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MATHEMATICAL MODELLING FOR DEVELOPMENT OF EGOCENTRIC VIRTUAL ENVIRONMENTS

CZANNER Silvester, (UK), PETRASOVA Alena, (UK), KWON Joung Hume, (UK), CHALMERS Alan, (UK)

Abstract. The aim of this work is to introduce a novel solution for Virtual Reality - Cognitive Behaviour Therapy based on Virtual EgoCentric Holistic Environments. This is an alternative to the classical virtual environments (VEs) currently used and it is built on acquired user based information. The high-fidelity system is accompanied with several important attributes which will stimulate the human senses such as vision and hearing. An intensive study of these senses is leading us to answer an important question, what level of realism is required to provide effective immersive experience for the end users. We will demonstrate the potentials of the virtual egocentric holistic environments on three projects: virtual reality for the efficient treatment of infants with feeding difficulties, virtual reality therapeutic intervention for social anxiety, virtual reality for treatment of flying ants phobia. All these projects are multi-sensory and require visuals and audio to provide an appropriate level of realism.

Key words and phrases. Virtual reality, computer graphics, modeling, psychology, virtual environment, cognitive behavior therapy.

Mathematics Subject Classification. Primary 68N30; Secondary 62-07, 62K20

1 Introduction

Cognitive behavioral therapy is a structured, brief psychotherapy which is comprised of many techniques, based on research evidence, and recognized as a treatment of choice for many psychological conditions [30]. One of the CBT techniques is exposure. This approach draws from the classical conditioning work of Pavlov, and also operant conditioning [25], research demonstrating that anxiety can be associated with neutral or mildly anxiety provoking stimuli.

The fear is then maintained by avoidance of that stimulus or approaching the stimulus with safety seeking behaviors. The use of exposure therapy with specific phobias has been an evidence based treatment for a considerable time [23]. Exposure therapy relies on habituation of the fight or flight response when presented with the feared stimuli - this habituation can occur fairly quickly, but may take up to 40 minutes in some cases. In order for the therapy to work, treatment must be prolonged to habituation [27], practiced regularly [24], and be as realistic as possible [15]. The use of virtual reality techniques to help clients become familiar with feared stimuli is not new and a number of cases are described in [30], but it has rarely if at all been undertaken in the context of exposure protocols. Most of the virtual environments used in [30] are non-interactive with low resolution and artificial non-realistic sound. Multi-modal high-fidelity virtual environments attempt to recreate a real scene including many of the sensory inputs a user would experience in the real world. This has been termed "there reality", providing the perceptual response from the user as if he/she were actually "there" in the real environment [33]. There has been a significant amount of research into recreating real places using virtual reality, see for example [29], although much of this has concentrated on only one sensory stimulus, typically the visuals. Physically-based high-fidelity graphics model the way in which light interacts with objects in the real world including aspects of the human visual system to simulate the visual experience in the virtual world of an observer in the real world. They are thus capable of achieving for more realistic results then rasterisation based methods. Although many physically accurate algorithms have been proposed (for a good overview see [13]) these can take many seconds and even longer to authentically render only a modestly complex scene. Modern graphics hardware (GPUs), traditional parallel rendering, and visual perception techniques, such as selective rendering and Level of Detail methods [12], are playing an increasingly key role in significantly reducing these computational times, but still quality is often compromised in order to achieve interactive rates within the VEs. Sound is another key sense which has frequently being included in virtual environments, for example [16]. In addition to increasing the sense of "presence" in the virtual environment [20], recent work has shown that that the addition of audio could in fact enable the quality of rendering of high-fidelity graphics to be significantly reduced, with thus a substantial saving in computational time, without the viewer being aware of this quality reduction. Further senses which have been incorporated in VEs include haptics, for example [1] and motion, especially for flight and driving simulators [21].

