Simulation of Cognitive Pedestrian Agents Crowds in Crisis Situations

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ABSTRACT

In crisis situations in an urban environment, first responder teams often must deal with crowds of people. Consider the case of a building fire in a dense city environment. People may be injured; walkways may be blocked, with fire equipment attempting to reach the scene. Crowd behavior can become an issue when trying to reach the injured, ensure safety and restore conditions to normal. The motivations of pedestrians that form the crowd can vary. Some are there because they are curious about the crisis situation. Others, attending to their individual concerns, may have found themselves in the 'wrong' location. They may be trying to leave the area, but the density of people as well as the spatial layout of the walkways may be impeding their progress. Other individuals, unaware of the fire, may be attempting to reach their intended destinations that happen to be near the crisis area, thus adding to crowd congestion.

With a model of crowd behavior, effective strategies for resource usage in managing crowd behavior can be developed. Our approach to this problem is that of agent-based modeling and simulation. We develop a cognitive pedestrian agent model. Utilizing this model, we simulate crowd behavior in a 'city fire' scenario. Characteristics of crowd behavior with different pedestrian personality mixes and a strategy for crowd management are investigated.

Keywords
Agent-based simulation, cognitive agent, crowds

1. INTRODUCTION

We consider crowds to be formed of individual pedestrian agents. The crowd behavior is then results from the activity of multiple individual agents. The agent model of an individual pedestrian should incorporate the cognitive processes of an individual, the emotional elements that influence the cognitive processes, and relevant physical capabilities and characteristics. Since the example crisis scenario involves agents walking in an urban environment, and then encountering (or learning of) a fire, a model of pedestrian locomotion is also required. Our model of a cognitive pedestrian agent is hybrid in nature, possessing (1) physical features, (2) cognitive skills, and (3) emotional and personality characteristics. Examples of relevant physical characteristics include the pedestrian agent's stride rate and stride length.

In the development of the agent model, we have utilized results from diverse areas of the literature for (1) personality and emotions framework development, and (2) pedestrian walking representation. A number of approaches to modeling non-cognitive pedestrian walking have been developed; those utilizing a cellular automata representation are pertinent. We select the rule set defined in the work of Blue and Adler [1], but must adapt it for simulation in the software agent framework.

The emotional aspects of our pedestrian agent model are defined within the framework offered by the OCC [2] cognitive model of emotions. Picard [3] succinctly summarizes the OCC model as one that provides a "grouping of emotions according to cognitive eliciting conditions". According to the OCC model, emotions are considered to arise as reactions (positive or negative) to events, objects, or actions. Although the work of OCC defined a set of 22 emotion types as well as rules for how they could be generated, other efforts [4] involving emotion often work with a reduced or modified set. Personality traits are viewed as more long term constructs through which the more transient emotions are filtered; we include them in the model of the cognitive pedestrian agent. Both emotions and personality influence cognition. For example, an emotional tag that is attached to an event (or object or action) will influence the cogitation regarding goals or plan state, and the nature of the influence will depend upon the personality type. We utilize the Five Factor Model [5], also termed the OCEAN model, of human personality, where the factors are: (1) Openness, (2) Conscientiousness, (3) Extraversion, (4) Agreeableness and (5) Neuroticism.

In section 2, we present the hybrid pedestrian agent model as well as details on the general simulation structure and the scenario. Section 3 discusses the verification activity. In Section 4, we present a detailed scenario involving crowd management, provide additional details of the agent behavior, and discuss the results. Section 5 provides concluding remarks.

2. HYBRID PEDESTRIAN AGENTS

Agent Model

The cognitive pedestrian agent is modeled as having a knowledge base, perception and calculation skills, and goal selection skills that support its cognition abilities. It also has an action set that supports progress on its goals. There are different personality types that are considered for the cognitive agents. Each agent has an emotion set, and engages in the "observation - cognition – action" cycle, incorporating the emotions that are triggered by meaningful events in the scenario, as shown in Figure 1.

We consider three personality types for cognitive pedestrian agents in the simulation: (1) the very Curious (open) agent, (2) the very Fearful (neurotic) agent, and (3) the Social (agreeable) agent. The agents' emotion sets are those relevant to a city fire scenario, and include emotions of satisfaction, surprise, distress, fear, etc. The Curious and Fearful agents are more extreme personality types than the Social agents; they incorporate a smaller set of emotions.

