群集の出口選択における歩行者同士の相互作用について

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概要

本発表では、避難時に出口が複数ある場合の群集の出口選択における歩行者同士の相互作用について検討する。静的フロアフィールドを用いてシミュレーションを行った結果、歩行者は周りの動きに追従するという効果が強くなると流れの相転移が起こり、流量の減少と脱出時間の増加が確認された。さらに、この相互作用によって引き起こされる混雑は入口付近に障害物を置くことで抑制可能であることがわかった。

Interaction of Pedestrians on Exit Selection

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Abstract

We investigate the interaction of pedestrians in an evacuation process in a room that has two exits, using the static floor field model. As a result of the simulation, a phase transition of pedestrian flow is observed when pedestrians tend to follow their neighbors, which causes a decrease of flux and an increase of travel time. In addition, we see that an obstacle in front of the entrance would be useful to repress the congestion caused by the interaction.

1 Introduction

Study of dynamical crowd behavior is needed to solve many congestion problems in various situations. In an evacuation, it might be fatal for those who fail to get out immediately. In order to investigate behavior of crowds, many methods of analysis have been developed, such as the floor field (FF)[1] model. There are many investigations into evacuation process from a room that has one exit. However, a large room usually has more than one exit for cases of emergency, and pedestrians have to choose which way to go in an actual emergency. In this study, we investigated how the crowd behavior changes under the interaction between pedestrians, using the assumption that they would tend to follow their neighbors' choices.

2 Method

2.1 Static floor field

We constructed a room that consists of two-dimensional $N \times N$ lattice sites labeled (i,j) $(i,j = 1,2,\cdots,N)$, including a two-cell entrance and two one-cell exits (see Fig.1). If a pedestrian occupies a site, no other pedestrians can step into the site. Pedestrians choose the next site every time step out of their nine neighboring sites including the present site (see Fig.1）according to the static FF. The transition probability p_{ij} for a jump to the neighboring site (i,j) is expressed as the following.

$$
p_{ij} = \begin{cases} Z\xi \exp(-k_s S_{ij}) \\ \qquad \text{(a horizontal or vertical jump)} \\ \\ Z\xi \exp\{-k_s(S_{ij} + 1/2)\} \\ \qquad\qquad \text{(a diagonal jump)} \end{cases} \tag{1}
$$

where k_s is the non-negative sensitivity parameter and Z denotes the normalization factor. ξ turns 0 for forbidden transitions such as to walls, obstacles, and neighboring occupied sites, and turns 1 for the other transitions. S_{ij} stands for the L^2 norm from the site (i, j) to the exit site. For a diagonal jump, we added 1/2 to S_{ij} to correct the geometrical difference: a diagonal jump is more advantageous than a horizontal or vertical jump due to the $\sqrt{2}$ times larger stride, then they move toward their exits straightly.

There are two static FFs for the two respective exits in this model.

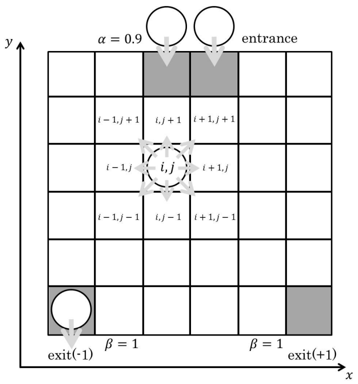

Fig.1: Update rules of the static FF

2.2 Exit selection

We considered the interaction between pedestrians when they choose their exits every time step according to the distance to the exit and their neighbors. The selection probability $p(s_i)$ is expressed as follows.

$$
p(s_i) = Z_i \exp\left(-k_d d_{s_i} + \epsilon \sum_{j \in V_i} s_i s_j\right) \tag{2}
$$

where s_i $(\in \{-1, +1\})$ represents the exit that pedestrian i has chosen, "-1" is the left exit and "+1" is the right. Z_i is the normalization factor. The first term in the exponential represents that they tend to choose the closer exit, where k_d is the non-negative sensitivity parameter and d_{s_i} is the L_2 norm distance from pedestrian i to the chosen exit. The second term represents the assumption that they tend to choose the same exit as the pedestrians' in the neighborhood V_i, as shown in Fig.2, using the non-negative tendency parameter ϵ.

