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assignment 1 of Computational Neuroscience course

## Abstract

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We usually simulate a spiking neuron in a relatively simple form, known as Leaky Integrate-and-Fire (LIF) model. The reaction of this model to different input currents **cannot** represent a real neuron's behavior **accurately**. But can we add some terms to this model in a way so that it behaves more real...?

# Introduction

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In this report, I will discuss 3 neuron models, including leaky integrate-and-fire (LIF), Adaptive LIF and Adaptive Exponential LIF, and study their dynamics in response to 5 different types of inputs which are as follows:

- constant current
- sine wave current
- step function current
- linear current
- GWN current

## Leaky integrate-and-fire (LIF) neuron model

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One of the simplest mathematical models of a neuron is the Leaky integrate-and-fire (LIF) model. The subthreshold membrane potential dynamics of a LIF neuron is described by:

$$C_m \frac{dV}{dt} = -g_L(V - V_L) + I,$$

where  $C_m$  is the membrane capacitance,  $V$  is the membrane potential,  $g_L$  is the leak conductance,  $V_L$  is the resting potential, and  $I$  is the external input current. Dividing both sides of the above equation by  $g_L$  gives:

$$\tau_m \frac{dV}{dt} = -(V - V_L) + \frac{I}{g_L}, \quad (1)$$

where the time constant  $\tau_m$  is defined as  $\tau_m = C/g_L$ . Below we will use Eqn.(1) to simulate the LIF neuron dynamics. If  $I$  is sufficiently

strong such that  $V$  reaches a certain threshold value  $V_{th}$ ,  $V$  is reset to a reset potential  $V_{reset} < V_{th}$  and voltage is clamped to  $V_{reset}$  for  $t_{ref}$  ms mimicking the refractoriness of the neuron during an action potential, *i.e.*,

$$\text{if } V(t) \geq V_{th} : V(t^+) = V_{reset}$$

## Adaptive LIF neuron model

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In order to make an adaptive LIF neuron model, we simply have to add an adaption term ( $-w$ ) to Eqn.(1). Then we have:

$$\tau_m \frac{dV}{dt} = - (V - V_L) - \frac{w}{g_L} + \frac{I}{g_L} \quad (2)$$

$w$  itself changes based on the following dynamics:

$$\tau_w \frac{dw}{dt} = a(V - E_L) - w$$

$$\text{at } t = t^f \text{ reset } w \rightarrow w + b$$

## Exponential Adaptive LIF neuron model

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The relative equation is as follows:

$$\tau_m \frac{dV}{dt} = - (V - V_L) + \Delta_T \exp\left(\frac{V - V_{th}}{\Delta_T}\right) - \frac{w}{g_L} + \frac{I}{g_L} \quad (3)$$

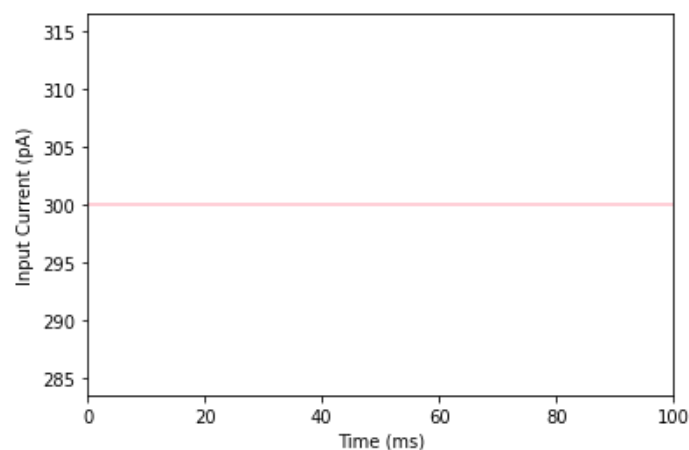
Let's move on to the notebook's results:

