Simulation of Crowd Behavior During Emergency Evacuation Based on Artificial Life

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Abstract

This paper presents the concept and simulation details of crowd behavior model in a panic situation in a huge, complicated, structured building. The simulation is part of the Virtual Reality Environment of Matsushita Electric Works, Ltd., to evaluate the building/city design.

Key words: Virtual Human, Behavioral Animation, Artificial Life, Smoke

1. Introduction

Crowd modeling and simulation is an active research area [1,2,3,4,5]. Recent developments in Artificial Life (ALife), Artificial Intelligence and Virtual Reality have been useful in modeling and analyzing crowd behavior in a better way. While traditional Artificial Intelligence uses top-down methodology, ALife operates in a bottom-up manner, starting from single elemental units, gradually building its way upwards through evolution, emergence and development. Many work has been reported in the literature for simulating intelligent and autonomous agents using Alife approach and most of the work refers to Reynolds' Flocking algorithm[6]. Though realistic animation could be achieved for birds and fishes by the flocking algorithm, more work has to be done for crowd animation due to the complexity of human behavior. Some work has been seen in the literature where sociological behavior and group relations have been taken care of[1]. In reality, the individual and the crowd behavior, while facing a dangerous situation, would be entirely different and extremely complex compare to their behavior while facing a normal situation. Still, the ultimate goal would be to escape from the danger at the earliest.

A number of evacuation models have been developed, by other researchers, to study human behavior while facing an emergency situation like fire, earthquake and smoke[9,10,11,12] and most of them use top-down methodology (where complex behaviors are identified and an attempt is made to build a system that presents all the details of the said behavior). If we could imagine the complexity arises due to the aggregate result of actions of individuals, each acting solely on the basis of its own local perception of the world, it would definitely be a better realistic model than the above mentioned. Problem remains in choosing an optimal rule-set for each individual. In this paper, an attempt is made to develop such a behavior model and the concepts and implementation details are described. It is to be noted that with the present technical possibilities we can't exactly reproduce the complex crowd behavior in a virtual environment. All we can achieve is a simplified model of the real environment. The panic situation would be realized by simulating smoke. Smoke simulation is also another active research area in computer graphics[15] and our simulation is based on particle-systems method[16].Through out this paper, panic situation corresponds to smoke in the building and the people facing the panic situation are said to be in the panic mode.

The objective of this work is to develop a behavioral animation system of crowd in a huge building/city that could be merged into an immersive VR application, in real time. With such a system, user can evaluate the safety of the building intuitively by viewing and experiencing the panic situation interactively.

The paper is organized as follows. Section 2 briefly describes the relevant concepts in Alife and how these concepts are used for crowd simulation is explained in section 3. Section 3 also describes our proposed model and other useful simulation techniques to model group behavior. Section 4 briefs the future work and the last section concludes the paper.

2. Artificial Life and Behavioral Animation

Artificial Life is often described as attempting to understand high-level behavior from low-level rules; Reynold's flocking algorithm[6] belongs to this category where he could simulate the flocking behavior using few local rules. This rule-based animation known as behavioral animation is an example of individual-based model, which is a class of simulation used to capture the global behavior of a large number of interacting autonomous agents. Some of the common rules applied in this type of animation are

- Avoid collisions with solid obstacles

- Avoid collisions with other moving objects
- Match velocity with nearby objects
- Move towards the center of the group

The basic building blocks to represent such individual model is shown in the figure 1.

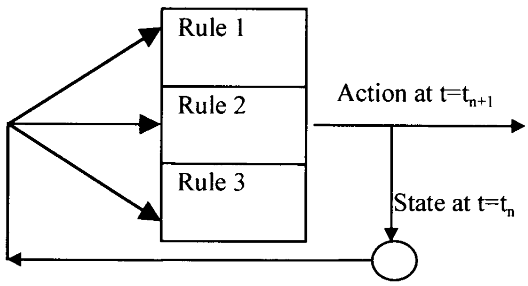

Figure 1. Basic building blocks of each virtual agent in a behavioral simulation

The selection of rule-set is made on a priority basis by checking the current state of the dynamic environment. By treating this way, each moving object in the simulation world will have its own localized behavior, that when combined produces the group behavior. The virtual agent created in this way would be intelligent as they can decide their next action by seeing the present state of the environment, and autonomous as the user interaction with the virtual agent is very less[7,8].

