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Thermodynamics of information: An introduction

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In the nineteenth century, J. C. Maxwell considered a hypothetical being that can observe and manipulate individual atoms and molecules, which leads to the apparent violation of the second law of thermodynamics. Such a being was named Maxwell's demon and has been an issue of intense controversies from the viewpoint of the foundation of thermodynamics. Nowadays, it is realized that information is the key concept to understand the consistency between the demon and the second law.

In this decade, thermodynamics of information has attracted renewed attention in light of modern nonequilibrium statistical mechanics, both theoretically and experimentally (see [1] for a review article). Theoretically, a general formulation of the second law has been established, where information contents, such as Shannon information and mutual information, and thermodynamic quantities, such as work and heat, are treated on an equal footing. Experimentally, Maxwell's demon has been realized by real experiments with various systems in both the classical and quantum regimes.

In this lecture, I will talk about a general theory of thermodynamics of information, starting from a brief introduction to nonequilibrium statistical mechanics and information theory. Specifically, I will focus on the generalization of the second law and the fluctuation theorem by incorporating information contents, leading to a general resolution of the paradox of Maxwell's demon. I will also talk about experimental realizations of Maxwell's demon by using colloidal particles and single electrons. Moreover, I will talk about a more advanced framework of thermodynamics for autonomous information processing, such as biochemical information processing, where continuous information flow plays a significant role.

[1] J. M. R. Parrondo, J. M. Horowitz, T. Sagawa, Nature Physics **11**, 131-139 (2015).