Information-theoretic characterization of relative and fluctuating system–environment distinction

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Defining a system in distinction from its environment is a fundamental but elusive problem in artificial life as well as in real-world complex systems. While many notions of closure gives a qualitative and absolute criteria for the system–environment distinction, the concept of "informational closure" proposed by Bertschinger et al. (Bertschinger et al., 2006, Proc. GWAL-7, p.9, IOS Press) gives gradual and relative evaluation of closure (or closedness). There, a system is tentatively defined in distinction to its environment, and the validity of the definition is judged according to how causally closed the system is, being quantified by information flow (transfer entropy) from the environment into the system. This quantitative approach for the characterization of closedness is expected to bring rich description of "relative" systems on a wide range of dynamical models.

In this study we proceed one step further in the direction of relativizing closure: for the evaluation of closedness we also utilize information-theoretic measures, such as the transfer entropy and difference of Boltzmann-type and KS-type entropies, but instead of evaluating closedness of a system with its elements fixed in time, we evaluate the closedness for the system's specific states which are dissociated from the history of interaction with the environment. This dissociation excludes from the system–environment correlation the components which are realized by the system modeling or controlling the environment. Therefore, the measures evaluate solely how a state can prevent the invasion of uncertainty from the environment. This setting can be effective in describing partial closures which appear transiently and fluctuate in uniformly structured degrees of freedom or in a directed flow of information processing, while the original setting of informational closure would be more efficient when the meanings of a system and its environment are clear, their boundary is fixed, and advanced notions such as cognition, learning, self-reference, etc. are of immediate interest.

We apply the method to discrete dynamical networks and a cellular automata model which simulates physico-chemical self-organization (molecular aggregation). The spectrum of closedness is shown to depend on the dynamical properties of each model. (The investigation of the spectra has some similarity with the exploration of characteristic structures in the phase spaces of chaotic systems.) We will also discuss how reversibility of the models and introducing dissipative irreversibility, that is, disregarding information flow into the environment as a heat-bath, can influence the evaluation of the closedness.