Using population decoding to understand neural content and coding

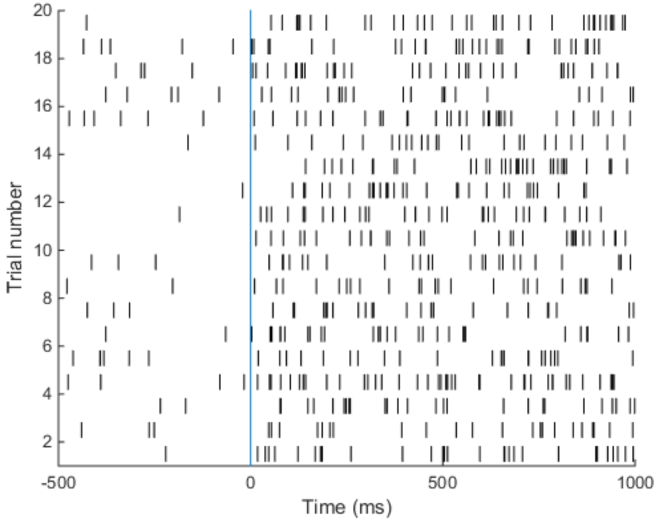
The Center for Brains, Minds & Machines

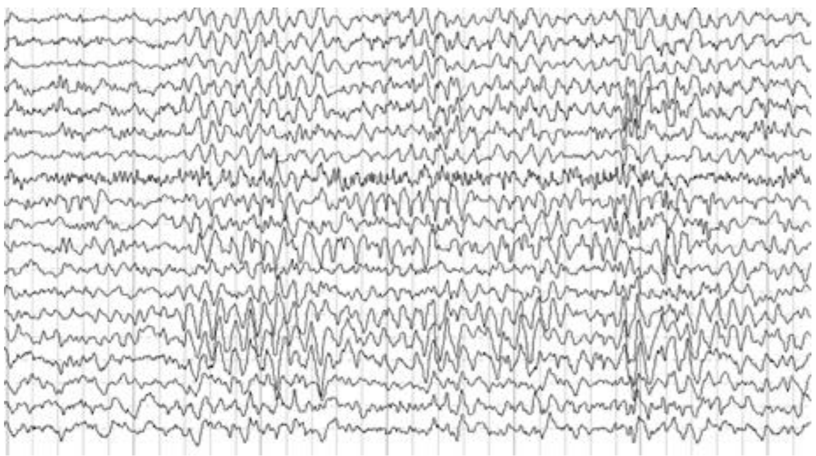
Motivation

We have some great theory about how the brain works

We run an experiment and make neural recordings

We get a bunch of data…





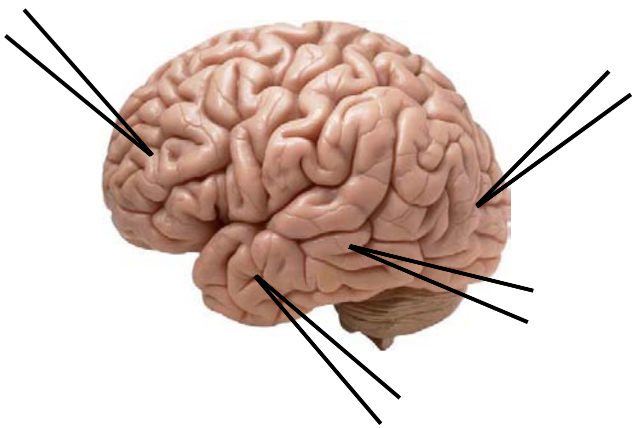
How can we convert data into answers?

What do I want from a data analysis method?

Clear answers to:

<u>Neural content</u>: What information is in a brain region?

<u>Neural coding</u>: 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

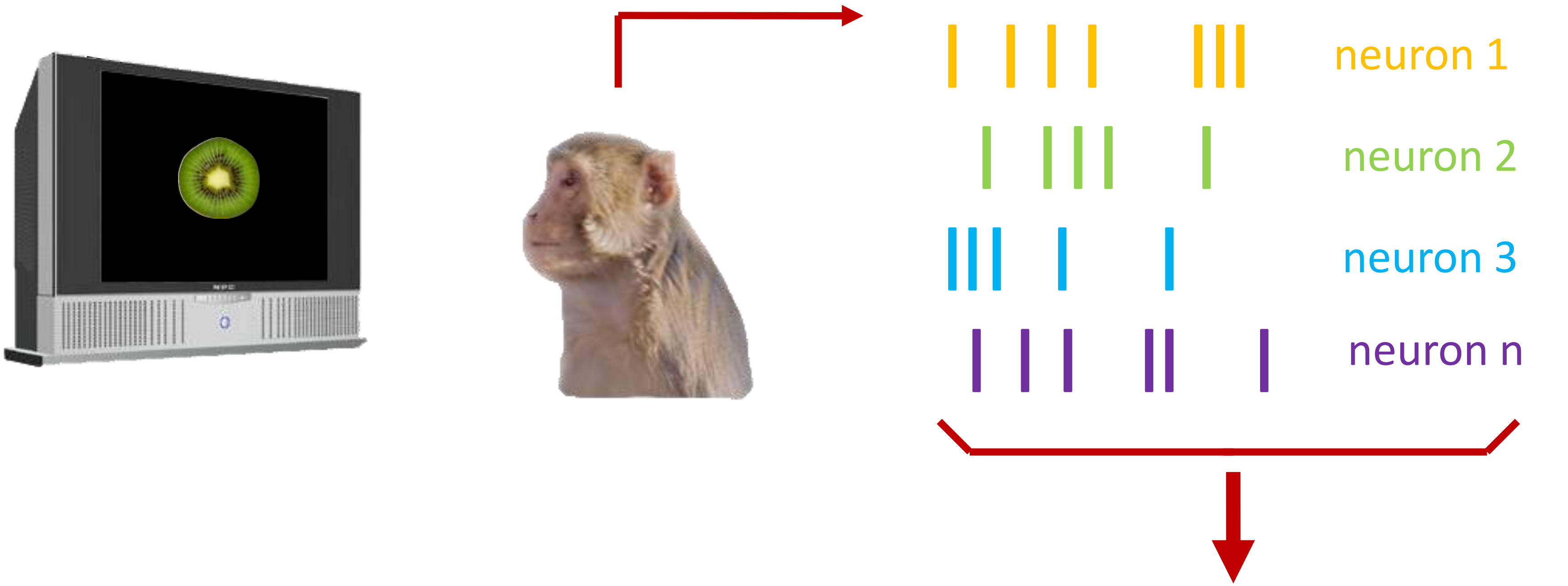
Decoding approaches have been used for 30 years

