

Question of the Day

You're at a concert and people start doing the wave.

Does the wave cause you to raise your arms, or does you raising your arms cause the wave?

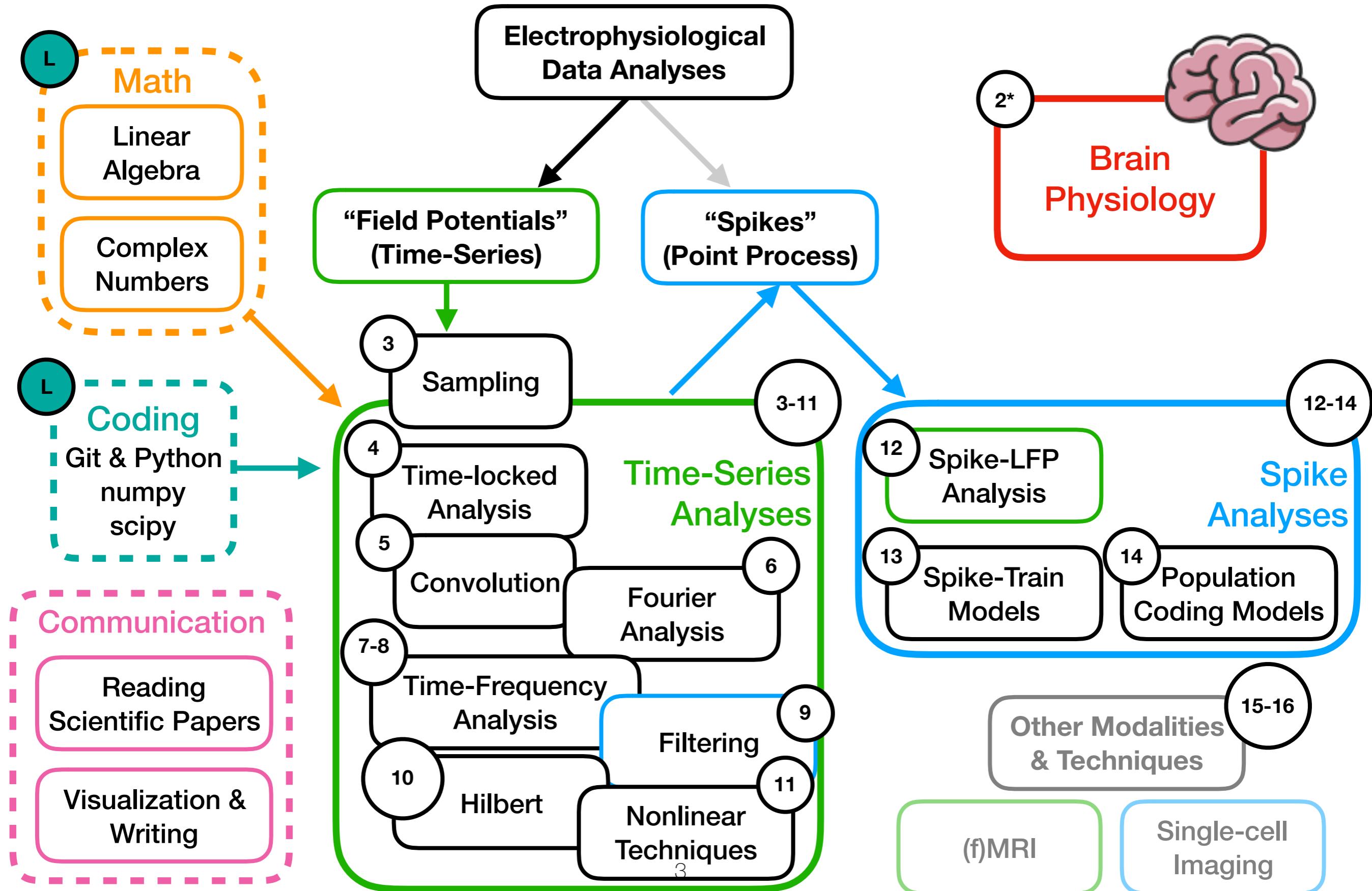


Spikes: Extraction & Spike Timing Analyses

Lecture 12
July 23, 2019



Course Outline: Road Map

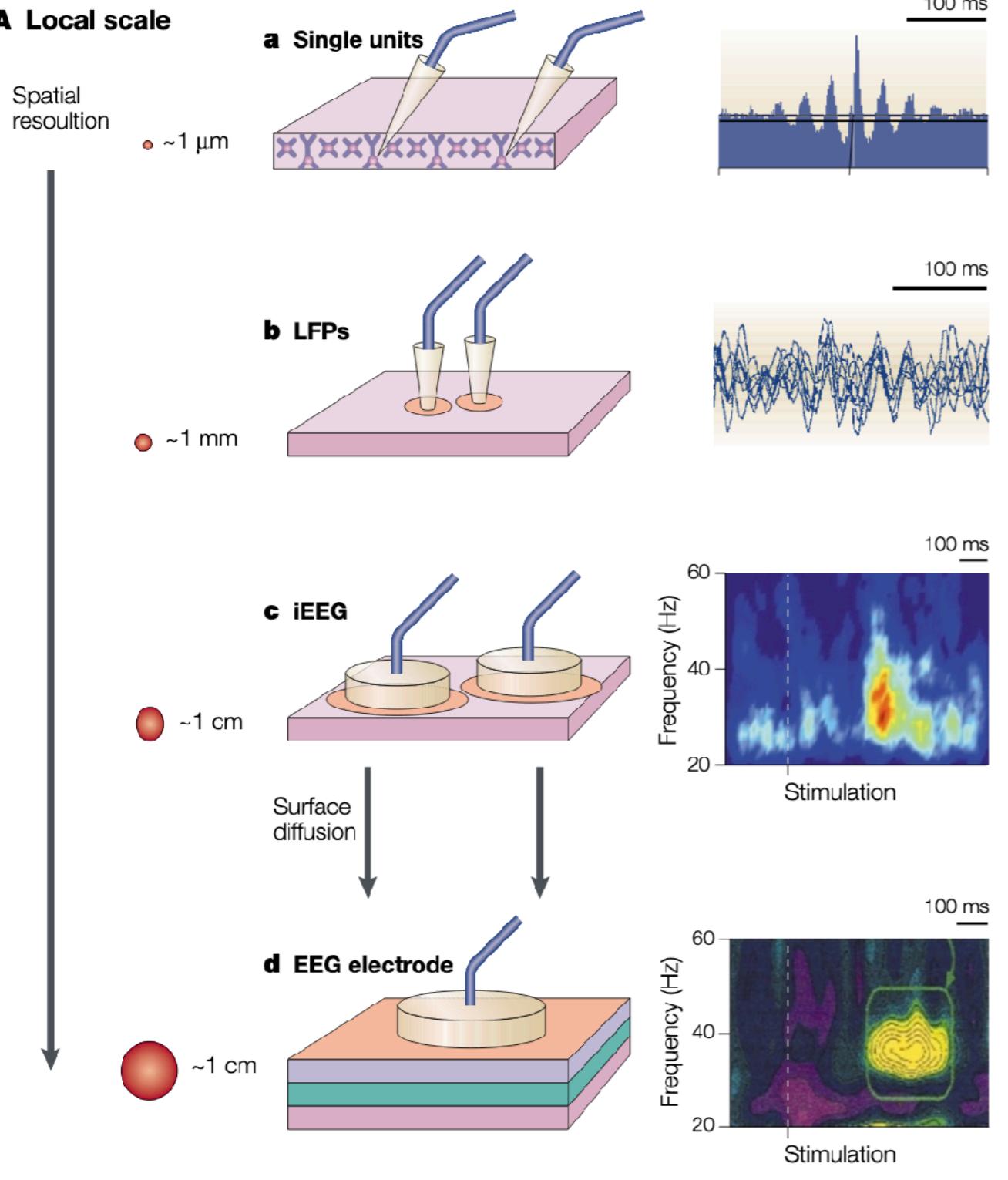


1. Review action potential physiology
2. Understand methods for spike detection & sorting
3. Spike train representation & spike-LFP analysis



Electrophysiology

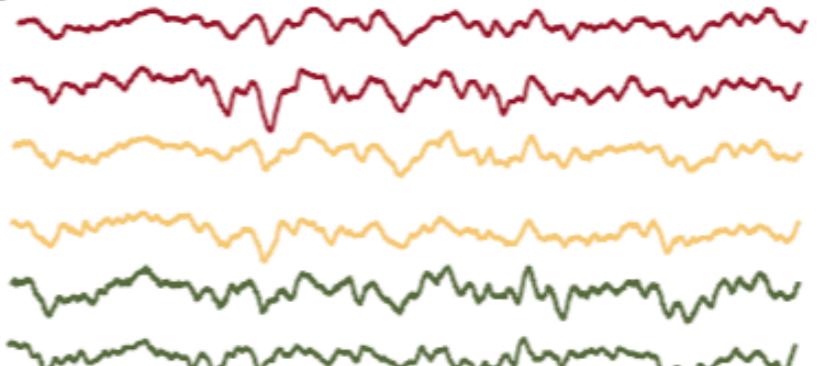
A Local scale



Varela et al., 2001. Nat Rev Neurosci

a

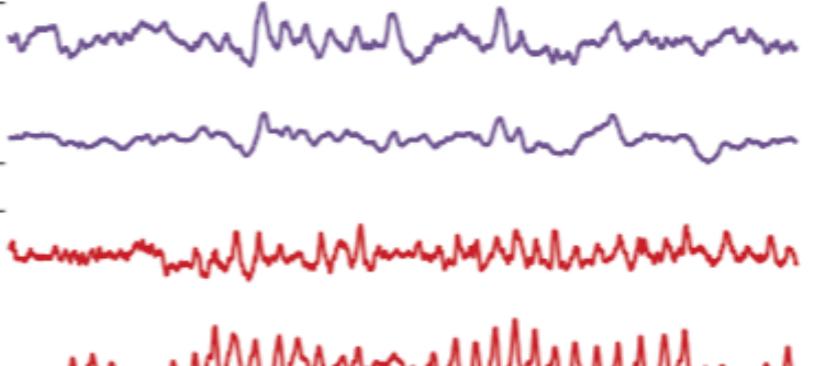
Depth
(LFP)



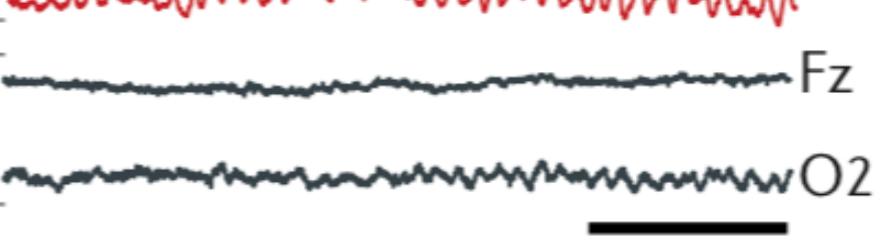
Grid
(ECoG)



Strip
(ECoG)



