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Editorial: Nonequilibrium and nonlinear processes in collective dynamical phenomena

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Editorial on the Research Topic
Nonequilibrium and nonlinear processes in collective dynamical phenomena

The power of statistical and nonequilibrium physics has extended significantly in the last years from the boundaries of classical and quantum physics to biology, chemistry, meteorology, and social arenas everywhere where the number of objects tends toward infinity [1, 2]. The vast number of objects is essential to ensure a correct mapping between the various theories and concepts of statistical physics and the corresponding experiments. It's important to point out that when the number of particles increases, the initial conditions become less significant. For a system extensive enough, the equilibrium state will be utterly different from the state of systems made of few objects/particles. This last fact is also the basis on which Isak Asimov built his famous trilogy Foundation, and it is crucial for the Foundation of the physics of complex systems.

The Research Topic "*Nonequilibrium and Nonlinear Processes in Collective Dynamical Phenomena*" in *Frontiers in Physics: Complex Physical Systems* features contributions covering a variety of cutting-edge topics in nonequilibrium systems, each offering exciting research avenues across different fields. The scope of subjects proposed within this Research Topic includes the exploration of intricate dynamics of complex systems where small changes can result in large-scale effects, phase transitions, and self-organization, leading to emergent collective behaviors, often unpredictable due to intrinsic or external nonlinearity symmetry breaking, and formation of complex patterns. Uncovering the core mechanisms behind phenomena like spontaneous, scale-invariant bursts of brain activity, grasping the large-scale nonequilibrium processes that influence climate dynamics, disease transmission in populations, the behavior of the driven disordered magnetic systems and earthquakes, is the nontrivial endeavor. With topics ranging from the identifiability of complex networks and state estimation for Markovian jump Hopfield neural networks to the impact of fear on collective motion in a threat environment, the studies that were contributed to this

Research Topic demonstrate the representative diversity of this challenging field of study. Each of these topics provides rich ground for research, contributing to the understanding of complex systems.

The study *Identifiability of complex networks*, focusing on real-world networked systems, examines the fundamental concepts of identifiability within the domain of complex networks. By differentiating between the structural, functional, and meta-identifiability categories, Zanin and Buldú develop a classification framework for network identifiability. They conclude that a complex system's structural identifiability depends on determining the structural pattern between its constituent parts through system dynamics observation, focusing on the interplay between the system size and variations in its composition. The issue of higher-order networks' identifiability remains yet to be resolved, and it is anticipated that deep learning would be a useful instrument in this regard.

Complex networks like neural networks, involving huge numbers of neurons with the capacity to handle massive amounts of data simultaneously, are commonly used in various fields from associative memory to speech recognition. The authors of *State estimation for Markovian jump Hopfield neural networks with mixed time delays* focus on the stability of these networks addressing the problem of state estimation with regards to time-invariant and time-variant discrete and distributed delays. Designing full-order state estimators that allow the filtering error systems to show exponential stability in the mean-square sense is the aim of the research by Guo and Huang. The required estimators were developed by removing nonlinear coupling elements using design techniques based on linear matrix inequalities. Matlab software was used to validate the findings, allowing for numerical implementation of the proposed design techniques.

Wu et al. made an effort to comprehend the pattern phase transition in intricate physical and biological collective behaviors in their paper *Pattern phase transition of spin particle lattice system*. This is a challenging undertaking because the interaction mechanism underlying the phase transition is unknown and it is not possible to accurately anticipate the ultimate equilibrium state and its stability. The study analyzed the XY model governed by Hamiltonian equations of motion examining a two-dimensional spin particle lattice system and observed phase transitions among four patterns of spin particles: vortex, ferromagnet, worm, and anti-ferromagnet. A new perspective on the emergence of spin particle systems' phase transitions and the development of a single vortex and tight vortex pairs in pattern phase transitions of spin particle groups can be gained from their revelation of the forming mechanism of such phase transitions. Furthermore, the observed phase change may provide insights into the self-assembly dynamics analysis of magnets, electron nematics, and quantum gases.

The mechanism of emotions is introduced into the modeling of dynamics to investigate collective avoidance behavior in response to hazards in the study *How fear emotion impacts collective motion in threat environment*. To evaluate the collective's ability to avoid and survive in the face of insufficient information, Lü et al. created a scenario with a hidden dynamic threat. They came to the conclusion that the collective may self-organize and skillfully reduce risks by maximizing their own advantages by using the activation and dissemination of emotion in modeling. Their model demonstrates the mechanisms of interaction within a collective's emotional layer

as well as how biological emotions affect individual dynamics. It is clear from the modeling studies that a certain level of empathy or emotional communication skills, especially the ability to appropriately transmit fear feelings, can greatly increase the collective's total capacity for survival. In addition to illuminating the behavioral mechanics of collectives in information-deficient situations, this innovative model of collective dynamics offers design insights for managing strategies in artificial intelligence agent clusters within complex environments.

In summary, this Research Topic reveals the significance of fundamental principles of statistical physics while examining new methodologies. It also highlights the impact of interdisciplinary research on unveiling complex dynamics of nonequilibrium and nonlinear processes. The contributed papers provide fresh perspectives and discoveries that deepen our understanding of the intricate behavior of diverse complex systems. In addition to supporting successful projects addressing open questions in contemporary science, we hope that these works will highlight their application in a variety of multidisciplinary settings and inspire scientists working in the complexity field to consider the challenges and opportunities they present.

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