Proposal for Everywhere Evacuation Simulation System

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Abstract. In the aftermath of the September 11 attacks, evacuation simulation has the potential for decreasing the amount of damage resulting from disasters, and, in particular, for saving human lives. Agent based simulation provides a platform for computing individual and collective behaviors that occur in crowds. Such simulations have led to proposals for enhanced prompt public evacuation.

For the public, it is desirable to simulate the behavior of evacuation in any building. We propose an everywhere evacuation simulation system. This system provides a software environment that permits evacuation simulation for any location for which plans are provided on the Web. Three-dimensional (3D) models of buildings and geographic information system (GIS) data for areas that are created for everyday purposes such as sightseeing are used as the environments for simulations. The characteristics of humans are set by users, and their evacuation behaviors are simulated with the relationships among them. The results of simulations can be viewed on the Web by allocating heterogeneous agents inside 2D/3D maps of buildings.

1 Introduction

A number of great disasters have occurred since RoboCup Rescue Simulation (RCRS) started at 2000. Figure 1 shows September 11 attack and disasters

Fig. 1. Many disasters have happened after RoboCup Rescue was started 9.11 WTC (2001), Tohoku earthquake and tsunami (2011), New Zealand earthquake (2011), Australia floods (2011)

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occured in 2011. There were other disasters such as Sichuan earthquake at 2008, Northern Sumatra earthquake at 2004, etc. Disaster management systems are assumed to be used before, during, and after disasters [5]. Evacuation simulations are becoming a tool for analyzing the level of safety for human life provided in buildings. A fluid-flow model and other macro-level simulations have been modeled on the basis of precedent cases or experiments; however, they do not compute the interpersonal interactions that occur in a crowd or the behavior of people returning to the site. Agent-based simulation (ABS) provides a platform that involves interactions and communications among agents. ABS makes it possible to simulate the following situations; some people may follow emergency announcements, others do not follow the announcements and continue their ordinary work. Moreover, the use of simulations has led to preparations for prompt evacuation in public places.

With regard to RoboCup, ten years have passed since the RoboCup Rescue Simulation (RCRS) league started in 2001. In competitions, rescue agents' performances are compared in various situations in different cities, and many issues have been discussed, presented, and resolved [15]. In 2010, the RCRS platform was revised into a Java based system [3]. The new RCRS(v.1) has adopted an open-space model to represent a map as a set of areas. The space presentation makes it possible to simulate human behaviors inside buildings and egress from buildings that could not be simulated by the previous version that used a network model.

We propose an everywhere evacuation simulation system (EESS). The system provides a software environment that enable evacuation simulation for any location for which plans are available on the Web. Three-dimensional (3D) models of buildings and geographic information system (GIS) data for areas are used as the environments for simulations. The characteristics of humans are set by users and their evacuation behaviors are simulated with the relationships among them. The results of simulations can be viewed on the Web by allocating heterogeneous agents in 2D/3D maps of the interior of buildings. The maps are created for everyday purposes such as sightseeing, information maps, or directions. Section 2 describes key components of our EESS. Section 3 explains our proposals for ESS and Section 4 presents the simulation results. A summary of our proposal and discussions are presented in Section 5.

2 Related Works on Evacuation Simulation

2.1 Agent-Based Evacuation System

Kuligowski et al.[8] reviewed 28 egress models and categorized them into three basic categories: movement models, partial-behavioral models, and behavioral models, and they stated that there is a need for a conceptual model of human behavior in time of disaster. Pelechano et al. suggested that simulations based on grids are limited in term of simulating crowd evacuation and that there is a need for behavior simulations; Pan's framework [12] deals with human and social behavior .

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. [7]. They noted some features that are not included in existing simulations. Table 1 lists the issues cited in Galea and provides a comparison among the systems of Pelechano et al., Pan and RCRSs. Issue groups in the table are as follows:

a) **Travel speed model:** It is well known that congestion occurs as people move [6]. For example, people congest at exits when they evacuate though a 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 are at a loss as to which way they can exit. They look for iconic warning signs, they exchange information with people nearby, or they follow persons who seem to be evacuating. The perception abilities or behavior patterns change according to their psychological states caused by anxiety.
c) **Group formation:** Guidance from well-trained leaders can make evacuation flow more smoothly [10]. Schools drill their students to follow the instructions of teachers and they evacuate together. In the time of disaster, people evacuate under various motivations, and they form a group or break away from the group.
d) **Experience and training:** In the WTC disaster, announcements affected the evacuation behavior of the occupants. Proper announcements save lives; incorrect announcements increase the amount of damage resulting from disasters.
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 the evacuation behaviors.

2.2 Evacuation Scenarios and Space Presentation Model

In disasters, various types of causalities and accidents occur. The following situations become scenarios of evacuation simulation when disasters occur at a school campus.

