An information perception-based emotion contagion model for fire evacuation

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Abstract: In fires, people are easier to lose their mind. Panic mood will lead to irrational behavior and irreparable tragedy. It has great practical significance to make contingency plans for crowd evacuation in fires. However, existing studies about crowd simulation always paid much attention on the crowd density, but little attention on emotional contagion that may cause a panic. Based on settings about information space and information sharing, this paper proposes an emotional contagion model for crowd in panic situations. With the proposed model, a behavior mechanism is constructed for agents in the crowd and a prototype of system is developed for crowd simulation. Experiments are carried out to verify the proposed model. The results showed that the spread of panic not only related to the crowd density and the individual comfort level, but also related to people's prior knowledge of fire evacuation. The model provides a new way to carry out safety education and evacuation management. In the future, it is possible to avoid and reduce unsafe factors in the crowd with the lowest cost.

Key Words: emotion, emotional contagion, crowd simulation, panic, crowd behavior

1. Introduction

Emotion is a kind of mental state that with organization, timeliness, and continuous changes. Emotional contagion is an interaction process that one person's emotions will trigger similar emotions in other people. Although emotion and emotional contagion have been studied deeply in the field of psychology [1] [2], their concepts are very abstract in the field of computer simulation. How to represent the phenomenon of emotional contagion vividly and describe the process with a quantitative model is a hot and difficult topic in the development of crowd simulation.

For crowd simulation, existing studies always focus on the collision avoidance and path planning. With these approaches, the crowd can be generated, but cannot behave realistically. In the real world, when fires happen, the crowd may in panic situation. In 1903, the Chicago Iroquois Theater had a major fire. The whole theater fell into chaos due to no orderly guidance. Panic crowd trampled each other and caused death and destruction on a massive scale. In 2005, another fire happened in a theater, Cairo, Egypt. When panic crowd rushed toward the exit, lot of people were pushed down. A great deal of people dead or injured in this accident. Similarly, a Shenzhen Dance Club had a fire in 2008. From surveillance video (shown in Fig. 1), it is not difficult to find that the crowd fled in panic. There are several exits in the club, but lots of people rushed to the

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front door (left in the picture). Only a few people fled from other exit. The accident caused 43 people dead and 65 people injured.

Fig.1. A surveillance video for a club fire

In the fire, people are likely to be irrational. In this circumstance, the process of emotional contagion and the judgment for behavior are different from the normal. As individuals in the crowd will be controlled by the emotion and panic, rational judgment is not suitable for individual's behaviors any more. Under the influence of emotion, shortest path finding and fast leaving will be replaced by an optimal path finding and aggregation behavior. Besides that, in existing models, the crowd density is always related to individual's velocity. Its impact on psychological burden and emotional contagion has not been discussed thoroughly. However, overweight psychological burden may cause falling or fainting in the crowd and lead to plague-like panic.

This paper studies the phenomenon of emotional contagion from the perspective of social psychology. Based on the individual information space, the model of emotional contagion is established. The model can effectively simulate behaviors during fire evacuation. By analyzing and comparing crowds with different initial states and corresponding behaviors, it provides a new way to manage crowd scientifically.

The paper has the following structure: in the next section, we review the related work. In the third section, we use information space and information type to describe the transmission process of the information. In the fourth section, we propose a method to describe individual's behavior in a panic crowd. In the fifth section, we use the proposed model to simulate various behaviors in the fire. Finally, we draw our conclusions in the last section.

2. Related work

Since 1980, researchers have started to simulate evacuation process using computer technology. Virtual simulation had become an important part of computer application. According to features of evacuation, exiting crowd simulation methods can be classified into three categories: flow-based approach, entity-based approach, and agent-based approach [3][4]. The flow-based approach significantly reduces computational cost as it ignores individual characteristics in the crowd. The entity-based approach generates crowd animation rapidly without character behaviors. The agent-based approach treats each individual as an autonomous agent. Hence, it can model individual's behavior and characteristics but with a high computational cost [5]. For example, Song et al. proposed an agent-based prototype simulation system to research emergency management. They use agent's identifier (ID), physical states, psychological states, social relationships list and other properties to describe agent's states and behaviors in computers [6].

Existing crowd evacuation model can be divided into five categories: the particle model, the social force model, the fluid dynamics model, the artificial intelligence model and the hybrid model.

In the particle model, every individual is regarded as a particle in N-dimensional space. Bouvier and Cohen [7] proposed a microscopic particle model that described and simulated the crowd behavior with the physical model. This classical algorithm could simulate large-scale crowd and can be applied to museum and dense crowd evacuation. With macroscopic dynamic behavior, Corradi [8] proposed an interactive particle model. In this model, pedestrians were regarded as particles interact through pairwise "social forces". Both of these studies focused on the crowd behavior model.

The social force model was first proposed by Helbing [9]. It is used to describe individual's behaviors and effects of forces between them. The model is particularly suitable for describing stress accumulation under a state of panic. Parisi and Dorso [10] proposed a dynamics social force evacuation model that considers velocity for both indoor and outdoor environment. Their model showed that the higher the degree of panic, the faster individuals would be willing to move in the room. After passing through the exit, the velocity of individual would slow down. Seyfried [11] treated individuals as self-driven objects moving in a continuous space. Based on the modified social force model, they analyzed several interactions among individuals qualitatively.

The fluid dynamics model uses the dynamics model in the fluid to simulate crowd movements. Hughes [12] extended 2D fluid equations with a continuous model to control pedestrian's movement. When an emergency occurs, pedestrian's movement could be presented and controlled by nonlinear partial differential equations. The most difficult point for this model is to set boundary conditions for corresponding psychological state of the crowd. Treuille [13] proposed a real-time crowd model based on continuum dynamics. The model simulated a continuum crowd as a particle. It is suitable for rendering and building a stable and efficient simulation system. In this model, a dynamic potential field simultaneously integrated global navigation with moving obstacles. It could efficiently solve the motion of large crowds without the need for explicit collision avoidance. However, this approach has its drawbacks in describing individual's reaction and sensitivity. Oguz [14] simulated virtual crowds in emergency situations caused by an incident, such as a fire, an explosion, or a terrorist attack. They used a continuum dynamics-based approach to simulate crowd.

