State-dependent effects of stochastic spiking upon neuronal burst generation

Peter Rowat, Institute for Neural Computation, University of California at San Diego.
Tel (858)-534-4187; Fax (858)-534-2014; Email prowat@ucsd.edu
Robert C. Elson, Institute for Nonlinear Science, University of California at San Diego.

Abstract. We explore the effects of stochastic sodium (Na) channel activation on the variability and dynamics of spiking and bursting in a model neuron. The complete model segregates Hodgin-Huxley-type currents into two compartments, and undergoes applied current-dependent bifurcations between regimes of periodic bursting, chaotic bursting, and tonic spiking. Noise is added to simulate variable, finite sizes of the population of Na channels in the fast spiking compartment.

During tonic firing, Na channel noise causes variability in interspike intervals (ISIs). The variance, as well as the sensitivity to noise, depend on the model's biophysical complexity. They are smallest in an isolated spiking compartment; increase significantly upon coupling to a passive compartment; and increase again when the second compartment also includes slow-acting currents. In this full model, sufficient noise can convert tonic firing into bursting.

During bursting, the actions of Na channel noise are state-dependent. The higher the noise level, the greater the jitter in spike timing within bursts. The noise makes the burst durations of periodic regimes variable, while decreasing burst length duration and variance in a chaotic regime. Na channel noise blurs the sharp transitions of spike time and burst length seen at the bifurcations of the noise-free model. Close to such a bifurcation, the burst behaviors of previously periodic and chaotic regimes become essentially indistinguishable.

We discuss biophysical mechanisms, dynamical interpretations and physiological implications. We suggest that noise associated with finite populations of Na channels could evoke very different effects on the intrinsic variability of spiking and bursting discharges, depending on a biological neuron's complexity and applied current-dependent state.