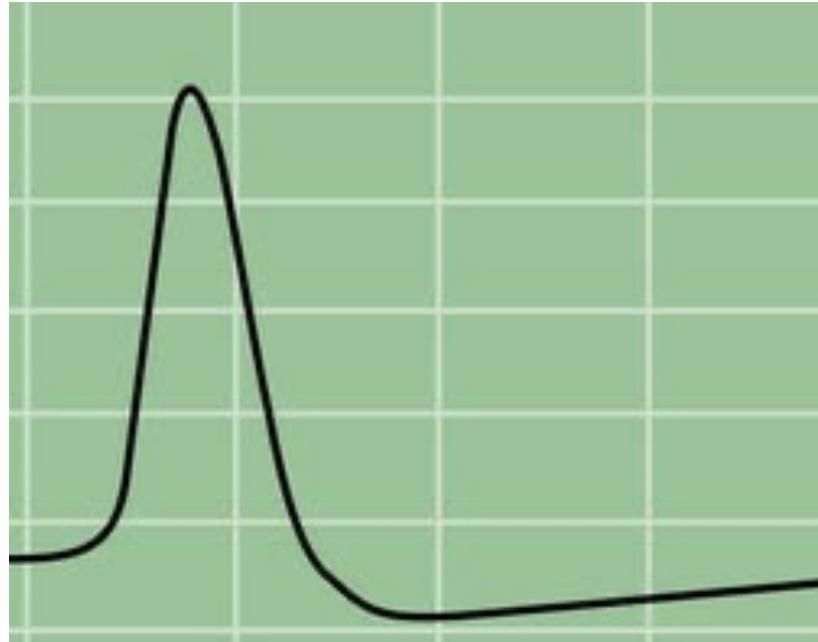


BMD ENG 301 Quantitative Systems Physiology (Nervous System)



Lecture 9: Neural Signals
2022_v3

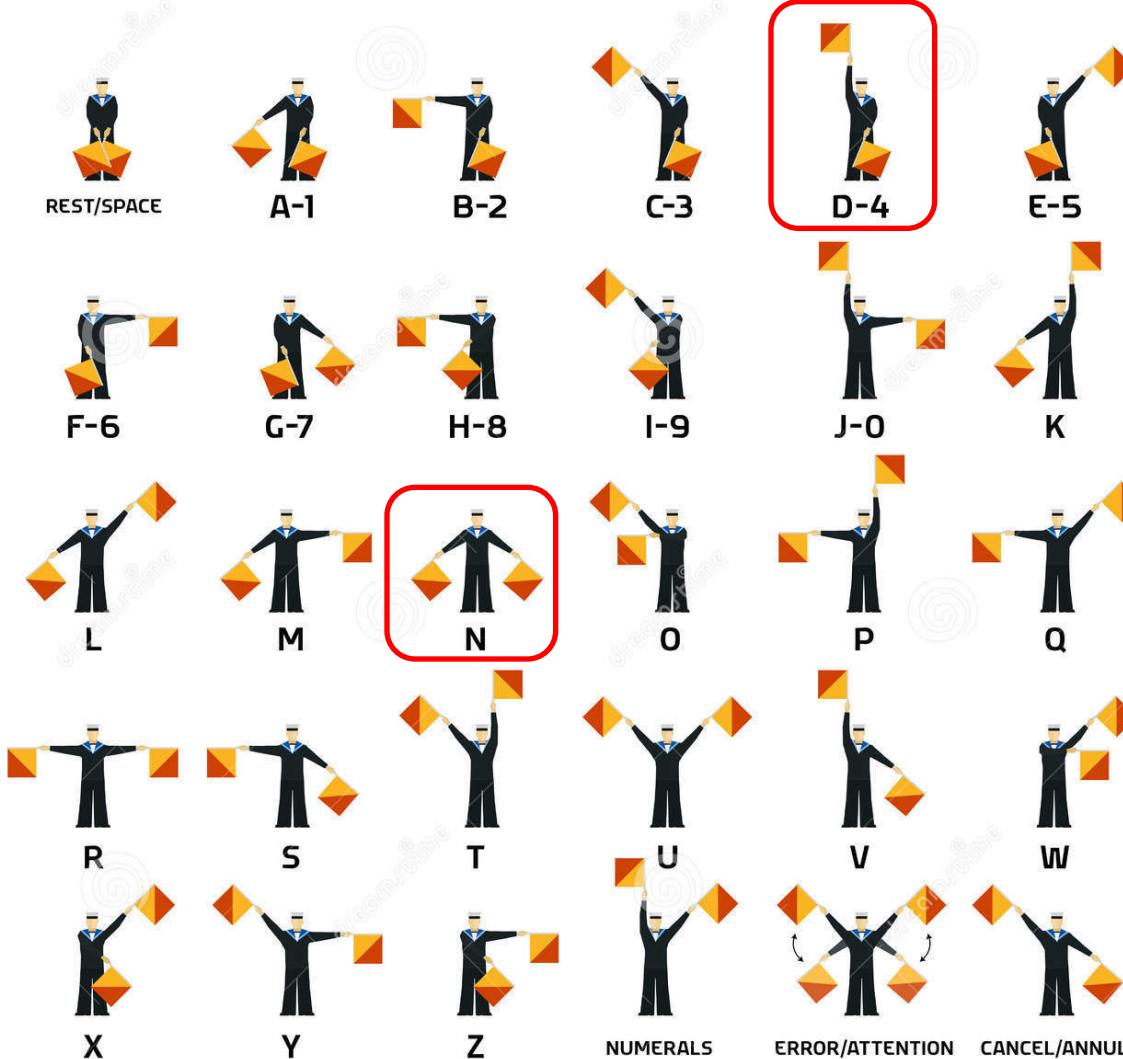
Professor Malcolm A. MacIver

Peace Sign

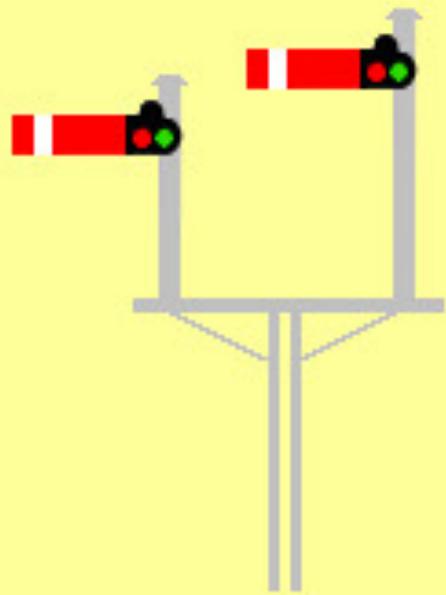


Designed by Gerald Holtom for the campaign for Nuclear Disarmament in 1958

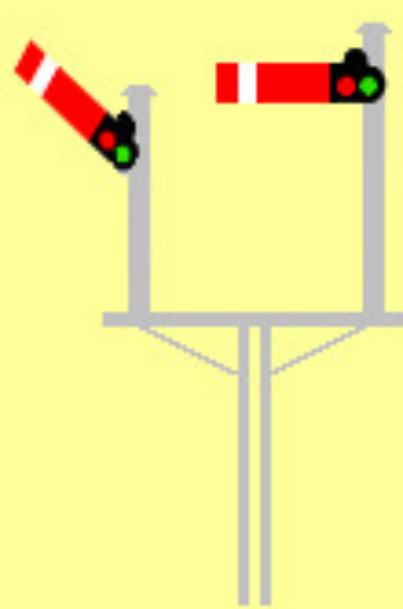
SEMAPHORE ALPHABET



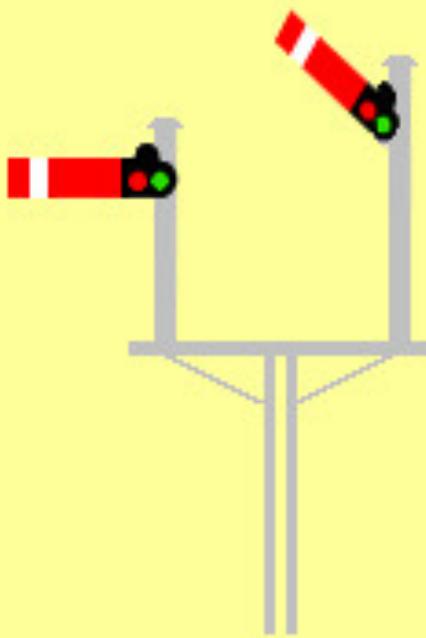
Stop



Train to travel
on branchline



Train to travel
on mainline



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

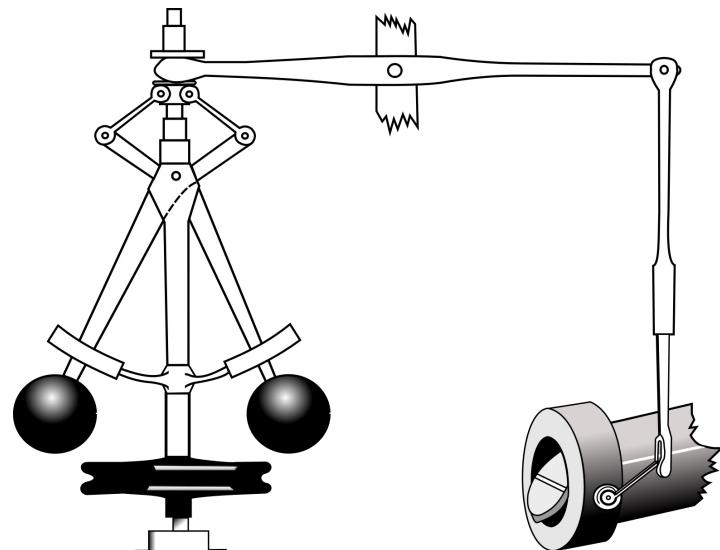
MORE RECENT THINKING: Signals are processed and outputs occur as a result of a (possibly high dimensional) continuous computation. Useful metaphor: the Watt governor

