Incorporating Social Behaviors in Egress Simulation

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ABSTRACT

Emergency evacuation (egress) is considered one of the most important issues in the design of buildings and public facilities. Given the complexity and variability in an evacuation situation, computational simulation tool is often used to help assess the performance of an egress design. Studies have revealed that social behaviors can have significant influence on the evacuating crowd during an emergency. Among the challenges in designing safe egress thus include identifying the social behaviors and incorporating them in the design analysis. Even though many egress simulation tools now exist, realistic human and social behaviors commonly observed in emergency situations are not supported. This paper describes an egress simulation approach that incorporates research results from social science regarding human and social behaviors observed in emergency situations. By integrating the behavioral theories proposed by social scientists, the simulation tool can potentially produce more realistic predications than current tools which heavily rely on simplified and, in most cases, mathematical assumptions.

KEYWORDS

Social behavior, egress, crowd simulation, multi-agent based modeling

INTRODUCTION

This paper articulates a computational approach that integrates human and social behaviors in emergency evacuation (egress) simulations. Despite the wide range of simulation tools currently available, “the fundamental understanding of the sociological and psychological components of pedestrian and evacuation behaviors is left wanting [in computational simulation] (Galea, 2003, p. VI)”, and the situation has been echoed by the authorities in fire engineering and social science (Aguirre 2009; Challenger et al. 2009; Still 2000). Our approach to address this shortcoming is to design a multi-agent based egress simulation framework that can incorporate current and future social behavior theories on crowd dynamics and emergency evacuation. This multi-agent based framework is architected to facilitate the generation of behavior profiles and decision models for a diverse population. This paper describes the system framework and the features that are currently implemented. The prototype system is capable of simulating some of the group and social processes that have been observed in real situations and identified in recent social studies.

LITERATURE REVIEW

Social behavior in emergency situations

Social scientists and disaster management researchers have been studying human behaviors in emergency situations and have developed a variety of theories about crowd behaviors in emergency situations (Aguirre et al. 2009; Averill et al. 2005; Cocking & Drury 2008; Proulx et al. 2004). A comprehensive review of various social theories about crowd behaviors has recently been reported by Challenger et al. (2009). Some examples of prevalent theories on crowd behaviors include self-organization (Helbing et al. 2005), social identity (Cocking & Drury 2008), affiliation model (Mawson 2005), normative theory (Aguirre 2005), panic theory (Chertkoff & Kushigian 1999) and decision-making theory (Mintz 1951). Earlier theories in crowd behavior suggest that people tend to behave individually and show non-adaptive behaviors in dangerous situations. For example, the **panic theory** suggests that people would become panicked in an emergency situation and act irrationally upon perceiving danger. In contrast, the **decision-making theory** argues that people would act rationally to achieve a better outcome in the situation. Recent theories, on the other hand, emphasize the sociality of the crowd (such as pre-existing social relationships or emerging identity during the emergencies) in explaining the occupants' reactions in past accidents. For example, the **affiliation model** suggests that people are typically motivated to move towards familiar people or locations and show increased social attachment behavior in an emergency situation. The **normative theory** stresses that the same social rules and roles that govern human behavior in everyday life are also observed in emergency situations. According to these recent theories, evacuating crowds retain their sociality and behave in a socially structured manner.

Incorporating social behaviors in egress simulation

The lack of human and social behaviors in current egress simulation tools has been recognized by social scientists, organizational psychologists and emergency management experts (Gwynne et al. 2005; Santos & Aguirre 2004). It is recommended that, future simulation tools should include the following features and their effects in relation to human social behavior (Aguirre 2009; Averill et al. 2005; Challenger et al. 2009; Cocking & Drury 2008; Mawson 2005):

- pre-existing relationships and group behavior in a simulated crowd.
- communication between crowd members and its impact on crowd behaviors.
- ability to account for the fact that crowd members are unlikely to have complete information or understanding of their environment.
- inter-group interactions and the influence of crowd members with different roles.

