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Impact of Confusion Factor on Simulation of An Agent-based Panic Crowd Evacuation Model

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Abstract. Aiming at how panic and chaos affect pedestrian behavior and evacuation efficiency, we propose a panic crowd evacuation model based on entropy. Boltzmann entropy and Shannon entropy are used to simulate people's escape behavior in panic disorder. The simulation results suggest that the proposed model can effectively reflect the negative impact of chaos on evacuation, which leads to longer evacuation time. Compared with Shannon Entropy, Boltzmann Entropy is more sensitive to the number of persons and helpful to identify the evacuation bottleneck area. This work provides a new insight for understanding how crowds behave in an emergency evacuation.

1. Introduction

In emergencies, such as fires, earthquakes, terrorist attacks, it is necessary to evacuate a considerable number of people in a short period of time. However, several problems, such as a lack of experience data, and the high cost of practical drilling, make the study for crowd evacuation much more difficult. Therefore, simulation is one of the main methods of pedestrian behavior analysis, crowd dynamic analysis, and emergency plan optimization.

In the process of modelling, many factors that may affect evacuation need to be considered [1]. Among them, the impact of panic on individual evacuation behavior and the process of evacuation, which is a typical uncertainty factor in the emergency evacuation, has been widely studied. In addition, excessive crowd chaos can easily reduce evacuation efficiency, even lead to casualties such as crowding and trampling. Therefore, it is quite necessary to study the crowd evacuation model considering crowd disorder and panic.

Unlike the macro-model for large-scale crowd evacuation, the micro-evacuation model focuses more on describing the attributes and behavior of individuals [2]. Individual-based models like social force (SF) model, cellular automata (CA) model and agent-based model are commonly used for emergency crowd evacuation research. SF model [3] [4] is based on mechanical principles for individual physiological factors. It is difficult to reproduce the inherent uncertainty of psychological factors [5]. CA model [6] [7] is a kind of discrete micro-model based on grid moving decision. Agent is a kind of autonomous individual who can adapt to the environment and realize self-control given a goal. Agent-based models have been widely used in group simulation, which is very suitable for evacuation modelling that considers micro-individual psychological and physiological factors [8] [9] [10].

During emergency evacuation, panic can lead to irrational or even anti-social escape behavior, eventually causing crowd congestion or trampling casualties. Understanding the impact of panic on individual evacuation behavior plays an important role in preventing crowd accidents. Existing works



have studied both the panic characteristic model [11] [12] [13] for describing individual behavior and the panic propagation model [5] for evaluating the evolution of panic behavior. However, there is still a lack of work on the chaotic state of panic crowd, i.e., how human panic mood and the degree of crowd chaos affect the evacuation process synthetically, which will be addressed in our model. Entropy is a measurement of uncertainty that is widely used in anomaly detection [14], evacuation process evolution [15], and performance evaluation [16].

This paper proposes an agent-based panic crowd evacuation model (APCEM) considering chaos of population. We use Shannon entropy and Boltzmann entropy to express the degree of crowd chaos, and evaluate the individual panic mood and evacuation behavior. Our model can provide an effective method to support the study of the comprehensive impact of crowd chaos on panic crowd.

2. Model Description

The APCEM draws on the simulation framework based on Boids Rules in [17]. Boids Rules [18] simulate the flocking phenomenon in bird flight through three basic behavioral rules: separation, alignment and cohesion.

Besides of the three basic rules, we take the escape behavior (moving to the exit or target) and the obstacle avoidance behavior into consideration. Specifically, our model has the following improvements comparing with the model in [17]. Firstly, Boltzmann entropy and Shannon entropy are used to calculate the panic factor, which affects the individual movement speed. Secondly, we adjust the panic model by selecting different factors to improve our evacuation model. Thirdly, the different particle radius and view radius of individuals are considered to explore the behavior characteristics of heterosexual people with limited vision. Finally, we simplify the selection mechanism of individual moving targets in the evacuation process, and do not need to establish a roadmap according to the scene, which is more general to model various scenarios.

2.1 Agent Model based on Boids Rules

In our model, a person is described by a circular particle that has five attributes: {particle radius, velocity vector, field of view radius, entropy, panic}. Without loss of generality, we assume there is only a single exit. The person who is moving will select the farthest point or exit in her/his visible region as the moving target. While the velocity vector is composed of five speed components with different weights, including target speed, cohesion speed, separation speed, alignment speed, obstacle avoidance speed. Table 1 summarizes the notation, description and the corresponding weight of these speeds.

