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Unveiling criticality in noisy nonequilibrium systems (G)*

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Neuronal systems have become emblematic of nonequilibrium biological systems with complex behaviour. Owing to observations of apparently scale-free cascades of causal activity (avalanches) in neural cultures, it has become a popular hypothesis that neural systems operate close to a nonequilibrium phase transition. That neural systems should operate at a critical point is supported by theory, which suggests that criticality is optimal for information processing and storage. A reduced framework, in terms of a branching process tuned to the critical point, is enough to reproduce the power-laws observed in experiments. However, this description fails to capture much of the relevant biological details of neuronal systems, like self-organization mechanisms, and ignore the role of spontaneous activity. In real neuronal systems, neurons will spontaneously fire, and can create avalanches that overlap both in space and time. This destroys the separation of time scales between initiation and propagation of new avalanches, an assumption that is implicit in the classical definition of avalanches. Simulating large ensembles of realistic neurons we demonstrate that the classical definition of the neuronal avalanche fails to describe the statistics of the system. However, by taking into account the ground-truth connectivity of the system, we employ "causal webs"to disentangle concurrent but independent cascades of activity. We show that this procedure can be generalized for when the connectivity map is not available (as is the case for most experimental conditions) and still recover the underlying statistics of the system under study.

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