1 The Leaky Integrate-and-Fire Neuron

We will begin our course with the basics of the neuron model at the centre of this course, the Leaky Integrate-and-Fire (LIF) Neuron. We will try different inputs and spike input patterns, and see how they shape the response of the neuron. The LIF neuron model only gives a very simplified description of a neuron's behaviour. In reality neurons are very elaborate structures with complex dynamics of membrane voltage. The approximation with a single value for the membrane voltage is called a "point-neuron" and is very frequently used in neural network models. More about this neuron model can be found in the book Theoretical Neuroscience [1], section 5.4: "Integrate-and-Fire Models".

1.1 A neuron with step current input

(Video 1.1) We start with the simplest version of the LIF neuron, which receives a constant current input. Constant current inputs were used in classical electrophysiology experiments to detect basic properties of the neuronal membrane. This neuron is characterized by the following membrane voltage equation:

$$\tau_{\text{mem}} \frac{dV}{dt} = E_{\text{leak}} - V + R_{\text{m}} I_{\text{ext}}. \tag{1}$$

Equation (1) describes the membrane voltage V, of which the units can be either in mV or Volt, although mV is used more frequently. τ_{mem} is the membrane time constant, 20 ms. E_{leak} is the reversal potential for the leak, -60 mV. R_{m} is the membrane resistance, 10 MΩ. Finally, I_{ext} is the external current applied to the neuron, 2.0 nA.

The neuron resets back to the reset value V_{reset} = -70 mV whenever its membrane voltage hits the threshold V_{thresh} = -50 mV. Set the program to record an "output spike" every time V hits the threshold. Using the above equation, make a simple python program to simulate a neuron for 200 ms, in response to 2.0 nA of constant applied current. Use Euler integration to solve the equations. It is helpful to make a separate python file in which the Euler integration is performed. At first, use an Euler integration time step of 0.1 ms. This integration time step will be looked at in more detail in a following section. Plot the membrane voltage over time. Show the spike times as vertical lines in the same plot. What is the spiking behaviour of the neuron? What happens if the external current is increased to 4.0 nA?

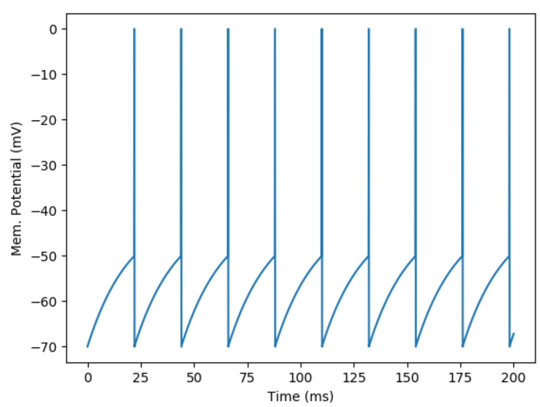

Figure 1: The membrane potential of the LIF neuron with a 2.0 nA current input should look like this. If the external current input is increased, then the neuron should spike more frequently.

References

1. P. Dayan and L. F. Abbott, “Theoretical Neuroscience,” *Cambridge, MA; MIT Press*, vol. 806, 2001.