

Study of crowd evacuation in multiple environments based on a meta-cellular automata model

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Abstract. To address the effect of anxiety level on evacuation situations, related papers point out that the level of anxiety in an accident is related to the individual's situation and the surrounding environment. For this reason, we used a computer to randomly simulate the individual situation as well as the evacuation environment, to develop a quantitative model of anxiety levels. To explore the change in anxiety levels over time, we build the SIS model to simulate the propagation of emotions. And the difference in anxiety level will determine whether the pedestrian decision is rational or not. Finally, based on the simulation results, the correlation between anxiety level and evacuation rate is analyzed to be negative, and the approximate correlation between several personal situations and evacuation environment with evacuation rate is derived, among which, the correlation between the type of accident occurrence and evacuation rate is the largest.

Keywords: Meta-automata model, SIS model, Evacuation situations.

1. Introduction

Over the past few decades, the issue of emergency evacuation has become increasingly important due to the increase in the number and size of mass assembly events. Evacuation through doors of limited width or narrow passageways is one of the situations of greatest concern. Many experiments and numerical simulations have been performed to better understand crowd behavior in various situations.

However, the results of many different studies are controversial or even contradictory because the realism of the environment and background, the pressure level, the density of people, and the sample size cannot be consistent with the real situation. For this reason, we need to conduct studies for different situations and parameters to understand the different dynamical behaviors that crowds may exhibit during evacuation and escape.

2. Metacellular Automata

2.1 Overview of metacellular automata

Metacellular automata are an important research method when simulating the behavior of pedestrians in a crowd.

A metacellular automaton is a model that reflects the complex changes of a meta cell in discrete time according to certain rules in a metal cellular space where both time and state are discrete. Its classical two-dimensional metacellular automaton, including the central meta cell and the surrounding 8 metacells. The central cell will reflect different states according to the states of the surrounding 8 cells, i.e., its state is determined by itself and also the surrounding cells. As shown in Figure 1.

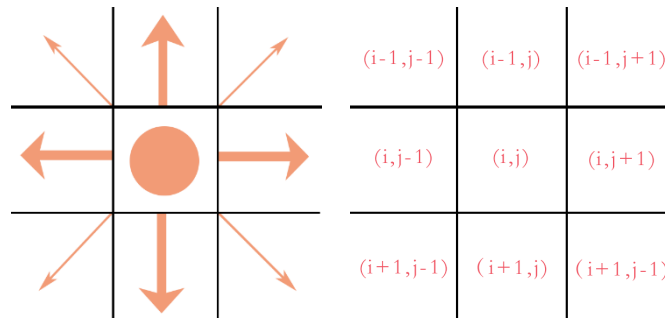


Figure 1. Neural network structure

2.2 The use of metacellular automata

In this paper, a two-dimensional metacellular automaton approach is used. It is assumed that the square room has a plan size of $16\text{m} \times 16\text{m}$ and is divided into dimensions of $0.4\text{m} \times 0.4\text{m}$. In this room, the evacuation space is a 40×40 grid. Each grid is a cell and can accommodate only one person. The exit is located at the upper end of a wall with a width of 0.8m , i.e., a maximum of two people can exit at the same time.

The pedestrians are discretized into the same time step during the simulation. The normal movement speed of a pedestrian in [1] is about 6 m/s , i.e., 1.65 m/s , while the edge length of each cell is 0.4 m and the diagonal length of the cell is 0.56 m . Timing the time of a person passing through each cell as a Timestep, we can calculate the average time of a pedestrian passing through a cell as 0.29 s , i.e., one Timestep is 0.29 s .

