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The neuronal response at extended timescales: long-term correlations without long-term memory

Daniel Soudry and Ron Meir

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Department of Electrical Engineering, the Laboratory for Network Biology Research, Technion 32000, Haifa , Israel

Abstract

Long term temporal correlations frequently appear at many levels of neural activity. We show that when such correlations appear in isolated neurons, they indicate the existence of slow underlying processes and lead to explicit conditions on the dynamics of these processes. Moreover, although these slow processes can potentially store information for long times, we demonstrate that this does not imply that the neuron possesses a long memory of its input, even if these processes are bidirectionally coupled with neuronal response. We derive these results for a broad class of biophysical neuron models, and then fit a specific model to recent experiments. The model reproduces the experimental results, exhibiting long term (days-long) correlations due to the interaction between slow variables and internal fluctuations. However, its memory of the input decays on a timescale of minutes. We suggest experiments to test these predictions directly.

1 Introduction

Long term temporal correlations, or "$f^{-\alpha}$ statistics" [22], are ubiquitously found at multiple levels of brain and behavior [50, and refrences therein]. For example, $f^{-\alpha}$ statistics appear in human cognition [14, 40], brain and network activity (measured using electroencephalograph or local field potentials [3, and refrences therin]), and even Action Potentials (APs) generated by single neurons [30, 11]. The presence of these long correlations in a neuron's AP responses suggests it is affected by processes with slow dynamics, which can retain information for long times. As a result, if these slow processes are also affected by APs, then the generation of each AP (indirectly) depends on a rather long history of the neuron's previous inputs and APs. This potentially allows a single neuron to perform complex computations over very long timescales. However, it remains unclear whether this type of computation indeed occurs.

Cortical neurons indeed contain processes taking place on multiple timescales. Many types of ion channels are known, with a large range of kinetic rates [1]. Additional new sub-cellular kinetic processes are being discovered at an explosive rate [2, 44, 9]. This variety is particularly large for very slow processes [29]. Such rich biophysical machinery