2 Virtual Reality

Virtual Reality (VR) is a simulation in which computer graphics are used to create a realistic-looking world or imagined environment, in which people are the active participants. VR system has been used in treatments of patients with different disorders, i.e. social phobia, acrophobia, fear of public speaking, post traumatic stress disorder, flying phobia, spider phobia, treatment of eating disorders [2, 3, 4, 5, 6, 7, 10]. Situations which are created in a virtual environment need to be sufficiently similar to real world situations for successful patient exposure therapy. The significant advantage of VR is that it is more controlled and cost-effective and it allows therapists to create many and varied situations and environments for patients which are not

life threatening for them. cite4 Therapists can also control how frightening individual objects and activities are. The virtual world thus provides a protected environment persuading the participants to be more willing to be treated by VR.

2.1 Characteristics of Virtual Reality

According to Sherman and Craig the defining features of virtual reality are: [9]

- It is a medium of communication
- It requires physical immersion
- It provides synthetic sensory stimulation
- It can mentally immerse the user
- It is interactive

Virtual reality as a medium offers interaction with models in three spatial dimensions and gives feedback from actions without noticeable pause. [10] These characteristics make virtual reality a useful tool for communication between therapist and participant. We have the ability to manipulate the sense of time and space and to change a degree of interactivity. The potential advantage for participants is that they can impact the narrative flow of the experience.

2.2 Virtual Reality in Cognitive Behavior Therapy

Virtual Reality-Enhanced Cognitive Behaviour Therapy offers many advantages over traditional treatment for an abundance of disorders. It can reduce the length of treatment, reduce relapse rates and is often more effective than traditional forms of therapy. VR therapy has been developed to overcome some of the difficulties inherent in the traditional treatment of phobias. It can provide stimuli for patients who have difficulty in imagining scenes or are too phobic to experience real situations. By providing a variety of stimuli such as 3D visual, binaural audio, vibratory, tactile, haptic and olfactory in an immersive and sometimes interactive manner, virtual reality enhances the therapeutic experience in a safe and controlled manner, especially in treatment that traditionally involves imagination. Virtual reality can be described as a technology or tool for influencing cognitive operations. The participant learns to consider different interpretations of a situation and he develops his own list of problem situations, which he discusses with the therapist and he makes the decision on how to proceed next. Cognitive behavior therapy (CBT) is an approach based on modifying distorted beliefs, attitudes and cognitive processes that maintain disordered behavior. [8] All of the existing VR systems in previous projects were focused on the individual human subject. Common indicators in these projects are that the patient is confronted with the feared stimuli and allows the anxiety to attenuate gradually. The most important thing to solve is the treatment of the individual's disorder. Not eating is a real problem whereas phobias are the products of anxiety. This

problem needs to be solved by altering and learning it is not enough just to imagine some scene.

