A CELLULAR AUTOMATA EVACUATION MODEL CONSIDERING FRICTION AND REPULSION

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ABSTRACT

There exist interactions among pedestrians and between pedestrian and environment in evacuation. These interactions include attraction, repulsion and friction. In former evacuation models, attraction has been well modeled, while repulsion and friction are not presented. Discrete models such as cellular automata model and lattice gas model have simple rules and high simulation efficiency, but aren't quite suitable for interaction simulation. In this paper, a cellular model is introduced in which repulsion and friction are modeled by the concept of "passing probability". It is indicated that the model can simulate some basic behaviors in evacuation, such as faster-is-slower, jamming and so on, but with high efficiency.

KEYWORDS: Evacuation, Cellular Automata, Lattice Gas, Pedestrian Flow, Power Law

INTRODUCTION

At present, the study of traffic flow has got constructive achievements [1-5]. The pedestrian flow, similar as traffic flow, is attracting more and more attention. Pedestrian evacuation [6-8] is a special pedestrian flow which occurs in emergency like fire, earthquake etc. Pedestrian evacuation is a multi-agent system composed of pedestrians with interactions. The local interactions among pedestrians and those between pedestrian and environment (e.g. wall, door, smoke) decide the complicated, global behaviors of pedestrians, e.g. jamming, arching and clogging [9-13]. During an emergent evacuation, e.g., evacuation in fire, pedestrians tend to move faster than usual, interactions thus become stronger and stronger with the spread of fire, resulting in severer and severer clogging that slows down the evacuation and increases the risk of fatalities. The fire occurred in Friendship Hall of Xinjiang Province of China killed 323 people in 1994, of which the main cause is the clogging caused by interactions at the exit, besides fire. How to present the interactions is one of the key problems in evacuation study.

To understand evacuation dynamics, many evacuation models have been composed.

The discrete models, such as cellular automata model and lattice gas model, quantify evacuation with discrete lattice. Each site in the lattice can be a pedestrian, a block or empty. A pedestrian can move to an empty neighboring grid in each time step. Discrete models have simple rules and easy to simulate. Muramatsu et al [14-15] studied pedestrian flow in two-dimensional environment with a lattice gas model of biased random walkers without back step. The jamming transitions of pedestrian flow are investigated and the critical density of jamming transition is simulated. In their studies, jamming is defined by the mean velocity of pedestrian flow. Further study of the model focuses on the influence of construction, i.e. hall, bottleneck, T-shaped channel and cross exit etc., on jamming transition [16-22]. However, these models can not describe the complex behaviors of emergent evacuation, for instance the faster-is-slower phenomenon [9].

The interactions among pedestrians and those between pedestrian and environment include attraction, repulsion and friction. The social force model introduced by Helbing et al. is a kind of multi-particle self-driven model. Pedestrians are represented by self-driven particles. The movement of pedestrians is described with a main function. The repulsion and friction forces, and thus the speed and acceleration, are decided by the main function. The arching, jamming, faster-is-slower phenomena exhibited in the model have the same characteristics to actual ones. These grouping behaviors are attributed to the interactions between pedestrians in their study. Song et al simulated and analyzed the influences of exit parameters to evacuation in detail. In summary, the social model describes the grouping phenomena such as lanes, crowd, jamming and faster-is-slower. But the disadvantage is its complex rules and simulation speed. How to consider interactions between pedestrians in discrete models is one of the hot-points of evacuation study.

In recent years, Kirchner et al. [23, 24] developed a new kind of CA model, considering the interpersonal friction. In fact, the so-called “friction” in their work is repulsion between pedestrians, i.e. when more than one pedestrian plan to move to the same grid, their movement is then restrained according to certain probability. CA model is improved by the simple rule of repulsion. However, friction among pedestrians, as well as interaction between pedestrian and environment has not been well modeled.

To take into account these interactions, the rules and parameters of friction and repulsion are constructively built, so that a new CA model is introduced in the paper. The new model is expected to both model evacuation in detail and have high simulation efficiency.

