A reduced and effective model of realistic neurons with spatial dendrites

With the support by the National Natural Science Foundation of China, and Science and Technology Commission of Shanghai Municipality, the research team led by Prof. Douglas Zhou (周栋焯) at the School of Mathematical Sciences, Institute of Natural Sciences, and Ministry of Education Key Laboratory of Scientific and Engineering Computing, Shanghai Jiao Tong University, developed an effective point neuron model that can capture dendritic computations of biological neurons. The work was published in *PNAS* (2019, 116(30): 15244—15252) and was dedicated to late David Cai.

Complex dendrites in general present formidable challenges to understanding neuronal information processing. To circumvent the difficulty, a prevalent viewpoint simplifies the neuronal morphology as a point representing the soma, and the excitatory and inhibitory synaptic currents originating from the dendrites are treated as linearly summed at the soma. Despite its extensive applications, the validity of the synaptic current description remains unclear, and the existing point neuron framework fails to characterize the spatiotemporal aspects of dendritic integration supporting specific computations. Using electrophysiological experiments (in collaboration with Prof. Zhang Xiaohui's group at the State Key Laboratory of Cognitive Neuroscience and Learning, and IDG/McGovern Institute for Brain Research, Beijing Normal University), realistic neuronal simulations, and theoretical analyses, Songting Li, David McLaughlin and Douglas Zhou demonstrated that the traditional assumption of linear summation of synaptic currents is oversimplified and underestimates the inhibition effect. They derived a form of synaptic integration current within the point neuron framework to capture dendritic effects. In the derived form, the interaction between each pair of synaptic inputs on the dendrites can be reliably parameterized by a single coefficient, suggesting the inherent low-dimensional structure of dendritic integration. They further generalized the form of synaptic integration current to capture the spatiotemporal interactions among multiple synaptic inputs and show that a point neuron model with the synaptic integration current incorporated possesses the computational ability of a spatial neuron with dendrites, including direction selectivity, coincidence detection, logical operation, and a bilinear dendritic integration rule discovered in experiment. This work has amended the modeling of synaptic inputs and improved the computational power of a modeling neuron within the point neuron framework.

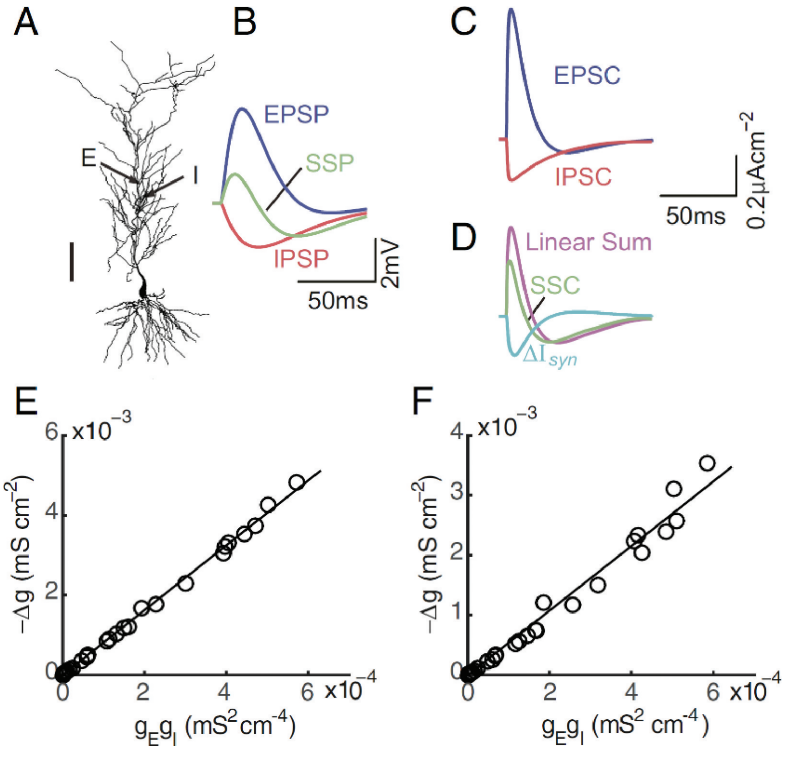

Figure Realistic neuron simulation to verify the bilinear conductance relation for a pair of excitatory and inhibitory inputs.