A cognitive pedestrian agent's goal selection is mediated by both environmental factors and its emotional response to these factors, which befit its personality. The goal state of the Curious agent is shown in Figure 2. We note that both the Curious and Fearful agent types are caricatures that represent extremes of behavior, while the Social (agreeable) agent is more thoughtful and complex. The possible goal states for the curious agent are consistent with its exaggerated behavior; note that a Curious-type agent's single-minded goal is to view the crisis (fire) scene, upon learning of its existence.

Simulation Development

The simulation structure supports the requirements of the hybrid agent model. For example, the structure of the cognitive agent module includes separate classes for (1) cognitive agent personality specialization, (2) cognition act, and (3) cognitive rules. Separate modules also support goal and emotion information. Moreover, all types of cognitive pedestrian agents have their cognition capabilities integrated with physical behavior. The locomotive behavior of each of the agent types is the same.

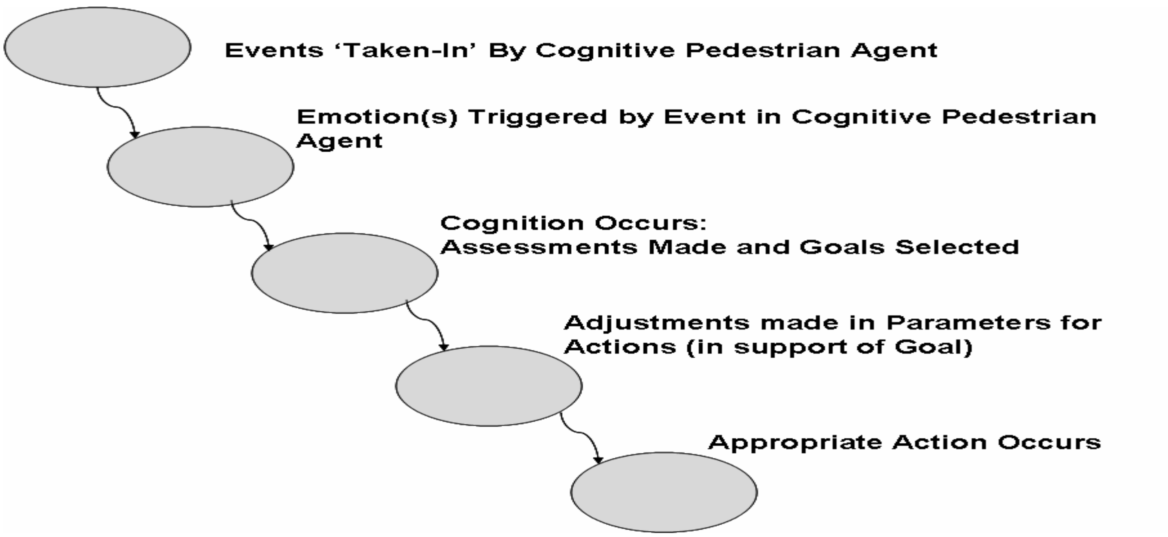


Figure 1 Cycle of 'Observation-cognition-action' in Hybrid Pedestrian Agent

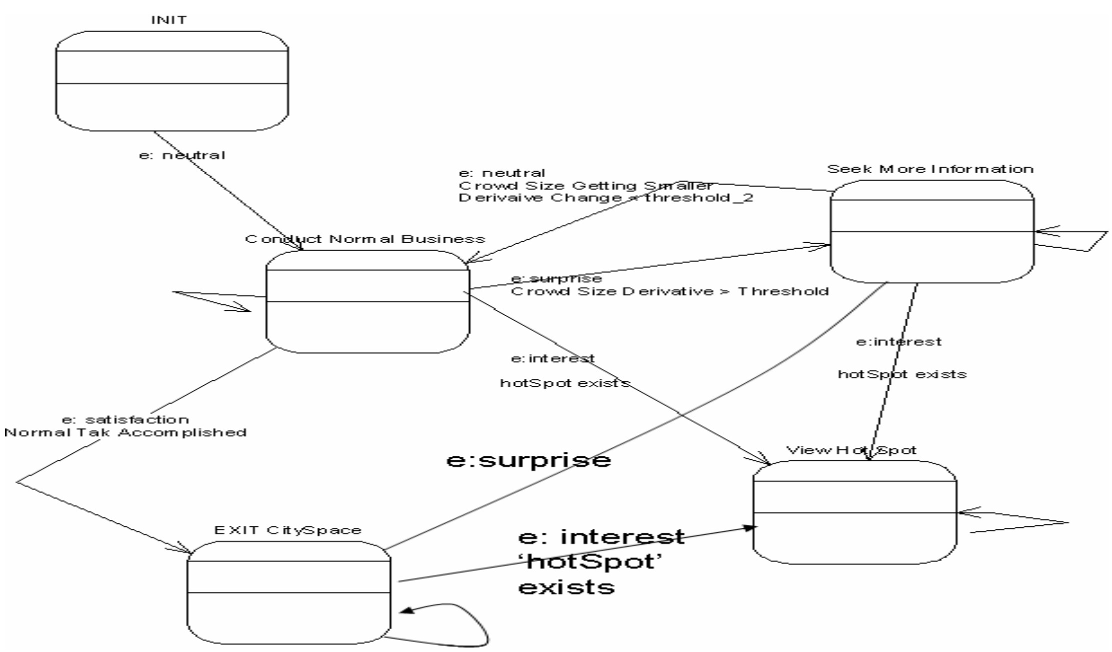


Figure 2 Goal State Diagram for Curious Cognitive Pedestrian Agent

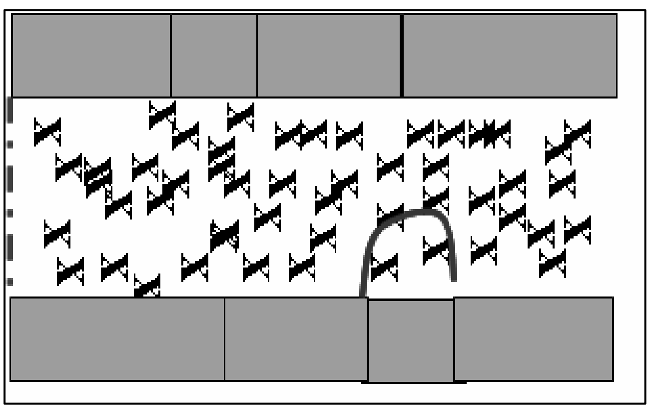
Main modules pertaining to the general framework support address city grid geometry, physical barrier, and fire location and visualization capabilities. The simulation framework was developed according to software engineering principles. It is built upon the Cybele [6] software agent platform. The agent platform offers low level services to the simulation, such as support for messaging between agents and simulation distribution across multiple machines. It also provides a lockstep mode and global clock for running simulations. Both the crowd simulation and the Cybele platform are in Java.

