

To Spike or Not to Spike: Optimal Change-Detection in Single Neurons

Angela J. Yu

Center for the Study of Brain, Mind, and Behavior
Green Hall, Princeton University, Princeton, NJ 08540

Survival in a non-stationary, potentially adversarial environment requires animals to detect sensory changes rapidly yet accurately, two oft competing desiderata. Neurons subserving such detections are faced with the corresponding challenge to discern “real” changes in inputs as quickly as possible, while ignoring “noisy” fluctuations. Mathematically, this is an example of a *change-detection* problem that is actively researched in the controlled stochastic processes community. In this work, we utilize sophisticated tools developed in that community to formalize an instantiation of the problem faced by the nervous system, and characterize the Bayes-optimal decision policy under certain assumptions. Focusing on the specific problem of a neuron detecting a hidden (Bernoulli) rate change in its input spike train, we demonstrate that the optimal strategy corresponds to an information accumulation and decision process that bears remarkable resemblance to the dynamics of a leaky integrate-and-fire neuron. This correspondence suggests that neurons are optimized for tracking changes in its input statistics. It sheds new light on the *computational* import of intracellular properties such as resting membrane potential, voltage-dependent conductance, and post-spike reset voltage. We also explore the influence that factors such as timing, uncertainty, neuromodulation, and reward *should* and *do* have on neuronal dynamics and sensitivity, as the optimal decision strategy depends critically on these factors. We also examine the implications of this optimization framework, in which the timing of every single input and output spike plays a critical role, in the regime of high firing rates – in this latter case, the objective function is equivalent to maximizing the difference between stimulus-evoked firing rate and spontaneous firing rate. More generally, the mathematical framework introduced in this work is useful for formalizing not only neuronal decision problems, but also time-pressured decision-making at all levels of systems and cognitive behavior.

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