Lectures 9 + 10: Discrete Classification

- Reading assignment:

  - Required (uploaded to CCLE):

    - PRML p. 38–46: Decision Theory
    - PRML p. 179–184, 196–203: Linear Models for Classification
    - Santhanam G*, Ryu SI*, Yu BM, Afshar A, Shenoy KV (2006) A high-performance brain-computer interface. *Nature*. 442:195-198.

- Optional (uploaded to CCLE):

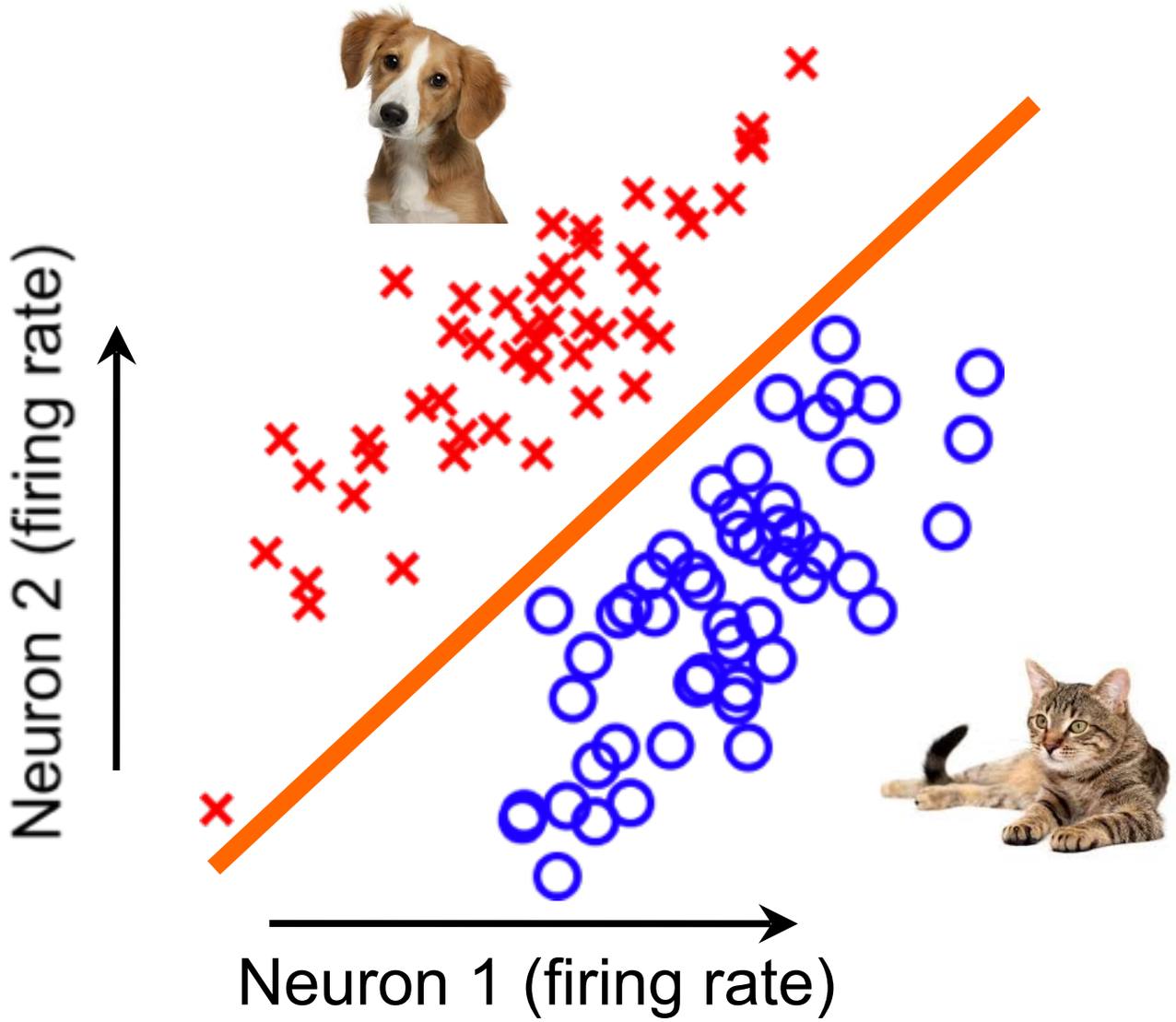
  - Achtman N*, Afshar A*, Santhanam G, Yu BM, Ryu SI, Shenoy KV (2007) Free-paced high-performance brain-computer interfaces. *Journal of Neural Engineering*. 4:336-347.

  - Santhanam G, Yu BM, Gilja V, Afshar A, Ryu SI, Sahani M, Shenoy KV (2009) Factor-analysis methods for higher-performance neural prostheses. *Journal of Neurophysiology*. 102:1315-1330.

Visual system

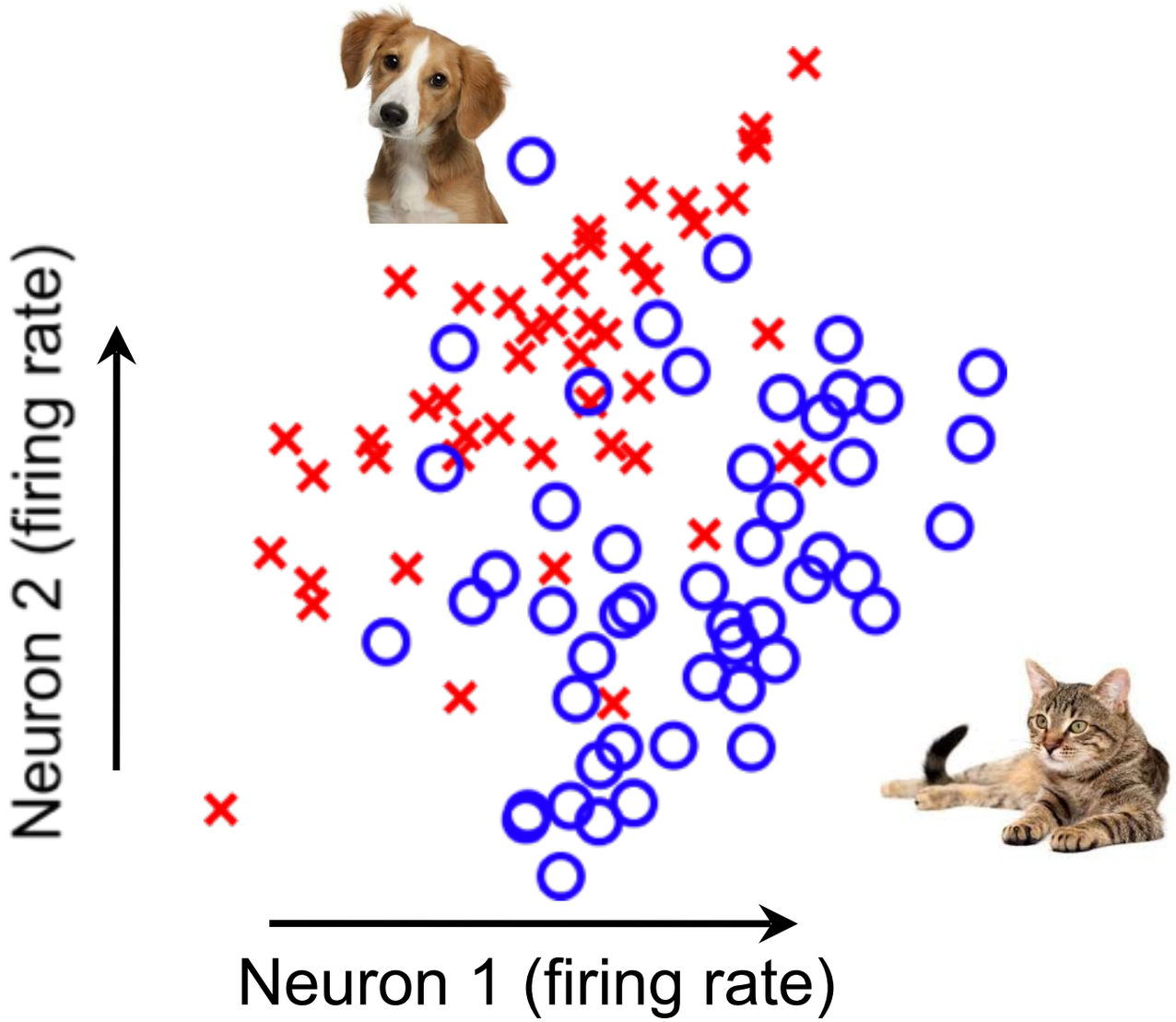
vs.

