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Review:

A review of behavior mechanisms and crowd evacuation animation in emergency exercises*

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Abstract: Emergency exercises are an efficient approach for preventing serious damage and harm, including loss of life and property and a wide range of adverse social effects, during various public emergencies. Among various factors affecting the value of emergency exercises, including their design, development, conduct, evaluation, and improvement planning, this paper emphasizes the focal role of evacuees and their behavior. We address two concerns: What are the intrinsic reasons behind human behavior? How do we model and exhibit human behavior? We review studies investigating the mechanisms of psychological behavior and crowd evacuation animation. A comprehensive analysis of logical patterns of behavior and crowd evacuation is presented first. The interactive effects of information (objective and subjective), psychology (panic, small groups, and conflicting roles), and six kinds of behavior contribute to a more effective understanding of an emergency scene and assist in making scientific decisions. Based on these studies, a wide range of perspectives on crowd formation and evacuation animation models is summarized. Collision avoidance is underlined as a special topic. Finally, this paper highlights some of the technical challenges and key questions to be addressed by future developments in this rapidly developing field.

Key words: Emergency exercises, Behavior mechanisms, Crowd evacuation animation, Collision avoidance
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1 Introduction

The occurrence of public emergencies has increased with rapid socio-economic development and ecological and environmental destruction. These frequent emergencies, from natural disasters, accidents, public health, and social safety to network sentiment, have penetrated people's lives in every area (Hao, 2011). Issues have been raised regarding the loss of human life and property, the lack of reasonable solutions for secondary disasters, and the adverse social impacts during emergencies.

Although no one can predict the occurrence of a public emergency, preparation for such an event is necessary. Emergency exercises are proven to be among the most effective solutions. The aims of emergency exercises include the comprehensive inspection of emergency response plans, synthetic evaluation of evacuation capabilities, significant increases in safety awareness and escape skills, and significant improvements in scientific emergency decision making (Dettinger *et al.*, 2012). The Homeland Security Exercise and Evaluation Program (HSEEP) (DHS, 2013) is a capability and performance-based exercise program which offers a standardized methodology and terminology for exercise design, development, conduct, evaluation, and improvement planning. In China, an official guide to emergency exercises was issued in 2009 (Emergency Management

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Office of the State Council, 2009), which improved the recognition of the importance of exercise assessments.

An emergency exercise is essentially a complex dynamic multidisciplinary system related to psychology, sociology, management, and computer science. Numerous studies are available which approach the subject from different perspectives, including psychological behavior and its influencing factors (Kobes *et al.*, 2010; Li *et al.*, 2012), building evacuation exercises (Jiang, 2012), diffusion of dangerous gases (He *et al.*, 2011), evacuation speed (Blair, 2010), and emergency dynamic decision making (Li *et al.*, 2008). Based on these studies, a notable characteristic of an emergency exercise is the gathering of many people. Significant differences in human behavior can be observed in an emergency compared to a normal situation. Among the various concerns, we focused on two essential problems: What are the intrinsic reasons behind human behavior? How are these behaviors modeled and demonstrated? Thus, in this study we investigate psychological behavior mechanisms, crowd evacuation models, and animations. We constrain the emergency scene to accidents, excluding natural disasters, public health events, and network sentiment. A number of theories and technologies considered in this study can be applied to various emergencies in general.

2 Analysis of logical patterns

When facing emergencies, a series of non-adaptive crowd behaviors may arise, such as stampedes, crushing, and trampling. Simulating realistic behavior in virtual crowds requires the extensive study of the semantics underlying the motion of real crowds. According to the theory of sociology, behavior is the external manifestation of internal psychology, which is affected by many factors. Psychologists study human nature to identify salient behavioral characteristics. During unpredictable emergencies, dissemination of information can be constrained on both temporal and spatial scales. Thus, evacuees experience a conflict between instant decision making and lack of information, which easily increases panic (Wang *et al.*, 2012). Factors that result in panic can be generally classified as objective information, with an emphasis on individual cognition, or subjective information, with an emphasis on context. An evacuation model with different stages can be constructed on the basis of human behavior and people's interactions with others and with circumstances. An analysis of a logical pattern based on previous studies is illustrated in Fig. 1. The structure of the pattern is focused on human behavior in relation to information, psychology, crowd aggregation, and evacuation.

