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Simulation of Crowd Evacuation Using an Emotion-Based Cellular Automata Model

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ABSTRACT

In this paper, we present a novel impatience model where impatience level dynamically changes with time. Quantitative formulas are introduced to calculate the dynamic impatience level considering both self-growth and the impatience propagation. Unlike conventional methods using either random updated sequence or fixed sequence. At each time step, all the pedestrians will move to the target cell depending on the impatience level. The dynamic impatience model is implemented in Cellular Automata model where space and time are discretized to simulate the crowd evacuation process.

Numerical simulations are conducted to demonstrate the feasibility of this model. The simulation results show that this model can successfully reproduce typical collective behavior (e.g., clogging phenomenon). We also performed parameter sensitivity study of the dynamics growth and the propagation speed. Results show that with the increase of propagation speed, the evacuation efficiency is initially promoted sharply and the efficiency begins to decline. Another finding is the psychological impatience is not always negative to the moving efficiency. At low impatience value, the increase of the impatience level can improve the evacuation efficiency, while at higher impatience value, the evacuation efficiency drops continuously with the increase of impatience level. These findings will be helpful to control pedestrian emotion (e.g.,impatience level) effectively.

KEYWORDS: Cellular Automaton Model, Emotion Propagation, Evacuation Simulation, Impatient

1 Introduction

In the last decades, microscopic evacuation models have been widely used to simulate the movements of each pedestrian and the interactions between them (Zheng, et al., 2009; Ma, et al., 2017; Shi, et al., 2018). Since they provide detail information of evacuation (i.e., overall evacuation time and flow pattern) for the building designers to adjust their design for efficient evacuation (Pelechano & Malkawi, 2008). Generally, microscopic models include continuous structure and discrete structure models. Social force model is one typical continuous structure model considering that forces between pedestrians and between pedestrians and the wall (Helbing, et al., 2005).In cellular automata (CA) model, evacuation space and time are discretized and pedestrians are updated based on the set of local rules at each time step (Varas, et al., 2007).

Update methods schedule the movement of pedestrian and thus they are with great practical importance in evacuation dynamic (Daoliang, et al., 2006). In CA model, the update methods are mainly divided into parallel update and sequence update methods. Parallel update method controls all pedestrians update synchronously at each time step and when more than one pedestrian try to move into the same cell, only one can enter the target cell and others stay at initial position (Hu, et al., 2014; Hao, et al., 2010). In sequence update method, all pedestrians update asynchronously depending on their update order. Update order can be determined by either random shuffle update or fixed-order sequential update methods. The main difference between them is that in random shuffle update, the order is randomly permuted every time step and in fixed-order sequential update the update order is not changed once created (Saegusa, et al., 2008; Cao, et al., 2016). However, previous sequence update models just generate update sequence randomly and do not reflect the real evacuation process.

Helbing et al. (2000) considered the impatience of pedestrians in their development of the social force model. However, they do not consider the growth of impatience along with time. In fact, many studies show that impatience is induced by waiting time. Kumar et al. (2014) reported that people may experience more impatience when waiting. The experimental study by Gjafirian and Reitter (2016) presented that impatience is induced by waiting.

The problem discussed above clearly indicate the necessity to develop a new emotion-based model for a more realistic simulation of the crowd movement. In this paper, we propose a dynamic impatience algorithm in which impatience level dynamically grows with time. In this model, impatience-based sequence update method is introduced to schedule the movement of each pedestrian. The dynamic emotion-based update method will be implemented in CA model to investigate pedestrian behavior from the psychological way. The paper is organized as follows. Section 2 introduces the algorithm for impatience level and the update rule in this model. Section 3 gives simulation results and corresponding discussion, followed by conclusions in the final section.

2 Model

In our model, the mathematical equations is proposed to calculate the impatience level considering both self-growth and the impatience propagation between pedestrians. At each time step, all pedestrians are updated asynchronously following the update method described below.