3 Virtual EgoCentric Holistic Environments

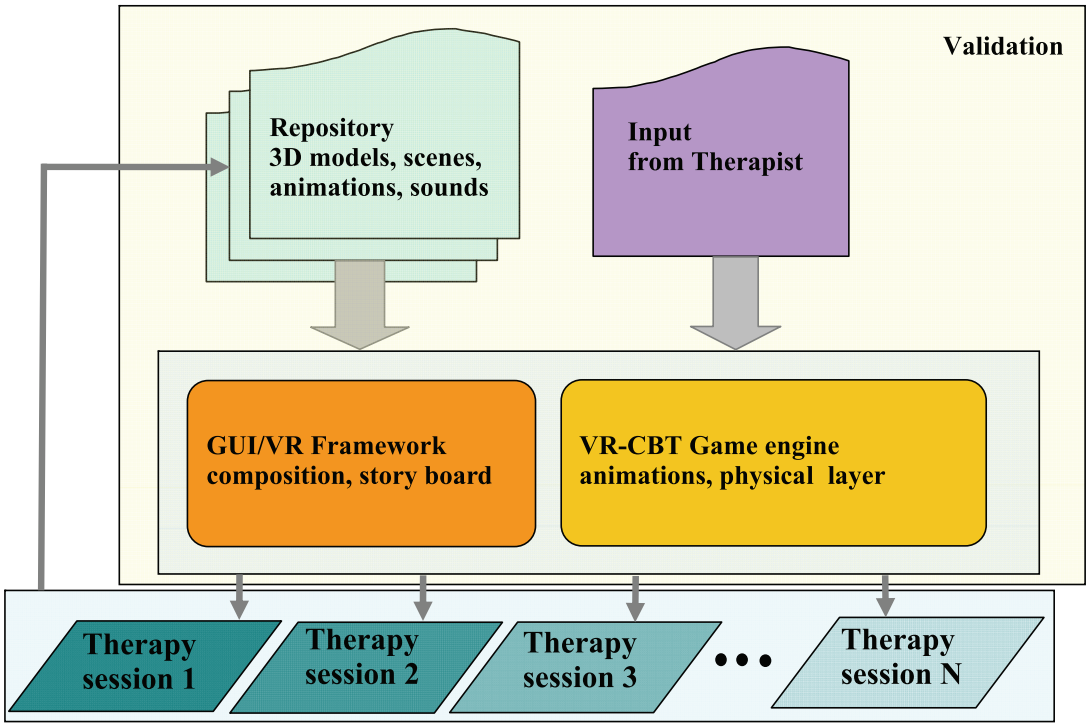

Figure 1: A development process of therapy sessions using VECeHe.

The Virtual EgoCentric Holistic Environments (VECeHE) is an alternative to the classical virtual environment used for CBT and will be built on various spectrum of information acquired by the therapist before the very first session; information that provides the framework for the therapist's understanding of a patient (see Figure 1). It has to include memorable information from childhood, because beginning in childhood people develop certain beliefs about themselves, other people and their words. Their most central beliefs are so fundamental and deep that they often do not articulate them, even to themselves. Another major aspect of the information package includes facts about patient's social life from the teenage years until present. It is important for the therapist to put himself in his patient's shoes, to develop empathy for what the patient is undergoing, to understand how the patient is feeling and to perceive the world through the patient's eyes. Cognitive therapy is based on the cognitive model, which hypothesizes that people's emotions and behaviors are influenced by their perception of events. Hypotheses are confirmed, disconfirmed or modified as new information is presented. The whole process is called conceptualization. During the conceptualization the therapist collects data and makes hypotheses about a patient, based on information the patient presents. After collecting all

necessary information and facts the therapist will then set up VECeHE and generate virtual environments suitable very precisely for that patient and treatment of his/her disorder. The VECeHE, with therapist's help, will teach the patient to identify, evaluate and modify his/her thoughts in order to produce relief of the symptom. The VECeHE is a combination of holistic and egocentric attributes with focus to particular needs for treatment of several cognitive behavior disorders. In psychology the term EgoCentricrism is defined as the characteristic of regarding oneself and one's own opinions or interests as most important. Our EgoCentric system is based on this definition with the focus to a patient and his/her needs. The system will be seamlessly adapted to patients needs in a controlled manner. The generated virtual environments will be based on the patient's health and psychological conditions and will be adequate to the phase of the treatment of his/her disorder.
The system is Holistic in the content of multimodal sources of perceptions. The system will be accompanied with several important attributes which will stimulate the human senses such as vision and hearing. All the different sources of stimulus will be then use together with the VR scenario to generate virtual environment with focus on particular disorder.