Table 1. Notation, description and corresponding weight of the velocity vector

Notation	Description	Corresponding Weight
\vec{v}_i^g	Move to the goal	m_g
\vec{v}_i^c	Cohere with visible particles	m_c
\vec{v}_i^a	Align with the average velocity of visible agents	m_a
\vec{v}_i^s	Keep distance from the surrounding particles	m_s
\vec{v}_i^o	Avoid obstacles	m_o

A noteworthy point is that, our proposed model considers the situation in which the individual's visible region is limited (e.g., darkness or fume area). Then the information acquired by an individual while moving is restricted, i.e., the people and obstacles she/he can see or perceive. In this paper, the visible region of an agent is a sector with the angle of 170° [19]. The touch range is a circular area around the particle whose radius is 4 times of its own size.

In fact, \vec{v}_i^g , \vec{v}_i^c , \vec{v}_i^a of an agent is affected by the visible region. \vec{v}_i^s relies on the touch region. \vec{v}_i^o considers both ranges. Assume that when the individual sees the wall, a reverse velocity component is generated to slow itself down. While it may deflect the direction of movement when the individual is just near the wall. In addition, the setting of the target depends on whether the agent can see the exit. If

the agent can see the exit, the target will be the exit rather than the farthest distance in the visible region.

For agent i , suppose that the speed at time t is $\vec{v}_i(t)$, the coordinate is \vec{p}_i , the position of the target is \vec{p}_g . If there is an obstacle in the visible region or touch region, assume that the obstacle's centre position is \vec{p}_o . The average velocity and position of the particles in the visible region are \vec{v}_i^* and \vec{p}_i^* respectively. Then the velocity at time $t+1$ can be calculated as follows.

$$\vec{v}_i^g = \frac{\vec{p}_g - \vec{p}_i}{\|\vec{p}_g - \vec{p}_i\|} \|\vec{v}_i(t)\| \quad (1)$$

$$\vec{v}_i^c = \vec{p}_i^* - \vec{p}_i \quad (2)$$

$$\vec{v}_i^a = \vec{v}_i^* - \vec{v}_i \quad (3)$$

$$\vec{v}_i^s = \sum_j (\vec{p}_i - \vec{p}_j) \quad (4)$$

$$\vec{v}_i^o = \sum_o (\vec{p}_o - \vec{p}_i) \quad (5)$$

Where, \vec{p}_j represents the position of other particles in the view of agent i , \vec{p}_o refers to the obstacles in the visible region and touch region of agent i . The predicted value of the agent's speed is

$$\vec{\lambda}_i(t) = \vec{v}_i^g \cdot m_g + \vec{v}_i^c \cdot m_c + \vec{v}_i^a \cdot m_a + \vec{v}_i^s \cdot m_s + \vec{v}_i^o \cdot m_o \quad (6)$$

Then the exponential smoothing method is used to update the speed of the agent at time $t+1$. The coefficient c is the panic value of the agent.

$$\vec{v}_i(t+1) = c \cdot \vec{v}_i(t) + (1-c) \cdot \vec{\lambda}_i(t) \quad (7)$$

2.2 Entropy Model

Shannon entropy and Boltzmann entropy are used to measure the chaos degree, by statistically analysing the distribution of particle velocity in individual's visible region. In order to calculate the individual's perceptual information regarding the chaos degree, we divide the velocity space into 4*4 subspaces according to the magnitude and direction (as shown in Figure 1). Calculate the number of particles corresponding to each subspace in each individual's visible region.

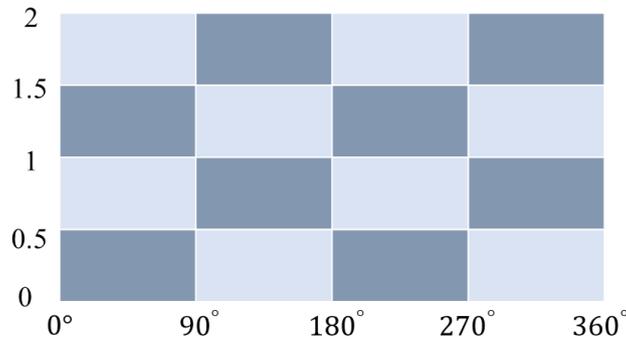


Figure 1. Velocity space distribution.

