EEE 5283/EEL 4930: NEURAL SIGNALS, SYSTEMS, AND TECHNOLOGY

Spring 2020

Assignment 2
Due: Friday 01/31/2020 (11:59 PM)

Reading Assignment

- Under the 'Reading Material/week 3' folder, read the article 'How Good Are Neuron Models?' and 'Integrate and Fire Model of Spike Generation'

Problem 1 *Detailed biophysical modeling of membranes*

You are given the MATLAB code clamp.m that implements a voltage clamp experiment using the Hodgekin-Huxley Model

a) Modify the code to output ion current traces for voltage clamp values ranging between -50 mV and 75mV. Take E_K= -89mV, E_{Na}= 55mV for a spherical cell with diameter 10 μm.
b) Compare the generated current traces to Figure 7-5 in Principles of Neuron Science Chapter 7 (provided under your reading folder). Are they similar? If yes, explain why. If no explain why not.
c) Assume that you were not provided E_K, E_{Na} or the membrane conductances. Describe **a step by step approach** to experimentally find them using a voltage clamp experiment and the current traces generated.

Problem 2*: Spatial Signal propagation and Properties of Axons*

Dielectric constant κ = 7, electrical permittivity $\varepsilon_0 = 8.85*10^{-12}$ $C^2/N*m^2$

a) Calculate the capacitance of an unmyelinated axon with surface area *S*, length L= 1m, membrane thickness b= 10nm and radius a = 2.5 μm using the formula
$$C = \frac{\kappa * \varepsilon_0 * S}{b}$$
b) Calculate the membrane resistance and time constant given membrane resistivity R_m= 1.6 10^3 Ω.cm^2
c) Calculate the space constant and signal speed given an axoplasm resistivity of R_i= 50 Ω.cm
d) Calculate how long it takes a signal to travel the length of the axon. Does the signal velocity seem fast or slow?
e) In myelinated axon fibers there exists a fixed relation between the radius of the axon and thickness of the myelin layer which simplifies the space constant equation to $\lambda = \sqrt{0.2 * a * \frac{R_m}{R_i}}$
Compare the signal speed in a myelinated and unmyelinated axon of similar thickness.
f) What is the radius of a myelinated axon with the same space constant as part c?

Problem 3: ***Integrate and Fire Model***

You are given MATLAB code intfire.m that implements a generic Integrate and Fire Model (IFM).

a) Change the constant current input to an **offset sinusoid with the same average amplitude** as the constant current input. Describe the model behavior and plot the results. Repeat the same experiment with a random amplitude input.
b) Modify this model to implement equation 1 and use the following model parameters E_L =-70 mV, R_m =10 MΩ, and τ_m =10 ms. Initially set V =E_L.
Equation 1:
$$\tau_m \frac{dV}{dt} = E_L - V + R_M I_e$$
c) When the membrane potential reaches V_{th} = -54 mV, make the neuron fire a spike and reset the potential to V_{reset} = -80 mV. Show sample voltage traces (with spikes) for a 300-ms-long current pulse (choose a reasonable current I_e) centered in a 500-ms-long simulation.
d) Determine the firing rate of the model for various magnitudes of constant I_e and compare the results with equation 2

Equation 2

$$r_{\mathrm{isi}} = \frac{1}{t_{\mathrm{isi}}} = \left[\tau_{\mathrm{m}} \ln\left(\frac{R_{\mathrm{m}} I_{\mathrm{e}} + E_{\mathrm{L}} - V_{\mathrm{reset}}}{R_{\mathrm{m}} I_{\mathrm{e}} + E_{\mathrm{L}} - V_{\mathrm{th}}}\right)\right]^{-1}$$

Problem 4: *Spike rate adaptation*

You are given MATLAB code alpha_neuron.m that implements the synaptic adaptation mechanism discussed in class. The postsynaptic neuron firing is mediated by an alpha type synapse function and a random input spike train from a presynaptic neuron.

a) Modify the threshold for generating spikes in the presynaptic neuron to lead to different spike train rates.
b) Implement a simple spike count routine that bins the spike train to calculate the spike rate in each case in a). Plot the input spike train rates as a function of the threshold values. Comment on your results.
c) Use the same routine you developed in b) to calculate and plot the output spike train rate as a function the threshold values.
d) Illustrate an input output transfer function by using a scatter plot of the output spike train rate versus the input spike train rate for different values of rate adaptation by varying the synaptic conductance every time a spike is fired.

*In all of the above, make sure you highlight the change you made in the code provided and justify your changes.