UNIVERSITY OF CYPRUS

COMPUTER SCIENCE DEPARTMENT

PHD Dissertation

Virtual Crowds, a contributing factor to Presence in Immersive Virtual Environments

PHD STUDENT

Marios Kyriakou

RESEARCH ADVISOR

Yiorgos Chrysanthou

Marios Kyriakou

VIRTUAL CROWDS, A CONTRIBUTING FACTOR TO PRESENCE IN IMMERSIVE VIRTUAL ENVIRONMENTS

Marios A. Kyriakou

University of Cyprus

As the use of entertainment multimedia and 3D technology increases in many sectors of our life, the expectation for more “realism” from the average user also grows higher. In most virtual reality systems there are virtual humans moving and interacting with each other, and the user expects to see them behaving as real people do, without any unusual effects (collisions etc.).

There are numerous approaches proposed for crowd simulation, but designing and developing virtual crowds, in terms of simulation and animation, is still a challenge for researchers. The difficulty lies in the complexity of the overall human behavior. Especially, if we add more entities in the environment, including interactions between them, forming a crowd, the complexity of the modeled system is increased exponentially. Furthermore, there is not sufficient research that studies how a user is being affected by virtual crowds in an Immersive Virtual Environment (IVE) and what are the main factors, in terms of virtual crowd, that affect the feeling of presence of the user who is immersed in an IVE. This thesis is concerned both with improving the quality of crowds simulation as well as with examining the main behavior characteristics that a believable virtual crowd should have.

Our first contribution is a novel approach for the crowd navigation problem. Our method is a data driven technique based on the principles of texture synthesis, where crowd navigation paths are produced based on example data, coming from real-world

Marios Kyriakou

video footage of people. The simulation of the crowd navigation is not done for each human individually, but whole spatiotemporal areas are being synthesized that may contain several humans inside. This has the possibility of capturing better the interaction between neighboring humans.

Assuming that we have a satisfactory method for crowd navigation, we study what other behavioral characteristics should virtual crowds have and how the user's behavior is being affected by virtual crowds in an IVE. Designing and conducting purpose-developed experiments, we found that facilitating collision avoidance between the user and the virtual crowd does not guarantee that the plausibility of the VR system will be raised or that it will be more pleasing to use. On the contrary, collision avoidance by itself, even if it is a significant factor of lifelikeness of the virtual crowd, could accommodate a feeling of discomfort under certain circumstances. We found that when crowd navigation is accompanied with basic interaction between the user and the virtual crowd, such as verbal salutations, look-at, waving and other gestures, both the plausibility and feeling of comfort in the VR system are increased, enhancing the sense of presence.

Numerous immersive VR (IVR) applications rely on user motivation to be actively involved in the environment. Conducting a second series of experiments, we examined the factors that cause a stronger feeling of presence to the user in a populated IVE and encourage the user to be more active. The results of the experiments show that if the virtual crowd is interacting with the user, then the user tends to intervene more to an incident and have stronger feelings than in a non-interactive scenario. Another interesting finding is that if the user belongs to a group of virtual people, then the possibility of the user intervening and participating in an incident is raised.

Marios Kyriakou

Overall, in this dissertation we propose a novel technique for crowd navigation and study what attributes of behavior are important to be integrated on the virtual crowd, towards the user's experience, in order to successfully simulate crowds in an IVR system.

Marios Kyriakou

VIRTUAL CROWDS, A CONTRIBUTING FACTOR TO PRESENCE IN IMMERSIVE VIRTUAL ENVIRONMENTS

Marios A. Kyriakou

A Dissertation
Submitted in Partial Fulfillment of the
Requirements for the Degree of
Doctor of Philosophy
at the
University of Cyprus

Recommended for Acceptance
by the Department of Computer Science
February, 2014

Marios Kyriakou

© Copyright by

Marios A. Kyriakou

All Rights Reserved

2014

Marios Kyriakou

APPROVAL PAGE

Doctor of Philosophy Dissertation

VIRTUAL CROWDS, A CONTRIBUTING FACTOR TO PRESENCE IN IMMERSIVE VIRTUAL ENVIRONMENTS

Presented by

Marios A. Kyriakou

Research Supervisor

Yiorgos Chrysanthou

Committee Member

Celine Loscos

Committee Member

Constantinos Pattichis

Committee Member

Katerina Mania

Committee Member

Chris Christodoulou

University of Cyprus

February, 2014

Marios Kyriakou

ACKNOWLEDGEMENTS

I would like to express my gratitude to all who encouraged and supported me throughout my doctoral studies. I am deeply obligated to my supervisor Associate Professor Yiorgos Chrysanthou. His guidance, valuable help and continuous support made possible to complete this research work.

I also gratefully acknowledge the other members of my thesis committee, Dr. Katerina Mania, Dr. Celine Loscos, Dr. Constantinos Pattichis and Dr. Chris Christodoulou for their time and effort.

I would like also to thank my research collaborators Dr. Efstathios Stavrakis for his productive comments and reviews on my research work.

I am especially grateful to Dr. Mel Slater for his thoughtful advice and guidelines and to Dr. Sylvia Xueni Pan for her collaboration and valuable help.

Moreover, I wish to express my gratitude to my parents, Antreas and Tasoula, who have always supported and encouraged me to complete this work. Last but not least, I want to express my appreciation and deepest love to my wife Elena for her understanding, patient and love that enabled me to fulfill this study and finally apologize to my two daughters Anastasia and Mary for all the time I was absent from their life.

Marios Kyriakou

To my wife and two daughters

Marios Kyriakou

This research was supported in part by Cyprus State Scholarship Foundation with the Grant #CYP3(05)Ph.D.

Marios Kyriakou

Table of Contents

Marios Kyriakou

Marios Kyriakou

Marios Kyriakou

List of Figures

Marios Kyriakou

Marios Kyriakou

Marios Kyriakou

List of Tables

Marios Kyriakou

Marios Kyriakou

Marios Kyriakou

Chapter 1
Introduction

> *"Virtual reality is the first step in a grand adventure into the landscape of the imagination."*
>
> Frank Biocca, Taeyong Kim, & Mark R. Levy,
>
> *Communication in the Age of Virtual Reality*

1.1. Motivation

In our daily routines, our lives intersect with other people. We see people going to work, going shopping, gathering with friends, going to events, etc. Today's fast-paced technology has enabled not only the observation of human crowds in the real world, but also the simulation of several characteristics and behaviors of human crowds in virtual environments. A virtual crowd is not just a large group of virtual humans, but can be consisted by groups and individuals, with different or similar behaviors. The motivation for this research lies in the need for designing an IVE (Immersive Virtual Environment) populated with virtual humans that are realistically simulated in terms of behavior and navigation, thereby deriving the immersed user's sense of presence.

Marios Kyriakou

An IVR (Immersive Virtual Reality) system provides to the participant the technical capabilities to interact in a surrounding and persuasive virtual environment [1]. A VE (Virtual Environment) may be a convincing representation of a real environment or even of an imaginary one. Immersion in IVR involves placing a person in a VE and attempts to create a fully captivating experience, where the user has the belief of being part of the virtual world. The immersion level can be measured independently of the user’s experience and is considered one of the system’s objective properties.

When we have a populated IVE with virtual humans, it is particularly important to convince the user who is immersed to participate, to feel and act (within the system limitations) as they would in similar environments in real life [2], but within the limitations of the system. The user can interact with this environment and, perhaps most interestingly, can interact with virtual humans. Virtual humans must navigate and interact with the immersed user in a realistic and convincing way and the user must not understand that the movement and the behavior of the virtual humans have been created in a synthetic manner. Thus, one of the most challenging tasks is to populate a virtual environment with virtual humans in a plausible way in terms of both navigation and behavior.

Nevertheless, there remains a research gap on how the user’s behavior is being affected by a virtual crowd in an IVE. The main purpose is to conduct purpose-built experiments, and analyze the responses and behavior of the user who is immersed in an IVE, with the aim of identifying the main factors in terms of the virtual crowd that have an impact on the user’s experience.

Marios Kyriakou

1.2. Scope

A crowd consists of a big number of virtual humans that may behave in a similar homogenous way (e.g. in a panic situation) or may present different behavior characteristics (e.g. pedestrians in a public area). They may look similar (e.g. fans in a football match wearing similar clothes) or completely different. They may walk in couples, in groups, they follow a leader or they can be just individuals.

For a successful simulation of a virtual crowd in an IVE, one needs to consider several issues (Figure 1). Firstly, virtual humans must be generated, each one with different characteristics, thereby creating a crowd with heterogeneous members. Secondly, it is essential to address the issue of how virtual humans should be animated from low-level (movement of limbs) to high-level (walking models, style, etc.).

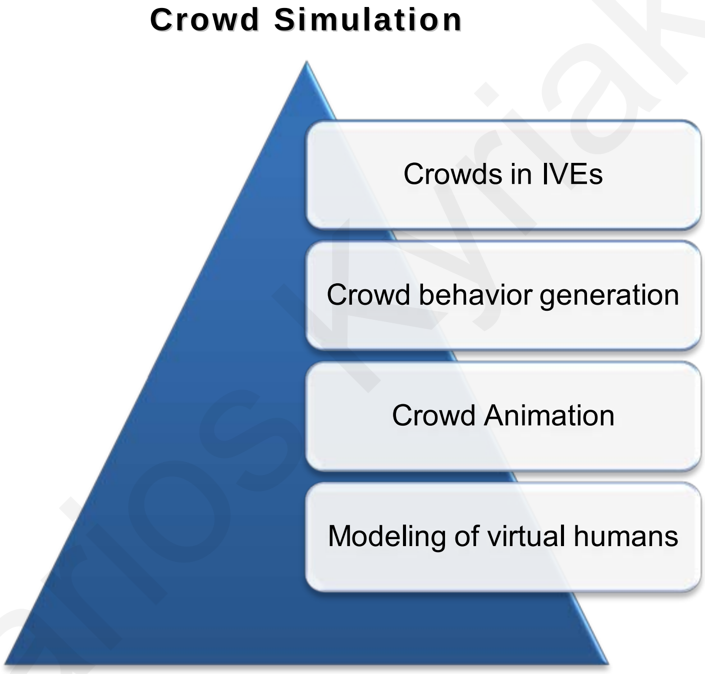


Figure 1: Crowd Simulation

Marios Kyriakou

The behavior of the virtual humans is another significant component of a simulated crowd and can be studied both from a high-level and low-level perspective. At the high-level, the crowd behavior can be addressed as the overall task that each individual must complete, such as path planning -go from location A to location B-, decision taking, needs etc. At the low-level, we care about crowd navigation and steering, how virtual humans follow a navigation path and avoid collisions with obstacles and other entities. An interesting challenge is to populate a virtual environment with a simulated virtual crowd, taking into consideration that the virtual humans must be able to behave as real humans, interact with others, avoid collisions, walk only in walkable areas and present a realistic human behavior in an environment with a large number of objects, restrictions and data.

In this research, two major topics are addressed regarding crowd simulation and IVEs. Firstly, the problem of crowd navigation is addressed, which is part of the crowd behavior generation problem. More specifically, in crowd navigation, we are interested in agent steering in a natural human-like behavior, creating navigation paths for each agent in order to go from one point to another, avoiding collisions and maintaining crowd characteristics. This implies two major issues. One of them is the demanding and lengthy procedure, of designing a behavioral and navigation model. The other is the realistic simulation of movements, including the navigation of each agent. It is still a challenge to create crowd behavior and navigation that look natural and believable as opposed to “robotic”.

Researchers, trying to solve the problem of crowd navigation, have developed several methods that are either macroscopic or microscopic. The former tries to simulate the crowd as a whole, while the latter simulates each individual's behavior separately.

Over the past few years, we have seen some data-driven techniques appearing in the literature. These techniques attempt to create a simulation by stitching together example behaviors that have been observed in a real-world video. Data-driven approaches have the advantage that they can capture many variations and subtle behaviors that would have required much painstaking labor to encode in a rule based system. In addition, they do this without requiring the subjective definition of rules by a modeler. The same implementation can work for different types of situations by just

Marios Kyriakou

changing the data. The method introduced and presented in this research (Chapter 3) was developed at the beginning of this new approach course.

The target is to be able to produce motion of characters making as few as possible computations for each character and still present natural human-like behavior. The actual goal is to design an efficient, real-time and easy to implement algorithm that will yield an automatic human-like crowd motion.

The second problem this research addresses is crowd behavior in an IVR system and the factors that affect the user's experience. More precisely, an IVR system must be able to evoke a sense of presence to the user who is immersed in the IVE. If the IVE is populated with virtual humans, it is important to take into consideration the virtual human behavior towards one another and more specifically, the virtual human behavior towards the user. The user must have the feeling of being there and be motivated to behave as in similar real environment. This can be achieved if we meet three conditions [3]:

1. Consistent and low latency sensorimotor loop between sensory data and proprioception.
2. Statistical plausibility. The images presented in the VE must be plausible and lifelike.
3. Behavior-response correlations. There must be appropriate correlations between the behavior of the user and the VE including virtual humans.

In this research, the third condition is examined, studying how a user behaves in an IVE with virtual crowds, when the virtual agents adopt real human behavior. The main target is to report the major factors that make a virtual crowd believable and to motivate a user in a populated IVE to feel and act as they would in reality, analogous to the virtual human behavior.

Marios Kyriakou

1.3. Contributions

For the problem of crowd navigation, a novel data driven technique has been developed based on the principles of texture synthesis. In the presented technique, crowd navigation paths are being produced based on example data. The examples come from a real-world video footage of people, taken with an overlooking static camera. The captured video is manually analyzed to extract the static geometry and the trajectories of people in them. This extracted data can be seen as a simplified video where at each frame we have the colored features, people and static geometry, over a neutral background. This video, or 3D texture, forms the input to the technique.

This input is being used as a large database with 3D blocks to synthesize new trajectories for the humans presented in an initial small video that will be continued. The main difference over the other data driven methods is that in the presented technique, the humans are not being processed individually as in [4], [5] and [6], but whole areas are being synthesized that may contain several humans inside. This has the possibility of capturing the interaction between neighboring humans better.

This thesis also examines attributes of virtual human behavior that may increase the plausibility of a simulated crowd and affect the user's experience in an IVE. In previous studies, researches used experiments to explore the impact of characteristics of groups in the perceived realism, concluding that the addition of virtual humans improves the plausibility of scenes if the group sizes and numbers are plausible [7] [8] [9]. It was also found that rule based formations are realistic than random formations of the virtual crowds [10] [11]. We designed and conducted purpose-developed experiments in IVE populated with virtual humans examining how

Marios Kyriakou

the different level of interaction with virtual humans affect the user's behavior. Firstly, we examined the impact of a major attribute of the virtual humans on the users – collision avoidance. In addition to the collision avoidance, we also added some basic interaction between the user and the virtual crowd, such as verbal salutations, looking and waving at the user and conducted further experiments.

Another hypothesis we have examined was whether the responsiveness of the virtual crowd towards the participant, motivated the participant to be more active during the experiment. This study concentrated on two major factors. One was the “responsiveness” of the virtual crowd towards the participant. We examined how the participant’s behavior and activity was affected when the virtual humans noticed and interacted with the participant.

The second major factor examined was “group membership”. Recent research [12] showed that if a participant felt that he belonged to the same group as a victim of a violent incident, this would act as an incentive for the participant to be more involved. We have also discovered that if a participant was member of a group of virtual characters in a virtual environment, this increased the possibility of user intervention and participation in an incident.

A remarkable finding was also that gender seems to play a significant role. We found that males had a considerably higher number of physical interventions.

Overall, to successfully simulate plausible crowds in an IVR system, a good navigation method should be accompanied with specific behavior attributes that seem to play a significant role on the user’s experience and behavior.

Marios Kyriakou

1.4. Overview of the thesis

This thesis begun with the first introductory chapter, analyzing the motivation and the scopes and presenting the contributions. In Chapter 2, there is a presentation of the state of the art of the crowd simulation, of different approaches for crowd navigation generation and of important topics of Immersive Virtual Reality, concentrating on the introduction of virtual humans in IVEs and the sense of presence for the immersed users .

In Chapter 3, a novel approach for the crowd navigation problem is presented which is a data driven technique based on the principles of texture synthesis, where crowd navigation paths are produced based on example data.

In Chapter 4, there is a study how different levels of interaction between virtual humans and the immersed user affect the user's behavior in immersive and semi-immersive virtual environments.

In Chapter 5, we present a second series of experiments, examining the factors that cause a stronger feeling of presence to the user in a populated IVE and encourage the user to be more active.

Finally, in Chapter 6 there is a summary of the results and contributions of this thesis are presented. Future directions are proposed based on the overall conclusions and limitations.

Marios Kyriakou

Chapter 2
Previous Work

The purpose of this chapter is to build a theoretical background to guide the research. Firstly, we explore the literature relating to crowd simulation and its various topics, presenting the main approaches on crowd behavior and navigation. Secondly, we explore the IVR systems, the sense of presence and immersion, the introduction of virtual humans in IVEs and finally how we measure presence using experiments in VR systems.

2.1. Crowd Simulation

Research in crowd simulation has been active in a number of fields, such as computer graphics, video games, movies, civil engineering, physics, sociology and robotics. The requirements of the simulation differ depending on the purpose of the application. In some applications, such as evacuation simulators and sociological crowd models, the focus is on the realism of behavioral aspects without giving emphasis to visual appearance. At the other end of the spectrum, we have areas such as video games and movie production, where the main goal is high-quality visualization. A virtual crowd should both look good and be animated in a believable manner. As Thalmann and Musse propose in their book [13], in order to create a virtual crowd in a virtual environment we need to address several issues:

1. **Modeling of virtual individuals.** Modeling virtual humans is a complex and difficult process. In addition, if we need to have a group of humans, then the

Marios Kyriakou

modeling process becomes even harder, since we have to present humans with different body types, faces and even clothing.

2. **Crowd animation**. Animating virtual humans has to be efficient and at the same time must allow variability, taking into consideration human animation and locomotion.

3. **Crowd behavior generation**. We can divide the behavior generation in to two levels of detail:
    - Low-level behavior: consider steering virtual humans, getting the virtual human going from point A to point B following a navigation path and at the same time avoiding collisions with any other characters or objects.
    - High-level behavior: focuses on the actions that an individual must do to complete his overall task such as path planning, decision taking, needs etc. (e.g. go to another room, go for lunch), without worrying about collisions, and other low-level actions.

4. **Virtual crowd rendering** depends on the rendering algorithms, the lighting but mainly on the quantity, i.e., the crowd size. It can vary from simple rendering engines that render dots, to sophisticated rendering engines that can preprocess the virtual humans, replacing geometry with impostors and various level of detail representations adapted to the environment and the current situation.

5. **Integration of crowds in IVEs** involves populating an IVE with virtual humans that realistically interact with each other and with the virtual environment, avoid collisions with the virtual obstacles, walk in the virtual corridors and other walkable, for humans, virtual areas and behave in a

Marios Kyriakou

plausible way, taking into consideration the factors that affect the immersed user's experience.

In this thesis, we are concerned about the crowd navigation and the integration of virtual crowds in IVEs. Thus, an examination of these in more detail follows.

2.2. Crowd Behavior Generation – Crowd Navigation

A major research topic in Crowd Behavior Generation is Crowd Navigation, where we try to navigate virtual characters without colliding with obstacles and/or other characters in a smooth way, presenting at the same time human behavior characteristics (e.g. stop to talk to someone and then continue). There are various popular methods for simulating crowd navigation. These methods can be divided into two main approaches: macroscopic and microscopic.

2.2.1. Macroscopic methods

Macroscopic crowd navigation methods try to simulate the crowd navigation/steering as a whole; individual character behavior is not needed. Some researchers derive ideas from fluid mechanics [14], [15] and gas-kinetic modeling paradigms [16] using the velocity or force fields to guide the agents; while others use the concept of utility and its maximization on the pedestrian's trip/trajectory [17]. Macroscopic methods can capture the overall behavior of the crowd, but not for each individual. If we focus at one individual, then the behavior might not be as realistic.

Marios Kyriakou

2.2.2. Microscopic methods

Microscopic methods focus on the behavior and decision-making of individuals and their interaction with other individuals. These methods are widely used and can be further divided into two subcategories: Social forces and rule-based methods.

2.2.2.1. Social Force Models

Marios Kyriakou

Most methods in this category consider the virtual human as a particle with mass upon which are applied a set of forces in the form of Newton's equations. Social force models are successful simulations of simple pedestrian behavior that considers socio-psychological and physical forces, including repulsive interaction, friction forces, dissipation and fluctuations.

Helbing's model [18] is considered to be the most significant social force model. It applies repulsion and tangential (attractive) forces to simulate the interaction between pedestrians and obstacles. The change of velocity of each individual in time t is given by the acceleration equation:

$$m_i \frac{dv_i}{dt} = m_i \frac{v_i^0(t) e_i^0(t) - v_i(t)}{\tau_i} + \sum_{j\,(\neq i)} f_{ij} + \sum_{w} f_{iw}$$

In this equation, an individual (i) has mass m_i moving with a certain desired speed v_i^0 in a direction e_i^0 adapting their instantaneous velocity v_i with time interval τ_i. The individual (i) tends to keep a distance from other individuals (j) and from walls (w) using forces f_{ij} and f_{iw}. Group motion with significant physics was introduced by Hodgins and Brogan [19] using particle systems and dynamics.

In these approaches individuals tend to vibrate in high density crowd and, in general, they behave more like particles than humans agents.

2.2.2.2. Rule–based methods

Rule-based methods define a set of state-action rules that guide the human agents. A human agent according to its current state follows a certain rule or a set of rules. The seminal work of Reynolds [20] proposed one of the earliest rule-based simulations, which focused on flocking behaviors for animal “crowds", based on three basic rules: separation (a bird that belongs in a flock sense nearby flock mates in a small circular area around them, tries to avoid collisions with neighbors), cohesion (staying near the center of the mass of the neighbors so that the flock does not break) and alignment (of their moving direction).

Reynolds added some more rules [21], [22] to his initial model simulating more complex characters as pedestrians. Each of these new rules defines only a specific reaction on the simulated environment of the autonomous system. There were simple behaviors for individuals and pairs (such as obstacle avoidance, path following etc.) and combined behaviors for groups (such as leader following, flocking etc.). This approach is popular and adopted by many researchers and commercial packages such as the Massive Prime crowd simulation tool [23]. Various works [24]–[27] followed this approach, both for animal and human crowds, using local reactive behavior rules for different behaviors such as path-planning and steering.

The works mentioned above focus mainly on the navigational aspect of each individual and the general flow of the crowd. A number of works look beyond the navigational aspect. Some have built a cognitive decision making mechanism for rule definitions. In the work of Terzopoulos et al. [28] a range of individual traits, such as *hunger* and *fear*, are defined for simulated fish, generating appropriate behaviors. Funge et al. [29] simulates agents that not only perceive the environment, but also

Marios Kyriakou

learn from it and use domain knowledge to choose the most suitable behavior out of a predefined set.

Applied to crowd simulation, the work of Musse et al. [30] takes into account sociological aspects for defining a behavioral model, where the crowd is structured in a hierarchy with three levels: the crowd itself, groups, and individuals. Sung et al. [31] represent the set of behaviors as a graph (a finite state machine) with probabilities associated to the edges. These probabilities are updated in real-time based on a set of behavior functions. In the work of Farenc et al. [32] and Thomas et al. [33], information is stored within the environment and triggers the agents to perform various actions.

In theory, these methods can be applied to simulated crowds; however, in practice they are difficult to use, since experts have to define almost always manually all the rules and if the situation changes then the rules must be redefined. In some cases they do not present realistic results for high density crowds or panic situations [34], since they apply conservative approaches using waiting rules, which even if they present realistic results for low density crowds, they lack realism. In addition, they are complicated to define [35] [23], when striving for behaviors that are more realistic.

Marios Kyriakou

2.2.3. Data driven methods

Real crowd behavior may vary according to the surrounding environment and can be too complex for a computational model (force-based, rule-based) to simulate. For this case there are approaches that look at real-world data in order to extract information to use it to refine one of the computational models or to synthesize behaviors from example data. These approaches are called data driven methods.

Some data driven methods use examples from real crowds to refine an underlying behavior model. Metoyer and Hodgins [36] allow the user to define specific examples of behaviors. Musse et al. [37] uses vision techniques to extract paths from a video for a specific environment. Paris et al. [38] use motion tracking to extract detailed behaviors from a crowd of people in various small scale environments. Brogan and Johnson [39] use the statistics from observed pedestrian paths to improve the navigation model. In the work of Lai et al. [40] a motion graph approach is used for synthesizing group behavior. These systems use the data to refine the behaviour rules or to define the parameters of the rules.

Other data driven solutions [4]–[6] use data from real crowds to extract rules automatically. In the work of Lerner et al. [6], a database of human trajectories is learned from videos of real crowds. The trajectories are stored along with some representation of the stimuli that affected them (Figure 2). During a simulation an agent extracts from the environment a set of stimuli that possibly affects its trajectory and searches the database for a similar one and copies a trajectory from the database (Figure 3).

Marios Kyriakou

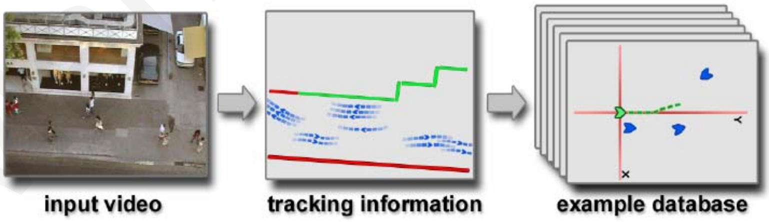


Figure 2: Pre-process phase: the input video is manually tracked generating a set of trajectories. These are encoded as examples and stored in the trajectory database [6].

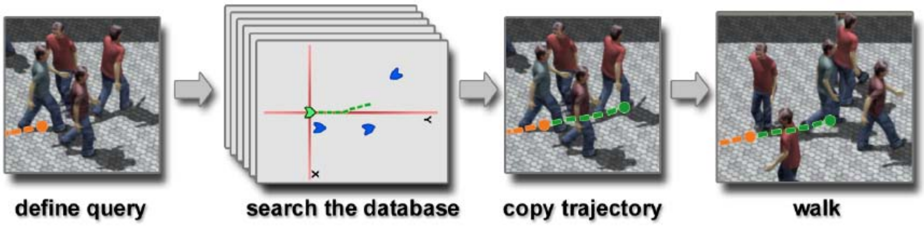


Figure 3: Synthesis phase: for each agent a query is formed encoding his surroundings. This query is used to search the database for similar example which will be copied to the simulated agent [6].

Lerner et al. [41] used the database in order to add secondary actions to the agents such as interacting with each other (talking, waving) etc. In the work of Lee et al. [4] from videos of real crowds are used to extract trajectories and stored in a database with some encoding of the stimuli that affected their navigation. More recent methods store crowd motions in patched and use them in the synthesis phase [42] [43].

Overall, data driven methods have the advantage that they can capture significant variation and subtle behaviors that would require lengthy and painstaking labor to encode in a rule based system. In addition, they do so without requiring the subjective definition of rules by a modeler.

2.3. Immersive Virtual Reality

Virtual Reality (VR) was first introduced by Sutherland [44] almost 50 years ago as a laboratory-based idea. During the past number of decades, the idea has become a very promising and more accessible system in entertainment, training, health and many other sectors able to simulate physical presence in Virtual Environments (VEs) representing places of a real or even an imaginary world.

Marios Kyriakou

A virtual environment is a "mental model" [45] that represents a physical environment. In a virtual environment, the mental model is generated by a presence medium (i.e., a sense stimulus) to represent a physical environment that may or may not exist. In other words, a virtual environment is a perceptual model generated by a presence medium that is different from the physical environment the model represents, since it is an illusion created by the virtual reality system.

In an IVE, the user becomes part of it and controls his viewpoint with head and body movements. In addition, in a VR system, convincing audio can be added in a perceptually plausible way [46], or haptics can be used to enable touch and force feedback by either using end-effectors [47] or an exoskeleton which is fitted on the participant in order to transmit forces on him [48].

In an IVE, one of the main targets is to achieve a sense of presence, the propensity of the users to respond to virtually generated sensory data as if they were real [1]. This is done not by the high fidelity to physical reality but by enabling the users to respond as if the sensory data they receive in an IVE were physically real [3].

Marios Kyriakou

2.3.1. Presence and Immersion

Immersion and presence are two terms that are often confused. According to literature [49], [50] [51], immersion is technology-depended, since it describes the level of fidelity of sensory modalities of what the IVR technology delivers. A system can be described as “immersive” if it *technically* manages to deliver sensory modalities that are closed to the ones caused by the real world.

