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Asymmetric Intimacy Based Positive Emotions Contagion Peer Public Safety Evacuation Behavior

YAN MAO[1], ZIXUAN FAN[2], HUA MAO[3], AND WU HE[2]

[1]School of Business, Sichuan Normal University, Chengdu 610101, China
[2]College of Movie and Media, Sichuan Normal University, Chengdu 610068, China
[3]College of Computer Science, Sichuan University, Chengdu 610065, China

Corresponding author: Wu He (wuhe83@163.com)

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ABSTRACT Behavioral simulation plays an important role in many scenarios, such as emergency evacuation and public safety. The importance of public security in modern life can be seen in the epidemic outbreak in 2020. In particular, the epidemic can affect people's psychology and emotions and change people's behavior. Therefore, how to effectively improve people's positive emotions in a panic has become an urgent problem. In social relations, most behaviors are produced by peer interaction. To simulate the interactions among peers more realistically, this paper studies the diversity and efficiency of evacuation behaviors from the trust of peers, the strength of social relations and empathy. First, a general framework of peer relationships is constructed based on asymmetric intimacy, including the relationship between intimacy relationship modeling. Then, the problem of the dynamic formation of peer groups is studied by employing the calculation method of asymmetric intimacy. The effect of positive emotion transmission mechanism on peer interaction behaviors is explored through asymmetric intimacy. Finally, the companion behaviors of the peers in several scenarios are simulated. The proposed method is compared with different emotion contagion models and the behavioral simulation models. Experimental results show that the positive emotions contagion of the peer behavior simulation method can concrete the macro group behavior and effectively simulate the peer group in an evacuation. The simulation effects are diverse and efficient.

INDEX TERMS Behavioral simulation, emergency evacuation, asymmetric intimacy, positive emotion transmission mechanism, emotion contagion.

I. INTRODUCTION

Behavior simulation technology [1] has gradually become important research of virtual reality due to its advantages of accuracy, adaptability, and efficiency. The related research results of group motion simulation control [2] can be applied to traditional computer games, films, television special effects production, and new virtual reality interactive simulation systems. In addition, researchers use computer technology to simulate group behaviors, predict and evaluate the safety of various behaviors in real life [3]-[4]. However, how to simulate peer behavior and the diversity of interaction methods are the problems that should be explored and solved in behavior simulation.

Most behavioral simulations are based on agent models [5]-[6] or cluster system models [7]-[8]. (Those models are the based model to simulate the evacuation behavior.) They analyze group behaviors from a macro angle. However, these models are relatively simple and only can simulate simple scenarios. As the scale of modern buildings grows larger and more complex, robust models are needed to simulate the large-scale crowd evacuation. At present, behavior simulation mainly studies from the aspects of the cognitive mechanism, double-layer relationship mechanism, group structure, and emotional communication [9]-[12]. However, groups in real life usually consist of peers. Peer interaction is affected by certain factors, such as intimacy, trust, social relationship, empathy and etc.

Psychological factors are added to the simulation, and group interaction is carried out by affecting individual subjective feelings. By giving individuals different personality traits [13] or using different emotion models [14]-[15] can achieve emotion contagion [16]-[19]. In this way, the crowd movement simulation can be enriched. Lv *et al.* [20]

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proposed the behavioral evolution method of an individual's emotional infection through OCEAN (openness, conscientiousness, extroversion, agreeableness, neuroticism) model and susceptible infected recovery (SIR) model. Xue *et al.* [21] studied the emotion contagion in crowd queuing behavior. It was found that reducing negative emotions can have better control of the queue order.

In the process of peer interaction, psychological factors are extremely susceptible to fluctuations. How to promote the generation of positive emotions is an important issue to enhance the favorability of peer interaction. For example, when an emergency occurs, the positive emotion between peers can effectively reduce indifference, panic, and disappointment. This will allow you to evacuate faster from the hazardous area and to reach a safe location. In order to stimulate peer interaction behavior more realistically and effectively, this paper proposes an interactive simulation method of peer positive emotion transmission behavior based on asymmetric intimacy by combing asymmetric intimacy and positive emotion transmission mechanism. Asymmetric intimacy reflects the degree of the sparseness of peer interaction and relies on positive emotions to improve the efficiency of peer evacuation. The main contributions of this paper are listed as follows:

1. An asymmetrical intimacy model is established. Integrate factors such as trust, social relationship, empathy, etc. based on psychology and sociology have been included into asymmetric intimacy, making peer interaction behavior diverse.

2. According to the asymmetrical peer intimacy relationship, a calculation method for asymmetrical intimacy is proposed to simulate the dynamic peer interaction in real life.

3. The behavior simulation between peers is simulated by the positive emotion transmission mechanism. In this way, we can improve the authenticity and efficiency of peer interactions.

The remainder of this work is organized as follows: Section 2 reviews some related work on behavior simulation, peer relationship, and emotional contagion. The method overview of this paper is given in Section 3. The establishment of the asymmetrical intimacy model is detailed in Section 4. We present the positive emotion transmission model in Section 5. Section 6 is the experimental confirmations. Finally, Section 7 concludes this work and indicates some future research directions.

II. RELATED WORK

Behavior simulation has been explored for a long time in computer applications, public safety, and other fields. Among them, researchers focus on group sports behavior simulation. For example, social force model [22], cluster system model [7]-[8], particle system model [23], etc. The influences of personnel density, fire location, exit width, fire spreading rate, and smoke spreading rate, on the evacuation efficiency were analyzed in detail [24]. Xu *et al.* [25] proposed mutual information and the social force model (miSFM) to improve the accuracy and robustness of crowd behavior. Xu *et al.* [26] used video extraction to calculate the crowd density of each public area, which realized the analysis of group movement and the detection of abnormal behavior in various scenarios. Vermuyten *et al.* [27] presented a review of the use of optimization models for pedestrian evacuation and design problems. Sun *et al.* [28] established an evolutionary game model for the diffusion of evacuation decisions among evacuees in a complex network environment through an in-depth analysis of individual behavioral decisions. Wang *et al.* [29] simulated the evacuation problem in flood disasters. Chen *et al.* [30] improved emergency management of urban communities based on the pre-evacuation time.

