MODELING SOCIAL GROUPS AND ROLES IN EGRESS SIMULATION

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ABSTRACT

Emergency evacuation (egress) design and planning are important aspects in building and facility engineering. Studies of past emergency events indicate that evacuating occupants often exhibit social behaviors during the evacuation process. Such behaviors are often shaped by pre-existing social relationships and influenced by perceived information. This paper describes an on-going research effort towards the development of an egress simulation tool that takes into account the human and social behaviors observed in post-fire studies and disasters investigations. The multi-agent based simulation framework, SAFEgress (**S**ocial **A**gent **F**or **Egress** simulation), is designed to allow the users to incorporate different occupants' behaviors into egress simulations. The prototype software is able to simulate certain social behaviors and the interactions among the occupants that are commonly observed during emergencies.

INTRODUCTION

Safe egress plays a very important role in facility design and management, particularly for large-scale events with high occupant density. For mass gatherings, such as sport events and public ceremonies, the crowd usually consists of many small groups. During emergency evacuation, people tend to interact with their social group and act in a collective fashion. Furthermore, the presence of authorities can greatly affect evacuees' behaviors as the evacuees often follow the instructions provided by the authorities during emergencies. This paper describes an implementation of social groups and authoritative roles in a multi-agent based simulation framework, SAFEgress (**S**ocial **A**gent **F**or **Egress** simulation). Simulation results are presented to illustrate the influence of social behaviors during evacuation.

LITERATURE REVIEW

People often participate in mass gatherings with their social group[1,2]. The social group has its own pre-existing social structure (relations between group members) and group norms (expectations of each other's behavior) that may in turn affect the behavior of an individual. Different theories have been proposed by social scientists to explain the effects of social relationship on individuals during emergency situations[3,4,5,6]. As reported in several empirical studies of recent accidents, occupants in emergencies make evacuation decision collectively with their group members; they gather information from one another, interpret the emergency cues, and initiate escape actions collectively[5,6,7,8]. Furthermore, the group has an effect on individual's navigation decision at both global (exit route and destination) and local (intermediate movement to reach the destination) level. At the global level, the whereabouts of group members would affect people's choice for an exit route[5,6]. For example, members of a closely related group would search for those who are missing or separated before exiting the building even under extreme emergency situation[7]. At the local level, members tend to stay close to each other and navigate as a group[6,7]. Recently, there has been research on group walking patterns that illustrate the important effects of group on individual traveling speed and the group navigation pattern in different crowd situations[2,10]. In short, to simulate occupants' movement in an evacuation situation, it is important to model the social group and its effect on the occupants' behaviors and navigation choice.

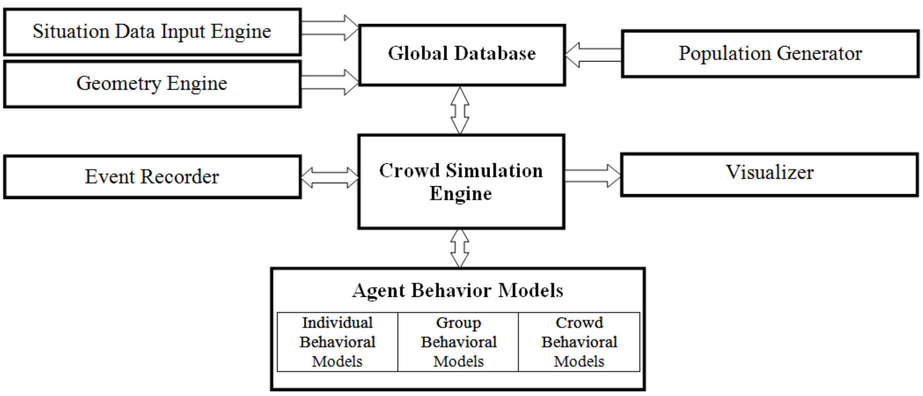
During an emergency, people often receive information from warning systems or authorities and make their evacuation decision accordingly. In some situations in which there is no clear authorities, such as fire wardens, among the occupants, organization leaders or staff members who are familiar with the place may extend their normal roles to offer evacuation instructions[4,7,8]. Studies have shown that people tend to follow instructions given by their group leaders and authorities, even when the information contradicts their preference and intention[4,11]. For example, in the 2001WTC terror attack, the occupants sought instructions from fire wardens before they started to evacuate[11]. In the King's Cross train station fire accident, as another example, passengers exited the station by following the instructions provided by the station staff and police, despite their intention to travel to their original destination[4]. It is clear that the roles of authorities and the instructions by the authorities can have a determining effect on emergency evacuation.

