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Moving and Staying Together Without a Leader: Minimal Ingredients for Collective and Cohesive Motion

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Abstract—Collective motion is ubiquitous in nature. Being physicists, we are interested in the degree of universality of this phenomenon, beyond the "details" and specific features of a given situation.

First we come back to the minimal model for collective motion introduced in 1995 by Vicsek and collaborators in which self-propelled point particles try to locally align their direction of motion. We provide evidence that the onset of collective motion is a first-order-like transition, contrarily to previous belief, and show that multi-scale, turbulence-like dymamics takes place during the phase ordering transient.

Vicsek's model cannot ensure the cohesion of a group: collective motion only occurs with a finite density of particles in a finite-extent domain. Here we show how the implementation of a second interaction force between particles can ensure the cohesion even in the "least-favorable" circumstances of strictly local interactions among an arbitrarily-large group of identical particles evolving in a strongly noisy environment. We describe the various phases emerging from this basic set of interactions and the transitions between them. Particular attention is paid to the onset of collective motion in the presence of cohesion, and to the interplay of density, shape, and velocity fluctuations.

In a last part, if time allows, we discuss applications and extensions of our approach to various problems such as flock collisions, inter-specific flocks, cell mixing and cell-sorting.