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Phase transition approach to bursting in neuronal cultures : Quorum Percolation models

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Abstract content
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Rather than describing collective behaviors observed in living neuronal networks grown in vitro in terms of oscillator synchronization, the Quorum Percolation model tackles the issue from the point of view of statistical physics and critical phenomena. Under its original form, it is a discrete time dynamics model of information propagation on a directed random graph similar to a cellular automaton and built up according to a simplification of the most relevant biological features : The neurons, located at the nodes, are two state systems whose activation is governed by a fixed threshold (Quorum) rule. A burst is seen as a discontinuity in the activity of the network, interpreted as the occurrence of a giant cluster. We go beyond such a model by introducing several biological relevant developments. The decay, modeled by a discrete time markovian process, accounts for ionic leakage through the membrane of neurons; as a main result, our Monte-Carlo simulations enable to understand how the decay changes the percolation transition, where discontinuities are replaced by steep but finite slopes, or even destroys the transition. Furthermore, while quenched disorder arises from the graph connectivity randomness, a variability in the neuronal excitability can be taken into account with the help of a Gaussian probability distribution of the Quorum. We derive a mean field approach and show its relevance by carrying out explicit Monte Carlo simulations. Such a variability shifts the position of the percolation transition, impacts the size of the giant cluster and can even destroy the transition. Moreover we highlight the occurrence of disorder independent fixed points above the Quorum critical value. A finite-size analysis enables us to show that the order parameter is weakly self-averaging with an exponent independent on the thresholds disorder. At last, we stress that the effects of the threshold variability can be understood by studying a global activation probability.

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