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Abstract
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Keywords
presence, crowd simulation, egocentric features

Disciplines
Computer Sciences | Engineering | Graphics and Human Computer Interfaces

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Being a Part of the Crowd: Towards Validating VR Crowds Using Presence.

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ABSTRACT
Crowd simulation models are currently lacking a commonly accepted validation method. In this paper, we propose *level of presence achieved by a human in a virtual environment (VE)* as a metric for virtual crowd behavior. Using experimental evidence from the presence literature and the results of a pilot experiment that we ran, we explore the egocentric features that a crowd simulation model should have in order to achieve high levels of presence and thus be used as a framework for validation of simulated crowd behavior.

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Categories and Subject Descriptors
I.3.7 [**Computer Graphics**]: Three-Dimensional Graphics and Realism—*Animation, Virtual Reality.*

General Terms
Experimentation, Human Factors, Verification.

Keywords
Presence, crowd simulation, egocentric features.

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1. INTRODUCTION
Large animated groups of autonomous agents are being widely used for computer graphics applications, video games, training, and education. An important practical problem in this research lies in how to validate the models. There has been considerable work done in validating egress for evacuation simulations based on the literature on human movement behavior, but there is no quantitative data on how to validate human behavior when it comes to decision-making in this context.

Controlled experiments are therefore needed where human behaviors in response to different crowd models can be tested. For example, during a fire, which exit routes would people select? If there are leaders giving instructions, how many people would follow them? If there are strangers communicating information, how much would others trust them? What motion paths are taken and what movements are made 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 [11] [17]. Presence is described as the extent to which people respond realistically to virtual events and situations. Responding *realistically* implies realism at many levels, ranging from physiological through behavioral, emotional and cognitive behaviors [17].

An accepted method of measuring presence has yet to be agreed upon. Classic presence work relied on questionnaires, but since questionnaires depend entirely on a user's subjective view of their experience [26], researchers found it necessary to develop other supplementary methods [8]. Those methods include behavioral measurements (social and postural responses, etc.) [1][9], physiological measurements (galvanic skin response, heart rate, etc.)[11][20], task performance measurements (completion times and error rates, etc.) [3], and counting breaks in presence [21].

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

- Being able to physically manipulate objects [18] and communicate with virtual humans in a VE increases a sense of presence [20].
- 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" [22].
- Breaks in presence [20] 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 an immersive environment, tripping over cables, and whiteouts [21].

These findings 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 guidelines, 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 computer animation community has been primarily concerned with 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 an active participant in the crowd simulation would perceive visually or kinesthetically, and thus provide computable measures of presence for the subject.

This paper first surveys the different crowd simulation models in the literature. We discuss egocentric features that may affect presence, and then qualitatively analyze which of these features may break or increase presence. Finally we present our pilot experiment and the results obtained.

2. VIRTUAL CROWD MODELS

2.1 Previous Work

Considerable research has been carried out in the area of crowd simulation. Most of this work has focused on creating crowds of virtual humans that would move within a virtual environment in a believable manner. The main applications of this work include video games, training, educational applications and for the study of space utilization (i.e: where bottlenecks appear) and evacuation of large areas (buildings, ships, cities, etc.).

Particle systems and dynamics have been used for modeling the motion of groups with significant physics [5]. Some recent work has focused on extending Helbing's model [12], but has resulted in equations that are not applicable in real-time simulations. Flow tiles have been used to drive individual movements by modeling spaces with simple "snap together" predefined flow regions [7]. Crowd simulation systems have also been described based on more general continuum dynamics and run at interactive rates [24].

Cellular Automata [11][23] approaches discretize time and space to simulate each agents' movement by changing position between adjacent cells. Reynolds [15] introduced rule based models as a distributed behavioral model where the aggregate motion is the result of the interaction of relatively simple rules.

Cognitive models have been used in combination with rule-based models to achieve more realistic behaviors for pedestrian simulation [19]. Different behavioral rules can be applied to the crowd, group or individuals to achieve more believable overall crowd behavior [25].

For the purpose of this work we focused on three models that have been widely used for crowd simulation (social forces [10], rule based [15][16] and cellular automata [11]) and a hybrid approach (HiDAC [14]) which applies a combination of psychological and geometrical rules with a social and physical forces model in an attempt to improve the quality of individual agent movement.

