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INTRODUCTIONS

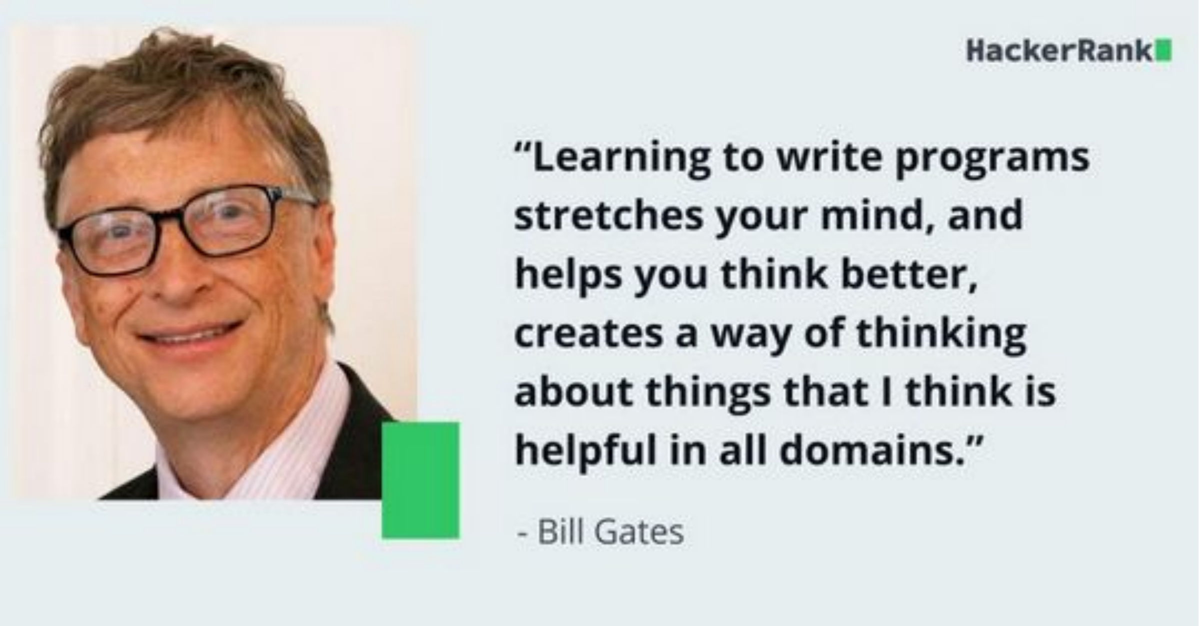
Hi! I am [NAME] working as [POSITION] at [AFFILIATION] and

- **My research interests are [THIS]**
- **Or My hobbies are [THIS]**

Agenda for the next TWO days

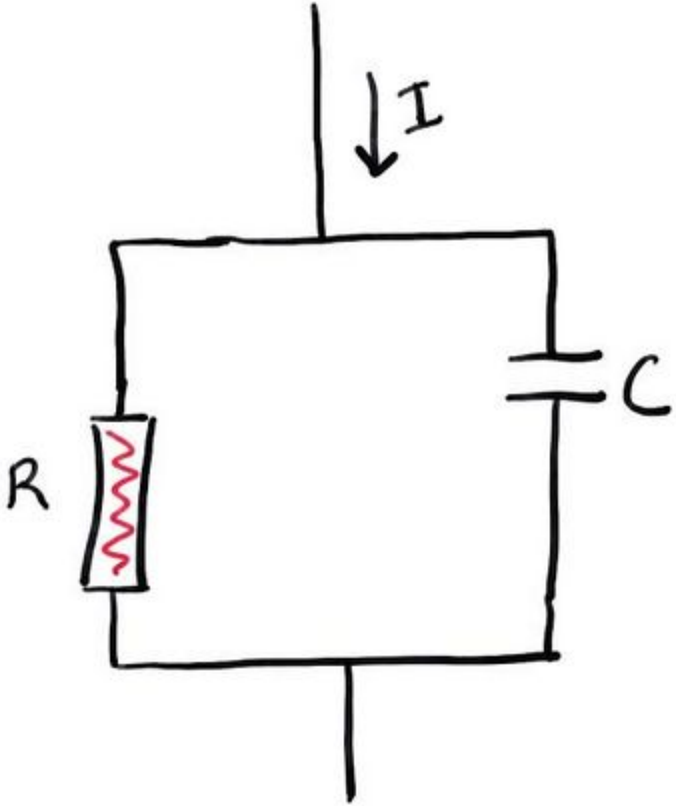
- **Day-#1**
  - Leaky Integrate-and-Fire (LIF) Neurons
    - 14 Exercises
- **Day-#2**
  - Spiking in LIF Neurons
    - 7 Exercises

Why?