- 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

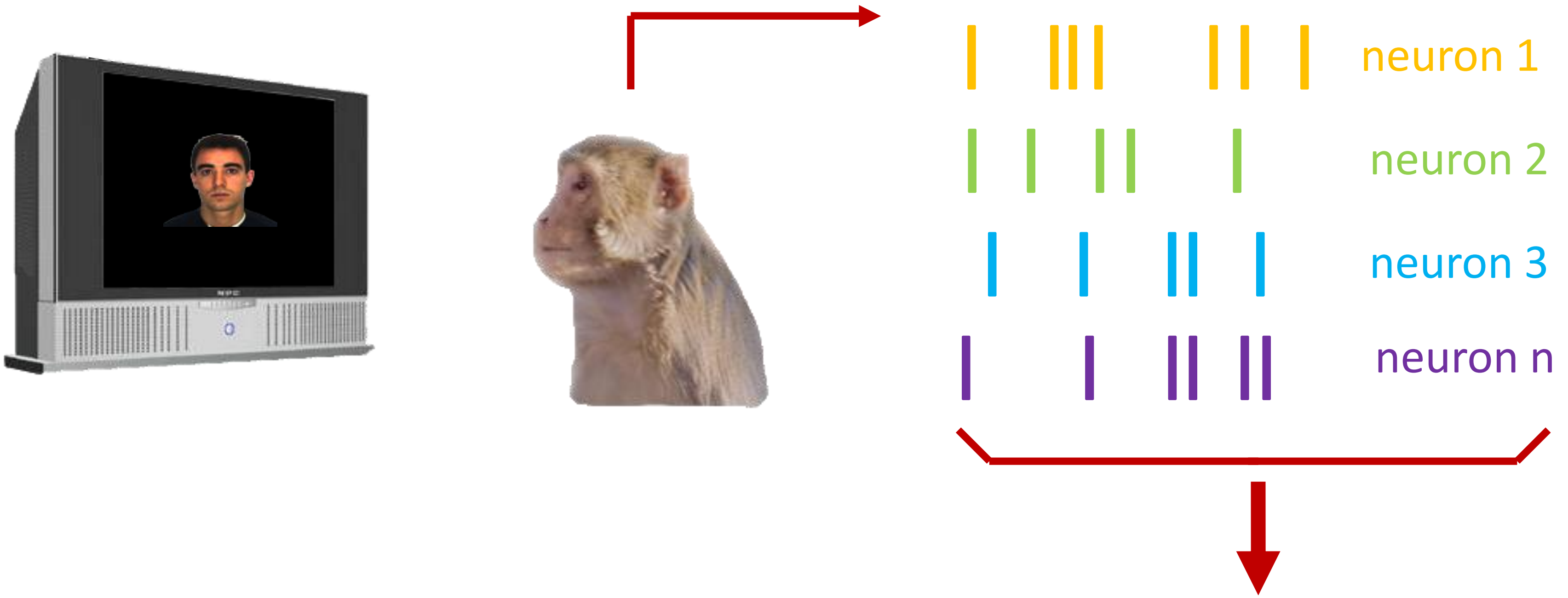
Training the classifier



Learning association between
neural activity an image

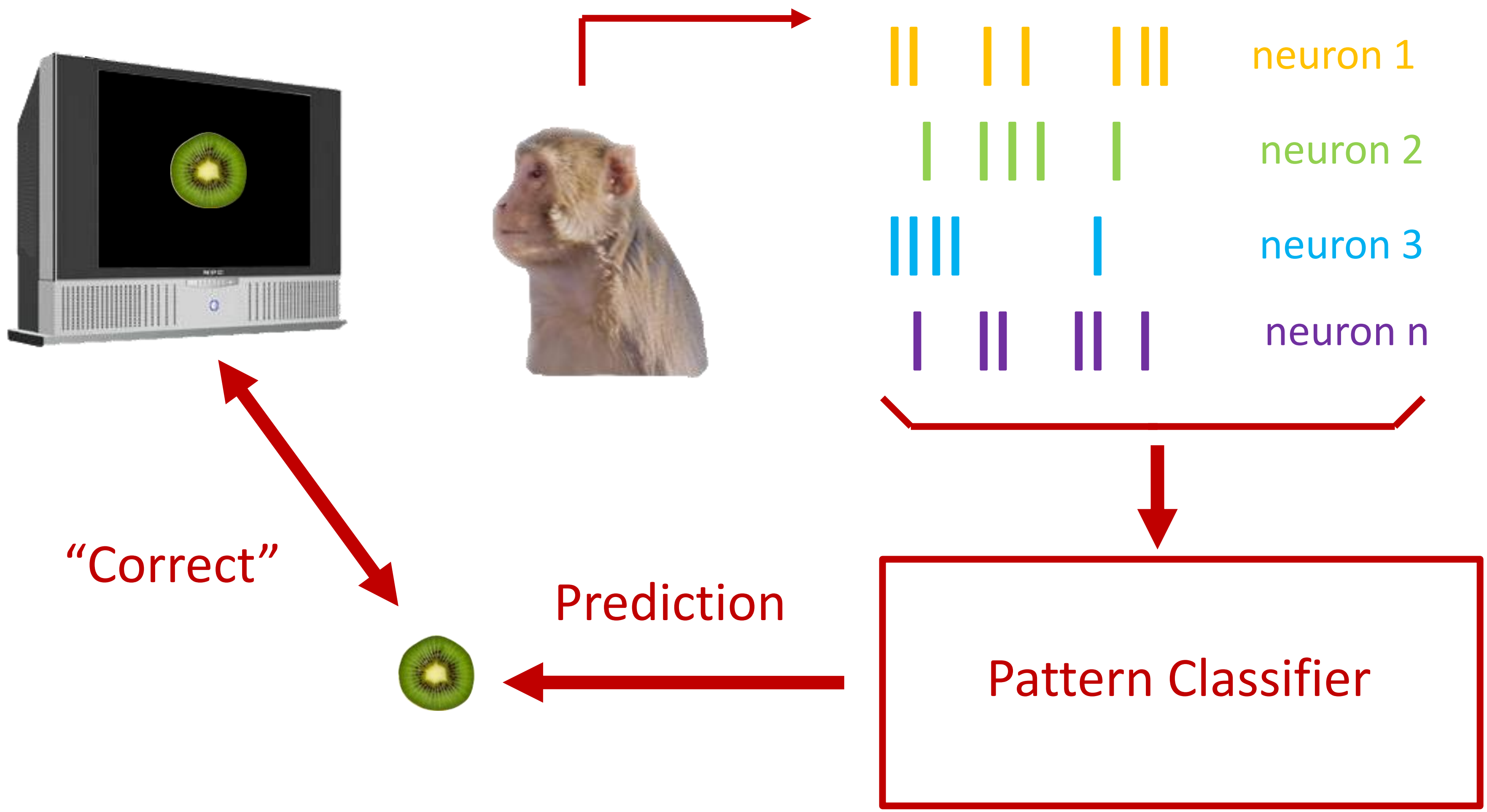
Pattern Classifier

Training the classifier

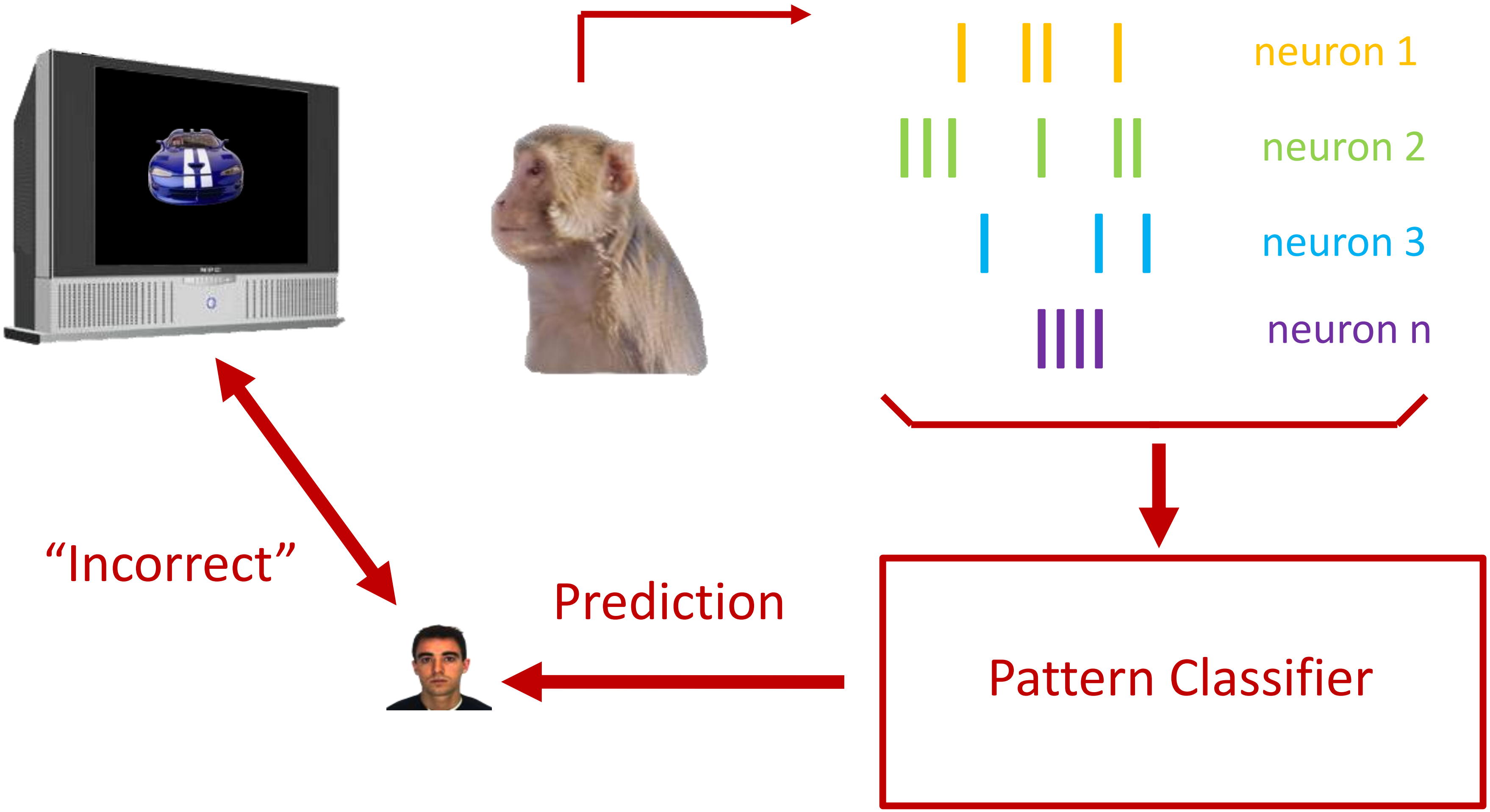


Learning association between neural activity an image

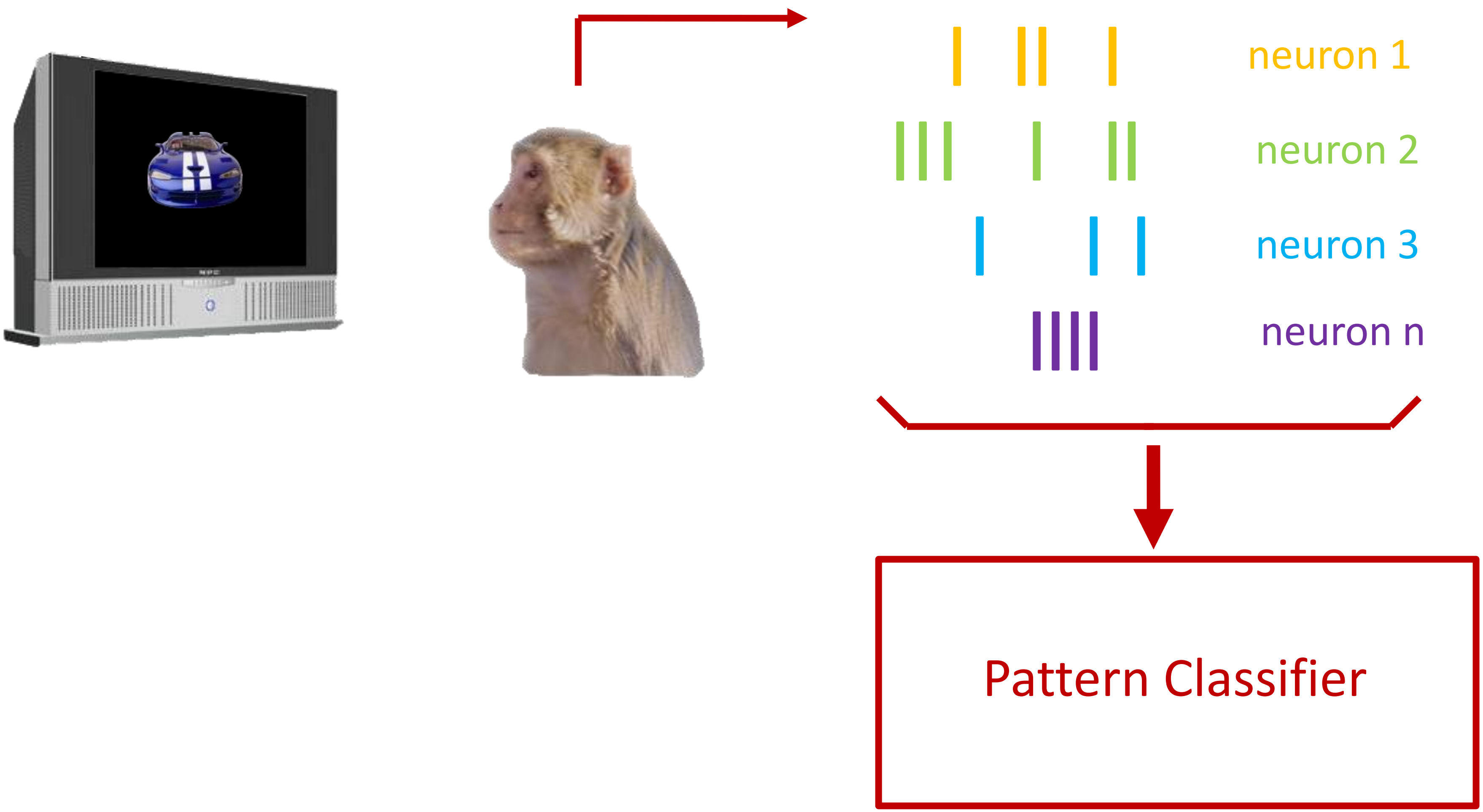
Using the classifier

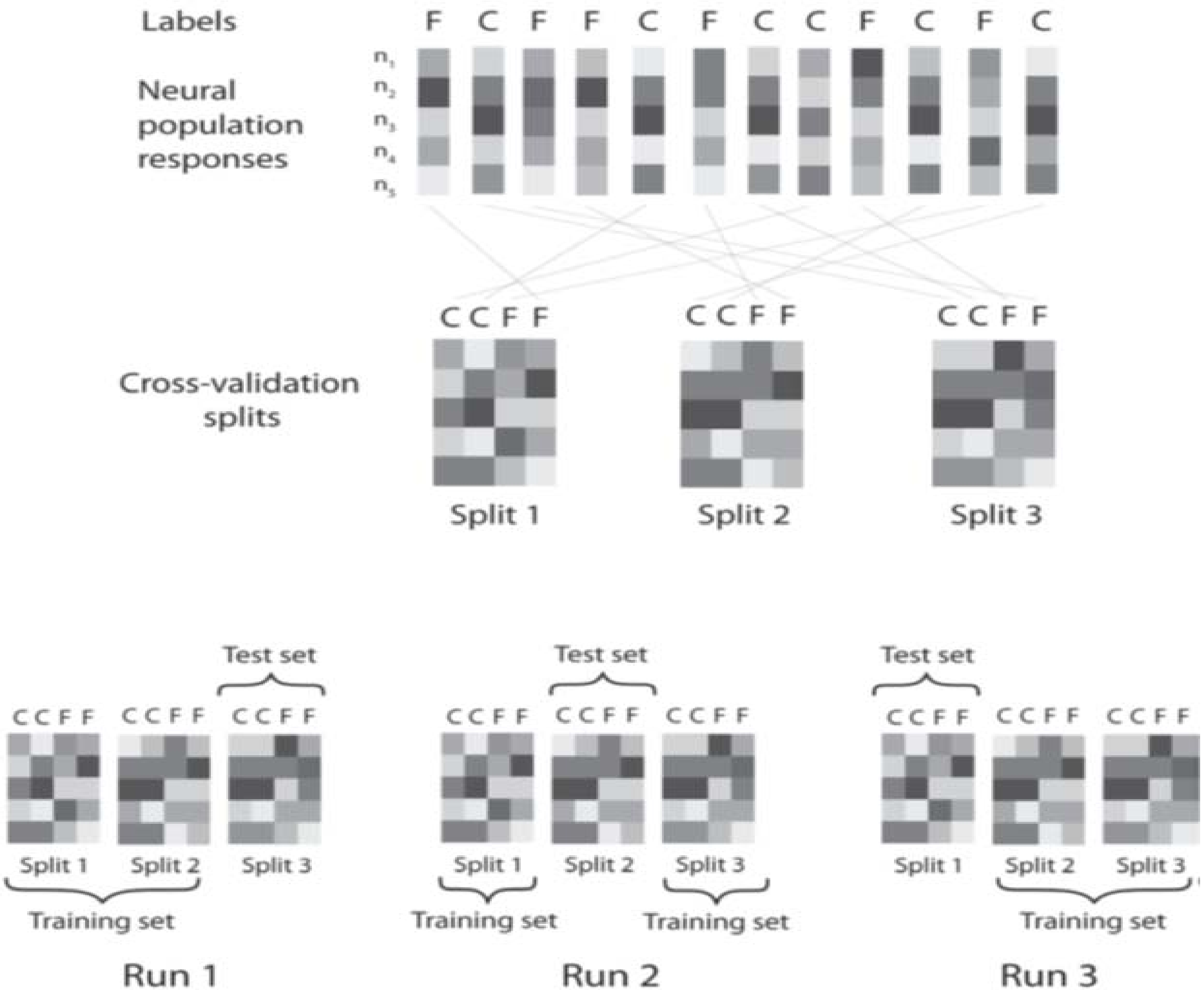


Using the classifier



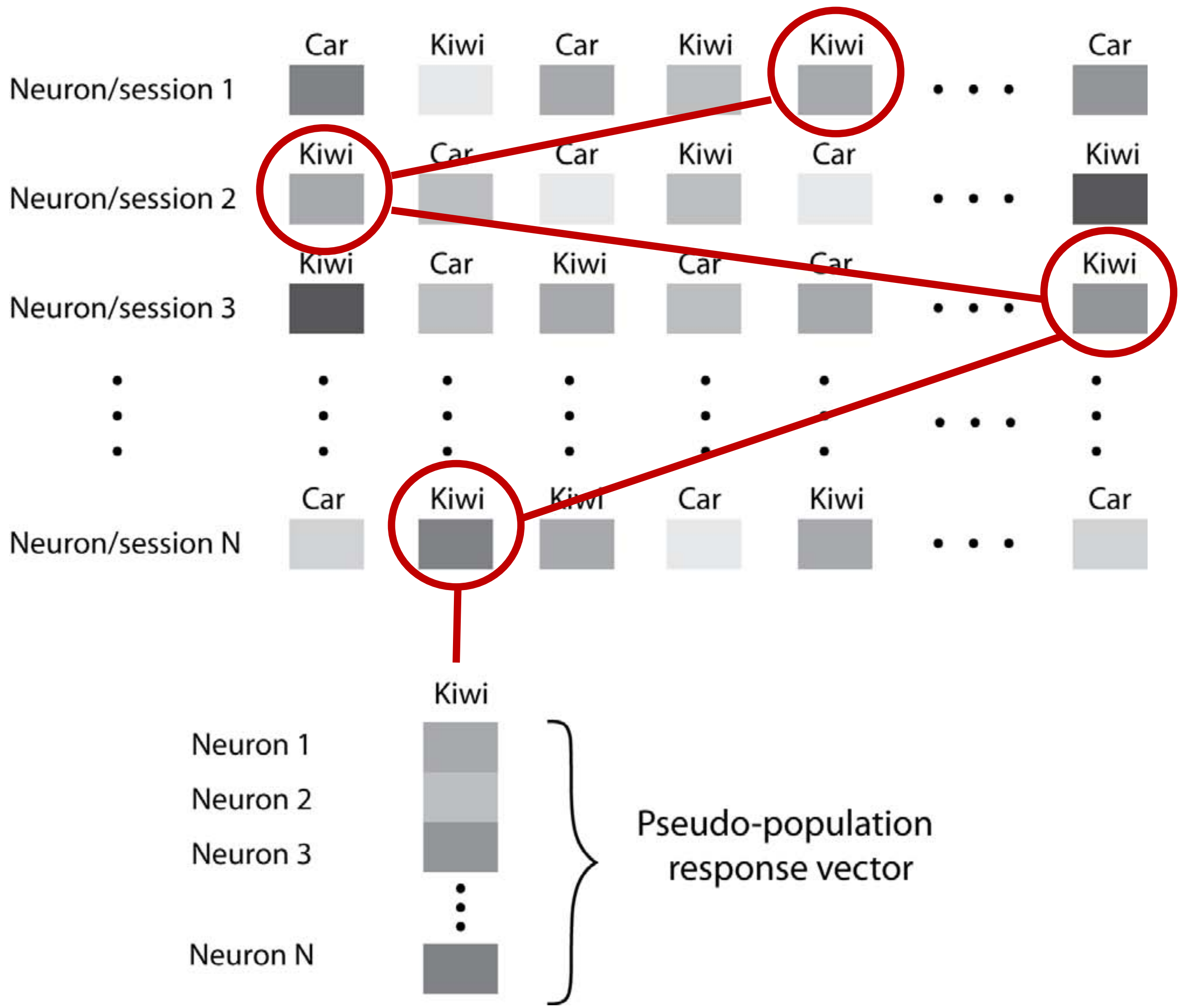
Using the classifier



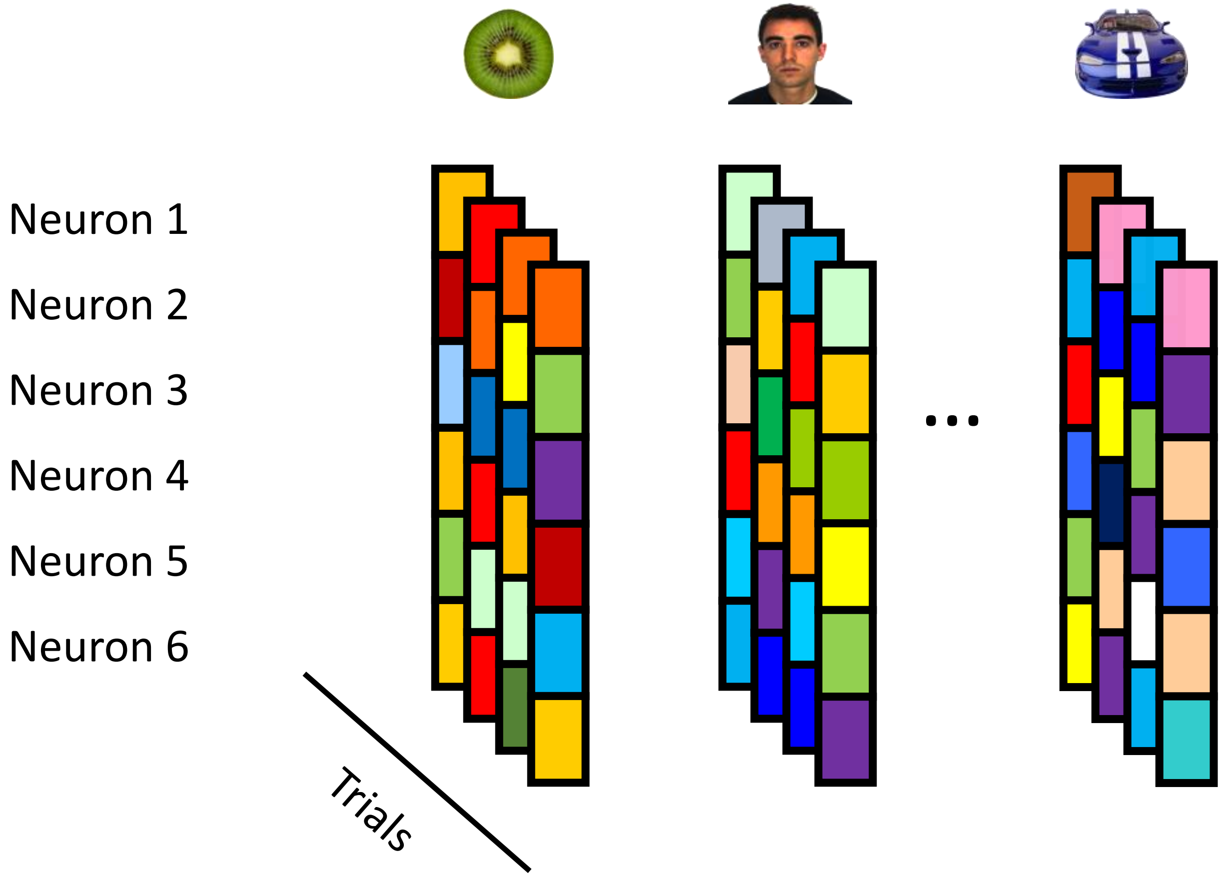


Source: Meyers, E. M., and Gabriel Kreiman. "Tutorial on pattern classification in cell recording." Visual Population Codes (2012): 517-538.

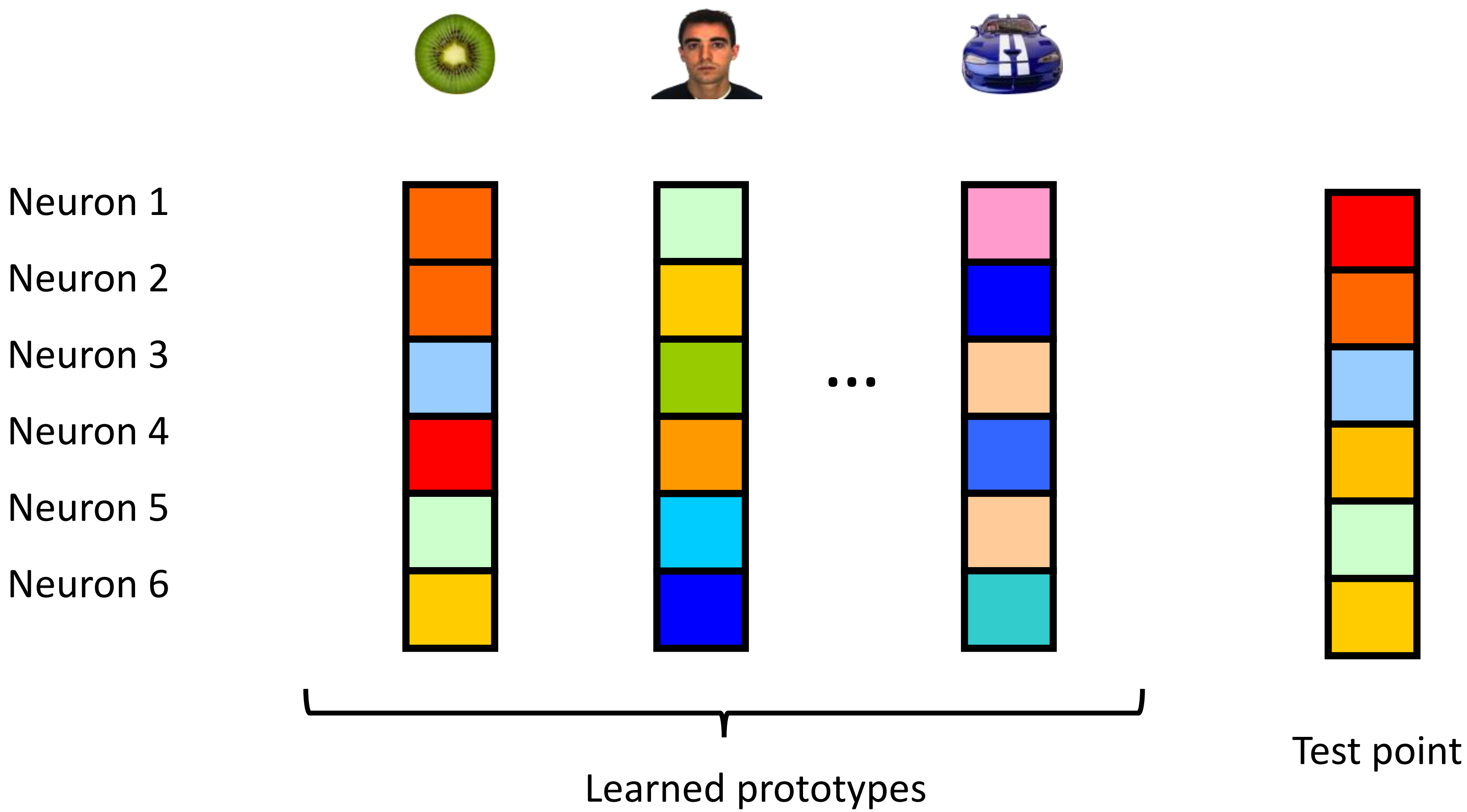
Pseudo-populations



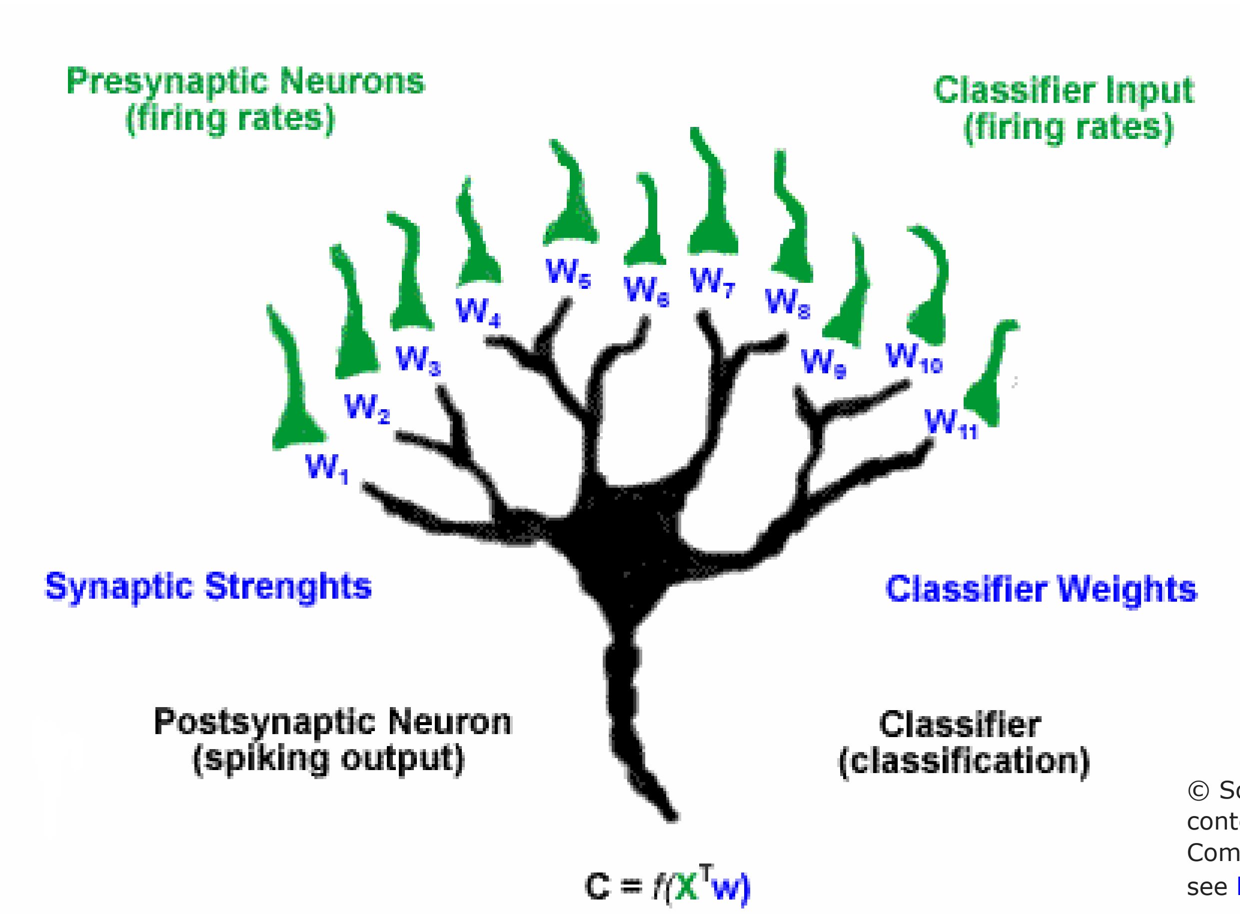
Maximum Correlation Coefficient Classifier



