ABSTRACT

Abstract: The goal of the project was to create a visual representation for simulated crowd behavior on a massive scale (many city blocks) as driven by cultural and other demographic considerations. Specifically, the representation was to take place in real-time and on top of existing geographical data. We wanted to observe the crowd behavior as prompted by several types of events, such as, to give some examples, road blockage, traffic accidents, or fire evacuation.

The key points of interest were the following: the observation of group dynamics as a result of human reaction to an event (potentially a panic situation), and based on the observation, the possibility of safety planning and behavior prediction.

We aimed to provide not only an effective visual representation, but also the tools for manipulating the environment by changing the size of the participating population and creating event occurrences at specific locations while the simulation is running. In addition, we intended to provide a way to interactively change the location of anybody in the population, reassign their current destination, and remap the route leading to that destination.

1. INTRODUCTION

Understanding the behavior and dynamics of crowds of people has been a longstanding area of interest for social sciences such as history, psychology, and sociology. The attention has been focused on the ability to understand how, as a consequence of certain events affecting the individuals, or as a result of having a shared goal, the behavior of separate individuals starts to resemble that of an entity. The micro-decisions taken at a level of an individual aggregate and form the macro-behavior of the new group. The behavior of that newly-formed entity can differ significantly from or as a result of having a shared goal, the behavior of separate individuals starts to resemble that of an entity. The micro-decisions taken at a level of an individual aggregate and form the macro-behavior of the new group. The behavior of that newly-formed entity can differ significantly from

In the field of computer science, simulation of crowds can and has been used to make inferences and predictions about different aspects of behavior and explore the crowd dynamics. The applications of computer crowd simulation range from entertainment to observation of well-known phenomena for the purpose of education to training for the police and the military. The analysis of human behavior at gatherings that attract a large number of people (such as demonstrations, concerts, and sports events) lets make predictions about the outcome of panic situations [2].

The remaining sections are organized as follows: the discussion of related work pertaining crowd simulation, the description of the system model used for the current project, the explanation of the system implementation and justification of the design decisions, results, description of possible additions in the future, and finally, conclusions.

2. RELATED WORK

The task of creating a realistic crowd simulation has been given a considerable amount of attention by the field of computer science.

Reynolds [11] developed a simulation of bird behavior (for a large number of birds). The flocking behavior in the simulation is defined by the bird’s current position relative to the other birds - in addition to steering clear of collisions, the bird also adjusts its speed based on the speed of the surrounding birds, and position-wise, the bird aims to become more central in the group as opposed to being in the periphery of the movement.

Tu and Terzopoulos [12] developed a simulation of a school of fish. They programmed their agents to perceive the surroundings and base their movement on that perception.

Bouvier et al. [1] built a human crowd simulation by encoding agents’ goals and employing the Newton’s laws of motion (the agents were represented as particles). They introduced a special decision system for the agents in the simulation somewhat analogous to an electric field. Each agent was endowed with a decision charge, and those individual decision charges were in interaction with the overall decision field of the population.

In a similar fashion, by employing the laws of physics to model the motion of the agents, Brogan and Hodgins’s [3], [4] programmed the agents to avoid collisions by finding target positions for each agent given the positions and speed of other agents that are visible to the agent in question at any particular moment. Other moving or immobile objects in the simulation were taken in consideration as well when determining the target position for each agent.

A hierarchical model of group behavior was attempted by Musse and Thalmann [10]. In their model, groups in the simulation differed with respect to the level of control they had over their own behavior and ranged from guided groups to independent ones. Each agent in the simulation possessed a set of rules of behavior based on their belonging to one of the groups in the hierarchy.

Now returning to the physics-based models, another one was introduced by Helbing et al. [5]. In addition to employing the physics laws of motion to describe the dynamics...
of the crowd, psychological aspects were considered as well, specifically as applicable to panic situations. Each agent is represented as a particle with a predefined desired velocity. For each time step, the agents’ instantaneous velocity is determined. The agents attempt to keep a certain distance from other agents (or other objects present, such as different obstacles) at any given point in time. The model accounts for dissipation, friction force and fluctuations. Helbing’s model has been successful in producing a realistic arch-shaped formation of particles when a large number of particles have to move through a narrow exit. Another example of a verified prediction is the faster-is-slower effect—an increased evacuation time in emergency situations as a result of increased desired velocity (often observed in real panic-inducing situations). Fig. 1 illustrates the effect.

Most crowd simulators make an assumption that all agents (by themselves) exhibit identical behavior patterns. Pelechano et al. [8] proposed to incorporate psychological model in crowd behavior simulation by assigning roles to the agents and providing them with a way to communicate with one another. Such social aspects as emotion, stress, ability, decision-making, personality, and motivation are also incorporated in the model. The simulation accounts for variability in agents’ knowledge about the environment (for instance, some agents may not be aware of the nearest exit location and thus slow down the evacuation from the building in case of fire). Stress levels can affect the overall functioning (by reducing the ability to orient oneself in the surroundings) and cause slow reaction times. The agents who have not yet received proper training can show the signs of impaired decision-making when imposed with time constraints. Other agents (such as firefighters, for example) are better at handling the sudden pressures of the situation since they have been trained to react fast to the changing environment.

