Multi-Agent Simulation for Crisis Management

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Abstract

Traditional crowd simulators are based on a simple numerical analysis of inputs such as the positions of people and structures; they do not consider leadership. Since leaders (in terms of evacuations) are present in many real-world situations, the validity of evacuation simulations can be increased through their introduction. We assess the results of a real-world evacuation experiment to develop more realistic scenarios for simulation. The simulations produced by the improved scenarios are found to closely mimic the experimental results. This work shows that scenario-based agent systems such as FlatWalk and FreeWalk offer excellent promise in simulating evacuations more realistically.

Keywords – Multi-agent Simulator, Evacuation Simulation, Social Interaction

1. Introduction

Many modeling systems based on an atomistic approach have been used to simulate economic phenomena and traffic flow. By considering large numbers of "entities," behavior that well mirrors actual events can be produced. The trick is to reduce the number of differences between the entities. However, these simulations fail when the "atoms" are people; people behave in quite different ways, particularly under stress. Since there are many critical systems that demand the behavior of people to be well predicted, such as sports stadiums, shopping malls, and railway stations, we need a new approach to simulating crowd behavior.

One major omission of traditional simulators is that they do not allow for the personal differences in behavior even though such differences are quite obvious. One reason for this omission is that such differences are extremely difficult to convert into physical models. This demands continued research and experimentation and no comprehensive solution is possible in the short term. However, we can correct one of the glaring omissions of traditional simulators, the absence of evacuation leaders (called *leaders* hereafter). We all know of several key situations in which some level of leadership anticipated to be provided by the police, security guards, railway attendants, or ushers. This issue is both interesting since it is a subset of the social interaction question raised above, and because of its importance. Sufficiently realistic simulations would allow us to train the leaders and rework the systems to minimize the human costs of disasters.

This paper examines how a multi-agent system can be modified to reproduce the interactions among leaders and evacuees. As our reference, we use the real-world experiment conducted by Sugiman in 1988 [7]; the output of the multi-agent system FlatWalk is compared with the results of the experiment. That is, first we describe the behavior of each leader and evacuee in scenarios written for the interaction description language *Q* [2]. Second, we simulate the experiment by setting an equal number of evacuees and leaders. Third, given the discrepancies noted between the simulation output and the experimental results, we investigated the experiment in more detail to discover further details about evacuee responses. The scenarios were then modified accordingly. The final simulation results are very close to the actual behavior recorded in the experiment.

One extension of this study will be to conduct a fire drill in 3D virtual space by having agents and humans (as avatars) interact within the virtual spaces established by FreeWalk [5]. Holding such fire drills in 3D virtual space will greatly reduce the costs involved. Moreover, the Internet will allow many people to take part in the fire drill [1,8]. We hope to run a fire drill involving twenty or more avatars and hundreds of agents using a 3D virtual space model of Kyoto station [3].

2. Evacuation Simulator

2.1 Multi-Agent Simulator

Traditional simulators ignore the difference between people and treat everyone as uniform bits that have the same simple behavior. For example, everyone in the room is assumed to move directly toward the nearest exit at the start of the evacuation event. Human action is predicted from a numerical analysis of his position without considering social interactions including what other people are saying or doing. However, social interaction is extremely common and strongly influences the response seen in real evacuations [6]. If the evacuees hear someone cry out, they tend to avoid that area. If leaders are present and are providing guidance, the evacuees are more likely to change their evacuation route. This means that social interactions, which are not considered by traditional simulators, vitally affect the evacuees' decisions and actions. For this reason, since 1998, we have been researching the impact of social interaction as simulated in 3D virtual spaces.

Based on the idea that a overall evacuation response is the cumulative behavior of many individuals with different responses, we adopted the multi-agent systems FreeWalk and FlatWalk for simulating evacuation situations. Each agent is given his own scenario, which determines the agent's response to his environment and peers. By refining and varying these scenarios, we can simulate the behavior of crowds. The following chapters describe these tools and the interaction description language *Q*.

2.2 FlatWalk and FreeWalk

FlatWalk, used in this paper as a multi-agent simulator, is based on Scheme[1]. It can control twenty or more agents simultaneously. A picture of FlatWalk appears in Figure 1. This interface makes it possible to grasp the movement of the group and because FlatWalk is based on the mother language of *Q*, the state of any agent can be displayed. In order to increase processing speed, only a two-dimensional plane is simulated.