Moore *et al.* [31] proposed an RCM (route choice model) based on AERS (available evacuation route set), which focuses on crowd evacuation under emergency conditions. The extended model converts the route choice into a key point in the evacuation route set. In addition, to control the selection frequency of route and keep the crowd flow stable, they implemented an inertia factor. Li *et al.* [32] established a system that individuals react to an emergency based on their social relationships. At the same time they found that various relationships present constraints on crowd dynamics and evacuation.

However, they only explored public safety issues in terms of evacuation links and evacuation factors. There is no in-depth discussion on how various aspects of subjective factors (behavior and receiver) change during the evacuation process, leading to changes in evacuation results. Most of them are used to simulate a single group movement and ignore the influence of group psychology, society, cognition, and other factors.

The main target of most peer group researches is youth peer groups. Lee *et al.* [33] studied the connection and significance between social relations and social cognition based on adolescents psychological behavior and relationship characteristics. Marshall-Denton *et al.* [34] compiled the Peer Group Normative Cognition Questionnaire, which can be used to study the impact of positive and negative normative cognition on adolescent behavior in the school environment. Mulvey *et al.* [35] revealed the important role of the theory of mind on the stereotype of young people challenging groups.

Davies *et al.* [36] investigated the ability of peer emotional expression of high school students and expanded the predictability of peer emotion. Narr *et al.* [37] proved that the first adolescent who establishes close friendships in peer relationships have stronger interpersonal skills. Szwedo *et al.* [38] studied the process of individual adolescence from a strong dependence on peers to independence. Brenick *et al.* [39] learned the behavior of peer groups through background and found that peer group behavior can affect the effectiveness of an intervention. Lin *et al.* [40] investigated the role of interaction history and message characteristics in peer communication by investigating Twitter user experience environmental awareness and intimacy.

But these peer groups are in lack of universality. The peer group in real life is not just composed of teenagers or classmates. Peers also include relatives, friends, colleagues, neighbors, etc. They should not be judged solely by their geographical proximity or age. They should be people with similar interests or can understand each others views.

Intimacy affects peers' behavioral interaction through the degree of intimacy relationships. It is an important factor to measure peer groups. Intimacy can also be used to predict conflict resolution methods. The higher the intimacy, the softer the way to deal with conflicts, and the lower the level of anger between peers. Under ideal communication conditions, the higher the success rate of conflict resolution [41]-[42]. Mastrocola and Flynn [43] explored the relationship between peer emotion and self-perceived effectiveness. It was found that the veterans peer emotional support was positively correlated with self-efficacy. Therefore, intimacy has a significant impact on peer relations.

Mao *et al.* [44] proposed the simulation of peer decision-making behavior based on emotion contagion, which started the study of peer behavior in group simulation. This method directly sat the intimacy of peers to the same value, that is, the intimacy between any two of the peer relationships was always equal. But in reality, the intimacy of peers is asymmetric and dynamically changing.

At present, the research on the influence of emotion on behavior has attracted the attention of many researchers. Related literatures in the past believe that emotions can change individual behavior under the influence of the environment. Even under appropriate conditions, these emotions can interact with groups through contagious ways.

Cao *et al.* [45] considered the influence of emotion and personality on crowd evacuation and proposed a method of emotional contagion for crowd evacuation. Hong *et al.* [46] proposed a control strategy for crowd emotional contagion coupling the virtual and physical cyberspace in emergencies.

Mao *et al.* [16]-[17] investigated group behavior simulation based on the model of emotion contagion and found that emotion is an important factor affecting behavior. Durupinar *et al.* [18] studied the influence of emotions on consumer shopping behavior through OCEAN personality traits and PAD-OCC emotion mapping model.

Nan *et al.* [47] provided a GPU-accelerated fast neighbor test and infection calculation algorithm, which is used to simulate the group's dynamic emotional infection behavior. Allen and Sun [48] used more psychologically realistic models as the basic building blocks for modeling emotions and emotional contagion, and explained emotion contagion by capturing data from human emotional contagion experiments.

The agent-based emotion contagion methods [49]-[51] are also an important means of stimulating group emotion contagion. Different types of behavioral interactions are completed by giving agents different characteristics.

Therefore, using asymmetric intimacy, this paper proposes a method of peer behavior simulation based on asymmetric intimacy. Under the premise of reasonable interaction of peer group behaviors, it implements behavior simulation of peer interaction in multiple scenarios. Through the combination of a positive emotion contagion mechanism, the computational efficiency of the simulation is improved. Simulation experiments further proves the authenticity and effectiveness of the proposed simulation method.

III. OVERVIEW OF THE METHODS

Behavior simulation is usually divided into group behavior simulation and individual behavior simulation. The whole research objects can be divided into groups of different sizes, and these groups interact within and among groups, or directly study the interaction between every individual. To achieve the interactive behavior of the peer group, this paper proposes a simulation method of peer positive emotion contagion behavior, which is based on asymmetric intimacy. First, an asymmetric intimacy model is established based on peer trust, social relationships, and empathy. Then, a positive emotional transmission mechanism is proposed to enhance the sense of reality and efficiency in the peer group. The mechanism of positive emotional transmission depends on asymmetric intimacy. Finally, the asymmetric intimacy and positive emotional transmission mechanism simulate peer interaction in different situations. The system framework is shown in Fig.1.

IV. ASYMMETRIC INTIMACY MODELING

In real life, the alienation and closeness of peer relationships are determined by intimacy. Peers with low intimacy are more alienated and those with high intimacy are closer. However, intimacy is an asymmetric factor. For example, A considers B to be his best friend, but B does not consider A to be his best friend, which is $I_{AB} \neq I_{BA}$ (I is asymmetrical intimacy, I_{AB} is the intimacy of A to B, and I_{BA} is the intimacy of B to A). This paper refers to this phenomenon as the asymmetry intimacy. This paper establishes an asymmetric intimacy model. Trust, social relations and empathy are the main factors that can affect asymmetric intimacy.

A. TRUST

Trust is an important factor that reflects peer communication. This paper affects personality characteristics and interpersonal communication through trusts, such as psychological distance and recognition. Then, the role of trust is judged in peer interaction.

When two people with low psychological distance and a high degree of recognition, we can consider that they have a high degree of intimacy, which can be calculated as

$$T = \frac{R \cdot \left[\left(S_{habits} + S_{friends} \right) \bigcap H \right]}{\tau \cdot \left(D_{psy} + D_{geo} \right)} \tag{1}$$

where T is the degree of trust, R is the degree of recognition, S_{habits} is similar habits, $S_{friends}$ is the same friends, H is the openness of the heart, τ is the distance coefficient, D_{psy} is the psychological distance, and D_{geo} is the geographical distance, $\tau \in [0, 1]$.