Outside buildings: Students evacuate from buildings to open-space areas or go to refuges. Rescue teams rush to the buildings to rescue injured students. The injured are transported to hospitals.

Inside buildings: Students go to exits of rooms, look for emergency exits, and take stairs to the ground floor. The rescue teams go to rooms, and check whether occupants remain there.

Outside and inside buildings: Emergency notices are announced to lead people to safe places.

Table 1. Research issues presented in Galea's work[7] and comparison to related works

	issue	Pelechano	Pan	RCRS(v.0)	RCRS(v.1)
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	debris (outside)	debris

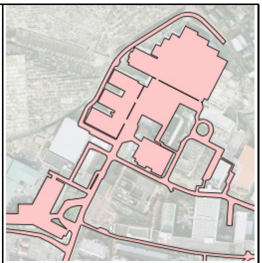
Two space-presentation models, namely, a network model and an open-space model, have been employed to simulate the movements of agents. Table 2 lists the features of the models. In a network model, intersections and buildings of a map are presented as nodes; edges connecting nodes are shown as roads. The movements of agents flow through the edges and the flows are calculated on the basis of the network model [16] [15]. An open-space model presents all objects on a map, such as intersections, buildings, roads and squares, as areas. Although the open-space model needs more computational resources than the network model, it calculates the position of agents and simulates congested situations in two-way traffic and squares [11].

2.3 Applications of Evacuation Simulation

After disasters, disaster-related measures have been taken in various countries and regions [13][2]. These measures aim to decrease the amount of damage caused by disasters. Some projects and systems have been proposed to ensure prompt planning for disaster mitigation, risk management, and support of IT infrastructures [5][9].

Technologies and concepts cited as Web 2.0 have provided users with the means to interact and collaborate with each other on the Internet. Google Earth is one of such applications; it can let us go anywhere on the earth and see terrain or 3D buildings. Not only can we enjoy them on the Web we can also update data of own concerns to the Web. The following are widely used in our everyday life:

Table 2. Space presentation and features of traffic simulations

real map	network	open space
		
jam in one-way traffic	✓	✓
jam in two-way traffic		✓
congestion in squares		✓
group behaviors		✓

3D models of buildings: We develop 3D models of buildings, and public facilities are created for landscape simulations or sightseeing guide signs; these are available on the Web.

GIS data of areas: OpenStreetMap (OSM) is a collaborative project to create a free editable map of the world by people's efforts to gather location data with GPS devices [1].

3 Proposal for EESS

3.1 Checking Safety of Buildings Everywhere

Figure 2 shows a snapshot of the Junior League at RoboCup 2010. Team members participate in games, and their mentors watch them from distant places. In the time of emergency, the following situations can be imagined: some rush to exits, or mentors go to their members to evacuate together rather than go to the exits. Some behaviors make the difference between life and death[14].

Before scheduling major events, safety managers of the events are required to assess the levels of safety for human life provided in the buildings and plan effective layout of escape route signs in case of emergency. In emergencies, human behaviors differ from those in ordinary times. There are various kinds of people in the buildings, such as young and old and men and women. It is desirable that the characteristics of occupants are taken into consideration in simulating the evacuation behavior and planning escape routes.

3.2 BDI Models at Evacuation and Motion Model in a Crowd

Evacuation behaviors are based on various intentions, which differ among people. Some people evacuate by themselves and others in groups. The behaviors depend

Fig. 2. Snapshot of an event where many people gather

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

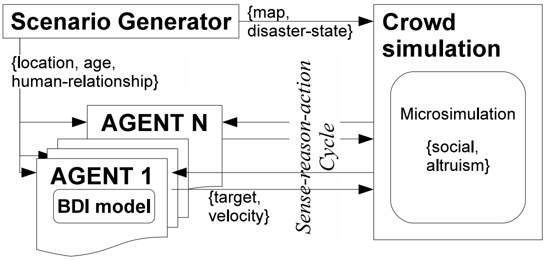


Fig. 3. Architecture of BDI based crowd evacuation system

on physical, mental and social states, as well as on the information that they have. Figure 3 shows the architecture of our system [deleted for blind review]. The properties of agents (in the left part) are sent to the crowd simulator at the start time as well as their targets at every sense-reason-action cycle. The targets present the agent's intentions that are selected from their belief, desire, and intention (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 their own and other agents' positions that are within their visible area.

BDI Models at Evacuation: In our model, human relations affect the stages of the sense-reason-act cycle. S_t is a set of input that agents receive as visual and auditory information according to their environmental conditions at time step t. B_t, D_t, and I_t are the sets of beliefs, desires, and intentions of the BDI model, respectively. We implement three types of civilian agents with different BDI models (Table 3).

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 each. They are anxious about their children 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 parents.

