Coursework 1: Neuron Model Simulation

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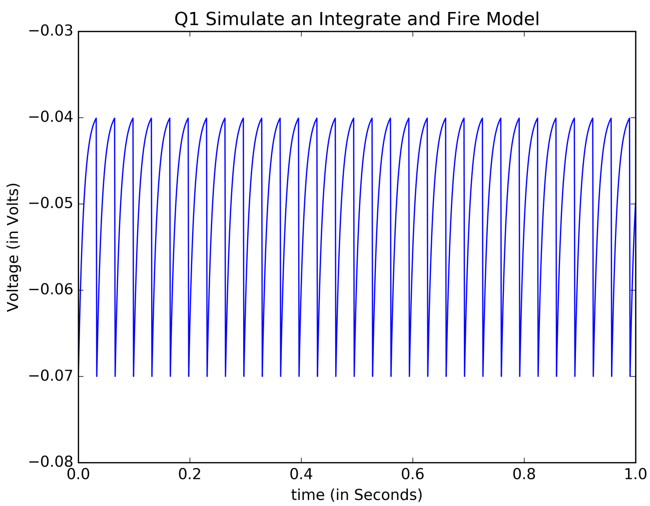
This report aims to simulate different neuron models and give answer to the coursework questions. Python is used as programming language, and helps to generate figures for different scenarios.

Q1. Simulate an Integrate and Fire Model

The figure blow shows a basic neuron simulation of the integrate and fire model. Euler's method is used with a timestep of $1ms$. Based on the equation, the voltage arises until it exceeds the threshold (- 40mV). A spike will be produced as a result and the voltage will be reseted to Vr (-70mV).



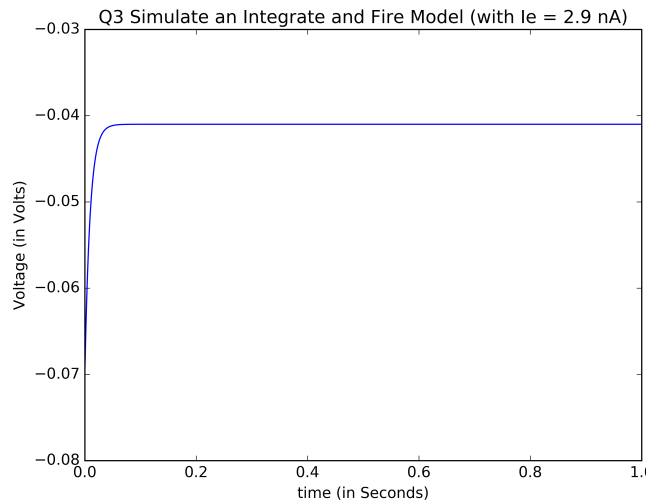
Q2. Compute the Minimum Current to Produce an Action Potential

$$I_e min = \frac{V_t - E_L}{R_m} \tag{1}$$

$$I_e min = \frac{-40mV - (-70mV)}{10M\Omega} = 3.0nA \tag{2}$$

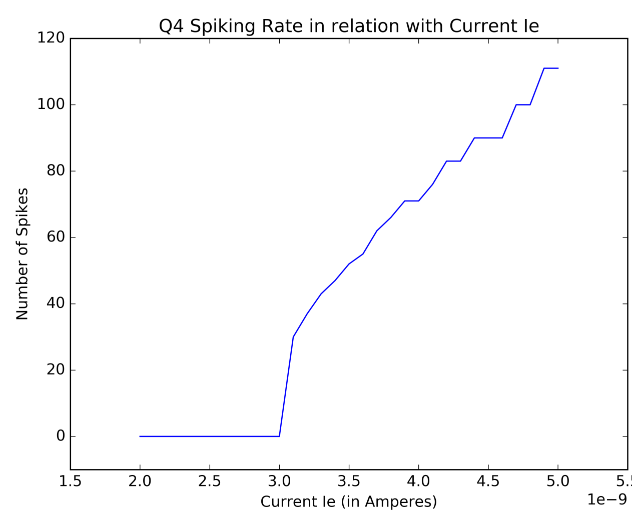
Q3. Simulate an Integrate and Fire Model with the Current Lower than the Minimum

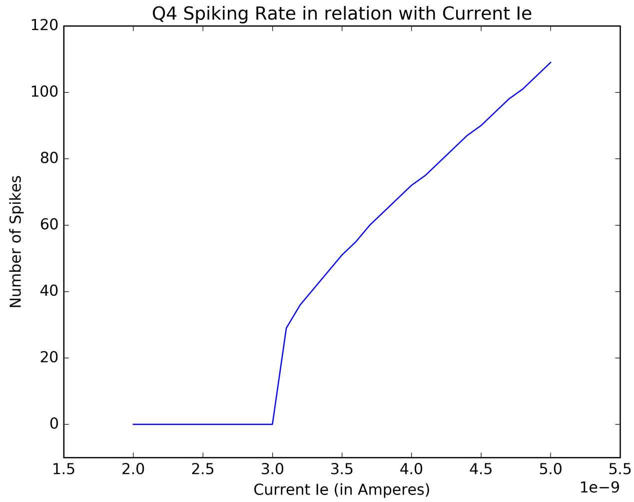
The minimum current value for this model is known as $3.0nA$ from previous question. The current used in this question is $0.1nA$ lower than the minimum, which is $I_e = 2.9nA$. As our expectation, no spikes are generated in this simulation.

