PRML Chapter 4

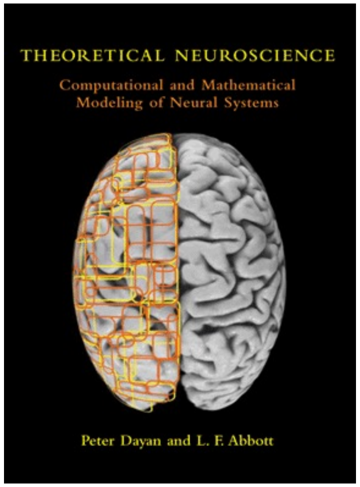
Classification

Carnegie Mellon

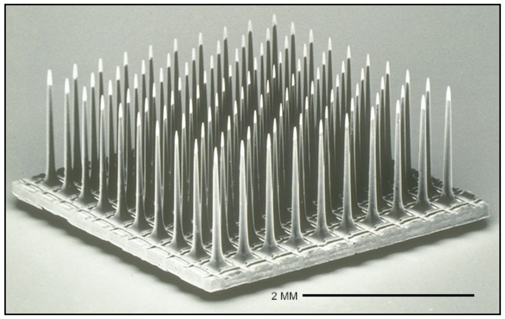
18-698 / 42-632
Neural Signal Processing
Spring 2022
Prof. Byron Yu

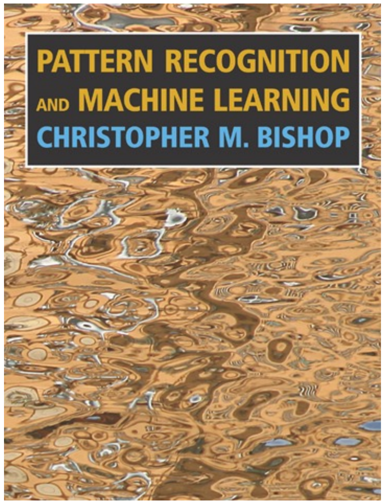
Roadmap

• Traditional neural signal processing methods
Theoretical Neuroscience, Chapter 1



• State-of-the-art neural signal processing methods
Patter Recognition and Machine Learning





Topics we will cover in PRML

Chap. 4: Classification. Naive Bayes.
Neuroscience application: discrete neural decoding

Chap. 8: Graphical models.

Chap. 9: Mixture models. Expectation-maximization.
Neuroscience application: spike sorting

Chap. 12: Principal components analysis. Factor analysis.
Neuroscience applications: dimensionality reduction, discrete neural decoding

Chap. 13: Kalman filter.
Neuroscience application: continuous neural decoding

Classification

- Reading assignment:
  PRML p. 38–46: Decision Theory
  PRML p. 179–184, 196–203: Linear Models for Classification

Please feel free to read the rest of Chapter 4, but we will focus on (and you will only be responsible for) the material covered in these pages.

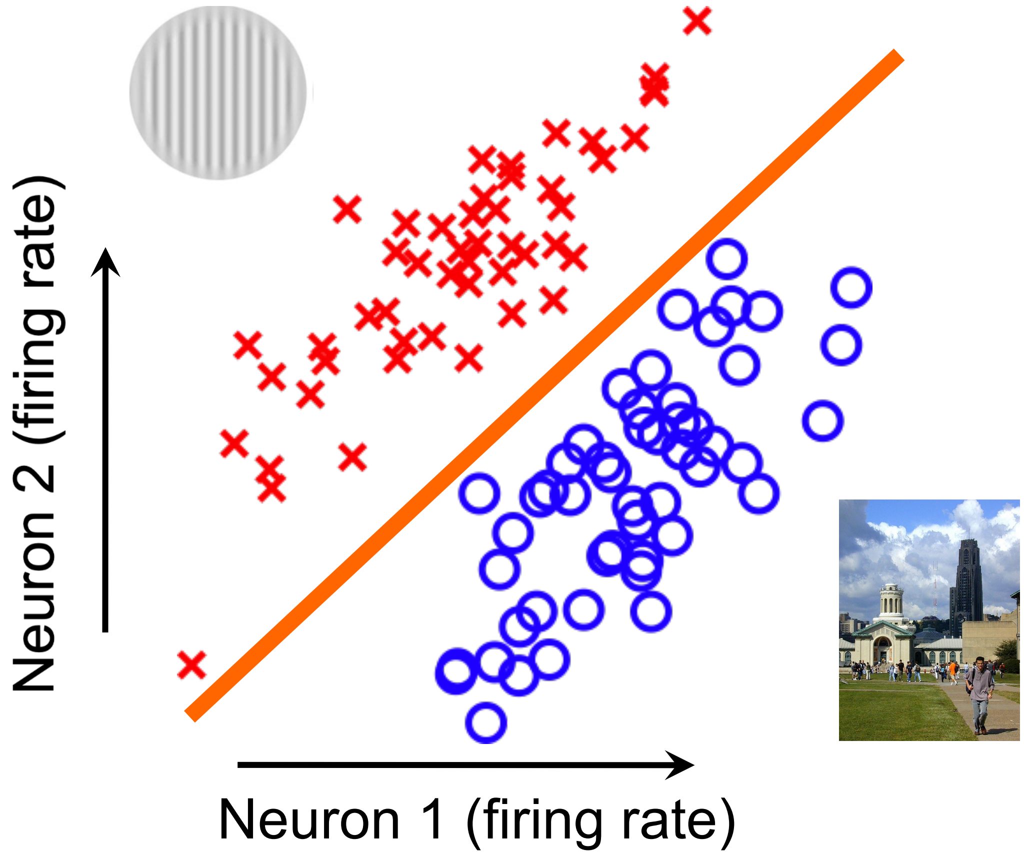
- Where does classification appear in neuroscience?

- One of the most basic questions we can ask is how the brain's activity differs under different stimulus conditions.