Presence can be related to immersion, but it is definitely a different concept. Presence has been thoroughly studied during the past number of years [52]–[55]. Psychologists have extensively studied the feeling of presence and have distinguished it into three main types: physical, social, and self-presence [56], [57].

Physical presence is the sense of being located in a virtual world, where a user experiences a fully functional depiction of the physical world in which that user actually is. Users feel being transported from the real physical environment to a virtual one.

Social presence has been defined as the "sense of being with another" [55]. An important issue is that the whole system must give the user the impression that there are other people present in the virtual world, since social presence represents the level to which individuals will experience social interaction in the virtual world.

Self-presence is the psychological identity of the user within the virtual world. The level of self-presence is an indication of the level of the identification with their virtual self in the virtual environment [49].

Sheridan [45] has distinguished three main categories of contributing factors to presence:

i. the level of sensory information presented to the participant,
ii. the level of control the user has over the sensor devices and
iii. the participant's ability to amend the environment.

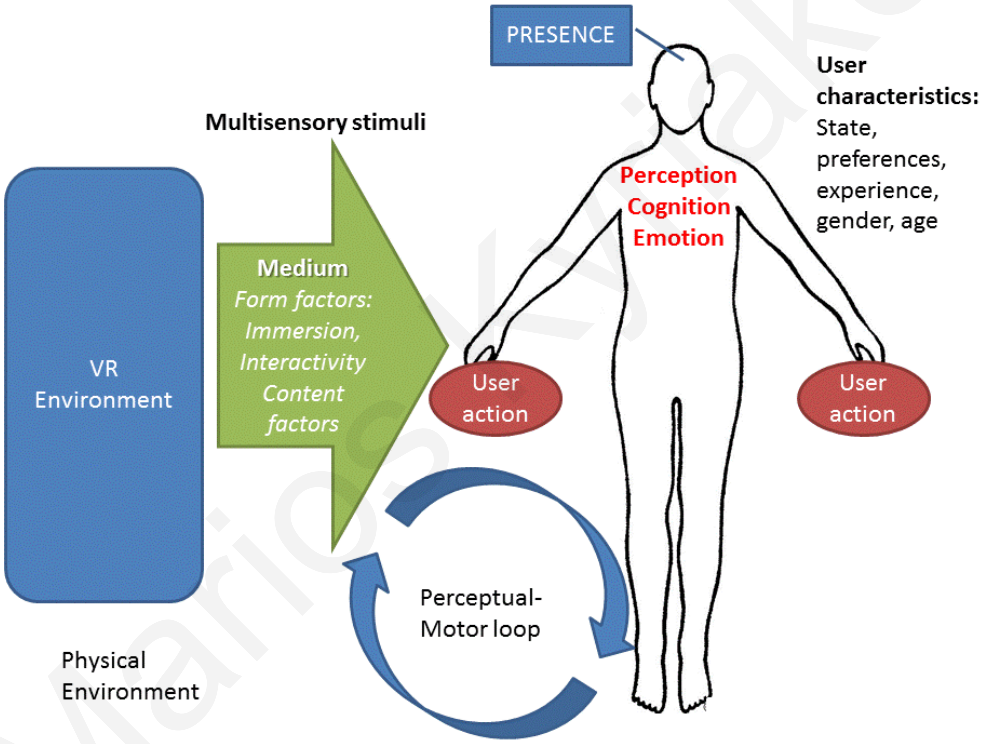
These three elements all refer to the physical, objective properties of a display medium.

It is possible that the presence experience will vary significantly across individuals, based on dissimilarities in perceptual-motor abilities, mental states, personalities, needs, preferences, experience, gender, age, etc. [56].

Marios Kyriakou

The central idea is that users experience the VE as an engaging reality and consider the environment specified by the displays as places visited, rather than as simply images seen [58].

Lombard and Ditton [57] define presence as the perceptual "illusion of non-mediation" that occurs when a person does not acknowledge the existence of a medium in his surrounding and interacting environment and responds as he would if the medium were not present.



Marios Kyriakou

Figure 4: Presence and its determinants in VR environments.

An outline of the determinants of presence through the continuous perceptual-motor loop between the user’s perception and interaction with the real and the virtual world is presented in Figure 4. Multisensory stimuli come from both the physical environment as well as the mediated environment. There is no vital difference in stimuli ascending from the medium or from the real environment.

If an IVR system manages to produce the feeling of presence to the participant, then the participant has the propensity of acting and feeling as if they were in a similar real situation. Thereafter, presence is the *result* of the *whole* system and the main question is how we maximize this feeling in an IVE. There are two approaches to answer this. One is to create an IVE with a high-level of fidelity to reality. The other is a more immersion independent approach, creating an IVR system taking into consideration what is important to the participant's perceptual system. The latter approach requires establishing how data is displayed to participant and how the participant is able to act and interact with the VE [1].

2.3.2. Types of Immersive systems

Today, virtual environments are implemented and presented in three categories with different levels of immersion [59]:

i. Fully immersive systems
ii. Semi-immersive systems
iii. Non-immersive systems

Fully immersive systems are the most complicated, as they try to minimize the user's perception of the real world and maximize the perception of the virtual world. One example of these is the use of an HMD (Head Mounted Display) with small monitors placed in front of each eye which can provide stereo, bi-ocular or monocular images. Another solution is the CAVE (CAVE Automatic Virtual Environment), a cube-like space in which images are displayed by a series of projectors, combining high-resolution, stereoscopic projection and 3D computer graphics. A major component of these systems is the interaction using a variety of input devices (e.g. a joystick, wand

Marios Kyriakou

or a haptics device). This gives the ability to the user to interact with objects and navigate in the VE.

Semi-immersive systems also try to minimize the user's perception of the real world but use less expensive and less sophisticated means. Semi-immersive systems usually use a projector and/or a large screen to display the virtual environment, usually including a wireless technology for motion capture and navigation in the virtual world. These systems are far cheaper, easier to buy and install than fully immersive systems. Nowadays, they are widespread in their use as entertainment and training systems.

Non-immersive systems are usually desktop-based VR systems, characterized as the least interactive and convincing systems and found mostly in videogames. Interaction with the VE can occur usually by conventional means such as keyboards, mice and trackballs. In these systems, there is almost no sense of immersion or presence.

2.3.3. Virtual Humans in IVEs

Quite often in VR applications we have to include virtual humans either as part of the VE or as the main concept of the system for the user to interact with. Consider, for example an IVE where a participant presents a talk to a group of virtual humans who are responding to the talk [60]. The experience was highly realistic to the participants and triggered similar level of social anxiety as they would experience when giving a talk in real life. Other experimental studies in VR also demonstrated that participants would react towards virtual humans with at a realistic psychological level. For instance, in [61] there is direct evidence that individuals attribute mental states to virtual humans.

Marios Kyriakou

Among the research studies with virtual humans in VEs, many have focused on the participants' behavior in maintaining the interpersonal distance with virtual humans (proxemics). Bailenson et al. [62] found that participants automatically maintained a greater distance with more realistic agents. In [63] participants showed negative reactions to violations of interpersonal space. In [64] and [65] there are a few interesting outcomes regarding the distances that participants maintain with virtual humans, how they are defined and governed: (1) participants showed increased physiological reaction the closer they are approached by virtual humans; (2) participants maintained greater distance from virtual humans when approaching their fronts compared to their backs; (3) participants gave more personal space to virtual humans who engaged them in mutual gaze; and (4) participants moved farthest from humans who entered their personal space. Obaid et al. [66] have also studied the user's perception of virtual humans embedded in virtual worlds. Their results revealed that users interacting with virtual humans in VR systems tend to unconsciously re-use their behavior patterns learned in real world interaction, such as raising or lowering their voice level during the interaction with virtual humans.

In a recent study, Slater et al. [12] studied the conditions under a bystander intervened to try and stop a violent attack by one person on another in an IVE. Their main findings were that the participant-bystander intervened more physically and verbally during the violent argument when he/she belonged to the same group as the victim. Additionally, the number of the total interventions increased when the victim was looking at him/her for help and at the same time belonged to the same group.

Marios Kyriakou

2.3.4. Virtual Humans and presence in IVEs

According to Schubert et al. [67], presence is observable when people interact in and with a virtual world as if they were there, while interaction is considered the "manipulation of objects and the influence on agents". Slater et al. [68] found that when a virtual human is talking to the users, the latter's heart rate increases. Thus, a significant factor that has an effect on users is their interaction with virtual agents.

In a set of experiments, Garau et al. [69] tried to understand how presence is maintained over time. They found that if we exclude the first seconds of the experience, when the participant is trying to understand what exactly is happening in the environment and if there is no interaction between the participant and the virtual humans, then the sense of presence is eliminated. Another study showed that a strong feeling of presence in VR is more likely to affect the participant's behavior in the real world [70]. Experiments were also carried out in IVEs to study different effects on males and females and more specifically, male risk-taking in the presence of observers, showing that male risk taking is enhanced by the presence of observers. Especially when the observers are females then the physical risk taking by males are significantly higher [71].

When dealing with a crowd (a bigger number of virtual characters), we have to consider particular issues. Being in a VE with a virtual crowd, the participant might not pay attention to who exactly is doing something; more likely, they will be focused on what is happening overall [31]. For instance, a participant can notice the direction of a crowd, any agitation or an intense situation. By understanding how the participant is being influenced and how he/she reacts to several virtual events and situations, we can develop IVR environments that are more convincing with a higher sense of presence for the participants.

Virtual crowds have been used in a number of experimental studies conducted in VR systems. In the experimental studies [7] [8] [9] researchers used experiments to explore the impact of characteristics of groups in the received realism, and they found that the addition of groups of virtual humans improved the realism of crowd scenes if

Marios Kyriakou

the group sizes and numbers were plausible. In [10] and [11] researchers studied the effects of the positions and the orientations of the virtual characters on the plausibility of the crowd, finding that rule based crowd formations are more realistic than random formations.

The use of the sense of presence in IVE as a possible validation method for crowd simulation approaches was investigated by Pelechano et al. [72]. During their experiments, they found that users interacted with a virtual crowd as they would in a similar real situation. In another related work [73], researchers proposed a visual validation method for crowd simulation approaches, placing the user within the crowd in an IVE.

2.3.5. Measuring presence in VR experiments

Enhancing presence offers the opportunity to developers and engineers to succeed at creating a better user experience and to elevate the effectiveness and efficiency of the different applications. The measurement of presence must be robust and consistent, and identify the factors needed to improve the level of presence for the user. Researchers, in order to accomplish this, have proposed a number of presence measures [74] [75].

Mostly, researchers are using the subjective approach because of the subjective nature of presence. Post-test questionnaires are mainly used, where each participant states his feelings and experience about the experiment. Using questionnaires as a method of measuring presence have the advantages that the experience is not being disrupted during the experiment and they are easy to administer.

There are questionnaires that are specific to experiments, environments and conditions and there are some general presence questionnaires, such as the Witmer-

Marios Kyriakou

Singer [49], the Slater-Usoh-Steed (SUS) questionnaire [76] and the [67] as well as questionnaires of co-presence such as the ITC-SOPI [77] questionnaire. A significant disadvantage of post-test questionnaires is that they are post immersion, they do not measure the time-varying levels of presence and they also may be more influenced and biased by events at the end of the experiment.

A second, less subjective, approach is the use of behavioral measures. The idea here is that the higher the participant's sense of presence in a VE, the more his behavior will match with the behavior he would exhibit in an similar real environment with the same stimuli. Usually, to grade the exhibited behaviors, the experiments are being videotaped. This gives the benefit of not disturbing the participant during the experiment. A main drawback of this method is that the researcher cannot know for a fact that a certain behavior will be exhibited using predefined experimental settings.

A third approach is the use of psycho-physiological measures, which are correlated to the multisensory stimuli, including heart rate, skin temperature and galvanic skin response [78]. When a stress-inducing environment is being used in the experiment [79], then the results are more objective than the two previously mentioned methods. Nevertheless, this method presupposes that all experiment conditions are identical for all participants, since these measurements are sensitive to all experiments aspects.

Ideally, to measure presence in VR experiments, a combination of methods (objective and subjective) should be used to overwhelm any limits of each approach [56] [80].

Marios Kyriakou

Chapter 3
Example Based Navigation of Virtual Crowd

3.1. Introduction

In this chapter, we present a novel data driven approach that is based on the principles of texture synthesis and addresses the issue of crowd navigation. Data driven techniques attempt to create a simulation by stitching together example behaviors that have been observed in real-world video. Our main difference over other data driven methods is that we do not process pedestrians individually, but synthesize whole areas that may contain several pedestrians inside. This has the possibility of capturing better the interaction between neighboring agents. Moreover, since the existing texture synthesis literature is so rich, there is a large arsenal of techniques that we can readily borrow from in order to solve issues that might arise in our approach. Therefore, a brief description of texture synthesis follows.

Marios Kyriakou

3.2. Texture Synthesis

Texture synthesis is a data-driven approach, which synthesizes big textures from small examples. This principle was also used in our algorithm. Texture analysis and synthesis have been in use since the 50's [81] in the field of psychology, statistics and later in CG (Computer Graphics). However, the real impulse for growth in this sector came from the pioneering work of Bela Julesz in the discrimination of textures [82], which proposed that two textures of images are perceptible from humans as the same, if certain concrete statistical characteristics of these textures of images suit.

Based on this, various approaches followed the problem of texture synthesis. Initially, the composition of textures was made taking a random image of noise and by changing it suitably, it was “forced” to present certain statistical characteristics relative to the input-image. Heeger and Bergen [83], inspired by psychological and calculating models of human discrimination of textures, proposed the analysis of textures in histograms using suitable filters. By matching these histograms, the researchers were capable of giving satisfactory results regarding the composition of meditative textures. However, because the histograms measure marginal and combined statistically, cannot capture important cross-correlations that emanate from different scales and adaptations and therefore ultimately fail in the composition of more structured textures.

A different approach was to begin the composition of the new image from an input image and differentiate it by applying on it “random conditions” in such a way that only the statistical characteristics that match are maintained. In Bonet’s [84] algorithm, the input-image is recomposed from a general to a refined state, maintaining the distribution of the filters’ outputs on different scales as unalterable. A simpler approach, presenting similarly and sometimes better results, came from Xu et al. [85]. His idea was to take random blocks from the input-textures and place them arbitrarily in the texture we compose.

Using pixel-based texture synthesis, Efros and Leung [86] developed a non-parametric sampling technique. In this instance, the composition of textures is done repeating the matching of neighborhood surroundings to the processed pixel in the texture that is being composed with the input-texture. Based on this technique, Wei and Levoy [87] developed their own algorithm using a pyramid of composition, which allows the use and examination of smaller neighborhoods for better and faster results. Simultaneously, they applied tree structured vector quantization for the

Marios Kyriakou

acceleration of the algorithm. A more developed differentiation was presented by Ashikhmin [88] where the space and time for the search is drastically decreased. Hertzmannet al. [89] combining the techniques of Wei and Levoy and Ashikhmin in a common frame, achieved enough interesting results and opened new avenues for applications.

Alternatively, there are techniques that use patch-based texture synthesis where they maintain the general structure, and create new textures based on the composition per piece. The algorithm of Efros and Freeman [90] aligns the neighboring limits of certain processed pieces, from an overlap region and then execute a technique of minimum-error-boundary-cut in this overlap region (described in the following section), so as to decrease the imperfections of the overlap. This technique has been adopted in many new algorithms even for 3D composition of textures, from which we took enough elements and developed our own algorithm [91].

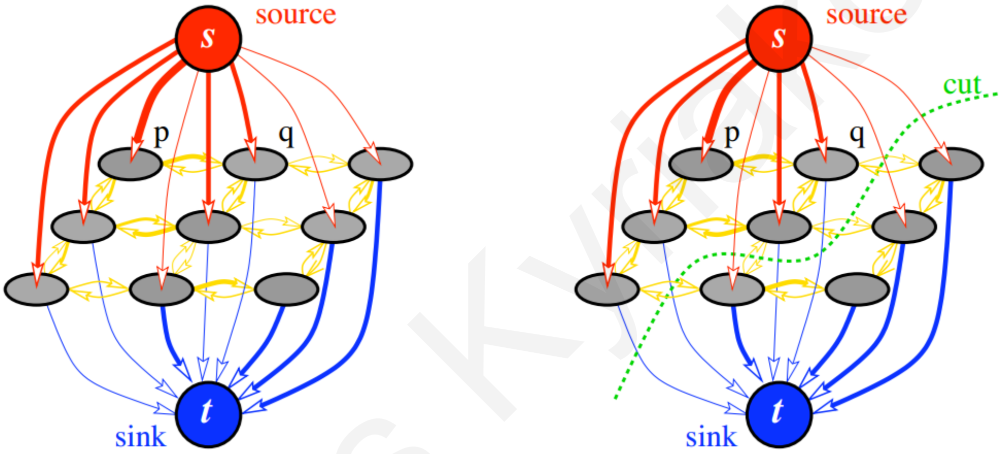
Marios Kyriakou

3.2.1. The Graph Cut technique

Our algorithm uses an adjusted graph cut technique, therefore a brief description of this process follows. Graph cuts were introduced in CG in a bid to try and solve a wide variety of low-level CG problems, such as image smoothing and restoration [92] [93], the stereo correspondence problem [94] [95], texture synthesis [96] and many other CG problems that can be expressed in terms of energy minimization, thereby defining a minimal cut of the graph. Under most formulations of such problems, the minimum energy solution corresponds to the maximum a posteriori estimate of a solution. While many CG methods involve cutting a graph, the term "graph cuts" is applied exactly to those models that include a max-flow/min-cut optimization. Graph cuts can apply piecewise smoothness while maintaining relevant sharp discontinuities.

Let us introduce the relevant terminology [97]:

Let $G = \langle V, E \rangle$ be a graph that consists of a set of nodes V and a set of directed edges E that connect them. The nodes set $V = \{s, t\} \cup P$ contains two special terminal nodes, which are called the source s, and the sink t, and a set of non-terminal nodes P. In Figure 5a there is a simple example of a graph with the terminals s and t.



(a) (b)

Figure 5: Graph construction [97]. (a) A graph G, consists of a set of nodes V and a set of directed edges E that connect them, including the source s and the sink t. (b) A cut on G, which is a subset of edges $C \in E$ such that the terminal nodes s and t become separated on the induced graph.

Marios Kyriakou

Each graph edge is assigned some non-negative weight/cost $w(p,q)$. A cost of a directed edge (p,q) may differ from the cost of the reverse edge (q,p). An edge is called a t-link if it connects a non-terminal node in P with a terminal. An edge is called an n-link if it connects two non-terminal nodes. A set of all n-links will be denoted by N. The set of all graph edges E consists of n-links in N and t-links $\{(s,p)(p,t)\}$

for non-terminal nodes $p \in P$. t-links are presented with red and blue color, and n-links are presented with yellow.

A cut is a subset of edges $C \in E$ such that the terminal nodes s and t become separated on the induced graph $G(C) = \langle V, E \setminus C \rangle$. Each cut has a cost that is defined as the sum of the costs of the edges that it cuts.

3.2.2. The Min-Cut problem

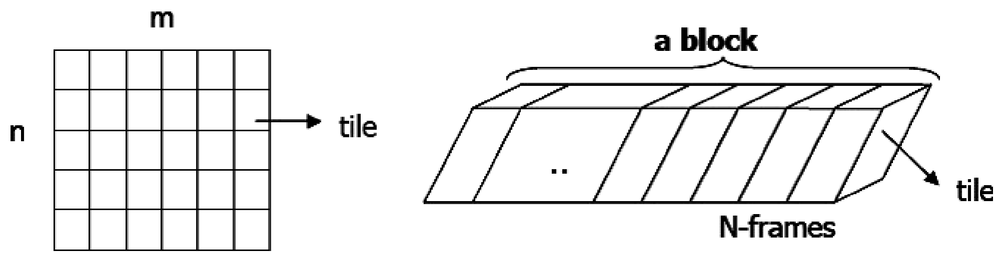
An s/t cut C is a split of the nodes in the graph into two disjoint subsets S and T such that the source $s \in S$ and the sink $t \in T$.

The cost of a cut is $|C| = \sum_{e \in E} w_e$, where e are “boundary” edges. An example of a cut is shown (with green color) in Figure 5b. The minimum cut problem is to find a cut that has the minimum cost among all cuts.

3.3. Algorithm overview

Our algorithm’s purpose is to produce pedestrian simulations based on example data. Our examples come from real-world video footage of people, taken with an overlooking static camera. The captured video is manually analyzed to extract the static geometry and the trajectories of the people. This extracted data can be seen as a simplified video where at each frame we have the colored features - people and static geometry - over a neutral background. This video, or 3D texture, forms the input to our algorithm. Every frame of the input video is segmented into mxn square tiles. N consecutive frames of the same tile form a block, (Figure 6). These blocks are the basic unit on which the algorithm operates.

Marios Kyriakou



(a) q (b)

Figure 6: (a) The frames of the input video are partitioned into tiles. (b) The same tile over N consecutive frames is a block.

Our method proceeds in two steps. At preprocessing, the input video is analyzed, and the blocks are placed into a tree structure for easier access. Then, at run-time, an output 3D texture is created by combining and blending together selected input blocks. The output 3D texture does not need to be the same size as the input. However, both its dimensions need to be a multiple of the side of the input tiles. The static geometry and the first K frames ($K < N$) need to be pre-defined and are used as the starting point of the algorithm. The algorithm proceeds in scan-line order using the K frames of a tile as a query into the tree in order to find a good match and bring the best “matching” block of N frames. At the end of one iteration over all the tiles, we have a video extended by N - K frames.

3.4. Initialization Phase

This is the pre-processing phase in which the database is prepared in an easy to search way. It starts by first creating the 3D blocks and then proceeds to assemble them together into an example tree.

Marios Kyriakou

3.4.1. Creation of 3D Texture Blocks

Once we have a video with tracked trajectories of individuals, we need to construct a large database with 3D blocks that will form the examples that will be used to synthesize new trajectories in the synthesis phase. From the video, we extract 3D textures. Every frame is split to 2D mxn tiles, (Figure 6 left). If we extend these 2D tiles in time we get the 3D block (Figure 6 right). In order to enrich our database with a larger number of examples we overlap the tiles. The overlap is done by shifting the grid of tiles by a few pixels iteratively in either direction until we get all possible segmentations of the frame.

3.4.2. Creation of the Example Tree

The 3D blocks created above are placed in the database, and arranged in a tree structure (Figure 7), in order to have faster search capabilities in the synthesis phase. The tree has six levels, with the internal nodes used for partitioning the data and only the leaf nodes actually holding the block data. The criteria used for the partitioning at the internal nodes are based on the count of pedestrians at the following locations:

Level 1 Present in the Kth frame.
Level 2 Leaving from the west side between the Kth and the Nth frames.
Level 3 Entering through the west side between the Kth and the Nth frames.
Level 4 Leaving from the north between the Kth and the Nth frames.
Level 5 Entering through the north side between the Kth and the Nth frames.

Marios Kyriakou

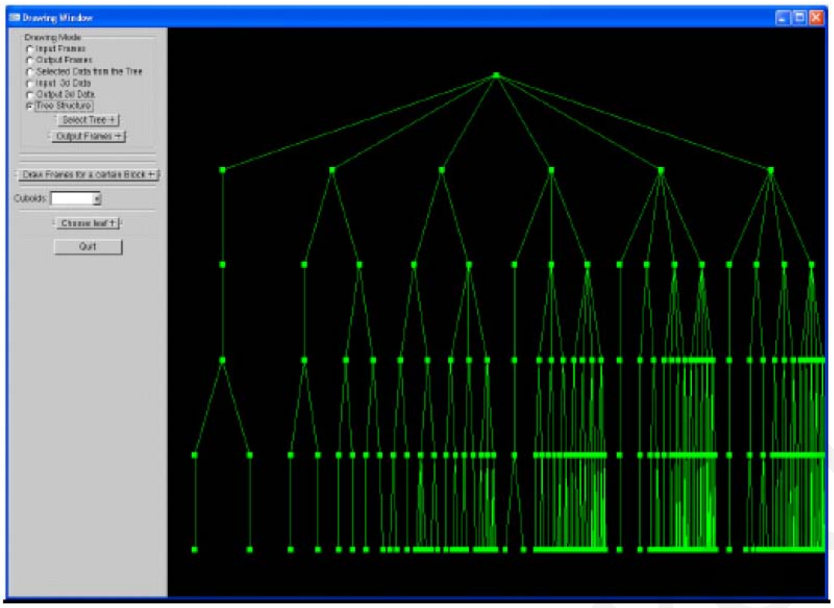


Figure 7: 6-level example tree with the 3D block data (examples) stored in the leaf nodes. The internal nodes are used for partitioning the data.

For accelerating the search, the block data are stored in a 6-level example tree. To save memory, the tree actually stores only references to the location of each block, while all the input data are stored in a separate common table.

3.5. Synthesis Phase

In the synthesis phase, we start from a given set of trajectories, K frames long, and extend them in time. In our implementation, we take as our starting point the trajectories of the last K frames of the input video. As already mentioned, the size of the output video can actually be different from the input if desired. The synthesis works one block at a time in scan-line order, in the manner of texture synthesis [87]. For each block, we first search in the example tree to find the best match and then add it to the output. These two steps are presented in the following sections; additionally some tuning is introduced to the basic algorithm in order to overcome certain problems we encountered.

Marios Kyriakou

3.5.1. Search for the Best Matching Block

In the spirit of texture synthesis, we look for the best matching 3D block by considering the already constructed neighborhood, both in space and in time, using an adjusted graph-cut method. To do this, we form a query that consists of the N frames of the northern, the western and the north-western 3D block, as well as the K frames of the tile that are already there (Figure 8). We examine the query to find the values for the five criteria and use them to traverse to the corresponding leaf of the example-tree. In this way we end-up to a leaf that contains 3D blocks that are similar in these five hard-constrains.

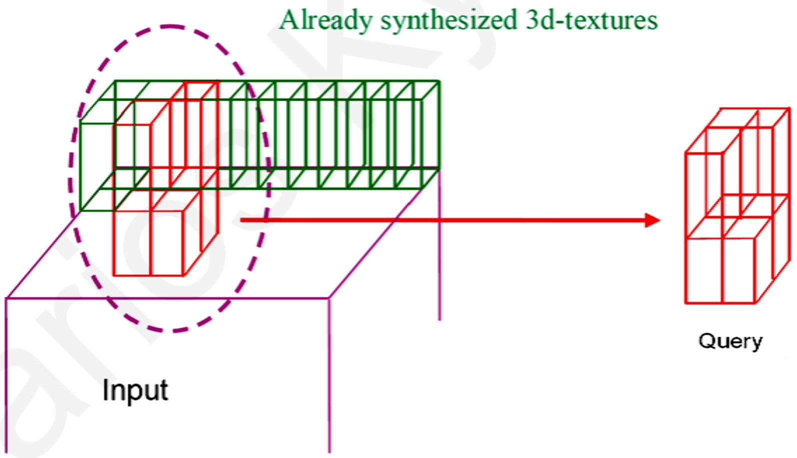


Figure 8: Forming a query using the already constructed neighborhood of the block, and the already existing K frames.

In the leaf, we evaluate the dissimilarity of the example blocks by comparing their neighborhoods against the query.

Firstly, we match each pedestrian from the example with a pedestrian from the query. The couples that are selected are those with the less dissimilarity value (Figure 9).

Marios Kyriakou

The dissimilarity (A) is calculated using the following measurement function, which is the sum of the distances between the couples through all N frames:

$$A = \sum_{f=1}^{N} \sum_{i=1}^{Nped} \sqrt{\left(x_{query}^{f,i} - x_{example}^{f,i}\right)^2 + \left(y_{query}^{f,i} - y_{example}^{f,i}\right)^2}$$

where N_{ped} is the number of pedestrians in the query, f runs over the frames, the $x_{query}^{f,i}$ is the x coordinate and the $y_{query}^{f,i}$ is they coordinate of the i^{th} pedestrian in the f frame of the query.

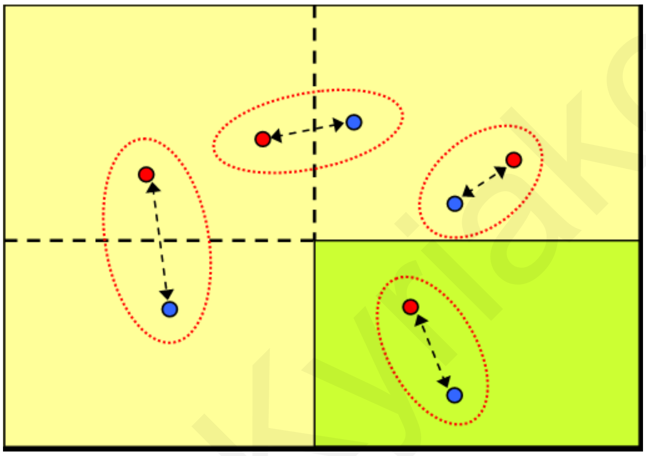


Figure 9: Match example pedestrians with query pedestrians.