Digital computation

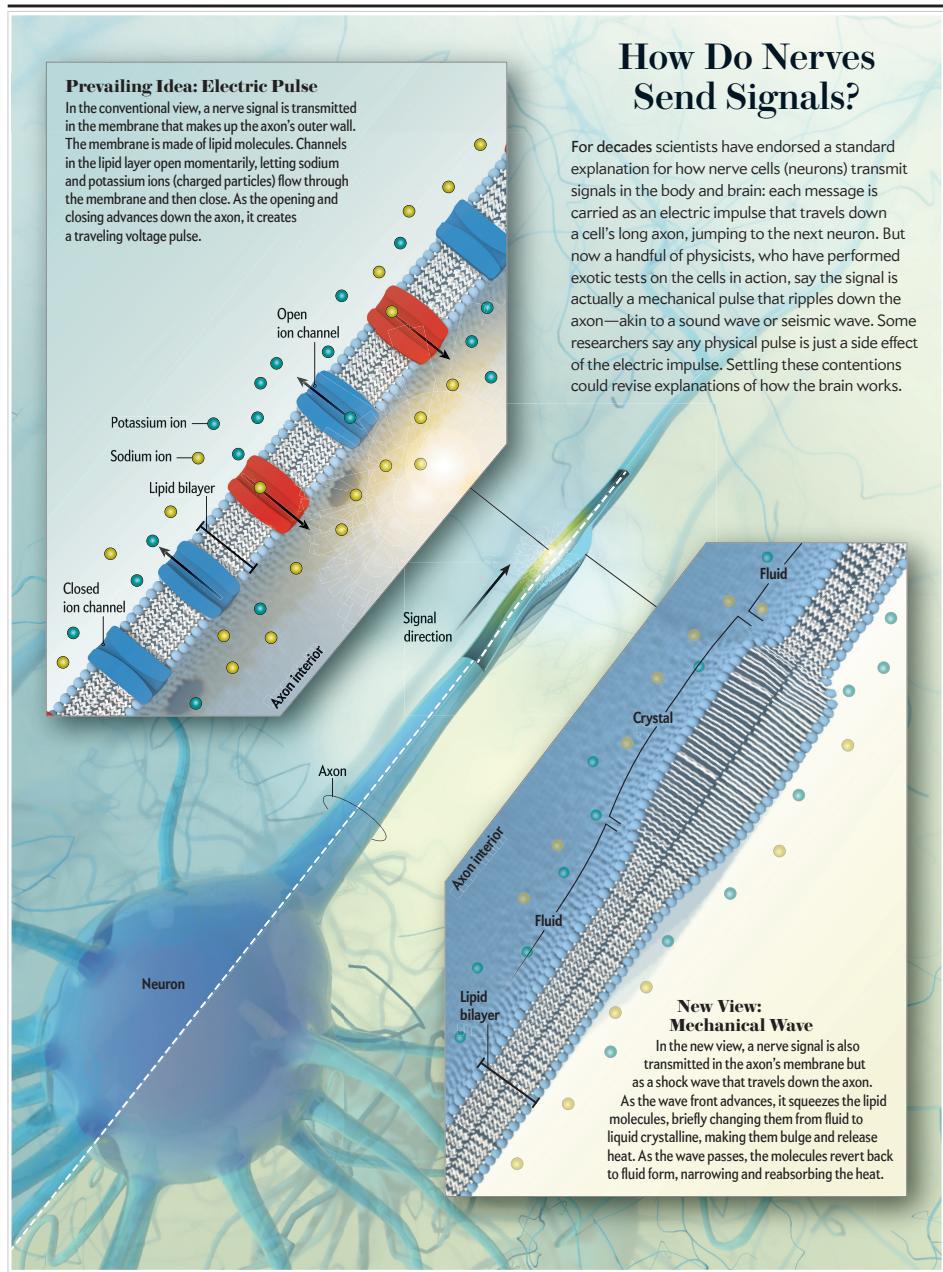
Algorithm for keeping a DC motor at the same revolutions per minute (RPM) as load varies, using a Hall Effect sensor on a flywheel attached to motor (note: In a DC motor, rotation speed is linear with input voltage):

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



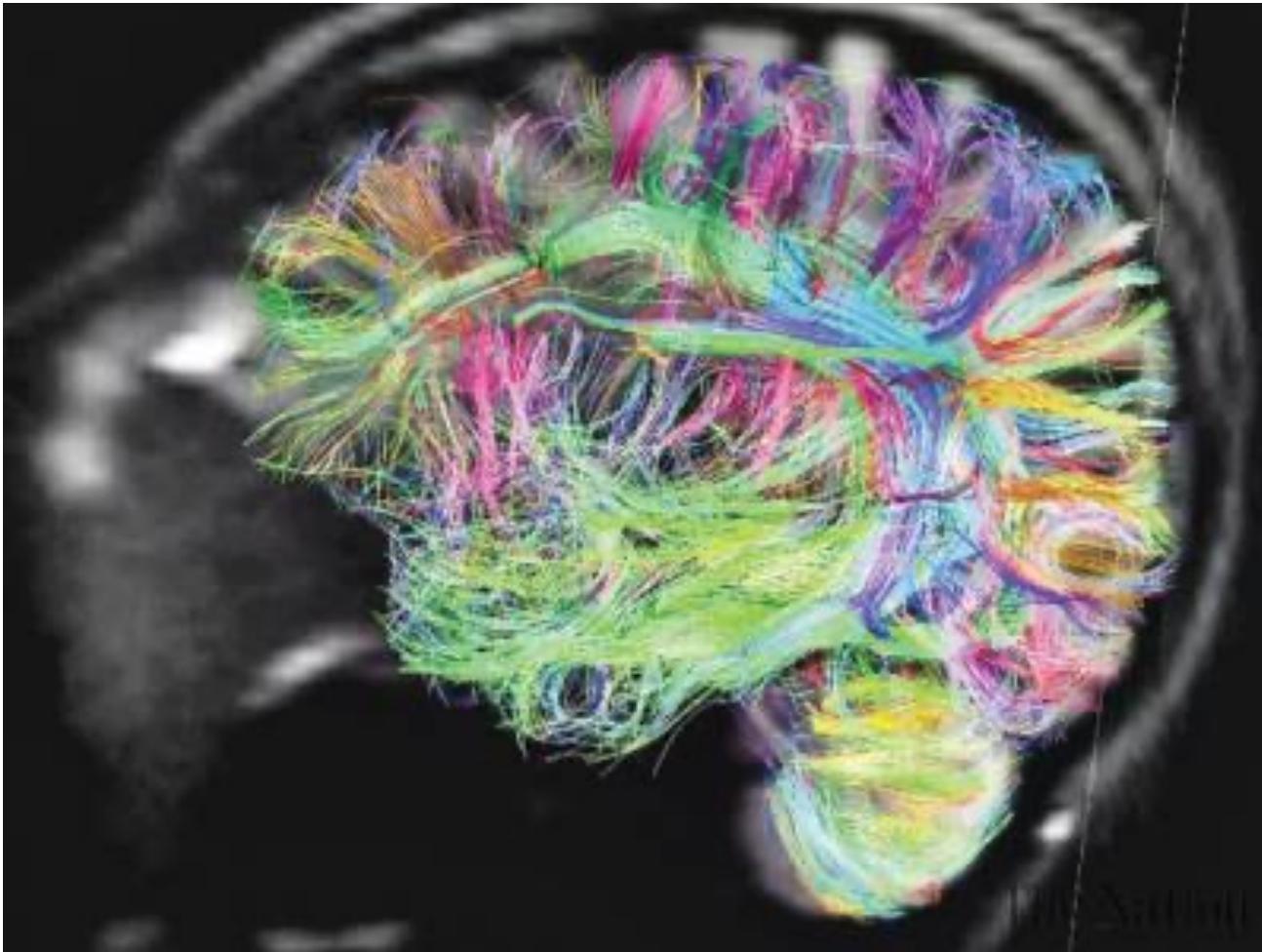
Watt governor



How Do Nerves Send Signals?