3. Crowd Behavior Simulation

Attempts have been made by other researchers to model the crowd behavior using the concepts in behavioral animation, in normal situations[1]. In Thalmann's approach, individual parameters are created by a distributed random behavior model which is determined by a few parameters[1]. They have also used some concepts from sociology to achieve better realistic behavior model. But, simulation of a panic situation using the rule-based approach is still open and any attempt of simulating the behavior transition of humans from normal mode to panic mode is not seen in the field of computational science.

To design an optimum model for virtual human in a panic situation, there are many issues we should take care of. Some of those important factors are the following.

- How should the virtual human extract information from the dynamic environment
- How the extracted information should be sent to the brain cells (rule-cells and decision cells)
- What are the minimum rule-set to be defined so that the virtual human could make a decision even in a complicated environment.
- How to make the decision block, concept independent, so that the model could be easily scaleable.
- How to make each individual behavior unique with a little memory.
- How social behavior could be incorporated

Next section briefly analyzes the environment and the possible grouping of each environment objects.

3.1 Problem Domain

In reality, all autonomous agents are equipped with sensors through which they get information from the environment. Everything they know from their environment they learn through their sensors. This information severely influences their behavior. Given a visibility range for the virtual humans in a huge building, the information received by them can be broadly classified into 2 objects, and there are two ways to categorize them. One way is to treat the environment as the combination of static solid objects and moving objects. So smoke and neighbors can be considered as moving objects; walls, buildings etc as static solid objects. Another way is to treat smoke and other static obstacles as _Obstacle_ and the virtual human as moving objects. We choose the latter approach where smoke is also a kind of obstacle. To differentiate the normal solid obstacles with smoke, Obstacle is again classified into two types. They are _dangerous obstacle_ and _normal obstacle_. Smoke belongs to the first type. The _normal obstacle_ contains any static solid obstacles and any other _bad location_ in the building ; Hereafter Obstacle means _normal obstacle_ through out this paper.

The possible combinations of obstacles, neighbors and smoke are shown in Figure 2.

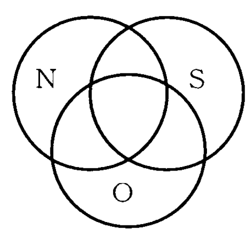

Figure 2. Objects in the dynamic environment and their possible combination; N=neighbor, S=smoke, O=obstacle.

If there is only one entity at a time in the visibility range of virtual human, the task would be simple. But, problem starts when the combination of the objects are seen in its visibility range. Decision making should be done on priority basis. Similarly, if nothing is seen in the visibility range, virtual human should use a pre-defined final target for navigation. There will also be cases where it would come across a bad location in the world (ie, a location surrounded by walls and no exit door) Those are the locations where he doesn't want to visit again. And if meets some other human, he should be able to exchange the information about the location of those bad spots. That means, virtual human should have memory.

Being the project is very specific to humans in a panic situation, the ultimate target of each virtual human is limited to escape from the building/city. In reality, whatever may be our behaviors, once we are in a panic situation like fire or earthquake, our goal also would be to escape from the panic situation at the earliest. It is true that the transition of behaviors from normal stage to panic mode will depend on each human's intensity of emotions at that instant. Also, if we are in a group while observing the panic situation (smoke), the group decision has major role for the next action of each individual. We can think of the final decision of the group will be a resultant of the behaviors of each individual taken together.

3.2 Virtual Human

Based on the above analysis, attributes and behavior model have been developed for virtual humans. Attributes consist of a small memory unit, knowledge about virtual human's present status, information about the final target and three significant indices to route the output of each rule-cell to respective decision-cell.

Memory unit consists of a list of bad location index in the simulation world it would come across. This information may also be got from the nearest neighbor. This list is a Most Recently Used Lists (mrulists).

Present status tells the present position, Velocity and direction of the virtual human and a mode index to indicate its present feeling (whether in panic mode or normal mode)

Behavioral model is the core part of virtual human . Figure 3 shows the building blocks and the relation between them

3.3 Behavior model for Virtual Human

The model consists of the following.

