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Behavior-based cellular automaton model for pedestrian dynamics

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ABSTRACT

Pedestrian evacuation is one open question in a myriad of scientific disciplines and has attracted considerable attention during the past decades. Aim to issue, various research approaches, such as mathematical modeling and simulation, experimental studied and socio-psychology surveys, have been extensively employed. Different from previous frameworks, here a behavior-based cellular automaton model is proposed, which involves the environmental characteristics and neighbors' behaviors. Given the certain range of degree of emergency, it is shown that enhancing the degree of emergency will shorten evacuation time yet decrease cooperation enthusiasm. The larger the degree of familiarity is, the shorter the evacuation time will be. In variance, larger the dependence of pedestrians will prolong the evacuation time. Besides, the novel model also produces some interesting self-organization phenomena, such as the collective behavior at the beginning of the evacuation and arch-like blocking at the end of the evacuation. When our model is finally applied to the evacuation scenario where a room has two symmetrically located exits, the symmetry breaking effect takes place. Our model may shed new light to the study of pedestrian dynamics in realistic world.

1. Introduction

During the recent decades, pedestrian evacuation has attracted considerable attention from different disciplines [1–3], such as sociology, physics and engineering and so on, and which belongs to the hot research topic named social systems [4–8]. It thus becomes of significance to understand the characteristics of pedestrian movement. In particular, it will be meaningful to avoid the jamming state of panicking pedestrians flowing out of a room due to the arching and clogging at exits, where many tragic disasters often occur [9]. These pedestrian evacuation problems have been investigated with various models, including macroscopic models and microscopic models [10–12]. In macroscopic models, the interaction among pedestrians has not been considered in detail, so they are not suitable for the pedestrian evacuation in complex space [13]. Since microscopic models overcome the above mentioned shortcoming, they have drawn more attention and usually include the cellular automata models [14,15], social force models [16,17] and RVO models [18,19]. Cellular automata models, which belong to the grid-based models, are successfully applied in road traffic simulations and well understood theoretically. Furthermore, they are well suited for large-scale simulations. Recently, some researchers had explored the pedestrian evacuation in different spaces via cellular automata models. For example, Alizadeh studied a dynamic cellular automaton

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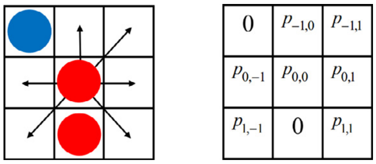

Fig. 1. Cellular automata model for the evacuation. Traditionally, each pedestrian can move into one of his Moore neighbors according to certain probability. However, we put forward a logit model to account for the factors of environmental characteristics and neighbors' interactive behaviors. According to these factors, the probability of each unoccupied Moore neighbors is calculated.

model for evacuation process with obstacles [20], Zheng et al. examined the evacuation dynamics based on cellular automaton when taking the fire spreading into account [21], Müller et al. studied the influence of groups on evacuation dynamics by using cellular automaton model [22], Blue et al. modeled bi-directional pedestrian walkways by cellular automata microsimulation [23], and Huang et al. put forward a static floor field model in cellular model in rooms with internal obstacles and multiple exits [24].

Besides, it is well-known that in the evacuation process, the behavior of pedestrians changes with the movement of pedestrians, which means that the process of evacuation is also a behavioral evolution process [25]. In the process of evacuation, pedestrians will adjust their behaviors according to the environmental characteristics and interactive neighbors' behaviors. Because of the limit of evacuation resource, there exists interdependence between pedestrians, which is in accordance with the classical prisoners' dilemma [26], namely, the optimal solution of populations is inconsistent with that of single individuals. Thus, the cooperative behavior evolution in the process of evacuation is also very important.

"How did cooperative behavior evolve?" is a fundamental question among many disciplines [27], which has attracted a great deal of attention. The pioneering work by Nowak has summarized five mechanisms for the evolution of cooperation: kin selection, direct reciprocity, indirect reciprocity, network reciprocity, and group selection [28]. Among them, the network reciprocity, also named spatial reciprocity, implies that some individuals interact more often than others on networks, which can promote the cooperation by forming into clusters. Since the games on graphs are easy to be simulated and the graph is ubiquitous in the real society, this mechanism has been extensively studied as a paradigm for illustrating how cooperative behavior evolves [29–39]. To sum up, researches on the pedestrian flow focus on the process of evacuation, and the main aim of them is evacuation time and self-organization phenomenon, while the behavioral evolution pays main attention to the mechanisms of cooperation. But in the process of evacuation, the movement of pedestrians not only depends on the environmental characteristics, but also relies on the neighbors' interactive behaviors. If behavior feedback is introduced into pedestrian evacuation, how does it affect the movement of pedestrians?

To this aim, a behavior-based cellular automaton model is proposed in this paper. The evacuation space is divided into discrete grids, and each pedestrian will move in the grids until leaving the evacuation space. Because there exist many grids as choices in the movement of pedestrians, we propose the logit-based discrete selection principle to formulate them [40,41]. Here, the parameter of logit model can be used to reflect the environmental characteristics and neighbors' interactive behaviors. Particularly, the proposed model is equivalent to filed floor model for some typical parameters. In spite of super simplicity, this model can characterize various pedestrian behaviors quite realistically, such as collective behavior, arch-like blocking phenomena and symmetry breaking effect.

2. Model

Here the space is discretized into small grids, which can either be empty or occupied by exactly one pedestrian. In each step, each pedestrian can move to one of its unoccupied Moore neighbors according to certain probability (See Fig. 1). Without loss of generality, we put forward a logit model based discrete choice principle, namely, the pedestrian move to the grid (x, y) with the probability:

$$p_{xy} = \frac{\exp(M_{xy})}{\sum_{x,y} \exp(M_{xy})}, \tag{1}$$

Where M_{xy} is the linear combination of the environmental characteristics and neighbors' interactive behaviors, namely:

$$M_{xy} = k_E E_{xy} + k_B B_{xy}, \tag{2}$$

where E_{xy} and B_{xy} represent the measurement of environmental characteristics and neighbors' interactive behaviors respectively, k_E and k_B represent the weight of E_{xy} and B_{xy}. In the process of evacuation, the physical meaning of k_E and k_B are the attributes of evacuation crowd, for example, relationship between pedestrians. In detail, the larger the k_E is, the more the pedestrians in the evacuation space will be; likewise, the larger the k_B is, the larger the dependence of pedestrian will be.

Next, we will introduce the measurement of environmental characteristics and neighbors' interactive behaviors. Environmental characteristics mean a set of environmental conditions that confine and/or influence human behaviors during the pedestrian evacuation. For the cellular automata, the most important of environmental characteristics is the exit position of the evacuation space. In this paper, we assume that the pedestrian will choose the nearest exit, and the distance between