Human Relationship Modeling in Agent-Based Crowd Evacuation Simulation

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Abstract. Crowd evacuation simulations are becoming a tool to analyze and assess the safety of occupants in buildings. Agent-based simulation provides a platform on which to compute individual and collective behaviors that occur in crowds. We propose a human behavior model in evacuation based on the Belief-Desire-Intention (BDI) model and Helbing's agent behavior model. Human relationships affect the states of BDI at each simulation step, and altruism forces among agents are introduced in Helbing's model to affect agents' intentions in calculating agent movements. Two evacuation scenarios are examined so that the results match quantitatively and qualitatively with past disasters. The simulations reveal typical behaviors in a crowd evacuation; for example, family-minded human behaviors that lead to interactions in the crowd and other behaviors. The simulation indicates that due to the interaction it takes a longer time to evacuate from buildings in actual situations.

1 Introduction

After disasters, disaster-related measures have been taken in various countries and regions[11]. In the aftermath of Hurricane Katrina and the September 11 attacks, evacuation simulation has attracted attention to decrease the amount of damage resulting from disasters, and in particular, to save more human lives. Various types of crowd evacuation simulation approaches have been presented. Helbing et al. proposed a particle model that can simulate jamming by uncoordinated motion in a crowd[3]. Whereas the fluid-flow model and other macro-level simulations are modeled on the basis of precedent cases or experiments, they do not compute the interpersonal interactions that occur in a crowd or the behavior that involves people returning to the site. For example, at the Great East Japan earthquake at 2011 March 11, teachers waited parents come to school to bring their children for a while. And the teachers and students evacuated when they heard the tsunami coming. However, they had little time to go to safe places.

Agent-based simulation (ABS) provides a platform on which to compute the individual and collective behaviors that occur in crowds. The evacuation of people in emergencies or disasters is a complex task. Many systems have been presented to solve the following problems using the features of ABS [14]:

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1. In Helbing's model, all agents perceive the accident at the same time. In real situations, people are not likely to perceive the emergency situation simultaneously, except when a global alarm system exists.
2. Depending on events that happen during the simulation, agents adopt one of the possible behaviors classified into normal life, escape, risk avoidance, rescue and other states.
3. Psychological states and knowledge of the agent affect the choice of actions. The level of knowledge about the environment or indications from other agents makes the agents change their evacuation routes.

Evacuation simulations are becoming a tool to analyze and assess the level of safety for human life provided in buildings. It is essential to verify the results of simulations. One method is to compare the simulations to real-life data, but it is difficult to conduct experiments of evacuations. Another method is to compare the data of past disasters at real situations. A detailed report on occupant behavior in the World Trade Center (WTC) disaster has been published and a related study has been carried out by Galea et al. [4]. They noted some features that are not supported by existing simulations. One of these features is that people either come together or break apart during an evacuation.

We believe that human relationships cause behaviors that make people either form a group to evacuate together or fall away from the group. We apply BDI-based agent model in which human relationships affect behavior. Human relationships result in a sense-reason-act cycle at each simulation step. Agent movement in a crowd is calculated using Helbing's model. The model is modified to calculate the factor of agent intentions as well as other physical factors. The remainder of this paper is organized as follows. Related works are introduced in Section 2. Section 3 describes the architectures of the evacuation system composed of BDI and crowd behavior models, taking human relations into consideration. Simulation scenarios and results are discussed in Section 4. Finally, a summary is provided in Section 5.

2 Related Works

Kuligowski reviewed 28 egress models and stated that there is a need for a conceptual model of human behavior in time of disaster so that we can simulate actions such as route choice, crawling, and even group sharing of information in order to make decisions on any kind of itinerary[5] [6]. Most crowd simulations model crowds as groups of people with common characteristics or objective. Some authors attempt to model an agent with individual characteristics to create a crowd evacuation behavior [13]. Steunebrink et al. reported how emotions can be used to specify constrains on the sense-reason-act cycle of an agent[1].

