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Impact of Anomalies in Simulated Crowds

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Abstract

Virtual simulations of crowds are useful for many different fields of research and entertainment, such as simulations of evacuation scenarios or in video games that use large amounts of moving agents. This study examines if the noticeability of movement anomalies are dependent on their location on the screen and the density of the virtual crowd. The study also examines if movement anomalies change the perceived realism of the crowd simulation even if it is not consciously found.

An user experiment with 12 participants was conducted, where the subjects watched 48 videos recorded from low and high density crowd simulation scenarios. An eye tracker gathered data from the participants while they watched the videos. Half of these videos had movement anomalies in specific locations. For each video, the observer filled in a part of a questionnaire to answer if they perceived the video to be realistic and if they saw a movement anomaly.

The results showed a small correlation between anomalies in the center of the screen and an increase in noticeability. They also showed that the density of the crowd will have an impact on the detection rate of an anomaly. Finally, the results showed no indication that unnoticed anomalies would effect the subjects perceived realism.

Contents

Chapter 1

Introduction

Real time simulations of crowds can be useful in many different fields of research and entertainment. They could for example be used in videos that are rendered in real time or in computer games for scenarios that need a large amount of virtual agents that move in a realistic way. If the developers that have created these scenarios that use virtual crowds that are simulated in real time intended the scenario to be perceived as realistic, movement anomalies that occur in the crowd could be an issue that they need to consider. An agent in the crowd that behaves in an unintended way could break the sense of realism and change the intended look of the scenario that the developer created.

We intend to study a real-time simulation of a crowd to examine if the location of a movement anomaly influences how easily it is noticed. We also intend to compare the effect that two different densities have on the noticing of anomalies. Lastly, we want to examine if movement anomalies in a crowd will break the sense of realism in a crowd simulation, even if they fail to notice the anomaly consciously.

1.1 Problem statement

Investigating how the location of an anomaly in a crowd of varying density changes an observers perception of a simulated crowd can help developers understand what factors have an impact on the perceived realism of a simulated crowd that their software generates.

Since simulating crowds is difficult, anomalies in the agents' behavior can be expected to happen even in the best simulations. The

aim of this study is to investigate what factors should be considered when trying to minimize the effects of these anomalies. From previous work in the field, it seems likely that anomalies in the center would be easier to spot, and that the density of the crowd will affect the perception by a viewer.

Our research questions are as follows:

- Are movement anomalies in a crowd more easily discovered in the center of the screen?
- Does the density of the crowd influence how noticeable the anomalies are?
- Can movement anomalies in simulated crowds change an observers perceived realism of the crowd even if it is not directly observed?

1.2 Approach

To be able to find answers to our problem statement, a user study will be designed where we will gather information about whether or not individuals can spot movement anomalies that we have introduced and how realistic they perceive the simulated crowd to be. The experiment will consist of videos of a virtual crowd simulation that will be shown to the test subject. While these videos are shown, data will be gathered with an eye tracking device and a questionnaire with questions that are related to our problem statement. The results from the questionnaire and the analysis of the gathered eye tracking data will then be used to answer our problem statement.

Chapter 2

Background

This chapter introduces the terminologies that are important for understanding this report. It will also introduce the crowd simulation algorithm that was used for our study. Lastly, this chapter will present related work that have researched relevant topics.

2.1 Terminology

Agent: An agent is a virtual individual that is a part of the simulated crowd.

Movement anomaly: A movement of an agent that deviates from the rest of the crowd. In our study, the anomaly that we introduce is an agent that at a specific time mark turns 180 degrees, moves for 2 seconds and then turns back towards the original direction and keeps moving.

Saccade: A rapid eye movement, where both eyes move simultaneously to look at the same position.

2.2 Simulating Crowds

The crowd simulation algorithm used in this study is presented by Narain et al. [8], and is an approach based on fluid dynamics. Their focus lay in creating a real time crowd simulation that would be easily scalable by treating the crowd as a flowing liquid. This algorithm

converts all the individuals to particles in a flowing liquid with special properties, and uses this liquid's flow to calculate the movements of each individual. This method divides the area that the crowd scenario into a grid and calculates the density and velocity of the 'liquid' in each geographical square.

2.3 Related work

2.3.1 Realism in generated crowds

There are several proposed methods to compare simulated data to real data, without resorting to a user study. Wang, Ondřej, and O'Sullivan [17] proposes an algorithm that gives each simulation program a realism rating, that can then be compared to the rating of real data. Such methods are an alternative to user studies, that can be performed without needing large groups of test subjects.

2.3.2 Social force model

Another approach to viewing crowd movements is presented by Helbing and Molnar [5]. The study discusses the theory that the:

> ”Motion of pedestrians can be described as if they would be subject to "social forces". These "forces" are not directly exerted by the pedestrians personal environment, but they are a measure for the internal motivations of the individuals to perform certain actions (movements).”[5]

Social force is described as an imaginary force that is applied to each person from the different stimuli in the vicinity. The direction and size of this force is seen by how much each person deviates from their preferred route. It also mentions that each person has their own desired speed, and movement that differs from this speed can be due to social forces. Normally, a person has a 'private sphere' that they get increasingly uncomfortable in, the further in someone else enters into it. The study calls this 'repulsive effects' which is not limited to other humans but can also be from walls. Suspicious people can give greater repulsive effects, which can be a way to detect these people in big crowds.

2.3.3 Scene and screen center bias

In studies of visual perception, observers tend to look at the center on the screen first, as shown by Bindemann [3]. The study discusses the tendency of observers gazes to be fixated towards the center of the screen. Bindemann conducts an experiment to investigate if the offsetting of the "scene", which is the image that is displayed on the screen, changes where the observers fixate their gaze when the image is shown. He concludes the report by writing that current experiments and research show that there is a viewing bias for both the center of the screen and the center of the presented scene, and that this can lead to potential artifacts in studies that involve visual perception.

2.3.4 Other crowd simulation algorithms

As previously mentioned, there are many existing approaches to simulating crowd movement in real time besides the one used in this study. The social force theory is implemented in a study by Kim et al. [6] into an algorithm that achieves realistic results in crowd movements.

Another, more common approach is to divide the individuals into hierarchical groups, to reduce the amount of computation required [7]. Paris, Donikian, and Bonvalet [10] continues with the hierarchical approach into the environment as well. They divide the environment into areas that are open, corridors, and dead ends. The small areas are then grouped together hierarchically, making path planning easier both in the immediate area and in the larger environment towards the goal.

Pelechano, Allbeck, and Badler [11] combines many different ideas, using both rules for agents as well as the social force model. The report also contains a larger discussion on several other approaches that have been introduced for simulating crowds.

Chapter 3

Methods

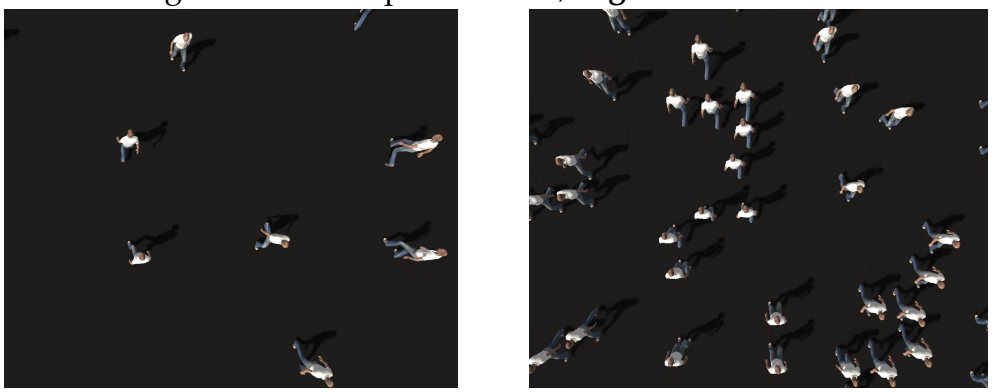
To answer our problem statement, we conducted an experiment which is the main focus of this chapter. The first section will go through the design of the experiment and the following sections will introduce the software, hardware and theory behind it. The last section will present one of the more prominent issues that we had with our experiment.

3.1 User experiment

To be able to test if individuals could spot agents with movement anomalies that were introduced and how they perceived the realism of the crowd simulation, we created an experiment that was designed to gather information that was relevant for the research question. The experiment was performed by showing an individual a total of 48 videos of the crowd simulation while tracking their eye movement with an eye tracking device. The test subject would fill in a part of the questionnaire related to each video after it was shown. The exact same setup with the same hardware and software was used in each performed experiment. In each test the observers head was measured to be the same distance from the screen, about 65 cm. These precautions were taken to eliminate any possible error sources related to hardware difference, screen size and distance from the screen. The instructions, consent form and the questionnaire that was used for the experiment can be found in the appendix.