For decades scientists have endorsed a standard explanation for how nerve cells (neurons) transmit signals in the body and brain: each message is carried as an electric impulse that travels down a cell's long axon, jumping to the next neuron. But now a handful of physicists, who have performed exotic tests on the cells in action, say the signal is actually a mechanical pulse that ripples down the axon—akin to a sound wave or seismic wave. Some researchers say any physical pulse is just a side effect of the electric impulse. Settling these contentions could revise explanations of how the brain works.

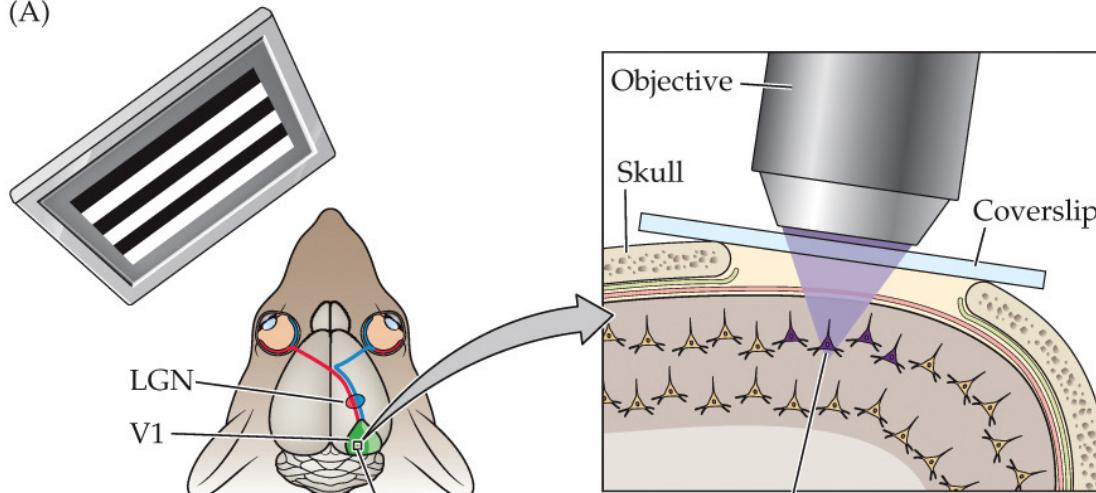
The Electrical and the Mechanical Hypotheses



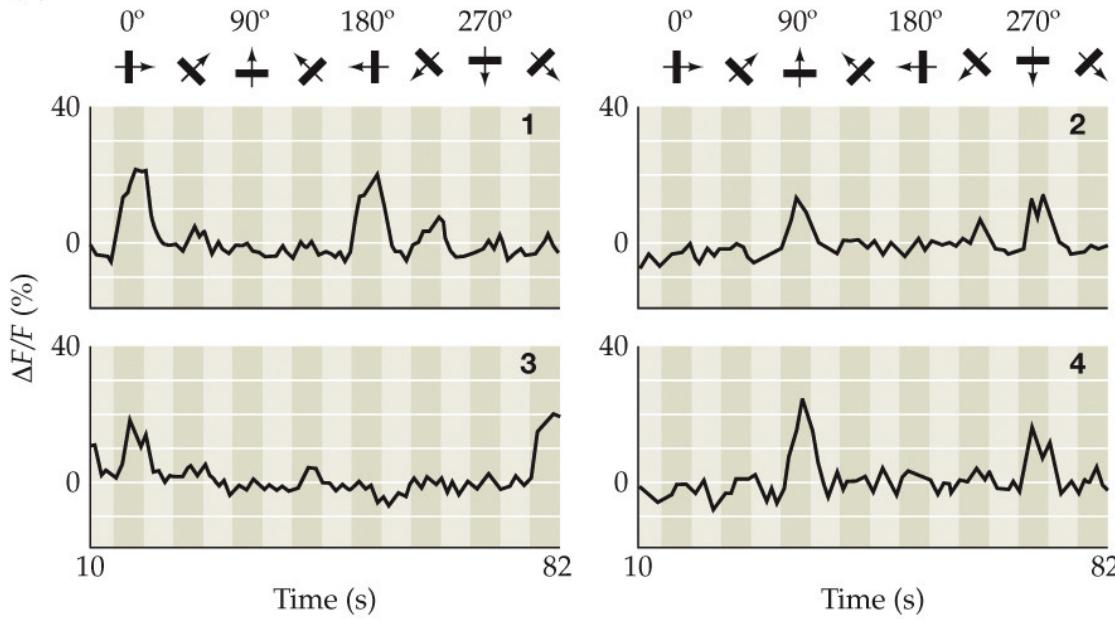
What is the Neural Code?

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

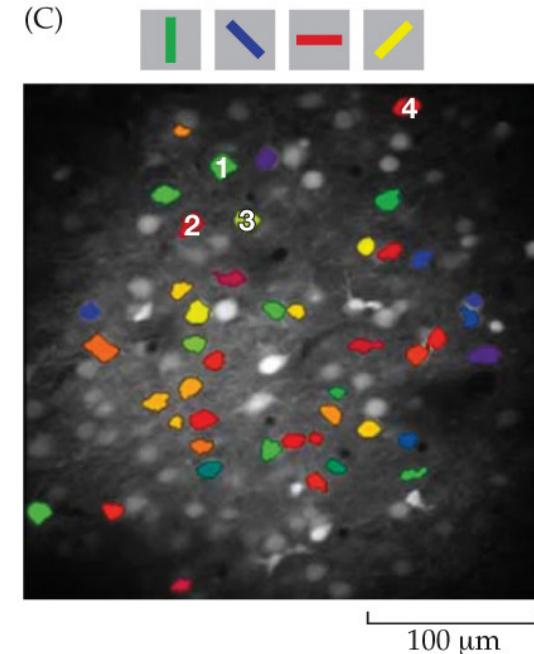
(A)



(B)

