EECE6036 - Homework 1

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1 Problem 1

1.1 Problem Summary

This problem involves simulating a single neuron as defined by the Izhikevich model [1]. This neuron is defined by the following differential equations:

$$\frac{\partial v}{\partial t} = 0.04v^2 + 5v + 140 - u + I(t) \tag{1}$$

$$\frac{\partial u}{\partial t} = a(bv - u) \tag{2}$$

$$if v \geq 30; v = c, u = u + d \tag{3}$$

The neuron is simulated in the *Regular Spiking* configuration ($a = 0.02$, $b = 0.25$, $c = -65$, $d = 6$), described in [1], [2], with a range of DC synaptic currents, $I(t)$, over 1000 ms with a time step of 0.25 ms. Each trial uses a static value of $I(t)$ ranging from $I(t) = 0$ to $I(t) = 20$ with a step of 0.5. The purpose of this problem is to measure the membrane potential of the neuron, as well as the mean spiking rate for each value of $I(t)$.

1.2 Results

Figure 1 shows the mean spiking rate plotted as a function of the synaptic current. Spiking rate is calculated by averaging the number of spikes per ms over the last 800 ms of each simulation. Figure 2 shows the membrane potential plotted over 1000 ms for various input currents.

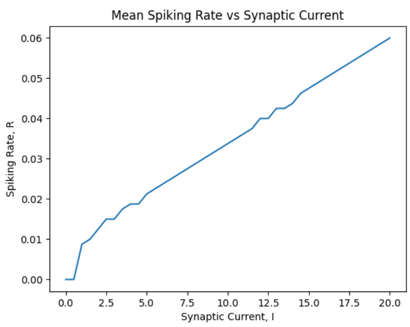

Figure 1: Mean spiking rate as a function of synaptic current of a single neuron.

1.3 Discussion

In Figure 1, the mean spiking rate is roughly a linear function of the input current. The spiking rate is more visually illustrated in Figure 2. When the simulation starts, there is an initial short burst of spikes, which then settles out into a steady sequence of spikes. This initial burst is why the first 200 ms of simulation are discarded before calculating the mean spiking rate. Effectively, this simulation demonstrates the use of a *Regular Spiking* neuron to translate a DC input into a spike train, where the higher DC level translates to a higher frequency spike train.

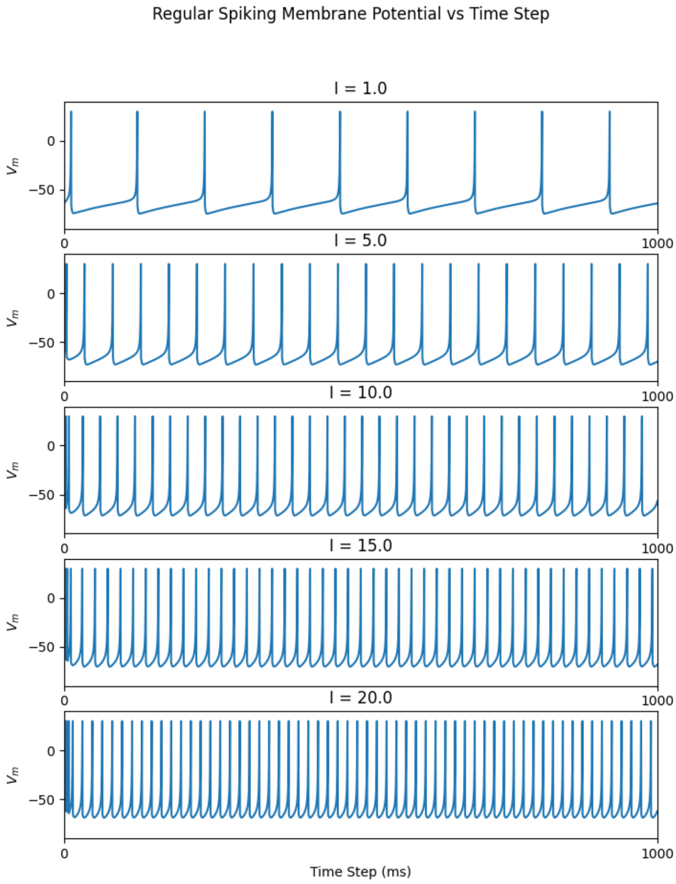

Figure 2: Membrane potential as a function of time for various input currents for a single neuron.

1.4 Conclusion

In this problem, a simulation of a single *Regular Spiking* neuron using the Izhikevich model [1] with various DC input levels is presented. The resultant membrane potential plots in Figure 2 reflect the intended behaviour described by Izhikevich [1], [2]. This work shows that a semi-realistic artificial neuron can be simulated using little computational overhead.

2 Problem 2

2.1 Problem Summary

This problem builds upon the first, involving the simulation of a simple network of two neurons with parameters as described in Problem 1. Neuron A gets the input $I_A = 5$ and outputs the spike train y_A, while neuron B gets input $I_B(t)$ and outputs the spike train y_B. The system can be defined as:

$$I_B(t) = I_B + w_{BA} * y_A(t) \tag{4}$$

$$y_i(t) = 1 \quad if \quad v_i > 30, \quad else \quad y_i = 0 \tag{5}$$

where w_{BA} is the weight between neurons A and B and is fixed at 10. Similarly to Problem 1, each trial uses a static value ofI_B ranging from 0 to 20 with a step of 5. The purpose is to measure the membrane potential of the neuron, as well as the mean spiking rate for each value of I_B.

