The Impact of Animations in the Perception of a Simulated Crowd

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Abstract. Simulating virtual crowds is an important challenge in many areas such as games and virtual reality applications. A lot of effort has been dedicated to improving pathfinding, collision avoidance, or decision making, to achieve more realistic human-like behavior. However, crowd simulation will be far from appearing realistic as long as virtual humans are limited to walking animations. Including animation variety could greatly enhance the plausibility of the populated environment. In this paper, we evaluated to what extend animation variety can affect the perceived level of realism of a crowd, regardless of the appearance of the virtual agents (bots vs. humanoids). The goal of this study is to provide recommendations for crowd animation and rendering when simulating crowds. Our results show that the perceived realism of the crowd trajectories and animations is significantly higher when using a variety of animations as opposed to simply having locomotion animations, but only if we render realistic humanoids. If we can only render agents as bots, then there is no much gain from having animation variety, in fact, it could potentially lower the perceived quality of the trajectories.

Keywords: Perception · Crowd simulation · Character animation

1 Introduction

Virtual environments have been used in many disciplines such as building design, teaching, medicine and simulating dangerous situations or evacuations that would not be reasonable to recreate with real people or materials. Achieving realistic and believable virtual scenarios depends on both the quality of the environment (affected by global illumination, surrounding sound, environmental effects or rendering quality) and the plausibility of the virtual humanoids and crowds. Simulating believable virtual humanoids can be an extremely hard problem, and its complexity rapidly escalates when simulating crowds due to the interactions between virtual humans.

Two important factors must be taken into account: characters' rendering and behavior, as was confirmed by Bailenson et al. [1]. Nowadays, realistic rendering of humanoids can be achieved with details such as wrinkles, the fibers of the

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clothes or even the hairs on the arms. However, simulating crowds of highly realistic models with unnatural looking motion can provoke an *Uncanny Valley* effect [18]. The Uncanny Valley tends to appear in crowd simulation when the behavioral response of the characters does not match their appearance, because as the virtual humans look more realistic, we expect them to also behave in a more human like way. Therefore any awkward behavior will be quickly perceived by the user and make the character not likeable.

Existing work in virtual reality to study user response to crowd simulations, has been primarily focused on improving the simulation models of collision avoidance [14], the use of interactions through gestures [11] or gaze to enhance a sense of immersion [19], and studies of proxemics [5].

Crowd simulation has become a mature field of research with many different applications areas. However, crowd simulation models present many difficulties when it comes to validating new models. There are currently two main alternatives for validations: (1) quantitative measurements to compare against existing models or real crowds, or (2) perceptual studies. The former is difficult because there are no standard measurements or perfect models to compare against, and comparing against the real world can also be extremely difficult due to the non-deterministic aspects of human behavior. The later, is also very challenging because humans are not capable of separating the quality of the simulation from other aspects such as appearance, animation artifacts, etc. Therefore, if we want to further enhance the realism of a simulated crowd to populate virtual environments, we may need to put further emphasis on secondary aspects instead of focusing exclusively on improving the local movement of the individuals.

In this work, we want to focus on studying how the characters' appearance and animations can impact the perceived level of realism of a simulated crowd, the quality of the trajectories and the animations. For this purpose we ran experiments of a simulated crowd with the avatars rendered with robotic (bot) or human-like appearance (humanoids), and performing two types of animations: (1) locomotion only, and (2) locomotion combined with animation variety such as gesturing during conversation, waving, using the phone or sitting down. Our main findings are:

- Animation variety with humanoid avatars provides the highest levels of realism.
- Appearance quality only has an impact on realism if we have animation variety, but not if we only use locomotion.
- If only locomotion animations are used, then trajectories are likely to be perceived as being more realistic if we render bots instead of humanoids.

The conclusions of this study are restricted to the specific stimuli that we used for the experiments. However, they provide useful information on what aspects of the appearance and animation can affect the perceptual evaluation of a crowd simulation and thus its plausibility when being used to populate virtual environments.