Two different crowd densities were used in the videos. 24 of these videos have a sparse crowd and the other 24 videos have a higher density crowd. The different crowd densities are shown in Figure 3.1.

Figure 3.1: **Left:** sparse crowd, **Right:** dense crowd



To test if the location of the movement anomaly has any effect on the users experience, the screen was divided into 9 sections of the same size. Figure 3.2 shows how the screen was divided. In the videos with movement anomalies, an agent in one of the sections was selected to perform the turn. We decided to group these sections into three different sets because we were interested in how these section groups would differ between each other. Firstly we have the "Edge group" that consists of section 2, 4, 6 and 8. Secondly we have the "Corner group" that consists of section 1, 3, 7 and 9. And lastly we have the "Middle group" which only consists of section 5.

For each crowd density there were 12 control videos which had no introduced anomalies. The rest of the 12 videos had agents with movement anomalies distributed into the sections as shown in Figure 3.3.

Figure 3.2: The sections of the screen used for the experiment, with each group color coded

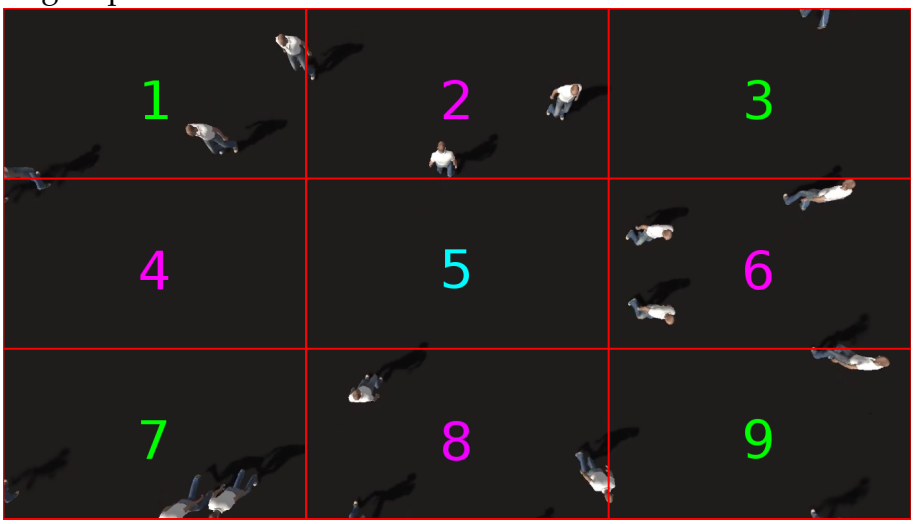
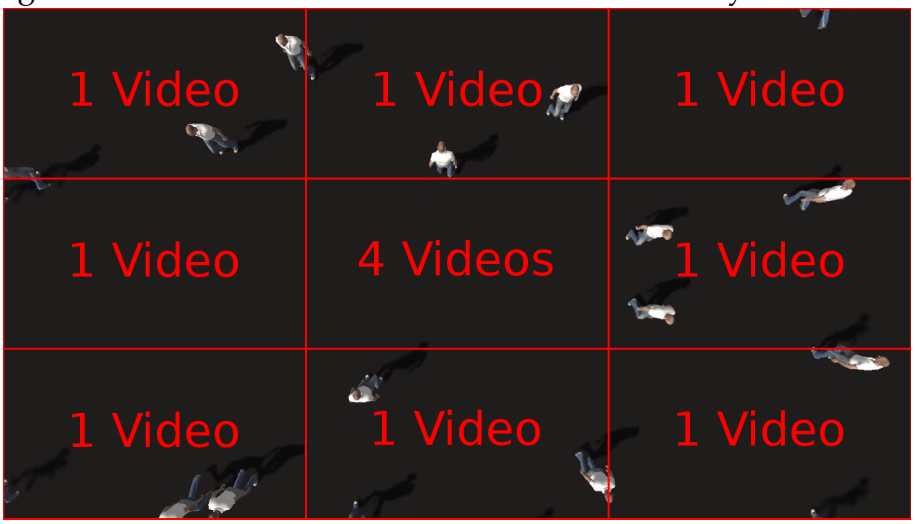


Figure 3.3: The distribution of videos for each density of the crowd



After the study, each test subject was also asked two questions:

- Did notice anything that repeatedly made a video feel unrealistic, or lead you to rate it as 'Strongly Disagree/Disagree'?
- Did you notice any recurring movements of specific agents, that led you to answer that someone behaved differently?

To clarify, the first question asked about the rating of whether the subject thought the agents behaved realistically in the video, meaning that 'Strongly Disagree/Disagree' implied that they did not think the video was realistic. The aim of the first question was to confirm whether it was only the anomaly we had created that led the subject to rate the videos as unrealistic, or if there were some other case that we had not considered which was a major factor.

The other question was firstly to confirm whether the subject thought the sudden turn matched the description of 'an agent behaved differently'. Secondly, it would show if any other recurring movements seemed different, so that we would know what to look for in the eye tracking data.

3.2 Unity game engine

The crowd simulation algorithm was implemented in the video game engine Unity[15] which is free to use as long as the organization using Unity does not make more than a specific amount of gross revenue or raised funds [14]. The scenario was created as described in section 3.4, and was then recorded in-engine. Each video was 20 seconds long, with the anomaly happening somewhere between 8 and 12 seconds into the video (if the video was not a control video).

3.3 Eye tracking hardware and software

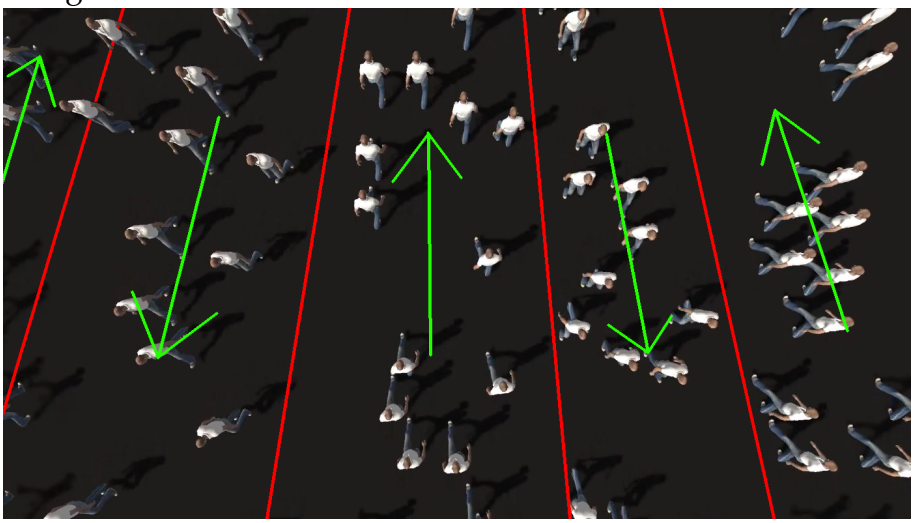
The eye tracking device that we used for our experiment was the Tobii X1 Light Eye Tracker[13] together with the open-source software OGAMA[16] (Open gaze and mouse analyzer). OGAMA is a software that is designed for experiments and allows for recording and analyzing of eye tracking data. It is published under the GNU General Public License (GPL) version 3, 29 June 2007.[9]

3.4 Crowd simulation scenario

The scenario created for the study is a simple scene where agents are crossing a large road. To make sure that the agent that turns around does not immediately stick out, agents need to be walking in both di-

rections. However, the algorithm used could not handle head-on collisions very well. For this reason, lanes for the agents were constructed, so that they would not collide with each other. At first completely parallel lanes were used, but a pilot study showed that this did not seem realistic enough. Therefore the lanes were changed to be slightly skewed, and not of equal size. Figure 3.4 shows the final design of the lanes.

Figure 3.4: The lanes and directions of the crowd movement



3.5 Latin squares & Counter balancing

A Latin square of order n is a square of size $n \times n$, where each number $1 \leq i \leq n$ is guaranteed to only occur once in every row, and once in every column [12]. In other words, a Latin square guarantees that each number will hold every position exactly once, in the permutations given by the square's rows. Latin squares can therefore be very useful for experiment design, since it can remove sources of extraneous variation from the experiment [2]. However, for the Latin square to guarantee an equal balance of placement in the experiment, the number of test subjects must be some number $k \cdot n$, where k is an integer.