The artificial intelligence model simulates crowd by constructing a hierarchical model according to people's thoughts and behaviors in the reality. Niederberger [15] proposed a hierarchical and heterogenous agent model for real-time crowd simulation. The approach facilitated behavior development through specialization of existing behavior types or weighted multiple inheritance in order to create new types. It is suitable for the multi-agent interactive simulation. Luo [16] designed a behavior model for virtual humans in a crowd simulation under normal-life and emergency situations. The model employed a layered framework to reflect the natural pattern of human-like decision making process. In this paper, the framework consisted of three modules: crowd behavior module, the individual behavior module, and the physical behavior module. However, the module is too specific to be applied to other crowd simulations. Stephane [17] proposed a multilevel model of a physic environment for the simulation of crowd in a virtual 3D building. With this model, agent is not only a moveable pedestrian. It can adapt to the surrounding environment.

The hybrid model does not belong to any category. With this approach, different models will be chose and mixed to deal with different situations. For example, Ondrej [18] proposed a vision-based approach for collision avoidance. Compared to previous vision-based models, this model utilized theories of cognitive science. Agent's movements and collision avoidance were controlled by an optic flow-based approach. Compared to previous collision avoidance models, this model improved agents' autonomous performance and enhanced their self-organization pattern. Furthermore, it can increase efficiency and avoid locking situations. Sean [19] proposed an asymmetric interaction mechanism. The mechanism could describe interaction between agents more authentically. Combined with other models, it can be applied in many scenarios.

Although numbers of models have been proposed for crowd simulation, most of them centered on behavior characteristics, path finding and collision avoidance. These models are scientific but not humanized. They can simulate normal crowd, but cannot describe irrational crowd. Actually, people tend to be irrational in lots of emergencies. In that case, mood and emotion should be taken into consideration. Ortony et al. proposed the famous OCC emotional model as early as 1998 [20]. According to objectives, events and actions, they divided emotion into 22 categories. The model is the first emotional model that can be easily implemented on the computer. It was quickly accepted by computer scientists and psychologists. Based on the matric in the OCC model, Egges [21] proposed a generic model for personality, mood and emotion simulation. Jed expended the OCC model in [22]. They allowed users to employ all of their social and cultural skills in both decision making and in interaction with other agents.

Individuals' emotion and emotional model have been applied in crowd simulation in recent years. Emotional contagion is the focus of these studies. Takeshi Sakuma [23] proposed a psychological model for simulating pedestrian behaviors in a crowded space. The avoidance behavior of the model depended on the positional relations among surrounding persons, on the basis of a two-stage personal space and a virtual memory structure as proposed in social psychology. Taking crowded subway station as an example, Liu Zhen [24] studied how emotion spread in the crowd and discussed how managers worked in the emergency. Huang Peng [25] proposed an agent emotional model for emergencies and constructed a formula to calculate the specific value of emotion. Soumya [26] studied and analyzed the crowd behavior by using an emotion based analytical model.

3. Information transmission description

3.1. Information space

Everyone has its own and independent information space. Just as computer's memory, the capacity of information space is limited that information has certain timeliness. Once the capacity is full, new information will cover the old one. According different sensory modalities (vision, audition, and touch), we divide information space into three kinds of categories: the visual information space, the auditory information space, and the tactile information space. Each space has its own rule for variety, range and degree. Following these rules, information can be perceived.

3.1.1 Visual information space

Within the range of vision, an individual can avoid collision with obstacles or other people. It can get information about evacuation guidance, current emergency, and surrounding building. In this paper, a fan-shaped view volume is limited to the direction of movement. As shown in Fig.2, the range is formed by rotating a certain angle from the current direction.

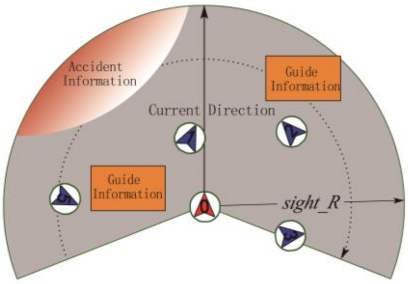


Fig. 2. Visual information space

Let v_i be the velocity of individual P_i , r_i be the radius of its body, and (x_i, y_i) be the current location. In the field of view, the path for each individual is determined by its information space. In the visual information space of individual P_i, we can get information about accident risk assessment, other individual P_j's location (x_i, y_i) and velocity.

3.1.2 Auditory information space

Information conveyed through the auditory pathway is known as auditory information. In contrast to visual information, the range of audition is related to the radius but not the direction. In the crowd, through the auditory pathway, an individual can share the evacuation knowledge and experience, emergency information and other effective information among groups. As auditory information derives from communication, it has initiative, sociality and selectivity. Based on certain social relationships, sender sent information actively to a specific target to reduce or avoid injury in the emergency. The recipient's ability to receive the auditory information also relates to these relationships. Meanwhile, non-target individuals within the valid range can also perceive the auditory information. However, since the non-target recipient and sender have no specific social relationship, individual's characteristics (e.g., sensitivity) will determine whether and how much it can obtain the information.

As shown in Fig. 3, the auditory radius of individual 0 is *hear_R*, within which individual 1 and individual 2 can transmit auditory information. Individual 1 is the sender; individual 2 is the receiver that has relationship with 1. Individual 0 can hear the information in its auditory radius. However, it may not receive the information as it has no relationship with individual 1. Hence, even the same information sent by the same individual, different receiver will obtain different levels of information. If the receiver has relationship with the sender, the obtainable information is determined by their relationships. If the receiver has no relationship with the sender, the obtainable information is determined by its personality and preference.

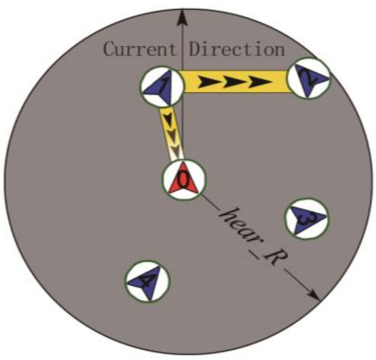


Fig. 3. Auditory information space

3.1.3 Tactile information space

Tactile information is the complementary to visual and auditory information. As audition, the range of touch is also related to the radius but not the direction. Through touching, individual could obtain information about emergency and comfort level, like temperature. This kind of emergency information is important and can only be obtained by the touch but not the vision and the audition.