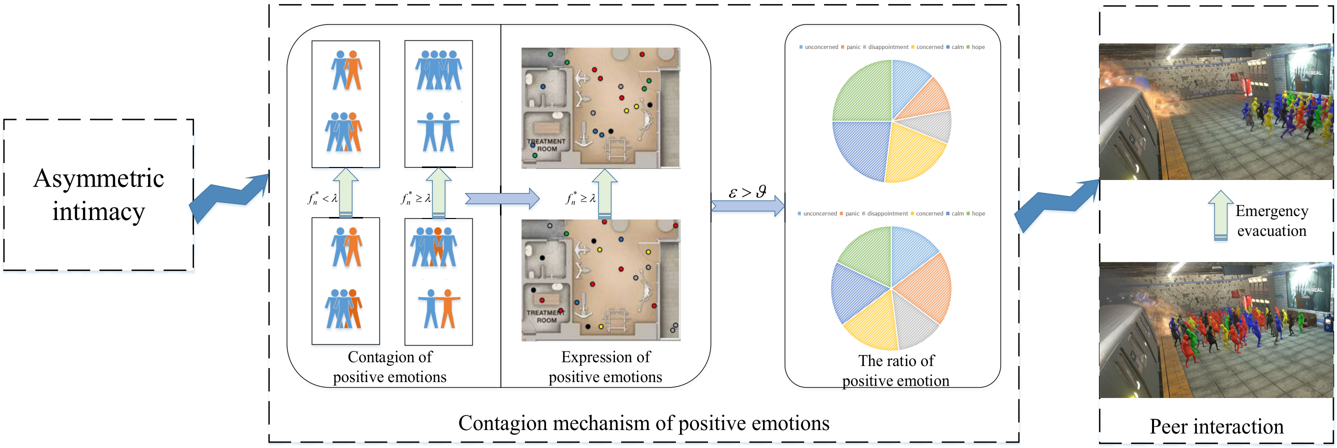


FIGURE 1. System framework.

The determination of psychological distance is related to physical distance and psychological openness. In general, under natural circumstances (individual communication is random and not affected by any conditions), people with close physical distances have close psychological distances, which can be presented as

$$D_{psy} = D_{geo}^{\frac{1}{H}} \tag{2}$$

where $D_{psy} > 0$, $D_{geo} > 1$ and $H > 0$. Heart openness H refers to the intensity of accepting the thoughts and behaviors of other individuals. When the interacting parties are strangers, $H = 0$; when the interacting parties are familiar, the maximum value of H is 1. Therefore, $H \in [0, 1]$. Under the same conditions, the stronger the heart openness, the shorter the psychological distance.

The relationship of trust is shown in Fig.2.

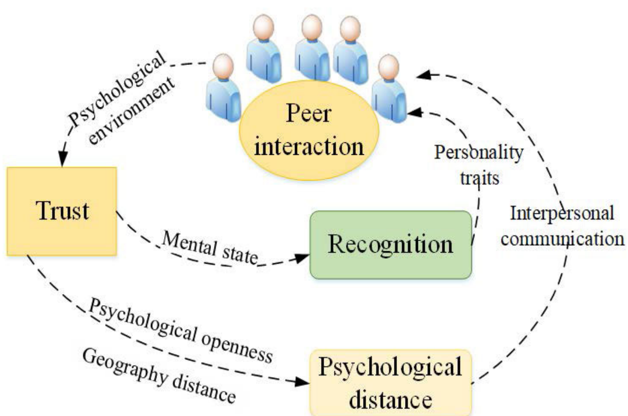


FIGURE 2. The trust relationship.

B. SOCIAL RELATIONSHIP

The influence of society on individuals is enormous. Social relations represent the attributes of individuals in society. In this paper, the calculation of social relations is composed of five factors: value orientation, fitness, geographical distance, and connection degree. The formula for calculating social relations is as follows:

$$S_r = \left(V^O \bigcap K\right) \cdot \frac{F}{D_{geo}} \tag{3}$$

where S_r is the degree of social relationship, V^O is the value orientation, K is the degree of fitness, and F is the frequency of communication and contact in the most recent period ($\leq$3 days).

In social relations, the value orientation is often related to the individual's living environment and the things he is exposed to. These influence the value orientation's formation and change. The value orientation includes three orientation functions of awakening attitude, guiding and regulating behavior. In the living environment, relatives, classmates, colleagues, friends, etc. all exist and can coexist. These relationships can affect the degree of fitness, and they can change the way and the intensity of interaction with peers. The degree of fitness can determine the degree of causality between phenomena. The tacit agreement is a reflection of a high degree of fitness. The frequency of interactions and connections is an intuitive reflection of the strength of social relations. Generally, the more frequent the contacts, the stronger the strength of social relations is. The frequency of communication and contact is related to the daily action trajectory. The judgment is based on the degree of dispersion of the trajectory.

C. EMPATHY

Generally, empathy changes dynamically. For example, when a child is fully respected and protected by society and family during his growth, he will be more resistant to social injustice. When he sees others have been subjected to violent behavior, he is more likely to have rebellious empathy. In this paper, empathy is calculated by concentration, patience, and understanding. For peer groups, empathy is an important part

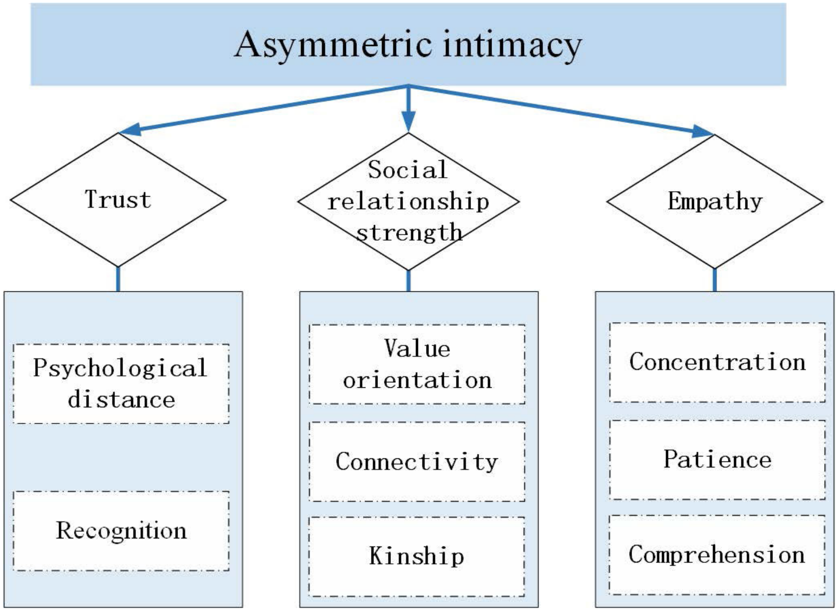


FIGURE 3. The asymmetrical intimacy profile.

