Exercise 1: Integrate-and-fire neuron model

Expected time: 3h

Hints

Note, this exercise requires you to numerically solve differential equations. The simplest method of solving ODE's is Euler's method (please refer to the lecture). Other methods are, for example, Runge-Kutta. You are free to use any method, but state the method used and describe the parameters. You should use the MATLAB software package.

Matlab files: *iandf.m*, *makeie.m*, *normal.m*

A. Constant spike rate

Build a model integrate-and-fire neuron from the equations:
(membrane potential V, threshold potential V_{th}, input current I_e, leakage potential E_L, membrane resistance R_m, membrane time constant τ_m)

$$\begin{aligned} \tau_m \frac{dV}{dt} &= E_L - V + R_m I_e \\ \text{Use} &: \lim_{t\to\infty} V(I_e = 0) = V_{\text{rest}} = -70\text{mV},\ R_m = 10M\Omega,\ \tau_m = 10ms \\ \text{Initially set} &: V(t=0) = V_{rest} \end{aligned}$$

When the membrane potential V reaches $V_{th} = -54mV$ make the neuron fire a spike and reset the potential to $V_{reset} = -80mV$. Please use the file *iandf.m* and add your code.

1. Show sample voltage traces (with spikes) for a 300ms-long current pulse (choose a reasonable current I_e) centered in a 500ms long simulation. Please briefly describe the model and show figures of the simulation results.

2. Then use the file *makeie.m* to compute the input current I_e. Plot the membrane potential V and the current over time. What do you observe?

B. Adaptive spike rate

The passive integrate-and-fire model does not show a spike-rate adaptation, which is a common feature of cortical pyramidal cells. Spike-rate adaptation can be included using an extra current in the integrate-and-fire model, as described in:

$$\begin{aligned} \tau_m \frac{dV}{dt} &= E_L - V - r_m g_{sra}(V - E_K) + R_m I_e(t) \\ \tau_{sra} \frac{dg_{sra}}{dt} &= -g_{sra} \end{aligned}$$

where r_m is the area specific membrane resistance, E_K the equilibrium potential, g_{sra} is the spike-rate adaption conductance, and τ_{sra} a time constant

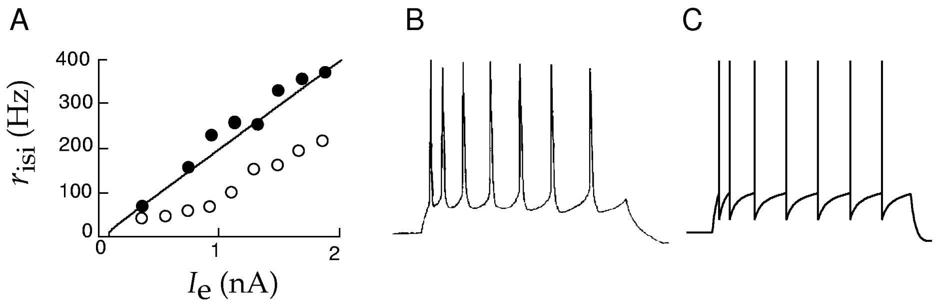

Figure 1: Interspike-interval firing

For the other parameters you should use the values from exercise A.

Fig. 1 gives an example: (A) Comparison of interspike-interval firing rates as a function of injected current for an integrate-and-fire- model and a cortical neuron measure in vivo. The line shows the interspike-interval r_{isi} for a model. The data points are form a pyramidal cell in the primary visual cortex of a cat. The filled circles show the inverse of the interspike interval for the first two spikes fired, and the open circles show the steady state interspike-interval firing rate after spike-rate adaptation. (B) A recording of the firing of a cortical neuron under constant current injection, showing spike-rate adaptation. (C) Membrane voltage trajectory and spikes for an integrate-and-fire model with an added current.

1. Include an extra current using: $\Delta g_{sra} = 0.06$, $r_m = 1M\Omega/mm^2$, $\tau_{sra} = 100ms$, and $E_K = 70mV$ in the integrate-and-fire model to introduce spike-rate adaptation, as described above.

2. Demonstrate the effect of spike-rate adaptation in your model similar as in the example given in Fig. 1 with a a constant current. Plot the time course of g_{sra} . Describe the effects.