Before the Collapse: Critical Slowing Down in Abrupt Desynchronization

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While the divergence of characteristic length and time scale, canonical signatures of criticality, has been well established for the second-order synchronization transition in the Kuramoto model, analogous theoretical characterization for abrupt (discontinuous) transitions remains lacking.

Focusing on the abrupt desynchronization transition in a Kuramoto model with higher-order interactions, we combine numerical simulations with analytical treatment to demonstrate the emergence of critical slowing down, manifested through a diverging relaxation time in the vicinity of the transition.

Furthermore, we establish a finite-time finite-size scaling framework in which the relevant scaling variables are the system size, coupling strength, and time. The resulting scaling relations consistently collapse the dynamical behavior near the transition, indicating an underlying universal structure despite the discontinuous nature of the phase change.

These results extend the theoretical framework of critical phenomena by incorporating abrupt synchronization–desynchronization transitions in coupled oscillator systems, thereby bridging features of discontinuous transitions with critical scaling theory.