

RESEARCH SPOTLIGHT

A COMPUTATIONAL FRAMEWORK TO SIMULATE HUMAN AND SOCIAL BEHAVIORS DURING EMERGENCY EVACUATIONS

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Introduction

Recent natural and man-made disastrous events underscore the importance of emergency evacuation planning and management for buildings and facilities (Averill et al., 2005). Although building codes include provisions for egress design, their prescriptive nature poses many limitations in terms of providing effective evacuation for specific buildings, each of which is unique. Human behaviors under emergency situations have been overly simplified in developing the codes and provisions. For instance, in the “Means of Egress” section of the International Building Code (ICBO, 2000), the methods for calculating the number of exits, width of exits, and the distribution of exits are based on the assumption that occupants are spatially distributed evenly and would utilize all available exits and channels to escape in case of an emergency. Many of such assumptions are not realistic. For instance, people often tend to exit a building based on their familiarity with the surrounding, ignoring many available means in favor of the entrances they normally use. In an emergency situation, people often look for cues and support information and follow the crowds. To fully study egress system through real experiments is not feasible not only because of the cost but they also may require exposing people to dangerous environment. Computer simulations can serve as a viable alternative, under the condition that such simulations are able to capture human and social behaviors in emergency situations. Many computational tools for the simulation of emergency evacuation and design of egress are now available. However, most of current tools focus primarily on the modeling of spaces and occupancies but rarely take into consideration human and social behavior. While these computational models may be more accurately simulate evacuation than simply following codes and guidelines, they tend to rely on a priori assumptions that are difficult to evaluate, inconsistent or unrealistic (Fire Protection Engineers 2002; Santos and Aguirre, 2004).

The objective of this research is to develop a computational framework that could facilitate incorporating human and social behavioral models for simulating emergency evacuation. The simulated results could potentially provide better insights into the design of egress and to assess the performance of evacuation systems. This note describes a prototype development of a dynamic, Multi-Agent based Simulation System for Egress analysis (MASSEgress) that is able to incorporate individual’s behavior and to model group interactions (such as competitive behavior, herding behavior, etc.).

Basic Methodology and Computational Framework

The study of crowd behaviors can be dated back to the 1800s, if not earlier. Many crowd behavior models have been proposed prior to the 1960s, and before computers were commonly used as simulation tools. Over the past decade, there have been increasing interests in studying human factors in emergency evacuation on one hand and developing simulation tools on the other. Research to better understand human and social behavior in emergency situations will likely to continue for quite some time. It is difficult, if not impossible, to determine at this time all the relevant behaviors relevant to egress analysis and simulations. Our objective is to develop a computational egress simulation framework that could incorporate different human and crowd behavior models as they evolve.

Multi-agent simulation has been widely accepted as a promising approach to study complex emergent phenomena (Epstein and Axtell,

1996) and has found many applications in fields such as economics, social behavior research and complex adaptive systems. A multi-agent based simulation paradigm is adopted in this work to model evacuee’s cognitive processes and behaviors and to explore emergent macro-phenomena such as social or collective behaviors.

The simulation system consists of six basic modules: a Geometric Engine, a Population Generator, a Global Database, a Crowd Simulation Engine, an Events Recorder, and a Visualization Environment.

- The purpose of the *Geometric Engine* is to produce the geometries representing the physical environments (e.g., a building or a train station, etc.). Spatial information, including obstacles, exits, spaces, spatial layouts, exit signs, etc., is most conveniently defined using CAD tools such as AutoCAD/ADT (Architectural Desktop Software).

- The *Population Generator* generates virtual agents to represent a crowd based on the distribution of age, mobility, physical size, type of facility (hospital, office building, train station, stadium, etc.) and other human factors. The population, its composition, and occupants’ behavior would be different for different facility type. This module allows the user to easily generate occupants and specify space assignments.

- The *Global Database* is to maintain all the information about the physical environment and the agents during the simulation. It maintains the state information (mental tension, behavior level, location) of the individuals. The database is also used to support the interactions and reactions among the individuals.

- The *Events Recorder* is intended to capture the events that have been simulated for retrieval and playback. The simulated results can be recorded for further analyses, for example, to derive evacuation patterns and statistical information. The events captured can also be used to compare with known and archived scenarios.

- Visualization is important to display the simulation results. The *Visualizer*, which is currently built using OpenGL, receives the positions of agents, and then dynamically generates and displays 2D/3D visual images.

- The *Crowd Simulation Engine* is the key module of the multi-agent simulation system. Based on the behavior models and rules classified, each agent is assigned with an “individual behavior model” based on the data generated from the population generator. An Individual Behavior Model is composed of three subsystems – a Perception System, a Behavior System, and a Motor System. The Perception System receives sensory (such as visual or audio) and surrounding information. The Behavior System determines ‘what’ to do by each agent as the agent responds to its surrounding environment using the behavior rules and initiates actions and reactions accordingly. Depending on the

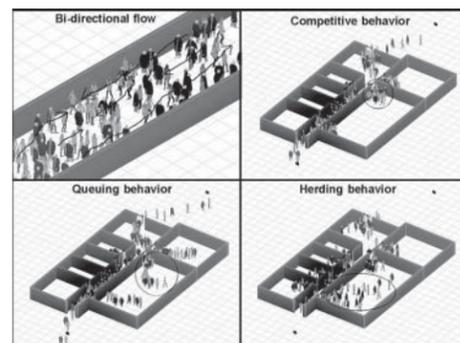


Figure 1: Social behavior simulation

environment and the behavior levels of individuals and their relationships with the group, the agent interacts with other agents and reacts in a collaborative or competitive manner. The Motor System specifies ‘how’ an agent maneuvers in an environment by controlling its movement once a particular behavior is selected.

