Feeling Crowded? Exploring Presence in Virtual Crowds

Nuria Pelechano, Catherine Stocker, Jan Allbeck, Norman I. Badler
University of Pennsylvania

Abstract

Virtual reality experiments with virtual crowds are necessary to study human behavior under panic or stressful situations that cannot be evaluated in the real world (i.e., building evacuation due to fire). In order to carry out those experiments it is necessary to use a crowd simulation model in which a real person is seamlessly immersed and experiences a high sense of presence when interacting with such a crowd.

This paper studies several crowd simulation models in order to determine which could best enhance presence for a user within a virtual environment. Egocentric features that affect presence are considered in the evaluation. Once we have a realistic simulation, we could use it to study human behavior and obtain relevant data. That data could then be used to update agent behaviors in the simulation system to further improve the overall realism of large groups of autonomous agents.

Keywords---Presence, crowd simulation, egocentric features.

1. Introduction

Large animated groups of autonomous agents are being widely used for computer graphics applications, video games, training, and education. The main limitation in simulating crowds lies in how to validate the models. There has been a lot of work done in validating egress for evacuation simulations based on the literature on human movement behavior, but there is not quantitative data on how to validate human behavior when it comes to decision-making.

Controlled experiments are therefore needed where different human behaviors can be tested. For example, during a fire, which exit routes will people select? If there are leaders giving instructions, how many people will follow them? If there are random people communicating information, how much will others trust them? What are the motion paths and movements actually taken by an individual in a crowd?

These experiments are usually either difficult to replicate in real life, or simply impossible to run in the first place (i.e., fire evacuation). Experiments in virtual environments (VEs) could be invaluable for gathering the behavioral information necessary to improve current crowd simulation models and consequently experimentally validate them.

In order to gather accurate information, it is essential to achieve presence so that a subject immersed in the virtual experiment will behave as close as possible to real life [9] [13]. Presence is generally described as "the sense of being in a VE rather than the place in which the participant's body is actually located."[7].

An accepted method of measuring presence has yet to be agreed upon. Classic presence work relied on questionnaires, but because questionnaires depend entirely on a user's subjective view of their experience [20], researchers found it necessary to develop other methods to supplement them [4]. Some of the methods they have discovered include behavioral measurements (social and postural responses, etc.) [1][5], physiological measurements (galvanic skin response, heart rate, etc.)[9][16], task performance measurements (completion times and error rates, etc.) [3], and counting breaks in presence [17].

Using one or more of the various measuring methods, a number of findings have been published about presence:

- Being able to physically manipulate objects [14] and communicate with virtual humans in a VE increases a sense of presence [16].
- Unnatural interactions with the VE, such as using a joystick to maneuver, can reduce the sense of presence when compared to techniques that resemble real life navigation such as "walking in place" [18].
- Breaks in presence [16] have been used to count the transitions from the virtual to the real world. These transitions can be triggered by occurrences such as bumping into a wall in a CAVE experiment, tripping over cables, and whiteouts [17].

These are important to consider when designing a realistic crowd simulation model. Although crowd simulation validation currently exists for safe egress during evacuation by using engineering guides, there has yet to be any validation based on human behavior during decision-making in more dangerous situations. With the knowledge that people act in a VE as if they are in a real-world situation when they experience a high sense of presence, we believe that a good crowd simulation model should promote this sense of presence. Once we have crowds that provide a high sense of presence, we can confidently run simulations to study human behavior and use the resulting data both to validate and improve current models.

Our contribution in this paper lies in differentiating external crowd motion features from internal or egocentric features. The community has been primarily concerned about the former, as a good simulation will produce crowd movements that appear realistic to an outside observer. Egocentric features, on the other hand, are about what a participant in the crowd simulation would perceive visually or kinesthetically, and thus provide computable measures of presence for the subject.

This paper begins by surveying the different crowd simulation models in the literature. Then we discuss egocentric features that may affect presence. Finally we will qualitatively analyze which of these features may break or increase presence according to previous experiments that have been carried out in the presence literature.

2. Virtual Crowd Models

2.1. Social Forces Models

The most representative social forces model is Helbing's empirical model [6], which solves Newton's equation for each agent and applies repulsion and tangential forces to simulate interactions between people and obstacles. The disadvantage of this model is that agents appear to shake or vibrate continuously.

2.2. Rule Based Models

These models describe human movement through a set of basic rules. The first model introduced was Reynolds' boids system [11][12]. Agents apply collision detection and avoidance to prevent colliding with other agents, but they do not perform collision response, and therefore collisions and overlaps may occur in certain circumstances. Some newer models apply stopping rules to avoid overlapping other agents [15].

2.3. Cellular Automata Models

Cellular automata (CA) [1][8][19] take an artificial intelligence approach to simulation modeling, defined as mathematical idealizations of physical systems in which space and time are discrete, and physical quantities take a finite set of discrete values. These models do not permit contact between agents since floor space is discretized and individuals can only move to a free adjacent cell. CA models tend to expose the underlying checkerboard of cells when crowd density is high, and individual movements may be artificial since they are dictated by the limited turning options to adjacent cells.