HackerRank
“Learning to write programs stretches your mind, and helps you think better, creates a way of thinking about things that I think is helpful in all domains.”
- Bill Gates

Day #1

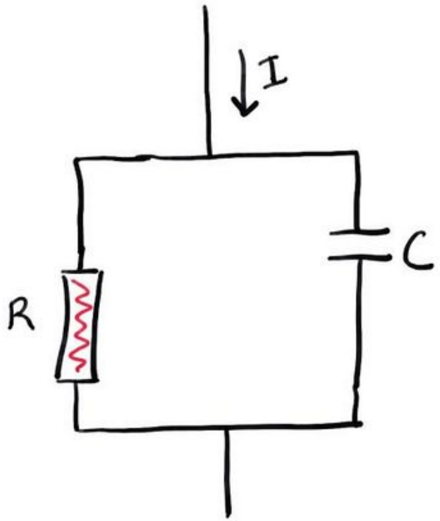
Concept of LIF Neurons



Leaky Integrate and Fire Neurons

Exercise#1

Membrane Equation and Reset Conditions



$$I(t) = IR + IC$$

$$IR = \frac{u}{R}$$

$IC = C\frac{du}{dt}$ because $C = \frac{q}{u}$

$$I(t) = \frac{u(t)}{R} + C\frac{du}{dt}$$

Multiply the equation by R and substitute for TC

$$\tau_m \frac{du}{dt} = -u(t) + RI(t)$$

Spiking Neuron Equation

$$\tau_m \frac{d}{dt} V(t) = E_L - V(t) + R\,I(t) \qquad \text{if} \quad V(t) \leq V_{th}$$

$$V(t) = V_{reset} \qquad \text{otherwise}$$

Ref: http://www.kaizou.org/2018/07/lif-neuron-tensorflow.html

Spiking Neuron Equation

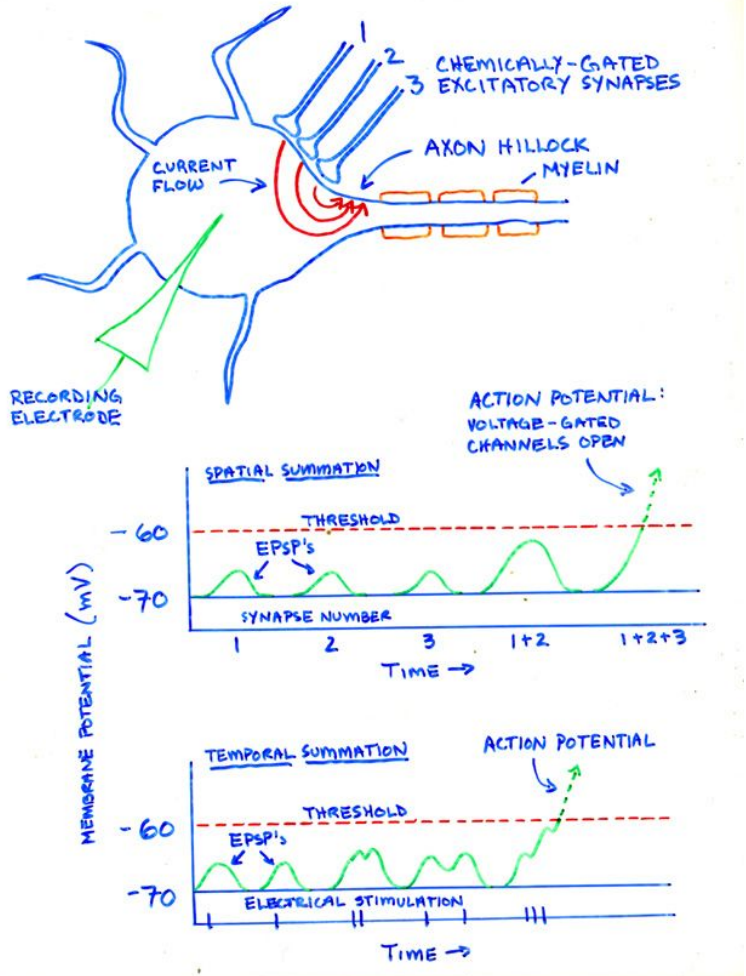
membrane potential   input current   firing threshold

$$\tau_m \frac{d}{dt} V(t) = E_L - V_t + R\,I(t) \quad \text{if} \quad V(t) \leq V_{th}$$

leak potential.

$$V(t) = V_{RESET} \qquad \text{otherwise.}$$

reset voltage.