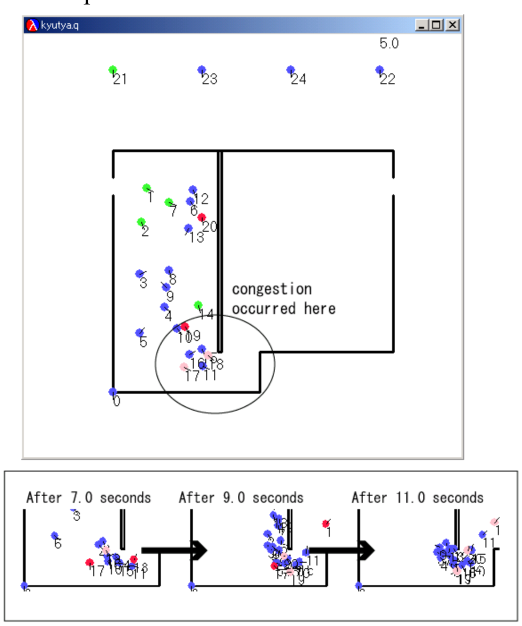

Figure 1. 2D Simulation with FlatWalk

[1] Scheme is a dialect of the Lisp programming language invented by Guy Lewis Steele Jr. and Gerald Jay Sussman.

FreeWalk is an exciting platform for developing 3D virtual spaces and establishing communication within the spaces. It enables agents to visually interact with each other as well as verbally; for example, gestures such as pointing can be used. A FreeWalk screen is shown in Figure 2.

The crucial difference between FreeWalk and FlatWalk is that FreeWalk enables users to operate their avatars in 3D virtual space.

Figure 2. 3D Simulation with FreeWalk

An example of rules in interaction description
Behavior of guide agents
(?see an evacuee)(!guide the evacuee)
Cue Action
Cue : sensing of the outside world <condition>
Action : affecting the outside world <action>

An example of scenarios in interaction description
A scenario for guide agents
(Start state of the experiment
((?hear a siren)(!put on a cap)(go state of guidance))
rule transition to the next state
..)
(State of guidance
((?see an evacuee)(!guide the evacuee))
..)

Parallel actions
(!say to the evacuee, "Please follow me.")
(!!start walking along an evacuation route)
(guard
((?find the evacuee in the distance)
(!wait for the evacuee to approach) …)
((?hear a evacuee speaking)
(!say to the evacuee, "Please follow me.")..))
Sensing the outside world with some cues while walking

Figure 3. An Example of Description in *Q* Language

Both FlatWalk and FreeWalk use plain text scenarios that are automatically parsed into *Q* language constructs to describe the behavior of agents, the same as FlatWalk [5]. The interaction description language *Q* consists of rules and scenarios. Rules represent agent behavior, and scenarios show the flow of management events.

An example of a description in *Q* language appears in Figure 3. The introduction of a guarded command enables agents to wait for multiple events simultaneously using some sensors. Additionally, the introduction of the notation "!!" enables agents to observe the outside world while performing other actions.

3. Evacuation Simulation

3.1 Previous Controlled Experiment

As a first step to addressing the problem of simulating social interaction, we considered the simple situation created by Sugiman [7]. He established a simple environment with a few subjects to determine the effectiveness of two traditional evacuation methods: the "Follow-direction method" and the "Follow-me method." In the former, the leader shouts out evacuation instructions and eventually moves toward the exit. In the latter, the leader tells a few of the nearest evacuees to follow him and actually proceeds to the exit without verbalizing the direction of the exit. He used university students as evacuees and monitored the progress of the evacuations with different numbers of leaders. We decided to reproduce the results of his experiment by using FlatWalk.