Scalp
EEG

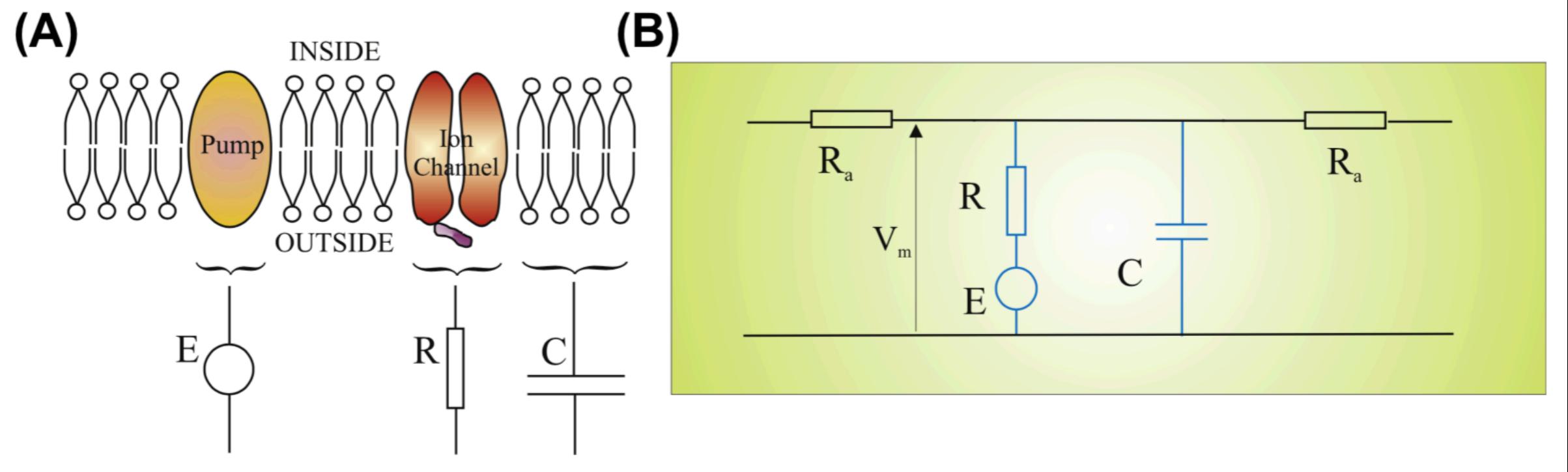


Buzsaki et al. 2012 Nat Rev Neurosci

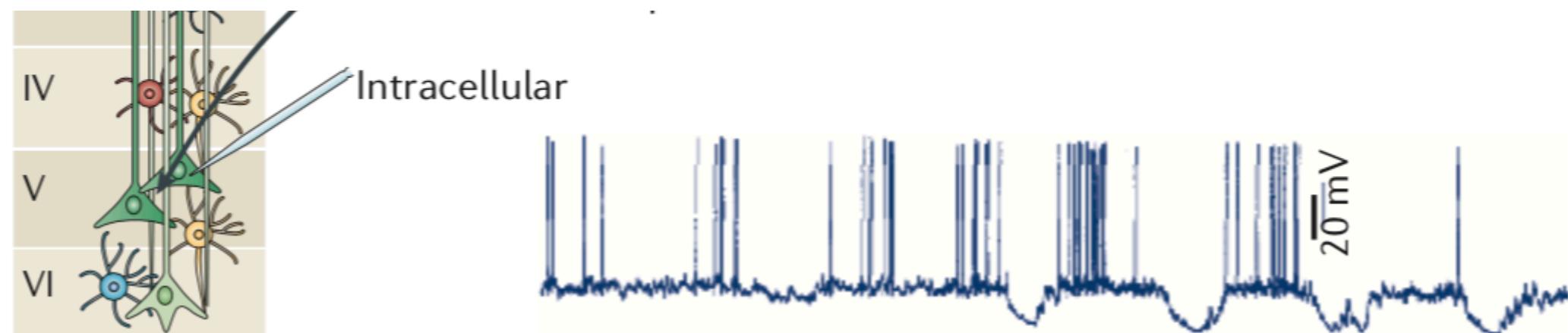


Membrane Potential

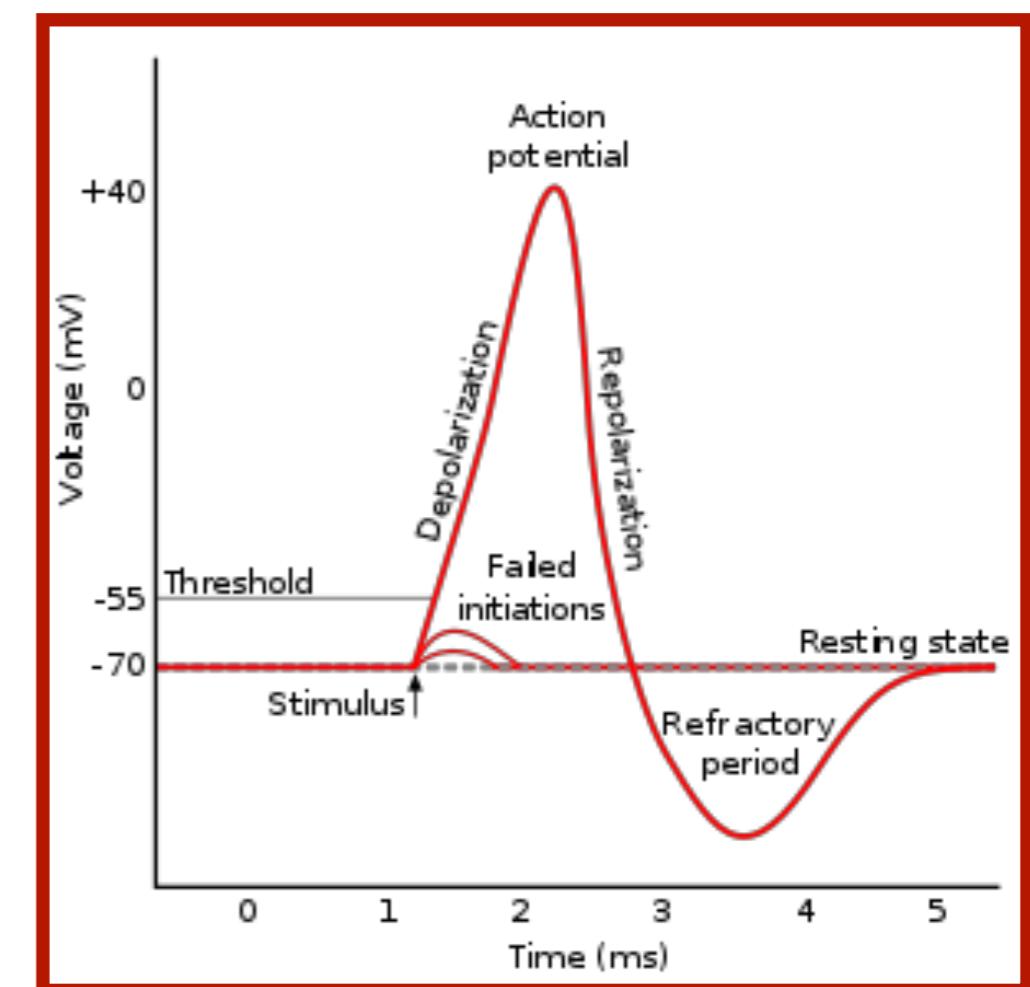
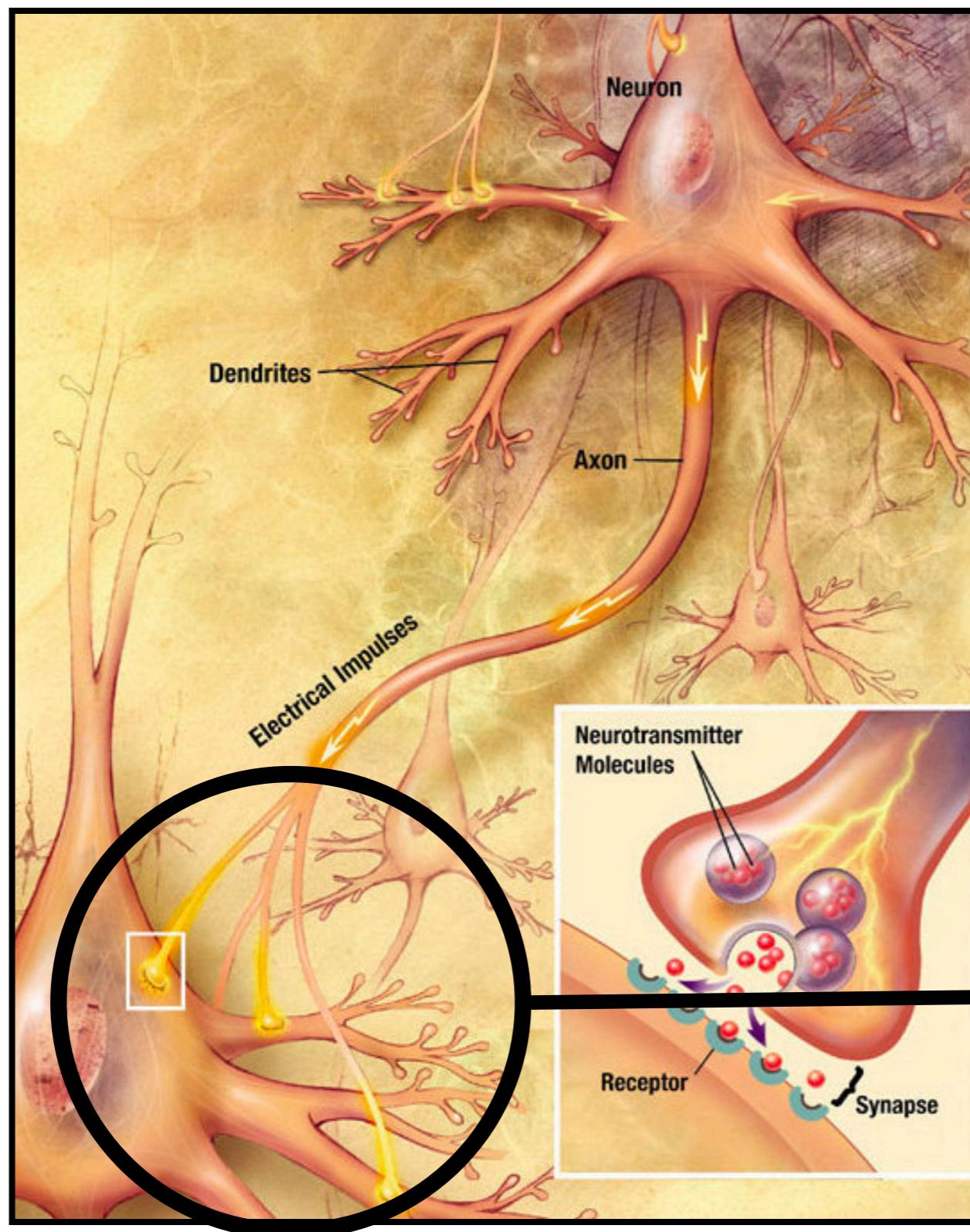
Cell Membrane as Electrical Circuit



WvD Ch.1



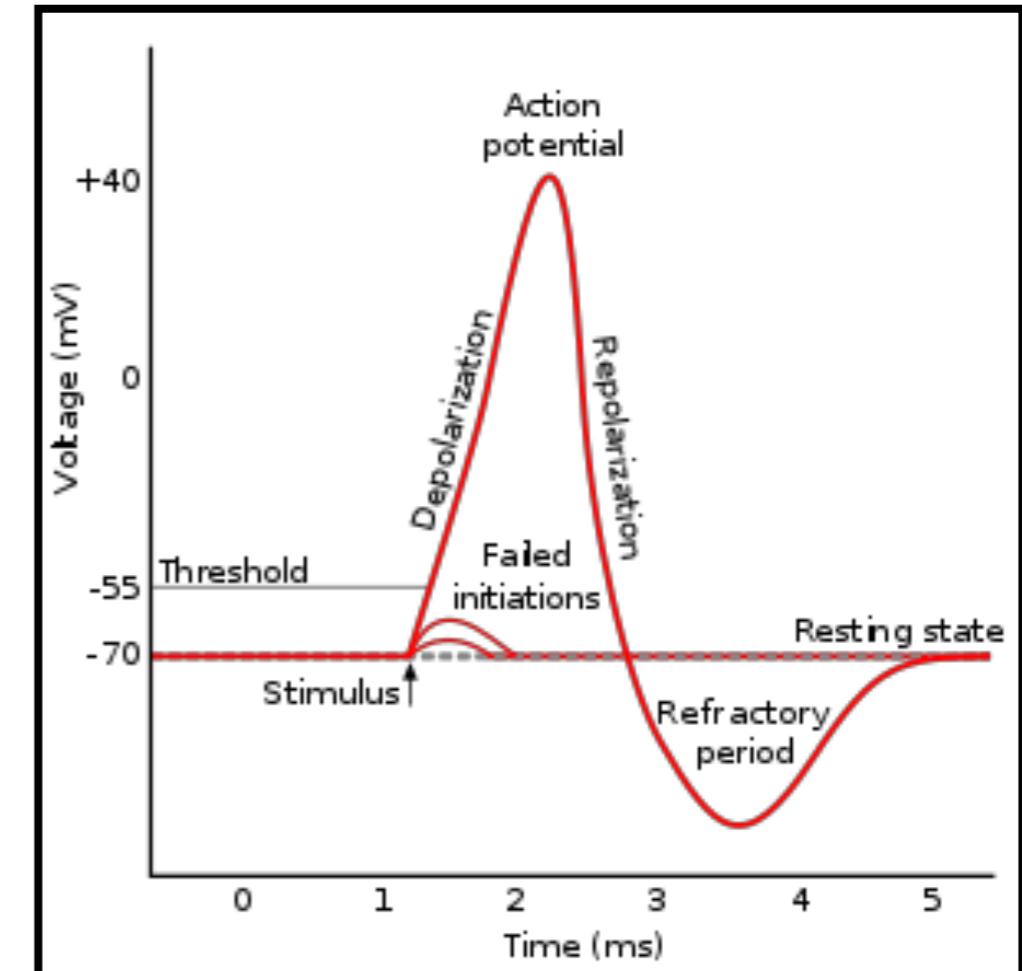
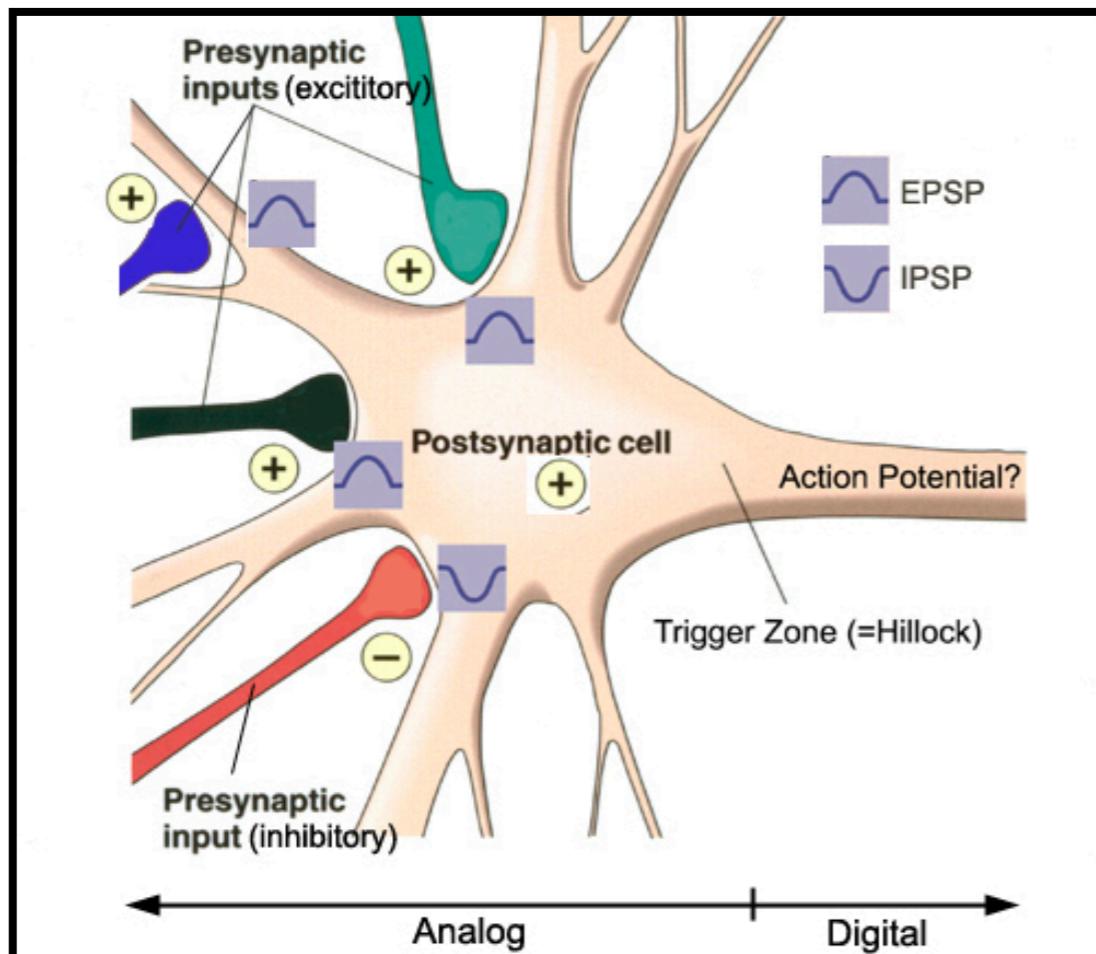
Neurons & Synapses