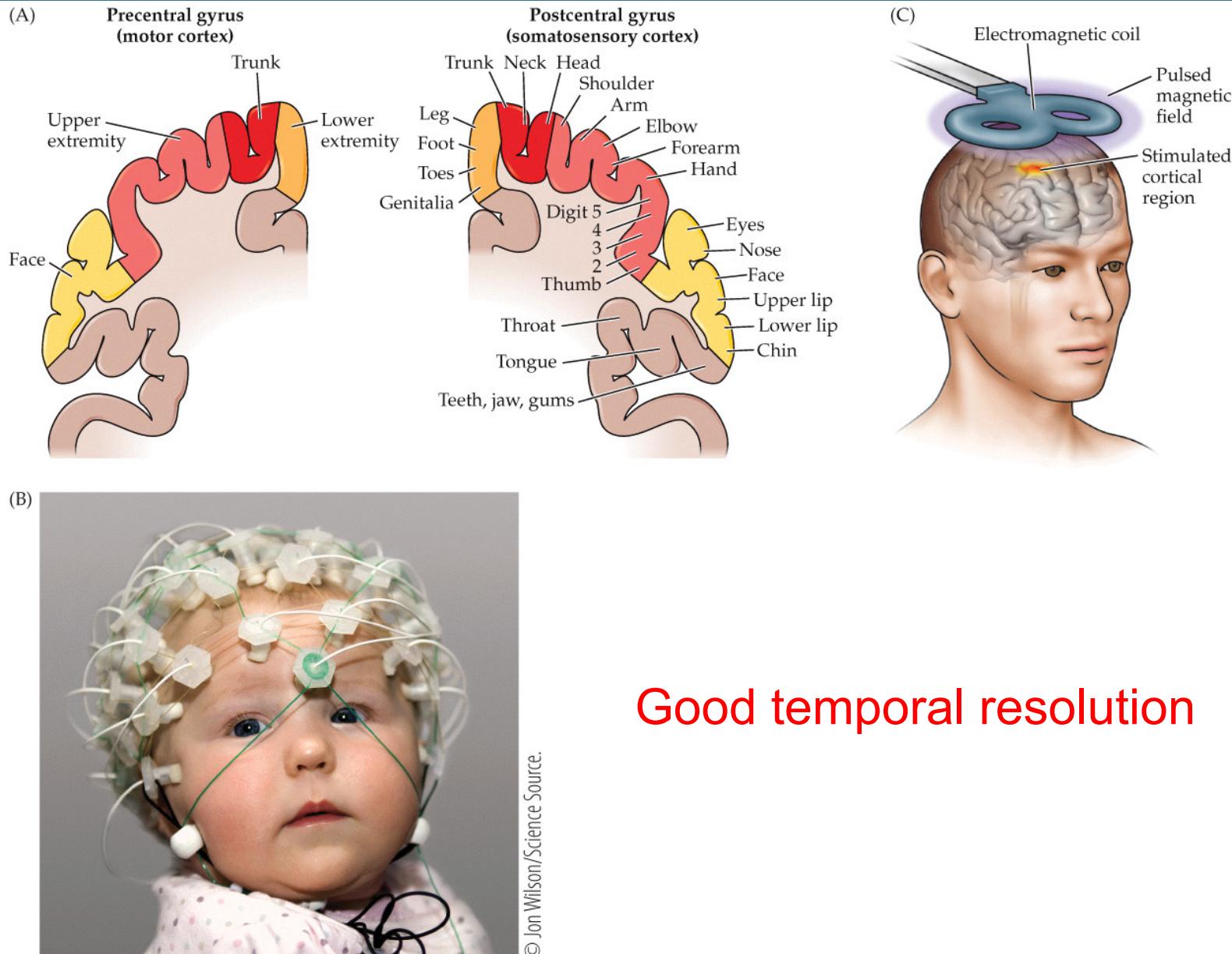


(C)

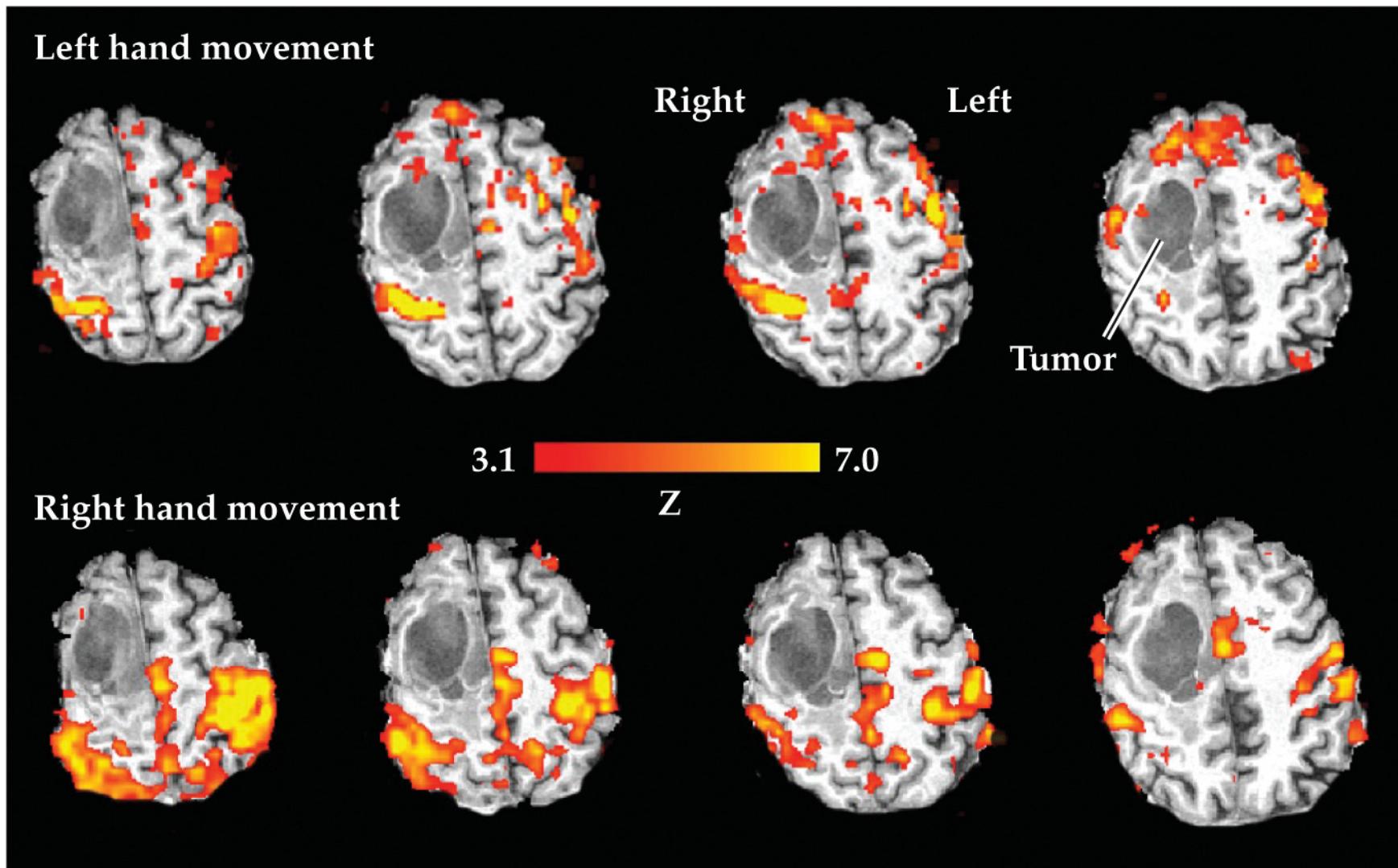


A from Mank et al. (2008) *Nat. Meth.* 5: 805–811. B,C from Ohki et al. (2005) *Nature* 433: 597–603.

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



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



NEUROSCIENCE 6e, Figure 1.21
© 2018 Oxford University Press

Poor temporal resolution

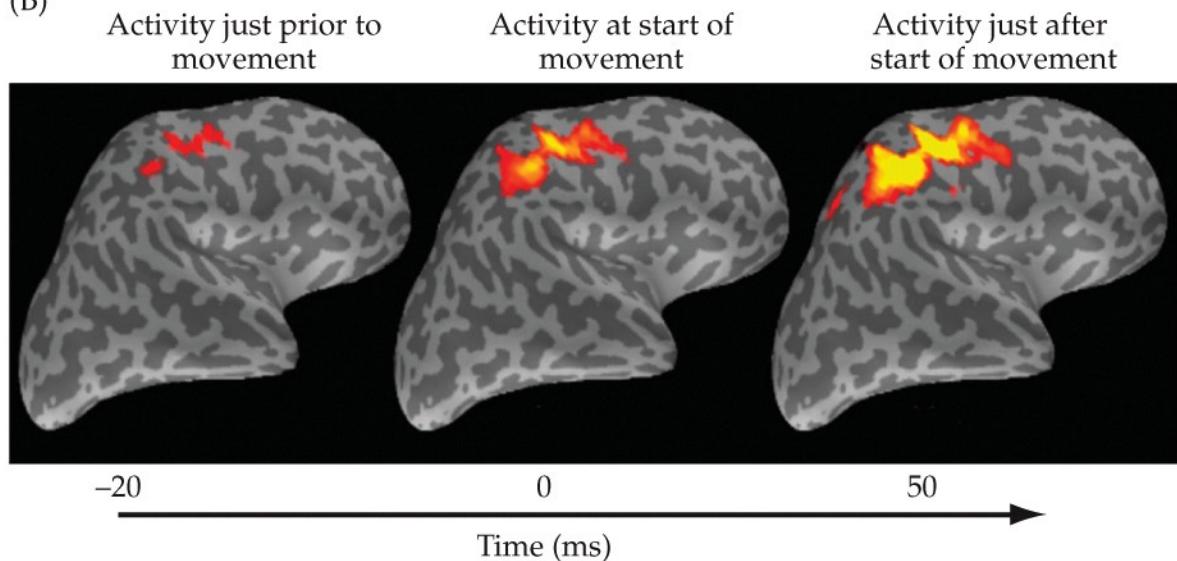
Magnetoencephalography (MEG) provides greater temporal resolution with useful spatial resolution

(A)



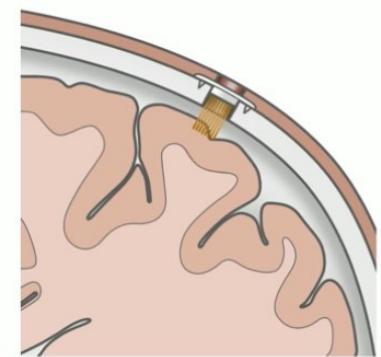
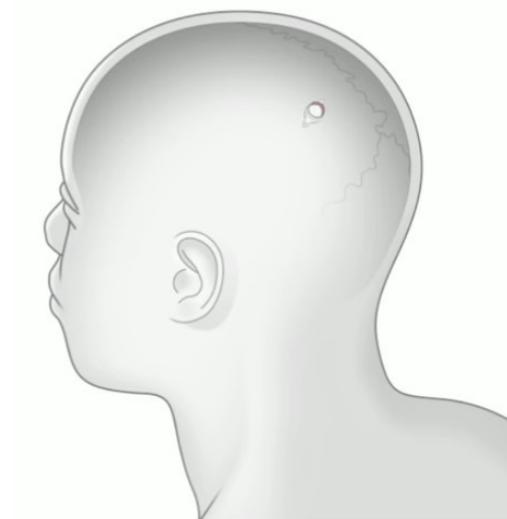
Courtesy of National Institute of Mental Health, Department of Health and Human Services.

