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Exercise sheet 1
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Neurodynamics 2023

HOMEWORK: (LEAKY-)INTEGRATE-AND-FIRE.

In this second homework, we will turn from the biophysical model of a patch of membrane developed by Hodgkin and Huxley to phenomenological models of spiking neurons: Simple Leaky-Integrate-and-Fire models. Additionally, we will be looking at implementing a conductance based synapse.
Hand-in for this sheet is end of day on June, 2nd

Question 1. Implement the following simple leaky-integrate-and-fire model in `brian2`:

$$\frac{\mathrm{d}V}{\mathrm{d}t} = -\frac{1}{\tau_M}\Big((V - V_R) + \frac{I}{g_L}\Big)$$
$$t_{\text{spike}} : V(t_{\text{spike}}) > V_t \ \ \& \ \ V \to V_R$$

Set $\tau_M = 20$ms, $V_R = -70$mV and $g_L = 0.1$µS. When the membrane potential hits the threshold $V_t = -50$mV, emit a spike and reset the membrane potential to resting. In `brian2`, thresholds and resets are part of a `NeuronGroup` definition. You can also attach a `SpikeMonitor` to the model neuron to easily collect all spike times.
Your task is to setup multiple experiments with 50 varying currents I from 0.0 to 20.0nA. For each value, record how many spikes the neuron fires in one second. Plot the f-I curve, frequency against current, to characterize the neuron's input-output function.

Question 2. Amend the model and include synaptic transmission.
In `brian2`, modelling synaptic conductance in response to spikes is easier as a dynamic variable. The equations for the integrate-and-fire model extend to:

$$\frac{\mathrm{d}V}{\mathrm{d}t} = -\frac{1}{\tau_M}\Big((V - V_R) + \frac{g_S}{g_L}(V - E_S)\Big)$$
$$\frac{\mathrm{d}g_S}{\mathrm{d}t} = -\frac{g_S}{\tau_S}$$
$$t_{\text{spike}} : V(t_{\text{spike}}) > V_t \ \ \& \ \ V \to V_R$$

Set $\tau_S = 5.0$ms and $E_s = 10$mV. g_L changes to 3µS
Additionally, use `PoissonGroup` to create 10 input neurons, and then use the `brian2.Synapse` to connect them to the neuron. On each spike, add 0.6mS to the synaptic conductance g_S (use the option `on_pre += 0.6`mS).
Now, setup the previous experiment – but instead of varying the current I, vary the firing frequency in Hertz that the `PoissonGroup` input neurons fire at from 0 to 200Hz in 20 steps. Record and plot the firing frequency the neuron responds with.