After this process, they move toward their exits according to the static FF of the chosen exit.

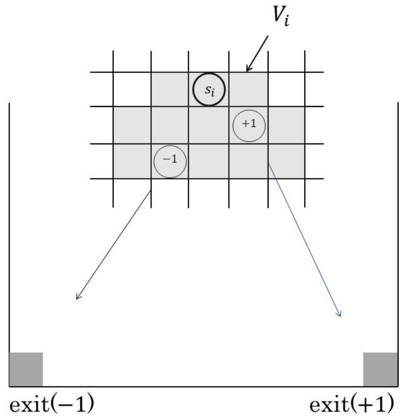

Fig.2: Neighborhood V_i

2.3 Conflict resolution

The conflict frequently happens in parallel update, which is the occurrence that more than one pedestrian try to move to the same site. A pedestrian flow is often clogged due to the influence of the conflict. To consider this effect, we introduced the friction parameter $\mu = 0.1$. In this model, no one can move at the conflict with the probability μ, and one of the pedestrians who have chosen the same site is randomly selected to step to the site with the probability $1 - \mu$ (see Ref.[2, 3]).

2.4 Entrance and exit

In this model, a pedestrian appears at an entrance cell with the probability $\alpha = 0.9$ if the cell is empty, and disappears at an exit cell with the probability $\beta = 1$.

3 Result

We set $k_s = 10$ and $k_d = 1$. The dimensions of the simulation area are 26×26, the entrance cells are set at $(13, 26), (14, 26)$, and the exits are at $(1, 1), (26, 1)$. In our simulation, we set an empty room as the initial state and calculated those parameters shown in Fig.4 during the time steps from 100,000 to 1,100,000.

3.1 Influence of ϵ on pedestrian flow

In Fig.3, we can see there are two phases in the pedestrian flow. The phase I appears when the parameter ϵ is low: the same number of pedestrians move toward the respective exits and smoothly get out of the room. As ϵ increases, pedestrians tend to choose the same exit as their neighbors' in V_i and then the local congestion around the exits becomes larger. Although many pedestrians move to the same exit in this state, a trigger pedestrian sometimes chooses the other exit and takes his followers to the exit, and the congestion oscillates between the left exit and the right exit. In the phase II, almost all pedestrians choose the same exit and some of them interfere the inflow at the entrance.

In Fig.4, the density is defined as the number of pedestrians in the room divided by the number of sites in the area, 26×26, the flux is the number of the pedestrians that get out of the room per time step, and the travel time is determined as the number of pedestrians in the room divided by the flux. When $\epsilon < 0.3$, phase I occurs and flux does not decrease in spite of the slight increase of density and travel time. Around $0.3 < \epsilon < 0.6$, we can see phase I at first and phase II when the congestion reaches the entrance. Once phase II occurs, the pedestrian flow never goes back to phase I. We have chosen Fig.4 to average the results of ten repetitions, but the deviation of the travel time is still large when $0.3 < \epsilon < 0.7$ since the time when phase II occurs varies under the same parameter. Phase II always occurs when $\epsilon > 0.7$.

