PHYSICAL MATH SEMINAR

Flocking and floating: collective behavior in fluid systems

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ABSTRACT:

Collective behavior emerges across biological scales, from the self-assembly of particles and cells to the coordinated motion of insects, fish, and birds. This talk explores mathematical approaches to two examples of collective behavior in fluid environments: passive particles interacting through a deformable interface at the capillary scale, and active agents interacting through wakes at the inertial scale. In the first half, we develop a generalized boundary-element framework for capillary interactions among arbitrary three-dimensional particle assemblies at a fluid interface. An iterative approach identifies equilibrium configurations while allowing for particle tilting and nontrivial contact-line geometry. This provides a general framework for characterizing how particle geometry and assembly configurations produce attraction, repulsion, and collective organization, with applications ranging from cellular and sub-cellular self-assembly to insects at the air-water interface. In the second half, we shift from passive particles to active agents, and from the capillary to the inertial scale. We develop a reduced-order model of the wake-vortex interactions between two flapping birds flying in tandem. The model retains essential unsteady flapping dynamics while remaining computationally tractable, enabling optimization over a six-dimensional state space comprising the follower's three-dimensional relative position and three independent flapping parameters. Applying the model to northern bald ibises, we identify an optimal configuration that minimizes the follower bird's aerodynamic power expenditure, and use these results to investigate the aerodynamic mechanisms underlying V-formations. While the two systems explored in this talk differ substantially in scale, physical mechanism, and mathematical formulation, both illustrate how reduced-order models of interactions among agents can reveal the principles underlying collective organization.

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2:30 PM – 3:30 PM

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