The study of Galea et al. on the WTC disaster presents the following five points that are required to simulate egress from buildings. They note that most of the current evacuation simulation models do not incorporate these points.

a) Travel speed model: It is well known that congestion occurs as people's move. For example, people congest at exits when they evacuate though a

Table 1. Research issues pointed in [4] and comparison to actual works [7] [9]

	issue	Pelech.	Pan
a	congestion at exit	✓	✓
	pass the injured (same direction)	✓	✓
	meet rescues (counter flow)	*	*
	join at staircase landing	*	*
b	sensing model of people	*	*
	information share among people	✓	✓
	communication among people		
	psychological model of people		✓
c	group evacuation	✓	✓
	group formation & break		
	human relation		
d	rescue agents		
	rescue headquarters		
	announce on evacuation		
e	exit routes barred by (debris, smoke, heat, water)	debris	debris

* Some of the issue can be handled.

narrow space, rescue teams that go to victims collide against people who are evacuating from buildings, and heavy congestion occurs at staircase landings where people from upper and lower floors come together.

b) Information-seeking task: People who are unfamiliar with buildings want to know how they can exit. They look for iconic warning signs, exchange information with people nearby, or follow others. Their perception abilities or behavior patterns change according to their psychological states caused by anxiety.

c) Group formation: Guidance from well-trained leaders enables evacuation flow to occur smoothly[7]. Schools drill their students to follow the instructions of teachers and evacuate together. In a time of disaster, people evacuate under different scenarios, and various factors of the scenarios result in people forming a group or breaking away from the group.

d) Experience and training: In the WTC disaster, announcements affected the evacuation behaviors of occupants. Proper announcements save lives; incorrect announcements increase the amount of damage resulting from disasters. How well information is gathered to rescue and how well the information is announced change the behaviors of occupants.

e) Choosing and locating exit routes: There are various kinds of obstacles in disaster situations that threaten safe and smooth evacuation. Choosing evacuation places and selecting routes affect evacuation behaviors.

Pelechano et al. examined the effectiveness of guidance by trained leaders. They suggested that simulations based on grids are limited in term of simulating crowd evacuation, and presented a system that simulates the local motion and global way finding behaviors of crowds moving under psychological and geometrical rules in a social and physical forces model [10]. Pan proposed a framework that deals with human and social behavior [9]. Table 1 presents the issues cited in Galea et al. and makes a comparison with the systems of Pelechano et al. and Pan.

Recently, human relationships among agents have been taken into consideration [8] [15]. These works show the difference in evacuation behaviors between agents with and without relationships. The communication model has not been taken into consideration.

3 Agent Intentions Selection by Human Relations and Evacuation Behavior Models

3.1 Requirements for Evacuation Simulation

The issues in groups (b), (c), and (d) in Table 1 are related to each other. We believe that human relationships are one of the factors that cause group formation. People either evacuate together or they fall away from the group. For example, occupants in buildings hear an emergency bell. Some people evacuate to safe places at once whereas others stay and begin to evacuate after confirming the reason why the bell rang. During an evacuation, some people may miss others and return to the room when they feel no anxiety.

We also assume that the following points are essential to simulate the aforementioned behaviors.

Behavior decision of agents: Agent behaviors during disasters make the difference between life and death[12]. There is no guarantee that people will know all the exits and split up to go to them to ensure efficient evacuation. Evacuation guidance or instructions from trained leaders are important when evacuations are begun or in deciding how to evacuate.

Micro-level evacuation simulation: Evacuation simulations consist of movements of humans - men and women of all ages. Differences in physical condition cause jams in human flows. When many people escape from an exit at one time, their behaviors cause congestion at the doors and collisions with people who go to other exits.

Verification of simulation results: The simulations are matched both quantitatively and qualitatively to the precedent cases to verify their results before using them in real applications. Qualitative considerations include the question of how the phenomena that occurred in the real cases can be simulated. The rate of evacuation is an example of quantitative measures.

3.2 Human Relations and Decision of Intentions

In emergencies, human behaviors differ from those in ordinary times. Behaviors are affected by people's mental condition. For example, when we fear for our physical safety, we think only of ourselves and will run away from a building with no thought to anything else. However, when we feel no anxiety, we think of other people and we evacuate together. Perry et al. summarizes these human

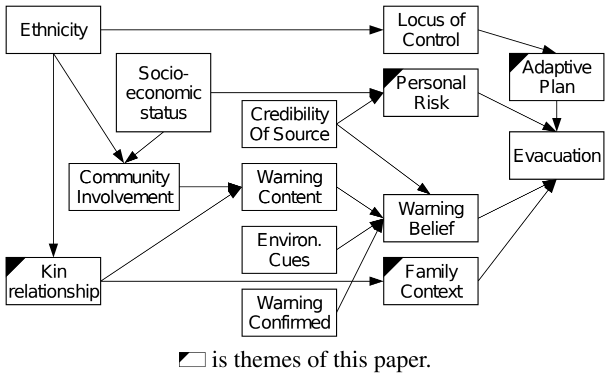

Fig. 1. Human relations factors in evacuation [11]

relation factors in decision making on the basis of empirical findings (Fig. 1). The marked factors are considered in this paper.