Table 3. Agent types and their behavior in BDI 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 removal	seek child evacuate with child
child	personal risk	risk avoidance	follow parent

Motion Model in a Crowd: The agent's actions are selected from their I_t. The intention is calculated in the sense-reason-act cycle at every simulation interval Δt. The motions of the agent are micro simulated according to a force calculated by the following equation. The micro simulation interval $\Delta\tau$ is smaller than the interval 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 particle model that can simulate jamming by uncoordinated motion in a crowd[4][6]. The first term is a force that moves the agents to their target. $\mathbf{f}_{ij}$ and $\mathbf{f}_{iW}$ are repulsive forces that 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 agent$_i$. In our model,

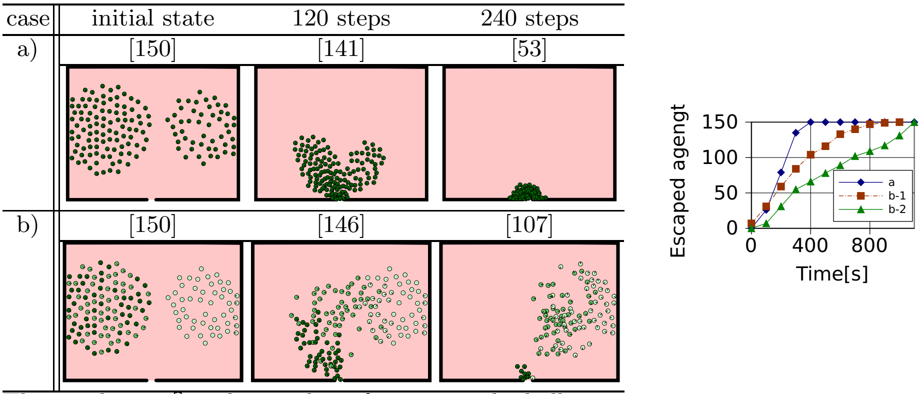
1. $\mathbf{e}_i^0$ is derived from the agents' intentions I_t. The targets are places or humans. When child agents follow their parents, the targets are their parent whose positions change during the simulation interval Δt.
2. $\mathbf{f}_{altruism}$ is an attractive force that keeps the agents in a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

4 Prototype System Based RCRS and Simulation Results

RoboCup Rescue Simulation v.1 (RCRS) is used as a platform [3]. RCRS comprehensively simulates agents' behavior in a simulated disaster world and our architecture can be run with small modifications.

4.1 ABS Example: Evacuation from Event Hall

Figure 4 shows 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 scenario is one of which agents evacuate from a hall that is $70m \times 50m$ and has one $4m$ wide exit. The parameters of the scenario are the number of agents and whether they are family members.



The number in [] is the number of agents in the hall.
case a) all agents are adults without human relations.
case b) 100 of 150 agents are parent-child relations. b-1)without $\mathbf{f}_{altruism}$. b-2)with $\mathbf{f}_{altruism}$. (bright: child, gray: parent, dark: adult)

Fig. 4. Snapshots of evacuation and change in number of agents who evacuate the room

(a) The 150 agents are all adults. They are divided in two groups; the left group is 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 group is composed of 50 children.

The following can be seen from the figure:

- All agents move toward the exit and congest there.
- Where adult agents move toward the exit, parent agents move to their child. When they move toward their children, some parents collide with other agents who move toward 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 that in case (a).

Figures of the right column show the number of agents that evacuate from the hall. The rows correspond to case (a) and (b). The figures show that congestion caused by the behavior of the parent agents takes more steps to evacuate from the hall. Three lines in the right column shows case (a) and two following settings;

b-1) without $\mathbf{f}_{altruism}$: When the parents lose their child, they look for their children at the level of the BDI cycle. The ⋄ marked line shows a case in which the v_i^0s of parent agents and child agent are the same. The □ marked line is that in which the v_i^0s of child agents are 0.8 of those of the parent agents.

b-2) with $\mathbf{f}_{altruism}$: The parent - child pair moves together keeping with their distance constant (△ marked line).

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

4.2 EESS Example: Evacuation from Library on Campus

People exit from rooms and evacuate from buildings. When they are out of buildings, they go to refuges. A global coordinate, Σ_{Global}, is necessary to simulate such evacuation behaviors and display. On the other hand, 3D data of buildings or agents are created in each coordinates system, $\Sigma_{Buildingk}$. (Figure 5). The data in $\Sigma_{Buildingk}$s are represented in corresponding KMZ files or they are converted ones in Σ_{Global} and merged into one KMZ file. Figure 6 shows an overview of EESS which consists of three phases.