2 Related Work

2.1 Appearance and Motion of Virtual Humans

Shape, material and rendering style can affect the way users perceive emotions from virtual agents. Zell et al. [29] compared cartoonish, medium and high realistic characters with different materials to analyze the perception of different facial expressions such as sadness, anger, happiness and surprise. Their results showed that shape is the main factor for the perceived realism and that some expressions are perceived more intense with cartoon shapes. Vihanga et al. showed that participants in a virtual reality classroom were more engaged when the lesson was taught by a virtual character rather than a voice-only version [7].

Lighting has been used over the decades in VFX and animation movies to transmit emotions. Wisessing et al. [28] studied whether the brightness and the intensity of light had an effect on the recognition of emotions such as happiness, sadness, anger and fear. Their results showed that brightness intensifies happiness while darker lighting intensifies sadness and that darker conditions did not affect anger or fear.

Several works have studied whether emotional responses of participants are affected by photorealism of virtual avatars [15,25,26]. In the works by Zibrek et al. [32] a single virtual character performed several emotions like sadness, guilt, friendly and unfriendly with different rendering styles (realistic, simple, toon, sketch) and the participants reported their emotional experience through questionnaires. Friendly emotions gave higher scores of perceived realism when having a realistic rendering style instead of a sketch style and the avatar's personality also played an important role on the perception of realism by the participants, meaning that both appearance and behavior must be combined carefully in immersive virtual reality to transmit the desired effect.

Emotional avatars play an important role in videogames, movies and simulations experiences. The better the avatars transmit emotions, the more truthful and realistic will be the experience. Randhaven et al. presented *EVA*, an algorithm to generate virtual agents with different emotions happiness, anger, sadness based on gaze and gait [22]. Their results indicated that avatars showing emotions generated from gait and gaze increased the sense of presence and the overall realism of the simulations.

2.2 Crowd Simulation

Populating virtual environments with convincing crowds has been investigated for decades by the computer graphics community. Including personality traits can further enhance the plausibility of a virtual crowd. The OCEAN personality model [27] has been used in different crowd simulation models (such as HiDAC [6], RVO [9], and Biocrowds [10]) to provide each virtual agent in a crowd with personality traits. These models successfully modify the decision making or local movement parameters, thus resulting in a more heterogeneous crowd simulation, although agents are still limited to showing exclusively locomotion animations.

Emergency simulations have been extensively used to determine whether building facilities like emergency exits are correctly designed, or whether there is a possibility of finding a bottleneck when people run towards an exit. There exists many studies to model the evacuation of virtual crowds in disaster scenarios like fire, earthquakes, flooding, storms or civil disorders [23,24]. Zhao et al. reproduced the 2010 Love Parade disaster using virtual reality to study the behavior of participants and help organizers to avoid this kind of disasters in the future [30].

Pelechano et al. [21], proposed using immersive virtual reality as a platform to evaluate crowd simulation models. This platform allowed them to study the behavior of the participants when interacting with a virtual crowd in a cocktail party scenario. The experiment showed what features of each model could enhance or break presence. Participants did exhibit behaviors that were consistent with the interaction with a real crowd, and their behavioral response indicated that a high level of presence could be achieved in such setup. The system included animations to further enhance the believability of the crowd, but without studying its impact. Bruneau et al. [4] studied the impact that crowd appearance could have on the collision detection maneuvering of a participant walking against a virtual crowd. They showed a crowd of humanoids with casual clothing, with military clothing, and with zombie appearance. Their study found that the avatars appearance affected the local movement of the participant to avoid collisions. Berton et al. [3] studied the trajectories of participants through a dense crowd by including vibrotactile armbands, and found that participants' movement (speed and torso rotation) was affected by the haptic feedback.

Emotional virtual characters is another aspect that has been studied along the literature to produce more realistic crowds. Liu et at. [12] used an emotion contagion model to simulate the evacuation process in a virtual scenario. Their model introduced two states for every individual: normal and evacuating states. The speed of a virtual agent increases when its state changes from normal to evacuating. The state of an agent is also influenced by the state of the surrounding agents in a certain radius. The use of emotion contagion produced simulated behaviors that resembled of those in the real world. Zhou et al. [31] combined both the OCEAN personality traits model with emotion contagion to simulate emergency evacuations.

