Coursework 3

This coursework is about the integrate and fire neuron. It is intended to make clear the particular way neuronal connectivity works: a neuron has synapses, when it fires the spikes go to its synapses and they in turn cause a change in conductivity for the post-synaptic neuron.

Question 1

Simulate an integrate and fire model with the following parameters for 1 s: $\tau_m = 10$ms, $E_L = V_r = -70$ mV, $V_t = -40$ mV, $R_m = 10$ MΩ, $I_e = 3.1$ nA. Use Euler's method with timestep $\delta t = 1$ ms. Here E_L is the leak potential, V_r is the reset voltage, V_t is the threshold, R_m is the membrane resistance, that is one over the conductance, and τ_m is the membrane time constant. Plot the voltage as a function of time. For simplicity assume that the neuron does not have a refractory period after producing a spike. You do not need to plot spikes - once membrane potential exceeds threshold, simply set the membrane potential to V_r.

Question 2

Simulate two neurons which have synaptic connections between each other, that is the first neuron projects to the second, and the second neuron projects to the first. Both model neurons should have the same parameters: $\tau_m = 20$ ms, $E_L = -70$ mV, $V_r = -80$ mV, $V_t = -54$ mV, $R_m I_e = 18$ mV, and their synapses should also have the same parameters: $R_m \bar{g}_s = 0.15$, $P = 0.5$, $\tau_s = 10$ ms; don't get confused by being given $R_m \bar{g}_s$ rather than $\bar{g}_s$ on its own, to get τ_m rather than the capacitance on the left hand side of the integrate and fire equation everything is multiplied by R_m. For simplicity take the synaptic conductance

$$g_s = \bar{g}_s s \tag{1}$$

to satisfy

$$\tau_s \frac{ds}{dt} = -s \tag{2}$$

with a spike arriving causing s to increase by P. This is equivalent to the simple synapse model in the lectures. Simulate two cases: a) assuming that the synapses are excitatory with $E_s = 0$ mV, and b) assuming that the synapses are inhibitory with $E_s = -80$ mV. For each simulation set the initial membrane potentials of the neurons V to different values chosen randomly from between V_r and V_t and simulate 1 s of activity. For each case plot the voltages of the two neurons on the same graph (with different colours). [7 marks; 3 for correct general approach but neurons connected up wrong, synapses coupled to the wrong voltage etc, 2 each for the inhibitory and excitatory graphs correct, 2 marks lost for problems with the graphs, eg no units, tiny script, cut and pasted screen shot, etc].

A few more optional questions!

This question uses parameters from Q1 above.

1. Compute analytically the minimum current I_e required for the neuron with the above parameters to produce an action potential. [2 marks]

2. Simulate the neuron for 1 s for the input current with amplitude I_e which is 0.1 [nA] lower than the minimum current computed above, and plot the voltage as a functions of time. [1 mark]

3. Simulate the neuron for 1s for currents ranging from 2 [nA] to 5 [nA] in steps of 0.1 [nA]. For each amplitude of current count the number of spikes produced, that is the firing rate. Plot the firing rate as the function of the input current. [2 marks]