Spiking Neuron

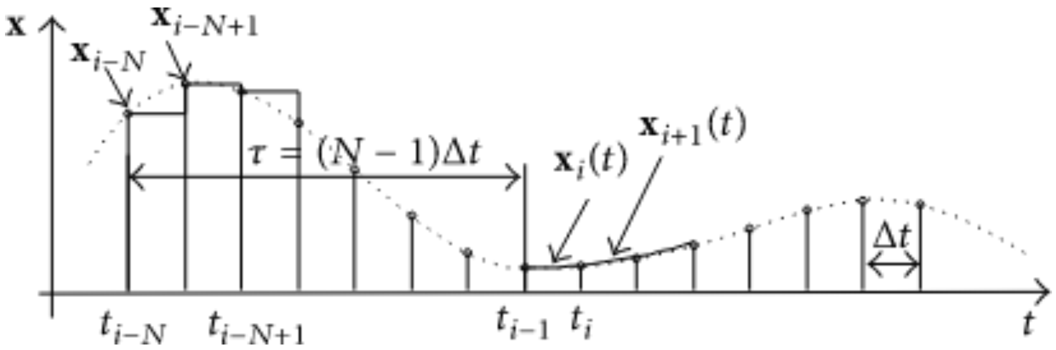
Exercise#2

Applying Sinusoidal Equation

$$V_{(t)} = V_m \sin(\omega t)$$

$$I(t) = I_{mean}\left(1 + \sin\left(\frac{2\pi}{0.01}t\right)\right)$$

Simulating evolution of equation in discrete time steps



Exercise#3, #4, #5, #6

Simulating evolution of equation in discrete time steps

$$\tau_m \frac{d}{dt} V(t) = E_L - V(t) + R\, I(t)$$

Time derivative of V(t) in the membrane equation without taking the limit Δt→0:

$$\tau_m \frac{V(t + \Delta t) - V(t)}{\Delta t} = E_L - V(t) + R\, I(t) \qquad (1)$$

Simulating evolution of equation in discrete time steps

$$\tau_m \frac{V(t+\Delta t) - V(t)}{\Delta t} = E_L - V(t) + R\,I(t) \qquad (1)$$

Make V(t+△t) the subject!

$$-V(t)+V(t+\Delta t) = \frac{\Delta t}{\tau_m}\left(E_L - V(t) + RI(t)\right)$$

$$V(t+\Delta t) = V(t) + \frac{\Delta t}{\tau_m}\left(E_L - V(t) + R\,I(t)\right)$$

Exercise#7

Synaptic inputs are random!

Stochastic Differential Equations!

$$I(t) = I_{mean}\left(1 + 0.1\sqrt{\frac{t_{max}}{\Delta t}}\,\xi(t)\right) \qquad \text{with } \xi(t) \sim U(-1,1)$$

Exercise#8 - #14

Ensemble Statistics

Multiple runs of the previous exercise may give the impression of periodic regularity in the evolution of V(t)

$$\langle V(t)\rangle = \frac{1}{N}\sum_{n=1}^{N} V_n(t) \qquad \text{sample mean}$$

$$\left\langle (V(t)-\langle V(t)\rangle)^2\right\rangle = \frac{1}{N-1}\sum_{n=1}^{N}(V_n(t)-\langle V(t)\rangle)^2 \qquad \text{sample variance}$$

$$\langle (V(t)-\langle V(t)\rangle)(V(s)-\langle V(s)\rangle)\rangle = \frac{1}{N-1}\sum_{n=1}^{N}(V_n(t)-\langle V(t)\rangle)(V_n(s)-\langle V(s)\rangle) \qquad \text{sample autocovariance}$$

Interpretation of Ensemble Statistics

What does "mean" mean when we talk about the brain?

The Average current could tell us about the activation in a certain region

What is the significance of variance and autocovariance?

VARIANCE: expectation of deviation from the mean

Linked with different variables like aging/development/mental degradation disorders.

AUTOCOVARIANCE: covariance at pairs of time points eg: within this range

Covariance tracks the changes in the brain structure over time (relationship of the variable with itself over time)

NOTE: **Variance** refers to the spread of a data set around its mean value, while a **covariance** refers to the measure of the directional relationship **between** two random variables.