Although many simulation tools are now available[12,13], there remains a dire need to improve the realism and accuracy in modeling crowd behaviors and movements[1]. There has been increasing interest to incorporate realistic social behaviors into egress analysis tools in order to achieve more reliable and realistic simulation results in assisting facility designs[9,14]. For example, Aguirre et al. describe the use of an agent-based simulation model to incorporate characteristics of a group and leader-following behavior[9]. This paper describes a modular computational framework that would allow different human and social behaviors to be incorporated into egress simulation[15]. Specifically, this paper discusses the implementation of social groups and authority roles and their effect on emergency evacuation.

COMPUTATIONAL FRAMEWORK

Figure 1 schematically depicts the system architecture of our multi-agent based computational framework, SAFEgress. The Global Database, Crowd Simulation Engine, and Agent Behavior Model constitute the key modules of the framework. The Global Database stores (1) the information about the agent population generated by Population Generator (such as the distribution of age, mobility, and physical size), (2) the physical environment from the Geometric Engine (such as the spatial layout, exit signs, and obstacles), and (3) the status of emergency situations from the Situation Data Input Engine (such as status of alarm, smoke, and fire). The Global Database also maintains the state information of the agents, including internal mental thresholds, behavioral decisions, and locations. The Agent Behavior Models contains the individual, group, and crowd behavioral models. The Crowd Simulation Engine interacts with the Global Database and the Agent Behavior Models to simulate the individual and crowd movements. The simulated results are displayed by the Visualizer (currently implemented using OpenGL) and time-stamped events are logged by the Event Recorder for further analysis.

Figure 1 Overall architecture of the framework



In the simulation, each individual is modeled as an autonomous agent who interacts dynamically with the physical environment and other agents. Agents defined by their population type and their social characteristics are incorporated with prior experience and knowledge of the dynamically changing situation. The agents are also equipped with sensors for perception of the environment and actuators for executing decisions and movements. An agent behavioral model consists of three basic components, namely, perception, decision-making, and execution. At each step, an agent updates its perceived environmental information and the social information about its group(s) and the surrounding crowd. Based on the perceived information and its behavioral profiles, an agent chooses a behavior among the different behaviors at the individual, group, and crowd level. After reasoning through the individual, group, and crowd level behaviors, the agent selects a final behavioral decision and defines a specific goal. At the execution level, the agent navigates towards the goal with low-level locomotion, with consideration of goal distance, interpersonal distances among its neighboring agent(s), and obstacle avoidance.

IMPLEMENTATIONS OF GROUPS AND ROLES

This section describes the current status of our effort in the implementation of social behavioral models to simulate the effects of group and role of authorities.

Group behaviors

We have implemented three typical group behaviors, namely, leader following, group member following, and group member seeking. Table 1 summarizes the basic rules for the three group behavioral models. Each agent decides whether it would exhibit a group behavior, based on information gathered from the situation and reasoning through the behavioral rules of each model. At the perception stage, an agent detects the existence and the whereabouts of the *visible group members* and the *neighboring agents*. At the decision-making stage, the agent reasons through the rules at the individual, group, and crowd level successively for each behavioral model as shown in Table 1. Note that the level of group members' influence on an agent is set by the parameter values defined by the users. If the agent is affiliated with a social group and the behavioral rules are satisfied, the agent will set its navigation target according to the specification in the selected behavioral model.

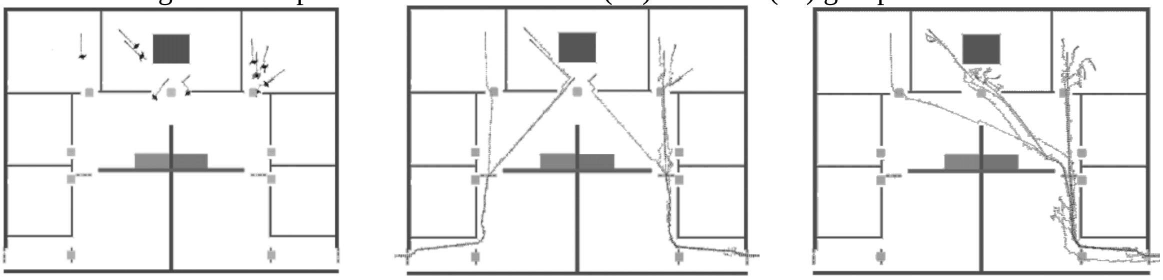
Table 1 Behavioral rules of group behavioral models

