Introduction to Computational Neuroscience (Spring 2018)

Simulating a Small Neural Network of HVC Neurons

We will now couple together the HVC neurons that we analyzed earlier. We examined models for the two types of neurons that project out of HVC, the HVC_{RA} neurons that project to nucleus RA (as well as having projections within the HVC), and the HVC_X neurons that project to the Area X nucleus (as well as projections within HVC). There are also **interneurons** (HVC_{int} neurons) in the HVC that project just within the HVC, thus the name. While the projection neurons secrete glutamate and are thus excitatory, the interneurons secrete GABA and are thus inhibitory.

Exploration

Download the file HVC_network.ode from my web site. This code contains a small network in which an HVC_{int} neuron synapses onto an HVC_X neurons, which synapses onto an HVC_{RA} neuron. We will begin by examining the behavior of this network when a 300 ms pulse of depolarizing current is applied to the HVC_{int} neuron.

(1) Start up the code and run it. Neuron number 1 is the interneuron, number 2 is the X-projecting neuron, and number 3 is the RA-projecting neuron. You should make 3 separate XPP windows, showing V1, V2, and V3. You can also look at the inhibitory synaptic current that V1 makes onto V2 by plotting iInh and the excitatory synaptic current that V2 makes onto V3 by plotting iExh, which are both auxiliary variables. You can also plot the fraction of GABA receptors activated on neuron HVC_X (called gaba) and the fraction of AMPA receptors activated on neuron HVC_{RA} (called ampa). The interneuron spikes rapidly during the 300 ms pulse of applied current, after which it comes to rest. What happens to the other two neurons while HVC_{int} is spiking so rapidly? Explain using the synaptic variables and current.

(2) After the pulse of applied current is over and the HVC_{int} neuron stops firing, what happens to the other neurons? To explain this you should think about the intrinsic currents in the HVC_X neuron as well as the synaptic variables and currents.

(3) Change the applied current pulse duration so that it only lasts 100 ms. What effects does this change have on the two projection neurons and why?

(4) The program also includes a term for electrical coupling (through gap junctions) between the projection neurons, assuming that they have equal areas. What happens to the voltage time courses (using a 300 ms depolarizing pulse)

of these neurons when there is a small coupling conductance, $g_{gap23} = 0.1$ nS? What happens when this conductance is 100 times larger? Why?

(5) Instead, add gap junctional coupling between the $\mathrm{HVC_{int}}$ neuron and the $\mathrm{HVC_X}$ neuron, with $g_{gap12} = 0.5$ nS. What effect does this have on the voltage time courses of the three neurons? Why? What happens when the conductance is increased by a factor of ten to $g_{gap12} = 5$ nS? Why? Do you see any other interesting behaviors if you make the coupling conductance even larger? (hint: you should)? Explain the basis for this behavior.

(6) Do the previous problem again, but this time also assume that the two projection neurons have gap junctional coupling with $g_{gap23} = 10$ nS. (This is in addition to the coupling between the $\mathrm{HVC_{int}}$ neuron and the $\mathrm{HVC_X}$ neuron.) What differences do you see when this additional coupling is added? Why?