of the interaction. The dynamic changes in concentration, patience, and comprehension can affect intimacy. Combining these factors, empathy is calculated as

$$E = C \cdot (P + U) \tag{4}$$

where E is empathy, C is concentration, P is patience, U is understanding, the values of which are not less than 0. The degree of concentration is determined based on the continuous-time the individual spends on the same thing. When the individual keeps observing in the same thing and the line of sight is not more than 1s away from the single shot, the range of sight is considered to be effective concentration. Patience is judged by the duration and emotional level. If the individual is attentive at the same time, his emotion will not fluctuate greatly. Then, we regard that individual patience continues. Understanding is related to the individual's growth and survival environment. It is the most externalized reflection of empathy.

D. ASYMMETRIC INTIMACY

Therefore, asymmetrical intimacy can be written as

$$I = T \cdot \left(S_r \bigcap E\right) \tag{5}$$

where I is asymmetrical intimacy.

The intimacy between peers has dynamic changes. Defining a dynamic peer group, when the trust, social relations, and empathy are high, the intimacy will increase, and vice versa. Set up a companion group:

$$\psi = \{i,\ j_1,\ j_2,\ j_3,\ \cdots,\ j_n\} \tag{6}$$

where, $i,\ j_1,\ j_2,\ j_3,\ \cdots,\ j_n$ are peer individuals, and they have at least one common friend.

The linear weighted sum of asymmetrical intimacy can be given as

$$f_n^* = min_{i,j\in\psi} f_n \left(\sum I_{ij_n} \cdot \rho_{j_n}\right) \tag{7}$$

where f_n^* is a linearly weighted sum of asymmetrical intimacy, ρ is the average interaction attraction of different peers associated with i, n is the individual with i in a peer relationship, and $n \geq 0$.

The formula for calculating the asymmetrical intimacy in this paper applies to the peer group of 4 or less, which is $n \leq 4$. The asymmetrical intimacy profile is shown in Fig.3. Under the influence of asymmetrical intimacy, peer interactions are realistic and reasonable. In a public social environment, peer interaction is an important factor in an evacuation.

V. POSITIVE EMOTION CONTAGION MODEL

When an emergency occurs, the individual's emotions will be affected. To achieve a higher efficiency of emotion contagion, this paper establishes a positive emotional transmission mechanism to simulate the emotional interaction of peer groups in an emergency evacuation. The transmission of positive emotions will reduce the negative impact of negative emotions on individual behavior. Within the effective time frame, increasing the transmission of positive emotions is an important way to reduce the time spent in an evacuation.

A. POSITIVE EMOTIONS TRANSMISSION MECHANISM BASED ON ASYMMETRIC INTIMACY

In this section, we construct a positive emotional transmission mechanism based on asymmetric intimacy to simulate the emotional interaction among peers. The mechanism starts from asymmetrical intimacy and determines the level of asymmetrical intimacy through trust, social relationship, and empathy. Different intimacy values show different effects on positive emotional transmission, and the positive emotional changes among peers are also different.

Most positive emotions are contagious and regulated only after intimacy reaches a certain level. Because in an intimate relationship, individuals can affect their emotions by feeling the positive emotions from their peers' in a period. That is to change the emotion from indifference, panic, and disappointment to care, calmness and hope. In this way, we can increase the proportion of positive emotions in the total value of emotions.

The positive emotion transmission mechanism can be divided into two parts. The first part is the determination of asymmetrical intimacy. It mains under what state, positive emotion contagion will occur. The second part is the calculation of positive emotional contagion. That is to say, how positive emotions are transmitted.

Section 4 has introduced the modeling process of asymmetrical intimacy. The value of the asymmetrical intimacy is calculated by the linear weighted sum of the asymmetrical intimacy. This value is calculated from the three dimensions of trust, social relationship, and empathy.

For peer groups, to spread positive emotions between every two individuals, it is necessary to determine the asymmetric intimacy value. The definition of the peer group indicates that, when there is a peer individual, it can be considered as one peer group. The requirement for positive emotional transmission is not so simple.

Positive emotion contagion requires asymmetric intimacy linear weighted sum f_n^* to reach the threshold λ. That is to say, when $f_n^* \geq \lambda$, positive emotions can be transmitted. The calculation formula of λ is given as

$$\lambda \begin{cases} \dfrac{\left(0.5 - 0.5 f_n^*\right) \cdot I}{2}, & if\ f_n^* > 0 \\ 0, & otherwise \end{cases} \tag{8}$$

when $f_n^* \geq \lambda$, positive emotion contagion among peers. The infection formula is calculated as

$$\varepsilon = f_n^* \cdot (\vartheta - \sigma) \tag{9}$$

where ε is the positive emotion contagion value, ϑ is the emotional arousal, and σ is the emotion resistance. When $\varepsilon > 0$, positive emotion contagion can occur. When $\varepsilon \leq 0$, emotion can not be changed. Individuals will maintain their emotions.

Emotional arousal and emotional resistance are important factors affecting positive emotional contagion. Emotional arousal refers to the power of one individual to stimulate the positive emotions of another individual when individuals are in contact with each other. Emotional resistance refers to the resistance of the affected individual to positive emotions. The calculation formulas are as follows:

$$\vartheta = E(T + I)^{\frac{1}{D_{psy}}} \tag{10}$$

$$\sigma = \frac{\omega \cdot D_{geo}}{S_r} \tag{11}$$

where, ω is the degree of cultural difference.

The equations to calculate the spread of positive emotion were all proposed by authors. We derived these formulas through a large number of experimental simulations and induction. The error of the formulas are less than 0.01%.

