

Follower Behavior in a Virtual Environment

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Abstract—Crowd simulation models typically combine low level and high level behavior. The low level deals with reactive behavior and collision avoidance, while the high level deals with path finding and decision making. There has been a large amount of work studying collision avoidance manoeuvres for humans in both virtual reality and from real data. When it comes to high level behavior, such as decision making when choosing paths, there have been many approaches to try to simulate the large variety of possible human decisions, for instance based on minimizing energy, visibility, or path length combined with terrain constraints. For long, it has been assumed that in an emergency situation, humans just follow the behavior of others. This social behavior has been observed in the real world, and thus mimicked in crowd simulation models. However there is not an accurate model yet to determine under what circumstances this behaviour emerges, and to what extend. This paper focuses on studying human behavior regarding following others, during an evacuation situation without imminent danger.

Index Terms—crowd following, immersive VR, studies of human behavior, evacuation studies

I. INTRODUCTION

Crowd simulation models can have a big impact on the overall believability of a populated environment. Given the variety of applications, such as video games, movies or training, it is important to tailor the behavior of the crowd to the particular simulation. In order to simulate realistically different types of crowds and behaviors it is essential to first study how humans behave in such scenarios.

Immersive virtual environments have proven to be a plausible platform to study human behavior. Being surrounded by a virtual crowd can provide high levels of presence [1] which leads to participants behaving as they would do in the real world. This observation has lead to many research groups to use immersive VR as a platform to study human behavior [2]. Most of the work dealing with immersive crowds has focused on studying low level reactive behavior (e.g. collision avoidance), however there has been little work studying higher level decision making in such environments.

In order to develop more accurate pedestrian evacuation models, it is necessary to study human behavior under this circumstances, and to find the relationships between individuals' personalities and their behavior. By doing so, we could achieve human models that more realistically simulate the decision making, route selection, or the inclination to follow others' movement. Most crowd evacuation models, assume that individuals know their way around, and will automatically run towards the closest exit. In this cases, egress depends



Fig. 1: Participant testing the evacuation scenario. As an alarm goes off, the participant will have to decide between looking for an exit, or following others.

exclusively on the formation of bottlenecks, the flow rates through doors, or the densities that appear in the environment. However, in a real scenario, there would be a large variety of personalities with different levels of knowledge about the environment that will influence their decision making.

Our main goal with this paper is to study to what extend people follow others during an evacuation. Given an everyday situation such as walking in a train station, suddenly an alarm goes off and people starts to evacuate the station. We want to study human decision making when looking for an exit depending on the crowd behavior under low stress levels. We achieve this by having an alarm going off, but without any sign of immediate danger (e.g. no fire or smoke).

II. RELATED WORK

Crowd simulation is a research field where validation can become an extremely challenging problem. Many approaches have been presented to tackle such a difficult problem. Quantitative measurement of features (densities, speeds, formations, etc. [3]–[7]) offer an estimate of how close the simulated crowd is to data gathered from real humans, however it may give overall good results and yet the simulation not feel natural to the human eye. Perception studies have been carried out to evaluate crowd behavior from a human perspective [8], [9], however, in the real world we rarely observe crowds from an outsider point of view. Therefore there is a need to perform such perceptual evaluations from a first person point of view. Immersive Virtual Environments offer a platform to study human behavior as long as the participant experiences high

levels of presence which will lead to real responses to the virtual characters [10], [11], [12].

The first steps toward using Immersive Virtual Environments as a validation tool, has focused on studying the impact of different collision avoidance algorithms on the level of presence experienced by the user [1], [13], [14]. Gupta et al. evaluated the impact of manipulating the instructions given to the participants to increase the engagement with a virtual crowd [15]. Bruneau et al. studied collision avoidance strategies against group of agents based on their appearance and formation [16]. [17] also studied collision avoidance but only between two persons walking along crossing trajectories.

Recent work by Narang et al. studied how behavioral plausibility increases when virtual characters not only move in a natural way, but also gaze at the participant [18]. The work by Kyriakou et al [19] studied plausibility of a simulated crowd in Immersive and semi-Immersive environments, and showed how handling correctly collision avoidance could enhance realism specially when adding basic social interaction (e.g. verbal salutations, gaze, and other gestures) by the virtual characters towards the user.

Immersive Virtual Environments have been used to develop platforms to gather data on human locomotion around virtual obstacles [20], and collision avoidance manoeuvres when walking through a virtual crowd [2]. The work by Rojas et al. focused on simulating group behavior and then used immersive VR with a head mounted display to evaluate the model when the participant was included in the group [21].

