Model: A Hodgkin-Huxley model for oscillating spinal segments

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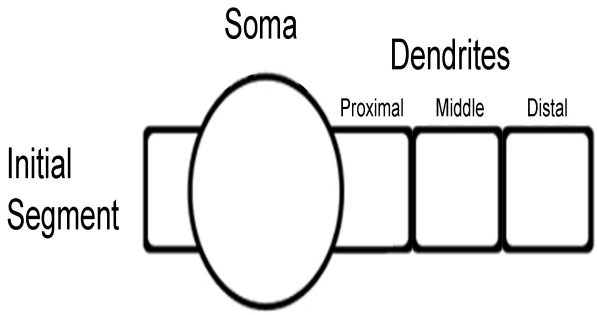
Brief Description *	This model implements a basic neural oscillator in the lamprey spinal cord.	
Narrative *	The model can be subdivided into the cell model and the network model:The cell model is a 5 compartment Hodgkin Huxley model. The compartments represent an initial segment (the axon hillock), endowed exclusivly with action potential generating Na+ and K+ ionic channels, a soma compartment with 4 ionic channels (Na, K, Ca, K_Ca), a gating variable, which represents the voltage-dependent magnesium block of the NMDA synapse, and 3 passive dendritic compartments. The calcium-dependent potassion channel K_Ca is driven by a variable, which represents the intracellular calcium concentration. In addition to ionic currents the model also features generic trans-membrane conductances, which can represent the steady-state fraction of docked agonist in pharmacological experiments (e.g. NMDA or AMPA/Kainate). A variable representing calcium entering through the NMDA synapse can be used to drive an additional K_Ca channel. The effect of K_Ca channels depends critically on calcium inflow and decay parameters. Synaptic currents can be of the fast AMPA or slowly decaying NMDA type for excitatory synapses. Inhibitory synapses are modeled after glycinergic synapses.Individual neurons can exhibit rich behavior, including adaptation when spiking (due to slowly accumulating calcium that drives a hyperpolarizing K_Ca current) or bursting when a second K_Ca channel is added, which is driven by a variable representing calcium entering at the NMDA synapse (with appropriate inflow and decay time scales) or the NMDA-bath conductance.The network model is inspired by information on the lamprey anatomy available at the time of publication and on numerous electrophysiological findings (see SED and references). The network represents a spinal cord segment of the lamprey. Specific subpopulations of neurons known to exist in the spinal cord are represented by a single neuron of the given type. Each hemi-segment consists an excitatory neuron coupled to itself. This neuron drives a local inhibitory neuron, and an inhibitory neuron, which projects to all neurons in the contralateral hemi-segment. When the interspike-interval on the currently active side of the network increases due to adaptation, the contralateral hemi-segment can escape from inhibition and suppress the activity in the previously active hemi-segment. The process results in stable oscillations, which cover large parts of the in-vivo frequency range of locomotion observed	

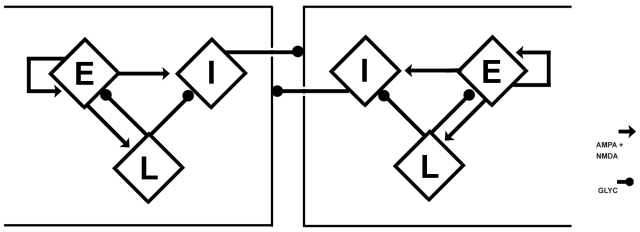
	in lampreys.The oscillation frequency is mainly controlled by the external drive and the parameters of the adaptation subsystem. Despite its complexity the model is easy to implement (though potentially time consuming for inexperienced modelers) and yields a rich repertoire of spiking behaviors with a limited number of ionic currents. It illustrates the appeal of the Hodgkin Huxley model as a mechanistic model of several physiological propertiessuch as spiking vs. bursting regimes, electrotonic properties of dendrites, pharmacological effects of agonists like NMDA or AMPA on single neurons and networks etc.This model has been continuously updated and expanded. See references for subsequent iterations of the model.
Tags	Hodgkin-Huxley, lamprey, locomotion, segmental network

Architecture

Diagrams



Compartmental structure of the Hodgkin Huxley neuron model used in Wallen et al. 1992. The model is composed of an initial segment with a high density of action potential generating Na and K conductances, a soma compartment with three dendritic compartments (see, Wallen et al. 1992 for the distribution of ionic channels).



Segmental spinal cord network as implemented in Wallen et al. 1992. E - excitatory interneuron, I - commissural inhibitory interneuron, L - lateral interneuron. Inhibitory synapses that terminate on the enclosing box indicate inhibition of all contralateral neurons. Excitatory synapses are composed of mixed NMDA/AMPA synapses.

Inputs

Name	Data Type	Description
Injected current	amp	current injected into the neurons
NMDA or AMPA bath concentrations	dimensionless quantity	representing the steady-state fraction of docked agonist

Outputs

Name	Data Type	Description
Membrane potential	volt	State variables are converted into net current flows in and out of the cell to compute the membrane potential.

States

Name	Data Type	Description
opening and closing rates of ionic channels	time constants	rate at which ionic channels open and close

synaptic activation	siemens	activation of excitatory or inhibitory synapses