This is, for the most part,
what generates the signals
we will be studying.



(Very) Brief Intro on Neuronal Dynamics

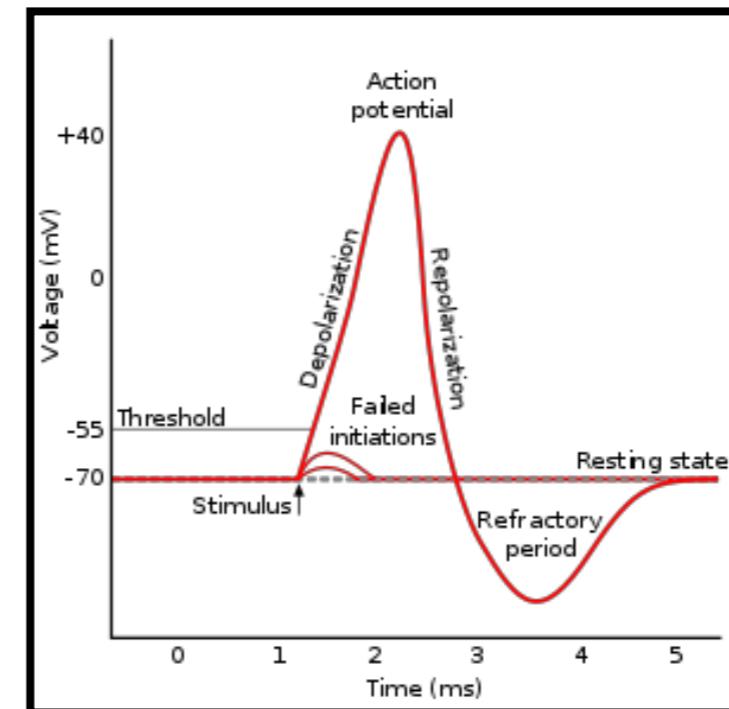
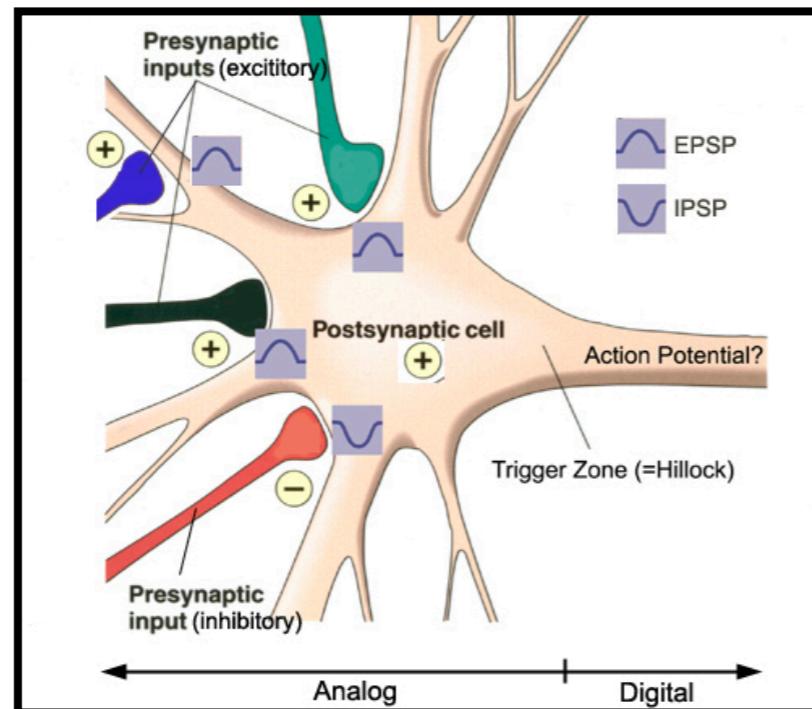


Synaptic & Slow Transmembrane
Potentials of Many Cells
(reflected in the LFP)

Action Potentials
(single-neuron activity)



Channel Dynamics in 5 Minutes



Dale's Law states: a neuron releases the same neurotransmitter to all its output neurons

Excitatory neurons (primarily) release glutamate, which opens sodium channels in the downstream neuron.

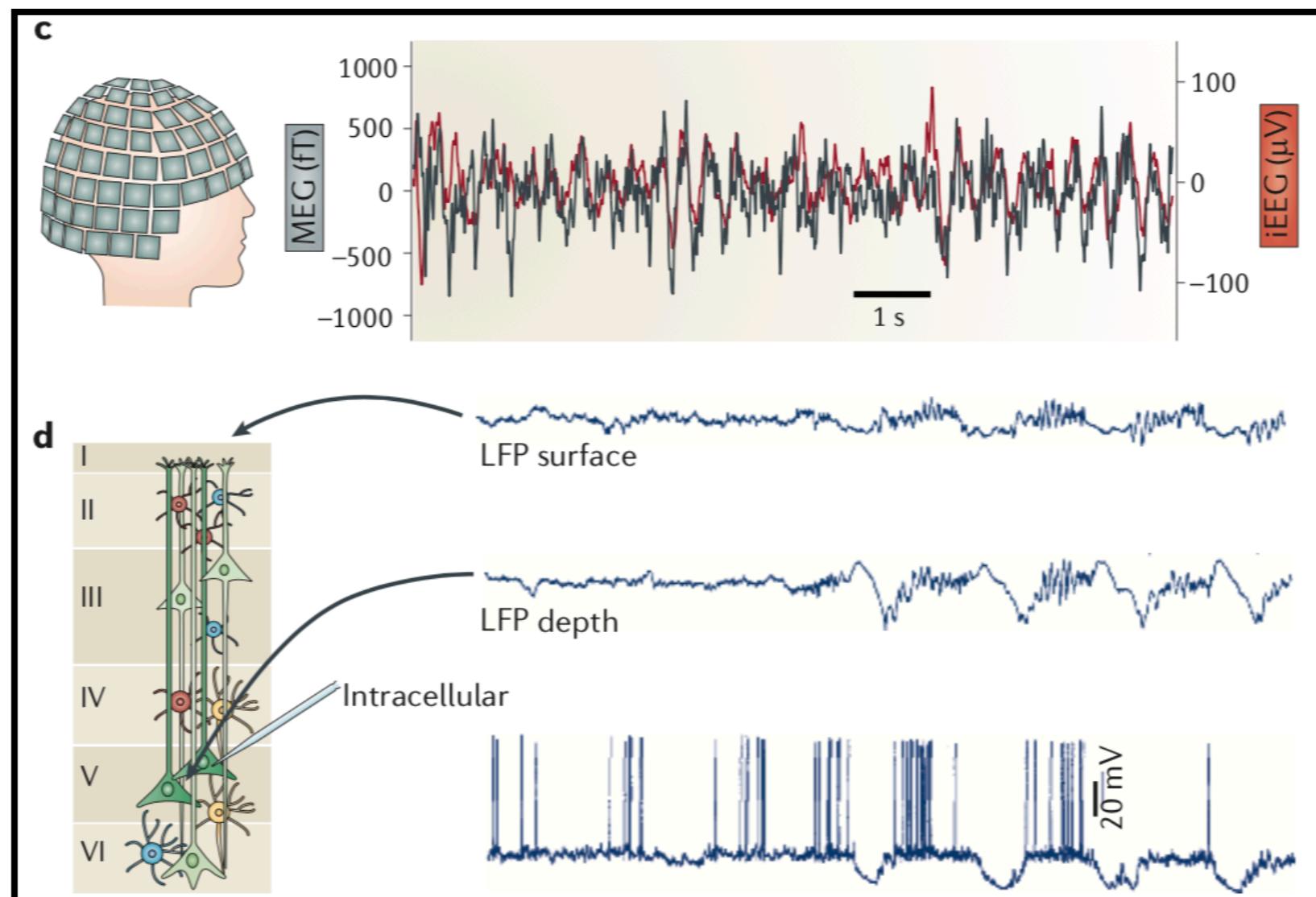
Inhibitory neurons (primarily) release GABA, which opens chloride (and potassium, calcium, and others) channels in the downstream neuron.

The depolarization phase of an action potential corresponds to an influx of sodium ions.

The hyperpolarization phase of an action potential corresponds to an influx of chloride ions, and an outflux of potassium ions.



Electrophysiology



Buzsaki et al. 2012 Nat Rev Neurosci

LFP/ECoG/EEG/MEG are a product of the spiking and synaptic inputs across many, many neurons!

But how?