There has been many approaches to simulate high level decision making for autonomous agents and crowds. For example the work by Van Toll et al. assumed agents decide the paths to follow by combining information regarding path length and density [22]. Gut et al. computed paths based on the idea that humans try to minimize the effort to reach a destination [23]. These methods compute paths assuming that humans tend to somehow optimize their trajectories, however more studies are needed to determine how humans decide paths in the real world. If we think of a large city, chances are that people choose paths based on width of the streets, how busy they are, or whether there are shops of interest. Turner and Penn proposed a model to simulate agents' movement based on visibility which has been evaluated against real data of pedestrians space occupancy; agents move towards the most available space within their field of view [24]; or in the direction where they could see further and thus would open more possibilities for exploration [25]. Visibility approaches have also been used to simulate collision avoidance, by implementing a synthetic vision algorithm to compute time to collision and determine the most immediate hazards to avoid [26].

There has been work on crowd simulation during an evacuation based on the 'follow the leader' behavior [27]. Quantitative measurements during an evacuation were taken and compared based on the percentage of people exhibiting a follower behavior as opposed to those exploring on their own looking for an exit. The results could show the



Fig. 2: Layout of the virtual train station, showing the location of the tasks, the exits, and the position where the participant will be when the alarm goes off.

impact on having followers combined with experts, would lead to the best evacuation times, however it was unclear which would be the real percentage of 'followers' observed in a real situation. Obtaining such data from a real scenario is hard, and thus in this work we want to study what is the likelihood of humans following others during an emergency situation.

III. EXPERIMENT

A. Design

The goal of our experiment is to induce users to navigate a virtual train station while interacting with different elements. The train station is populated with a virtual crowds exhibiting an everyday behavior (e.g. buying tickets, going to the platforms and getting on and off the trains, walking in the shops, etc.). The layout of our virtual train station is inspired by the Valencia Nord train station, Figure 2 shows the map of the station indicating location of tasks, exits and participant position when an alarm is set off.

B. Physical Set-up

All the experiments were conducted in a 1.5x2m indoor lab area since it is not necessary for the participants to move physically. Position tracking was performed using an HTC VIVE immersive virtual display and a VIVE controller



Fig. 3: On the left, participant wearing the HTC VIVE head mounted display, while interacting with the VE using the controller. On the right, controller with the green point showing where the user has to touch for walking or press for running.

was used to move around the virtual space to carry out the different tasks. Touching or pressing the front area of the VIVE controller (marked as a green dot in Fig. 3) the participant can move through the environment walking or running. The direction of movement was given by the pointing direction of the controller. The surroundings can be inspected by moving the head. In the station, over a hundred avatars move around simulating an everyday situation. The participants also wore earphones to hear the typical sounds in a train station (the train announcements, people talking, steps, etc.). Unity Game Engine was used to render the environment and animate the avatars.

C. Procedure

Before executing the experiment, participants read a document with information and instructions about the simulation such as how to use the controller to interact with the virtual objects or navigate through the environment. They also signed a consent form with information regarding the possibility of dizziness while performing navigation using an HMD, and were told that they could leave the experiment at any time if needed.

When the simulation starts the user is located on the street in front of the main entrance of the train station. In addition to the main entrance, the train station has two more exits: one located at the center of the shopping area (named exit A) and another one located behind the shops, in one of the side aisles and less accessible from the main area (named exit F). Both exits can be seen in (see Fig. 2).

Tasks are shown to the participant in a semitransparent text box, that appears partly overlapping the virtual environment for a few seconds, at the user eye level. Once a task is performed, the next task is shown (see Fig. 4).

The tasks are sorted in a specific way to make the participant walk through the entire station, starting from the main entrance and arriving to the platforms that are located at the far end. Tasks involve the participant looking for a vending machine

(tickets or drinks) or to be placed on a specific platform. To complete a task related to a vending machine the user must approach the VIVE controller to the machine until a collision with a trigger is detected and a blink occurs. After that, the next task appears for a few seconds. The complete list of tasks shown to all the participants is the following:

- Task 1: Look for a tickets machine.
- Task 2: Look for a drinks machine.
- Task 3: Go to Platform 1.
- Task 4: Look for a green drinks machine.

Figure 5 shows a sequence of screen-shots from a simulation with the tasks described above.

Once the last task is performed, an audible alarm goes off, a red emergency light flashes continuously and is visible from the entire station (see Fig. 6). The participant is then informed that he/she must find an exit and, at the same time, a certain number of virtual agents may begin to run in the direction of the least obvious exit (Exit F, which is the one hidden in the alley behind some shops). The doors of the main entrance get locked when the alarm goes off, so the user must look for an alternative exit in the eventual case that he/she tries to exit through them. When the participant finds an exit, the simulation ends.