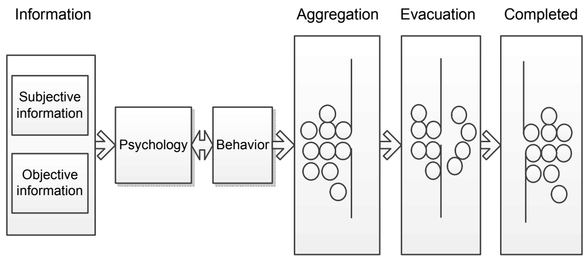

Fig. 1 Six stages of the analysis of a logical crowd behavior pattern

3 Psychological behavior mechanism

3.1 Types of information

In general, information during an emergency exercise can be categorized as objective or subjective. Objective information, which comes from outside the context situation, is always limited and insufficient. Unfortunately, objective information is also easily distorted because of overstrain. Moreover, untimely information is a common problem because of crucial changes in events and communication delays. Subjective information varies according to differences among individuals. Three types of typical subjective information included in this study are personality, prior experience of a similar emergency, and ability to stay calm.

Li *et al.* (2012) analyzed the factors that affect people's psychology and behavior and summarized them into four types of information: environment, guidance, acceptance, and basic information. The mechanisms of action of these factors were also examined. Zhang *et al.* (2012) selected seven indices of psychological parameters to reflect the emergency handling ability of miners, using sample data testing and analysis. However, the weights of the seven indices and the correlations between them and the handling abilities were not clear. Tsai *et al*. (2012) constructed mobile escape guidelines (MEG) using geographical information and augmented reality techniques, which are capable of identifying the correct locations of users, showing escape routes, and rapidly generating relief reports.

Personality is a pattern of a person's behavioral, temperamental, emotional, and mental traits. Applying a combination of psychological and geometrical rules to a model of social and physical forces enables the high-density autonomous crowds (HiDAC) model to exhibit a wide variety of emergent behaviors (Pelechano *et al.*, 2007). HiDAC models individual differences by assigning each person different psychological and physiological traits. Durupinar *et al.* (2011) extended the HiDAC system by providing each agent with a personality based on the OCEAN (openness, conscientiousness, extroversion, agreeableness, neuroticism) personality model. Specifying an agent's personality leads to automation of low-level parameter tuning.

3.2 Intrinsic psychology

The significance of intrinsic psychology always emerges during emergencies. A typical example is panic, which comes mainly from the lack of the necessary psychological ability to handle an emergency situation. Tian (2008) proposed the CDENP (convergence, deindividuation, emergent norm, nervousness, panic) theory, which generalizes crowd psychology and corresponding behavioral laws observed in both panic and normal situations. A pedestrian's behavior in a crowd under panic was described, and a panic emotional contagion model constructed (Liu and Huang, 2012). Aguirre (2005) linked panic with a crisis. He pointed out that the formation of panic is strongly related to building structure, crowd membership, crowd density, relationship between crowds, and quantity of information. His premise coincides with the logical design of the analysis pattern described in Section 2.

Another important aspect of psychology comes from the small group concept, which frequently occurs among family members or close friends (An *et al.*, 2010). Certain individuals within a small group will give up preference of evacuation earlier than others and elect to stay with each other until the entire group can evacuate. The last aspect, often easily ignored, is role conflict. An example would be a teacher during an earthquake (Liu *et al.*, 2009). A teacher, as an individual, has the instinct to escape. However, a teacher also has a responsibility to help students. Role conflict may affect a teacher's behavior, and a simple valuation of his or her decision may be cursory. Commanders may be subjected to the same conflict during an emergency exercise.

