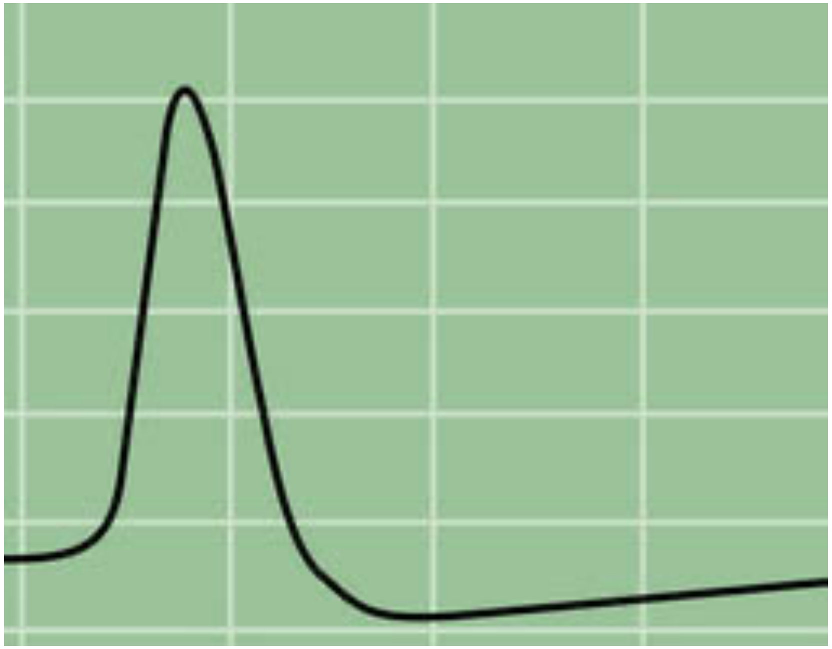
BMD ENG 301Quantitative Systems Physiology (Nervous System)

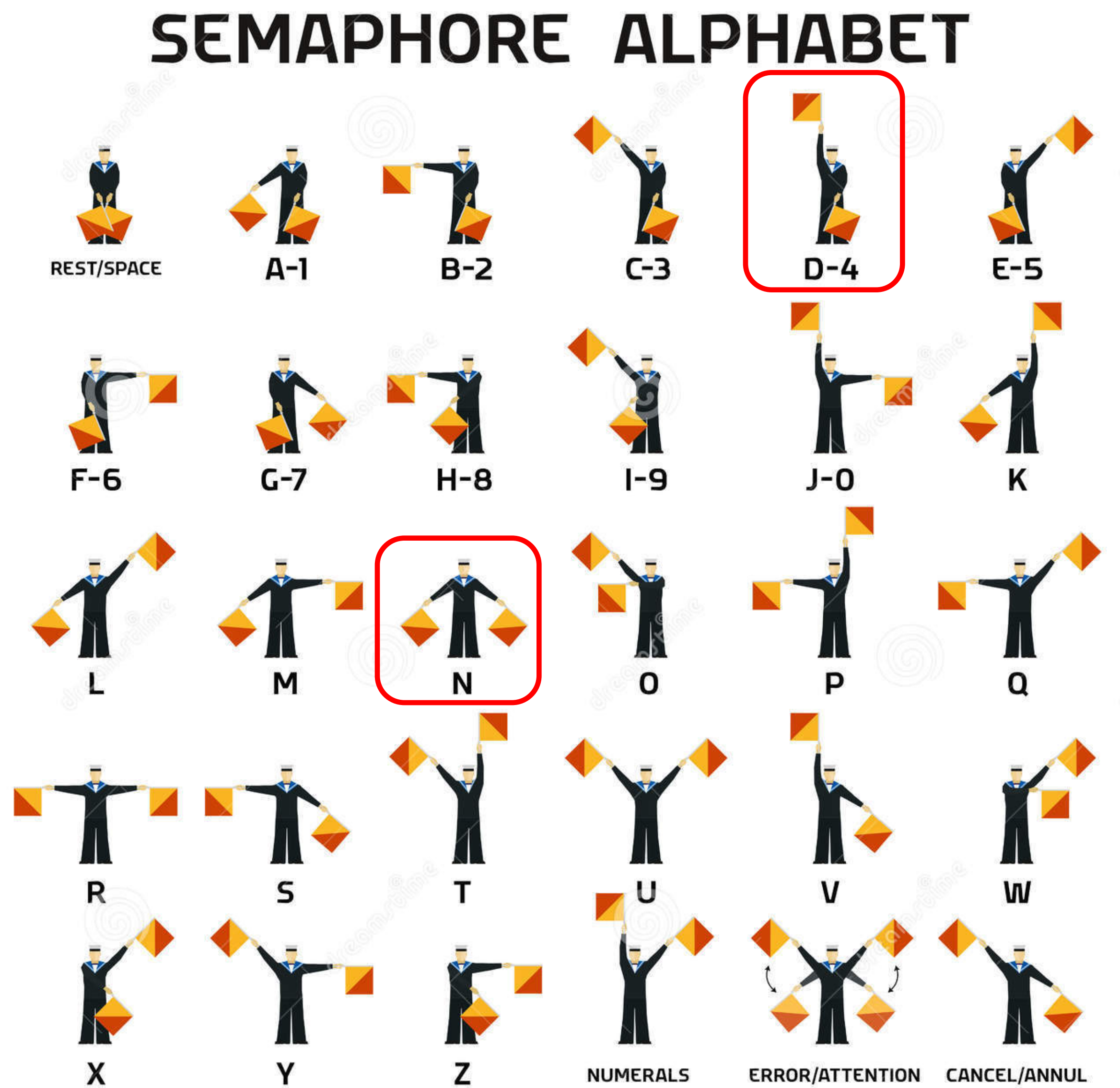


Lecture 9: Neural Signals
2022_v1
Professor Malcolm A. MacIver

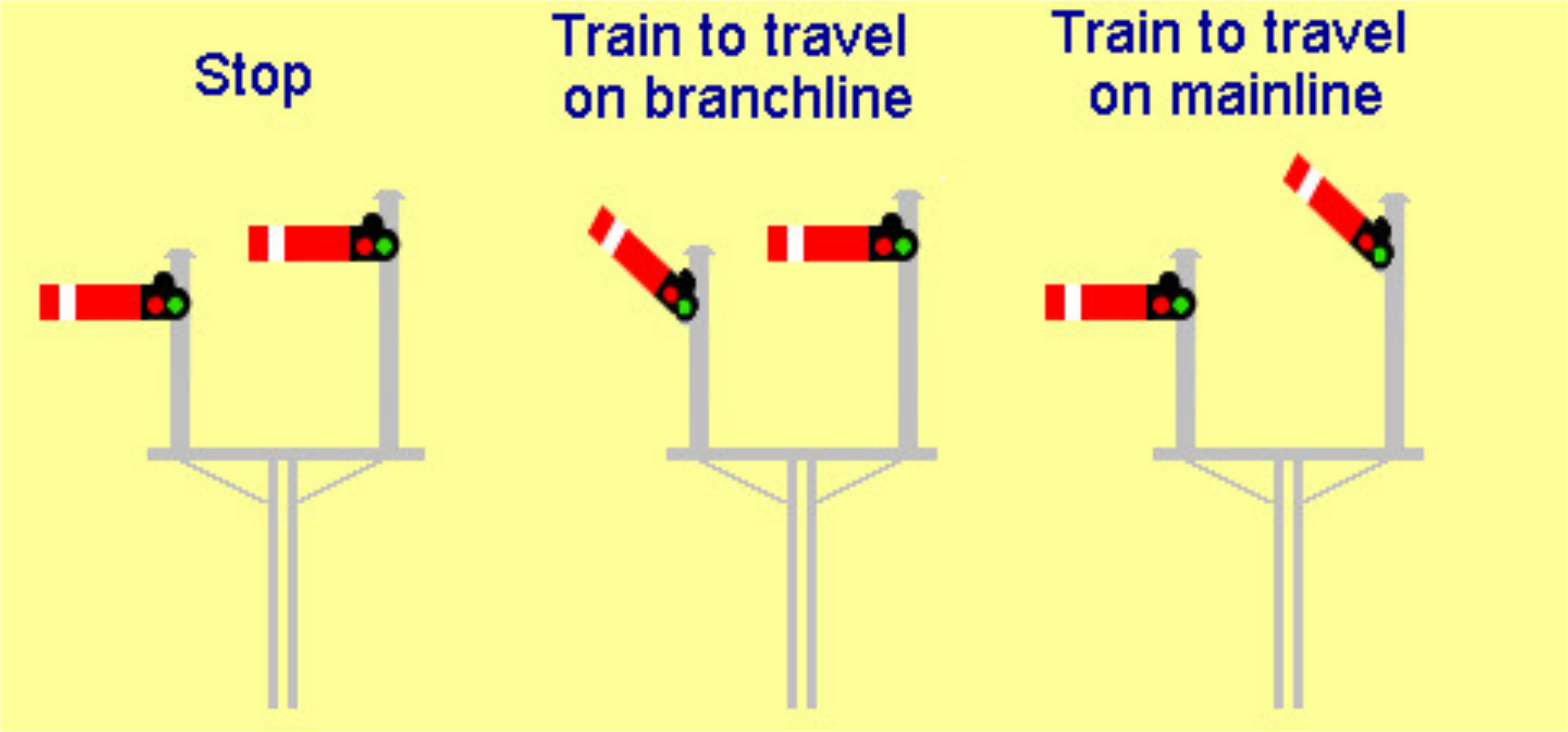
Peace Sign

Designed by Gerald Holtom for the campaign for Nuclear Disarmament in 1958

N for Nuclear, D for Disarmament



Railway Signals



OLD THINKING: Codes (the “neural code”) sent between brain regions, where neuronal algorithms process the data to produce an output. Useful metaphor: a digital computer running an algorithm such as a digital motor speed governor, speed and voltage encoded as binary numbers