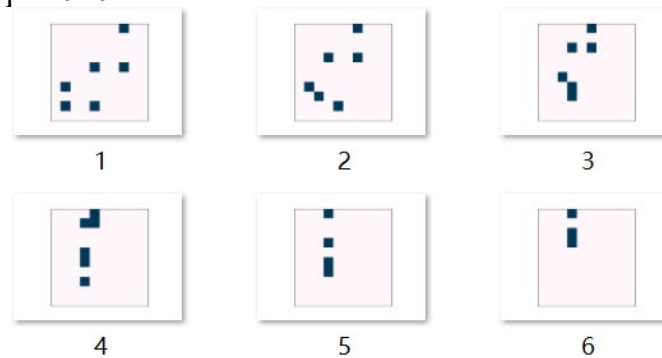


Figure 2. Pedestrians simulations

When the anxiety level of pedestrians is not considered, then every pedestrian can make rational decisions.

3. Model Establishment

3.1 Pedestrian optimal decision

In simulating the optimal decision of pedestrians, a static field model is used in this paper. In each time step, the pedestrian chooses the best moving position according to the transfer probability p . Define p_{ij} as the transfer probability of cell (i,j) , which is calculated as shown in equation (1):

$$p_{ij} = N \exp(k_s S_{ij}) \alpha_{ij} (1 - n_{ij}) \quad (1)$$

where N is the normalization factor to ensure $\sum p_{ij} = 1$. S_{ij} denotes the static field with a factor k , which reflects the attractiveness of the target tuple. α_{ij} is the type identification factor, and if the target cell is an obstacle $\alpha_{ij} = 0$, otherwise $\alpha_{ij} = 1$; and n_{ij} is the state identification factor. If the target cell is not occupied by pedestrians at the current moment, then $n_{ij} = 0$, otherwise $n_{ij} = 1$.

Static field s_{ij} is negatively correlated with the distance between the location of this meta cell and the exit, with the more distant location from the exit being less attractive to pedestrians, calculated as shown below.

$$s_{ij} = \max_{(i,j)} \{ \sum \sqrt{(x_e - x_{ij})^2 + (y_e - y_{ij})^2} - \min_{(i,j)} \sum \sqrt{(x_e - x_{ij})^2 + (y_e - y_{ij})^2} \} \quad (2)$$

x_e and y_e denote the coordinate values of the outlet respectively, x_{ij} and y_{ij} denote the value of the meta cell coordinates.

3.2 Pedestrian optimal decision

3.2.1. Quantitative model of anxiety level

The level of anxiety can affect a person's optimal decision-making. The level of anxiety, on the other hand, is related to two main factors. On the one hand, it is related to personal characteristics, including age, education, gender, personality, and safety education. On the other hand, it is related to the evacuation environment, including the density of people, the location of the disaster, and the type of disaster. The anxiety level was quantified by combining the anxiety factor modification of the social force model of personnel evacuation [2], and the evacuation anxiety level model was established as:

$$k = \frac{\sum \gamma_i a_i}{\sum \gamma_i} \cdot \frac{\sum \beta_j b_j}{\sum \beta_j} \quad (3)$$

where k is the anxiety level of pedestrians when a disaster occurs in the closed interval, and its value is between $[0,1]$, the larger the value, the greater the anxiety level of pedestrians. γ_i is the weight value of the individual pedestrian factor, $i=1\sim5$; β_j is the weight value of the evacuation environment factor, $j=1\sim3$; a_i is the anxiety level score of the person factor; b_j is the anxiety level score of the evacuation environment factor.

3.2.2. Quantitative model of anxiety level

Since the quantitative model of anxiety level requires questionnaires to calculate the weight of the influence of each factor on anxiety level. In this paper, the results of a questionnaire distributed by [3] Wang Chunxue et al. in several communities, including Beijing, were selected to analyze the probability of fearful emotion infection by a type of unexpected events. Since the Cronbach coefficient of this emotion scale was 0.89, the internal consistency coefficient of the scale reached above moderate. Therefore, the probability of infection has a high confidence level. Also, five individual indicators were selected to reflect the weight of individual factors on fear of infection for 40 citizens in Beijing. To reflect the level of anxiety, the subjects were shown different pictures and their physiological indicators were measured after each stimulus. This is an objective way to reflect the correlation between individual factors and anxiety level and has high reliability.

