論文の内容の要旨

論文題目：Information thermodynamics on causal networks and its application to biochemical signal transduction
（ネットワーク上の情報熱力学とシグナル伝達への応用）

氏名：伊藤 創祐

We develop a general formalism of nonequilibrium thermodynamics with complex information flows (i.e., the transfer entropy) induced by interactions among multiple fluctuating systems. Characterizing nonequilibirium dynamics by causal networks (i.e., Bayesian networks), we obtain novel generalizations of the second law of thermodynamics and the fluctuation theorem, which include an informational quantity given by the topology of the networks. Our formalism on causal networks gives thermodynamics for small subsystems as a generalization of the stochastic thermodynamics with information. Our theory is called “information thermodynamics on causal networks”.

Information thermodynamics on causal networks is applicable to quite a broad class of nonequilibrium stochastic dynamics such as information transfer between multiple Brownian particles, an autonomous biochemical reaction described by the master equation, and complex dynamics in multiple fluctuating systems. Our result can produce the previous study of Maxwell’s demon for a special case of the feedback control with a single measurement.

As an application of our general formalism, we can discuss the accuracy of the information transmission in the biochemical signal transduction of sensory adaptation, where there is not any explicit channel coding in

contrast to the case of Shannon's information theory. Focusing on the robustness of the signal transduction against the environmental noise, we show the analogical similarity between our information thermodynamic result and Shannon's noisy-channel coding theorem. Our result can open up a novel biophysical and thermodynamic approach to understand information processing in living system.

In our study, we clarify the physical meaning of information flow from a thermodynamic point of view. Information flow given by the transfer entropy from the target system to the outside worlds characterizes the thermodynamic benefit of the target system under the condition of the outside worlds. We also propose the novel information flow called the "backward" transfer entropy, which characterizes the inevitable thermodynamic dissipation of the target system because of the effects of outside worlds.

By the above, information thermodynamics on causal networks will be the basis of the statistical physics and biophysics from the viewpoint of the information flow.