B. THE EXPRESSION OF POSITIVE EMOTIONS

Positive emotion expression is the externalized expression of positive emotions. When an individual is infected with positive emotions, whether to externalize these emotions and reflect the influence of positive emotions is an important part of positive emotion transmission. When $\varepsilon \geq \vartheta$, positive emotions can be expressed externally. The steps of externalized expression are as follows:

1. The positive emotions of individual i are mobilized by the positive emotion of individual j, and the positive emotions proportion in the total proportion of emotions can be increased;
2. If $f_n^* \geq \lambda$, spread the positive emotion through Eq.9;
3. If $\varepsilon \geq \vartheta$, the positive emotions of individual i, such as care, calmness, and hope, can be expressed, and other peers can also feel the change of emotions. That is, positive emotions are expressed.

VI. EXPERIMENT

In this section, four groups of experiments are designed to demonstrate the effectiveness of asymmetric intimacy and positive emotional transmission. These experiments include the effects of asymmetric intimacy on peer gathering, positive emotional infection simulation and interactive simulation of evacuation behavior in different public places. Compared with other methods and models, it proves the efficiency of our method. At the same time, an attempt was made for the direction of future peer interaction behavior simulation.

In this paper, all the experiment results are collected on a personal computer with Intel i7-3770 3.4GHz CPU, NVIDIA GTX960 graphics card, and 8 GB of RAM.

A. PEER GATHERING

This paper starts from the influence factors of asymmetrical intimacy and studies the influence of asymmetrical intimacy in peer groups. By simulating a large number of different factors of trust, social relations and empathy factors, the correlation and effect of asymmetric intimacy influencing factors on asymmetric intimacy are obtained.

The initial scenario is in a classroom, the students are randomly distributed. The next class is an outdoor activity class. The students will go out of the classroom to reach the activity site. Usually, in this situation, peers will go together. We explored the effect of asymmetrical intimacy by simulating this situation.

Individuals of the same peer group were of the same color. Two-person groups (blue), three-person groups (yellow, green, purple) and four-person groups (red) were randomly generated. Fig.4(a) is the initial scene, where the individuals are randomly distributed. Fig.4(b) and 4(c) show the gathering of different peer groups at frame 142 and

(a) initial scene (b) at frame 142

(c) at frame 259 (d) at frame 391

FIGURE 4. Asymmetric intimacy factor.

TABLE 1. The proportion of asymmetric intimacy factors.

Peer group	Trust(%)	Social relationship(%)	Empathy(%)	Asymmetric intimacy(%)
Blue group	59	63	46	53.28
Yellow group	67	48	33	54.16
Green group	43	51	65	60.37
Purple group	72	39	66	70.87
Red group	60	55	58	56.73

frame 259. Fig.4(d) is the frame at frame 391, in which some individuals have walked out of the classroom, and the peer group has also completed gathering and walked out of the classroom together.

The aggregation of peer groups depends on asymmetric intimacy factors. Table 1 shows the proportion of asymmetric intimacy factors randomly generated by the experiment in a group of different color groups. The value of each factor is between 0 to 1. (The values of ''trust'' ''social relationship'' and empathy are randomly generated. The value of ''asymmetric intimacy'' is calculated by formula 5-7.)

In a large number of random experiments, three randomly selected experimental data are shown in Table 2. Through experimental data and use spss (Statistical Product and Service Solutions), it can be concluded that trust, social relationship, and empathy are positively correlated with asymmetrical intimacy.

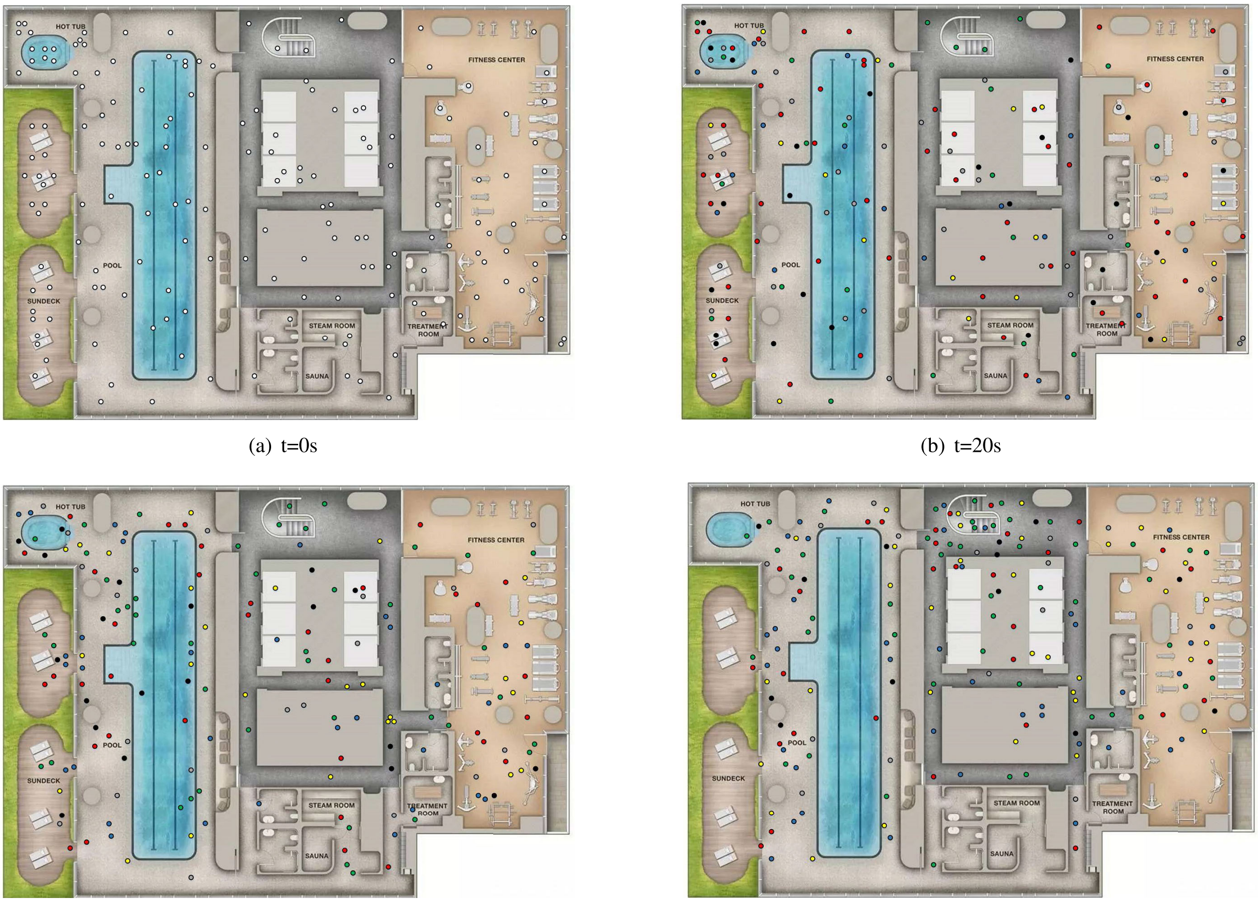
B. THE SIMULATION OF POSITIVE EMOTION CONTAGION

To investigate the impact of positive emotional infection on peer interaction in public places, we conducted simulation experiments in gym scenario. The initial scene is shown in Fig.5(a), each individual is assumed to be an emotionless individual. Individuals without emotion are indicated in white.