Scenario: General Details

In the simulation scenario, a 'normal' state of activity involves cognitive pedestrian agents arriving at a city pedestrian area, proceeding to fulfill their goal of shopping at a store located in one of the buildings, and then leaving the city. The extensible block geometry shown by Figure 3 was selected to enable validation with (non-cognitive) results in the literature. A fire is indicated by the circle. Pedestrians are indicated by the X's. The rectangles represent buildings. In the simulation, the entry and exit areas, indicated by the dashed lines at the left, are considered as the notional subway. Shopping goals are designated as specific buildings located at upper and lower grid squares at the right end of the block.

The scenario unfolds with the occurrence of a fire in the city area. The fire has a mean radius; its center is positioned at a specific location. Pedestrians nearest the fire see it first; they respond appropriately for their type. Many pedestrians will try to distance themselves from the fire, but only some will panic. A subset of pedestrians is interested in viewing the fire. Of particular interest are crowd events such as bottlenecks and 'crowd-crush'.

The crowd management mechanism involves the use of authoritative information to direct crowds; a (agent) police officer conveys information on the fire and directs pedestrian



agents to

Figure 3 Goal State Diagram for Curious Cognitive Pedestrian Agent

leave the area. Information transmitted via social interaction has been used in the context of pedestrian evacuation dynamics [7]; we note that what information is accepted as 'authoritative' may be subject to a cultural bias as well as the personality filters of different pedestrian agents.