Visual system

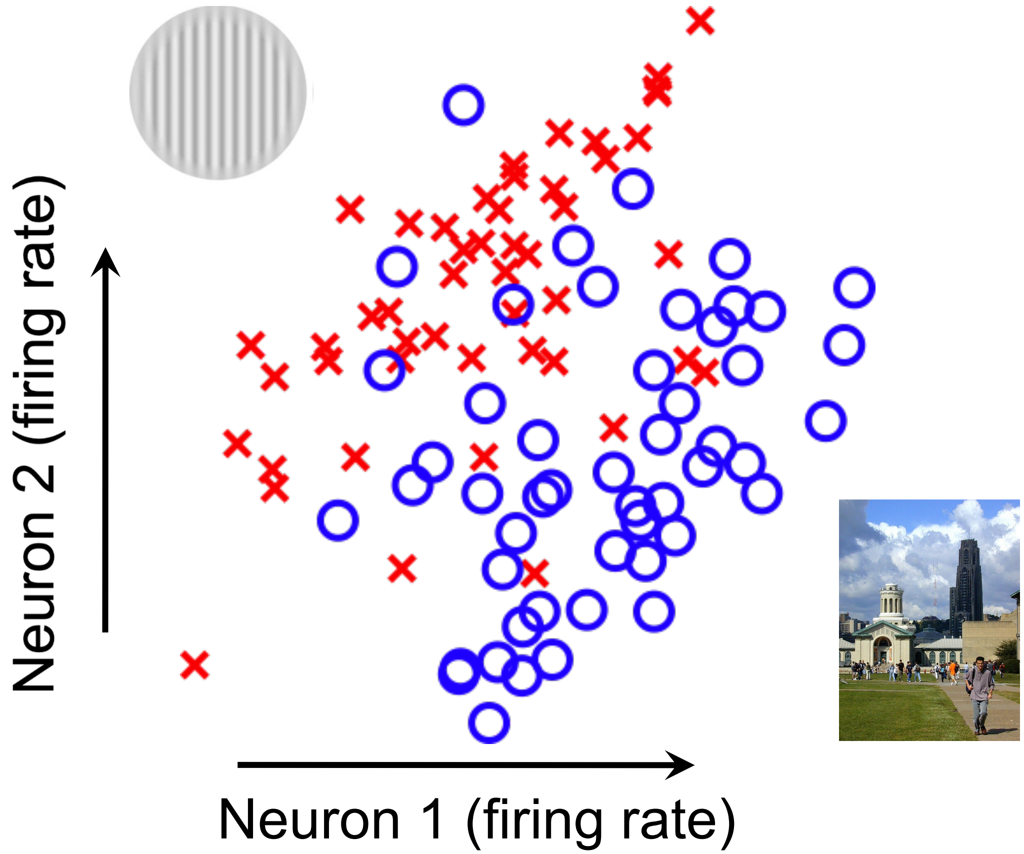
vs.

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*.

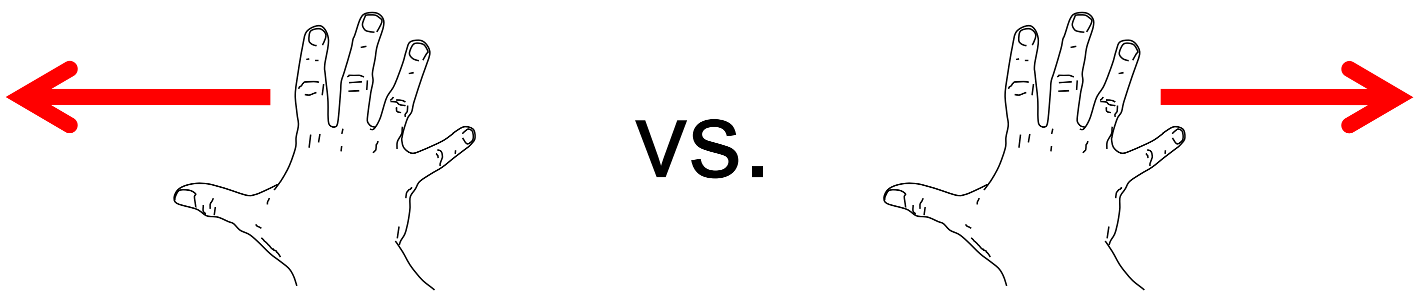
Olfactory system

vs.

Auditory system

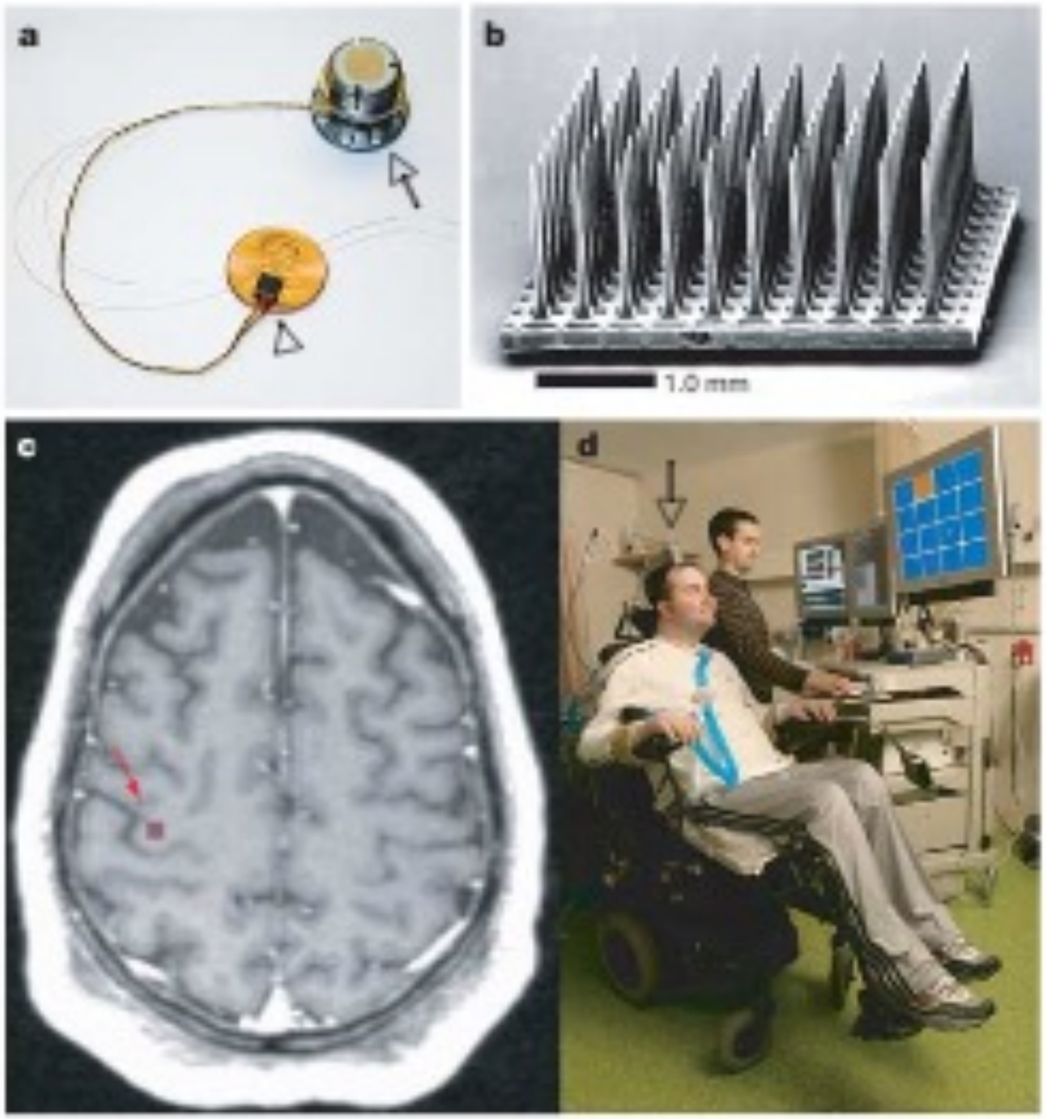
vs.

