How somatic spikes are influenced by nonlinear active dendrites

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In this work, we consider the propagation of dendritic spikes [H05, MLS13, Bre14] in a dendrite composed of a single branch. These local dendritic spikes are due to voltage dependent ion channels observed in dendrites (i.e. sodium, calcium or NDMA spikes). Because all the dendritic compartments are connected through a linear cable equation, dendritic spikes propagate in both sides, although with possibly different speeds. Two dendritic spikes propagating in opposite directions will cancel out when they collide as in the case of the axon because of the refractory period.

The local dendritic spikes are triggered by synaptic bombardment that is modeled by a doubly stochastic jump process with stochastic intensity r_t. We are interested in two aspects.

In a first part, we explore the deterministic aspects of the propagation for a given pattern of synaptic stimulations. The novelty of our approach lies in the use of algebra rather than analysis. An efficient procedure for the simulation of the dendritic propagation is provided. This is based on a formulation using the theory of partially ordered sets [Sta86]. In particular, a new analytical formula for the number of somatic spikes is provided (using Dilworth's Theorem). However, several patterns of somatic excitations may lead to the same somatic dynamics, hence are indistinguishable from the soma point of view. The topology [God71] of such equivalence classes of synaptic excitations is then explored. Several extensions are finally investigated. The first is the case of a branched dendrite. The second is when the spikes carry a real number modeling for example a current, a label (NMDA, sodium...) and the way they interact according to their label. We then study how these extensions affect the number of somatic spikes and their relative timings.

In a second part, we study stochastic aspects of the number of dendritic spikes reaching the soma as function of the properties of the autocorrelation of r_t. In particular, we are interested in the mean somatic spike number N as function of the autocorrelation length l of the intensity process r_t. Based on simulations, we show that N decreases as a function of l. We are able to prove this fact under simplifying assumptions of the process r_t.

Thus, we highlight a qualitative feature of active dendrites: they filter out correlations. The optimal environment for generating of lot of somatic spikes is to have locally correlated synapses (so as to generate a lot of dendritic spikes) and globally uncorrelated synapses (so as to avoid dendritic spike collisions). This is one of the first general quantitative result concerning dendrites.

Most of these findings are independent of the underlying details of the propagation of the dendritic spikes. They can be reproduced in chains of Fitzhugh-Nagumo systems for example.

References

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