3. VALIDATION EFFORT

In the first segment of the simulation validation effort, we seek to recover results from the literature that involve the patterns made by non-cognitive pedestrian crowds. This involves the emergence of self-organizing lane behavior, as shown in the work of Blue and Adler for their cellular automata-based pedestrian agents. Thus, we 'turn-off' the pedestrian agent's cognitive faculties. As shown illustratively in Figure 4, we recover the patterns found in simple cellular automata formulations of pedestrian motion. The simulation time allows for 'sub-ticks' to provide for sequential actions to be done before advancing the clock to the next tick. For the non-cognitive validation results there are 10 sub-ticks to the simulation clock tick. The initial distribution of the agents on the city grid was random; by this time step they have sorted themselves into an eastward and westward moving group. This is the type of behavior that is found when different groups of pedestrians are trying to walk in opposite directions.

As illustrated in Figure 5, we recover the results of Still [8], involving the emergence of 'bubble voids' and 'viscous fingers' patterns. The non-cognitive pedestrian agent density is 20 percent; groups comprised of individuals moving in one (generally horizontal) direction tend to form. Note the top edge of the city; all individuals are moving in the same direction.

Results in Figure 6 involve cognitively-enabled pedestrian agents that are of the curious type. The validation effort is to determine if the behavior of each of the agent types is as was modeled. This must be determined before using the simulation framework to investigate crowd behavior involving a mix of cognitive pedestrian agent types. We show illustrative results for the Curious-type pedestrian agents. They enter at the notional subway, which is a set of grid squares located at the left end of the city. Those individuals who learned of the fire attempt to view it, and those who did not learn of the fire proceed to accomplish their original 'shopping' goal. This result is consistent with the personality, emotions, and goal set of the Curious-type agent.

4. RESULTS

As both the Curious –type and Fearful-type cognitive pedestrian agents are somewhat of a caricature, the most interesting crowd behavior in a crisis arises when there is a mix of behaviors and potential interaction among the agents. We investigate cases of crowd management where the crowds are composed variously of agreeable (social) agents, fearful agents, or both agreeable and fearful agents (in various proportions). The results reported here are typical of multiple runs that were made for each type of sub-scenario.

Simulation Scenario: Specific Details

In the simulation set, agents of predefined number and type enter at the 'metro' edge. Crowding is allowed; that is, more than one agent can occupy a grid space in the same time step. The agents each have an initial business goal, which is to reach either the 'bank' or 'bookstore'; both are located at the edge of the city grid on the right side.

At some pre-selected time step, a (circular) fire breaks out. The location and the radius of the fire are predefined. Any agents which are located on a grid square at which the fire breaks out are immobilized for the duration of the simulation run. When the fire breaks out, the police officer pedestrian agent is immediately notified. The police officer agent proceeds to the area of the fire, starting from a notional police kiosk located roughly in the center of the city grid. The police officer agent's behavior as it walks to the fire area is to issue a directive to pedestrians encountered along its path of motion. The directive is for the pedestrian to leave the area. Once in the vicinity, the police officer circumnavigates the fire area, issuing a directive to pedestrian agents it encounters. The police officer's communication ability is 'local' – pedestrian agents that are not occupying squares in the police agent's line of motion do not 'hear' its directive.

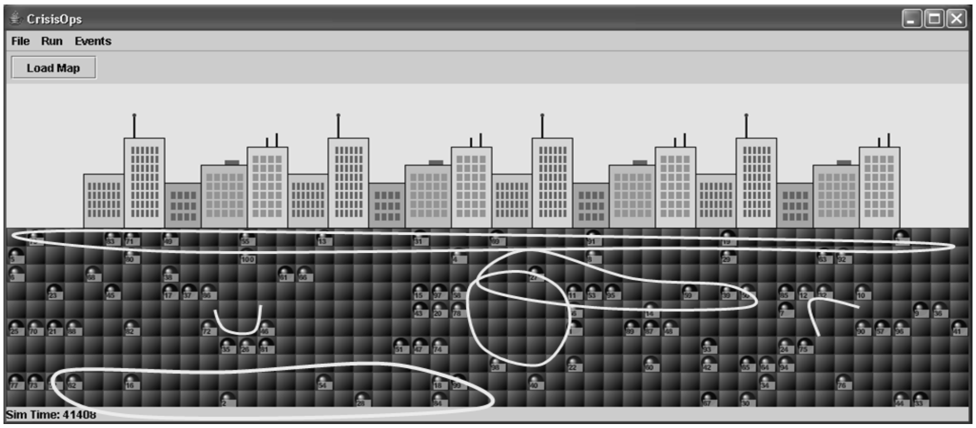


Figure 4 Recovery of self –organized lane formation, an example of emergent behavior

