Brain Inspired Computing (WS 21): Exercise sheet 3

Hand in on 16.11.2021, 14:00

Name(s): Group:

Question:	1	2	3	4	Total
Points:	20	25	15	40	100
Score:					

Exercise 1: Stimulating currents (20 points)

Use the simplified equivalent circuit of a LIF neuron from the course to calculate the effect of various stimulus currents on the membrane potential of a cell. Sketch the results.

(a) (5 points) A Dirac delta function: $I(t) = I_0 \cdot \frac{c_m}{g_l}\delta(t - t_0)$.

(b) (5 points) A step current: $I(t) = I_0 \cdot \Theta(t - t_0)$, where Θ represents the Heaviside step function.

(c) (10 points) An exponential current: $I(t) = I_0 \cdot \Theta(t - t_0) \cdot \frac{c_m}{\tau_s g_l} \cdot \exp(-\frac{t-t_0}{\tau_s})$. Later in the lecture, we will discuss why this is a good approximation of the synaptic input current following a spike.

Hint: From your result from c) you should obtain the result from a) in the limit of very short synaptic time constants ($\tau_s \to 0$).

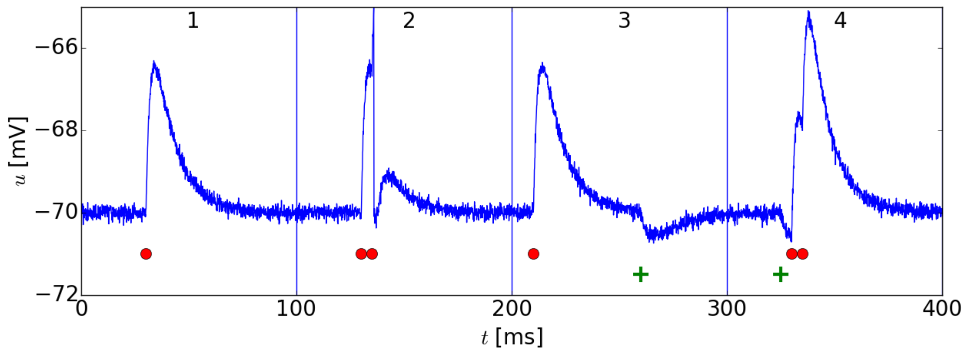
Exercise 2: Conductance-based synapses (25 points)

Consider the LIF neuron model with COBA exponential synapse kernels, as given in the lecture.

a) Show that you can reformulate the COBA LIF ODE as follows. Give expressions for τ_{eff} and U_{eff}.

$$\tau_{\text{eff}}(t)\dot{u}(t) = U_{\text{eff}}(t) - u(t) \quad .$$

b) Consider the following (simulated) voltage data from a COBA LIF neuron which receives input from an excitatory and an inhibitory presynaptic neuron. For the purpose of the discussion, the experiment has been partitioned into 4 sections.



The excitatory (inhibitory) reversal potential is 20 mV (−80 mV), and the exc. (inh.) neuron's spikes are indicated by red dots (green crosses). Synaptic transmission delays are negligible. A single EPSP (Sec. 1) almost drives the neuron over the threshold (at −65 mV), and two of them (Sec. 2) easily elicit a spike at 136 ms. However, despite a single IPSP being much smaller in amplitude (Sec. 3), it can prevent the neuron from firing (Sec. 4).

Explain this phenomenon based on a model of conductance-based synapses. Base your argumentation on a). Could such a phenomenon even occur if the inhibitory reversal potential was above the resting potential?