As for comfort level, it refers to individual's feeling about environment. With different personalities, different individuals may have different standards for comfort. In this paper, we only consider the comfort level in panic situation. As in this kind of situation, influenced by the crowd assimilation and the psychological pressure, personality can be ignored. Comfort level is mainly related to the surrounding local crowd density ρ, which can reflect crowd density in a space. For individual i, the local crowd density ρ_i refers to the number of people per square meter that surround it.

Fig. 4 represents the overall information space for individual i, *Sight_R*, *hear_R*, *touch_R*, and *body_R* are visual radius, auditory radius, tactile radius, and physical space radius that occupied by the individual respectively.

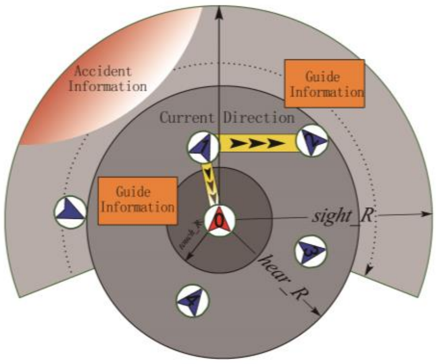


Fig. 4. Information space for an individual

3.2. Different types of information in the crowd

Information exchange is a behavior that happened consciously or unconsciously, anytime, anywhere between people. There are various types of information can be shared. Different people process and evaluate information in different ways under different circumstances. In this paper, we discuss information that will affect individual decisions in times of panic. According to factors that have effects on crowd's evacuation ability in times of panic, we divide the information into five categories: accident information (*AI*), building information (*BI*), dynamic obstacle information (*SI*), knowledge and experience of evacuation (*KI*) and comfort information (*CI*).

3.2.1 Accident information (AI)

Accident information affects individuals or crowd directly. When the crowd is surrounded by the smoke in a fire, individuals would try to escape through the smoke. During the evacuation, some of them would give up, return, or stay in a place waiting for rescue as they are scared of the dark or have a poor sense of direction. *AI* information can be classified into implicit information and explicit information. Implicit information refers to information that has positive effects on the individual or the crowd. For example, when an individual is in a danger zone, it can obtain dangerous information through auditory information. Then it will have active avoidance behavior, which can avoid or reduce panic. Explicit information refers to information that has negative effects on the individual or the crowd. This kind of information may increase fear among individuals or the crowd. For example, when the crowd is in a danger zone and cannot escape from it, the explicit accident information will increase their fear sharply.

The value of *AI* is set between -1 and 1. It is assigned according to the extent and influence of the fire. 1 means *AI* has the greatest negative effect on the individual, -1 means *AI* has no effect on the individual. *AI* is determined by the fire point and the tactile information space of individual. Let *Fire* (*x, y*) be the location of the fire, $fire\_R(0)$ be the initial radius of the fire, $fire\_d_i$ be the distance between the source of information and individual *i.* as shown in Fig.5, there are three types of relative positions between an individual and accident information:

(1) If $fire\_d_i \leq fire\_R(0)$, the individual is in the fire area:

$$AI_i = 1 - \frac{fire\_d_i}{fire\_R(t)} \tag{1}$$

(2) If $fire\_R(0) < fire\_d_i \leq fire\_R(0) + sight\_R_i$, the individual is not in the fire area, but it can see the fire:

$$AI_i = 1 - \frac{2\,fire\_d_i}{fire\_R(0) + sight\_R_i} \tag{2}$$

(3) If $fire\_d_i > fire\_R(0) + sight\_R_i$, the individual is far from the fire and the fire has no influence on the individual itself. However, the individual can obtain the accident information by others round it:

$$AI_i = \sum_{j=1}^{hear\_n_i} \frac{n+1-j}{(n+1)} AI_i \tag{3}$$

Where j is an individual within auditory range of individual *i*, $hear\_n_i$ is the total number of individuals around, *fire_R* is a variable that varies with time *t*. In most emergencies, the extent of emergency expands over time. The expanding speed is determined by several factors, such as the type and the place of emergency. We use function $fire\_R\ (t)$ to represent the fire area. $fire\_R\ (0)$ is the fire radius at the initial status ($t = 0$).

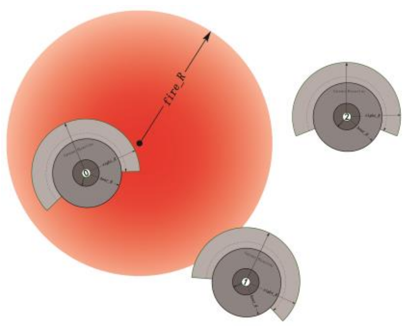


Fig. 5. Relative positions of an individual and accident information

3.2.2 Comfort information (CI)

Comfort refers to the individual's feeling about the surroundings. It not only relates to local crowd density, but also relates to the distance between individuals. For example, if the unit crowd density of *i* is 3 persons/m^2. These three persons may be at the edge of *i*'s tactile radius or surround it tightly. For these two circumstances, although they have the same ρ_i, which equals to 3, the comfort level of the individual is different.

Assuming that there are $touch\_n_i$ individuals in the tactile radius $touch\_R_i$ of the individual i, $body\_R_i$ represents the physical space radius that occupied by i, d_{ij} is the distance between the individual i and the individual j that is one of other individuals around i. $d_{min}=\min\{d_{i,1}, d_{i,2}...d_{i,touch\_nexj}\}$, which represents the minimum distance between individual i and others. Comfort information CI_i can be calculated by formula (4):

$$CI_i = \begin{cases} 0, d_{min} > R_{ti} \\ \left(\dfrac{n_t d_{\min}}{\sum_{j=1}^{n_t} d_{ij}} \right) \dfrac{\rho_i}{\rho_{\max}}, R_{t0} < d_{min} \le R_{ti} \\ 1, d_{min} \le R_{t0} \end{cases} \quad (4)$$

Where ρ_i is the density of the crowd and $\rho_{\max}$ is the maximum density of the crowd.

The comfort level affects the degree of panic of an individual. When $CI_i =0$, the individual is in the comfortable status. It won't feel panic. When $CI_i =1$, the individual is very uncomfortable. The feeling will have the maximum effect on the panic. Details are described in the next section. While the value of CI_i is between 0 and 1, CI_i is closely related to the crowd density. Usually higher crowd density leads to bigger CI_i.