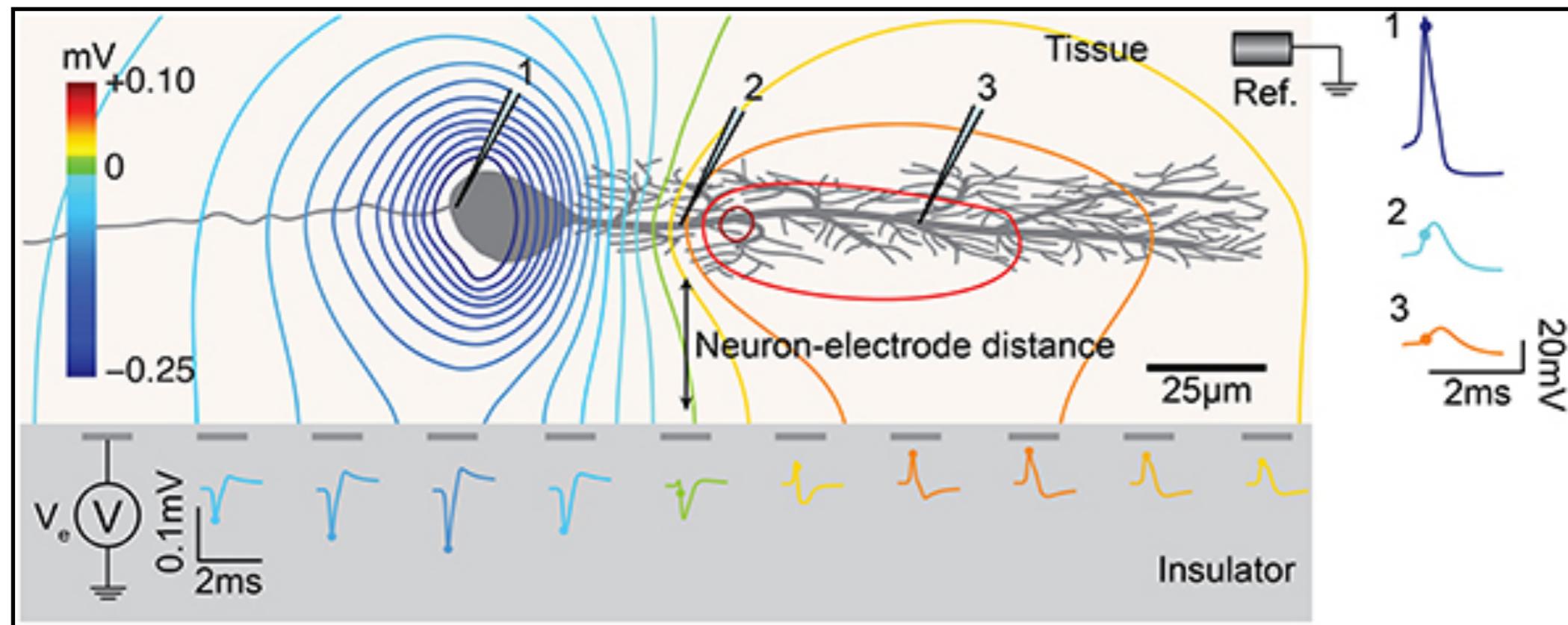


Goals for Today

1. Review action potential physiology
2. Understand methods for spike detection & sorting
3. Spike train representation & spike-LFP analysis



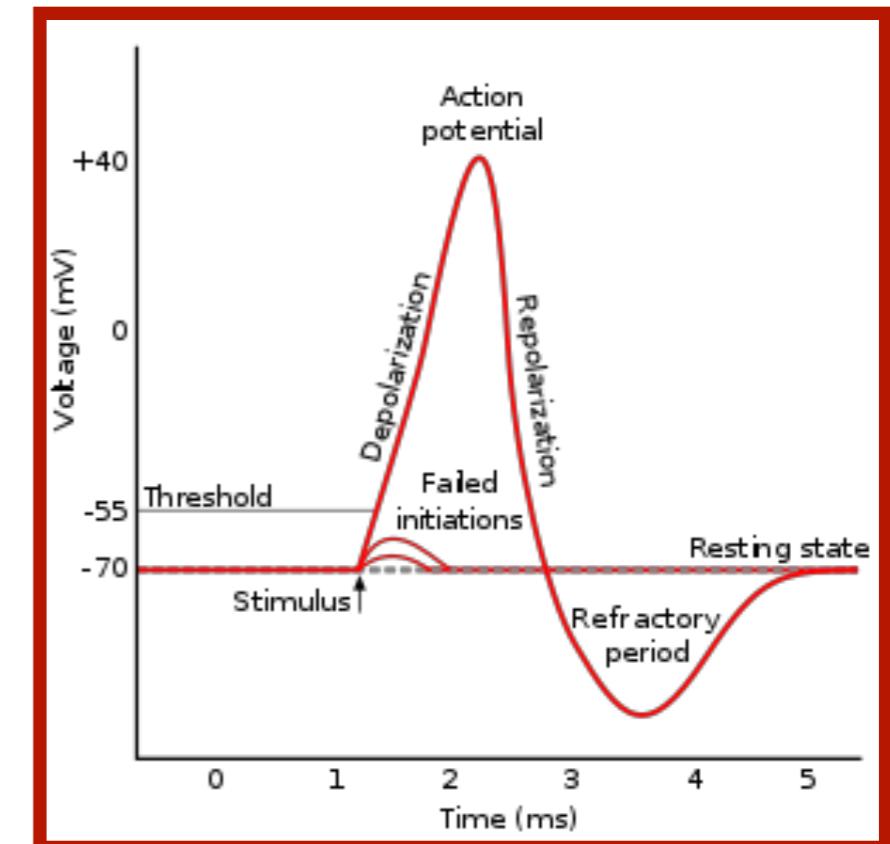
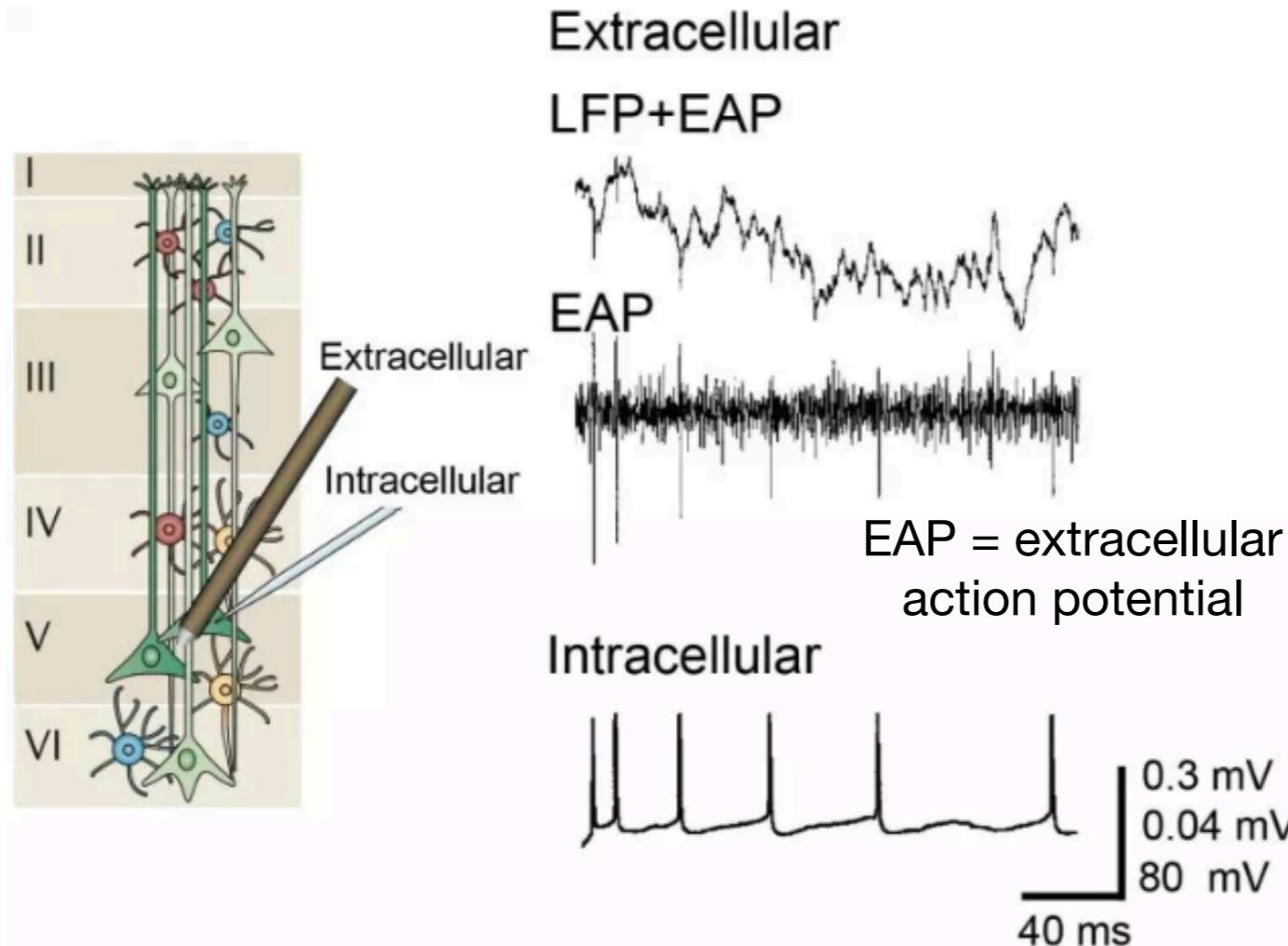
Extracellular Recording



Extracellularly recorded spikes are much smaller in amplitude compared to intracellular recordings, and vary in shape depending on neuron morphology and electrode location.



Extracellular Recording



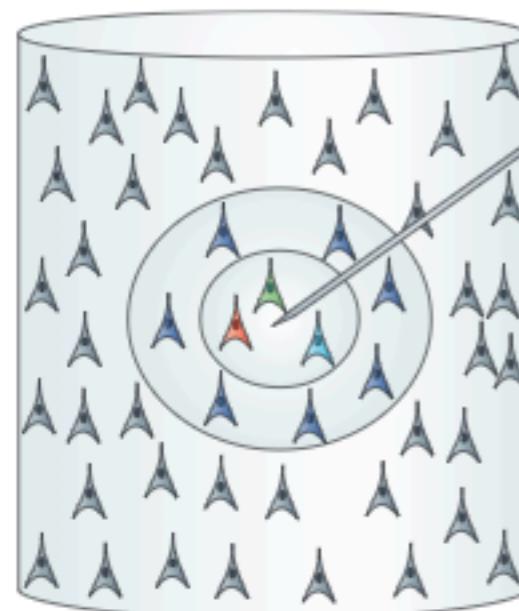
Voltage fluctuation recorded in the extracellular space contains **spikes** (small, fast) and **LFP** (big, slow)

Spikes occur in the timescale of 1ms:
how fast to sample and how do we isolate them?