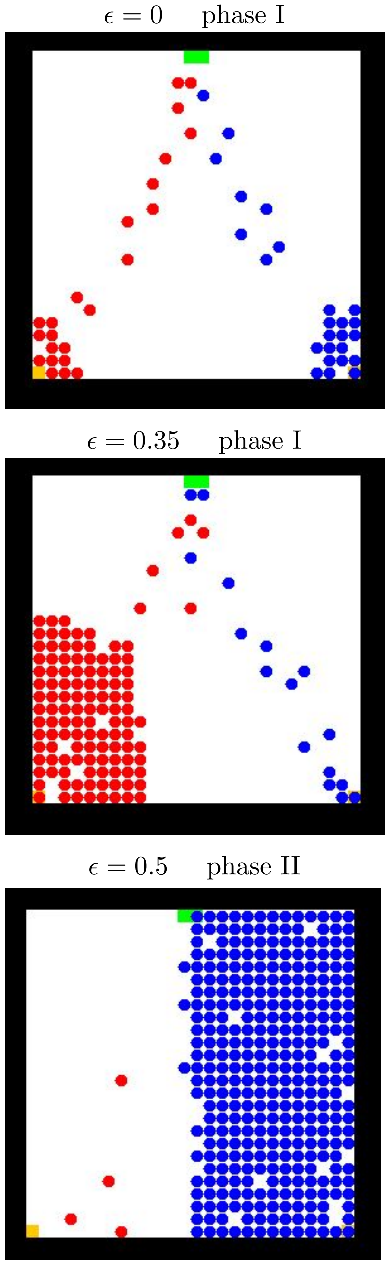

Fig.3: (Color) Snapshots of the simulations varying ϵ. The green sites (at the top) and the orange sites (at the bottom) indicate the entrance and the exits, respectively. The pedestrians that have chosen the left exit are colored red, and the others are blue.

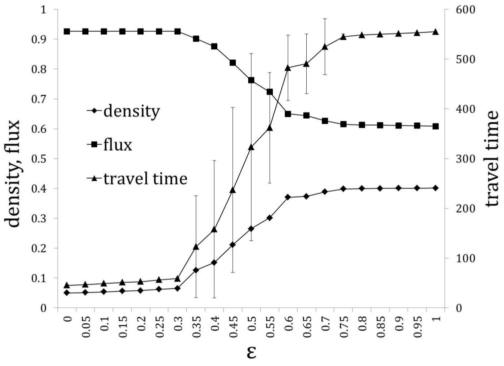

Fig.4: Average of flux, density and travel time in 10 times × 1,000,000 steps. The error bar is shown using the deviation.

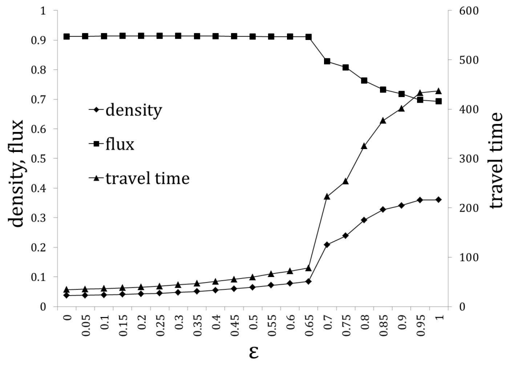

Fig.6: Average of flux, density and travel time in 3 times × 1,000,000 steps with an obstacle

3.2 Repression of phase transition with obstacle

Congestions caused by the parameter ϵ decreases the flux and increases the travel time of the pedestrian flow. To repress the phenomenon, we introduced an obstacle in front of the entrance (see Fig.5). In this configuration, the pedestrians have to make decisions immediately after entering the room, and then the interactions between them are cut out. Although a smaller obstacle around the entrance is also effective, we set such a huge obstacle to focus on the effect of the early decision. As a result, we found that the phase transition can be repressed using the obstacle (see Fig.6). When the obstacle is closer, the inflow at the entrance significantly decreases due to the interference of the obstacle itself. By contrast, its effect becomes weaker when it is located at a distance.

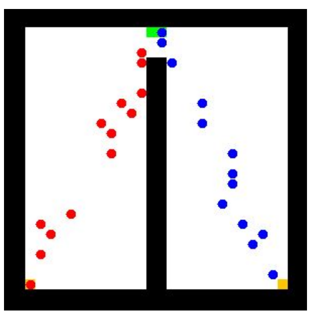

Fig.5: A snapshot of the simulation using an obstacle

4 Conclusion

In this research, we are trying to mitigate pedestrian congestions caused by the interaction between pedestrians. As the first step of this research, we investigated the case that pedestrians have to choose one of the two exits to get out of the room. The result of the simulations shows that the interaction that pedestrians tend to follow their neighbors causes a local congestion at one exit and increase travel time, and that a phase transition occurs and decreases flux when $\epsilon > 0.3$. In addition, we found that an obstacle such as in Fig.5 would be useful to repress the phase transition in this model.

Although we collected the data of average density, flux and travel time for this research, chronological data should be collected to analyze the oscillation of the congestion. Additionally, we can consider the another interaction that pedestrians tend to avoid the popular exit in the room in future works.

References

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