Classifying neural responses



Given only red and blue points, how do we set the decision boundary?

Classifying neural responses



In general, data won't be *linearly separable*.

Olfactory system

VS.

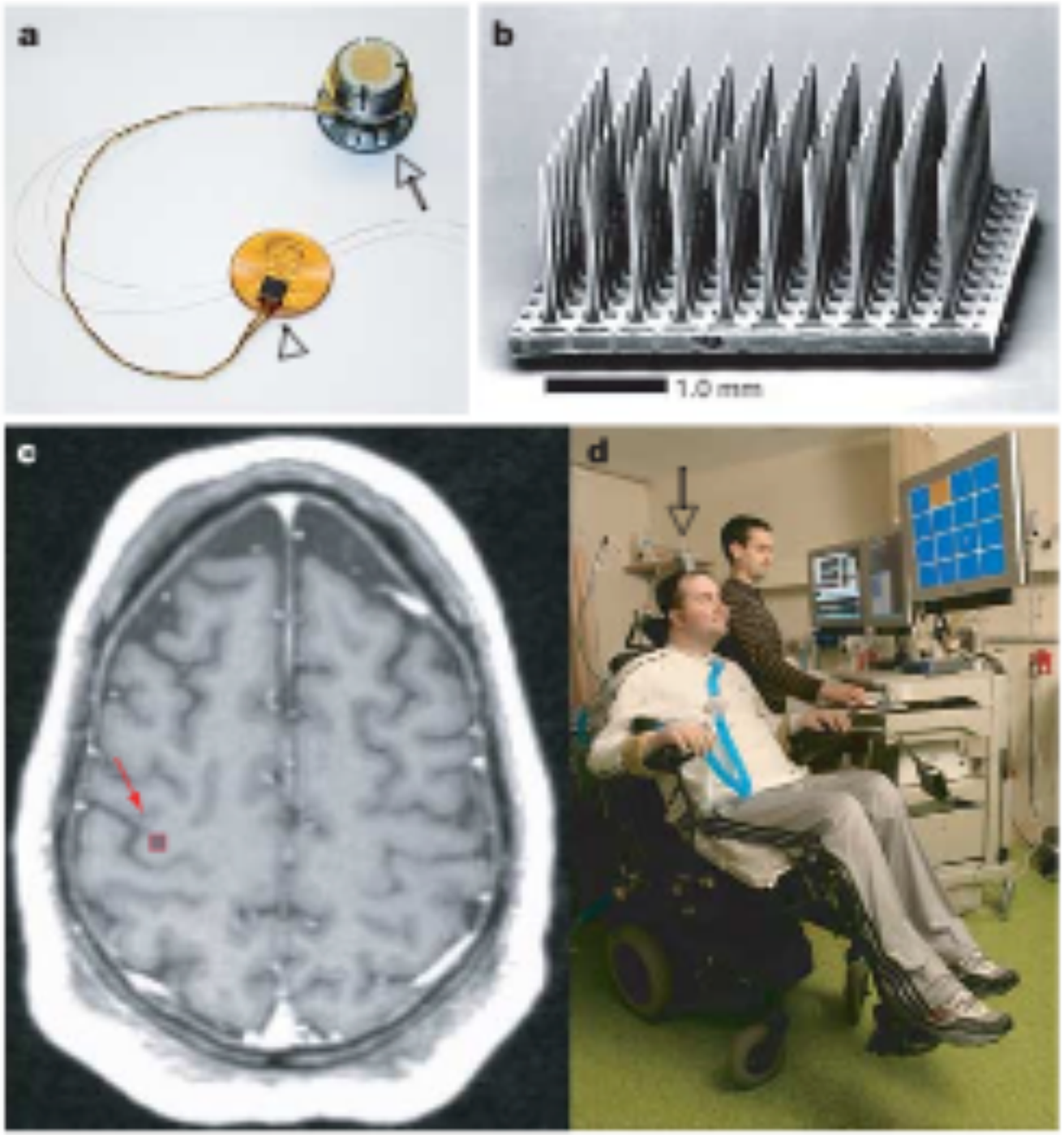
Auditory system

vs.

Motor system

Classifying such neural responses can be used to help human patients.

Neural communication prostheses



Hochberg et al., *Nature*, 2006.

Email	TV	Music
Lights		Wheel chair
Heater	Window	Food

Patient's workspace

Neural communication prostheses

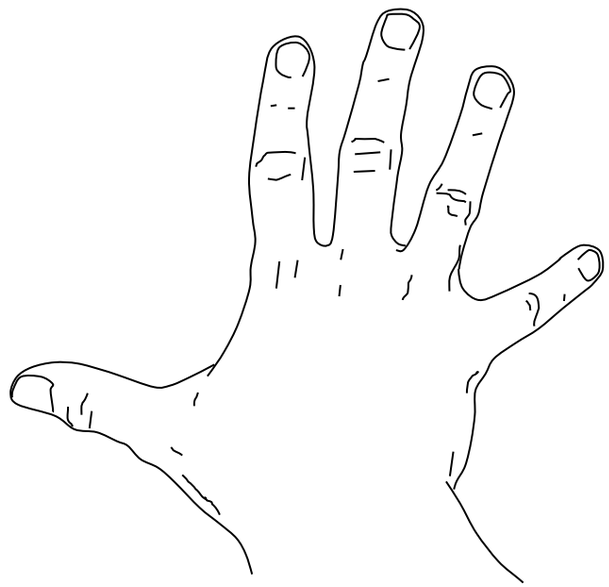
- These systems are usually based on arm movement intentions. I.e., think reach to the right => move cursor to the right

- Look at the subject's neural activity and decide where to place the cursor (at one of *K* possible locations).

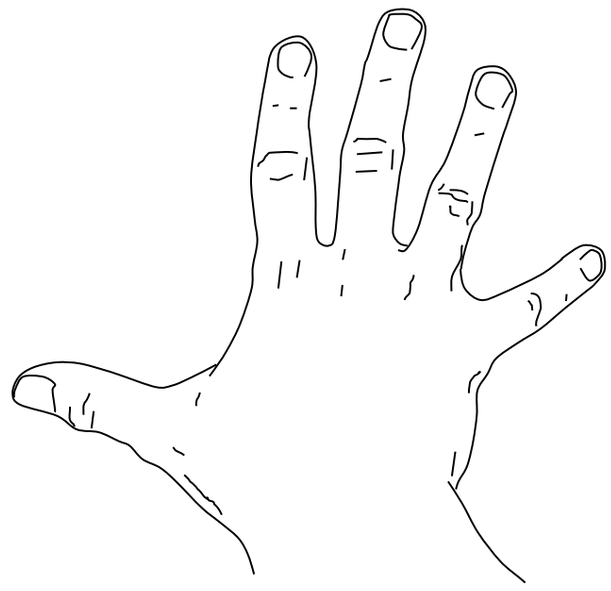
- Like typing on a keyboard.

- This is a classification problem!