Herein, a BDI model in which human relation factor affects the choice of behaviors is presented. In our model, human relations affect the stages of the sense-reason-act cycle (Fig. 2).

Agents receive visual and auditory information according to their environment conditions. S_t is a set of sensor input at time step t. B_t, D_t, and I_t are the sets of belief, desire, and intention of the BDI model, respectively.

$$S_t = \{s \mid s \in sensor\ input\}$$
$$B_t = belief(S_t, B_{t-1})$$
$$D_t = option(B_t, I_{t-1})$$
$$I_t = filter(D_t, I_{t-1})$$

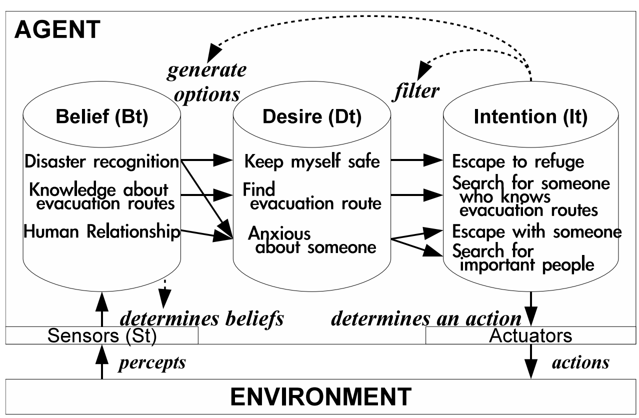

Fig. 2. BDI model of evacuation behavior that takes human relationships into consideration

belief: S_t updates B_t.

$B_t = \{PersonalRisk \cup FamilyContext \cup AdaptivePlan\}$

$FamilyContext \in \{KinRelationship\}$

B_t consists of human relation factors described in Figure 1. $KinRelationship$ handles the relations of agents and affects their evacuation behavior.

$AdaptivePlan$ are actions related to rescue actions including guiding others to safe places and coordinating the evacuation from rooms.

option: D_t is created from previous intentions and present beliefs.

$D_t = \{RiskAvoidance,\ Anxiety\}$

$RiskAvoidance = f(PersonalRisk,\ AdaptivePlan)$

$Anxiety = f(FamilyContext)$

$RiskAvoidance$ is one kind of desires that relates to the agents themselves. $Anxiety$ is a set of desires that are related to the agent's family.

filter: I_t is updated and the action determined.

$I_t = I_{RiskAvoidance} \cup I_{Anxiety}$

$I_{RiskAvoidance}$ and $I_{Anxiety}$ are intentions dragged from the variant desires regardless of whether they are their own or others. Their preference criteria are different from those of the agents.

3.3 Crowd Evacuation Behavior Simulation

Some people evacuate by themselves and others in groups. The behaviors are based on various intentions, which differ among people. These differences in intentions result in various movements, and are taken into consideration in the simulation of people behavior. In a crowd, agent behaviors are influenced by the behaviors of others.

The agent's actions are selected from their I_t. The intention is calculated in the sense-reason-act cycle at every simulation step Δt. The motions of the agent are micro simulated according to a force calculated by the following equation. The micro simulation step $\Delta\tau$ is finer than the step Δt.

$$m_i \frac{d\mathbf{v}_i}{dt} = \mathbf{f}_{social} + \mathbf{f}_{altruism} \tag{1}$$

$$\mathbf{f}_{social} = m_i \frac{v_i^0(t)\mathbf{e}_i^0(t) - \mathbf{v}_i(t)}{\tau_i} + \sum_{j(\neq i)} \mathbf{f}_{ij} + \sum_{W} \mathbf{f}_{iW}$$

$$\mathbf{f}_{altruism} = \sum_{j \in G} \mathbf{f}_{ij}$$

$\mathbf{f}_{social}$ is a social force in Helbing's model. The first term is a force that moves the agents to their target. $\mathbf{f}_{ij}$ and $\mathbf{f}_{iW}$ are repulsion forces to avoid collision with other agents and walls, respectively. $\mathbf{e}_i^0$ is a unit vector to the targets , $\mathbf{v}_i(t)$ is a walking vector at t, m_i is the weight of agents i, and v_i^0 is the speed of walking. m_i and v_i^0 are set according to the age and sex of the agent$_i$. In our model,

