Geometric housekeeping-excess decomposition of information flow

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Information thermodynamics explores the fundamental principles underlying the interconversion between information and energy [1]. The origins of this field can be traced back to Maxwell's demon, an entity that converts information into energy. In recent years, research has advanced on the autonomous demon, which processes information autonomously based on its internal dynamics. This concept has been investigated across diverse fields, including biophysics and computer science [2].

Despite its importance, there remains scope for theoretical development in our understanding of Maxwell's demon. Previous studies have characterized demons in two distinct scenarios: one is a stationary demon, driven in a steady state [2]; the other is a non-stationary demon, corresponding to the demon in the feedback protocol considered in the seminal work by Sagawa and Ueda [3]. While these previous studies provide foundational insights, it is still challenging to separate and quantify the extent to which these two functions manifest in general dynamics. This difficulty mainly stems from the fact that the function of a demon is typically characterized by a single quantitative measure, information flow. Establishing a method for this quantitative separation would not only deepen the fundamental understanding of Maxwell's demon, but also broaden the scope of analysis for concrete physical systems.

In this presentation, we propose a general framework for separating and characterizing the demons arising from stationarity and non-stationarity in general Markov bipartite systems [4, 5]. Specifically, we decompose information flow into two distinct parts. The stationary part is the housekeeping information flow that maintains the correlation between the demon and the system. The non-stationary part is the excess information flow that changes the correlation. The theoretical foundation for this decomposition is based on the recent research on the optimal transport theoretic decomposition of entropy production [6].

We expect that our decomposition of information flow provides new insights into information thermodynamics. For example, we can derive inequalities that hold for both the housekeeping and excess information flows, respectively, which can be interpreted as generalizations of the second law of information thermodynamics. In specific non-stationary dynamics, these generalized second laws allow us to determine whether the manifestation of Maxwell's demon originates from stationarity or non-stationarity. This framework has the potential to refine the conventional picture of Maxwell's demon.

References

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