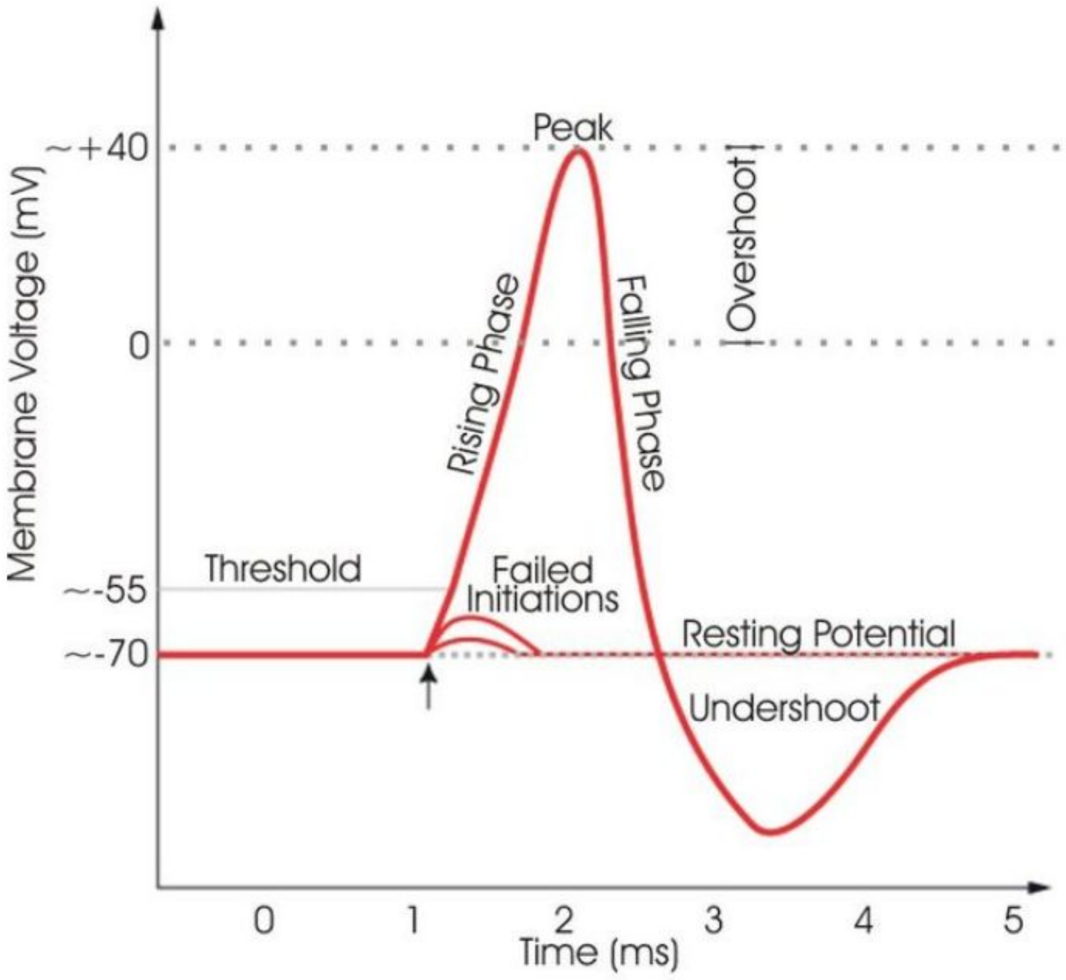
Day #2

Agenda for the next TWO days

- **Day-#1**
  - Leaky Integrate-and-Fire (LIF) Neurons
    - 14 Exercises
- **Day-#2**
  - Spiking in LIF Neurons and Refractory Periods
    - 7 Exercises

Introduction to Spiking Neural Networks

Spiking with time to see effect on membrane potential

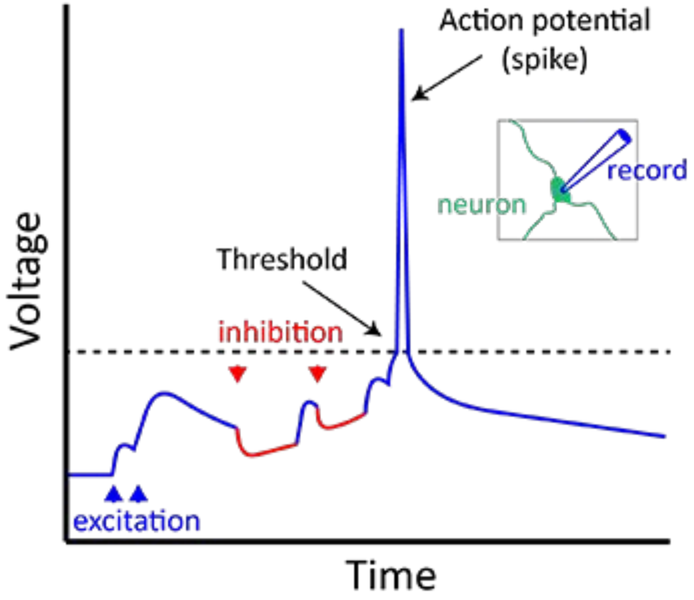


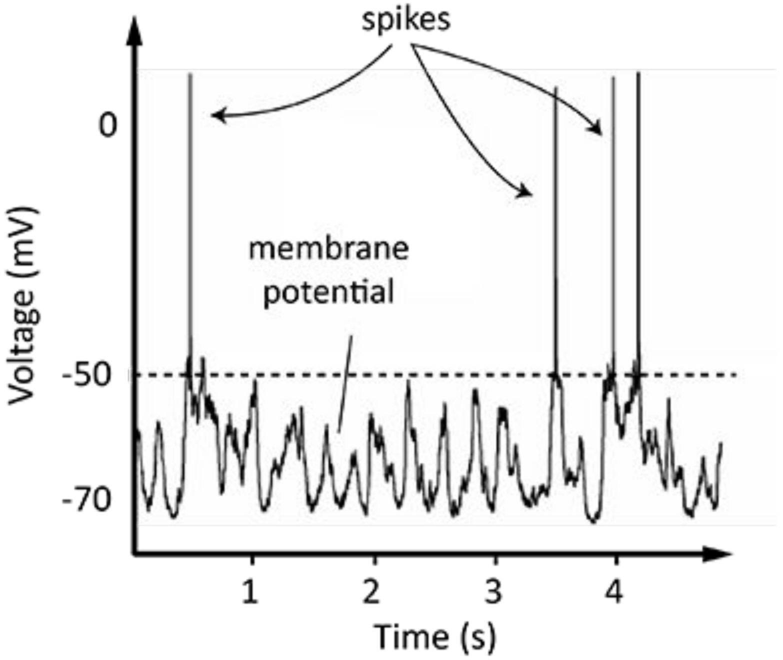
SNN in machines and brains

Neurons do not fire at each propagation cycle (as it happens with typical multi-layer perceptron networks), but rather fire only when a membrane potential – an intrinsic quality of the neuron related to its membrane electrical charge – reaches a specific value. When a neuron fires, it generates a signal that travels to other neurons which, in turn, increase or decrease their potentials in accordance with this signal. They receive input from previous layer and signal to subsequent layer.