1. $\mathbf{e}_i^0$ is derived from the agents' intentions I_t. The targets are places or humans. When child agents follow their parent, the targets are their parent whose positions change during the simulation step Δt.
2. $\mathbf{f}_{altruism}$ is an attractive force that keeps the agents in a group. It works when a parent waits till his or her child catches up. Group G is a unit in which members physically recognize each other. So it becomes zero when parents lose sight of their child. In this case, parents intend to look for their child. This change of intentions I_{t+1} causes the setting of a different $\mathbf{e}_i^0$.

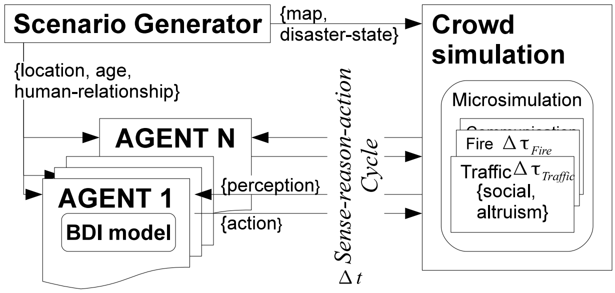

Fig. 3. Architecture of BDI based crowd evacuation system. $\Delta t > \Delta\tau_{Traffic}$

4 Evacuation Scenarios and Simulations

4.1 Prototype System and Behavior Model of Agents

Figure 3 shows the architecture of our system. Agents (in the left part) send their own properties to the crowd simulator at the start time and their targets at every sense-reason-action cycle. The targets present the agent's intentions that are selected from their BDI models. The crowd simulator calculates the movements of agents according to equation (1). The results of micro simulation are returned to the agents as its own and other agents' positions that are within their visible area.

RoboCup Rescue Simulation v.1 (RCRS) is used as a platform [2]. RCRS comprehensively simulates agents' behavior in a simulated disaster world and supports two kinds of agents: a civilian agent and a rescue agent. We implement three types of civilian agent with different BDI models (Table 2) and modify related simulators.

adult agents move autonomously and have no human relations with others. This type of agent can look for exits even when they have no knowledge of escape routes.

parent agents are adult agents who have one child. They are anxious about their child and have methods related to *anxiety*.

child agents have no data on escape routes and no ability to understand guidance from others. They can distinguish and follow their parent.

Two scenarios have been simulated to examine the effect of human relations on evacuation behaviors.

Table 2. Agent types and their behavior model

type	Belief	Desire	Intention
adult	personal risk	risk avoidance	evacuate to refuge, hear guidance
parent	personal risk	risk avoidance	evacuate to refuge, hear guidance
	family context	anxiety	seek child, evacuate with child
child	personal risk	risk avoidance	follow parent

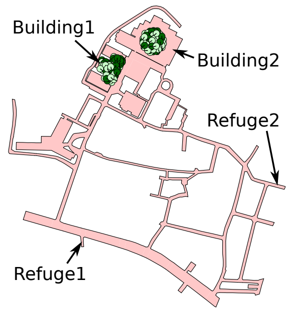

Fig. 4. A snapshot of an event (left) and campus layout and location of agents (right)

4.2 Evacuation from an Event Hall

Figure 4 presents a snapshot of an event site at a hall in which many families participate. Children enjoy the events and their parents watch them from distant places. The first scenario is one of which agents evacuate from a hall that is $70m$ by $50m$ and has one $4m$ wide exit. The parameters of the scenario are the number of agents and whether they are family members.

Figure 5 presents snapshots of evacuation simulations in two cases.

a) The 150 agents are all adults. They are divided in two groups, the left group composed of 100 adults and the right group, 50 adults.
b) The 150 agents comprise 50 adults and 50 parent-child pairs (50 parents and 50 children). The left group is composed of 50 adults and 50 parent agents the right, 50 children.

The following can be seen from the figure:

a) All agents move to the exit and congest there.
b) Where adult agents move to the exit, parent agents move to their child. When they move to their child, some parents collide with other agents who move to the exit.

At 120 steps, there are approximately 140 agents in the hall in both cases. However, it is clear that their behaviors differ. At 240 steps, the number of agents in case b) is twice as many as that in case a).

