Refractory period in a network of excitable nodes leads to dynamical stability, extended region of criticality as well as oscillatory behavior

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Various physical, biological and chemical systems are composed of interacting excitable agents and thus networks of excitable nodes are widely used to model the behavior of such systems. Examples of such systems include tectonic plates, Neural networks, models of self-organized criticality (SOC), and epidemic (contagion) spreading. In particular, excitable nodes have been used extensively in models of neuronal dynamics where criticality is proposed to be a fundamental property. Refractory behavior, which limits the excitability of neurons is thought to be an important dynamical property. We therefore consider a simple model of excitable nodes which is known to exhibit a transition to instability at a critical point ($\lambda = 1$), and introduce refractory period into its dynamics. We use mean-field analytical calculations as well as numerical simulations to calculate the activity dependent branching ratio that is useful to characterize the behavior of critical systems. We also define avalanches and calculate probability distribution of their size and duration. We find that in the presence of refractory period the dynamics stabilizes while various parameter regimes become accessible: a subcritical regime, a standard critical point with exponents close to the critical branching process with $\lambda = 1$, a regime with $1 < \lambda < 2$ that exhibits an interesting scaling (critical) behavior, and an oscillating regime for $\lambda > 2.0$. The critical regime is characterized by power-law avalanche statistics in both time and space, as well as activity-dependent branching ratio that converges to one in the thermodynamic limit. We have therefore shown that refractory behavior leads to a wide range of scaling as well as periodic behavior which are relevant to real neuronal dynamics. We note that the existence of extended criticality is of particular interest since it provides an answer to how complex systems exhibit scaling behavior without any apparent tuning to a specific critical point.

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