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

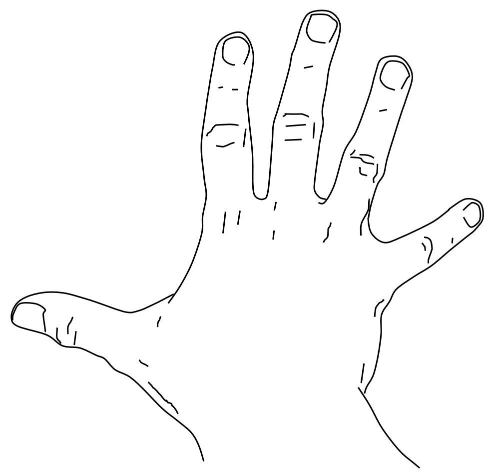
• These systems are usually based on arm movement intentions. I.e., think reach to the right => move cursor to the right

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

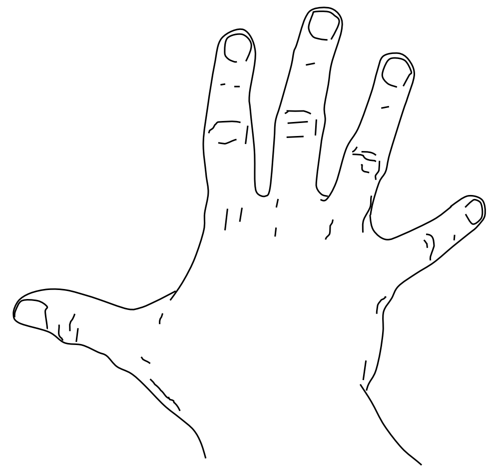
• Like typing on a keyboard.

• This is a classification problem!