(B)

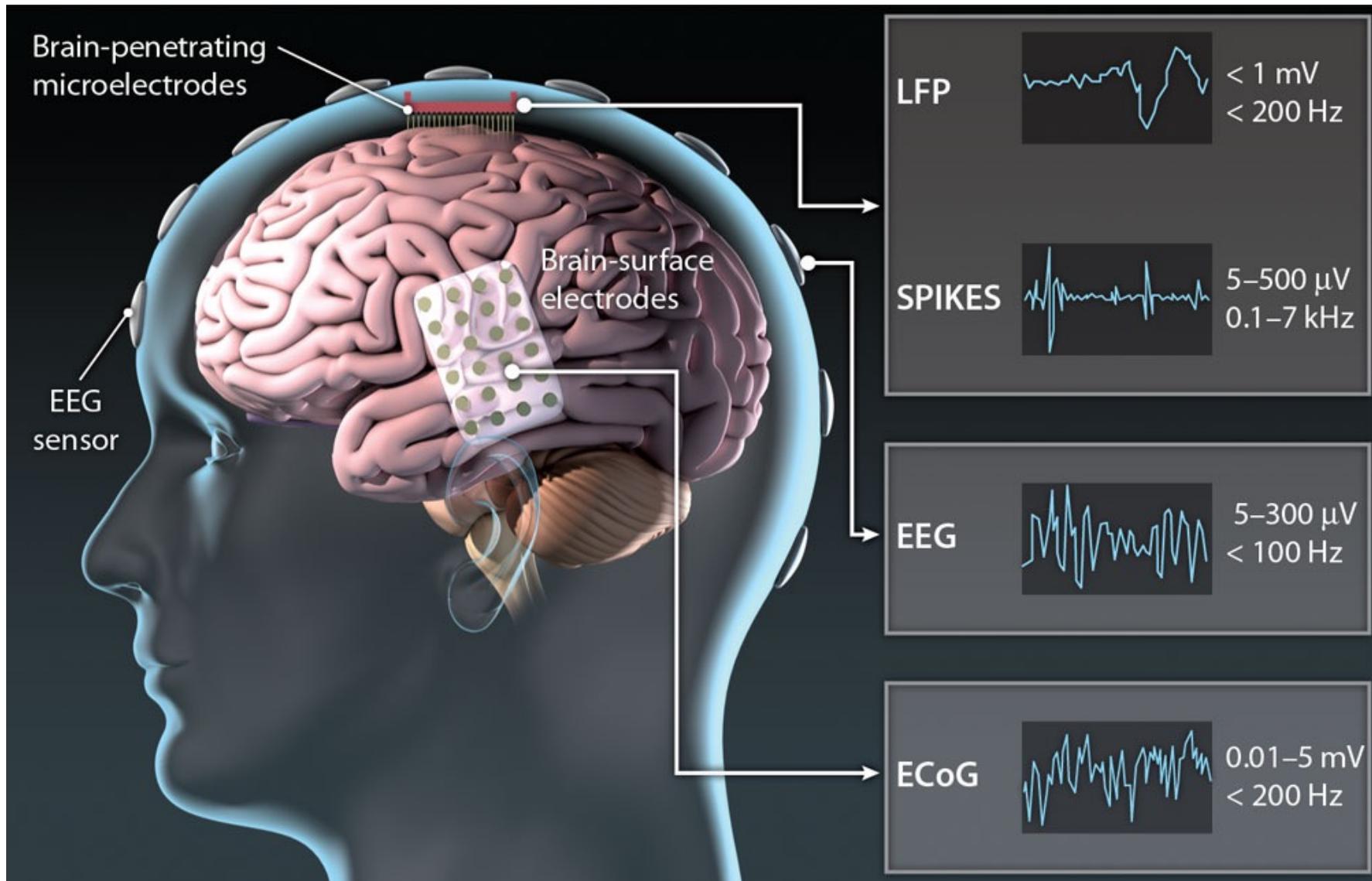


Courtesy J. Schaechter, MGH Martinos Center for Biomedical Imaging.

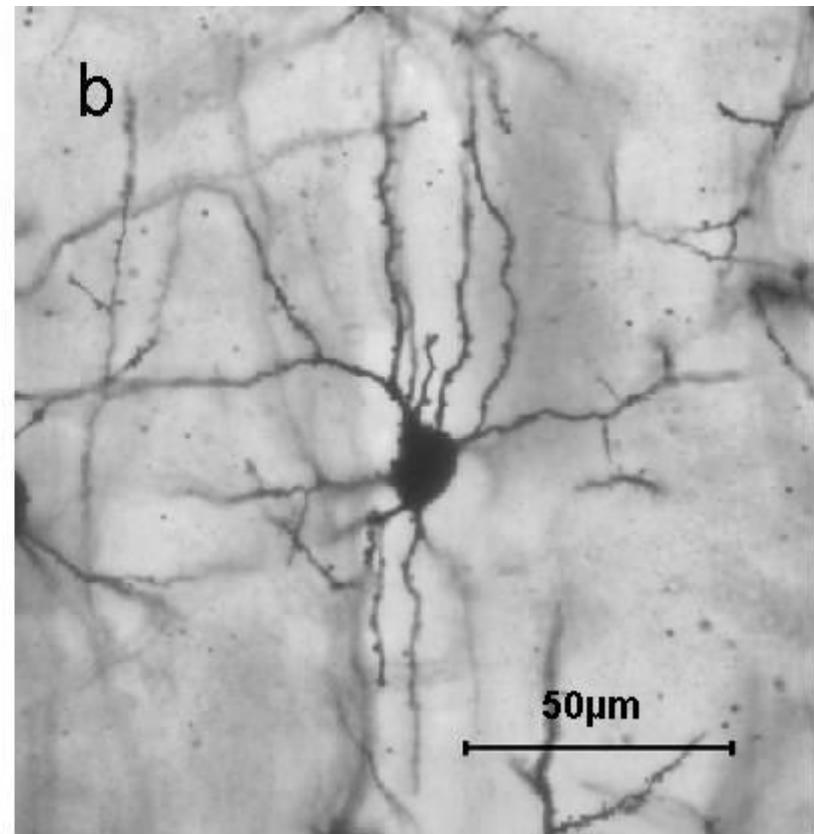
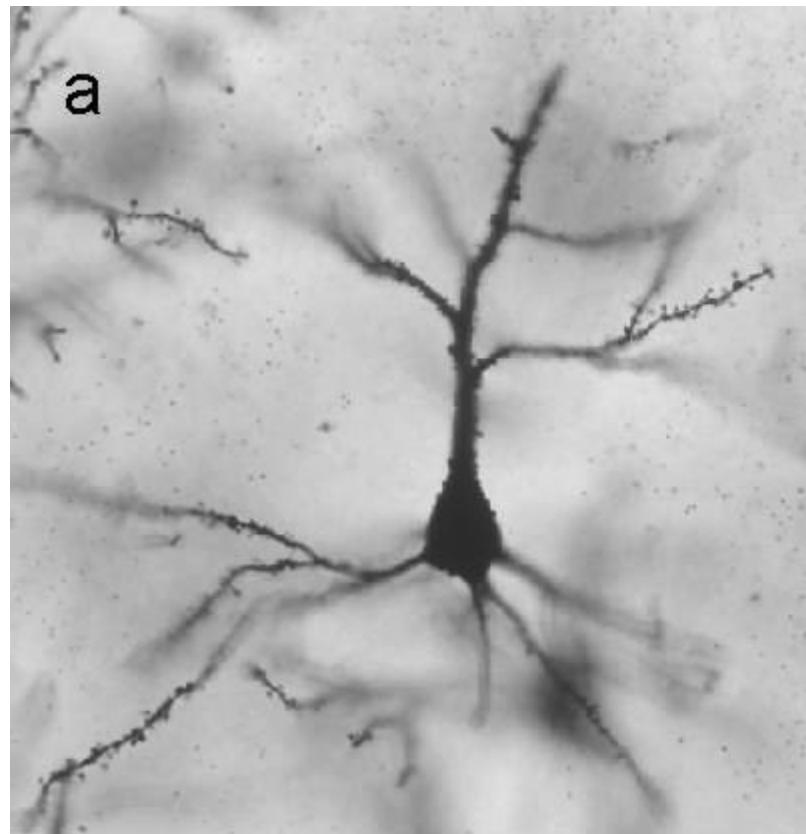
Why should we care?