Exercise#1

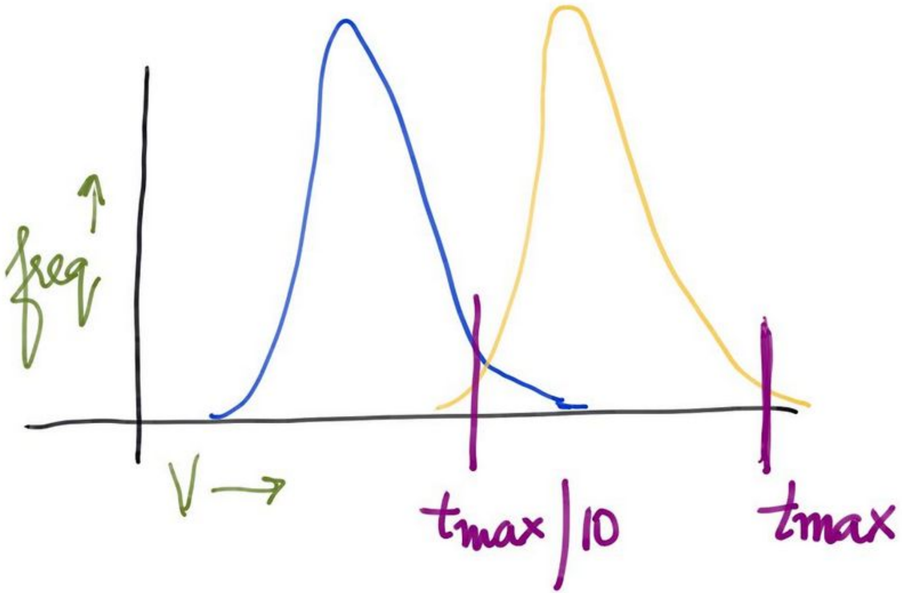
Spiking in the brain





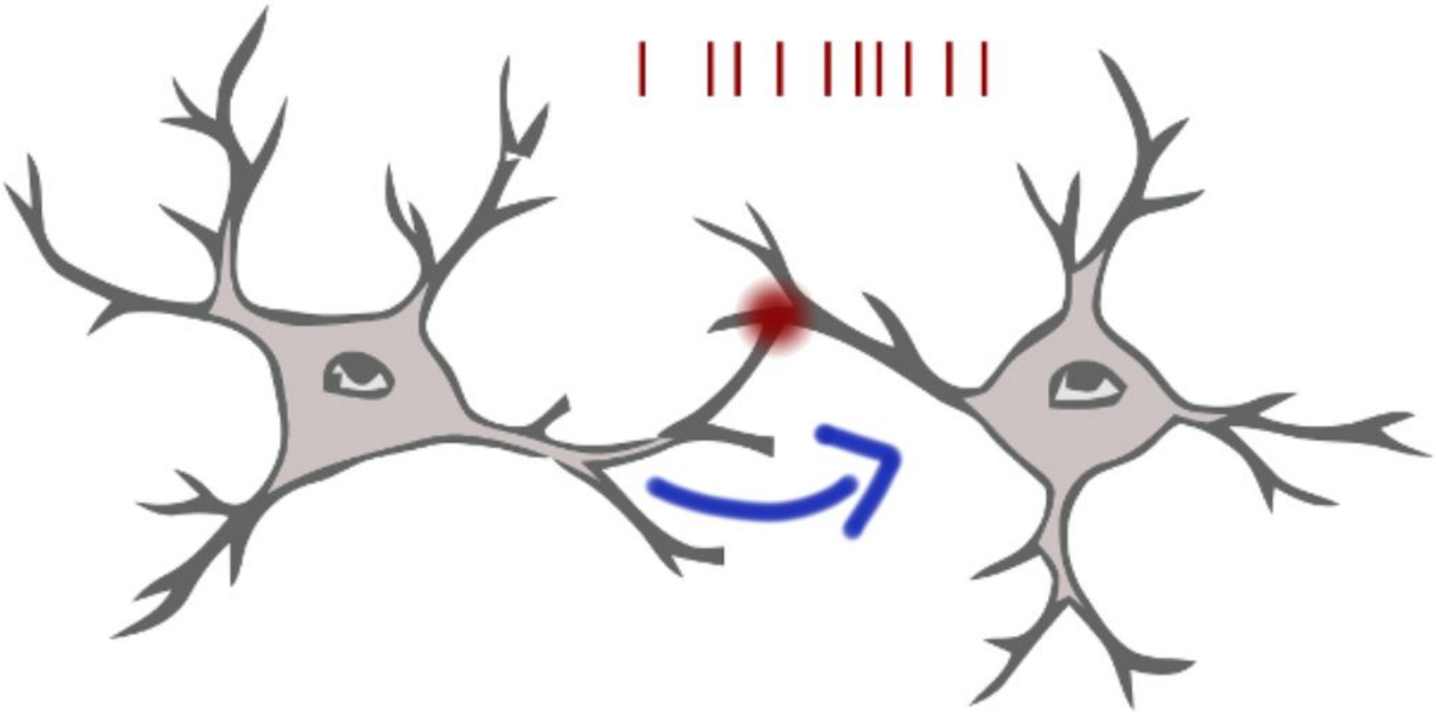
Expected Output:
(With output explanation)

NOTE: these images are only to communicate ideas and hence are not drawn to scale.