Assume that at time t , there are N particles in the i -th agent's visible region. The corresponding numbers of particles in the velocity subspaces are $\{n_1, n_2, \dots, n_k, n_{k+1}, \dots, n_{16}\}$, where $\sum_{j=1}^k n_j = N$, and $n_j = 0$ ($j \in [k+1, 16]$). The Boltzmann entropy [20] of agent i is

$$BE = k_B \cdot \ln \left(\prod_{i=1}^k C_{N - \sum_{w=1}^{j-1} n_w}^{n_j} \right) \quad (8)$$

where, k_B is the Boltzmann coefficient. The Shannon entropy is defined as

$$SE = - \sum_{j=1}^k \frac{n_j}{N} \log_2 \frac{n_j}{N} \quad (9)$$

2.3 Panic Model

Panic has a non-negligible impact on individual's evacuation behavior. The main factors influencing panic include the number of exit distances, speed gaps, abnormal speeds, and the number of people nearby [17]. Moreover, loneliness and the chaos degree of the crowd can also increase individual's

emotional anxiety [21]. The panic model defined in this paper includes the export distance, speed gap, speed anomaly, entropy and loneliness. The former three components refer to the partial panic model in [1]. The fourth component is determined by the individual's entropy. The last one considers the influence of loneliness on panic.

Assume that in a space with length L , for any agent at any time t , the panic is normalized into $[0,1]$. Denote D_i as the distance from agent i to the exit, r_i as particle radius, e_i as entropy, \vec{v}_i^* as the average speed of visible particles, n_i^* as the number of visible particles, and e_i^* as the average entropy of visible agents. Besides, assume v_{max} as the maximum walking speed, v_{norm} as the walking speed of the person under normal situation, and e_{max} as the maximum entropy of the global particle at the current timestamp. The panic can be calculated by the following equations.

$$\delta_1 = (D_i - 10 * r_i) / L \quad (10)$$

$$\delta_2 = (\|\vec{v}_i^*\| - \|\vec{v}_i\|) / v_{max} \quad (11)$$

$$\delta_3 = (v_{norm} - \|\vec{v}_i\|) / v_{max} \quad (12)$$

$$\delta_4 = (e_i^* - e_i) / e_{max} \quad (13)$$

$$\delta_5 = \begin{cases} 1, & \text{if } n_i^* = 0 \\ \frac{1}{n_i^* + 1}, & \text{if } n_i^* \geq 1 \end{cases} \quad (14)$$

$$\Delta_i(t) = \frac{1}{5} \sum_{k=1}^5 \delta_k \quad (15)$$

$$\gamma_i(t) = \frac{\gamma_i(t-1) + \Delta_i(t)}{2} \quad (16)$$

3. Simulation Results and Discussion

The simulation scenario is a square room that side length is 33 meters. The width of single exit is 3 meters. For the discussion below, the ranges and default settings of parameters is shown in Table 2. The sum of weights $\{m_g, m_c, m_a, m_s, m_o\}$ is 1. When the panic value of an individual is larger than 0.5, the weights m_a, m_s, m_o would be set to 0 for simulating the herding behaviour.

Table 2. Parameter selection of simulation experiment

Parameter	Default Value	Span
v_{max}	2.0	2.0
v_{norm}	1.6	[1.2,1.8]
r_i	random	[0.25,0.4]
touch-r	3.0	3.0
m_g	0.7	[0.5,1]
m_c	0.05	[0,0.3]
m_a	0.05	[0,0.3]
m_s	0.1	[0,0.3]
m_o	0.1	[0,0.3]

3.1 Entropy and Evacuation Time

By varying the radius of visible region and the number of particles, the comparison results are shown in Table 3 and Table 4.

Table 3. Average evacuation time vs. radius of visible region (200 particles by default)

Vision Radius	5m	7.5m	10m	12.5m	15m
Without Entropy	684.1	342.3	153.6	83.7	37.8
Shannon Entropy	686.7	362.2	155	85.9	38.8
Boltzmann Entropy	704.4	373	173.9	90.2	40.2

Table 4. Average evacuation time vs. number of particles (vision radius is 10m by default)

Number of Particles	50	100	150	200	250
Without Entropy	132.4	149.1	153.2	163.6	178.1
Shannon Entropy	140.2	166.6	167.9	172.4	186.5
Boltzmann Entropy	144.5	169.1	179.2	186.7	204

It is obvious that the crowd chaos led to the increase of evacuation time. The smaller the radius of visible region or the more evacuation particles, the longer the evacuation time. As the radius of visible region increases, the influence of crowd chaos on evacuation behaviour gradually weakens. Compared with Shannon entropy, Boltzmann entropy is more sensitive to the increase of evacuation number.

3.2 Entropy and Panic

Let the default number of particles be 200 while the radius of visible region is 10m. In Figure 2, the mean Shannon entropy decreases more slowly than mean Boltzmann entropy during the whole evacuation process. Figure 3 shows that the mean panic based on Boltzmann entropy fluctuates more smoothly in the late evacuation period than in the other two methods, which is more in line with the actual evolution trend of panic.