MORE RECENT THINKING: Signals are processed and outputs occur as a result of a (possibly high dimensional) continuous computation. Useful metaphor: the Watt governor

Digital computation

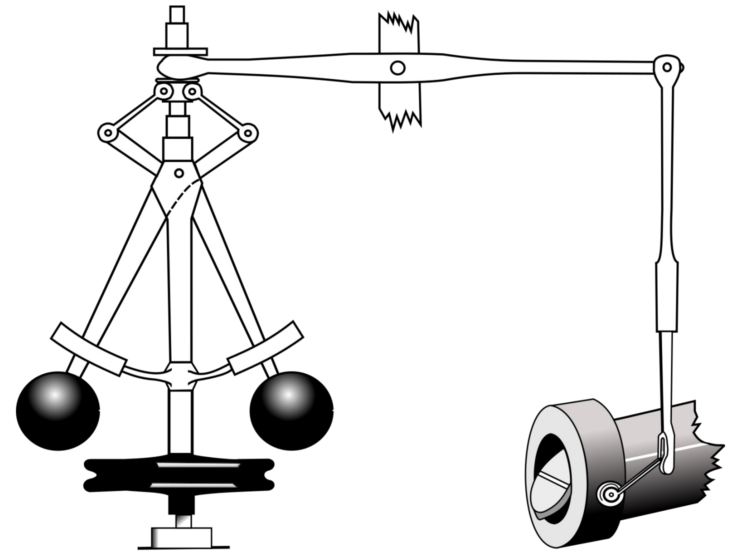
Algorithm for keeping a DC motor at the same revolutions per minute (RPM) as load varies, using a Hall Effect sensor on a flywheel attached to motor (note: In a DC motor, rotation speed is linear with input voltage):

1. Measure the rotations per minute (RPM)
2. Compare the RPM_actual to RPM_desired.

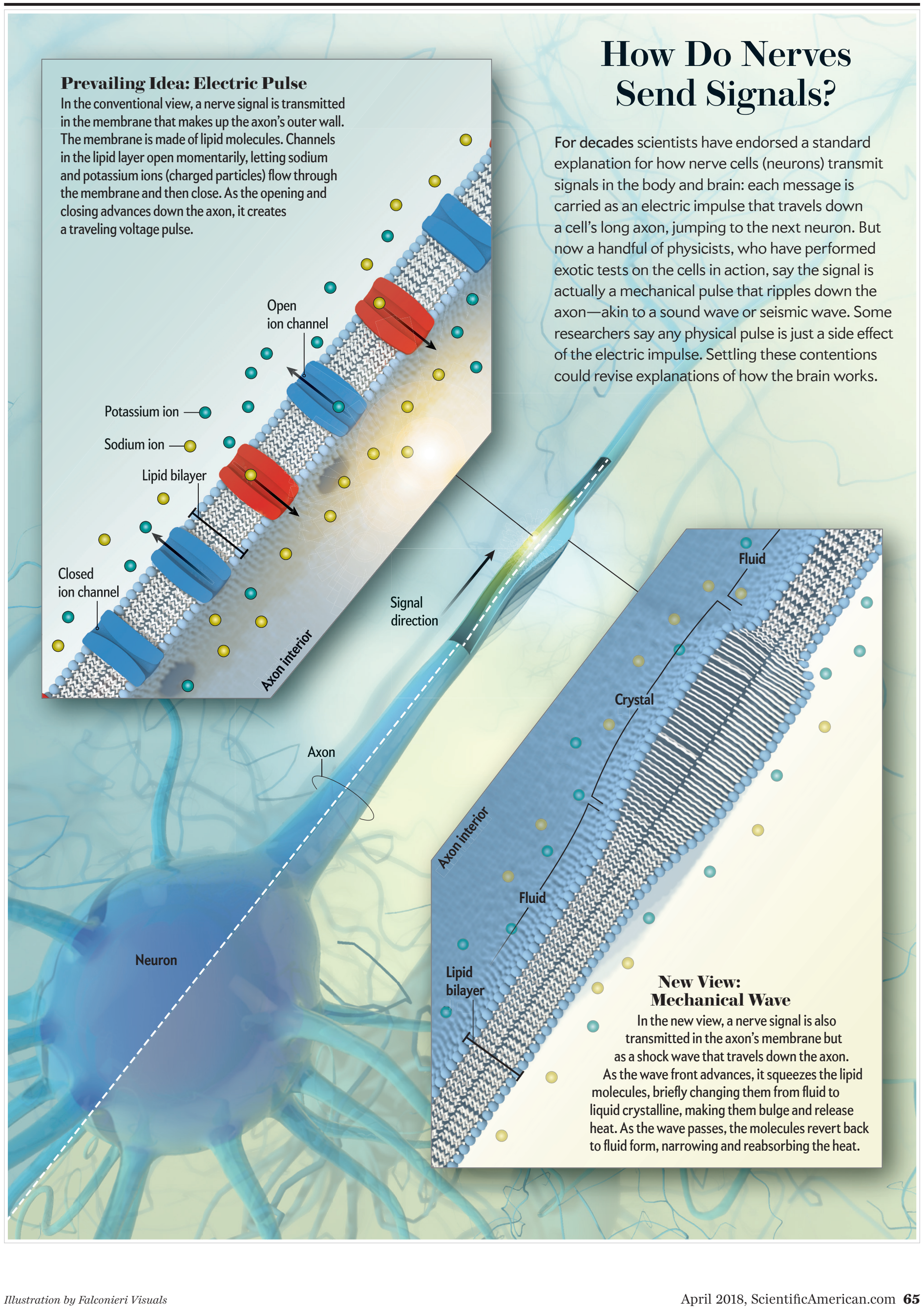
3. If there is no discrepancy, return to step 1. Otherwise,
   a. measure the voltage going to motor;
   b. calculate the RPM error (RPM_desired - RPM_actual);
   c. calculate the needed new voltage for zero RPM error.

