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Role of Information Flow in Sustaining Self-Organized Dynamics

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Complex system arises as a result of nonlinear interactions within its components. Characterizing how the self-organization is sustained through multivariate interaction, which leads to the “whole is greater than the sum of its parts”, remains an open question. We formulate the notion of causal history, that is, the history of multivariate interactions that inform the present state of any variable and provide quantitative metrics for estimation. In this presentation, we propose an information-theoretic framework to unravel the multivariate dynamics from the causal history that maintains the self-organized structure. Specifically, we partition the causal history into a recent dynamics, or immediate causal history, and the remaining earlier dynamics, or distant causal history. The quantification of information flows from these two components of causal history illustrates the memory dependency of a system. Also, due to the strong self-feedback interactions in many ecosystems, we further partition either parts of causal history into self-and cross-dependencies, and their interplay using partial information decomposition (PID). We hypothesize that (1) the self-organization of a system is mainly sustained by a self-dependency dominated immediate causal history as well as a cross-dependency dominated distant causal history; and (2) the dynamics of each variable can be characterized by the PIDs in both immediate and distant causal histories. To verify the hypotheses, we implement the proposed framework to analyze two systems using observational data: solute dynamics in stream and atmospheric dynamics in the boundary layer. The result shows the dominant information flows from the cross- and self- dependencies in distant and immediate causal history, respectively, that influence the current state of each variable. Furthermore, different PID results imply different dynamics of analyzed variables. For instance, in the stream chemistry analysis, such differences in information content of each solute reveal their different origins. The proposed data-driven approach proves to be an efficient approach in unraveling the complexity due to the multivariate interactions in causal history, and thus open up new avenues for studying complex system dynamics.