Modelling Neurons

Exercises

1. For most real neurons, their activity is in the form of **electrical spikes**.
   (a) What is the technical name for these spikes?
   (b) Under some circumstances, it is sufficient to represent the activity of a neuron using spike rate (rather than spike times). Why? Under what conditions?
   (c) The list below contains a number of items that describe the Hodgkin-Huxley neuron model and/or the leaky integrate-and-fire neuron model. Indicate which items below describe the Hodgkin-Huxley model with "**HH**", and those that describe the leaky integrate-and-fire model with "**LIF**". Note that some items might describe both models.
      - Only models the dynamics of sub-threshold membrane potential.
      - Is a non-linear model.
      - Does not model the spikes, but simply determines spike times.
      - Models the dynamics of the electrical spikes.
      - Includes a term for current leakage.
      - Involves the interaction of multiple dynamic variables.

2. A LIF neuron's sub-threshold membrane potential is governed by the DE

$$\tau \frac{dv}{dt} = v_{\text{in}} - v \; . \tag{1}$$

   Show that

$$v(t) = v_{\text{in}} - (v_{\text{in}} - v_0) \exp\left(\frac{t_0 - t}{\tau}\right)$$

   is the solution of (1) when $v(t_0) = v_0$.

3. If you are unfamiliar with numerically solving differential equations, and Euler's method, then you might want to look at the notebook `Solving_DEs.ipynb`.

4. The notebook `ex01_neuron_models.ipynb` has some exercises involving the implementation of the LIF neuron model and its integration into a network. Look through the notebook and do the exercises in the blue boxes.

5. Suppose a pre-synaptic neuron generates a spike train, $a(t)$, where

$$a(t) = \sum_{p=1}^{P} \delta(t - t_p) \; ,$$

   for spikes occurring at times t_p, and $\delta(t)$ is the Dirac delta function. If the post-synaptic current filter is $h(t)$, prove that the post-synaptic current

$$s(t) = \big(a * h\big)(t) = \int_0^\infty a(\tau) h(t - \tau) d\tau$$

can be written

$$s(t) = \sum_{p=1}^{P} h(t - t_p) \ .$$

6. The diagram below shows three neurons on the left: two neurons, A and B, that synapse onto a neuron C with connection weights **-0.5** and **1**, respectively. The diagram on the right shows spike trains for A and B. Given the post-synaptic filter, $h(t)$, plotted below, **draw the net input current entering neuron C in the white box**.