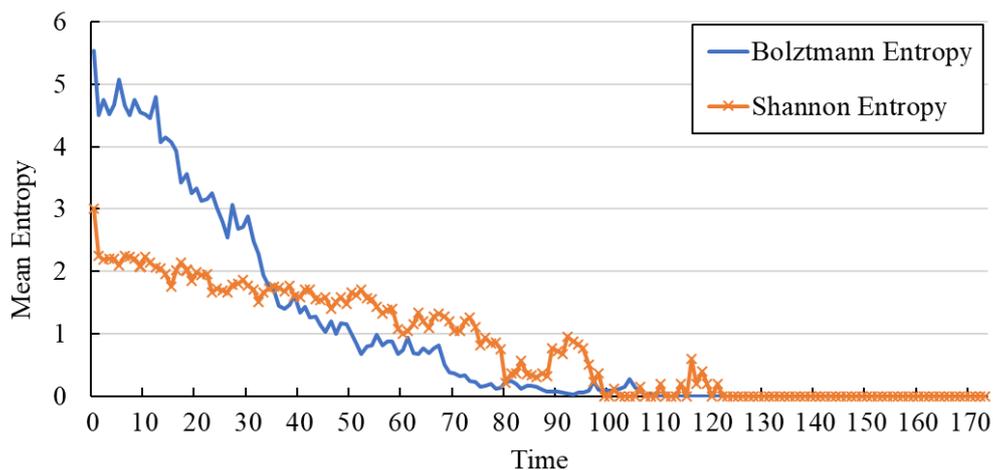


Figure 2. comparison of mean entropy.

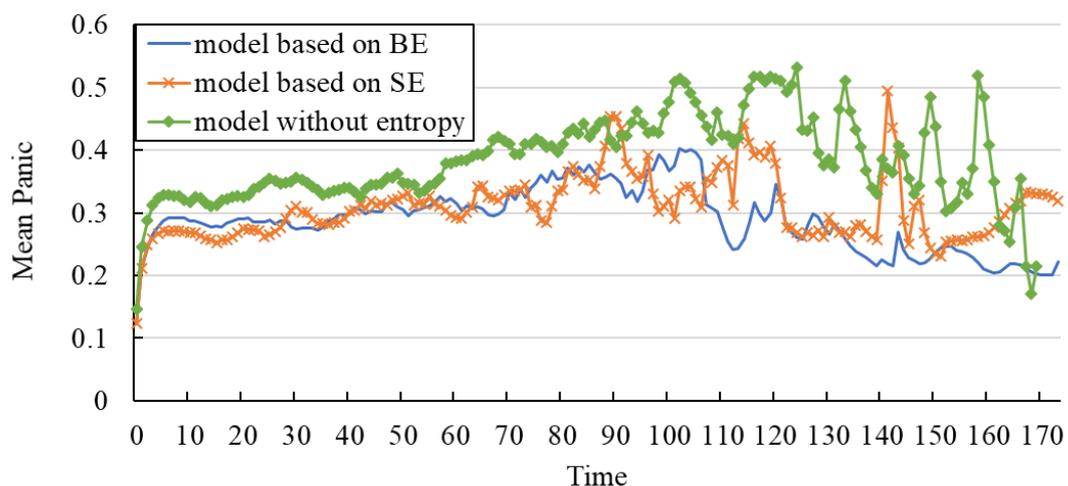


Figure 3. comparison of mean panic.

3.3 Distribution of Entropy

We also observed the escape path of the agent, which reflects the individual evacuation behavior. Then mark the coordinates of the agent with the maximum entropy at each time during evacuation for inferring the bottleneck in the room that is prone to crowd confusion or even crowded trampling accidents. Figure 4 shows that when the visible region is limited, agents tend to hover and gather in places where the exit is not visible, resulting in low evacuation efficiency. Under the same conditions, Boltzmann entropy is better than Shannon entropy in reflecting the chaotic state of people in panic.

