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Oren Rimer, Gil Ariel

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Kinetic Order-Disorder Transitions in a Pause-and-Go Swarming Model with Memory

Oren Rimer and Gil Ariel

Department Of Mathematics, Bar Ilan University, Ramat-Gan, Israel

Abstract

A two dimensional model of self-propelled particles combining both a pause-and-go movement pattern and memory is studied in simulations. It is shown, that in contrast to previously studied agent based models in two-dimensions, order and disorder are metastable states that can co-exist at some parameter range. In particular, this implies that the formation and decay of global order in swarms may be kinetic rather than a phase transition. Our results explain metastability recently observed in swarming locust and fish.

1 Introduction

The question of when and how groups of moving animals can form large masses of coordinated swarms using only short-ranged, local interactions has been under intense investigation both experimentally and theoretically using computer simulations or analytic approximations. See [1] for a recent review. In particular, the original Vicsek model [2] showed that a change in system parameters, for example noise or density, can result in the particles clustering and synchronizing their direction. Moreover, the macroscopic behavior of the system can be divided into distinct phases in the sense of statistical physics with a phase transition occurring at a critical noise or density. A large number of generalizations and extensions of the Vicsek model have been suggested and studied, including, for example, different types of noise [3], heterogeneous systems [4], obstacles [5] and more. The main goal shared by these approaches is a characterization of the possible phases of the system at different parameter ranges.

On the other hand, recent experiments with schooling fish [6] and swarming marching locusts [7, 8, 9] have shown that the coarse grained dynamics of such moving animal collectives can be approximated by an effective stochastic differential equation [8, 10]. Under this description, the dynamics of the system quickly relaxes into one of the available metastable states and fluctuates around a local stable point. Transitions between the states are kinetic and