COMPUTATIONAL SIMULATION FRAMEWORK

This work extends a multi-agent based framework, MASSEgress, which is designed to model and to implement human and social behaviors in emergency evacuation (Pan 2006; Pan et al. 2007). In the simulation, each individual is modeled as an autonomous agent who interacts with other agents. The multi-agent based approach can simulate not only individuals, but also social and emerging behaviors of crowds in a virtual setting. This approach also allows a software agent to mimic human decision making process and individual behavior execution. Furthermore, the framework offers the flexibility to implement a variety of human behaviors as proposed by social scientists. For example, users can create different roles for the agents and assemble behavior models to reflect a specific behavioral theory.

System architecture

Figure 1 schematically depicts the system architecture of the multi-agent simulation framework. The Global Database, Crowd Simulation Engine and Agent Behavior Model constitute the key modules of the framework. The **Global Database** maintains all the information about the physical environment and the agent population during a simulation. It obtains physical geometries from the **Geometric Engine** and sensing information from the **Sensing Data Input Engine**, as well as the agent population distribution and physical parameters from the **Population Generator**. The **Agent Behavior Model** contains the agent decision profiles and agent group information. The Global Database and the Agent Behavior Model interact with each other through the **Crowd Simulation Engine**, which generates visual output and event logs.

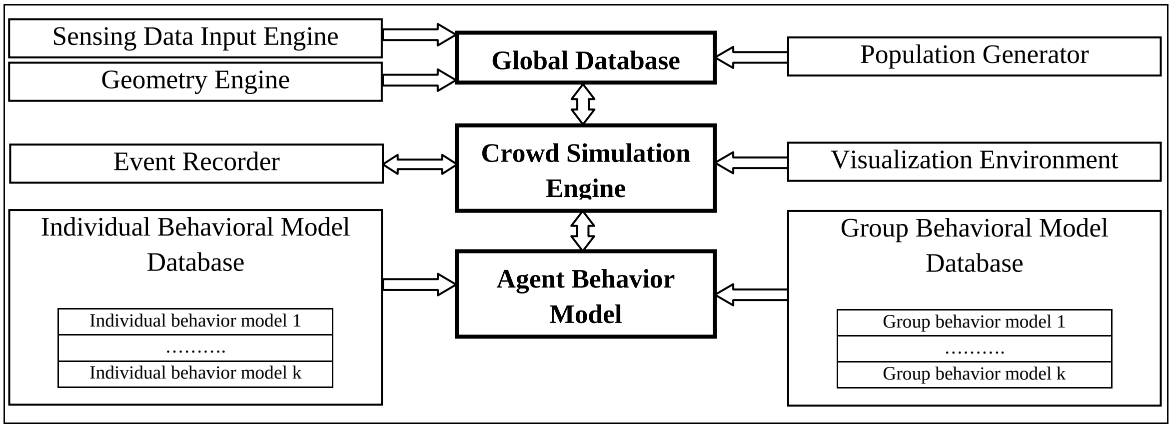


Figure 1. Overall architecture of the framework

Agent behavior model

Figure 2 shows the agent behavior model consisting of three fundamental steps, namely perception, decision making and execution. An agent possesses a list of distinct traits (such as physical sizes and its affiliation to a group) and decision profile. At each simulation step, an agent perceives and assesses information about the surrounding environment. The information can be visual, audio, or time-related data, such as the visibility of a leader or an exit sign, evacuating time, etc. Based on the perceived data, an agent prioritizes the different behaviors that the agent may exhibit and chooses the one with the highest priority. After a decision is made, the agent executes the actions according to the selected behavior, and invokes the appropriate locomotion.