If we have a pedestrian that is not present in a frame (he has left or has not yet been inserted) then we add to a penalty factor to A:

A = A + Penalty.

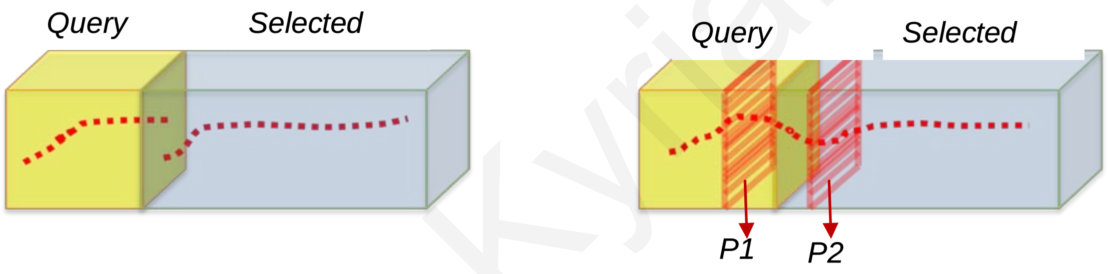
Having found the L "best" similar 3D blocks, where L is a predefined number, we choose one of them randomly.

3.5.2. Creation of the new 3D texture

Once the block is selected, we need to merge it into the output that has already been constructed. Copying the selected 3D block and pasting as it is does not give us a smooth transition between the query and the selected block (Figure 10a).

Marios Kyriakou

This problem is solved using interpolation between all matched couples, between the template and the similar 3D block, and creating the new synthesized 3D-texture. We find the two points (frames) where the two trajectories have the less difference between them (P1 from the query and P2 from the selected) and we make the cut at these points (Figure 10b). Between these points, we create a piece of new trajectory which is the result following the interpolation of the position of the pedestrian at the P1 and the P2 points. We do this for every couple and we create the new synthesized 3D block.



(a) (b)

Figure 10: (a) Before smoothing the new synthesized trajectory. (b) After smoothing using interpolation.

The new synthesized 3D block with N frames, is inserted in the output, to replace the existing K frames. The new N-K frames that have actually added to the data come from the input data that are real trajectories of real pedestrians. After we apply the algorithm for a complete loop over all m x n tiles we have extended trajectories by N-K frames.

Marios Kyriakou

3.5.3. Problems and solutions with the Synthesis

3.5.3.1. Tele-transporting characters

In the algorithm as described up to this point, a pedestrian moving in a direction opposite to the scan-line order used in the composition, might create problems. The problem arises from the fact that the query accounts only for the three sides that are already in the output and has no way of accounting for people entering from the other side (Figure 11). The query accounts only for the sides that are already in the output. Anyone coming from the part of the neighborhood that we did not examine had not been considered when those textures were processed and synthesized and would therefore have no trajectory entering.

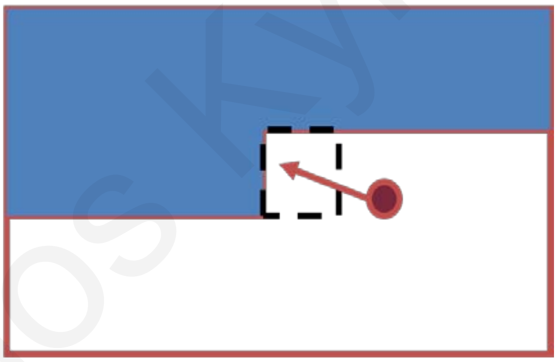


Figure 11: Tele-transporting characters problem.

We solved this problem by considering a circular neighborhood for the first K frames and calculating a Neighborhood Similarity Measurement Function for each pedestrian. This is an indication for the presence of pedestrians near the examined 3D block.

Marios Kyriakou

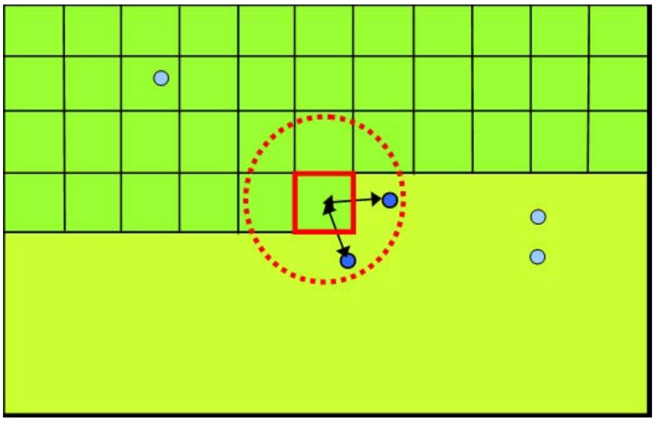


Figure 12: Calculation of the dissimilarity value A.

We calculate a weight measurement (B) for every pedestrian who is in the radius we examine in the 3D blocks that we have already processed:

$$B = \sum_{f=1}^{K} \sum_{i=1}^{Nped} \sqrt{\left(x_{T_{centre}} - x_{pedestrian}^{f,i}\right)^2 + \left(y_{T_{centre}} - y_{pedestrian}^{f,i}\right)^2}$$

where $x_{T_{centre}}$ and $y_{T_{centre}}$ are the x and y coordinates of the center of the tile, the $x_{pedestrian}^{f,i}$ and the $y_{pedestrian}^{f,i}$ is the x and the y coordinates of the ith pedestrian in the f frame. In the search process, after we end-up to a leaf, we choose a number of 3D blocks that have similar B values. This means that the example that we will finally choose will have similar indication for the presence of pedestrians and in this we are considering these incoming pedestrians. For these 3D blocks we calculate the dissimilarity value A to find the examples most similar to the query (Figure 12).

Marios Kyriakou

3.5.3.2. Insufficient Examples in the Database

The initial size of the tiles is the same for all the video, depending on the scene size and is set manually. The video was captured from a stable camera, so the scene for all the video recording has the same size. Since our input data is finite, there is always the possibility that a query defines behaviors substantially different from any of the examples in the database. In such a case, the dissimilarity values will be very high and choosing any of the examples will give unsatisfactory results.

To solve this problem we create another database with smaller blocks than the initial one, i.e., we use multiresolution on the size of the tiles.
We use 1/2 height x 1/2 width of the initial block (Figure 13).

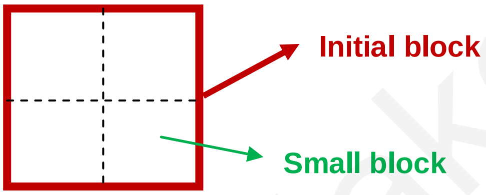


Figure 13: Use of multiresolution of the initial blocks.

Thus, if we cannot find a similar 3D block matching a query, we divide the query to four equal parts and for each one of these smaller blocks we do a search in the second database with the smaller examples. The synthesis phase for these smaller blocks remains the same.

3.6. Results

To test our algorithm, we used different sets of data each one exhibiting different behavior. These sets were divided into two categories. The first contained controlled simple data and the second real data taken from real people trajectories.
The synthesis phase was executed in real-time for all cases, while the preprocessing was done before the synthesis and its execution time depended on the size of the input data.

Marios Kyriakou

3.6.1 First category experiments – controlled input data

In this category, we conducted three sets of experiments, where the input data were simple controlled trajectories.

3.6.1.1. First category – first set of experiments

In the first set, we used the most simple input data possible, using two straight trajectories for two virtual characters. We expected to see the trajectories continued from our algorithm in the same direction and speed.

The parameters used for this first experiment were:

[Input data] = 100 frames

K = 12 frames

N = 50 frames

Number of iterations = 2

➔The trajectories were extended by 2x(N-K)= 2x(50-12)= 76 frames.

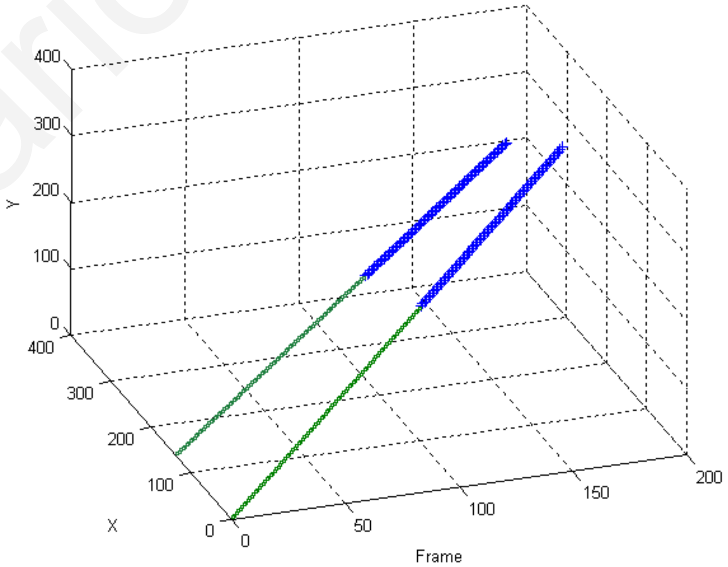


Figure 14: First experiment - two agents.

Marios Kyriakou

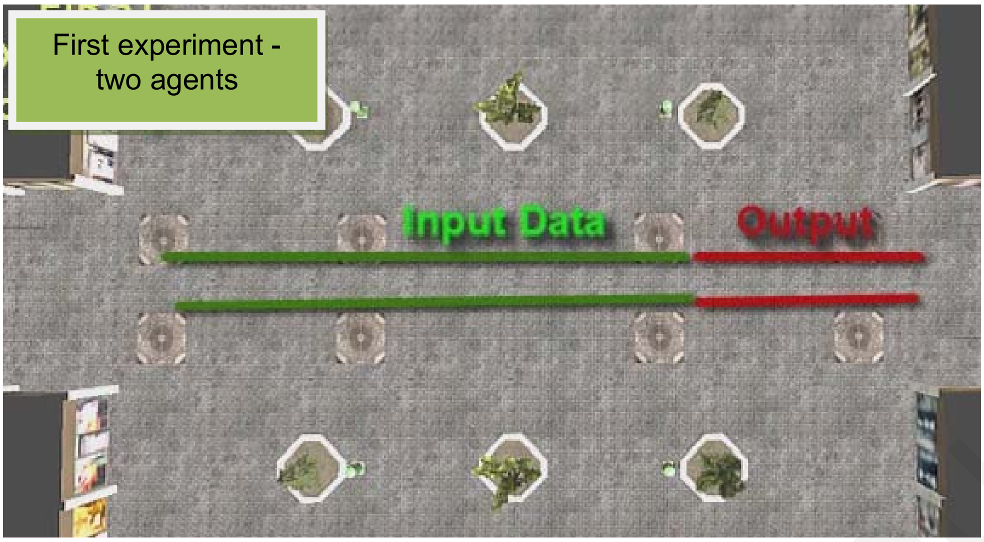


Figure 15: Input Data and Output - First experiment - two agents.

In Figure 14 we can see the input trajectories with green color and the output trajectories with blue color. The output trajectories for this set of data follow exactly the same behavior as the input trajectories, i.e., following a straight line to the same direction with the same stable speed and the distinction between input and output trajectories is impossible to determine. The same can be noticed in Figure 15.

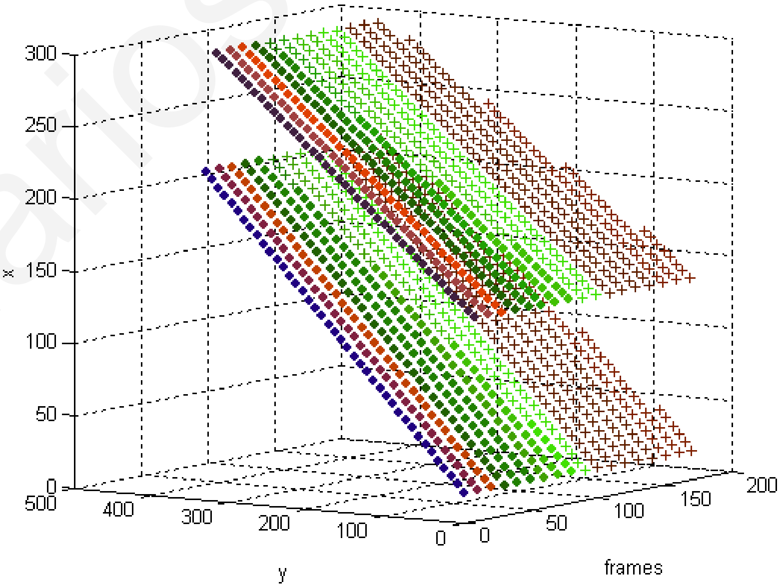


Figure 16: First set of experiments - multiple agents.

Marios Kyriakou

Figure 17: Input Data and Output - First set of experiments - multiple agents.

The same experiment was repeated with multiple agents present in each frame, all following one of the two shown trajectories (Figure 16 and Figure 17). Again, finding the distinction between input and output trajectories is impossible.

3.6.1.2. First category – second set of experiments

In the second set, we slightly increased the complexity of the input data, using three trajectories with one of the trajectories intersecting the other two. The number of agents in each frame was increased.

The parameters used for the second experiment were:

[Input data] =150 frames

K = 12 frames

N = 50 frames

Number of iterations = 3

The trajectories were extended by 3x(N-K)= 3x(50-12)= 108 frames.

Marios Kyriakou

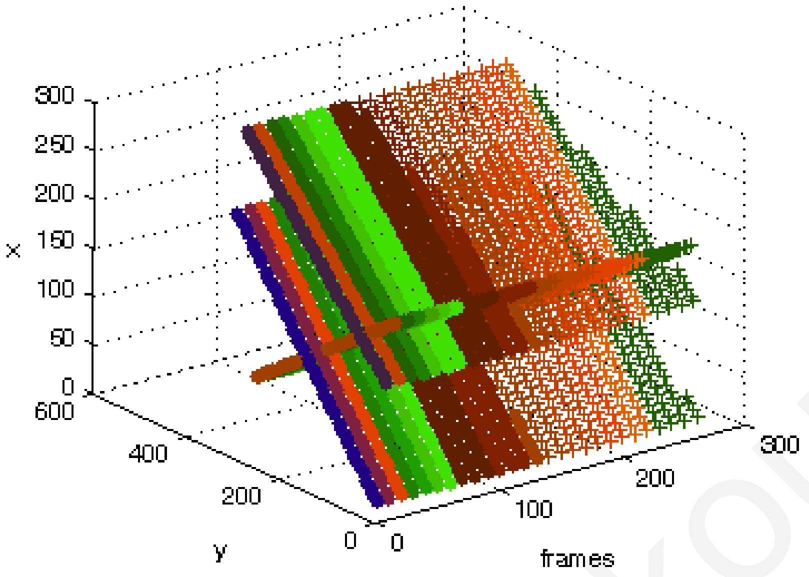


Figure 18: Second set of experiments.

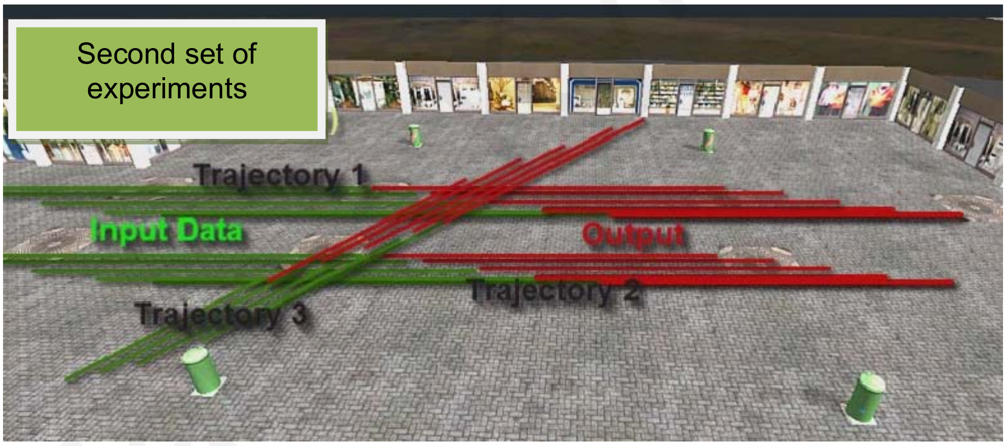


Figure 19: Input Data and Output - Second set of experiments

In this set of experiments we see exactly the same adequate performance (Figure 18 and Figure 19) as the first set. The agents' trajectories are in the same direction and speed as the input trajectories. Still, the distinction between input and output trajectories is impossible to determine.

Ma riakou

3.6.1.2 First category – third set of experiments

In the third set, there are more input data than the previous sets. The trajectories in this experiment correspond to a number of couples moving in the environment.

The parameters used for the third experiment were:

[Input data] = 160 frames

K = 14 frames

N = 60 frames

Number of iterations = 3

The trajectories were extended by 2x(N-K)= 2x(60-14)= 92 frames.

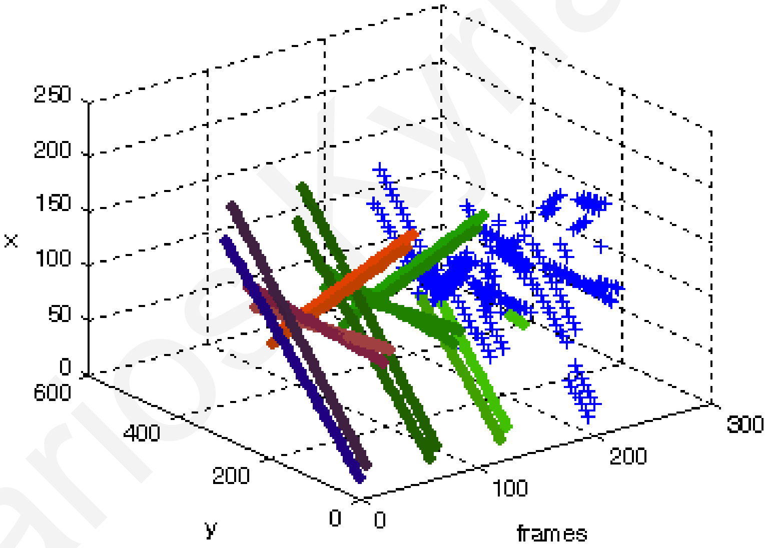


Figure 20: Third set of experiments.

Studying the results of these experiments (Figure 20), we can infer that even though the algorithm does not exhibit the same successful output as in the previous experiments, the synthesized trajectories follow the same behavior as the input data.

Marios Kyriakou

3.6.2. Second category experiments - Real input data

To further test our algorithm we created an example database using real data much more complicated and richer than in the first category of experiments. From the roof of a five story building we used a static camera to capture a video of approximately five minutes in length. Using a semi-automatic system, we tracked the pedestrians in the video and extracted the position (x, y) of each one of them in every frame.

At consecutive frames, the positions of the same pedestrians are most likely to be identical or very close. Thus, we sampled the data every 1:5 and the number of frames were thereby reduced. In total, we had about 10.000 frames. Every frame was divided in tiles by m columns and n rows (m=6, n=5, total 30 tiles). Setting the window size at 420 x 350 points, the tile size was 70 points. Overlapping the tiles (every 14 points in x and y) we have 26 tiles every column and 21 tiles every row (total 546 tiles). In order to create the 3D blocks we set N=60 (the number of the consecutive frames for each block) and K=15. Thus, we created about 5.460.000 3D blocks. A large number of these were actually empty, so we discarded them and we stored only those that had some information (positions of pedestrians). The actual multitude of these was about 1.700.000 3D blocks and they were stored in the database using the 6-level example tree.

Constructing the output using the 3D blocks of real data means that in effect, we are assigning our virtual agents the behaviors that are observed in the real data. If we have pedestrians in the video that are avoiding each other and have natural and plausible behavior, then this will be presented in the synthesized output.

Marios Kyriakou

Our results showed that for simple situations (a few pedestrians simply walking in a rather straight line) it works as expected, the pedestrians continued their trajectories with the same speed in the same direction as in the input data.

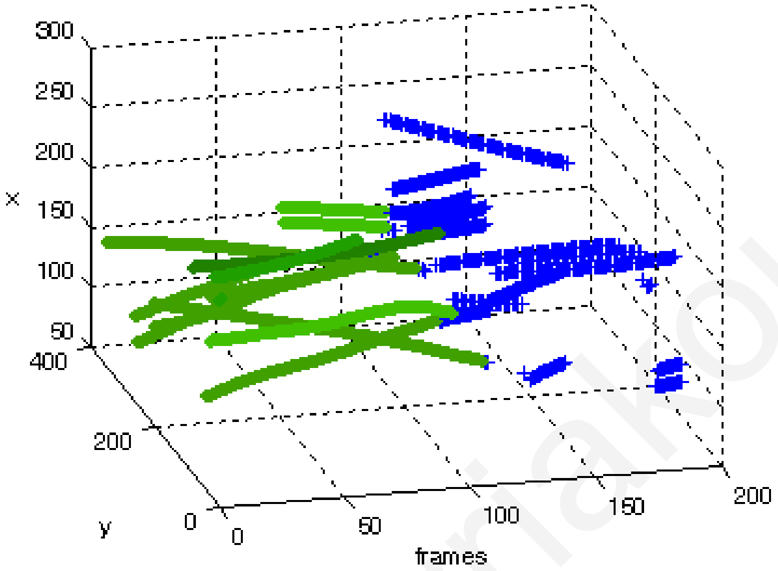


Figure 21: Real input data experiments and results.

Figure 22: Input data - Second category experiments.

Figure 23: Output - Second category experiments.

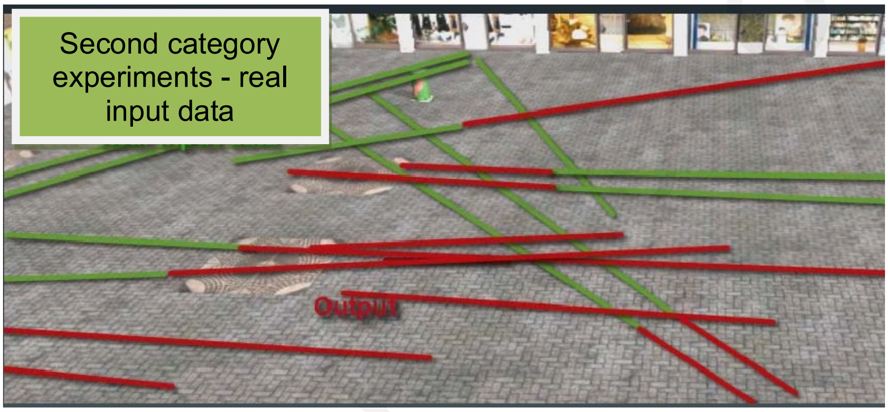


Figure 24: Input Data and Output - Second category experiments.

3.7. Discussion

In this chapter, a novel crowd simulation technique based on texture synthesis principles was presented. Since we do not make any assumptions on the behavior of the pedestrians, we can take examples from any real situation and from those we can synthesize new crowd behavior (new trajectories) that can run indefinitely. Our technique addresses the problem of populating virtual scenes with large virtual crowds at low computation costs and with plausible results.

Our main difference over the other data driven methods is that we do not process pedestrians individually, but we synthesize whole areas that may contain several pedestrians inside. This has the possibility of better capturing the interaction between neighboring agents.

Marios Kyriakou

Chapter 4
Interaction with Virtual Crowds in Immersive and semi- Immersive Virtual Reality systems

4.1. Introduction

In this chapter, we examine other behavioral characteristics that virtual crowds should have, besides a satisfactory crowd navigation method, and how is the user's behavior affected by virtual crowds in an IVE.

When it comes to dealing with a crowd (a bigger number of virtual characters) in a VE, a few different issues emerge since the participant might not pay so much attention to individuals, but rather what is happening overall [31]. For instance, a participant could notice the direction of a crowd, any agitation or an intense situation. Understanding how the participant is being influenced and how they react to several virtual events and situations could help us develop VEs that are more convincing, and with higher level of presence for the participants.

A number of studies have been carried out investigating how we perceive virtual crowds in VEs. Researchers used experiments to explore the impact of characteristics of groups in the received realism [7] [8] [9] and they found that the addition of groups of virtual humans improved the plausibility of crowd scenes if the group sizes and numbers were plausible.

The participant's behavior which is immersed in an IVE with virtual humans has been studied by a number of researchers in terms of maintaining the interpersonal distance

Marios Kyriakou

with the virtual humans (proxemics). Bailenson et al. [62] found that the more realistic are the virtual humans the greater distance the participant maintain with them. Participants tend to show negative reactions to violations of interpersonal space [63] and increased physiological reaction the closer they are approached by virtual humans [64] [65]. A more thorough background analysis is presented in Chapter 2.

Many aspects concerning the relationship between the user and the virtual crowd in a VR system remains to be studied. The objective of our study is to discover what effect the relationship between the user and the virtual crowd has on the user's behavior, perception of realism and his sense of presence under certain circumstances.

In particular, we examined the socialization of the user with virtual crowds that was implemented at different levels of interactivity in order to identify the user's reaction at a subjective and objective level. Additionally, we conducted our experiments with different type of Virtual Reality system in order to compare and discuss the sense of presence in relation to different user's VR experience.

Marios Kyriakou

4.2. Methodology

For the experiments, 50 volunteers were recruited. Thirty of them participated in experiments in a semi-IVR system and twenty in an IVR system. In every experiment, only one volunteer participated at a time. Each volunteer participated in three different experiments; each experiment presenting a scenario with virtual crowd exhibiting different level of interaction towards the participant.

The design of the experiment was repeated-measures (within-subjects), testing all participants under all three levels of interaction (Table 1). Since the number of subjects was rather small (n_1 = 30 & n_2 = 20) this method was preferred, making scheduling, organizing and training much faster and easier. Another reason for using a repeated-measures design was that there is less variance due to participant disposition [98]. A participant who is prone to being scrupulous will likely exhibit the same behavior in all the experiments he/she will participate in. Thus, the variability of the experiments' results will be more dependent on the different levels of interaction, rather than on behavioral differences between participants. Furthermore, the order that the three scenarios were presented to the participant was random, so as to get a more objective feedback.

Level 1	No collision avoidance and no interaction between participant and virtual characters
Level 2	Collision avoidance enabled but no other no interaction between participant and virtual characters
Level 3	Both collision avoidance and basic interaction between participant and virtual characters enabled

Table 1: Levels of interaction.

Marios Kyriakou

All participants were informed regarding the procedures of the experiment. They also gave their permission to be filmed. The participants were informed about the equipment they would use and were informed that they could withdraw from the experiments at any time. Finally, they completed a three-minute training session using the IVR and navigation system prior to the actual experiment, in order to familiarize themselves with the system.

After each scenario, participants were asked to fill in a web-based questionnaire (Table 10 – see Appendix A). There were questions taken from the SUS questionnaire [76] and some from the PQ questionnaire [49] slightly changed to fit to the experiment's content. The first questions concerned their gender and their prior experience with video games, while the rest of the questions addressed their experience in the experiment they had just completed. Some questions were about the virtual crowd’s awareness of each other and of the participant’s presence, while others asked about the realism of the virtual characters and the environment. There were also questions about the participant’s comfort, sense of presence and ease of completing his/her task.

4.2.1. The systems

The 3D interactive virtual environment was developed using the Unity3D[1] game engine. Several virtual character models were used in the scenarios, featuring different faces and somatotypes. The animations used for the motion of the virtual agents were motion-captured offline. A volunteer was asked to perform several different motions, which were recorded using the Phasespace Impulse X2 system and manipulated in Autodesk's MotionBuilder[2] prior to importing them into the Unity3D game engine. Motions were semantically segmented (i.e. walk, turn, stand, talk, wave, etc.) and were programmatically used in the scenarios. This allowed us to synthesize complex and dynamic behaviors for virtual characters in real-time.

The virtual characters were programmed to exhibit crowd behavior characteristics. Their trajectories were pre-calculated, including collision avoidance with each other. Collision avoidance with the user was not enabled in the first scenario.

The experiments took place in two different VR systems: an immersive and a semi-immersive one.