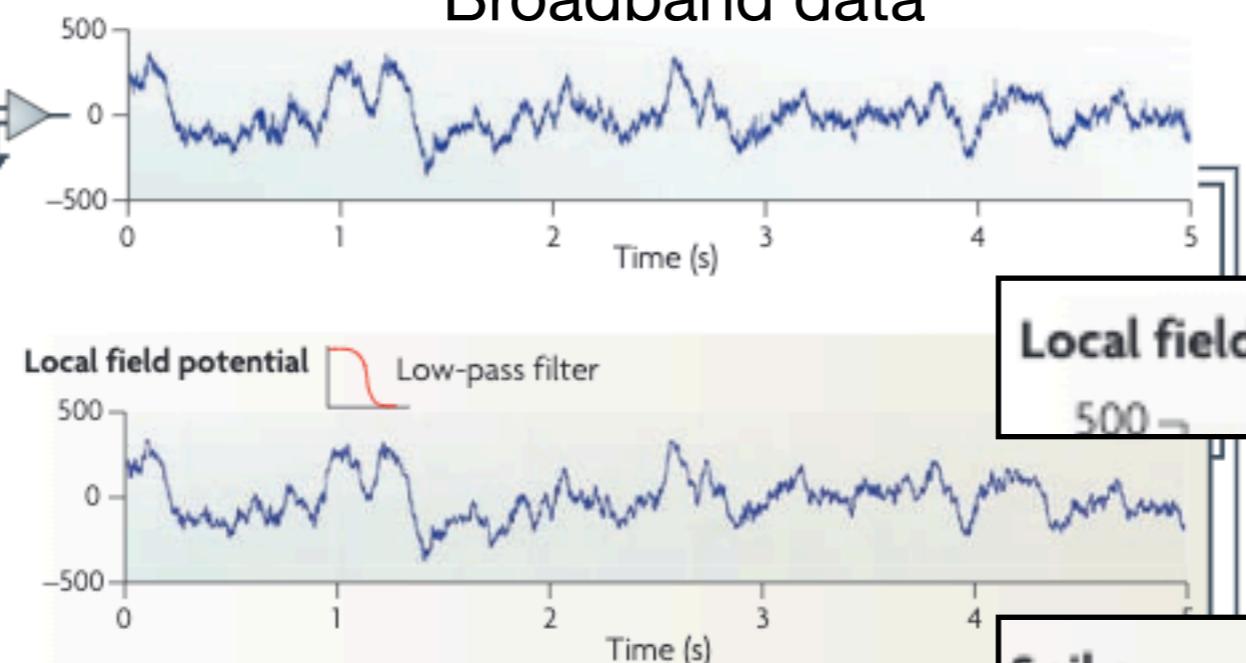


Filtering

Box 1 | Extracellular recordings

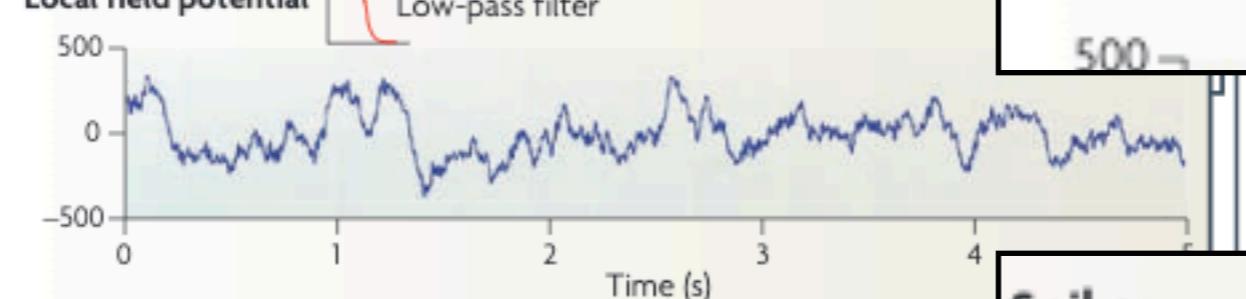


Broadband data

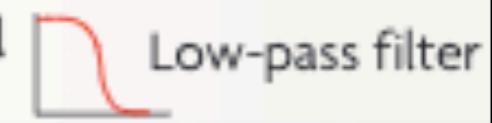


+ downsampling & anti-aliasing

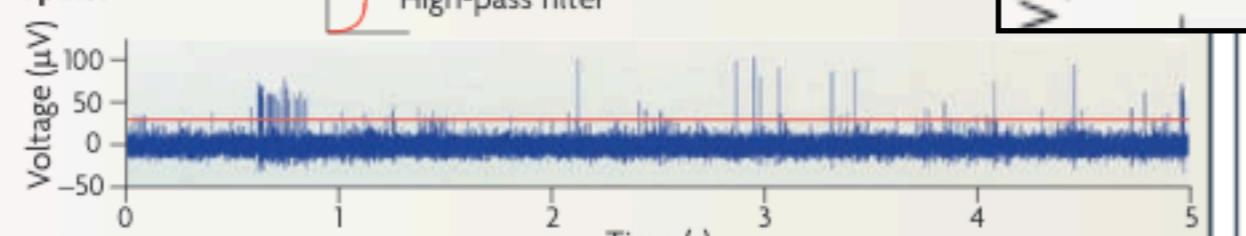
Local field potential



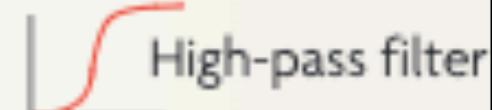
Local field potential



Spikes



Spikes

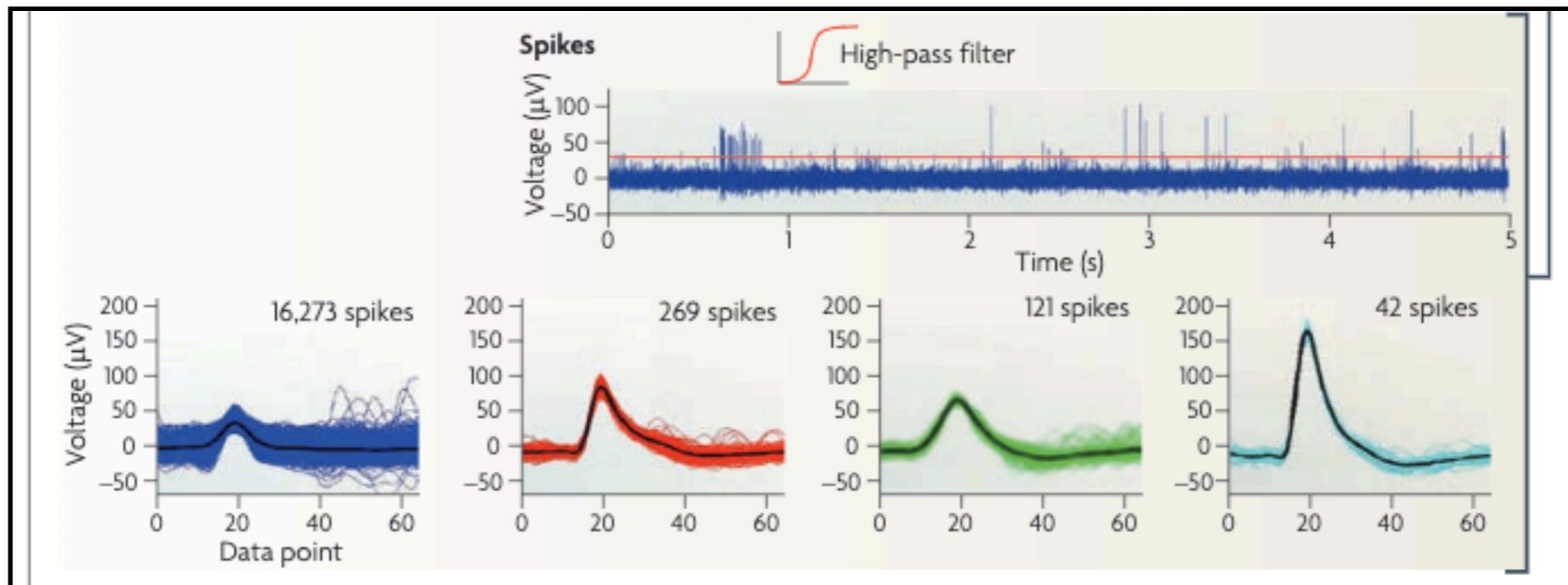


Quian Quiroga & Panzeri, 2009

EC Recordings typically sampled at 20kHz or above.
Lowpass filter (<300Hz) for LFP, highpass filter (300-3000Hz) for spikes.



Thresholding



Any data points that cross a set threshold is registered as a **potential spike**.

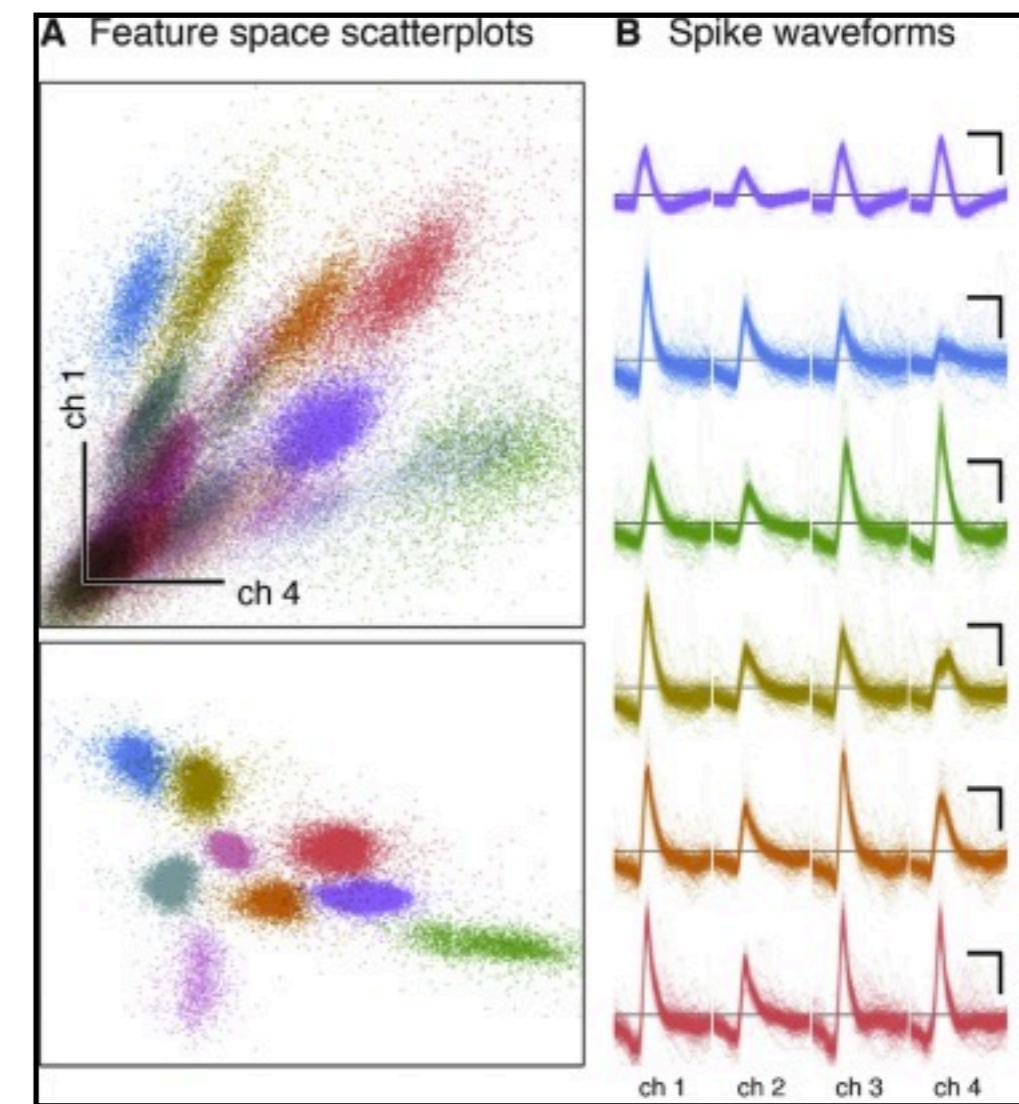
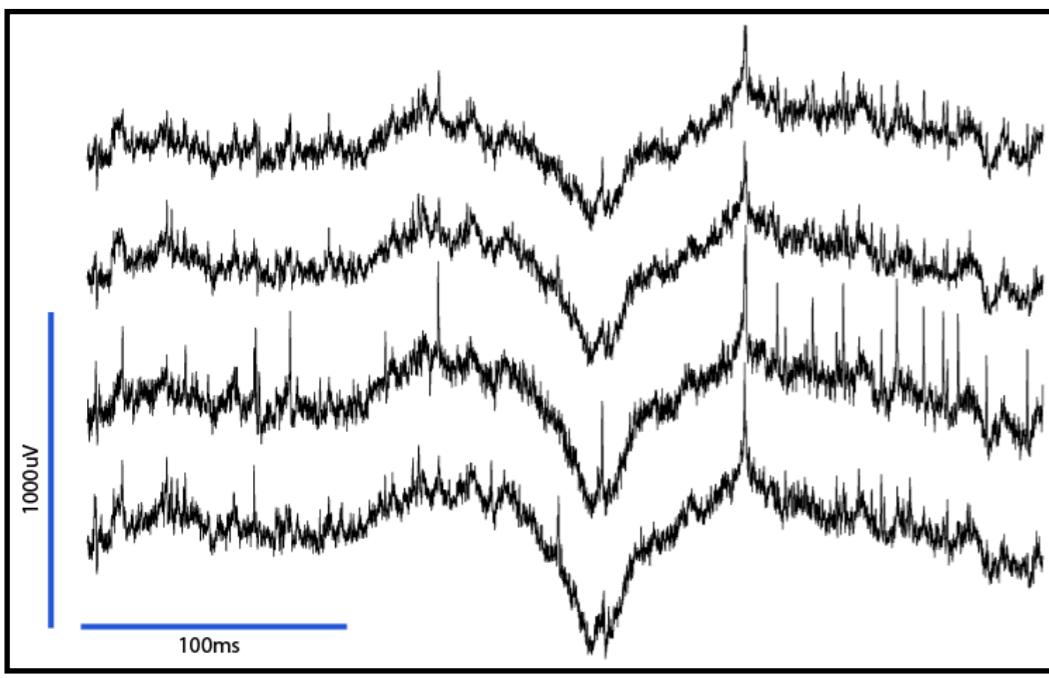
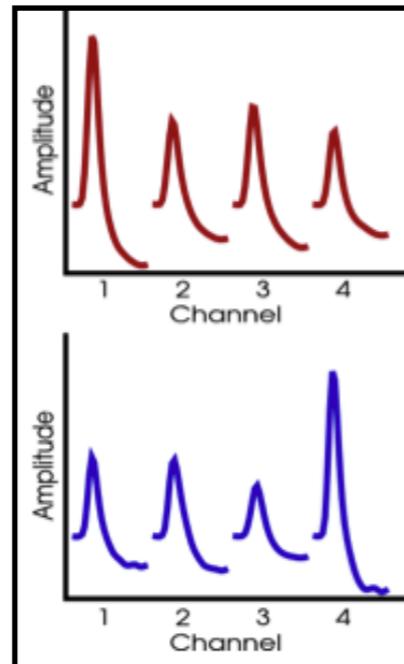
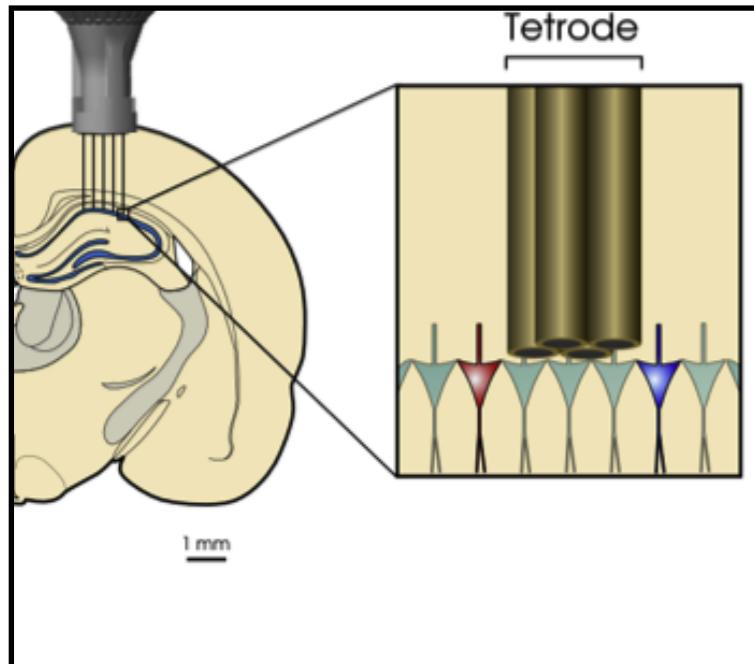
Many ways to set this threshold for **anomaly detection**:

- 5 x Standard Deviation
- Adaptive StdDev (history)
- etc...