1. Sensor

The information from the dynamic environment would be captured independently by each sensor. The obstacle sensor would detect if there is an obstacle in the visibility range. We use ray-obstacle intersection method. A ray is sent by the virtual human and if it intersects with any obstacle, the point of intersection and the normal vector at the point of intersection would be detected. The smoke sensor would detect the density of smoke near its location. The neighbor sensor would detect the location, direction vector and information stored in the memory of his nearest neighbor.

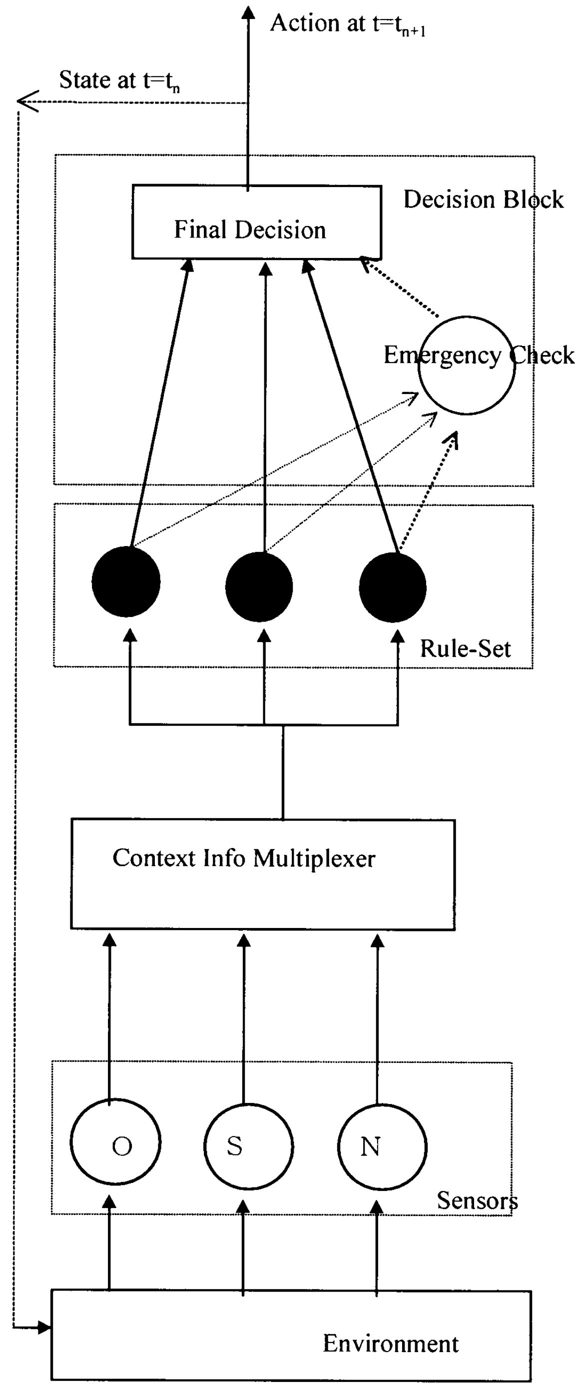

Figure 3. Behavior model of Virtual Human

2. Context Info Multiplexer

This module is a multiplexer where all the individual sensor information would be combined. The combined information would be broadcasted to all the rule-cells.

3. Rule-Cells (Brain cells)

Each virtual human has 3 rule-cells. One deals with obstacles. One takes care of smoke and the last one deals with neighbors. After processing the received information, the sole aim of each rule-cell is to recommend an action to the decision block. This action would be a proposed direction vector. The importance of this action would depend on the magnitude of the recommended direction vector. This magnitude represents the proposed acceleration by each rule-cell and this value is normalized between 0 and 1. Imagine that the visibility range of each virtual human is normalized between 0 and 1. Let's have a brief look into the processing of each rule-cell.

Obstacle :As all the information about the dynamic environment would be available in the broadcasted message from the multiplexer, Each rule-cell has the freedom to choose only the needed information. In the case of obstacle rule-cell, it selects the information about the obstacle. It also extracts the memory information of the neighbor. In our model, the memory of each human contains only the information about a bad location (Position) if it come across. Since the virtual human should avoid going to those location, the memory information could be considered as obstacle. The magnitude of the resultant, proposed action vector from obstacle cell varies with the distance of the obstacles from the virtual human as shown in figure 4.

