Interdisciplinary Area

Title of Project：Information physics of living matters

OKADA Yasushi
(The University of Tokyo, Graduate School of Science, Professor)

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【Purpose of the Research Project】

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 framework(s) are still missing that can handle information in biological systems in a quantitative and unified manner.

Meanwhile, in physics, a new theory is emerging at the interface of the thermodynamics and the information theory. Now, information can be treated as a physical quantity just like heat or mechanical works.

In this project, 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. We would build a research group to explore this new research field through active feedbacks between biologists and physicists.

【Content of the Research Project】

The goal of this project is to establish a new physics theory that unites information with other physical quantities based on the real biological problems. To explore such interdisciplinary area, it would be essential to establish real collaborations between biologists and physicists. Therefore, each of the three groups in this project has both physical theorists and biological experimentalists, so that they can collaborate to tackle the problems.

The main target of the group A is to dissect the biological molecular machineries, such as molecular motors. The behavior of a single protein will be measured and analyzed in the non-equilibrium environment of the cytoplasm. Moreover, the interactions between the biomolecules in the cytoplasm will also be discussed, which would help us to understand the basic physical principles of liquid-liquid phase separations in the cytoplasm.

Group B will work on the cellular level, such as the chemical reaction networks of the signal transduction or chemotaxis. The information thermodynamics theory will be extended by the application of the information geometry or other mathematical concepts to handle those problems. Quantitative measurements and perturbation experiments would enable us to examine the theory, and would guide the further development of the theory.

Group C will work on the emergence of the functions in the multi-cellular systems, such as the collective cell movement or the developmental processes of multi-cellular organisms. The theory would further cover the adaptation or evolution. These processes include the noisy feedbacks between individual cells and a whole population via a macroscopic field. Information physics will be expanded to discuss such processes.

【Expected Research Achievements and Scientific Significance】

The current abstract theory of information thermodynamics will be materialized by solving the real biological problems. For example, the discussion of the theoretical limits of the efficiency of the cell signaling pathways would not only deepen our understanding how good the existing biological systems is, but also enable us to establish a general theory of the efficiency of information-heat engines.

At the same time, such approach would also enable us to discuss the (design) principles of the biological systems rather than making up a list of the molecules involved in some specific functions.

【Key Words】

Information thermodynamics = A theory to integrate the information theory into the framework of thermodynamics.

【Term of Project】 FY2019-2023

【Budget Allocation】 1,150,100 Thousand Yen

【Homepage Address and Other Contact Information】

http://infophys-bio.jp/