3.3 Evacuation behaviors

Behaviors are the direct expression of intrinsic psychology. Taking panic and the instinct for survival into account, evacuation behaviors can be summarized as follows (Guo *et al.*, 2009):

1. Purpose behavior

People make instant decisions to reach their intended locations using the shortest available route and at the fastest speed. In many cases, the intended location is an exit. Once a direction of escape is chosen, the individual does not withdraw, even if blocked, thereby increasing the 'faster-is-slower' effect (Helbing *et al.*, 2000). At the same time, crowds may ignore all other exits.

2. Herding behavior

The individual gives up his or her personal opinion and tends to be swayed by the surrounding crowd, particularly under certain inducements. This action is referred to as herding behavior. Thus, individuals imitate and follow one another, and finally become aggregated (Wang *et al.*, 2012).

3. Collision avoidance behavior

The individual adopts different methods, such as waiting or going around, to avoid colliding with barriers and other people.

4. Autonomous behavior

Individuals with autonomous behavior have strong judgment and do not follow others or others' guidance.

5. Backward direction behavior

When emergencies occur, evacuees may escape backwards in relation to the route they were taking while entering the disaster area. This opposing movement within the crowd easily causes sudden congestion and high crowd density.

6. Small group behavior

A small group with close social relationships prefers to evacuate together. If a leader appears, small groups also form even without prior social relationships.

Based on individual behaviors under irregular emergencies, an evaluation indicator system influencing individual behavior has been built (Zhao and Cheng, 2010). This system considers several factors, including material, social environment, and individual attributes. The value of family members is also important in emergency evacuations; both weaker family members and minimum time cost need to be considered (An *et al.*, 2010). Experiments showed a nearly 15% time increase in evacuation when considering family aggregation behavior.

Details regarding information, psychology, and behavior are listed in Table 1, to show the interactive mechanism of these factors.

Table 1 Interactive mechanism of information, psychology, and behavior

Information type	Information instance
Subjective information	
Physiological attribute	Age, gender, and health
Social attribute	Relationship, value orientation
Experience weight	Familiarity with the situation, training attendance
On-site cognition	Control of on-site situation
Objective information	
Static guidance information	Guide plate, indicator light
Dynamic guidance information	Broadcast, warning, network, and on-site commander
Building space information	Location and channel
Facility and devices information	Fire devices and transport buses
Local context information	Local position and emotion

4 Crowd evacuation animations

4.1 Crowd formation and evacuation models

Crowd formation and evacuation processes have been simulated by computers since the 1980s, and this has become one of the most important uses of computer simulation (Helbing *et al.*, 2000). According to the features of evacuated people, methods for simulating crowd formation can be divided into three categories (Qiu and Hu, 2010; Zhou *et al.*, 2010): stream-, entity-, and individual-based methods. Stream-based methods do not consider individuals and cliques in the crowd, which significantly reduces the computational requirements of this type of simulation. Entity-based methods are capable of quickly demonstrating crowd animation, but lack the ability to exhibit the behavior and expression of individuals. In contrast, in individual-based methods each individual is seen as an independent agent (Kim and Kim, 2010), which enhances realism at the cost of efficiency.

4.2 Investigation of crowd evacuation animation

Crowd animation research covers a large range of applied areas, including emergency response. In this study, we searched the SCI-E and IEEE databases. The literature was divided into general crowd animations and specific crowd evacuation animations. We found that studies concerning crowd evacuation animations have increased over the years (Fig. 2).

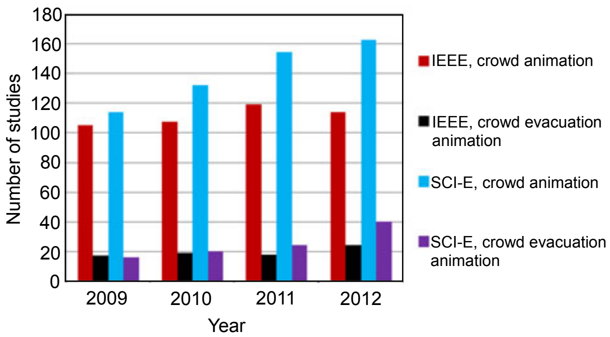

Fig. 2 Number of studies concerning crowd evacuation animation

Prominent studies in this field are illustrated and listed chronologically in Fig. 3. Detailed descriptions of and comments on these studies are included in the following.