Individual level →	Group level →	Crowd level →	Target
	Leader following		
• The agent is not a *group leader* of its *affiliated group* • *Group leader* of its *affiliated group* is visible	• The *group influence* of *group leader* is <HIGH> • Separation distance between the *group leader* and the agent is larger than <NEAR>	• Crowd density is <LOW>	*Group leader*
	Group member following		
• The agent is not a *group leader* of its *affiliated group* • There exist(s) *visible group member(s)*	• The *group influence* of all *visible group members* are the same • Average separation distance among *visible group member* and the agent is larger than <NEAR>	• Crowd density is <LOW>	Nearest *visible group member*
	Group member seeking		
• The agent is a *group leader* of its *affiliated group*	• Percentage of *visible members* is less than <*group seeking*> of the *affiliated group*	• Crowd density is <LOW>	Exploring floor

(<   > denotes parameter values defined by users)

Figure 2 shows an example illustrating the effect of group behavior. The initial locations of 10 evacuating agents are shown in Figure 2a. Figure 2b shows the simulation results assuming the agents act individually without any assigned group affiliations. In this case the agents choose to exit through the nearest exit and, as a result, utilize both exits evenly. Figure 2c illustrates the case that the preference of an exit route by other group members affects the choice of exit of individual agents. The agents with group affiliation tend to evacuate together via the same exit route. It can be seen that the evacuation patterns can vary quite differently when different group settings are assumed.

Figure 2 Comparison of results without (2b) and with (2c) group behaviors



2a Initial simulation setting | 2b Evacuation pattern of individual agents | 2c Evacuation pattern of agents in group

Group Navigation

Groups and crowd flow also affect the group walking patterns[2,10]. We have implemented the effect of group on agent's navigation as follows: at the perception stage, an agent detects the *neighboring agents* within a specified radius and calculates the crowd density and the crowd flow direction; at the execution stage, when encountering cross flows in a dense crowd, the agent will reset its navigation target from its original target to a nearby group member (according to the separation distance and the member's influence) temporarily.

Figure 3 shows the walking patterns of groups in different crowd flow situations. The agents are assigned to different groups and the lines joining the agents indicate the presence of social ties between the agents. As shown in Figure 3a, without any cross flow, the groups tend to walk as a cluster with formation in a V-shape or horizontally along the travelling direction. Figure 3b shows the emerging lane-forming patterns as groups are walking across each other in opposite direction.

Figure 3 Different group walking patterns in different flow situations

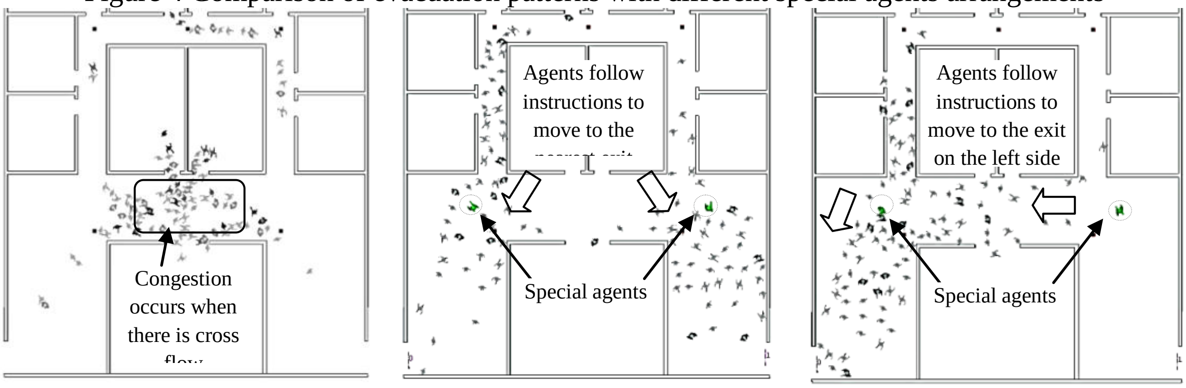
3a Groups form clusters initially | 3b Groups form lanes in cross flow

Modeling the role of authorities

People interact with each other to gather information and tend to follow authority's instruction during emergency evacuation[4,8,11]. We have implemented a special agent that models the role of authorities. Additional functionalities can be assigned to the special agent to mimic the roles that different authorities can play to facilitate the emergency evacuation process. Specifically, two behavioral models have been incorporated: (1) to instruct the crowd to exit; and (2) to fulfill the authority's duty by checking assigned spaces.