4. Change the voltage to motor according to (3c). Return to step 1.

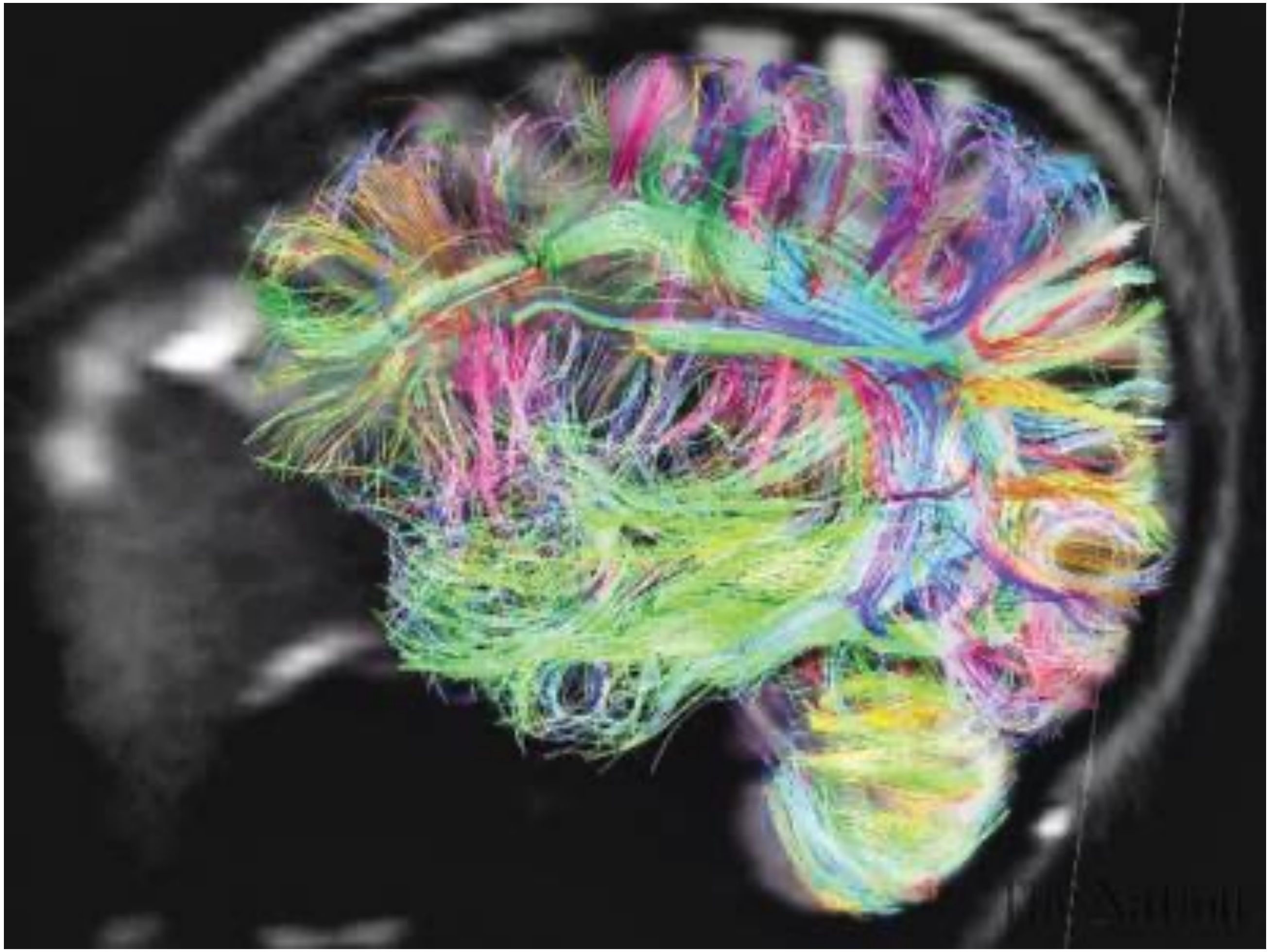
Analog computation



Watt governor

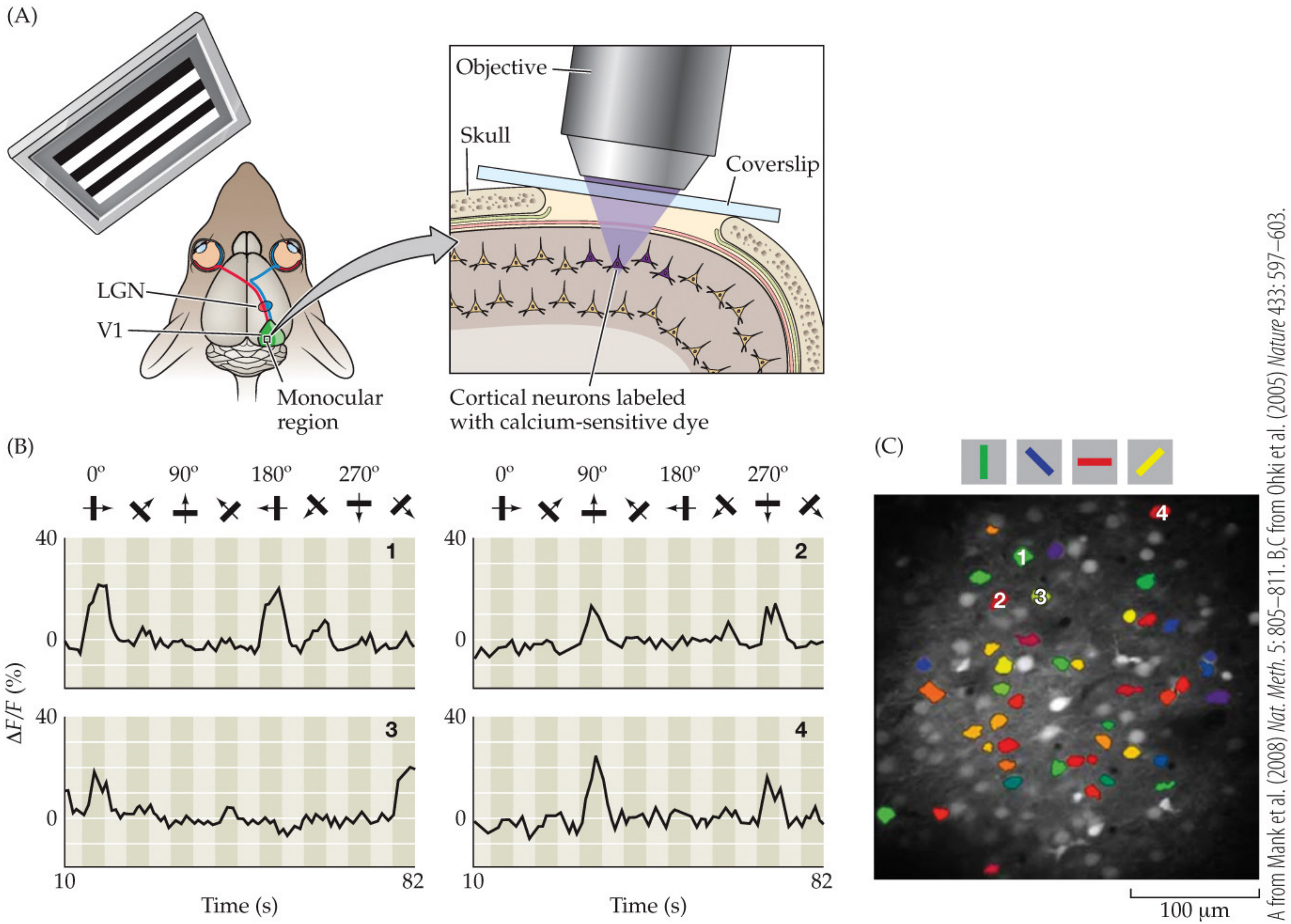


The Electrical and the Mechanical Hypotheses



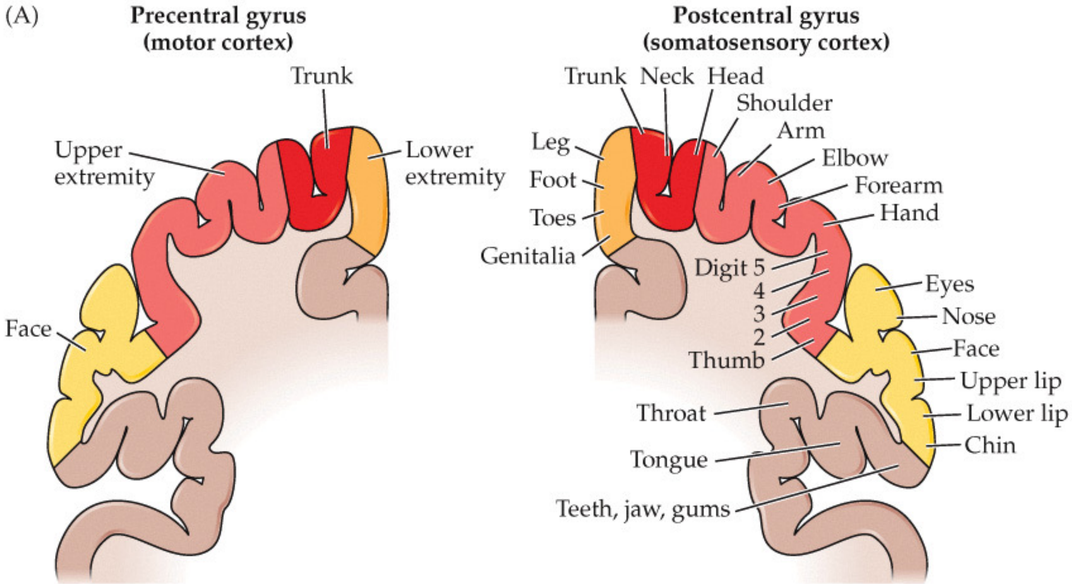
What is the Neural Code?