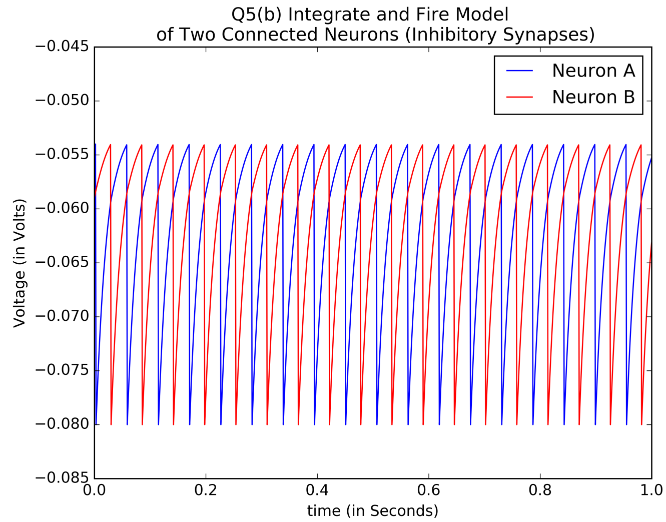


Q4. Simulate with Varies Input Current and their Firing Rate of Neuron

This question requires to plot of the fire rate as a function of the input current. No spikes are observed if I_e is blow $3.0nA$, which is the minimum current required. The number of spikes generated are increased as the value of I_e goes up. The figure here is in a stair like shape. If changes the timestep from $1ms$ to $0.1ms$, we could observe that the number of spikes are more or less proportional with the input current value, which forms like a straight line in the figure.



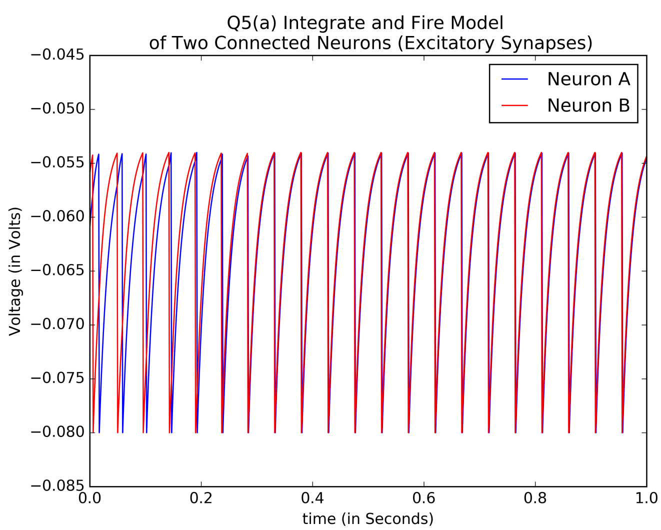




Q5. Simulate Two Connected Neurons

Same parameters are used for both neurons for simulation.The simple synapse model is as a time-dependent conductor in series with a battery. The simulation is performed in two sections where synapses is excitatory or inhibitory.The initial membrane potentials of two neurons are selected randomly within the range

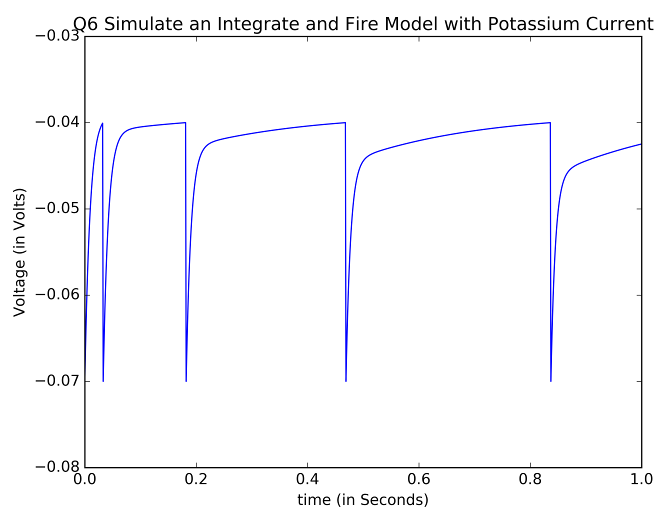
In Q5(a), the synapses are excitatory where reversal potential $E_s = 0mV$. It can be observed that even two neurons voltage are started at different value, both voltage value can be converged after few cycles.



In Q5(b), the synapses are inhibitory where reversal potential $E_s = -80mV$. It can be observed that the voltage of two neurons remains at the same difference in steps and not affected by the performance of each other.

Q6. Simulate an Integrate and Fire Model with Potassium Current

The neuron model simulated is similar with the model in Q1 but with a slow potassium current. This current is caused by the reversal potential $E_K = -80mV$. While the voltage of the neuron model is escalating as usual, it decays towards zero with the time constant of $200ms$ and the value of decay accumulates. In fact, this decay slows down the incremental of voltage and the voltage still rise. Once the threshold is exceeded, a spike is generated and the conductance should increase by 0.005. These characteristics makes the neuron have lesser and lesser spiking rate over the time. That also means the time required for generate a spike becomes more. After some time, the neuron will lost the ability to produce a spike as what is shown in the figure below



Q7. Alpha Function Model Vs Single Exponential Model

Single exponential model is one of the simplest way of modelling synapse behavior, it assumes an instant rise of conductance every time there is a spike as long as an exponential decay with a time constant.

However the rise of conductance is not instance in alpha function. It describes a rising phase with certain amount of time instead. Such behavior of rising phase of conductance happens for most synapses and has strong effects on dynamics between neurons. The way of change in voltage will also be affect.

Besides, alpha function modelling only has one time constant value. That means the rise and decay are very closely related. The values could not be set independently.