D. Participants

A total of 24 subjects participated in the experiment (19 males and 5 females) aged from 20 to 70 who had not been previously warned about the emergency situation that they would experience during the simulation. 23 of them had a lot of experience with computers, 9 had good experience with virtual reality and 17 had played a lot of video games before the experiment.

E. Scenarios

Since the purpose of this experiment was to study the impact that crowd behavior had in user's decisions, the experiments were carried out under three different conditions. The independent variable was the percentage of avatars that would start running towards the most hidden exit (Exit F) as soon as the alarm would go off. We tested with 0% as the base case, 50%



Fig. 4: Example of how the next task to perform is shown to the user.



Fig. 5: Sequence of images showing the train station and the tasks to be performed: (a) Tickets machines located at the entrance hall (task 1). The screen shows the next train departures (platform and time). Audio announcements are also given through speakers. (b) Crowded shopping area near the entrance. (c) A drinks machine (task 2). (d) Walking towards the trains. (e) Platform number 1 (task 3). (f) The green drinks machine (task 4).



Fig. 6: Alarm going off.

and 100% of the avatars exhibiting the follower behavior. Each participant experienced only one of the conditions. The virtual characters that did not run towards the exit kept wandering around the train station carrying out randomly generated goals and animations, as if nothing was happening. 10 participants tried the scenario with 100% of virtual agents behaving as followers and running towards Exit F, 7 participants tried the condition with 50% of followers and the last 7 participants tried the condition with 0% of followers.

F. Questionnaire

Besides collecting some basic personal information about the participants such as: age, gender, previous experience with computers, with virtual reality and playing video games. We were also interested in evaluating the overall realism of the virtual environment, the level of immersion experienced and to what extend participants felt like following others, depending on the condition of the experiment that they had tested.

Participants were asked to fill a questionnaire, after running the experiment, with questions about their opinion regarding the realism of the virtual environment, the animations of the

virtual characters, and the surrounding audio. It also gathered information about the feelings and reactions of the participants when the alarm went off. The list of question appears in table I. All questions were rated on a scale of 0 (completely disagree) to 9 (completely agree). Questions 1 to 6 are about the perceived realism and feeling of immersions, whereas questions 7 to 11 are about the participants behavior once the alarm goes off.

TABLE I: Questionnaire

Q#	Question/Statement
Q1	The overall the quality of the visualization was good.
Q2	The quality of the VE makes it easy to perform the assigned tasks.
Q3	I consider the navigation in the VE to be intuitive.
Q4	At all times I felt in control of my avatar.
Q5	The virtual humans' movement and appearance looks realistic.
Q6	The surround sound helped me feel more immersed in the VE.
Q7	When the alarm went off I felt anxious/nervous as I did not know what to do.
Q8	The behavior of the other agents when the alarm went off made me fell nervous.
Q9	Answer this question only if you found the main entrance locked when trying to exit the station: I looked for an alternative exit keeping into account where the rest of the virtual avatars where running to.
Q10	I felt the need to look for an exit myself as opposed to follow others.
Q11	I found difficult to look for an exit different to the one where the avatars where running to.

G. Results

In this section we describe the results obtained from our study. Each participants tried only one condition, to avoid results being affected by what they could have learned in a previous experience. All participants were given the same

questionnaire (see Table I). Questions 1 to 6 allowed us to obtain information about the level of realism that participants perceived, as well as the level of immersion they experienced. As the results show (Figure 7) participants rated above 7 these six questions, meaning they highly agreed that the environment, avatars movement and surround sound made the experiment immersive and realistic.

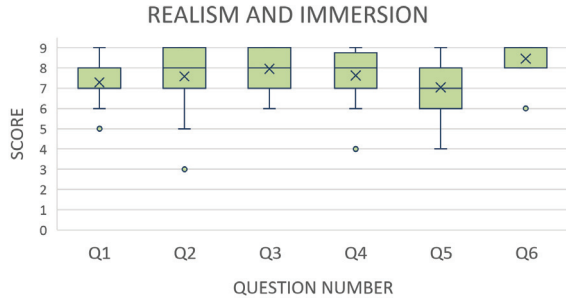


Fig. 7: Reported levels of realism and immersion.

In terms of the participants decision making response when the alarm went off, we observed major differences depending on what condition they had experienced.