2.1 The dynamic impatience model

Helbing et al. used the desired velocity $v_i^o(t)$ to represent the impatience of a pedestrian (Helbing, et al.,

2000) as follows:

$$v_i^o(t) = [1 - p_i(t)]v_i^o(0) + p_i(t)v_i^{max}\ ,\ where\ \ p_i(t) = 1 - \bar{v}_i(t)/v_i^o(0) \tag{1}$$

where $v_i^o(t)$ is the desired velocity at time t and v_i^{max} is the maximum desired velocity. After taking derivation of Eq. (1),

$$\frac{dv_i^o(t)}{d\bar{v}_i(t)} = 1 - \frac{v_i^{max}\ (t)}{v_i^o(0)} < 0 \tag{2}$$

where $\bar{v}_i(t)$ is the average velocity. According to (Kumar, et al., 2014; Ghafurian & Reitter, 2016), the dynamic impatience level is velocity-dependent and time-dependent. Let $\varphi(v,t)$ be the impatience level at time t with walking speed v. Applying Eq. (2) to our proposed impatience model, the following feature of impatience is obtained:

$$\frac{\partial\varphi(v,t)}{\partial v(t)} < 0 \tag{3}$$

This equation shows that the impatience level increases when the pedestrian's speed is reduced and vice versa. Zeltyn and Mandelbaum (2004) investigated impatient customers' behavior in call centres and found that the probability to quit the queueis positively correlated with the service arrival time. The same theory is also applicable to evacuation process. If a pedestrian walks slower than the full speed(v_{max}), the impatience grows and the growth rate is governed by the algorithm.

$$\frac{\Delta\varphi_i(v_i,t)}{\Delta t} = \left(1 - \frac{v_i(t)}{v_{max\ i}}\right) exp\left[-\alpha\left(\frac{v_i(t)}{v_{max\ i}}\right)t\right] \tag{4}$$

where α is a parameter of the impatience growth rate and Δt is set to be 0.4sin CA model. When the velocity is fixed, with the increase of α, the impatience growth rate is reduced. Jones and Jones (1995) found that emotion can spread rapidly through a crowd. This observation can also be applied to impatience model:

$$\frac{\Delta\varphi_i(v_i,t)}{\Delta t} = \sum_{j=1}^{j=Total} \gamma_j\left(\varphi_j(v_j,t) - \varphi_i(v_i,t)\right),$$

$$\begin{cases} \gamma_j = \gamma & \text{For cell in diagnonal directions} \\ \gamma_j = \sqrt{2}\gamma & \text{For cell in N, E, W and S directions} \end{cases} \tag{5}$$

where γ_j is the emotion propagation speed between pedestrian *i* and his/her neighbours j . Total is the sum of neighbours j. The propagation speed is √2 times for neighbours in N, E, W and S directions compared with neighbours in diagonal directions which is consistent with result in Nilsson and Johansson (2009).The change in impatience level over time is as follows:

$$\frac{\Delta\varphi_i(v_i,t)}{\Delta t} = \left(1 - \frac{v_i(t)}{v_{max\ i}}\right) exp\left[-\alpha\left(\frac{v_i(t)}{v_{max\ i}}\right)t\right] + \sum_{j=1}^{j=Total} \gamma_j\left(\varphi_j(v_j,t) - \varphi_i(v_i,t)\right),$$

$$\begin{cases} \gamma_j = \gamma & \text{For cell in diagnonal directions} \\ \gamma_j = \sqrt{2}\gamma & \text{For cell in N, E, W and S directions} \end{cases} \tag{6}$$

The dynamic impatience level at time $t + \Delta t$ is calculated as the following function:

$$\varphi_i{}^{t+\Delta t}(v_i, t + \Delta t) = \left(1 - \frac{v_i(t)}{v_{max\ i}}\right) exp\left[-\alpha\left(\frac{v_i(t)}{v_{max\ i}}\right)t\right]\Delta t + \left(\varphi_j(v_j,t) - \varphi_i(v_i,t)\right)\Delta t + \varphi_i{}^t(v_i,t),$$

$$\begin{cases} \gamma_j = \gamma & \text{For cell in diagnonal directions} \\ \gamma_j = \sqrt{2}\gamma & \text{For cell in N, E, W and S directions} \end{cases} \tag{7}$$

2.2 Floor field method

In our work, the room is discretized into foursquare cells with sizes corresponding to 0.4 m × 0.4 m. Once the room geometry is determined, each cell is labelled with a constant value called a static floor field (SFF), which represents the cell's distance from the exit. We adopted the SFF method developed by Varas (2007).

2.3 The emotion-based update method

In this model, the Von Neumann neighborhood is adopted. At each time step, the pedestrian moves towards the neighboring four cells with the lowest SFF values. A new sequence update method corresponding to impatience level was adopted in our model. This method is based on Nicolas's finding that an impatient pedestrian is more likely to move forward than the other relatively patient pedestrians (Nilsson & Johansson, 2009). In our emotion-based update method, the pedestrians are updated in turn according to the descending order of their impatience level.

