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Noise-induced transitions in slow wave neuronal dynamics

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Introduction

Many neuronal systems exhibit slow random alternations and sudden switches in activity states. Noisy relaxation oscillator models for such systems generate random switching with fluctuations in active phase AP) and silent phase (SP) durations. Noise can induce transitions even if the noise-free model is not oscillatory, but rather excitable or bi-stable.

Slow negative feedback is an essential feature of such models setting the time scale of AP and SP durations. It provides memory-like properties and can lead to correlations in successive AP and SP durations. The statistics of durations and correlations may provide insight on the underlying mechanisms of the relaxation dynamics [1].

The AP and SP correspond to slow motion along a pseudo-steady state, i.e., drift on a slow manifold. Transitions between states correspond, in the noise-free case, to encountering and "falling off" a fold or knee of the manifold. In the presence of noise, transitions typically occur before getting to the knee. The rate of noise-induced transitions can be computed using Kramer's theory which describes the escape rate of a Brownian particle moving in a potential well [2,3]. We use this rate to obtain the distributions of jumping locations in AP and SP, as well as durations in each phase and correlations of successive durations.

We apply the analysis to two different biophysically-based, relaxation-like models of bursting neurons in the rat respiratory central pattern generator circuit [4]. One involves slow inactivation of a rapidly-activating persistent sodium current, a multiplicative negative feedback. The other is slow activation of a slow potassium current which is additive. We disable spike-generating currents to get idealized slow wave systems. These reduced models can be either autonomous oscillators or excitable. When the slow negative feedback is additive, distributions of jump position in AP and SP are symmetric which means similar variances of the two distributions. But the distributions are asymmetric with multiplicative feedback due to different sensitivities to noise on the AP and SP manifold. These differences in sensitivity lead to differences in temporal correlation. We seek to develop criteria, based on the dependence of these statistical properties on biophysical parameters, by which to distinguish among biophysical mechanisms, such as multiplicative or additive negative feedback.

This framework can be extended to slow wave firing rate models of network dynamics. In several models of binocular rivalry neuronal populations compete for dominance via mutual inhibition; slow negative feedback (additive and/or multiplicative) and noise may both contribute to causing the alternations [5,6].

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