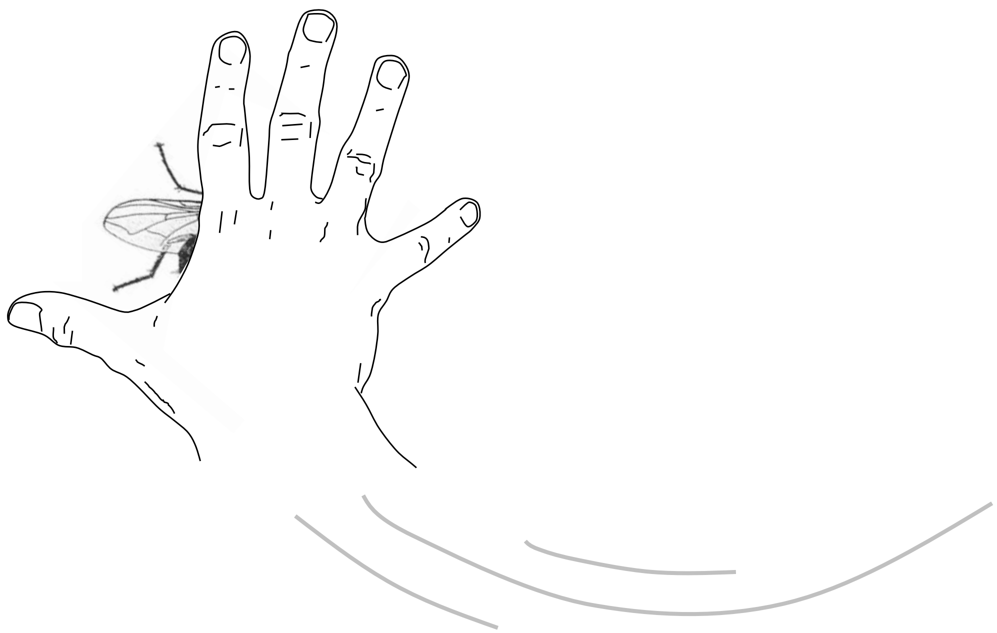
Motor planning



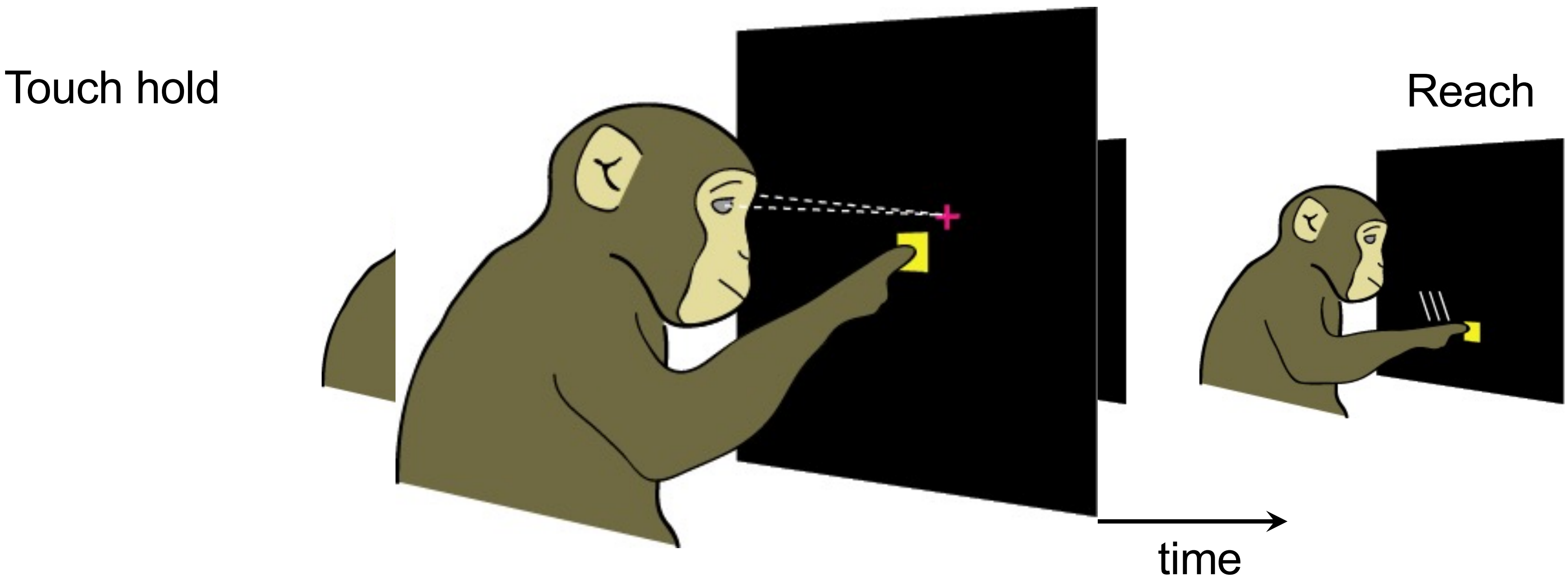
Motor planning



Motor planning

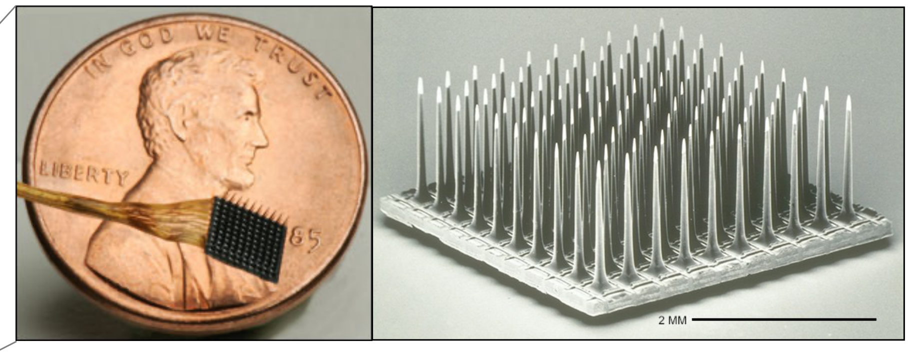


Delayed reach task

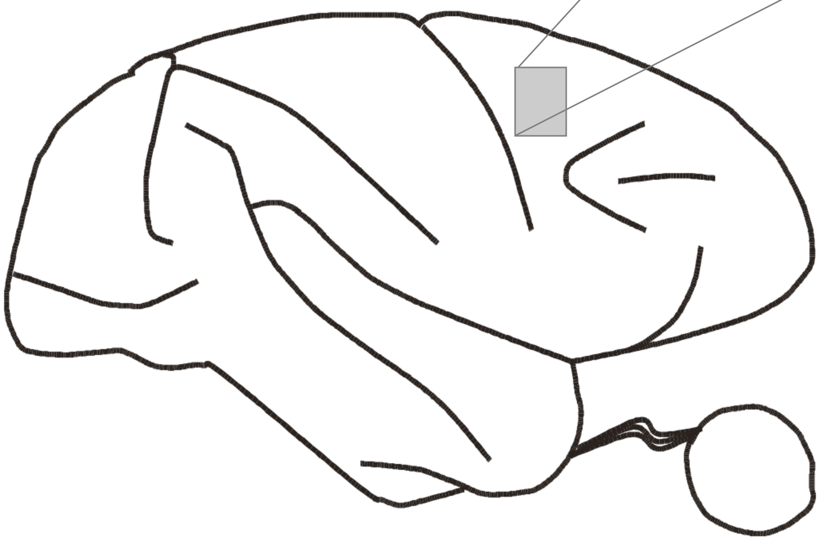


