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Can the clocks tick together despite the noise? Stochastic simulations and analysis of the mean-field limit

The suprachiasmatic nucleus (SCN), also known as the circadian master clock, consists of a large population of oscillator neurons. Together, these neurons produce a coherent signal that drives the body's circadian rhythms. What properties of the cell-to-cell communication allow the synchronization of these neurons, despite a wide range of environmental challenges such as fluctuations in photoperiods? To answer that question, we present a mean-field description of globally coupled neurons modeled as Goodwin oscillators with standard Gaussian noise. Provided that the initial conditions of all neurons are independent and identically distributed, any finite number of neurons becomes independent and has the same probability distribution in the mean-field limit, a phenomenon called propagation of chaos. This probability distribution is a solution to a Vlasov-Fokker-Planck type equation, which can be obtained from the stochastic particle model. We study, using the macroscopic description, how the interaction between external noise and intercellular coupling affects the dynamics of the collective rhythm, and we provide a numerical description of the bifurcations resulting from the noise-induced transitions. Our numerical simulations show a noise-induced rhythm generation at low noise intensities, while the SCN clock is arrhythmic in the high noise setting. Notably, coupling induces resonance-like behavior at low noise intensities, and varying coupling strength can cause period locking and variance dissipation even in the presence of noise.