In this study a Latin square is used to decide the order for the videos. Since it was not feasible to get 48 test subjects for the study, all the videos were divided into 4 groups of 12 videos. The groups were ordered by a 4×4 Latin square, and the videos in each group

were ordered by a 12×12 Latin square. This means that each video is *not* guaranteed to hold each position in respect to all the videos. However, the design does guarantee the following:

- Each group will hold each position in the ordering of groups. If the study is divided into 4 blocks of size 12, then it follows that each video is guaranteed to occur in each block the same amount of times.
- Each video will hold every position in its group.
- A video will never be played in a position it has already been played in.

In the experiment, there is a possibility that the video that was just watched can affect the next video. A Latin square does not guarantee that each video will be preceded and followed by unique videos each iteration. To ensure this, the Latin square must be counterbalanced. There are several different methods to construct counterbalanced Latin squares. If the number of rows and columns are equal to $p - 1$, where p is prime, then a method to create a counterbalanced Latin square is proposed by Alimena [1]. Our implementation is based on the report by Bradley [4], and is shown in table 3.1. This method is slightly more simple, and is usable for any square of size $2k \times 2k$, where k is an integer.

Table 3.1: The counterbalanced Latin square used in the experiment

1	12	2	11	3	10	4	9	5	8	6	7
2	1	3	12	4	11	5	10	6	9	7	8
3	2	4	1	5	12	6	11	7	10	8	9
4	3	5	2	6	1	7	12	8	11	9	10
5	4	6	3	7	2	8	1	9	12	10	11
6	5	7	4	8	3	9	2	10	1	11	12
7	6	8	5	9	4	10	3	11	2	12	1
8	7	9	6	10	5	11	4	12	3	1	2
9	8	10	7	11	6	12	5	1	4	2	3
10	9	11	8	12	7	1	6	2	5	3	4
11	10	12	9	1	8	2	7	3	6	4	5
12	11	1	10	2	9	3	8	4	7	5	6

3.6 Defective videos

Since the algorithm used to create the crowds in the videos isn't perfect, some of the videos contained unintended imperfections. In some cases, these imperfections were very obvious to many viewers, even more so than the introduced anomalies. This mostly consisted of agents colliding with each other at the edge of lanes, which led to both of them getting stuck, or one of the agents getting pushed by a larger group of agents. Since the data from these videos become unreliable, all the data presented in the results chapter are presented either without including these cases, or containing a special group for the so called *defective videos*. In both cases, it is stated in the table/diagram how the defective videos were handled in this data.

In total, 5 videos were defective, 3 of which were cases with no anomaly, and 2 of which were cases with an anomaly. The defects were exclusive to the dense crowd, since the agents had a much higher chance of walking on the edge of the lane.

Chapter 4

Results

This chapter presents the results and data that we gathered from the experiment. The first section describes the gaze paths of the subjects and how the gaze path changed when they noticed an anomaly in the crowd. In the following sections, we have presented the data that was most relevant to our problem statement with diagrams and graphs.

4.1 Subject gaze paths

When a test subject noticed an anomaly, their gaze tended to stay on the person that moved differently. It usually stayed until the person left the scene, or the scene ended. Figure 4.1 shows the gaze path of a subject who spotted an anomaly, where their gaze were mostly collected in the lane that the anomaly happened in. Conversely, Figure 4.2 shows how the gaze might look when a subject did not see any anomaly. The test subjects applied different methods when looking at the scene. Some were very focused on the middle, and saccaded to any points of interest outside the middle. Others scanned the entire screen while viewing the scene, but all subjects gazes were focused on following individual agents or a group of agents as they moved across the screen.

Figure 4.1: Gaze path for one subject on a video where the anomaly was spotted

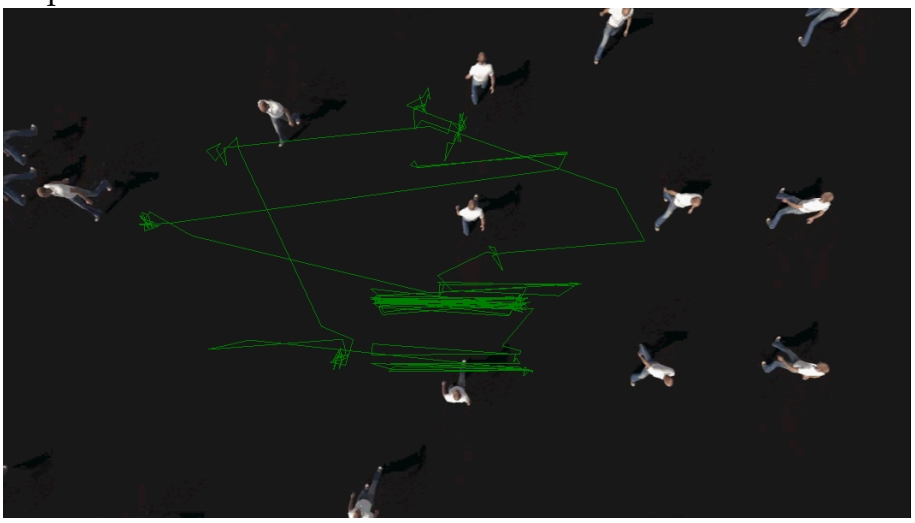
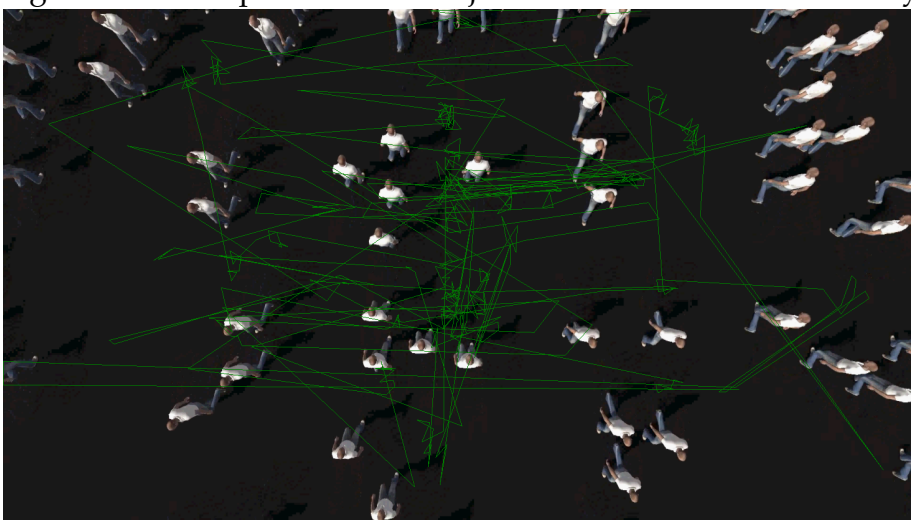


Figure 4.2: Gaze path for one subject on a video with no anomaly



When comparing the heatmaps of data where subjects saw the anomaly and data where subjects missed it, the same pattern arises. Figure 4.3 shows the heatmap of subjects that noticed an anomaly on the left side of the screen. After the anomaly, the subjects focused almost exclusively on the lane where the anomaly appeared. The subjects that did not see this anomaly continued to view the entire screen, as seen in Figure 4.4, which shows the heatmap of the same video for these sub-

jects.