MODEL

The model we developed is based on traditional cellular automata model. A lattice is used to present the field; each site on the lattice can be a pedestrian, a part of building or be empty site. Considering the average size of a pedestrian, the size of a lattice is 0.4m long and 0.4m wide. Because all pedestrians move to the exit in an emergent evacuation, the floor field [23] is usually used in CA models. The static floor filed is decided by geometry of the construction, and dynamic floor field by pedestrian trail. In general, the static floor field can be calculated by the distance to exit. When pedestrians move from large value to small value, they can reach and pass the exit. In our model, only the static floor field is considered.

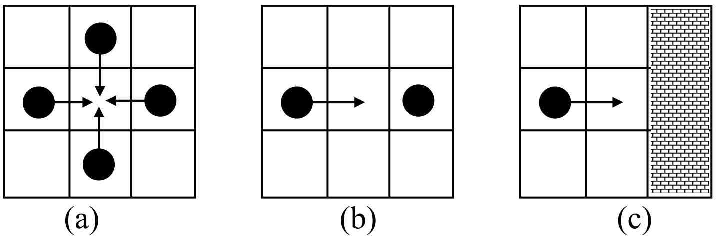


Fig.1 Occurrence of repulsion

Repulsion occurs when a pedestrian is near other pedestrians or walls, as shown in fig.1. There are 3 kinds of repulsion: that between moving pedestrians, that between a moving pedestrian and a stationary one, and that between a moving pedestrian and a wall. The result of repulsion is the action of slowdown and avoiding. Kirchner et al [24] introduced repulsion probability r_1 to model the repulsion for Fig.1(a). The moving probability of each pedestrian is shown in formula 1.

$$p_i = (1 - r_1) / m \qquad (i = 1, 2...m) \tag{1}$$

Here $m(m \geq 2)$ is the number of pedestrians involved in the conflict. Each pedestrian involved in the conflict move to the empty site with probability $(1 - r_1) / m$.

For Fig.1(b,c), we can calculate the moving probability with formula 2 and 3.

$$p = 1 - r_2 \tag{2}$$

$$p = 1 - r_w \tag{3}$$

Here r_2 is repulsion probability for the conflict between a moving pedestrian and a stationary one, and r_w repulsion probability for the conflict between a moving pedestrian and a wall. Once the value of r is obtained, the repulsion probability is calculated. The larger is the relative speed, the more likely is the pedestrian to avoid collapse. The repulsion probability is related to the relative speed. Furthermore, there is an endure threshold for the pedestrian, if the relative speed is greater than the threshold, the pedestrian always avoid it. Thus Sigmoid function is reasonable to express repulsion probability, as shown in formula 4:

$$r \equiv \frac{1 - e^{-\alpha V}}{1 + e^{-\alpha V}} \tag{4}$$

Where V is relative speed, $\alpha \in [0, \infty]$ is the hardness degree. For the repulsion between 2 moving pedestrians, $V = 2 * v$; for the repulsion between a moving and a stationary pedestrians, $V = v$; and for that of between a moving pedestrian and wall, $V = v$. The hardness degree is corresponding to the pedestrian’s endurance to physical collision, as well as the roughness of the pedestrian or wall.

In an emergent evacuation, friction is another key factor affecting evacuation behaviors. The result of friction is the slowdown when two pedestrians, or a pedestrian and wall, touch with each other. In CA model, the expected speed of all pedestrians are same, i.e. one grid one time step, so that there are three types of friction, as shown in Fig.2.