3 Simulation result

We consider a two-dimensional lattice representing a room with an exit, consisting of 32 × 32 sites labeled. Each grid has approximately $0.4 \times 0.4 m^2$ and the maximum velocity in Eq. (7), , and the time step, Δt, are set to be 1m/s and 0.4 s, respectively. Based on the update method introduced in section 2.2, total 200 pedestrians update their position sequentially. The simulation will stop if all pedestrians left the room. Figure 1 shows the snapshots of evacuation process in different stages. Initially, all pedestrians are randomly distributed in the room as shown in Figure 1 (a). During the evacuation process, as pedestrians move towards the exit, the clogging appears around the exit. Over time, the size of the clogged area becomes smaller as shown in Figure 1(c). As shown in Figure 1 (d), in the final stage of the evacuation, almost all of the pedestrians have left the room, leading to the number of pedestrian in room close to zero.

Figure 2 shows the parameter analysis of both self-growth rate α and propagation speed γ. With the increase of α value, the evacuation time is reduced initially and the time begins to increase. Figure 2 (b) indicates that the evacuation time reaches the minimum value in $\gamma=1$. With the further increase of γ value, thought the evacuation time is fluctuated, evacuation time has an increasing trend.

Figure 3 is the scatter plots of evacuation time against log of average maximum impatience level distinguished by different α values and different γ values in Figure 3 (a) and (b) respectively. The result shows that the impatience level is not always negative to the moving efficiency. At low impatience value, the increase of the impatience level can reduce the evacuation time, while at higher impatience value, the evacuation time increases continuously with the increase of impatience level. When $\alpha=1$, the evacuation process reaches the highest efficiency.

4 Conclusions

This study presents a new impatience-based update method for the evacuation process. Both impatience growth and propagation have been introduced in this model. To demonstrate the feasibility of this model, we apply this method into a typical scenario that is evacuation from a large room with single exit. The results show that this model can successfully reproduce clogging phenomenon. The parameter sensitivity study of the two factors shows that with the increase of propagation speed, the evacuation efficiency is initially promoted and then begins to decline. Another finding is the appropriate impatience level will improve the evacuation efficiency and lead to a faster evacuation process. Since it is only a computational study, we will carry out evacuation experiments to verify the simulation results as the future works of this research.

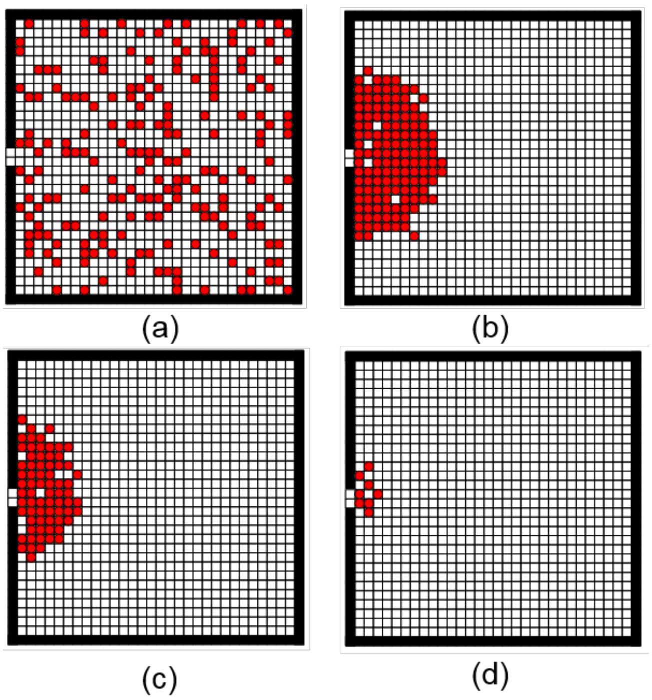

Figure 1 The snapshot of evacuation in: (a) t=0 s, (b) t=20s, (c) t=40 s and (d) t=60s

