FISHER INFORMATION IN A SIMPLE NEURON MODEL WITH SIGNAL DEPENDENT NOISE

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ABSTRACT

Noise in a neural system is an integral part of information transfer. Well known examples of the role of noise in signaling at the single neuron level are: enhancement of the signal by noise for subthreshold stimulation, resonant behavior in phase-locking periodic signal, synchronization by noise and linearization of the signal transfer function by noise. In most studies of effects of noise in neural information transfer, it has been implicitly assumed that the amplitude of the noise is independent of the incoming signal. This viewpoint is useful in establishing that noise can augment information transmission. Here we pursue an alternate approach, building into our model a plausible relation between noise and signal and looking for the values of the signal where the resulting system obtains the most information.

There are several ways to measure information, which can be deduced from the neuronal activity. A theoretically well-established one is Fisher information or its approximations corresponding to the classical frequency coding paradigm.

Following McCulloch and Pitts, the minimal stochastic model of a neuron can be seen as a threshold detector represented by a sequence of independent Bernoulli random variables. Two variants of this simple neuron model are investigated. In the first, a Bernoulli model, the behavior of the neuron is sampled at unit time steps. The second variant, with a geometrically distributed waiting time to threshold crossing, despite its discrete time steps reminds us of the variable interspike intervals of real neurons. Since the geometric distribution is a discrete analog of the exponential, we are close to a Poissonian neuron which is often encountered in real situations especially under low firing rate conditions.

The Fisher information is calculated for both variants of the model under the condition that the noise is functionally related to the incoming signal. If noise grows with signal we find best identification is in subthreshold signal ranges. The identification attains the same quality under weak as well as strong noise, but the coding range decreases at both extremes of noise level.

Keywords: Stochastic neuronal model, Fisher Information, signal dependent noise