Marios Kyriakou

---

[1] http://www.unity3d.com

[2] http://usa.autodesk.com/adsk/servlet/pc/index?id=13581855&siteID=123112

4.2.1.1. Immersive VR System

The first set of experiments was conducted in a Cave-like projection based system [99]. This has three back-projected vertical screens (front, left and right) (3 m × 2.2 m) and a floor screen (from a ceiling mounted projector) (3 m × 3 m). Participants' heads were tracked with an Intersense IS 900 tracker, and they were given a wand to navigate through the environment (Figure 25).

Figure 25: A participant using the wand to navigate in the CAVE.

4.2.1.2. Semi - Immersive VR System

A custom-built semi-immersive VR system was also used for the second set of experiments, using a large screen projection wall, driven by a workstation computer with an Intel Pentium i5 3.2Ghz CPU, 8GB of RAM and an NVidia GeForce 525M graphic card.

Using a Kinect ([100]) for motion detection and human body tracking, the participants were able to navigate into the virtual world.

In order to move forward in the virtual world, the participants walked in place (Figure 26). To rotate their view, they raised their arm in the height of their shoulder (Figure 27) (left hand for rotating to the left; right hand to rotate to the right). The participants could walk and rotate at the same time (Figure 28).

Figure 26: A participant walks in place to move forward in the virtual world.

Figure 27: A participant raises her left arm to rotate to the left and her right arm to rotate to the right.

Figure 28: A participant walks and rotates at the same time.

4.2.2. The methods

We designed a 3D virtual environment representing an open-space mall with a significant number (33) of animated virtual characters. All virtual characters were programmed with collision avoidance behavior (enabled in the second and in the third scenario) and some basic interaction behavior towards the user (enabled only in the third scenario). These behaviors were setup prior the experiments and required no intervention by an operator.

The collision avoidance feature was enabled with a simple rule-based algorithm that calculates the appropriate path for each character to follow avoiding any upcoming collisions with other characters that are close to him (1-3 meters).

The instructions for participants about their task were to locate a child (a little girl) who was singing loudly and follow her wherever she would go. This was their primary goal and was clearly stated to them. In particular, the participants were told to try to be at a close distance to the child at all times, navigating into the virtual world. The child was programmed to follow a trajectory, where she came across other virtual characters, mostly coming from the opposite direction (Figure 29).

Marios Kyriakou

Figure 29: Following a child (little girl) going in the opposite direction of a group of other virtual characters.

The trajectories of the virtual characters were preprogrammed, so that the user would come face-to-face with many of them. The purpose of this was to have several possible interaction points between the participant and the virtual characters.

We distinguished three levels of interaction between the virtual crowd and the user. Based on this, we designed three different scenarios, introducing in each one a different level of interaction.

More specifically, we developed these three scenarios with different levels of interaction:

Scenario S1: the virtual crowd ignores the participant (the virtual characters do not avoid any collision with the participant, and have no other interaction with him/her) (Figure 30).

Scenario S2: the crowd avoids collisions with the participant but has no other interaction (Figure 31).

Scenario S3: the crowd interacts with the participant using some basic socialization (talking to him/her, looking at him/her, waving etc.) as well as applying collision avoidance with the participant (Figure 32).

Marios Kyriakou

Figure 30: Scenario S1 - virtual crowd ignores the participant (no collision avoidance).

Figure 31: Scenario S2 - virtual crowd avoids any collisions with the participant.

Figure 32: Scenario S3 - virtual crowd interacts with the participant (including collision avoidance).

In this study, the questionnaires were not the only method for getting participants' opinions and evaluating their behavior. As indicated in the literature, when studying presence, questionnaires are not viable as the only means for receiving participants' feedback. Experts suggest using both subjective and objective methods [56] [80].

Marios Kyriakou

A more objective method we used was the analysis of participants' trajectories. During each experiment, the trajectories in the virtual world of each participant and the virtual characters were recorded. Our main analysis interest was in the distance between the participant and the child in the virtual world during the experiment, calculating how close and for how long the participant remained with the child. This was used as a goal achieving evaluation.

Another method of studying participants' responses was the examination of the videos we recorded with the participant's behavior. More specifically, in the second and the third scenarios, most participants were trying to avoid collisions with virtual humans. When they realized a collision between them and a virtual character was about to happen, they either stopped walking and waited for the virtual character to pass, or they tried to turn and change their trajectory. Some participants returned a virtual character's wave or even answered their verbal salutation.

Moreover, many participants reported that they felt uncomfortable when they collided with virtual characters; this was mostly the case in scenario S2. In the first scenario, this was not the case. Participants mentioned that they stopped considering about collisions with the crowd after they realized that virtual characters did not avoid collisions with them and their only concern was following the child.

Marios Kyriakou

4.3. Results

Participants answered a questionnaire with nine closed-ended questions on a Likert scale ranging from 1 to 5 (1 = Minimum, 5 = Maximum) (Table 10 - see Appendix A). The answers of the questionnaires were gathered and statistically analyzed. Each question was treated as a variable and is presented in Table 2, in the subsequent statistical analysis.

Question number	Question
Aware_self	Virtual characters aware of myself
Aware_others	Virtual characters aware of each other
Easiness	Easiness of following the child
Presence	Feeling of presence
Comfort	Feeling comfortable
Realism_Child	Realism of child
Realism_Crowd	Realism of the virtual crowd (except for child)
Realism_Env	Realism of environment

Table 2: Questions descriptions.

Here we present the results of the questionnaire divided into 3 different categories: Validation (*Aware_self*) as a check for the validity of the participants' answers, Presence (*Aware_others, Presence, Realism_Child, Realism_Crowd,* and *Realism_Evn*) as questions concerning the user's sense of presence, and Performance (*Easiness* and *Comfort*) asking about their ability to complete their task. Finally, we present the results from our behavior measurements (distance analysis).

Marios Kyriakou

4.3.1. Validation question

We used question 1 (*Aware_self*), which concerned the crowd’s awareness of the participant, as a validation check for the overall participants' responses. Our assumption is that in the third scenario the crowd’s awareness of the participant would be stated as the highest, while the lowest one would be stated in the first scenario. As expected, the perceived virtual crowd’s awareness of themselves was significantly different between the 3 scenarios in both IVR and semi-IVR (test of Friedman, IVR: X^2 (2, n = 20) = 28.37, p <0.001 and semi-IVR: X^2 (2, n = 30) = 54.18, p <0.001). The Wilcoxon signed-rank test further suggested that, for both IVR and semi-IVR, there was a significant increase between scenario two to one (IVR: z = –3.25, p < 0.001, semi-IVR: z = -3.80, p < 0.001), three to one (IVR: z = –3.87, p < 0.001, semi-IVR: z = –4.90, p < 0.001), as well as three to two (IVR: z = –2.92, p < 0.001; semi-IVR: z = –4.76, p < 0.001).

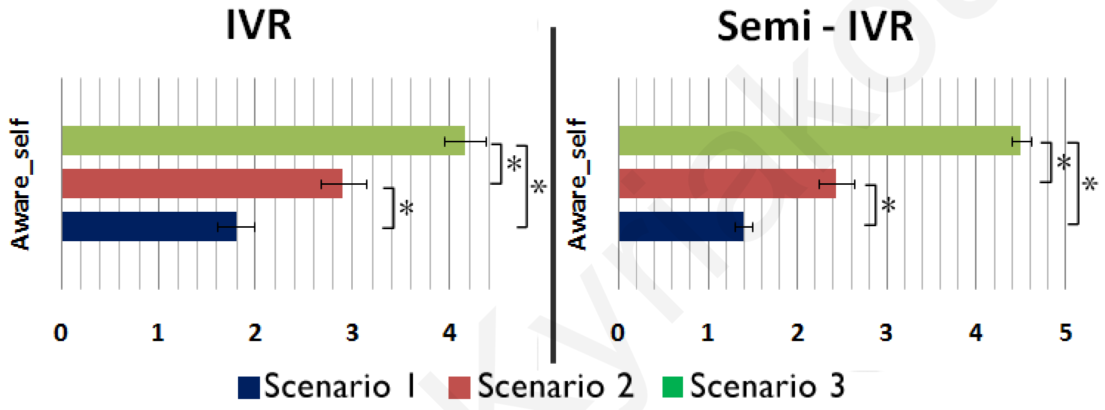


Figure 33: Evaluation of awareness of myself (Aware_self).
Means of participants' answers of both systems. Error bars present standard error of means. * = p<0.001.

Marios Kyriakou

4.3.2. Presence

Examining the answers of *Aware_others* gave us some interesting findings. The awareness among the virtual characters was programmed to be at the same level across the three scenarios. Still, the participants falsely believed that it had been raised from scenario S1 to scenario S2. This belief was even stronger in scenario S3 in the semi-IVR system.

The difference between the 3 scenarios of the IVR system was not statistically significant, in contrast with the results of the semi-IVR that were significant (test of Friedman, IVR: X^2 (2, n = 30) = 3.37, p =0.19) and semi-IVR: X^2 (2, n = 30) = 29.10, p

<0.001). The Wilcoxon signed-rank test revealed a statistically significant increase between scenario two to one for both systems (IVR: z = –2.15, p = 0.03, semi-IVR: z = –2.05, p = 0.04). The difference between scenario three to one was statistically significant only for the semi-IVR system (IVR: z = –1.86, p=0.06, semi-IVR: z = –4.08, p<0.001). Also, the difference between scenario three to two was statistically significant only for the semi-IVR system (IVR: z = –3.53, p = 0.77, semi-IVR: z = –3.75, p<0.001).

The evaluation of *Presence* concerning the sense of presence delivered responses as expected. The stated level of the presence feeling was significantly different between the 3 scenarios in both IVR and semi-IVR (test of Friedman, IVR: X^2 (2, n = 20) = 10.03, p =0.01 and semi-IVR: X^2 (2, n = 30) = 52.13, p <0.001). The Wilcoxon signed-rank test further suggested that, for both IVR and semi-IVR, there was a significant increase between scenario two to one (IVR: z = –1.98, p=0.048, semi-IVR: z = –4.27, p < 0.001), three to one (IVR: z = –2.83, p = 0.01; semi-IVR: z = –4.85, p <0.001), as well as three to two (IVR: z=–2.64, p = 0.01, semi-IVR: z=–4.52, p < 0.001).

The question *Realism_Child* addressed the perceived realism of the child. Note that the participant was almost always behind the child, trying to catch up with it and there were almost no collision and no interaction between the participant and the child. The difference between the 3 scenarios was statistically significant in both IVR and semi-IVR (test of Friedman, IVR: X^2 (2, n = 20) = 14.00, p < 0.001 and semi-IVR: X^2 (2, n = 30) = 6.09, p = 0.048). The Wilcoxon signed-rank test further suggested that there was a significant increase between scenario two to one only in the IVR system (IVR: z = –2.53, p = 0.01, semi-IVR: z = –1.63, p = 0.10). Also, there was an increase between scenario three and one, that was again statistically significant in the IVR system (IVR: z = –3.21, p < 0.001, semi-IVR: z = –1.90, p = 0.06). Nevertheless,

Marios Kyriakou

there was no statistically significant difference between scenario three and two in either system (IVR: z = –1.41, p=0.16, semi-IVR: z = –1.41, p = 0.16).

The realism of the crowd -the rest of the virtual characters- was stated as significantly different in all scenarios (*Realism_Crowd*) in both IVR and semi-IVR system (test of Friedman, IVR: X^2 (2, n = 20) = 6.76, p =0.02 and semi-IVR: (2, n = 30) = 38.95, p<0.001). The Wilcoxon signed-rank test further suggested that, for both IVR and semi-IVR, there was a significant improvement on the crowd realism between scenario two to one (IVR: z = –3.17, p =0.01, semi-IVR: z = –3.35, p <0.001), three to one (IVR: z = –2.14, p = 0.02; semi-IVR: z = –4.18, p < 0.01), as well as three to two (IVR: z = –2.56, p =0.01, semi-IVR: z = –4.41, p < 0.001).

The virtual environment was exactly the same in all three scenarios. Nevertheless, answers to question *Realism_Env* exhibited a slightly more positive perception about the realism of the environment in scenario two than in scenario one.
The difference between the 3 scenarios was statistically significant only in the semi-IVR (test of Friedman, IVR: X^2 (2, n = 20) = 0.32, p =0.85 and semi-IVR: X^2 (2, n = 30) = 8.67, p =0.01). The Wilcoxon signed-rank test further suggested that, there was a significant improvement on the virtual environment realism between scenario two to one only for the semi-IVR (IVR: z = –0.58, p = 0.56, semi-IVR: z = –2.24, p = 0.03). Also, there was an increase between scenario three and one, that was again statistically significant in the semi-IVR system (IVR: z =–0.04, p = 0.97, semi-IVR: z = –2.33, p = 0.02). Nevertheless, there was no statistically significant difference between scenario three and two in both systems (IVR: z = –0.56, p = 0.58, semi-IVR: z = –1.00, p= 0.32).

Marios Kyriakou

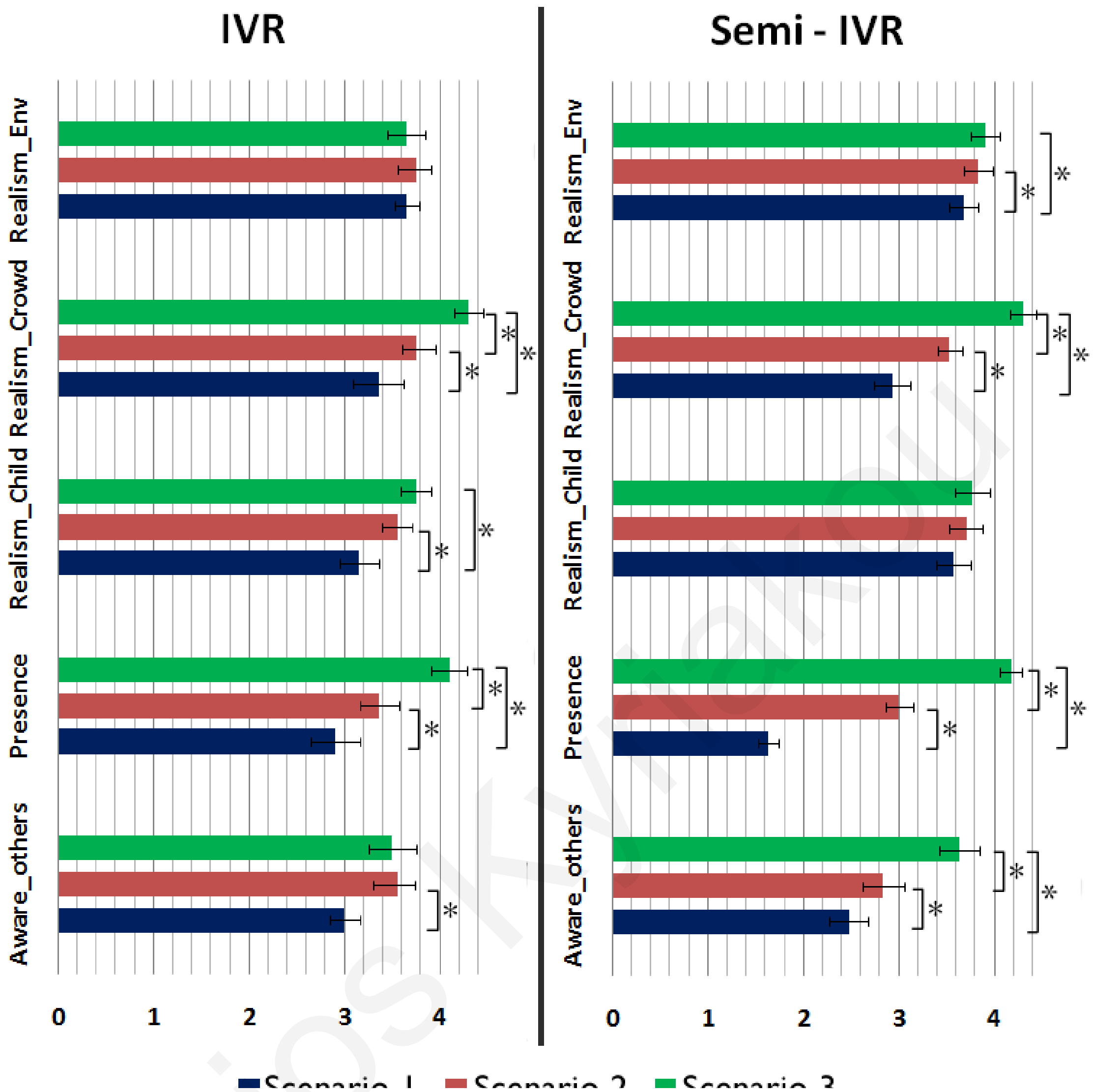


Figure 34: Evaluation of feeling presence questions of both systems. Error bars present standard error of means. * = p<0.05.

Marios Kyriakou

4.3.3. Subjective performance- Goal Achievement

Two questions were asking the participants how easy it was for them to complete their target -follow the child- and how comfortable was the use of the system. The outcome of the evaluation of the *Easiness*, showed some interesting findings.

This was stated as significantly different in all scenarios in both IVR and semi-IVR system (test of Friedman, IVR: X^2 (2, n = 20) = 618.45, p <0.001and semi-IVR: (2, n = 30) = 16.94, p <0.001). The Wilcoxon signed-rank test further suggested that, for both

IVR and semi-IVR, there was a statistically significant decrease on the *easiness* comparing scenario two to one (IVR: z = –2.31, p = 0.02, semi-IVR: z = –2.29, p = 0.02). However, there was a statistically significant increase comparing three to one (IVR: z = –2.17, p=0.03, semi-IVR: z = –2.86, p<0.001), as well as three to two (IVR: z = –3.53, p < 0.001, semi-IVR: z = –3.62, p < 0.001).

Overall, participants stated the scenario two as the least easy in terms of achieving their goal (i.e., follow the child). Scenario one had a slightly higher mean score, while the easiest (highest mean score) scenario was identified as the third.

The question inquiring about the participants' feeling of comfort in the system, showed the same responses as for *Easiness*. This was stated as significantly different in all scenarios in both IVR and semi-IVR system (test of Friedman, IVR: X^2 (2, n = 20) = 24.70, p <0.001 and semi-IVR: (2, n = 30) = 19.40, p <0.001). The Wilcoxon signed-rank test further suggested that, for both IVR and semi-IVR, there was a statistically significant decrease on the comfort comparing scenario two to one (IVR: z = –2.60, p = 0.01, semi-IVR: z = –2.38, p = 0.02). However, there was a statistically significant increase comparing three to one (IVR: z = –3.21, p<0.001, semi-IVR: z = –2.35, p = 0.02), as well as three to two (IVR: z = –3.81, p < 0.001, semi-IVR: z = –3.62, p < 0.001).

We believe that, in both the IVR and semi-IVR system, a low feeling of comfort negatively affected the participant's opinion of being able to achieve his/her task. This is also based on the fact that the behaviors of these two variables (*Easiness* and *Comfort*) are similar in all three scenarios.

Marios Kyriakou

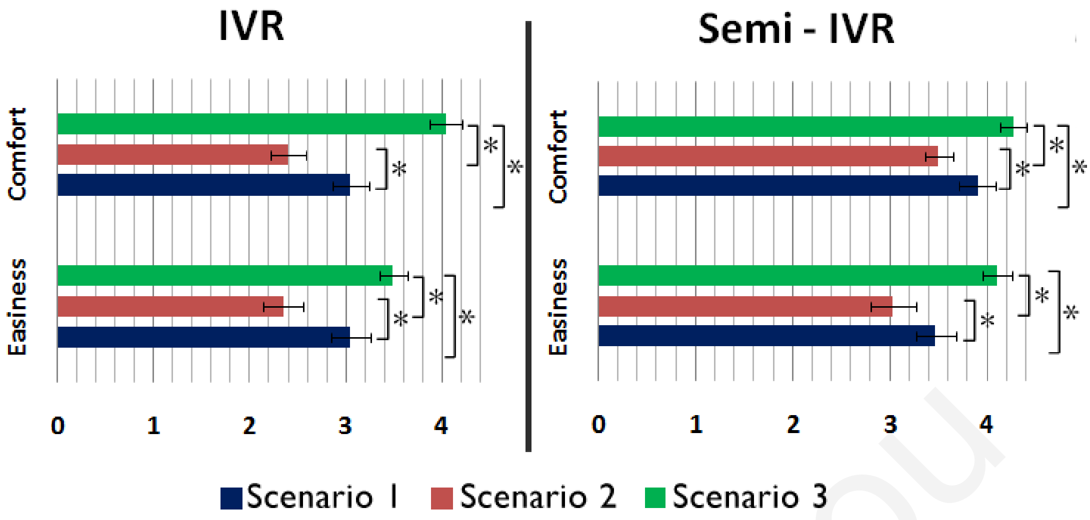


Figure 35: Evaluation of ease of following the child (Easiness), and feeling comfort in the VR system (Comfort) of both systems.
Error bars present standard error of means. * = $p<0.05$.

Marios Kyriakou

4.3.4. Behavioural Analysis

During the experiment, the trajectories in the virtual world of the participant and the virtual characters were recorded and analyzed. From the trajectories over time we extracted objective measurements for the participants' performance. In particular, participants were told that their goal was only to follow the child that was in front of them and remain close to it wherever it went. We concentrated our analysis on the distance between the participant and the child during the experiment, measuring how close and for how long the participant was to the child. More specifically, we took three measurements (in meters) and calculated their averages for each scenario: the minimum, maximum and average distance.

In addition, we calculated the time (in seconds) that the participant remained more than five meters away from the child (Table 3).

Variable	**Description**
$\boldsymbol{D_{min}}$	The minimum distance (in meters) between the participant and the child during the experiment.
$\boldsymbol{D_{max}}$	The maximum distance (in meters) between the participant and the child during the experiment.
$\boldsymbol{D_{avg}}$	The average distance (in meters) between the participant and the child during the experiment.
$\boldsymbol{T_{D>5}}$	The time (in seconds) that the participant remained more than five meters away from the child.

Table 3: Variables **-** Objective Analysis.

In Table 23 and Table 24 (see Appendix) there is an analysis of means and standard errors for each of the four objective measurements. Inspecting the following figures (Figure 36 and Figure 37); we can infer that the participant managed to be closer to the child in the first scenario when there was no collision avoidance and no interaction between the participant and the virtual crowd. The worst scores were recorded in the third scenario with collision avoidance and basic interaction enabled. The second scenario, with collision avoidance enabled but no other interaction, was somewhere in the middle.

Marios Kyriakou

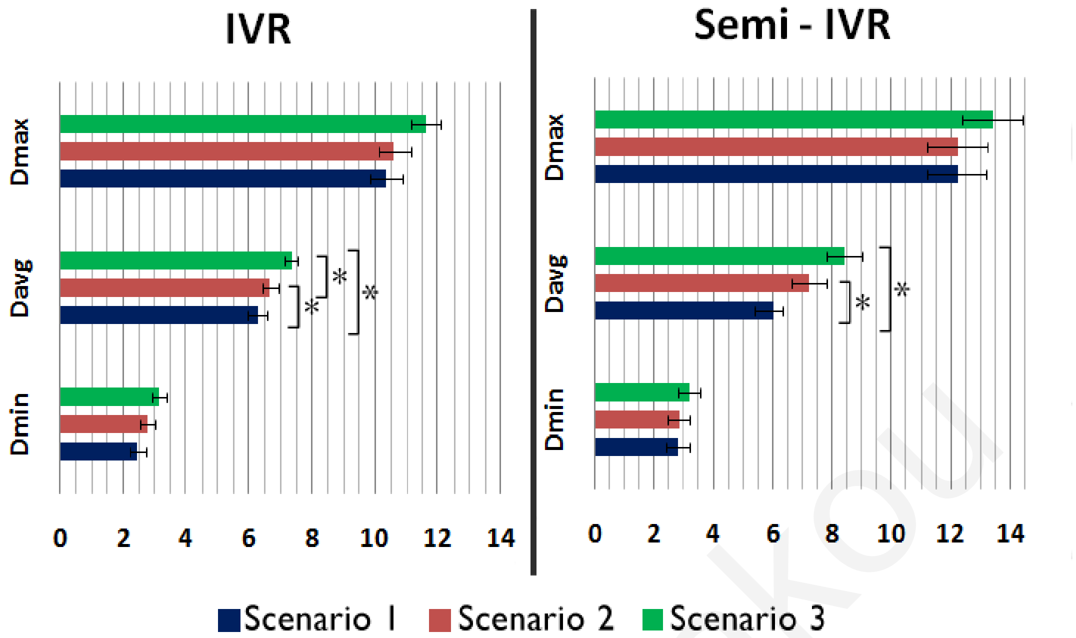


Figure 36: Minimum (D_{min}), Average (D_{avg}) and Maximum Distance (D_{max}) between the participant and child in each scenario.
Error bars present standard error of means. * = p<0.05.

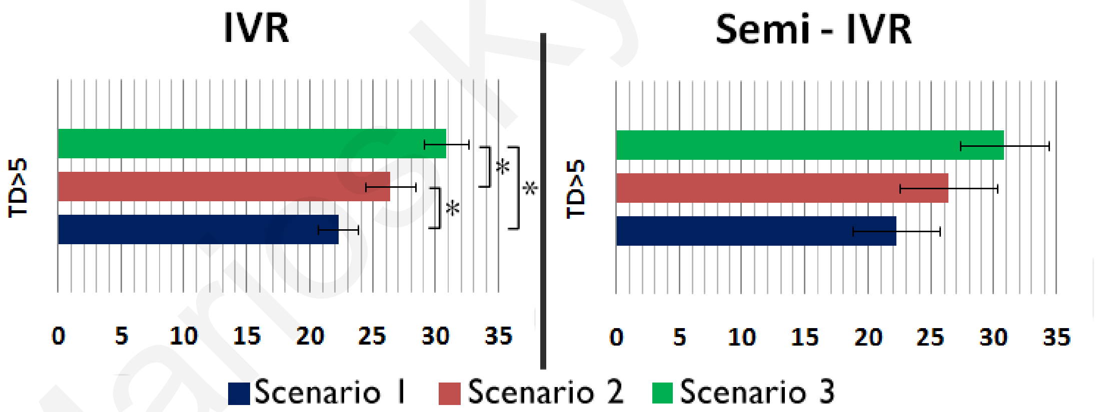


Figure 37: Mean time ($T_{D>5}$) that the participant remained more than five meters away from child in each scenario.
Error bars present standard error of means. * = p<0.05.

Data were tested for normality using the one-sample Kolmogorov-Smirnov test and the Shapiro-Wilk test. The results of these tests showed that almost all p-values were above 0.05, revealing that our datasets are normally distributed (Table 25 and Table 26 - see Appendix A). Thus, for the statistical analysis of these data we used parametric tests for repeated-measures experiments' data.

Maria Kyriakou

To examine whether the four variables statistically differed between scenarios we conducted four repeated measures ANOVA with Greenhouse-Geisser correction. The variables D_{min} and D_{max} in both the IVR and the semi-IVR system had no statistically significant differences. Moreover, the $T_{D>5}$ in the semi-IVR also had no statistically significant differences. On the other hand, the variable D_{avg} did differ statistically significantly between scenarios in both systems (F(1.42. 26.96) = 14.95. p < 0.001 in the IVR system -Table 29 and F(1.99, 39.87) = 9.65, p < 0.001 in the semi-IVR system - Table 30). Additionally, the variable $T_{D>5}$ (F(1.98. 38.00) = 36.23. p < 0.001 - Table 31) in the IVR system did differ statistically significantly between scenarios.

Post hoc tests using the Bonferroni correction (to reduce the chances of obtaining false-positive results) revealed that for the IVR system, comparing scenario S1 with scenario S2, there was an increase in average distance between the user and the child (6.27 ± 0.30 m. and 6.65 ± 0.31 m. respectively) which was statistically significant (p= 0.016). Average distance in scenario S3 was higher than in the other two scenarios (7.39 ± 0.22 m) which was statistically significant compared to scenario S1 (p = 0.001) and scenario S2 (p = 0.017) (Table 32 – see Appendix A).

Studying the semi-IVR system using the Bonferroni correction, we found that there was also an increase in average distance between the user and the child (6.00 ± 0.32 m, 7.20 ± 0.59 m, respectively) when comparing S1 with S2, which was not statistically significant (p= 0.107). However, average distance in scenario S3 was higher than in the other two scenarios (8.41 ± 0.60 m) which was statistically significant compared to scenario S1 (p = 0.001), but not statistically significant compared with scenario S2 (p = 0.129) (Table 33 – see Appendix A).

Observing the average distance of each participant with the child (Figure 38 and Figure 39) and the time that each participant remained more than five meters away from the child (Figure 40 and Figure 41), our conclusions were the same. Overall, in scenario S3, the average distance and the time that the participant remained further

Marios Kyriakou

than five meters from the child was higher, while in scenario S1, these measurements presented lower scores.