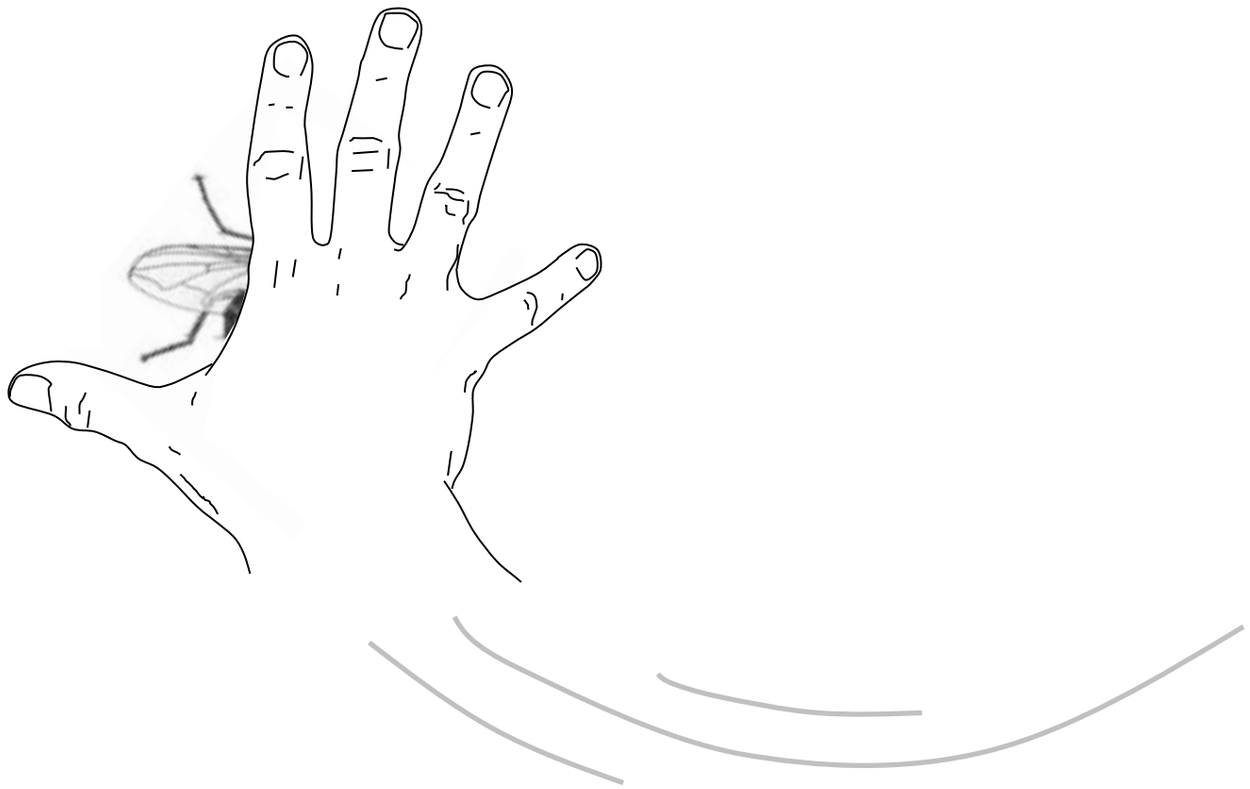
Motor planning



Motor planning



Motor planning



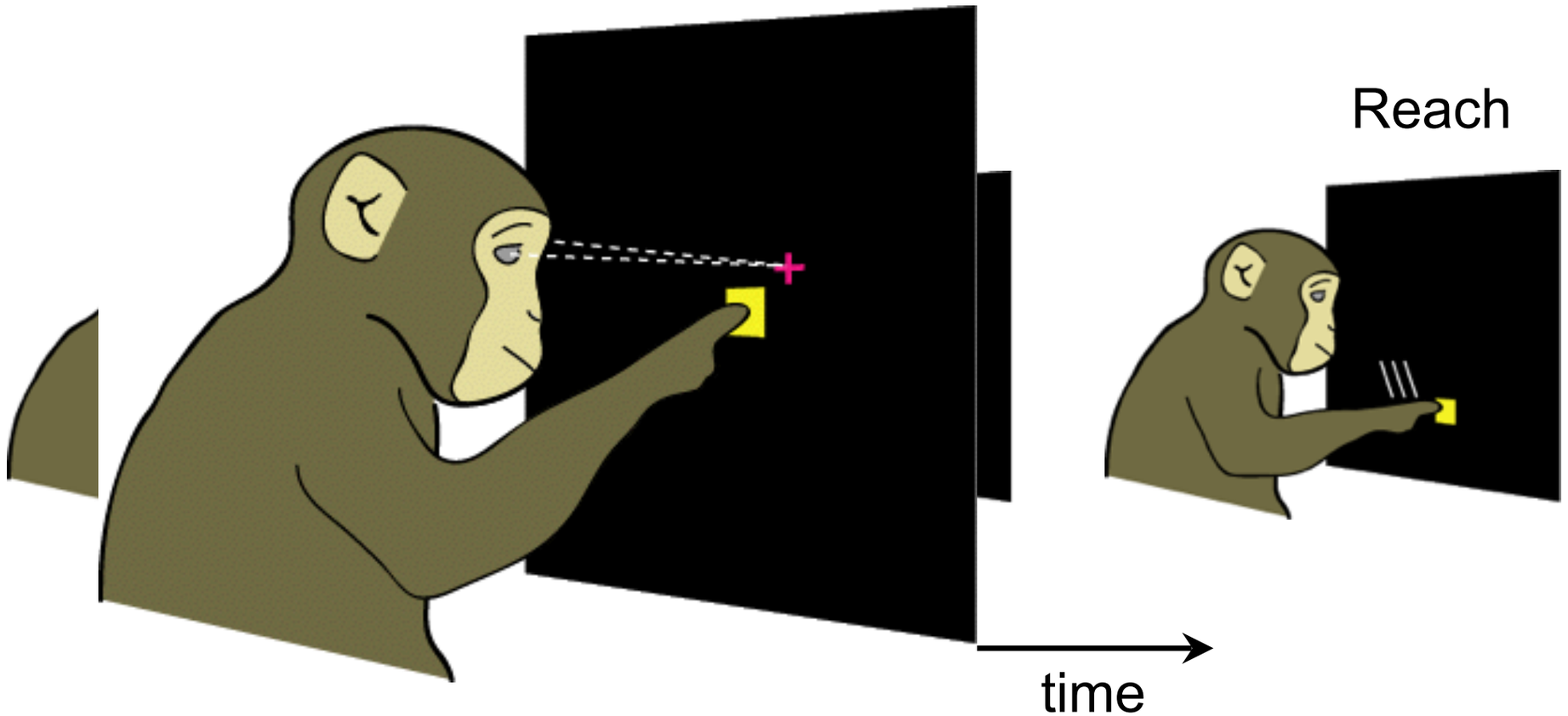
Plan and Movement Neural Activity

- Two types of neural activity are well suited for driving prosthetic movements

- **Plan activity**
  - Present before arm movements begin, or even without an eventual movement
  - Reflect preparatory processing, required for fast and accurate movements
  - Tuned for direction, distance, and speed of upcoming arm movement
  - Found in neurons in Parietal Reach Region (PRR) and dorsal aspect of premotor cortex (PMd); some in primary motor cortex (M1)

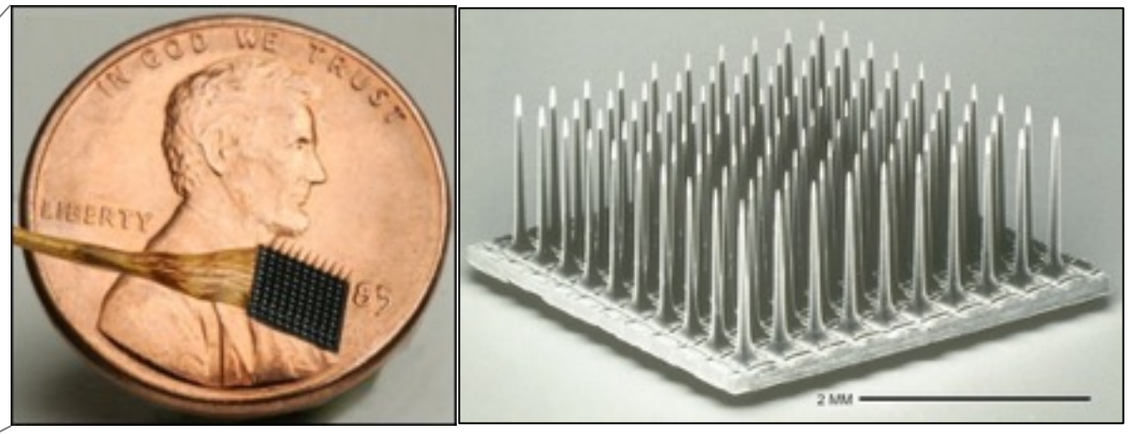
- **Movement activity**
  - Follows plan activity in a “delayed reach task”, and any movement
  - Present 100-200ms before and during the movement
  - Tuned for direction and speed of arm movement
  - Found in M1 and PMd; some in PRR