Spike Sorting

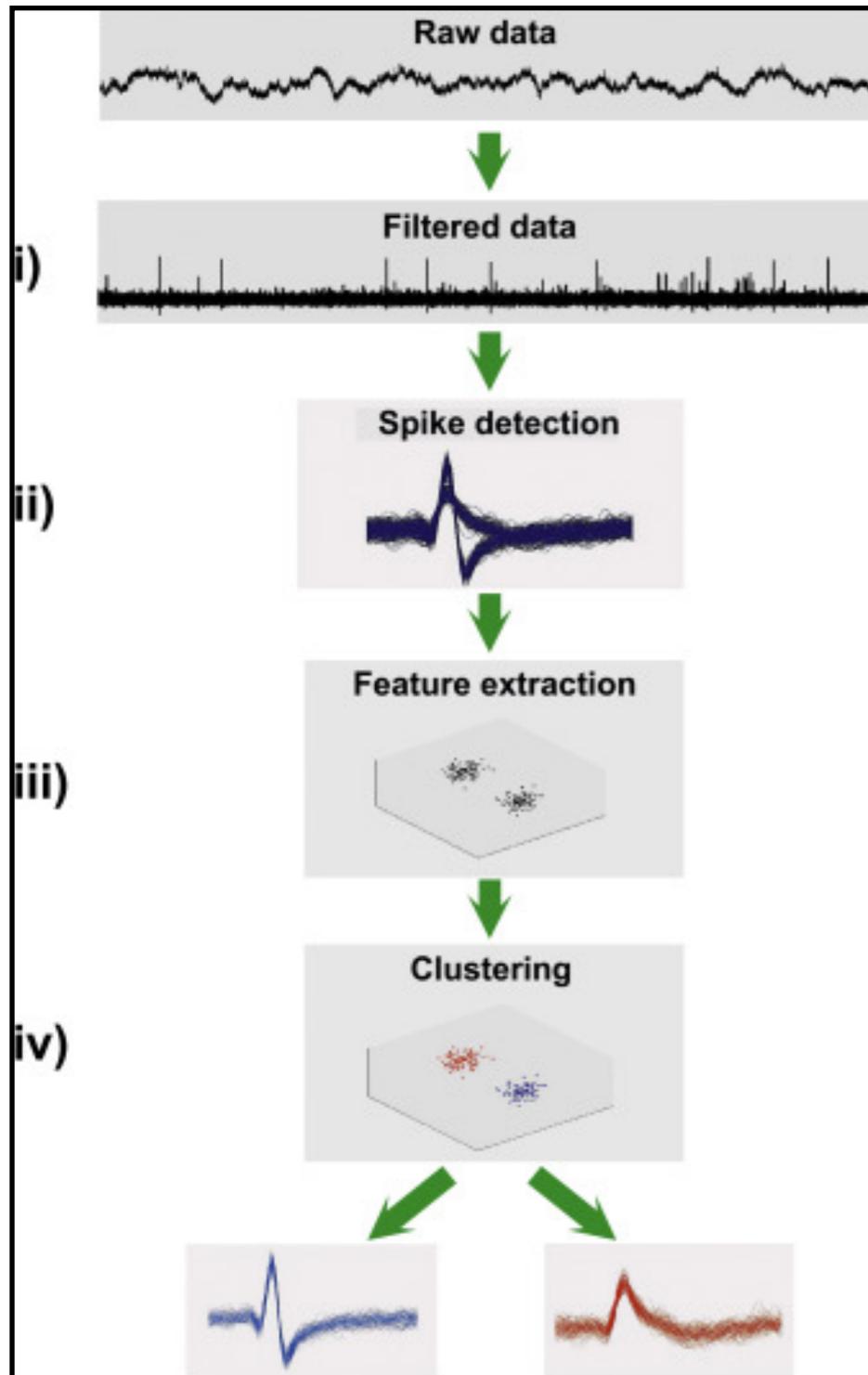
Identification of neurons: matching the spike with the cell



Combination of dimensionality reduction (e.g., PCA) and clustering techniques (or manually)



Spike Sorting Process Overview

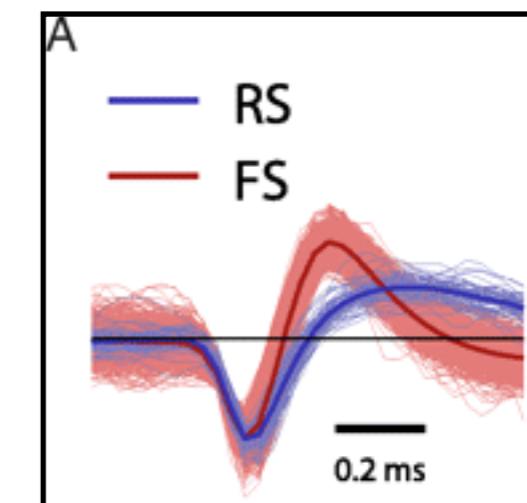


Bandpass filtering

Thresholding

Dimensionality Reduction

Clustering



Can sometimes identify cell-type
Excitatory (pyramidal cells): **wider spikes**
Inhibitory (interneurons): **narrower spikes**

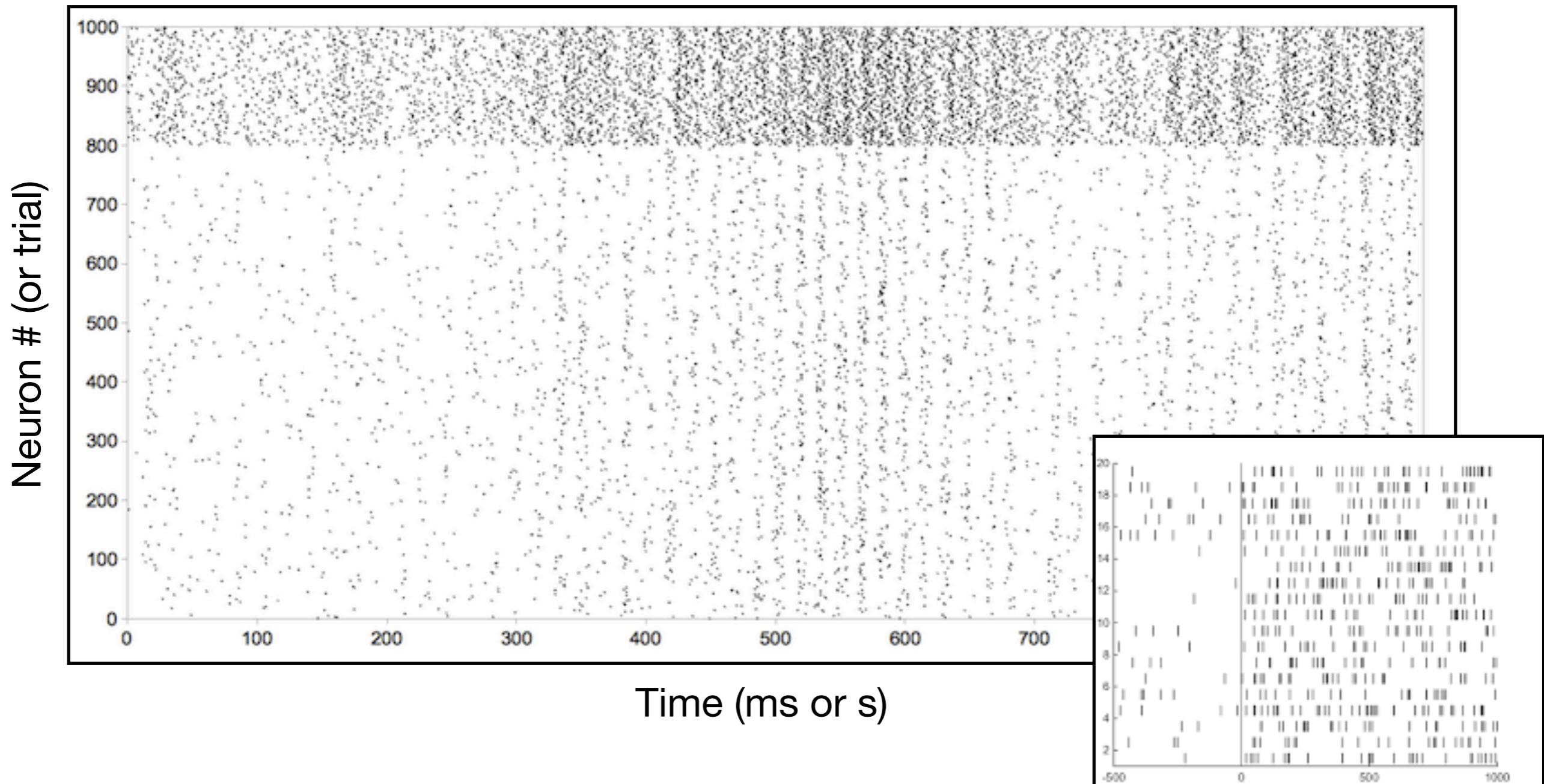
Output: timestamps of action potentials
from **putative** single neurons

e.g., [1.453, 4.982, 12.200, ...] ms

Gonzalo Rey et al., 2015



Spike Raster



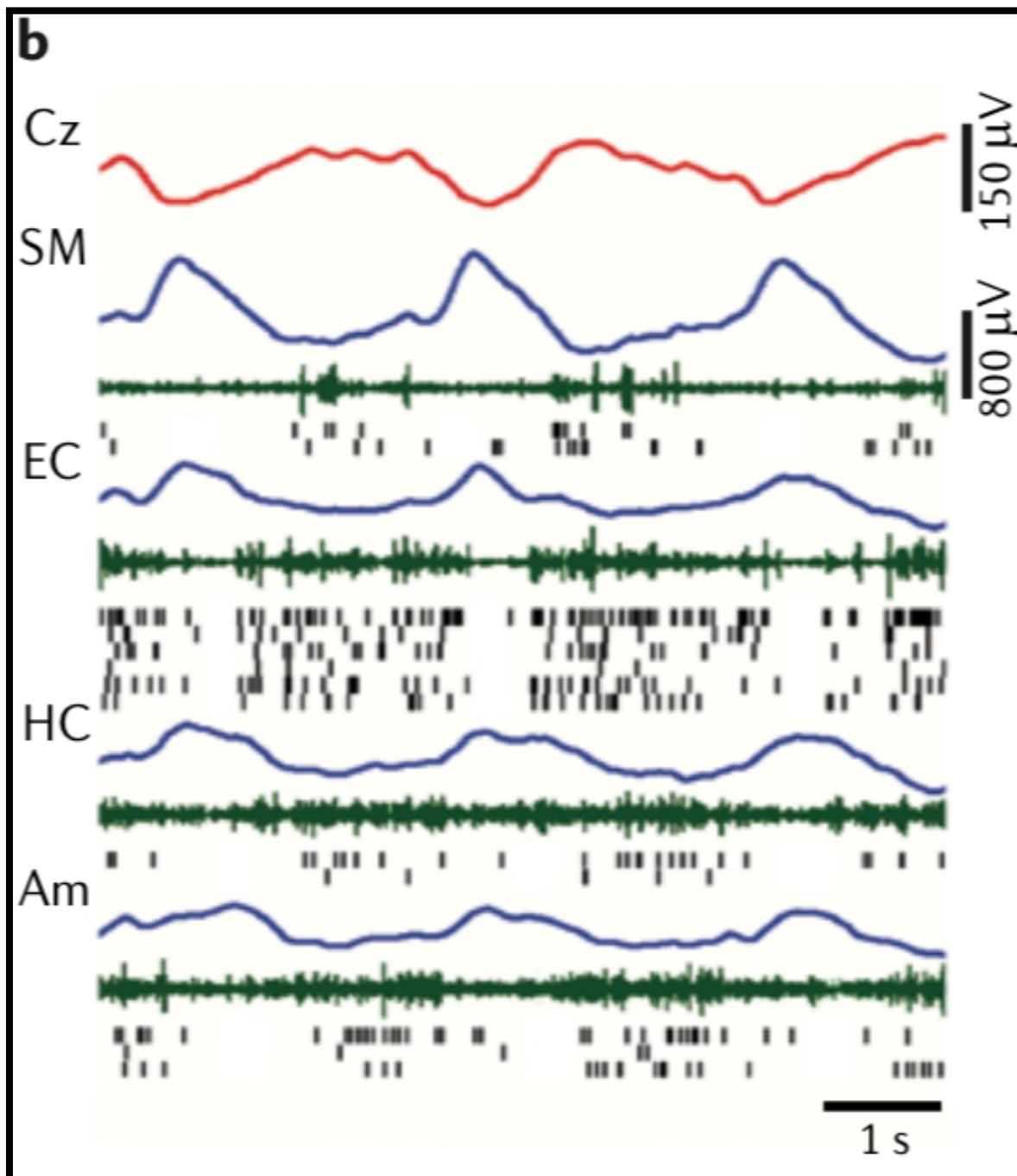
Each tick denotes that an action potential was emitted by that cell, at that time.