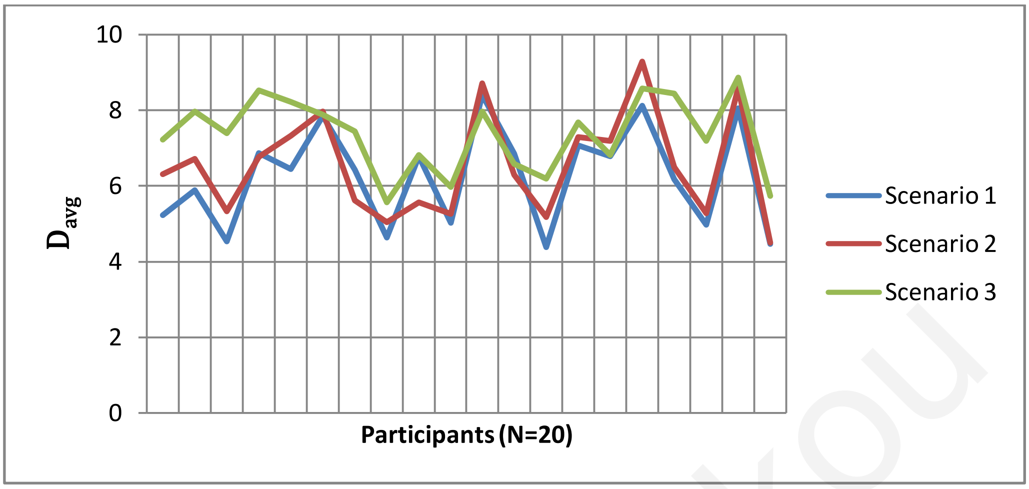


Figure 38: Average distance between each participant and child – IVR system.

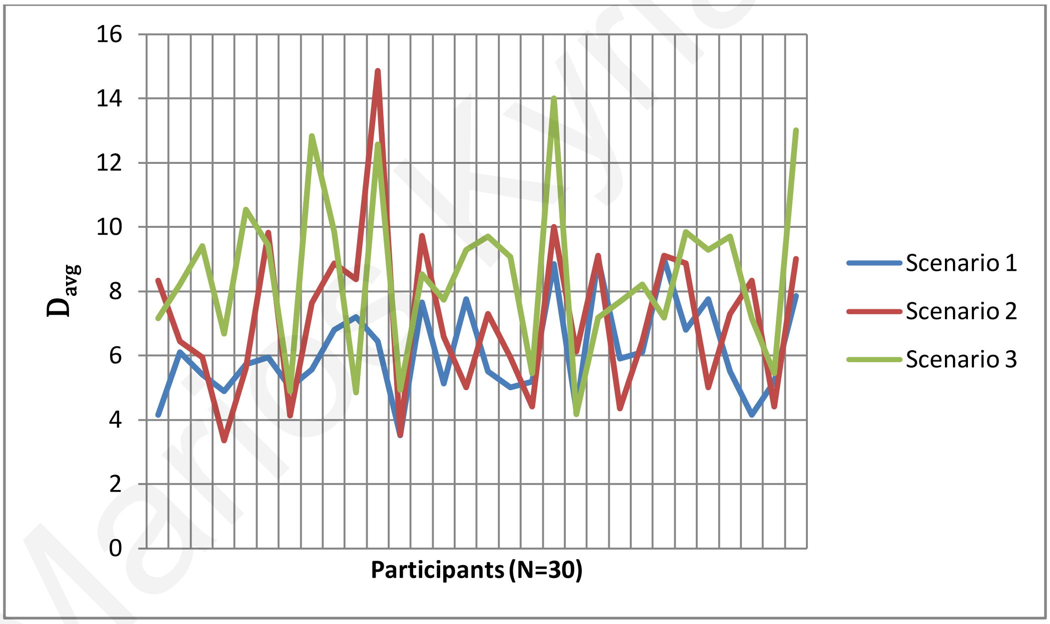


Figure 39: Average distance between each participant and child – semi-IVR system.

Marios Kyriakou

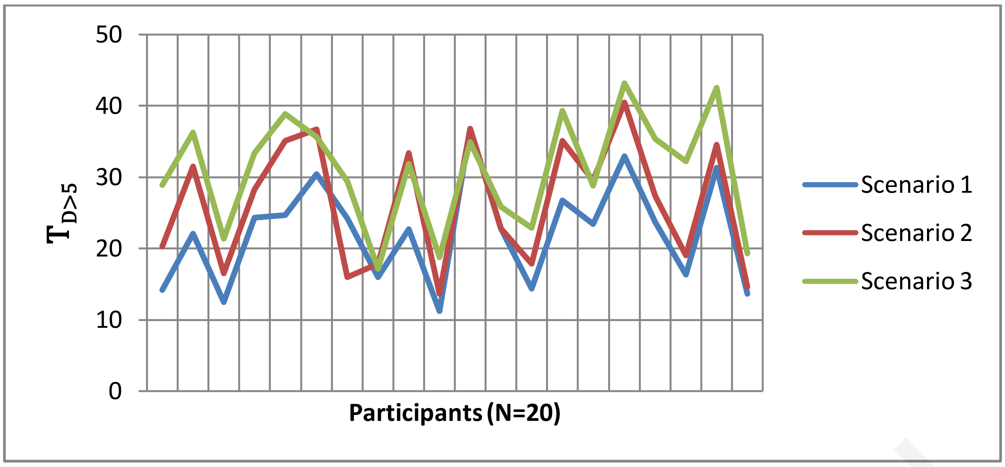


Figure 40: Time (in seconds) that the distance between participant and child was more than five meters –IVR system.

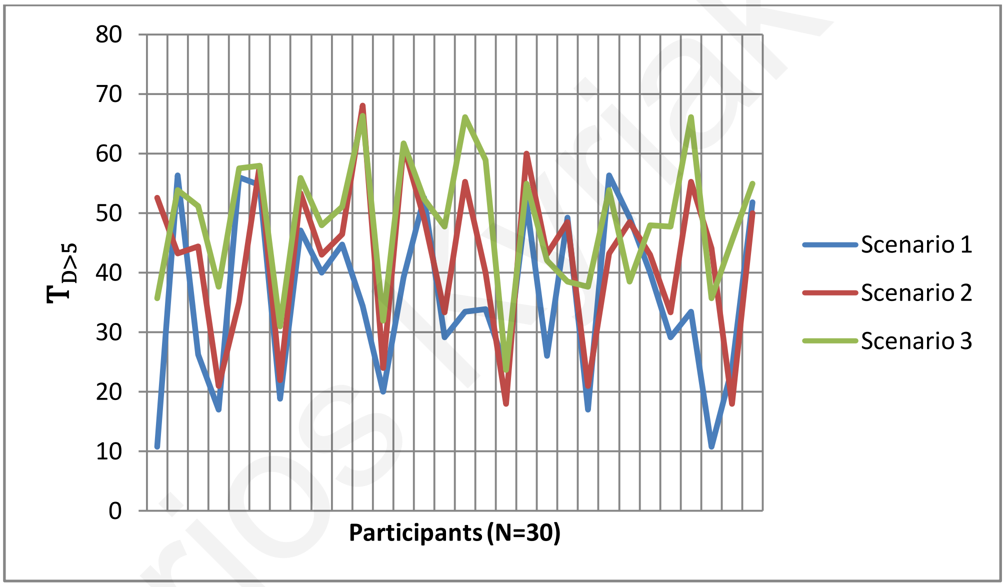


Figure 41: Time (in seconds) that the distance between participant and child was more than five meters – semi-IVR system.

Marios Kyriakou

Therefore, we can conclude that when we enabled both collision avoidance and interaction with the users for the virtual characters, the users elicited a statistically significant increase in average distance between themselves and the child, but a non-statistically significant increase if we only enabled collision avoidance.

4.4. Discussion

This study yielded several important insights regarding user interaction with a virtual crowd. To begin with, enabling collision avoidance between the virtual crowd and the user in an IVR or in a semi-IVR system proved to be an arguable issue. On one hand, we found a small statistically significant increase in the distance between the user and the child in the virtual world in the IVR system, and a small non-statistically significant increase in the semi-IVR system when we enabled collision avoidance between the virtual characters and the participant. The growth in the distance was even bigger and statistically significant in both systems when we enabled both collision avoidance and interaction with the user. This may mean that both the interaction and the collision avoidance may reduce the user's performance regarding his/her primary goal, which included navigating into the VR environment with a certain target. Additionally, users stated that they felt less comfortable when there was collision avoidance than when there was no collision avoidance.

On the other hand, when collision avoidance between virtual characters and the user was enabled, the user judged the characters, the environment and the whole VR system as more realistic and lifelike.

Moreover, extending the relationship between the user and the virtual crowd with more than collision avoidance, i.e. introducing some basic level of interaction between them, made the user's experience even more positive. The evaluation of all examined factors by the user was considerably better when there was a basic level of interaction with the virtual crowd. The behavior of the crowd was perceived as more realistic and the user reported a stronger sense of presence.

Marios Kyriakou

Facilitating collision avoidance between the user and the virtual crowd was not enough to create a plausible and pleasing-to-use VR system. On the contrary, collision avoidance by itself, even when it is a significant factor of lifelikeness of the virtual crowd, accommodated a feeling of discomfort.

We conclude that collision avoidance should be accompanied with basic interaction between the user and the virtual crowd, such as verbal salutations, look-at the user, waving and other gestures. This may increase both the plausibility and feeling of comfort in the VR system, thereby enhancing the sense of presence.

Marios Kyriakou

Chapter 5
User-crowd interactions in an IVE and the effect on presence

5.1. Introduction

In many IVR applications, users are expected to be actively involved in the presented environment. Conducting a second series of experiments, we examined the factors that may cause a stronger sense of presence to the user in a populated IVE and encourage the user to be more active. The user in these experiments has the opportunity to connect with the crowd, since he might be part of a team, people talk to him, stand around him and interact with him. Thus, he might be more affected by the crowd behavior than by the basic behavior that virtual humans may present like collision avoidance, waiving etc.

Marios Kyriakou

We need to know how the participant interacts and behaves with the presence of a virtual crowd, so that in the creation of an IVR system, these aspects can be more attentively addressed. We concentrated our research on intense events, where a participant was in VE with other virtual humans and a fight was commenced, since it is expected that in intense events there is a higher possibility for stronger participant involvement, thereby provoking a higher sense of presence, and “forcing” the participant to react. Furthermore, the participants behavior can be more objectively measured in such as stress-induced environment [78] [79].

In social psychology there have been several studies exploring the participant-bystander behavior [101] [102] [103] in intense events. Recent research in the context of bystander intervention in violent incidents [12] showed that if the participant belonged to the same group as the a victim of a violent incident, this would act as an incentive for the bystander to intervene. Of particular importance is that this circumstance operates even when the perpetrator and the victim are virtual characters. Another interesting aspect of this work is that the bystander participant intervened more often when the victim looked at to the bystander for help, rather than when the victim did not interact with the bystander.

This chapter concentrates on the effects of two fundamental factors. One is the *group membership* of the participant. The participant could be in a group of virtual humans that were presented in the IVR system. In our system we created two groups of virtual humans that were fans of two different football teams (two of the most historical and important football clubs in our country). For the participant it was easy to understand which team supported each virtual human, since they all wore t-shirts, jackets or caps with their team's colors and signs.

The other factor that we examined was the *responsiveness* of the virtual humans towards the participant. This was implemented with several ways. The virtual humans were looking at the participant; they were talking him, and they were calling on the participant to take part the occurring event in a number of ways.

Our main hypothesis is that if the participant is a member of one group (Ingroup), then he/she is more likely to intervene and stop the fight than if he/she is not (Outgroup). Secondly, we address the hypothesis that if the virtual characters are responsive towards the participant and interact with him/her in several ways, then this would encourage the participant to be more involved in the incident, thereby increasing his/her interventions.

Marios Kyriakou

5.2. Methodology

We recruited 40 adult volunteers to participate in a two-factor between-groups experiment, with a single volunteer participating at a time. We selected 20 participants that were fans of the victim's team (Ingroup) and 20 that were not affiliated with any of the teams presented in the VE (Outgroup). Each of these two groups of participants were further divided into two subgroups of 10, one group participating in the experiment with virtual characters interacting with the participant (Responsive), and the other group with virtual characters that ignored the participant (Non-Responsive). Therefore, the 40 participants were divided in 2x2 groups, as shown in Table 4.

Number of participants	Group Membership	Responsive (On/Off)
10	Ingroup	On
10	Ingroup	Off
10	Outgroup	On
10	Outgroup	Off

Table 4: Experiment design and number of participants for each scenario.

As the participants entered the laboratory with the virtual reality system (one by one), they were informed about the procedure of the experiment. They were asked forconsent to be filmed. Nobody disagreed. They then filled in a questionnaire providing information about their age, health, and their experience with game playing and previous familiarity with virtual reality (Table 34 - see Appendix B). The participants were also informed of the equipment that they would use and were assured that they could withdraw from the experiment at any time, especially in case they felt discomfort. Finally, they were fitted with the motion tracked rigid bodies and

Marios Kyriakou

spent five-minutes in a training session using the IVR and navigation system, prior to the actual experiment, in order to familiarize themselves with the technical aspects of the experiment.

The navigation system involved motion tracking the legs of participants only, freeing their arms from holding any controller (e.g. a gamepad). This way, participants could explore the environment more naturally, while they could intervene both verbally and physically. This navigation system was custom-built taking into consideration that participants should be able to move in the open-space mall and importantly, their hands should be free, allowing them to make physical interventions. On the floor, there was a mark-up circle with one meter in diameter. The participants stood inside this circle and could move forward by placing their foot outside the circle in the same direction they was facing. To move backwards, they had to place their foot outside of the circle behind them, similar to the way we naturally walk towards a location, however without making the physical steps. To change their viewpoint, the participants would place their foot outside the circle but at a considerably wide angle (more than 30 degrees) in the desired direction. This re-orientation of view was performed smoothly and at a natural speed.

After the experiment, the participants completed a questionnaire (Table 35) with a set of 11 closed-ended questions about their experience in the experiment, including questions from the SUS questionnaire [76] and questions from the PQ questionnaire [49] slightly changed to fit to the experiment's content and scenario. Finally, the participants were interviewed with a set of short questions about their feelings, what they thought were the factors that distracted them and what had affected their disposition to intervene while taking part in the experiment. Each experiment, including the filling out of questionnaires and the interviews, lasted about 25 minutes.

Marios Kyriakou

In the experiments, two binary variables were examined that were assumed to have affected the participant's response in several ways:

1. **Crowd responsiveness**: this is a binary factor that defines whether the virtual crowd notices the presence of the participants or not (Responsive = 'On' or 'Off'), enabling the virtual characters to interact with the participants with several ways. Some just stare at the participants, others can talk to them and others called them to participate in the incident.

2. **Group membership**: this was defined according to the participant. The participant could be a fan of either one of the two teams (Ingroup), or not (Outgroup).

Marios Kyriakou

5.2.1.The Virtual Reality System

The experiments were conducted in a specially fitted Virtual Reality laboratory with a three-screen surround projection wall, which was driven by a workstation computer with an Intel Pentium i7 3.2Ghz CPU, 8GB of RAM and a pair of NVidia GeForce 280 graphic cards. The display resolution was 3072 x 768 pixels produced by a set of three View Sonic projectors. Participants wore custom made rigid bodies on their shins, which were used to interactively navigate in the virtual environment. A Phasespace Impulse X2 optical active motion tracking system with eight cameras was used to track the rigid bodies at a high frequency (480Hz).

The 3D interactive virtual environment was developed using the Unity3D[3]game engine. Several virtual agent models were used in the scenario, featuring different faces and somatotypes. All 3D models were dressed in fan outfits of the two

---

[3] http://www.unity3d.com

respective local football clubs featuring the teams' colors and logos. The animations used for the motion of the virtual agents had been motion-captured offline. A volunteer was asked to perform several different motions, which were recorded using the Phasespace Impulse X2 system and manipulated in Autodesk's MotionBuilder[4], prior to importing them into the Unity3D game engine (in FBX format). Motions were semantically segmented (i.e. walk, turn, stand, talk wave, etc.) and were programmatically used in the scenario. This allowed us to synthesize complex and dynamic behaviors for virtual characters in real-time for a more complicated animation scenario.

(a) (b) (c)

Figure 42: (a) The three-screen wide projection IVR set-up. (b) A user in the Phasespace Impulse X2 motion capture system (c) The user's captured animation.

The Phasespace Impulse X2 system (Figure 42) uses eight cameras that are able to capture 3D motion using modulated LEDs. These cameras contain a pair of linear scanner arrays operating at high frequency each of which can capture the position of any number of bright spots of light as generated by the LEDs.

Using a lab equipped with a three-screen wide projection immersive virtual reality set-up the participant was able to move and interact with the environment and the virtual characters. The movements of the participant were again captured using the Phasespace Impulse X2.

Marios Kyriakou

---

[4] http://usa.autodesk.com/adsk/servlet/pc/index?id=13581855&siteID=123112

5.2.2. The Scenario

A 3D virtual environment was designed to represent an open-space mall with two groups of animated virtual characters. The outfits of the characters closely resembled those of two local football fan clubs, i.e. green outfits for the victim's team and yellow for the perpetrator's team. All virtual characters were programmed agents with predefined event-triggerable behaviors that required no intervention by an operator. The instructions for the participants about their task in the scenario were to locate two specific virtual characters of one team that were having a conversation. The participants were told to act as they saw fit during the scenario. Any other information was deliberately withheld from the participants regarding the nature of the scenario. The scenario involved no interaction or engagement of the participant with the victim prior to or during the violent incident. This enabled us to examine whether virtual bystanders could instigate intervention behavior in the participant, despite the participant having had no direct contact with the victim before.

When the participant approached the two specific virtual characters, the characters automatically initiated a conversation. Depending on the experimental condition examined, the virtual characters involved the participant in the conversation (Responsive) or ignored him/her (Non-Responsive). A few seconds later, one member from each group of characters moved quickly to face one another and a verbal argument ensued (Figure 43). As the argument began, a group of twelve fans, later to be identified as fans from the same team as the perpetrator, moved to the location of the incident (Figure 44a). The incident then escalated from a verbal dispute to a physical fight (Figure 44b). One of the virtual characters (the victim) was kicked to the ground, by another (the perpetrator), and called for help (Figure 45a). Immediately, fans of the victim's football club responded by running to the incident and trying to help stop the fight (Figure 45b).

Marios Kyriakou

Figure 43: One group of fans moving forward.

(a) (b)

Figure 44: (a) Two virtual humans from different groups facing each other at a closed distance. (b) The two virtual humans get into a physical fight.

(a) (b)

Figure 45: (a) One of the two fighting virtual humans (the victim) falls down and calls for help. (b) Virtual humans from the same team with the victim are responding to the victim's calls for help.

5.3. Results

In order to get participant feedback, three methods were used. Firstly, each experiment was recorded and analyzed in order to see how many verbal and physical interventions the participant made. Verbal interventions were counted as verbal utterances trying to stop the fight. Physical interventions were physical hand moves made towards the two virtual characters involved in the fight (the victim and the perpetrator). When the participant was using the navigation system to move in the environment, this was not counted as physical intervention.

Secondly, the participants were given a questionnaire following the experiment that contained closed-ended questions. Thirdly, they were interviewed using short questions about their feelings and reactions. These included questions about the factors they thought were more important for their reactions and the factors that distracted them from the experience. Their answers were coded and analyzed; conducting a statistical analysis to these three types of data, we checked whether the initial hypothesis was correct concerning the two major influencing factors for the participant's behavior. In addition, using symbolic regression for the interventions of the participants and the experimental factors as reported by the participants (questionnaires and coded interviews), any correlation between them is explored.

Marios Kyriakou

5.3.1. The participants’ interventions

In the analysis phase, we counted the number of interventions that each participant made, both verbally and physically, using the recordings of the experiments.

Firstly, we see from Table 5 that in general, we had more interventions when the virtual crowd was responsive, and when the participant was in the same group as the virtual victim (Ingroup).

Verbal Interventions						
	Responsive					
	Off		On		All	
	Mean	St.Dev	Mean	St.Dev	Mean	St.Dev
Outgroup	0.30	0.67	2.00	2.30	1.15	1.87
Ingroup	1.80	2.15	2.90	2.84	2.35	2.51
All	1.05	1.731	2.45	2.56	1.75	2.27
Physical Interventions						
	Responsive					
	Off		On		All	
	Mean	St.Dev	Mean	St.Dev	Mean	St.Dev
Outgroup	1.40	1.776	1.60	2.221	1.50	1.96
Ingroup	2.20	2.098	2.80	2.616	2.50	2.32
All	1.80	1.936	2.20	2.441	2.00	2.18
Total Interventions						
	Responsive					
	Off		On		All	
	Mean	St.Dev	Mean	St.Dev	Mean	St.Dev
Outgroup	1.70	2.263	3.60	2.914	2.65	2.720
Ingroup	4.00	3.496	5.70	4.620	4.85	4.082
All	2.85	3.100	4.65	3.911	3.75	3.600

Table 5: Means and standard errors of number of Verbal, Physical and Total Interventions.

The Poisson regression model with robust variance was used to determine adjusted prevalence ratios and a 95% confidence interval was adopted [104] [105]. Poisson regression with robust variance is an option for estimating Prevalence Ratio in cross-sectional studies, when the dependent variable is count, as it was in our case.

Marios Kyriakou

The inclusion of variables was made one by one, as were the interaction terms between the variables. In the final model we kept only those variables with a significance level of $p<0.05$.

5.3.1.1. Verbal interventions

The evaluation of the ratio between the residual deviance of the model (79.51) and degrees of freedom (33) in the Poisson regression showed a rather high value (2.4), which indicates that there was over-dispersion of our data.

To solve this violation of the Poisson condition we used a quasi-likelihood function.

The gender factor had no statistically significant difference ($p=0.57$). In addition, the results indicated that there was no interaction between Responsiveness and Gender ($P=0.64$) or between Group_Membership and Gender ($p=0.92$), and these factors were thus excluded from the final model (Table 6).

Parameter	**Estimate**	**p**
Constant	-1.20	0.037
Responsiveness	1.90	0.002
Group_Membership	1.79	0.004
Responsiveness x Group_Membership	-1.42	0.039
AIC = 158.44		

Table 6: Final model for Verbal Interventions.

As such, the model is statistically significant according to an Omnibus test (Likelihood X2=25.069, df=3, p=0.000).

There was no significant relationship between Gender and Verbal Interventions. However, there was a significant relationship with respect to Responsiveness and Group_Membership.

Marios Kyriakou

5.3.1.2. Physical interventions

The evaluation of the ratio between the residual deviance of the model (76.76) and degrees of freedom (33) in the Poisson regression showed a rather high value (2.3), which indicated that there was over-dispersion of our data.

To solve this violation of the Poisson condition, we again used a quasi-likelihood function.

The only statistically significant aspect in this model was the Gender (p=0.011). Responsiveness and Group_Membership had no statistically significant difference (p=0.39 and p=0.13). In addition, the results indicate that there was no interaction between Responsiveness and Group_Membership (p=0.64), between Responsiveness and Gender (p=0.25) or between Group_Membership and Gender (p=0.22), and these factors were thus excluded from the final model (Table 7).

Parameter	**Estimate**	**p**
Constant	0.54	0.043
GenderFemale	-2.66	0.011
AIC = 162.44.		

Table 7: Final model for Physical Interventions.

As such, the model is statistically significant according to an Omnibus test (Likelihood X2=16.046, df=1, p=0.000).

There was no significant relationship between Responsiveness and Physical Interventions and between Group_Membership and Physical Interventions. However, there was a significant relationship with respect to Gender.

Marios Kyriakou

5.3.1.3. Total interventions

The evaluation of the ratio between the residual deviance of the model (88.75) and degrees of freedom (33) in the Poisson regression showed a rather high value (2.7), which indicated that there was over-dispersion of our data.

To solve this violation of the Poisson condition we again applied a quasi-likelihood function.

The results indicate that there was no interaction between Responsiveness and Gender (p=0.50), between Responsiveness and Group_Membership (p=0.10) or between Group_Membership and Gender (p=0.92), and these factors were therefore excluded from the final model (Table 8).

Parameter	**Estimate**	**p**
Constant	0.89	0.000
Responsiveness	0.54	0.001
Group_Membership	0.58	0.001
GenderFemale	-0.96	0.000
AIC = 203.60		

Table 8: Final model for Total Interventions.

As such, the model is statistically significant according to an Omnibus test (Likelihood X2=43.051, df=3, p=0.000).

There was no statistically significant interaction term between variables. However, there was a significant relationship with respect to Responsiveness, with respect to Group_Membership and with respect to Gender.

Marios Kyriakou

5.3.2. The participants' interventions - Qualitative Analysis

It was interesting to see whether there was a relationship between other factors (except "Responsiveness" and "Group_Membership") and the number of interventions made by participant. In order to study this, we used symbolic regression [106] which does not rely on linearity. Symbolic regression uses genetic programming to discover symbolic expressions of functions that fit the given data set [107]. We used a free software tool called Eureqa [108] for detecting any mathematical relationships in our experimental data.

Physical Interventions

Using the Eureqa program (run for 1600 core hours, 22 equations were reported) we ended up with Equation (1), where:

$$Group = \begin{cases} 0{:}Outgroup \\ 1{:}Ingroup \end{cases}$$

$$Responsive = \begin{cases} 0{:}Non-responsive \\ 1{:}Responsive \end{cases}$$

$$Gender = \begin{cases} 0{:}Male \\ 1{:}Female \end{cases}$$

The rest of the variables were derived from the questionnaire (Table 35 - see Appendix B).

$$\mathbf{PhysicalInterventions}$$
$$= Group\left(OtherSafety + Responsive\left(ShouldStopIt - 3.2\right) - CallHelp\right)$$
$$+OtherSafety^2 + 0.8Uncomfortable^2 - 1.8OtherSafety.Uncomfortable$$

Eq. 1: Physical Interventions (R^2 = 0.75, Fitness = 0.34, Size = 28)

Marios Kyriakou

This equation (Eq.1) shows that if Group = 0 (Outgroup) then the first term vanishes, and the Physical Interventions are influenced strongly by the variable *OtherSafety* (feeling of worrying about the safety of other agents) and there is a small positive influence by the variable *Uncomfortable* (feeling of being uncomfortable with the whole situation).

Verbal Interventions

The Eureqa program was used again and run for 1800 core hours. It reported 25 equations. The model with one of the smallest fitness values and low complexity value for the Verbal Interventions is shown in Eq(2).

$$\boldsymbol{VerbalInterventions}$$
$$= Responsive\left(1.76Uncomfortable - ShoudStopIt\right)$$
$$+\frac{0.171OtherSafety.CouldStopIt}{Uncomfortable - 0.377} - 0.0379OwnSafety.CallHelp$$

Eq. 2: Verbal Interventions (R^2 = 0.67, Fitness = 0.29, Size = 29)

The equation (Eq.2) shows that if Responsive =0 (non-Responsive) then the first term vanishes, and the Verbal Interventions are influenced strongly by the variable *OtherSafety* (feeling of worrying about the safety of other agents) and the variable *CouldStopIt* (feeling of having the ability to stop the fight) and a negative influence by the variable *OwnSafety* (feeling of worrying for own safety) multiplied by the variable *CallHelp* (feeling of asking for help).

5.3.3. The questionnaires

The post-experiment questionnaire included 11 closed-ended questions on a Likert scale ranging from 1 to 5 (1 = strongly disagree, 2= disagree, 3 = neutral, 4 = agree,

Marios Kyriakou

5 = strongly agree) (Table 35 - see Appendix B). These questions were used to collect data about the participant's emotional state and intentions during the experiment. Each question was treated as a variable in a subsequent statistical analysis and the results of which are presented in Table 9**.**

Variable number	Variable description
V1	I felt fear about the fight outcome
V2	I felt afraid for my own safety
V3	I wanted to call for help
V4	I wanted to help the victim
V5	I was angry with the perpetrator
V6	I was angry with the victim
V7	I felt that I could stop the fight
V8	I wanted to stop the fight
V9	I felt like I was watching a movie
V10	I wanted to get out of the scene
V11	I felt uncomfortable with the whole situation

Table 9: Variables' descriptions.

Marios Kyriakou

Variables were tested for normality using the one-sample Kolmogorov-Smirnov test. The finding was that the majority of variables were not normally distributed (Table 38 - see Appendix B). Thus, the use of non-parametric tests is more appropriate for analysis of these variables and are presented below.