3.2.3 Knowledge and experience of evacuation (KI)

The knowledge and experience of evacuation is positive to an individual, since it makes an individual has positive emotion in the emergency. With *KI*, individual can calm down quickly and make a sensible judgment. *KI* transmits within the auditory information space. The receiving effect is affected by the distance between the information source and the individual, and the social relationship between the sender and the receiver. In this paper, $KI \in [0,1]$.

Let D_{ij} be the distance between the individual and the sender, δ be the social relationship coefficient of the individual i and the sender j, $\delta \in [1,2]$. Bigger δ indicates closer relationship. Let KI_{ij} be the evacuation knowledge and experience received by i from j, $\mu(KI_{ij})$ be the receiving effect of KI_{ij}. It can be expressed by D_{ij} and δ together, and is affected by the auditory radius of i:

(1)If $D_{ij} \le 2body\_R_i$, the auditory information can be received best:

$$\mu\left(KI_{ij}\right) = \delta - 1 \quad (5)$$

(2)If $2body\_R_i < D_{ij} \le hear\_R_i$, let $D_+ = 2body\_R_i + hear\_R_i$, $D_- = hear\_R_i - 2body\_R_i$. Then $\mu(KI_{ij})$ can be calculated as follows:

$$\mu\left(KI_{ij}\right) = \left[\frac{1}{2} - \frac{1}{2}\sin\frac{\pi}{D_-}\left(D_{ij} - \frac{D_+}{2}\right)\right]\delta \quad (6)$$

(3)If $D_{ij} > hear\_R_i$, the distance between individuals is "far enough", and the auditory information cannot be shared completely.

$$\mu\left(KI_{ij}\right) = 0 \quad (7)$$

Assuming there are $hear\_n_i$ individuals in the auditory radius of i. KI_i is the maximum value of $\mu(KI_{ij})\cdot KI_j$ that represents effects from other $hear\_n_i$ individuals, and its own KI_i:

$$KI_i(t) = \max\left\{KI_i(t-1), \max_{j=1}^{hear\_n_i}\left[\mu\left(KI_j\right)KI_j\left(t-1\right)\right]\right\} \quad (8)$$

Where t is an arbitrary time, t-1 is the last moment of the time, j is an individual within the auditory radius of individual i. The value of j is: j=0, 1, 2, … , $hear\_n_i$. Equation (8) means an individual will select the most effective knowledge or experience of evacuation. If the received information is less effective than its own information, it will use its own knowledge or experience to escape.

3.2.4 Building information (BI) and dynamic obstacle information (SI)

Dynamic obstacle information is updated in each animation frame according to all existing building information and dynamic obstacle information. Individuals can perceive environment through visual information, auditory information and tactile information.

Obstacles are something that block progress or affect path planning of an individual. Dynamic obstacle information refers to information that has timeliness. It can be an obstacle that occurs suddenly (such as coordinates for expanding fire range, or falling objects from a building in the fire).

Building information (*BI*) and dynamic obstacle information (*SI*) affect the movement of an individual. *SI(x, y)* and *BI(x, y)* are the coordinate information for building and dynamic obstacle respectively. Building information (*BI*) is static and never changes once it generated. Dynamic obstacle information (*SI)* has the timeliness and updates output regularly.

4. Individual behaviors in crowd contagion

4.1 Calculating the panic

Panic is caused by the lack of ability to cope with problems or get rid of terrible or unfamiliar situations. Panic is an extreme tense and frightened emotion that caused by people are confronting with dangerous cases. The emotion is a human instinctive reaction that will enhance the ability of self-defense and danger avoidance. Since the panic in the crowd is spreading continuously, we regard emotional contagion as a kind of information dissemination that happened in panic. In the previous section, we presented three types of information transmission paths (vision, audition and touch); proposed five types of information (*AI*, *BI*, *SI*, *KI*, and *CI*), and described the transmission of the information. Next, we will discuss how individual's panic will be affected by information that obtained from its own information space.

For an individual, there are four radii in its information spaces: *sight_R, hear_R, touch_R,* and *body_R.* Information spaces can be represented by a five-tuple array P_i [AI_i, CI_i, KI_i, BI_i, SI_i]. Table 1 describes the transmission path of each component, the range of effective radius that can be used to calculate, and the number of individuals within the radius that can interact with the individual. There are differences between the five components due to the shared method, storage space and the effective range.

Table 1 Parameters for information transmission

Information type	Transmission path	Relevant radius	The number of interactive individuals

AI	vision、audition	sight_R hear_R	sight_n∩hear_n
CI	touch	touch_R body_R	touch_n
KI	audition	hear_R body_R	sight_n
BI	vision	sight_R	sight_n
SI	vision	sight_R	sight_n

In this table, sight_n, sight_n, touch_n and sight_n∩hear_n represent the number of individuals in the range of vision, audition, touch and mutual range of vision and audition respectively.

After obtaining information from other agents within the valid range (listed in Table 1), individual will update its information space to generate the next behavior. In the P_i [AI_i, CI_i, KI_i, BI_i, SI_i], AI_i, CI_i, KI_i are abstract information that can be used to update the panic degree of individual i at each moment with the formula 9. It means in the stage of information processing, the main task is to make an emotional process for the information that is obtained by the individual. The process transforms the information into the emotion. BI_i, SI_i are specific information which can be used to navigate and update the direction of individual i at each moment.

$$Panic_i(\mathrm{t}) = \begin{cases} \dfrac{CI_i^{\frac{1}{2}}(\mathrm{t}-1)\cdot\left[1+AI_i^{3}(\mathrm{t}-1)\right]}{\lambda KI_i(\mathrm{t}-1)}, AI_i \le 0 \\ \alpha AI_i(\mathrm{t}-1)+\beta CI_i(\mathrm{t}-1)-\gamma KI_i^{\frac{1}{2}}(\mathrm{t}-1), AI_i > 0 \end{cases} \quad (9)$$

In formula (9), λ, α, β and γ are the correlation coefficients.

4.2 The characteristics of individual behaviors

When the density of crowd is lo-w enough, people will change their directions to avoid obstacles 15-30m before them. When the density of crowd is high enough, there is no space for pedestrians to change direction. They will adopt "sideways and step" approach or slow down approach to avoid obstacles. These approaches may be adopted at approximately 1.5m before obstacles. Panic behavior can be considered as a kind of frightened or escaped behavior, which is the sensitive behavior that surpasses the rational behavior. Unlike common situation, rules for crowd movement in panic scenarios are different. The specific rules are as follows:

(1) When people are in crowded situations, it is better for them to choose the route which can help them to reach the destination fast instead of the shortest one.