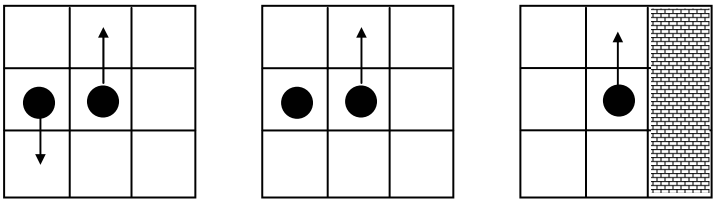

(a) (b) (c)

Fig.2 Occurrence of friction

We introduce friction probability to quantify the effects of friction. For the three conditions of Fig.2, the moving probability is calculated with formula 5-7, respectively.

$$p_i = 1 - f_1 \tag{5}$$

$$p_i = 1 - f_2 \tag{6}$$

$$p_i = 1 - f_w \tag{7}$$

Here *f* is the friction probability. The value of moving probability is calculated as soon as the friction probability is obtained. The value of friction probability is decided by relative distance, relative speed and friction coefficient. In our model, all grids have the same size, so that the relative distance is the same for all neighboring pedestrians. The friction probability is defined as formula 8.

$$f \equiv \theta * V \tag{8}$$

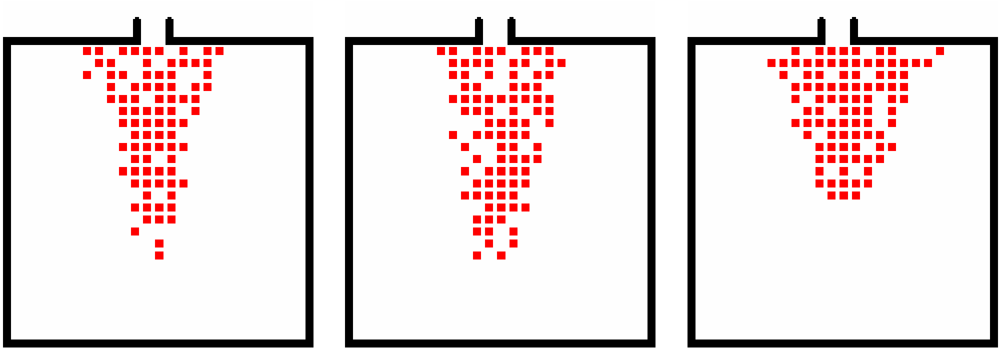
Here V is relative speed and $\theta \in [0,1]$ is friction coefficient reflecting the roughness of pedestrian and wall. For 2 moving pedestrians, $V = 2 * v$; for a moving and a stand pedestrian, $V = v$; for a pedestrian and wall, $V = v$.

SIMULAITON AND RESULTS

The new model is used in a one-door, 15m by 15m room. The width of the door is 1m. There are 200 pedestrians in the room. Other parameters used are as follows:

$$\alpha = \begin{cases} 1 & \text{(between 2 pedestrians)} \\ 2 & \text{(between pedestrian and wall)} \end{cases}$$

$$\theta = \begin{cases} 0.1 & \text{(between 2 pedestrians)} \\ 0.5 & \text{(between pedestrian and wall)} \end{cases}$$



(a) v=1m/s (b) v=3m/s (c) v=5m/s

Fig.3 Grouping behavior

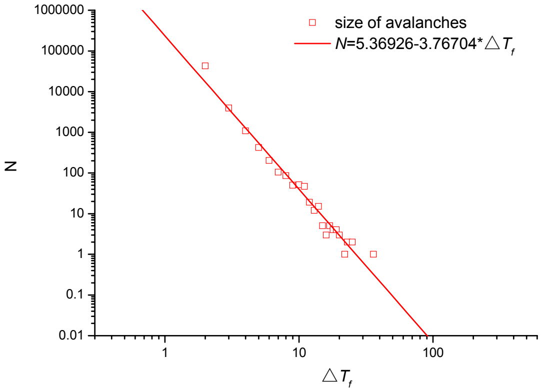


Fig.4 Power law distribution of avalanches

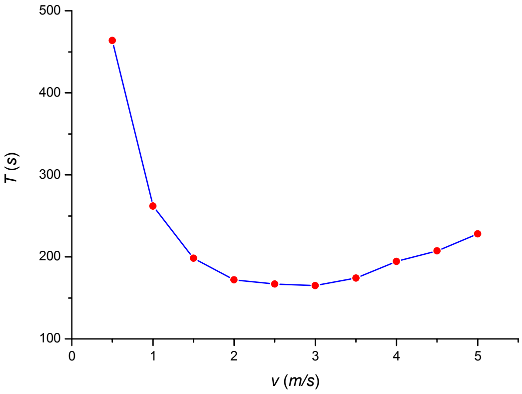


Fig.5 Faster is slower phenomenon

The main simulation results are presented here.