Delayed reach task

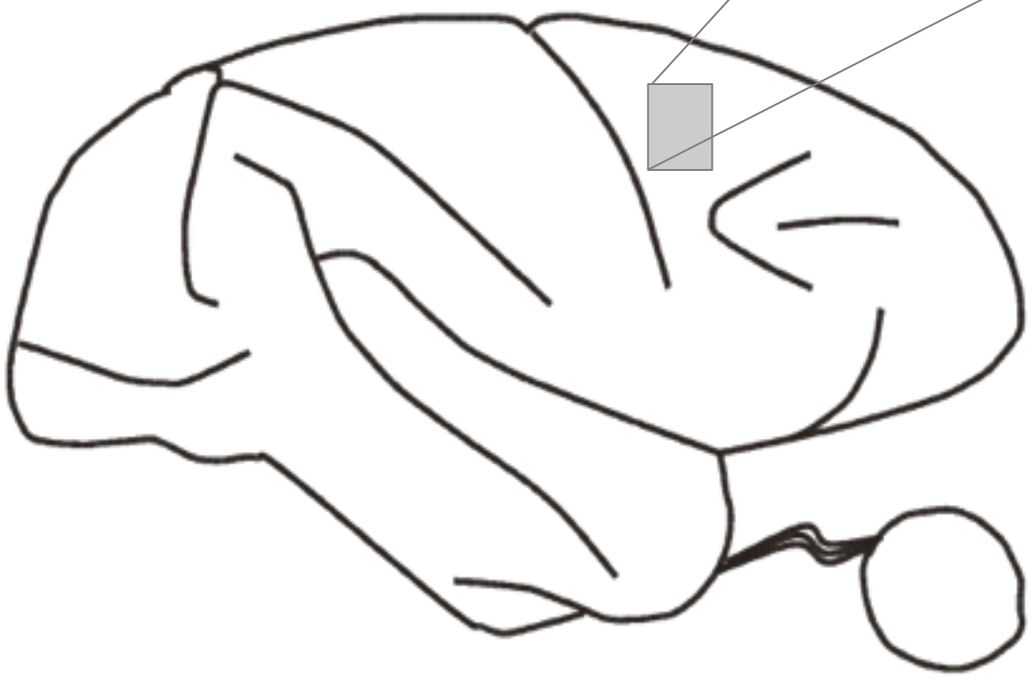


Delayed reach task

Recordings in premotor cortex

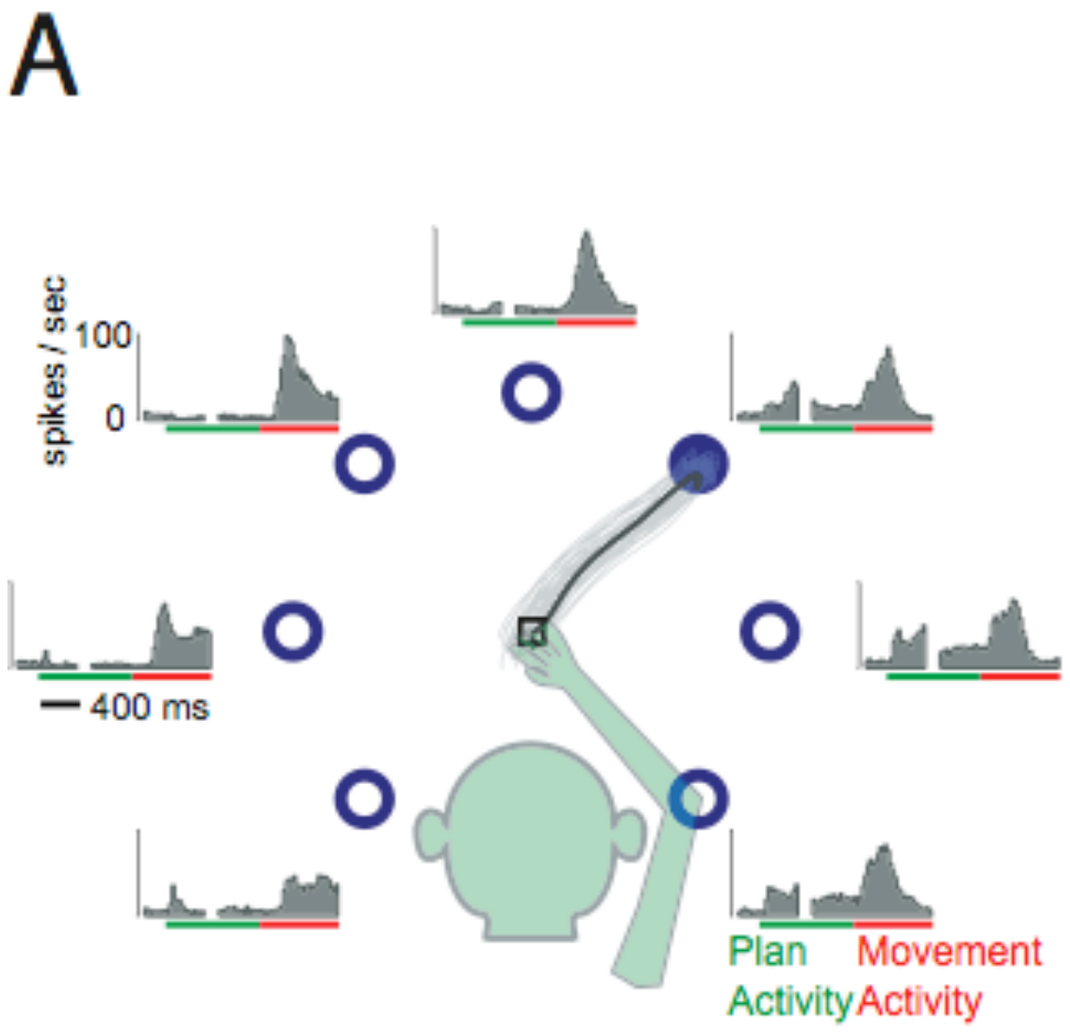