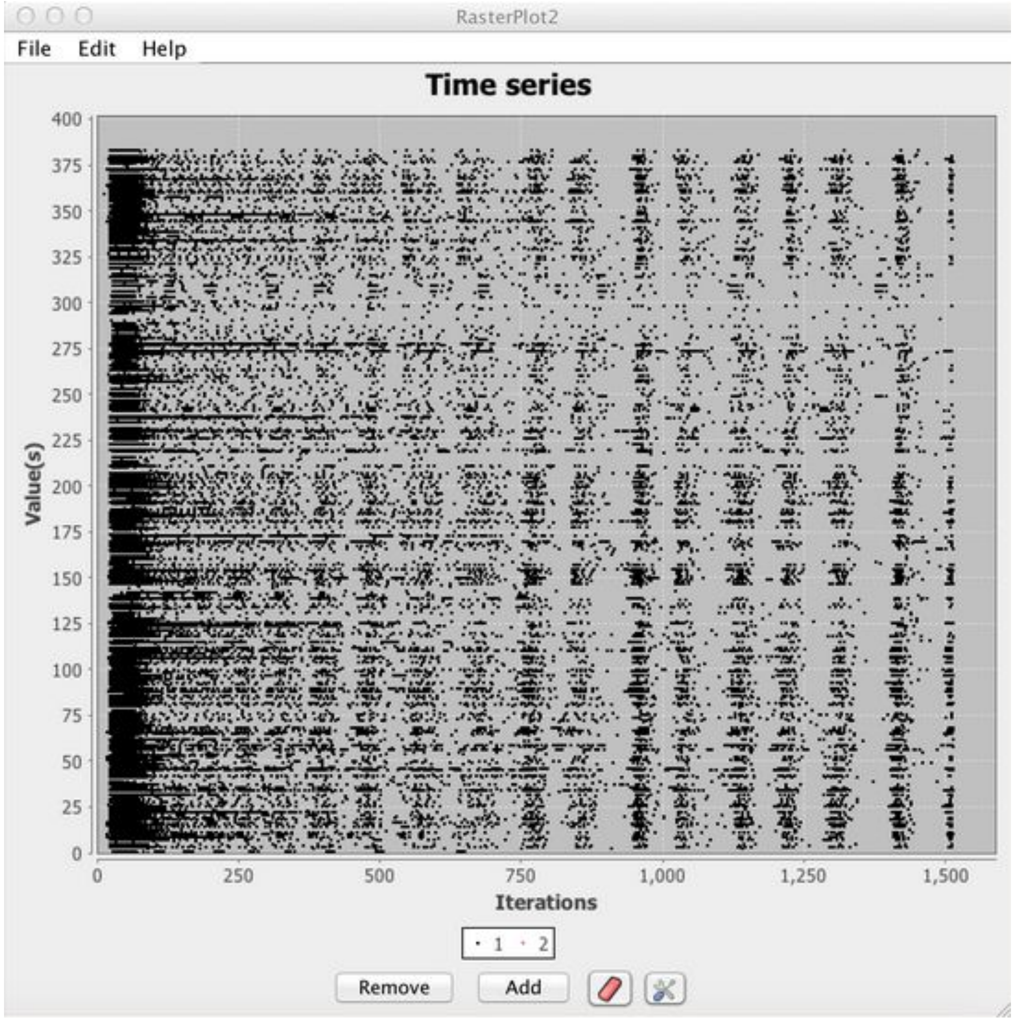
Exercise#2

Introducing Spikes



Raster Plots

A spike **raster plot** displays the spiking activity of a group of neurons over time (for more information see this page). In a **raster plot** each row (y-axis) corresponds to the index of a neuron in a neuron group. The columns (x-axis) corresponds to the current time in the simulation.


RasterPlot2
File
Edit
Help
Time series
400
375
350
325
300
275
250
225
200
175
150
125
100
75
50
25
0
Value(s)
0
250
500
750
1,000
1,250
1,500
Iterations
1
2
Remove
Add