Figure 6 shows the number of agents that go out of the hall. The left and right columns correspond to case a) and b), respectively. The second row shows the results of simulation with 600 agents. In case b) of 600 agents, they are 200 adults and 200 parent-child pairs (200 parents and 200 children). The figures show that the congestion caused by the behavior of the parent agents takes more steps evacuate from the hall. Three lines in case b) are following settings of the parent agent;

without $\mathbf{f}_{altruism}$: When the parents lose their child, they look for their child at the level of BDI cycle. The $\diamond$ marked line shows a case that v_i^0s of parent agent and child agent are the same. The $\square$ marked line is that v_i^0s of child agent is 0.8 of that of parent agent.

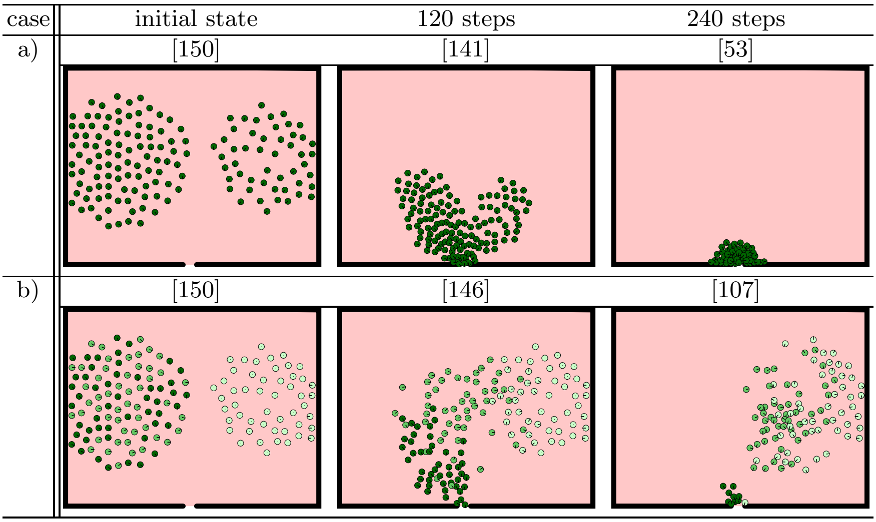

Fig. 5. Snapshots of evacuation. The number in [ ] is the number of agents in the hall. a) all agents are adults without human relations. b) 100 of 150 agents are parent-child relations.

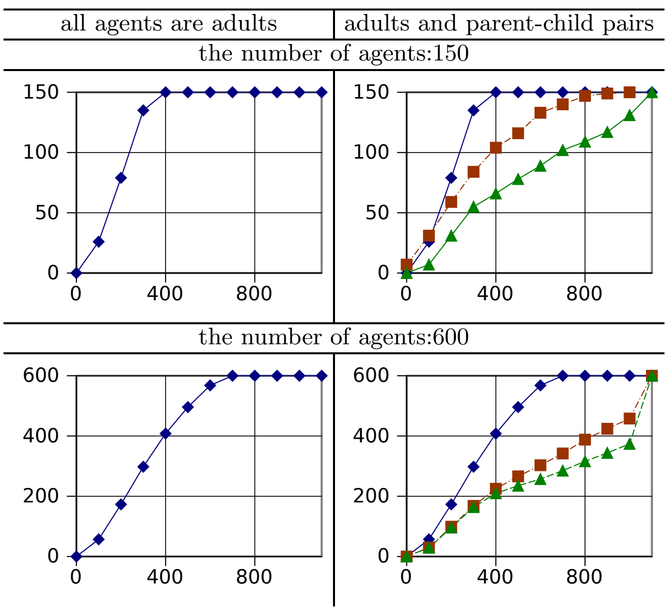

Fig. 6. The number of the agents that go out of the hall in time sequence

with $\mathbf{f}_{altruism}$: The parent - child pair moves together keeping with their distance constant (△ marked line).

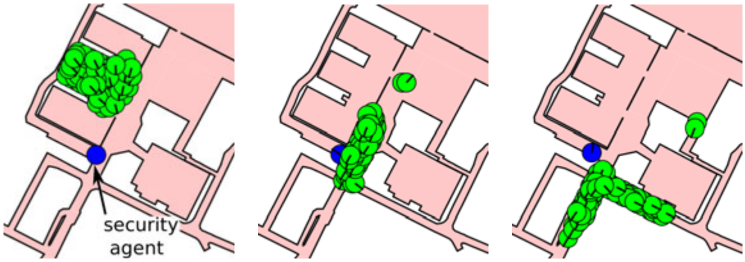

Fig. 7. Agents take different routes to Refuge2. One group goes down the road and the others up the road.