**Point:** in all following models **parameters** are:

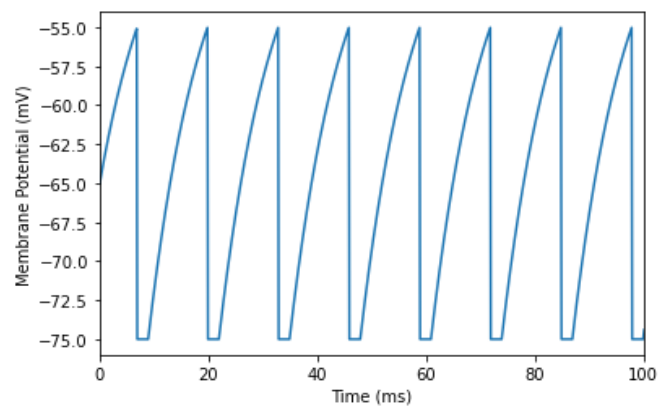
- $V_{th} = -55$  (mV)
- $V_{reset} = -75$  (mV)
- $\tau_m = 10$  (ms)
- $g_L = 10$
- $V_{init} = -65$  (mV)
- $V_L = -75$  (mV)
- $t_{ref} = 2$  (ms)
- $T = 400$  (ms)
- $dt = 0.1$  (ms)
- $\Delta_T = 1$  (mV)
- $w_{init} = 0$
- $a = 6$
- $b = 10$  (pA)

### 1) Constant Current:

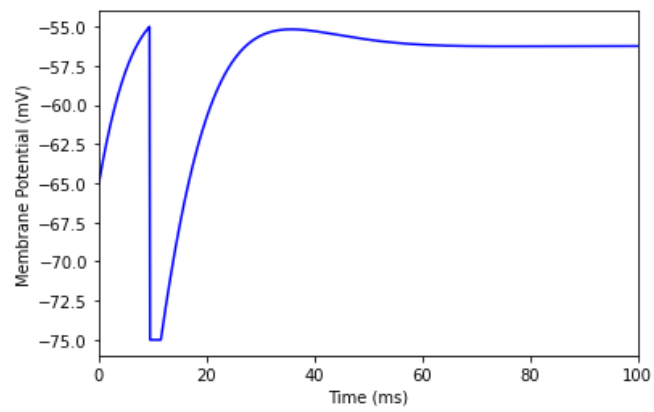
$$I = 300$$



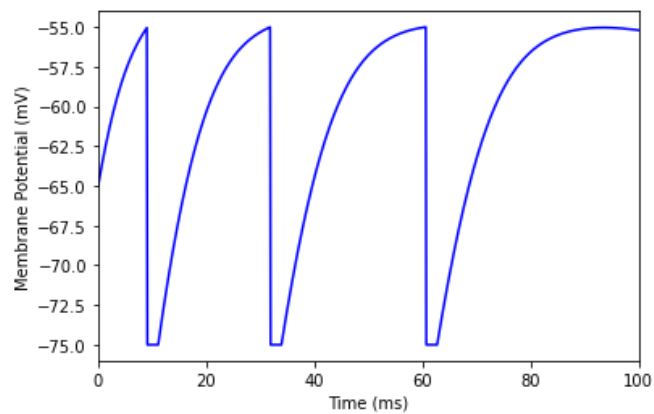
### LIF reaction:



### Adaptive LIF reaction:

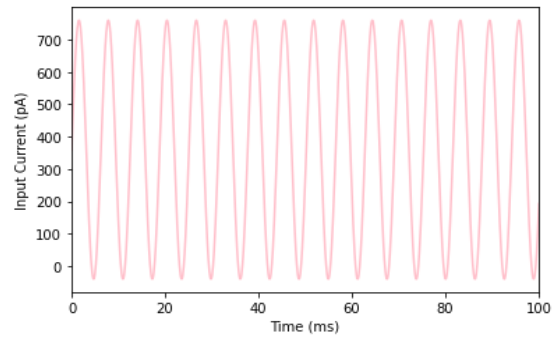


### Adaptive Exponential LIF reaction:

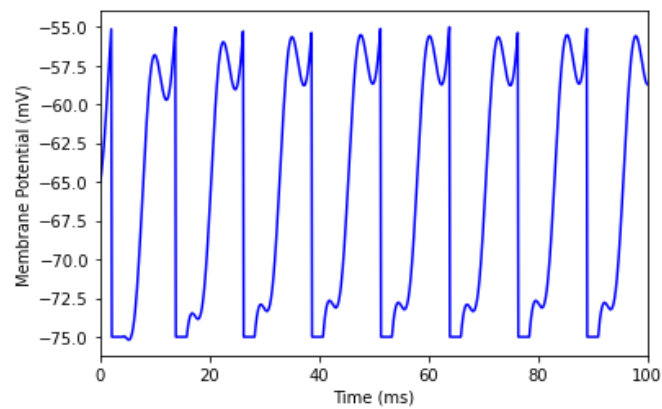


## 2) Sine Wave Current

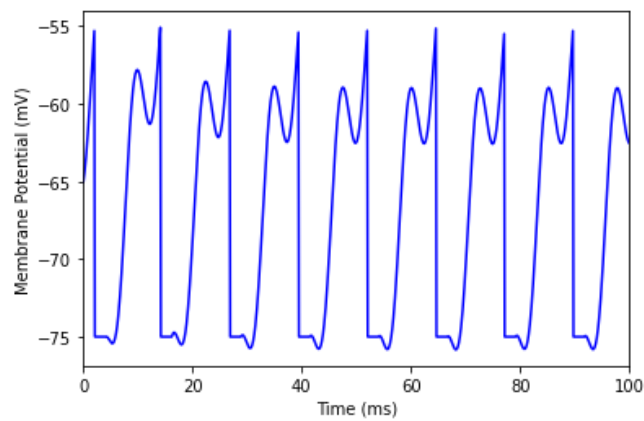
$$I = 400 * (\sin(t) + 0.9)$$



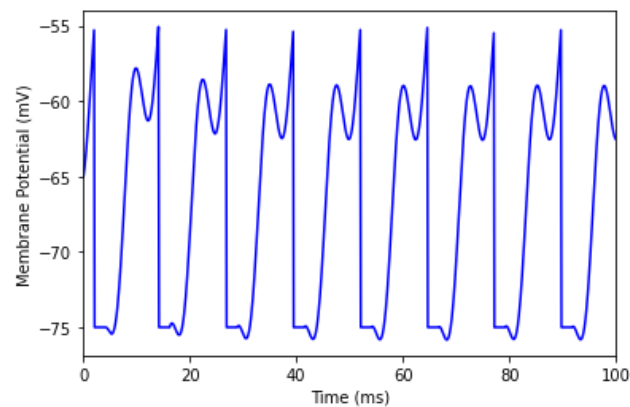
LIF reaction:



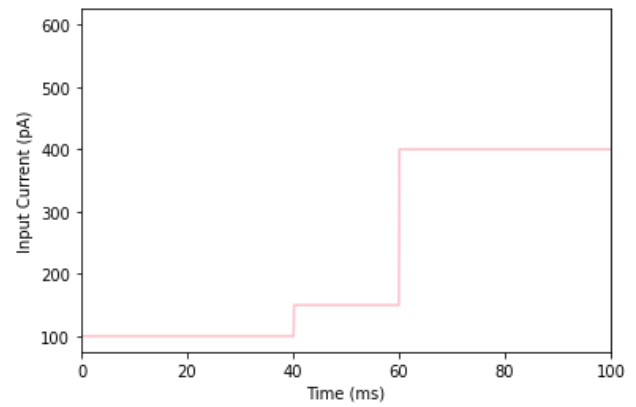
Adaptive LIF reaction:



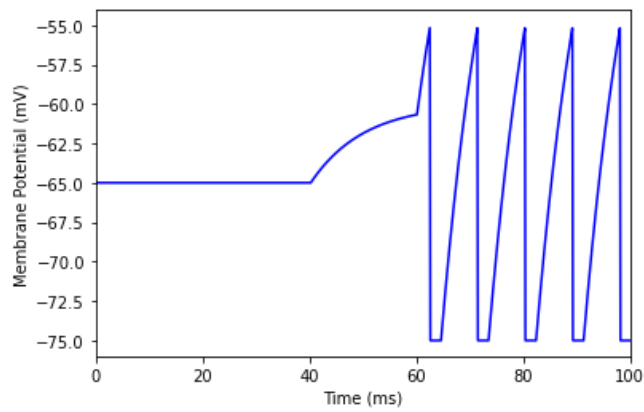
Adaptive Exponential LIF reaction:



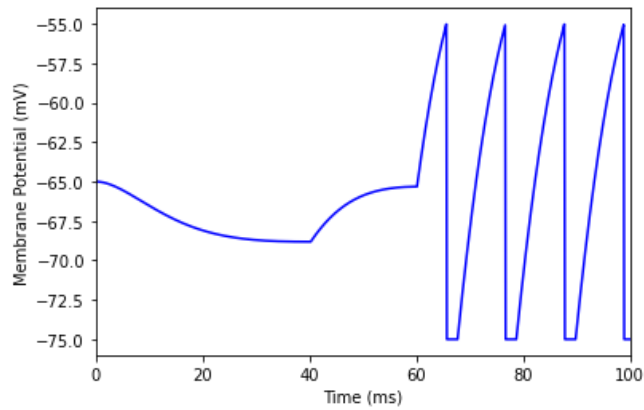
### 3) Step Function Current



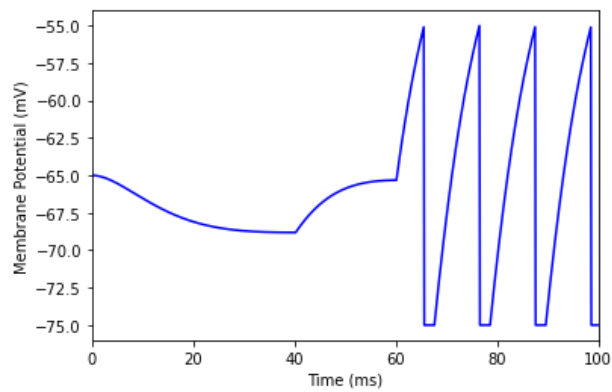
LIF reaction:



Adaptive LIF reaction:

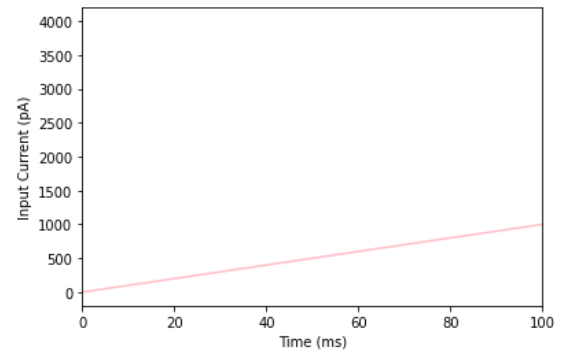


Adaptive Exponential LIF reaction:

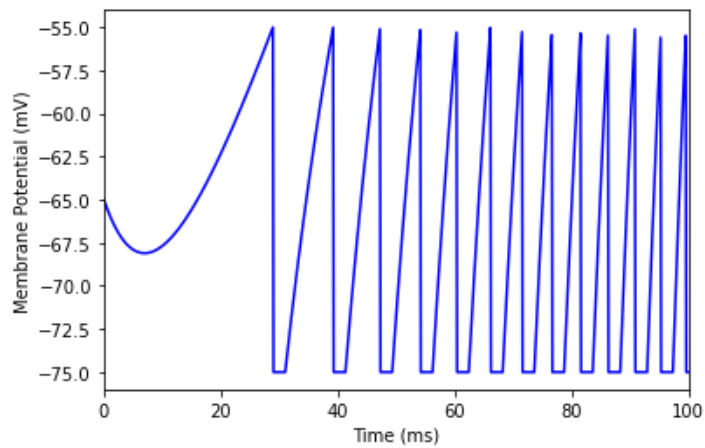


#### 4) Linear Current

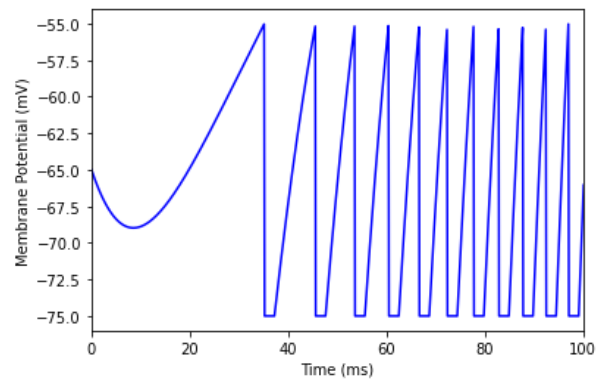
$$I = 10 * t$$



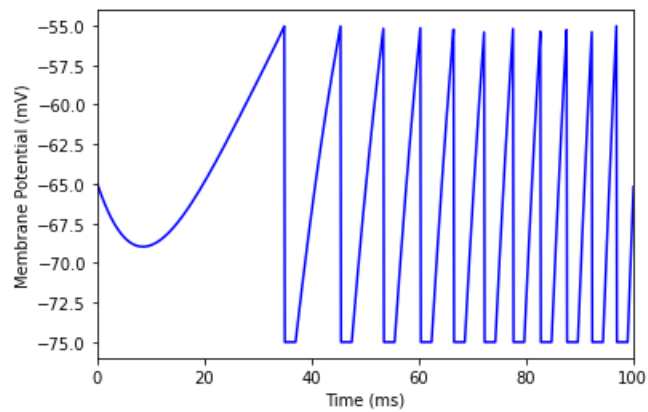
LIF reaction:



Adaptive LIF reaction:

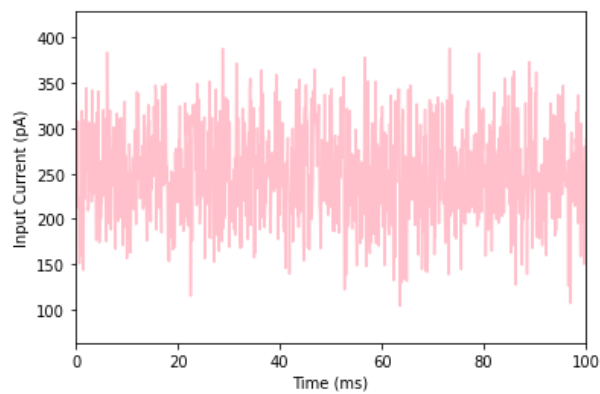


Adaptive Exponential LIF reaction:

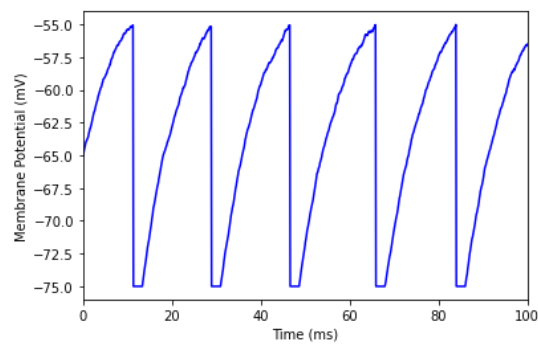




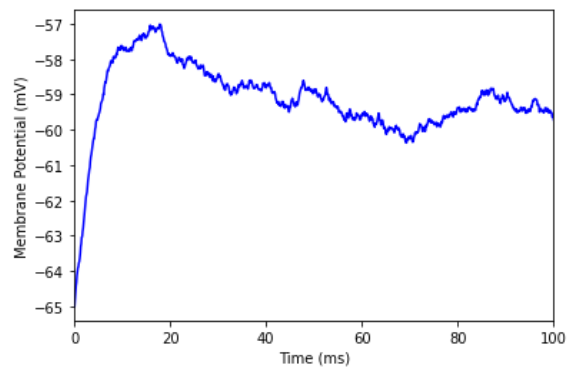
## 5) (Gaussian white Noise) GWN Current



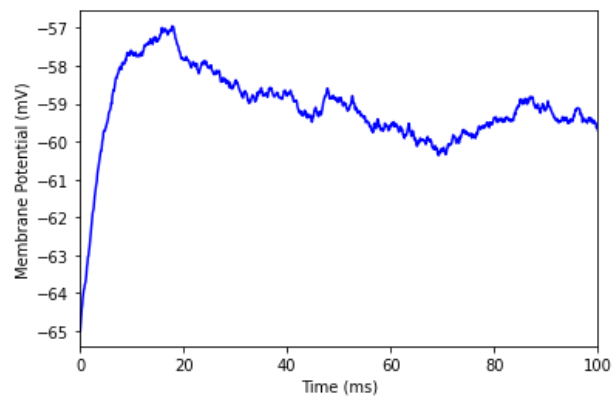
LIF reaction:



Adaptive LIF reaction:

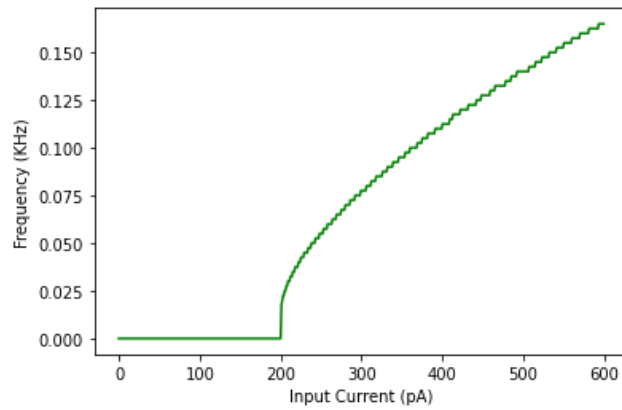


Adaptive Exponential LIF reaction:

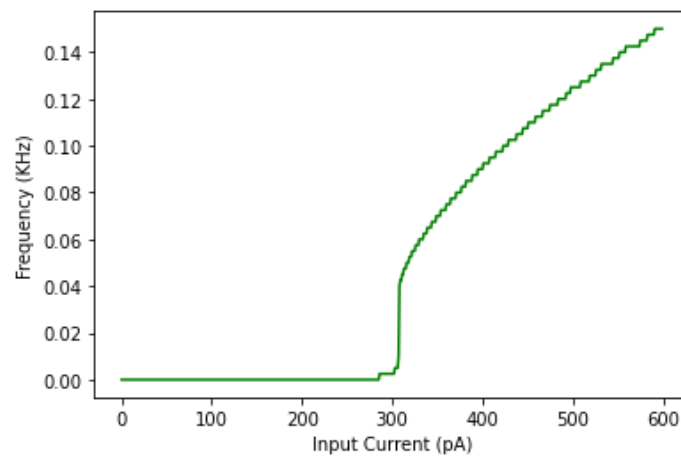


At the end, The following plots are showing the frequency of spikes for each neuron model as a response to a range of constant input currents:

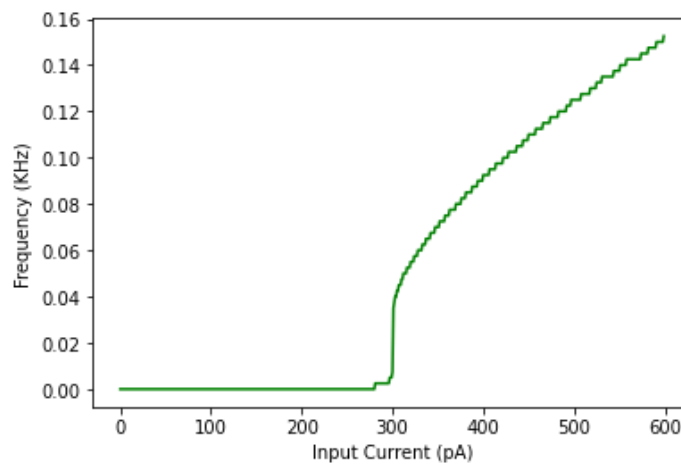
- LIF



- ALIF



- AELIF



## Resources:

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- [http://www.scholarpedia.org/article/Adaptive\\_exponential\\_integrate-and-fire\\_model](http://www.scholarpedia.org/article/Adaptive_exponential_integrate-and-fire_model)
- [https://colab.research.google.com/github/johanjan/MOOC-HPFEM-source/blob/master/LIF\\_ei\\_balance\\_irregularity.ipynb#scrollTo=BoL7Mub0eMzT](https://colab.research.google.com/github/johanjan/MOOC-HPFEM-source/blob/master/LIF_ei_balance_irregularity.ipynb#scrollTo=BoL7Mub0eMzT)
- [https://colab.research.google.com/github/NeuromatchAcademy/course-content/blob/NMA2020/tutorials/W3D1\\_RealNeurons/student/W3D1\\_Tutorial1.ipynb#scrollTo=QcnfVdHX4JPU](https://colab.research.google.com/github/NeuromatchAcademy/course-content/blob/NMA2020/tutorials/W3D1_RealNeurons/student/W3D1_Tutorial1.ipynb#scrollTo=QcnfVdHX4JPU)