2.2 Results

Figure 3 shows the mean spiking rate plotted as a function of the synaptic current for both the single neuron in Problem 1 and the network from this problem. Spiking rate is calculated by averaging the number of spikes per ms over the last 800 ms of each simulation. Figure 4 shows the membrane potential is plotted over 1000 ms for various values of I_B.

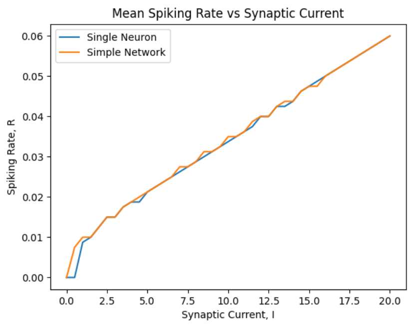

Figure 3: Mean spiking rate as a function of synaptic current of a single neuron (blue) vs the simple network (orange).

2.3 Discussion

In Figure 3, the mean spiking rate of the network exhibits similar characteristics as the single neuron, with both of them roughly a linear function of the input current. While there are slight fluctuations between the two plots, the overall trend is identical. In Figure 4, the spiking rate looks very similar to those shown in the single neuron in Figure 2. When $I_B = 1$, there are slight perturbations which can be observed as the neuron gradually approaches its spike. They can be seen in most of the values of I_B, but they are the most evident when $I_B = 1.0$. These perturbations are caused by the spike train generated by neuron A, but they do not seem to have an impact on the overall behaviour of neuron B.

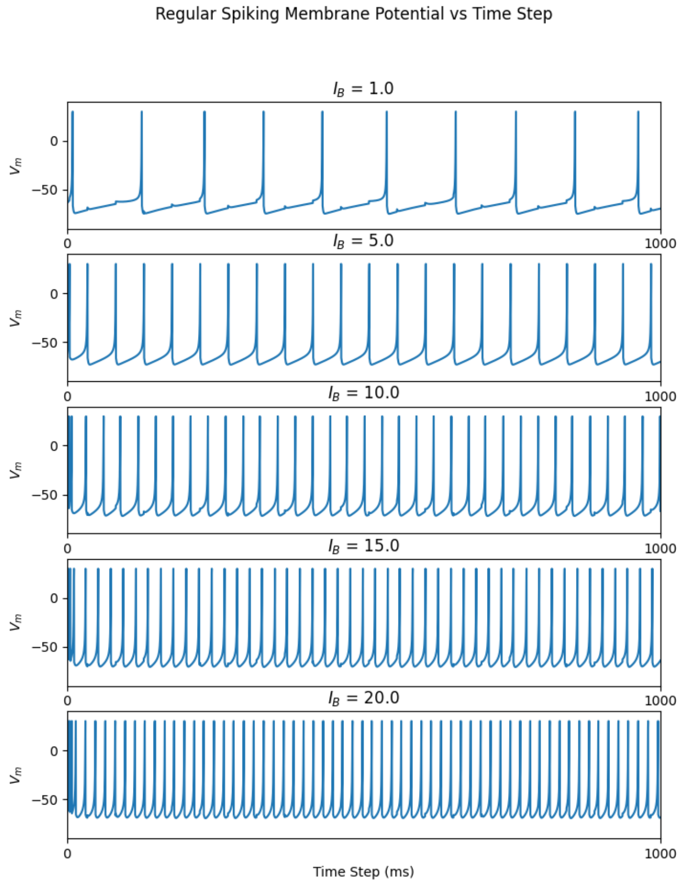

Figure 4: Membrane potential as a function of time for various input currents for a simple network.

2.4 Conclusion

In this problem, a simulation of a network of two *Regular Spiking* neurons using the Izhikevich model [1] with various DC input levels is presented. The resultant membrane potential plots in Figure 4 do not deviate much from the results of a single neuron in Figure 2, and the mean spiking rate in Figure 3 shows how similar the behaviour of the network of neurons is to the single neuron. The perturbations induced by neuron A were quickly dissipated in neuron B, which suggests that in order for artificial spiking neurons to impact each other, either a more dense spike train is needed as an input into neuron B, or neuron B should be tuned to not dissipate incoming spikes as quickly.

References

[1] E. Izhikevich, "Simple model of spiking neurons", *IEEE Transactions on Neural Networks*, vol. 14, no. 6, pp. 1569–1572, Nov. 2003, ISSN: 1045-9227. DOI: 10.1109/TNN.2003.820440. [Online]. Available: http://ieeexplore.ieee.org/document/1257420/.

[2] ——, "Which Model to Use for Cortical Spiking Neurons?", *IEEE Transactions on Neural Networks*, vol. 15, no. 5, pp. 1063–1070, Sep. 2004, ISSN: 1045-9227. DOI: 10.1109/TNN.2004.832719. [Online]. Available: http://ieeexplore.ieee.org/document/1333071/.