When the emergency alarm sounds, each individual has different emotions, including indifference, panic, disappointment, care, calmness, and hope. Among them, black represents indifference, red represents panic, gray represents disappointment, yellow represents concern, blue represents calm, and the green represents hope. Fig.5(b) is a random sentiment graph generated immediately after the alarm sounds. From Fig.5(b), we can know that when an emergency occurs, the panic individuals account for the main part, and the rest of the individuals with greater emotions

TABLE 2. **The influence of three factors on asymmetric intimacy.**

Peer group	Trust(%)	Social relationship(%)	Empathy(%)	Asymmetric intimacy(%)
The first group	62	60	60	56.77
	73	60	60	68.40
	41	60	60	42.92
The second group	60	38	60	40.35
	60	59	60	42.18
	60	71	60	45.67
The third group	60	60	66	42.49
	60	60	66	58.53
	60	60	66	79.94



(a) t=0s

(b) t=20s

(c) t=40s

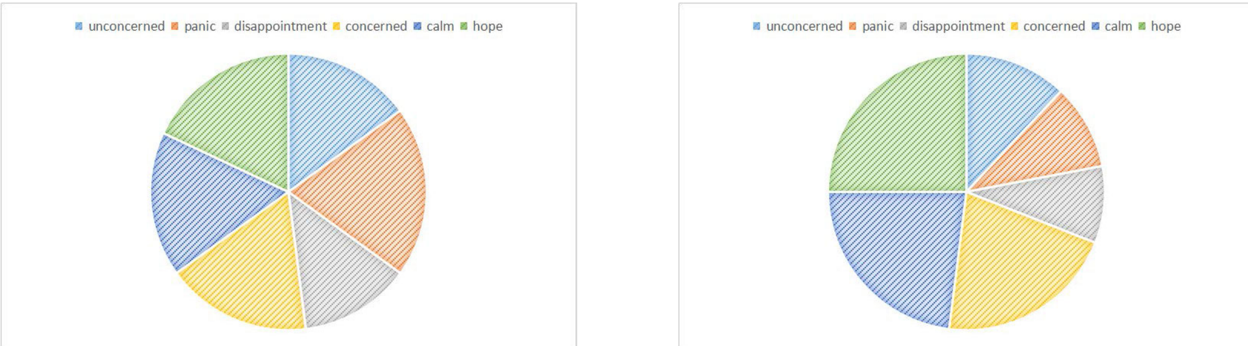
(d) t=60s

FIGURE 5. **Positive emotion contagion simulation.**

are indifference and disappointment. Fewer individuals are caring, calm or hopeful.

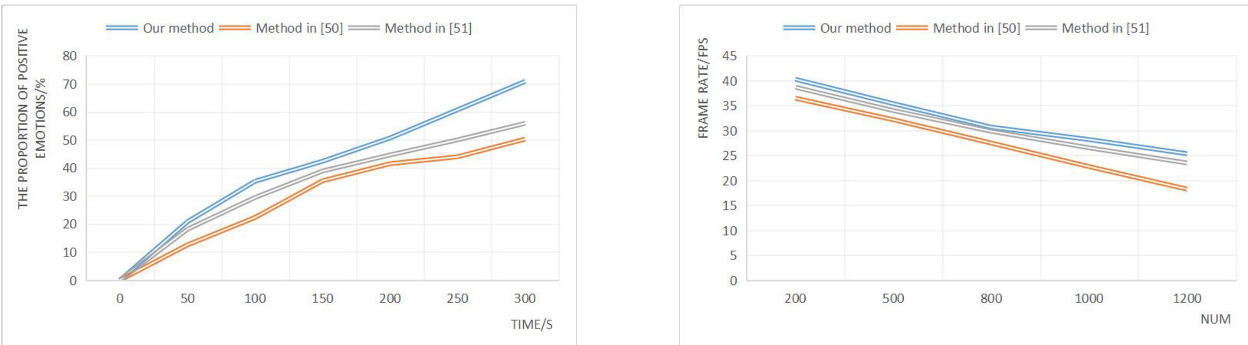
After a reaction time of 1-2s, the peer group began to spread positive emotions. Fig.5(c) and 5(d) simulate the process of positive emotion contagion. Emotion contagion is transmitted through Eq.8 and Eq.9. When positive emotions are contagious. Otherwise, the individual will keep his emotions and actions. Fig.5(d) shows the distribution of emotions after positive emotions are transmitted. As the behavior continues, the peers gradually tend to have more stable emotions. Each individual tends to move in the direction of the exit, and the closer to the exit, the more frequent the interaction of positive emotions. (Because the closer you are to the exit, the higher the rate of success for people's escape. Therefore, the more frequent the interaction of positive emotions.)

Fig.6 is a graph of the proportion of positive emotions, respectively reflecting the proportion of six emotions under the scenarios with t=20s and t=60s. These proportion of different emotion are gotten by our system. The system framework is described in section three. When the randomly



(a) t=20s (b) t=60s

FIGURE 6. Proportion of positive emotions.



(a) The comparison of the infection time. (b) The frame rate of different emotion contagion methods in different individual

FIGURE 7. Comparison of different emotion contagion models.

generates data is produced from the system, the system will ''print'' the data in the background. In this way, we can get the data in the system.

Fig.7(a) is a comparison of the infection time of our method and the emotion contagion methods of [50] and [51]. It can be seen that our method takes less time to achieve emotion contagion. By increasing the proportion of positive emotions in emergencies, the occurrence of emergency behaviors can be improved.