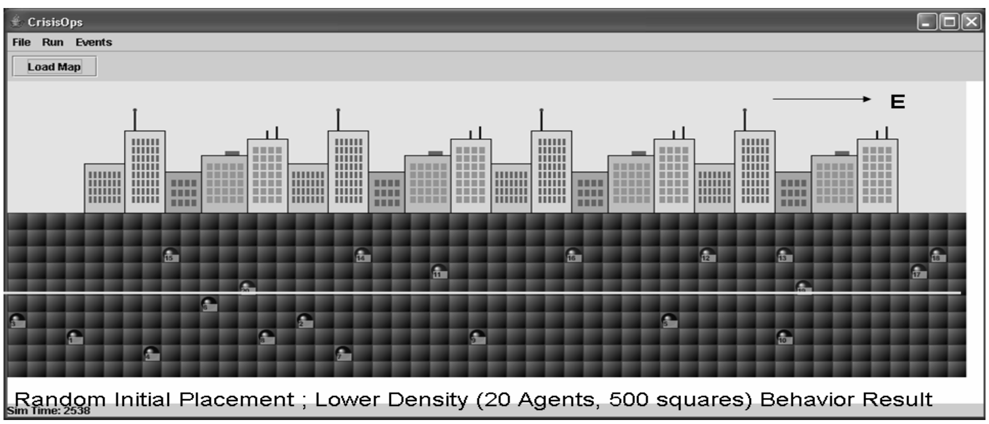


Figure 5 Bubble voids and viscous fingering structures in oppositely moving crowds

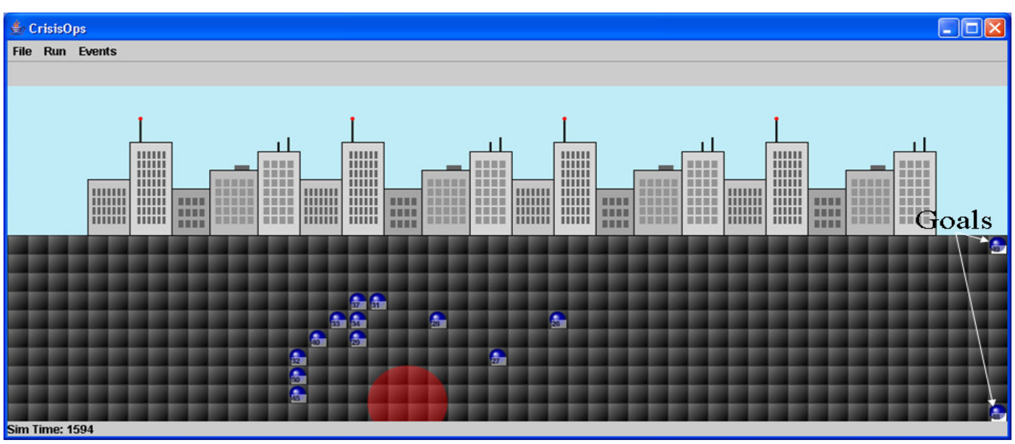


Figure 6 Curious cognitive pedestrian agents view fire or accomplish business goals

For this set of simulation runs, once the agents reach the rightmost city edge, they remain in place. That is, the focus of the simulation is on the crowd behavior is on the early stages of the crisis and on the crowd dispersal away from the fire area, which is due, in part, to the police officer's intervention.

Agent Goals, Interactions and Simulation Results

Both the Fearful –type agent and the Agreeable (social) agents *comply* with the police officer directive. That is, they will proceed to move out of the fire area. Whether they move metro or to the rightmost city edge depends on their grid location relative to that of the fire's.