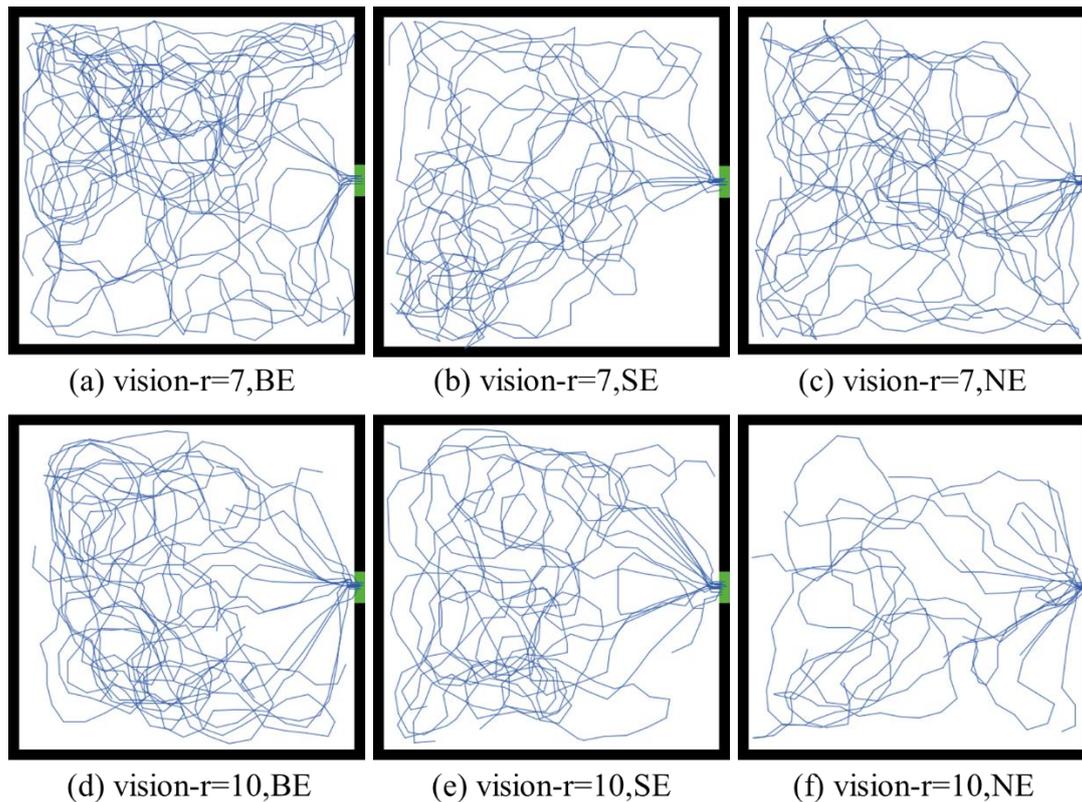


Figure 4. Trajectories of random 20 of 200 particles.

In Figure 5, pink area is the location of the particle with the maximal entropy at each time step when vision radius is 10. It can be found that the maximal entropy labelled by Boltzmann entropy is more concentrated than Shannon entropy. Therefore, the bottlenecks are easier to identify by using Boltzmann entropy.

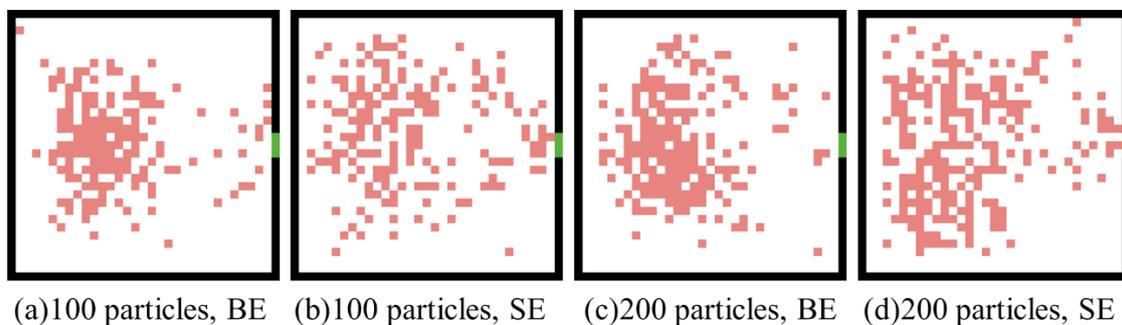


Figure 5. location of the particle with the maximum entropy at each time during evacuation.

4. Conclusions

This paper develops an agent-based model to simulate the characteristics of panic pedestrian during emergency evacuation. Another important factor, chaos which is usually overlooked, is taken into consideration in this model. The proposed model describes individual behavior through Boids Rules, while Boltzmann Entropy and Shannon Entropy are used to quantify the chaotic degree of evacuation speed and to express individual panic emotion. The simulation results show that our model can fully reflect the chaos of the evacuation panic. In future work, evacuation scenario with obstacles and guidance information would be taken into account to optimize the building structure and guidance information distribution.

Acknowledgments

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