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Special Issue Editorial: Emergent Collective Behavior: From Fish Schools to Bacterial Colonies

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Active systems, that is, systems driven internally by self-propelled individual units, are ubiquitous in nature. They span a wide range of length and time scales, from schools of fish and flocks of birds to suspensions of motile bacteria and assemblages of subcellular extracts, and exhibit rich emergent dynamics, typically at a scale much larger than the scale of the individual unit. Their emergent behavior is the topic of extensive research, spread across several scientific disciplines, and using diverse theoretical, computational and experimental tools.

The goal of this special issue is to offer select samples of research articles that demonstrate the diversity and versatility of this exciting field. These articles are not intended to provide a comprehensive review of this exciting area of research or to focus on a specific approach and model system. The model systems considered here range from fish swimming to propulsion of microscopic organisms.

The coordinated motion in fish schools is addressed in two papers. The paper of Mwaffo, Anderson and Porfiri studies computationally the effects of random changes in the individuals' orientation on the overall coordination of fish schools in the context of two rule-based models. The first is based on the classical Vicsek model, where each individual averages the orientation of its geographically proximal neighbors, and the second is a metric-free vectorial network model, where neighbors are selected randomly, independent of the group's geometric configuration. They find that, in both

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models, large deviations in the individual's reorientation rate significantly alter the group dynamics and polarization. The paper of Swain, Couzin and Leonard performs experiments in which they analyze the trajectories of individual fish in small schools of killifish. They report a convincing evidence of synchronized oscillations in the speed of the individual fish, which lead to oscillating patterns in the relative configuration between individuals in the school. These oscillating patterns are shown to affect the communication of visual information among the individuals, leading to faster convergence towards consensus in the heading and average speed of the school.

The emergent dynamics in populations of micro-swimmers is the topic of three papers, each focusing on a different mode of hydrodynamic interactions among the swimmers. The paper by Lushi and Vlahovska provides a theoretical study of hydrodynamic interactions among actively rotating units, under the action of internal or external torques. Such rotating units were recently realized in various experiments using chemical, optical, magnetic or electric modalities to drive the rotors. Here, the authors show that point rotors in viscous flows can exhibit regular and chaotic behavior that is qualitatively similar to two-dimensional point vortices, and highlight many intriguing analogies and differences between viscous rotors and inviscid vortices.

Collective motion in large suspensions of hydrodynamically interacting swimmers is the subject of the paper by Brotto, Bartolo and Saintillan, who focus on the effects of the unsteady cyclic strokes of individual microorganisms, which can result in the periodic time reversal of the dipolar hydrodynamic fields that they induce. Using both a continuum model and numerical simulations, they demonstrate that a suspension of such cyclic swimmers displays a similar collective behavior as one composed of non-cyclic swimmers characterized by a steady dipole given by the population average of the former.

In the paper by Kanso and Tsang, the interactions of self-propelled particles confined to two dimensions between parallel plates are analyzed theoretically. In this geometry, hydrodynamic interactions are described by potential dipoles, whose sign is dictated by particle shape fore-aft asymmetry. The dynamics of swimmer pairs are described in details, and the authors discover two types of stable trajectories, called pursuit and synchronization modes, depending on whether the particles have large tails or large heads. The existence of these two modes also sheds light on the nature of collective motion in larger collections of swimmers.

Last, but not least, the study by Yazdi, Ardekani and Borhan distinguishes itself by considering the effects of fluid viscoelasticity on the dynamics of microswimmers. They present a model for the dynamics of spherical self-propelled particles known as squirmers in a weakly elastic fluid and analyze their motion in the vicinity of a rigid boundary. They uncover the presence of fixed points and limit cycles in the trajectories, and a key result of their paper is that elasticity of the fluid can dramatically increase the residence time of the swimmers near the boundary, with possible implications for the formation of bacterial biofilms.