The Fearful agents have a more limited set of goals and emotions than the Agreeable (Social) agents. The goals that the Fearful agents can have (1) satisfy the normal business goal, (2) seek information, (3) seek safety, and (4) seek to exit the city area. The emotions that the Fearful agent can have are: (1) fear, (2) distress, (3) surprise, (4) satisfaction, (5) relief, and (6) neutral. The last emotion serves as an initial condition to start the simulation. Events trigger emotions. A transition to a new goal state depends on the current emotional state (and goal state) as well as on environmental conditions. For example, if, as far as a Fearful agent knows, there is no fire, then that agent will transition to a satisfied emotional state upon completion of its business goal.

The Agreeable (social) agent has the largest goal and emotion set of the three types. Moreover, its goals and emotions are more complex. The possible goals are (1) satisfy the normal business goal, (2) seek information, (3) seek safety,(4) seek safety compassionately, (5) think what to do, and (6) seek to exit the city area. The possible emotions are (1) fear, (2) distress, (3) surprise, (4) satisfaction, (5) pride, (6) disappointment, (7) relief, and (8) neutral.

If a Fearful agent learns of a fire it will seek safety, which may cause a new goal of exiting the city area to be set. Its original business goal is no longer relevant. If an Agreeable agent learns of a fire, its response (and new goal selection) will be based on how far from the fire it is. If the agreeable agent is far enough for safety, it will think what to do. If it has not accomplished its business goal, it will feel disappointed. After assessment of whether or not the business goal can be safely attempted, it will feel pride in having addressed the issue, no matter what its finding.

Consider the goal of 'seek information', which all types of cognitive pedestrian agents have. If an agent notices that a crowd is forming, it will walk towards the crowd and 'ask' an agent in that crowd for information. However, there are differences in implementation according to agent type. For example, a Curious-type agent will be aware of smaller crowds. Also, the amount of message interaction that each type of agent will engage in will be different.

In the simulation scenario presented here, the Agreeable agents, when they have a goal of 'seeking safety compassionately', will send messages to all agents in its vicinity, alerting them to the location of the fire. The Fearful agents are never proactively helpful. Moreover, the Agreeable agents will respond to all requests for information, while the Fearful agents will do this infrequently (every so many messages).

The city grid is 10 cells high and fifty spaces wide. In this next set, the fire erupts at simulation time 200, location (35, 5) and radius 2. Forty pedestrian agents are involved. Agents enter at the metro (x location 0). We report illustrative results of a set.

The first simulation run has a mix of 50% Agreeable agents, 50% Fearful agents. By simulation time 354, all but two Agreeable agents know of the fire. The Agreeable agents have been sending messages, and the Fearful agents have benefited. At this time, no agents have received information/directive from the police officer agent. By simulation time 474, all of the Fearful agents are heading for the metro exit. Multiple Agreeable agents have decided that it is safe enough to attempt to satisfy the business goal even though a fire is raging. However, some of these are intercepted by the Police officer agent and do not satisfy the business goal. By time 974, 5 Agreeable agents (25% of this type) have satisfied the business goal, all of the Fearful agents have left via metro.

The mix is then changed to 90% Fearful, 10% Agreeable agents. By simulation time 474, all agents have learned of the fire, some from direct viewing, some from compassionate messages from the Agreeable agents, and some from police officer direction. The mix is then changed to 100% Fearful agents. By simulation time 394, 16 agents do not yet know of the fire. Only 5 have learned from the police officer. By simulation time 554, which is later than the above cases, 4 agents do not know of the fire. The lack of compassionate messages has resulted in more agents heading for the fire vicinity.

In a second set of simulation runs, the fire continues to erupt at simulation time 200, but it is located at (25, 5), with a radius 2. This places the fire closer to the metro, where it is more quickly discovered by the pedestrian agents. We remark on the results of simulations involving two mixes of agent types; that of the 90% Fearful, 10% agreeable, and that of the 100% Fearful. There is no significant difference in the time at which all agents know of the fire between the two cases. For a 50-50 mix, all agents know of the fire slightly sooner. The benefits of receiving informative messages from social agents are reduced when the Fearful agents encounter the fire more quickly.

The simulation case of 100% Agreeable agents was investigated for the case where the fire is located at (42, 5). The police officer has an effect on the Agreeable agents later, since the officer and the agents take longer to come into the vicinity of the fire, which is where the police officer has the greatest effect. Therefore, fewer Agreeable agents can be directed away from pursuing their own goals. Figure 7 presents the interesting spatial grouping from one such simulation run: there are three groups visible. From the left side, these are Agreeable agents leaving of their own accord, those directed by the police officer to leave via the metro, and those that are following their decision to seek the business goal.