Delayed reach task

Recordings in premotor cortex

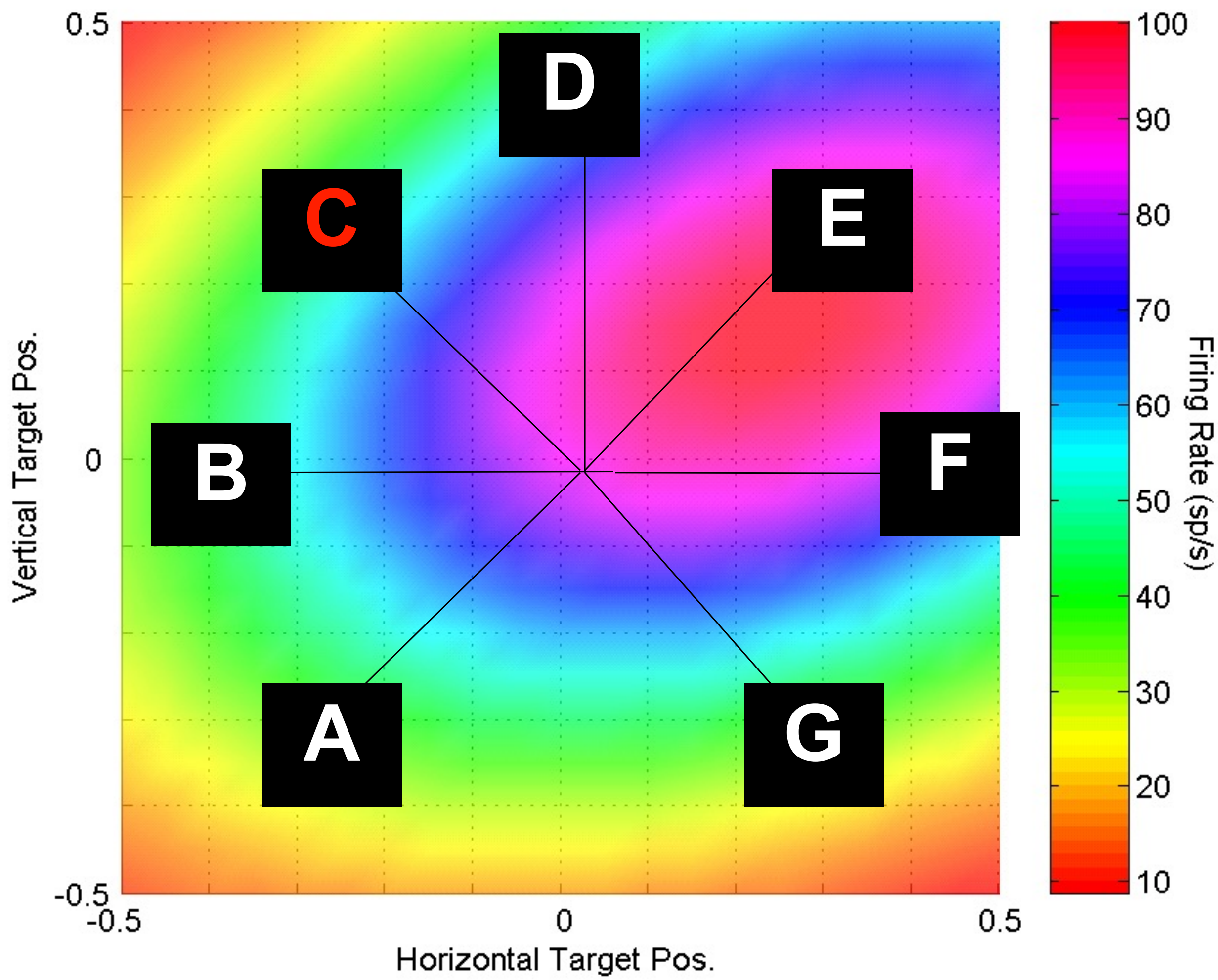


Utah 96-electrode array

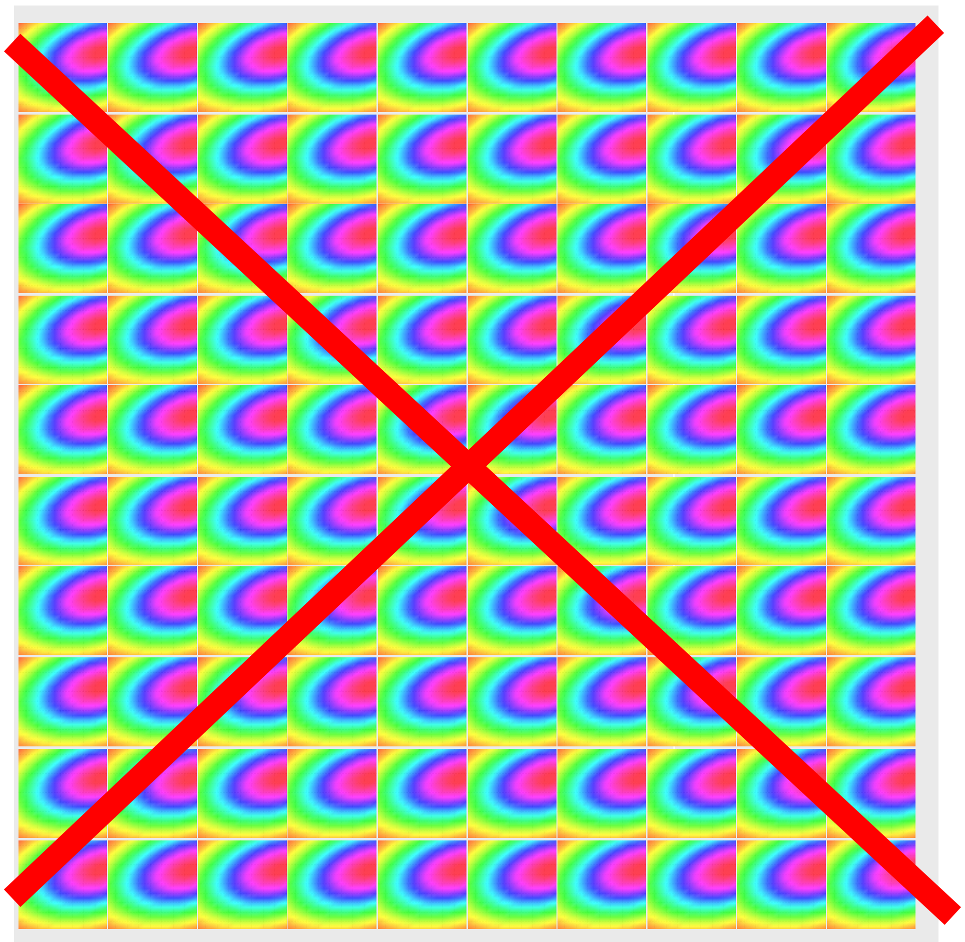


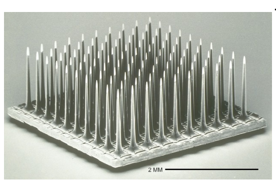
Neural "plan" activity represents endpoint locations