Maximum Correlation Coefficient Classifier

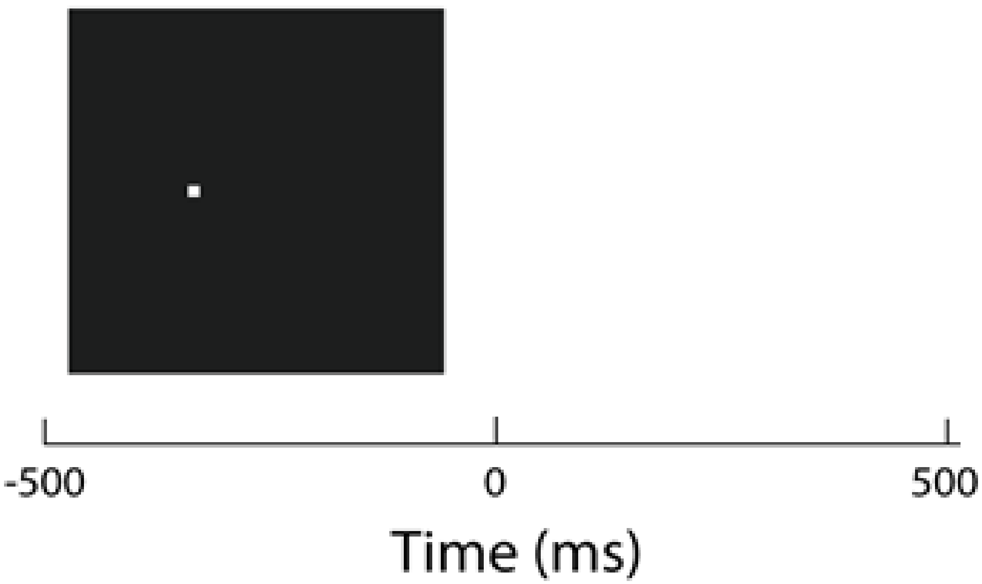


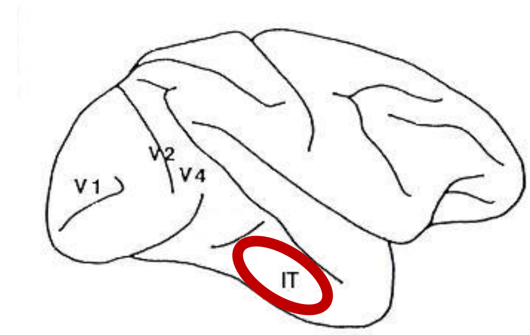
Decoding can be viewed as assessing the information available to downstream neurons



Neural content

A simple experiment



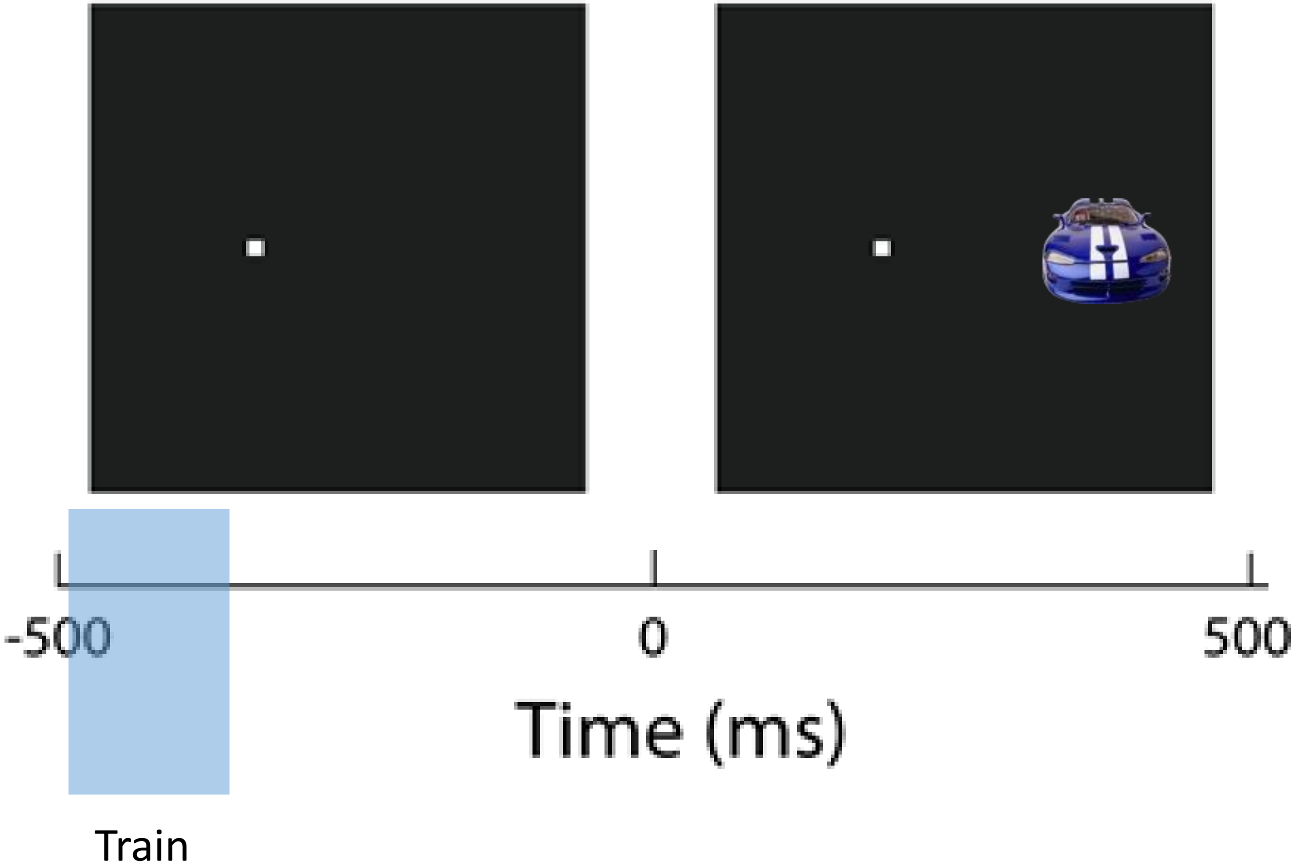


132 neurons recorded from IT

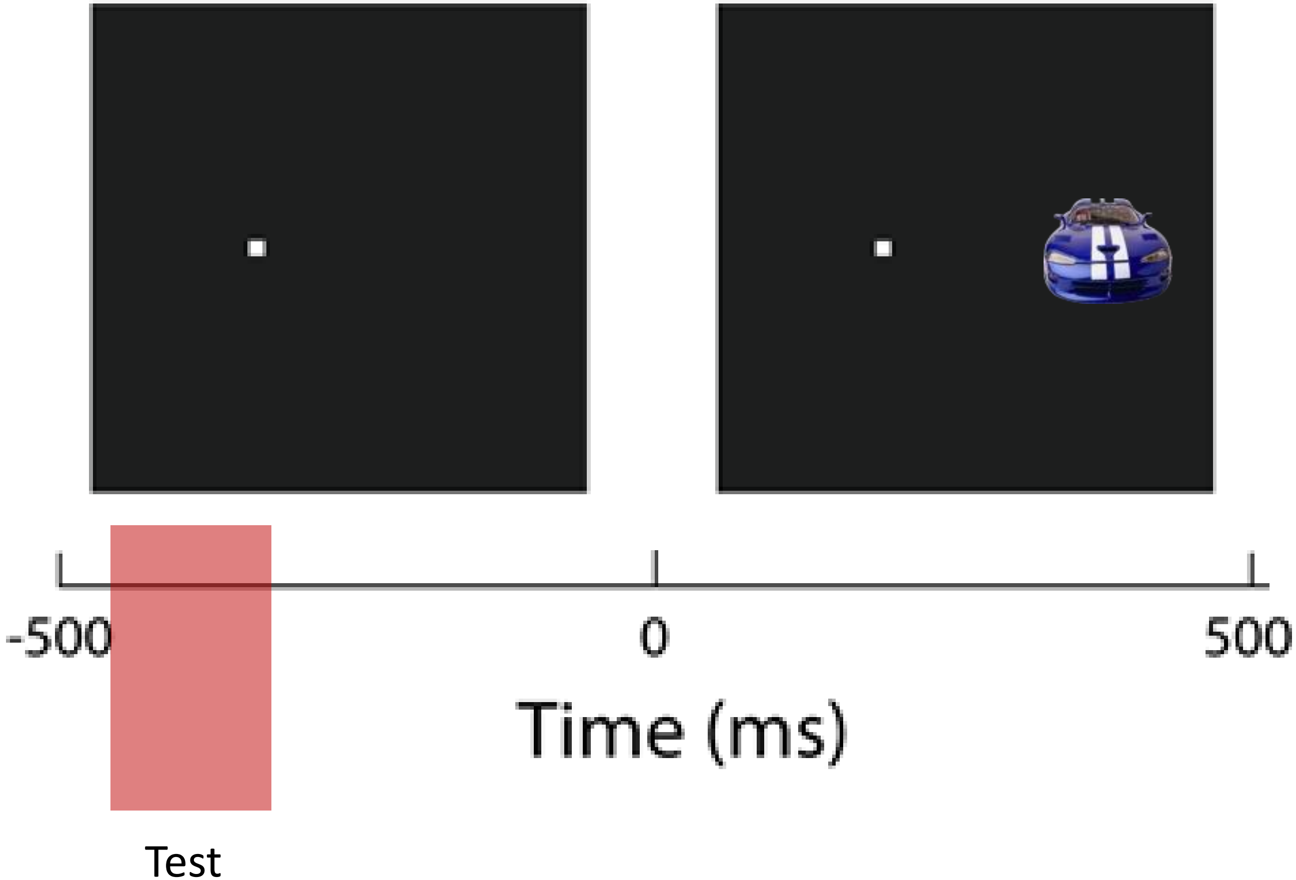
Seven objects:

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

Applying decoding

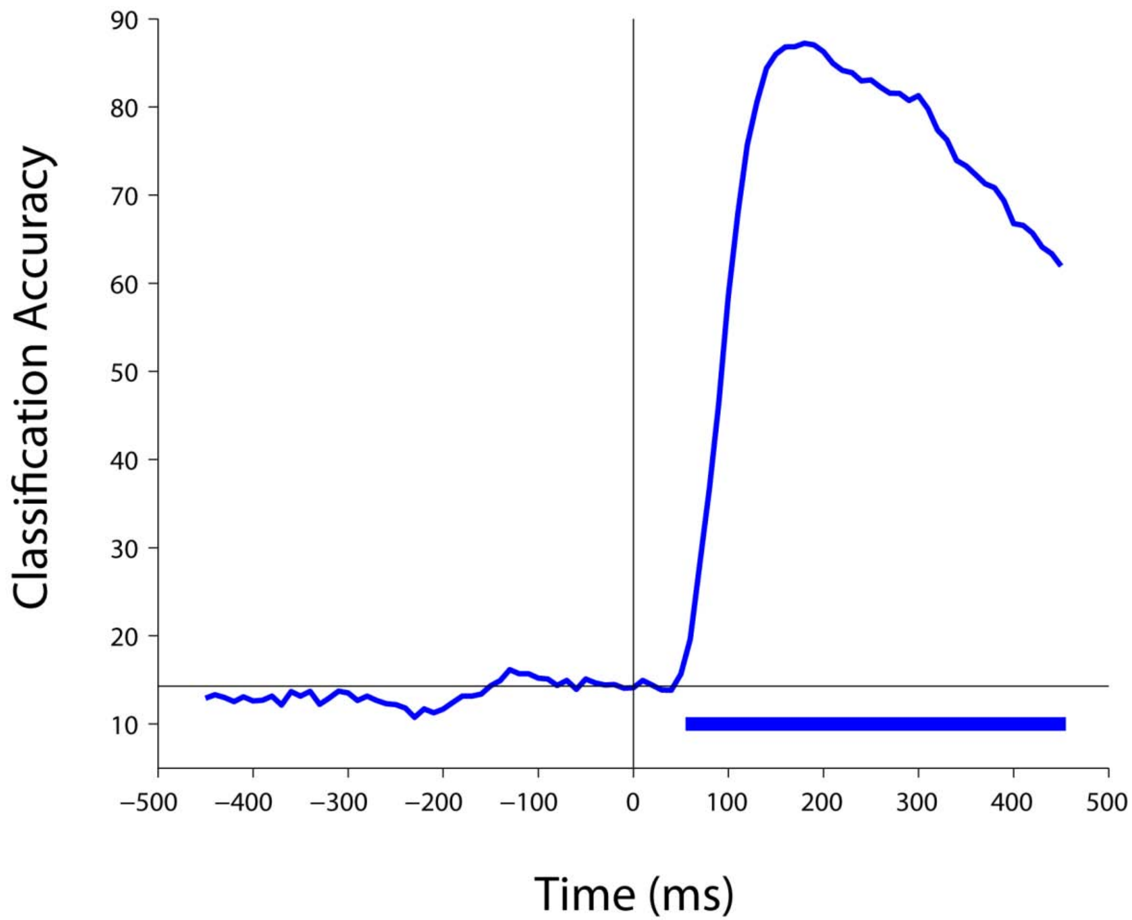


Applying decoding

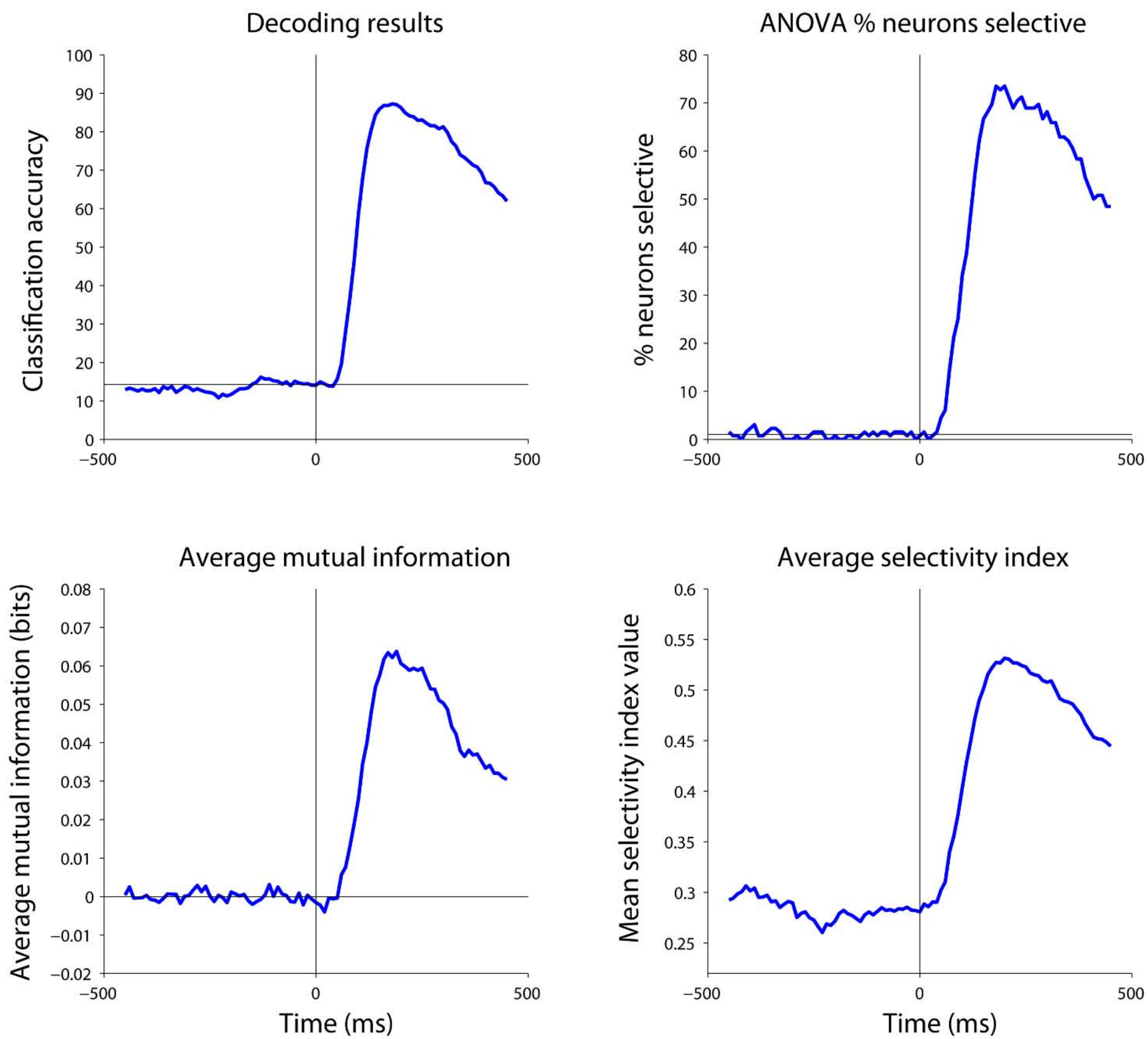


100 ms bins, sample every 10 ms

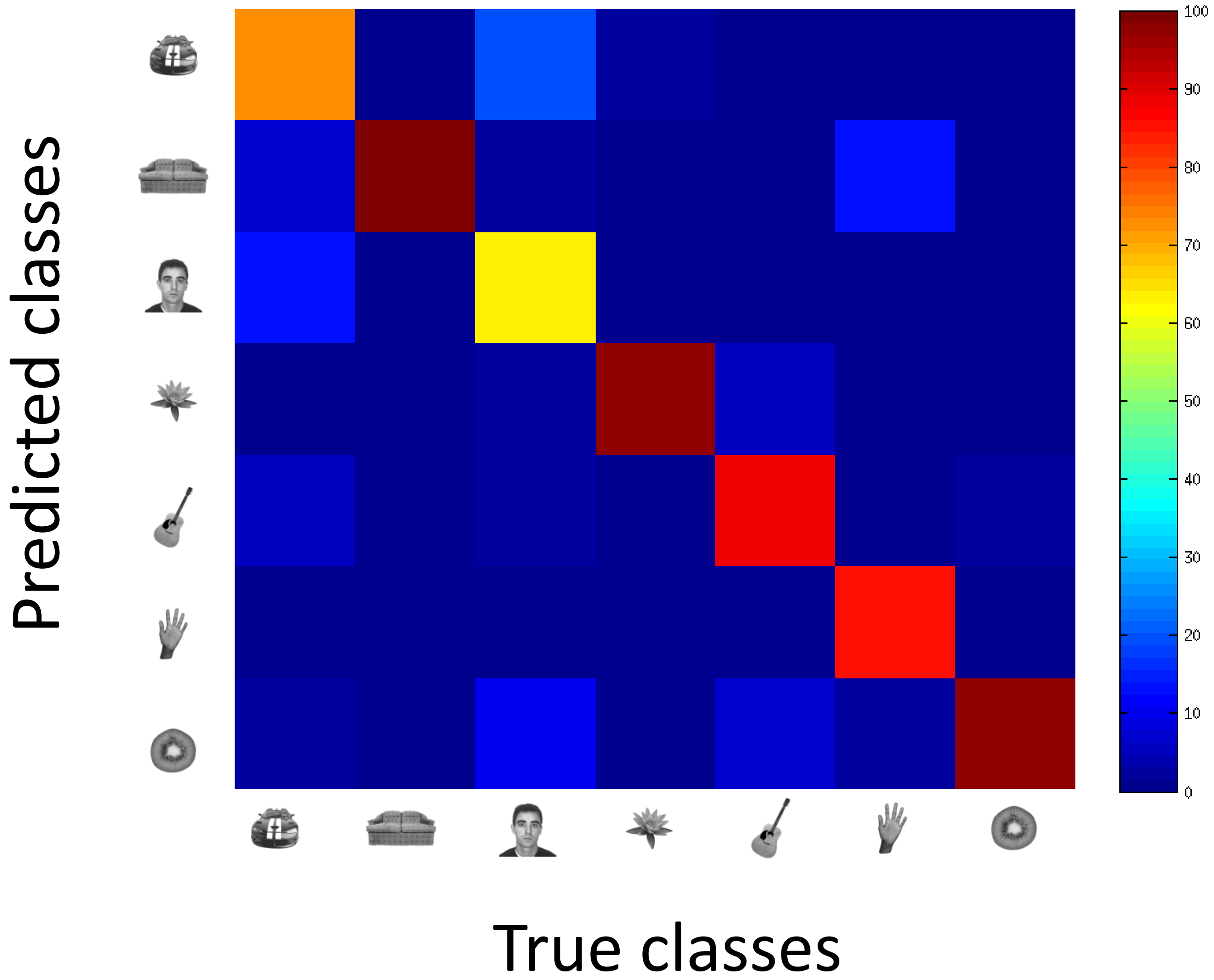
Basic decoding results



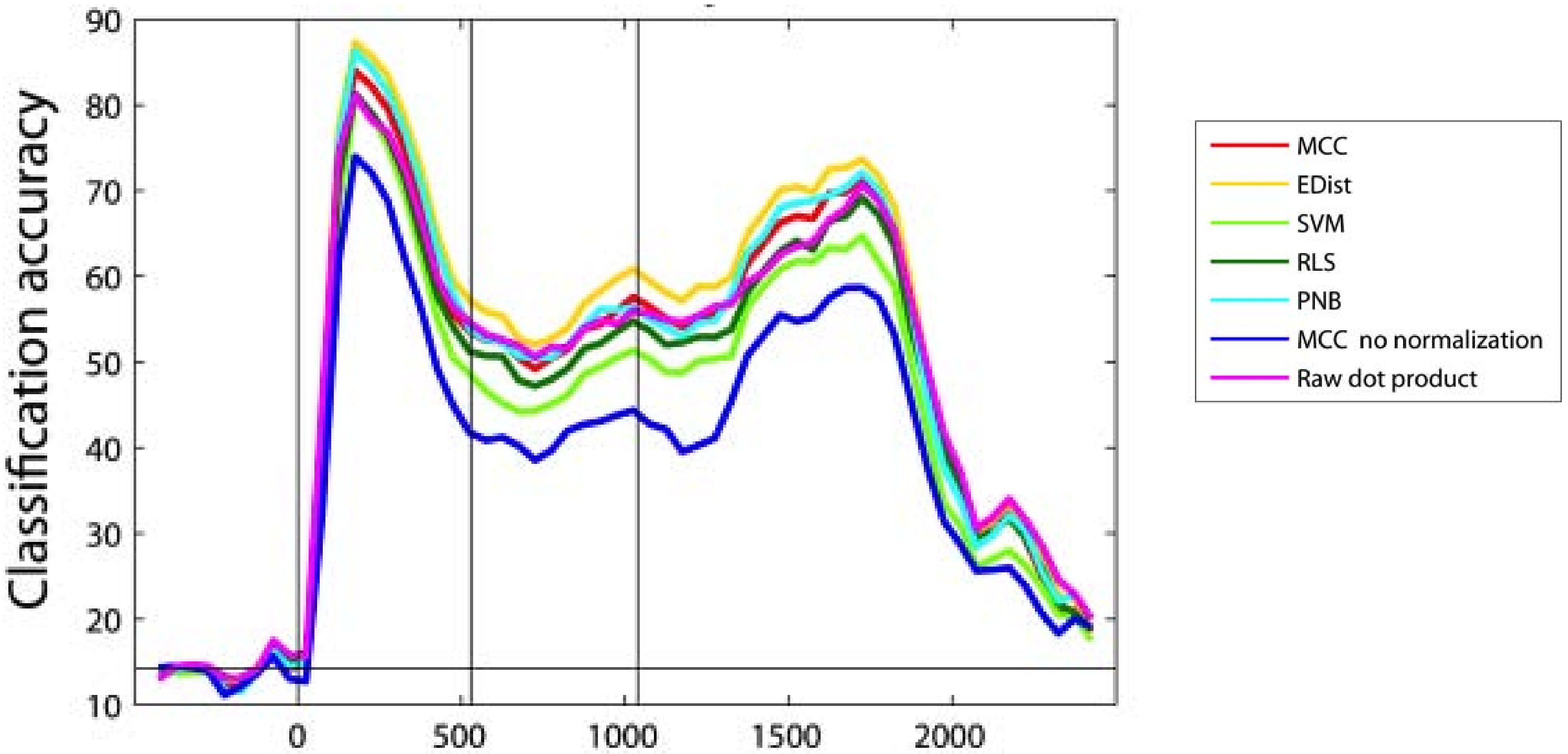
Basic results are similar to other methods



Confusion matrices



Generally robust to the choice of classifier

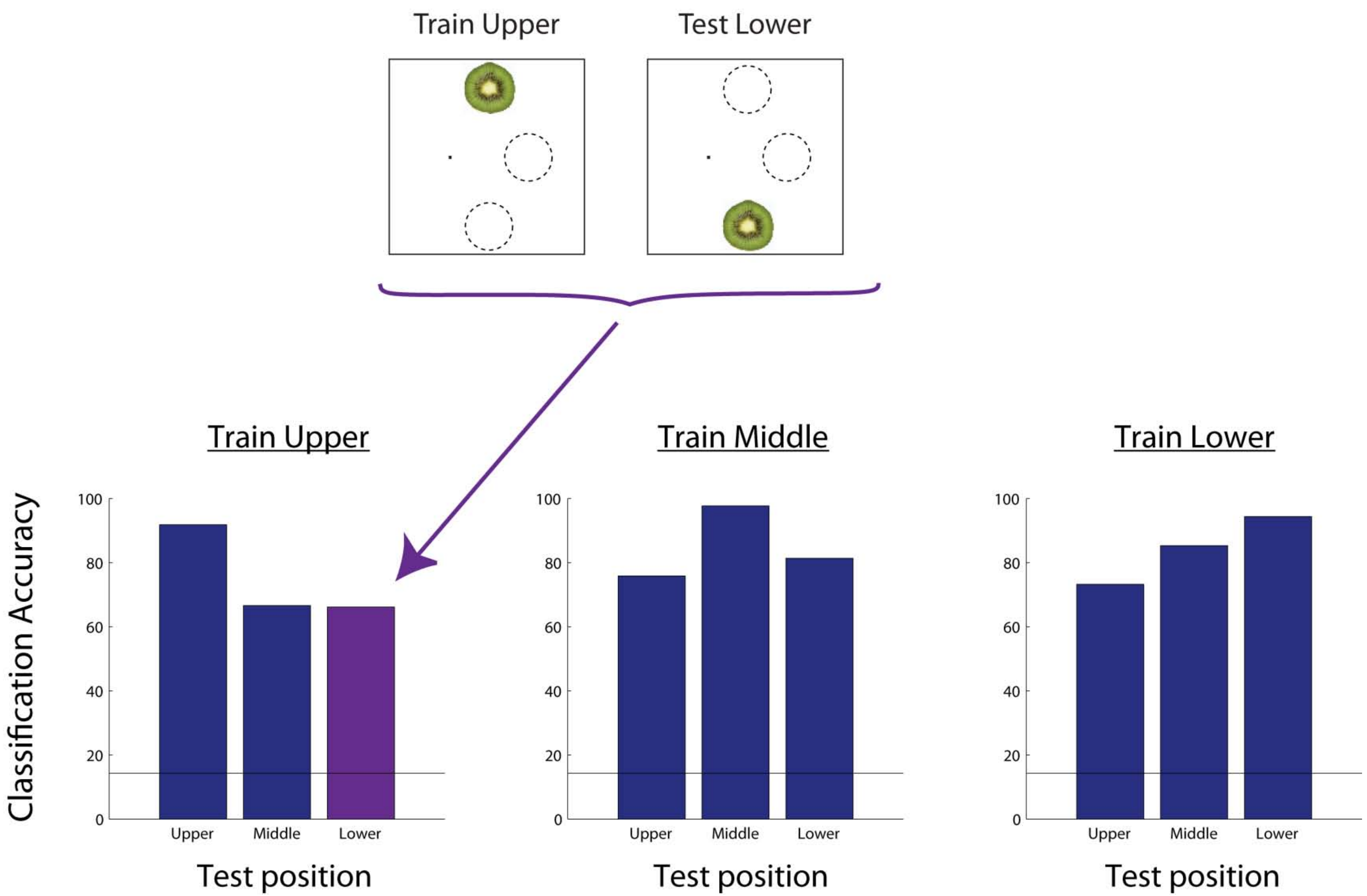


Time (ms)

Abstract/invariant representations

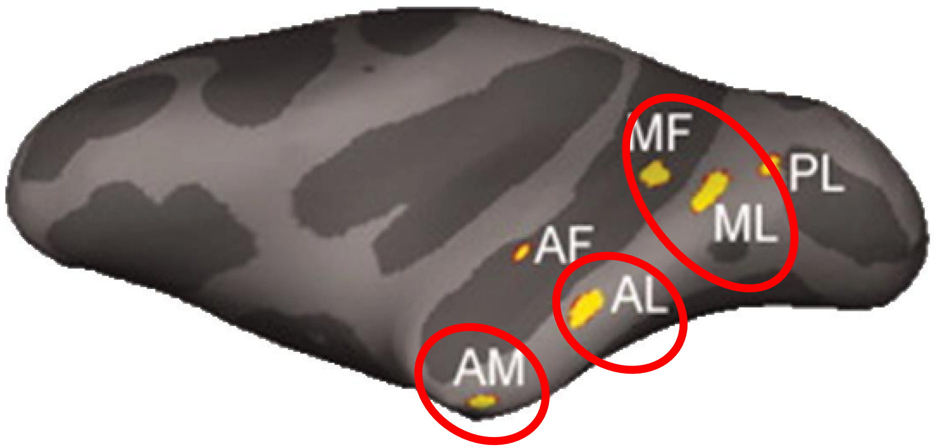
The ability to form abstract representations is essential for complex behavior

Example: position invariance



Hung, Kreiman, Poggio, and DiCarlo, Science, 2005

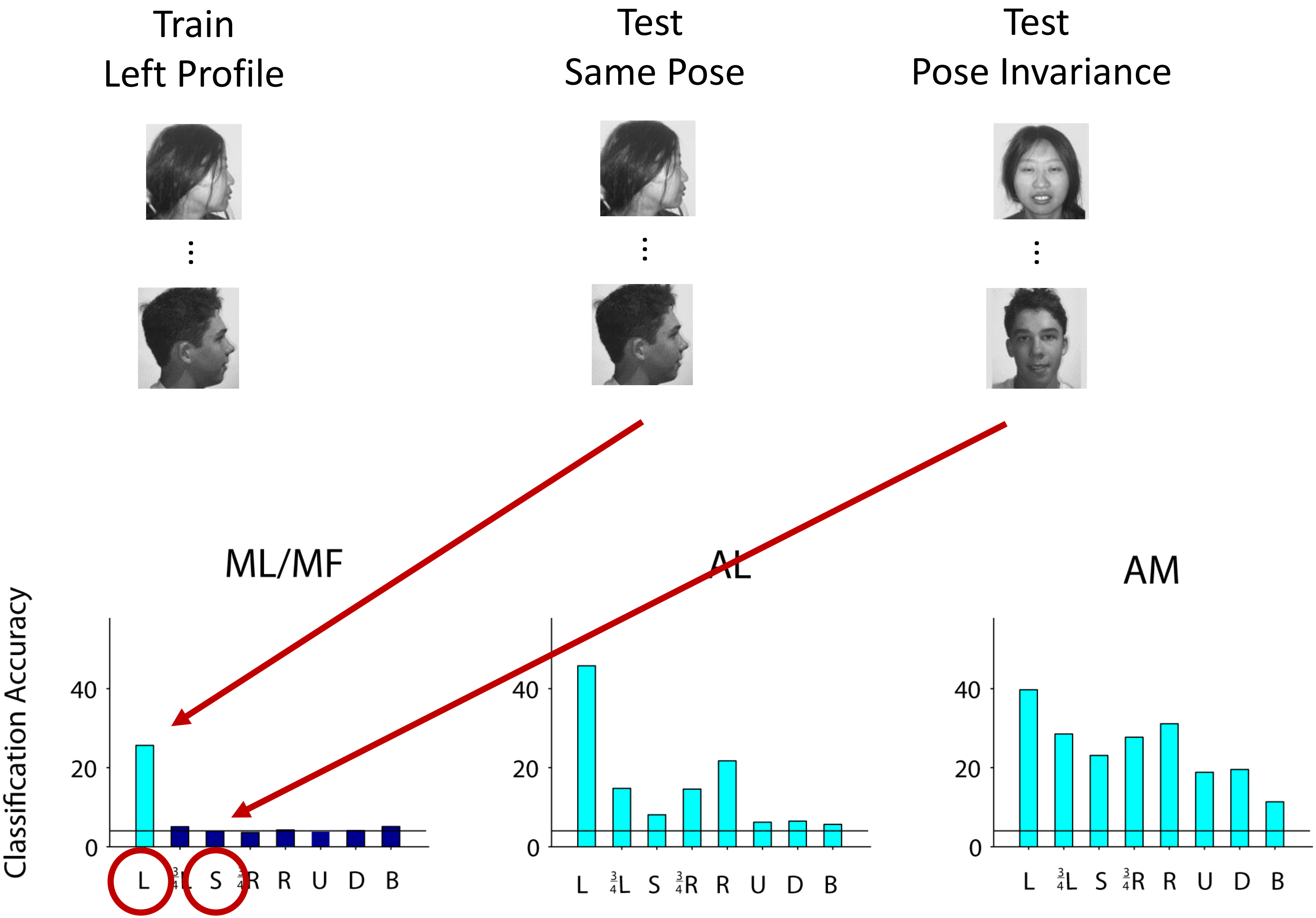
Face identification invariant to head pose



Stimulus set: 25 individuals, 8 head poses per individual

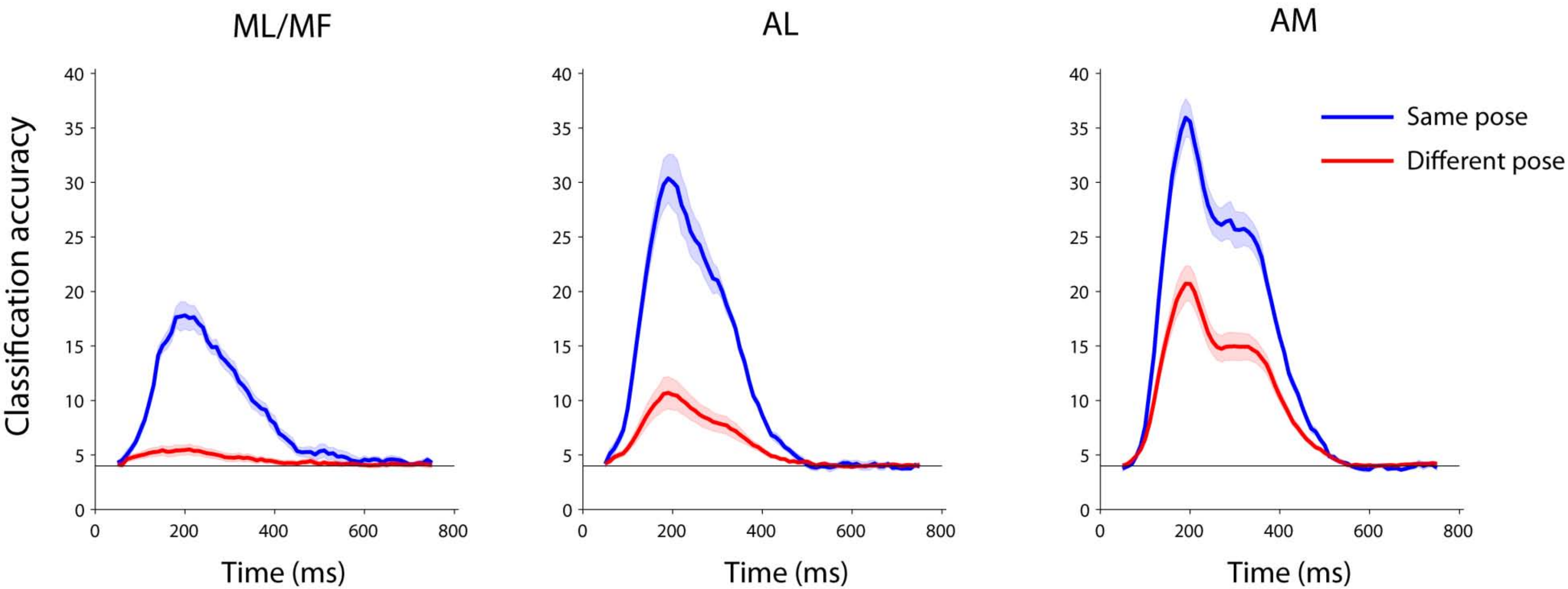
Meyers, Borzello, Freiwald, Tsao, J Neurosci, 2015

Face identification invariant to head pose



Source: Meyers, Ethan M., Mia Borzello, Winrich A. Freiwald, and Doris Tsao. "Intelligent information loss: the coding of facial identity, head pose, and non-face information in the macaque face patch system." Journal of Neuroscience 35, no. 18 (2015): 7069-7081.

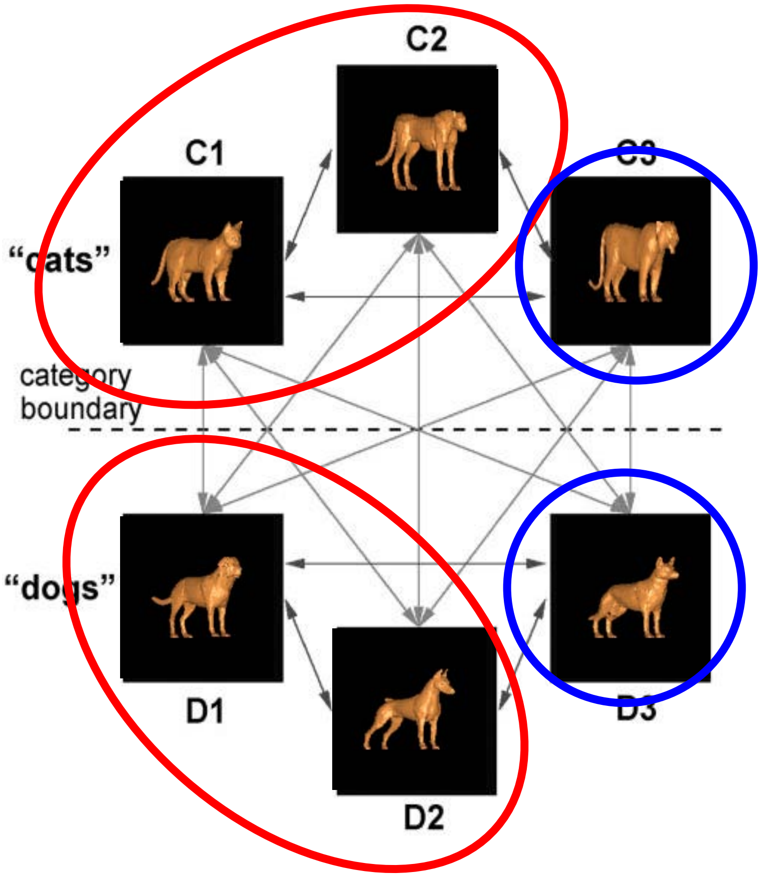
Face identification invariant to head pose

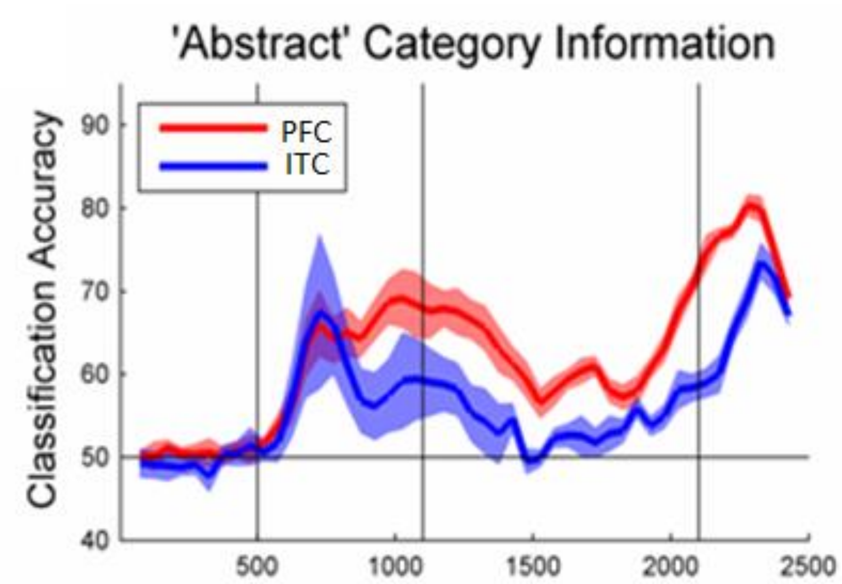


Posterior → Anterior

Source: Meyers, Ethan M., Mia Borzello, Winrich A. Freiwald, and Doris Tsao. "Intelligent information loss: the coding of facial identity, head pose, and non-face information in the macaque face patch system." Journal of Neuroscience 35, no. 18 (2015): 7069-7081.