For the influencing factors of evacuation environment, only the types of emergencies are available in the above, and the influencing weights of pedestrian density and the location of the occurring accidents are missing. Therefore, this paper combined with another paper by [4] Chunxue Wang et al. selected the influence weights of pedestrian density and the location of occurrence of accidents.

① Weighting analysis of individual pedestrian factors.

The Pearson correlation coefficients of individual pedestrian factors were gender (0.081), age (0.186), personality type (0.147), education level (0.22), and security education level (0.303). Based on the Pearson coefficients to determine the probability weight of fearful emotion infection k_i , the formula for the probability weight of fearful emotion infection for each pedestrian factor is as follow, where k_i is the weight of the probability of fear infection for each pedestrian factor; p_i is the Pearson correlation coefficient between each pedestrian factor and the subject's heart rate change.

$$k_i = p_i / \sum p_i \quad (4)$$

The weights of the influence of the probability of fear infection for each pedestrian individual factor can be calculated. When the initial moment of the accident occurs, the anxiety level of a certain pedestrian can be calculated using equation (4). According to the basic characteristics of pedestrians and the evacuation environment, the probability of emotional infection of the corresponding factor can be found, and then the corresponding weight values of each factor can be found, which are

multiplied and then added together to obtain the anxiety level of a certain pedestrian at the beginning of the accident.

3.2.3. SIS model simulates the propagation of anxiety

Since the quantitative model of anxiety can only calculate the initial value, it does not change accordingly over time. In practical situations, the anxiety level of pedestrians is not always constant, especially when it is influenced by other people. To establish a mathematical model of anxiety, we use the SIS model.

S is a susceptible person, who receives anxiety from the infected person, but can still make ideal decisions; I is an infected person, who acts as a transmitter of anxiety and can also receive emotional infection from other infected persons, which increases the level of anxiety, and at this time, the infected person cannot make ideal decisions. Infected and susceptible individuals are not constant but can shift from one to the other as soon as they reach the appropriate threshold. When a susceptible person's anxiety exceeds a certain threshold, he becomes an infected person and can spread his anxiety to others; when the infected person's emotion decays to a certain value, he becomes a susceptible person and no longer spreads his anxiety, but can receive emotions from other infected people. Define the anxiety threshold η as the emotional threshold of susceptible and infected individuals.

The calculation of anxiety for a given individual at a given moment in time is shown in (5).

$$p_{t+1} = p_t - p_{decay} + \sum_{s < R_p} p'_t \Delta p \quad (5)$$

where p_{t+1} and p_t are the anxiety values of the pedestrian at $t+1$ and t , respectively, and when $t=0$, the anxiety values are calculated by applying Equation (3); p_{decay} is the degree of decay of the anxiety value; s is the pedestrian seeing distance, m; R_p is the radius of infection, which generally takes the value of $\sqrt{2}$, indicating that anxiety can only be infected to the neighborhood; p'_t is the anxiety value of the infected person; Δp is the emotional infection value, indicating the proportion of the infected person transmitting the anxiety value at each emotional infection.

Among them, the degree of attenuation of anxiety values p_{decay} decreases with the time of the accident, but at the same time increases with the influence of the surrounding infected individuals. Differences in the personality of individuals also lead to differences in the degree of emotional decay. Extroverted individuals decay emotions faster than introverted individuals [3].

In addition to the above factors, the degree of attenuation is also related to the distance of pedestrians from the doorway. When close to the doorway, pedestrians will have the feeling of being in the aftermath of a robbery, and their anxiety value will drop significantly. Therefore, the difference in the intensity of emotional attenuation during evacuation further complicates the emotional attenuation. The difference in the intensity of emotional decay affects the change of state of each pedestrian. According to the distance of pedestrians from each other to the doorway, the emotional attenuation intensity is analyzed by conditions with different personality emotional expressions, and the anxiety emotional attenuation intensity is defined to be calculated as follows [4].

