Reconstruction of complex networks dynamics from data: Emergent higher-order interactions and critical phenomena

Deniz Eroglu
Kadir Has University, Istanbul, Turkey

Real-world complex systems such as ecological communities and neuron networks are essential to our everyday lives. These systems are composed of units that interact through intricate networks. The ability to predict sudden changes in network behavior (critical transitions) from data is essential to avert disastrous consequences of significant disruptions. Predicting such changes is a major challenge as it requires forecasting the behavior for parameter ranges for which no data on the system is available. We address this issue for networks with weak individual interactions and chaotic local dynamics by introducing a unified reconstruction scheme by blending dynamical systems theory and machine learning tools. Although our approach works perfectly under the given assumptions, the model reconstruction scheme can also surprisingly lead to recovering emergent hypernetworks with triplet and higher interactions among oscillators for slightly different settings. This appears paradoxical at first glance because, initially, such models are defined as oscillator networks with pairwise interactions. In this work, we uncover a general mechanism for emerging hypernetworks when recovering models of nonlinearly coupled oscillators from data. We present a full description of such emergent hypernetworks using normal form theory and the local tree structure of the original network. Our findings shed light on the apparent abundance of hypernetworks and provide a constructive way to predict their emergence. Using the approach, we can create a proxy of a complex system and thereby make predictions about the critical transitions in the system.