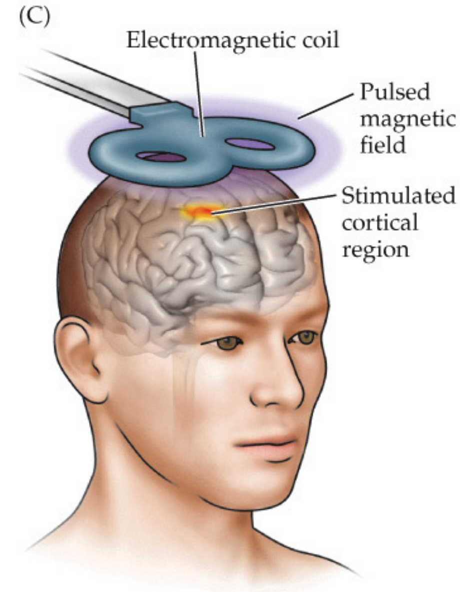
Imaging cortical neurons responding to visual stimuli using calcium-sensitive dyes



NEUROSCIENCE 6e, Figure 1.10

Indirect “images” of functional localization and maps using invasive and noninvasive neurophysiological approaches

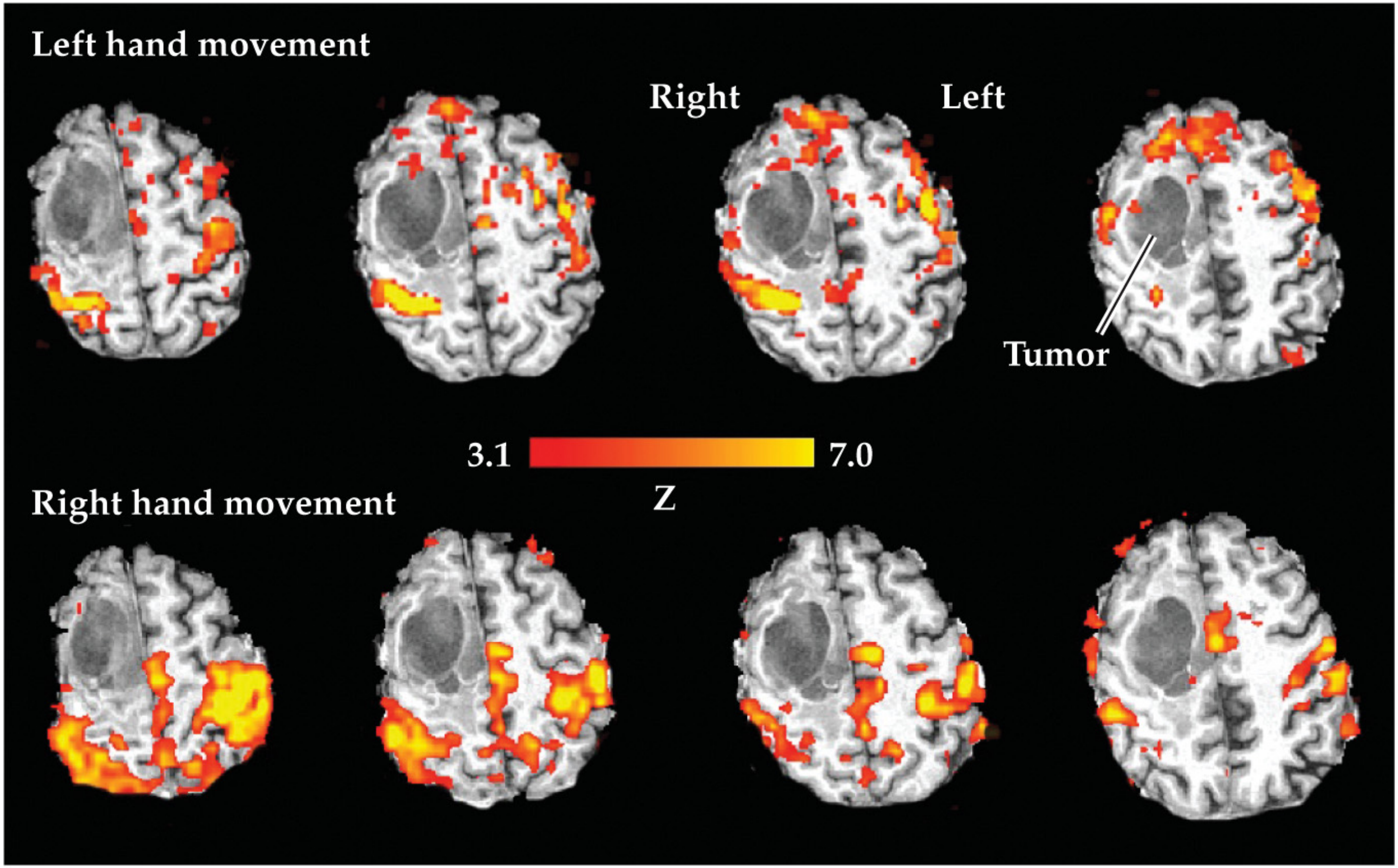




Good temporal resolution

NEUROSCIENCE 6e, Figure 1.18

fMRI of a patient’s brain that harbored a right frontal lobe glioma (gray area)

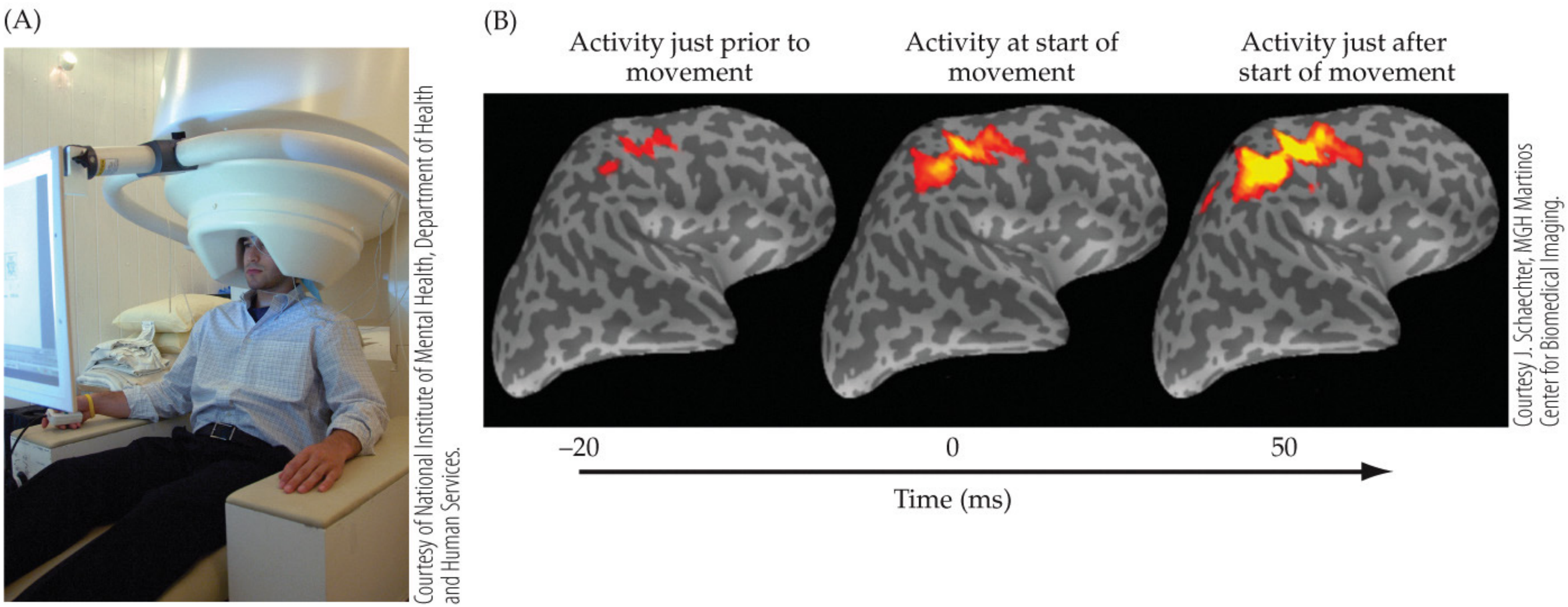


From Goodyear and Mosher (2014). *InTech*. doi: 10.5772/58270.

