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*Commentary and Perspective*

# Information biophysics of gradient sensing in organisms

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Biological sensory systems, such as chemotaxis, phototaxis, gradient sensing and so on, are functions that are widely available in the biological world. For example, bacterial chemotaxis is one of the most well-studied areas from both theoretical and experimental perspectives. Various methods have been used in experiments, including genetics, biochemistry, and imaging. Theories have been discussed from various perspectives such as Ising model, information theory, and efficiency. For the issue, we have a symposium at the 59th Annual Meeting of the Biophysical Society of Japan held in November 2021 inviting six speakers.

Takeshi Sugawara at the University of Tokyo reports on a biophysical mechanism of chemotaxis-like behavior of cargos in bacterial cells. Based on the previously proposed theory referred to as chemophoresis, he introduced the *chemophoresis engine* as a physicochemical mechanism of cargo motion, which transforms chemical free energy to directed motion through the catalytic ATP hydrolysis. He applied the engine to plasmid DNA motion in a ParABS system to demonstrate the self-organization for directed plasmid movement and pattern dynamics of ParA-ATP concentration, thereby explaining reports experimental results. Finally, he proposed its possible role as a universal principle of hydrolsis-driven intracellular transports.

Yusuke V. Morimoto at Kyushu Institute of Technology reports on flagellar motility and chemotaxis in *Salmonella. E. coli* and *Salmonella* are propelled by rotating flagella to swim in liquid environments [1]. The basal body is located at the base of the flagellar filament and works as a rotary motor. The flagellar motor rotates in both counterclockwise (CCW) and clockwise (CW) directions. When one or more motors switch the rotational direction from CCW to CW, the cells change the swimming direction. Then bacterial cells carry out chemotaxis by a biased random walk toward various chemicals, pH, and temperature. These systems are commonly conserved in *E. coli* and *Salmonella* with proton-driven motors, but there are some differences. This presentation focused on these differences and discussed them from the perspective of *Salmonella* research.

Tom Shimizu at NWO Institute AMOLF reports on Near-critical tuning of conformational spread revealed by single-cell FRET in bacterial chemoreceptor arrays. Dynamics of allosteric complexes are crucial for signal processing by protein networks, but direct observation of switches between distinct conformational states has been limited to relatively small assemblies such as ion channels. Using in vivo FRET in single bacterial cells [2], the authors discovered spontaneous switches in the activity of *E. coli* chemosensory arrays, huge membrane-associated protein complexes comprising thousands of proteins. Analysis of the temporal statistics using a conformational spread model revealed coupling energies within 3% of the Ising phase transition, indicating that these bacterial sensory arrays are poised at criticality. These results demonstrate how even the simplest biological systems can enhance performance by tuning their nonlinear dynamics close to a critical point.

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Satomi Matsuoka at Osaka University reports on subpopulation of chemotactic cells with extremely high sensitivity [3]. Chemotaxis is a fundamental function seen universally in vast kinds of eukaryotic cells in complicated natural environments. To understand the highly responsive yet flexible mechanism for the gradient sensing and motility biasing, it is required to quantify the movement under the chemoattractant gradient generated in a reproducible manner. Using a microfluidic device that enables a large-scale observation of individual cells' movement under the same gradients, they revealed a subpopulation of *Dictyostelium discoideum* cells showed higher sensitivity to chemoattractant, cAMP, than the rest of the cells. It became clear that at least 6 cAMP molecules are sufficient for biasing the motility, suggesting an underlying mechanism resilient to molecular noises.

Yuki Akieda at Osaka University reports on Embryonic cell community senses and eliminates the noise of morphogen gradient. Morphogen signaling forms an activity gradient and instructs cell identities to pattern developing tissues. However, developing tissues stochastically may produce cells with unfit morphogen signaling and consequent noisy morphogen gradients. They show that embryonic cell community actively corrects such noisy morphogen gradients. Zebrafish imaging analyses of the Wnt morphogen signaling gradient, which acts as a morphogen to establish embryonic anterior-posterior patterning, identify that unfit cells with abnormal Wnt activity spontaneously appear. Unfit cells are eliminated by apoptosis via cell-cell communication. This elimination is required for proper gradient formation and patterning [4].

Hidehiko Inomata at Riken reports on Spatiotemporal regulation of morphogen distribution in zebrafish embryo. During the developmental processes, complex tissues of the embryo are formed by secreted proteins such as morphogen. Morphogens are secreted by the producing cells and diffuse through the extracellular space, forming a concentration gradient. It is known that cells differentiate into various tissues depending on local morphogen concentration [5,6]. They have developed a novel method for spatiotemporal regulation of morphogen distribution in the embryo. Furthermore, they found that perturbation of morphogen distribution disrupts pattern formation in zebrafish embryos. They think that this method will be an effective tool for understanding the interactive mechanisms of morphogen dynamics and tissue patterning.

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