Figure 4.3: Heatmap representation of eye tracking data where subjects spotted the anomaly on the left side of the screen

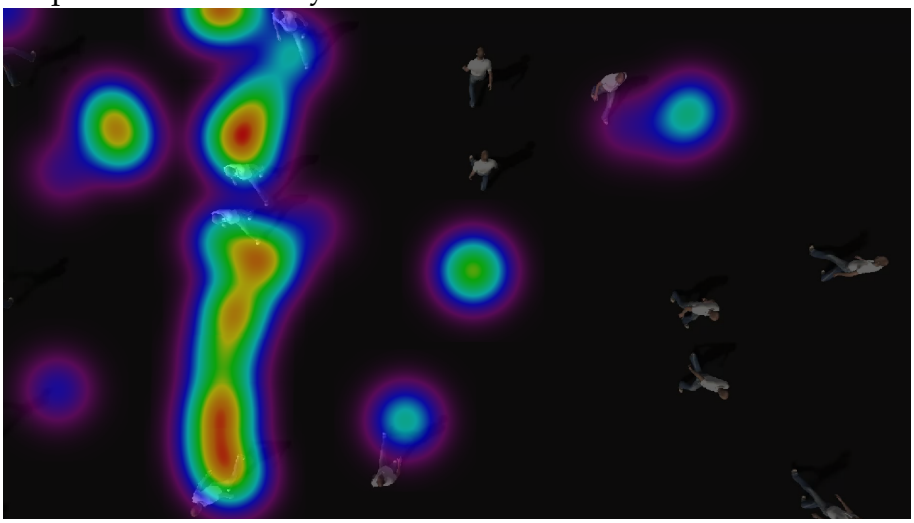
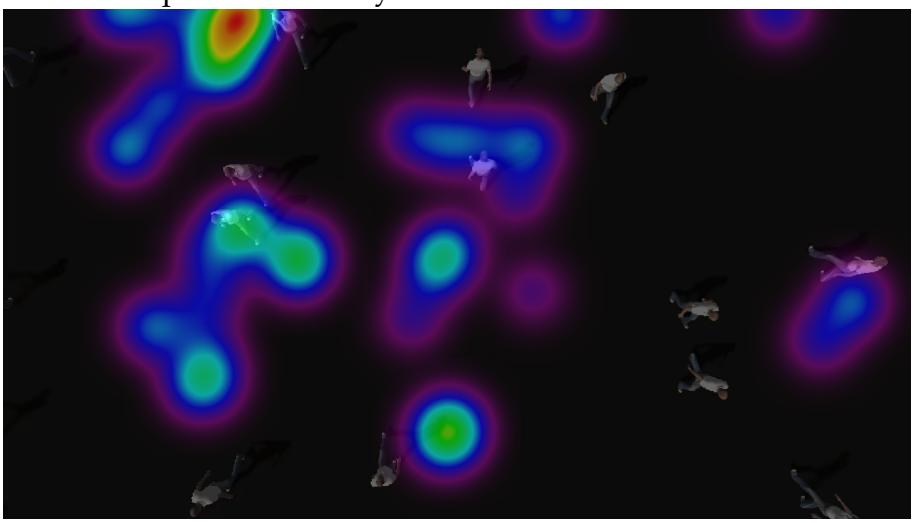


Figure 4.4: Heatmap representation of eye tracking data where subjects did not spot the anomaly on the left side of the screen



All the subjects in the study scanned the scene person-to-person, and discovered anomalies in two cases: either they looked close to the location of the anomaly when it happened, or they switched their gaze directly to an agent that was currently colliding with another agent. In

a few cases, the subjects noticed strange formations of people that were created when people collided due to an anomaly.

4.2 Response from test subjects after the study

As stated in section 3.1, all test subjects were asked two questions after they had viewed all of the videos.

The first question, being whether they noticed anything that repeatedly led them to see the video as unrealistic, had quite similar responses from all the test subjects. All subjects mentioned the defective videos, where people would get stuck and form large groups of unmoving people. 9 out of the 12 test subjects mentioned that it seemed unrealistic when two people walked closely together, but not beside each other. They stated that this seemed unrealistic, since the people did not seem to know each other (otherwise they would have walked beside each other).

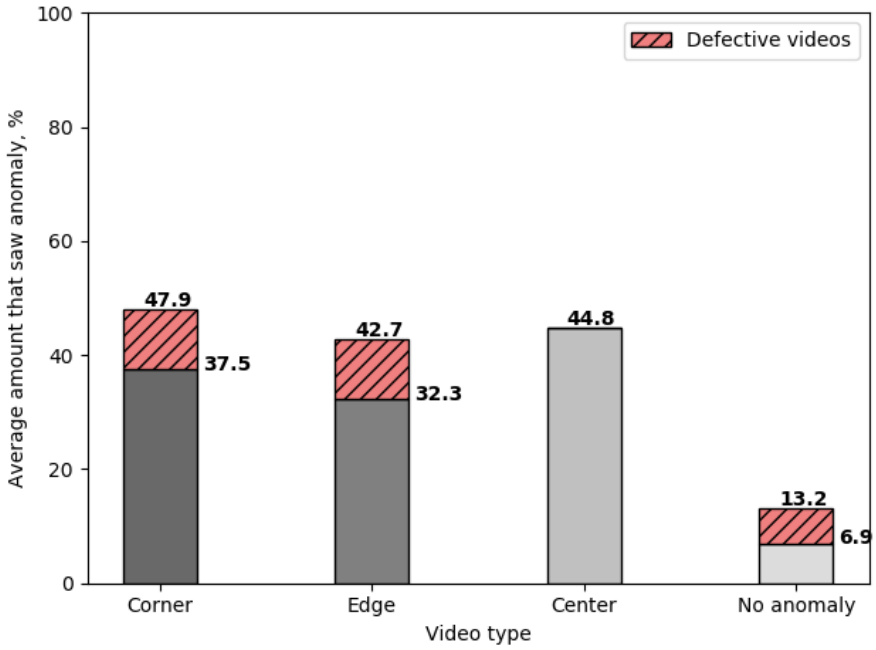
The second question, whether there was any reoccurring movement that led them to check 'an agent behaved differently', also got mostly similar results from each subject. All subjects mentioned the 180 degree turn as something they noticed. 10 out of 12 subjects mentioned that agents collided with agents and got stuck, forming large groups of agents (correlating to the behavior in the defective videos).

4.3 Anomaly screen location and crowd density

To collect the data about the impact of the location of the anomaly, the second statement in the questionnaire was used ('A specific agent behaved differently'). However, the two questions asked at the end of the study showed that this was not always enough. A few subjects said that they had noticed people turning around, but had not thought that this was 'different'. Therefore they had answered 'No' to the statement, and instead put that the crowd did not behave realistically. Since the aim of the study is to find whether the anomaly is easier to spot or not, this issue had to be addressed. Instead of only using the response to this statement, the data presented will answer whether the subjects saw the anomaly or not. The requirement we set was that they either

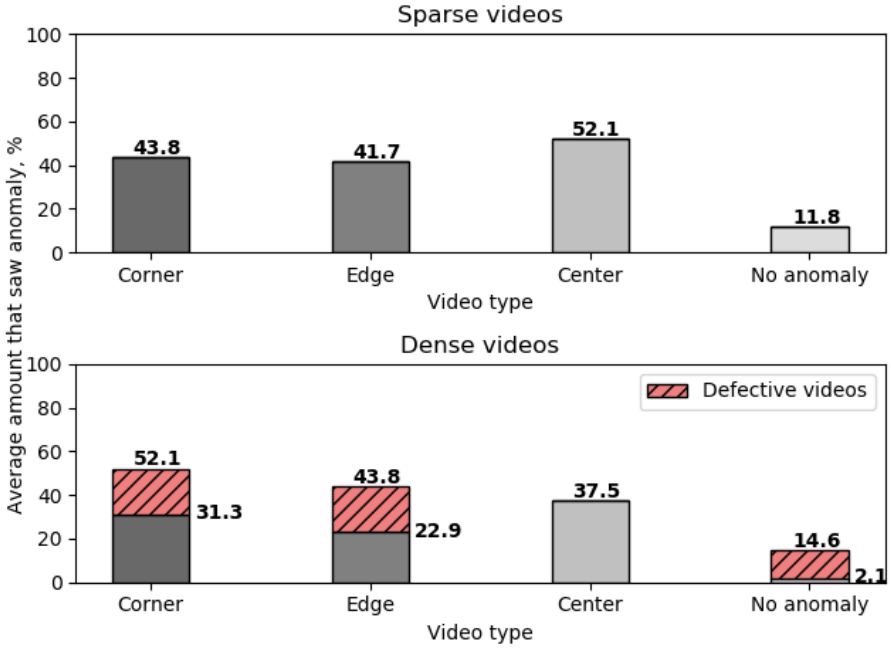
check 'Yes' in the questionnaire, or that they followed the anomaly with their gaze as discussed in 4.1. The data in the following diagrams will be based on this definition of an anomaly being seen.

Figure 4.5: Amount of anomalies seen for each category



The first figure, Figure 4.5, shows the average amount of test subjects that saw the anomaly, for each type of video. The defective videos have been specifically marked, since the anomalies in these video were not of the same type, and also much more noticeable. If the defective videos are disregarded, this diagram shows that the center videos had a scarce increase in average amount of subjects.

Figure 4.6: Amount of anomalies seen for each category and density



The pattern holds when we split the data into sparse and dense videos, as in Figure 4.6. We still see a slight increase in anomaly detection for sparse videos in the center, and if we disregard the defective videos the same is true for dense videos.

