Collective dynamics of repulsive self-propelled particles

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Collective motion is widely seen in biological systems of various scales, from migrating cells to swarms of insects, schools of fish and flocks of birds. For last two decades, there has been a growing interest among physicists on the universality that these systems exhibit. The self-propelled particle model proposed by Vicsek et al.[1] has been extensively studied by using numerical simulations and has been shown to display the two properties that characterize the collective motion, the long-range order and the giant number fluctuation, by only assuming the alignment with neighboring particles[2].

The collective motion is seen not only in biological systems but also in non-biological systems such as vibrated grains[3] and driven colloids[4]. Human pedestrians are known to present characteristic self-organized patterns when walking in a crowd[5]. However, the interaction in such systems is not always a tendency to align with each other; it is rather considered that the particles or the agents interact by repulsive force, namely, the exclude volume or the so-called social force.

In this talk, we discuss the behavior of two-dimensional self-propelled particles that purely interact through repulsion[6]. The model is described by deterministic equations including polar self-propulsion, damped dynamics both for the velocity and the polarity, and steric repulsion. The particle dynamics simulations show that polar-ordered motion emerges from randomized initial configurations, as shown in Figure1. By changing the damping strength of polarity and the packing fraction, we also find that the system undergoes an order-disorder transition. We show that by analyzing the binary particle scattering process, we obtain a simple understanding of the mechanism underlying the collective behavior. Since the model can be regarded as a generalized version of previously proposed models for cellular motility, active colloids, and pedestrian movements, our findings elucidate the universality of collective motion in repulsive systems.

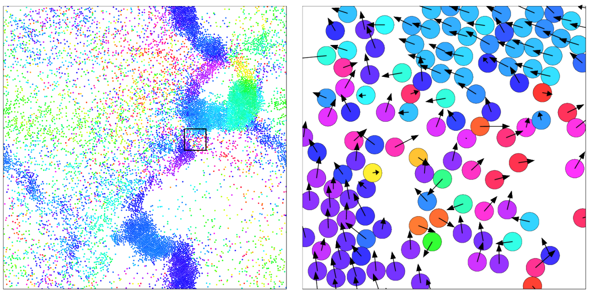

Figure1: Snapshots of a system of N=10000 at the onset of collective motion. The whole system is shown on the left; enlarged image of boxed area on the right. The arrows and the colors denotes the direction of the velocity of each particle.

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