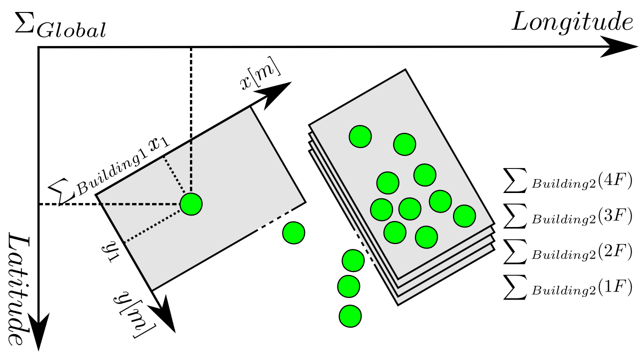


Fig. 5. Global and local coordinate systems in evacuation simulation

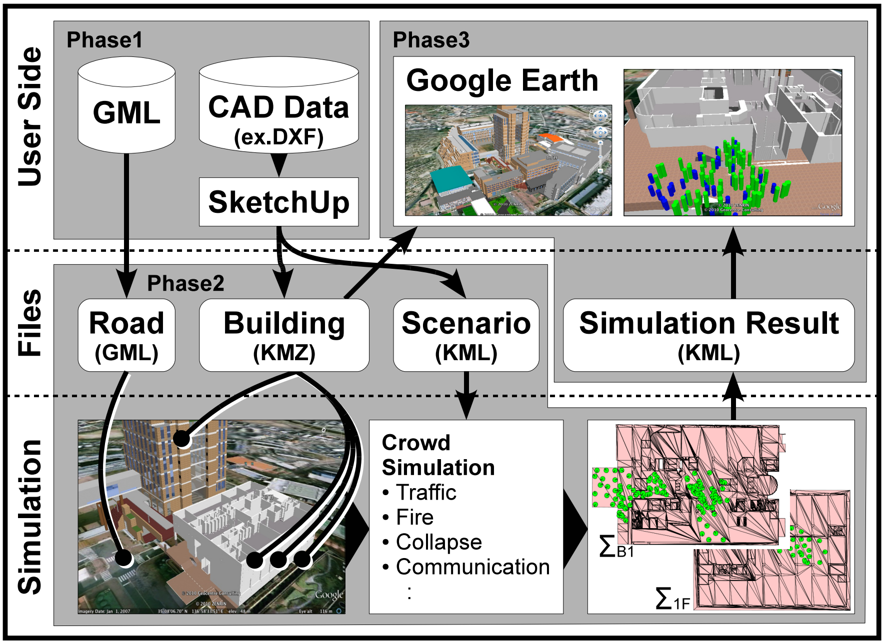


Fig. 6. Three phases of EESS. Users prepare 3D models of buildings and set properties of agents (Phase 1), ABS evacuation simulation (Phase 2), and display on the Web (Phase 3).

Phase1: Modeling 3D Buildings and Web World. 3D models of buildings or GIS data of towns are created and used for sightseeing or guidance every day. They are represented in several formats such as DXF and are converted into a format that can be input to a Web browser. The EESS system uses two types of files, namely, KMZ and GML files. KMZ files have the geographical data and location data of objects in their own Σ_{Global}, and GML files contain map data of the area.

Phase2: Evacuation Simulation on Converted Pseudo-3D World. Evacuation from buildings is simulated using the 3D data created in Phase 1 and an ABS described in Section 4.1. Inside building, the movements of agents are simulated and their motions are calculated in an open space in Σ_{Local} of the building. Figure 6 shows the simulation results of an evacuation behavior in a two-story library. Two figures correspond to two floors, i.e., B1F and 1F, which are connected with a stairway that is also represented in an open-space models.

Phase3: Displaying Simulation on the Web. The results of evacuation simulation are embedded in `<Placemark>` tag in KML files. The tag consists of three sub-tags, i.e., <styleUrl>, <TimeStamp>, and <Point>, which are used to display the motions of agents in Google Earth. Displaying the results of simulations on the Web provides a good instructional material for evacuation drills. The following shows a listing of the KML file.

```
<kml>
 ...
 <Placemark>
  <styleUrl>#civilian-parent</styleUrl>
  <TimeStamp>
   <when>2007-01-14T21:05:02Z</when>
  </TimeStamp>
  <Point>
   <coordinates>-122.536226,37.86047,0</coordinates>
  </Point>
 </Placemark>
 ...
</kml>
```

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 for computing individual and collective behaviors that occur in crowds. The report on occupant behavior in the WTC disaster noted some features that are not included in existing simulations.

This paper proposes an agent-based evacuation system that simulates evacuation behaviors in any location where 3D models have been created for everyday usage such as sightseeing and guidance. The evacuation behaviors are simulated with a BDI model in which the mental disposition of each agent is represented. The BDI-based evacuation system solves the group formation issues cited in the WTC disaster report. The results are embedded into a KML file and can be viewed on the Web.

Our prototype system shows that the simulation results can be displayed on the Web and can be used for public relations to illustrate how proper behavior will save human lives and decrease the harm from disasters.

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