For the situation with 100% of virtual agents running towards Exit F, 9 out of 10 participants started following the crowd straight away. Only one participant went first to the entrance doors and, after finding them locked, started looking for an exit. By the time the participant left the entrance area, all the virtual agents had already left the train station, therefore he did not have the chance to follow anybody, and thus after searching for a short period of time, he found exit A (the most visible one). This one participant had plenty of experience playing video games, and in his written comments after the experiment, he mentioned that he did not feel any danger and was not at all affected by the alarm nor by the virtual agents running. The rest of the participants followed the crowd immediately after the alarm went off and they did not even attempt to look for an alternative exit by themselves, nor even tried to go back towards the main entrance which is the only one they knew. Note that from the location where they are standing when the alarm goes off, they cannot see that the main entrance doors have been locked, unless they walk inside the entrance area.

For situation with 50% of virtual agents running towards Exit F, 4 out of the 7 participants checked the main entrance doors first and when they found them locked they turned around and started to follow the crowd. 3 participants, though, did not even consider the possibility of leaving through the main doors, and followed the crowd immediately after the alarm went off.

Finally we tested the condition with 0% of followers. In this case, all virtual agents simply continue with their errands without running for any exit after the alarm goes off. However, there is the possibility of having some avatars with the randomly assigned errand being to walk to an exit (but not running). Under this condition, the behavior of all participants

was to first walk back to the main entrance doors and after finding them locked they started looking for an exit. All 7 participants went back to the shopping area and after walking around for a while, 4 of them finally found exit A. Casually, two of the participants once back at the shopping area, found a few virtual agents walking calmly towards the corridor leading to exit F. These participants followed the virtual agents and did not look for an alternative exit. This shows that even without a large crowd running, the fact that they appeared to be walking in a group was enough to get these 2 participants to follow them. Unfortunately one of the participants had to withdraw from the experiment due to motion sickness. Figure 8 shows a summary of our findings, with 'Check' meaning that the participant looked for the entrance doors before deciding to follow others or search for an exit. Note that we did not have any participant looking for an exit without checking for the main entrance doors first.

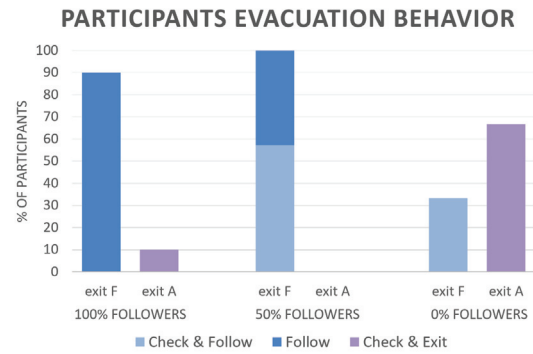


Fig. 8: Participants exit choice during the evacuation.

An interesting result from our experiment, is that there seems to be a correlation between the participants' choice when deciding to follow others or search for an exit, and the level of nervousness they experienced. Participants that decided to follow the crowd towards exit F, reported higher levels of anxiety and nervousness when the alarm went off or after observing the behavior of the virtual crowd. However, participants that decided to search for an exit, and left through exit A (the most visible one), reported lower levels of nervousness. These results are shown in Figure 9.

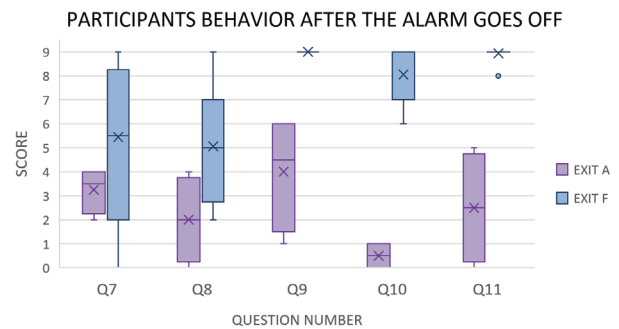


Fig. 9: Participant behavior after the alarm goes off.

IV. CONCLUSIONS AND FUTURE WORK

In this paper we have carried out an experiment to study human decision making during an evacuation. We were interested to evaluate to what extend the behavior of a virtual crowd can affect individuals decisions. Our results show how as the number of followers increases, there are more chances of people not taking their own decisions and simply follow what most of the people in a crowd are doing. It was also interesting to observe, that the chances of exploring the environment are higher for people that experience low levels of stress in such situation. This observations should be further investigated, to obtain the relationship between personality and decision making strategies.

Another of our observations was that, when participants are given a specific list of tasks to perform, they concentrate so much on it, that they do not spend enough time simply wandering around or inspecting their surroundings. This had as a consequence, that even though they all walked near an obvious exit, they did not notice it (the door was widely opened and they could see the buildings and street outside). Some participants commented that it would have helped if there was an Exit sign above the door. Therefore in future experiments we are planning to incorporate these signs and try to create tasks to force the participants to simply look around a bit more.

As future work we would also like to run experiments with a more stressful situation such as a having a fire and smoke propagating through the virtual train station.

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