Critical phenomena and noise-induced phase transitions in neuronal networks

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Neuronal networks in the brain are nonlinear dynamical systems in which transitions from one to another state have bifurcation nature. One can mention the appearance of brain rhythms, epileptic seizures, and transitions stimulated by an electric field. In this work, we study numerically and analytically first- and second-order phase transitions in neuronal networks stimulated by shot noise (a flow of random spikes bombarding neurons). Using an exactly solvable cortical model, we find critical phenomena accompanying the transitions and their dependence on the shot noise intensity. We show that a pattern of spontaneous neuronal activity near the critical point of the transitions is a characteristic property that can be used to identify their bifurcation mechanism. We demonstrate that bursts and avalanches are precursors of a first-order phase transition, paroxysmal-like spikes of activity precede a second-order phase transition caused by a saddle-node bifurcation, while irregular spindle oscillations represent activity near a second-order phase transition caused by a supercritical Hopf bifurcation. Our most interesting result is the observation of the paroxysmal-like spikes. We show that a paroxysmal-like spike is a single nonlinear event that appears instantly from a low background activity with a rapid onset, reaches large amplitude, and ends up with an abrupt return to lower activity. These sharp oscillations are similar to single paroxysmal spikes and sharp waves observed in electroencephalographic (EEG) measurements. Figure 1 shows sequence of transitions that occur with increasing short noise intensity <*n*>. Above the saddle-node bifurcation (<*n*> = *n_c2*), sustained network oscillations appear with a large amplitude but a small frequency in contrast to oscillations near the Hopf bifurcation (<*n*> = *n_c3*) that have a small amplitude but a large frequency.

REFERENCES

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