Fluctuations and oscillations in a driven Potts model

Maciej Chudak,[1] Massimiliano Esposito,[2] and Krzysztof Ptaszyński[1]

[1] *Institute of Molecular Physics of the Polish Academy of Sciences*

[2] *Department of Physics and Materials Science, University of Luxembourg*

The Potts model is a generalization of the Ising model where spins can take more than two states. We study a driven three-state nonequilibrium Potts model with homogeneous all-to-all coupling. This is the minimal model, which at the mean-field level exhibits complex behavior, such as synchronization that leads to the emergence of persistent macroscopic oscillations (limit cycles). [1]

We first consider the mean-field limit, where the model dynamics is described via deterministic equations of motion for macroscopic variables of the system. The choice of the transition rate function can drastically reshape the phase diagram of the model, generating much richer behavior than that originally reported in Ref. [1].

Beyond the mean-field analysis, we further characterize the effect of rare fluctuations on the model behavior. Using the method of Gaspard [2], we determine the coherence lifetime of the oscillations and compare it to a thermodynamic bound given by the entropy production per cycle. [3,4] In this way, we show that the trade-off between coherence lifetime and entropy production can be tailored by adjusting the parameters of the transition rate model. We also investigate the scaling of fluctuations with system size.

Using the instanton approach [5,6], we characterize rare stochastic transitions among the coexisting mean-field attractors, which tend to relax the system to a single "most likely" attractor that determines the macroscopic behavior of the model. In particular, we show that in the region of multistability, the ordered state is usually more likely than disordered or oscillating state.

References:

[1] T. Herpich, J. Thingna and M. Esposito, Phys. Rev. X 8 (2018) 031056
[2] P. Gaspard, Journal of Statistical Physics 106 (2002) 57
[3] L. Oberreiter, U. Seifert and A. C. Barato, Phys. Rev. E 106 (2022) 014106
[4] D. Santolin and G. Falasco, Phys. Rev. Lett. 135 (2025) 057101
[5] M. I. Dykman, E. Mori, J. Ross and P. M. Hunt, J. Chem. Phys. 100 (1994) 5735
[6] R. Zakine and E. Vanden-Eijnden, Phys. Rev. X 13 (2023) 041044