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LFP-Spike Timing Analyses



We have some spike times, now what?

We can treat them just like event timings in A1 for the ERP analysis.

In fact, these two types of data cover almost all cases of analyses you will encounter:

time series: discrete time, regularly sampled, e.g., LFP, EEG

point process: time indices, usually sampled at much higher frequencies, denoting a binary event, e.g., stimulus time, spike times

Buzsaki et al. 2012 Nat Rev Neurosci



Time Alignment

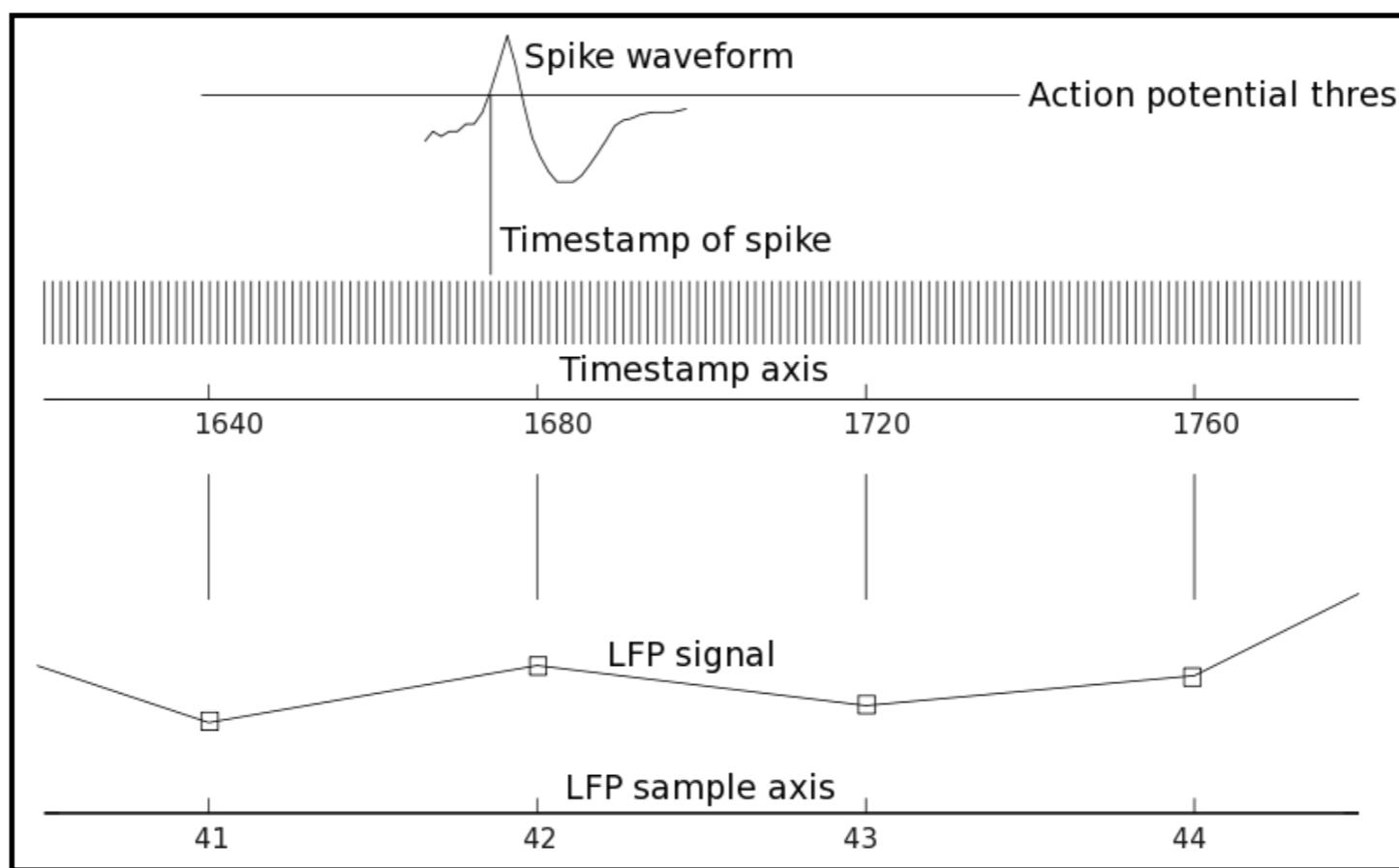
Broadband data (& spikes) sampled at 20kHz.

$$dt =$$

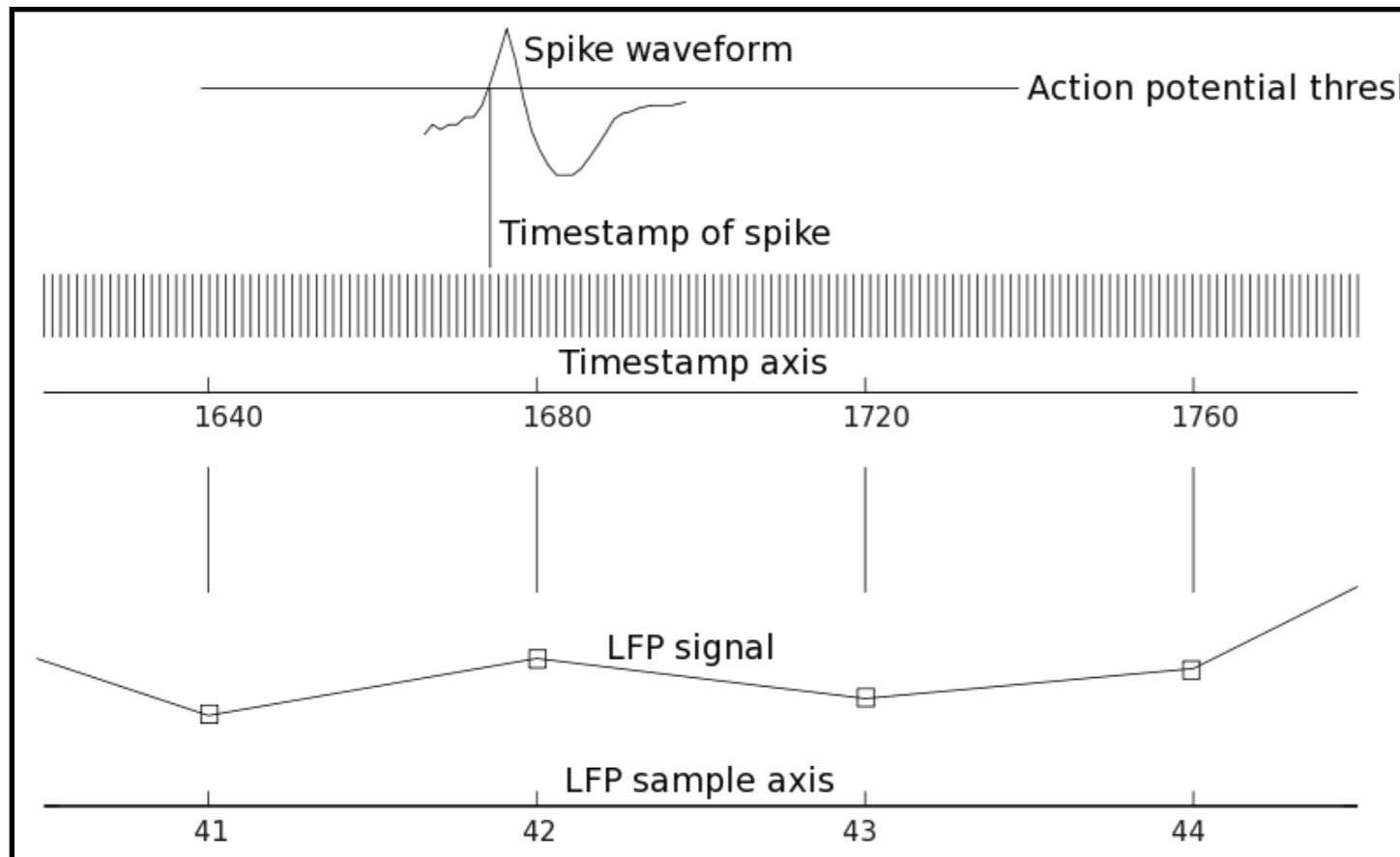
LFP data downsampled to 1,000Hz.

$$dt =$$

First we have to match spike times with
closest LFP index.



Time Alignment



$fs_{spike} = 20,000\text{Hz}$

$fs_{LFP} = 1,000\text{Hz}$.

How to find corresponding array index in LFP?

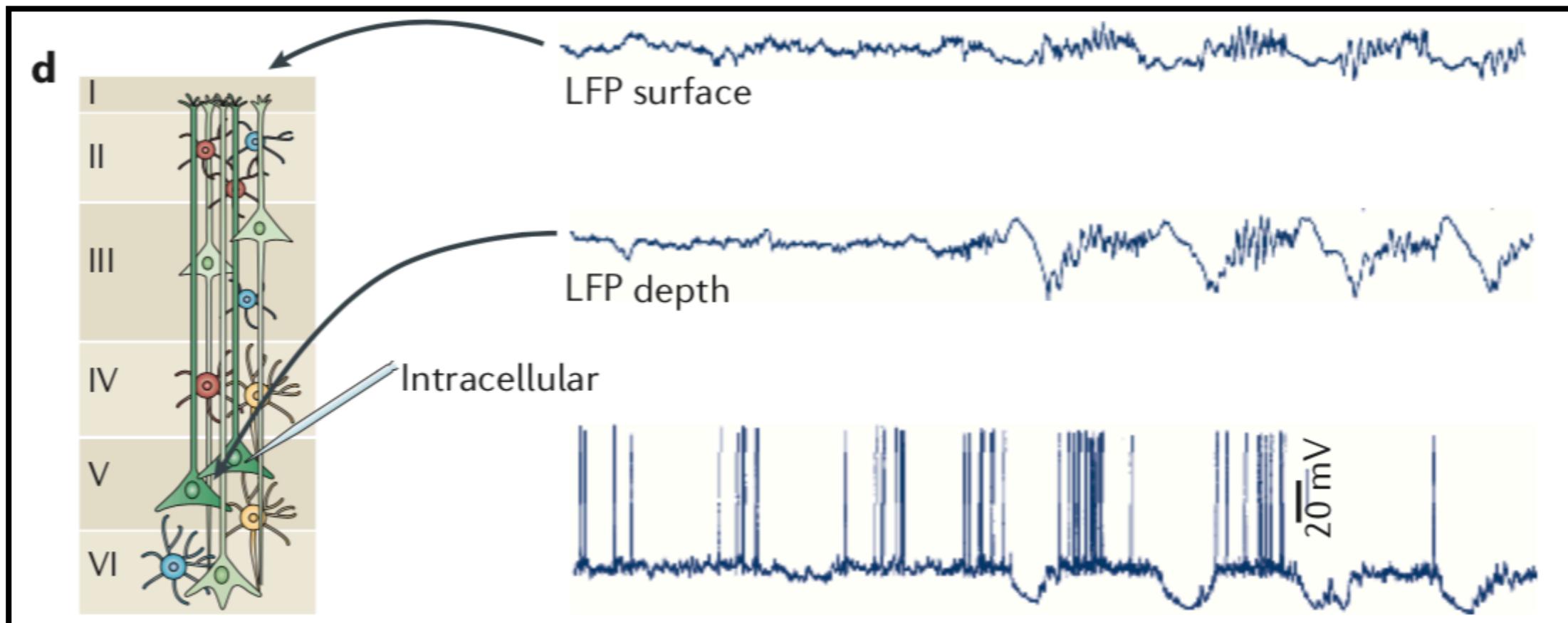
Given a spike time (e.g., 1.05ms), find the corresponding index in the LFP vector

```
corresp_lfp_index = round(spike_time * fs_lfp)
```



Spike-LFP Analyses

All follow the same idea: are there any consistent relationship between spike timing and a quantity (power, phase, etc) in the LFP?