1. Arching. Arching phenomenon is found near exit, as shown in Fig.3. In Fig.3(a), (b) and (c), the desired speed of pedestrians is 1m/s, 3m/s and 5m/s respectively. Because all pedestrians move toward exit, the exit becomes bottleneck of pedestrian flow. With the increase of desired speed of pedestrians, the arching phenomenon becomes more and more evident. A pedestrian can not decide his activity freely, but go with the pedestrian stream, because the interactions add up.

2. Clogging. When the desired velocity is small or normal, i.e. 1m/s, the

simulated outflow from the room is regular, coordinated and continuous. With the increase of desired velocity, friction and repulsion become stronger and stronger, clogging occurs when desired velocity is large enough. The outflow becomes irregular, discontinuous and avalanche-like. In Fig.4, it is shown that the lasting time of continuous pedestrian flow distributes as power law. The frequency-size distribution of continuous flow time is $N \propto (\Delta T_f)^{-3.767}$. Sometimes, the outflow stopped because of interactions, and sometimes many pedestrians flow out one by one, forming an avalanche. The distribution of the avalanches satisfies power law relation, as does the distribution of the interval between two avalanches.

3. Faster is slower. If the desired velocity increases, average velocity will increase and evacuation time will decrease on condition that the desired velocity is small. However, trying to move faster (increasing desired velocity) can cause a smaller average speed of leaving and longer evacuation time when the desired velocity is large, because clogging becomes severe. Fig.5 demonstrates the faster is slower phenomenon. It is shown that the evacuation time is smallest when desired speed is 2.5m/s, after that the evacuation time increase with desired speed. This effect is fatal in fire. Both huge interactions and long evacuation time can cause injuries and fatalities.

To check the model, simulation results are compared with those of the social force model. Comparison indicates that this CA model is as powerful as social force model in modeling pedestrian behaviors and runs much faster than social force model.

CONCLUSIONS

Emergent evacuation has been an interesting issue in the study of fire safety. Enormous deaths and losses are caused every year. To mitigate evacuation danger, evacuation models have been developed to study the dynamics of evacuation and pedestrian flow. Because emergent evacuation is concerned with psychological and behavioral characteristics of pedestrians, it is difficult to model evacuation. Recent study observed some basic phenomena of emergent evacuation, including arching, clogging, faster-is-slower etc. The reason for these phenomena is the interaction between pedestrians and between pedestrian and environment. The model introduced in the paper quantifies the interactions with the rules of forces, i.e. attraction, repulsion and friction. It is found that the new model modeled some basic phenomena of emergent evacuation as good as a continuous model, i.e. social force model. The forces are represented by probabilities. One advantage of probability rules is the fast simulation speed; another is that the parameters in the model are easy to obtain by observing and statistic of real evacuation and pedestrian flow. It is expected to be a new way to explore emergent evacuation.

ACHONWLEDGEMENT

The study is supported by China National Key Basic Research Special Funds project (No. 2001CB409600) and National Natural Science Foundation(No. 50320120156).