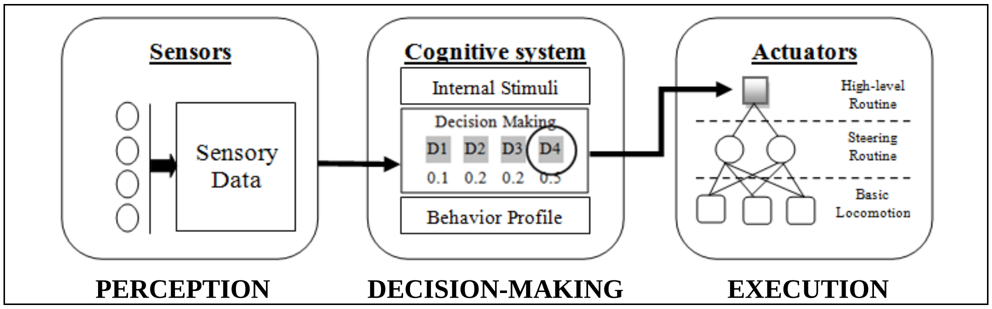


Figure 2. The three subsystems of an agent behavior model

Creation of agents with specific social roles and functions

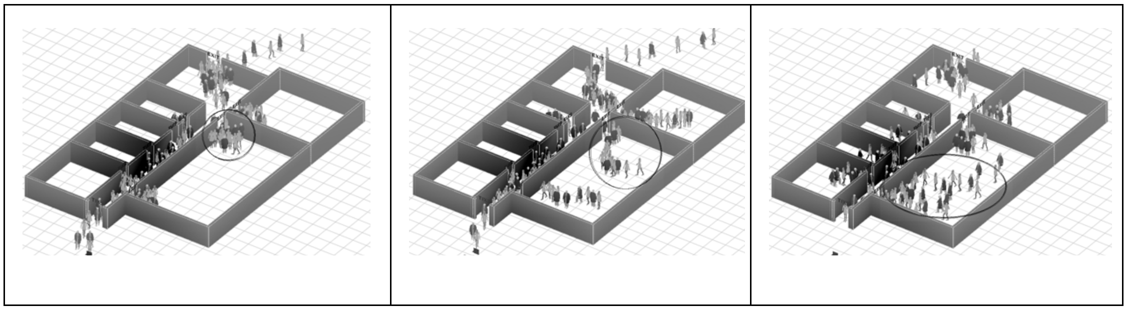
Each agent is defined by physical characteristics (such as physical size, gender and mobility) and psychological traits (such as decision model). Taking the advantage of building the computational framework on an object-oriented programming (OOP) paradigm, certain types of agents can be extended conveniently through inheritance. For example, a “leader” can be specified as an agent who possesses some leadership abilities with a high degree of autonomy when maneuvering in an environment. A “marshall” can be modeled as an agent who inherits from a “leader” but with additional knowledge about the egress routes and additional path-finding ability. Different agents with specific functionality and social role can be created by extending or modifying a base agent type.

Group level parameters

Studies in social science have shown the importance of group dynamics and social behaviors as observed from past accidents. Besides modeling the interactions of individual agents, it is desirable to explicitly model the social behaviors, for using certain social parameters, as identified by social science researchers. Our framework implements an additional layer of agent definition by affiliating each agent to a group, whose collective behavior can affect the behavior of its members. For example, group size may have influence on the speed of agent in that group. Another example is the concept of “stickiness” which defines the likelihood of an agent to “stick” with its group path despite the presence of other options (Aguirre et al. 2010). In our framework, the group-sticking parameter defines the tendency of the agents to keep looking for other members before they evacuate. Another group level parameter is the group influence matrix representing the social structure of the group, such that different members in the same group can have different levels of influence to each other. In the current implementation, all members are weighed equally except for the group leader (if any) who has a high influence to the other members.

IMPLEMENTATION OF SOCIAL BEHAVIORS IN THE PROTOTYPE

By capturing certain individual psycho-social parameters, decision-making models, etc., MASSEgress was able to demonstrate the ability of the multi-agent based framework for simulating some common emergent social behaviors such as those shown in Figure 3 (Pan 2006; Pan et al. 2007). One objective of this work is to extend the MASSEgress framework to include additional group level social behavioral models: group influence, following members with better knowledge of the environment and seeking group members.