Why should we care?

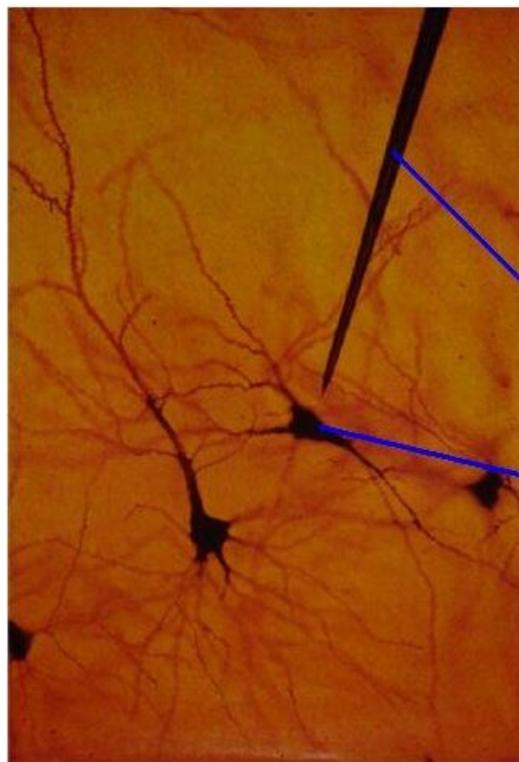


Cortical pyramidal and stellate cells



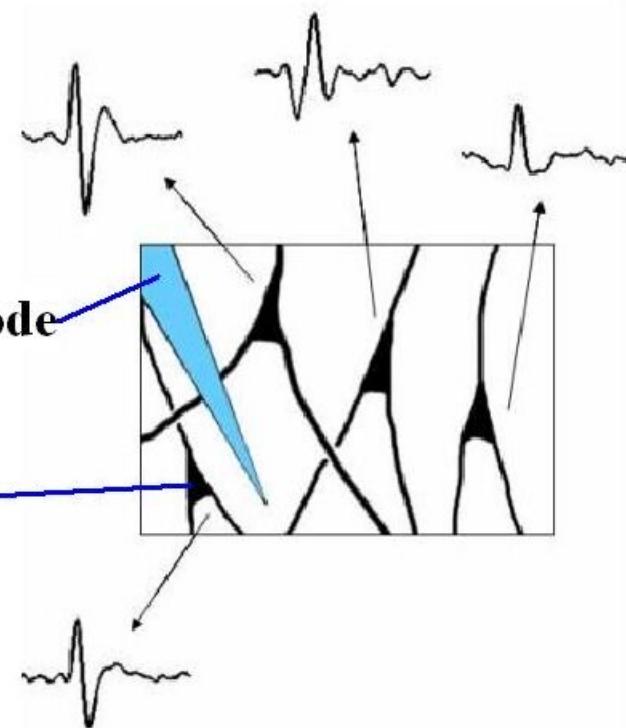
Neural signals at the single cell level

Sub mV signals



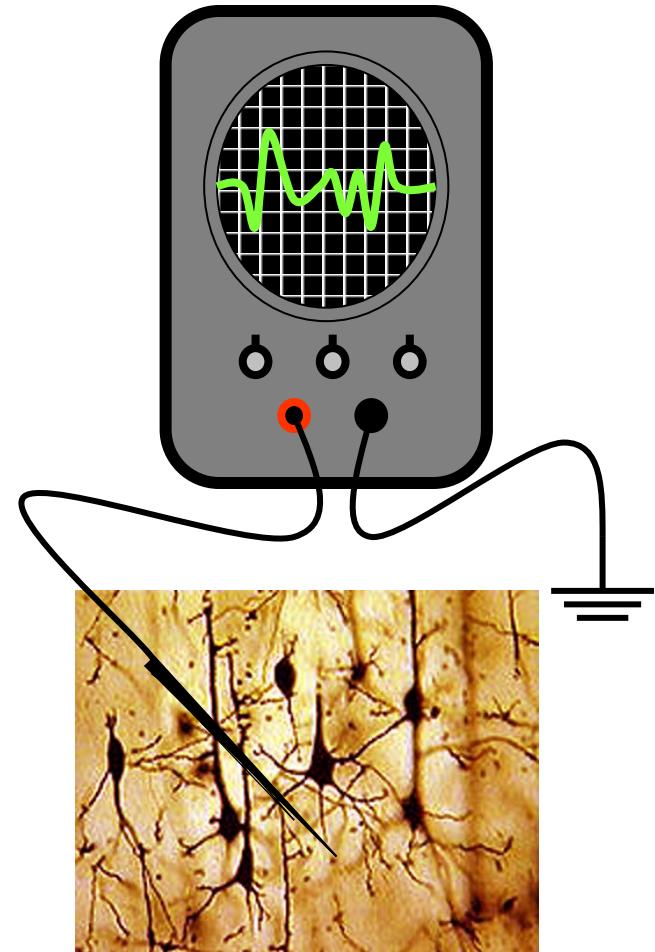
Microelectrode

Neuron



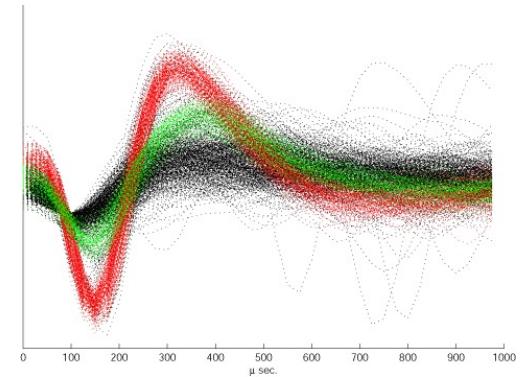
Characterize the relation
between stimuli and
neural responses

The activity of neural
ensembles is critical to
understanding how
information is coded,
learned, processed,
and retained by the
nervous system

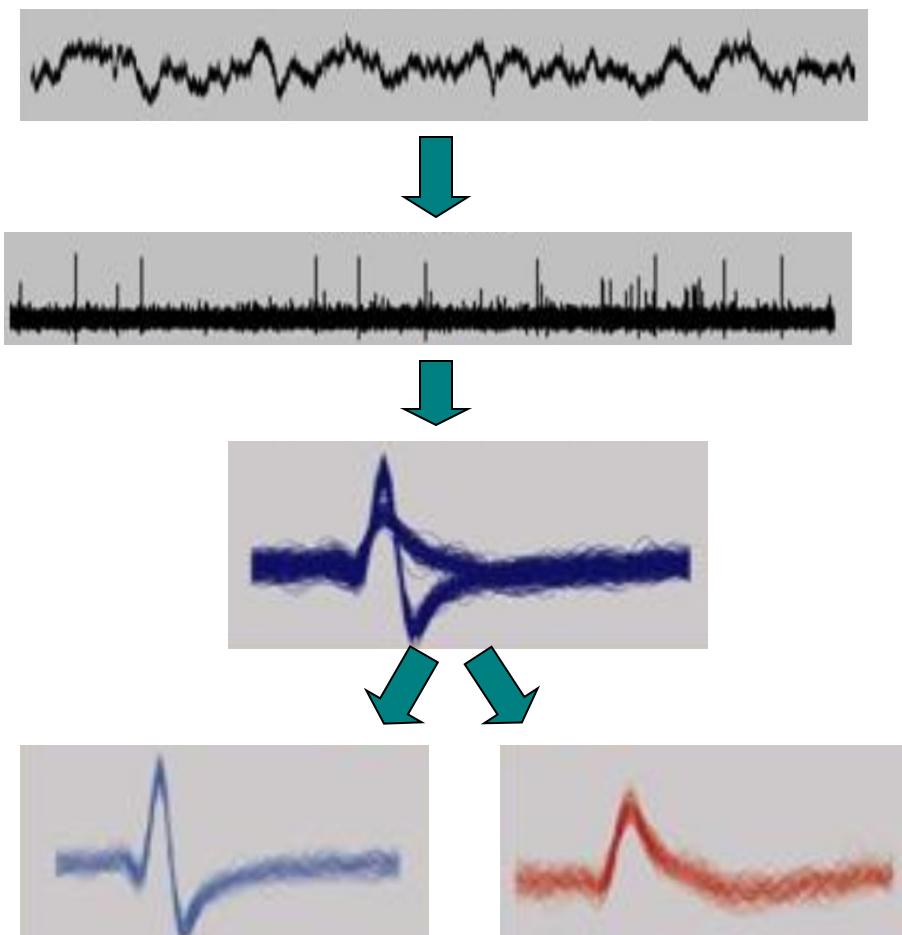
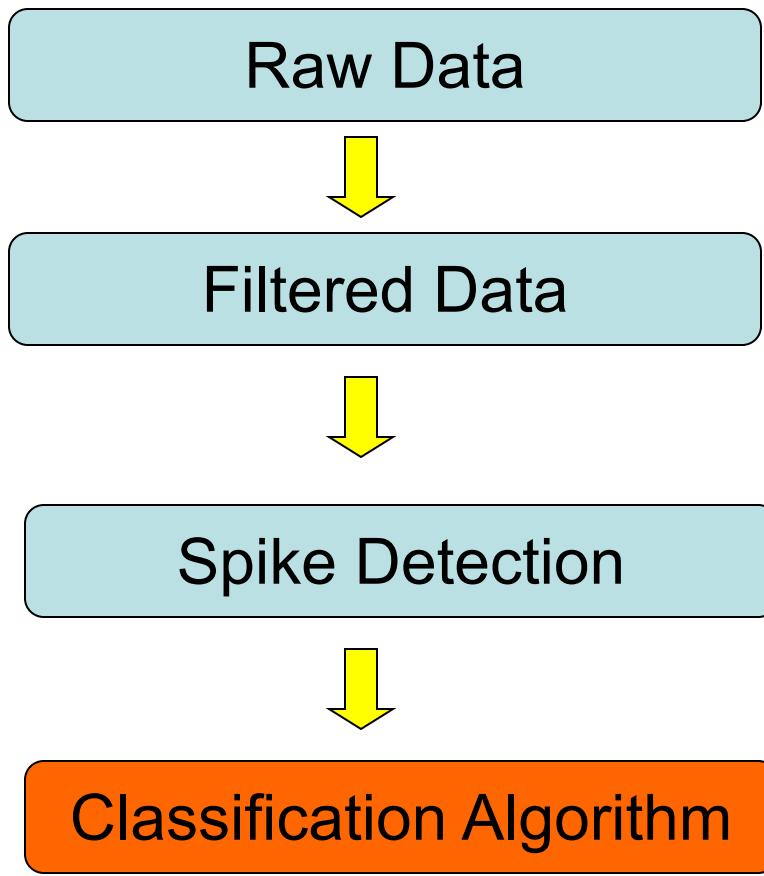


