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EDITED AND REVIEWED BY
Sauro Succi,
Italian Institute of Technology (IIT), Italy

*CORRESPONDENCE
Masaki Itatani,
✉ itatani@sci.hokudai.ac.jp

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Editorial: Static and dynamic pattern formation from nano to macroscales

Masaki Itatani[1]*, Gábor Holló[2], Pawan Kumar[3], Muneyuki Matsuo[4], Hideki Nabika[5] and István Lagzi[6,7]

[1]Department of Chemistry, Faculty of Science, Hokkaido University, Sapporo, Hokkaido, Japan, [2]Department of Fundamental Microbiology, University of Lausanne, Lausanne, Switzerland, [3]Department of Chemical Engineering, Indian Institute of Technology Kanpur, Kanpur, India, [4]Graduate School of Integrated Science for Life, Hiroshima University, Hiroshima, Japan, [5]Faculty of Science, Yamagata University, Yamagata, Japan, [6]HUN-REN–BME Condensed Matter Physics Research Group, Budapest University of Technology and Economics, Budapest, Hungary, [7]Department of Physics, Institute of Physics, Budapest University of Technology and Economics, Budapest, Hungary

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Editorial on the Research Topic
Static and dynamic pattern formation from nano to macroscales

This Research Topic of *Frontiers in Physics* and *Complex Physical Systems*, "*Static and Dynamic Pattern Formation from Nano to Macroscales*," focused on collecting a current research edge and a compressive review of the related field of self-assembly and self-organized phenomena, especially pattern formation in both nonliving and living systems. The contributions treated various problems from physics, chemistry, chemical engineering, computational sciences, and economics. Pattern formation is one of the attractive phenomena in nature exhibiting periodic and spatio-temporal localizations (static aspect) and development (dynamic aspect) of some entities' concentration/number/density. Understanding the underlying mechanisms of pattern formation could shed light on fundamental questions such as "What is life?", "How did life emerge?", and "How do natural systems evolve, form patterns, and function in an orderly manner?". Static patterns (SPs) and dynamic patterns (DPs) are two categories extensively studied in both living and non-living systems. SPs have unique spatial structures, likely found in geological systems and biological species, and arise when mass transport processes are coupled with chemical and/or physical interactions among two or more components in a medium. DPs, on the other hand, are associated with dynamic phenomena, such as spatiotemporal patterns and collective motion observed in animal cells. The formation of DPs requires the presence of both negative and positive feedback mechanisms, as well as physical and/or mechanical synchronization mechanisms. The study of pattern formation is broad and interdisciplinary. Therefore, insights from a multidisciplinary perspective are essential. Also, the mechanism of pattern formation should provide an innovative guiding principle for the design of systems in chemistry and engineering because pattern formation in nature is spontaneous and driven by efficient energy consumption. This Research Topic has garnered significant attention across various research fields, including physics, chemistry, biology, geology, computational sciences, and engineering.

Two interesting research papers were published to study SPs, which focused on reaction-diffusion systems in solid hydrogels consisting of diffusional mass-transport and colloidal crystallization/precipitation reactions. The study by Saadi and Badr covers experimental studies on the mechanism of the dendritic structure of inorganic salts, a quintessential example of SPs. The controlling factors for structure branching in terms of size and morphology of copper dendrites are discussed based on the fractal dimension, lacunarity, and Shannon entropy. It shows that the morphologies of spatial copper dendrite patterns with fractal characteristics are quantitively described by determining the lacunarity and Shannon entropy of the systems.

Hayashi and Yamada investigate the Liesegang phenomenon, one of the typical phenomena of SPs. Their study reports that self-organized Ag_2O discrete periodic banding structures are formed in a solid agarose hydrogel connected to a cathode and anode. Notably, the periodic banding cartelistic is controlled by the applied voltage, duration of application, and concentration of $NaNO_3$ initially loaded in the gel. The resulting band consists of gelatinous Ag_2O and micrometer-scale (1–50 μm) clusters, suggesting potential applications for preparing heterogeneous Ag-related catalysts.

The fundamental perspectives of DPs were discussed in four research studies. Yoshii et al. explore the basic mechanism of spatio-temporal fluid pattern formation in a Hele–Shaw cell known as viscous fingering. Their findings underscore the crucial role of viscoelasticity in the initially purged aqueous viscous fluid. In the case of the focused system using organic inner and aqueous outer fluids with the oleophilic resin as a substrate, the pattern morphology is influenced by the delamination of viscoelastic fluid from the bottom substrate surface. Therefore, the study implies that modifying the interfacial energy of the surface of the substrate can affect fingering behavior in the injection process.

In the study by Cohen-Cobos et al., the unique possibility of Belousov–Zhabotinsky (BZ) patterns applying to understand gravitational lensing as a model is shown from both points of view of experiments and simulation. Gravitational lensing is one of the exciting topics in astrophysics, resulting from the deflection of light's path caused by large mass concentrations. The authors experimentally demonstrate that BZ wave propagation across various obstructs, creating a hollow in a quasi-two-dimensional system, is distorted depending on the morphology of the obstructs. Additionally, simulation considering reaction–diffusion equations reproduce the same effect of obstruct presence, and finally, the efficiency of BZ patterns to understand gravitational lensing is discussed considering the physics of light deflection.

Tetteh and Kiss investigate the synchronization of electrochemical oscillators in a closed bipolar cell, which results from kinetic competition between nickel and hydrogen reduction reaction. The synchronization behavior is interpreted by a combination of experiments using the bipolar cell with Ni electrodes and simulation considering the kinetically coupled cathode-anode dynamics and interactions on the cathode and the anode side through migration current-mediated potential drops in the electrolyte.

The study by Issa and Sultan analytically reports the evolution of the COVID-19 pandemic, focusing on the case of Lebanon. The disease spread dynamics is characterized mainly by four eruption phases or waves, possibly interrupted by minima attributed to various factors such as vaccination, lockdowns, distancing, and face mask protection. The main finding of the study is that the spread dynamics of the COVID-19 disease obey a quasi-chaotic dynamical evolution. It could contribute to predict future COVID-19 pandemic scenario.

One of the important aspects of this Research Topic is to summarize both the interpretation and general things of recent and historical findings. In this context, Kubodera et al. discuss the mechanism of some experimental examples of the up-and-down motion of a resin bead, where ferroin is absorbed on its surface (called a BZ bead), coupled with chemical BZ oscillation. The essence of the discussion is the variation in bead buoyancy, which increases due to CO_2 bubbles produced by the oxidation of malonic acid. This buoyancy is counteracted by the loss of buoyancy as these bubbles disappear at the air-liquid interface.

In the mini-review by Aizawa and Asakura, the theory of Turing pattern, which is one of the most famous classes of SPs in reaction–diffusion systems, and experimental finding of this type of SP in a chlorite–iodide–malonic acid (CIMA) reaction system is comprehensively described. The Turing mechanism is a theoretical framework of SPs proposed by Alan Turing, and it helps explain the formation mechanisms of periodic structures, as represented by the body surface patterns of animals. The discovery of the CIMA system, a chemical model system, is an essential event that bridges theory and biology, and inspired the search for and discovery of similar patterns in other chemical systems.

This overview of the latest and comprehensive studies and reviews on pattern formation in multidisciplinary will inspire this fascinating research field based on non-equilibrium and non-linear sciences perspectives.

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