Computational Neuroscience Assignment 1 (2019)

MPhil in Computational Biology

February 13, 2019

If there are errors found, I will update the assignment on the web at
`http://github.com/sje30/cn2019`

Questions 1–3 refer to chapters 5 and 7 of TN: this is *Theoretical Neuroscience* book by Dayan and Abbott.

Due date: to be confirmed; default is 2019-03-01

Anonymise your submission as before.

Your report must be a maximum of fifteen pages, excluding the appendix. Your appendix should contain only a copy of your code (in R or matlab). Please check with me if you plan to use any R packages that are not part of base R.

This assignment is worth 50% of your overall mark for this module. Items marked **(Advanced:)** should be attempted if you have time and are confident with your work on the rest of the assignment.

1 Hodgkin Huxley Model [10 marks]

Build a Hodgkin-Huxley model neuron by numerically integrating the equations for V, m, h, and n given in chapter 5 of TN (see, in particular equations 5.6, 5.17–5.19, 5.22, 5.24, and 5.25). Take $c_m = 10$ nF/mm^2, and as initial values take: $V = -65$ mV, $m = 0.0529$, $h = 0.5961$, and $n = 0.3177$. Use an integration time step of 0.1 ms. Use an external current with $I_e/A = 200$ nA/mm^2 and plot V, m, h, and n as functions of time for a suitable interval. Also, plot the firing rate of the model as a function of I_e/A over the range from 0 to 500 nA/mm^2. Show that the firing rate jumps discontinuously from zero to a finite value when the current passes through the minimum value required to produce sustained firing. Finally, apply a pulse of negative current with $I_e/A = -50$ nA/mm^2 for 5 ms followed by $I_e/A = 0$ and show what happens.

[Hints: You will need to find values for some parameters; check the scientific units that you use. Also, watch the integration time step – for Euler integration, you need a smaller time-step.]

2 Coupled integrate and fire neurons [15 marks]

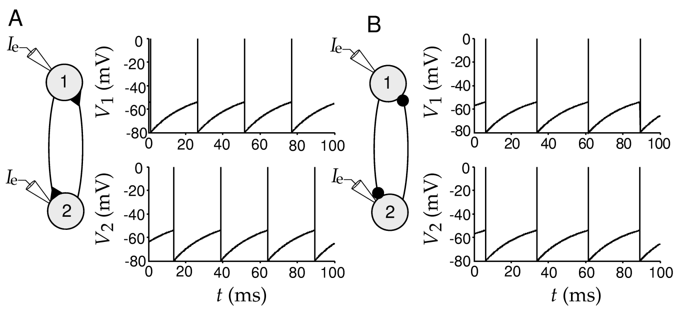

Figure 1: Two coupled integrate-and-fire neurons (figure 5.20 of Dayan and Abbott, TN).

(Refer to chapter 5 of TN for equations.)

Construct a model of two coupled integrate-and-fire neurons (Figure 1). Both model neurons obey equation 5.43 [of TN] with $E_L = -70$ mV, $V_{th} = -54$ mV, $V_{\text{reset}} = -80mV$, $\tau_m = 20ms$, $r_m\bar{g}_s = 0.15$, and $R_m I_e = 18$ mV. Both synapses should be described with an alpha function (equation 5.35 of TN) with $\tau_s = 10$ ms and $P_{\max} = 0.5$. To incorporate multiple presynaptic spikes, P_s should be described by a pair of differential equations,

$$\tau_s \frac{\mathrm{d}P_s}{\mathrm{d}t} = exp(1)P_{\max}z - P_s$$

$$\tau_s \frac{\mathrm{d}z}{\mathrm{d}t} = -z$$

with the additional rule that z is set to 1 whenever a presynaptic spike arrives.

Consider cases where both synapses are excitatory, with $E_s = 0$ mV, and both are inhibitory, with $E_s = -80$ mV. Show how the pattern of firing for the two neurons depends on the type (excitatory or inhibitory) of the reciprocal synaptic connections. For these simulations, set the initial membrane voltages of the two neurons to slightly different values, randomly, and run the simulation until an equilibrium situation has been reached, which may take a few seconds of simulated run time. Start from different random initial conditions to study whether the results are consistent. Investigate what happens if you change the strengths and time constants of the reciprocal synapses.

3 Networks [5 marks]

Build and study a simple model of oscillations arising from the interaction of excitatory and inhibitory populations of neurons. The firing rate of the excitatory neurons is v_{E} , and that of the inhibitory neurons is v_{I} and these are characterized by equations 7.50 and 7.51 (from TN). Fix $\mathrm{M_{EE}} = 1.25$, $\mathrm{M_{IE}}$=1, $\mathrm{M_{II}} = -1$, $\mathrm{M_{EI}} = -1$, $\gamma_{\mathrm{E}} = -10$ Hz, γ_{I} = 10 Hz, τ_{E} = 10 ms, and vary the value of τ_{I}. Use TN equation 7.53 to predict the value of τ_{I} for which the fixed point switches from being stable to unstable. Simulate the system for two values of τ_{I} around this critical value to verify your result.

4 Hopfield network [20 marks]

Construct a Hopfield network with binary units, and test its ability to recall binary-valued input patterns. Comment on the following features of your model:

1. Storage capacity: how many patterns can it store? How does the sparseness (fraction of units set to +1 rather than -1) of the pattern affect this result?
2. Robustness: how is pattern recall affected by the random loss of weights?
3. **(Advanced:)** Explore an alternative method for setting the weights and see how it affects network performance. [5 of 20 marks]

Consult Chapter 42 of David Mackay's book as well as the course notes to get started.