NEUROSCIENCE 6e, Figure 1.21

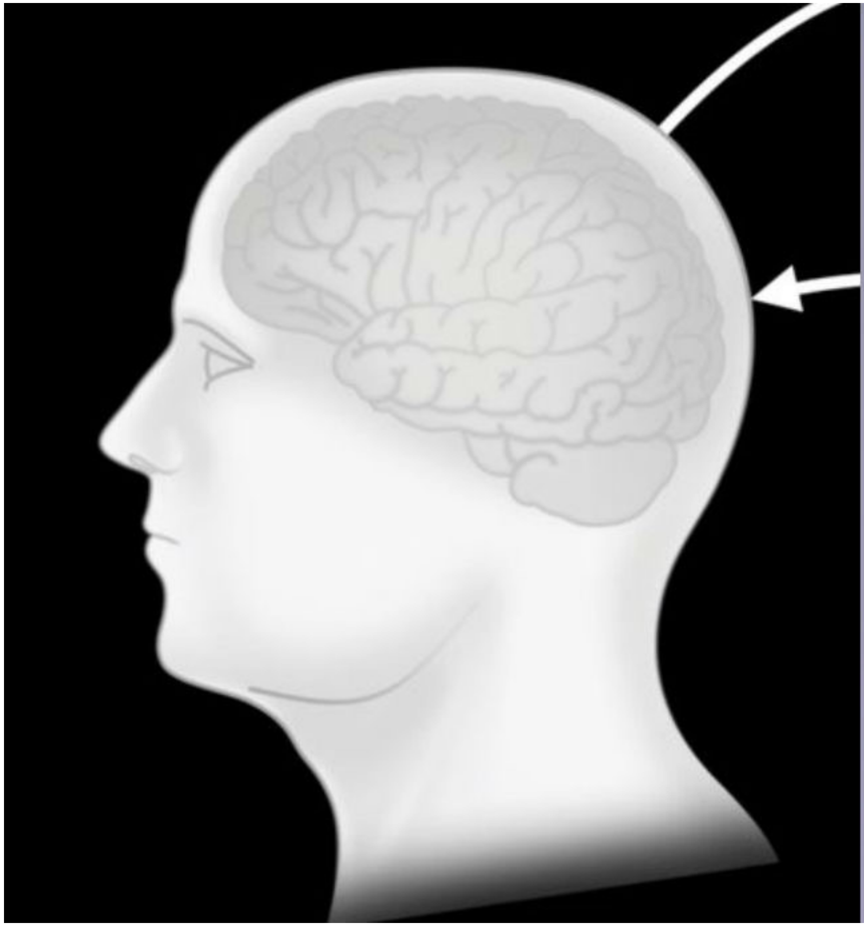
Poor temporal resolution

Magnetoencephalography (MEG) provides greater temporal resolution with useful spatial resolution

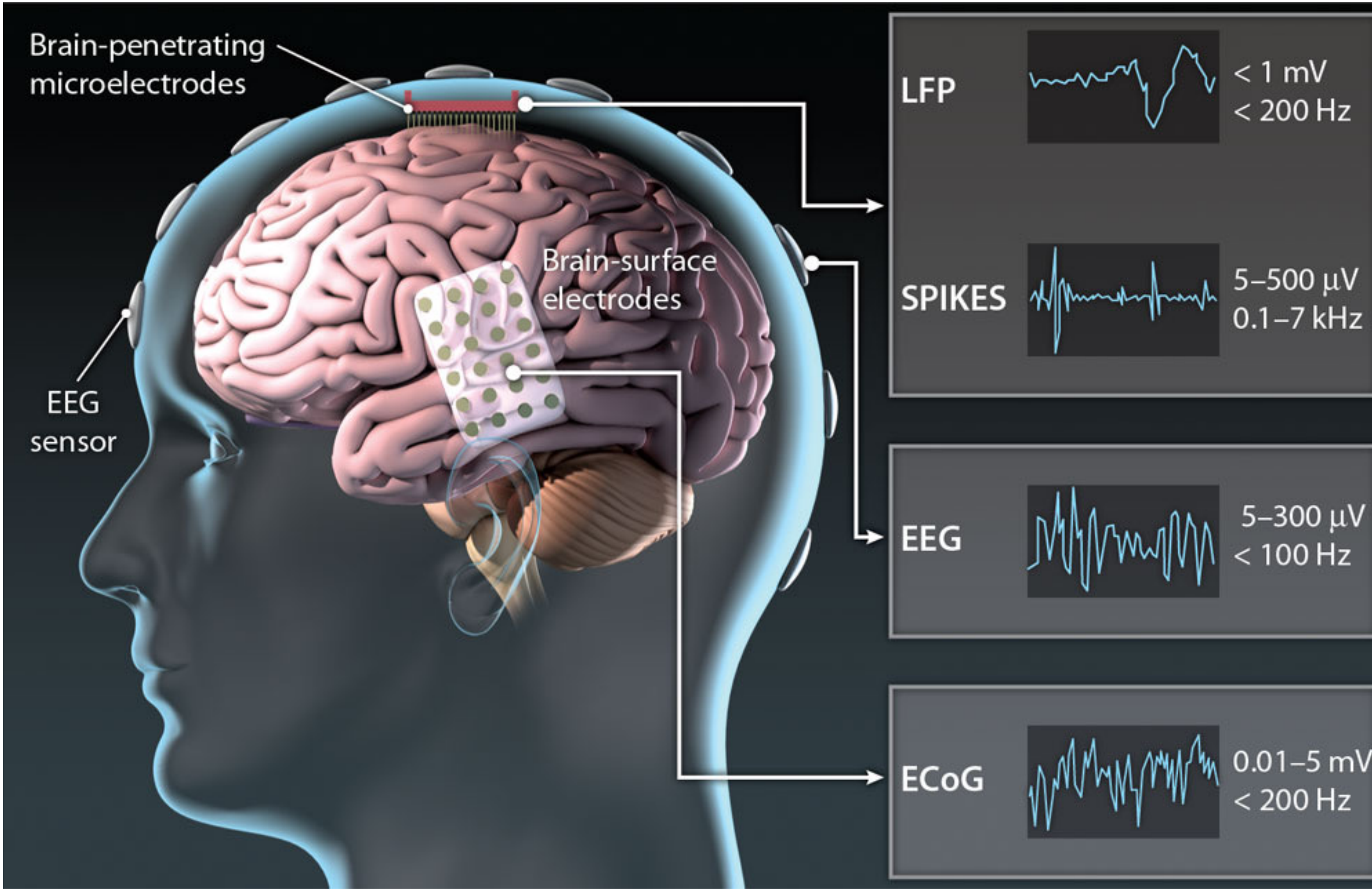


NEUROSCIENCE 6e, Figure 1.22

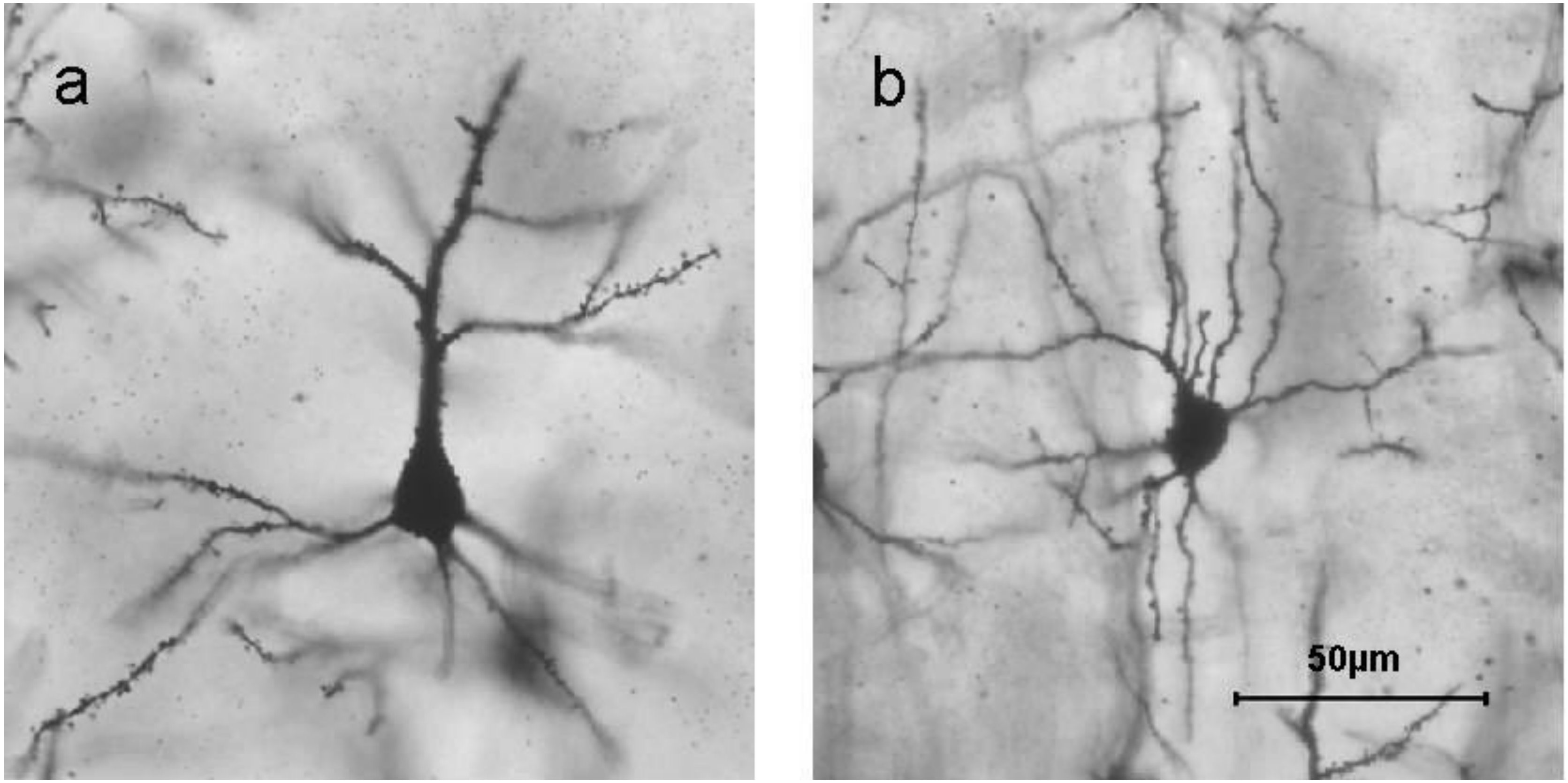
Why should we care?