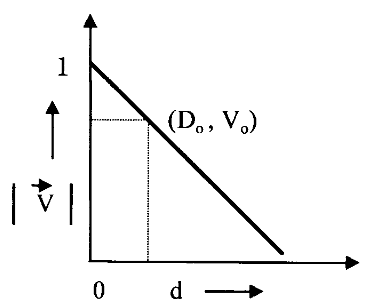

Figure 4. The magnitude of the recommended action vector of obstacle rule-cell as a function of distance from the obstacle; (eg: $V_o = 0.6\text{-}0.8$)

When the obstacle is very nearby, avoiding obstacle would be an emergency action. Each human has a significant index[V_o] for deciding whether they should propose a normal action or emergency action. The proposed action vector would be routed to final decision-cell if its magnitude is less than the index and otherwise to emergency cell.

Smoke: The received information from the broadcasted message would be smoke density at its location and nearest neighborhood and information about emergency signals. It also check if the neighbor is in the panic mode.

The magnitude of the proposed action vector of this rule-cell depends on density of smoke at its location.

If there is no signal from the neighbor and if the smoke density is less, proposed action would be _no change in the present direction vector_ and this information will be sent directly to the final decision cell. When the smoke density exceeds the pre-defined cut off value (K_s), it checks for emergency signal and propose an action vector along the signal direction. If there is no signal information, it checks the density in the nearest neighborhood to find low-density region. The final action vector will be sent to the emergency cell with magnitude keeping at a maximum value (Normalized). If the smoke density is less than the cut-off and if a neighbor is found in the panic mode, then the direction of action vector would be along the signal direction if available. Else, the direction would be set to the neighbor's direction and this information would be sent to emergency-cell with maximum priority.

Neighbor :Here again the magnitude of the action vector depends on the distance between the neighbor and self as shown in figure 5.

When the neighbor is far, virtual human should try to reach the neighbor fast. The direction would be towards the neighbor with increased acceleration. Similarly, if the neighbor is very close, it should reduce the acceleration and should try to match the velocity with the neighbor. The proposed action vector would be routed to the final decision cell if its magnitude is greater than the cut-off and otherwise to emergency cell.

Briefly, the output of each rule-cell is a vector, with a varying magnitude

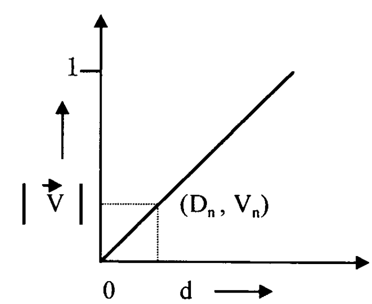

Figure 5. The magnitude of the recommended action vector of neighbor rule-cell as a function of distance; (eg: $V_o = 0.1\text{-}0.3$)

Crowd density and smoke density would be calculated and updated at each simulation update. World is divided into a number of smaller units with each unit having a pre-defined maximum capacity of total number of humans and smoke density. The crowd density information about the nearest neighborhood would be extracted by the neighbor-rule-cell so that queuing behavior could be achieved.

Decision Block

As shown in the figure 3, it contains 2 modules. One is the final decision-cell and the other is the emergency cell.

Final decision-cell: If there is no proposed action vector from the emergency-cell, final decision-cell would just sum up all the input it receives from the each rule-cell and that would be the final action vector of that virtual human to calculate the next desired velocity. Otherwise, the proposed action from the emergency block would be given the highest priorityt. This cell also contain the pre-defined final target of each virtual human. If there is no input from the rule-cells, the action vector would be set along the pre-defined final target vector.

Emergency-cell: It also do the summing up of all the vectors it receives from each rule-cell and the resultant would be sent to the final decision block. However, there are some special cases it would be checking for. If the emergency cell get action vectors from all the rule-cells simultaneously (Which means that human is very close to an obstacle, very close to the neighbor and smoke density is very high), the proposed action would be the recommended action from the neighbor rule-cell (i.e, follow neighbor). Any other combination of input vectors, highest priority is given to escape from smoke.