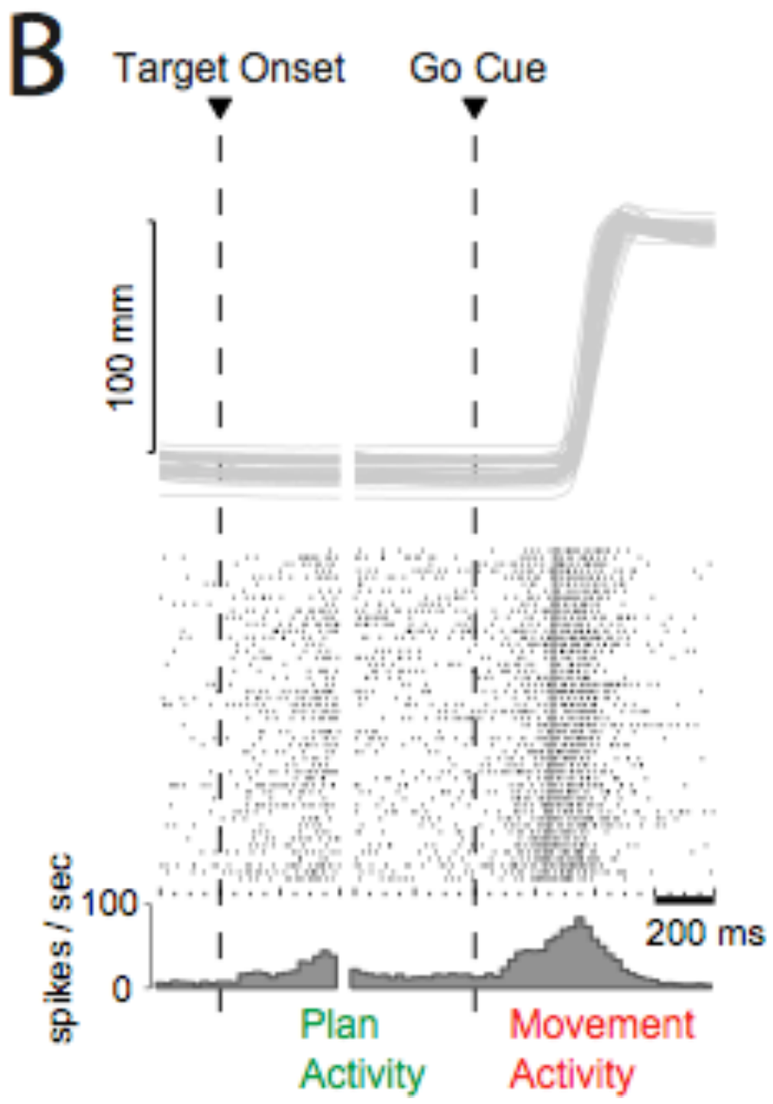
Utah 96-electrode array



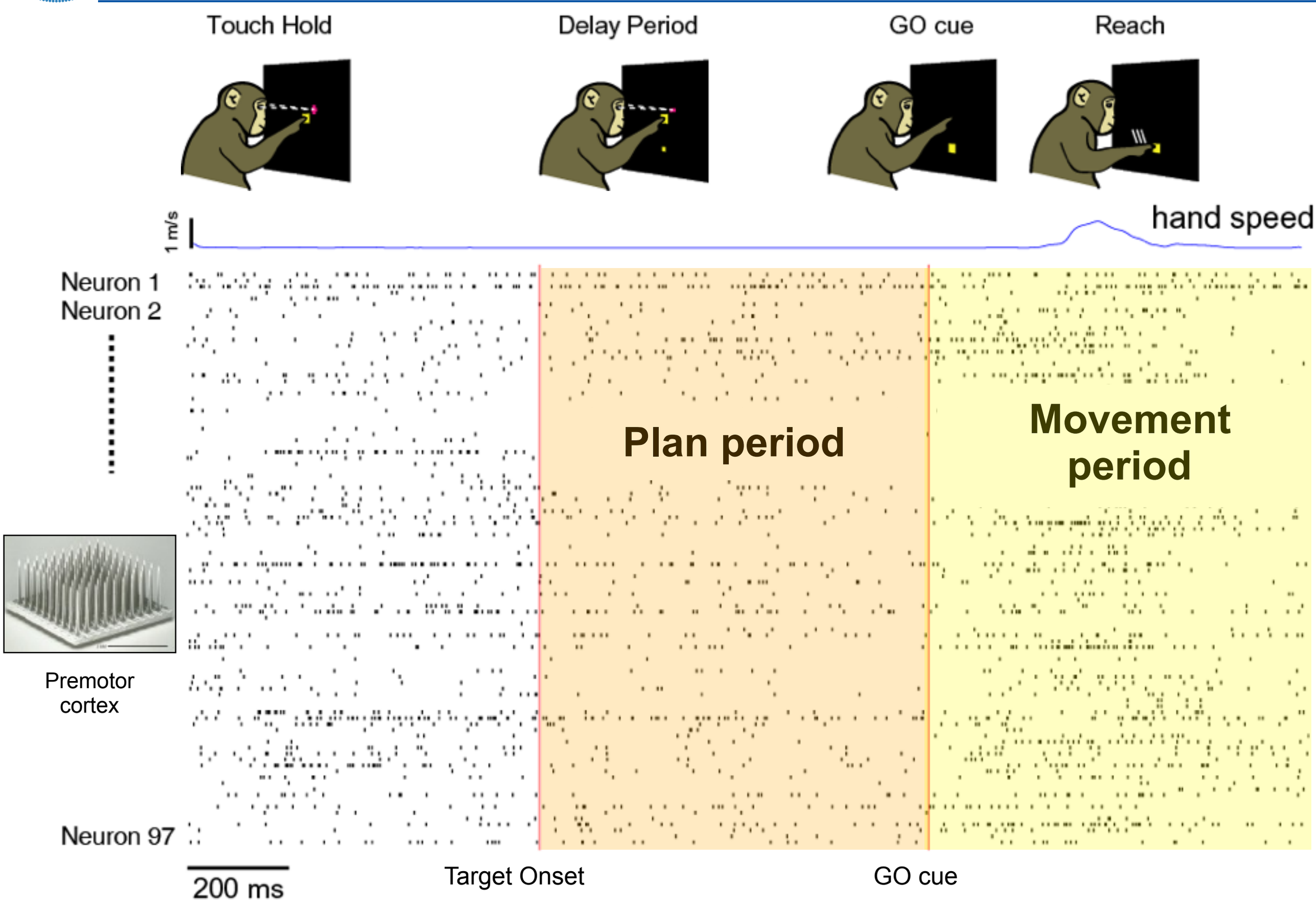
Delayed Reach Task, Plan & Movement Activity