Exercise 3: COBA membrane trace analysis (15 points)

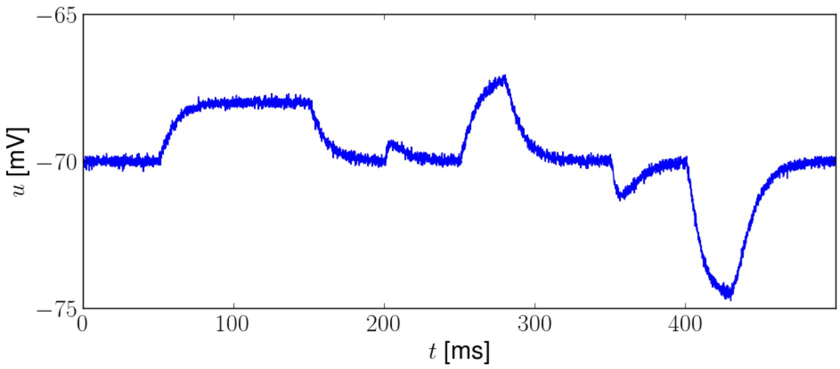
You are given three membrane potential datasets of a COBA LIF neuron (see `cobaSynapse_V_weak.npy`, etc., use `numpy.load()`, sampling rate 10 kHz). The neuron has been exposed to different types of so-called synaptic background stimuli (random spike times) of balanced excitation and inhibition. In each dataset, the background stimulus has a different strength. In addition, the neuron has been stimulated with regular "probe" spikes which arrive via another synapse at times $t_s \in \{20\,\text{ms}, 40\,\text{ms}, \ldots, 2000\,\text{ms}\}$.

Identify and discuss the influence of the different background stimuli on the membrane by proceeding along the following steps:

1) Extract the (noisy) PSPs induced by the probe spikes from the membrane potential.
2) Average them by temporal alignment at the spike times t_s (for each dataset).
3) Plot the averaged PSPs from all three datasets into one plot.
4) Compare the PSPs qualitatively with respect to amplitude and time constant and discuss the result.

Exercise 4: Parameter estimation for a COBA LIF neuron (40 points)

You are given access to membrane potential data (sampled at 10 kHz) from a COBA LIF neuron with exponential synaptic kernels stimulated by two presynaptic neurons: an excitatory and an inhibitory one (see moodle for membrane voltage data and spike times (`membrane_trace_3.4.npy`). Use `numpy.load()`):



The weak noise on the membrane potential trace is inherent to the hypothetical measurement apparatus and can be neglected in the following.

A similar membrane potential dataset can been generated by a NEST simulation that you can find in `bic_3_4_template.ipynb`. You'll need to use the Jupyter kernel `EBRAINS_release_v0.1_202109` provided by the `Experimental Docker image for EBRAINS tool developers` Collab setup. (Note if you started the `Official EBRAINS Docker image` you'll need to shut it down first. Go to File > Hub control panel > Stop my server. This will take a while.)
The provided script contains wrong neuron and synapse parameters. Your task is to estimate the correct parameters from the membrane potential data.

Between 50 and 150 ms, the neuron is stimulated by an external DC pulse. The spike times of the excitatory presynaptic neuron occur at 200, 250, 253, 256, 259, 262, 265, 268, 271, 274 and 277 ms. The inhibitory presynaptic neuron has the same spike pattern, only 150 ms later. From a previous measurement, you know that the membrane capacitance is 1 nF and that the synaptic reversal potentials are 20 mV and −80 mV, respectively.

(a) (10 points) Describe qualitatively how the resulting membrane trace for the initial parameters differs from the target trace.

(b) (10 points) Start adapting neuron parameters (e.g., the leak voltage E_l and conductance g_l and the synaptic weights w_e, w_i and synaptic time constants τ^e_{syn}, τ^i_{syn}) manually and show that your description from a) fits.

(c) (10 points) Now optimize the parameters from b) automatically. (Hint: Define a function that measures the absolute difference between the resulting voltage and the provided membrane trace and use `scipy.optimize.minimize`)

(d) (10 points) Perform the NEST simulation using your estimated parameters, and plot your simulated membrane potential data alongside the given one in one figure (with different colors). Also plot the residuals.