Fig.7(b) shows the frame rate (frame rate refers to the number of the still frames displayed per second. When capturing dynamic simulation effect video content in simulation experiments, the higher the number is, the better the performance achieves. The large number proves the low computational complexity of evacuation simulation.) of different emotion contagion methods in different individuals under the same time conditions. It can be seen that our method can degrade the computational complexity and can improve the operating efficiency of the computer.

C. THE SIMULATION OF SUBWAY EVACUATION BEHAVIOR

To verify the role of positive emotion contagion in emergencies, this experiment simulated the interactive behavior process of peers in a subway station after a fire. A subway station is a public place, and simulating the fire evacuation behavior in the subway station is of great significance to real life. Peers perform evacuation simulations and compare them with different evacuation simulation models. The simulation is shown in Fig.8.

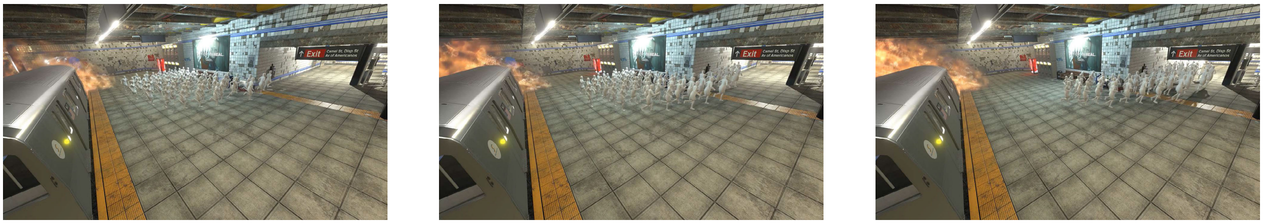
Fig.8(a), (b), (c), (d) and (e) are screenshots of the evacuation behavior simulation of our method, the method in [5], the method in [8], the method in [12] and the method in [48] at the same frame number. At the beginning of the experiment, the individual entered the scene. When the fire broke out, the peers started the positive emotional contagion.

It can be seen from Fig.8, under the same frame number, the positive emotions of individuals in this method account is more, which reduces the impact of panic and other negative emotions on evacuation and can achieve evacuation more efficiently. Also, the method in this paper completes the evacuation in a relatively short time and effectively completes the interactive behavior.

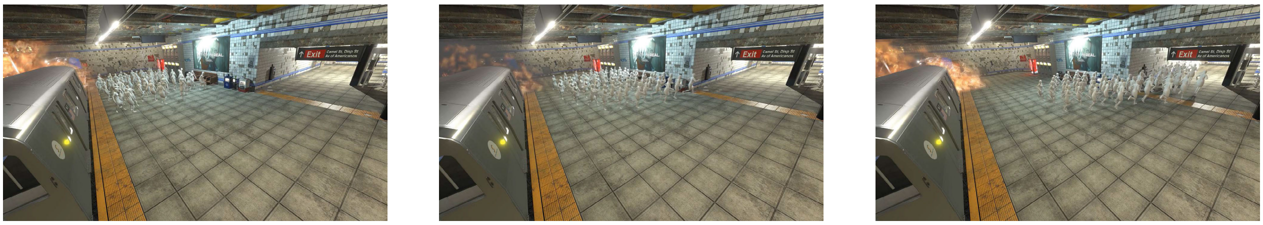
Table 3 shows the indicators of our method, the method in [5], [8], [12] and [48]. Although these methods can complete the evacuation behavior of the group, the average simulated frame rate is lower than our method. Moreover, the evacuation completion time was longer than our method.

The method in [5] adopted an agent-based evacuation model, without considering the emotional impact between groups during the evacuation process. The method in [8]

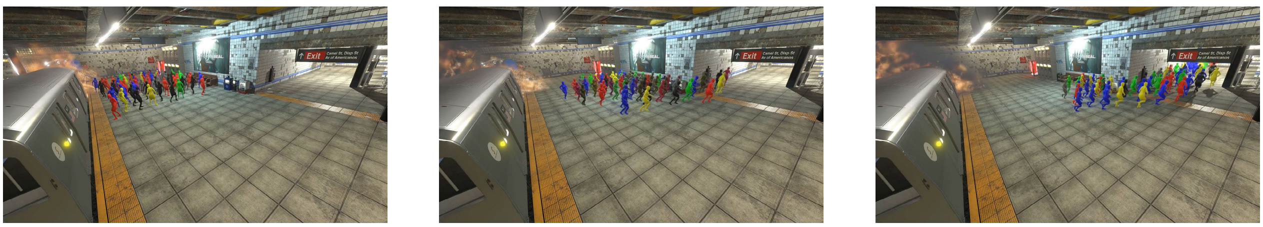
(a) our method



(b) the method in [5]



(c) the method in [8]



(d) the method in [12]

(e) the method in [48]

FIGURE 8. Emergency evacuation scenarios with different methods.

showed the population scale and the relationship of the different densities. However, it ignores many factors affect the bi-direction pedestrian flow, such as psychological factors and the complexity of the scene with obstacles. The method in [12] integrated with pedestrian movement and emotion propagation. In terms of pedestrian movement, the multi-grid approach was employed. However, the relationship between pedestrians is not discussed, and the impact based on these relationships is ignored. For example, the results of experiments that pedestrians bring to relatives and strangers are different. The method in [48] realized evacuation based on emotion contagion, but the effect of improving evacuation through the influence of emotion is not obvious. The effect of positive emotions on evacuation behavior was not discussed.

It can be seen from the simulation that under the premise of the same time-consuming, our method can make individuals have more positive emotions while reducing the impact of negative emotions such as panic on evacuation. Our method

TABLE 3. Evacuation results of different methods.

Method	Evacuation time(s)	Evacuation speed $(m \cdot s^{-1})$	Proportion of positive emotions(%)	Frame rate$(fps \cdot s^{-1})$
Our method	26.7	1.07	52	40.8
Method in [5]	32.4	0.82	0	30.5
Method in [8]	34.8	0.77	0	26.9
Method in [12]	30.3	0.90	27	35.7
Method in [48]	30.6	0.98	30	36.1

TABLE 4. The simulate statistical data in different methods.