From the literature review we can conclude that, the presence of dynamic elements in the virtual environment, global illumination and good quality rendering of avatars can have an impact on the participants' response. It seems that the correct combination of realistic appearance and animations in the simulation of virtual avatars could have a high impact on the perception of realism by participants in an immersive virtual reality environment. Therefore, we are interested in exploring to what extend, improving appearance and/or animation can enhance the perceived realism of a virtual crowd.

3 Experiment Design

The goal of the experiment was to study whether the perception of realism of a virtual crowd was affected by the characters appearance and by the variety of animations. For this purpose, we generated a virtual city scene with decorative elements such as benches, fountains, street lamps, signs and trees (see Fig. 3 in the appendix) Five viewpoints were selected to show various aspects of the environment such as wide spaces for the crowd to move, narrow spaces to observe close interactions and sections with benches to see the action of sitting.

3.1 Stimuli Creation

We had two independent variables, which were appearance and animation type, each one with two possible values (Bot/Humanoid and Locomotion/Animation variety). A total of four videos[1] were recorded with the possible combinations between avatar appearance and animation type. In the first video the city was populated with bots extracted from Mixamo ([16]) that blended between walking cycles to move through the city with no other animation than locomotion. In the second video the same bots performed blending between walk cycles combined with other actions such as chatting with other avatars, looking around, sitting down or talking on the phone. In the third and fourth videos the robots were replaced by humanoid avatars extracted from the RocketBox library ([8]) and performed the same animations as the first and second videos. Table 1 shows the labels for each video and Fig. 1 shows screen captures.

Table 1. Labels for the four conditions.

BL	Bots with locomotion only
BA	Bots with animation variety
HL	Humanoids with locomotion only
HA	Humanoids with animation variety

The recorded videos were published on a web page to run the studies remotely and thus access a larger number of participants (this was strongly influenced by the impact of the Covid-19 pandemic). The site, first gathered demographic data such as gender, age, experience with computers and experience with video games, then provided instructions on how to run the experiment, and finally asked participants to agree to a consent form before starting with the experiment. The web page also showed the sequence of all videos in a random order (balanced Latin squares) to avoid undesirable learning or fatigue factors affecting our results. For each video, questions regarding the perception of realism of the overall crowd simulation, the trajectories and the animations were asked. The specific questions appear in Table 2.

[1] https://www.cs.upc.edu/~npelechano/videos/CGI2021perceptionAnimCrowds.mp4.

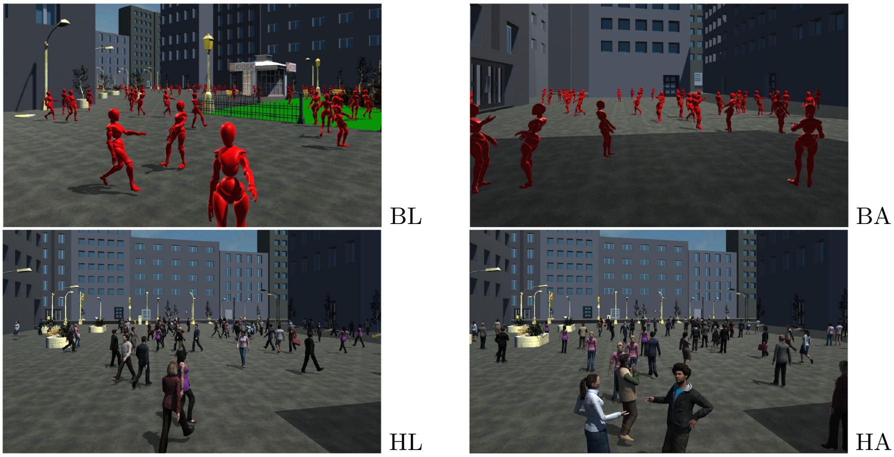

Fig. 1. Images from the videos: (BL) Bots with just locomotion. (BA) Bots with animation variety (walking, chatting, sitting down, and talking on the phone). (HL) Humanoids with just locomotion. (HA) Humanoids with animation variety.

Each participant could see the videos only once and answered the three questions using a Likert scale from 0 to 7, where 0 means *strongly disagree* and 7 means *strongly agree*. We wanted to study the differences across all the possible combinations of type of avatar and animation variety.

