1.2 Excitatory and inhibitory inputs

(Video 1.2) We now remove the constant input current and add inputs that more closely resemble the synaptic inputs neurons would receive from other neurons. The equation for the neuron is now:

$$\tau_{\mathrm{mem}} \frac{dV}{dt} = E_{\mathrm{leak}} - V + g_{\mathrm{e}}(E_{\mathrm{e}} - V), \tag{1}$$

where we have added a conductance g_e for an excitatory input synapse. This conductance obeys the following equation, which contains a simple exponential decay:

$$\frac{dg_{\mathrm{e}}}{dt} = -\frac{g_{\mathrm{e}}}{\tau_{\mathrm{e}}} + w_{\mathrm{e}} \sum_{s=1}^{N} \delta(t - t_s). \tag{2}$$

The g_{e} term represents the excitatory input conductance that comes from another neuron. Note that $\delta(s)$ is the Dirac delta function. E_{e} is the reversal potential for excitatory (depolarizing) inputs, here let us set it to 0 mV. τ_{e} is the postsynaptic potential (PSP) time constant, let us use $\tau_{\mathrm{e}} = 3$ ms.

For each spike t_s that arrives, the conductance is increased by an amount w_{e}, which is the strength, or weight, of the excitatory synapse. The equation above is written for a single excitatory synapse. In the case of multiple synapses onto a postsynaptic neuron, g_{e} is increased by each arriving spike by the respective synaptic weight of that synapse. The next step is to adapt the model used in the previous section to include the excitatory input of another neuron, in the form of a single synapse as described by equation (3). Assume periodic (regularly spaced) spikes with firing rate 6 Hz. Set w_{e} to 0.5. Make a plot of the membrane potential again, and look at the spiking behaviour. What happens to the spiking of the neuron if w_{e} is increased? A larger excitatory synaptic weight should lead to larger depolarization and more frequent postsynaptic spikes.

Let us also add an inhibitory synapse to the same neuron:

$$\tau_{\mathrm{mem}} \frac{dV}{dt} = E_{\mathrm{leak}} - V + g_{\mathrm{e}}(E_{\mathrm{e}} - V) + g_{\mathrm{i}}(E_{\mathrm{i}} - V), \tag{3}$$

$$\frac{dg_{\mathrm{i}}}{dt} = -\frac{g_{\mathrm{i}}}{\tau_{\mathrm{i}}} + w_{\mathrm{i}} \sum_{p=1}^{P} \delta(t - t_p). \tag{4}$$

Where g_{i} is the inhibitory conductance, τ_{i} is the PSP time constant of inhibition, 5 ms, and E_{i} the reversal potential for inhibition, -80 mV, w_{i} is the strength of the inhibitory synapse, and t_p the time of an inhibitory input spike. Now add the inhibitory synapse to the neuron by combining equations (3-5), and assume periodic spikes with frequency 6 Hz for excitatory, and 3 Hz for inhibitory input synapses. Show the membrane potential of the neuron for 2 seconds. In order to obtain any spikes in the neuron, the excitatory synapse should be sufficiently strong. Therefore, set $w_{\mathrm{e}} = 3.0$, and $w_{\mathrm{i}} = 3.0$ to match. In following units we will deal with more realistic settings of multiple synaptic inputs.

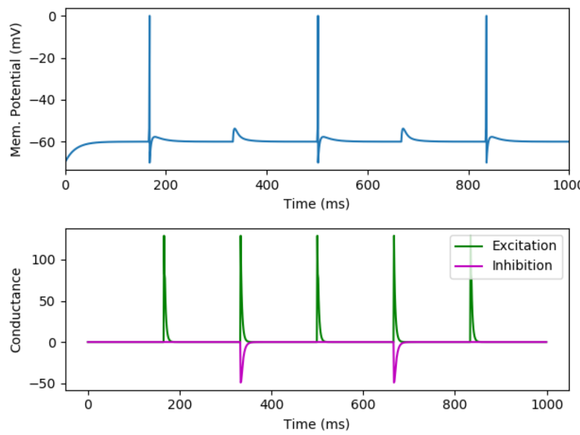

Figure 1: After adding the periodic excitatory and inhibitory synaptic inputs, the membrane potential follows the curve shown in the top figure. The excitatory and inhibitory conductances g_{e} and g_{i} are shown in the bottom figure. As can be seen from the figures, when inhibition arrives, it prevents an output spike caused by excitation.