Exercise#3

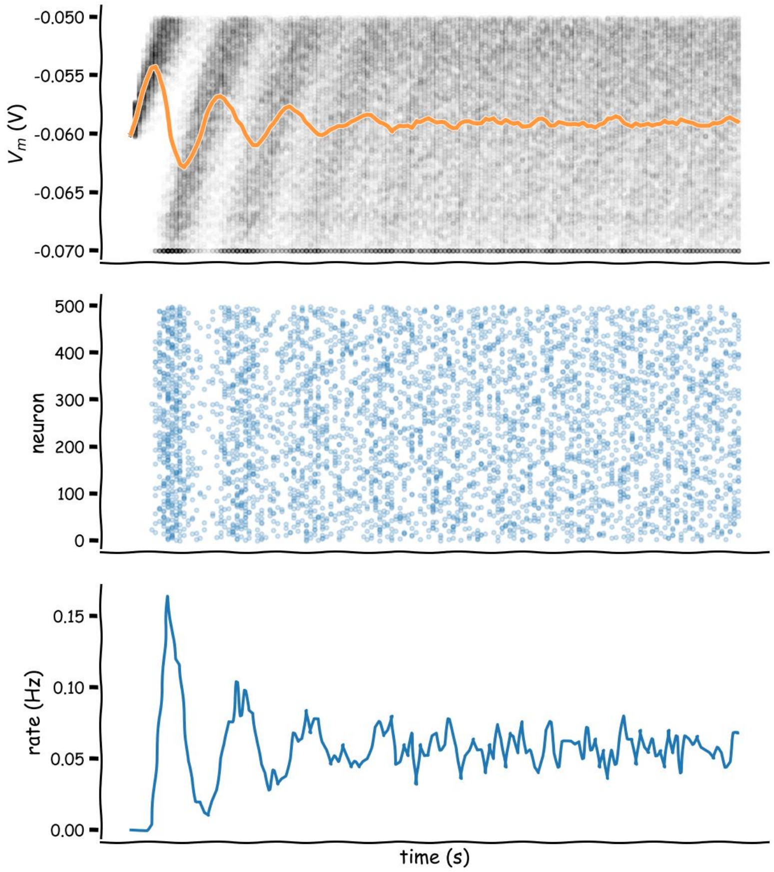
Boolean Indexes

In boolean indexing, we will select subsets of data based on the actual values of the data and not on their row/column labels or integer locations. In boolean indexing, we use a boolean vector to filter the data.

Input:

You're given a dictionary:
{Neuron_no:
[list-of-spike-times]}

Expected Output:



OPTIONAL Fun programming exercise #1 (Impress your TA session)

Try to find out if and how we can get boolean indexes from Bloom Filters?

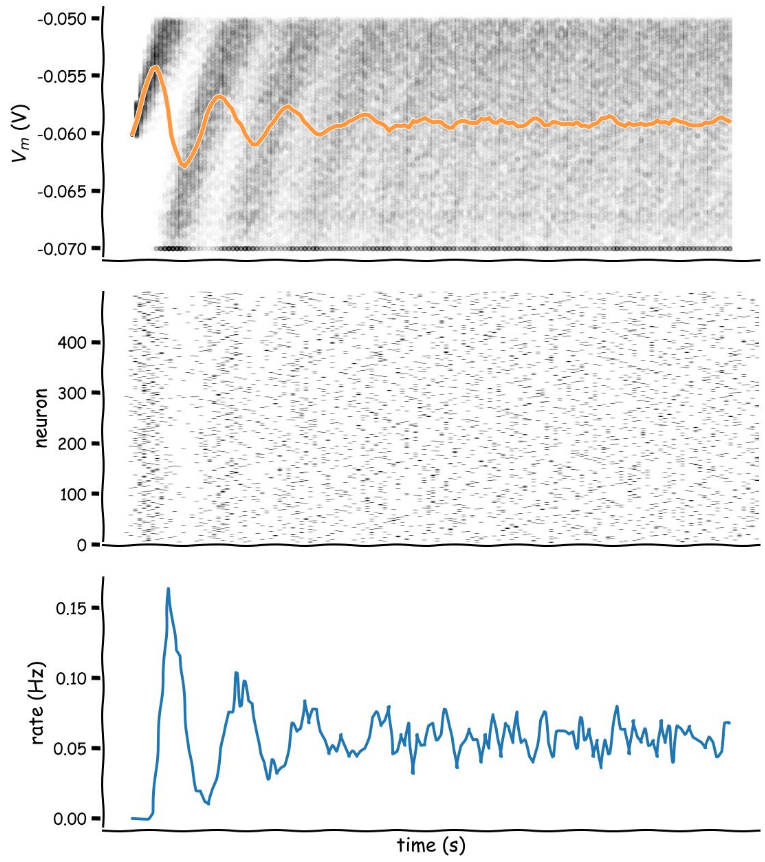
For help on bloom filters: https://llimllib.github.io/bloomfilter-tutorial/

Exercise#4

#TASK:

Convert raster plot of Exercise 3 to binary raster plot.

