Introduction to Computational Neuroscience (Spring 2018)

Mutual Inhibition with Synaptic Depression

In the last project we coupled together HVC neurons, using both chemical synapses and electrical synapses (gap junctions). In that example the synaptic strength was constant. In this project we will look at the effects of **synaptic depression**, which is a ubiquitous form of short-term synaptic plasticity. We will couple together two HVC interneurons, so the coupling is inhibitory. When a cell is active it will release transmitter, however the amount released will decline over time, reflecting a decline of docked vesicles in the readily releasable vesicle pool.

Exploration

Download the file mutual_inh.ode from my web site. This code contains a small network of two HVC interneurons. Each neuron has a *synaptic activation variable* that reflects the level of activation of synaptic current due to input from the other neuron. If $s = 1$ then the maximum amount of synaptic conductance is activated, while $s = 0$ means no activated conductance. Each neuron has a differential equation for s, which depends on the activity of the other neuron. The *synaptic efficacy* reflects the filled state of the pool of docked synaptic vesicles. If this pool is completely full, then $d = 1$. If completely empty, then $d = 0$. Each of the two neurons has a d variable, with dynamics for neuron 1 described by:

$$\frac{dd_1}{dt} = \frac{d_\infty(T_{12}) - d_1}{\tau_d} \tag{1}$$

where T_{12} is the transmitter release from neuron 1 onto neuron 2 (it is an increasing sigmoidal function of V_1) and d_∞ is a decreasing sigmoidal function,

$$d_\infty(T) = \frac{K_d}{K_d + T} \quad . \tag{2}$$

The synaptic current in neuron 2 due to transmitter release from neuron 1 is then

$$I_{syn12} = g_{syn} d_1 s_2 (V_2 - V_{inh}) \tag{3}$$

where g_{syn} is the maximal conductance from these GABAergic synapses, s_2 is the synaptic activation variable in neuron 2, and $V_{inh} = -90$ mV is the reversal potential for the synapse. There is a similar current in neuron 1, called I_{syn21}.

(1) Starting at time t=100 ms an applied current of 150 pA is applied to each neuron, so that if uncoupled the neurons fire continuously. Verify this by running the code with the synaptic conductance g_{syn} set to 0. (It helps to just look at just a small window of time, so set Xmin=800 and Xmax=1000 in your

viewing window.) In addition to the voltage window, open a window for the synaptic activation variable s_1 and another for the synaptic efficacy variable for neuron 1 (called d_1). These both lie in the range of 0 to 1. In each of these windows add another curve for the corresponding variable in neuron 2 (using a different color). Why do the synaptic activation variables increase on average once the applied current is turned on? Why do the efficacy variables decrease on average? Plot transmitter release from each neuron, using variable names *Trans12* and *Trans21*, and explain the behavior of each.

(2) Now rerun, but with a little bit of synaptic conductance ($g_{syn} = 1$ nS). What effect does this have on the pattern of spiking in the neurons? Explain why the synaptic coupling has this effect on the spiking patterns.

(3) What happens with stronger synaptic conductance, $g_{syn} = 5$ nS, and why does it happen?

(4) What happens with even stronger synaptic conductance, $g_{syn} = 10$ nS, and why does it happen?

(5) Now increase synaptic conductance to $g_{syn} = 20$ nS. What happens and why does it happen?

(6) Redo everything, but with a larger synaptic depression time constant of $\tau_d = 50$ ms. This would reflect a larger readily releasable vesicle pool, which therefore depletes much slower. How does this change things, and why? (To get the full drama when $g_{syn} = 20$ nS, open the viewing window to the full 1000 ms.) Compare this to what happens without synaptic depression, which can be simulated by setting $K_d = 0.000001$.