Theoretical Neuroscience (BITS F317)

Assignment 2

You have to submit following problems. From part-1, problem no. 2. From part-2, problem no.1 (that's the only problem there) Deadline is 20-March 3 PM.
Part-2 problem-1 should be entirely uploaded on Moodle along with your MATLAB codes. One .doc/pdf file should contain all figures & your responses . The other file (include a .m file) should contain the code
Part-1 should be submitted in hard-copy.

1 Part-1

1. Consider an integrate and fire neuron. An external current I_{ext} is injected into the neuron.

   (a) Calculate the time taken by potential to reach the threshold V_{th} from its reset value V_{reset}

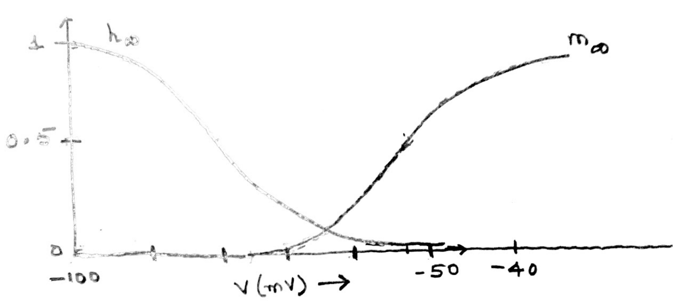
   (b) Find an expression for the firing rate r in terms of the various parameters that go into the equations describing an Integrate & fire neuron.

   (c) Plot firing rate r vs. I_{ext}. Does this neuron show class-1 or class-2 behaviour?

2. Certain neurons (in Hippocampus, thalamic relay cells, photoreceptors) possess a channel called the h-channel that allows both Na+ & K+ ions to pass through. The h-channels contain inactivation gates but no activation gates. The inactivation gate of the h-channel is closed at resting potential & opens (de-inactivates) on hyperpolarization.

   Consider a neuron with 3 types of channels (i) h-channels (i) Na+ channels with 1 activation gate & no inactivation gate - different from those in HH model (ii) channels for leak current. Denote current through h-channels by I_h. Since the Na+ current does not have an inactivation gate it will be persistent & hence lets denote the Na+ current as $I_{Na,p}$

   The steady state curve for the inactivation gate h of h-current & activation gate m for Na+ currents are shown in figure. Values of parameters are : $E_{Na} = 20mV$, $E_h = -43mV$, $E_L = -80mV$, $g_L = 1.3$, $g_{Na} = 0.9$, $g_h = 3$. Units of g's are mS/cm^2. When external current $I_{ext} = 0$ the resting potential is $-52mV$.



   (a) Write an expression for net ionic current across the membrane at potential V.

   (b) If we depolarize the membrane, what are the various possible qualitative variations that can occur in membrane potential. Sketch these.

   Think of the following: Will an action potential arise for any depolarization. If so, then what is the threshold potential above which an action potential will occur. If an action potential does arise then which current will lead to a fall in potential (there is no K+ current here which does this job in HH neuron).

   Explain each of these in additon to sketching.

(c) Suppose the time constant of h-current τ_h is small and comparable to that of the fast Na+ current τ_m. That is, τ_h, $\tau_m < 1msec$. Inject a strong & brief pulse of current to hyperpolarize the neuron. Sketch (qualitatively) the time course of the membrane potential $V\ vs\ t$ soon after the pulse ends.

(d) Next, suppose that τ_m is small but $\tau_h >> \tau_m$. Once again hyperpolarize and hold for extended period of times before removing the current causing hyperpolarization. After removal of external current, sketch qualitatively the various possible membrane potential $V\ vs\ t$ that you may get depending on the relative magnitudes of τ_m & τ_h with the condition $\tau_h >> \tau_m$.

(e) Imagine that the h_∞ curve is shifted to the left in a certain neuron and $V_{1/2} = -100mV$. Send a brief hyperpolarizing current pulse that hyperpolarizes the membrane to $-110mV$. What will the time course of membrane potential after the pulse ? Qualitative sketch. Explain the sketch in terms of the ionic currents that are causing the changes in potential.

(f) In situation (e) will the resting value of membrane potential be different from what it was in the earlier situations?

3. Read up & understand the Ca2+ dependent K+ current discussed in Dayan & Abott. This is a model for a central pattern generatorw

2 Part-2 (Simulation of Hodgkin-Huxley neuron)

1. In the lecture we had discussed synchronization of two neurons connected to each other via a synapse. The synchronization is in-phase for inhibitory synapses and out-of-phase for excitatory synapses . Look at the textbook or classnotes for further description.

   Integrate and fire model

   The membrane potential V in an Integrate & fire model with synapses varies according to the following equation when V is less than its threshold for firing a spike (i.e., $V < V_{th}$)

$$\tau_m \frac{dV}{dt} = f(v) \tag{1}$$

   with

$$f(V) = E_L - V - r_m \bar{g}_s P_s (V - E_s) + R_m I_e \tag{2}$$

   If V crosses V_{th}, then V is said to fire a spike and is instantaneously reset to a lower potential V_{reset}. Subsequently, the membrane voltage once again varies according to the above differential equation till it crosses the threshold.

   On solving the above ODE numerically

   We had solved the differential equations representing Hodgkin-Huxley using the MATLAB function ode45. This function implements the variable time step Runge-Kutta 4-5 method (some of you would know about it. Others needn't bother about it right now). However, the above differential equation for Integrate & fire neurons can be solved by an elementary method (called Euler method). This is as follows

   Euler Method

   To solve the ODE do the following. Find voltage $V(t_{i+1})$ at time t_{i+1} from its value $V(t_i)$ at time t_i use the following equation (that gives an approximate solution for V at time $t_i's$)

$$V_{i+1} = V_i + [f(V_i)/\tau_m]\Delta t \tag{3}$$

   where V_i is the membrane voltage at the time instant $t_i = i\Delta t$

   (a) Write a code in MATLAB for simulating 2 neurons connected via synapses using Euler method stated above.

   (b) Run the code for the parameters given in the textbook. Reproduce the results therein for excitatory and also inhibitory synapses. Plot V vs. t for the 2 neurons for both kind of synapses showing in-phase and out-of-phase synchronizations.
   Upload the plots on Moodle.