4 Virtual Reality for the Efficient Treatment of Infants with Feeding Difficulties

We are developing a VECeHE for individualized interactive therapy incorporating components of Cognitive Behaviour Therapy, which will be built on various information, such as the right environmental conditions for meal times, eating distractions, the right positioning during feeding, adaptive and social skills of the child, suggested by physicians and psychologists which will enable parent's successful experience with our application. It is necessary to make this environment easy to use for the participant and to let them think what to do in the current situation to build their self-confidence. People often develop certain beliefs about themselves, other people and their world, for example they believe that their baby doesn't eat enough or is not able to feed itself and they force-feed the baby. The basic hypotheses of cognitive therapy are that people's emotions and behaviors are influenced by their perception of events. It is important to teach the user to identify, evaluate and modify his/her own thoughts. We are developing a stand-alone application to conduct a pilot study and a series of experiments in conjunction with new parents to build the preliminary VR system (see Figure 2). All the experiments are discussed with clinical psychologists and pediatricians. We will compare how different levels of quality and multimodal aspects of a virtual reality system may influence the users. We will undertake initial comparisons for the VR solution, such as a solution with or without sound, different quality levels of animation, and several types of display techniques. On the basis of the pilot study we refine the VR system and fully investigate a novel, on-line Virtual Reality solution, which will be available for a wide range of users.

The main idea is to give the caregiver the ability to build his/her own scenario according to his/her problem. They should be able to choose a room to feed in for example, a kitchen or a living room, as a mealtime environment with the food and set up options relating to the child's problem. They should be able to simply select everything from the menu, so there would be no need to navigate around the environment, but they could also change the environment later by rearranging the furniture, adding some people and pets, and perhaps to be able to drag and

Figure 2: Cartoon avatar represents a 12 months old child.

drop some objects. We decided to have a child who would not yet be mobile and will not be breastfeeding. We consider that a significant object in the virtual world is a reclining adjustable chair with the help of a sensible pillow, because one of the prerequisites for successful feeding is appropriate positioning and body posture during feeding [32]. Many parents usually pay attention only to nutritional intake. They loose any fun and play during the feeding of their child, therefore the main focus of therapy is to make eating a pleasurable experience again [32]. Parents may not feel able to ask for help and may struggle on until they have a serious problem. Consequently, our project is aimed at prevention not treatment. We are aiming to help parents deal with the normal problems that many parents experience when feeding their children to prevent them from escalating into the sorts of problems that require clinical interventions. It is very important to give caregivers support to learn independently what to do in different situations and to attempt it with virtual babies and professional and skilled support, offered by intelligent decision support systems based on experts' knowledge.

5 Virtual Reality Therapeutic Intervention for Social Anxiety

A virtual reality exposure is based on the assumption that people feel "present" in the virtual environment [28]. The sense of presence is elicited by the user developing a mental representation of the virtual stimuli as one's own environment. Thus, it can occur when people feel deeply involved in the simulation then they can experience a variety of emotions [34]. Based on this fundamental phenomenon, we are developing a virtual therapeutic intervention for social anxiety with high-fidelity 3D graphics so as to increase the sense of presence. The aim of our initial study is to create a fear provoking virtual job interview that might elicit anxiety as a real job interview. The job interview situation is very simple to reconstruct for comparison in the real world, but it is an exceptional situation to have repeated exposure without limita-

tions. We therefore designed a virtual office that was consisted of desks, chairs, a bookcase, a white board, and a female interviewer sitting on the chair (see Figure 3). In order to simulate natural attitudes of virtual human (VH) in real-time, the human models was scripted by Maya Embedded Language (MEL) to express positive, neutral, negative reactions, For instance, deadpanning, smiling, nodding, head-shaking, yawning, turning away, avoiding eye contact, interlocking fingers and interesting looking, folding arms and disinteresting looking. In addition, real interviewer's voices were implemented to the virtual human for delivering 10 job interview questions and a number of short sentences such as Thank you, Yes, I heard enough, Ok I am goanna go to the next question, and Yes good! Tell me more please. Here we want to outline