(2) Walking at people desired velocity (ie, minimum energy consumption). The expected velocity of the crowd is Gaussian, with an approximate average of *1.34 m / s* and a standard deviation of *0.26 m / s.*

(3) It will maintain a certain distance that between pedestrians and pedestrians, or pedestrians and borders (walls, obstacles). If the anxious is rising, the distance will become smaller; if the crowd density increasing, the distance will be narrowing.

4.2.1 Individual velocity

The individual motion posture can be defined by two Cartesian coordinates x, y and the direction angle θ. If these three values are arranged in a vector, any particular state can be defined by $P_i(t)$=($x_i(t)$,$y_i(t)$,$\theta_i(t)$).

The deterministic motion model for each time interval is:

$$P_i(t+1) = P_i(t) + \begin{pmatrix} v_i(t)\cdot\Delta t\cdot\cos\theta_i(t) \\ v_i(t)\cdot\Delta t\cdot\sin\theta_i(t) \\ \omega_i(t)\cdot\Delta t \end{pmatrix} \tag{10}$$

Where v_i *(t)* and $w_i(t)$ are the translational velocity and the rotational velocity of agent *i* at time *t*. $v_i(t)$ is affected by the density of the surrounding crowd [27] and agent's emotion [28]. It can be expressed by the following formula:

$$v_i(\mathrm{t}) = \begin{cases} [1-panic(t)]v_i(0) + panic(t)v_{i\max}, \rho \le 0.75 \\ [1-panic(t)]\left[1-e^{-1.913\left(\frac{1}{\rho_i}-\frac{1}{\rho_{\max}}\right)}\right]v_i(0), 0.75 < \rho_i \le \rho_{\max} \end{cases} \tag{11}$$

Where $V_{i\,(0)}$ is the initial velocity of the agent *i*; $V_{i\max}$ is the maximum ideal velocity of the agent *i*, and

panic (t) is the degree of the panic of the individual at time *t*. When the crowd density is low enough, the main factor that affects velocity is individual's own panic. That means individuals are more eager to escape with more panic. Therefore, higher emotional value will lead to faster speed. Whereas, when the crowd density is very high, the velocity depends not only on panic but also on crowd density. When the panic is increasing, and the crowd density is increasing, the individual's speed will decrease. That is "faster is slower" phenomena. When the crowd density reaches its upper limit, the speed of the individual will be 0. It is hard to move since there are loads of people are stuck here.

4.2.2 Finite state machine based behavior selection

According to the actual analysis of the crowd behaviors in the panic situation, the individual behaviors can be divided into four states: start, walking, staying, and falling-down. Each state can be represented by a point. As shown in Fig. 6, the motion diagram indicates paths between each state transition. Every state is corresponding to the respective trigger conditions and manifestations.

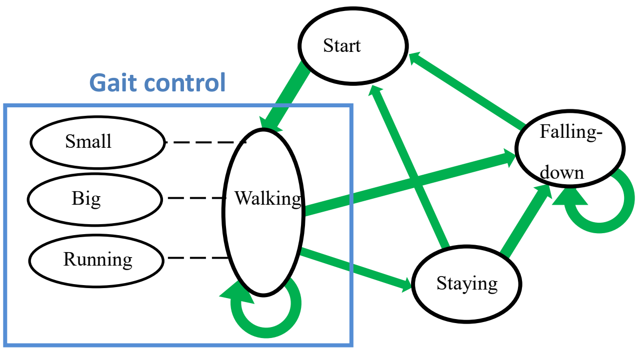


Fig.6. A transitions diagram for each state

The initial state for each individual is the start. In the start state, the initial velocity for an individual *i* is $v_i(0)$. The start state can be re-entered from the other states. Once an individual enters into the start state, its velocity will be reset to $v_i(0)$. After the start state is the walking state. With the local crowd density ρ_i and the current panic degree *panic*(*t*), the walking velocity and the gait control can be calculated by the formula (11). While walking, if the crowd density exceeds 4.2 people/m^2, or it is difficult to find a path, or individual encounters an obstacle that cannot be avoided, the individual will go to the staying state until the predicament relieved. After that, it will re-enter the start state. There is some probability that individual will fall down. The falling-down state may be transferred from the walking state or the staying state. The probability is determined by a variety of factors, such as genders, ages, constitution, surroundings, crowd density and so forth. In the experiment, the falling probability of each individual can be randomly assigned according to the fall rate in real life.

5. Experiments and results

We carry out two experiments in this paper. The first one compares the proposed model and the social force model, which is a representative model in crowd simulation [9]. Experimental results show that the proposed model can well describe the mutual effect between agents. The second experiment simulates the crowd evacuation process with the proposed model. We explore how the navigation, evacuation knowledge and comfort affect emotion in this experiment.

5.1 Experimental environment

This paper focuses on the behavior simulation of the panic crowd in the fire, and realizes the proposed model of emotional contagion and related algorithms. Experiments are implemented on a computer with Intel Xeon E5-2630, 2.60GHz, six-core CPU, 12G RAM, Nvidia Quadro K6000 graphics card, and Windows 7 Professional 64-bit system. Experiment 1 is developed using Visual Studio and experiment 2 is developed using Unity3D.

In Experiment 2, an optical motion capture device-Motion Analysis is used to capture the data of human motion. The device has some special clothes suits, 12 cameras, 40 sensitive points (per person) and Cortex 5.3 software.

Before the collection, 40 sensitive points need to be stuck on important parts of the performer's body and motions need to be calibrated. 3D human motion data can be collected from the performer that performed in the stage (see Fig.7). Then we bind these motion data to skeleton models to generate character animations for characters. To sum up, the motion capture device collect common actions that may exist in the evacuation and save them in FBX files. After that, Unity3d call these motion data from FBX files and render motions for each character according to character’s current state.