2.2 Crowd Models Implemented for our Pilot Experiment

2.2.1 Social Forces Models

The most representative social forces model is Helbing's empirical model [10], which solves Newton's equation for each agent and applies repulsion and tangential forces to simulate interactions between people and obstacles. A drawback of this model is that agents appear to shake or vibrate continuously.

2.2.2 Rule Based Models

These models describe human movement through a set of basic rules. The first model introduced was Reynolds' boids system [15][16]. 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 [19].

2.2.3 Cellular Automata Models

Cellular automata (CA) [11][23] 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 appear artificial since they are dictated by the limited turning options to adjacent cells.

2.2.4 HiDAC

HiDAC [14] 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 are applied based on agent 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 are significant factors influencing presence in VEs are: shaking, discrete/continuous movement, overlapping, communication and pushing. We will now describe how each of these features is present or absent in each of the four models used for our study (a summary appears in Table 1).

- **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, and whether it is discretized or continuous in space. 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 [19]. 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 models and HiDAC do perform collision detection and response to minimize overlapping.
- **Communication**: Represents the ability of the agents to exchange information about the virtual environment [13]. The original social forces, rule-based and CA models 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 giving 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 or CA models.

Table 1. Simulation methodology impact on presence.

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

*"+" 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. [20] discovered that when a whiteout occurs while a participant is immersed in a VE there is a break in presence. This effect occurs, for example, 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 there be no overlapping.

According to Schubert et al. [18]: "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 of 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 [20].

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.

4. PILOT EXPERIMENT

For this work we carried out a pilot experiment to closely study the behavior of people interacting with a virtual crowd.

For the experiment we created a virtual scenario simulating a cocktail party. At the party were virtual party-goers who walked around "mingling" with others through non-verbal communication and gestures. After a specified time, a bell rang and the virtual agents calmly exited the party.

The virtual agents were rendered using Cal3D [6] and they had several animations assigned including different walking styles that could be blended smoothly, and a set of idle and gesturing animation clips that could be used when agents stop walking or gather around a table.

Figure 1 shows a crowd of virtual agents interacting during a cocktail party. People gather around the tables to eat and engage in (non-verbal) conversation with others. On the right we can observe a close-up of one of the tables.

4.1 The Setup

Participants were members of a university community. They were recruited throughout the campus, by posting signs. Each volunteer subject was randomly assigned to a group when they arrived.

The stimulus was a 3D model of a building, populated with virtual characters and furniture, and presented using an eMagin Z800 3DVisor head mounted display (with a resolution of 800x600, field of view of 40 degrees and 60Hz refresh rate). In addition, participants wore four head sensors that are part of the ReActor2 suit, an opitical motion capture system from Ascension Technology. The head sensors were used to determine where participants were looking and located in the virtual environments.

4.2 The Task

Each subject was placed in the same virtual environment with the same virtual characters, varying only in the crowd model implemented (Social Forces, Rule Based, Cellular Automata, HiDAC) according to their group. They were told that the purpose of the research was to assess the validity of the virtual environment that we had created. The potential risks of the experiment -- eyestrain and nausea -- were explained to them and they were told that they could withdraw at any time. The experimental protocol was formally approved by our institution's IRB.

The subject's first experience in the virtual world was to locate three objects in the environment while the virtual characters in the environment were stationary. This was used as a training phase to get them comfortable with moving through the environment, but not influenced by a particular crowd model.

The subject was then assigned the task of walking around the cocktail party, counting the number of red haired party-goers, and leaving when an alarm sounded. They were told to feel free to explore the environment after finishing their task, but not to leave the room until they heard the bell sound. When the alarm sounds all of the party-goers also exit. We included this part of the experiment so that each subject was guaranteed to experience a high density crowd.

After completing the task, subjects were administered a questionnaire to help us determine the level of presence that they experienced during their time in the virtual environment. They were questioned about their experience with video games and virtual environments to ensure that the independent variable (the different crowd models) was the only contributing factor to the differences in achieved presence.