- Firing rate of a typical PMd neuron in a delayed-reach behavioral task

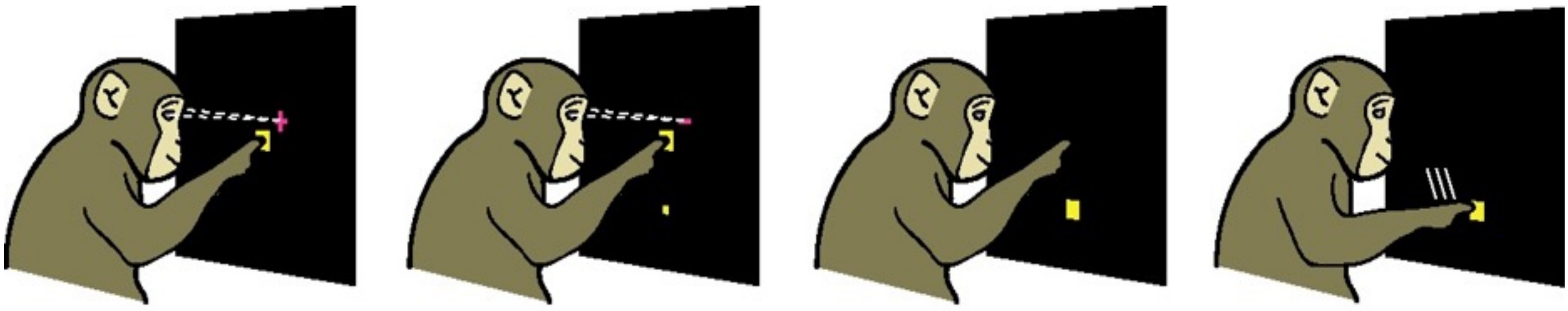


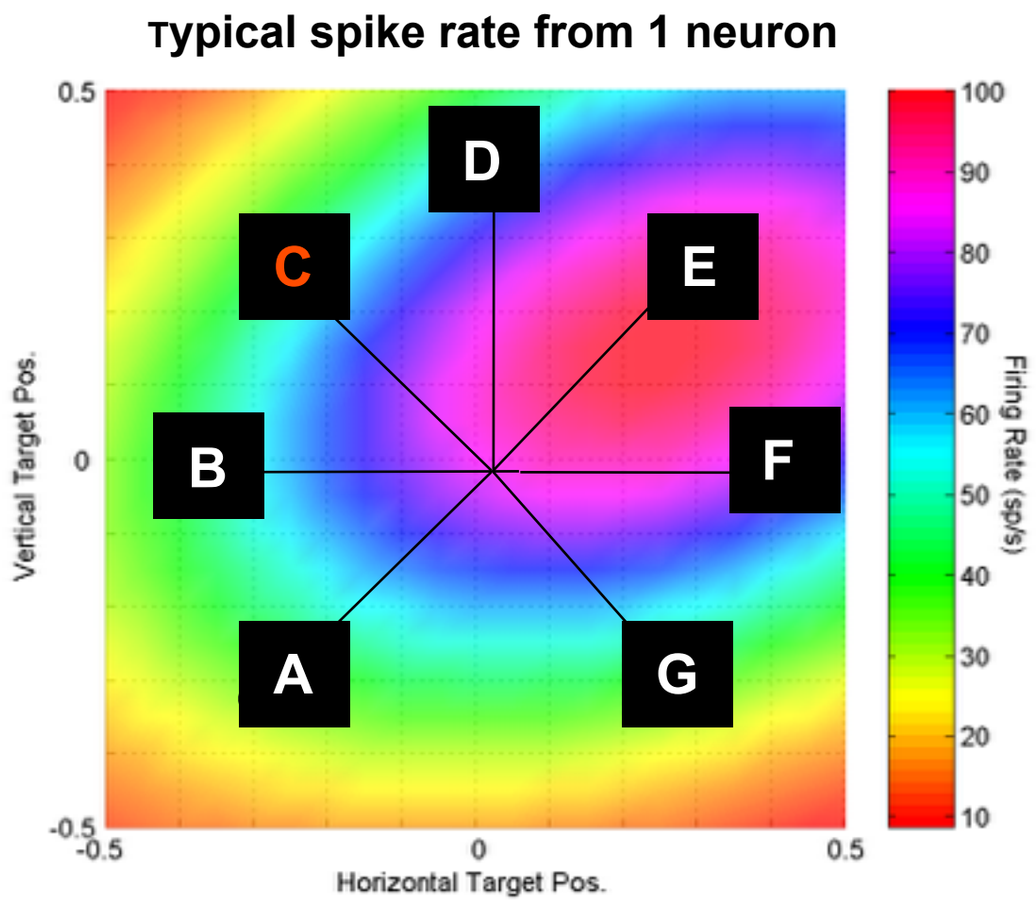


Delayed Reach Task, Plan & Movement Activity

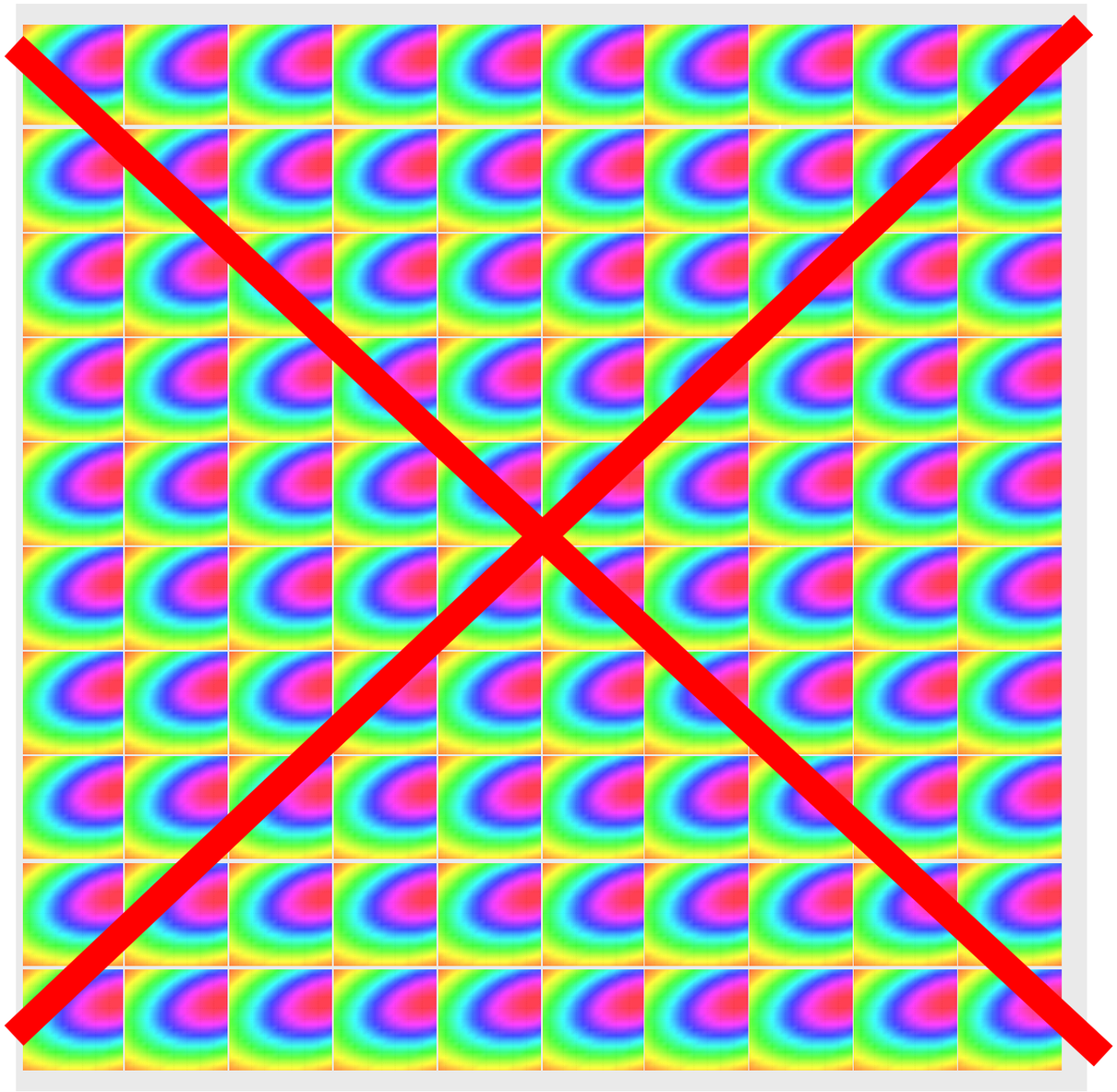


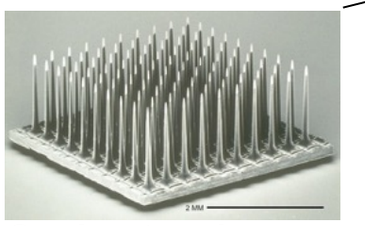
Plan Activity Reflects Movement Endpoint