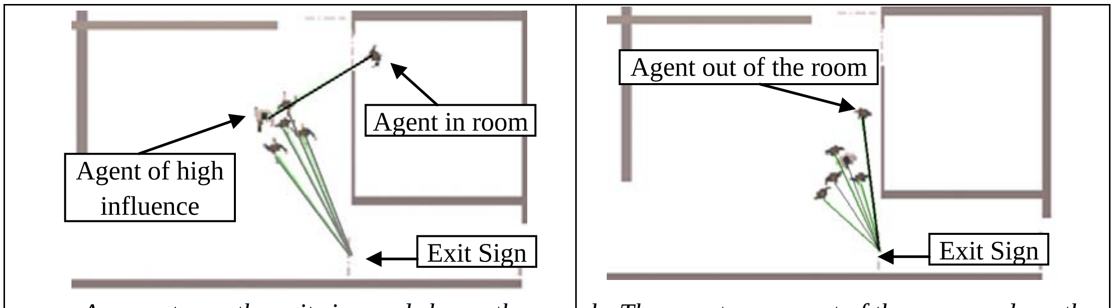


a. Competitive behavior *b. Queuing behavior* *c. Herding behavior*

Figure 3. Simulation of human behaviors (adopted from Pan (2006) Figure 5-5)

Behavior model 1- Group Influence

Communication among group members is often observed in emergency situations (Cocking & Drury 2008; Averill et al. 2005). Individuals in the same group may have different interpretation of a situation but the ones with certain social roles can influence others' decisions (Gwynne et al. 2005). This influence among group members is demonstrated through the ability of sharing information within the group and the level of influence is represented in a group influence matrix. For example, when an agent detects an exit, the agent shares the information about the exit with other group members. Other agents may or may not pursue that exit, depending on the level of influence that the information-sharing agent has. In our simulation, the group influence phenomenon is observed when the following conditions are satisfied: (1) "group influence" is included in the behavior decision model (i.e. group influence matrix takes effect in the decision making process); (2) an agent with a high level of influence detects an exit sign and sets the exit sign as a goal; (3) the agent shares the information about the exit sign with other agents. Figure 4 shows an example of information-sharing and the group influence behavior.



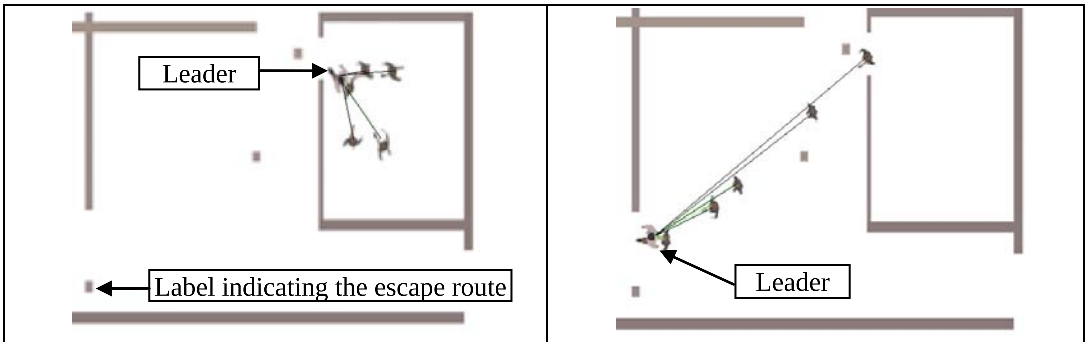
a- An agent sees the exit sign and shares the information with the other members. Note the agent in room can see the information-sharing agent but not the exit sign.

b- The agent moves out of the room and see the exit sign, his goal point becomes the exit sign since the information is shared with it earlier by the information-sharing agent.

Figure 4. Screenshots showing the "group influence" process in a group of 6.