Having a psychological model alleviates the need to precisely prescribe the behavior. Instead, it lets the agents form their own perception of the world and react in a way they find suitable to the events they perceive. Models that achieve the goal of simulating such non-scripted behaviors as described above (where agents can coordinate knowledge and ability and agree on common goals) let agents engage in problem-solving and plan their actions in the context of the situation. Such models can be used to simulate both everyday situations and emergency cases (such as an evacuation from a burning building).

Multi-Agent Communication for Evacuation Simulation (MACES) by Pelechano and Badler [7] implements agent actions as determined by their roles and communication. It incorporates route planning (to let agents navigate to the exit) by assigning each agent a mental map with an abstracted plan of the building. As the agent explores the sur-

![Figure 1: Faster-is-slower effect.](image)

![Figure 2: Crowd simulation inside a building.](image)
roundings and communicates with others, its mental map expands to include the new information regarding obstacles and exit locations. The roles of the agents are based on leadership and training. Trained leaders have a complete knowledge of the environment. Untrained leaders are able to handle stress well and are willing to explore their surroundings to find paths to exit and help others by communicating their knowledge. Untrained non-leaders are not good at coping with stress and break down when they need to make a decision under pressure.

The results obtained with MACES show increased rates of evacuation when communication is used. They also demonstrate the significance of the presence of trained professionals during evacuation. Interestingly, the experimental data indicates that even a relatively small percentage of trained leaders gets the evacuation rate up on the level with the case when everybody has the complete mental map (i.e. when everybody’s trained). To diversify the agents not only based on their roles, but on other more psychological characteristics, it was proposed to use PMFserv (Performance Moderator Functions) - a software system to model decision-making based on emotional utility subject to stress level.

Crowd simulation for the current project originated as a continuation of the idea of integrating wayfinding algorithms with different roles assigned to agents along with the added psychological component of decision-making under stress conditions.

3. SYSTEM MODEL

The project involved the visual geographical representation of the data provided by the crowd simulation. The simulation was provided by a framework incorporating MACES, CAROSA (Crowds with Aleatoric, Reactive, Opportunistic, and Scheduled Actions), and HiDAC for movement, collision detection and collision prevention [9].

CAROSA provides information about the agents and the environment, and lets the agents produce the context-appropriate behavior. The actions taken by the agents can be deliberative, reactive, and opportunistic (statistically driven). The agents navigate the complex environment consisting of roads, various obstacles such as car traffic, and buildings (exterior and interior - taking into account doors, stairs, and rooms). Fig. refcrowd illustrates a crowd inside a complex building with multiple rooms, doorways, and obstacles positioned inside the room.

The environment is navigated by the agents with the help of a wayfinding algorithm that finds the path and dynamically updates the mental maps of the agents, thus directing them toward their destinations. Based on their roles, all agents start with mental maps complete to various extents. They can fill in the gaps in their mental maps by exploring the environment first-hand or acquiring knowledge by communicating with other agents who possess the information.

The agents can engage in decision-making to choose to follow one of the routes they have stored in their mental maps, change their behavior based on what is happening in their environment and their psychological factors such as stress and coping style.

An example of a change in the environment is appearing locked. An occurrence such as that may lead some agents to slow down their progress and be stuck for a while or induce them to explore and as a result discover a different path. Each location in the building stores the shortest path to the exit which the agents will follow in case of an emergency. The communication between the agents occurs in the following manner: every time the agents (2 or more) meet at a single location, they exchange the information about what rooms have been explored by them but did not contain a path to an exit. They also tell each other what obstacles they have found that block the paths. Such mental map sharing is the foundation of the wayfinding algorithm employed by the agents. Fig. 3 shows the interaction between CAROSA, MACES, and HiDAC.

Previously, CAROSA has been used to simulate evacuation behavior, and the action was concentrated entirely inside the buildings. The purpose of this project was to provide a visual geographic representation and tracking of the simulation that is taken outside and can now span numerous city blocks.

The events possible in the simulation have been expanded to those that take place primarily on the streets: road blockages and car accidents. The back and forth communication between CAROSA and the visual geographic representation
was needed to make interactive creation of agents and events possible (i.e. the user can start the simulation with some predetermined number of agents, and then while the simulation is running and he’s getting the visual feedback, the user can click on some location and create a new agent there). The change then has to be taken back to CAROSA so that the newly-added agent can become a part of the existing population. Events (such as fire, road blockage, or car accident), can be directly added to the simulation in progress, and the agents will immediately start perceiving it as a part of their world. Please refer to Fig. 4 for the depiction of the workflow of the model described above.