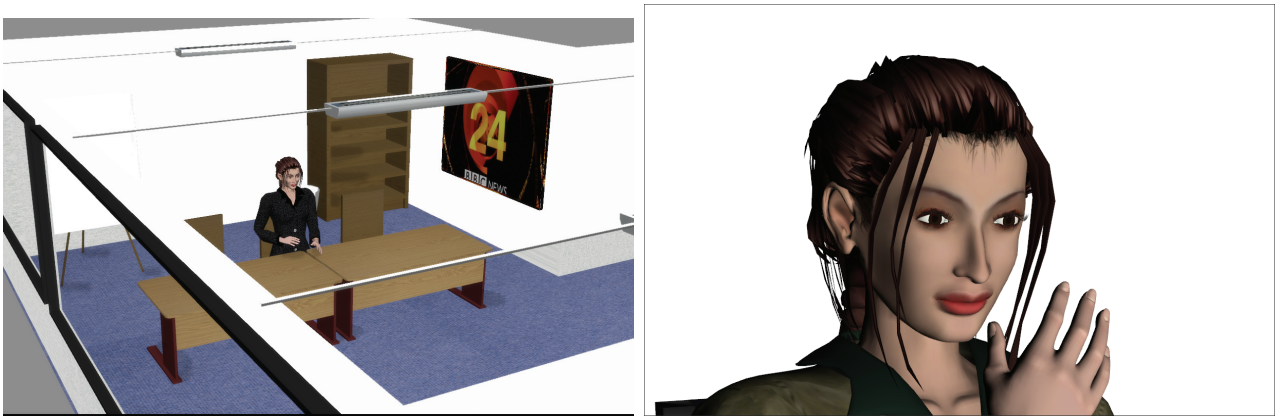

Figure 3: Virtual job interview scene. (left) a virtual office scene (right) closed up VH's face

our result of pilot study. Our pilot study was conducted with four volunteers (2 male and 2 female) who have not any history of mental illness. We measured subjects' gaze avoidances with a face tracking device (FacelabTM), and also asked several questions to obtain their feeling about the virtual job interview. When participants started being exposed to the virtual job interview, the VH interviewer performed in response neutrally with smiling or nodding from first to third job question. We also controlled the VH interviewer to simulate negative reactions (e.g. head-shaking, yawning, and turning head way) with a heavy sigh during the fourth to sixth question, and positive reactions (e.g. big smiling, frequently nodding, and interest looking) with expression of interesting chat "Yes Good! That sounds interesting" from seventh to last question. All participants successfully completed the virtual job interview exposure study without any difficulties, and demonstrated very obvious results on it. Firstly, we compared the subject's gaze movements depending on VH interviewer's three different reactions: negative, neutral and positive. The result showed similar tendencies for each subject that presented less visual contact avoidance at positive reactions, and more avoidance at negative reactions. Due to the limited sample size we could not conclude the difference with statistical significant, however, it were able to see that the gaze tracker seemed to be a potential measurement to identify subject's avoidance behaviours. The animation of VH model could be an essential factor to elicit user's anxiety during the virtual reality exposure session. Moreover, we could obtain very interesting comments from the subjects. Most subjects said that they did not expect too much about the virtual interview, however, after entering the virtual interview they were able to feel pressure or tense as much as real job interview. Especially, three subjects said they wanted to

stop the interview when the VH interviewer yawned or turned the head away, and these kinds of reactions made them to be nervous or irritated. Overall from this pilot study, we could see the potentiality of virtual reality to use as a therapeutic tool for social anxiety care. Clearly we have to do more experimental study with large number of subjects to verify the relationship between the sense of fear and meaningful set of stimulus in other virtual conditions.

6 Virtual Reality for Treatment of Flying Ants Phobia

Insect phobias are very common it is believed that at least one person in 10 is affected at some time in their life. A severe phobia about them can be as disabling as any anxiety disorder. In some cases they become almost prisoners in their own homes for fear of common insects that the majority of people literally never notice [35]. Most people are at least wary, if not