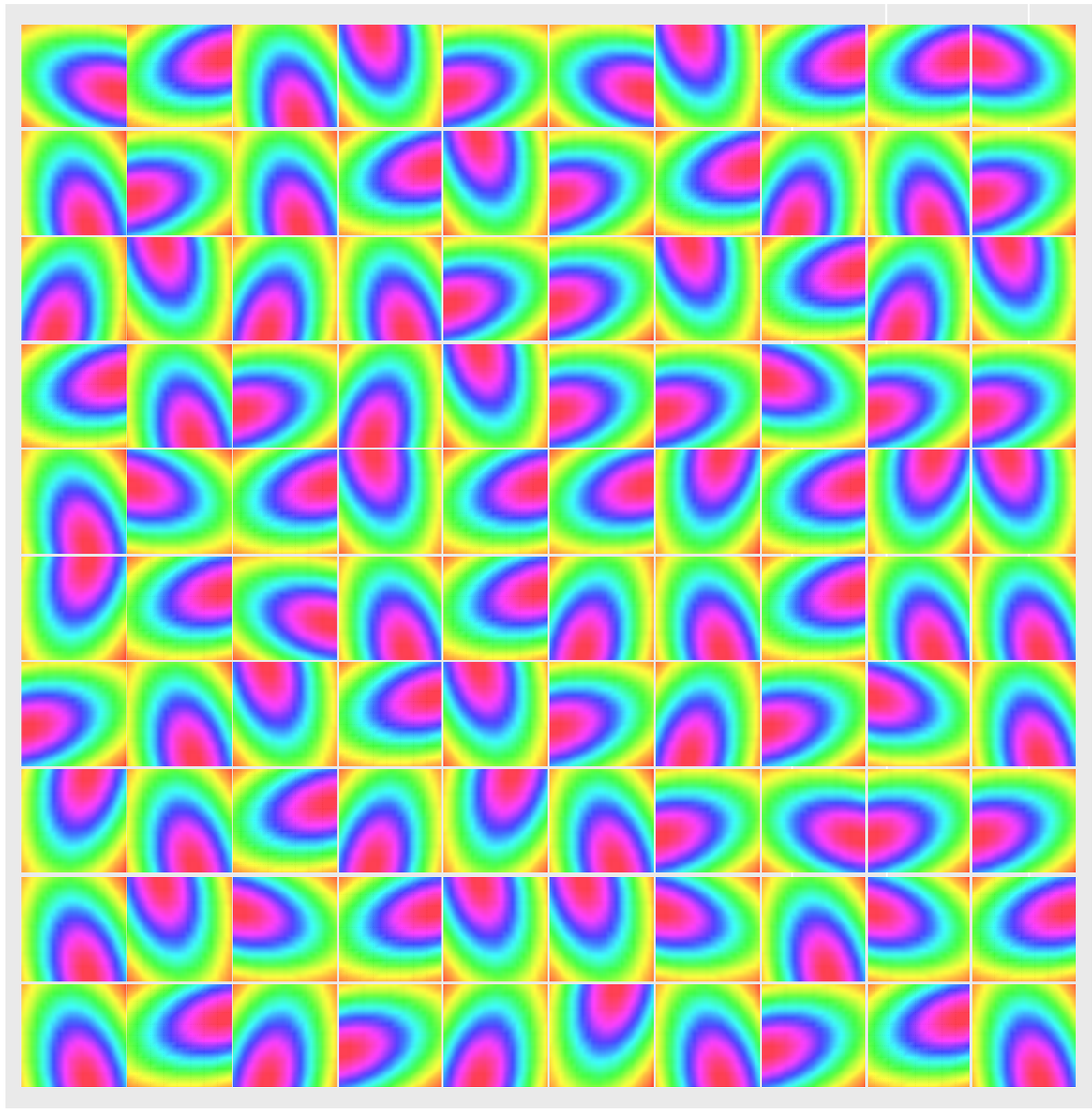


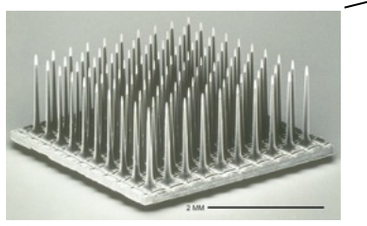
Each neuron is “tuned” differently





100 electrode array

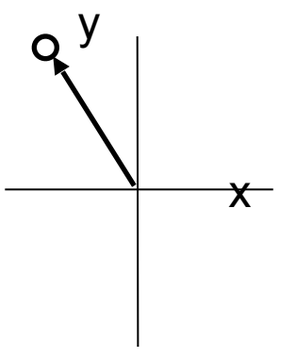


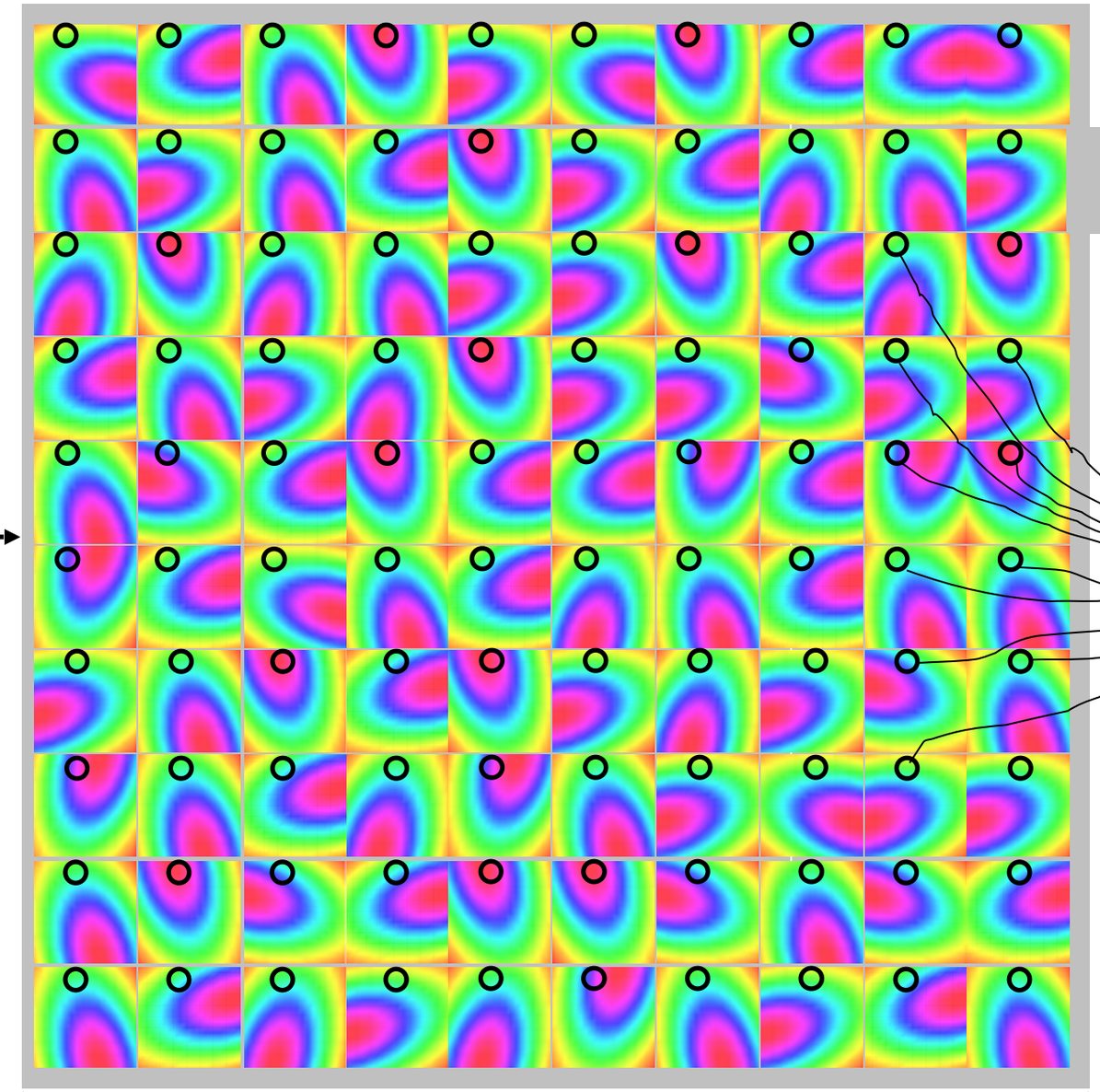


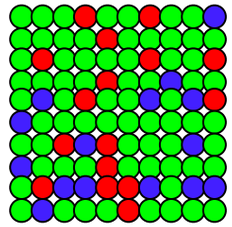
100 electrode array

How to predict the desired target

Real Target

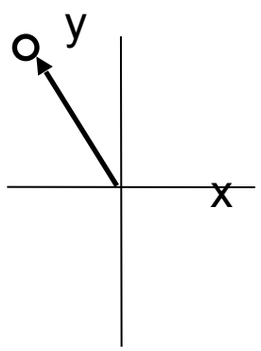


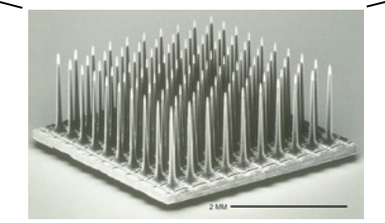




Select Target

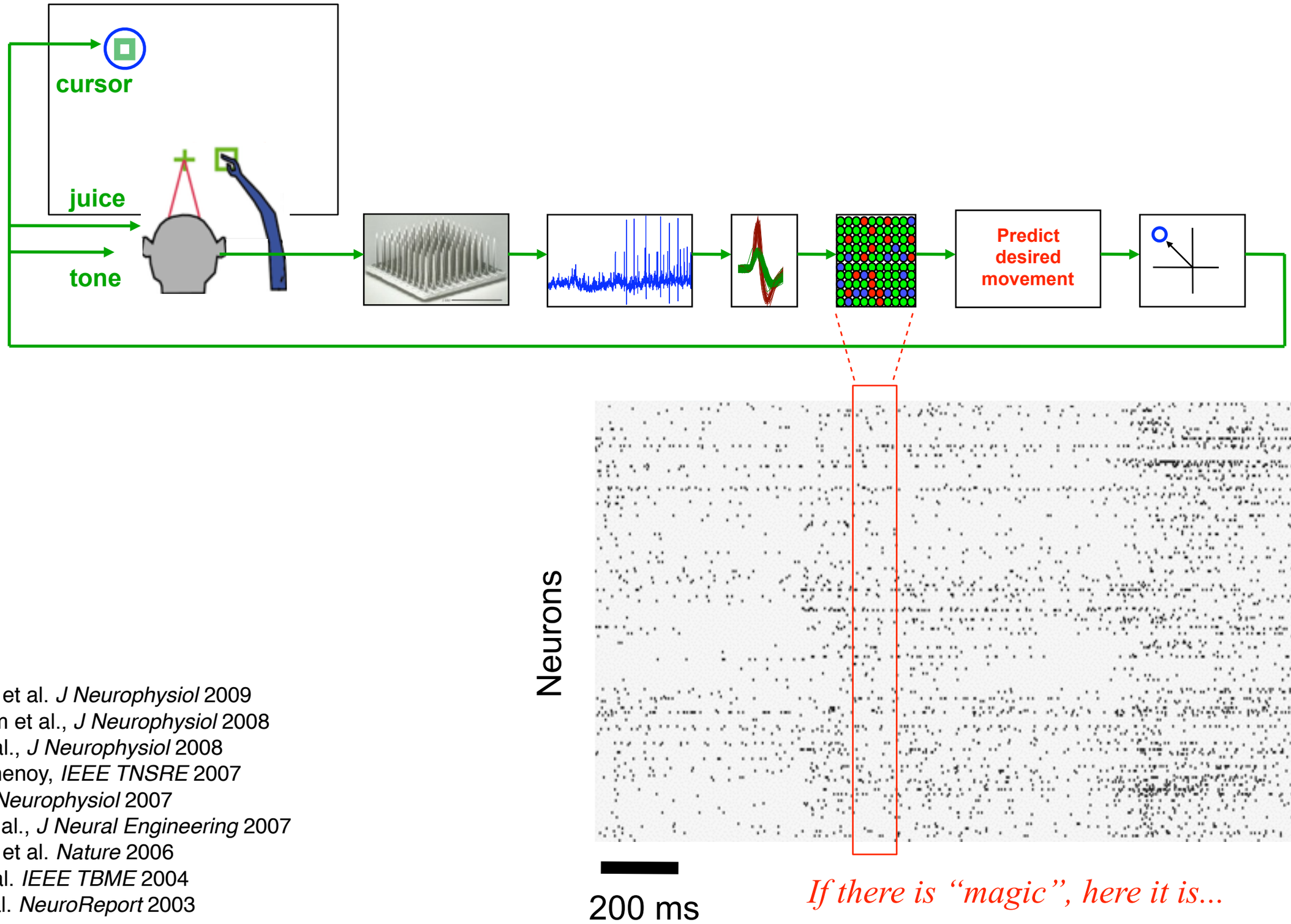
Selected Target





100 electrode array

End-to-End System Performance Measurements

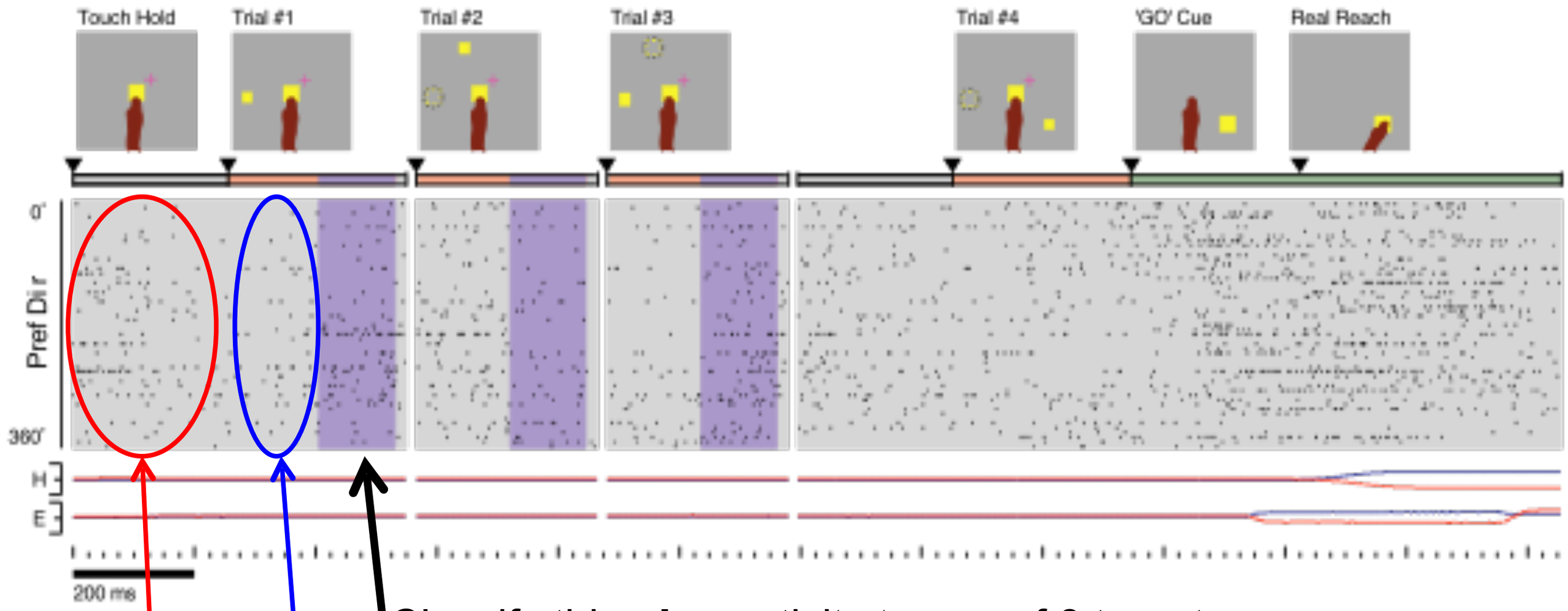


Santhanam et al. *J Neurophysiol* 2009
Cunningham et al., *J Neurophysiol* 2008
Kemere et al., *J Neurophysiol* 2008
Batista... Shenoy, *IEEE TNSRE* 2007
Yu et al., *J Neurophysiol* 2007
Achtman et al., *J Neural Engineering* 2007
Santhanam et al. *Nature* 2006
Kemere et al. *IEEE TBME* 2004
Shenoy et al. *NeuroReport* 2003

Brain-controlled target selection

Approximately 2.5 bps (~5 words/min equivalent)

Task timeline



Classify this **plan** activity to one of 8 targets

Time required for target information to arrive in premotor cortex
(due to action potential propagation, visual processing)

Baseline neural activity

High-performance brain-controlled target selection

Approximately 5.0 bps (~10 words/min equivalent)

Santhanam, Ryu, Yu, Afshar & Shenoy, *Nature* 2006.

Homework 4

• You will be implementing such a decoder and applying it to real neural data (planning activity).

• The neural data were recorded from the monkey you see in the video.

• Only a small handful of research groups around the world, and even fewer university courses, have access to this type of large-scale neural recording!

Classification algorithms

• MANY classification algorithms are available. Examples include:

Discriminant functions
Probabilistic generative models
Probabilistic discriminative models

Neural networks
Gaussian processes
Support vector machines
Relevance vector machines

• They mainly differ in the *cost function* that is optimized to find the decision boundary.

Classification algorithms

• It would take many weeks, if not more than half of the course to go through each of these in detail.

• Rather than give you an overview of all possible algorithms, we will go in depth into one class of algorithms (Probabilistic generative models) that is commonly used and has found great success in its application to neural data.

• The classifier used in the prosthetic system I just described is based on a probabilistic generative model.