$$p_{decay} = \begin{cases} p_t \exp\left(\frac{\alpha}{t-t_u}\right) & d \leq R_e \\ p_t * \lambda * \exp\left(\frac{-\rho * gS}{p^r_E * t}\right) & d > R_e \end{cases} \quad (6)$$

where α is the emotional decay rate of the pedestrian near the exit; p_t is the fearful emotion value of the pedestrian at the moment; t_u is the time when the individual was most recently emotionally infected; d is the distance between the pedestrian and the exit, m; λ is the emotional decay rate of the pedestrian itself; ρ is the emotional adjustment factor, which regulates the emotional decay at different moments and scenarios, and can be simply understood as λ the real-time changes. gs (group size) denotes the group size, the larger the group, the emotion decays more slowly, and the longer the evacuation time. p^r_E indicates the extroversion of the individual, if the individual tends to be extroverted, the easier the emotion is to ventilate and the slower the emotion decays.

3.2.4. Decision modification model considering anxiety

When pedestrian anxiety does not accumulate to a certain level, pedestrians have the reason to make the best action strategy. When the anxiety value of pedestrians accumulates to a certain level, pedestrians are likely to act irrationally. Definition p_b is the decision correction probability, which is the probability of pedestrians changing their current movement strategy, and when the anxiety value of pedestrians is higher, pedestrians are more likely to change their current decision. As shown in equation (7), the p_b is related to the current anxiety value of the pedestrian.

$$p_b = \lambda p \tag{7}$$

where λ is the regulating factor. When $p_b < \eta$, the pedestrian will make the optimal movement strategy; when $p_b \geq \eta$, the pedestrian will move with probability p_b does random movement.

4. Results

The above model is simulated using python to analyze the evacuation performance of pedestrians under anxiety conditions. During the simulation, the variable parameters were set as follows, unless otherwise specified.

The images can be analyzed to show that the evacuation performance of pedestrians is significantly different when the anxiety level is considered than when it is not considered. From, the image, it is clear that the time difference is 20 seconds. The correlation between anxiety level and evacuation speed was analyzed, and the result was 0.38. The individual factors of pedestrians and evacuation environment factors reflect the anxiety level of pedestrians, so the individual factors of pedestrians, including education, gender, safety education, age, personality type, and the factors of evacuation environment, including the type of disaster, location of the accident, and density of people, can cause differences in the results of the experiment. the experimental results. Also, in the SIS model, several parameters are assumed that likewise affect the level of anxiety. These parameters include the emotional threshold, the rate of decay of one's own emotion, the rate of decay of emotion when approaching the doorway, and the proportion of infected people spreading emotion.

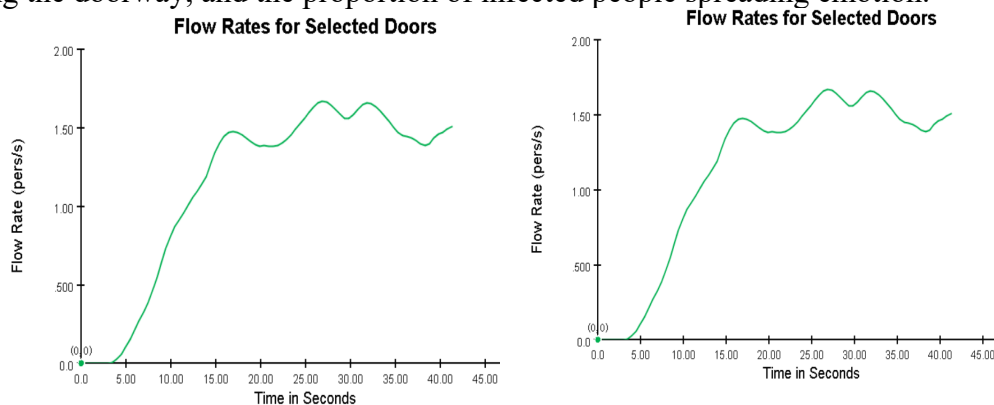


Figure 3. Simulation results

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