Typical spike rate from 1 neuron

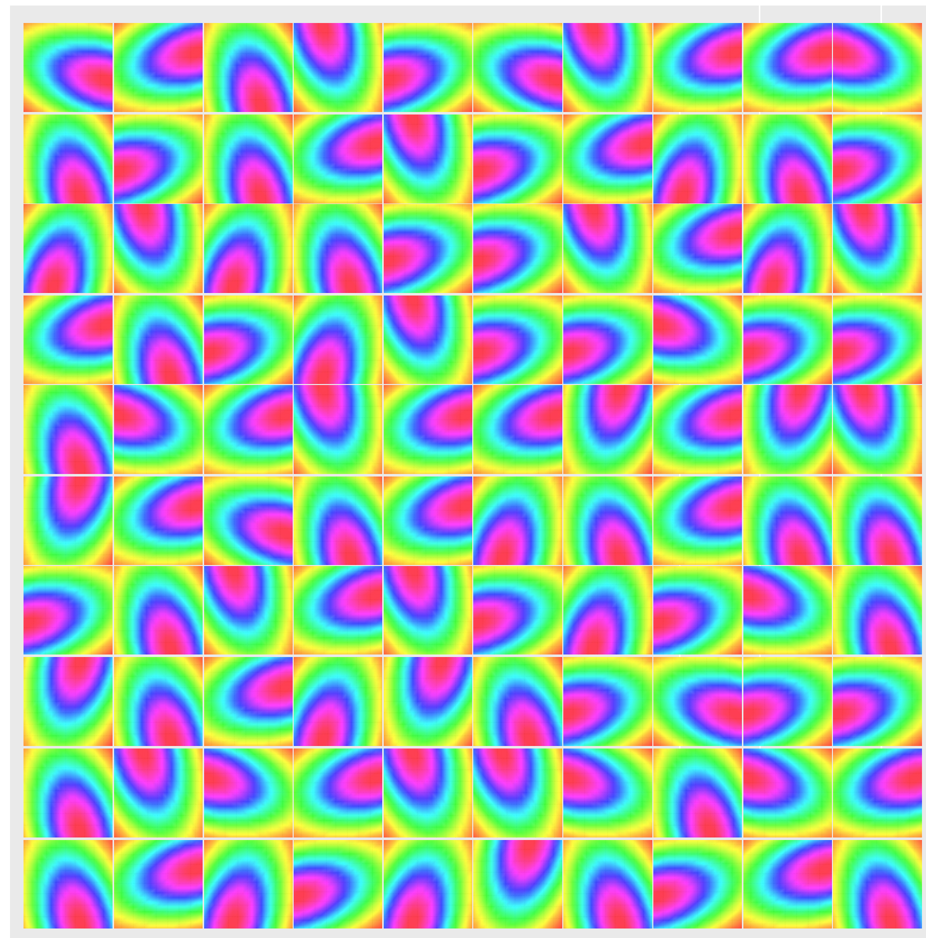


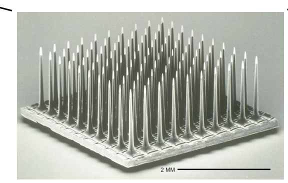
Each neuron is “tuned” differently





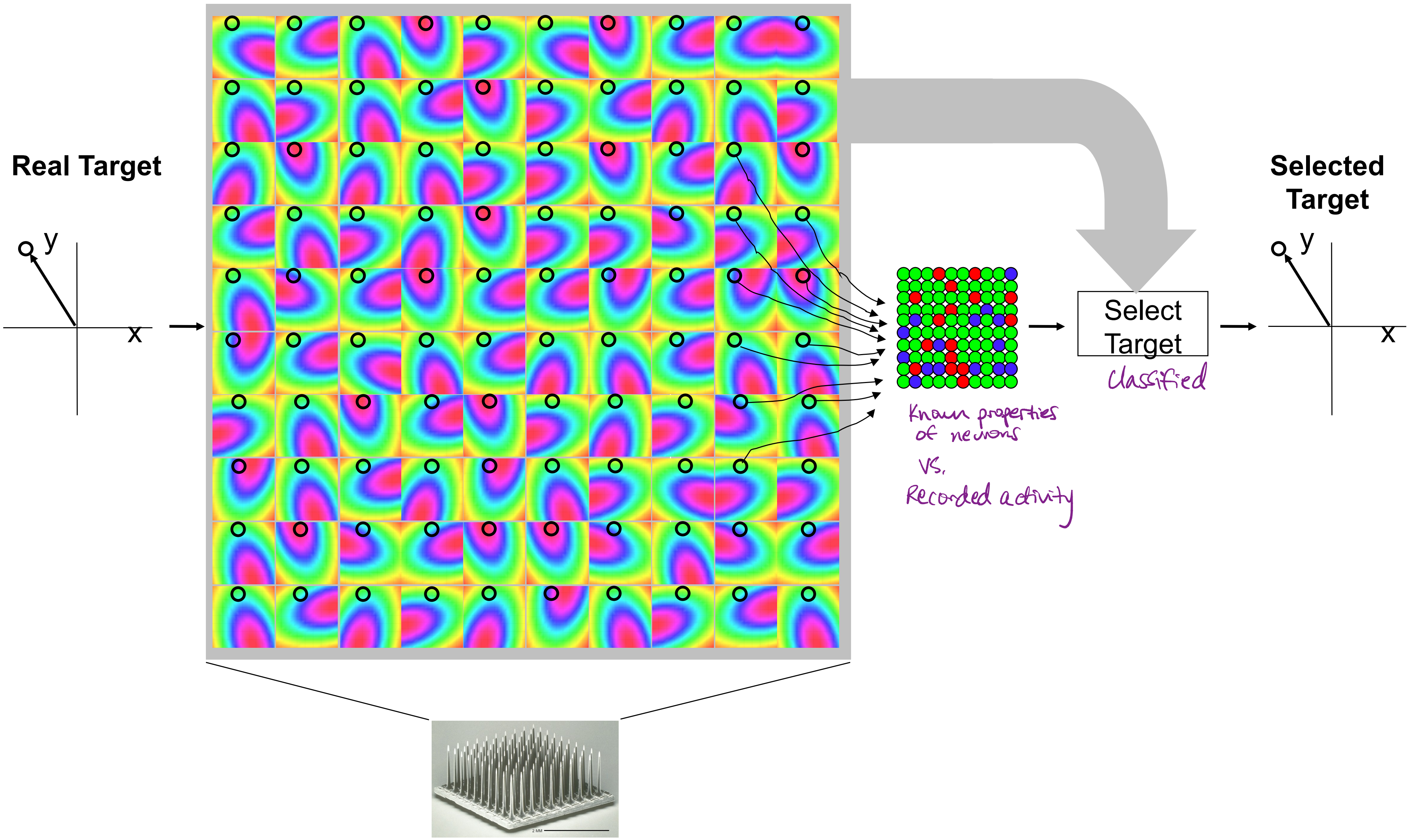
100 electrode array





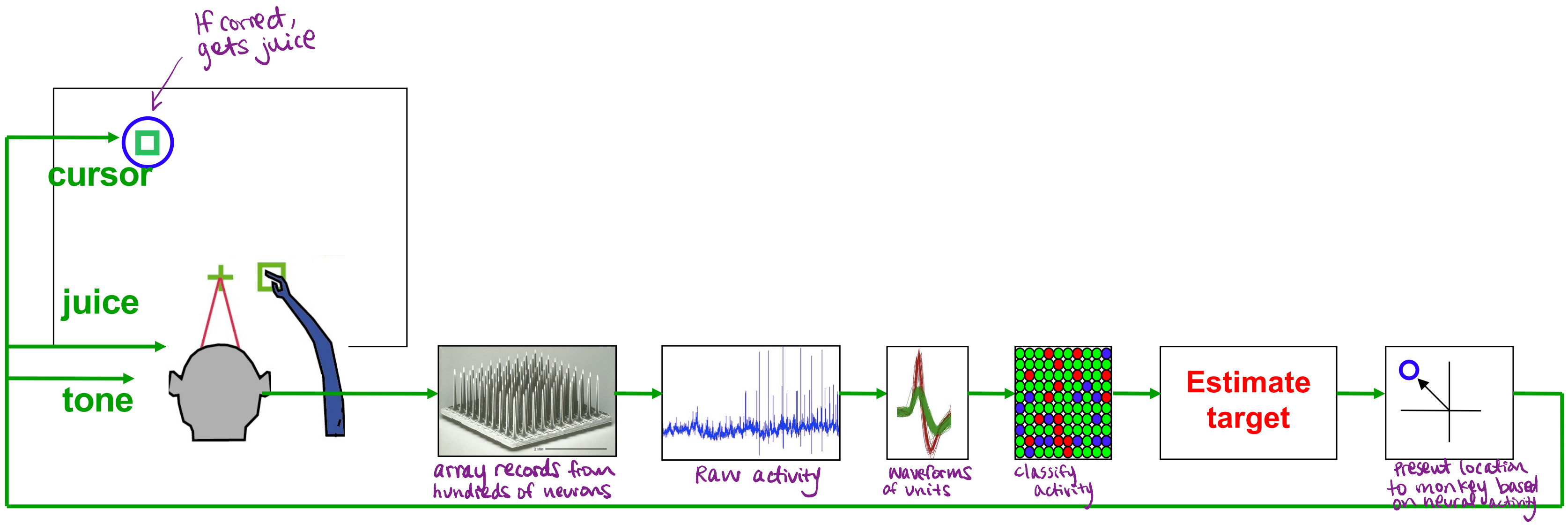
100 electrode array

How to predict the desired target



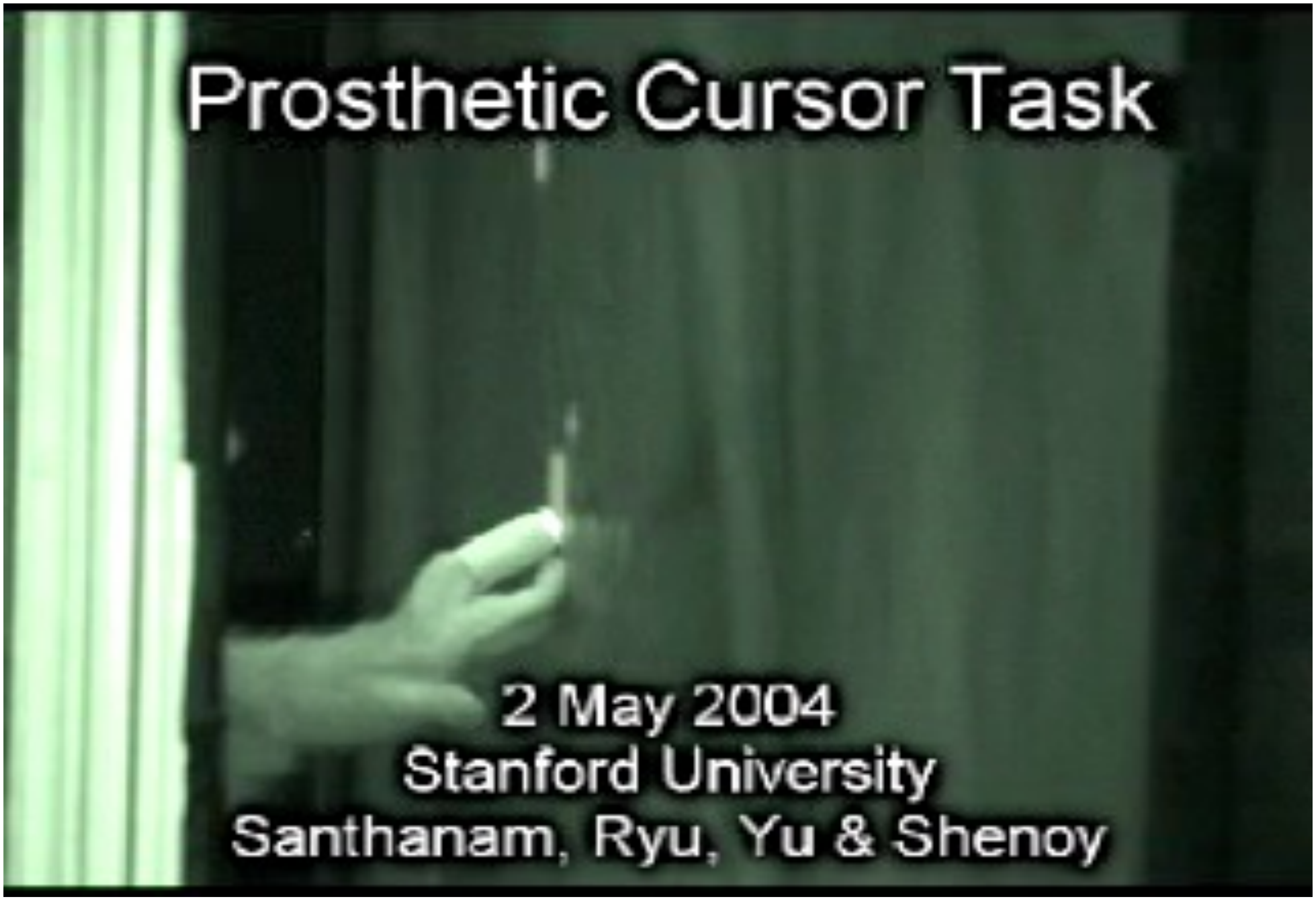
100 electrode array

Experimental setup: signal flow

