Shahid Beheshti University

Anita Soroush

Abstract

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

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

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 τ_m is defined as τ_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 Vreset for tref ms mimicking the refractoriness of the neuron during an action potential, *i.e.*,

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

Adaptive LIF neuron model

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

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

w itself changes based on the following dynamics:

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

$$at \quad t = t^f \quad reset \qquad w \rightarrow w + b$$

Exponential Adaptive LIF neuron model

The relative equation is as follows:

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

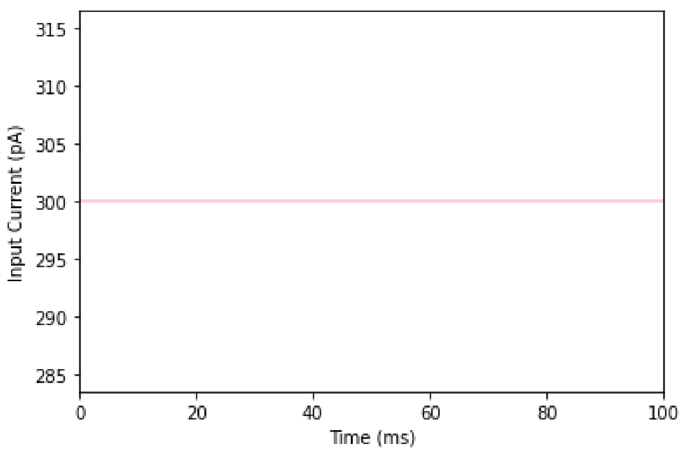
Let's move on to the notebook's results:

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

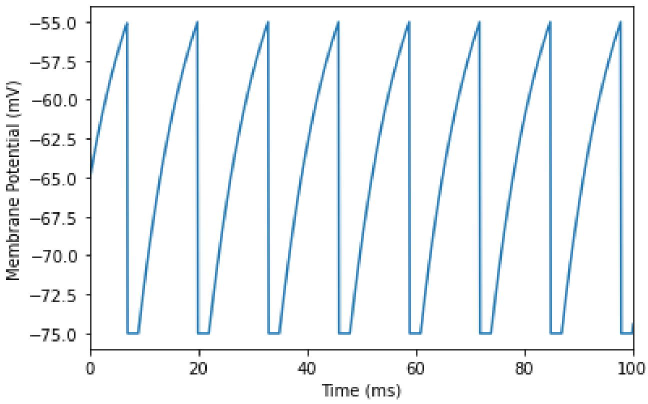
- V_{th} = -55 (mV)
- V_{reset} = -75 (mV)
- τ_m = 10 (ms)
- g_L = 10
- V_{init} = -65 (mV)
- V_L = -75 (mV)
- t_{ref} = 2 (ms)
- T = 400 (ms)
- dt = 0.1 (ms)
- Δ_T = 1 (mV)
- w_{init} = 0
- a = 6
- b = 10 (pA)

1) **Constant Current:**

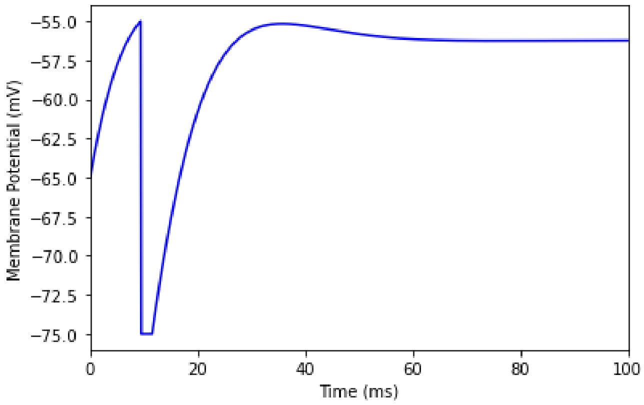
I = 300



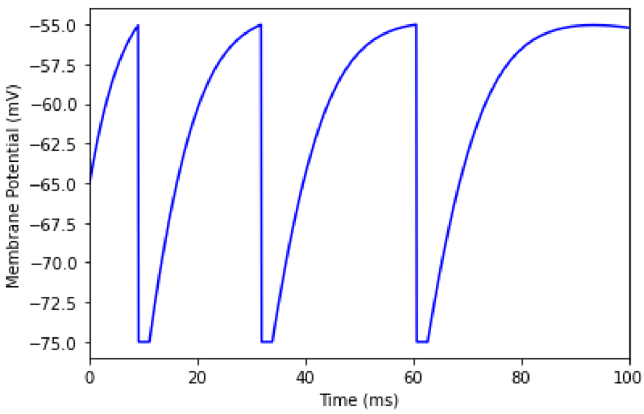
LIF reaction:



Adaptive LIF reaction:

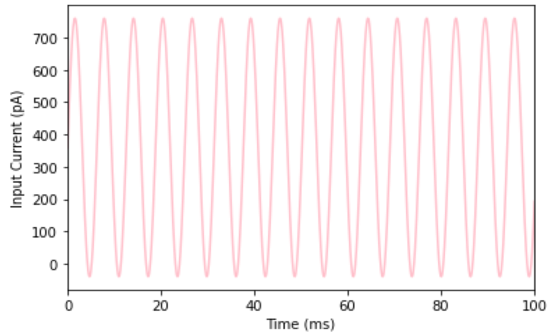


Adaptive Exponential LIF reaction:

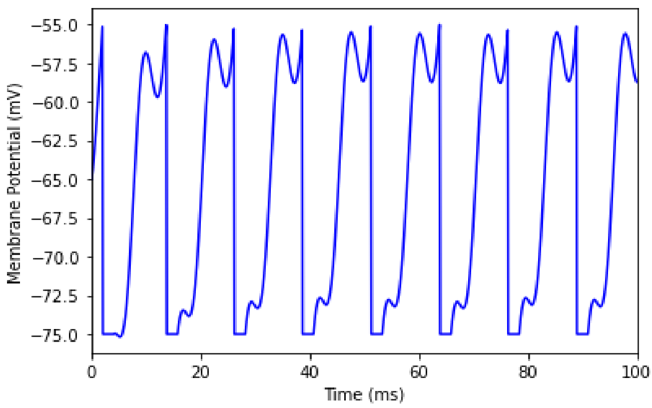


2) Sine Wave Current

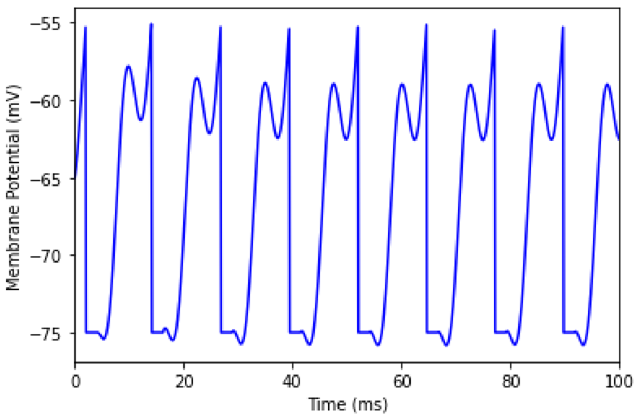
$I = 400 * (\sin(t) + 0.9)$



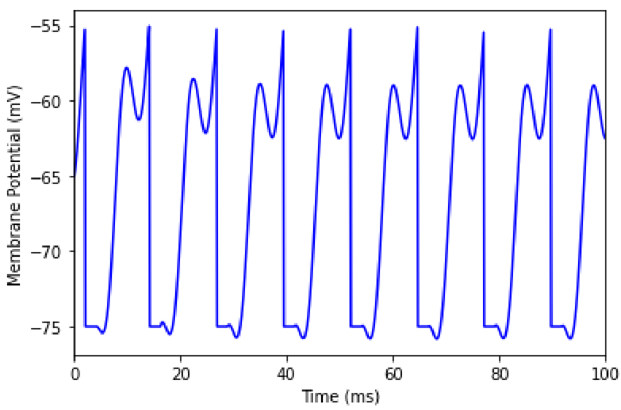
LIF reaction:



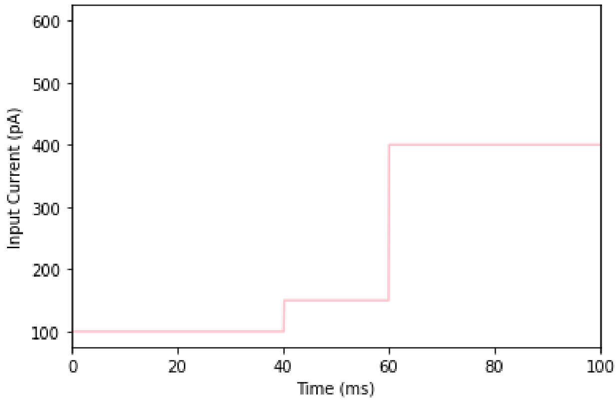
Adaptive LIF reaction:



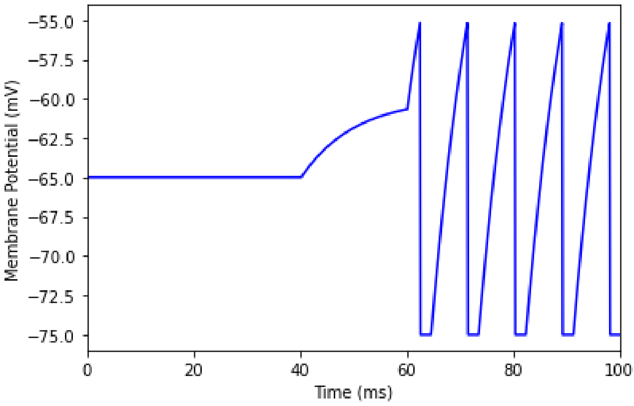
Adaptive Exponential LIF reaction:



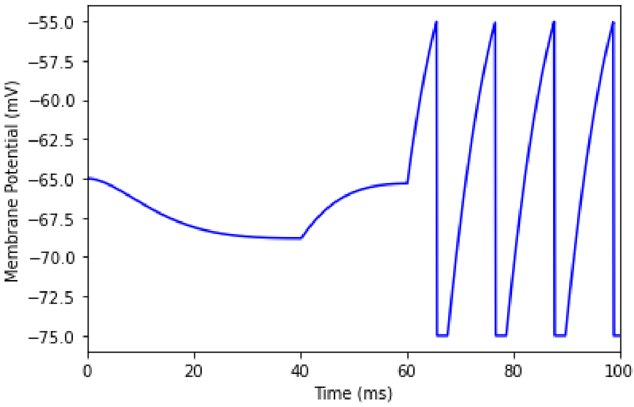
3) Step Function Current



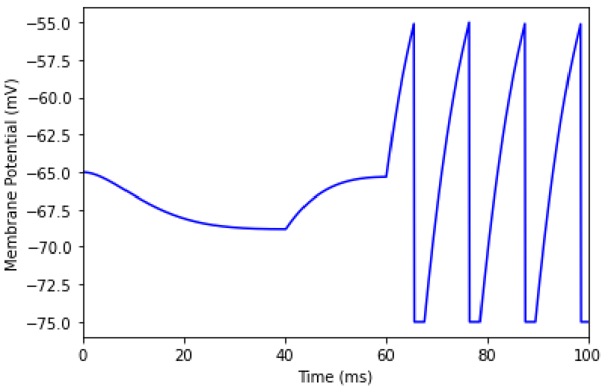
LIF reaction:



Adaptive LIF reaction:

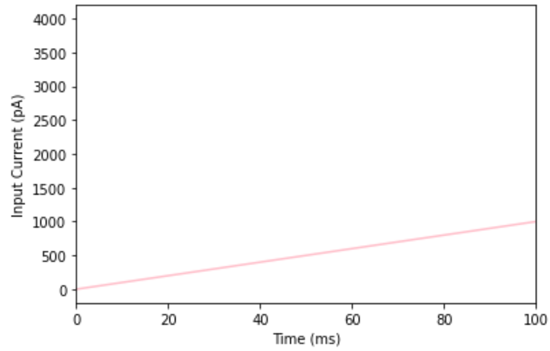


Adaptive Exponential LIF reaction:

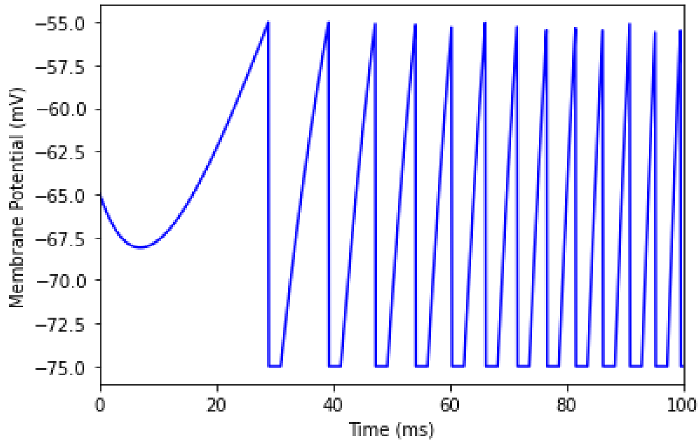


4) Linear Current

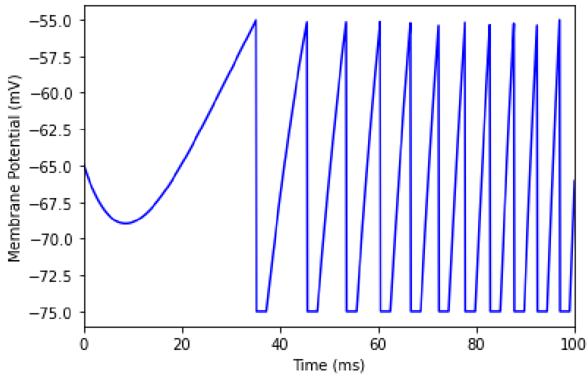
$I = 10 * t$



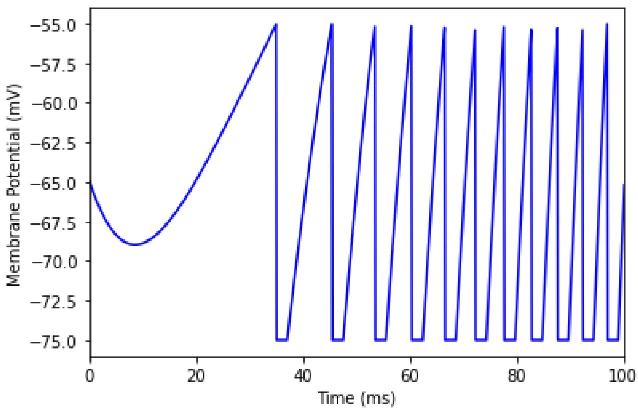
LIF reaction:



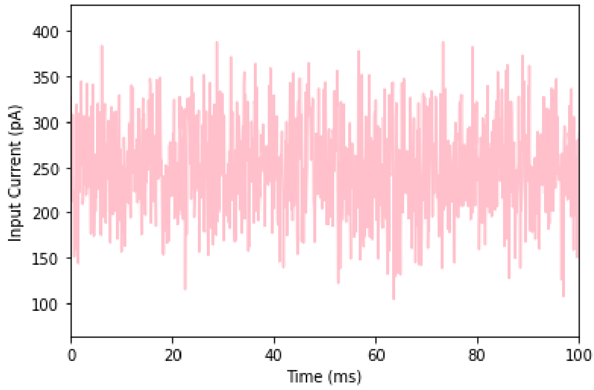
Adaptive LIF reaction:



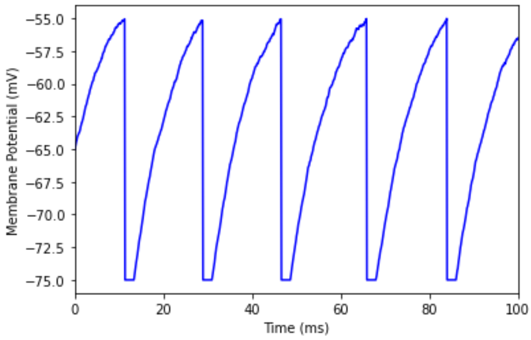
Adaptive Exponential LIF reaction:



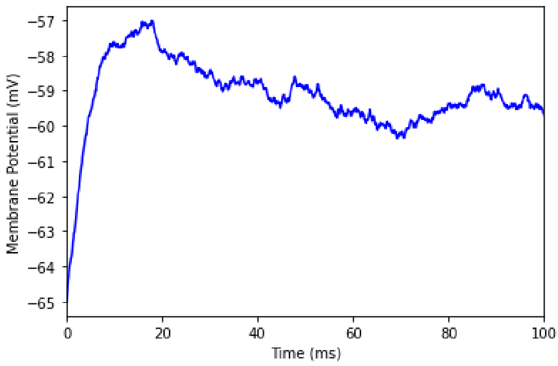
5) (Gaussian white Noise) GWN Current



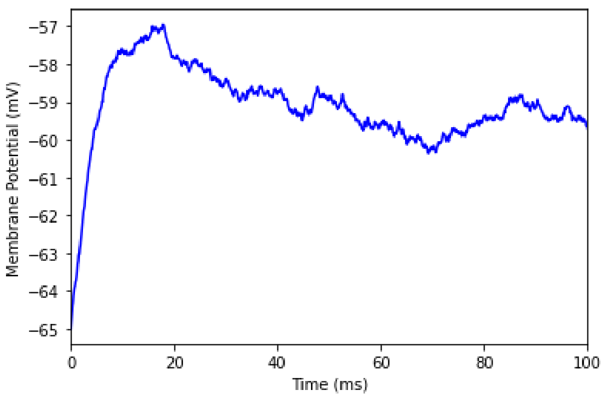
LIF reaction:



Adaptive LIF reaction:

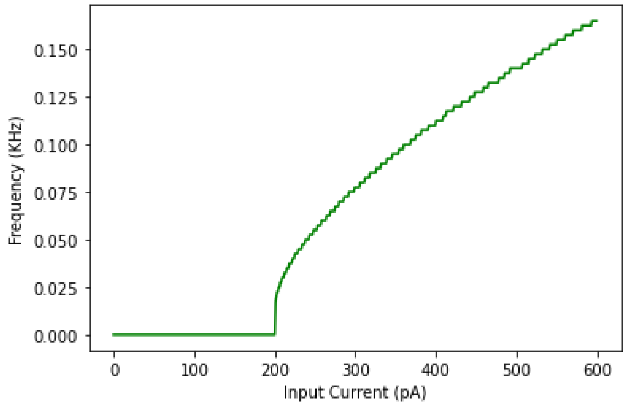


Adaptive Exponential LIF reaction:

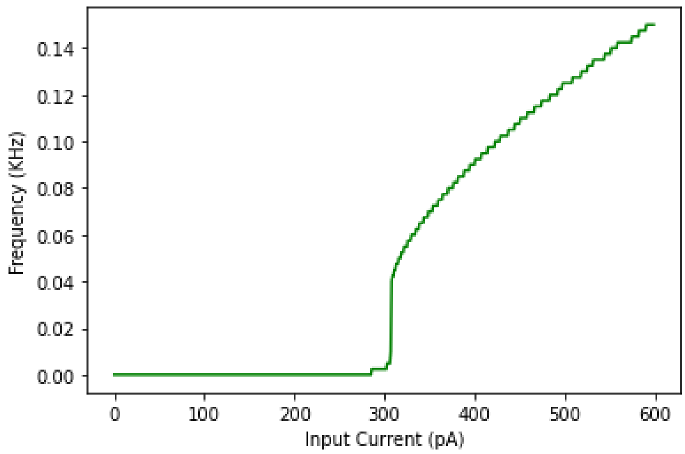


At the end, The following plots are showing the frequency of spikes for each neuron model as a response to a range of constant input currents:

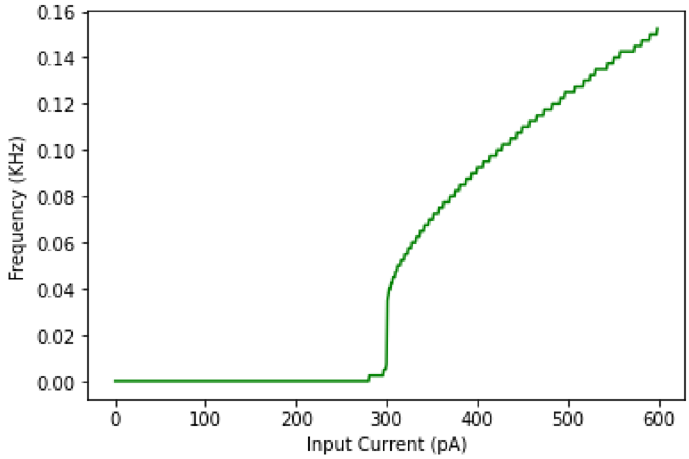
- LIF



- ALIF



- AELIF



Resources:

- 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/NeuromatchAcademy/course-content/blob/NMA2020/tutorials/W3D1_RealNeurons/student/W3D1_Tutorial1.ipynb#scrollTo=QcnfVdHX4JPU