4.3 Crowd evacuation animation models

Exploring the psychological behavior of individuals produces many indices, parameters, and categories. When considering these results in the context of crowds, crowd evacuation animation models can be abstracted and implemented using computer animation. According to previous studies, crowd evacuation animations can be classified into particle, social force, fluid dynamics, intelligent, and hybrid models.

4.3.1 Particle models

In particle models, each individual is viewed as a particle within an N-dimensional space. Individuals have meaningful individual differences among them.

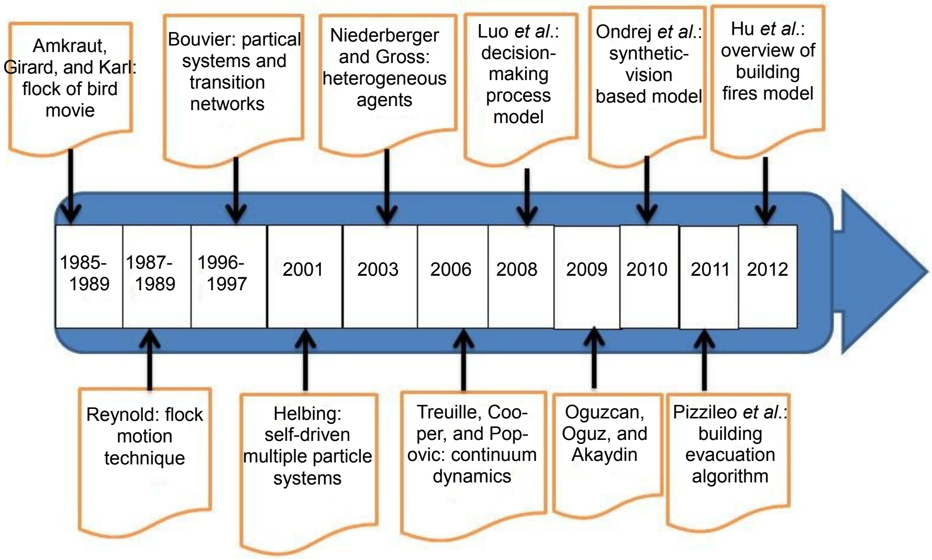

Fig. 3 Prominent research on crowd evacuation animation

Human flow is a complex system in which each individual's behavior contributes to the evolution of a global phenomenon. Bouvier and Cohen (1995) presented a microscopic approach that consists of describing and simulating crowd behavior using a physical-based model. Their classic work enables the simulation of a large range of situations, from the evacuation of a museum to very dense gatherings where dramatic situations occur. Corradi *et al.* (2012) proposed an interacting particle model with macroscopic dynamic behavior. A crowd of pedestrians represented by particles interacting via pairwise forces was considered. Both studies focused their investigation on the collective behavior aspects of the model.

4.3.2 Social force models

Social force was used to describe the behavior of individuals and the force of influence between them. Helbing *et al.* (2000) simulated crowd behavior based on a model of pedestrian behavior and a universal force model, which is particularly suited to describing the build-up of pressure observed during panic situations.

The Helbing model successfully simulates crowd evacuation. Experiments involving crowd evacuation in fire conditions are shown in Fig. 4.

Parisi and Dorso (2007) presented evacuation dynamics and considered the floating rate within a space with a single exit. The animations of the model showed that the higher the degree of panic, the faster the individuals move, but the slower they can pass through the exit.