Fig.7. Motion capture

5.2 Experiment 1: Compare the proposed model and the SFM

In this experiment, we simulate a fire in a supermarket. The supermarket has a rectangular shape, with a length of 120m and a width of 60m. Every shelf in the supermarket is a rectangular obstacle (green rectangle in Fig 8), with a length of 10m and a width of 3m. Assuming fire source is on the left side of the supermarket, with radius of 1m. Fire-affected area expands with the speed of 0.1m/s and fire information transmits with the speed of 2m/s. In the supermarket, there are 400 agents, with radius of 0.4m and initial velocity of 1.5m/s. The width of the exit is 6m. With the expansion of fire, the value of AI will be increased. When an agent's AI reaches 1, it will change to the evacuation state. By training input and output data in many experimental scenes, we choose one set of parameter ($\lambda = 3.5$, $\alpha = 0.654$, $\beta = 0.558$, $\gamma = 0.454$) to calculate panic degree for agent.

For each agent, evacuation route is from its current position to the blank area that near the exit. Navigation points (filled circles in Fig.8) are in the middle of the blank area. They are used to guide an agent to the exit. During the evacuation, an agent will move from one navigation point to another, which is closer to the exit. In this paper, building information *BI* refers to information about navigation point and the position of a shelf. An agent will keep at least 0.4m from the shelf. It will avoid shelves on the basis of its current coordinates and *BI*. Besides that, RVO collision detection is used to detect upcoming collision between agents [29]. With this method, dynamic obstacles can be avoided.

In this experiment, 80% of agents are familiar with the evacuation route (*KI*=1) and 20% of them are not. If an agent does not know much about the evacuation route, it will follow other agent who shares the most knowledge of the evacuation within its auditory radius (10 m).

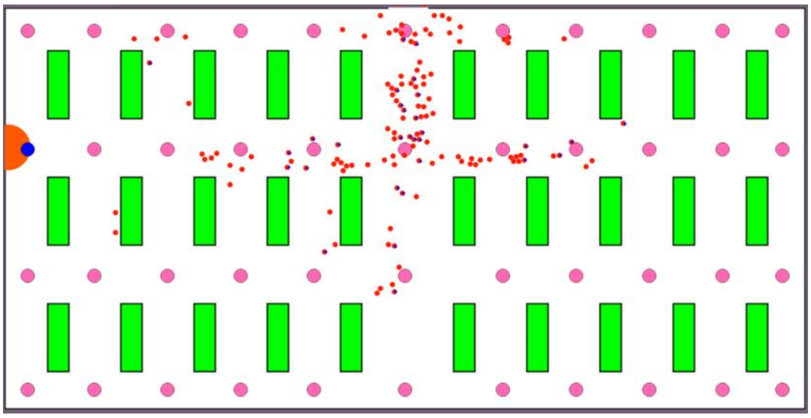


Fig. 8. Simulating fire evacuation with the proposed model

We compare the SFM and the proposed model in evacuation simulation with same parameters. Experimental results (shown in Fig. 9-11) show that SFM need more time to evacuate all agents from the supermarket. Different with the SFM, we consider navigation information and communications between agents in our model. The proposed model can simulate a phenomenon that evacuation efficiency can be increased with emotion during the evacuation. This phenomenon is consistent with the crowd evacuation characteristics in real evacuation cases [30]. This experiment proves the validity of the proposed model.

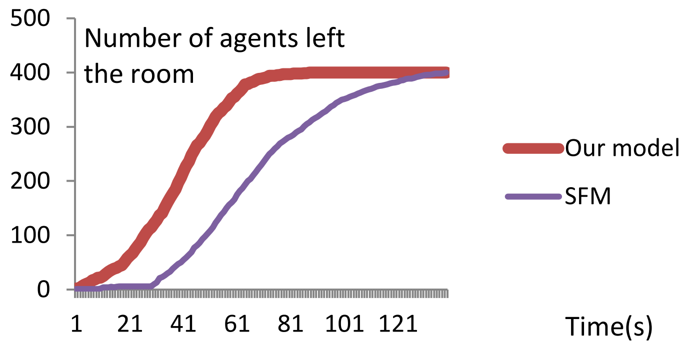


Fig. 9. Comparison of the proposed model and SFM

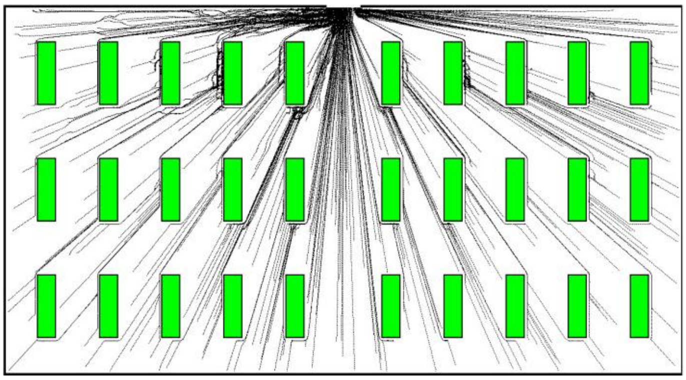


Fig. 10. Trajectories generated by SFM

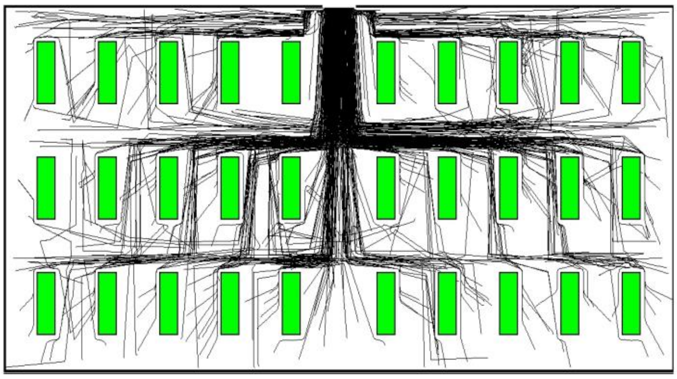


Fig.11. Trajectories generated by the proposed model

5.3 Experiment2:3D simulation for crowd evacuation

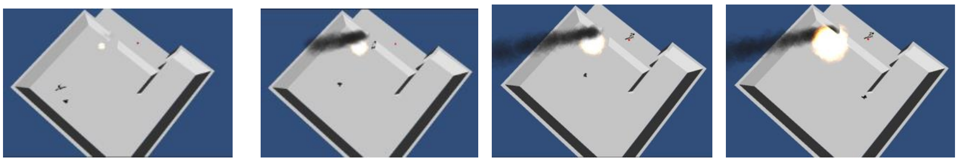
5.3.1 Navigation simulation based on BI and SI

Based on the building information *BI* and the dynamic obstacle information *SI,* we simulate navigations for agents. In this experiment, *sight_R*=10m, *hear_R*=5m, *touch_R*=1m and *body_R*=0.25m. There are two exits in the scenario that shown in Fig.12 and Fig. 13.