Why should we care?

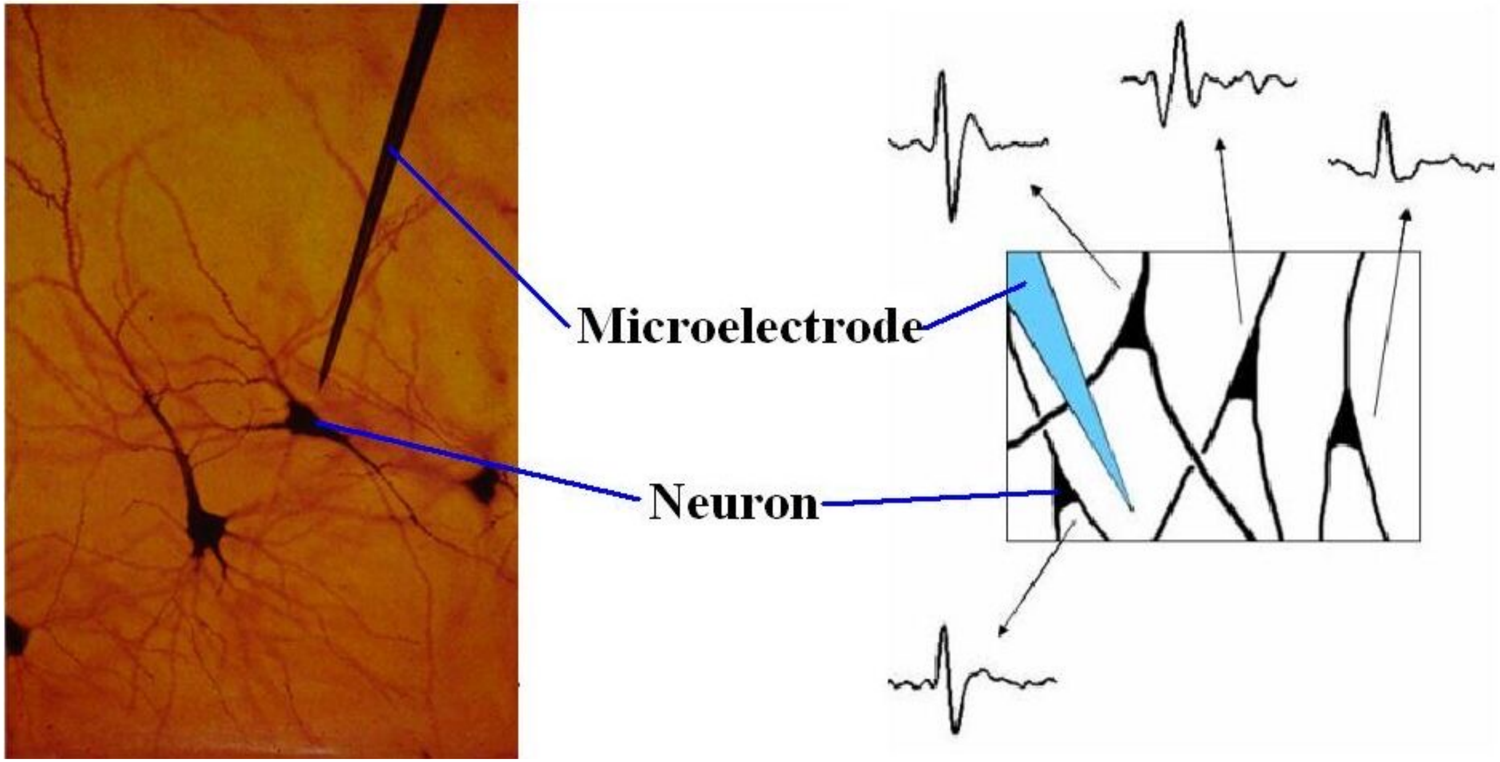


Cortical pyramidal and stellate cells

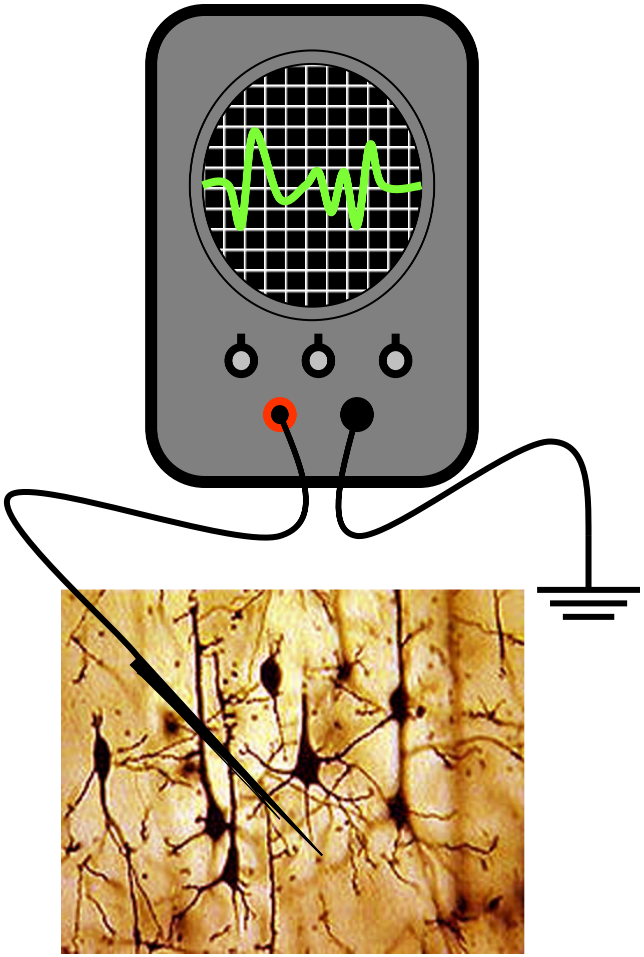


Neural signals at the single cell level

Sub mV signals



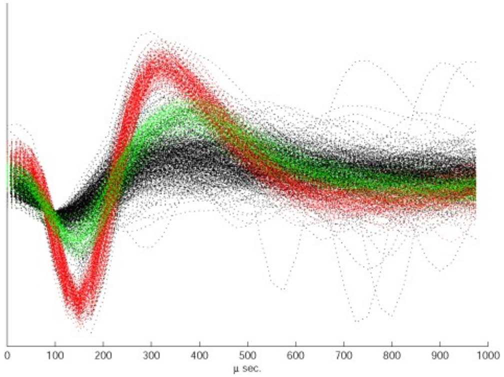
- Characterize the relation between stimuli and neural responses
- The activity of neural ensembles is critical to understanding how information is coded, learned, processed, and retained by the nervous system



Neural Recordings

Neural signals are what we use to control neuroprostheses

If we do not understand what they mean to the brain how can we use them intelligently?



