EasyChair Preprint

№ 1744

Rethinking Natural Swarm Intelligence from the Crowded Selfish Herd Scenario

Wen-Chi Yang

October 22, 2019

Rethinking Natural Swarm Intelligence from the Crowded Selfish Herd Scenario

Wen-Chi Yang[1]

[1]NeuHelium Co., Ltd., Shanghai, China
(Tel : +86-21-3362-0262; E-mail: wenchi.yang@neuhelium.com)

Keywords: Selfish Herd, Crowding Effect, Collective Motion, Behavioral Evolution, Intraspecific Competition

1. INTRODUCTION

It has long been observed that the structure of collective behavior in gregarious organisms can bring additional functions beyond individual capabilities. Several phenomena in group foraging and collective evasion exhibited by fish, birds, bees, and ants are widely known examples and have inspired various useful algorithms in the swarm robotics domain [1]. These algorithms address target tasks through the decentralized control of cooperative agents for 'the power of solidarity' compared to the appearance of certain animal species in nature.

An interesting issue is that to what extent the successful practice of computational swarm intelligence explains the underlying mechanisms of collective animal behavior. For example, the coordinated movements of starlings and sardines under predation have typically been rather eye-catching figures of natural swarm behavior. And these self-organizing mechanisms based on local and straightforward interactions have been introduced into computational models and intelligent systems such that these applications have also influenced the understanding of collective animal behavior in return [2]. Nevertheless, similar to artificial neural networks versus biological nervous systems, those effective and reliable swarm algorithms can be quite different from the adaptation of social animals driven by natural selection.

Unlike robots and agents which are programmed for seeking optimal solutions, the evolution of natural organisms is more a neutral dynamic of trait distributions with generations, and hence group benefit is not an objective during the approach of an evolutionary equilibrium [3]. It is imprecise to consider that sardines exhibit collective motion to fight against predators for their average survival rate. Instead, a more evolutionary viewpoint would be those sardines in collective motion were more adapted than the other conspecifics in evolution, regardless of the foraging benefit of their predators. In other words, the competitions should happen between prey individuals and between predator individuals, rather than between prey and predators [4].

2. THE CROWDED SELFISH HERD SCENARIO

A famous explanation of animal swarm formations based on the evolutionary viewpoint is the selfish herd scenario [5]. It indicates that the tendency of social prey assembling compact groups in danger, e.g., fish, birds, sheep, and crabs, can be irrelevant to the anti-predator functions. In contrast, since border positions are more dangerous than central positions within a group, those prefer to squeeze into the crowd should be selected in evolution for their better survival fitness compared with those staying at the border. Consequently, prey individuals evolved into the flocking nature, and prey aggregation emerges from this behavioral trait.

Although the above explanation of animal herding tendencies is relatively simple and clear, illustrating the dynamics of behavioral adaptation has remained challenging in many species of social animals due to the complex interplay among numerous hidden factors. One pending question of popular interests is the collective evasion of vigilant shoal fish, which swim and change directions in high coordination as a union. This adaptation does not entirely fit the selfish herd scenario because a mobile group must contain fish leaders that swim outwards their group rather than squeezing into the crowd. Those fish willing to be leaders at the frontal positions bear a higher predation risk than other conspecifics, and hence their behavioral traits should have been removed from the gene pool if the selfish herd scenario had occurred [6].

In our latest works, we have reported new findings on this specific conundrum through a series of computational simulations [7-9]. The key factor is the consideration of crowding conditions [9]. In previous models, a prey individual used to be simplified into a location or a point, and hence, was always possible to enter the group center for safety despite the overlaps between body extensions or private areas. To address this modeling bias, we adopted the lattice gas framework and constructed a selfish herd model incorporating the crowding condition. As the typical selfish herd scenario, prey agents in our model moved on the lattice to seek more neighbors than one another, and those staying with fewer neighbors during a given period were eliminated through the procedure of evolutionary selection. The distinct design was that a prey agent was forbidden to move into a lattice cell which had already been occupied such that a border agent had no option to enter a dense herd due to crowding.

Our simulations demonstrated that this physical constraint completely changed the adaptation of prey agents. In early generations, prey agents evolved to consistently move into their herds as illustrated by the selfish herd scenario.