Learning abstract category information





Source: Meyers, Ethan M., David J. Freedman, Gabriel Kreiman, Earl K. Miller, and Tomaso Poggio. "Dynamic population coding of category information in inferior temporal and prefrontal cortex." Journal of Neurophysiology 100, no. 3 (2008): 1407-1419.

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

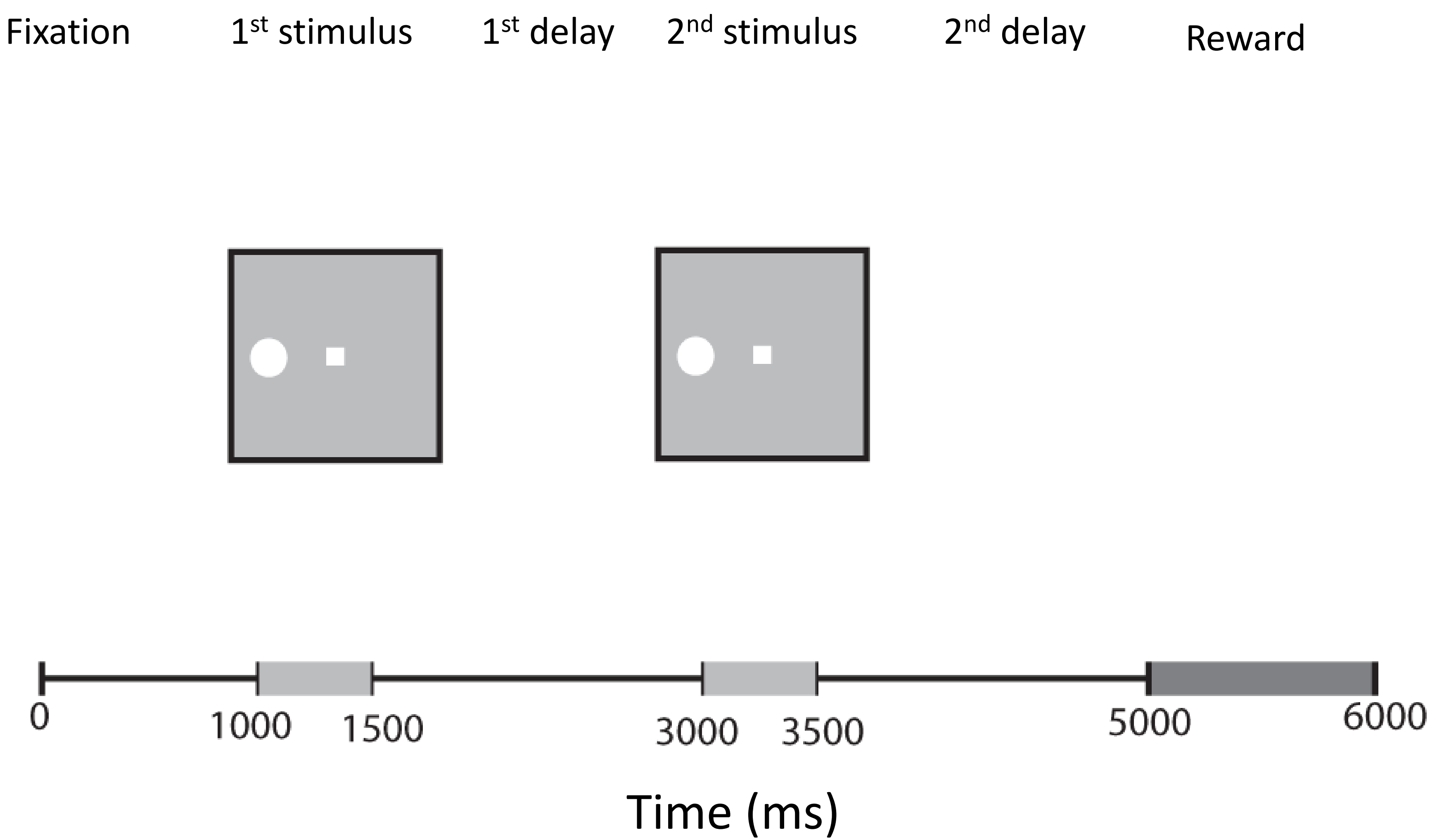
Decoding allows one to assess whether information is contained in an abstract/invariant format, which is not possible with other methods

Neural coding

Motivating study

Meyers, Qi, Constantinidis, PNAS, 2012

Monkeys were first trained to passively fixate



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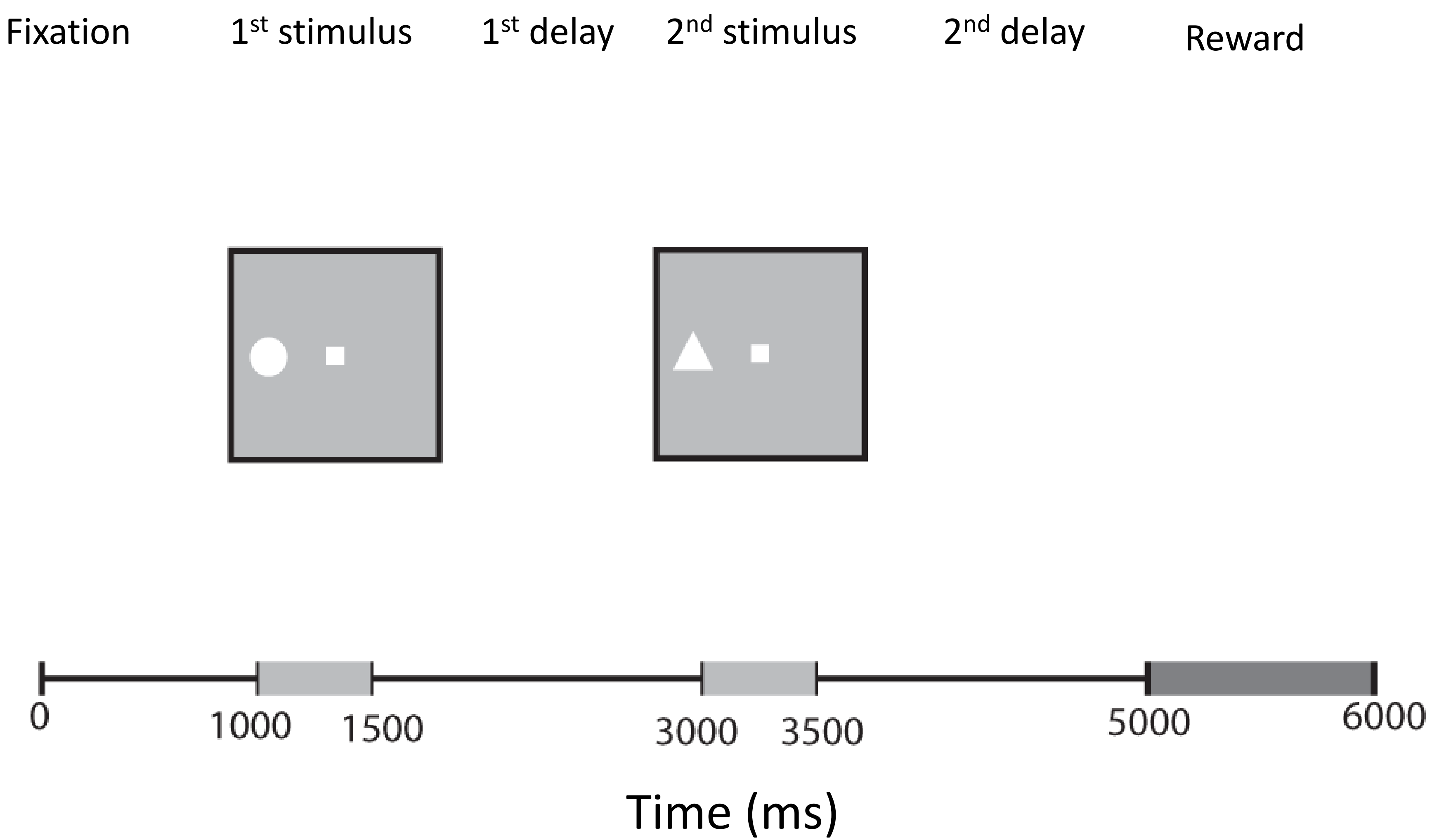
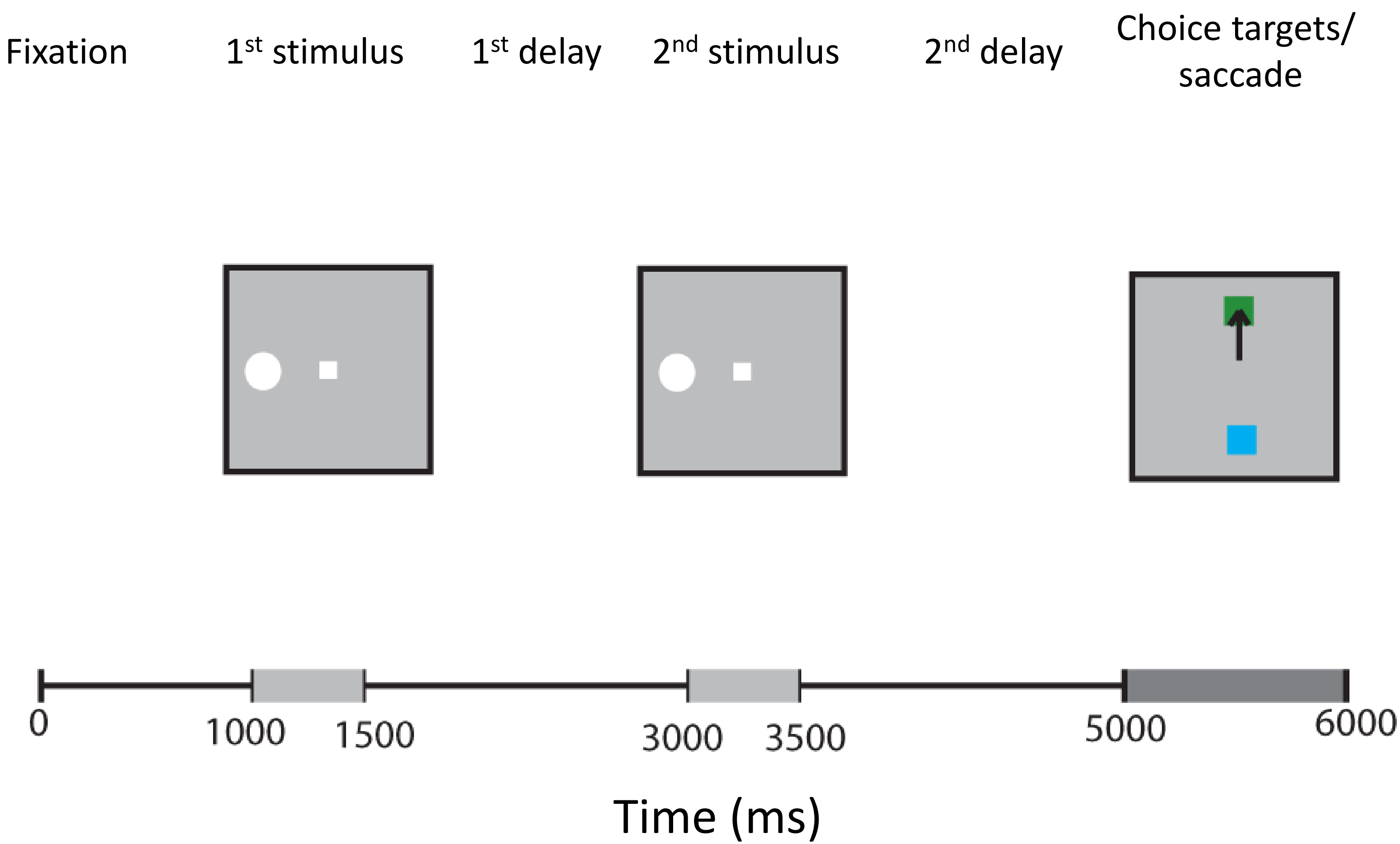
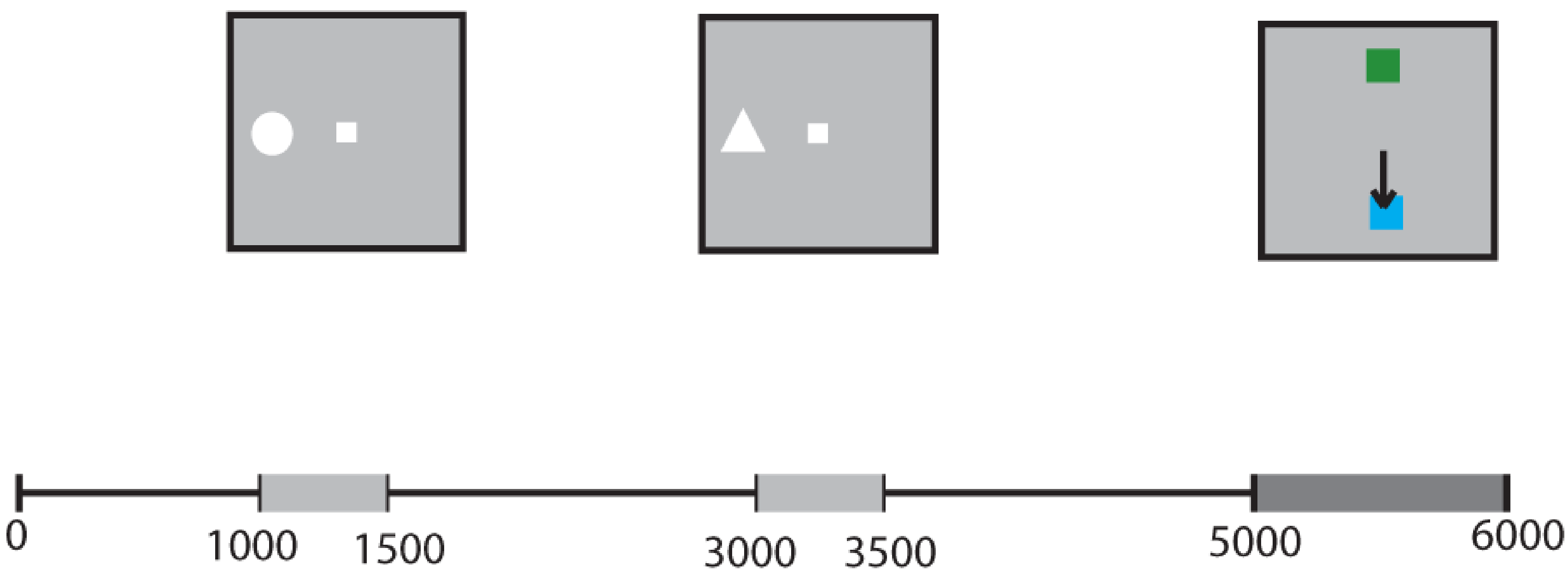


Monkeys then engaged in a delayed-match-to-sample task (DMS task)



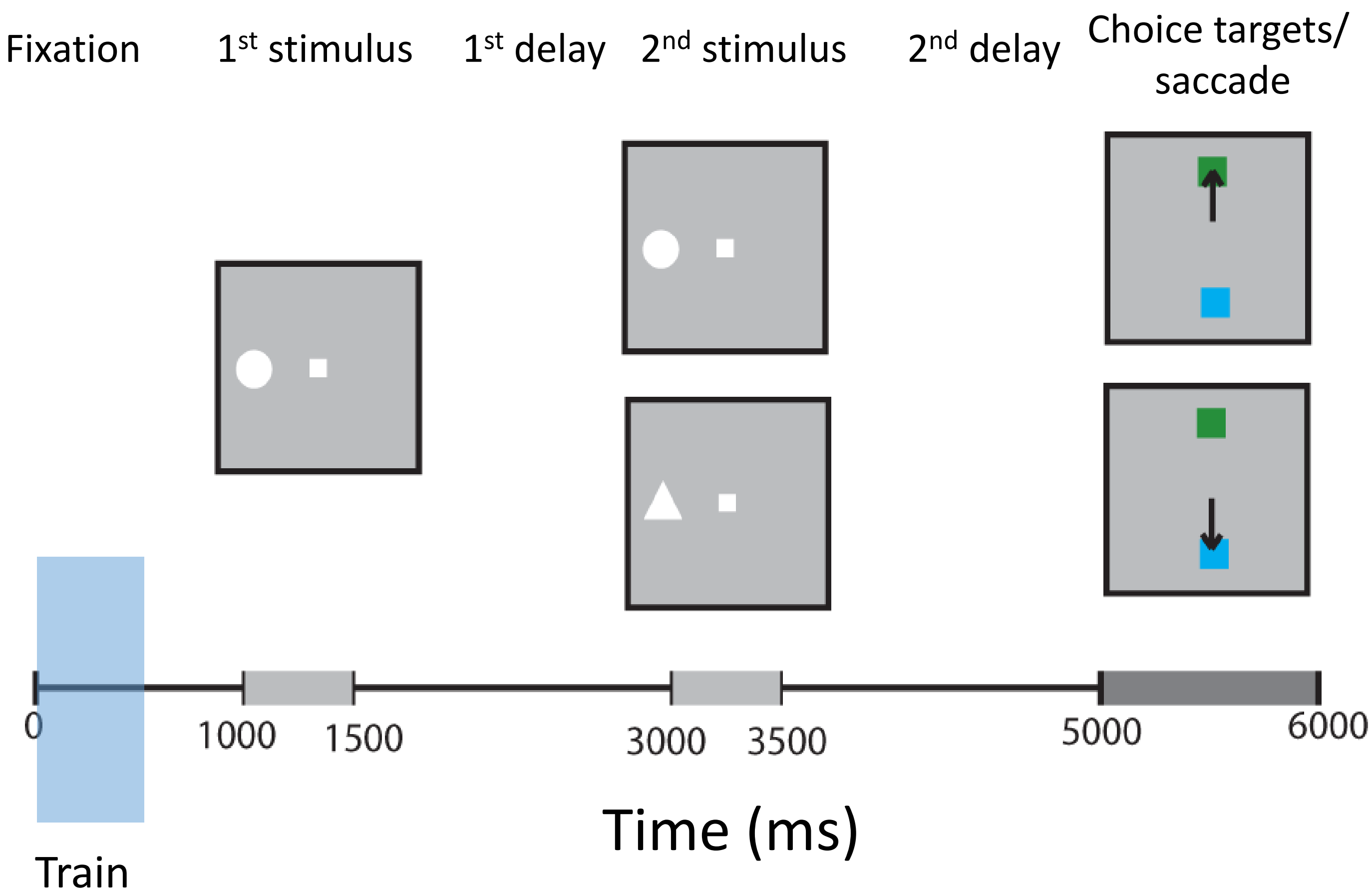
Monkeys then engaged in a delayed-match-to-sample task (DMS task)