To make each individual unique, a range has been defined for the pre-defined cut-off values of each rule-cells. Each individual is allowed to choose a random value in the defined range. By doing this way, each virtual human could be considered as coward or brave depends on the value assigned to them. For example, if the cut-off value for smoke density is 0.6 for one human and 0.75 for another human , the one with higher value is more brave compare to one with lower value.

Even otherwise each individual would be unique as they have their own memory.

The information exchange of the virtual humans in the proposed model is limited to the nearest neighbor and the self. Though it would gradually result in group behavior, better results could be obtained if we could simulate the information exchange between all the neighbors in the visibility range. In reality, when people hear about some danger, the behavior transition from normal stage to panic is gradual and it depends on each individual's emotional status. Yet, they all would come to a steady state with a common goal, after some time. Following section describes two techniques for simulating the behavior transition from normal mode to panic mode.

3.4 Simulation of Behavior transition of crowd from normal mode to panic mode

There are some constraints and drawbacks for these approaches. Still, we would like to mention these methods due to their potential use if we could meet the constraints and overcome the drawbacks in the future.
Constraints:

a) Behavior model should be such that virtual human's priority in choosing a rule at any instant should depend on its intensity of emotion at that instant.
b) Emotion intensity should be a function of situations virtual human faces from its dynamic environment

Imagine that there are few neighbors in the visibility range of a virtual human each having its own intensity of emotion. Suppose they get an emergency information to escape from the building. Let the final goal of that group is to escape from the danger. Considering this final goal be an attractor (fixed point) of a system, the random behavior of each individual, before reaching this fixed point could be simulated using Iterated Function Systems or Auto-correlation method.

Iterated Function System Method

This approach is known as an inverse problem, which is the basis of Fractal Compression Technique[13,14]. Given the image to be compressed, considering that image as the attractor of the system, the aim of this method is to find a few transformation parameters which when multiply with any initial image iteratively, eventually converge to the original image.

In our case, the initial image is a set of behaviors(emotion values) of each individual and the attractor is a well-defined final behavior (goal). Imagine we have a set of transformation coefficients for the final behavior. When the crowd get the information about the panic situation, multiply the present behavior matrix with pre-calculated transform matrix so that, the next emotion value of each individual would be a scaled sum of emotions of all the neighbors. The process should be repeated iteratively until the emotion values of all individuals converge. By keeping the time for iteration update more compare to the simulation update, each individual will have a random behavior and random decision taking before attaining the final group goal. Since the calculation of emotion intensity of each individual is utilizing neighbor's emotion also, this method seems to be a good approach for simulating the behavior transition and social behavior. Still there are a lot of issues to be taken care of . Some of them are: How to keep the matrix with a varying size, if some one join the group; what should be the transformation matrix etc.

Auto-correlation Method

Interactions among large number of elementary components in physical systems made from a large number of simple elements are a widely studied subject area. The interactions of those elementary components yield collective phenomenon such as the stable magnetic orientations and domains in a magnetic system or the vortex patterns in a fluid flow. We could apply the similar simulation techniques used for those systems, which is based on auto-correlation matrix. This matrix would be symmetric diagonal matrix and if a person can see a neighbor, the corresponding matrix element can be set to a non-zero value, which is the emotion intensity of the neighbor. This matrix, when multiply with the emotion values of all the neighbors iteratively, eventually converges to a stable system.

4. Future Work

Smoke simulation is not completed at the moment. Our approach is based on Particle-System method and the concept used is from diffusion-type Cellular Automata. We are planning to model the behavior transition of crowd from normal mode to panic mode using the methods described in this paper. This behavior model would be merged to the Spherical screen VR experiencing system where it would act as a simulation engine for the virtual humans.

5. Conclusion

A behavior model for people facing a panic situation in a huge complicated building/city has been developed based on the concepts in Artificial Life and behavioral animation. Encouraging results of group behavior and other basic behaviors like obstacle avoidance, following neighbors etc. were obtained by implementing this model.

While designing the model, care is being taken to meet the questions mentioned in section 3 and an attempt is made to keep the model analogues to that of real human as described by neural network.

A main issue about any evacuation model would be about the validation of the model. For a realistic validation, we should be able to monitor the crowd behavior by creating the panic situation in the building ,which is not practical. As the final target of each virtual human is to escape from the danger, one test could be to check whether the virtual humans choose an optimal path to reach the nearest exit.

(p.s)

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