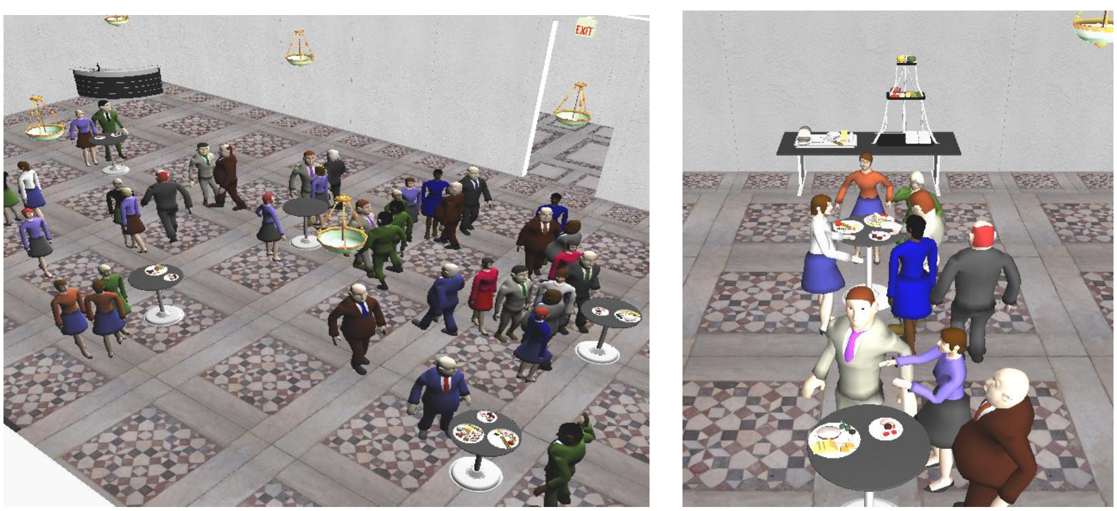

Figure 1. Virtual crowd in a cocktail party.

The scenario where all four crowd models were run was composed of a large room with round tables distributed so that virtual agents could move around and stop around any of them to engage in non-verbal conversation with other members of the crowd. When the bell rings, they all start walking calmly towards the door with the exit sign above it. As the participant will walk within the crowd as another agent, individuals will react depending on the crowd model being used (i.e.: perform collision avoidance (in rule based and HiDAC), respond to interactions such as being pushed (in HiDAC and social forces), not occupy the same cell (in CA), etc.)

After the first questionnaire was completed, they returned to the virtual cocktail party and were asked to count the number of red haired party-goers again. As in the first part of the experiment, they were asked to exit the room when a bell sounded. This time the party-goers were driven by a different crowd model. After the second experience they filled out another copy of the questionnaire.

All the participants were videotaped during their participation for collection of data that could be used to study their involvement with the virtual people. After the experiment participants would answer several questions regarding their experience.

Figure 2 shows a participant during the experiment wearing the head mounted display and a large screen showing what the participant is observing. By videotaping the subject's behavioral response together with the scene we can simultaneously study the response of the person to the behavior of the virtual crowd.

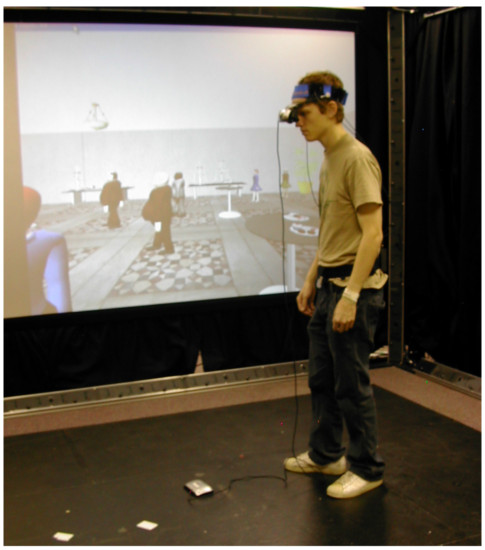

Figure 2. Participant during the experiment.

5. INITIAL RESULTS AND FUTURE WORK

The goal of this pilot experiment was to examine whether participants interacting with a virtual crowd experience would react to the virtual crowd as they would do in a similar real situation.

From our current experiments we have been able to observe that some participants did exhibit some behaviors consistent with the notion that they were responding to the crowd realistically. As we indicated in Section 4.2, each participant did two experiments, the scenarios were exactly the same, but in each case we used a different crowd simulation model. Our goal for this pilot experiment is to study presence in a virtual crowd regardless of the crowd model being implemented.