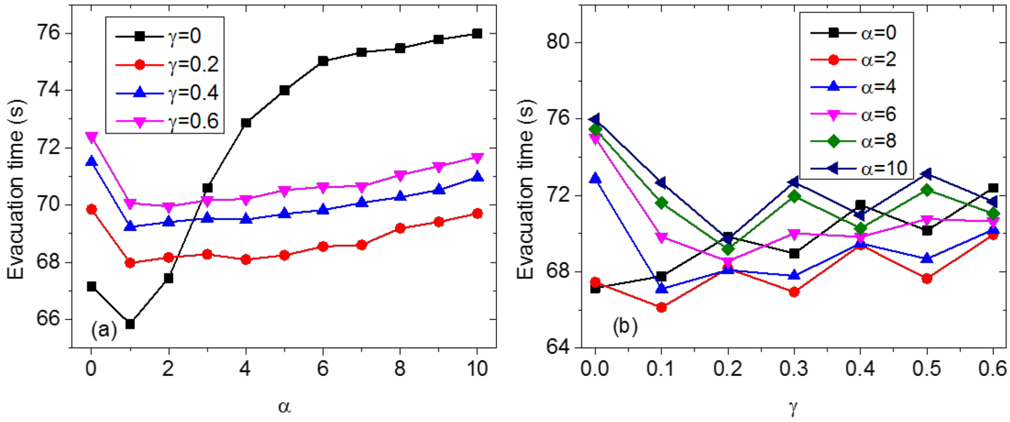

Figure 2 The parameter analysis of (a) Influence of α on evacuation time at different values of γ and (b) Influence of γ on evacuation time at different values of α

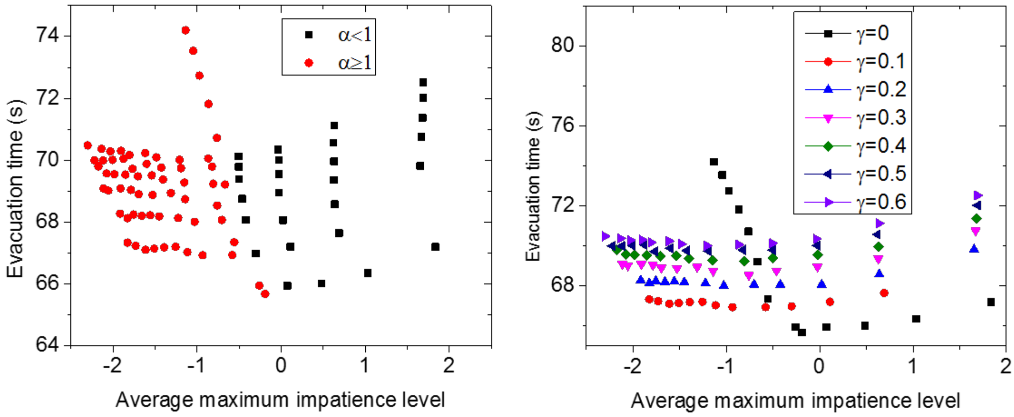

Figure 3 Scatter plots of evacuation time (s) against log of average maximum impatience level distinguished by (a) different α values and (b) different γ values

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使用以情感為基礎的細胞自動機進行人群疏散模擬

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摘 要

在本文中，我們提出了一種新穎的急躁模型，其中急躁程度隨著時間的推移而動態變化。本研究使用定量公式以計算考量自我增長和急躁情緒傳播的動態急躁程度。與使用隨機更新序列或固定序列的傳統方法不同。在每個時間階段，所有行人將依據急躁程度移動到目標細胞。動態急躁模型在細胞自動機模型中呈現，其中空間和時間被離散化以模擬人群疏散過程。

本研究亦執行數值模擬，以證明該模型的可行性。模擬結果顯示，該模型可以成功地再現典型的集體行為（例如，堵塞現象）。本研究亦對動力學增長和傳播速度進行了參數靈敏度研究。結果顯示，隨著情緒傳播速度的增加，疏散效率最初急劇提升，但後續效率開始下降。另一個發現是，在某些程度之中，急躁情緒傳播的最大不耐煩程度會低於情緒未傳播的情況。這一結果顯示溝通可以在一定程度上緩解不良情緒。此外，心理上的不耐煩並非總是對疏散移動效率不利。在低急躁值時，急躁程度的提高可以提高疏散效率，而在較高的急躁程度下，隨著急躁程度的增加，疏散效率反而不斷下降。這些發現可以提供對動態疏散過程的新見解，並將有助於合理地控制和引導人群情緒（例如，急躁程度）。

關鍵字：細胞自動機模型，情緒傳播，疏散模擬，不耐煩，人類行為