Robust Swarm Model Based on Mutual Anticipation: Swarm as a Mobile Network Analyzed by Rough Set Lattice

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ABSTRACT

The authors propose a novel model for a swarm in which inherent noise positively contribute to generate a swarm. In the authors’ model diverse behaviors of individuals are mutually anticipated to give rise to robust collective behavior. Because a swarm is generated due to inherent perturbation, a swarm can be maintained even under highly perturbed conditions. Thus, the model reveals robust rather than stable collective behavior. The authors elaborate behavior of the model with respect to density and polarization. The authors show that mutual anticipation structure can be expressed as a fixed point with respect to a particular operation derived by equivalence relation, a collection of the fixed points can form a particular algebraic structure, called a lattice, and a swarm as a mobile network can be characterized by the structure of a lattice.

Keywords: Network, Robustness, Rough Set, Soldier Crab, Swarm

1. INTRODUCTION

Previous models proposed to mimic a swarm, flock and school are based on the stability-thinking which implements conflict between internal mechanism to make an order and external perturbation. One of the most important models called BOIDS is proposed by Reynolds (1987). An individual of this flock model is employed to the basic mechanism to keep a flock, namely, velocity matching, collision avoidance and flock centering. The model called self-propelled particle (SPP) is based only on velocity matching (Vicsek, Cziruk, Ben-Jacob, & Shochet, 1995; Vicsek, 2001). Each individual
has its own velocity that is reset by averaging all flockmate velocities in the neighborhood (velocity matching). Other mechanism, collision avoidance and flock centering are also employed in neighborhood with constant but different radii. External perturbation is coupled with neighborhood rule. Thus, perturbation is conflict to the mechanism to make a collective behavior. There is no possibility of which perturbation positively contributes to the order, no matter how any additional mechanisms are implemented in the dualism of the force to make a swarm and perturbation (Couzin, 2008). The more perturbation is, the less collective behavior appears. These models are under the stability thinking.

Since development of image analysis recently makes it possible to obtain kinetic data on how real organisms move (Carere, Montanino, Moreschini, Zoratto, Chiarotti, Santucci, & Alleva, 2009), internal dynamical structures within a group are recently found such as topological distance (Ballerini et al., 2010), scale free correlation (Cavagna, Cimarelli, Giardina, Parisi, Stefanini, & Viale, 2010), and inherent noise (Simpson, Sword, Lorch, & Couzin, 2006). It also suggests that inherent perturbation could play an essential role in collective motion (Buhl, Sumpter, Couzin, Hale, Despland, Miller, & Simpson, 2006; Yates et al., 2009).

The aspect that inherent noise positively contributes to a collective behavior makes us to change a way of approach to complex systems from stability-thinking to robustness-thinking. Thus we first elaborate distinction of stability-thinking and robustness thinking, and then we propose a swarm model under the robustness thinking. Actually it is implemented by interactions of individuals based on mutual anticipation. After showing the behavior of the proposed swarm model, we show a structure of mutual anticipation structure in terms of a lattice theory.

2. ROBUSTNESS VS. STABILITY

Signal and/or information in living system must be robust since they are always exposed in strong perturbation. First of all, we refer to the difference between robustness and stability. We refer the term stability to the case in which the force to keep order is against perturbation, and the term robustness to the case in which perturbation positively contribute to keep order. In other words, the order in a stable system is achieved by removing perturbation. The order in a robust system is achieved by cooperation of the inherent mechanism of the system and perturbation.

Most systems described in physics are stable systems but not robust systems. After removing the external force, the body is relaxed and recovered to the stable state. Soon after a planet is taken away from its own orbit, it turns to the original orbit again. The essential property of a dynamical system is estimated by the degree of separation from an original orbit triggered by perturbation, known as Lyapunov exponent. It shows how stability is only privileged in dynamical systems (Rosenstein, Collins, & De Luca, 1993).

Chaotic dynamics and the notion of complex systems reveal systems far from stable states. Coupled map lattice (CML) is composed of local interactions of chaotic dynamics, and features inherent noise in a whole system (Kaneko, 1989). Depending on the coupling strength, system shows various patterns such as collective behavior of local periodic oscillation, chaotic behavior, and chaotic itinerancy that reveals a trajectory from stable attractor to attractor. Bak and his colleagues (Bak, Tang, & Wiesenfeld, 1987, 1988; Bak & Sneppen, 1993) also introduce the complex behavior composed of both order and chaos in statistical mechanics, and call it self-organized criticality (SOC). In CML and SOC, intermediate behavior between chaos and order is evaluated in time and space. Thus, stable and instable behaviors co-exist in the form of distinct manner, in time and space, and never co-operate with each other. Stable behavior is separated from instable behavior in time and space. They constitute mosaic pattern at most equipped with fractal boundary between them.

How robust system appears in nature? How is it implemented? Perturbation has to
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