Another pattern shows when we look at the anomalies seen for each video instead of the average. As Figure 4.7 shows, the responses are not evenly distributed over the videos in each class. For the sparse videos, all section groups have one video that only 2 subjects spotted the anomaly in. Meanwhile, all the categories also have videos that more than 8 subjects spotted the anomaly in, with the center category even having two such videos. The dense videos are a little more evenly distributed, except for the defective videos and one video in the corner category.

Figure 4.7: Amount of anomalies seen for each individual anomaly video and section groups

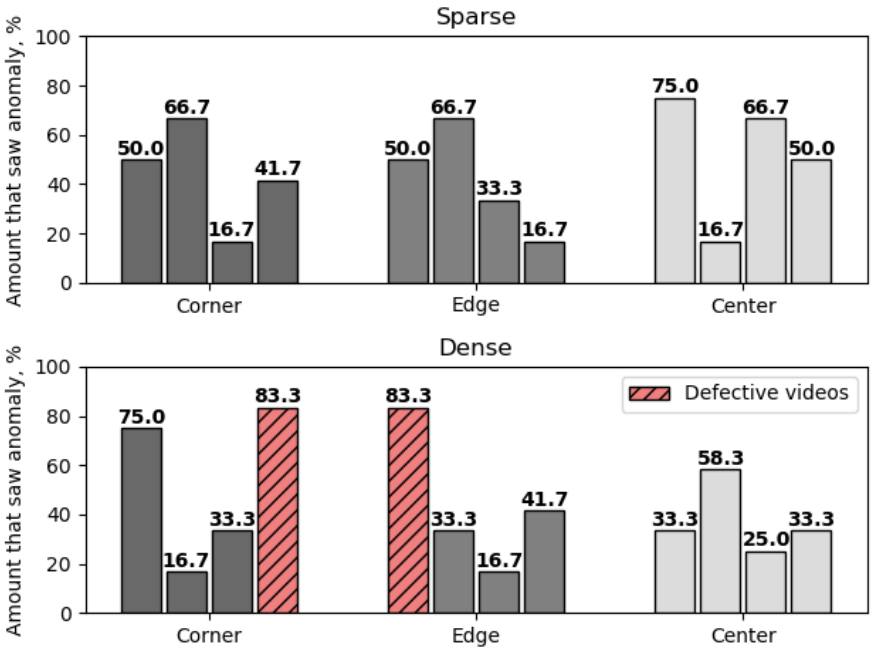


Figure 4.8: Amount of anomalies seen for each individual video, non-anomaly videos only

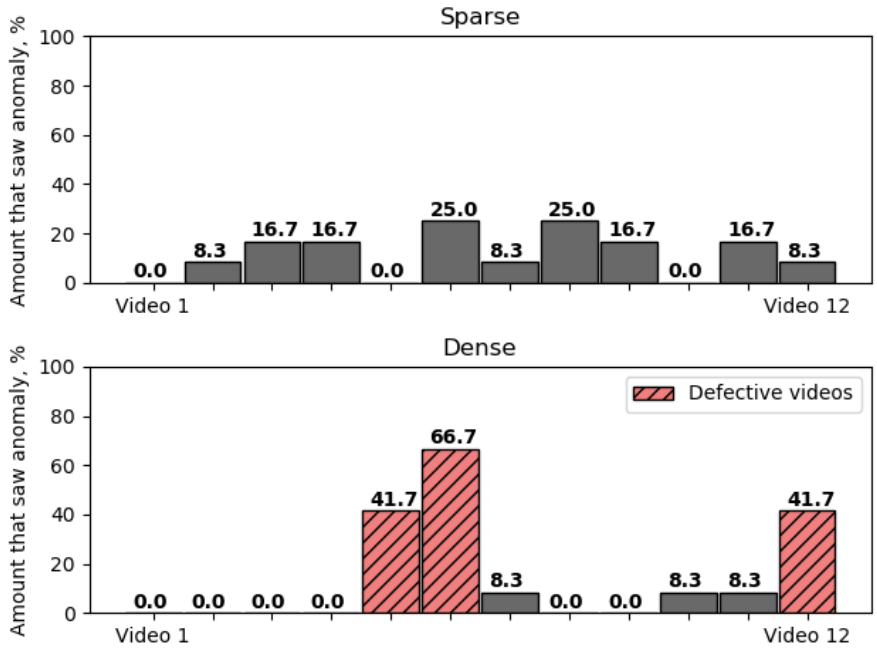


Figure 4.8 shows how many of the subjects saw an anomaly in a control video, the videos where no anomalies were introduced. The difference between sparse and dense videos here is very clear. If the defective videos are disregarded, then there are some videos with sparse crowds that had as many subjects that saw an anomaly in them as all the dense videos combined.

4.4 Impact of movement anomalies on perceived realism

Figure 4.9 shows that more subjects answered that they saw an anomaly in the videos that we introduced anomalies compared to the videos without an anomaly that we introduced.

Figure 4.9: Amount of anomalies seen per realism rating

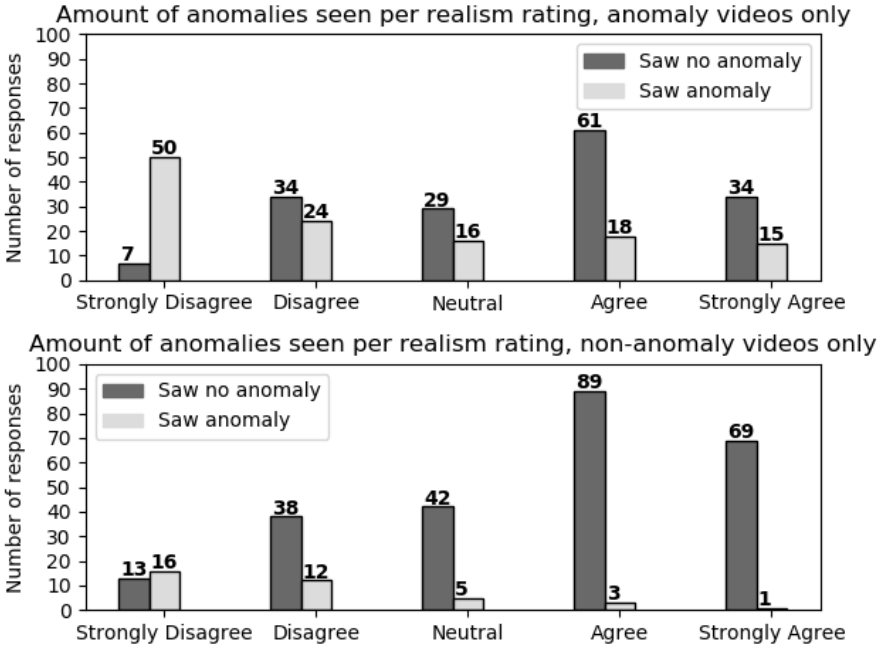


Figure 4.9 also shows that more subjects answered 'Agree' or 'Strongly Agree' for the non-anomaly videos and that more subjects chose 'Disagree' or 'Strongly Disagree' for the anomaly videos. The amount of 'Neutral' answers were almost the same for the non-anomaly and the anomaly videos.

Figure 4.10 shows that the amount of videos are evenly distributed over the ranks when no anomaly was seen by the subject. The only notable differences are that subjects were 5 % more likely to check 'Disagree' on anomaly videos, and 7 % more likely to check 'Strongly Agree' on non-anomaly videos.

Figure 4.10: Amount of subjects that did not see an anomaly per realism rating

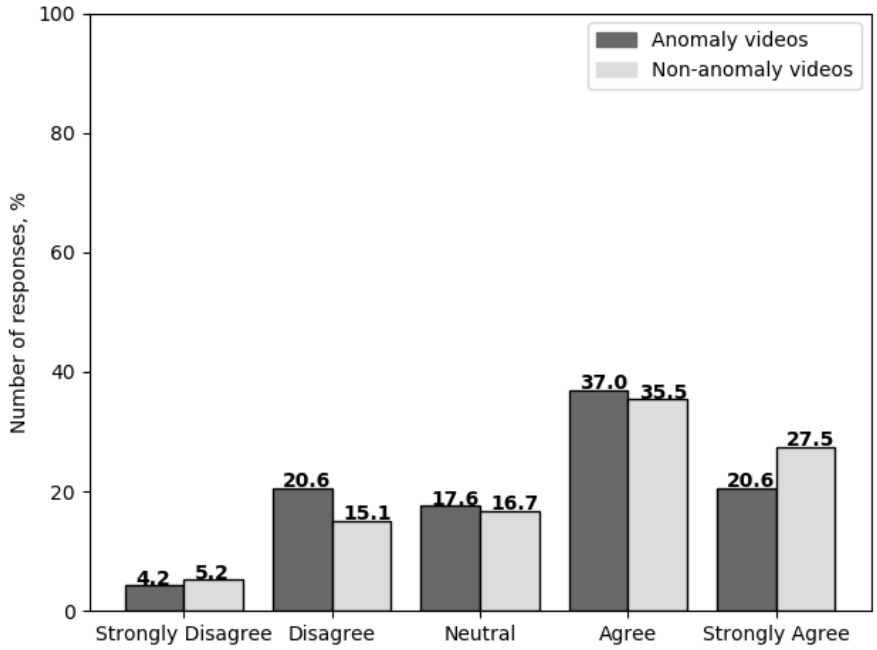


Figure 4.11 shows that the test subjects chose 'Agree' and 'Strongly Agree' for the realism rating more often when they saw no anomaly in the crowd. These options were also chosen in some cases even if the subjects saw the anomaly in the video. We can also see that the only realism rating that the subjects chose more times when they saw an anomaly was 'Strongly Disagree' which was the most picked answer if they saw an anomaly.