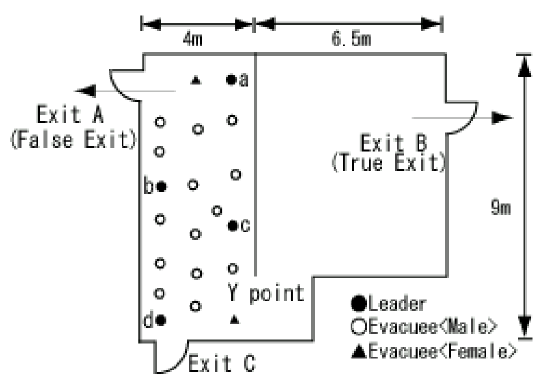

Figure 4. Ground Plan of the Experiment Place and Initial Position of Subjects (by T. Sugiman)

The experiment was held in a basement that was roughly four meters wide by nine meters long; there were three exits, one of which was not obvious to the evacuees as shown in Figure 4. The ground plan of the basement and the initial position of subjects are also shown in the figure. Exit *C* was closed after all evacuees and leaders entered the room. At the beginning of the evacuation, Exit *A* and Exit *B* were opened. Exit *A* was visible to all evacuees, while Exit *B*, the goal of the evacuation was initially known only by the leaders. Exit *A* was treated as a danger. Each evacuation method was assessed by the time it took to get the evacuees out.

The experiment was run four times with new evacuees and leaders each time. The two methods were tested with two and four leaders each; there were sixteen evacuees in every run. The results are plotted on the left-hand side of Figure 6. All sixteen evacuees were successful guided to Exit *B* in all runs except for the "Follow-me method" with two leaders. As shown in Figure 6, eleven evacuees left the room via Exit *A* (wrong exit), and five evacuees via Exit *B* (correct exit).

3.2 Scenario Creation Process

Extracting rules from a paper

We reviewed the paper written by Sugiman, and used our understanding to write scenarios for the agents representing leaders and evacuees. The main rules extracted from the paper are shown below. The scenario for the leaders using the "Follow-direction method" consists of about 200 lines and 10 rules. The one for leaders using the "Follow-me method" consists of about 300 lines and 11 rules. The one for evacuees consists of about 600 lines and 18 rules.

a) Scenario for leaders using the "Follow-direction method"

- When the leader sees someone, he indicates the direction of the exit with a loud voice.
- When the leader finds someone heading towards the wrong exit, he shouts out a warning.
- When the leader finds that all the evacuees around him are correctly evacuating, he joins them.
- When the leader finds someone who is not moving, he directly encourages him to move to the exit.

b) Scenario for leaders using the "Follow-me method"

- When the leader identifies the evacuee closest to him at the beginning of the evacuation, he takes him to the exit.
- When the leader finds that the evacuees being guided by him have fallen behind, he waits for them to close up.
- When the leader finds that the evacuees being guided by him are close again, he continues moving toward the evacuation point (Exit *B*).
- If the leader loses the evacuee being guided by him, he starts looking for another evacuee and takes him to the exit.

- When the leader finds that all evacuees being guided by him are out of the basement, he stops the guiding process.

c) Scenario for evacuees

- If the evacuee sees an exit near him, he heads toward it.
- When the evacuee recognizes that a leader is present, he follows their direction.
  - In the "Follow-direction method," he goes in the direction indicated by the leader.
  - In the "Follow-me method," he follows the leader.

Extracting rules from analysis of video and interview

The simulation results yielded by the preliminary scenarios deviated significantly from those of the experiment. One major point was that the simulation showed that there would be no difference between the "Follow-me method" and the "Follow-direction method." One major reason was that actual people respond more slowly to speech than action; the agents, however, responded immediately to both speech and action. Obviously some delay should be added to the scenarios.

Figure 5. Situation of a Fire Drill (by T. Sugiman)
(Some leaders guide to the backward exit by Follow-direction method, and the other leaders guide to the forward exit by Follow-me method.)

We analyzed the video of each evacuation recorded by Sugiman and found some other interesting behaviors [4]. Figure 5 is a snapshot of Sugiman's drill performed in an underground shopping complex. The evacuees acceptance of the leader's guidance can be overruled if the many of the surrounding evacuees move in different way, or the leader's instructions are overlaid by those of another leader. Moreover, the distance over which a leader can exert influence is not great, particularly if the room is dark or filled with smoke. Therefore, we added the following five rules to the evacuees' scenario.

- If each evacuee sees leaders indicate within a fixed distance, he follows their directions.
- If each evacuee hears any directions by leaders simultaneously, he ignores their directions.
- An evacuee moves toward the nearest group of evacuees.
- An evacuee does not move until the crowd around him moves.
- An evacuee follows the people around him.

