Extending Berger-Levy Information-Energy Efficiency Neuron Theory to a Model with Unequal Synaptic Weights

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How neurons in the cerebral cortex process and transmit information is a long-standing question in systems neuroscience. To analyze neuronal activity from an information-energy efficiency standpoint, Berger and Levy (2010) calculated the maximum Shannon mutual information rate per energy expenditure, based on an idealized integrate-and-fire (IIF) model where the excitatory synapses have the same weight. Here, we seek to extend the IIF model to a more biophysically realistic model where synaptic weights are unequal, using information theory, random measures, maximum entropy principle, and calculus of variations. In particular, we propose a mathematical framework for the stochastic processing and transmission of information performed at the neuronal level. We implicitly find the optimum distribution that characterizes the afferent excitatory postsynaptic potential (EPSP) intensity by maximizing the Shannon mutual information rate given a constraint on the total energy cost that a cortical neuron expends for metabolism, postsynaptic potential generation, and action potential propagation during one interspike interval (ISI). This generalized theory is closer to the neurophysiology of cortical networks, paving the way to analyzing a wider range of experimental data.