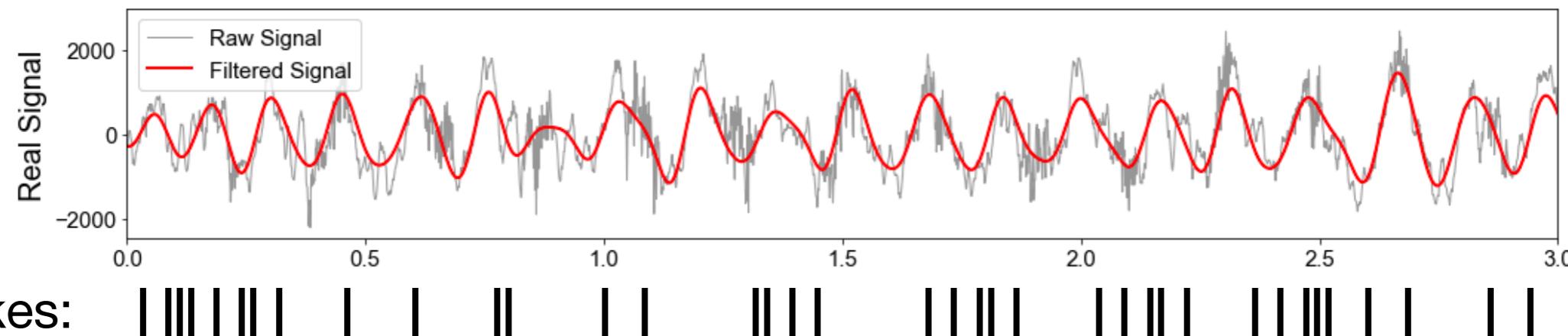


Analyses locking to spike times:

Physiologically, this usually implies modulation of spike by LFP, or vice versa

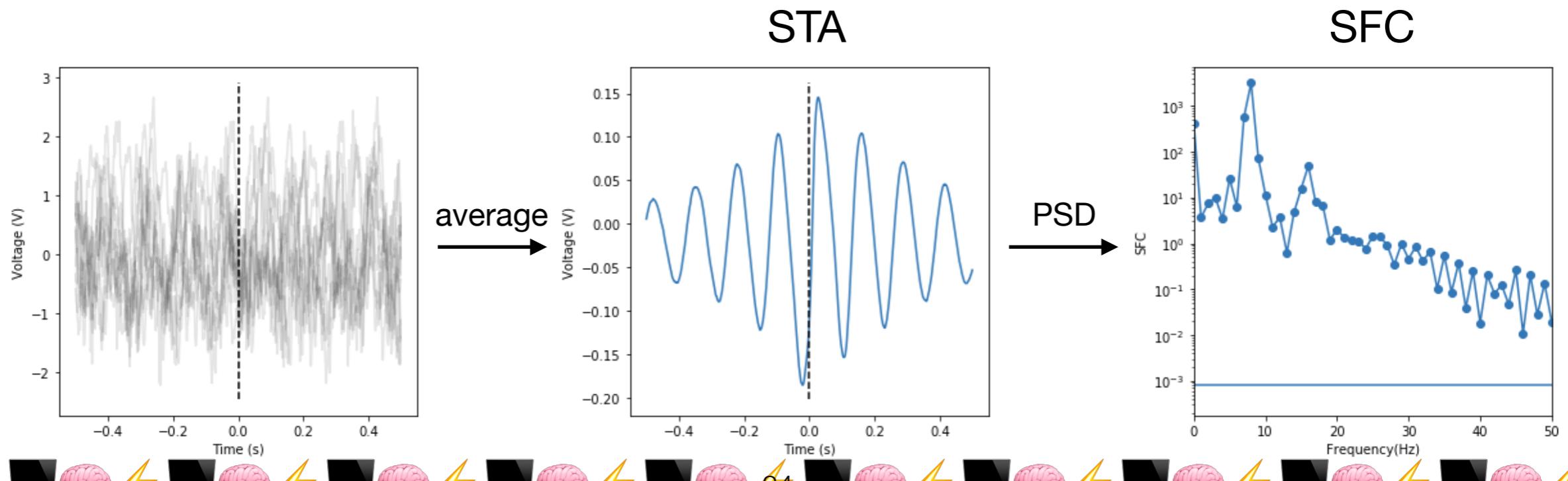
- Spike-Triggered Average (STA)
 - Spike-Field Coherence
 - Spike-Phase Coupling
 - etc...

Spike-Triggered Average & Spike-Field Coherence

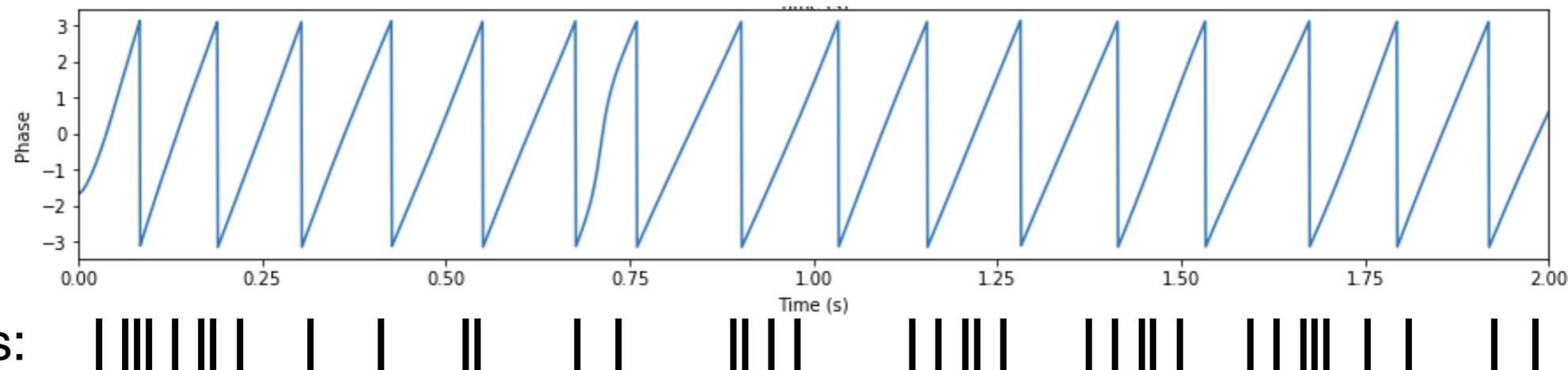


Grab a window of LFP around spike time, and take average across all windows.

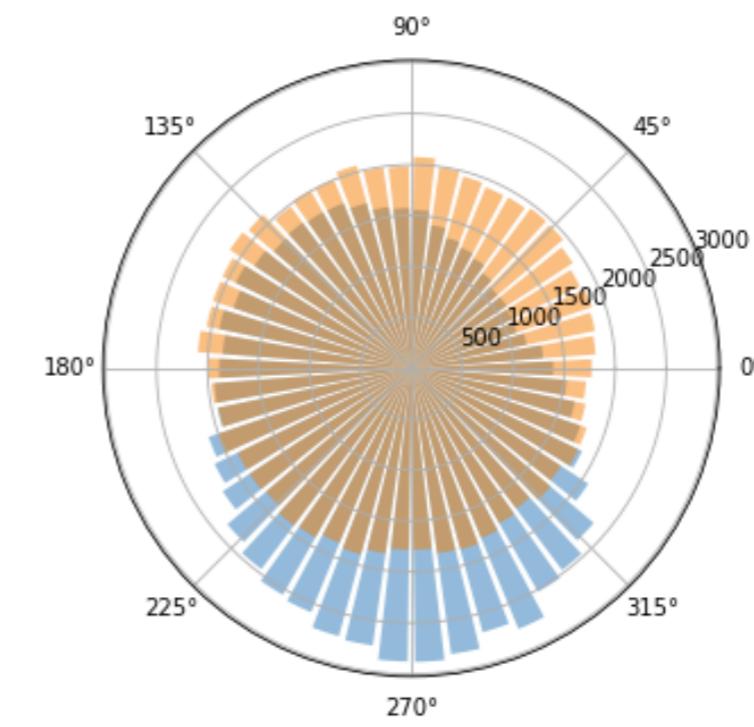
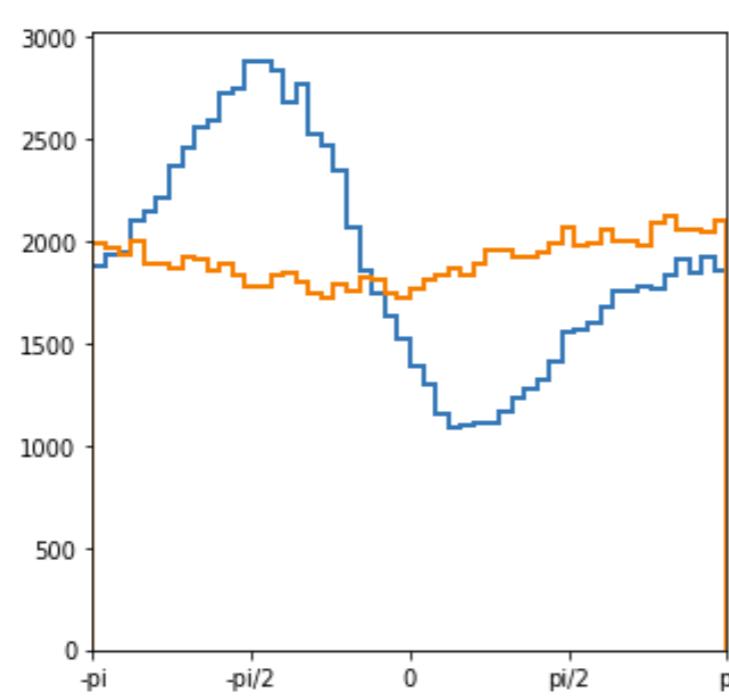
Exactly analogous to ERP analysis, only instead of stimulus events, we trigger on spikes.



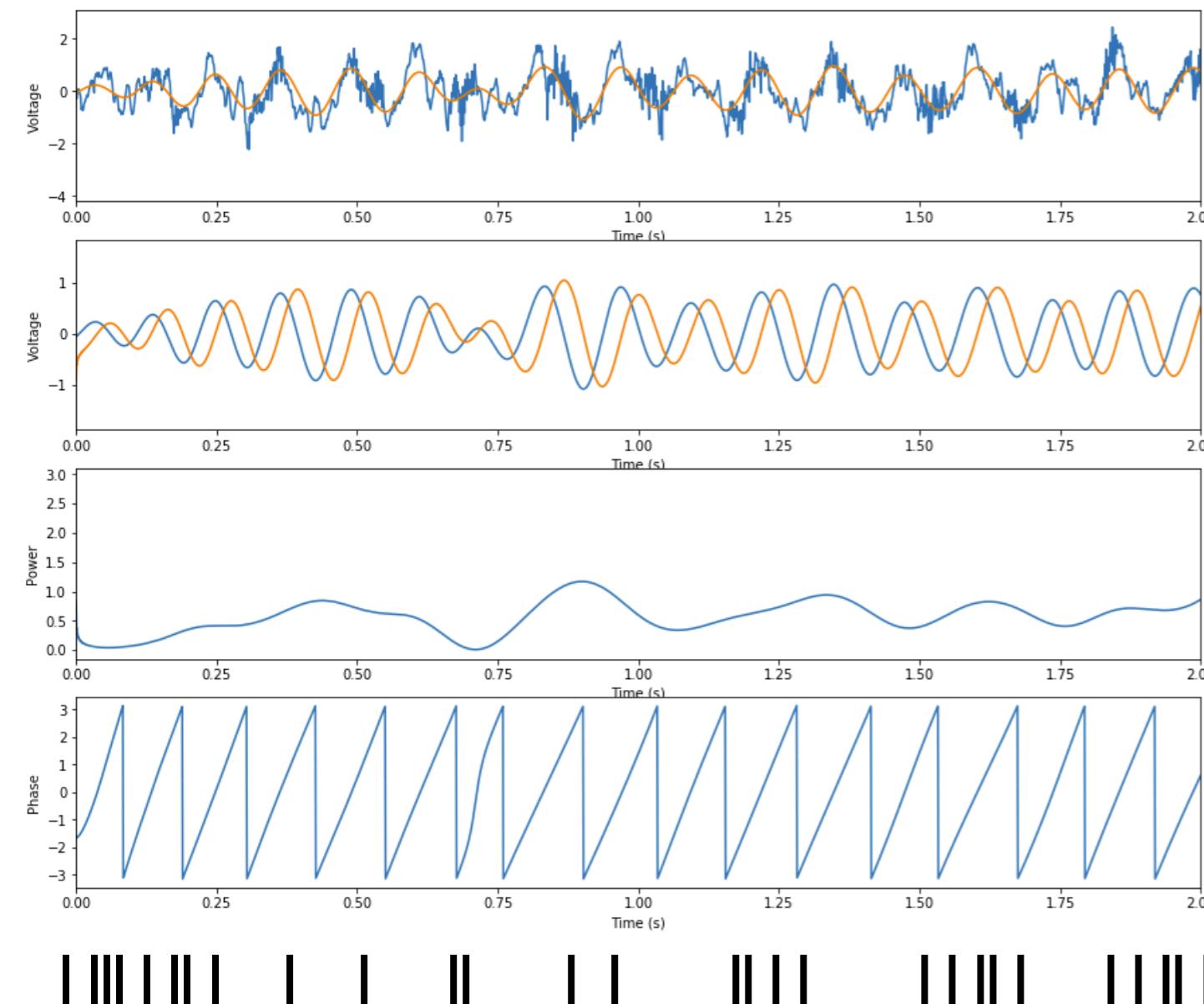
Spike-Phase Coupling



Record all the phases indexed by a spike, plot the distribution of those phases: **uniform or structured?**



Can Be Extended (for your Project?)



You can imagine doing the above for any combination of the spike-LFP quantities.

e.g., spike-triggered FT/spectrogram

Probe different aspects of the relationship between action potentials and LFPs.



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<https://tinyurl.com/cogs118c-att>

Final Project Uploaded