Table 2. Questionnaire

Q1	Do you consider this video to be a realistic representation of a crowd? (Does it display the behaviors expected of a real crowd?)
Q2	Do you think this video could represent recorded trajectories from the real world?
Q3	Do you consider that the animations shown appear realistic?

3.2 Participants

Since the study was available through a public web page, we could reach a larger variety of profiles. Therefore, we tried to reach for university students, and also participants without computer science background. We gathered a total of 81 responses from anonymous participants (38 females, 43 males) aged from 14 to 62 ($\mu = 32$, $\sigma = 14$). Half of them had very high experience with computers (6 or above in a 7 points Likert scale), and high (4 or above) with video games (see details in Fig. 4 in the appendix).

3.3 Hypothesis

Our set of hypothesis was the following:

$H1$: The overall crowd simulation will be perceived as being more realistic when having animation variety with humanoid figures (for condition HA).
$H2$: Trajectories will be perceived as being more realistic when having animation variety.
$H3$: Animation variety will increase the perceived realism of the crowd animation for both bots and humanoids.

3.4 Statistical Analysis

Our goal is to understand whether having animation variety and using realistic humanoid figures, can affect the perceived realism of a crowd simulation. To do so, we analyze the differences across our 4 conditions (HA, HL, BA and BL). For all dependent variables, we establish a significance level to $\alpha = 0.05$. Normality of the data in each factor level, was tested with a Ryan-Joiner test, and the homogeneity of variances for each factor level was tested using the Levene's test (see results from both tests in appendix, Tables 3 and 4) .

Since the data follows a normal distribution and all variances are equal among the factor levels, we can apply a one-way analysis of variance (ANOVA) for the three hypothesis. Pos-hoc was then performed using a Tukey Pairwaise comparison with Bonferroni correction to analyze any significant effects between conditions.

4 Results

4.1 Realism of Simulated Crowds (H1)

We first studied the overall perceived realism achieved for each crowd simulation condition (BA, BNA, HA, and HNA). A one way ANOVA with significance level $\alpha = 0.05$ showed that there was a main effect ($F_{(3,320)} = 10.27, p = 0.000$). This validates our first hypothesis $H1$ because it proves that not all the means of the realism scores are equal, and thus we can further study which condition is significantly different from others. Pos-hoc was then performed using a Tukey Pairwaise comparison with Bonferroni correction. It was found that the perceived realism of HA ($\mu_{HA} = 5.38$) was significantly higher that all other three conditions ($\mu_{BA} = 4.5, \mu_{HL} = 4.18$, and $\mu_{BL} = 4.18$).

There was no significant difference among any other combination of conditions. Therefore animation variety offered a higher realism only when human avatars were used, but it did not have an impact when using bots. Similarly, when using only locomotion, the perceived realism was the same regardless of the avatar appearance being a robot or a humanoid.

Our statistical analysis showed an interaction effect between the animation type and appearance, but no main effect on only one of the variables.

4.2 Realism of Trajectories (H2)

Our second hypothesis was that animation variety and human appearance would affect the perceived realism of the avatars trajectories. We thus asked participants to determine whether the avatars' trajectories appeared to be real pedestrians' trajectories. A one way ANOVA with significance level $\alpha = 0.05$ showed that there was a main effect ($F_{(3,320)} = 11, p = 0.000$). This also validates hypothesis H2. Pos-hoc was then performed using a Tukey Pairwaise comparison with Bonferroni correction. It was found that the trajectories realism of HA ($\mu_{HA} = 5.43$) was significantly higher that all other three conditions ($\mu_{BA} = 4.75, \mu_{HL} = 4.02$, and $\mu_{BL} = 4.38$). Therefore having humanoids with animation variety achieves higher levels of perceived realism on the trajectories. Trajectories realism for BA was also significantly higher than for condition HL, which means that animation variety with bots can make users perceived the trajectories as being more realistic than having humanoids that only perform locomotion. This shows that animation variety in a simulated crowd can have a very large impact on the plausibility of the trajectories. An interesting observation from our results was that if only locomotion was used, then trajectories had a higher level of realism when rendering bots ($\mu_{BL} = 4.38$) as opposed to humanoids ($\mu_{HL} = 4.02$). However this difference is only an observed trend, as it was not statistically significant. As in the previous case, our statistical analysis showed an interaction effect between the animation type and appearance, but no main effect on only one of the variables.

