DCS2017 Tutorial: Introduction to neuronal networks

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1 Starting out with neurons and synapses

Here we will begin to construct some simple neuronal networks. The way we will do this is to learn to connect one neuron to another. That is, we have to consider how to simulate a synapse driven by the firing of one neuron's action potential, which in turn will drive other neurons.

There are two broad categories of synapses: One of these is an electrical synapse (mediated by gap junctions) which is essentially modelled as an electrical (diffusive) resistance between two cells. The other is a chemical synapse: Here the firing of an action potential causes release of a neurotransmitter (hence "chemical") in the synapse (the joint between one neuron and the next), which in turn can cause the *postsynaptic* neuron to fire.

A good reference point for studying synapses that are more relevant to real experiments is:
`http://www.math.pitt.edu/~bard/classes/synapse/node3.html`.

But first, let us study a simple caricature of a network with a few neurons and a synapse:

```
# pas_syn.ode
v1'=-gl*v1+gc*(v2-v1)+i
v2'=-gl*v2+gc*(v1-2*v2+v3)
v3'=-gl*v3+gc*(v2-2*v3+v4)-gsyn*heav(t-ton)*heav(toff-t)*(v3-vsyn)
v4'=-gl*v4+gc*(v3-2*v4+v5)
v5'=-gl*v5+gc*(v4-v5)

p i=0, gc=1, gl=0.05, vsyn=0, gsyn=0.1
p ton=10, toff=15
```

```
done
```

Here the neurons are modelled by simple exponentially decaying functions. "Neuron" v_1 is driven by current i. Notice how both v_1 and v_2 are connected by an electrical synapse to $g_c(v_1 - v_2)$, and so on. v_3 is, additionally, driven by a synapse. The synaptic current is composed of a pulse; note carefully the synaptic current term, and when the pulse is active.

What are are synapses on neurons v_4 and v_5?

2 Neuronal networks

The synapse here is oversimplified: It simply turns on and off independently, that is, not really in response to some neuron's firing. Here are some exercises to build networks of increasing sophistication. Refer to the notes at the link above to carry these out.

1. Replace (one of) the simple neurons here with the Hodgkin-Huxley and Morris-Lecar neuron models. Investigate how the response to synapses can be different in these models, with numerical experiments.

2. Replace the synapse model here to generate current (only) when some neuron fires.

3. Construct a simple network in which one neuron fires (the pre-synaptic neuron), causes a synaptic current, which in turn causes another (post-synaptic) neuron to fire.

4. Construct a bi-directionally coupled neuronal network. That is, one neuron excites (inhibits) another neuron, which in turn excites (inhibits) the first. Such a network has very interesting properties with respect to synchrony of firings in the network. Experiment with this network.

This template can be used to construct networks of larger sizes and complexity (in principle!).