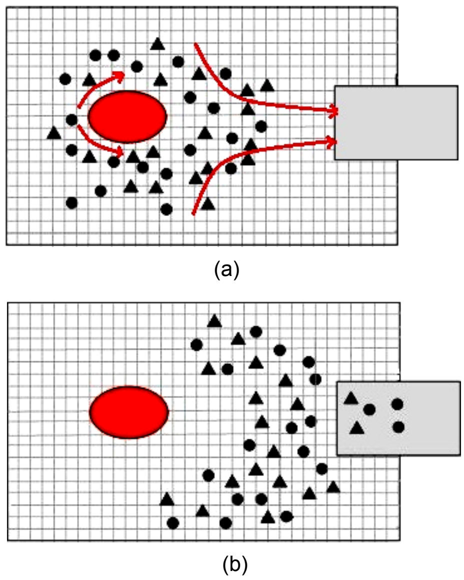

Fig. 4 Crowd evacuation animation under fire condition using a social model
(a) Fire emerging scenario; (b) Crowd evacuation scenario

Seyfried *et al.* (2006) treated persons as self-driven objects moving in a continuous space. Based on a modified social force model, they qualitatively analyzed the influence of various interactions between pedestrians, and reached the following conclusion: if the model increases the required space for a person with varied velocities, reproduction of the typical form of the fundamental diagram is possible.

4.3.3 Fluid dynamics models

Hughes (2000) derived a 2D flow equation to control the motion of pedestrians using a continuum model. In this model, when an emergency situation arises, a nonlinear partial differential equation is used to display and control the movement of pedestrians. The biggest difficulty in applying this formulation involves the appropriate choice of boundary conditions to match the psychological state of the pedestrians. Treuille *et al.* (2006) proposed a real-time crowd model based on continuum dynamics, simulating a continuous crowd as particles, which is suitable for rendering and establishing a stable and efficient simulation system. In their model, a dynamic potential field integrates global navigation with moving obstacles and combines local collision avoidance with global path control, efficiently solving the motion of large crowds without the need for explicit collision avoidance. However, this approach is limited by its treatment of adaptability and individual variability sensitivity.

Oguz *et al.* (2010) simulated virtual crowds in emergency situations caused by accidents, such as fires, explosions, and terrorist attacks. They used a continuum dynamics-based approach to simulate the escaping crowd, thereby producing more efficient simulations than agent-based approaches. In their model, pedestrians are simulated as mutual-connection individuals, making the crowd rendering more realistic. A cutting method is used to delete unnecessary drawing areas, greatly speeding up the virtual environment simulation.

4.3.4 Intelligent models

Based on layered crowd modeling, Niederberger and Gross (2003) proposed an architecture of hierarchical and heterogeneous agents for real-time applications. Behaviors are defined via the specialization of existing behavior types or by weighted multiple inheritance when creating new types. A behavior engine allows the specification of a maximal time for one-step running to guarantee a minimal and constant frame rate. This model is particularly useful for interactive simulations involving multiple agents, although some individual behaviors may be lost.

Luo *et al.* (2008) proposed a behavior model for virtual humans in normal-life and emergency situations. This model adopts an agent-based approach and employs a layered framework to reflect the natural pattern of human-like decision-making processes. This framework consists of three modules: a group behavior module, an individual behavior module, and a physical behavior module. However, the application of this model is relatively specific, such that it cannot be widely used in military training, digital security, or entertainment. Integrating the model into an agent execution process enables each individual agent to respond differently to the perceived environment and make reasonable decisions based on various physiological, emotional, and social group attributes.

4.3.5 Hybrid models

Many different models can be organically united to exploit fully each advantage. Bouvier *et al.* (1997) combined particle systems with transition networks. At a lower level, attractive and repulsive forces enable people to move around the environment. At a higher level, behavior is modeled by transition networks depending on time, visiting of the points, changes in local population densities, and global events.

Ondrej *et al.* (2010) explored a novel vision-based approach to collision avoidance between walkers, which fits the requirements of interactive crowd simulation. Compared to previous vision-based approaches, this model relies on statements from cognitive science that identify the visual stimuli humans extract from their optic flow to control their locomotion and avoid obstacles. Compared to previous avoidance models, this model improves the emergence of self-organized patterns exhibited by walkers in crowd simulations. Several examples reinforce the emergence of self-organized patterns of walkers. More importantly, this model improves the overall efficiency of the walkers' traffic and avoids improbable locking situations.