4.3 Realism of Animation (H3)

Finally we studied the overall perceived realism of the animations for each crowd simulation condition (BA, BL, HA, and HL). A one way ANOVA with significance level $\alpha = 0.05$ showed that there was a main effect ($F_{(3,320)} = 10.71, p = 0.000$). This validates our third hypothesis H3. Pos-hoc using a Tukey Pairwaise comparison with Bonferroni correction, found that the perceived realism of HA ($\mu_{HA} = 5.16$) was significantly higher than all other three conditions ($\mu_{BA} = 4.3, \mu_{HL} = 4.02$, and $\mu_{BL} = 3.67$). There was no significant difference among any other combination of conditions. Once again, our statistical analysis showed an interaction effect between the animation type and appearance, but no main effect on only one of the variables. Therefore animation variety offered a higher realism only when human avatars were used, but it did not have an impact when using bots. When using the same animation variety for both humanoids and bots, participants perceived that the humanoid render made the animation look significantly more realistic than when rendering bots (Fig. 2).

5 Discussion

Having human-like avatars performing a variety of animations beyond walking, can significantly enhance the overall perceived realism of a simulated crowd, only

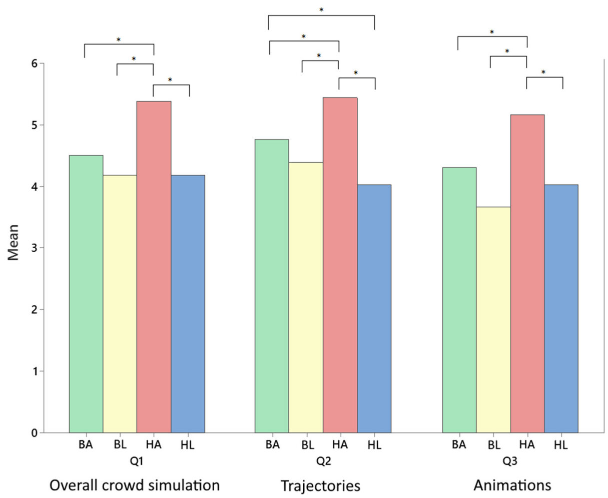

Fig. 2. Results

if we use humanoids. If we use bot avatars, we can say that there is a trend to perceive them as more realistic when including animation variety, however this difference is not statistically significant. So, it appears that animations play a more important role than appearance, in terms of enhancing the perceived realism or a simulated crowd. Another very interesting outcome of our study is that if we can only display locomotion animations, then improving the appearance of the avatars will not increase the overall realism of our simulated crowd. This finding is consistent with a previous study that we performed in an immersive VR emergency experiment, where they studied the differences in realism and presence when improving the appearance of the virtual characters [17].

Trajectories were perceived as better resembling real humans when having animation variety. For the case of having human avatars, this difference was significantly higher. It was also higher when using bots, although we can only refer to as a trend, since the difference was not statistically significant. It is interesting though, that including animation variety over a crowd of bots made the trajectories realism significantly higher that a human like crowd that only perform locomotion. We also observed that when using only locomotion, the bot appearance rated higher in trajectory realism than the human appearance. This finding was also a trend as it was not significantly higher, however it could be explained by the Uncanny Valley effect. Therefore, if we were interested in perceptually validating the output trajectories of a crowd simulation model, it maybe counterproductive to render highly realistic avatars if they are simply walking.

The results on perceived animation variety were very similar to those for overall realism of the crowd. Humanoids with animation variety was perceived as showing more realistic animation than any of the other 3 conditions. An interesting outcome of our study is that, even though we had the exact same animations for both bots (BA) and humanoids (HA), the second one (HA) was perceived as showing significantly more realistic animations that the first condition (BA). Therefore, appearance can affect the way we perceive animation quality.

6 Conclusions and Future Work

From the results of our study, we can conclude that the combination of having human like avatars with animation variety can increase the overall realism of a crowd simulation, trajectories and animation. And not only that, but if we ask users to evaluate the trajectories of a crowd simulation that only performs locomotion, the realism may be rated as higher if we render bots instead of humanoids. Although this difference was not statistically significant in our experiment, we would like to further study this issue, because it could have a very important impact when it comes to validating and comparing crowd simulation models through perceptual studies.