Figure 4.11: Amount of anomalies seen or not seen per realism rating, all videos

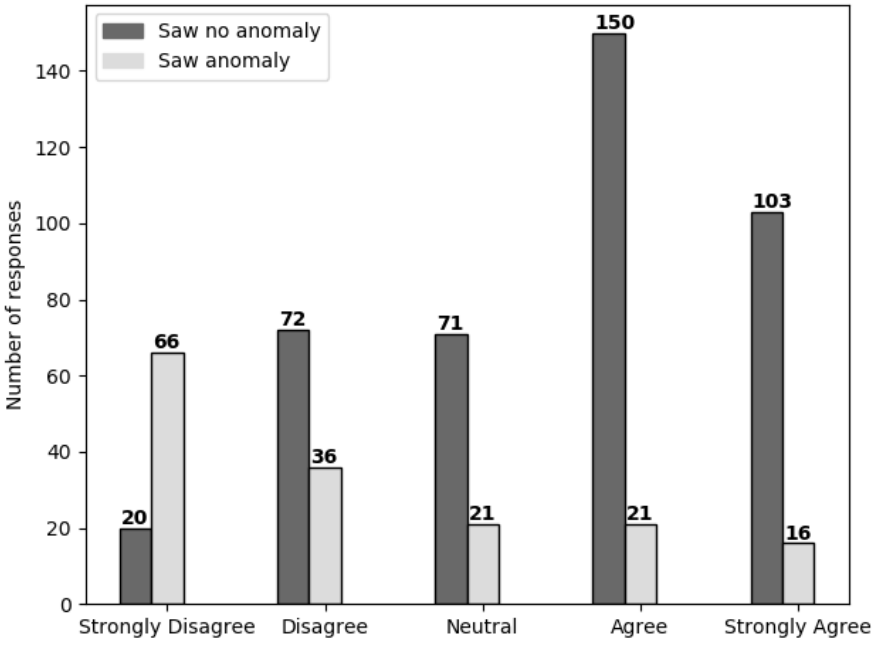


Figure 4.12: Average realism rating for video positions and mean deviation

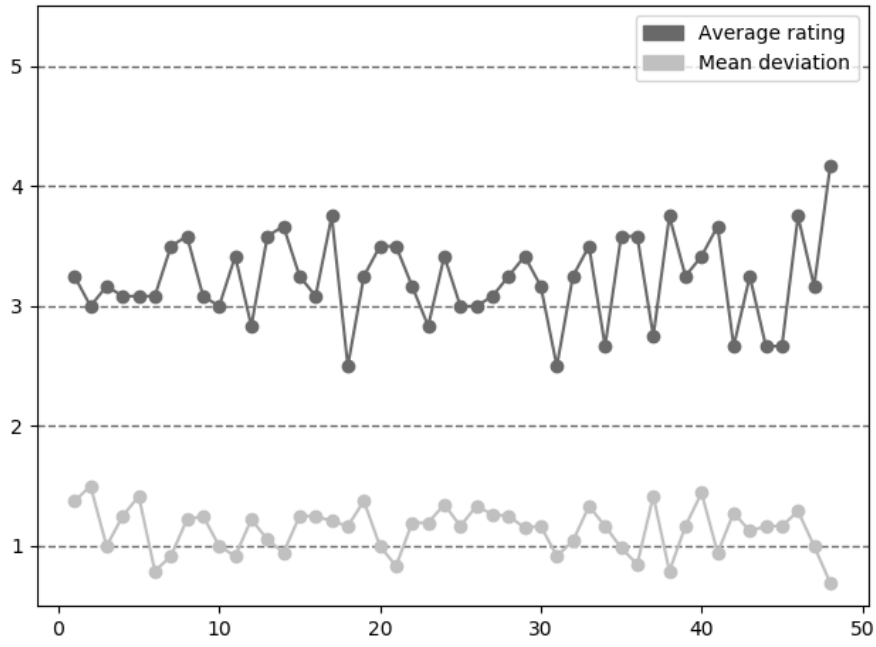


Figure 4.12 shows the average rating for each video position, and the mean deviation for this rating. This means that the first dot is for the first video shown each subject, which would be a different video for each subject. This is to show a possible trend in ratings for video positions, which could occur if the subjects start to rate the videos higher or lower over time. The graph does not show any significant change over time however, both the average rating and the mean deviation continues in a near-constant fashion.

Chapter 5

Discussion

The first section of this chapter will discuss what limitations and issues our experiment had and how that could have affected our final results. The following section will discuss how the lack of social forces in our crowd simulation affected the subjects perceived realism of the crowd and their ability to spot anomalies. Finally we will present some improvements that could be done in future experiments that are similar to the one conducted in this study.

5.1 Limitations

5.1.1 Experiment instructions

The first limitation encountered with our experiment was that the instructions for the experiment could seem unclear for some of our test subjects. Some subjects asked questions about whether they should check 'Strongly Disagree' if they saw an anomaly or not. The subjects that asked this were told that there did not necessarily need to be a connection between strongly disagreeing and seeing an anomaly, and that they should only check 'Strongly Disagree' if they did not feel that the simulation was realistic.

5.1.2 Homogeneous pool of participants

Over 90 % of the participants in the experiment were students from the same technical university, and most of them also studied the Computer Science program. The pool of subjects was therefore very homo-

geneous. If the students that study Computer Science can be assumed to have more experience with computer generated content in general, then this could affect the results of the study. The subjects could have seen similar crowd simulations or scenarios before and might have gotten the impression that our videos were unrealistic or similar to previous crowd simulations that they have seen. Ideally, we would have had test subjects from all the different age groups and fields of professions that a crowd simulation such as this one would be shown to.

5.1.3 Defective videos

Another large issue was the 'defective' videos mentioned in both Section 3.1 and Chapter 4. Ideally, these anomalies should of course not be part of the experiment, since they reduce the reliability of the results for the dense crowds. During our first pilot study, three anomalies not introduced by us were discovered, and these videos were replaced. We did also look for more of these defects, but with the big number of videos to look through, it was inevitable that we would miss some. The best way to avoid this would be to perform more pilot studies, if there are enough test subjects for it.

5.1.4 Amount of test subjects

Related to the defective videos is the limited amount of test subjects. Ideally, we would have liked to have 48 test subjects, for a true counterbalanced Latin square division of the videos. We would also have liked more test subjects for the pilot study, as discussed previously.

5.1.5 Camera angle

With the camera being in the center of the scene, the agents in the middle of the screen become smaller than the agents at the edge of the screen that are shown from a slight angle. This could make the anomalies harder to spot in the middle of the screen as they cover less screen space, which could then lead to the amount of anomalies detected in the middle to be smaller than it should be. Figure 4.6 shows a small increase in detection in corners over edges. This could be due to this camera effect, since the agents in the corners would take up the most space on the screen.

5.2 Social force

One slightly unexpected result from the study was that so many of the subjects mentioned that people walking closely behind each other was unrealistic. This complies well with the predictions made by the social force model however, since the people walking so close to each other would exert social force on one another and separate. This also holds for the strange formations that would sometimes form after agents collided in the dense videos. The social force should have separated these agents from each other, which would likely make the anomaly more difficult to discover after it had happened. We think that this could be one of the reasons that the subjects were more likely to see an anomaly in the sparse control videos.