Fig.12 illustrates a comparison experiment for two agents A and B. Fig.13 illustrates a comparison experiment for the crowd. The initial state in Fig. 12(a) generates two agents A and B that with close location and different initial velocities (v_A>v_B). These two agents will start off at the same time, and move to the room exit. The agent can use building information *BI* as navigation instructions to find the path intelligently toward the target. In the fire, agents need to update their information space constantly to keep pace with the changing obstacle information *SI* (shown in Fig.12 (b)). In Fig.12(c), the agent A is the first one that goes through the nearest exit. At that time, the dynamic obstacle information *SI* in A's information space shows that the fire has not blocked the exit. The exit can be passed. However, while agent B arrives at the exit, the dynamic obstacle information *SI* shows that the exit has been covered by the fire and cannot be passed. In Fig.12 (d), agent B is rerouted based on the latest building information *BI* and the dynamic obstacle information *SI*.

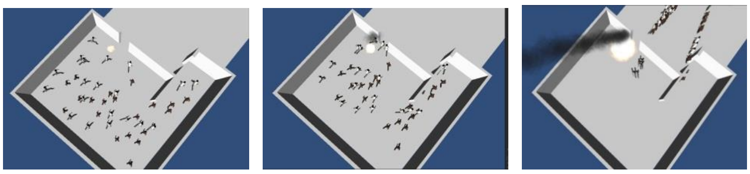
In Fig.13 (a), a crowd is generated randomly at the initial state. Fig.13 (b) shows that the fire is small. Agents in the crowd are using building information *BI* and dynamic obstacle information *SI* to find the nearest exit from the target. When the fire spread to the exit, agents will adjust their direction and find a new path according to *BI* and the latest *SI*. (shown in Fig. 13(c)).

Our experimental results are consistent with the real situation. As mentioned in the introduction, in the fire happened in Shenzhen Dance Club, most of people fled from the front door as they know where the exit is. People always use building information *BI* to determine the general movement direction and adjust their path by the dynamic obstacle information *SI*. Experiments in Fig.12 and Fig.13 show that the building information *BI* and the dynamic obstacle information *SI* in the proposed information space can simulate evacuation in fire authentically.



(a) (b) (c) (d)

Fig.12. The navigation for agents



(a) (b) (c)

Fig.13. A simulation for crowd evacuation in the fire

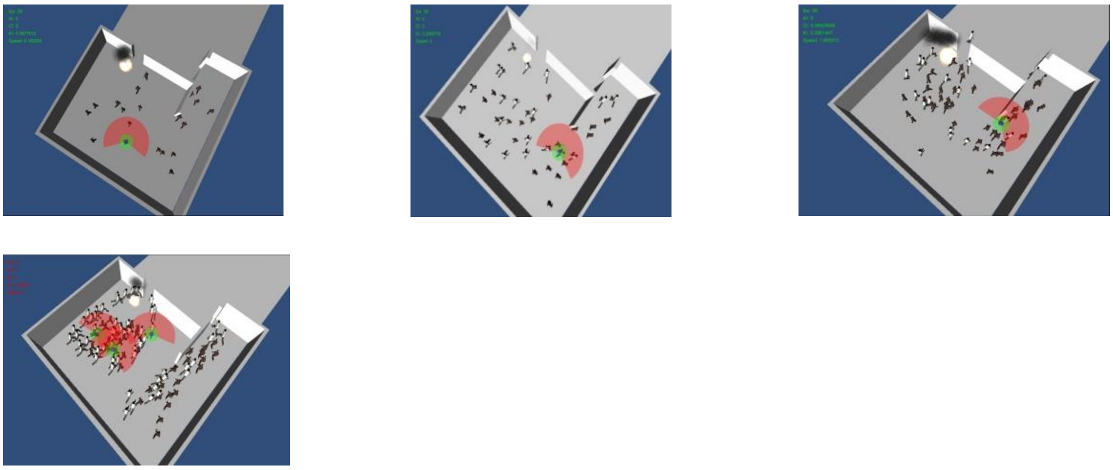
5.3.2 The impact of crowd comfort on the panic

Assuming there is no trample in the crowd, the value of comfort level will be between 0 and 1 in this experiment. According to the comfort formula, we can use crowd density to represent the comfort level approximately.

We carried out 5 experiments to simulate the indoor fire evacuation. The initial parameters for each experiment are shown in Table 3. In the scene, if the exit catches fire suddenly when the crowd leaving the room, some individuals in the crowd will be in panic. As the transmission of information is a two-way communication, the panic individuals can make the surrounding people panic and surrounding people may calm down the panic individuals with their evacuation knowledge. Finally, the overall emotion will achieve a uniform normal level with the mutual contagion and the crowd will evacuate through the other exit. Typical screenshots of this experiment is shown in Fig.14, the experiment analyzes different panic contagions that generated by different crowd densities that stands for different comfort levels.

Table 3 Initial parameters for each experiment

No.	number of persons	Scene area	Average density
1	20 persons	$25m^2$	0.8 persons/ m^2
2	40 persons	$25m^2$	1.6 persons/ m^2
3	60 persons	$25m^2$	2.4 persons/ m^2
4	80 persons	$25m^2$	3.2 persons/ m^2
5	100 persons	$25m^2$	4 persons/ m^2



(a) (b) (c) (d)

Fig.14. Evacuation simulation for indoor fire

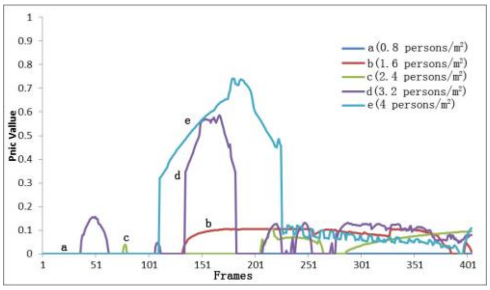


Fig.15.The change of individual panic with various crowd densities

Fig. 15 shows the trend of individual panic with different crowd densities. From the trend of curve a, b, c, we can find that when the average crowd density is less than 2.4 persons/m^2, the individual has a lower panic value in the fire. The value increases gently with less fluctuation. It indicates that the individual is able to maintain a relatively good attitude to face the emergency. From the trend of curves d and e, we find that when the average crowd density is higher than 3.2 persons/m^2, the individual has a lower panic value at the beginning. However, with time going, the panic value will explode to a larger value suddenly. The higher the crowd density, the shorter time it used to interval from normal state to panic state. During the evacuation, individual gradually away from the accident, its emotion will gradually return to normal state with time going. Through the downward trend of the second half of the curves d and e, it can be seen that the time required for calming individual from panic mood will increase with the crowd density.

