The Electrically Dancing Neuron

Albert Gidon and Idan Segev
Department of Neurobiology and the Interdisciplinary Center for Neural Computation, the Hebrew University, Jerusalem, Israel.

Dendrites – with their most aesthetic tree-like structure - are the major receptive region of nerve cells. Thousands of synaptic inputs from other nerve cells bombard the dendritic tree and consequently, the dendritic membrane undergoes numerous local brief conductance changes resulting in a transient voltage change at each synaptic site called *the post-synaptic potential* (PSP). The PSPs from the activated synapses spread in the dendritic tree and summate in the axon to generate there, if a certain depolarized voltage threshold is reached, the output in the form of a train of spikes.

The morphology of most dendrites seems to be rather fixed in the mature brain; however, their electrical properties continuously change in an activity-dependent manner. Indeed, when many synapses bombard the dendritic tree, as is the case in the living behaving brain, then the dendritic membrane becomes more leaky due to the conductance increase at each synaptic site and, thus, the *electrical length* of the dendrites (which reflects the degree of voltage attenuation in the tree) increases. The more enhanced the synaptic input is (in number or in frequency), the more electrically long the dendritic tree becomes. Therefore, the dendritic tree is a dynamical input-output electrical device whose electrical length, as well as its effective membrane time constant are controlled by the activity it experience in its environment (Bernander and Koch, 1991; Rapp et al., 1992).

The movie depicts this 'changing electrical self' of dendrites as they receive synaptic inputs. A reconstructed cortical pyramidal neuron from layer 2/3 was modeled in the NEURON simulator (Carnevale and Hines, 1997). The model neuron received 1024 excitatory synapses that were activated by background music. A bank filter divided the audio signal into 1024 bands and a snapshot of the bands spectral power was taken every millisecond. Each band activated one synapse - high (low) frequencies activated distal (proximal) synapses. The movie runs 40 times slower than real time.

Synaptic conductance at each location is represented by the white glow superimposed on dendritic spines. Membrane potential is coded by the color of the dendrite (from hyperpolarization in blue to large depolarization in red). The electrotonic length of the dendritic tree is represented in units of the space constant, λ.

The reconstructed neuron appears for the first 30 seconds in morphological units. It is then transformed into an electrotonic representation (in units of λ), calculated using the passive properties of the dendritic membrane, R_m= 20,000Ωcm^2 and the axial resistance, R_i=200Ωcm.

Keyanimation creative company developed, especially for this project, a new set of tools that enable one to generate 3D animated movies from NEURON simulations. In particular for exporting morphologically reconstructed neurons and any pre-selected simulation variables into Maya (Alias Systems Corp.) - a modeling and animation development environment.

Note that with strong music in the entire audio spectrum – the frequency of the activated synapses increases and as a result the tree is more strongly stretched electrically. This *"electrically dancing neuron"* thus reflects the synaptic music it "hears". The functional consequence is that both the temporal resolution (degree of synchrony requirement) as well as the degree of voltage attenuation in the dendritic tree change constantly as a function of synaptic activation. Unlike the static view by which books and papers portray neurons, this animation conveys the functionally important notion that the electrical nature (and thus the input-output capability) of neurons is strongly modulated by the interaction with their environment. The new tool provided here can be extended to animate – based on realistic simulations – signal flow in large cortical networks, thereby serving as an eye-opener voyage into the working brain.

References

Bernander, O., R. Douglas, et al. (1991). Synaptic Background Activity Influences Spatiotemporal Integration in Single Pyramidal Cells. *PNAS* 88(24): 11569-11573.

Hines, M. L. and N. T. Carnevale (1997). The NEURON Simulation Environment. *Neural Computation* 9(6): 1179-1209.

Rapp, M., Yarom, Y., and Segev, I. (1992). The impact of parallel fiber background activity on the cable properties of cerebellar Purkinje cells. *Neural Computation* 4: 518-532.

Animations by:
Key Animation Studios
36 Derech Beit Lechem
Jerusalem, Israel
www.keyanimtion.com