In both the sparse and dense videos, the agents don't act according to social forces, since the algorithm does not calculate them. In the dense videos, the density makes it more difficult for a viewer to predict social forces, since each agent is affected by forces from a larger number of other agents. This means that it is harder to spot someone who doesn't act according to the forces. Conversely, in the sparse videos, there are many cases where it should be easy to predict how an agent should move. Especially in the case when two agents move very closely to each other, as seen by the responses from section 4.2. In the case where two agents are walking close to each other, but not beside each other, they should exert social force on each other and move away from each other. It is very possible that since the algorithm did not take this into consideration, and the agents continued to move closely together, the subjects expected force was not seen and the scene seemed unrealistic to them.

5.3 Future Research

Due to the limitations discussed in section 5.1, the results in this study are rather restrictive in some areas. Further research could include:

- A larger pilot study, or several pilot studies, to reduce the risk of defective videos.
- A larger pool of test subjects, to complete the Latin square for the videos.

- A different camera angle, to see if it affects the results
- A more diverse pool of test subjects.
- A study using a crowd simulation that takes social force into consideration

Since the main goal in this study is to find factors that impact the perceived realism of generated crowds, future studies could focus on how to use the results from this report to make simulations more realistic. Especially interesting is the density of the crowd. Since the lower density seems to make unrealistic behavior easier to spot, but denser crowds require more computing, there should be some optimal compromise between low and dense crowds. A simpler algorithm that can simulate a larger amount of agents in real time might seem more realistic than a more complex one that only has a small amount of agents, since the anomalies are harder to detect with more agents.

Chapter 6

Conclusion

This last chapter will go through the three research questions that we asked in our problem statement and answer them by drawing conclusions from the results and discussion in this study.

6.1 Screen location of anomalies

From the results shown in section 4.3, there is a small correlation between sections of the screen and how noticeable the anomaly is. The center of the screen seems to have a slightly larger chance of having an anomaly discovered, especially in sparse crowds. However, since the discovery rate of anomalies varies greatly between videos in both cases, as seen in Figure 4.7, it seems likely that some other factor also impacts the result. Due to this other unknown factor, and the fact that the correlation between the center and anomaly discovery rate is quite small, we do not feel comfortable with drawing the conclusion that anomalies in the center are always easier to spot. Instead, the conclusion is that this study seems to imply that they are, and that further studies are needed to verify this.

6.2 Crowd density and anomaly noticeability

In contrast to the screen location of the anomaly, the crowd density seemed to have a large impact on the detection rate of an anomaly. In general, the sparser crowd had a larger discovery rate, as seen in

Figure 4.6. Particularly interesting is the result shown in Figure 4.8. The result here seems to strongly imply that the dense crowd is able to hide anomalies better. We have two possible explanations of why this is.

The first possibility is that the sparse crowd makes it easier for the test subject to scan every person in the crowd, and look for an anomaly in this way. This is not feasible in the denser crowds, leading to the person either spending less time per person, looking at fewer examples, or just scanned the entire crowd. This is also supported from the gaze paths traced from the subjects, where most would prefer to scan individual persons at a time instead of looking at the entire crowd.

The second possibility is that the sparse crowds make it easier to spot strange behavior for agents, since the agents behavior is easier to predict. With a small number of agents, the test subject should be able to easily form an opinion of how a specific agent should behave regarding nearby agents. If the agent fails to meet the expectation set by the subject, it is very possible that the subject sees the video as unrealistic. This possibility is supported by the work done by Helbing and Molnar [5] about social forces, and by the answers is section 4.2.

6.3 Movement anomalies and perceived realism

As Figure 4.9 shows, the anomalies had a big impact on the observers' eye fixations and perceived realism when seen. Comparatively, Figure 4.10 shows no major correlation between undetected anomalies and a change in realism rating. There is a slight difference between the anomaly videos and control videos realism rating (as can be seen when comparing the 'Disagree' and 'Strongly Agree' responses in Figure 4.10). However, since the test subjects were very inconsistent about what they based our ratings on, we would have to see a larger difference than 5-7 percentage before we could confidently state that there was a connection.

Our conclusion is that this study does not show any correlation between unseen anomalies and a change in perceived realism. This is further supported by the fact that all of our test subjects scanned people in the scene individually, as discussed in section 4.1. Since the subjects mostly focused on an individual at a time, it would be unfea-

sible for them to notice if another individual behaved unexpectedly. Conversely, if the agent they were observing was the one that performed the anomaly, they would of course spot the anomaly. Therefore it seems unreasonable to us that unseen anomalies would be a factor in the subject's realism rating.

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Appendix A

Instructions

Instructions

You are about to see videos of people crossing an intersection. Some of these videos are 1:1 mappings of real movements, and some are generated by the computer. The videos with real data will have simulated people that move exactly as a recording of real people walking. The generated videos will only have the starting and ending positions taken from real life, the path between them will be simulated. The figures below show what the videos will look like.

Figure 1: Example of a crowded situation shown in a video.

Figure 2: Example of a less crowded situation shown in a video.

You will view each video, and afterwards enter three things into your questionnaire:

- The id of the video you just saw.
- If you believe that the video was based on real data or not. This should not be based on things such as every person's legs moving in unison, but rather if the paths people choose seem unrealistic.
- If you saw someone specific behave abnormally. This can be things such as a sudden change in direction, or an abnormal increase in speed.

If there is anything unclear about the study, please ask us for clarification!

Appendix B

Consent form

Consent form

Study title: TBD
Researchers Simon Edström Kawaji, Johan Ribom

The aim of this study is to find patterns that leads crowd simulations to seem unrealistic. The study will be particularly focused on general movement of individual agents in the crowd. The subject of the study will view generated videos of crowds, some based on real data and some simulated. They will then rate each video on how realistic it seemed, and if they saw any particular agent who behaved strangely. Through an eye tracking device, data about where the subject is looking will be collected to locate patterns that lead a generated crowd to seem unrealistic.

Draw a cross the box below if you agree with the following statements:

- I have read and understood what the aim of the study is and have had the opportunity to ask questions about it.
- I agree that the data will be recorded and used only for the purpose of this study.
- I understand that the responses will be anonymized in the reports of the study.

☐

.....
Name of participant

.....
Signature of participant

.....
Signature of researcher

.....
Date

Appendix C

Experiment questionnaire

Subject ID:

Question	Statement	Response
Video ID:		
1.1	The crowd in the video behaved realistically	Strongly Disagree ☐ ☐ ☐ ☐ ☐ Strongly Agree
1.2	A specific agent behaved differently	Yes ☐ No ☐
Video ID:		
2.1	The crowd in the video behaved realistically	Strongly Disagree ☐ ☐ ☐ ☐ ☐ Strongly Agree
2.2	A specific agent behaved differently	Yes ☐ No ☐
Video ID:		
3.1	The crowd in the video behaved realistically	Strongly Disagree ☐ ☐ ☐ ☐ ☐ Strongly Agree
3.2	A specific agent behaved differently	Yes ☐ No ☐
Video ID:		
4.1	The crowd in the video behaved realistically	Strongly Disagree ☐ ☐ ☐ ☐ ☐ Strongly Agree
4.2	A specific agent behaved differently	Yes ☐ No ☐
Video ID:		
5.1	The crowd in the video behaved realistically	Strongly Disagree ☐ ☐ ☐ ☐ ☐ Strongly Agree
5.2	A specific agent behaved differently	Yes ☐ No ☐
Video ID:		
6.1	The crowd in the video behaved realistically	Strongly Disagree ☐ ☐ ☐ ☐ ☐ Strongly Agree
6.2	A specific agent behaved differently	Yes ☐ No ☐

Question	Statement	Response
Video ID:		
7.1	The crowd in the video behaved realistically	Strongly Disagree ☐ ☐ Neutral ☐ ☐ Strongly Agree
7.2	A specific agent behaved differently	Yes ☐ No ☐
Video ID:		
8.1	The crowd in the video behaved realistically	Strongly Disagree ☐ ☐ Neutral ☐ ☐ Strongly Agree
8.2	A specific agent behaved differently	Yes ☐ No ☐
Video ID:		
9.1	The crowd in the video behaved realistically	Strongly Disagree ☐ ☐ Neutral ☐ ☐ Strongly Agree
9.2	A specific agent behaved differently	Yes ☐ No ☐
Video ID:		
10.1	The crowd in the video behaved realistically	Strongly Disagree ☐ ☐ Neutral ☐ ☐ Strongly Agree
10.2	A specific agent behaved differently	Yes ☐ No ☐
Video ID:		
11.1	The crowd in the video behaved realistically	Strongly Disagree ☐ ☐ Neutral ☐ ☐ Strongly Agree
11.2	A specific agent behaved differently	Yes ☐ No ☐
Video ID:		
12.1	The crowd in the video behaved realistically	Strongly Disagree ☐ ☐ Neutral ☐ ☐ Strongly Agree
12.2	A specific agent behaved differently	Yes ☐ No ☐