Acting to instruct the crowd to exit, the special authority agent is assigned with location(s) to carry its duty and the exit instruction. During the simulation, the special agent first moves to the assigned position and gives exit instruction to the evacuating agents. The evacuating agents, upon detecting the special agents, then weigh the instructed exit or exit route and change their exit preference. Figure 4 shows the comparison of evacuation patterns of 120 agents with different arrangements of special agents. In Figure 4a, without any special role agents assigned, congestion is observed at the corridor where agents encounter each other when moving to their preferred exit. In Figure 4b, two special agents are positioned to instruct the evacuating agents to exit through the nearest exit and, as a result, cross flow is avoided. In Figure 4c, the evacuating agents are instructed by the two special agents to exit through the left exit and again and no cross flow is observed in this case. The simulations illustrate that the presence of special agent with authority roles and the instructions given by them can greatly affect the congestion pattern and evacuation time.

Figure 4 Comparison of evacuation patterns with different special agents arrangements



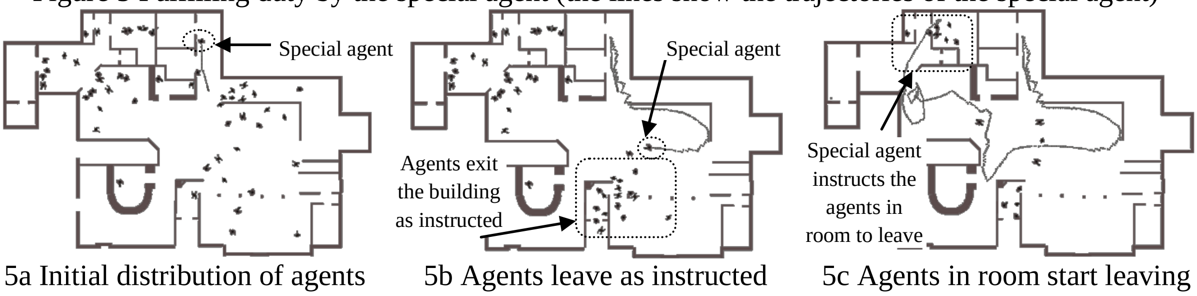
4a Congestion at the corridor when there is no special agent

4b Agents are instructed to exit via the nearest exit

4c Agents are instructed to exit via left exit

Besides providing guidance for exiting, a special agent can be assigned with other duties, such as inspecting and searching for occupants in assigned spaces. Given a set of assigned spaces, the special agent will plan its route and instruct the evacuating agents remaining in the rooms, if any, to leave via the designated exit. Figure 5 shows the process of fulfilling the inspection and searching duty by the special agent. Figure 5b shows the special agent giving instructions to other visible agents to leave the building during the inspection route. Figure 5c shows the route of the special agents, searching for occupants. The incorporation of roles and duties, such as instructing the crowd to exit and fulfilling the duty of inspection and searching for occupants, serve to illustrate the possibility of defining special agents to mimic authorities and to study the effects of different staff arrangements on evacuation.

Figure 5 Fulfilling duty by the special agent (the lines show the trajectories of the special agent)



5a Initial distribution of agents

5b Agents leave as instructed

5c Agents in room start leaving

CONCLUSION AND FUTURE WORK

Although the importance of modeling realistic human and social behaviors in egress simulations has been recognized by social scientists and disaster management researchers, such factors are still seldomly considered in current egress simulation tools. This paper describes an on-going research in bridging this gap by modeling human behaviors with group and crowd considerations in egress simulations. Our prototype has demonstrated the potential of including group behaviors and roles of authorities in a multi-agent based simulation platform. The simulation framework can be used to model different social behaviors that are deemed appropriate in a specific emergency situation, obtain valuable information to evaluate egress design, and to derive insight on emergency planning and management. Along the development of the computational framework, we will continue to carry out analysis on people's egress behaviors, derive behavioral models, and implement human and social behaviors for egress simulation.

ACKNOWLEDGEMENT

The first author is supported by a fellowship from the Croucher Foundation and a John A. Blume fellowship at Stanford University. This research is partially supported by the Center for Integrated Facility Engineering, Stanford University. Any findings and opinions are those of the authors and do not necessarily reflect the views of the Croucher Foundation, Stanford University, or any organizations.

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