Method	Description	Level
Our method	Peer behaviors interact more frequently, and positive emotions have a significant effect during emergency evacuation.	Highest
Method in [5]	Group behavior interaction is medium, and there is no change in mood during emergency evacuation.	Medium
Method in [8]	Group behavior interaction is low, and there is no change in mood during emergency evacuation.	Low
Method in [18]	Group behavior interaction is high, and there are emotional changes during emergency evacuation, but positive emotions do not play a role.	High

can achieve evacuation more efficiently. Besides, our method completed the evacuation in a relatively short time and effectively completed the interaction.

D. THE SIMULATION OF HOSPITAL EVACUATION BEHAVIOR

Covid 19 is one of the emergencies affecting public safety. And everyone is affected. It has influenced our daily life in every aspect. Meanwhile, Covid 19 can make our emotion change. Especially, effect the emotion of the people who is in the hospital. In order to study the positive emotions contagion in this situation, we have an experiment in hospital.

During the epidemic, the evacuation in the hospital is particularly important. Moreover, the development of the epidemic affects people's psychology and emotions. Simulating the evacuation in hospitals is of great significance in the field of public safety. Reasonable judgments of emotions and behaviors are made by watching simulated videos to verify the effectiveness and reality of our method.

We initiated voluntary invitations on the Internet, with a total of 305 invitations. The participants came from different regions and had different career and life experiences. It includes 152 males and 153 females. Participant's choice was random, and the age of them was 18-60 years old.

At first, participants were asked to watch the simulation methods of our method, the method in [5], the method in [8] and the method in [18]. It contains a total of 12 videos. Each method has 3 videos, and these 12 videos are randomly arranged. Then, after watching each video, the participants will record the feeling of information at that time, e.g., the feelings about the emergency evacuation, the rationality of emotions, the rationality of peer interaction and the authenticity of evacuation. Finally, the method is used to analyze the authenticity and rationality of the method.

For each video experiment, participants were compared on a five-point scale "strongly disagree (1)-strongly agree (6)". It mainly contains 4 questions:

TABLE 5. Five-point statistical data.

Method	Five-point scale 1	2	3	4	5
Our method	5.02%	7.25%	12.33%	32.57%	42.83%
Method in [5]	11.06%	19.85%	24.69%	23.51%	20.89%
Method in [8]	18.72%	21.39%	21.74%	15.05%	13.10%
Method in [18]	9.43%	16.77%	20.11%	28.49%	25.20%

TABLE 6. Reflect data of simulation rationality.

Method	Evacuation	Emotion	Interaction	Simulation
Our method	88.31%	89.47%	82.19%	85.34%
Method in [5]	71.92%	0%	77.65%	72.08%
Method in [8]	70.01%	0%	75.92%	67.30%
Method in [18]	80.15%	83.29%	79.44%	78.26%

1. Does the emergency evacuation seem reasonable?
2. Does the emotion change is reasonable during evacuation?
3. Does the interaction between peers is reasonable?
4. Does the evacuation simulation match the evacuation in real life?

The research scene contained 200 simulation characters, and each method corresponds to a different simulation effect. Table 4 is the statistical data of the simulation rationality of various methods. Table 5 shows the statistics about the five-point scale. Table 6 shows the average response of the participants to the simulation scenarios. As can be seen from Table 4 and Table 6, the experimental results of different simulation methods are different. The method in this paper can reflect the evacuation behavior in real life through the intimacy and emotional interaction of peers. It is more reasonable and effective in an emergency evacuation. In an emergency evacuation, improving positive emotions effectively can reduce the time spent in the evacuation.

Under the influence of asymmetric intimacy, the method in this paper can improve the efficiency of crowd evacuation through a positive emotional transmission mechanism. Through simulation comparisons, it is proved that the method in this paper can more completely simulate the behavior interaction of peers in emergencies. While reducing the computational complexity and improving the simulation efficiency, it also enhances the authenticity and rationality of peer interaction.

VII. CONCLUSION

This paper proposed a behavioral simulation method for public safety evacuation based on peer asymmetric intimacy and a positive emotional transmission mechanism. We aimed to study the impact of positive emotions on evacuation. The spread of positive emotions can reduce the evacuation time and improve the evacuation efficiency in an emergency evacuation. The peer interaction model that combines asymmetric intimacy and positive emotional transmission mechanism can simulate peer interaction behavior more realistically and efficiently. Besides, we simulated the interaction behaviors of peer groups and compared the proposed method with different emotion contagion methods and simulation methods.

But the factors that affect peer interaction are complex, and the factors also include individual personality traits and behavior styles. At the same time, the size of the peer group and the relationship between the groups are also important aspects that affect peer interaction.

In future research, we will use particle swarm optimization to improve the simulation efficiency of small cardinal populations. An in-depth study of the personality characteristics of peers will be carried out according to the personality characteristic model, to explore the influence of behavior style on interactive behavior according to behavior styles, to discuss the size of the peer group, the relationship between the individuals in the group and the individuals in the group. Through these ways, the peer interaction model can be further studied and expanded.

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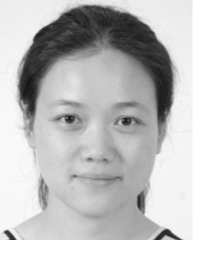
YAN MAO received the B.S. degree from the Education Science College, Sichuan Normal University, Chengdu, China, in 2007, the M.S. degree from the Psychology College, Southwest University, Chongqing, China, in 2010, and the Ph.D. degree from the School of Economics and Management, Southwest Jiaotong University, Chengdu, in 2018. She is currently a Lecturer with the School of Business, Sichuan Normal University. Her research interests include emotion, emotion decision, and virtual reality.

ZIXUAN FAN is currently pursuing the B.S. degree with the College of Movie and Media, Sichuan Normal University. She has gained experience in research projects. She is also a Junior Researcher with the Visual Computing and Virtual Reality Key Laboratory of Sichuan Province, Sichuan Normal University. Her research interests include crowd animation and emotion simulation.



HUA MAO received the B.S. and M.S. degrees in computer science from the University of Electronic Science and Technology of China (UESTC), in 2006 and 2009, respectively, and the Ph.D. degree in computer science and engineering from Aalborg University, Denmark, in 2013. Her current research interests include neural networks and big data.

WU HE received the B.S. degree in computer science and technology from the North University of China, Taiyuan, China, in 2004, and the M.S. and Ph.D. degrees in computer application technology from Southwest Jiaotong University, Chengdu, China, in 2008 and 2017, respectively. He is currently an Associate Professor with the College of Movie and Media, Sichuan Normal University. His research interests include computer graphics, virtual reality technology, crowd animation, and traffic simulation.