The last three rules involve some form of social interaction. In addition, we prepared two types of evacuee scenarios. In one, evacuees closely followed the leaders' directions, and in the other, evacuees paid more attention to the people around them. Each type of scenario was assigned to one half of the evacuees at random.

3.2 Simulation Results

We simulated the fire drill again using the modified scenarios, the results of which are shown in Figure 6. The "Follow-me method" by two leaders is illustrated as two lines: some evacuees went out via Exit *A* and others via Exit *B*. We rank the combinations from these simulation results in order of decreasing effectiveness.

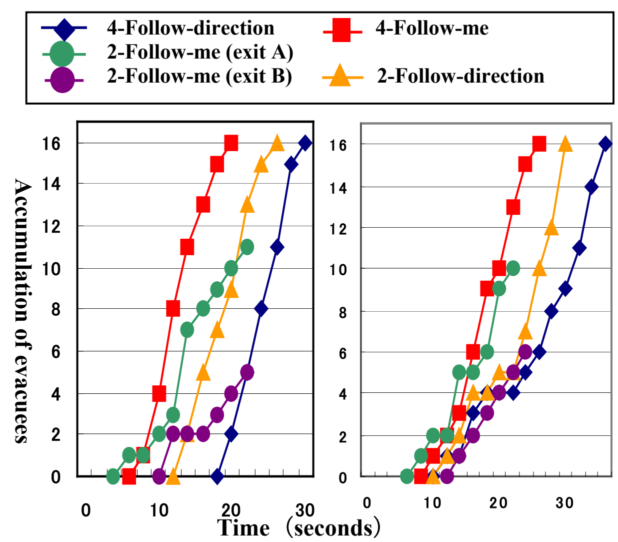

Figure 6. Comparison between Control Experiment by Sugiman (left) and Evacuation Simulation (right)

1. "Follow-me method" with four leaders (most effective): The rule creating conformance to the group speeded up the initial movement of evacuees, even those not directly next to a leader were able to reach Exit *B* quickly.
2. "Follow-direction method" with two leaders: This combination was less effective because some instructions overlapped and groups of evacuees were slow to form and move.
3. "Follow-direction method" with four leaders: Some evacuees did not move for four seconds since they

received instructions from several leaders simultaneously. Movement became more rapid once the number of leaders decreased and group movement became more obvious

4. "Follow-me method" by two leaders (least effective): This confirms the advantage of the social interaction rules. The poor performance of this combination reflects the weakness of the "Follow-me method" when a significant number of evacuees cannot get close enough to a leader to benefit from his guidance. Ten evacuees left through Exit *A* and so must be considered as lost. This result also confirms the power of voice in providing guidance provided there is no overlap.

The simulation results closely parallel those recorded in the experiment

4. Conclusion

This paper has accomplished the following goals.

1. Constructed a FlatWalk and FreeWalk for multi-agent simulation to control twenty or more avatars and hundreds of agents simultaneously.
2. Reproduced the results of the control experiment conducted by Sugiman.
3. Clarified the importance of feedback from real experiments in refining rules and scenarios.

Based on this first assessment, we have the following comments on using FlatWalk to simulate crowd behavior.

- Feedback from the real world: More feedback from the real world is essential if we are to produce more useful rules and scenarios. FlatWalk makes it relatively easy to include real-world knowledge. This is because we can conduct new simulations after modifying only a small part of the scenario, not the whole system.
- Feedback to the real world: The flexibility offered by FlatWalk allows us to simulate environments that no one has thought of testing in the real-world.
- Readability of scenario descriptions: The refined scenarios are rather hard for non-experts such as social psychologists and researchers into disaster prevention to understand. We are currently developing a card interface that extracts patterns from scenarios. End users can create scenarios by filling in the blanks on the cards and combining them, which will make the scenarios easier to understand.

The following two points are considered as new positioning of this simulator with such achievement as the purpose of this research.

- The verification tool of knowledge acquired from the analysis of a real experiment.
- The media for endusers, for example, social psychologists and researchers of disaster prevention.

The former refines scenarios simultaneously while verifying the knowledge. The latter urges activation of an argument by visualizing the scenario description while simultaneously showing a refined scenario description intelligibly by a card interface.

Further direction of this research will include verifying how much the scenarios, which are refined through feedback between FlatWalk and the real world, will contribute to the elucidation of human action in the evacuation.

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