Responsiveness (On vs Off)

A Mann-Whitney U test was used to test possible differences in the eleven variables between Non-Responsive and Responsive groups (Table 39 - see Appendix B). The results of this test showed that the mean ranks between the Non-Responsive and Responsive groups did not statistically significant differ for all the tested variables.

Group_Membership (Ingroup vs Outgroup)

A Mann-Whitney U test was also used to test for possible differences in the eleven variables between Outgroup and Ingroup categories (Table 40 - see Appendix B). The results showed that the Group_Membership feeling significantly affected some of the variables.

More specifically, participants were more angry with the perpetrator (variable V5) when they belonged to the same group as the virtual victim (mean rank = 25.95) than when they did not belong to the same group (mean rank = 15.05), U= 91.00, z=-3.13, p= 0.002.

Similarly, the feeling of "wanting to stop the fight" (variable V8) was stronger for participants belonging to the same group as the virtual victim (mean rank = 24.43) than not (mean rank = 16.58), U= 121.50, z= -2.36, p= 0.018.

Gender (Male vs Female)

Another Mann-Whitney U test was used to test for possible differences in the eleven variables between males and females (Table 41 - see Appendix B). The main finding was that gender affected the feeling of being able to stop a fight, since the feeling "I felt that I could stop the fight" (variable V7) was stronger for male participants (mean rank = 23.39) than females (mean rank = 13.75) U= 87.00 , z=-2.46, p= 0.014.

5.3.4. The Interviews

After each experiment, each participant was interviewed with questions regarding their feelings and thoughts about their experience. The answers of the participants were coded and analyzed. The interviews mainly focused on the participant's feelings, factors that they believed were significant for their reactions and factors they believed distracted them from their experience.

Marios Kyriakou

5.3.4.1. Responsiveness

Tables 42 to 49 (See Appendix B) show the different answers for each interview question and their frequencies for the categories Responsiveness = On and Responsiveness = Off, since these were the most interesting ones. Following on, the most important findings are presented:

1. The participants answered that their responses were genuine (realistic) in both categories (Responsiveness = On and Responsiveness = Off) at a high percentage 75% (Table 42 - see Appendix B). This implies that we can consider the answers of both categories to be reliable.

2. In the Responsiveness = Off scenario, a significant percentage (45%) of participants answered that they would have intervened more if the system was more interactive (45%), while only a few (15%) stated the same opinion in the Responsiveness = On (Table 43 - see Appendix B). This may mean that the participants in the experiments with the responsive crowd believed that the system was interactive enough to provoke their interventions and that there was no need for more interaction.

3. If the victim was an acquaintance of the participants, this would have made them intervene more (Responsive= 25%, Non-Responsive = 30%) (Table 43 - Appendix B). This statement increases the impact of the conclusion that group membership raises the possibility of the participant intervening, which is analyzed in detail in the following section “Group membership” at points 2 and 4.

Marios Kyriakou

4. Only 15% of the Responsiveness = On scenario compared to 30% of the Responsiveness = Off said that if the incident was less intense/violent they would have intervened less (Table 44 - see Appendix B). This may mean that the participants in the Responsiveness = On paid less attention to the severity of the incident rather than those in the Responsiveness = Off scenario.

5. The main factor that tended to draw the participants out of experience was the use of the navigation system. Other factors were different for each scenario (Reactive, Non-Reactive) (Table 45 - see Appendix B).

6. Except for the feeling of anxiety/stress, the percentages of the other feelings were quite different in the Responsiveness = Off and in the Responsiveness = On scenario. Curiosity was given as answer by 60% in the Responsiveness = Off scenario, while only half of this percentage (30%) mentioned the same feeling in the Responsiveness = On scenario. Moreover, when Responsiveness = On, participants seemed to experience stronger feelings such as anger, fear, and embarrassment (Table 46 - see Appendix B).

7. The most realistic characteristic about the crowd was answered for both scenarios to be their conversations/voices. Especially in the case of the participants in the Responsiveness = On scenario, this was mentioned by almost everybody (90%). Crowd steering, fighting and general character animations were mentioned by participants of both scenarios in similar percentages (~33%) (Table 47 - see Appendix B).

Marios Kyriakou

8. In the Responsiveness = Off scenario, 50% of participants answered that crowd behavior regarding the fight was realistic, but only 20% of participants from the Responsiveness = On scenario, gave the same answer. On the other hand, 35% of participants in the Responsiveness = On scenario, stated that the characters' appearance/graphics were realistic, while only 5% in the Responsiveness = Off mentioned the same characteristics (Table 47 - see Appendix B). This might mean that when the crowd was responsive, the participant paid more attention to the characters' appearance. Perhaps this was because the more realistic behavior raised participants' expectations regarding the appearance of the virtual characters.

9. The characteristic that most participants mentioned as less realistic about the crowd was their behavior regarding the fight (30%) for the Responsiveness = Off scenario, while for the Responsiveness = On scenario, 35% answered the character animations as less realistic (Table 48 - see Appendix B). This can again be explained as a result of more realistic behavior raising the participants' expectations on the appearance.

Marios Kyriakou

5.3.4.2. Group Membership

We also separated the tables using group membership as a criterion into two categories; the Outgroup, consisted of participants that did not belong to the same group as the victim, while the Ingroup consisted of participants that were in the same group as the victim. This variable appears to play an important role in the behavior and perception of the participant. More specifically:

1. Some participants in the Outgroup category stated that they would prefer more interaction (25%) and some felt detached from the system (10%). On the contrary, a very small percentage of Ingroup participants said that more interaction was needed (5%) and nobody said that he/she felt detached. (Table 50 - see Appendix B).

2. The most frequent answers of Ingroup participants on what would have made them intervene more in the incident was the acquaintance with the victim (30%) and the intensity/violence (30%) of the incident (Table 51 - see Appendix B). This implies that the Ingroup participants consorted with the victim, considering also the statement that if the victim was alone some Ingroup participants would intervene more (10%) but this was not the case for anyone in the Outgroup.

3. The interactivity of the system was also an important reason for more interventions, but was mentioned at a higher percentage by Outgroup (35%) than Ingroup (25%) participants. The realism (of the whole scenario) was also stated by Outgroup participants (20%) as a reason of more interventions, while this was not important for Ingroup participants (5%) (Table 51 - see Appendix B).

4. The conclusion that Ingroup participants consorted with the victim was strengthen by the statement that, if only strangers were involved (abolishing group membership) in the incident then some Ingroup (25%) participants would intervene less, while this was not mentioned at all by Outgroup participants (Table 52 – see Appendix B).

Marios Kyriakou

5. There was no difference in the answers of Ingroup and Outgroup participants in terms of the factors that drew them out of the experience. Both categories answered the main reason for this to have been the use of the navigation system (Outgroup = 45%, Ingroup = 35%) (Table 53 – see Appendix B).

6. There were some interesting results in the analysis of the statements of feelings from both categories of group membership. Ingroup participants stated stronger feelings than Outgroup participants. More specifically, anxiety and stress were stated as by 70% of Ingroup participants but only by 25% of Outgroup participants. In addition, feelings of anger and fear were stated almost twice as many times by Ingroup than by Outgroup participants. The most frequent mentioned feeling for Outgroup participants was curiosity (60%) (Table 54 - see Appendix B).

7. Both Ingroup and Outgroup participants stated the most realistic characteristic of the crowd as being their conversations/voices. The difference in their answers was that Ingroup participants mentioned as a realistic characteristic of the crowd their character animations at high percentages (general = 45% and fight animations = 40%) and the character appearance/graphics (30%), while Outgroup participants stated these characteristics at a much lower percentage (general animations = 20%, fight animations = 25%, character appearance/graphics = 10%). (Table 55- see Appendix B). This can be explained as if the participant belonged to the same group then he/she would intervene more, which consequently make the participant pay more attention to the appearance and the animations of the crowd.

Marios Kyriakou

8. For the less realistic characteristics of the crowd both categories gave almost identical answers except for one. Ingroup participants stated ata much higher percentage (25%) the faces/facial expressions of the virtual characters as a less realistic characteristic than was the case for the Outgroup participants (5%) (Table 56 - see Appendix B). Note that there was no facial expression on any facial expression or lip sync imposed any virtual character. From this, we can imply that when the scenario involved the affiliation of the participant with a group of virtual characters, then the participant expected realistic facial expressions.

5.4. Discussion

The main conclusion that we can draw from the results of these experiments is that if the virtual crowd is responsive towards the participant, then the participant tends to intervene more in an incident in an IVE. In particular, participants in the responsive-scenario experiments showed a higher number of interventions, had stronger feelings (anger, fear) and were affected less by the intensity of the incident than the participants in the non-responsive scenario. In addition, participants in responsive-scenario experiments paid more attention to character appearance and animations than to crowd behavior.

Another interesting finding is that if the participant belongs to a group of (virtual) people in a virtual environment increases the possibility of the participant intervening and be more involved in an incident.

Marios Kyriakou

Gender seems to play a significant role that must be taken into consideration when designing this kind of system, since males showed a considerably higher number of physical interventions.

In order to enhance the sense of presence in IVR, we can introduce a responsive virtual crowd and provide characteristics to the IVR in order for the participant to identify themselves as member of a group of characters (e.g. choose specific colors, clothes, gestures, etc.).

Marios Kyriakou

Chapter 6
Conclusions

6.1. Main Contributions

This thesis concentrated on improving the quality of crowds simulation by introducing an example-based technique as a solution to the crowd navigation problem as well as on examining the main behavior characteristics that a believable virtual crowd should have towards the user's experience, in order to successfully simulate crowds in an IVR system.

Firstly, in Chapter 3, we presented a solution for the crowd navigation problem. In particular, we introduced a novel example-based technique based on the principles of texture synthesis. Our technique addresses the problem of populating virtual scenes with large virtual crowds at low computation costs and with plausible results. We do not process pedestrians individually, but synthesize whole areas that may contain several pedestrians inside. This has the possibility of better capturing the interaction between neighboring agents.

Our method does not make any assumptions about the behavior of the pedestrians; instead, it takes examples from real situations and from those synthesizes new crowd navigation paths (new trajectories) that can run indefinitely.

Supposing that we have a satisfactory method for crowd navigation, we studied what other behavioral attributes the virtual crowds should have and how the user's behavior is affected by virtual crowds in an IVE. In Chapter 4, we used experiments

Marios Kyriakou

to examine the user’s behavior in IVR and semi-IVR systems by enabling collision avoidance and basic interaction between virtual humans and the user.

We found that enabling only collision avoidance between virtual humans and the user, does not necessarily guarantee that the plausibility of the VR system will be raised or that it will be more pleasing to use. Conflictingly, facilitating only collision avoidance under certain circumstances may accommodate a feeling of discomfort and could have a negative impact on the user’s effort to accomplish his/her predefined target.

Furthermore, we found that by extending the relationship between the user and the virtual crowd with more than collision avoidance and introducing some basic level of interaction between them, the user’s experience becomes more positive. The evaluation of all examined factors by the user is as a result considerably better and the behavior of the virtual crowd was perceived as more realistic and plausible.

We can conclude that in certain circumstances, such as in our presented stress-induced scenario within a populated environment, collision avoidance should be accompanied with basic interaction between the user and the virtual crowd. This may increase both the plausibility and feeling of comfort in the IVR system, thereby enhancing the sense of presence.

In Chapter 5 we conducted a different set of experiments examining the main factors that cause stronger feelings and may encourage the user to be more active in a populated IVE. In these experiments, the scenario included an intense incident; a fight between virtual humans who were divided into two adversarial groups. The virtual crowds where either “responsive” or “non-responsive” towards the user. The participants in the experiments were either members of one group or not members of

Marios Kyriakou

any group. Thus, we actually studied two major factors: the “responsiveness” of the virtual crowd regarding the user and the “group membership” of the user.

The results showed that if the virtual crowd is noticing and interacting with the user, then the user tends to be more involved in an incident, has stronger feelings and is less affected by the intensity of the incident than the users in the non-responsive scenario. Moreover, users are more likely to pay more attention to character appearance and animations than to crowd behavior, when the crowd is responsive to the user.

Examining the second factor, we found that if the user belongs to a virtual crowd group, then the possibility of being more involved and intervening in an incident is higher than if he/she does not belong to any group.

We also discovered that in experiments that comprised of intense incidents, gender seems to play an important role. Male users are more likely to commit a higher number of physical interventions; thus, the possibility of males being more involved is higher than for females.

Therefore, in order to enhance the sense of presence and raise the possibility of the user being more active in a similar scenario, virtual crowds with responsive behavior towards the user can be used in the simulation and combined with characteristics (identity, clothes, colors) the user may identify with as a member of a group of virtual humans.

Marios Kyriakou

6.2. Future directions

In terms of crowd navigation, it would be interesting to use our proposed technique to produce more complex crowd behavior in terms of crowd navigation. In this way, we can use the proposed technique to combine several inputs and simulate a crowd shown in real complex situations. We can therefore, simulate the conditions present in a real city (crosswalks, shops, entrances, squares, malls, dense and sparse crowds), enriching our database, by capturing and analyzing video-clips from these places.

Many aspects need to be thoroughly examined regarding the virtual crowd and the user's behavior. We believe that there are several important directions for future work in reference to virtual crowd behavior in an IVE.

- It would be useful to examine the plausibility of different group formations and sizes in different types of environments. The environments could be open areas (such as an open-space mall or a square) or closed constrained areas (such as halls or corridors). The crowd might consist of different sizes of groups. The virtual humans could be individuals (singles), groups of two virtual pairs, groups of three (triples) or more. These two characteristics can be combined and studied using experiments, and by having participants evaluate each case. The outcomes may help to decide a plausible way for populating a virtual environment of a specific type. We can also observe real crowds in real environments to extract statistics for the formations they present. Using these statistics, we can create similar crowd formations and again measure the perception of users. The results of the evaluations can

Marios Kyriakou

show whether users perceive the formations of real people as realistic in virtual environments.

- An interesting aspect that needs to be further analyzed is how the users' point of view affects their perception of a virtual crowd. Some important viewpoints that might be examined include:
    a. eye-level: the user sees everything at the height of the human eye, as in the case of first person video games.
    b. canonical view: canonical viewpoint is often a rotation of 10 degrees about each axis [109]. This can be implemented by using a slightly elevated camera angle with a small rotation. If the user can navigate freely in a scene, canonical viewpoint is often inspected for the longest period of time [110].
    c. top-down view: an important view, especially when we have large crowds, or when large scale populated scenes need to be presented, as in movies.

- Many IVR applications are being used to help train professionals or everyday people to properly react in certain situations. In a number of these cases, the environments include virtual crowds either as a main component of the training, or to make scenes more realistic. Our study showed that the immersed user behavior is affected by the virtual crowd's behavior in a IVE. Still, there is no sufficient evidence that the presence of virtual humans/crowds can help the training procedure in these systems. For example, in a panic situation like a fire, the crowd will run to the nearest exit. Under what conditions will the user feel the same need to find the nearest exit, or follow the crowd in an IVE? What behavior attributes should virtual

Marios Kyriakou

humans have in order to enhance the user’s sense of presence and motivate him/her to act as they would in real situations?

- Another appealing research area, but not thoroughly examined to date, is the use of virtual crowds in Augmented Reality. More specifically, it would be interesting to see how the user’s behavior is affected by virtual humans in real environments. This would be beneficial for training, emergency planning, education and other applications, fortifying learning through physical experience in the users’ natural environment.

Marios Kyriakou

References

.[1] M. V Sanchez-Vives and M. Slater, “From presence to consciousness through virtual reality.,” *Nat. Rev. Neurosci.*, vol. 6, no. 4, pp. 332–9, Apr. 2005.

[2] M. Slater, “Place illusion and plausibility can lead to realistic behaviour in immersive virtual environments.,” *Philos. Trans. R. Soc. Lond. B. Biol. Sci.*, vol. 364, no. 1535, pp. 3549–57, Dec. 2009.

[3] M. Slater, B. Lotto, M. M. Arnold, and M. V Sanchez-vives, “How we experience immersive virtual environments : the concept of presence and its measurement,” vol. 40, no. 2773, pp. 193–210, 2009.

[4] K. H. Lee, M. G. Choi, Q. Hong, and J. Lee, “Group Behavior from Video : A Data-Driven Approach to Crowd Simulation,” *Computing*, vol. 1, pp. 109–118, 2007.

[5] J. Pettré, J. Ondrej, A. Olivier, A. Cretual, and S. Donikian, “Experiment-based modeling, simulation and validation of interactions between virtual walkers,” *Proc. 2009 ACM SIGGRAPH/Eurographics Symp. Comput. Animat.*, p. 189, 2009.

[6] A. Lerner, Y. Chrysanthou, and D. Lischinski, “Crowds by Example,” *Comput. Graph. Forum*, vol. 26, no. 3, pp. 655–664, 2007.

[7] C. Peters and C. Ennis, “Modeling groups of plausible virtual pedestrians.,” *IEEE Comput. Graph. Appl.*, vol. 29, no. 4, pp. 54–63, 2009.

[8] R. McDonnell, C. Ennis, S. Dobbyn, and C. O’Sullivan, “Talking bodies: Sensitivity to desynchronization of conversations,” *ACM Trans. Appl. Percept.*, vol. 6, no. 4, pp. 1–8, 2009.

[9] C. Ennis, R. McDonnell, and C. O’Sullivan, “Seeing is believing: body motion dominates in multisensory conversations,” *ACM Trans. Graph.*, 2010.

[10] S. Huerre, J. Lee, M. Lin, and C. O’Sullivan, “Simulating believable crowd and group behaviors,” *ACM SIGGRAPH ASIA 2010 …*, 2010.

[11] C. Ennis, C. Peters, and C. O’Sullivan, “Perceptual effects of scene context and viewpoint for virtual pedestrian crowds,” *ACM Trans. Appl. Percept.*, vol. 8, no. 2, p. 10, 2011.

[12] M. Slater, A. Rovira, R. Southern, D. Swapp, J. J. Zhang, C. Campbell, and M. Levine, “Bystander responses to a violent incident in an immersive virtual environment.,” *PLoS One*, vol. 8, no. 1, p. e52766, Jan. 2013.

Marios Kyriakou

[13] Daniel Thalmann; Soraia Raupp Musse, “Crowd Simulation,” *Springer*, 2007.

[14] R. Hughes, “The Flow of Human Crowds.,” *Annu. Rev. Fluid Mech.*, vol. 35, pp. 169–182, 2003.

[15] A. Treuille, S. Cooper, and Z. Popović, “Continuum crowds,” *ACM Trans. Graph.*, vol. 25, no. 3, p. 1160, 2006.

[16] S. Hoogendoorn and P. H. L. Bovy, “Gas-Kinetic Modelling and Simulation of Pedestrian Flows,” *Transp. Res. Rec.*, vol. 1710, no. 189, pp. 28–36, 2000.

[17] S. P. Hoogendoorn and P. H. L. Bovy, “Pedestrian travel behavior modeling,” *Networks Spat. Econ.*, vol. 5, no. 2, pp. 10–15, 2005.

[18] D. Helbing and P. Molnar, “Social Force Model for Pedestrian Dynamics,” *Phys. Rev. E*, vol. 51, no. 5, pp. 4282–4286, 1998.

[19] J. Hodgins and D. Brogan, “Robot herds: Group behaviors for systems with significant dynamics,” *Proc. Artif. Life IV*, 1994.

[20] C. W. Reynolds, “Flocks, herds and schools: A distributed behavioral model,” *ACM SIGGRAPH Comput. Graph.*, vol. 21, no. 4, pp. 25–34, 1987.

[21] C. W. Reynolds, “Steering behaviors for autonomous characters,” *Game Dev. Conf.*, vol. 1999, no. 9602, pp. 763–782, 1999.

[22] C. Reynolds, “Big fast crowds on PS3,” *Proc. 2006 ACM SIGGRAPH Symp. Videogames Sandbox 06*, vol. 30, no. 4, pp. 113–121, 2006.

[23] MASSIVE, “Massive software,” 2007.

[24] B. Ulicny and D. Thalmann, “Towards interactive real-time crowd behavior simulation,” *Comput. Graph. Forum*, vol. 21, no. 4, pp. 767–775, 2002.

[25] C. Loscos, D. Marchal, and A. Meyer, “Intuitive Crowd Behaviour in Dense Urban Environments using Local Laws,” *Proc. Theory Pract. Comput. Graph. 2003*, vol. 0, pp. 122–129, 2003.

[26] F. Lamarche and S. Donikian, “Crowd of virtual humans: a new approach for real time navigation in complex and structured environments,” *Comput. Graph. Forum*, vol. 23, no. 3, pp. 509–518, Sep. 2004.

[27] W. Shao and D. Terzopoulos, “Autonomous pedestrians,” *Proc. 2005 ACM SIGGRAPH/Eurographics Symp. Comput. Animat. - SCA ’05*, p. 19, 2005.

Marios Kyriakou

[28] D. Terzopoulos, X. Tu, and R. Grzeszczuk, “Artificial Fishes,” *Artif. Life*, vol. 1, no. 4, pp. 327–351, 1995.

[29] J. Funge, X. Tu, and D. Terzopoulos, “Cognitive modeling: knowledge, reasoning and planning for intelligent characters,” in *Proceedings of the 26th annual conference on Computer graphics and interactive techniques*, 1999, vol. 43, no. 7, pp. 29–38.

[30] S. R. Musse and D. Thalmann, “A model of human crowd behavior: Group inter-relationship and collision detection analysis,” in *Computer Animation and Simulation*, 1997, vol. 97, pp. 39–51.

[31] M. Sung, M. Gleicher, and S. Chenney, “Scalable behaviors for crowd simulation,” *Comput. Graph. Forum*, vol. 23, no. 3, pp. 519–528, 2004.

[32] N. Farenc, R. Boulic, and D. Thalmann, “An Informed Environment Dedicated to the Simulation of Virtual Humans in Urban Context,” *Comput. Graph. Forum*, vol. 18, no. 3, pp. 309–318, 1999.

[33] G. Thomas and S. Donikian, “Modelling virtual cities dedicated to behavioural animation,” *Comput. Graph. Forum*, vol. 19, no. 3, pp. 71–80, 2000.

[34] N. Pelechano, J. Allbeck, and N. Badler, “Controlling individual agents in high-density crowd simulation,” *Proc. 2007 ACM SIGGRAPH Symp. Comput. Animat.*, 2007.

[35] Plugin Autodesk Softimage Crowdfx, “http://www.autodesk.com/products/autodesksoftimage/Overview.”

[36] R. A. Metoyer and J. K. Hodgins, *Reactive pedestrian path following from examples*, vol. 20, no. 10. IEEE Comput. Soc, 2003, pp. 635–649.

[37] S. R. Musse, C. R. Jung, J. C. S. Jacques Jr, and A. Braun, “Simulating the motion of virtual agents based on examples,” in *ACM SIGGRAPH/Eurographics Symposium on Computer Animation-Posters and Demos*, 2006, pp. 35–36.

[38] S. Paris, J. Pettré, and S. Donikian, “Pedestrian Reactive Navigation for Crowd Simulation: a Predictive Approach,” *Comput. Graph. Forum*, vol. 26, no. 3, pp. 665–674, 2007.

[39] D. C. Brogan and N. L. Johnson, “Realistic Human Walking Paths,” *Proc. 11th IEEE Int. Work. Progr. Compr.*, pp. 94–101, 2003.

[40] Y.-C. Lai, S. Chenney, and S. Fan, “Group motion graphs,” *Proc. 2005 ACM SIGGRAPHEurographics Symp. Comput. Animat. SCA 05*, no. July, p. 281, 2005.

Marios Kyriakou

[41] A. Lerner and E. Fitusi, “Fitting behaviors to pedestrian simulations,” *ACM SIGGRAPH Symp. Comput. Animat.*, 2009.

[42] M. Kim, Y. Hwang, K. Hyun, and J. Lee, “Tiling motion patches,” in *Proceedings of the 11th ACM SIGGRAPH/Eurographics conference on Computer Animation*, 2012, pp. 117–126.

[43] B. Yersin, J. Maïm, J. Pettré, and D. Thalmann, “Crowd patches: populating large-scale virtual environments for real-time applications,” *Proc. 2009 Symp. Interact. 3D Graph. games. ACM*, 2009.

[44] I. E. Sutherland, “The ultimate display,” *Proc. IFIP Congr. 2*, pp. 506–508, 1965.

[45] T. B. Sheridan, “Musings on telepresence and virtual presence,” *Presence Teleoperators Virtual Environ.*, vol. 1, no. 1, pp. 120–126, 1992.

[46] J. Blauert, H. Lehnert, J. Sahrhage, and H. Strauss, “An interactive virtual-environment generator for psychoacoustic research, I: Architecture and Implementation,” *Acta Acustica*, vol. 86, no. 1. pp. 94–102, 2000.

[47] J. K. Salisbury and M. A. Srinivasan, *Phantom-based haptic interaction with virtual objects*, vol. 17, no. 5. 1997, pp. 6–10.

[48] S. D. Laycock and A. M. Day, “Recent Developments and Applications of Haptic Devices,” *Comput. Graph. Forum*, vol. 22, no. 2, pp. 117–132, 2003.

[49] B. G. Witmer, “Measuring Presence in Virtual Environments : A Presence,” *Technology*, vol. 7, no. 3, pp. 225–240, 1998.

[50] C. Heeter, “Being there: the subjective experience of presence,” *Presence Teleoperators Virtual Environ.*, vol. 1, no. 2, pp. 262–271, 1992.

[51] J. M. Draper, J. V.; Kaber, D. B.; Usher, “Human Factors,” *Telepresence*, vol. 40 (3), pp. 354–375, 1998.

[52] E. B. Nash, G. W. Edwards, J. A. Thompson, and W. Barfield, “A Review of Presence and Performance in Virtual Environments,” *Int. J. HumanComputer Interact.*, vol. 12, no. 1, pp. 1–41, 2000.

[53] A. Mert, W. Bles, and W. Wertheim, “Presence in virtual environments.,” *Clinical Rehabilitation*, vol. 23, no. 5. Lawrence Erlbaum Associates, Inc., pp. 465–466, 2009.

[54] F. Biocca, “The cyborg’s dilemma: embodiment in virtual environments,” *Proc. Second Int. Conf. Cogn. Technol. Humaniz. Inf. Age*, 1997.

Marios Kyriakou

[55] F. Biocca, C. Harms, and J. K. Burgoon, “Toward a More Robust Theory and Measure of Social Presence: Review and Suggested Criteria,” *Presence: Teleoperators and Virtual Environments*, vol. 12, no. 5. pp. 456–480, 2003.

[56] W. A. IJsselsteijn, “Presence: concept, determinants, and measurement,” *Proc. SPIE*, vol. 31, no. 0, pp. 520–529, 2000.

[57] M. Lombard and T. Bolmarcich Ditton, “At the heart of it all: The concept of telepresence,” *J. Comput. Mediat. Commun.*, vol. 3, no. 2, 1997.

[58] M. Slater and S. Wilbur, “A framework for immersive virtual environments (FIVE),” *Presence Teleoperators Virtual Environ.*, vol. 6, no. 6, p. 603, 1997.

[59] F. Gutiérrez, Mario A. A ; Thalmann, Daniel ; Vexo, *Stepping Into Virtual Reality*. London: Springer-Verlag London Limited, 2008.

[60] D. Pertaub, M. Slater, and C. Barker, “An experiment on public speaking anxiety in response to three different types of virtual audience,” *Presence Teleoperators Virtual Environ.*, vol. 11, no. 1, pp. 68–78, 2002.

[61] D. Freeman, M. Slater, P. E. Bebbington, P. A. Garety, E. Kuipers, D. Fowler, A. Met, C. M. Read, J. Jordan, and V. Vinayagamoorthy, “Can virtual reality be used to investigate persecutory ideation?,” *J. Nerv. Ment. Dis.*, vol. 191, no. 8, pp. 509–514, 2003.

[62] J. N. Bailenson, J. Blascovich, A. C. Beall, and J. M. Loomis, “Equilibrium Theory Revisited: Mutual Gaze and Personal Space in Virtual Environments,” *Presence: Teleoperators and Virtual Environments*, vol. 10, no. 6. pp. 583–598, 2001.

[63] L. M. Wilcox, R. S. Allison, S. Elfassy, and C. Grelik, “Personal space in virtual reality,” *ACM Trans. Appl. Percept.*, vol. 3, no. 4, pp. 412–428, 2006.

[64] J. Llobera, B. Spanlang, G. Ruffini, and M. Slater, “Proxemics with Multiple Dynamic Characters in an Immersive Virtual Environment,” *ACM Trans. Appl. Percept.*, vol. 8, no. 1, pp. 1–12, 2010.