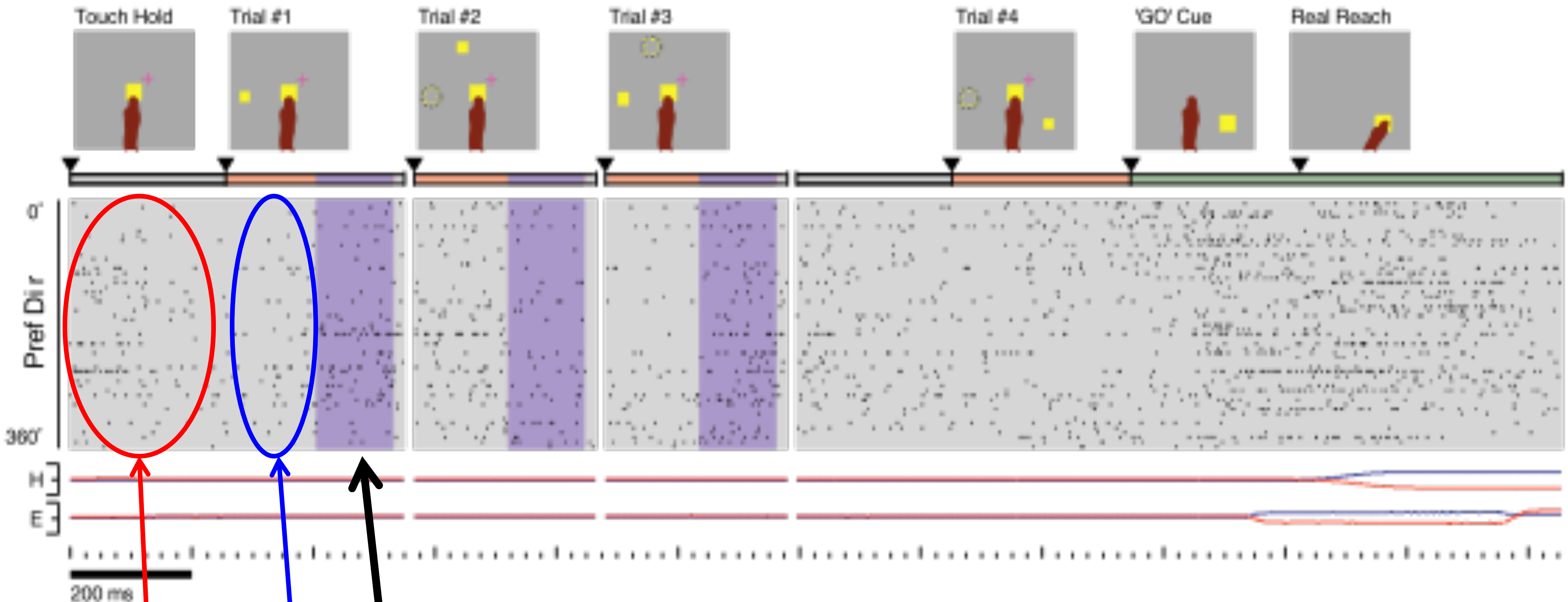


Brain-controlled target selection

Approximately 2.5 bps (~5 words/min equivalent)



Task timeline



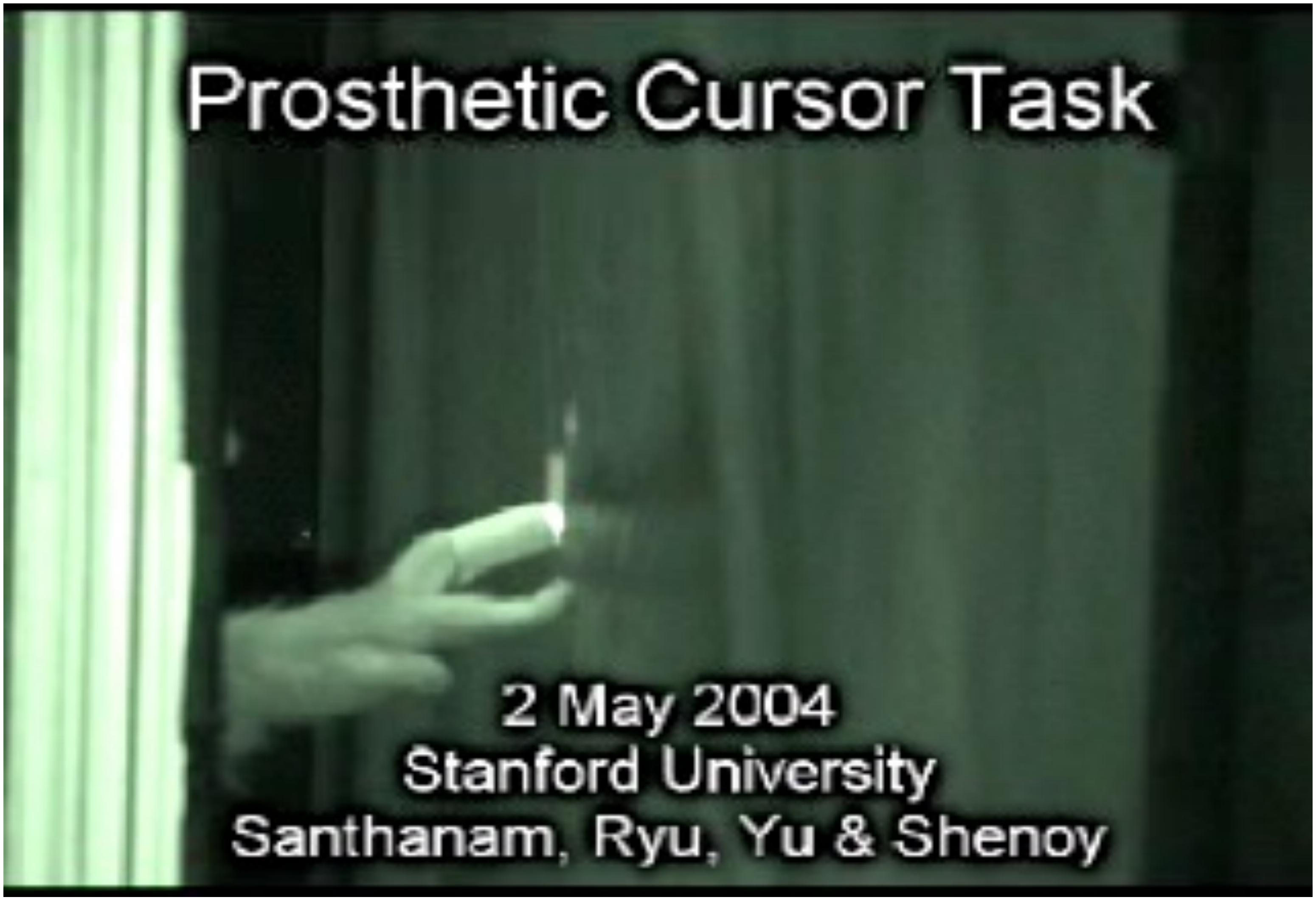
Classify this **plan** activity to one of 8 targets

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.

Problem Set 3

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

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

• Only some 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 (Chap. 4.1)
Probabilistic generative models (Chap. 4.2)
Probabilistic discriminative models (Chap. 4.3)

Neural networks (Chap. 5.7.3)
Gaussian processes (Chap. 6.4.5)
Support vector machines (Chap. 7.1)
Relevance vector machines (Chap. 7.2.3)

• 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.

SEE “CLASSIFICATION” HANDOUT