It is shown that the behaviors of the parents who care about their child take more time to evacuate.

4.3 Evacuation from a Campus with Guidance

The second scenario is evacuation from a campus. An event is held at the campus, and agents in two buildings evacuate to two refuges (Fig. 4). In an emergency, notices that urge people to evacuate to refuge locations are announced on the campus. Some agents hear the announcements and follow the instructions, and others do not. One hundred adult agents in Building 1 start to evacuate to Refuge 1, which is near Building 1. They know that there are two refuges and where the locations are. A security agent is at an intersection where agents that go to Refuge 1 pass. The security agent announces that it is safer to go to Refuge 2 than Refuge 1, so they go to Refuge 2. The agents can hear the guidance when they are within $30m$ from the security agent.

Five cases are simulated; the percentage of agents that follow the security agent varies from 0% to 100%, at every 25%. Figure 7 depicts the behavior of agents who hear the guidance. The agents at the front of the group turn left at the intersection to go to Refuge 2, whereas some others take a different route. They go up and turn right to reach the refuge.

Figure 8 presents the number of agents who arrive at Refuge 1 and 2. The numbers of agents who arrive at the refuge locations differ according to the percentage of those following the security agent's guidance. The rates and arrival time complement each other. There is one worth noting point around 1650 time steps. It takes a longer time for all agents to arrive at Refuge 1 in the cases of the 50% and 75% than 0% and 25% group, even though less agents evacuate to Refuge 1 in the 50% and 75% than 0% and 25% groups.

Figure 9 illustrates interesting snapshots that occur in the case of the 75% group. Some agents are involved in the flow of the other group that moves to the other refuge. The agents are divided into two groups: one (yellow) goes to Refuge1, and the other (green) goes to Refuge 2 from (1) to (3). Figure 9 (4) illustrates emergent behaviors that three agents are involved in the other group and return to go to Refuge 1 after some time. The behaviors explain the late arrival at Refuge 1 in the cases of the 50% and 75%.

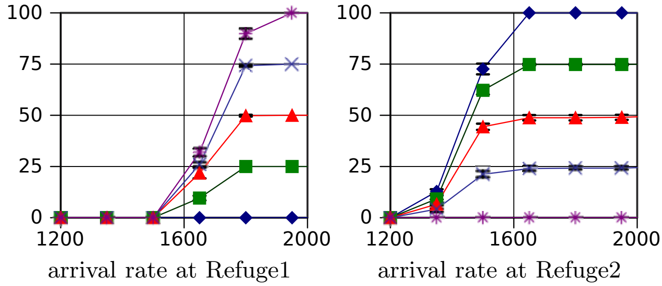

Fig. 8. Numbers of agents who arrive at refuge locations. ⋄, □, △, ×, and ∗ correspond to 0%, 25%, 50%, 75%, and 100% cases, respectively.

Fig. 9. Several agents are involved in the movements of a number of people that go to different destinations

5 Summary

The analysis of building evacuation has recently received increase attention as people are keen to assess the safety of occupants. Agent based simulation provides a platform on which to compute individual and collective behaviors that occur in crowds. We believe that psychological conditions must be taken into consideration in order to produce accurate evacuation simulations. We also assume that human relationships are factors that influence psychological conditions. We propose a model in which human relationships affect the states of BDI at each simulation step. We modify Helbing's model to include the factor of agent intentions as they are affected by their human relationships as well as other physical factors.

The model is implemented in an agent based simulation system using RCRS. Two evacuation scenarios are presented. The results of evacuation simulations reveal the following:

1. Family-minded human behaviors result in family members evacuating together, which causes interactions in the crowd.
2. Evacuation guidance affects crowd evacuation behaviors. The movements of a small number of agents are involved in a number of agent behaviors.
3. As in real life, evacuation takes more time when congestion occurs.

These are not programmed explicitly in the code of agents. The emergent behaviors occur as a result of agents' behavior-decision stages implemented as part of human relationships. These results demonstrate that our model provides an effective method of crowd simulation in an emergency.

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