[65] J. N. Bailenson, J. Blascovich, A. C. Beall, and J. M. Loomis, “Interpersonal distance in immersive virtual environments.,” *Personal. Soc. Psychol. Bull.*, vol. 29, no. 7, pp. 819–833, 2003.

[66] M. Obaid, R. R. Niewiadomski, and C. Pelachaud, “Perception of spatial relations and of coexistence with virtual agents.,” *Intell. Virtual Agents*, pp. 363–369, 2011.

Marios Kyriakou

[67] F. Friedmann, T. Schubert, and H. Regenbrecht, “The Experience of Presence: Factor Analytic Insights,” *Presence: Teleoperators and Virtual Environments*, vol. 10, no. 3. pp. 266–281, 2001.

[68] M. Slater, C. Guger, G. Edlinger, R. Leeb, G. Pfurtscheller, A. Antley, M. Garau, A. Brogni, and D. Friedman, “Analysis of Physiological Responses to a Social Situation in an Immersive Virtual Environment,” *Presence Teleoperators Virtual Environ.*, vol. 15, no. 5, pp. 553–569, Oct. 2006.

[69] M. Garau, D. Friedman, H. Ritter Widenfeld, A. Antley, A. Brogni, and M. Slater, “Temporal and Spatial Variations in Presence: Qualitative Analysis of Interviews from an Experiment on Breaks in Presence,” *Presence Teleoperators Virtual Environ.*, vol. 17, no. 3, pp. 293–309, 2008.

[70] J. Fox, J. Bailenson, and J. Binney, “Virtual Experiences, Physical Behaviors: The Effect of Presence on Imitation of an Eating Avatar,” *Presence Teleoperators Virtual Environ.*, vol. 18, pp. 294–303, 2009.

[71] W. E. Frankenhuis, R. Dotsch, J. C. Karremans, and D. H. J. Wigboldus, “Male physical risk taking in a virtual environment,” *J. Evol. Psychol.*, vol. 8, pp. 75–86, 2010.

[72] N. Pelechano and C. Stocker, “Being a part of the crowd: towards validating VR crowds using presence,” *Proc. 7th Int. Jt. Conf. Auton. agents multiagent Syst.*, vol. 1, no. Aamas, pp. 12–16, 2008.

[73] J. Ahn, N. Wang, D. Thalmann, and R. Boulic, “Within-Crowd Immersive Evaluation of Collision Avoidance Behaviors,” in *VRCAI*, 2012, pp. 231–238.

[74] P. van Schaik, S. Martin, and M. Vallance, “Measuring flow experience in an immersive virtual environment for collaborative learning,” *J. Comput. Assist. Learn.*, vol. 28, no. 4, pp. 350–365, Aug. 2012.

[75] W. IJsselsteijn, H. De Ridder, J. Freeman, S. E. Avons, and D. Bouwhuis, “Effects of Stereoscopic Presentation, Image Motion, and Screen Size on Subjective and Objective Corroborative Measures of Presence,” *Presence Teleoperators Virtual Environ.*, vol. 10, no. 3, pp. 298–311, 2001.

[76] M. Slater, M. Usoh, and A. Steed, “Depth of presence in virtual environments,” *Presence*, pp. 1–33, 1994.

[77] J. Lessiter, J. Freeman, E. Keogh, and J. Davidoff, “Development of a new cross-media questionnaire: the ITC sense of presence inventory,” *Presence 2000 Work.*, no. ii, 2000.

Marios Kyriakou

[78] M. Meehan and B. Insko, “Physiological measures of presence in stressful virtual environments,” *ACM Trans. Graph. - Proc. ACM SIGGRAPH*, p. 645, 2002.

[79] M. Kotlyar, C. Donahue, P. Thuras, M. G. Kushner, N. O’Gorman, E. a Smith, and D. E. Adson, “Physiological response to a speech stressor presented in a virtual reality environment.,” *Psychophysiology*, vol. 45, no. 6, pp. 1034–7, Nov. 2008.

[80] K. Stanney, G. Salvendy, J. Deisinger, P. DiZio, S. Ellis, J. Ellison, G. Fogleman, J. Gallimore, M. Singer, L. Hettinger, R. Kennedy, J. Lackner, B. Lawson, J. Maida, A. Mead, M. Mon-Williams, D. Newman, T. Piantanida, L. Reeves, O. Riedel, T. Stoffregen, J. Wann, R. Welch, J. Wilson, and B. Witmer, “Aftereffects and sense of presence in virtual environments: Formulation of a research and development agenda,” *Int. J. Hum. Comput. Interact.*, vol. 10, no. 2, pp. 135–187, 1998.

[81] J. J. Gibson, *Perception of the Visual World*. Houghton Mifflin, 1950, p. 235.

[82] B. Julesz, “Visual pattern discrimination,” *Ire Trans. Inf. Theory*, vol. 8, no. 2, pp. 84–92, 1962.

[83] D. J. Heeger and J. R. Bergen, “Pyramid-based texture analysis/synthesis,” *Proc. Int. Conf. Image Process.*, vol. 3, pp. 648–651, 1995.

[84] J. S. De Bonet, “Multiresolution sampling procedure for analysis and synthesis of texture images,” *Proc. 24th Annu. Conf. Comput. Graph. Interact. Tech. SIGGRAPH 97*, vol. 31, no. Annual Conference Series, pp. 361–368, 1997.

[85] Y. Xu, B. Guo, and H. Shum, “Chaos Mosaic : Fast and Memory Efficient Texture Synthesis,” 2000.

[86] A. A. Efros and T. K. Leung, “Texture synthesis by non-parametric sampling,” *Proc. Seventh IEEE Int. Conf. Comput. Vis.*, vol. 2, no. September, pp. 1033–1038 vol.2, 1999.

[87] L.-Y. Wei and M. Levoy, “Fast texture synthesis using tree-structured vector quantization,” *Proc. 27th Annu. Conf. Comput. Graph. Interact. Tech. SIGGRAPH 00*, vol. 00pages, pp. 479–488, 2000.

[88] M. Ashikhmin, “Synthesizing natural textures,” *Proc. 2001 Symp. Interact. 3D Graph. SI3D 01*, pp. 217–226, 2001.

[89] A. Hertzmann, C. E. Jacobs, N. Oliver, B. Curless, and D. H. Salesin, “Image analogies,” *Proc. 28th Annu. Conf. Comput. Graph. Interact. Tech. SIGGRAPH 01*, vol. 2001, no. August, pp. 327–340, 2001.

Marios Kyriakou

[90] A. A. Efros and W. T. Freeman, “Image quilting for texture synthesis and transfer,” *Int. J.*, vol. 1, no. 2, pp. 1–6, 2001.

[91] M. Kyriakou and Y. Chrysanthou, “Texture synthesis based simulation of secondary agents,” *Motion in Games*, 2008.

[92] D. M. Greig, B. T. Porteous, and A. H. Seheult, “Exact maximum a posteriori estimation for binary images,” *J. R. Stat. Soc. Ser. B Methodol.*, vol. 51, no. 2, pp. 271–279, 1989.

[93] Y. Boykov, O. Veksler, and R. Zabih, *Fast approximate energy minimization via graph cuts*, vol. 1, no. 11. IEEE, 1999, pp. 1222–1239.

[94] S. Ebastien, “Stereo Without Epipolar Lines : A Maximum-Flow Formulation,” *Framework*, vol. 34, no. 2/3, pp. 147–161, 1999.

[95] V. Kolmogorov and R. Zabih, “Multi-camera scene reconstruction via graph cuts,” *Comput. Vision—ECCV 2002*, vol. vol, pp. 82–96, 2002.

[96] V. Kwatra, I. Essa, and A. Bobick, “Graphcut Textures : Image and Video Synthesis Using Graph Cuts,” *Image Rochester NY*, vol. 22, no. 2, p. 277, 2003.

[97] Y. Boykov and O. Veksler, “Graph cuts in vision and graphics: Theories and applications,” *Math. Model. Comput. Vis.*, pp. 100–118, 2006.

[98] D. W. Martin, *Doing psychology experiments*. CengageBrain. com, 2008.

[99] C. Cruz-Neira, D. J. Sandin, T. A. DeFanti, R. V. Kenyon, and J. C. Hart, “The CAVE: audio visual experience automatic virtual environment,” *Communications of the ACM*, vol. 35, no. 6. pp. 64–72, 1992.

[100] J. Smisek, M. Jancosek, and T. Pajdla, “3D with Kinect,” *2011 IEEE Int. Conf. Comput. Vis. Work. (ICCV Work.*, pp. 1154–1160, 2011.

[101] M. Levine and S. Crowther, “The responsive bystander: how social group membership and group size can encourage as well as inhibit bystander intervention.,” *J. Pers. Soc. Psychol.*, vol. 95, pp. 1429–1439, 2008.

[102] P. Fischer, J. I. Krueger, T. Greitemeyer, C. Vogrincic, A. Kastenmüller, D. Frey, M. Heene, M. Wicher, and M. Kainbacher, “The bystander-effect: a meta-analytic review on bystander intervention in dangerous and non-dangerous emergencies.,” *Psychol. Bull.*, vol. 137, pp. 517–537, 2011.

[103] M. Levine, A. Prosser, D. Evans, and S. Reicher, “Identity and emergency intervention: how social group membership and

Marios Kyriakou

inclusiveness of group boundaries shape helping behavior.," *Personal. Soc. Psychol. Bull.*, vol. 31, pp. 443–53, 2005.

[104] M. R. Petersen and J. A. Deddens, "A comparison of two methods for estimating prevalence ratios.," *BMC Med. Res. Methodol.*, vol. 8, p. 9, 2008.

[105] A. J. D. Barros and V. N. Hirakata, "Alternatives for logistic regression in cross-sectional studies: an empirical comparison of models that directly estimate the prevalence ratio.," *BMC Med. Res. Methodol.*, vol. 3, p. 21, 2003.

[106] M. Jones and A. Champion, *Nature's way.*, vol. 94, no. 34. 2008, pp. 75, 78.

[107] M. Schmidt and H. Lipson, "Distilling Free-Form Natural Laws," *Science* , vol. 324, no. April, pp. 81–85, 2009.

[108] R. Ehrenberg, "Software Scientist," *ScienceNews*, vol. 181, no. 1, p. 20, 2012.

[109] M. J. Tarr, "Rotating objects to recognize them: A case study on the role of viewpoint dependency in the recognition of three-dimensional objects," *Psychonomic Bulletin & Review*, vol. 2, no. 1. pp. 55–82, 1995.

[110] V. Blanz, M. J. Tarr, and H. H. Bülthoff, "What object attributes determine canonical views?," *Perception*, vol. 28, no. 5, pp. 575–599, 1999.

Marios Kyriakou

APPENDICES

Marios Kyriakou

APPENDIX A

Please fill the following questions:

1. Gender:
    a. Male
    b. Female

2. What is your experience with video games?
    a. No experience at all
    b. Novice user
    c. Average user
    d. Expert user

3. How aware are the others of your presence? (1=Min. 5=Max)

1	2	3	4	5
○	○	○	○	○

4. How aware are the others of each other? (1=Min. 5=Max)

1	2	3	4	5
○	○	○	○	○

5. How easy was for you to follow the child? (1=Min. 5=Max)

1	2	3	4	5
○	○	○	○	○

6. How much did you feel present in the environment? (1=Min. 5=Max)

1	2	3	4	5
○	○	○	○	○

7. How comfortable were you in the system? (1=Min. 5=Max)

1	2	3	4	5
○	○	○	○	○

Marios Kyriakou

8. Overall, how would you rate the realism of the following? (1=Min. 5=Max)?

	1	**2**	**3**	**4**	**5**
Child	○	○	○	○	○
Others	○	○	○	○	○
Environment	○	○	○	○	○

9. How would you overall rate the whole system? (1=Min. 5=Max)

1	2	3	4	5
○	○	○	○	○

Table 10: Questionnaire of experiment 1.

Marios Kyriakou

	Question	Q1	Q2	Q3	Q4	Q5	Q6	Q7	Q8	Q9
Scenario S1	Mean	1.80	3.00	3.05	2.90	3.05	3.15	3.35	3.65	3.60
	N	20	20	20	20	20	20	20	20	20
	Std. Error of Mean	0.19	0.16	0.21	0.26	0.19	0.20	0.27	0.13	0.15
Scenario S2	Mean	2.90	3.55	2.35	3.35	2.40	3.55	3.75	3.75	3.85
	N	20	20	20	20	20	20	20	20	20
	Std. Error of Mean	0.24	0.19	0.21	0.22	0.18	0.15	0.20	0.16	0.18
Scenario S3	Mean	4.15	3.50	3.50	4.10	4.05	3.75	4.30	3.65	3.95
	N	20	20	20	20	20	20	20	20	20
	Std. Error of Mean	0.21	0.25	0.14	0.19	0.17	0.16	0.15	0.20	0.11
Total	Mean	2.95	3.35	2.97	3.45	3.17	3.48	3.93	3.68	3.80
	N	60	60	60	60	60	60	60	60	60
	Std. Error of Mean	0.17	0.12	0.12	0.14	0.14	0.10	0.12	0.10	0.10

Table 11: Mean analysis - IVR system.

Marios Kyriakou

Question		Q1	Q2	Q3	Q4	Q5	Q6	Q7	Q8	Q9
Scenario S1	Mean	1.40	2.47	3.47	1.63	3.90	3.57	2.93	3.67	3.50
	N	30	30	30	30	30	30	30	30	30
	Std. Error of Mean	0.10	0.21	0.20	0.11	0.19	0.18	0.19	0.15	0.14
Scenario S2	Mean	2.43	2.83	3.03	3.00	3.50	3.70	3.53	3.83	3.80
	N	30	30	30	30	30	30	30	30	30
	Std. Error of Mean	0.2	0.22	0.23	0.15	0.14	0.17	0.13	0.15	0.09
Scenario S3	Mean	4.50	3.63	4.10	4.17	4.27	3.77	4.30	3.90	4.27
	N	30	30	30	30	30	30	30	30	30
	Std. Error of Mean	0.10	0.21	0.15	0.11	0.14	0.18	0.14	0.15	0.11
Total	Mean	2.78	2.98	3.53	2.93	3.89	3.68	3.59	3.80	3.86
	N	90	90	90	90	90	90	90	90	90
	Std. Error of Mean	0.16	0.13	0.12	0.13	0.10	0.10	0.11	0.09	0.07

Table 12: Mean analysis – semi-IVR system.

Question	Scenario	Kolmogorov-Smirnov[a]			Shapiro-Wilk		
		Statistic	df	Sig.	Statistic	df	Sig.
Q1	Scenario S1	0.255	20	0.001	0.804	20	0.001
	Scenario S2	0.187	20	0.064	0.926	20	0.128
	Scenario S3	0.286	20	0.000	0.774	20	0.000
Q2	Scenario S1	0.250	20	0.002	0.815	20	0.001
	Scenario S2	0.297	20	0.000	0.841	20	0.004
	Scenario S3	0.375	20	0.000	0.788	20	0.001
Q3	Scenario S1	0.243	20	0.003	0.838	20	0.003
	Scenario S2	0.246	20	0.003	0.841	20	0.004
	Scenario S3	0.345	20	0.000	0.723	20	0.000
Q4	Scenario S1	0.180	20	0.089	0.925	20	0.125
	Scenario S2	0.295	20	0.000	0.855	20	0.006
	Scenario S3	0.255	20	0.001	0.787	20	0.001
Q5	Scenario S1	0.258	20	0.001	0.772	20	0.000
	Scenario S2	0.268	20	0.001	0.858	20	0.007
	Scenario S3	0.324	20	0.000	0.796	20	0.001
Q6	Scenario S1	0.234	20	0.005	0.826	20	0.002
	Scenario S2	0.294	20	0.000	0.829	20	0.002
	Scenario S3	0.336	20	0.000	0.821	20	0.002
Q7	Scenario S1	0.238	20	0.004	0.846	20	0.005
	Scenario S2	0.258	20	0.001	0.877	20	0.016
	Scenario S3	0.276	20	0.000	0.780	20	0.000
Q8	Scenario S1	0.324	20	0.000	0.744	20	0.000
	Scenario S2	0.336	20	0.000	0.821	20	0.002
	Scenario S3	0.355	20	0.000	0.798	20	0.001
Q9	Scenario S1	0.322	20	0.000	0.817	20	0.002
	Scenario S2	0.373	20	0.000	0.768	20	0.000
	Scenario S3	0.389	20	0.000	0.688	20	0.000
a. Lilliefors Significance Correction							

Table 13: Tests of Normality – IVR system.

Marios Kyriakou

Question	Scenario	Kolmogorov-Smirnov[a]			Shapiro-Wilk		
		Statistic	df	Sig.	Statistic	df	Sig.
Q1	Scenario S1	0.395	30	0.000	0.669	30	0.000
	Scenario S2	0.201	30	0.003	0.896	30	0.007
	Scenario S3	0.342	30	0.000	0.710	30	0.000
Q2	Scenario S1	0.193	30	0.006	0.902	30	0.009
	Scenario S2	0.177	30	0.017	0.918	30	0.024
	Scenario S3	0.227	30	0.000	0.879	30	0.003
Q3	Scenario S1	0.197	30	0.004	0.865	30	0.001
	Scenario S2	0.156	30	0.060	0.919	30	0.025
	Scenario S3	0.250	30	0.000	0.834	30	0.000
Q4	Scenario S1	0.291	30	0.000	0.753	30	0.000
	Scenario S2	0.267	30	0.000	0.879	30	0.003
	Scenario S3	0.344	30	0.000	0.755	30	0.000
Q5	Scenario S1	0.224	30	0.001	0.846	30	0.001
	Scenario S2	0.273	30	0.000	0.853	30	0.001
	Scenario S3	0.273	30	0.000	0.785	30	0.000
Q6	Scenario S1	0.239	30	0.000	0.878	30	0.003
	Scenario S2	0.295	30	0.000	0.852	30	0.001
	Scenario S3	0.262	30	0.000	0.862	30	0.001
Q7	Scenario S1	0.207	30	0.002	0.916	30	0.021
	Scenario S2	0.272	30	0.000	0.845	30	0.000
	Scenario S3	0.258	30	0.000	0.769	30	0.000
Q8	Scenario S1	0.220	30	0.001	0.873	30	0.002
	Scenario S2	0.279	30	0.000	0.859	30	0.001
	Scenario S3	0.316	30	0.000	0.828	30	0.000
Q9	Scenario S1	0.340	30	0.000	0.791	30	0.000
	Scenario S2	0.427	30	0.000	0.646	30	0.000
	Scenario S3	0.343	30	0.000	0.745	30	0.000

a. Lilliefors Significance Correction

Table 14: Tests of Normality – semi-IVR system.

Marios Kyriakou

	Mean Rank
Question Q1	
Scenario1	1.20
Scenario S2	2.03
Scenario S3	2.78
Question Q2	
Scenario S1	1.70
Scenario S2	2.15
Scenario S3	2.15
Question Q3	
Scenario S1	2.13
Scenario S2	1.33
Scenario S3	2.55
Question Q4	
Scenario S1	1.63
Scenario S2	1.90
Scenario S3	2.48
Question Q5	
Scenario S1	1.93
Scenario S2	1.30
Scenario S3	2.78
Question Q6	
Scenario S1	1.53
Scenario S2	2.10
Scenario S3	2.38
Question Q7	
Scenario S1	1.50
Scenario S2	1.83
Scenario S3	2.38
Question Q8	
Scenario S1	1.93
Scenario S2	2.00
Scenario S3	2.08
Question Q9	
Scenario S1	1.73
Scenario S2	2.08
Scenario S3	2.20

Table 15: Friedman tests on questions - IVR system.

Maria Kyriakou

Question	**Q1**	**Q2**	**Q3**	**Q4**	**Q5**	**Q6**	**Q7**	**Q8**	**Q9**
N	20	20	20	20	20	20	20	20	20
Chi-Square	28.37	3.37	18.45	10.03	24.70	14.00	6.76	0.32	4.41
df	2	2	2	2	2	2	2	2	2
Asymp. Sig.	0.00	0.19	0.00	0.01	0.00	0.00	0.02	0.85	0.11

Table 16: Test statistics for Friedman tests on questions– IVR system.

	Mean Rank
Question Q1	
Scenario1	1.20
Scenario S2	1.82
Scenario S3	2.98
Question Q2	
Scenario S1	1.53
Scenario S2	1.83
Scenario S3	2.63
Question Q3	
Scenario S1	1.98
Scenario S2	1.53
Scenario S3	2.48
Question Q4	
Scenario S1	1.12
Scenario S2	1.97
Scenario S3	2.92
Question Q5	
Scenario S1	1.98
Scenario S2	1.62
Scenario S3	2.40
Question Q6	
Scenario S1	1.85
Scenario S2	2.03
Scenario S3	2.12
Question Q7	

Marios Kyriakou

Scenario S1	1.40
Scenario S2	1.88
Scenario S3	2.72
Question Q8	
Scenario S1	1.80
Scenario S2	2.05
Scenario S3	2.15
Question Q9	
Scenario S1	1.80
Scenario S2	2.05
Scenario S3	2.15

Table 17: Friedman tests on questions - semi-IVR system.

Question	**Q1**	**Q2**	**Q3**	**Q4**	**Q5**	**Q6**	**Q7**	**Q8**	**Q9**
N	30	30	30	30	30	30	30	30	30
Chi-Square	54.18	29.10	16.94	52.13	19.40	6.09	18.95	8.67	30.13
df	2	2	2	2	2	2	2	2	2
Asymp. Sig.	0.00	0.00	0.00	0.00	0.00	0.048	0.00	0.01	0.00

Table 18: Test statistics for Friedman tests on questions– semi-IVR system.

Marios Kyriakou

Question	**Scenario**	**N**	**Mean**	**Std. Deviation**	**Min**	**Max**	**Percentiles**		
							25th	Median	75th
Question 1	Scenario S1	20	1.80	0.83	1.00	4.00	1.00	2.00	2.00
	Scenario S2	20	2.90	1.07	1.00	5.00	2.00	3.00	4.00
	Scenario S3	20	4.15	0.93	2.00	5.00	4.00	4.00	5.00
Question 2	Scenario S1	20	3.00	0.72	2.00	4.00	2.25	3.00	3.75
	Scenario S2	20	3.55	0.82	2.00	5.00	3.00	3.00	4.00
	Scenario S3	20	3.50	1.12	1.00	5.00	2.25	4.00	4.00
Question 3	Scenario S1	20	3.05	0.94	1.00	4.00	2.00	3.00	4.00
	Scenario S2	20	2.35	0.93	1.00	5.00	2.00	2.00	3.00
	Scenario S3	20	3.50	0.60	2.00	4.00	3.00	4.00	4.00
Question 4	Scenario S1	20	2.90	1.16	1.00	5.00	2.00	3.00	4.00
	Scenario S2	20	3.35	0.99	1.00	5.00	3.00	4.00	4.00
	Scenario S3	20	4.10	0.85	3.00	5.00	3.00	4.00	5.00
Question 5	Scenario S1	20	3.05	0.89	2.00	4.00	2.00	3.00	4.00
	Scenario S2	20	2.40	0.82	1.00	4.00	2.00	2.50	3.00
	Scenario S3	20	4.05	0.76	2.00	5.00	4.00	4.00	4.75
Question 6	Scenario S1	20	3.15	0.88	1.00	4.00	3.00	3.00	4.00
	Scenario S2	20	3.55	0.69	2.00	5.00	3.00	4.00	4.00
	Scenario S3	20	3.75	0.72	2.00	5.00	3.00	4.00	4.00
Question 7	Scenario S1	20	3.35	0.93	1.00	5.00	2.00	3.00	4.00
	Scenario S2	20	3.75	0.63	2.00	5.00	3.00	4.00	4.00
	Scenario S3	20	4.30	0.89	2.00	5.00	4.00	4.00	5.00
Question 8	Scenario S1	20	3.65	0.59	3.00	5.00	3.00	4.00	4.00
	Scenario S2	20	3.75	0.72	2.00	5.00	3.00	4.00	4.00
	Scenario S3	20	3.65	0.87	2.00	5.00	3.00	4.00	4.00
Question 9	Scenario S1	20	3.60	0.68	2.00	5.00	3.00	4.00	4.00
	Scenario S2	20	3.85	0.81	2.00	5.00	4.00	4.00	4.00
	Scenario S3	20	3.95	0.51	3.00	5.00	4.00	4.00	4.00

Table 19: Wilcoxon signed-rank Test, Descriptive Statistics – IVR system.

Marios Kyriakou

Scenario-Question	Z	Asymp. Sig. (2-tailed)
S2Q1 - S1Q1	-3.25[b]	0.00
S3Q1 - S1Q1	-3.87[b]	0.00
S3Q1 - S2Q1	-2.92[b]	0.00
S2Q2 - S1Q2	-2.15[b]	0.03
S3Q2 - S1Q2	-1.86[a]	0.06
S3Q2 - S2Q2	-0.29[c]	0.77
S2Q3 - S1Q3	-2.31[c]	0.02
S3Q3 - S1Q3	-2.17[b]	0.03
S3Q3 - S2Q3	-3.53[b]	0.00
S2Q4 - S1Q4	-1.98[b]	0.048
S3Q4 - S1Q4	-2.83[b]	0.01
S3Q4 - S2Q4	-2.64[b]	0.01
S2Q5 - S1Q5	-2.60[c]	0.01
S3Q5 - S1Q5	-3.21[b]	0.00
S3Q5 - S2Q5	-3.82[b]	0.00
S2Q6 - S1Q6	-2.53[b]	0.01
S3Q6 - S1Q6	-3.21[b]	0.00
S3Q6 - S2Q6	-1.41[b]	0.16
S2Q7 - S1Q7	-3.17	0.01
S3Q7 - S1Q7	-2.14[b]	0.02
S3Q7 - S2Q7	-2.56[b]	0.01
S2Q8 - S1Q8	-0.58[b]	0.56
S3Q8 - S1Q8	-0.04[a]	0.97
S3Q8 - S2Q8	-0.56[b]	0.58
S2Q9 - S1Q9	-1.29[b]	0.20
S3Q9 - S1Q9	-2.33[b]	0.02
S3Q9 - S2Q9	-0.58[b]	0.56

a. Wilcoxon Signed Ranks Test
b. Based on negative ranks.
c. Based on positive ranks.
d. The sum of negative ranks equals the sum of positive ranks.

Table 20: Test Statistics for Wilcoxon signed-ranks test – IVR system.

Marios Kyriakou

Question	Scenario	N	Mean	Std. Deviation	Min	Max	Percentiles		
							25th	50(Median)	75th
Question 1	Scenario S1	30	1.40	0.56	1.00	3.00	1.00	1.00	2.00
	Scenario S2	30	2.43	1.07	1.00	5.00	1.75	2.50	3.00
	Scenario S3	30	4.50	0.57	3.00	5.00	4.00	5.00	5.00
Question 2	Scenario S1	30	2.47	1.14	1.00	5.00	1.75	2.00	3.00
	Scenario S2	30	2.83	1.18	1.00	5.00	2.00	3.00	4.00
	Scenario S3	30	3.63	1.13	1.00	5.00	3.00	4.00	4.25
Question 3	Scenario S1	30	3.47	1.11	2.00	5.00	2.75	3.00	4.25
	Scenario S2	30	3.03	1.25	1.00	5.00	2.00	3.00	4.00
	Scenario S3	30	4.10	0.80	2.00	5.00	4.00	4.00	5.00
Question 4	Scenario S1	30	1.63	0.61	1.00	3.00	1.00	2.00	2.00
	Scenario S2	30	3.00	0.83	1.00	5.00	2.75	3.00	3.25
	Scenario S3	30	4.17	0.59	3.00	5.00	4.00	4.00	5.00
Question 5	Scenario S1	30	3.90	1.03	2.00	5.00	3.00	4.00	5.00
	Scenario S2	30	3.50	0.78	2.00	5.00	3.00	3.00	4.00
	Scenario S3	30	4.27	0.74	3.00	5.00	4.00	4.00	5.00
Question 6	Scenario S1	30	3.57	0.97	2.00	5.00	3.00	4.00	4.00
	Scenario S2	30	3.70	0.92	2.00	5.00	3.00	4.00	4.00
	Scenario S3	30	3.77	0.97	2.00	5.00	3.00	4.00	4.25
Question 7	Scenario S1	30	2.93	1.01	1.00	5.00	2.00	3.00	4.00
	Scenario S2	30	3.53	0.73	2.00	5.00	3.00	4.00	4.00
	Scenario S3	30	4.30	0.75	2.00	5.00	4.00	4.00	5.00
Question 8	Scenario S1	30	3.67	0.84	2.00	5.00	3.00	4.00	4.00
	Scenario S2	30	3.83	0.83	2.00	5.00	3.00	4.00	4.00
	Scenario S3	30	3.90	0.80	2.00	5.00	3.75	4.00	4.00
Question 9	Scenario S1	30	3.50	0.78	2.00	5.00	3.00	4.00	4.00
	Scenario S2	30	3.80	0.48	3.00	5.00	3.75	4.00	4.00
	Scenario S3	30	4.27	0.58	3.00	5.00	4.00	4.00	5.00

Table 21: Wilcoxon signed-rank Test, Descriptive Statistics– semi-IVR system.