5.3.3 The influence of evacuation knowledge and experience

In this section, we discuss how evacuation knowledge and experience (*KI*) will affect the crowd emotion. With different density and distribution of *KI*, experiments are carried out to simulate emotion of the crowd. Distributions of *KI* for each experiment are described in Table 4 and 5.

Table 4 Distribution of *KI* in the crowd with 1.6 persons/m^2

No.	The number of person with *KI*>0.9	Percentage of the crowd
1	5	12.5%
2	10	25.0%
3	15	37.5%
4	20	50.0%
5	25	62.5%
6	30	75.0%

Table 5 Distribution of *KI* in the crowd with 4persons/m^2

No.	The number of person with *KI*>0.9	Percentage of the crowd
7	6	6%
8	13	13%
9	25	25%
10	50	50%
11	75	75%
12	88	88%

Fig. 12 and ig.13 are results for experiments. By comparing these two pictures, we find that greater number of people with *KI* will leader to lower panic value per capita. Before reaching the highest density, the greater the crowd density, the faster the panic generated, and the shorter time needed for recovering from the panic emotion. After declining, emotional value is fluctuant in lower density crowd and stable in higher density crowd.

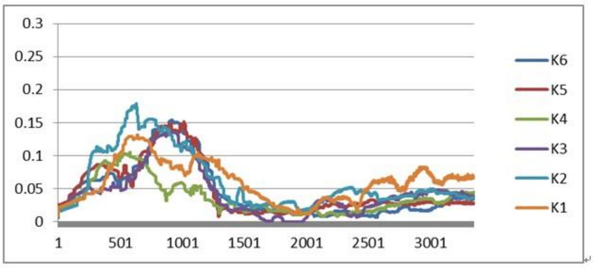


Fig.12. Different crowd panic value with different distribution of *KI* at the density of 1.6 person/m^2

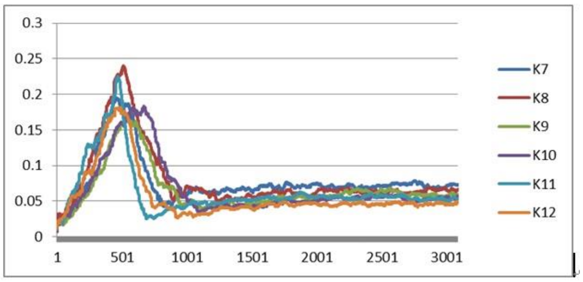


Fig.13. Different crowd panic value with different distribution of *KI* at the density of 4 persons/m^2

6. Conclusion

With continuing rise in emergencies in public places, it is of great practical significance to carry out the virtual simulation research for crowd in emergencies. Through simulation, we can deduct different crowd behaviors in different extreme scenarios to help decision-makers find corresponding solutions. In the emergencies, emotion is a crucial factor that will affect the trend of the incident. Analyzing the law of mental activities in the emergency and informing corresponding workers earlier is very important for effective management of the crowd.

Cellular automata model and social force model (SFM) [7] are typical models in the existing crowd model. However, these models regard people as a "particle" in the space. In those models, emotional factors are not fully considered and it is difficult to accurately describe crowd behavior characteristics in the emergency. Furthermore, most of the existing crowd theories are based on the data that obtained from non-emergent events or daily exercises. These data cannot reflect crowd behaviors in real emergencies. Therefore, the existing simulation methods cannot simulate crowd behaviors very well.

Aiming at the shortcomings of existing studies on crowd emotion simulation, this paper considered the process of information transmission and factors that may influence individual's emotion in the fire, explored a deduction method for crowd computing and presented a crowd emotional contagion model. Following results are obtained in this paper:

(1) Proposing the concepts of visual information space, auditory information space and tactile information space from the perspective of individual's perception. Dividing information into five categories: accident information, building information, dynamic obstacle information, evacuation knowledge and experience, and comfort level. Corresponding mathematical descriptions are given out for the information.

(2) Regarding accident factors as obstacles that change dynamically and spread continually with the time. Crowd movement can be simulated with this dynamic obstacle information.

(3) Simulating a supermarket evacuation. The validity of the model is verified by comparing with the social force model.

(4) Pointing out the correlation between the level of evacuation knowledge and the change of panic mood and presenting a calculating method for knowledge sharing among individuals in a panic crowd. The method can effectively describe the law of the change of crowd panic in varying degrees of knowledge. It also provides a theoretical basis for the preparation of crowd simulation.

(5) Realizing a 3D interactive simulation program for emotional contagion in panic crowd. By comparing several groups of data, we find that the degree of individual panic in the panic

crowd is mainly determined by three factors: accident information, individual evacuation knowledge and individual comfort level. Among them, the accident information is uncontrollable information, while individual comfort level and individual evacuation knowledge and experience are controllable factors which can be prepared in advance or use on-site management and other methods to make the crowd to achieve the most "stable" state.

When 50% of the crowd with evacuation knowledge and experience, the individual’s panic in the panic crowd can be effectively controlled, and the average value of individual panic will be smaller; When less than 50% of the crowd with evacuation knowledge and experience, the individual’s panic will spread to the crowd and constantly going on, the average value of individual’s panic is larger. Finally, the whole crowd will get into panic.

When the crowd density within the effective space is less than 3 persons / m2, and the average panic value of the crowd is small, the crowd can be maintained at a normal psychological level even in the emergency; whilst when the crowd density within the effective space is higher than 3 persons / m2, the average panic of the crowd will appear "quick increase and slow decrease" phenomenon, that is, the panic rises rapidly, and falls back slowly.

The simulation of panic crowd’s behavior is a challenging research topic, which involves many subjects, and there are also many problems worth exploring in depth. Since the work of this paper has a lot of exploration space, the next step is to collect manifold panic crowd behavior parameters and psychological parameters to improve simulation experiment of emotional contagion for the panic crowd through the technology of medical equipment, somatosensory equipment, video tracking, and so on.

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