Neural signals are what we use
to control neuroprostheses

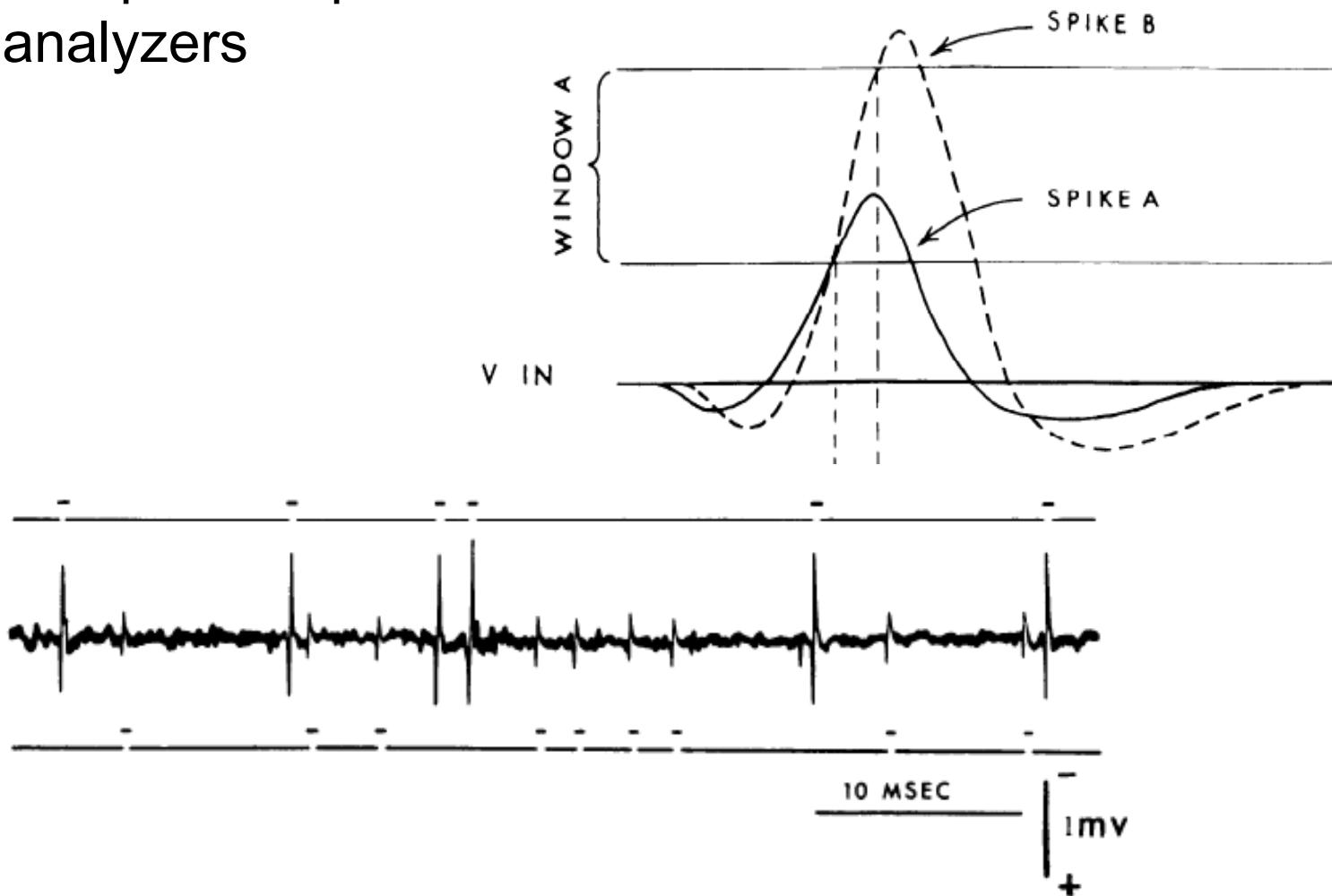
If we do not understand what
they mean to the brain how
can we use them intelligently?



Basic Steps for Spike Sorting

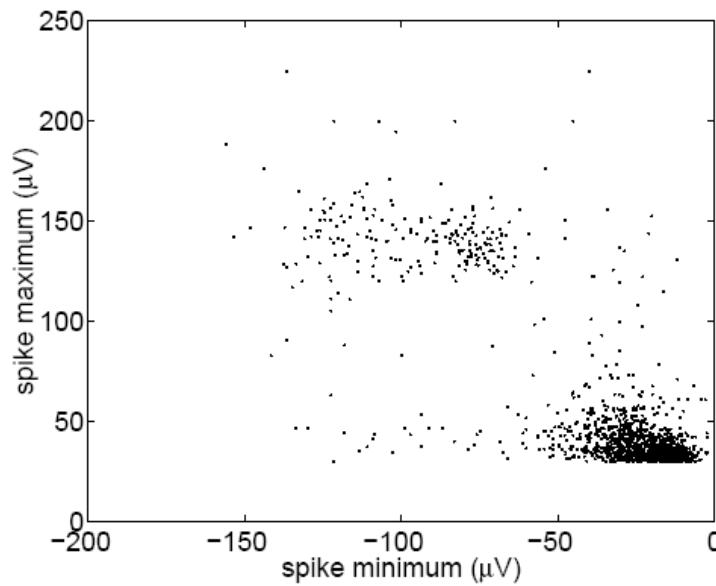


Relatively simple with pulse height analyzers

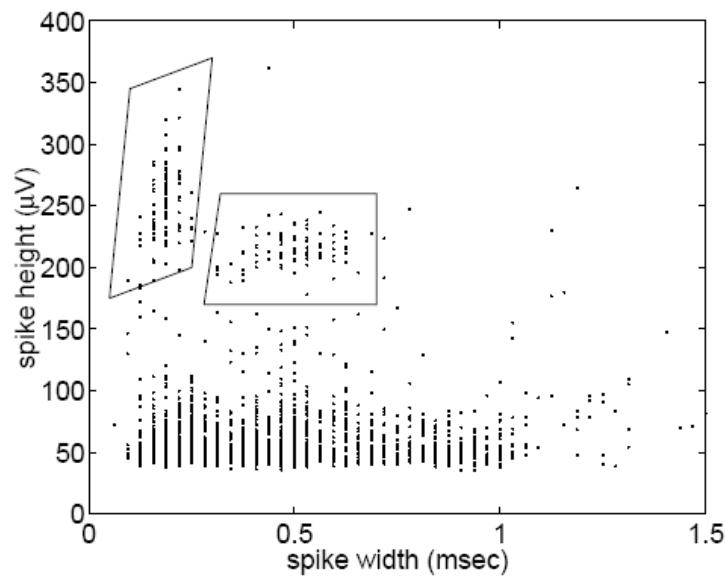


Sorting Based on Shape

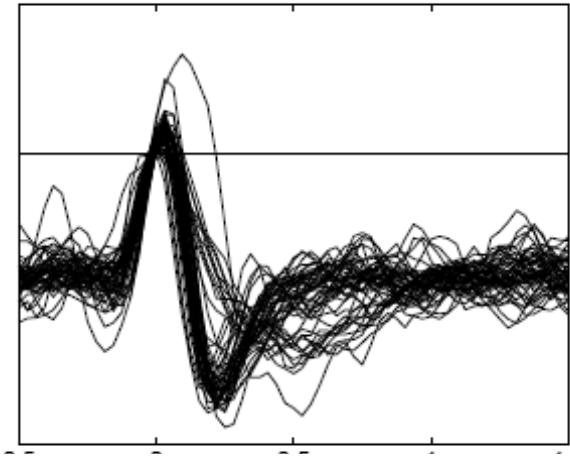
What if spikes have similar height?
Select features to analyze



