Quadratic Leaky Integrate and Fire Model

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Aim: To explore and understand how quadratic leaky integrate and fire model (QLIF) behaves.

Motivation: We have in the class learnt linear leaky integrate and fire model (LLIF). Now, in this project we explore how a quadratic function can model how a neuron behaves when stimulated.

The equation that governs LLIF is:

$$\tau \frac{\partial u}{\partial t} = -(u - u_{rest}) + RI_{ext}$$

Whereas the equation that governs QLIF is:

$$\tau \frac{\partial u}{\partial t} = a_o(u - u_{rest})(u - u_c) + RI_{ext}$$

Here,
τ is time constant, u is the voltage of the neuron, u_{rest} is the resting potential, u_c is a voltage constant that is greater than u_{rest}, R is the resistance of the neuron, a_o is a constant greater than 0 and I_{ext} is the external stimulus given to the neuron.

Our main motivation to pick and explore the model is as follows: We thought LLIF was extremely simplified and cannot model neuron's behaviour to one's satisfaction. In this context, we thought that QLIF can model the neurons' behaviour better since there will be more parameters to tune.

Methods: From the above section one would notice that there are two parameters to tune.

1. a_o: we analysed the role that a_o is playing by changing its value.
2. u_c: we changed the difference between u_{rest} and u_c. We talk about ‘effective threshold’ later when we look at this in detail.

3. Apart from these the above parameters, we tried different current inputs: step, ramp and sinusoidal. We have changed the parameters in each of the inputs as well to see how those affect the model.
    a. Step Current: We tried changing the amplitude to see how that affects the model.
    b. Ramp Current: We changed the rampness of the input current.
    c. Sinusoidal Current: We changed the frequency of the input to see how that changes the output of the model.

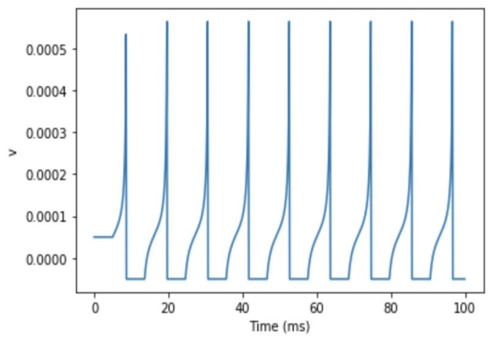
Further, we have always used the same parameters (wherever possible) and simulated LLIF too. This we thought will act like a control group. We encourage you to look at our detailed report for this

<u>Results:</u>

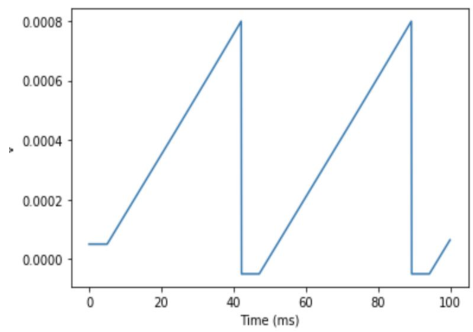
We set u_c as 0.06 mV, τ as 10ms, threshold voltage as 0.08 mV, resting potential as 0.05 mV, refractory period as 5ms, reset voltage as -0.05 mV and resistance as 10 Mohm to maintain consistency.

Step current as the input:

We set amplitude as 0.02 nano amps.

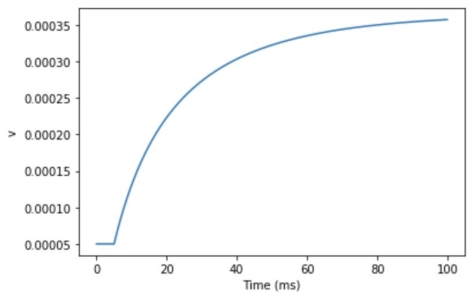


When a_o is 100/(mV)

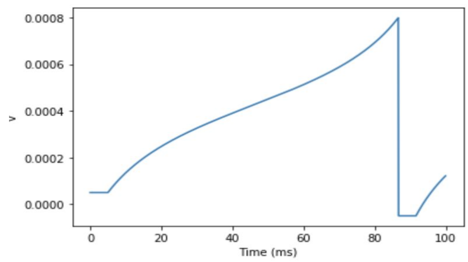


When a_o is 0.01/(mV)

We now set a_o as 1/(mV) and try to understand the role that u_c.