2.4. HiDAC

HiDAC [10] presents a hybrid approach where the local motion is carried out through a parameterized social forces model based on psychological and geometrical rules. It performs collision detection and response, while reducing the shaking behavior inherent in the forces model. Rules apply depending on agents' personality and the state of the environment (relative direction of other agents, rules of social behavior, perceived hazards, etc.)

3. Presence in crowd simulation models

3.1 Important Egocentric Features

The main egocentric features that we can extract from these crowd models, which we believe to be significant factors influencing presence in VEs are:

- **Shaking**: How much the agents appear to vibrate while trying to move. Force-based models are unstable and thus the position of each agent is slightly modified for each time step, which yields the illusion of agents shaking continuously. In contrast CA or rule-based models do not suffer from this artifact, and HiDAC − although built on top of a forces model − corrects this behavior through rules.
- **Discrete/Continuous movement**: How the agent moves from one position to another, whether it is discretized in space or not. In CA models, agents

move between discrete adjacent cells in one time step, limiting turn direction options. The other models do not discretize the space and therefore allow the agent to move within continuous space.

- **Overlapping**: Whether overlapping with other agents can occur. This effect can be observed in some rule-based models where only collision avoidance is performed but not collision response. Later versions of these models apply stopping rules to prevent overlapping [15]. Although CA models avoid collisions by not allowing agents to move to occupied cells, they allow agents to seemingly cross *through* each other. This occurs when two agents simultaneously wish to move into each other's occupied cells. Because the cells are occupied, they choose instead to move diagonally to the empty cells next to the occupied ones, resulting in the trajectories of the agents crossing each other within one simulation step. Social forces and HiDAC do perform collision detection and response.
- **Communication**: Represents the ability of the agents to exchange information about the virtual environment. The original social forces, rule-based and CA do not include this feature. HiDAC as well as some later versions of rule-based models incorporate communication as a way of sharing information about the environment and give instructions to other members of the crowd.
- **Pushing**: Having physical contact between the agents' bodies. If this interaction occurs then one agent should be able to push others through the crowd. This feature is exhibited by social forces models and HiDAC, but it is not performed in rule-based models or CA.

A summary of these features is shown in Table 1.

	Social Forces	*Rule-Based*	*CA*	*HiDAC*
Shaking avoidance	–	+	+	+
Continuous movement	+	+	–	+
Overlapping avoidance	+	*	–	+
Communication	–	*	–	+
Pushing	+	–	–	+

Table 1**. Simulation methodology impact on presence.** "+" means the model readily admits this feature; "–" means it does not. * means later versions of this model have built these features on top of the original model.

3.2 Experimental evidence from the literature

There have been many experiments to date studying which elements of a virtual environment could enhance or reduce presence.

Slater *et al.* [16] discovered that when a whiteout occurs while a participant is immersed in a VE there is a break in presence. A similar effect occurs if while navigating a VE the participant walks through a virtual object or agent. The observed result would be as if the virtual environment had suddenly disappeared. Based on these results we conclude that it is essential to not allow *overlapping*.

According to Schubert *et al.* [14]: "Presence is observable when people interact in and with a virtual world as if they were there, when they grasp for virtual objects or develop fear of virtual cliffs." Interaction means "the manipulation of objects and the influence on agents". Accordingly we conclude that to enhance the sense of presence, a participant must be able to manipulate virtual objects. One way a participant could feel as if they were affecting the virtual world would be by *pushing* other agents they came into contact with.

Another way of interacting that increases the sense presence is through *communication* with the virtual agents. Some studies show that the heart rate of a participant increases when a virtual agent speaks directly to him [16].

Studies show that discontinuous movement or jerkiness reduces presence. Jerkiness can be observed when for example the VE suffers from low frame rate. As Barfield and Hendrix concluded [2]: "The subjective report of presence within the virtual environment was significantly less using an update rate of 5 and 10 Hz when compared to update rates of 20 and 25 Hz". Therefore we can expect that crowd models suffering from agents *shaking* continuously or appearing to move between large *discrete* positions will likewise diminish the participant's sense of presence.

5. Conclusions

Crowd simulation models are currently lacking a commonly accepted validation method. In this paper we present the sense of presence in immersive VE as a possible method of validation. With the experimental evidence found in the presence literature, we can make a decision on which features a crowd simulation model should have in order to achieve high levels of presence.

Using egocentric features based on established presence enhancing experiences, we hypothesize that *interacting with the other agents in a crowd* (by being pushed physically and by communicating with them) and *being able to materially affect the movements of other members of the crowd* (by pushing on them and having them avoid collisions with the self) will likely enhance a subject's sense of presence. Experiments are in progress to test these hypotheses.

When having a participant immersed in a VE with such a crowd, we expect to observe the same type of behavior as in real life. Therefore we could run experimental scenarios in order to study human behavior and decision-making in stressful situations such as fire evacuation. Immersive virtual environments have successfully been applied to cure some phobias, such as fear of public speaking, heights, flying, etc. Likewise we would like to use VE for two main purposes: (1) study human behavior to improve current crowd simulation models and (2) employ this VE for building design simulations.

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