PKU Summer Lectures on Neural Computation
Exercise 1: Neuronal Model

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Numerical Integration of Spiking Neuron models

Limit your answer to one page

In a starter code zip file released to you, you should find a number of Matlab routines that simulate a number of models of spiking neurons. Here, we will consider the Hodgkin-Huxley's model (`hh.m`). Please refer to the description of these programs in Chapters 2 and 3, as well as Appendix E of Trappenberg's Fundamentals of Computational Neuroscience that we are providing in the Course Materials folder in Blackboard. There is a nice description of the routines as a way of introducing you to Matlab in Chapter 12.2, which is particularly valuable for beginners.

Study the code in `hh.m` and modify the code appropriately to perform the following experiment to obtain the so-called frequency-current (f-I) curve, which specifies the input-output relationship of the neuron.

(a) First, you can run a number simulations on the HH model, with a number of current input. For each 5 sec simulation, stimulate the HH model neuron with an external current input I_{ext} for a duration of 5 sec (5000 time points) at the set current level. You can change to a longer time if needed. Try different stimulation currents I_{ext} = current = 4, 7, and 14 and see what happen. It might be easier to see the spikes if you only plot the 200 ms instead of the whole 5 seconds. Note that the resting membrane voltage in this routine is not set to -70 mV, but to -10 mV, with the Nernst potentials adjusted accordingly. Don't worry about this. You don't need to fully understand every line of codes or equations that are implemented, as your primary objective is to evaluate the effect of noises on the I/O function.

(b) We provide you with a 'window discriminator' in spikeFrequency.m which is a Matlab function that given the input potential time series, a defined threshold, and the duration of the time series, return the spiking rate (spikes/second or Hz) in the time series. Set your threshold based on the observation on the spike height so that the window discriminator will count the number of spikes generated in each 5-sec simulation in (a). Write a for-loop to test the neuron with I_{ext} value ranging from 0 to 15, at 0.5 increment (or finer if you wish), and plot the frequency-current (f-I) curve, with spiking rate (spikes/second) on the y-axis and input current strength in the x-axis. You are not required to plot it and submit it, just see for yourself. But you are welcome to do whatever you wish.

(c) A neuron's input is often not deterministic, but stochastic. The input to a neuron can be modeled by a deterministic current input as above, superimposed on a Gaussian noise. You can introduce Gaussian white noise to the HH model neuron by adding $\sigma * randn$ to the input or directly to variable x (which is the membrane potential) in the integration step in the program, where σ is a scalar number that is the standard deviation of the Gaussian white noise of your choice provided by $randn$. Study the effect of noises on the spiking of the neurons and the f-I curve trying a range of σ (e.g. try 0.001 to 0.1, to 1). In generating the f-I curve, for each particular fixed input current, you may want to run 10-20 trials to compute the average response so that your f-I curve would be more smooth and more stable.

Treat this as a scientific experiment to discover the impact of noises on the "effective activation function" of the neuron. Write a simple one-page report, making your observations and backing up your claims and conclusions with graphs and observations. For examples, what do you observe about the I/O or f-I curve that you find interesting? What are the implications of these features? What could have contribute to these features? Are these features desirable or not desirable? Is having noise a good thing or bad thing? You are welcome to speculate, any answer would be acceptable, and you don't have to answer every suggested question.

Challenge Question: While your basic mission is to discover the impact of noises on the "effective activation function" of the neuron (for 80%), my challenge for you is to come up with new and creative ideas of what to do with this HH model (to reach 85% or above of the grade). These ideas can be anything, big or small, simple or complicated, crazy or incremental – but you have to implement these ideas to back them up. Usually, an idea comes from a question. Be curious and explore. Maybe your ideas will make the problem set more exciting for future students.