5. CONCLUSIONS

We have developed a hybrid pedestrian agent model that incorporates locomotion, utilizes a framework for emotion and personality, and provides for cognition activity. We developed a simulation framework in which we also implemented the hybrid cognitive pedestrian agent model. Within the simulation

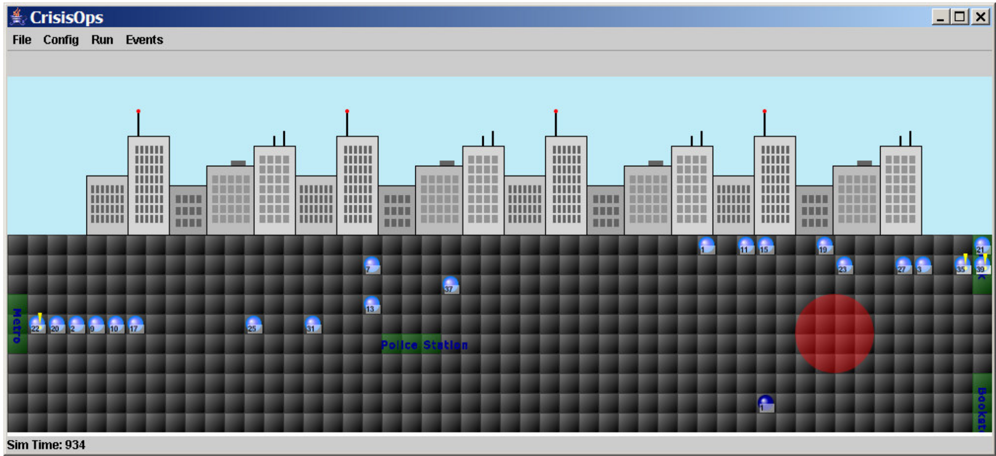


Figure 7 Spatial distribution of Agreeable agents at time 934 in fire hazard scenario where fire appears at time 200. The middle group has been directed to leave via metro by police officer.

framework, we investigated preliminary studies of crowd behavior and crowd management in a fire hazard scenario.

The simulation grid was chosen as a rectangular pedestrian area to permit comparison of our results with results in the literature pertaining to non-cognitive pedestrian locomotion. Good agreement over a number of runs with qualitatively observed structures reported in the literature was obtained, indicating that the agent –based pedestrian locomotion has been correctly designed and implemented. The implemented behavior of the different hybrid cognitive pedestrian agents was verified in a simplified scenario in which the fire hazard was instantiated. The verification considered small crowds of one type of agent only; there was no crowd control mechanism. The agents behaved as modeled. It was previously noted that the Fearful and Curious agent models were designed to be exaggerated types; while the Agreeable model reflected a more reasonable 'human' type.

In the preliminary studies of crowd behavior and management, the crowd control mechanism that was utilized is the information directive of the police officer. The officer proceeds to the fire hazard vicinity and directs any nearby agents away from the fire. The officer circumnavigates the fire hazard, and thus may 'see' pedestrian agents that strictly have passed beyond the fire by circumventing it to the north or south. Nonetheless, the police officer tells the pedestrian agents to leave the area, and proceed to the city edge or leave by the metro. It was found in certain cases that the resource of a single police officer was not sufficient to inform all agents that came through the general fire area. This was particularly the case in scenarios in which the nominal police 'kiosk' at which the officer was instantiated was relatively far from the fire, and the fire appeared relatively later than the entrance of agents from the metro into the city area.

When a crowd with a mix of Agreeable and Fearful agents was considered, it was found that the pro-active (compassionate) informative messages sent by the Agreeable agents reduced the time needed to learn of the fire by other agents in cases in which the agents did not 'see' the fire shortly after issuing into the city area from the metro.

Potential directions for future work include the introduction of other cognitive pedestrian agent types based on the emotional and personality framework used here. As the agents become more complex, the representation of their behavior in response to events would be made easier through introduction of a rule engine. The simulation framework is designed to allow this.

ACKNOWLEDGEMENTS

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