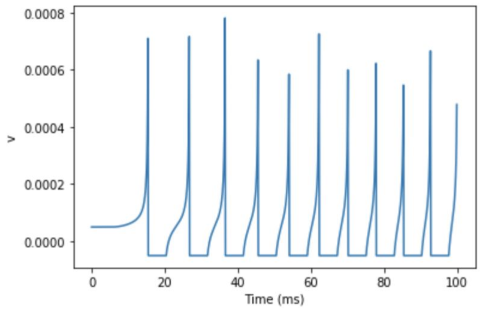
When u_c is 1 mV

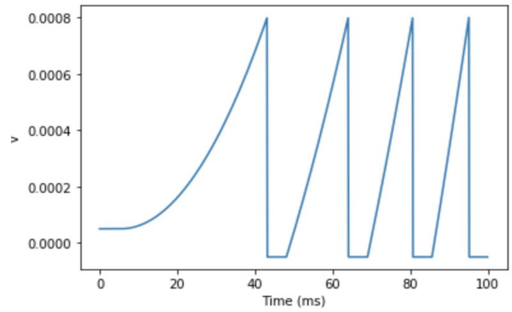


When u_c is 0.055 mV

Ramp Current as the input:

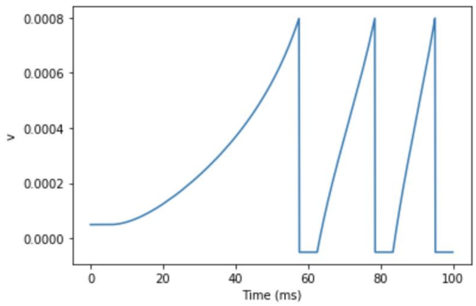
We set the amplitude to 0.01 nano amps, u_c to 0.06 mV and the ramp to 100ms.

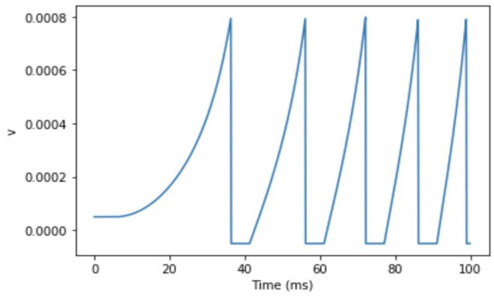




When a_o is 100/(mV) When a_o is 0.01/(mV)

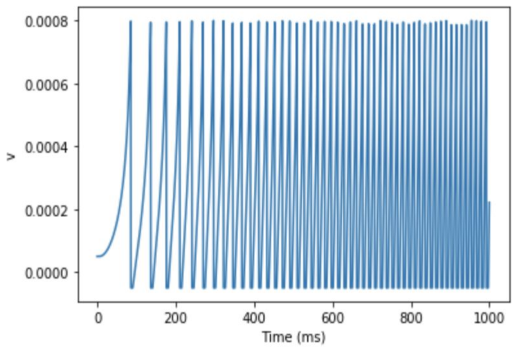
We now set a_o to 1/(mV).

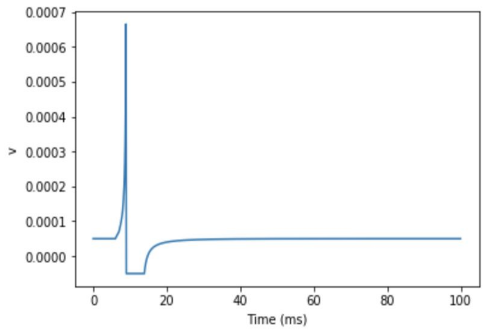




When u_c is 1 mV When u_c is 0.055 mV

We now set u_c back to 0.06 mV.

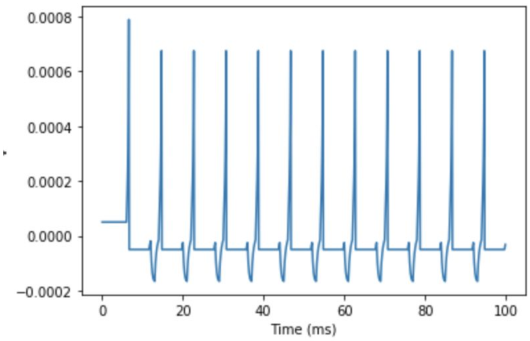




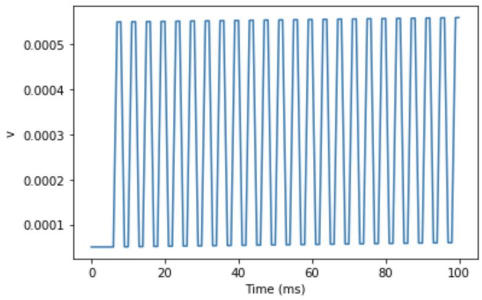
When ramp is 1000ms When ramp is 10ms

Sinusoidal Current as Input:

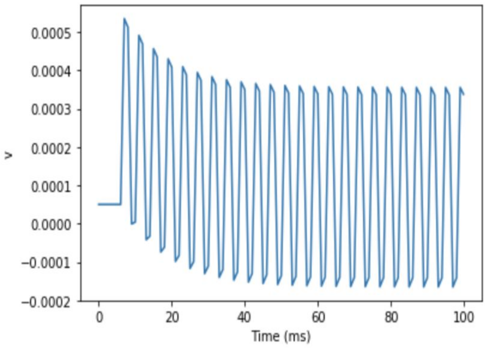
We set the frequency of the sinusoidal input to 250 Hz, u_c to 0.06 mV, a_o to 1/(mV), and amplitude to 0.5 nano amps by default.