Simulation of human social behavior

Social behaviors are complex phenomena emerged from the interactions of a group of autonomous agents. In the prototype implementation, for each time increment, the agents are selected in a random fashion and do not have a pre-defined order of execution. At the microscopic perspective, each agent’s behavior is essentially nondeterministic. Therefore, if the system is executed multiple times with the same initial setting, due to the randomness embedded in the system, the agents would not behave exactly the same way each time. However, at a macroscopic level, certain behavioral patterns could be observed across the multiple simulations. These social behavioral patterns are called emergent phenomena. As of this writing, the prototype system can demonstrate social emergent phenomena including bi-directional crowd flow, competitive, queuing, and herding behaviors (see Figure 1).

The behavior of an agent is primarily driven by its decision rules. By defining the interactions among the agents through their behavior rules, social pattern is emerged through a hierarchically structured (from simple to complex) set of activities: locomotion, steering, and social. As an example, for a group of agents to form a queue at a narrow exit, the process could involve (1) the motion (such as moving a step) of an agent that takes place at the locomotion layer, (2) avoiding obstacle using a steering motion, which consists of a sequence of different locomotion, (3) exiting a door in an orderly manner as a type of social behavior that involves several steering activities.

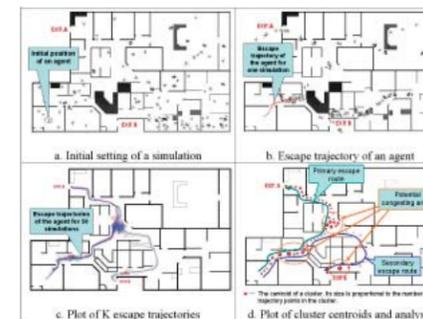


Figure 2: Statistical analysis of escape routes and potential congestions

Statistical analysis of evacuation pattern using clustering algorithm

The simulation tool, MASSEgress, can potentially be used for many practical applications. One example is to facilitate egress analysis for building designs. When designing a floor plan for a building, although the intended usage of the space is usually known, it is difficult to account for every possible scenario for safe evacuation, because of the uncertainties such as spatial distributions of the occupants and their behaviors. However, with the layout of a floor plan, some typical evacuation patterns can be drawn statistically by conducting multiple evacuation simulations with different occupant configurations.

To illustrate, Figure 2a shows a floor plan with two exits, A and B. At first, we place a ‘test’ occupant in a specific room with the presence of other occupants distributed randomly in other spaces. Evacuation simulations are then performed many times, with different spatial distribution of the occupant. That is, for each simulation, while fixing the location of the ‘test’ occupant, we randomize the locations and behavioral types of other occupants, so that the ‘test’ occupant would exhibit different evacuation behaviors for a range of different situations. Figure 2b shows an example escape trajectory of the ‘test’ occupant in one of the simulations. Figure 2c shows the trajectories of the ‘test’ occupant from 50 simulations. Using

a K-Means clustering algorithm (MacQueen, 1967), the trajectory points are categorized into clusters represented by a set of centroids. The resultant centroids are plotted as shown in Figure 2d, and the size of each centroid reflects the number of trajectory points that the centroid contains. By analyzing the distribution of the centroids, we can identify the primary and the secondary escape routes of the occupant, the relative frequency for the usage of the routes, and the potential congested areas during evacuations. By exploring different geometric configurations and re-arranging exit signs, a designer can modify the floor plan to alleviate congested areas and to provide more efficient egress routes.

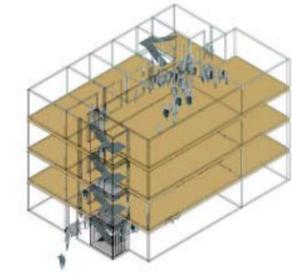


Figure 3: 3-D simulation of evacuating a high rise building

Summary and Discussion

This research spotlight summarizes the prototype development of MASSEgress that simulates human and social behavior during emergency evacuations. The system is able to simulate some frequently observed evacuation behaviors. As shown in Figure 3, extension to 3-D simulation of evacuating high rise buildings is currently under development. Such a computational framework not only can provide insight to current prescriptive and, often, ambiguous codes and provisions for egress design, but also can potentially serve as a means to study safety engineering, such as assessing building designs, testing safety and evacuation procedures, and assisting crowd management. Also, the computational models can potentially serve as a means to study safety engineering, such as assessing building codes and designs, testing safety and evacuation procedures, and crowd management. Our future work will include incorporating other behavior and physical models (such as knocking, pushing, etc.) and to further extend the tool to perform statistical analysis of evacuation patterns, times, flows and other design parameters.

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