Biophysical determinants of single neuron computation
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Single neurons can perform a range of computations, including integration, coincidence detection or differentiation [1,2,3], and gap detection [4]. A central goal of neurophysiology is to understand how the information processing of a neuron is influenced by its biophysical properties. Recently, it has been suggested that the maximal conductances of a neuron affect its response in non-trivial ways [5,6]. This presents a challenge in understanding not only how a neuron’s computation depends on its conductance parameters but also how its computational role is maintained or altered during active regulation of its biophysical properties. Here, we examine two different characterizations of the neuron’s coding strategy: the neuron’s mean firing rate as a function of input statistics, and its linear filters and threshold functions. For both measures, we found that the parameter space of Hodgkin-Huxley conductance-based model neuron can be parsed into distinct regimes of computation.

First, with respect to the neuron’s mean firing rate response, these computational regimes are characterized by either repetitive firing or isolated bursts in response to noiseless inputs. We find that these regimes are separated by a planar boundary in the multi-dimensional parameter space of conductances. We show the basis for this change in computation by analyzing the dynamical system of a reduced model; we find that channel conductance parameters affect the position and geometry of a voltage-dependent threshold.

From the coding perspective, we employed white noise analyses to derive a linear-nonlinear cascade model. We show that two components of the model, the linear features and nonlinear threshold functions, behave differently: as conductance parameters vary continuously, the features barely change, suggesting that this characteristic of computation is almost insensitive to change in maximal conductances. However, the nonlinearity undergoes a rapid change at a linear boundary, and is otherwise almost invariant. We show a theoretical derivation of these properties in terms of the underlying dynamical system. Using a reduced model derived directly from the neuronal dynamical system, we derive the predicted linear filters and show that a change in shape of the voltage dependent threshold drives change in the patterns of threshold crossing, which in turn changes the nonlinearity.

These results help to bridge the gap between the dynamical system description of a neuron and its function in information processing, and suggest ways in which slowly adapting channels may modulate channel conductances as means of altering computation or as a homeostatic mechanism to preserve a particular computational strategy.

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References