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

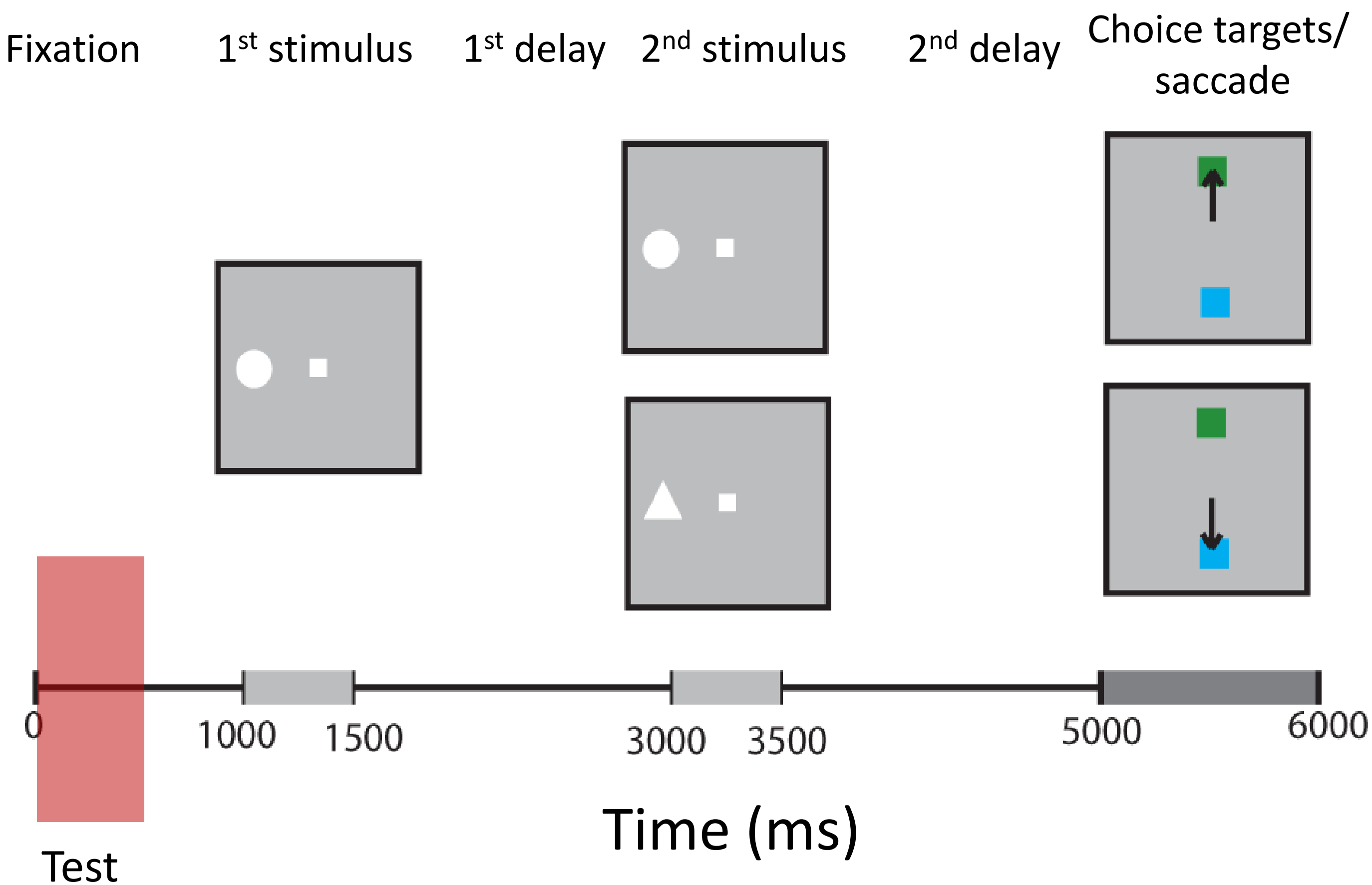


Time (ms)

Decoding applied

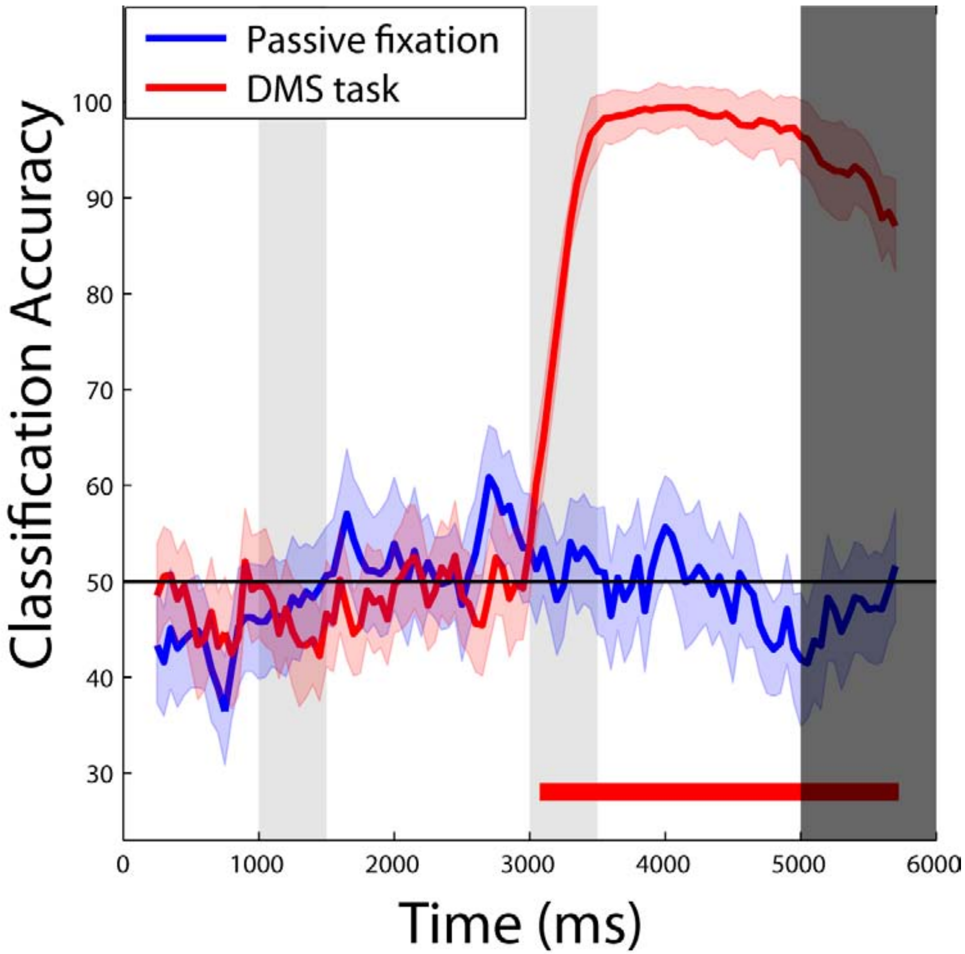


Decoding applied



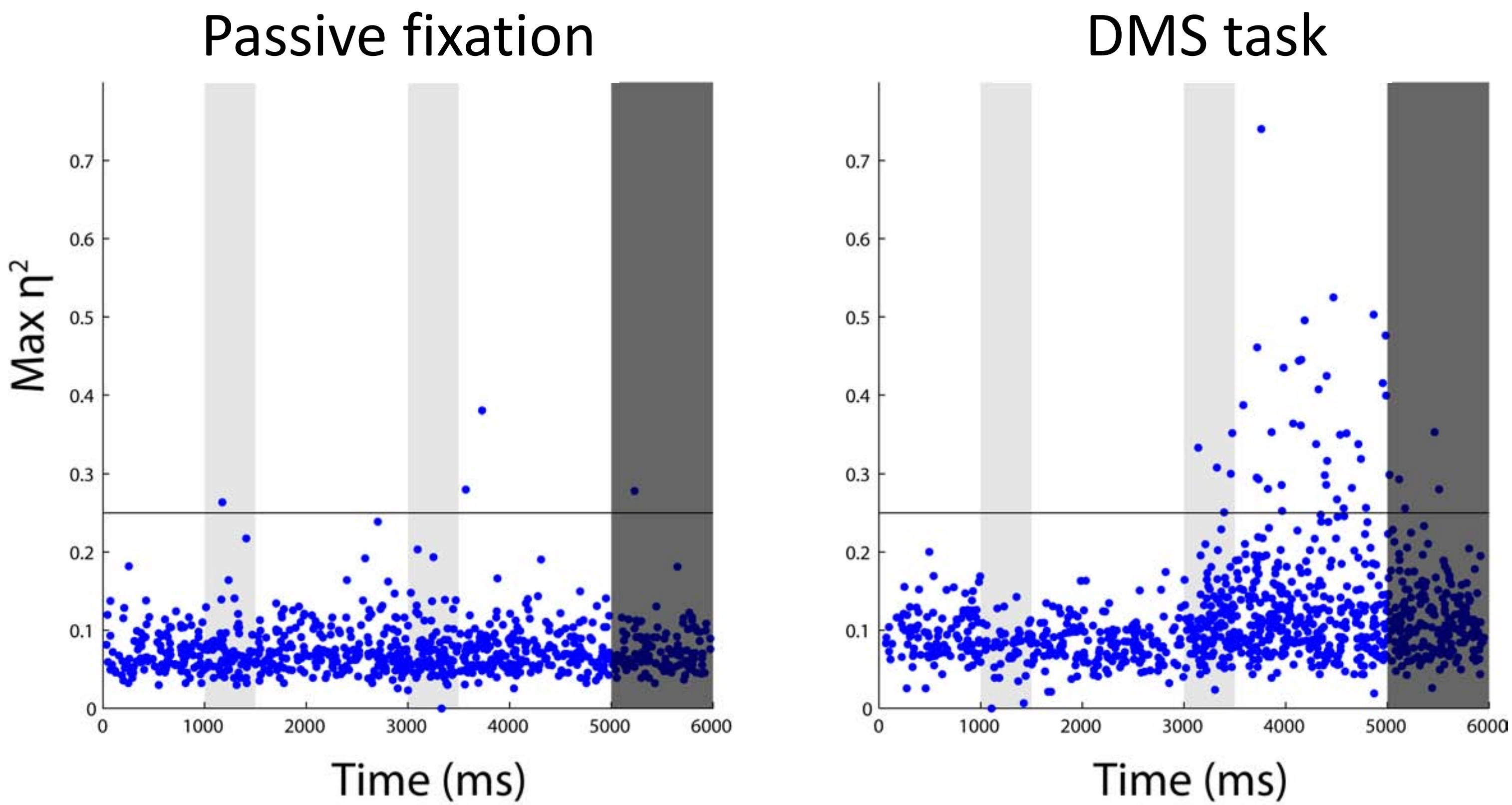
500 ms bins, sample every 50 ms
Decoding is based on 750 neurons

Decoding match/nonmatch information



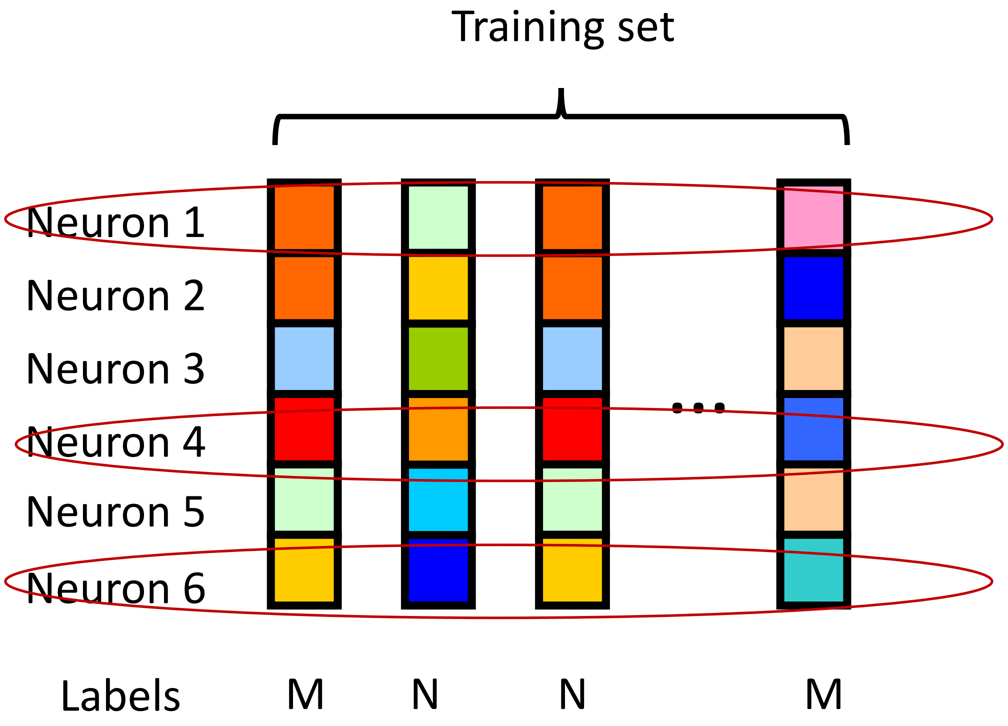
Source: Meyers, Ethan M., Xue-Lian Qi, and Christos Constantinidis. "Incorporation of new information into prefrontal cortical activity after learning working memory tasks." Proceedings of the National Academy of Sciences 109, no. 12 (2012): 4651-4656.

Is the new information widely distributed?



Source: Meyers, Ethan M., Xue-Lian Qi, and Christos Constantinidis. "Incorporation of new information into prefrontal cortical activity after learning working memory tasks." Proceedings of the National Academy of Sciences 109, no. 12 (2012): 4651-4656.

Compact/sparse coding of information



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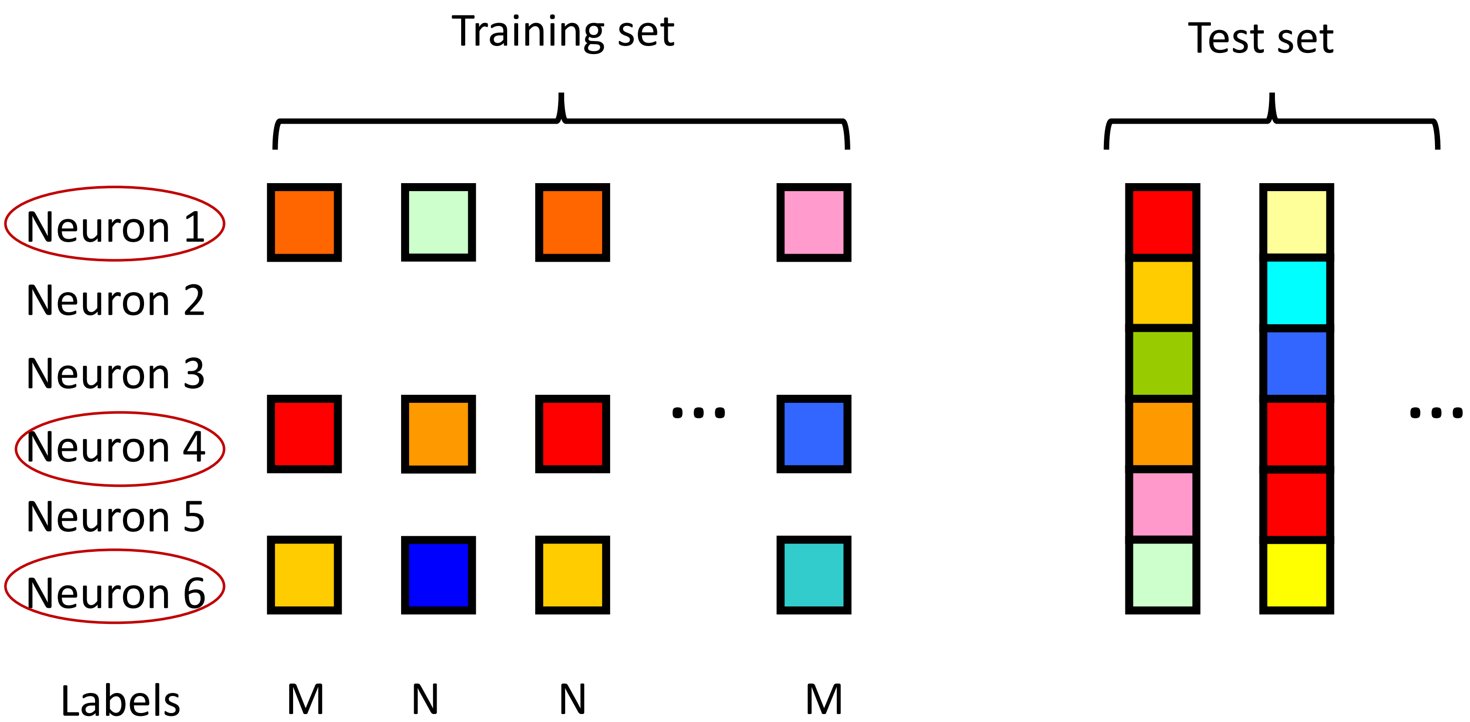
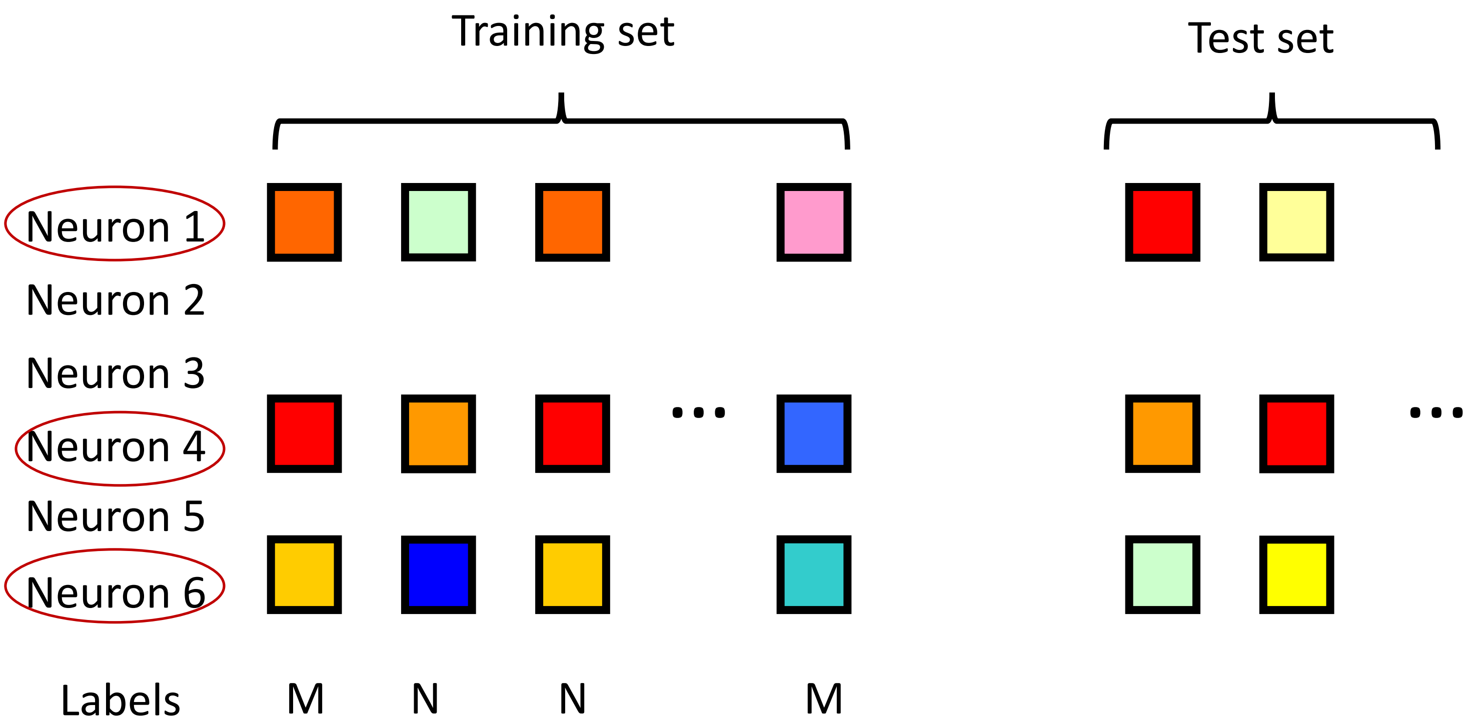
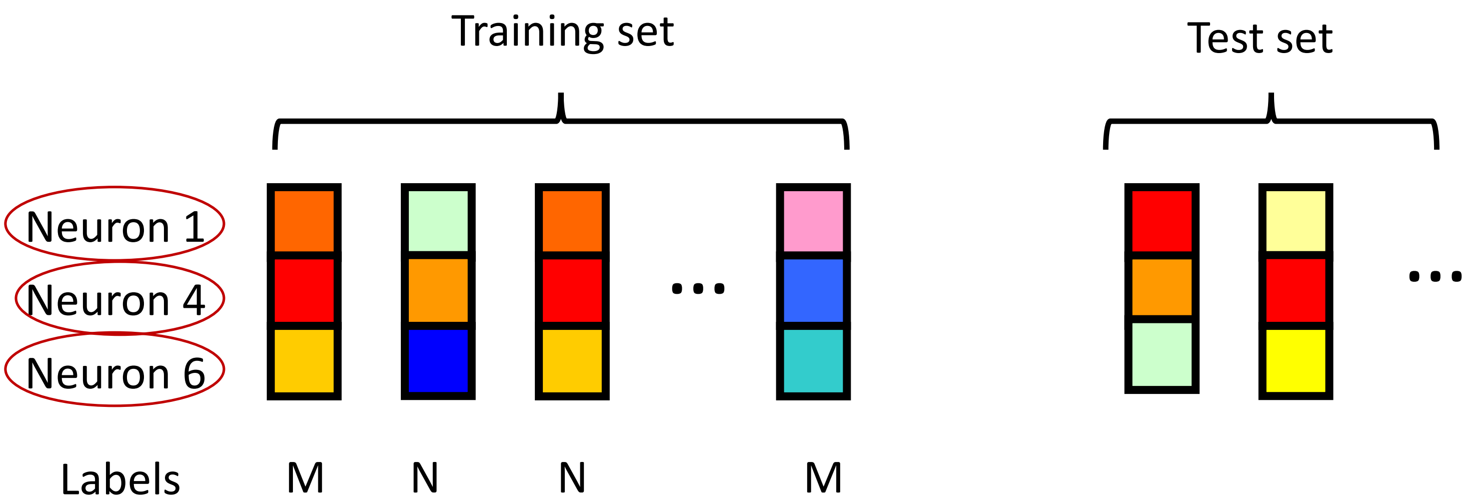