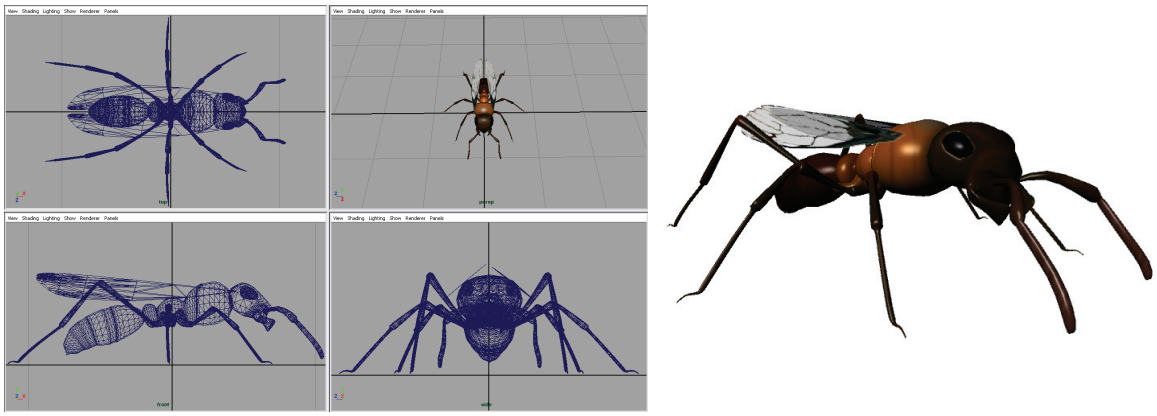

Figure 4: 3D model of a flying ant.

fearful, of certain insects (more correctly arthropods). This may be a reasonable fear based on knowledge or experience (bees, wasps, spiders, mosquitoes), an unreasonable but culturally understandable repulsion (cockroaches or flies), or a misplaced fear resulting from inadequate information (dragonflies, moths, crickets). A true insect phobia, on the other hand, is defined by the following criteria [35]:

1. A persistent irrational fear of and compelling desire to avoid insects, mites, spiders, or similar phobic objects.

2. Significant distress from the disturbance despite recognition by the individual that the fear is excessive or unreasonable.

3. Not due to another mental disorder such as schizophrenia or obsessive compulsive disorder (modified from [36]).

Traditional specialist treatment will be as for other phobias, and is largely determined by the therapist's individual preferences. Methods reported in the literature include supportive psychotherapy, desensitization [37], insight psychotherapy, combination of therapies (possibly

including group therapy), drug therapy (anxiolytics), modeling [38], hypnotic regression and reframing [39], and implosive therapy [31].

Our approach for treatment of flying ants phobia combines the traditional approaches with novel VR technologies. We are using immersive VECeHE and head mounted display to maximize the level of presence. To create the VECeHE a Spheron 3D camera has been used to capture the real living environment (see Figure 5). A model of wild flying ant and its animations have been created and combined with VECeHE (see Figure 4). As the last step, the strategy of the treatment has been developed and consulted with cognitive behavior therapist.

Figure 5: Virtual environment for treatment of flying ants phobia (left) panoramatic image of a kitchen captured by spheron 3D (right) part of a virtual kitchen used during the therapy session

7 Conclusion

An interesting question for every creator of virtual environments is how important the role of realism in immersion perception is. What kind of input and output devices do we need for good immersion? What are the key elements of virtual reality? In order to increase the reality in VR environments, several studies combined VR immersive devices to provide a better quality of VR environments. Although VR immersive systems can create different levels of presence, the levels may not directly lead to an enhanced treatment outcome. It is important to determine whether we need extremely realistic environments or we can also add some elements like having a cartoon-like look to the environment. Therefore we create both low and high quality models of babies, avatars, furniture and the rest of the objects in the virtual world. Another question is if full mental immersion is necessarily required for the application to be useful. Most current VR systems are primarily visual experiences, displayed either on a computer screen or through special stereoscopic displays, but some simulations include additional sensory information, for example, sound through speakers or headphones. A sense of how the world looks and sounds is very useful to improve the participant's immersion, so they should be chosen carefully.

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Current address

Silvester Czanner, RNDr., PhD
Warwick Manufacturing Group
International Digital Laboratory
The University of Warwick
Coventry, CV4 7AL
United Kingdom
e-mail: S.Czanner@warwick.ac.uk
tel. : +44 (0) 24 765 28028