The results obtained for this study came from standard questionnaires that contained a part with general questions, and a part where participants could give any comments they had about their experience. The other source of results came from the authors' observing their behavioral response from the videos. The part on questions was done initially to study the differences when running different crowds models and the part on gathering their comments and observing the videos were done to evaluate their presence in (by reactions to) a virtual crowd. In this section we will focus on the comments and the behavioral response, since the questionnaires did not provide significant differences. As indicated in the literature on presence, questionnaires are not good enough by themselves and therefore in future work we should include other methods such as Galvanic Skin Response, ECG, respiration, administering personality tests, etc.

From the comments that our participants provided after doing the experiments it is worth mentioning a few:

- *"The sense of crowd movement was most compelling during the evacuation."*
- *"I felt bad whenever I bumped into someone."*
- *"The second time, everyone immediately started leaving and it made me really want to leave as well."*

These examples show that some people do think about the interaction with virtual agents in a similar way as when they interact with real people.

In addition to administering a questionnaire, we also gained insight by examining videotapes of participants' behavioral responses. In those videos we observed people moving backwards after bumping into a virtual agent, stepping sideways to avoid a virtual agent walking into them, and turning their head to watch an agent walk around them. One of the participants even waved back in response to a virtual agent's wave.

The pilot experiment had background crowd noise as well as the noise of the bell. A participant reported after the experiment "*I don't remember if the tables or people made sounds when I bumped into them. If they didn't that might have helped knowing when I hit something*." This comment is very interesting from two perspectives, on one hand it shows such a high level of presence that the person is not even aware of what he has or has not heard during the experiment, and on the other hand it provides us with a valuable way of improving the next experiments. Given that it is not feasible to provide force feedback for such a scenario, it would be interesting to have some "natural" feedback that could allow the participant to realize that there is something wrong about the interaction or help in feeling more immersed in the virtual environment. There were more comments from several participants regarding this topic, and although in general they were all pleased by the background noise enhancing their experience in a virtual crowd, several improvements should be made in the future such as:

- Including stereo sound through headphones to enhance presence by being able to realize when, as a participant, you are bumping into an object or a person in the virtual crowd (i.e., when you bump into virtual agent you hear a noise or complaint).
- Making the sound localized and clearer as the participant approaches a small group of people engaged in conversation, so that the participant can hear what they

are talking about instead of just the noise of background voices.

As introduced in Section 4.2, during our pilot experiment, participants were first given a training session where they learned to navigate the environment, followed by two identical scenarios where different crowd simulation models where used. During training, participants were allowed to walk around and observe the environment until they located all three objects. This time varied from subject to subject. After the objects were located, subjects returned to the center of the room and the crowd of agents began to move according to the crowd simulation model being used. The vast majority of the participants reported feeling more comfortable with the interaction during the second experiment, probably because the training time was not long enough or should have included agent movement.

"Much easier to navigate the second time. I had a feel for how fast I would be moving in the virtual world and felt like I could pay more attention to the task and less on walking/looking."

An additional finding from the comments that were made about the insufficient training is that people appear to gauge their virtual movement based on the relative movement of others. Since subjects claim to have not understood their movement relationship with the world until they saw the virtual humans move, this is evidence that they are very sensitive to not only the general movement of the members of the virtual crowd, but specifically to the inconsistencies between their own real movement and the artificial crowd movements. If this is the case, it is essential for the crowd members to move in a realistic way that the subject expects and can mimic.

Another important element that is mentioned in Section 3.1 is the communication factor, which would highly increase the feeling of being part of a virtual crowd and the level of interaction with the agents:

"… it would be more realistic to be able to make out conversations while close to groups of people."

Finally it is worth mentioning the current limitations of the equipment, mainly the low resolution of the head mounted display and the narrow field of view:

"Restricted field of view made it harder, but I'm used to that from (other) games."

"..., *low resolution made identifying the shrimp hard,…"*

In the future we are considering using equipment that can provide higher levels of immersion and increase the feeling of presence, such as a CAVE® which offers higher resolution and wider field of view.

6. 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 our virtual representation 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. Arranging for the virtual crowd to push back (physically) on the subject is clearly more difficult, and we may be able to explore a haptic solution using vibrotactile elements [4]. Experiments are in progress to test these hypotheses.

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.

With a participant immersed in a VE 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. Immersive virtual environments have successfully been applied to cure some phobias, such as fear of public speaking, heights, flying, etc. Likewise we could use a VE for two new purposes: studying human behavior to improve current crowd simulation models and employing this VE for building design simulations.

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