Compact/sparse coding of information

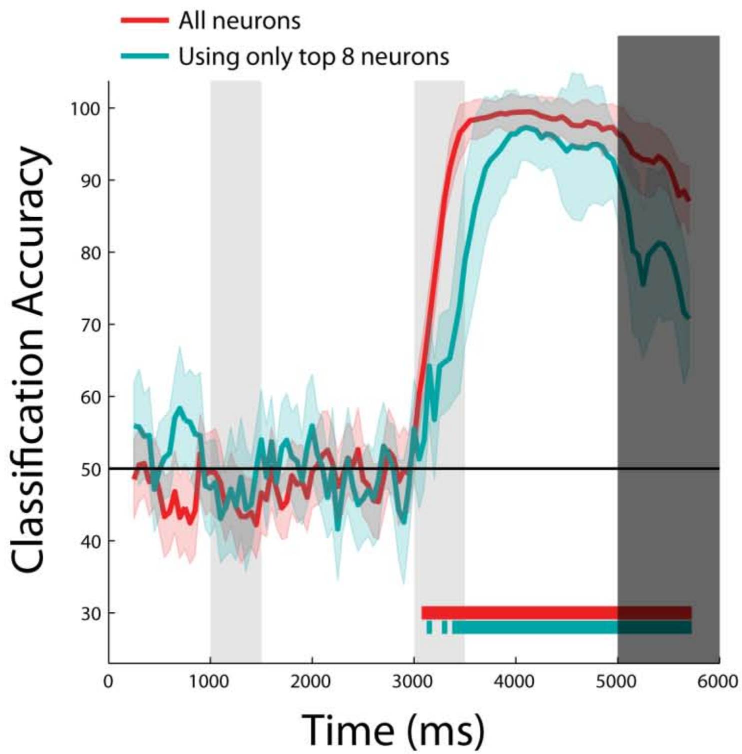


Compact/sparse coding of information

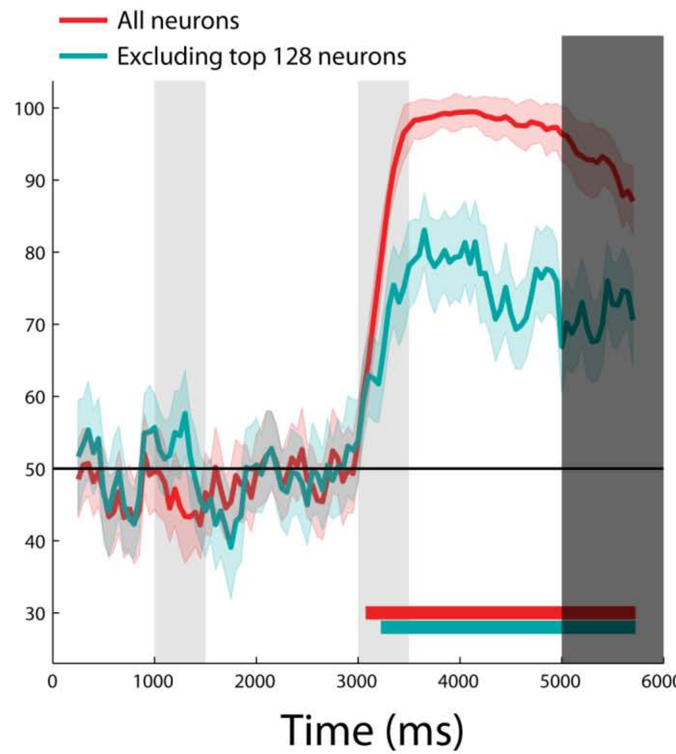


Is the new information widely distributed?

Using only the 8 most selective neurons

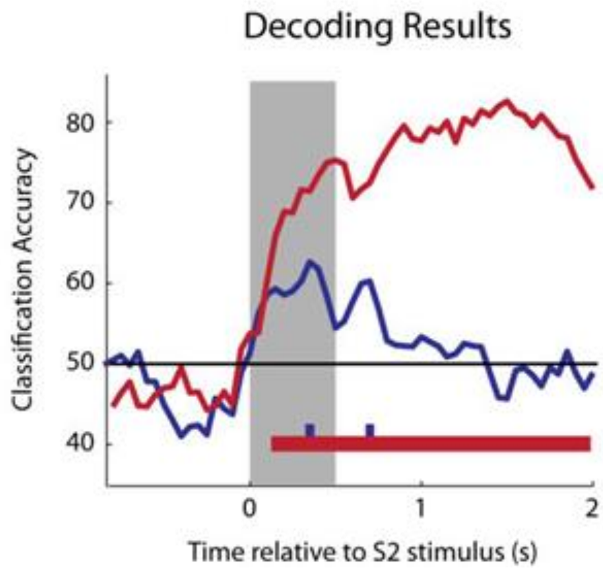


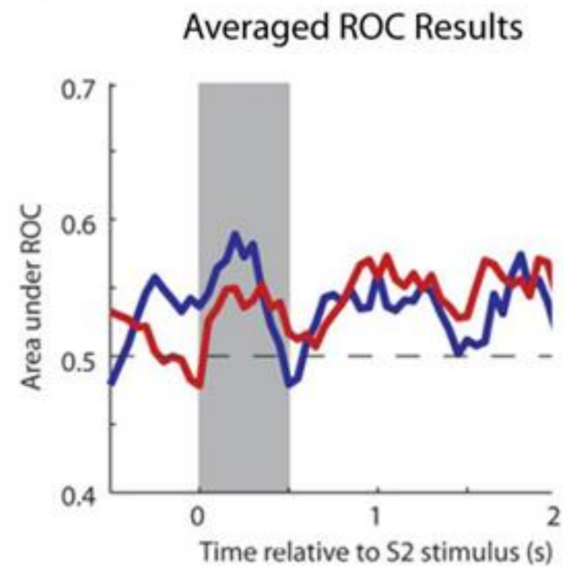
Excluding the 128 most selective neurons

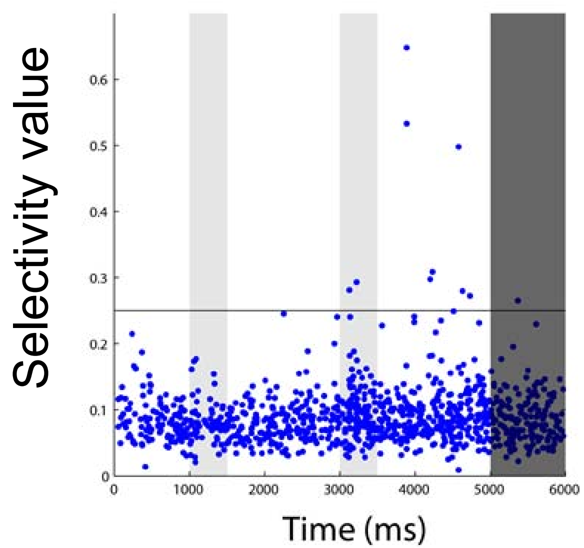


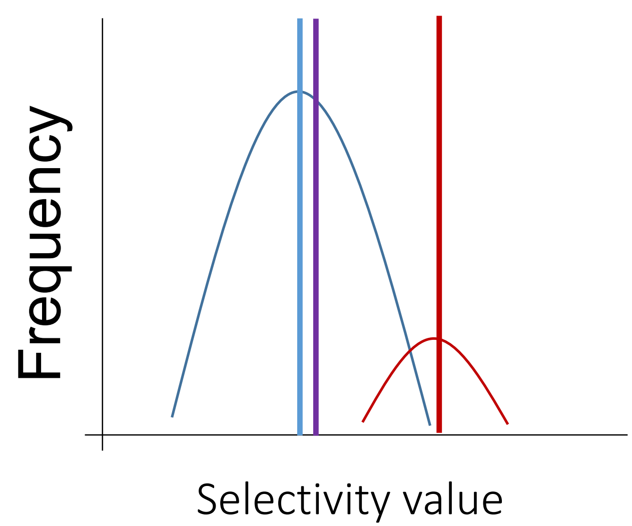
Source: Meyers, Ethan M., Xue-Lian Qi, and Christos Constantinidis. "Incorporation of new information into prefrontal cortical activity after learning working memory tasks." Proceedings of the National Academy of Sciences 109, no. 12 (2012): 4651-4656.

Implications for analyzing data

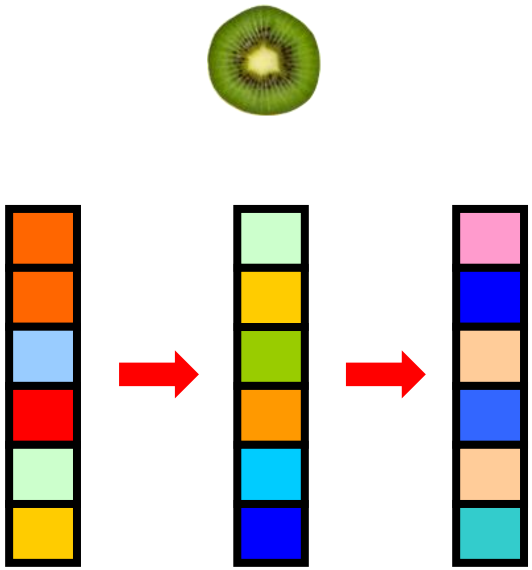




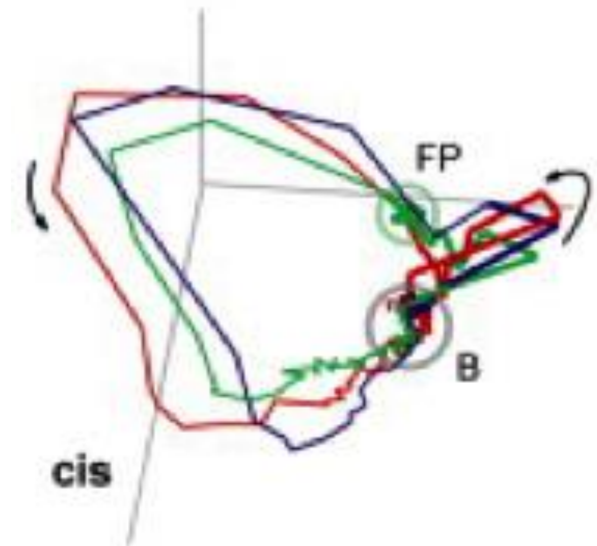




Is information contained in a dynamic population code?



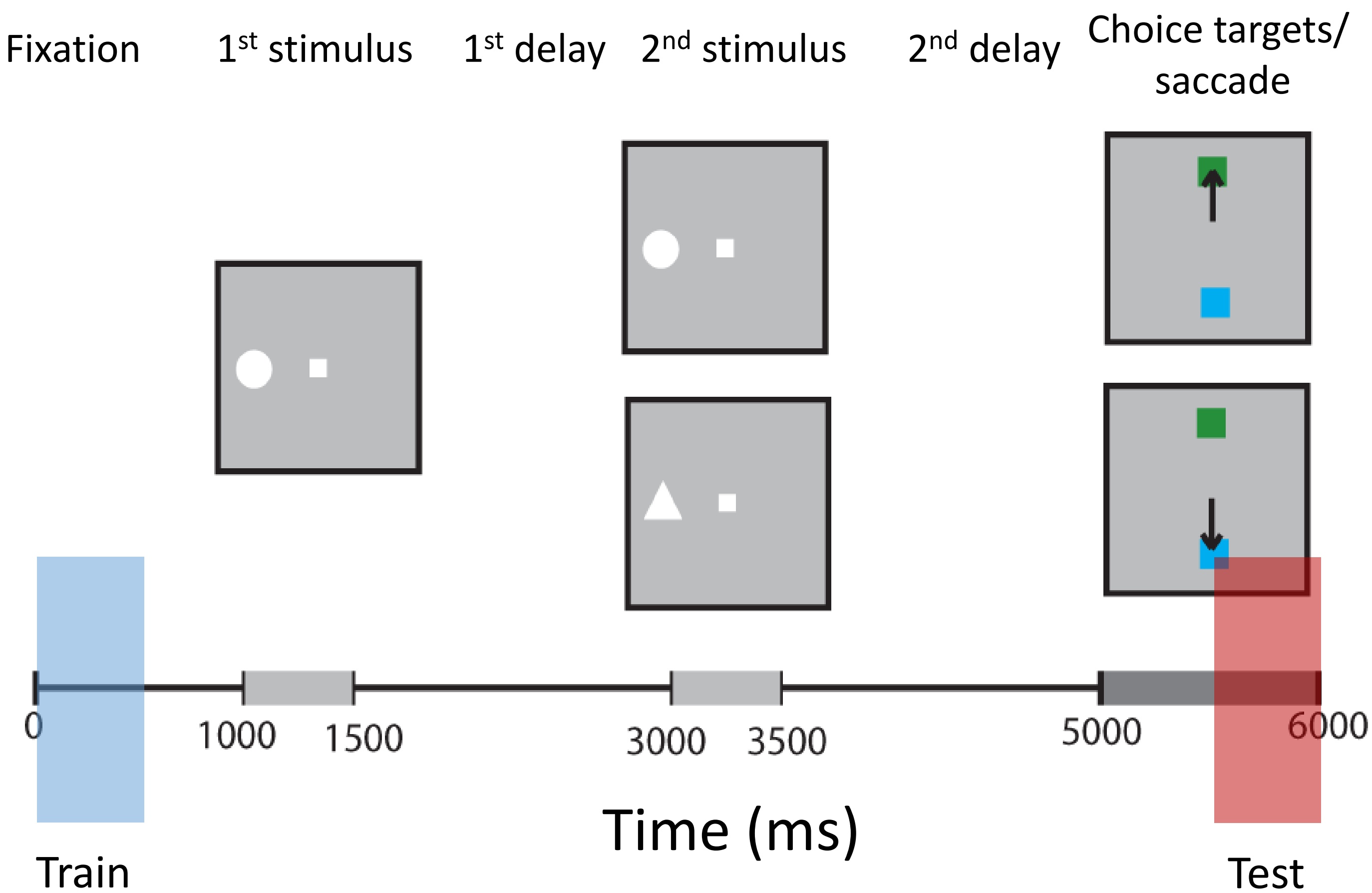
Time



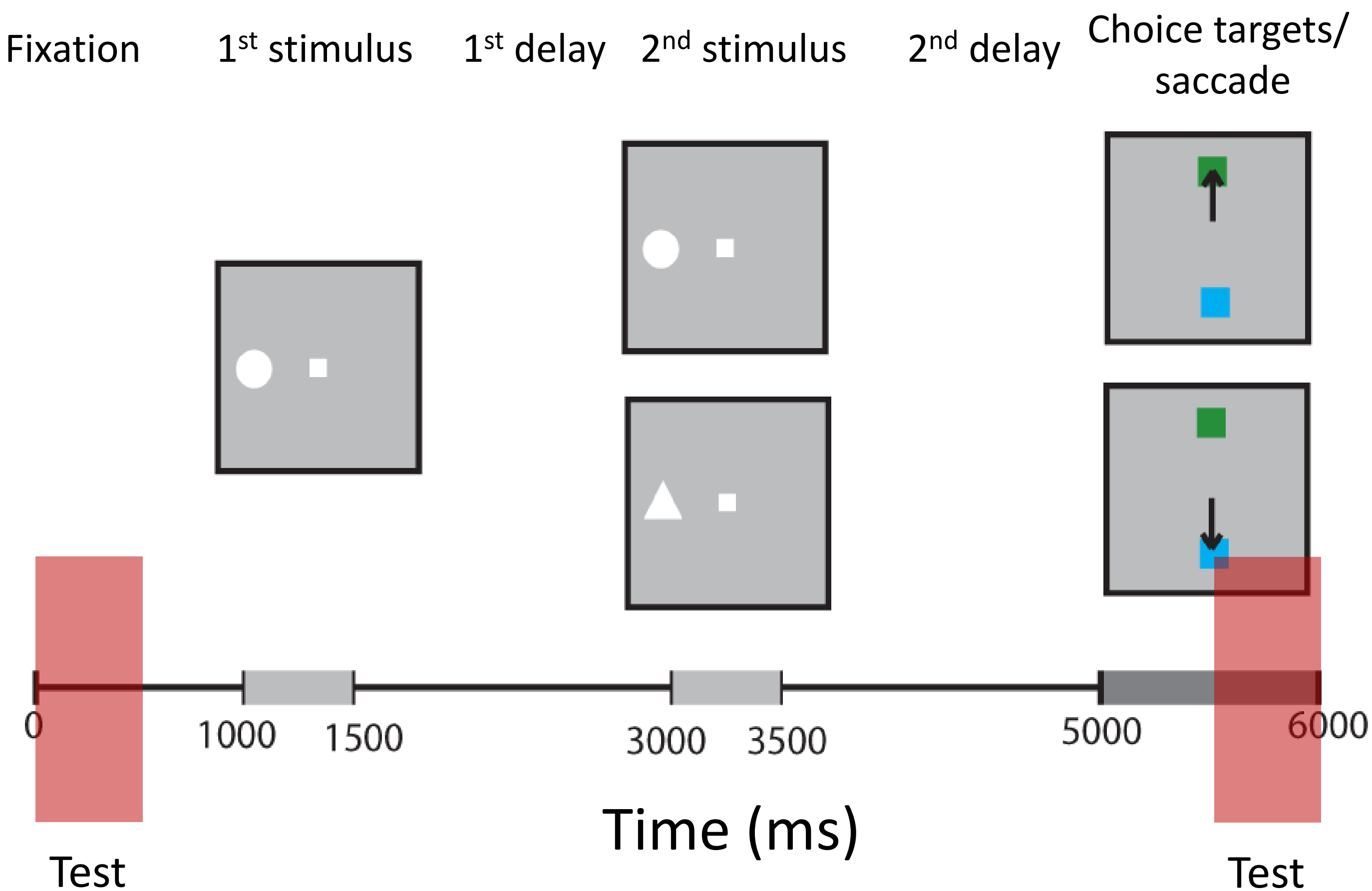
Source: Mazor, Ofer, and Gilles Laurent. "Transient dynamics versus fixed points in odor representations by locust antennal lobe projection neurons." Neuron 48, no. 4 (2005): 661-673.