REFERENCES

1 Biham O, Middleton AA, Levine D. Self-organization and a dynamical transition in traffic-flow models. Phys Rev A, 1992, 46: 6124-6127

2 Wang BH, Woo YF, Hui PM. Improved mean-field theory of two-dimensional traffic flow models. J Phys A-Math Gen, 1996, 29: 31-35

3 Chung KH, Hui PM, Gu GQ. 2-Dimensional Traffic Flow Problems with Faulty Traffic Lights. Phys Rev E, 1995, 51: 772-774

4 Cuesta JA, Martinez FC, Molera JM, Brito R. Phase-Transitions in 2-Dimensional Traffic-Flow Models. Phys Rev E, 1993, 48: 4175-4178

5 Fruin JJ. Designing for pedestrians: a level-of-service. In: Highway Research Board. Highway Research Record, 1971, Number 355: Pedestrians, Washington, D.C., pp. 1-15

6 Graham TL, Roberts DJ. Qualitative overview of some important factors affecting the egress of people in hotel fires. Hospitality Management, 2000, 19: 79-87

7 Livesey GE, Taylor IR, Donegan H.A. A Consideration of Evacuation Attributes and Their Functional Sensitivities. 2nd International Symposium on HUMAN BEHAVIOUR IN FIRE, 2001, 111-121

8 Livesey GE, Taylor IR, Donegan HA. A Consideration of Evacuation Attributes and Their Functional Sensitivities. 2nd International Symposium on HUMAN BEHAVIOUR IN FIRE, 2001, 111~121.

9 Helbing D, Farkas I, Vicsek T. Simulating dynamical features of escape panic. Nature, 2000, 407: 487-490

10 Helbing D, Keltsch J, Molnar P. Modelling the evolution of human trail systems. Nature, 1997, 388: 47-50

11 Helbing D, Molnar P. Social Force Model for Pedestrian Dynamics. Phys Rev E, 1995, 51: 4282-4286

12 Helbing D, Schweitzer F, Keltsch J, Molnar P. Active walker model for the formation of human and animal trail systems. Phys Rev E, 1997, 56: 2527-2539

13 Song W, Yu Y, Chen T. Influences of exit on evacuation and its analysis. Fire safety science, 2003, 12(2): 100-104

14 Muramatsu M, Nagatani T. Jamming transition in two-dimensional pedestrian traffic. Physica A, 2000, 275: 281-291

15 Muramatsu M, Nagatani T. Jamming transition of pedestrian traffic at a crossing with open boundaries. Physica A, 2000, 286: 377-390

16 Tajima Y, Nagatani T. Scaling behavior of crowd flow outside a hall. Physica A, 2001, 292: 545-554

17 Tajima Y, Takimoto K, Nagatani T. Scaling of pedestrian channel flow with a bottleneck. Physica A, 2001, 294: 257-268

18 Tajima Y, Nagatani T. Clogging transition of pedestrian flow in T-shaped channel. Physica A, 2002, 303: 239-250

19 Nagatani T. Jamming Transition in the Traffic-Flow Model with 2-Level Crossings. Phys Rev E, 1993, 48: 3290-3294

20 Nagatani T. Jamming transition in a two-dimensional traffic flow model. Phys Rev E, 1999, 59: 4857-4864

21 Nagatani T. Dynamical transition and scaling in a mean-field model of pedestrian flow at a bottleneck. Physica A, 2001, 300: 558-566

22 Chen Tao, Song Weiguo, Fan Weicheng, Lu Shouxiang. Jamming Transition of Pedestrian Evacuating Flow in Crossing Exit. In Huang P, Wang Y, Li S, Qian X.(eds) Progress in Safety Science and Technology, Vol. III, Science Press, Beijing, 2002, 507-512

23 Kirchner A, Schadschneider A. Simulation of evacuation process using a bionics-inspired cellular automaton model for pedestrian dynamics. Physica A, 2002, 312: 260-276

24 Kirchner A, Nishinari K and Schadschneider A. Friction effects and clogging in a cellular automaton model for pedestrian dynamics. Physical Review E, 2003, 67: 056112

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标题：　An Evacuation CA Model Considering Friction and Repulsion
主题：
作者：　yuyanfei
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备注：
创建日期：　2004-2-10 13 时 29 分
修订号：　3
上次保存日期：　2004-2-10 13 时 30 分
上次保存者：　mac
编辑时间总计：　10 分钟
上次打印时间：　2004-2-10 13 时 36 分
打印最终结果
　页数：　7
　字数：　2,572 (约)
　字符数：　14,666 (约)