In all our results, animation variety combined with humanoid figures achieved the highest levels of perceived realism. Our experiments, showed the strong impact that animation variety can have on the perceptual evaluation of a crowd, to the extend that all three factors (overall simulation, trajectories and animations) where rated as significantly more realistic when having animation variety. This was also observed for bots, although not with a statistically significant difference. This shows that if we want to further achieve believable and plausible crowd simulation model for computer graphics applications, we need to dedicate more resources to improve animation variety, and not only to develop better local movement methods.

In future work we would like to evaluate whether this conclusions are also observed in immersive VR, were virtual humanoids have the same size as the participant and animation artifacts or unnatural local movement can have a stronger negative effect on the plausibility of the crowd. In such setup, we would like to also evaluate presence, to understand the impact that good quality animations can have on the participant perception.

Appendix

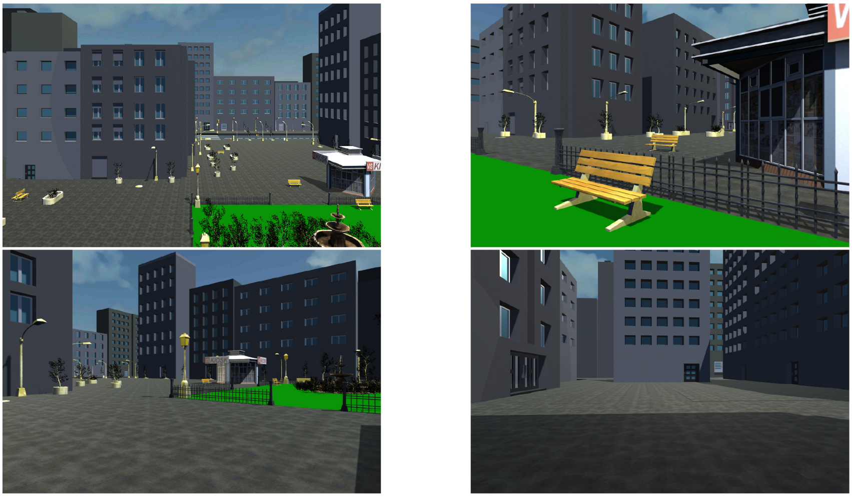

Fig. 3. Images showing the city scene from different points of view.

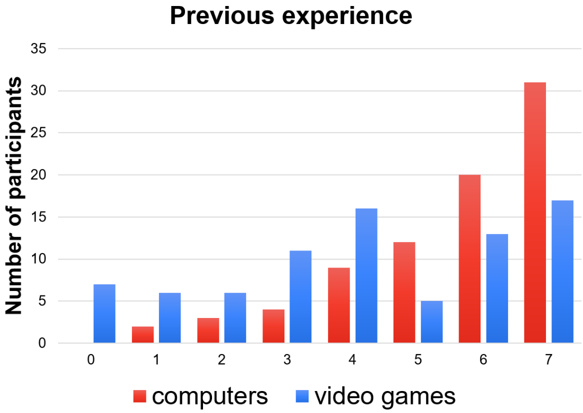

Fig. 4. Participants' previous experience.

Table 3. Ryan-Joiner correlation coefficients and p-values.

Cond.	Crowd realism	Trajectories	Animations
BNA	RJ = 0.997 $p > 0.1$	RJ = 0.996 $p > 0.1$	RJ = 0.997 $p > 0.1$
BA	RJ = 0.990 $p > 0.1$	RJ = 0.992 $p > 0.1$	RJ = 0.985 $p = 0.055$
HNA	RJ = 0.999 $p > 0.1$	RJ = 0.996 $p > 0.1$	RJ = 0.997 $p > 0.1$
HA	RJ = 0.989 $p > 0.1$	RJ = 0.989 $p > 0.1$	RJ = 0.992 $p > 0.1$

Table 4. Levene's values and their corresponding p-values for each factor level

Realism of crowd	Trajectories	Realism of animations
Value = 0.53	Value = 1.45	Value = 0.18
p-value = 0.665	p-value = 0.229	p-value = 0.912

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