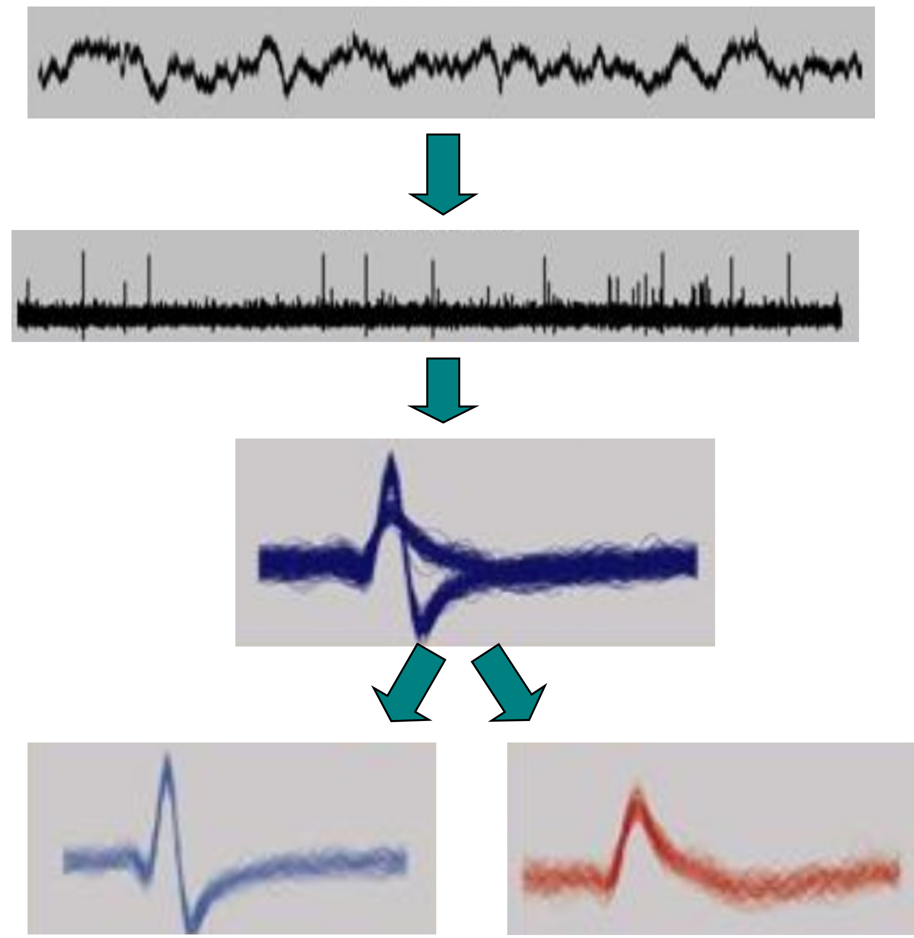
Basic Steps for Spike Sorting

Raw Data

Filtered Data

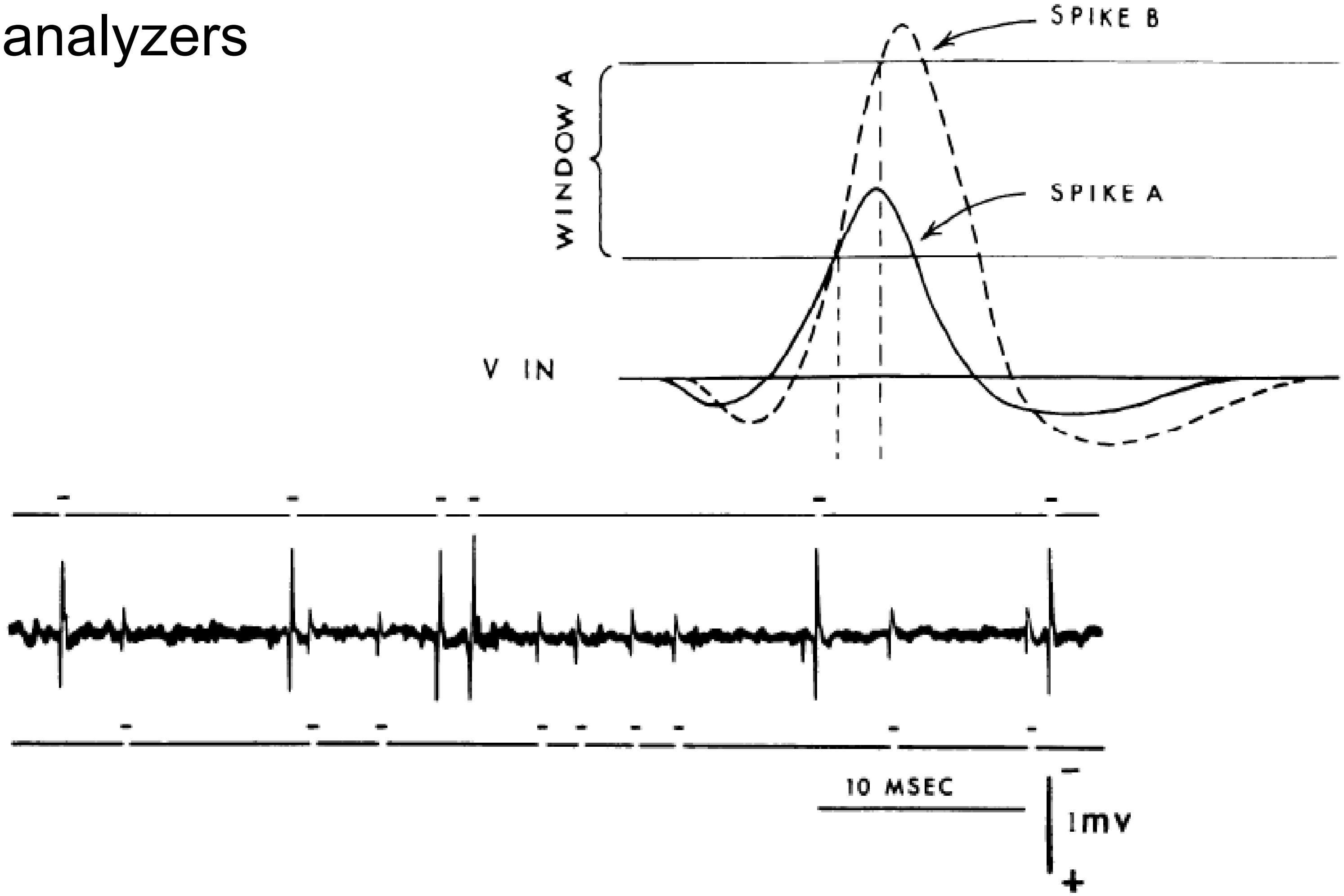
Spike Detection

Classification Algorithm



Sorting Based on Height

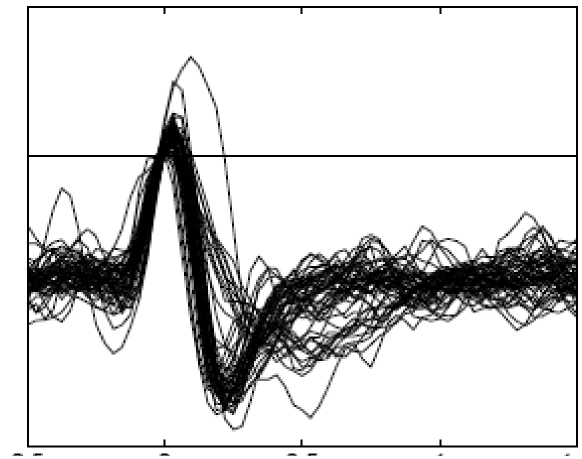
Relatively simple with pulse height analyzers

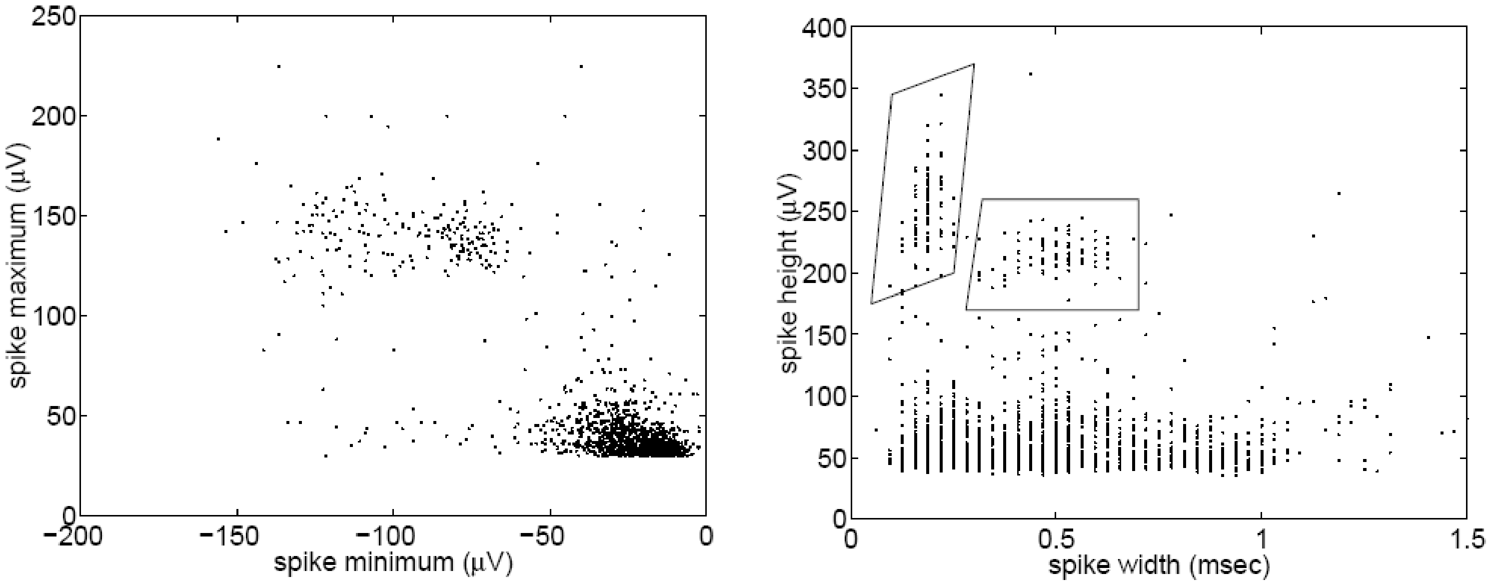


Sorting Based on Shape

What if spikes have similar height?