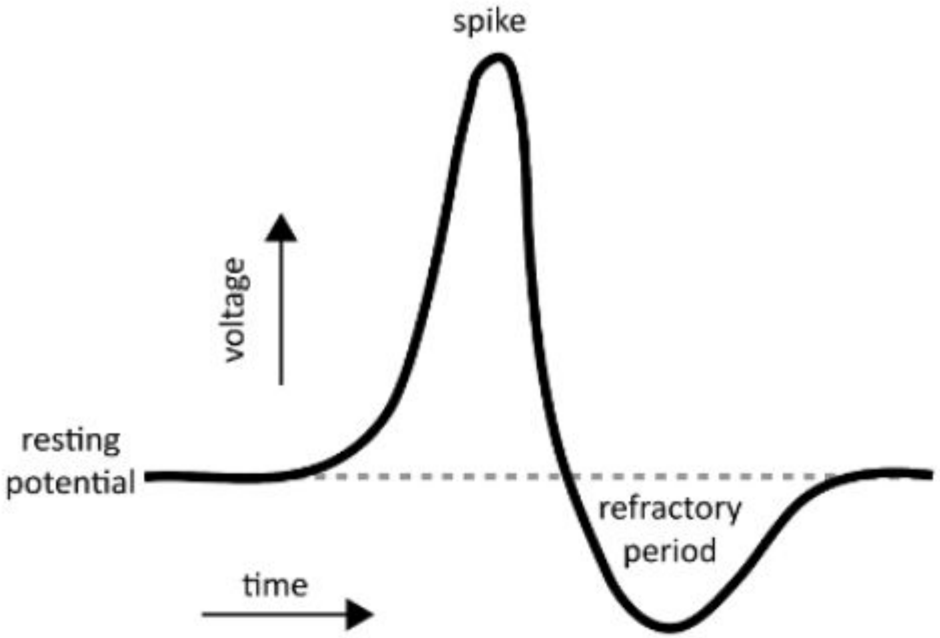
Expected Output:



Exercise#5, #6

Refractory Periods

The absolute refractory period is a time interval in the order of a few milliseconds during which synaptic input will not lead to a 2nd spike, no matter how strong.

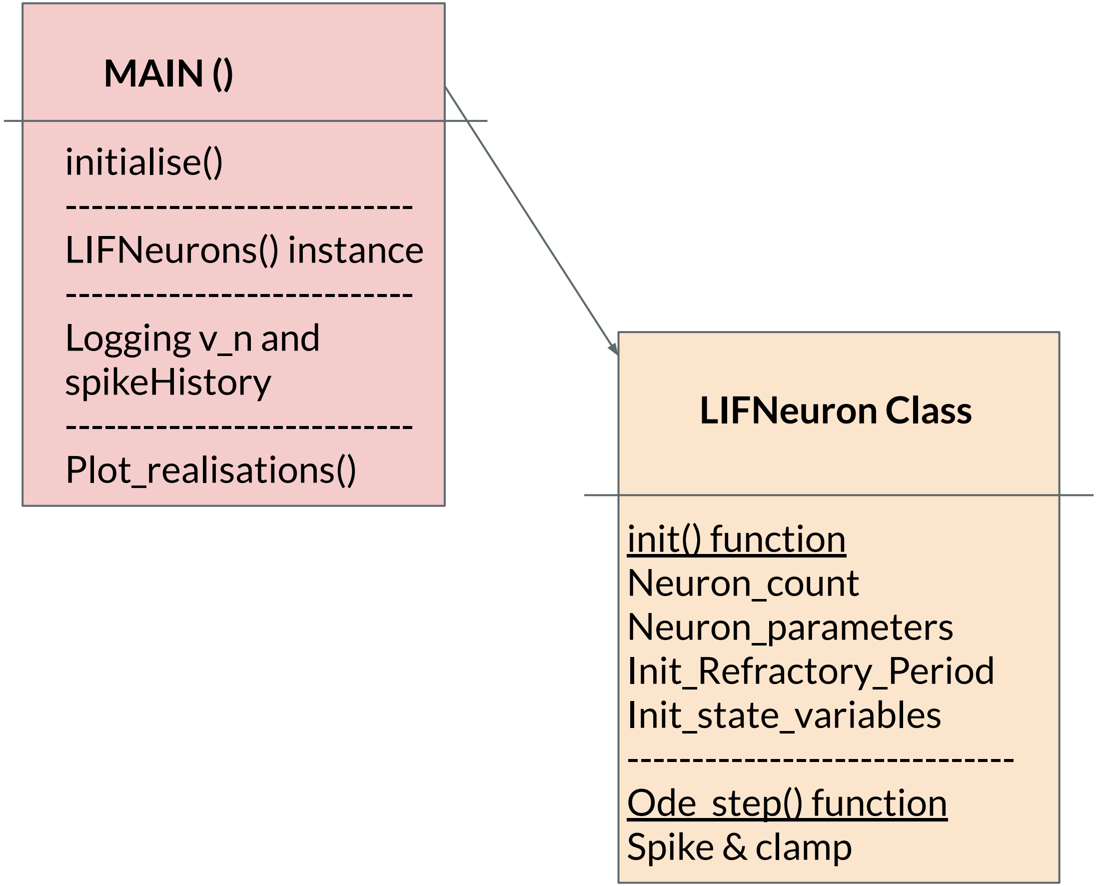

spike
voltage
resting
potential
refractory
period
time

Psychological Refractory Periods in the brain

The term psychological **refractory period** (PRP) refers to the **period** of **time** during which the response to a second stimulus is significantly slowed because a first stimulus is still being processed.

Exercise#7

Informal class diagram to help with implementation:



NOTE

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