Behavior model 2- Following member with better knowledge of the environment

During an emergency, people usually have limited or incomplete knowledge about the environment (Challenger et al. 2009). The presence of individuals who are familiar with the egress route can have significant impact to the evacuation outcome (Mawson 2005; Proulx et al. 2004). Generally, the agents who are less familiar with the environment will follow the ones who are more certain about the escape route. This phenomenon is observed under the following conditions: (1) there is no (or little) guidance (such as exit signs) from the environment; (2) there is at least one member in the group who has knowledge about the egress path; (3) the decision model of members in a group is defined as "group member following". Figure 5 shows an example where there is no guidance available in the environment while one of the agents has perfect knowledge about the egress route. Other examples can be created by varying the exit sign arrangement and agents' familiarity about escape routes.



a- Members are attracted to the leader (who possesses knowledge of the escape route).

b- Agents continue to follow the leader who navigates according to defined route.

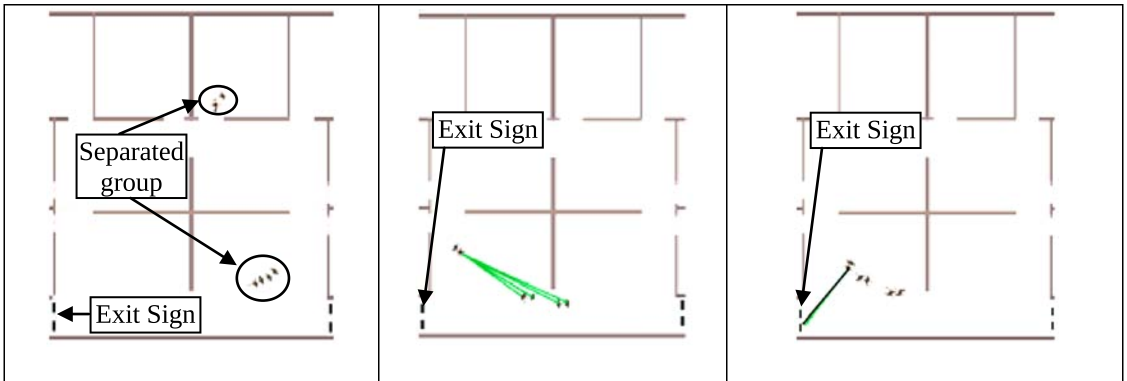
*The user-defined escape route is symbolized by the square labels

Figure 5. Screenshots showing members following the leader with better knowledge of escape route

Behavior model 3- Seeking group members

Several social theories suggest that, even under an emergency situation, people demonstrate group behavior rather than individual behavior (Aguirre et al. 2009;

Cocking & Drury 2008; Mawson 2005). People who are in the same social group tend to stay together during evacuation and even search for other members. This phenomenon can be modeled using a “group-sticking” parameter in our simulation. This parameter has a value between 0 and 1, which indicates the proportion of the group that has to gather before the group evacuates. The closer the pre-existing relationship among the group members is, the larger size the group has to attain before evacuating. By adjusting the “group-sticking” parameter, different levels of group closeness can be simulated. Figure 6 demonstrates the behavior of a group of 6 agents with group-sticking value of 1 (i.e., the group has to find all the members before searching for exit signs).



a- Initially, the group members are separated.

b- The members explore the floor until they see each other

c- The group starts to look for exit sign when all members are visible

Figure 6. Screenshots showing the member seeking behavior in a group of 6

CONCLUSION AND FUTURE WORKS

Although the importance of modeling realistic human social behaviors in egress simulations has been recognized, such efforts are still seldomly considered in current tools. Adopting a multi-agent based approach to model human social behaviors is promising, because software agents are capable of capturing both human individual behavior (through simulating individual characteristics and decision-making process) and diverse social behaviors (through simulating the interactions among individuals).

This paper describes an extension of a prior MASSEgress model, focusing on group and social behaviors, including group influence, following group member (who is more familiar with the environment), and seeking group members. This development demonstrates the potential to include group behaviors in a multi-agent based simulation environment. Our current work continues to incorporate additional behaviors, particularly those identified in social science research. Additionally, we plan to enrich the simulation environment both at the individual level and at the group level, develop benchmark models for validation, and develop tools to facilitate design of egress.

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