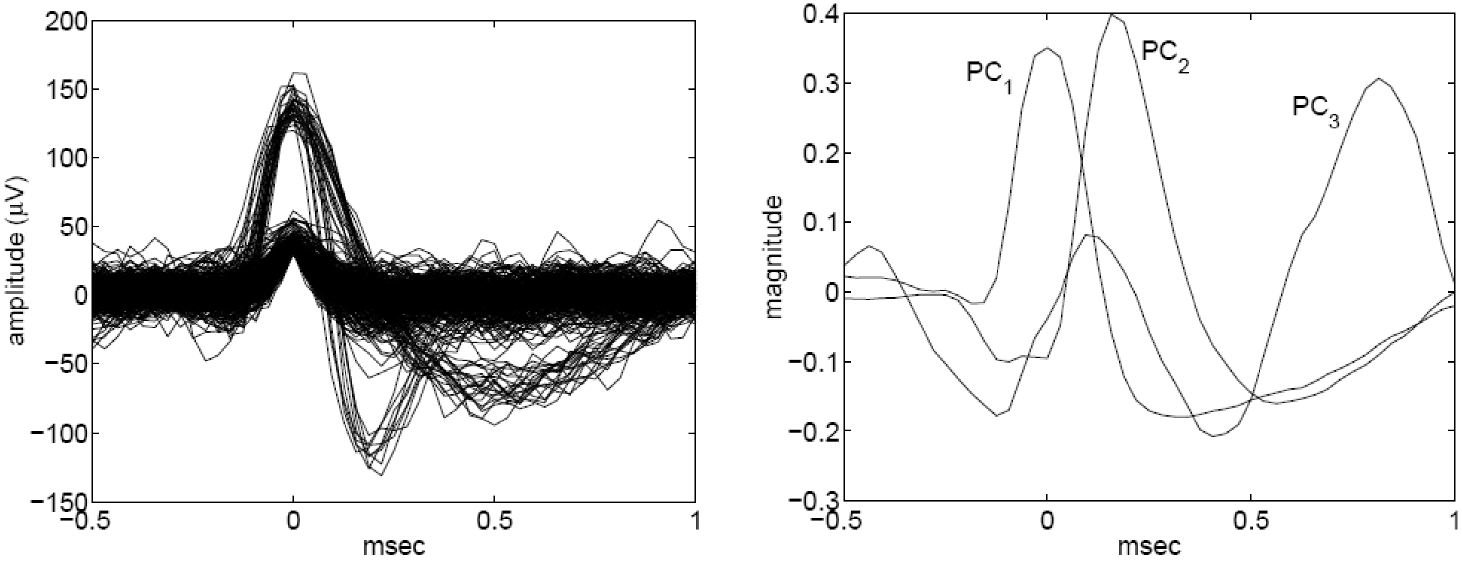
Select features to analyze



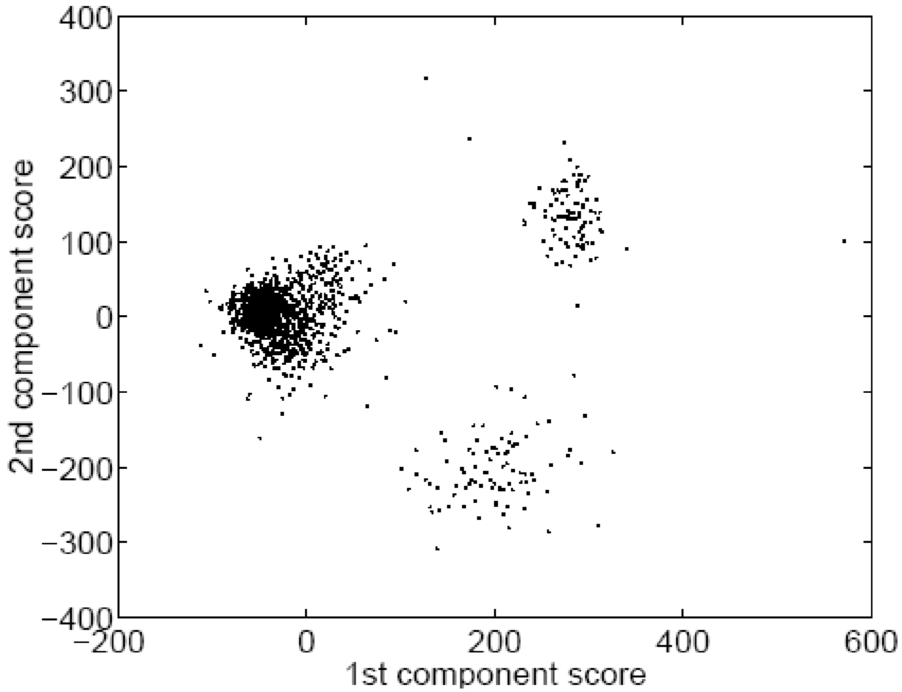


(a) (b)

- Instead of selecting obvious features of the waves (height, width, max, min…) describe them as sum of weighted principal components
  - Analogous to Fourier Series approximation



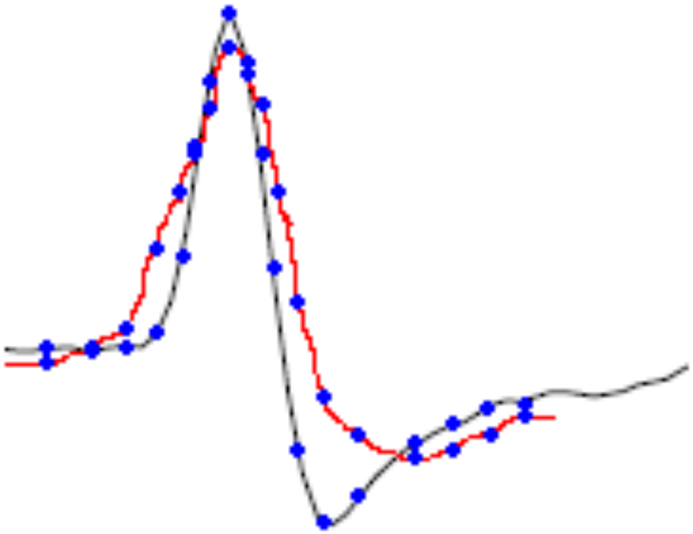
Principal Component Analysis



Score is the “coefficient” of each principal component

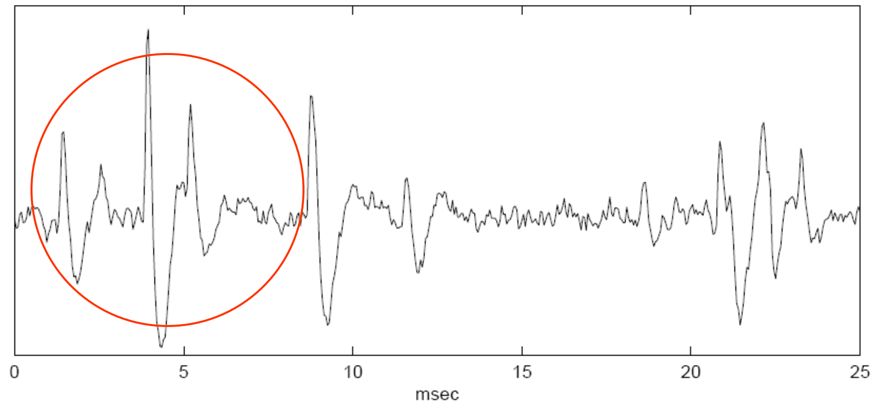
- First choose a “standard” spike shape
- Calculate the difference between a recorded spike and the “standard”
  - Add up the weighted differences at a number data points ⇨

    “dissimilarity number”



Overlapping Spikes

Problematic since superposition of spikes changes the shape of the signal



Occurs frequently

- Example: Consider 3 neurons, each firing at 50 Hz with 1 ms pulse durations ⇨ 15 superpositions per second

- Algorithms to sort overlapped spikes:
  - Subtract a template from the superposition
    - Easiest, but only works when two spikes are separated enough to identify
    - Introduces more noise
  - Choose two templates and compare the recorded waveform with all possible combinations of two templates
    - Computationally Expensive

- More accurately sort multi-unit recordings
  - Analogous to having 2 ears
- Single electrode algorithms can extend to multi-electrode recordings

Other Problems

Spikes are non-stationary

Noise is non-stationary

Electrode drift

Spike alignment