Synchronization and criticality in brain models

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The criticality hypothesis for neural systems has been roposed because information processing, sensitivity, long-range and memory capacity is optimal in the neighborhood of criticality. Real neural systems are expected to self-tune themselves close to the critical point, but heterogeneity may extend this region is a same way as in case of Griffiths phases of condensed matter [1]. We investigate the synchronization transition of the Shinomoto-Kuramoto (SK) model on networks of the fruit-fly and two large human connectomes. Besides the exactly known largest brain network of the fruit-fly we consider large connectomes, obtained by diffusion MRI, representing the white matter of the human brain, showing some degree of universality [2]. Earlier we have shown nontrivial critical behavior with continuously changing exponents, frustrated synchronization and chimera states in the resting state [3,4,5]. The SK model contains a force term, thus is capable of describing critical behavior in the presence of external excitation. By numerical solution we determine the crackling noise durations with and without thermal noise and show extended non-universal scaling tails characterized by the exponent $2 < \tau < 2.8$, in contrast with the Hopf transition of the Kuramoto model, without the force $\tau = 3.1$ (1). Comparing the phase and frequency order parameters we find different transition points and fluctuations peaks as in case of the Kuramoto model. Using the local order parameter values we also determine the Hurst (phase) and β (frequency) exponents and compare them with recent experimental results obtained by fMRI. We show that these exponents, characterizing the auto-correlations are smaller in the excited system than in the resting state and exhibit module dependence [6].

References

[1] G. Odor, M. T. Gastner, J. Kelling, G. Deco, Modelling on the very large-scale connectome, J. Phys. Complex. 2, 045002 (2021).
[2] M.T. Gastner, G. Ódor, The topology of large Open Connectome networks for the human brain, Sci. Rep., 6, 27249 (2016).
[3] G. Odor, J. Kelling, Critical synchronization dynamics of the Kuramoto model on connectome and small world graphs, Sci. Rep., 9, 19621 (2019).
[4] G. Odor, J. Kelling, G. Deco, The effect of noise on the synchronization dynamics of the Kuramoto model on a large human connectome graph, Neurocomputing, 461, 696-704 (2021).
[5] G. Odor, G. Deco, J. Kelling, Differences in the critical dynamics underlying the human and fruit-fly connectome, Phys. Rev. Res. 4, 023057 (2022).
[6] G. Ódor, I. Papp, S. Deng, J. Kelling, Synchronization transitions on connectome graphs with external force, Front. Phys. 11, 1150246 (2023).