Subject ID:

Question	Statement	Response
Video ID:		
13.1	The crowd in the video behaved realistically	Strongly Disagree ☐ ☐ ☐ ☐ ☐ Strongly Agree
13.2	A specific agent behaved differently	Yes ☐ No ☐
Video ID:		
14.1	The crowd in the video behaved realistically	Strongly Disagree ☐ ☐ ☐ ☐ ☐ Strongly Agree
14.2	A specific agent behaved differently	Yes ☐ No ☐
Video ID:		
15.1	The crowd in the video behaved realistically	Strongly Disagree ☐ ☐ ☐ ☐ ☐ Strongly Agree
15.2	A specific agent behaved differently	Yes ☐ No ☐
Video ID:		
16.1	The crowd in the video behaved realistically	Strongly Disagree ☐ ☐ ☐ ☐ ☐ Strongly Agree
16.2	A specific agent behaved differently	Yes ☐ No ☐
Video ID:		
17.1	The crowd in the video behaved realistically	Strongly Disagree ☐ ☐ ☐ ☐ ☐ Strongly Agree
17.2	A specific agent behaved differently	Yes ☐ No ☐
Video ID:		
18.1	The crowd in the video behaved realistically	Strongly Disagree ☐ ☐ ☐ ☐ ☐ Strongly Agree
18.2	A specific agent behaved differently	Yes ☐ No ☐

Question	Statement	Response
Video ID:		
19.1	The crowd in the video behaved realistically	Strongly Disagree ☐ ☐ ☐ ☐ ☐ Strongly Agree
19.2	A specific agent behaved differently	Yes ☐ No ☐
Video ID:		
20.1	The crowd in the video behaved realistically	Strongly Disagree ☐ ☐ ☐ ☐ ☐ Strongly Agree
20.2	A specific agent behaved differently	Yes ☐ No ☐
Video ID:		
21.1	The crowd in the video behaved realistically	Strongly Disagree ☐ ☐ ☐ ☐ ☐ Strongly Agree
21.2	A specific agent behaved differently	Yes ☐ No ☐
Video ID:		
22.1	The crowd in the video behaved realistically	Strongly Disagree ☐ ☐ ☐ ☐ ☐ Strongly Agree
22.2	A specific agent behaved differently	Yes ☐ No ☐
Video ID:		
23.1	The crowd in the video behaved realistically	Strongly Disagree ☐ ☐ ☐ ☐ ☐ Strongly Agree
23.2	A specific agent behaved differently	Yes ☐ No ☐
Video ID:		
24.1	The crowd in the video behaved realistically	Strongly Disagree ☐ ☐ ☐ ☐ ☐ Strongly Agree
24.2	A specific agent behaved differently	Yes ☐ No ☐

Subject ID:

Question	Statement	Response
Video ID:		
25.1	The crowd in the video behaved realistically	Strongly Disagree ☐ ☐ ☐ ☐ ☐ Strongly Agree
25.2	A specific agent behaved differently	Yes ☐ No ☐
Video ID:		
26.1	The crowd in the video behaved realistically	Strongly Disagree ☐ ☐ ☐ ☐ ☐ Strongly Agree
26.2	A specific agent behaved differently	Yes ☐ No ☐
Video ID:		
27.1	The crowd in the video behaved realistically	Strongly Disagree ☐ ☐ ☐ ☐ ☐ Strongly Agree
27.2	A specific agent behaved differently	Yes ☐ No ☐
Video ID:		
28.1	The crowd in the video behaved realistically	Strongly Disagree ☐ ☐ ☐ ☐ ☐ Strongly Agree
28.2	A specific agent behaved differently	Yes ☐ No ☐
Video ID:		
29.1	The crowd in the video behaved realistically	Strongly Disagree ☐ ☐ ☐ ☐ ☐ Strongly Agree
29.2	A specific agent behaved differently	Yes ☐ No ☐
Video ID:		
30.1	The crowd in the video behaved realistically	Strongly Disagree ☐ ☐ ☐ ☐ ☐ Strongly Agree
30.2	A specific agent behaved differently	Yes ☐ No ☐

Question	Statement	Response
Video ID:		
31.1	The crowd in the video behaved realistically	Strongly Disagree ☐ ☐ ☐ ☐ ☐ Strongly Agree
31.2	A specific agent behaved differently	Yes ☐ No ☐
Video ID:		
32.1	The crowd in the video behaved realistically	Strongly Disagree ☐ ☐ ☐ ☐ ☐ Strongly Agree
32.2	A specific agent behaved differently	Yes ☐ No ☐
Video ID:		
33.1	The crowd in the video behaved realistically	Strongly Disagree ☐ ☐ ☐ ☐ ☐ Strongly Agree
33.2	A specific agent behaved differently	Yes ☐ No ☐
Video ID:		
34.1	The crowd in the video behaved realistically	Strongly Disagree ☐ ☐ ☐ ☐ ☐ Strongly Agree
34.2	A specific agent behaved differently	Yes ☐ No ☐
Video ID:		
35.1	The crowd in the video behaved realistically	Strongly Disagree ☐ ☐ ☐ ☐ ☐ Strongly Agree
35.2	A specific agent behaved differently	Yes ☐ No ☐
Video ID:		
36.1	The crowd in the video behaved realistically	Strongly Disagree ☐ ☐ ☐ ☐ ☐ Strongly Agree
36.2	A specific agent behaved differently	Yes ☐ No ☐

Subject ID:

Question	Statement	Response
Video ID:		
37.1	The crowd in the video behaved realistically	Strongly Disagree ☐ ☐ ☐ ☐ ☐ Strongly Agree
37.2	A specific agent behaved differently	Yes ☐ No ☐
Video ID:		
38.1	The crowd in the video behaved realistically	Strongly Disagree ☐ ☐ ☐ ☐ ☐ Strongly Agree
38.2	A specific agent behaved differently	Yes ☐ No ☐
Video ID:		
39.1	The crowd in the video behaved realistically	Strongly Disagree ☐ ☐ ☐ ☐ ☐ Strongly Agree
39.2	A specific agent behaved differently	Yes ☐ No ☐
Video ID:		
40.1	The crowd in the video behaved realistically	Strongly Disagree ☐ ☐ ☐ ☐ ☐ Strongly Agree
40.2	A specific agent behaved differently	Yes ☐ No ☐
Video ID:		
41.1	The crowd in the video behaved realistically	Strongly Disagree ☐ ☐ ☐ ☐ ☐ Strongly Agree
41.2	A specific agent behaved differently	Yes ☐ No ☐
Video ID:		
42.1	The crowd in the video behaved realistically	Strongly Disagree ☐ ☐ ☐ ☐ ☐ Strongly Agree
42.2	A specific agent behaved differently	Yes ☐ No ☐

Question	Statement	Response
Video ID:		
43.1	The crowd in the video behaved realistically	Strongly Disagree ☐ ☐ ☐ ☐ ☐ Strongly Agree
43.2	A specific agent behaved differently	Yes ☐ No ☐
Video ID:		
44.1	The crowd in the video behaved realistically	Strongly Disagree ☐ ☐ ☐ ☐ ☐ Strongly Agree
44.2	A specific agent behaved differently	Yes ☐ No ☐
Video ID:		
45.1	The crowd in the video behaved realistically	Strongly Disagree ☐ ☐ ☐ ☐ ☐ Strongly Agree
45.2	A specific agent behaved differently	Yes ☐ No ☐
Video ID:		
46.1	The crowd in the video behaved realistically	Strongly Disagree ☐ ☐ ☐ ☐ ☐ Strongly Agree
46.2	A specific agent behaved differently	Yes ☐ No ☐
Video ID:		
47.1	The crowd in the video behaved realistically	Strongly Disagree ☐ ☐ ☐ ☐ ☐ Strongly Agree
47.2	A specific agent behaved differently	Yes ☐ No ☐
Video ID:		
48.1	The crowd in the video behaved realistically	Strongly Disagree ☐ ☐ ☐ ☐ ☐ Strongly Agree
48.2	A specific agent behaved differently	Yes ☐ No ☐

Appendix D

Experiment video

Example of a high-density crowd scenario that was used in the experiment:

`https://www.youtube.com/watch?v=ruluSXWNxPU`

Example of a low-density crowd scenario that was used in the experiment:

`https://www.youtube.com/watch?v=HYVSM1Jz4nQ`