However, since individual mobility was restrained by crowding in our model, the attempt to squeeze into a dense group from outside finally equaled remaining at the dangerous group edge and creating a safe environment to the inner members. Thus, an undocumented behavioral trait, named 'dodger strategy,' evolved from the prey agents, that those stuck outside their herds exhibited a collective departure to share the predation risk with the exposed inner neighbors [9]. As a herd must contain border positions, the continuous departure of newly exposed group members led to the collective movement of selfish herds. The patterns of these mobile selfish herds can be highly polarized, dramatically distorted, or at a relatively slow pace [7]. However, those seemly coordinated movements all emerged purely from short-term selfishness and even reduced the average individual survival fitness in our model for the marginal individuals harming the beneficial central positions.

3. DISCUSSIONS

Before the proposed crowded selfish herd scenario, explanations of the collective evasion in fish and birds were mainly put on the emergent antipredator benefits [10]. For example, it has been reported that coordinated movements can enhance the efficacy of information exchange among group members, i.e., the information transfer effect, and aggregating can decrease the attack accuracy of their predators, i.e., the confusion effect. These findings have promoted the recognition of natural swarm intelligence. Specifically, linked to the evolutionary mechanism, the inference from this viewpoint was that the improvement of group benefit could bring excess fitness to the members, and hence, would relieve the competition within a group.

However, several challenges on this kind of explanation may arise. For example, while all prey individuals have evolved into the same tactic, the excess fitness should disappear, and the conundrum about the stability of leader roles in evolution keeps unanswered. Secondly, lowering the attack accuracy of predators cannot increase prey's fitness if a predator simply performs more attacks. Rare empirical studies have examined whether antipredator functions can improve the survival rate during a hunt, rather than during an attack. Lastly, taking starlings for example, their aerial display itself attracts predators, and the ratio of caught individuals to the aggregation size is minimal. The force to evolve antipredator functions might be insufficient.

Although additional evolutionary mechanisms are possible to repress short-term selfishness and evolve cooperative behaviors for more survival benefit [11], the crowded selfish herd scenario reveals a rather direct mechanism to shape social animals into coordinated movements. We may fairly infer that the collective evasion of some species of social animals in predation could be irrelevant from harming their predators. Instead, that could be a pattern in which selfish prey evolved to harm one another for individual short-term fitness. In other words, it might be possible that certain seemly functional swarm behaviors in nature can be not as 'intelligent' if intelligence refers to the improvement of overall utilities. We expect our findings and hypothesis may bring a new perspective on the understanding of natural swarm behavior and hint some new ideas about computational swarm intelligence.

REFERENCES

[1] Bonabeau, Eric, Directeur de Recherches Du Fnrs Marco, Marco Dorigo, and Guy Theraulaz. *Swarm intelligence: from natural to artificial systems*. No. 1. Oxford university press, 1999.

[2] Naldi, Giovanni, Lorenzo Pareschi, and Giuseppe Toscani, eds. *Mathematical modeling of collective behavior in socio-economic and life sciences*. Springer Science & Business Media, 2010.

[3] Smith, John Maynard. *Evolution and the Theory of Games*. Cambridge university press, 1982.

[4] Williams, George C. *Natural selection: domains, levels, and challenges*. Oxford University Press, 1992.

[5] Hamilton, William D. "Geometry for the selfish herd." *Journal of theoretical Biology* 31, no. 2 (1971): 295-311.

[6] Parrish, Julia K., and Leah Edelstein-Keshet. "Complexity, pattern, and evolutionary trade-offs in animal aggregation." *Science* 284, no. 5411 (1999): 99-101.

[7] Yang, Wen-Chi. "When the selfish herd is too crowded to enter." In *2017 IEEE Symposium Series on Computational Intelligence (SSCI)*, pp. 2247-2254. IEEE, 2017.

[8] Yang, Wen-Chi. "When the selfish herd is unsafe in the middle." In *2018 22nd Asia Pacific Symposium on Intelligent and Evolutionary Systems (IES)*, pp. 55-62. IES 2018 Program Committee, 2018.

[9] Yang, Wen-Chi, and Thomas Schmickl. "Collective Motion as an Ultimate Effect in Crowded Selfish Herds." *Scientific reports* 9, no. 1 (2019): 6618.

[10] Krause, Jens, Graeme D. Ruxton, Graeme D. Ruxton, and Ibls Graeme Ruxton. *Living in groups*. Oxford University Press, 2002.

[11] Nowak, Martin A. "Five rules for the evolution of cooperation." *science* 314, no. 5805 (2006): 1560-1563.