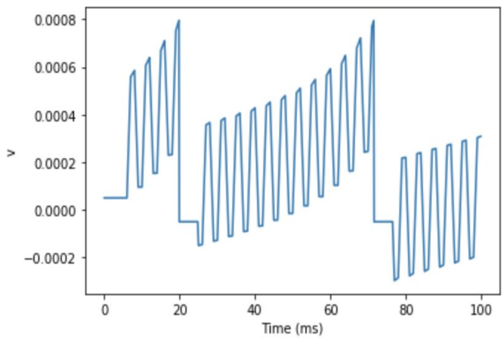
When a_o is 100/(mV)



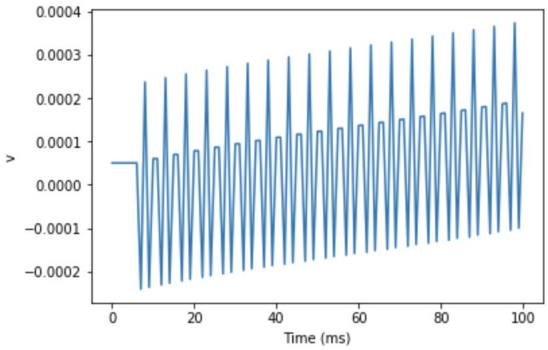
When a_o is 0.01/(mV) [No spikes]



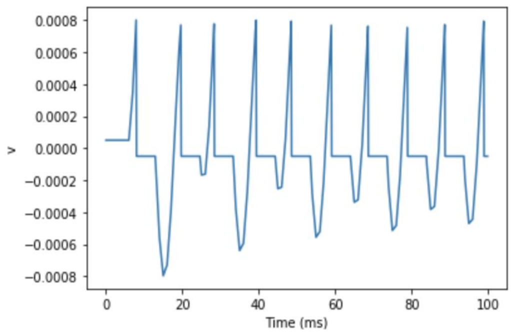
When u_c is 1 mV [No spikes]



When u_c is 0.055 mV



When freq of input is 600Hz [No spikes]



When freq of input is 100Hz

Conclusion:

1. When u_c is 1 mV the difference between u_{rest} and u_c is higher than when u_c is 0.055 mV. We see, in all cases, that the number of spikes is lower when u_c is

1mV. This illustrates the idea of 'effective threshold'. When the voltage crosses u_c the model autonomously spikes.

2. Higher the value of a_o higher the chances of the model having higher number of spikes. a_o is just a multiplicative factor. The higher it is, the higher the final voltage is. This implies that it directly affects the number of times the model spikes. We see this in all the above cases.
3. Increasing the rampness of the input current increasing the chances of the model spiking. This shows that it is not just the amplitude but the change in the amplitude that matters. We actually see this in both LLIF and QLIF (have a look at the detailed report for more info).
4. Decreasing the frequency of the sinusoidal current input, increases the chances of the model spiking. We see this when we reduce the frequency of the input from 250Hz to 100Hz and then increase it to 600Hz. Although, this is not always consistent. When we increase the frequency to 300Hz from 250Hz we don't see a decrease in the spikes in the model. In fact, we see an increase in the number of spikes by the model.

In our detailed report, we not only analysed how QLIF behaves but also compared it with LLIF and found some interesting differences. Please go through the detailed report if you're interested.

References:

[1] Nonlinear integrate-and-fire models - School of Mathematical ...www.maths.nottingham.ac.uk › pmzsc › neurodynamics › NonlinearIF

[2] https://brian2.readthedocs.io/en/stable/resources/tutorials/1-intro-to-brian-neurons.html [for understanding how brian2 works]

[3]https://neuronaldynamics-exercises.readthedocs.io/en/latest/_modules/neurodynex/leaky_integrate_and_fire/LIF.html#simulate_LIF_neuron [to understand how to use Timed Array for inputting current into the model]

[4] https://buildmedia.readthedocs.org/media/pdf/brian2/2.0rc/brian2.pdf [used it to understand what method to use to solve quadratic diff. equations]