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Group chase and escape model with chasers' interaction

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HIGHLIGHTS

- We consider the group chases and escapes with two different strategies.
- We examine the influence to the catch efficiency and to the chasing patterns.
- We find that the effectiveness of two strategies is different depending on the number of chasers.

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ABSTRACT

Group chase and escape is a new direction of studying collective behaviors merged with the traditional mathematical problems of chases and escapes proposed by Kamimura and Ohira in 2010. In their model, the chasers recognize only the escapees and pursue the nearest neighbor escapee, and the escapees recognize only the chasers and flee from the nearest neighbor chaser. We call the basic moving rule the nearest opponent interaction (NOI) strategy. In this paper we introduce a new strategy in the model. It is a local interaction that the chasers do not get too close each other, where we call the chasers' local interaction (CLI) strategy. The result of comparisons of the two strategies shows that when the number of the chasers is relatively small compared to the number of the escapees, the trapping time by the CLI strategy is much shorter than that by the NOI strategy. On the other hand, when the number of the chasers is larger than that of the escapees, this advantage of the CLI strategy does not appear. Also, we find that although chasers form clusters (spatial aggregates of chasers) when we apply the NOI strategy, the clusters appear less when we apply the CLI strategy.

1. Introduction

Problems relating to chase and escape are very old, which have its roots in the work of Bouguer in 1732 [1] and Boole in 1877 [2]. In the simplest case there is one chaser and one escapee, the chaser pursues the escapee and the escapee flees from the chaser [3–5]. A more complicated case was also studied, in which one escapee flees from many chasers [6–9].

Another line of a research field to which much recent attention is paid is a study on swarms and flocks of animals, insects, cars and humans [10–15]. They are considered as collective motions of "self-propelling particles" in contrast to physical particles. Experimental observations, theoretical frameworks, and engineering endeavors have sprung in order to understand such collective behaviors.

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Recently there has been renewed interest in the problems of chase and escape by Kamimura and Ohira [16]. They have proposed a new concept termed ‘‘group chase and escape’’, in which they look into situations that there are many chasers and escapees. In this sense their proposal is a fusion of the traditional problems of chase and escape and the recent studies on swarms and flocks.

As mentioned above, in the previous studies there is only one escapee in most cases, and there is one to several chasers in some cases [3–9,17]. It might be a conceptually simple extension to increase the number of chasers and escapees by Kamimura and Ohira [16]. However, it becomes difficult to solve the problem of chase and escape in groups mathematically.

Plainly speaking, the chase and escape strategy Kamimura and Ohira used in their model is quite simple [16]. In the model, the chasers recognize only the escapees and move toward the nearest neighbor escapee, and the escapees recognize only the chasers and move away from the nearest neighbor chaser. Hence, even in groups, there is no mutual communications among the peers except for exclusion volume interactions. Let us call this basic moving rule the nearest opponent interaction (NOI) strategy. Although the model with the NOI strategy is simple, the collective behaviors are rather intricate. After the initial proposal, the problem of group chase and escape with various situations and extensions has been studied by computer simulations and by theoretical analysis. The examples include a model with conversions of caught escapees into chasers [18], the group chase and escape not by two groups but three groups [19], models with some fast chasers [20], off-lattice model [21], three aggregation strategies for the prey [22], a wolf-pack hunting behavior reproduced by simple rules including intentional repulsions (beyond exclusion volume) [23] and so on.

Let us describe behaviors of the model with the NOI strategy. We first consider that the number of chasers is relatively smaller than that of the initial escapees. As the escapees are caught by the chasers and the number of the escapees decreases, we observe that clusters (spatial aggregates) of chasers emerge and they pursue one escapee in various places. As the chasers and escapees move at the same speed, some chasers basically have to impound or surround one escapee in order for a catch. Hence, the clusters of chasers are not necessarily desirable because chasers cannot impound escapees effectively.

On the other hand, clusters of chasers do not appear when the number of chasers is much larger than the number of the initial escapees. In this case the trapping time is short. For example, when the number of the initial chasers is 500 and that of the initial escapees is 10 in the field of 100×100 square grid, all escapees are caught in only around 10 chasing move steps. When the number of chasers is relatively larger than that of escapees, the chasers can catch the next escapees without moving many steps even with the decreasing number of the uncaught (surviving) escapees. In other words, as the initial positions are set randomly with sufficient number of chasers, the chasers can impound the escapees without much effort. Given this advantageous initial conditions for chasers, they are not required, or do not have time, to form clusters to catch the escapees.

Recently improvements of measurement technology enable us to analyze collective behaviors or movements of actual insects, fishes and birds [24,25]. Cavagna et al. investigated starling flocks and obtained an indicative result that there are local interactions based on the topological distance among the starling flying in flocks [25]. However, the above mentioned studies on the group chase and escape do not include communications or interactions among peers; i.e., the chasers (escapees) do not react to other chasers (escapees) except for exclusion volume [16,18–20]. Considering the real situations, such as group hunting by some animals, interaction among peers, however, are quite common.

Against these background, the main theme of this paper is an introduction of interaction among chasers. We consider the extension of the model that chasers take into account the positions of each other. Also, there is a local interaction so that the chasers do not get too close to each other. This kind of intentional repulsion among chasers has been observed in real wolf-pack huntings, and inclusion of such interactions in a simulation model with a single escapee is shown to reproduce some aspects of wolf-pack hunting ethogram [23]. We name this interaction among chasers as the chasers’ local interaction (CLI) strategy and examine its effect on the collective behaviors. In particular, we are interested in phenomena caused by this interaction when the number of chasers is relatively small compared to that of escapees, the case in which clusters of chasers appear in the original model with the NOI strategy [16]. To evaluate the effect of the introduced chasers’ interaction, the CLI strategy, we compare the results with that of the NOI strategy.

This paper is organized as follows. In Section 2, we briefly review the NOI strategy which is the basic moving rule originally proposed by Kamimura and Ohira. In Section 3 we describe new strategy we introduce. In Section 4 we present results when we employ the NOI and CLI strategies, and compare the results. Section 5 is for the discussions and summary.

2. Group chase and escape with the NOI strategy

We briefly review the model of group chase and escape proposed by Kamimura and Ohira [16]. The problem of group chase and escape is a tag where there are many chasers and escapees. Although the individual rule is simple, rather complex collective behaviors emerge.

The problem is considered on a two-dimensional square lattice $L_x \times L_y$ with periodic boundary conditions. Chasers and escapees are initially placed randomly on this state. Each site is occupied by only one chaser or one escapee, as every chaser and escapee moves by one site at each time step, the speed of the motion is the same for all players. At each time step, the chasers and escapees move based on the following rules as shown in the schematic diagram of Fig. 1. Each chaser moves toward the nearest neighbor escapee, and each escapee moves away from the nearest neighbor chaser. When the position of a chaser is (x_C, y_C) and that of a escapee is (x_E, y_E), the distance d between the chaser and the escapee is