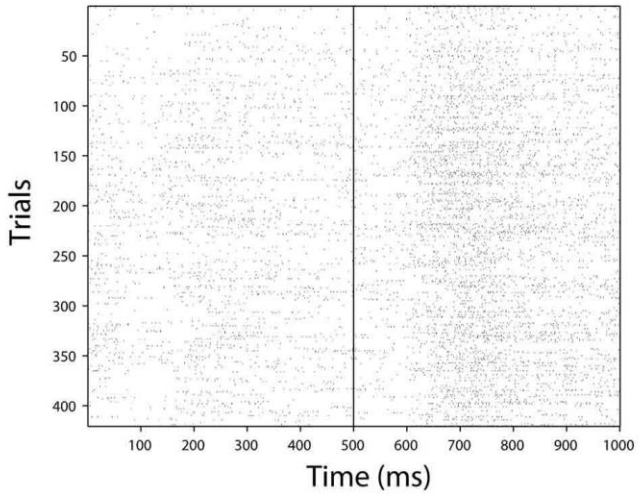
raster_site_info

.session_ID = 12

.recording_channel = 1

.brain_area_name = 'IT'

raster_data from one example site



Questions?

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