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Commentary and Perspective

Information physics of living matters

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Information or signaling has been one of the core concepts to understand the biological systems. Recent progress in technologies has enabled quantitative measurements of biological phenomena even at a single molecule level. However, theoretical frameworks are still missing that can handle information in biological systems in a quantitative and unified manner.

We aim at establishing a new interdisciplinary research field by applying this new information physics to biological systems. The theoretical frameworks of information physics will deepen our understanding of the biological systems. For example, we will be able to discuss the design principles of the existing biological systems through the quantitative analyses of their efficiencies, which will be enabled by the theoretical tradeoff relations among various (thermo) physical quantities and information. At the same time, many good model systems or interesting questions will be found in the real biological systems, which will stimulate the further development of the theory of information physics.

For the issue, we have a symposium at the 58th Annual Meeting of the Biophysical Society of Japan held in September 2020 inviting six speakers.

Andreas Dechant at Kyoto University reported on thermodynamic inequalities. These inequalities are universal relations between different physical observables. On the one hand, they provide constraints that every physical system must obey, limiting for example the power output of molecular motors. On the other hand, thermodynamic inequalities can offer a way to estimate quantities like entropy production, which are often difficult to measure directly, by using measurable quantities. They illustrated how such inequalities arise from information-theoretic bounds and provided some suggestions how they might be applied to biological systems [1].

Sosuke Ito at the University of Tokyo reported that he revealed a thermodynamic interpretation of the Fisher information, which gives a Riemannian metric in information geometry [2,3]. If they focused on chemical reaction networks described by the rate equation, the Fisher information of time is related to the Gibbs free energy change under near-equilibrium condition [4]. This relation reveals a connection between thermodynamics and information geometry. He here proposed the thermodynamic efficiency of the reaction speed based on this connection. It might be interesting to estimate this efficiency using biological data.

Kazumasa A. Takeuchi at the University of Tokyo reported about an experimental device that can culture dense cell populations under uniform and controlled conditions. He developed such a microfluidic device, named the extensive microperfusion system (EMPS), in which cells can be confined in a large region and uniformly supplied with fresh medium through a porous membrane. He showed the outline of EMPS and results of performance evaluation, then presented a few attempts he undertook to seek for statistical physics and information physics of bacterial populations. The latter include scaling properties of cell size fluctuations and crowding of motile bacterial

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populations [5].

Tetsuya J. Kobayashi at the University of Tokyo reported that the chemotactic network of *Escherichia coli* was mathematically equivalent to an information-theoretically optimal filtering dynamic. Moreover, they demonstrated that an experimentally observed nonlinear response relation can be reproduced from the optimal dynamics. These results suggested that the biochemical network of *E. coli* chemotaxis was designed to optimally extract gradient information in a noisy condition [6].

Kiyoshi Kanazawa at University of Tsukuba reported that a microscopic theory to derive the Levy-flights dynamics in an active matter system by extending the kinetic theory. He started from a microscopic setup composed of a tracer particle and active swimmers (such as Chlamydomonas). The tracer dynamics was shown to obey a colored Poisson process, by studying the swimmer-tracer interactions. This model finally exhibits the Levy flights at a longer timescale. This work provided the first theoretical derivation of the Levy flights from microscopic physical dynamics by appropriate coarse-graining [7].

Kyogo Kawaguchi at RIKEN described how the collective dynamics of molecular motors, bacteria, and mammalian cells have been studied under the name of active matter physics. Recent progress both in theory and experiments have further clarified how concepts of nonequilibrium many-body physics can emerge from biological examples. He introduced several examples of these developments, such as active topological nematics and quantum active matter, through experiments using cells and theory involving non-Hermitian physics [8–10].

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