4. SYSTEM IMPLEMENTATION

While the final goal was to have the information about agent locations sent from CAROSA, the initial stages of implementation were focused on creating an interactive simulation directly on the geographical map.

Google Maps were used to depict the agent motion. The agents were placed on the map and given starting and ending locations. Since at that point the position location was not yet coming from CAROSA, the wayfinding algorithm could not be accessed, instead, the route planning features of Google were used through Google Maps API’s. A number of extensions were added to the Google Maps API’s to facilitate implementing the simulation. Additional JavaScript functions included those for calculating the length of the path traveled, determining whether the point is inside the polygon, finding latitude and longitude of a point that is a given distance away from the current location of a moving object etc.

The simulation was run by creating several agents prior to the beginning, entering the addresses of their starting and ending locations, placing markers on the map to mark the indicated locations, and then proceeding with the simulation ([6] served as an inspiration here and as a good starting point). From that point on, we would zoom in on one pre-selected agent (other agents didn’t stop - they would just sometimes be outside the displayed chunk of the displayed chunk of the map). For that preselected agent, we would be tracking speed, distance traveled, and next action (for example, Turn left on Walnut St).

We also implemented a collision detector and the ability for one agent to follow another. The interactive addition of markers (to signify events and agents) can be positioned on the map interactively in real-time, so that the updated information can then be sent to CAROSA. The new final destinations (goals) can be set interactively as well - the agent’s route gets remapped by taking his current location as the new starting position. Thus, the agents can be redirected without interrupting the simulation. At the final stage, the visual representation of the simulation would be achieved by projecting the input from CAROSA onto Google Maps.

The new locations (latitude and longitude) for each agent are contained in the mposition variable outputted by the runSimulationStep method of the Chumanoid class which would be obtained by sending an HTTP request. It is important to note that the simulation with CAROSA is different from the simulation build directly in Google Maps due to the fact that CAROSA employs a specific wayfinding algorithm that works with the agents’ mental maps, psychological characteristics, and assigned roles, while in Google Maps the routing is done from a purely geographical perspective.

5. RESULTS

The visual representation of the simulation was accomplished, along with the ability to interactively add new components (agents, obstacles, and events) to the map. Changing the agents’ goals and thus redirecting their motion has been successful.

Figure 4: Workflow of the visual representation system.
Figure 5: The beginning of the simulation. Green markers indicate starting positions.

Figure 6: In the middle of the travel.
Collision detection and following-another-agent behavior were implemented. For the duration of the simulation, we can track an agent’s speed, next action, and distance traveled and follow any of the agents with a camera (i.e. zooming in). Fig. 5, 6, and 7 show the simulated travel of 3 agents (purple rectangles) traveling from close locations on Spruce Street to the Reading Terminal Market. 6 screenshots are shown taken with random time intervals.

6. FUTURE WORK

The anticipated next step in the nearest future is to try out the integration of the implemented system with CAROSA (unable to get access to CAROSA yet). Several events we specifically want to investigate are fire/fire drill, road blockage, and a car accident. Fig. 8 illustrates those events.

The integration with CAROSA should not prove difficult since the information exchange is limited to agent and object locations and the identity thereof. There will have a demonstration on May 12, 2010, involving the simulation of one of the proposed events.

Also, the representation of agents in the buildings might be somewhat cumbersome in Google Maps since the rooms are obviously not displayed and we just have the building in its entirety. However, by zooming in sufficiently and perhaps choosing smaller markers for the agents, the emergent behavior can still be observed.

7. CONCLUSIONS

While various simulations usually do have some sort of a visual representation, it’s often detached from the geographical information. In this project, we wanted to pair the large scale crowd simulation with existing underlying geographical information to observe the group behavior in as realistic setup as possible.

We wanted to see the emergent behavior in panic situation and thus render the simulation useful for education and training purposes. By making it possible to interact (and to a certain extent, manipulate) the simulation in real-time through its visual representation in Google Maps instead of passively viewing, we hope to have made it more flexible and relevant to the events occurring in the real world.

8. REFERENCES


Figure 7: Nearing the goal.

<table>
<thead>
<tr>
<th>#</th>
<th>type</th>
<th>information receiving mechanism</th>
<th>action taken</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>Road block</td>
<td>the agent is within a certain proximity to the blockade (and thus within the broadcast area), or after a specified amount of time since the occurrence has passed</td>
<td>remapping the route to reach destination</td>
</tr>
<tr>
<td>2</td>
<td>Traffic accident</td>
<td>the agent is within a certain proximity to the blockade (and thus within the broadcast area)</td>
<td>based on the type of agent, redefining route to reach destination, arriving at the place of the accident (police, ambulance), some stuck at the accident site</td>
</tr>
<tr>
<td>3</td>
<td>Fire drill</td>
<td>central fire broadcasting</td>
<td>evacuation, route remapping for traveling agents, firefighters arriving at the site (fire only)</td>
</tr>
</tbody>
</table>

Figure 8: Candidate events for the simulation.