4.4 Collision avoidance

Highly crowded locations, such as gymnasiums, subways, shopping malls, and supermarkets, typically feature large-space structures together with high concentrations of people. Emergency events in such places often result in heavy casualties and property damage. Most cases of death are the result of crowd trampling.

This study investigated the method of collision avoidance between individuals. To simulate the crowd movement, Reynolds (1987) described a distributed behavioral model, and then studied various steering behaviors, such as goal seeking, obstacle avoidance, and path following. Musse and Thalmann (2001) presented a hierarchical model combining crowds, groups, and individuals. This model defines three levels of virtual human behavior: guided crowds, programmed crowds, and autonomous crowds. Ondrej *et al.* (2010) proposed a model based on virtual human adaptive levels. This model incorporates not only detailed geometry and movement, but also complex behavior levels. Recent interesting work in collision avoidance takes human vision into account.

5 Prospects and discussion

Although many studies have investigated behavior mechanisms and crowd evacuation animation, certain issues and challenges require a deeper understanding and clearer expression. Large spaces have attracted the attention of researchers interested in analyzing, designing, developing, and evaluating related topics. From our review of the literature, we have identified several areas worthy of further investigation:

1. One-step forward focus. Exterior behavior is greatly motivated by interior psychology. The analysis of logical patterns should be developed into psychological analysis. Physiological indices of individuals that affect behavior in emergency situations need to be identified. More attention should be given to the effects of human gatherings on the behavior of individuals.

2. Weighting between objective and subjective information. Objective information can be obtained through communication technologies and design methodology. Greater efforts should be put into collecting subjective information. The quantization of subjective information on individuals, followed by the linking of this information to an individual's ability to handle emergencies, has become increasingly important. Based on this result, the evaluation order and assigned position of an individual can be easily determined. Not all kinds of objective information are useful under such special situations.

3. More efficient assessment methods. Questionnaires and exercises given after emergencies are frequently used approaches, being fairly simple methods. However, discussion has arisen concerning the value of such assessment data, because the emergency has already passed. Exercises using virtual reality technology exploit the experience of immersion, which provides more credible data.

4. Establishing crisis trust. Trust can help reduce panic. Crisis trust can be established among a small group, which then moves in an orderly fashion as a whole (Wang et al., 2009). Current research on how to establish crisis trust is insufficient.

5. Macro-micro crowd evacuation models. Crowd evacuation models are necessarily built hierarchically. Macro-level models focus on the overall situation. Thus, navigation information can be integrated at this level. Micro-level models concentrate on the psychological and behavioral parameters mentioned above.

6. Semantic virtual scenes. Movement in a complex environment is difficult to describe. Semantic virtual scenes enhance the cognition of virtual humans and the realism of simulations.

7. Affection computation and augmented reality. Panic is an unavoidable factor for humans in emergency situations. Affection computation with intelligent agents is essential for crowd movement simulation. Augmented reality enlarges the simulation model with on-site and real-time information.

8. Balance between realistic effect and efficiency. Large numbers of virtual people, intelligent instead of partial agents, and 3D avatars with facial expressions undoubtedly improve the realism of evacuation animation. However, the computation burden increases correspondingly. Furthermore, emergency exercises require a rapid response. This contradiction sets the balance between realistic effects and efficiency for a practicable and stable simulation system.

6 Conclusions

Research involving emergency exercises has many dimensions. Many related studies have been published investigating types of emergencies, stages of the exercise, and focus points of various disciplines. Focusing on human individuals and individual behavior, this study investigated existing research from two directions. One direction was from exterior behavior to interior psychology and directly to objective/subjective information. The other direction was from individual behavior to crowd behavior. Actually, these two directions form a continuum. Several parameters, such as information, psychology, and behavior, are helpful in constructing a reliable crowd evacuation model. Based on the summarized analysis pattern, psychological behavior and crowd evacuation animation are reviewed. Based on existing research and our own work, some prospects and suggestions for future work are discussed.

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