(a)

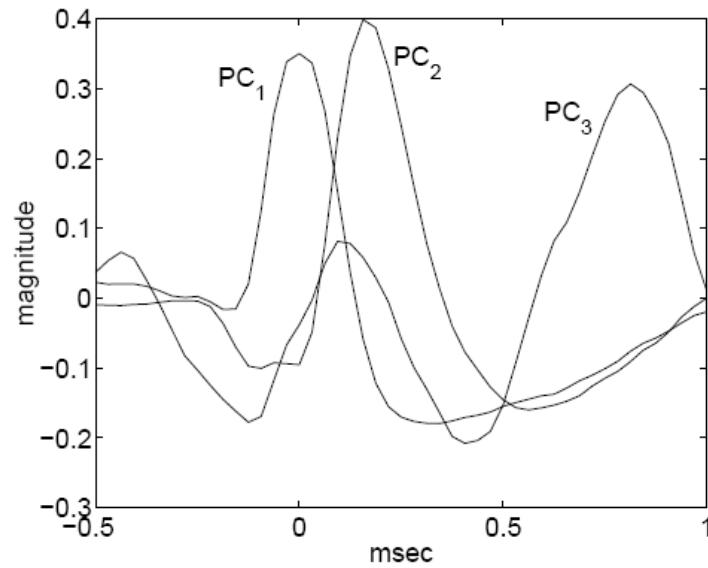
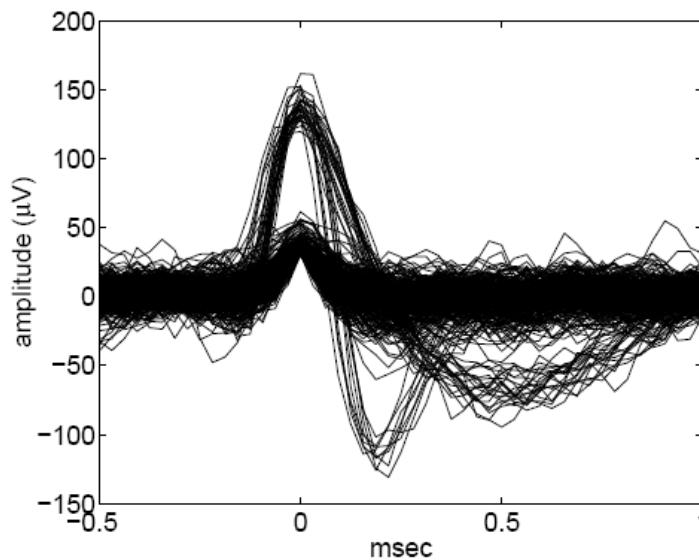


(b)

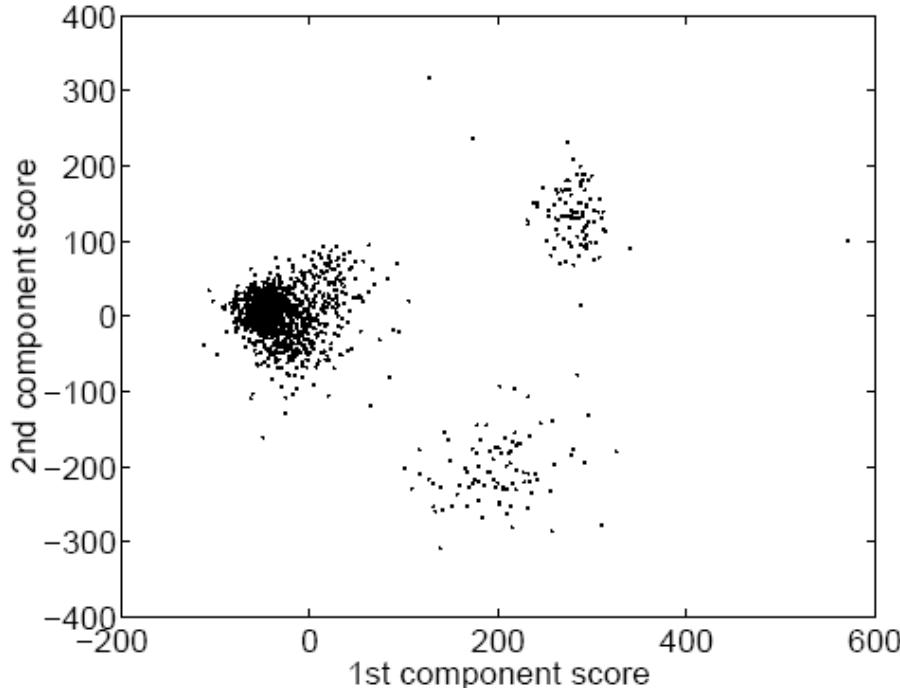


Instead of selecting obvious features of the waves (height, width, max, min...) describe them as sum of weighted principal components

- Analogous to Fourier Series approximation



Principal Component Analysis

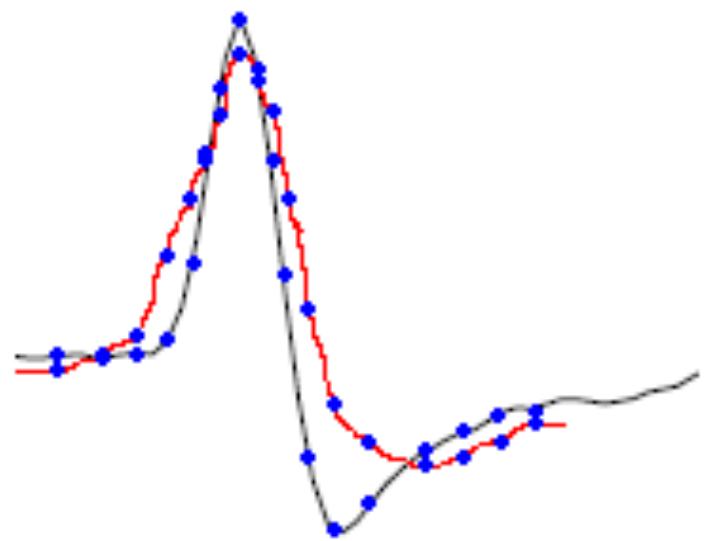


Score is the “coefficient” of each principal component

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”

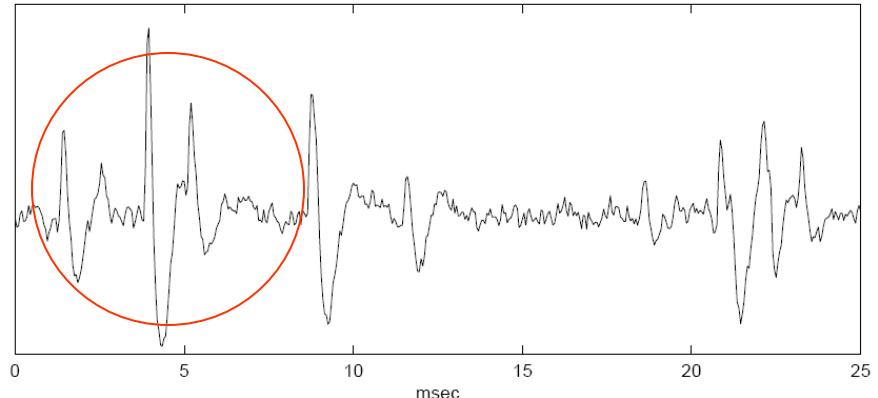


Overlapping Spikes

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

Spikes are non-stationary

Noise is non-stationary

Electrode drift

Spike alignment