Marios Kyriakou

Scenario-Question	Z	Asymp. Sig. (2-tailed)
S2Q1 - S1Q1	-3.80[a]	0.00
S3Q1 - S1Q1	-4.90[a]	0.00
S3Q1 - S2Q1	-4.76[a]	0.00
S2Q2 - S1Q2	-2.05[a]	0.04
S3Q2 - S1Q2	-4.08[a]	0.00
S3Q2 - S2Q2	-3.75[a]	0.00
S2Q3 - S1Q3	-2.29[b]	0.02
S3Q3 - S1Q3	-2.86[a]	0.00
S3Q3 - S2Q3	-3.62[a]	0.00
S2Q4 - S1Q4	-4.27[a]	0.00
S3Q4 - S1Q4	-4.85[a]	0.00
S3Q4 - S2Q4	-4.52[a]	0.00
S2Q5 - S1Q5	-2.38[b]	0.02
S3Q5 - S1Q5	-2.35[a]	0.02
S3Q5 - S2Q5	-3.62[a]	0.00
S2Q6 - S1Q6	-1.63[a]	0.10
S3Q6 - S1Q6	-1.90[a]	0.06
S3Q6 - S2Q6	-1.41[a]	0.16
S2Q7 - S1Q7	-3.35[a]	0.00
S3Q7 - S1Q7	-4.18[a]	0.00
S3Q7 - S2Q7	-4.41[a]	0.00
S2Q8 - S1Q8	-2.24[a]	0.03
S3Q8 - S1Q8	-2.33[a]	0.02
S3Q8 - S2Q8	-1.00[a]	0.32
S2Q9 - S1Q9	-3.00[a]	0.00
S3Q9 - S1Q9	-3.91[a]	0.00
S3Q9 - S2Q9	-3.74[a]	0.00

a. Based on negative ranks.

b. Based on positive ranks.

Table 22: Test Statistics for Wilcoxon signed-ranks test – semi-IVR system.

Marios Kyriakou

Scenario		Min Distance (m)	Max Distance (m)	Average Distance (m)	Over5m (sec)
S1	Mean	2.46	10.34	6.27	22.21
	Std. Deviation	1.12	2.31	1.36	7.28
S2	Mean	2.77	10.60	6.65	26.36
	Std. Deviation	1.12	2.46	1.37	8.84
S3	Mean	3.13	11.63	7.34	30.80
	Std. Deviation	1.02	2.03	.98	7.90
Total	Mean	2.79	10.86	6.75	26.45
	Std. Deviation	1.10	2.30	1.30	8.65

Table 23: Mean analysis for objective measurements – IVR system.

Scenario		Min Distance (m)	Max Distance (m)	Average Distance (m)	Over5m (sec)
S1	Mean	2.79	12.23	6.00	39.21
	Std. Deviation	1.89	4.26	1.50	15.57
S2	Mean	2.82	12.22	7.20	41.62
	Std. Deviation	1.72	5.71	2.71	17.78
S3	Mean	3.18	13.41	8.40	44.62
	Std. Deviation	1.74	4.65	2.74	16.13
Total	Mean	2.93	12.63	7.22	41.86
	Std. Deviation	1.76	4.88	2.56	16.41

Table 24: Mean analysis for objective measurements – semi-IVR system.

	Scenario	Kolmogorov-Smirnov[a]			Shapiro-Wilk		
Variable		Statistic	df	Sig.	Statistic	df	Sig.
Min_Distance	Scenario S1	0.116	20	0.200*	0.980	20	0.939
	Scenario S2	0.117	20	0.200*	0.957	20	0.481
	Scenario S3	0.113	20	0.200*	0.958	20	0.503
Max_Distance	Scenario S1	0.096	20	0.200*	0.960	20	0.548

Marios Kyriakou

	Scenario S2	0.153	20	0.200*	0.965	20	0.653
	Scenario S3	0.160	20	0.196	0.930	20	0.156
Average_Distance	Scenario S1	0.129	20	0.200*	0.943	20	0.274
	Scenario S2	0.134	20	0.200*	0.958	20	0.513
	Scenario S3	0.094	20	0.200*	0.963	20	0.613
Time_Over5m	Scenario S1	0.144	20	0.200*	0.946	20	0.313
	Scenario S2	0.153	20	0.200*	0.911	20	0.067
	Scenario S3	0.106	20	0.200*	0.956	20	0.464
*. This is a lower bound of the true significance.							
a. Lilliefors Significance Correction							

Table 25: Tests of Normality for objective measurements –IVR system.

	Scenario	Kolmogorov-Smirnov[a]			Shapiro-Wilk		
Variable		**Statistic**	**df**	**Sig.**	**Statistic**	**df**	**Sig.**
Min_Distance	Scenario S1	0.155	20	0.200*	0.910	20	0.064
	Scenario S2	0.149	21	0.200*	0.931	21	0.143
	Scenario S3	0.188	21	0.051	0.900	21	0.034
Max_Distance	Scenario S1	0.169	20	0.135	0.938	20	0.220
	Scenario S2	0.213	21	0.014	0.768	21	0.000
	Scenario S3	0.101	21	0.200*	0.947	21	0.297
Average_Distance	Scenario S1	0.122	20	0.200*	0.957	20	0.487
	Scenario S2	0.113	21	0.200*	0.935	21	0.170
	Scenario S3	0.109	21	0.200*	0.957	21	0.464
Time_Over5m	Scenario S1	0.121	20	0.200*	0.966	20	0.677
	Scenario S2	0.200	21	0.028	0.915	21	0.069
	Scenario S3	0.182	21	0.067	0.918	21	0.078
*. This is a lower bound of the true significance.							
a. Lilliefors Significance Correction							

Table 26: Tests of Normality for objective measurements – semi-IVR system.

Marios Kyriakou

Scenarios	Mean	Std. Error	95% Confidence Interval	
			Lower Bound	Upper Bound
S1	6.271	0.303	5.637	6.905
S2	6.647	0.306	6.007	7.286
S3	7.338	0.219	6.880	7.796

Table 27: Estimates for Average_Distance – IVR system.

Scenarios	Mean	Std. Error	95% Confidence Interval	
			Lower Bound	Upper Bound
S1	6.003	0.318	5.339	6.667
S2	7.200	0.592	5.966	8.434
S3	8.405	0.598	7.157	9.652

Table 28: Estimates for Average_Distance – semi-IVR system.

Source		Type III Sum of Squares	df	Mean Square	F	Sig.	Partial Eta Squared
Scenarios	Sphericity Assumed	11.718	2	5.859	14.952	0.000	0.440
	Greenhouse-Geisser	11.718	1.419	8.258	14.952	0.000	0.440
	Huynh-Feldt	11.718	1.500	7.810	14.952	0.000	0.440
	Lower-bound	11.718	1.000	11.718	14.952	0.001	0.440
Error (Scenarios)	Sphericity Assumed	14.890	38	0.392			
	Greenhouse-Geisser	14.890	26.960	0.552			
	Huynh-Feldt	14.890	28.508	0.522			
	Lower-bound	14.890	19.000	0.784			

Table 29: Tests of Within-Subjects Effects - Average Distance – IVR system.

Marios Kyriakou

Source		Type III Sum of Squares	df	Mean Square	F	Sig.	Partial Eta Squared
Scenarios	Sphericity Assumed	60.571	2	30.286	9.647	0.000	0.325
	Greenhouse-Geisser	60.571	1.994	30.381	9.647	0.000	0.325
	Huynh-Feldt	60.571	2.000	30.286	9.647	0.000	0.325
	Lower-bound	60.571	1.000	60.571	9.647	0.006	0.325
Error (Scenarios)	Sphericity Assumed	125.573	40	3.139			
	Greenhouse-Geisser	125.573	39.875	3.149			
	Huynh-Feldt	125.573	40.000	3.139			
	Lower-bound	125.573	20.000	6.279			

Table 30: Tests of Within-Subjects Effects - Average Distance –semi-IVR system.

Source		Type III Sum of Squares	df	Mean Square	F	Sig.	Partial Eta Squared
Scenarios	Sphericity Assumed	738.142	2	369.071	36.229	0.000	0.656
	Greenhouse-Geisser	738.142	1.975	373.722	36.229	0.000	0.656
	Huynh-Feldt	738.142	2.000	369.071	36.229	0.000	0.656
	Lower-bound	738.142	1.000	738.142	36.229	0.000	0.656
Error (Scenarios)	Sphericity Assumed	387.118	38	10.187			
	Greenhouse-Geisser	387.118	37.52	10.316			
	Huynh-Feldt	387.118	38.00	10.187			
	Lower-bound	387.118	19.00	20.375			

Table 31: Tests of Within-Subjects Effects - Over5m Time – IVR system.

Marios Kyriakou

(I) Scenarios	(J) Scenarios	Mean Difference (I-J)	Std. Error	Sig.^{b}	95% Confidence Interval for Difference^b	
					Lower Bound	Upper Bound
S1	S2	-0.376*	0.120	0.016	-0.690	-0.061
	S3	-1.067*	0.233	0.001	-1.680	-0.454
S2	S1	0.376*	0.120	0.016	0.061	0.690
	S3	-0.692*	0.221	0.017	-1.271	-0.112
S3	S1	1.067*	0.233	0.001	0.454	1.680
	S2	0.692*	0.221	0.017	.112	1.271
Based on estimated marginal means						
*. The mean difference is significant at the 0.05 level.						
b. Adjustment for multiple comparisons: Bonferroni.						

Table 32: Pairwise Comparisons - Average_Distance –IVR system.

(I) Scenarios	(J) Scenarios	Mean Difference (I-J)	Std. Error	Sig.^{b}	95% Confidence Interval for Difference^b	
					Lower Bound	Upper Bound
S1	S2	-1.197	0.532	0.107	-2.587	0.193
	S3	-2.402*	0.550	0.001	-3.840	-.964
S2	S1	1.197	0.532	0.107	-0.193	2.587
	S3	-1.205	0.558	0.129	-2.662	0.253
S3	S1	2.402*	0.550	0.001	0.964	3.840
	S2	1.205	0.558	0.129	-0.253	2.662
Based on estimated marginal means						
*. The mean difference is significant at the 0.05 level.						
b. Adjustment for multiple comparisons: Bonferroni.						

Table 33: Pairwise Comparisons - Average_Distance – semi-IVR system.

Marios Kyriakou

APPENDIX B

Please fill the following questions:
1. Gender: a. Male b. Female
2. In what year were you born? _______
3. Do you suffer from epilepsy? a. Yes b. No
4. Do you have any health issue? If yes please describe it briefly:
5. What is your experience with video games? a. No experience at all b. Novice user c. Average user d. Expert user
6. Have you ever used any Virtual Reality system? a. Never b. 1-2 times c. Sometimes d. Very often
7. What football club do you support in Cyprus? a. Apoel b. Omonia c. None of the above

Table 34: Pre-experiment questionnaire of experiment 2.

Marios Kyriakou

1. I felt fear about the fight outcome

1	2	3	4	5
○	○	○	○	○
strongly disagree	disagree	neutral	agree	strongly agree

2. I felt afraid for my own safety

1	2	3	4	5
○	○	○	○	○
strongly disagree	disagree	neutral	agree	strongly agree

3. I wanted to call for help

1	2	3	4	5
○	○	○	○	○
strongly disagree	disagree	neutral	agree	strongly agree

4. I wanted to help the victim

1	2	3	4	5
○	○	○	○	○
strongly disagree	disagree	neutral	agree	strongly agree

5. I was angry about the man who was hitting the victim

1	2	3	4	5
○	○	○	○	○
strongly disagree	disagree	neutral	agree	strongly agree

6. I was angry with the victim

1	2	3	4	5
○	○	○	○	○
strongly disagree	disagree	neutral	agree	strongly agree

Marios Kyriakou

7. I felt that I could stop the fight

1	2	3	4	5
○	○	○	○	○
strongly disagree	disagree	neutral	agree	strongly agree

8. I wanted to stop the fight

1	2	3	4	5
○	○	○	○	○
strongly disagree	disagree	neutral	agree	strongly agree

9. I felt like watching a movie

1	2	3	4	5
○	○	○	○	○
strongly disagree	disagree	neutral	agree	strongly agree

10. I wanted to get out of the scene

1	2	3	4	5
○	○	○	○	○
strongly disagree	disagree	neutral	agree	strongly agree

11. I was feeling uncomfortable with the whole situation

1	2	3	4	5
○	○	○	○	○
strongly disagree	disagree	neutral	agree	strongly agree

Marios Kyriakou

Table 35: Post – experiment questionnaire of experiment 2.

Number	Interview Question
1	Were your responses authentic?
2	What would have made you intervene more?
3	What would have made you intervene less?
4	What factors tended to draw you out of the experience?
5	What feelings did you have while this was happening?
6	What characteristics did you find more realistic about the crowd?
7	What characteristics did you find less realistic about the crowd?
8	What do you think would be the outcome of the evidence?

Table 36: Interview Questions.

			Verbal Interventions	Physical Interventions	Total Interventions
Responsiveness	Non-Responsive	Kolmogorov-Smirnov Z	1.243	1.001	1.255
		Asymp. Sig. (2-tailed)	0.091	0.269	0.086
	Responsive	Kolmogorov-Smirnov Z	0.958	1.040	0.731
		Asymp. Sig. (2-tailed)	0.318	0.229	0.659
Group	Outgroup	Kolmogorov-Smirnov Z	1.478	1.243	0.828
		Asymp. Sig. (2-tailed)	0.025	0.091	0.500
	Ingroup	Kolmogorov-Smirnov Z	0.918	1.051	1.229
		Asymp. Sig. (2-tailed)	0.368	0.219	0.098
Gender	Male	Kolmogorov-Smirnov Z	1.223	0.855	1.218
		Asymp. Sig. (2-tailed)	0.100	0.457	0.103
	Female	Kolmogorov-Smirnov Z	0.948	1.263	0.751
		Asymp. Sig. (2-tailed)	0.330	0.082	0.626

Table 37: One-Sample Kolmogorov-Smirnov Test.

Marios Kyriakou

		V1	V2	V3	V4	V5	V6	V7	V8	V9	V10	V11
N		40	40	40	40	40	40	40	40	40	40	40
Normal Parameters[a.b]	Mean	3.0	2.78	3.25	4.25	4.00	2.20	2.98	4.28	2.05	2.35	3.15
	Std. Dev.	1.0	1.31	1.26	1.01	0.9	1.0	1.3	1.04	0.9	1.3	1.4
Most Extreme Differences	Absolute	0.22	0.20	0.20	0.32	0.25	0.18	0.22	0.31	0.21	0.22	0.25
	Positive	0.15	0.19	0.140	0.23	0.16	0.18	0.15	0.24	0.21	0.22	0.17
	Negative	-0.22	-0.20	-0.20	-0.32	-0.25	-0.18	-0.22	-0.31	-0.16	-0.17	-0.25
Kolmogorov-Smirnov Z		1.4	1.26	1.26	2.04	1.5	1.1	1.3	1.95	1.3	1.3	1.5
Asymp. Sig. (2-tailed)		0.03	0.08	0.08	0.00	0.01	0.13	0.04	0.001	0.06	0.04	0.01
Exact Sig. (2-tailed)		0.03	0.070	0.071	0.000	0.01	0.11	0.03	0.001	0.05	0.03	0.01
Point Probability		0	0	0	0	0	0	0	0	0	0	0

a. Test distribution is Normal.

b. Calculated from data.

Table 38: One-Sample Kolmogorov-Smirnov Test for the eleven variables.

Marios Kyriakou

Variable	Responsiveness	N	Mean Rank	Sum of Ranks	Mann-Whitney U	Wilcoxon W	Z	P-value
V1	Non-Responsive	20	20.30	406.00	196.00	406.00	-0.11	0.910
	Responsive	20	20.70	414.00				
V2	Non-Responsive	20	18.93	378.50	168.50	378.50	-0.88	0.377
	Responsive	20	22.08	441.50				
V3	Non-Responsive	20	17.10	342.00	132.00	342.00	-1.89	0.059
	Responsive	20	23.90	478.00				
V4	Non-Responsive	20	19.70	394.00	184.00	394.00	-0.48	0.632
	Responsive	20	21.30	426.00				
V5	Non-Responsive	20	21.28	425.50	184.50	394.50	-0.45	0.656
	Responsive	20	19.73	394.50				
V6	Non-Responsive	20	21.30	426.00	184.00	394.00	-0.45	0.650
	Responsive	20	19.70	394.00				
V7	Non-Responsive	20	19.68	393.50	183.50	393.50	-0.46	0.646
	Responsive	20	21.33	426.50				
V8	Non-Responsive	20	20.33	406.50	196.50	406.50	-0.11	0.916
	Responsive	20	20.68	413.50				
V9	Non-Responsive	20	20.83	416.50	193.50	403.50	-0.19	0.853
	Responsive	20	20.18	403.50				
V10	Non-Responsive	20	17.43	348.50	138.50	348.50	-1.73	0.083
	Responsive	20	23.58	471.50				
V11	Non-Responsive	20	18.63	372.50	162.50	372.50	-1.05	0.295
	Responsive	20	22.38	447.50				

Marios Kyriakou

Table 39: Mann-Whitney U test for differences between Non-Responsive and Responsive groups.

Variable	Group	N	Mean Rank	Sum of Ranks	Mann-Whitney U	Wilcoxon W	Z	P-value
V1	Outgroup	20	19.23	384.50	174.50	384.50	-0.72	0.470
	Ingroup	20	21.78	435.50				
V2	Outgroup	20	17.80	356.00	146.00	356.00	-1.52	0.130
	Ingroup	20	23.20	464.00				
V3	Outgroup	20	18.23	364.50	154.50	364.50	-1.26	0.206
	Ingroup	20	22.78	455.50				
V4	Outgroup	20	18.80	376.00	166.00	376.00	-1.02	0.309
	Ingroup	20	22.20	444.00				
V5	Outgroup	20	15.05	301.00	91.00	301.00	-3.13	0.002
	Ingroup	20	25.95	519.00				
V6	Outgroup	20	20.13	402.50	192.50	402.50	-0.21	0.832
	Ingroup	20	20.88	417.50				
V7	Outgroup	20	19.83	396.50	186.50	396.50	-0.38	0.707
	Ingroup	20	21.18	423.50				
V8	Outgroup	20	16.58	331.50	121.50	331.50	-2.36	0.018
	Ingroup	20	24.43	488.50				
V9	Outgroup	20	20.18	403.50	193.50	403.50	-0.19	0.853
	Ingroup	20	20.83	416.50				
V10	Outgroup	20	20.00	400.00	190.00	400.00	-0.28	0.778
	Ingroup	20	21.00	420.00				
V11	Outgroup	20	18.48	369.50	159.50	369.50	-1.13	0.258
	Ingroup	20	22.53	450.50				

Table 40: Mann-Whitney U test for differences between Outgroup and Ingroup.

Marios Kyriakou

Variable	Gender	N	Mean Rank	Sum of Ranks	Mann-Whitney U	Wilcoxon W	Z	P-value
V1	Male	28	20.32	569.00	163.00	569.00	-0.16	0.877
	Female	12	20.92	251.00				
V2	Male	28	19.30	540.50	134.50	540.50	-1.03	0.305
	Female	12	23.29	279.50				
V3	Male	28	21.98	615.50	126.50	204.50	-1.26	0.208
	Female	12	17.04	204.50				
V4	Male	28	22.18	621.00	121.00	199.00	-1.54	0.125
	Female	12	16.58	199.00				
V5	Male	28	21.39	599.00	143.00	221.00	-0.78	0.434
	Female	12	18.42	221.00				
V6	Male	28	22.18	621.00	121.00	199.00	-1.45	0.146
	Female	12	16.58	199.00				
V7	Male	28	23.39	655.00	87.00	165.00	-2.46	0.014
	Female	12	13.75	165.00				
V8	Male	28	21.73	608.50	133.50	211.50	-1.13	0.257
	Female	12	17.63	211.50				
V9	Male	28	20.23	566.50	160.50	566.50	-0.23	0.816
	Female	12	21.13	253.50				
V10	Male	28	19.50	546.00	140.00	546.00	-0.86	0.390
	Female	12	22.83	274.00				
V11	Male	28	21.68	607.00	135.00	213.00	-1.01	0.315
	Female	12	17.75	213.00				

Table 41: Mann-Whitney U test for differences between Males and Females.

Marios Kyriakou

Question	Frequency of statement		
Were your responses authentic/realistic?	Non-Responsive	Responsive	Total
Realistic / Realistic enough	75%	75%	75%
Needed more Interaction	10%	20%	15%
VR made me more reactive	15%	5%	10%
Detached	5%	5%	5%

Table 42: Interview Question 1 –Responsiveness.

Question	Frequency of statement		
What would have made you intervene more?	Non-Responsive	Responsive	Total
More interactive	45%	15%	30%
More intense/violent event	25%	25%	25%
Acquaintance victim	25%	30%	28%
Know the reason	5%	0%	3%
Not football fans	5%	0%	3%
More realism	10%	15%	13%
Victim alone	0%	10%	5%
Self-threatened	5%	5%	5%

Table 43: Interview Question 2 – Responsiveness.

Question	Frequency of statement		
What would have made you intervene less?	Non-Responsive	Responsive	Total
More interactive/more senses	5%	0%	3%
Self-threatened	20%	30%	25%
Less realistic/ no sound	20%	10%	15%
Less intense/violent event	30%	15%	23%
Only strangers involved/(not Omonoia)	15%	10%	13%
Less interactive	5%	5%	5%
Victim responsible	5%	5%	5%
Victim not needing help	0%	15%	8%

Table 44: Interview Question 3 – Responsiveness

Marios Kyriakou

Question	Frequency of statement		
What factors tended to draw you out of experience?	Non-Responsive	Responsive	Total
Not interactive enough	25%	10%	18%
The use of panels/lack of stereo	20%	0%	10%
The use of navigation system	35%	45%	40%
Quality of sound	5%	5%	5%
Insufficient graphics and modeling of the characters	10%	0%	5%
I couldn't see myself/my body	0%	5%	3%
I was not sure how should I react	0%	5%	3%
Somebody else was in the room/lab watching me	0%	5%	3%
Not realistic environment	0%	5%	3%

Table 45: Interview Question 4 – Responsiveness.

Marios Kyriakou

Question	Frequency of statement		
What feelings did you have while this was happening?	Non-Responsive	Responsive	Total
Curiosity	60%	30%	45%
Anxiety/Stress	50%	45%	48%
I wanted to help the victim	15%	15%	15%
Helplessness	10%	0%	5%
Anger	10%	30%	20%
Embarrassment	5%	15%	10%
Sad	5%	5%	5%
Repulsion	5%	5%	5%
Fear	10%	20%	15%
Confusion	0%	10%	5%

Table 46: Interview Question 5 – Responsiveness.

Question	Frequency of statement		
What characteristics did you find more realistic about the crowd?	Non-Responsive	Responsive	Total
Their conversations/voices	70%	90%	80%
Their behavior regarding the fight	50%	20%	35%
Their songs/anthems	45%	35%	40%
Their faces	5%	0%	3%
Crowd steering	35%	30%	33%
General Character Animations	35%	30%	33%
Fight Animations	30%	35%	33%
Character appearance/graphics	5%	35%	20%

Table 47: Interview Question 6 – Responsiveness.

Question	Frequency of statement		
What characteristics did you find less realistic about the crowd?	Non-Responsive	Responsive	Total
Limited conversations	0%	15%	8%
Their behavior regarding the fight	30%	10%	20%
Their faces/no facial expressions	15%	15%	15%
Crowd steering	0%	5%	3%
General Character Animations	15%	35%	25%
Fight Animations	25%	20%	23%
Character appearance/graphics	20%	15%	18%

Table 48: Interview Question 7 – Responsiveness.

Question	Frequency of statement		
What do you think would be the outcome of the incident?	Non-Responsive	Responsive	Total
It would get worse	60%	60%	60%
It would ended	15%	20%	18%
Not sure	5%	0%	3%
I would get more involved	20%	5%	13%
Someone else would try to stop the fight	20%	10%	15%
The police would intervene and stop the fight	15%	15%	15%
It would continue	0%	10%	5%

Table 49: Interview Question 8 –Responsiveness.

Marios Kyriakou

Question	Frequency of statement		
Were your responses authentic /realistic?	Outgroup	InGroup	Total
Realistic / Realistic enough	70%	80%	75%
Needed more Interaction	25%	5%	15%
VR made me more reactive	5%	15%	10%
Detached	10%	0%	5%

Table 50: Interview Question 1 - Group Membership.

Question	Frequency of statement		
What would have made you intervene more?	Outgroup	InGroup	Total
More interactive	35%	25%	30%
More intense/violent event	20%	30%	25%
Acquaintance victim	25%	30%	28%
Know the reason	0%	5%	3%
Not football fans	5%	0%	3%
More realism	20%	5%	13%
Victim alone	0%	10%	5%
Self-threatened	5%	5%	5%

Table 51: Interview Question 2 - Group Membership.

Question	Frequency of statement		
What would have made you intervene less?	Outgroup	InGroup	Total
More interactive/more senses	0%	5%	3%
Self-threatened	25%	25%	25%
Less realistic/ no sound	20%	10%	15%
Less intense/violent event	25%	20%	23%
Only strangers involved/(not Omonoia)	0%	25%	13%
Less interactive	5%	5%	5%
Victim responsible	5%	5%	5%
Victim not needing help	5%	10%	8%

Table 52: Interview Question 3 - Group Membership.

Marios Kyriakou

Question	Frequency of statement		
What factors tended to draw you out of experience?	Outgroup	InGroup	Total
Not interactive enough	15%	20%	18%
The use of panels/lack of stereo	10%	10%	10%
The use of navigation system	45%	35%	40%
Quality of sound	5%	5%	5%
Insufficient graphics and modeling of the characters	5%	5%	5%
I couldn't see myself/my body	0%	5%	3%
I was not sure how should I react	0%	5%	3%
Somebody else was in the room/lab watching me	5%	0%	3%
Not realistic environment	5%	0%	3%

Table 53: Interview Question 4 - Group Membership.

Question	Frequency of statement		
What feelings did you have while this was happening?	Outgroup	Ingroup	Total
Curiosity	60%	30%	45%
Anxiety/Stress	25%	70%	48%
I wanted to help the victim	15%	15%	15%
Helplessness	5%	5%	5%
Anger	15%	25%	20%
embarrassment	15%	5%	10%
Sad	5%	5%	5%
Repulsion	5%	5%	5%
Fear	10%	20%	15%
Confusion	5%	5%	5%

Table 54: Interview Question 5 - Group Membership.

Marios Kyriakou

Question	Frequency of statement		
What characteristics did you find more realistic about the crowd?	Outgroup	InGroup	Total
Their conversations/voices	85%	75%	80%
Their behavior regarding the fight	35%	35%	35%
Their songs/anthems	45%	35%	40%
Their faces	5%	0%	3%
Crowd steering	30%	35%	33%
General Character Animations	20%	45%	33%
Fight Animations	25%	40%	33%
Character appearance/graphics	10%	30%	20%

Table 55: Interview Question 6 - Group Membership.

Question	Frequency of statement		
What characteristics did you find less realistic about the crowd?	Outgroup	InGroup	Total
Limited conversations	5%	10%	8%
Their behavior regarding the fight	20%	20%	20%
Their faces/no facial expressions	5%	25%	15%
Crowd steering	0%	5%	3%
General Character Animations	25%	25%	25%
Fight Animations	20%	25%	23%
Character appearance/graphics	20%	15%	18%

Table 56: Interview Question 7 - Group Membership.

Question	Frequency of statement		
What do you think would be the outcome of the incident?	Outgroup	InGroup	Total
It would get worse	55%	65%	60%
It would ended	15%	20%	18%
Not sure	0%	5%	3%
I would get more involved	10%	15%	13%
Someone else would try to stop the fight	10%	20%	15%
The police would intervene and stop the fight	15%	15%	15%
It would continue	10%	0%	5%

Table 57: Interview Question 8 - Group Membership.

Marios Kyriakou