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

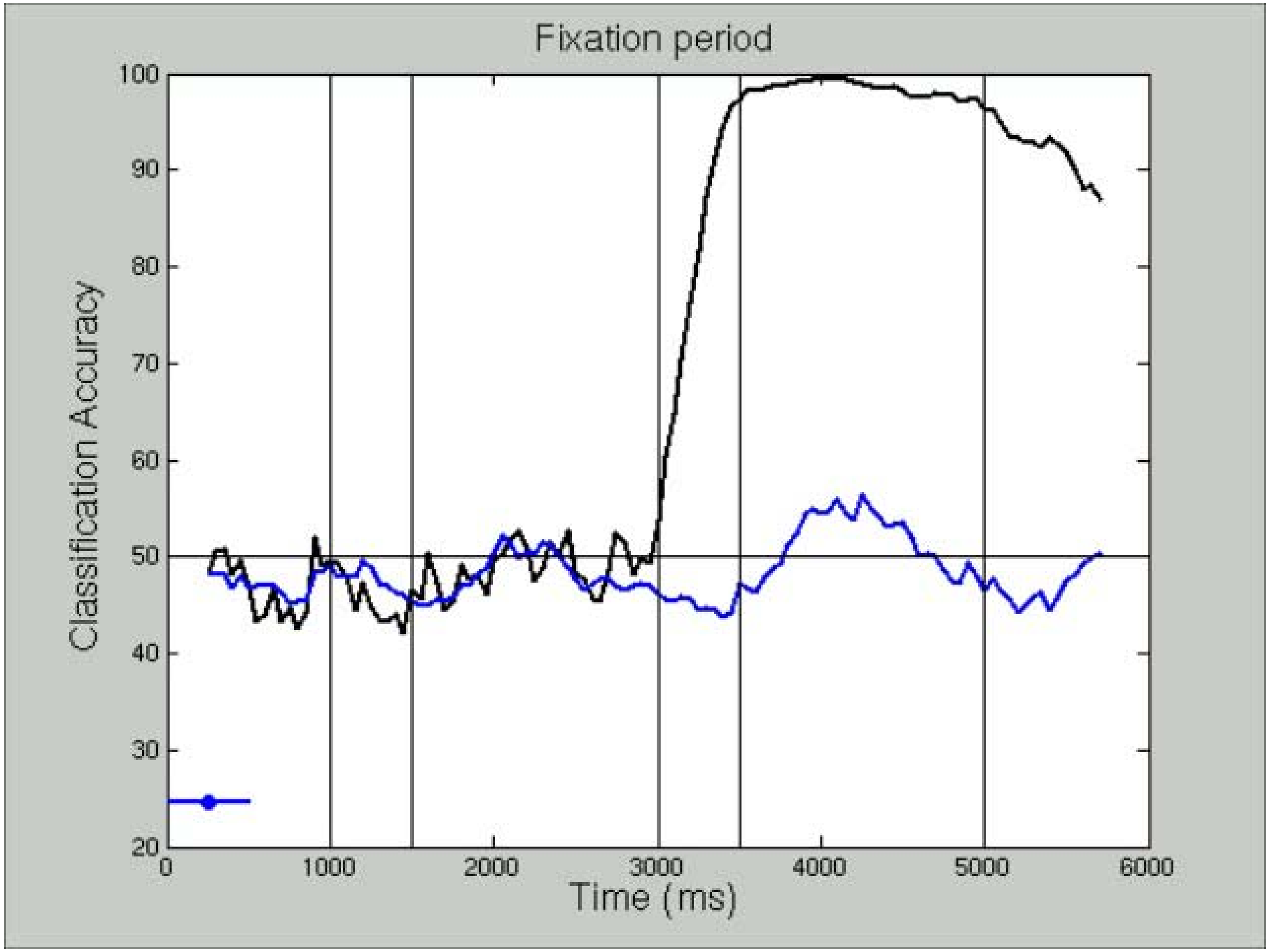
Decoding applied



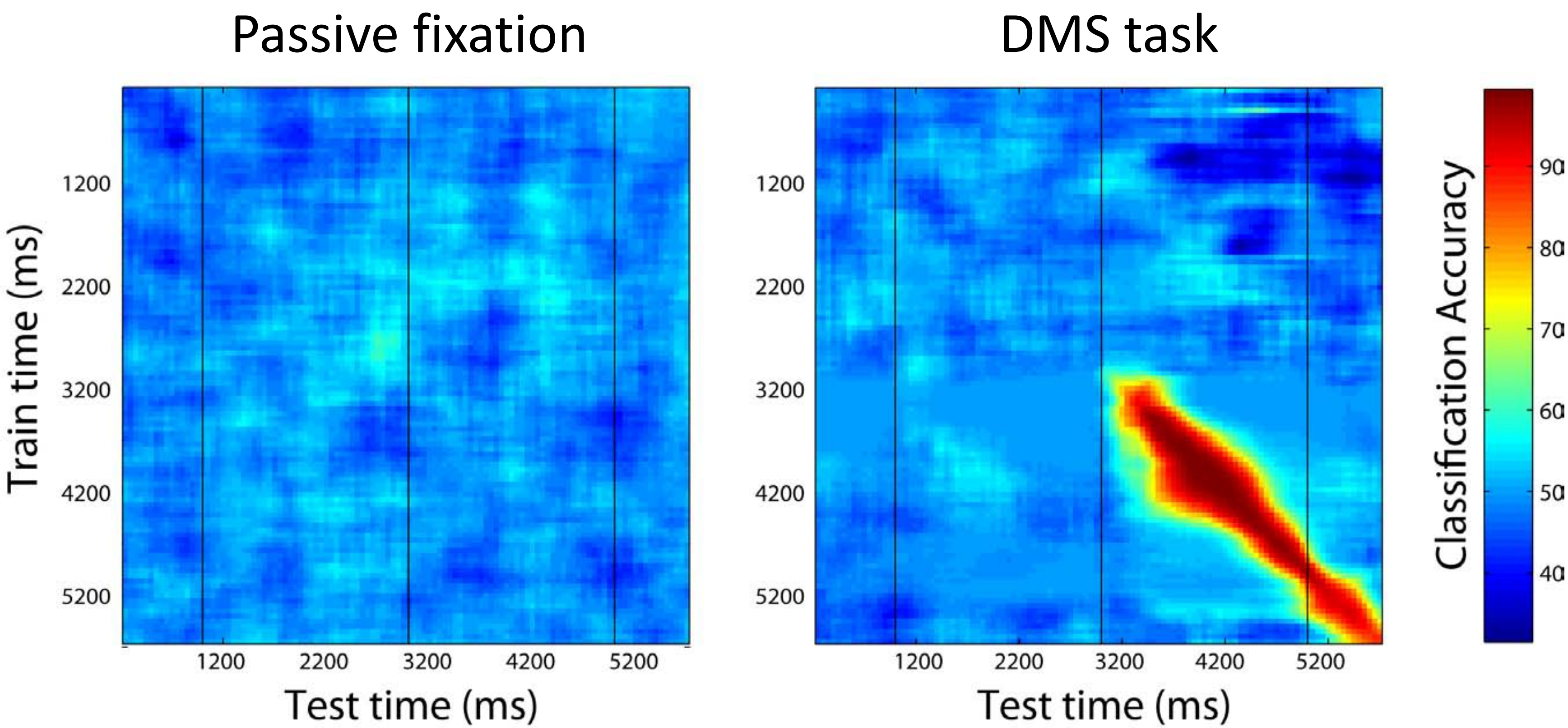
Decoding applied



Dynamic population coding



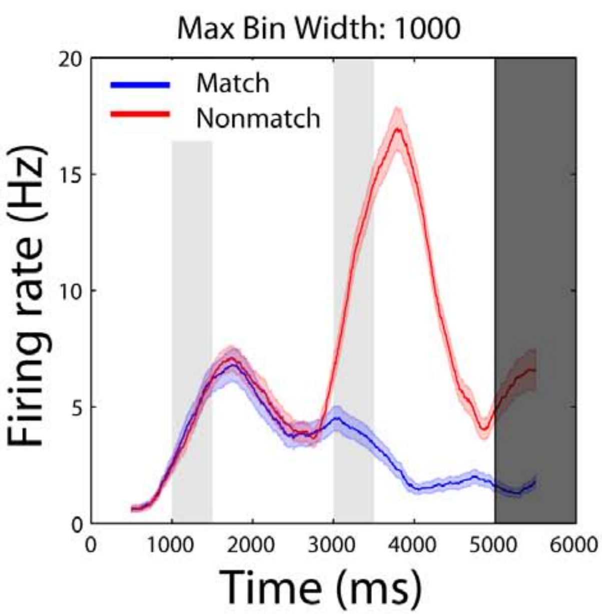
Dynamic population coding



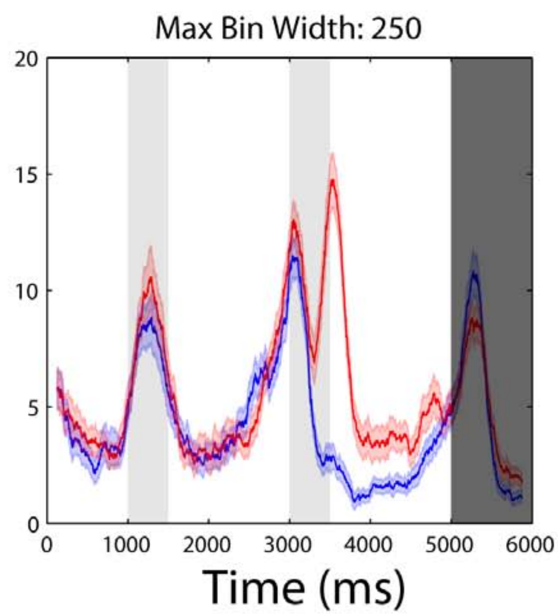
Courtesy of Proceedings of the National Academy of Sciences. Used with permission.
Source: Meyers, Ethan M., Xue-Lian Qi, and Christos Constantinidis. "Incorporation of new information into prefrontal cortical activity after learning working memory tasks." Proceedings of the National Academy of Sciences 109, no. 12 (2012): 4651-4656.

The dynamics can be seen in individual neurons

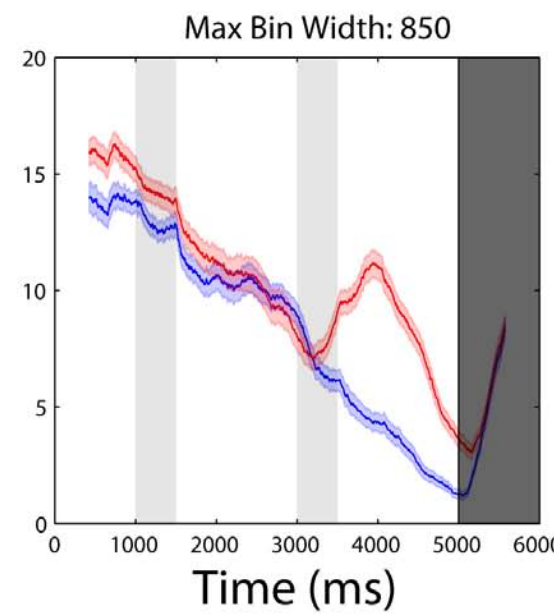
Neuron 1



Neuron 2



Neuron 3



Source: Meyers, Ethan M., Xue-Lian Qi, and Christos Constantinidis. "Incorporation of new information into prefrontal cortical activity after learning working memory tasks." Proceedings of the National Academy of Sciences 109, no. 12 (2012): 4651-4656.

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

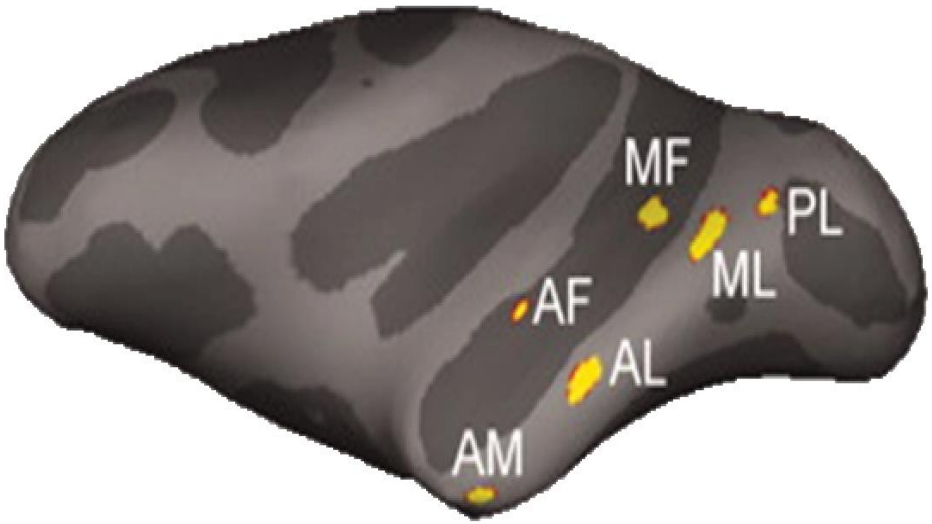
$$\arg\max_c \ |\overline{w}_c - \overline{x}|$$

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

$\mathbf{x}$ is the test point to be classifier

Is information coded in high firing rates or patterns?

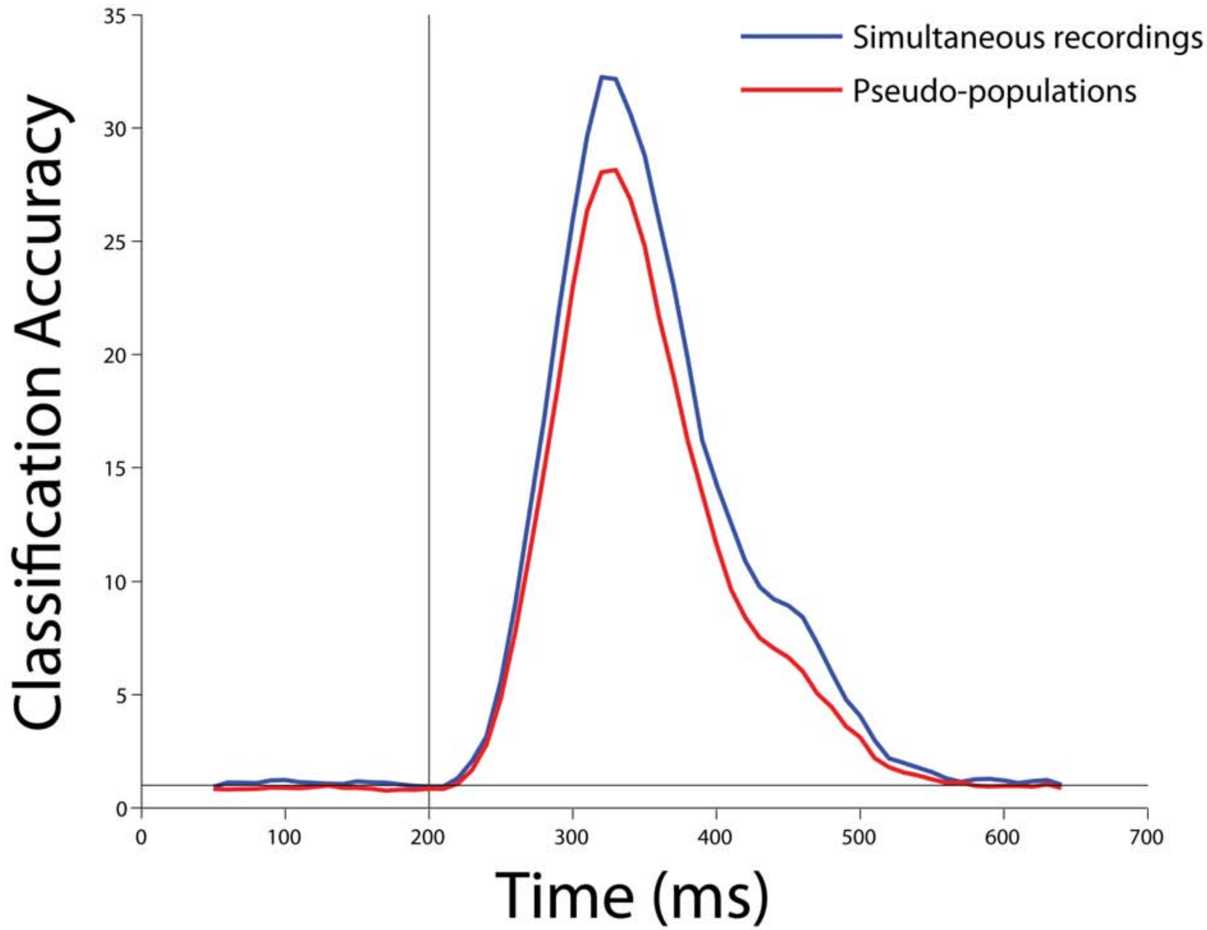
Pose specific face identification



Poisson Naïve Bayes – Total activity and pattern
Minimum Angle – Pattern only
Total Population Activity - Total activity only

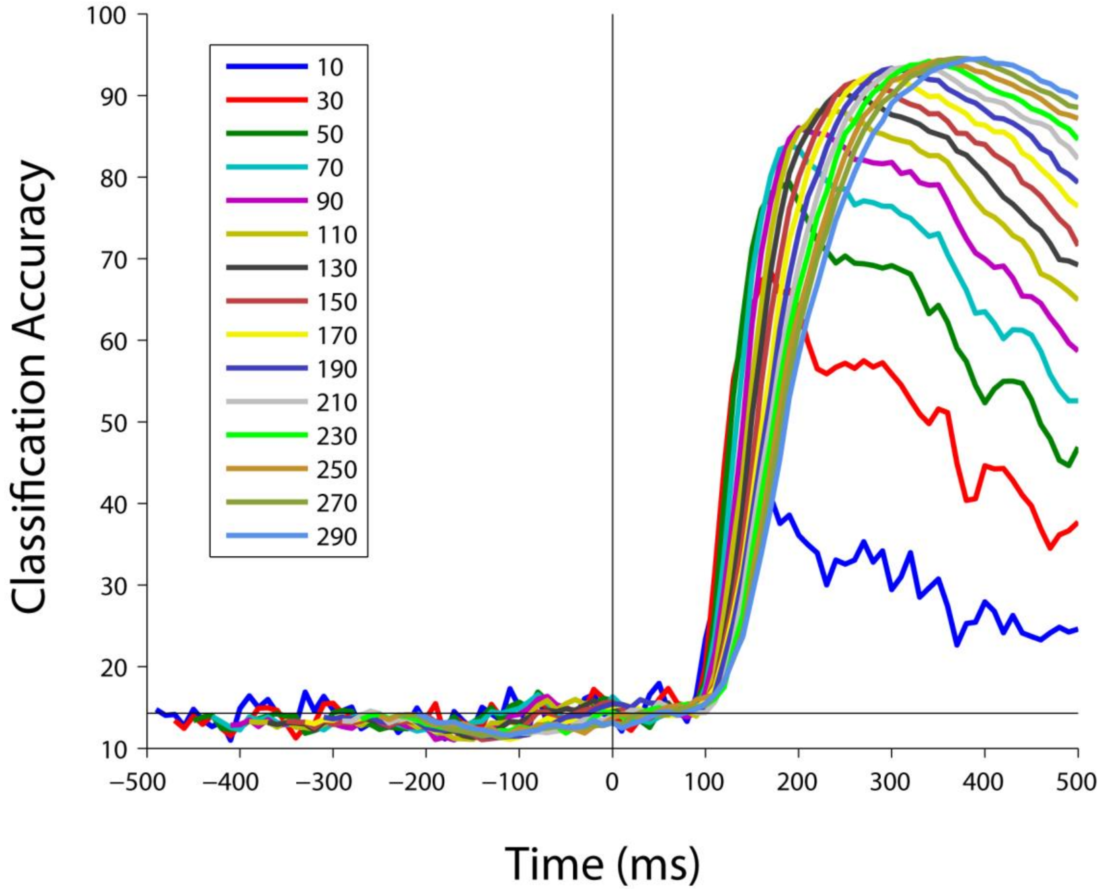
Meyers, Borzello, Freiwald, Tsao, 2015

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

Figure removed due to copyright restrictions. Please see the video.
Source: Figure 2, Isik, Leyla, Ethan M. Meyers, Joel Z. Leibo, and Tomaso Poggio. "The dynamics of invariant object recognition in the human visual system." Journal of neurophysiology 111, no. 1 (2014): 91-102.

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:

```
binned_file = 'Binned_data.mat';
ds = basic_DS(binned_file, 'stimulus_ID', 20);
cl = max_correlation_coefficient_CL;
fps{1} = zscore_normalize_FP;
cv = standard_resample_CV(ds, cl, fps)
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

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Meyers, Front Neuroinfo, 2013

The Neural Decoding Toolbox Design

<u>Toolbox design: 4 abstract classes</u>

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'

Figure removed due to copyright restrictions. Please see the video or Figure 3 from Meyers, Ethan M. "The neural decoding toolbox." Frontiers in neuroinformatics 7 (2013).

Questions?

Funding: The Center for Brains, Minds and Machines, NSF STC award CCF-1231216

Acknowledgements:

Narcisse Bichot, Mia Borzello, Christos Constantinidis, Jennie Deutsch, Jim DiCarlo, Robert Desimone, David Freedman, Winrich Freiwald, Leyla Isik, Gabriel Kreiman, Andy Leung, Joel Liebo, Earl Miller, Ami Patel, Tomaso Poggio, Xue-Lian Qi, Doris Tsao, Ying Zhang

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