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Symmetry associated with symmetry break: Revisiting ants and humans escaping from multiple-exit rooms

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ABSTRACT

Crowd panic has incurred massive injuries or deaths throughout the world, and thus understanding it is particularly important. It is now a common knowledge that crowd panic induces "symmetry break" in which some exits are jammed while others are underutilized. Amazingly, here we show, by experiment, simulation and theory, that a class of symmetry patterns come to appear for ants and humans escaping from multiple-exit rooms while the symmetry break exists. Our symmetry pattern is described by the fact that the ratio between the ensemble-averaging numbers of ants or humans escaping from different exits is equal to the ratio between the widths of the exits. The mechanism lies in the effect of heterogeneous preferences of agents with limited information for achieving the Nash equilibrium. This work offers new insights into how to improve public safety because large public areas are always equipped with multiple exits, and it also brings an ensemble-averaging method for seeking symmetry associated with symmetry breaking.

1. Introduction

The emergent evacuation of human beings has become a much more crucial problem worth studying due to the complicated international situations, terrorist attacks, and growing population around the world nowadays. It can also happen in crowded places such as stadiums or fire sites. It would be costly if the exits and architectures are not properly designed. Therefore, numerous simulations [1] and active-matter experiments [2] have been carried out regarding this problem [3–12]. Helbing et al. [3] first established a model with uncoordinated-moving pedestrians to simulate the panic and jamming mechanisms of crowds. Saloma et al. observed self-organized queuing (scale-free) behavior [10] and herding [11] in escape panic of mice. Shiwakoti et al. [12] did an ant experiment for modeling pedestrian crowd egress under panic conditions. The last three researches [10–12] are especially heuristic since they studied the escape behavior regarding the number or width of exits using mice or ants. In particular, through computer simulations, Helbing et al. studied dynamical features of crowds in escape panic, and they revealed a kind of "symmetry break" in which some exits from enclosed spaces are jammed while others are underutilized [3]. Their findings have been experimentally demonstrated by the experiments of ants undergoing panic escape [5]. So far, the symmetry break has become a common knowledge in the field of escaping dynamics. However, in this paper, we discover a symmetry pattern within both the panic escape of ants and emergent evacuation of humans, which provide a new perspective regarding such issues.

Nevertheless, the existing researches have never touched the situation of escaping the area with several exits of various widths [13,14], which, however, has practical significance because large public areas must have more than one exit. Here, we propose and conduct an ant experiment to study ants' collective behavior when escaping from a room with multiple exits of

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different widths. The result turns out to be that the ensemble-averaging number of ants escaping from an exit is proportional to the width of the exit, thus yielding a state equation. This finding reminds us that the collective behavior of escaping ants in our experiment can be treated as human behavior based on strategies in competition and cooperation, while the widths of exits in the escape problems can be regarded as resources competed by players in competition games. This is reasonable since animals will compete for limited exits in such dangerous situations. Meanwhile, our experiment is inspired by the idea that the behaviors of various species under panic situations may show similar patterns, which can be classified as animal instinct. Thus, by studying animals other than human, such as mice and ants, we are able to reveal human behaviors under similar situations, and solutions can be found by controlling experimental parameters and conditions. This can be helpful to research areas limited by moral troubles of human experiments, etc.

Competition and cooperation exist everywhere in human society. People are always competing for limited resources in their daily lives. So it is important to study competition and cooperation in order to understand and predict human behavior. In Refs. [15,16], based on the minority game [17], some researchers proposed a resource-allocation model to investigate the human collective behavior while facing heterogeneous preferences. The advantage of such agent-based simulations is that it is convenient to model the collective behavior of a large number of agents under specific evolutional rules and system topologies.

We conducted the experiment of ants escaping from a confining room (vessel) with varying widths and numbers of exits. We observed that they have a relatively strong willing to escape from the room. In the end, almost all ants would leave the room since there is nothing for them. It can be seen that animals (active matters) have their own strategies to escape from a confined space. Studies considering such kind of animals are useful since their expressed behaviors could be a good reference for the behavior of humans under similar emergent conditions. Some other simple reasons for our choice of ants are that they are cheap, small, and easy to keep.

As inspired by the agent-based simulations on resource allocation, we further conducted a controlled human evacuation experiment for mimicing human behavior during emergent evacuations. To be specific, we controlled the parameters (the numbers and/or widths of exits) to study their influences on human collective behavior in the case of rapid evacuation. The results echo with those of the ant experiments and agent-based simulations. Therefore, we reveal a rule, identified as the state equation, for ants and humans facing emergent evacuations, which could be understood by the resource-allocation model. To proceed, we introduce the ant experiment first.

2. Ant experiment

We conducted a series of ant experiments in May, 2015, by using a breed of ants called Polyrhachis vicina Roger. They were initially fostered in Guangxi province, China, and were later transported to a temporary nest in our laboratory. For each session of experiment, 30 individuals were randomly selected, and they were guided into a circular vessel with two exits located at two opposite sides (Fig. 1). The average length and width of the selected ants were 1.0 cm and 0.6 cm, respectively. The vessel was a plastic Petri dish with a diameter of 9.0 cm and height of 1.5 cm. For different sessions of experiment, Exit I was fixed at a width $W_1 = 1.0$ cm, while Exit II had widths $W_2 = 1.0$, 1.5, 2.0, and 3.0 cm in the four sessions, respectively.

After the ants being introduced into the room (vessel), they were allowed to stay in the room for several minutes with the exits blocked. When the ants were calmed down and well-distributed, we opened the two exits simultaneously, and the ants would run away from the vessel through the exits spontaneously. The whole experiment was recorded by a camera placed 30 cm above the vessel. It is worth noting that not all the ants were able to escape successfully from the vessel due to accidental injury during the experiment, or that some of them chose to stay in the vessel for quite a long time. We counted the number of ants escaping from each exit within 15 minutes. Those who failed to escape from the vessel were replaced by new ants in the following sessions of the experiment.

The total number of escaping ants was about 27 on average in each session of experiment. We did four sessions of experiments altogether, each session was repeated for 10 times, and the average results are illustrated in Fig. 2. Since we kept the width (W_1) of Exit I fixed at 1.0 cm and altered the width (W_2) of Exit II to various values, the width ratios ($W_2 : W_1$) in the four sessions were 1:1, 1.5:1, 2:1, and 3:1, respectively. It is clearly shown in Fig. 2 that with the increasing width of Exit II, the number of ants escaping from Exit II also increases, which reveals a class of symmetric patterns. The ratios of the average numbers of ants escaping from the two exits are drawn as blue squares in Fig. 3.

This result reminds us of a class of resource-allocation games played by humans. In such kind of games, participants compete for limited resources. However, during the escape of ants, they also have to compete for limited exits to keep them away from the "dangerous" area. Due to this analogy, we conduct a series of computer simulations based on similar settings to imitate the behavior of ants by the agent-based model introduced in [15,16]. The details of the simulations are elaborated in the following section.

3. Agent-based modeling and simulations

There are two particular amounts of resource (characterized as W_1 and W_2) associated with the two exits, namely, Exit I and Exit II. For all the N players, they should choose one of the exits in each round of game to acquire the access of the resource of the chosen exit. The exit chosen by relatively fewer players becomes the winning side of that round, i.e., those who choose Exit I win if $W_1/N_1 > W_2/N_2$ (here N_1 or N_2 denotes the number of players choosing Exit I or Exit II), and vice versa. We try to find out the relationship between the players' behavior and the resource-allocation ratio (W_2/W_1).